U.S.NRC
United States Nuclear Regulatory Commission
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RIL 2022-10

PROCEEDINGS OF THE SEVENTH ANNUAL PROBABILISTIC FLOOD HAZARD ASSESSMENT RESEARCH WORKSHOP

February 15-18, 2022

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U.S. Nuclear Regulatory Commission
Rockville, MD 20852

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Research Information Letter
Office of Nuclear Regulatory Research

Disclaimer

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research (RES) is conducting the multiyear, multi project Probabilistic Flood Hazard Assessment (PFHA) Research Program to enhance the NRC's risk-informed and performance-based regulatory approach with regard to external flood hazard assessment and safety consequences of external flooding events at nuclear power plants. RES initiated this research in response to staff recognition of a lack of guidance for conducting PFHAs at nuclear facilities that required staff and licensees to use highly conservative deterministic methods in regulatory applications. Risk assessment of flooding hazards and consequences of flooding events is a recognized gap in the NRC's risk-informed, performance-based regulatory framework. The RES Probabilistic Flood Hazard Assessment Research Plan describes the objective, research themes, and specific research topics for the program. While the technical basis research, pilot studies, and guidance development are ongoing, RES has presented annual PFHA research workshops to communicate results, assess progress, collect feedback, and chart future activities. These workshops have brought together NRC staff and management from RES and user offices, technical support contractors, interagency and international collaborators, and industry and public representatives.

These conference proceedings transmit the agenda, abstracts, and presentation slides for the Seventh Annual NRC Probabilistic Flood Hazard Assessment Research Workshop held virtually in February 2022 via web conference software. The workshop took place February 15–18, 2022 and was attended by members of the public; nuclear industry and nuclear industry consultants; NRC technical staff, management, and contractors; and staff from other Federal agencies and academia. The workshop began with an introductory session that included perspectives and research program highlights from RES, the Federal Emergency Management Agency, and international working groups. NRC contractors and staff, as well as invited Federal and public speakers, gave technical presentations (including virtual poster sessions) and participated in various styles of panel discussion. The workshop included eight focus areas:

(1) overview of flooding research programs of the NRC, other Federal agencies, and selected international organizations

(2) sensors

(3) climate influences on flooding hazards

(4) precipitation processes and modeling

(5) riverine flooding processes and modeling

(6) coastal flooding processes and modeling

(7) Duane Arnold derecho operational experience

(8) Tornado wind loads in the ASCE/SEI 7-2022 Standard

(9) U.S. Army Corps of Engineers National Inventory of Dams and National Levee Database updates

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1 INTRODUCTION

This research information letter (RIL) details the Seventh Annual U.S. Nuclear Regulatory Commission (NRC) Probabilistic Flood Hazard Assessment (PFHA) Research Workshop held virtually from February 15–18, 2022. These proceedings include presentation abstracts and slides. The workshop was attended by members of the public; nuclear industry and nuclear industry consultants; NRC technical staff, management, and contractors; and staff from other Federal agencies and academia.

The workshop began with an introduction from Ray Furstenau, Director, NRC Office of Nuclear Regulatory Research (RES). Following the introduction, staff members from RES and the Federal Emergency Management Agency (FEMA) described their flooding research programs. Additionally, John Nakoski, RES, provided an overview of external hazard efforts (including flooding) underway by the Nuclear Energy Agency, Committee on the Safety of Nuclear Installations (CSNI), Working Group on External Events (WGEV).

Technical sessions followed the introduction session. Most sessions began with an invited keynote speaker, followed by several technical presentations, and concluded with a panel of all speakers, who discussed the session topic in general. At the end of each day, participants provided feedback and asked generic questions about research related to PFHA for nuclear facilities. At the end of the third day, a virtual poster session was held with each poster presenter being assigned a unique web conferencing room where attendees were free to attend and leave at will.

1.1 Background

The NRC is conducting the multiyear, multi project PFHA Research Program. It initiated this research in response to staff recognition of a lack of guidance for conducting PFHAs at nuclear facilities that required staff and licensees to use highly conservative deterministic methods in regulatory applications. The staff described the objective, research themes, and specific research topics in the “Probabilistic Flood Hazard Assessment Research Plan,” Version 2014-10-23, provided to the Commission in November 2014 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML14318A070 and ML14296A442). The NRC Office of Nuclear Reactor Regulation and the former Office of New Reactors endorsed the PFHA Research Plan in a joint user need request (ADAMS Accession No. ML15124A707). This program is designed to support the development of regulatory tools (e.g., regulatory guidance, standard review plans) for permitting new nuclear sites, licensing new nuclear facilities, and overseeing operating facilities. Specific uses of flooding hazard estimates (i.e., flood elevations and associated affects) include flood-resistant design for structures, systems, and components (SSCs) important to safety and advanced planning and evaluation of flood protection procedures and mitigation.

The lack of risk-informed guidance with respect to flooding hazards and flood fragility of SSCs constitutes a significant gap in the NRC’s risk-informed, performance-based regulatory approach to the assessment of hazards and potential safety consequences for commercial nuclear facilities. The probabilistic technical basis developed will provide a risk-informed approach for improved guidance and tools to give staff and licensees greater flexibility in evaluating flooding hazards and potential impacts to SSCs in the oversight of operating facilities (e.g., license amendment requests, significance determination processes, notices of enforcement discretion) as well as the licensing of new facilities (e.g., early site permit applications, combined license applications), including proposed small modular reactors and advanced reactors. This methodology will give the staff more flexibility in assessing flood hazards at nuclear facilities so the staff will not have to rely on the use of the current deterministic methods, which can be overly conservative in some cases.

The main focus areas of the PFHA Research Program are to (1) leverage available frequency information on flooding hazards at operating nuclear facilities and develop guidance on its use, (2) develop and demonstrate a PFHA framework for flood hazard curve estimation, (3) assess and evaluate the application of improved mechanistic and probabilistic modeling techniques for key flood-generating processes and flooding scenarios, (4) assess potential impacts of dynamic and nonstationary processes on flood hazard assessments and flood protection at nuclear facilities, and (5) assess and evaluate methods for quantifying reliability of flood protection and plant response to flooding events. Workshop organizers used these focus areas to develop technical session topics for the workshop.

1.2 Workshop Objectives

The Annual PFHA Research Workshops serve multiple objectives: (1) inform and solicit feedback from internal NRC stakeholders, partner Federal agencies, industry, and the public about PFHA research being conducted by RES, (2) inform internal and external stakeholders about RES research collaborations with Federal agencies, the Electric Power Research Institute (EPRI), and the IRSN, and (3) provide a forum for presentation and discussion of notable domestic and international PFHA research activities.

1.3 Workshop Scope

The scope of the workshop presentations and discussions included the following:

- overview of flooding research programs of the NRC, other Federal agencies, and selected international organizations
- sensors
- climate influences on flooding hazards
- precipitation processes and modeling
- riverine flooding processes and modeling
- coastal flooding processes and modeling
- Duane Arnold derecho operational experience
- Tornado wind loads in the ASCE/SEI 7-2022 Standard
- U.S. Army Corps of Engineers National Inventory of Dams and National Levee Database updates

1.4 Organization of Conference Proceedings

Section 2 provides the agenda for this workshop. The agenda is also available from NRC's Agencywide Documents Access and Management System (ADAMS) at Accession No. ML22061A099.

Section 3 presents the proceedings from the workshop, including abstracts and presentation slides and abstracts for submitted posters.

The summary document of session abstracts for the technical presentations is available at ADAMS Accession No. ML22061A100. The complete workshop presentation package is available at ADAMS Accession No. ML22061A095.

Section 4 lists the workshop attendees and Section 5 summarizes the workshop.

1.5 Related Workshops

The NRC's Annual PFHA Research Workshops take place approximately annually at NRC Headquarters in Rockville, MD. The proceedings from the Sixth Annual PFHA Research Workshop (held February 22–25, 2021) have been published as RIL-2022-02. The proceedings from the Fifth Annual PFHA Research Workshop (held February 19–21, 2020) have been published as RIL-2021-01. NRC has published the collected proceedings from the first four workshops, listed below, as RIL-2020-01, available on the agency's public Web site:

- First Annual NRC PFHA Research Workshop, October 14–15, 2015
- Second Annual NRC PFHA Research Workshop, January 23–25, 2017
- Third Annual NRC PFHA Research Workshop, December 4–5, 2017
- Fourth Annual NRC PFHA Research Workshop, April 30–May 2, 2019

In addition, an international workshop on PFHA took place January 29–31, 2013. The workshop was devoted to sharing information on PFHAs for extreme events (i.e., annual exceedance probabilities (AEPs) much less than $2x10^{-3}$ per year) from the Federal community. The NRC issued the proceedings as NUREG/CP-302, "Proceedings of the Workshop on Probabilistic Flood Hazard Assessment (PFHA)," in October 2013 (ADAMS Accession No. ML13277A074).

2 WORKSHOP AGENDA

Day 1 (February 15, 2022) Oral Presentations

*** denotes speaker**

	Session 1A: Introduction	**Chair: *Joseph Kanney, NRC/RES***		
1A-0	Webinar Logistics	***Kenneth Hamburger**, *NRC/RES*	10:00	10:10
1A-1	Opening Remarks	***Ray Furstenau**, *Director, NRC Office of Research*	10:10	10:25
1A-2	NRC PFHA Research Program Update	***Tom Aird**, *NRC/RES*	10:25	10:40
1A-3	Moving FEMA towards Probabilistic Flood Risk Analysis and Probabilistic Flood Hazard Analysis	***David Rosa**, *Christina Lindemer, Federal Emergency Management Agency (FEMA)*	10:40	11:05
1A-4	Committee on the Safety of Nuclear Installations (CSNI) Working Group on External Events (WGEV)	***John Nakoski**, *NRC/RES (WGEV Chair)*	11:05	11:20
	Break		11:20	11:35
	Session 1B: Sensors	**Chair: *Joseph Kanney, NRC/RES***		
1B-1	(Keynote) Flood & Fire Sensors for Resilient Communities	***Jeffrey Booth**, *Department of Homeland Security, Science & Technology Directorate*	11:35	12:00
1B-2	USACE Instrumentation and Monitoring Program	***Georgette Hlepas*, Christopher Schaal****, *U.S. Army Corps of Engineers*	12:00	12:25
1B-3	USGS Water Mission Area Observing Systems Research and Development Program	***R. Russel Lotspeich**, *U.S. Geological Survey*	12:25	12:50
1B-4	State and Local Experience in Virginia Implementing IoT Sensors and Data Systems	***David Ihrie**, *Virginia Innovation Partnership Corporation*	12:50	13:15
1B-5	Sensor Panel Discussion	*All Presenters*	13:15	13:35
	Lunch		13:35	14:35

	<u>Session 1C: Climate</u>	**Chair: *Elena Yegorova, NRC/RES***		
1C-1	(KEYNOTE) Big Stories from the Historic Winter of 2020/21	***David Novak****, National Oceanic and Atmospheric Administration, National Weather Service (NOAA/NWS)*	14:35	15:05
1C-2	Linking Arctic variability and change with extreme winter weather in the US including the Texas Freeze of February 2021	***Judah Cohen*[1]****, Laurie Agel[2], Mathew Barlow[2], Chaim Garfinkel[3], Ian White[3]; [1]Atmospheric and Environmental Research, [2]University of Massachusetts Lowell, [3]Hebrew University of Jerusalem*	15:05	15:30
1C-3	2021 U.S. Billion Dollar Weather and Climate Disasters in Historical Context including New County-Level Exposure, Vulnerability and Projected Damage Mapping	***Adam Smith****, National Oceanic and Atmospheric Administration, National Centers for Environmental Information (NOAA/NCEI)*	15:30	15:55
1C-4	Climate Panel Discussion	*All Presenters*	15:55	16:25
1D	**Day 1 Wrap-up**		16:25	16:30

Day 2 (February 16, 2022) Oral Presentations

	Session 2A: Precipitation	**Chair: *Kevin Quinlan, NRC/NRR***		
2A-1	Uncertainty in Precipitation Frequency Estimates Under Current and Future Climate	***Azin Al Kajbaf****, *Michelle Bensi, Kaye Brubaker; University of Maryland*	10:05	10:30
2A-2	(KEYNOTE) Gridded Surface Weather Data with Uncertainty Quantification - Daymet V4	***Peter Thornton****, *Oak Ridge National Laboratory*	10:30	11:00
2A-3	Utility of Weather Types to Improve the Nonstationary Frequency Analysis of Extreme Precipitation	***Giuseppe Mascaro****, *Arizona State University*	11:00	11:25
	Break		11:25	11:35
2A-4	Characteristics and Causes of Extreme Snowmelt over the Conterminous United States	***Joshua Welty*[1]***, *Xubin Zeng[2]; [1]U.S. Navy Fleet Numerical Meteorology and Oceanography Center, [2]Univerity of Arizona*	11:35	12:00
2A-5	LIP PFHA Pilot Study	***Rajiv Prasad****, *Arun Veeramany, Rajesh Singh; Pacific Northwest National Laboratory (PNNL)*	12:00	12:25
2A-6	Precip Panel Discussion	*All Presenters*	12:25	12:55
	Lunch		12:55	14:00

	Session 2B: Riverine Flooding	Chair: ***Joseph Kanney, NRC/RES***		
2B-1	(KEYNOTE) Flood Typing and Application to Mixed Population Flood Frequency Analysis: An Interagency Collaborative Effort	***Nancy Barth**[*1]*, *Michael Bartles[2], John England[2], Jory Hecht[1], Gregory Karlovits[2], William Lehman[2]; [1]U.S. Geological Survey (USGS), [2]U.S. Army Corps of Engineers (USACE)*	14:00	14:30
2B-2	Applying Stochastic Weather Generation and Continuous Hydrologic Simulation for Probabilistic Flood Hazard Assessments	***Joe Bellini**[*1]*, *Bill Kappel[2], Dennis Johnson[2], Doug Hultstrand[2]; [1]Aterra Solutions, [2]Applied Weather Associates*	14:30	14:55
2B-3	IWRSS Flood Inundation Mapping for Flood Response	***Robert Mason*[1], Julia Prokopec*[1], Adam Barker*[2], Cory Winders*[3], Darone Jones*[4]***; *[1]U.S. Geological Survey, [2]Federal Emergency Management Agency, [3]U.S. Army Corps of Engineers, [4]National Weather Service*	14:55	15:20
2B-4	Using HEC-WAT for NRC's PFHA Process	***William Lehman****, *Gregory Karlovits, David Ho, Leila Ostadrahimi, Brennan Beam, Sara O'Connell, Julia Slaughter; U.S. Army Corps of Engineers Hydrologic Engineering Center (USACE/HEC)*	15:20	15:45
2B-5	Riverine Panel Discussion	*All Presenters*	15:45	16:15
2C	**Day 2 Wrap-up**		16:15	16:25

Day 3 (February 17, 2022) Poster Presentations

	<u>Session 3A: Posters</u>	**Chair: *Thomas Aird, NRC/RES***		
3A-1	Flood Fragility Function Methodology for a Conceptual Nuclear Power Plant	***Joy Shen****, *Michelle Bensi, Mohammad Modarres; University of Maryland*	10:00	11:00
3A-2	Quantifying Uncertainty in Hurricane Warning Times to Inform Coastal Hazard PRA	***Somayeh Mohammadi****, *Michelle Bensi; University of Maryland*	10:00	11:00
3A-3	HEC-WAT Interface and Set Up for the Trinity River PFHA Pilot Project	***David Ho****, *William Lehman, Brennan Beam, Sara O'Connell, Leila Ostadrahimi; U.S. Army Corps of Engineers, Hydrologic Engineering Center*	10:00	11:00
3A-4	Riverine Flooding HEC-WAT Pilot Project Dam Break Modeling	***Brennan Beam****, *William Lehman, Sara O'Connell, David Ho, Leila Ostadrahimi; U.S. Army Corps of Engineers, Hydrologic Engineering Center*	10:00	11:00
3A-5	Flooding from Below – The Groundwater Emergence Hazard	***Kevin M. Befus*[1]***, *Patrick L. Barnard[2], Peter W. Swarzenski[2], Clifford Voss[2]; [1]University of Arkansas, [2]U.S. Geological Survey*	10:00	11:00
3A-6	External Flooding PRA Guidance	***Marko Randelovic*[1], Raymond Schneider*[2]***; *[1]Electric Power Research Institute (EPRI), [2]Westinghouse Company*	10:00	11:00
	Break		11:00	11:10

Day 3 (February 17, 2022) Oral Presentations

	Session 3B: Coastal Flooding	Chair: *Joseph Kanney, NRC/RES*		
3B-1	(KeyNote) An Overview of CSTORM Model Development and Results for the South Atlantic Coastal Study (SACS)	***Margaret Owensby**[*1]*, *Chris Massey[1], Tyler Hesser[1], Mary Bryant[1], Andrew Condon[2]; [1]U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center, Coastal and Hydraulics Laboratory, [2]USACE Jacksonville District*	11:10	11:40
3B-2	Compound Flood Hazard Assessment using a Bayesian Framework	***Somayeh Mohammadi**[*1]*, *Michelle Bensi[1], Shih-Chieh Kao[2], Scott DeNeale[2], Joseph Kanney[3], Elena Yegorova[3], Meredith Carr[4]; [1]Univeristy of Maryland, [2]Oak Ridge National Laboratory, [3]U.S. Nuclear Regulatory Commission, [4]U.S. Army Corps of Engineers, Engineer Research and Development Center, Coastal and Hydraulics Laboratory*	11:40	12:05
3B-3	Coastal Flooding PFHA Pilot Study	***Victor M. Gonzalez****, *Meredith L. Carr, Karlie Wells, Norberto C. Nadal Caraballo; U.S. Army Corps of Engineers, Engineer Research and Development Center, Coastal and Hydraulics Laboratory*	12:05	12:30
3B-4	Probabilistic Wave Height Hazard Assessment Method at the NPP Site Considering Storm Surge	***Beom-Jin Kim****, *Daegi Hahm, Minkyu Kim; Korea Atomic Energy Research Institute*	12:30	12:55
3B-5	Comparative Assessment of Joint Distribution Models for Tropical Cyclone Atmospheric Parameters in Probabilistic Coastal Hazard Analysis	***Ziyue Liu**[*1]*, *Michelle Bensi[1], Meredith Carr[2], Norberto Nadal-Caraballo[2]; [1]University of Maryland, [2]U.S. Army Corps of Engineers Engineer Research and Development Center Coastal and Hydraulics Laboratory*	12:55	13:20
3B-6	Coastal Panel Discussion	*All Presenters*	13:20	13:50
3C	**Day 3 Wrap-up**		13:50	14:00

Day 4 (February 18, 2022) Oral Presentations

	Session 4A: Duane Arnold Derecho Operational Experience	Chair: ***Joseph Kanney, NCR/RES***		
4A-1	Duane Arnold Energy Center (DAEC) Loss of Offsite Power (LOOP) Due to Derecho	***Terry Brandt****, *Nextera Energy*	10:00	10:25
4A-2	The NRC's Regional Response to the Duane Arnold Derecho	***John Hanna****, *U.S. Nuclear Regulatory Commission, Region 3 (NRC/R3)*	10:25	10:50
4A-3	Why the Risk of the Extended Loss of Offsite Power Was Almost a Significant Precursor?	***Christopher Hunter****, *U.S. Nuclear Regulatory Commission, Office of Research (NRC/RES)*	10:50	11:15
4A-4	The NRC's Response to the Duane Arnold Derecho Event using the LIC-504 Process	***Matthew Leech****, *U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation (NRC/NRR)*	11:15	11:40
4A-5	Duane Arnold OpE Panel Discussion	*All Presenters*	11:40	11:40
	Break		11:40	11:55
	Session 4B: ASCE-7 Tornado Wind Loads	Chair: ***Elena Yegorova, NRC/RES***		
4B-1	Introduction to Tornado Loads in the New ASCE 7-22 Standard - Including Long Return Period Tornado Hazards Maps with Applications to Nuclear Facilities	***Marc Levitan****, *National Institute of Standards and Technology*	11:55	12:25
	Lunch		12:25	13:25
	Session 4C: USACE Dam and Levee Database Updates	Chair: ***Joseph Kanney, NRC/RES***		
4C-1	National Inventory of Dams	***Becky Ragon****, *U.S. Army Corps of Engineers*	13:25	13:55
4C-2	National Levee Database	***Brian Vanbockern****, *U.S. Army Corps of Engineers*	13:55	14:25
4D	**Workshop Wrap-up Discussion**		14:25	14:45

3 PROCEEDINGS

3.1 Day 1: Session 1A – Introduction

Session Chair: Joseph Kanney, NRC/RES/DRA

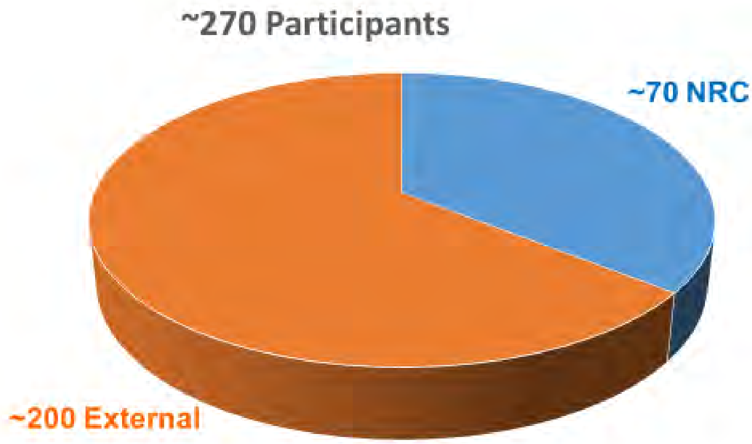
There are no abstracts for this introductory session.

3.1.1 Presentation 1A-1: Opening Remarks

Speaker: Raymond Furstenau, Director, NRC Office of Nuclear Regulatory Research

3.1.1.1 Presentation (ADAMS Accession No. ML22061A138)

Workshop Participation Snapshot



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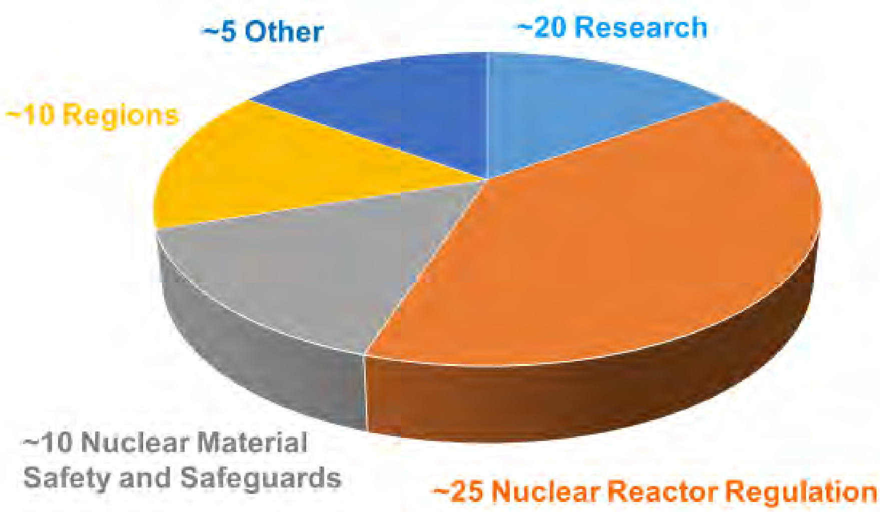
NRC Participation (~70 total)



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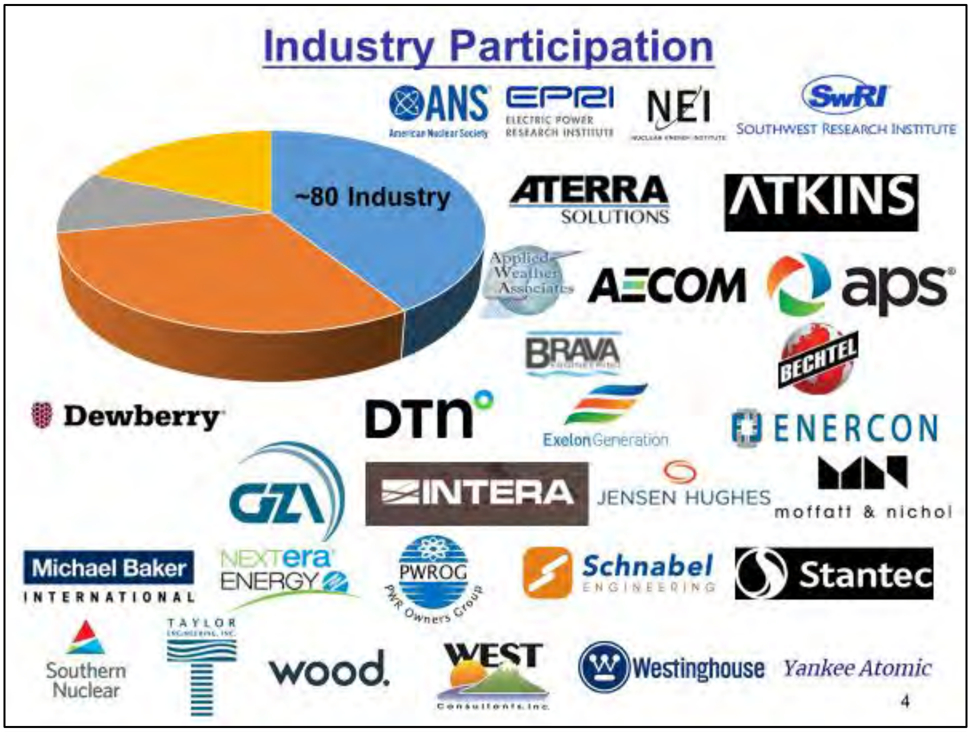
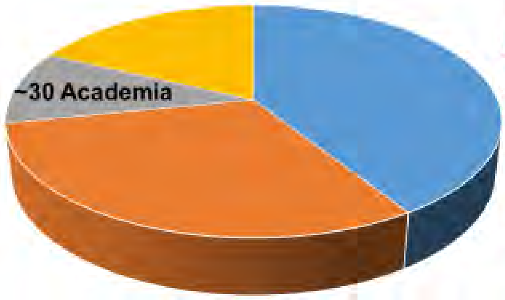

Industry Participation
~80 Industry
ANS
American Nuclear Society
EPRI
ELECTRIC POWER RESEARCH INSTITUTE
NEI
SwRI
SOUTHWEST RESEARCH INSTITUTE
ATERRA SOLUTIONS
ATKINS
Applied Weather Associates
AECOM
aps
BRAVA
BECHTEL
Dewberry
DTN
Exelon Generation
ENERCON
GZA
INTERA
JENSEN HUGHES
moffatt & nichol
Michael Baker INTERNATIONAL
NEXTera ENERGY
PWROG
PWR Owners Group
Schnabel ENGINEERING
Stantec
Southern Nuclear
TAYLOR
wood.
WEST
Consultants, Inc.
Westinghouse
Yankee Atomic
4


Non-NRC Government Participation
~70 Government (Non-NRC)
US Army Corps of Engineers.
TVA
INL
Idaho National Laboratory
OAK RIDGE
Pacific Northwest
BERKELEY LAB
FEMA
USGS
science for a changing world
BUREAU OF RECLAMATION
NIST
National Institute of Standards and Technology
U.S. Department of Commerce
NCEI
NOAA
NATIONAL WEATHER SERVICE
CO
DNR
Office of the State Engineer
Interstate Stream Commission
DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA
5

Academic Participation



Arizona State University

Harvard

Idaho State University

Massachusetts Institute of Technology

George Mason University

NCAR

The University of Arizona

University of Arkansas

University of Maryland

The University of Iowa

University of Notre Dame

Virginia Commonwealth University

Virginia Tech

University of Oxford

Wisconsin

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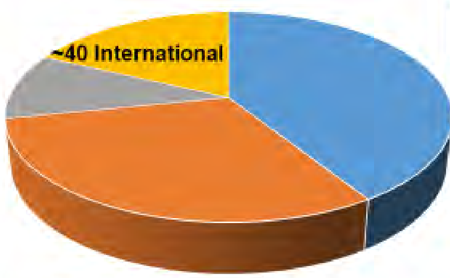
International Participation



Authority for Nuclear Safety and Radiation Protection

CNSC CCSN

FANR
الهيئة الاتحادية للرقابة النووية
Federal Authority for Nuclear Regulation

EDF

framatome

GRS

IAEA

IRSN
Institut de Radioprotection et de Sûreté Nucléaire

BC Hydro
Power smart

Government of India
AERB
Atomic Energy Regulatory Board

STCU

NEA

KAERI
Korea Atomic Energy Research Institute

RATEN ICN PITEŞTI
Institutul de Cercetări Nucleare

Joint Research Centre JRC

OECD

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3.1.2 Presentation 1A-2: NRC Probabilistic Flood Hazard Assessment Research Program Overview

Authors: *Thomas Aird, Joseph Kanney, Elena Yegorova*, NRC Office of Nuclear Regulatory Research

Speaker: Thomas Aird

3.1.2.1 Presentation (ADAMS Accession No. ML22061A137)

NRC Probabilistic Flood Hazard Assessment Research Program Update

Thomas Aird*, *Joseph Kanney, Elena Yegorova*

Fire and External Hazards Analysis Branch
Division of Risk Analysis
Office of Nuclear Regulatory Research

7th Annual PFHA Research Workshop
NRC HQ, Rockville, MD
February 15 – 18, 2022

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Outline

- Objectives, key challenges, approach
- Phase 1 Overview (Technical Basis)
- Phase 2 Projects (Pilot Studies)
- Thoughts on Phase 3 (Guidance)



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PFHA Research Objectives

- Develop resources, tools and selected guidance to:
  - Address significant gap in the technical basis for guidance for probabilistic assessment of external hazards
    - Probabilistic: seismic, high winds
    - Deterministic: flooding
  - Support risk-informed licensing and oversight activities involving assessment of flooding hazards and potential consequences
    - Licensing and oversight in operating reactor program
    - Design basis flood hazard assessments for new facilities
      - Readiness for licensing of advanced reactors

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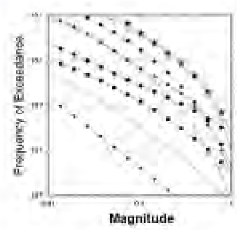
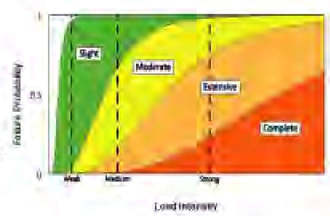
Key Challenges

- Hazard Estimation
  - Range of annual exceedance probabilities (AEPs)
    - Moderately rare to extreme floods
  - Multiple flooding mechanisms
    - Coincident and correlated mechanisms
  - Uncertainty characterization and estimation
    - Aleatory (e.g., storm recurrence rates)
    - Epistemic (e.g., model structure, parameters)
- Fragility
  - Information on reliability of flood protection features and procedures is sparse
  - Cliff-edge effects





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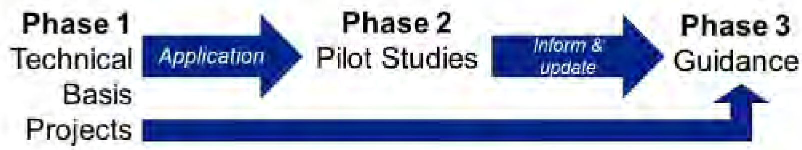
Phased Research Approach



- Phase 1 – Technical Basis Research - ***Complete***
  - *Climate and precipitation*
  - *Mechanistic, statistical and probabilistic modeling of flooding processes*
  - *Reliability of flood protection features and procedures*
  - *Modeling Frameworks*
  - *Natural Hazard Information Digest (NHID)*
- Phase 2 – Pilot Studies - ***In Progress***
  - *Local Intense Precipitation (LIP) Flooding*
  - *Riverine Flooding* - Complete
  - *Coastal Flooding*
- Phase 3 – Develop Guidance - ***In Progress***

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Phase 1 Technical Basis Research

- **Climate**
  - ***Historical trends and future projections for U.S. regions***
- **Mechanistic, statistical and probabilistic modeling of flooding processes**
  - ***Extreme precipitation***
  - ***Riverine flooding***
  - ***Coastal flooding***
- **Methods for Estimating Joint Probabilities of Coincident and Correlated Flooding Mechanisms**
  - ***Riverine flooding***
  - ***Coastal flooding***
- **Reliability of flood protection features and procedures**
  - ***Flood barriers (seals, etc.)***
  - ***Environmental effects on manual actions***
- **Modeling Frameworks**
  - ***Structured hazard assessment committee process for flooding (SHAC-F)***
  - ***Dynamic analysis of flooding events***
  - ***USACE HEC-WAT***
- **Natural hazards information digest (for internal NRC staff use)**
  - ***Collect and organize natural hazard information for operating reactors***

For more details on Phase 1 completion see Digital Exhibit #11 at the 34th Annual Regulatory Information Conference (RIC), March 8-10, 2022:
https://www.nrc.gov/public-involve/conference-symposia/ric/index.html

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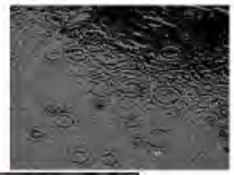
Phase 2: Pilot Studies

Objective: **Synthesize results from technical basis research**

- **Multiple flooding mechanism contribution to hazard curves**
- **Quantify key aleatory variabilities and epistemic uncertainties**



- **LIP Flooding PFHA Pilot**
  - **PNNL**
  - *In Progress; completion expected in March 2022*

- **Riverine Flooding PFHA Pilot**
  - **USACE/HEC**
  - *Completed in January 2022*

- **Coastal Flooding Pilot PFHA Pilot**
  - **USACE/ERDC/CHL**
  - *In Progress; completion expected in June 2022*

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Phase 2: LIP Pilot Study

- **Objectives**
  - *Inform guidance development for probabilistic assessment of site-scale flooding hazards due to local intense precipitation*
  - *Synthesize results from technical basis research*
  - *Incorporate site-scale features (curbs, buildings, drains)*
- **Key elements**
  - *Point rainfall (aleatory variability) based on NOAA Atlas 14*
  - *Sensitivity study to identify key epistemic uncertainties wrt site features*
  - *Propagation of uncertainties to construct hazard curve families for selected flood hazard metrics (e.g., depth, velocity, duration)*
  - *Monte Carlo simulation with stratified sampling*
- **More detailed information:**
  - *Presentation 2A-5 (Wednesday at 12:00)*

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Phase 2: Riverine Pilot Study

- **Objectives**
  - *Inform guidance development for probabilistic assessment of riverine flooding hazards*
  - *Synthesize results from technical basis research*
  - *Incorporate multiple flooding mechanism contributions to hazard curves*
- **Key elements**
  - *Stochastic rainfall model (aleatory variability)*
  - *Epistemic uncertainties in hydrologic (runoff and routing), reservoir, and hydraulic models*
  - *Multiple dam failure scenarios*
  - *Propagation of uncertainties to construct hazard curve families for selected flood hazard metrics (e.g., elevation, velocity, duration)*
  - *Monte Carlo simulation approach using HEC-WAT*
- **More detailed information:**
  - *Presentation 2B-4 (Wednesday at 15:20)*
  - *Posters 3A-4 and 3A-5 (Thursday at 10:00)*

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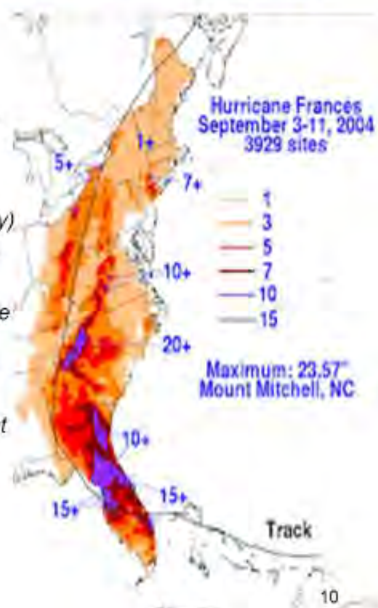
Phase 2: Coastal Pilot Study

- **Objectives**
  - *Inform guidance development for probabilistic assessment of coastal flooding hazards*
  - *Synthesize results from technical basis research*
  - *Incorporate multiple flooding mechanism contributions to hazard curves*
- **Key elements**
  - *Tropical cyclone rainfall model (aleatory variability)*
  - *Epistemic uncertainties in hydrodynamic (surge), hydrologic (runoff and routing), and hydraulic models*
  - *Flooding due to surge and rainfall-induced riverine discharge*
  - *Propagation of uncertainties to construct hazard curve families for selected flood hazard metrics (e.g., elevation, velocity)*
  - *USACE Probabilistic Coastal Hazard Assessment (PCHA) framework*
- **More detailed information:**
  - *Presentation 3B-3 (Thursday at 12:05)*



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Protecting People and the Environment

Phase 3: PFHA Guidance

- **FY 22/FY23: Develop draft guidance based on:**
  - *Technical basis research*
  - *Pilot projects*
  - *User office needs*
  - *Stakeholder & public interests*

- **FY23: Publish draft guidance for public comment**
- **FY23: Finalize guidance based on public comment**

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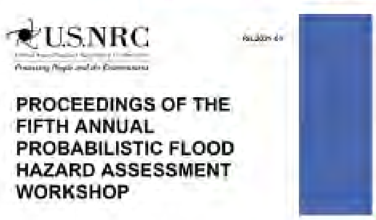
Past Workshops

- **Proceedings of 1st-4th Annual NRC PFHA Research Workshops**
  - ***NRC Research Information Letter (RIL) 2020-01***
- **Proceedings of 5th Annual NRC PFHA Research Workshop**
  - ***RIL 2021-01***
- **Proceedings of 6th Annual NRC PFHA Research Workshop**
  - ***RIL 2022-02***

NRC Research Information Letters are available at:

https://www.nrc.gov/reading-rm/doc-collections/index.html#ril



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Questions?

Contacts:
Joseph.Kanney@nrc.gov
Thomas.Aird@nrc.gov
Elena.Yegorova@nrc.gov

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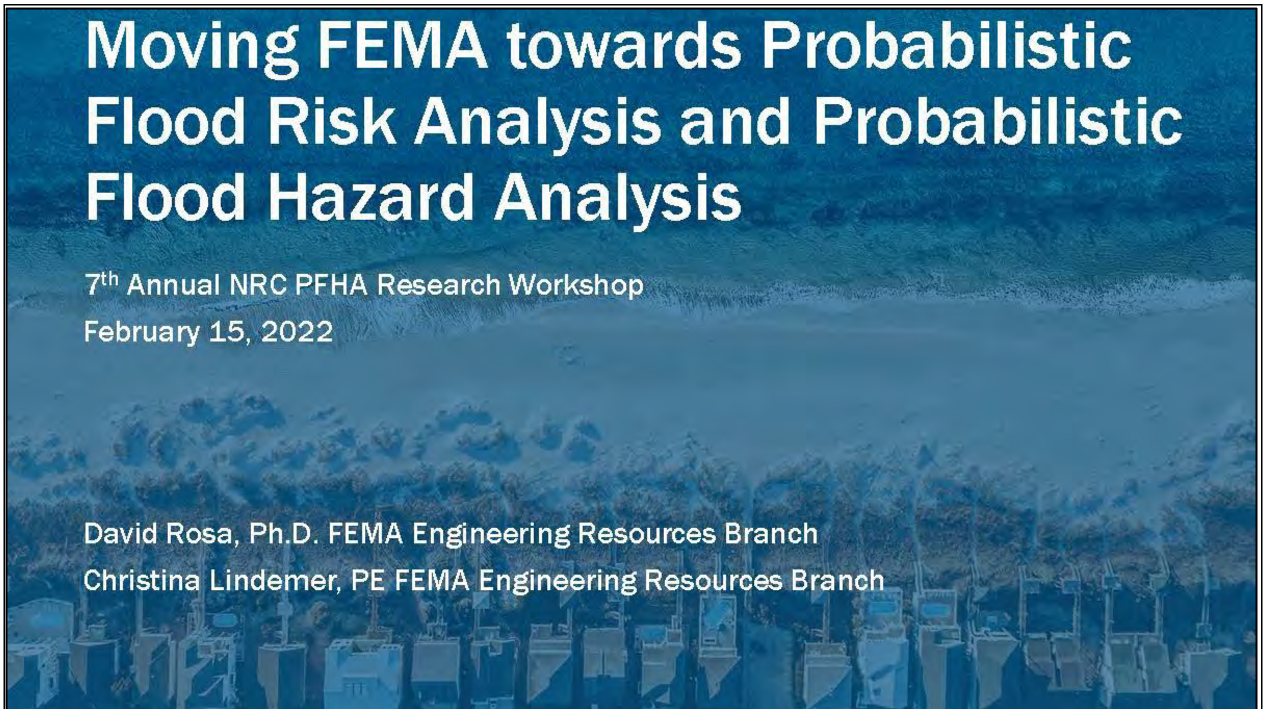
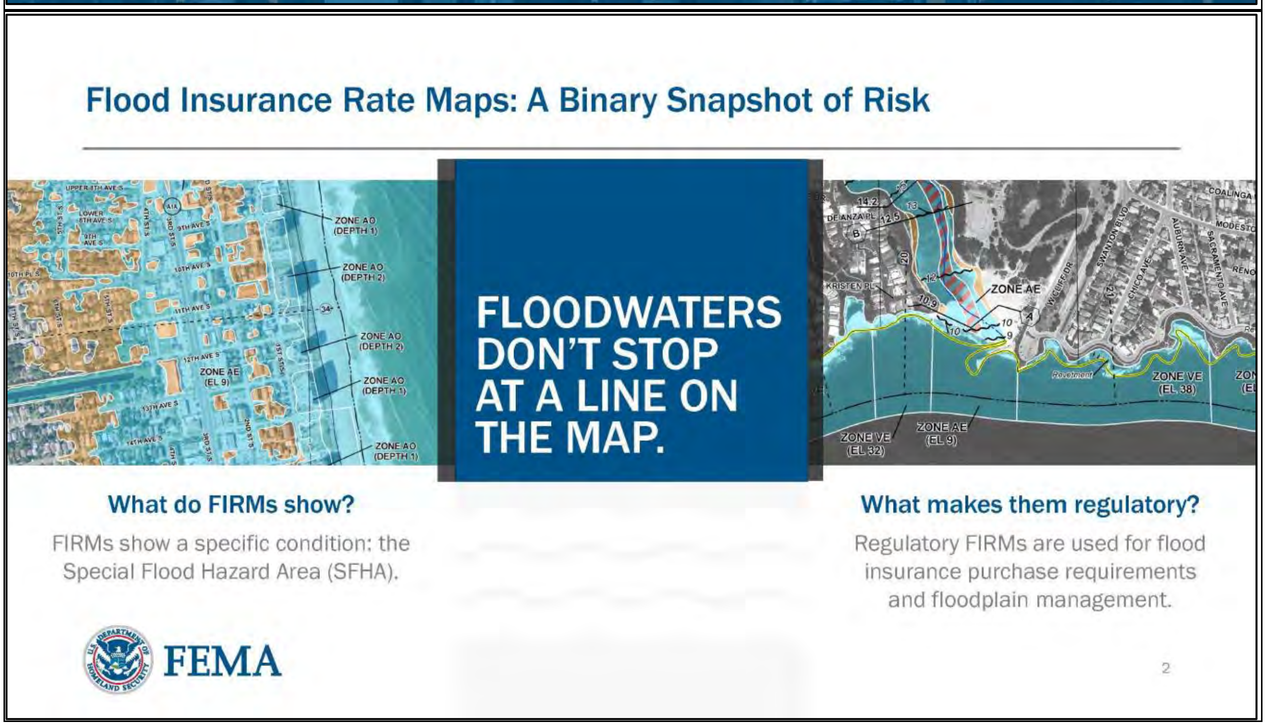
3.1.3 Presentation 1A-3: Moving FEMA towards Probabilistic Flood Risk Analysis and Probabilistic Flood Hazard Analysis

Authors: David Rosa, Christina Lindemer, Federal Emergency Management Agency (FEMA)*
Speakers: *David Rosa*

3.1.3.1 Presentation (ADAMS Accession No. ML22061A136)





- Regulatory FIRM leads people to believe that if they are 'out' of the SFHA, they are not at risk.
- Leads to communities to focus on lines on a map as a complete picture of flood risk.

<u>A more complete picture</u>

- Flooding can take many forms, can be minimal or severe, can have several driving factors
- FEMA's Future of Flood Risk Data (FFRD) initiative seeks to improve the state of mapping, adopting a probabilistic, risk-based approach to displaying graduated data

FEMA

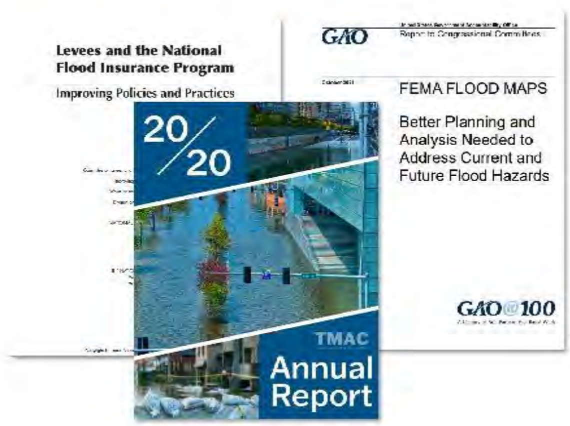
3

Transition to Future of Flood Risk Data (FFRD)

<u>Feedback from stakeholders</u>

- Technical Mapping Advisory Council (TMAC)
- GAO
- National Academy of Sciences
- Other Agencies

- Also, unmet statutory authorities including identifying residual risk behind levees



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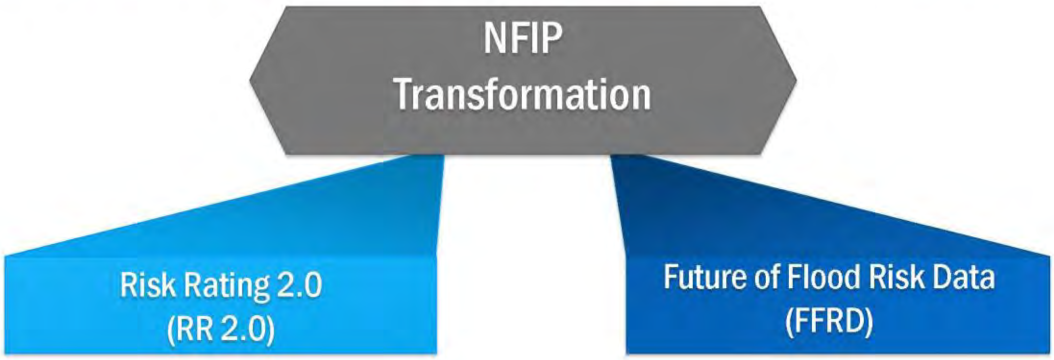
The NFIP in transforming to a risk-informed framework that enhances the Nation's understanding of risks from flood hazards. Risk Rating 2.0 and Future of Flood Risk Data are two components of this initiative.



FEMA

5

What is different about FFRD?

	Risk MAP	Future Flood Risk Data
Service Model	*Product (FIRMs)*	*Data service model; user decision behavior drives product*
Investments	*Project driven - base data only generated for project area*	*National scale base data with federal partners*
Model Coverage	*Patchwork of models and flood hazard assessment*	*Nationwide flood hazard/risk assessments*
Frequency Interval	*Optimized around 1-percent annual-chance*	*Multiple flood hazards, multiple frequencies*

6

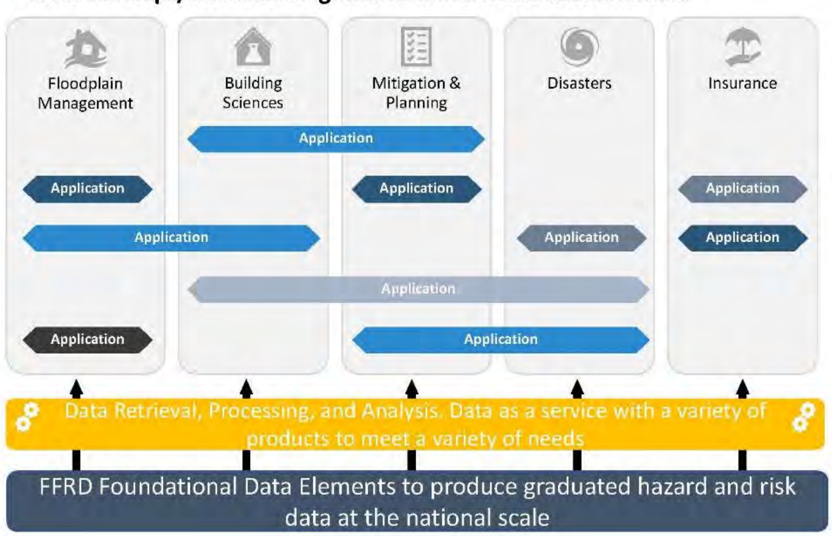
Graduated Flood Hazard and Flood Risk Application and Use Case Examples

FEMA

7

Reimagining the Opportunities created by improved Hazard and Risk Data

- **FFRD Concept/Use Case Alignment to Individual Stakeholders**

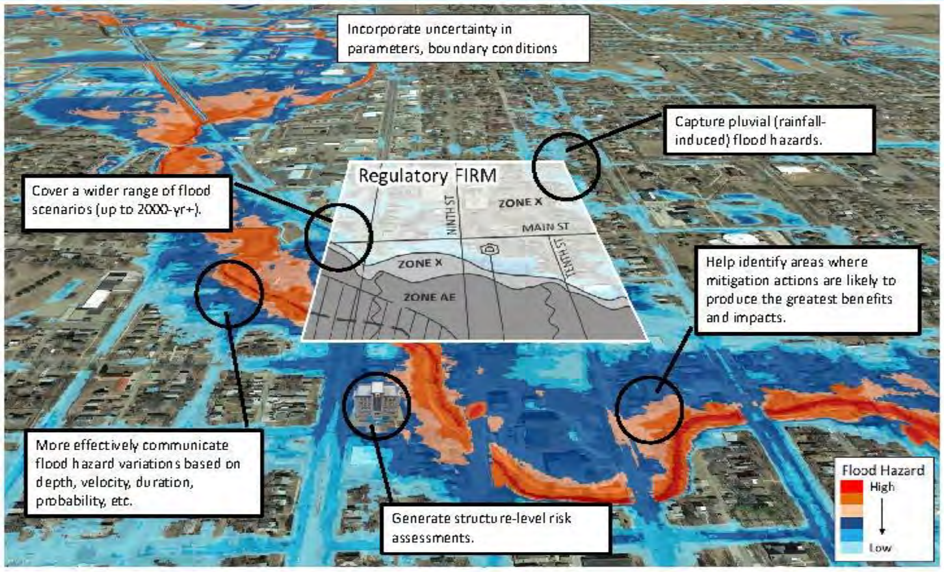


Applications of FFRD

- Data applications by multiple stake-holders with cross-cutting benefits
- Flexibility for FEMA, other agencies, state and local partners, private entities, and other data users to develop tools and products to help meet their needs in reducing flood risk and increasing resiliency

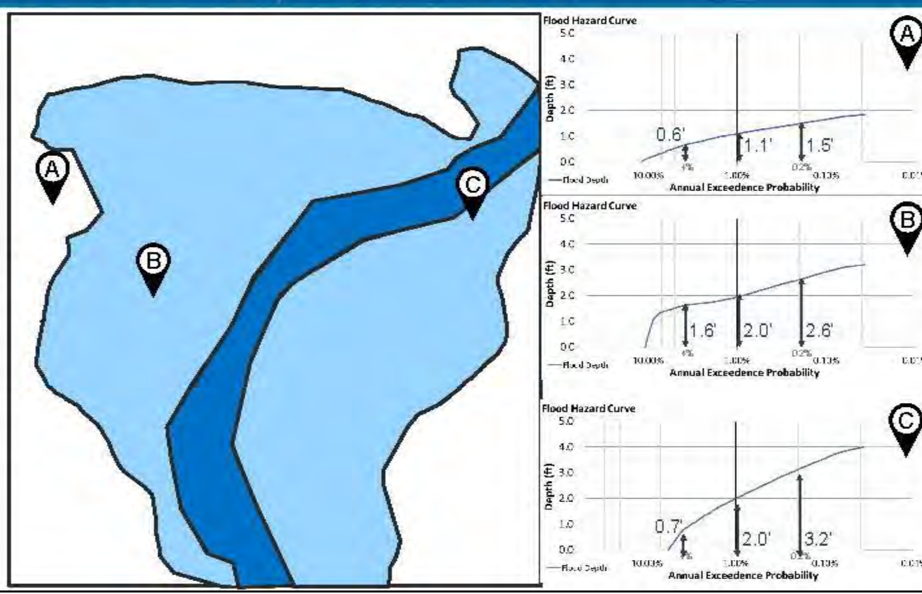
8

What does FFRD tell us about the Nation's Risk?
Comparison of Probabilistic Data to Traditional FIS Products

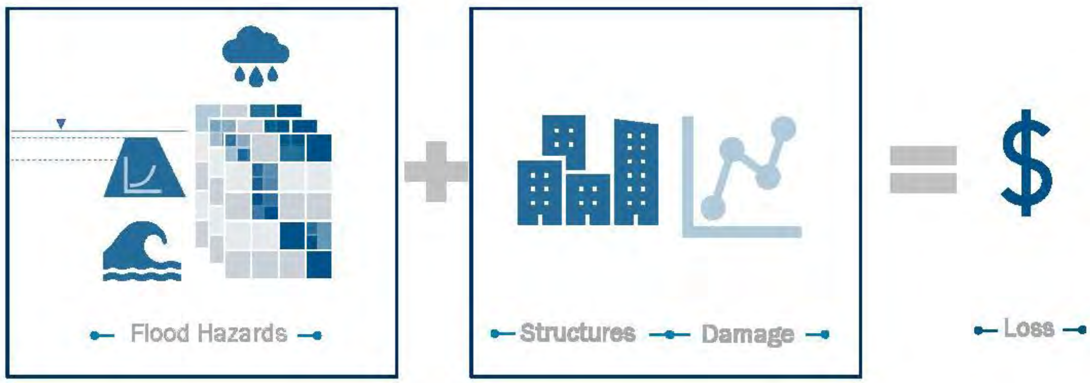


What does FFRD tell us about the Nation's Risk?
FFRD improves the understanding of unique flood hazards

- FFRD accounts for a range of conditions, frequencies, and severities
- Instead of being "inside" or "outside" the floodplain, each structure can have an associated annual exceedance probability (AEP) for each dimension of flood hazards studied.



FFRD highlights where there is RISK



FEMA

RiskMAP
Increasing Resilience Together

11

Potential Applications for Graduated Flood Risk Data

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Hazard Data Beyond the SFHA

13

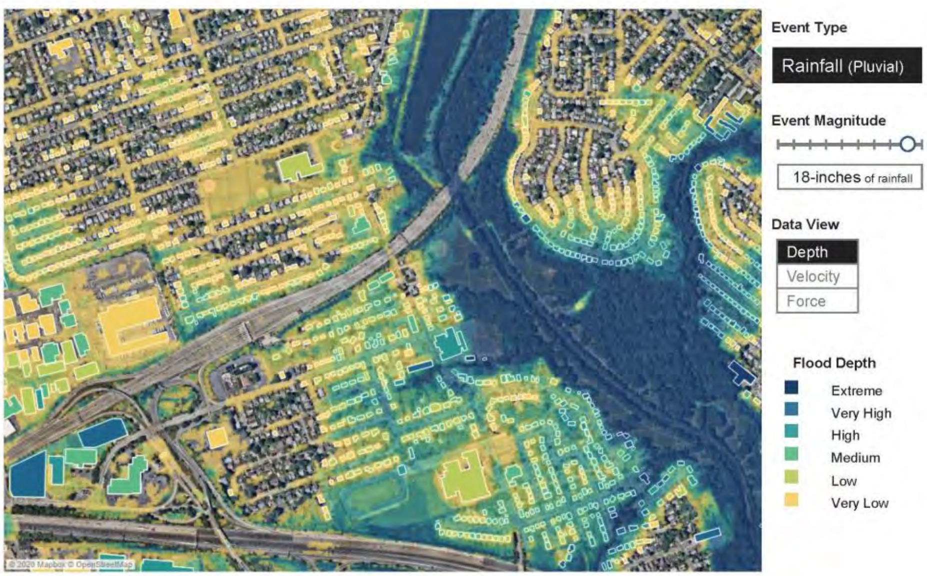
Hazard Data Beyond the SFHA

14

Beyond the SFHA: Fluvial Scenarios

15

Beyond the SFHA: Pluvial Scenarios



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Beyond the SFHA: Graduated Hazard

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Graduated Flood Zones by Hazard Level

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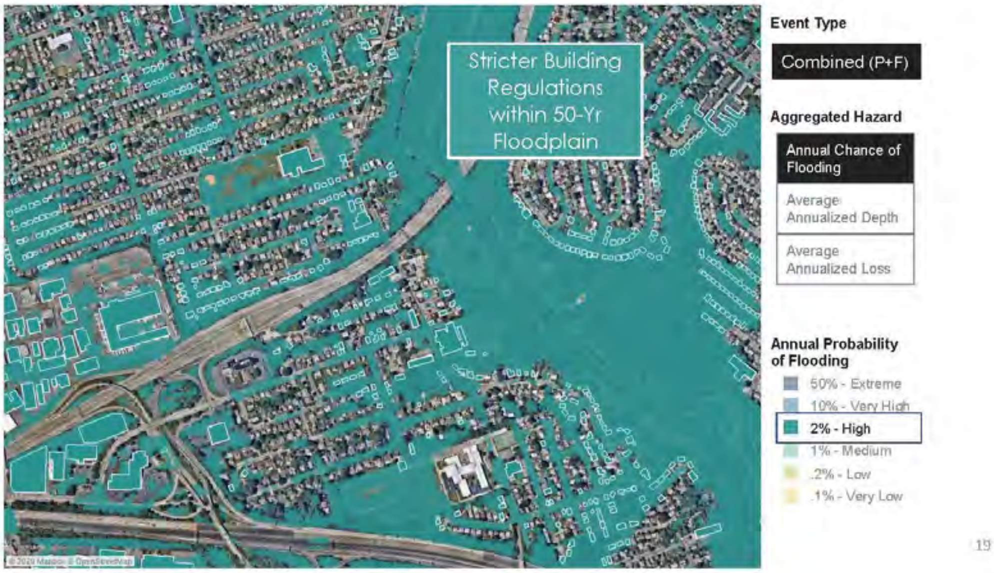
Graduated Flood Zones by Hazard Level



Graduated Flood Zones by Hazard Level

Graduated Risk at the Building Level

21

Graduated Risk Hot Spots

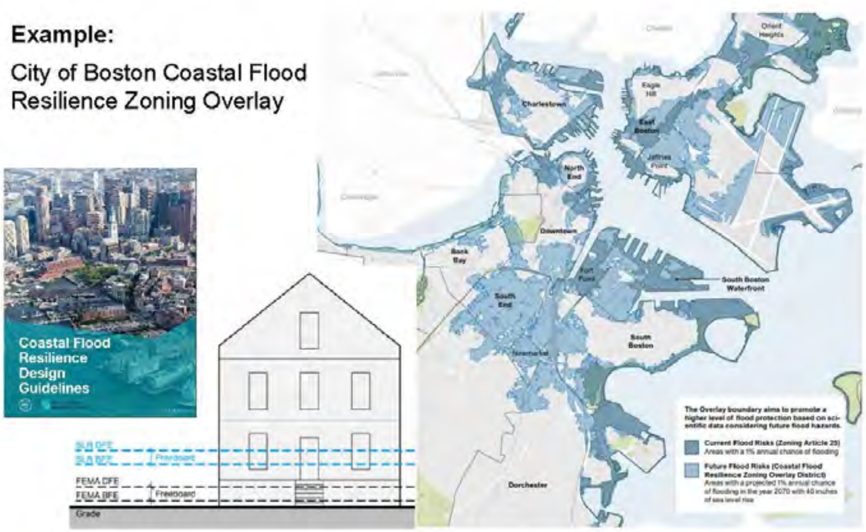
22

Graduated Flood Zones by Existing Risk

23

Example:

City of Boston Coastal Flood Resilience Zoning Overlay



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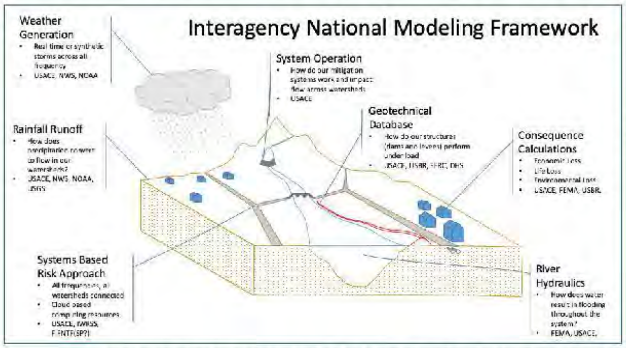
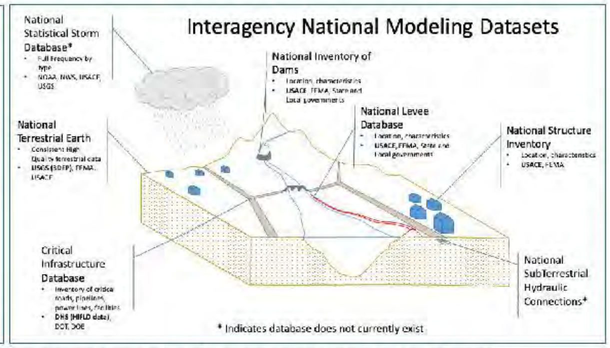
Authorities of FEMA and Other Federal Agencies

The increased data set and methodology for the shift to graduated risk can't be done by FEMA alone...





...so we are currently exploring the best way to leverage the strengths of our federal, state, local, tribal, and territorial community partners to develop and deliver graduated risk data.

FEMA | USGS | USACE | IWRSS | NOAA | NWS

FEMA

RiskMAP
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Q & A

FEMA

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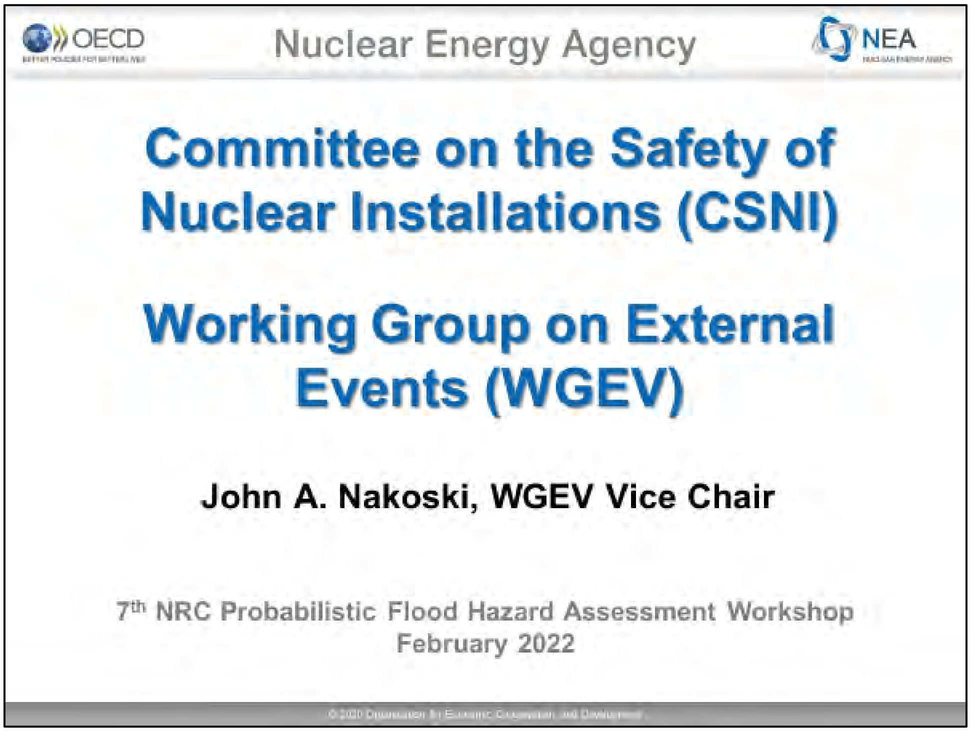
3.1.4 Presentation 1A-4: Committee on the Safety of Nuclear Installations (CSNI) Working Group on External Events (WGEV)

Speaker: John Nakoski, NRC/RES/DRA (WGEV Chair)

3.1.4.1 Presentation (ADAMS Accession No. ML22061A135)



Nuclear Energy Agency

WGEV Administration

- **WGEV Chair:** Min Kyu Kim (KAERI, South Korea)
- **WGEV Bureau:** John A. Nakoski – Vice Chair (NRC, USA), ShiZhong Lei (CNSC, Canada), Dana Havlin Novakova (SONS, Czechia), Vincent Rebour (IRSN, France), Gernot Thuma (GRS, Germany), Stef Carelsen (ANVS – Netherlands)
- **WGEV Participants from:**
  - Belgium (BelV), Bulgaria (Kozloduy NPP), Canada (CNSC, OPG), Czech Republic (SONS), Finland (STUK), France (IRSN, EdF), Germany (GRS), Japan (NRA), Netherlands (ANVS), Poland (PPA), Romania (Cernavoda NPP), Spain (CSN), South Korea (KAERI), Sweden (SSM), Switzerland (ENSI), United States (NRC, DOE, EPRI)
  - International Atomic Energy Agency, and World Metrological Organization
- **NEA Technical Secretariat:** Taehee Kim
- **Established in 2014**
- **Meets twice a year**

Nuclear Energy Agency

Completed Activities

- NEA/SEN/SIN/WGEV(2015)1 – Technical Note on Severe Weather with Concurrent Flooding and High Winds
- NEA/CSNI/R(2017)13 – Proceedings for the Workshop on Severe Weather and Storm Surge
- NEA/CSNI/R(2018)7 – Examination of Approaches for Screening External Hazards
- NEA/SEN/SIN/WGEV(2018)1 – Topical Report on Riverine Flooding
- NEA/SEN/SIN/WGEV(2018)13 – Proceedings for the Workshop on Riverine Flooding
- NEA/CSNI/R(2020)9 – Concepts and Definitions for Protective Measures in Response to External Flooding Hazards

Ongoing Activities (1 of 4)

- **Benchmark on Hazard Frequency and Magnitude Model Validation for External Events**
  - Approved by CSNI in June 2021, currently in publications
  - For more information contact Curtis Smith (Curtis.Smith@inl.gov) or Vincent Rebour (Vincent.Rebour@irsn.fr)
- **High winds and tornadoes**
  - Survey responses – February 2020
  - Preparation of initial draft report – June 2020
  - Final report – June 2021
  - Workshop – March 22nd – 25th, 2022 (Virtual)

OECD Nuclear Energy Agency NEA

Ongoing Activities (2 of 4)

- **High winds and tornadoes Workshop** March 22nd – 25th, 2022 (Virtual)
  1. **Phenomenological aspects of HW &T** – Main objective is to have subject matter experts share their understanding of the phenomena associated with HW&T.
  2. **Data** – Main objective is to have subject matter experts share their understanding of the sources of the data associated with HW&T.
  3. **Design& Operation** – Main objective is to better understand how the impacts from the HW&T are reflected in design and operation, including the issues associated with direct and indirect effects, and their combinations.
  4. **Safety case approaches** – Main objectives is to better understand the development of the safety case based on deterministic, probabilistic or combined assessments to demonstrate the design and operation of the facility will be done safely, considering HW&T. Also considering how climate change and/or combination of effects influences the safety case.

OECD Nuclear Energy Agency NEA

Ongoing Activities (3 of 4)

- **Combinations of External Hazards**
  - Hazards and Impact Assessment and Probabilistic Safety Analysis for Nuclear Installations (joint project of WGEV and WGRISK)
  - Kick-off meeting – February 2020
  - Survey responses – September 2020
  - Preparation of initial draft report – September 2021
  - Final survey response report – June 2022
  - Joint WGEV/WGRISK workshop – Fall of 2022

OECD Nuclear Energy Agency NEA

Ongoing Activities (4 of 4)

- **Uncertainties in the Assessment of Natural Hazards**

Phase 1 - Sources of Uncertainty

- **Decision on Spectrum of natural hazards to consider – March 2021**
- **Draft report based on literature review – March 2022**
- **Workshop on Sources of Uncertainty – April 15th to 18th, 2022 (hybrid – virtual/in person in Prague)**
- **Technical Report and Workshop Proceedings – December 2023**

Phase 2 - Methods to Deal with Uncertainties

- **Report Structure and Content decided – September 2022**
- **Workshop on Methods to Deal with Uncertainties – March 2024**
- **Technical Report and Workshop Proceedings – December 2024**

Potential Future Activities

- **Local Intense Precipitation** – under development
- **Topical discussions and issues being considered**
  - Geomagnetic Storms and Space weather
  - Improving data sources for hazards assessment
  - Climate Change impacts on Hazards Assessment

OECD Nuclear Energy Agency NEA

Thank you for your attention!

3.2 Day 1: Session 1B –Flood & Fire Sensors for Resilient Communities

Session Chair: Joseph Kanney, NRC/RES/DRA

3.2.1 Presentation 1B-1 (KEYNOTE): Flood and Fire Sensors for Resilient Communities

Author: Jeffrey Booth, Department of Homeland Security, Science & Technology Directorate

Speaker: Jeffrey Booth

3.2.1.1 Abstract

Flooding and Wildland Fires are the nation's leading natural disasters, accounting for the greatest loss of life, property damage and economic impact while threatening the resiliency of communities across the country. Current flood damage is estimated at $5 billion per year and wildland fires annualized losses are estimated to range from $63.5 billion to $285 billion. The human cost is much greater.

The Department of Homeland Security (DHS) has been working with small businesses on the development, evaluation, and commercialization of low-cost Internet of Things (IoT) flood and wildland fire sensors. The goal is to provide earlier alerts, warnings and notifications of rising waters and fire ignitions, allowing communities the ability to better respond, mitigate and possibly prevent catastrophic disasters.

3.2.1.2 Presentation (ADAMS Accession No. ML22061A134)

U.S. Department of Homeland Security | Science and Technology Directorate

Nuclear Regulatory Commission: Probabilistic Flood Hazard Assessment Workshop:

Flood and Fire Sensors for Resilient Communities

Science and Technology

Jeff Booth, Director, Sensor & Platform Technology Center
Department of Homeland Security
Science and Technology Directorate

February 15, 2022

Executive Summary

Flood and Fire Sensors for Resilient Communities

Flooding and Wildland Fires are the nation's leading natural disasters, accounting for the greatest loss of life, property damage and economic impact while threatening the resiliency of communities across the country.

Current flood damage is estimated at $5 billion per year and wildland fires annualized losses are estimated to range from $63.5 billion to $285 billion.

The human cost is much greater.

2

2017. (Santa Barbara County Fire Department)

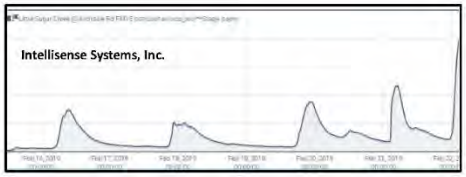
Science and Technology

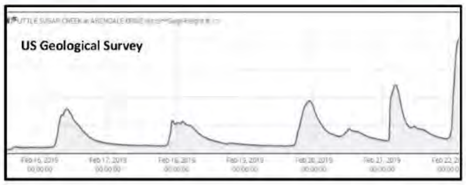
Low-Cost IoT Flood Sensors

Flood Sensor Technology Video:
https://www.dhs.gov/medialibrary/assets/videos/19974

Low-Cost IoT Flood Sensors: Phased Approach

Low-Cost IoT Flood Sensors: Relative Accuracy





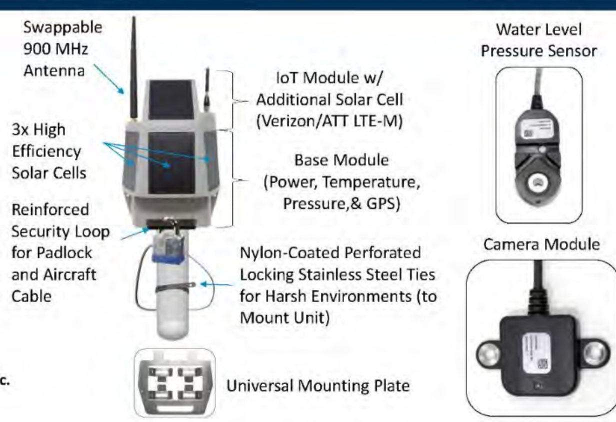
"The DHS APEX gauges have assisted Howard County In our efforts to improve and advance the flood warning system in Ellicott City.

Additionally, we shared data with US National Weather Service (NWS) and they indicated that among the gages there was data provided by the pilot program that could "absolutely" be accepted the into their system."

- Brian Cleary, Howard County, MD
Storm Water Management Division

Science and Technology

Low-Cost IoT Flood Sensors: Hardware Configuration



Intellisense Systems, Inc.

Science and Technology

Flood Sensor Stakeholders and Use Cases

STAKEHOLDERS
- US Army Corps of Engineers
- US Geological Survey
- Kentucky
- North Carolina
- Texas
- Virginia
- Charlotte-Mecklenburg County, NC
- Montgomery County, MD
- Ellicott City, MD
- Nashville, TN
- Norfolk, VA
- Torrance, CA
- State University, Albany NY
- The Nature Conservancy

USE CASES
- Urban flash flooding
- Culvert runoff
- Coastal flooding
- Storm Surge
- Repetitive Loss valuation
- Dam Safety Monitoring
- Storm Water Management
- Water supply fire suppression
- Sheet wash over highways
- Critical Infrastructure shutdown
- Wetland mitigation monitoring
- Agriculture irrigation








Wildland Fire Sensors

National Fire Activity Synopsis

The 2020 fire season saw an increase in the annual number of acres burned with over 10 million acres. The large fire activity in 2020 was well above average.

A total of 17,904 structures were reported destroyed by wildfires in 2020, including 9,630 residences, 7,255 minor structures, and 1,119 commercial / mixed residential structures.

- National Interagency Coordinating Center Wildland Fire Summary & Statistics Annual Report 2020

2017. (Santa Barbara County Fire Department)

Science and Technology

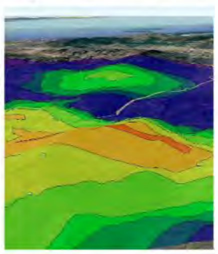
Wildland Fire Sensors

Wildland Fire Sensor Technology Video:
https://www.dhs.gov/medialibrary/assets/videos/21982

Wildland Fire Sensors: Phase 1 Prototype

Wildland Fire Sensors: Phase 2 Modeling and Testing

Conducted **extensive modeling** to define and understand the level of concentrations of smoke composition and particulate matter at a variety of distances and wind conditions



Designed a Test Lab approach and mechanism to test the sensors at low levels of smoke concentrations in a repeatable manner using chaparral fuel

Tested many scenarios of different burn characteristics (ignition, smoldering, flaming combination, etc.) and different environmental conditions

Conducted test and demonstration at a prescribed burn over 2 days in Red Bluff, CA. Sensors repeatedly demonstrated ability to detect smoke, at ignition and at a distance

Wildland Fire Sensors: Stakeholders

California Department of Forestry & Fire Protection CAL FIRE Since 1885

California Office of Energy Infrastructure Safety

Cal OES Governor's Office of Emergency Services

The Nature Conservancy

U.S. Fire Administration

Forest Service U.S. Department of Agriculture

U.S. Department of Homeland Security FEMA

Thanks to our continuous Stakeholders from FEMA, Cal OES, Cal Fire, Cal OEIS, USFA, USFS throughout the Phases.

Science and Technology

Wildland Fire Sensors: Phase 2 Findings

- Backend algorithms need revision and need to combine data from multiple sensors and meteorological conditions to provide greatest situational awareness of wildfires
- Multi-modal sensors are necessary to detect wildfires and avoid nuisance alarms (multiple gas types and multiple PM types)
- Multiple sensing algorithms should be developed for near vs. far detection (smoke particles clumped over longer distances and smaller particles traveled farther)
- Cellular data back-haul was most reliable with long-range radios, an option in cellular denied areas
- Initial ability to distinguish a new ignition vs. background smoke

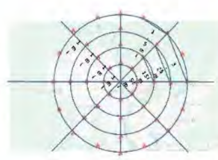
Science and Technology

Wildland Fire Sensors: Phase 3 Next Steps

Breeze Technologies UG

N5 Sensors, Inc.

- The sensors deployed in Phase 2 were spaced between 150 ft and 3 mi of the ignition sites. This lead to the plan for Phase 3 sensors to be placed within 1 mile of each other to balance detection time vs. density
- 100 sensors / performer to be deployed to determine optimal densification of sensors vs. detection
- Stakeholder infrastructure discussions for sensor installation & monitoring



[SCIENCE AND TECHNOLOGY DIRECTORATE]

Engage with us:

scitech.dhs.gov

SandT.Innovation@hq.dhs.gov

@dhsscitech

Science and Technology

Low-Cost IoT Flood Sensors

QUESTIONS?

Wildland Fire Sensors

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2017. (Santa Barbara County Fire Department)

Science and Technology

3.2.2 Presentation 1B-2: USACE Instrumentation and Monitoring Program

Authors: Georgette Hlepas, Christopher Schaal, U.S. Army Corps of Engineers

Speakers: Georgette Hlepas, Christopher Schaal

3.2.2.1 Abstract

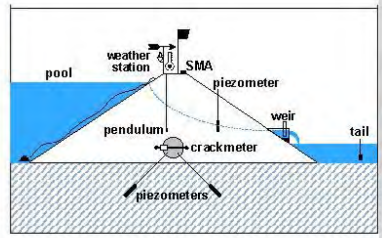
USACE's instrumentation and monitoring program monitors over 700 dams and 4,000 miles of levees. As part of USACE'S advancement in monitoring, this presentation will focus on the MIDAS (Monitoring Instrumentation Data Acquisition System) project, an enterprise-wide instrumentation database. USACE will also provide an overview of their ongoing evaluation of DHS developed Low-Cost IoT Flood Inundation Sensors, and their potential use to complement USACE's monitoring programs.

3.2.2.2 Presentation (ADAMS Accession No. ML22061A133)

USACE INSTRUMENTATION AND MONITORING

Georgette Hlepas, PhD, PE
Geotechnical, Geology, and Material CoP Lead, HQ USACE

Christopher Schaal, EIT
Geotech – Dam & Levee Section, Chicago District, USACE



NRC PFHA WORKSHOP
15 FEB 2022

US Army Corps of Engineers

U.S.ARMY

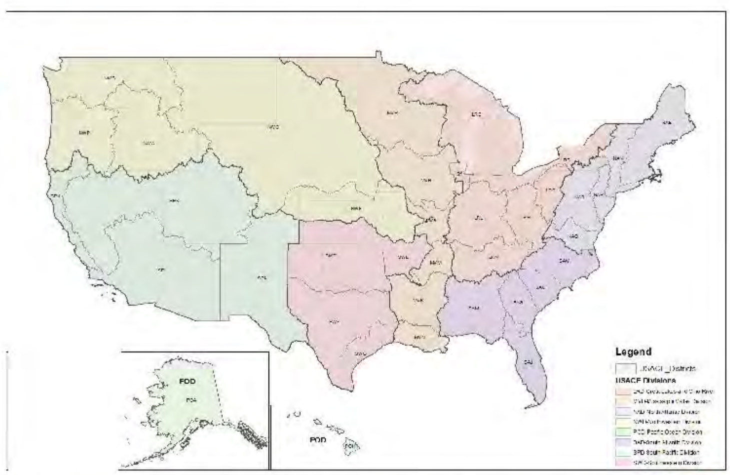
US Army Corp of Engineers

~32,000 employees

HQ in DC

9 Divisions

44 Districts

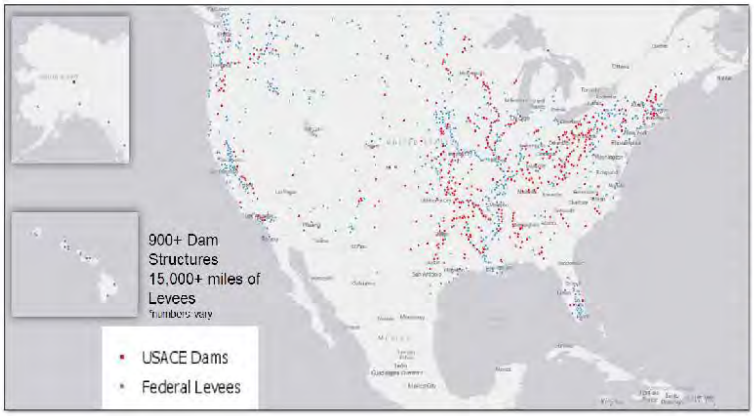


DAMS & LEVEES OPERATED AND MAINTAINED BY DISTRICTS

US Army Corps of Engineers

U.S.ARMY

National Inventory of Dams and Levees



- ~715 Dams
- Population at Risk +12.8M
- Property at risk = +1T
- Total length of 267 miles
- 80% earthen/20% concrete

- ~2,137 levee systems
- Population at Risk +12M
- Property at risk = +1.3T
- Total length = 14,100 miles
- 97% earthen/3% floodwall

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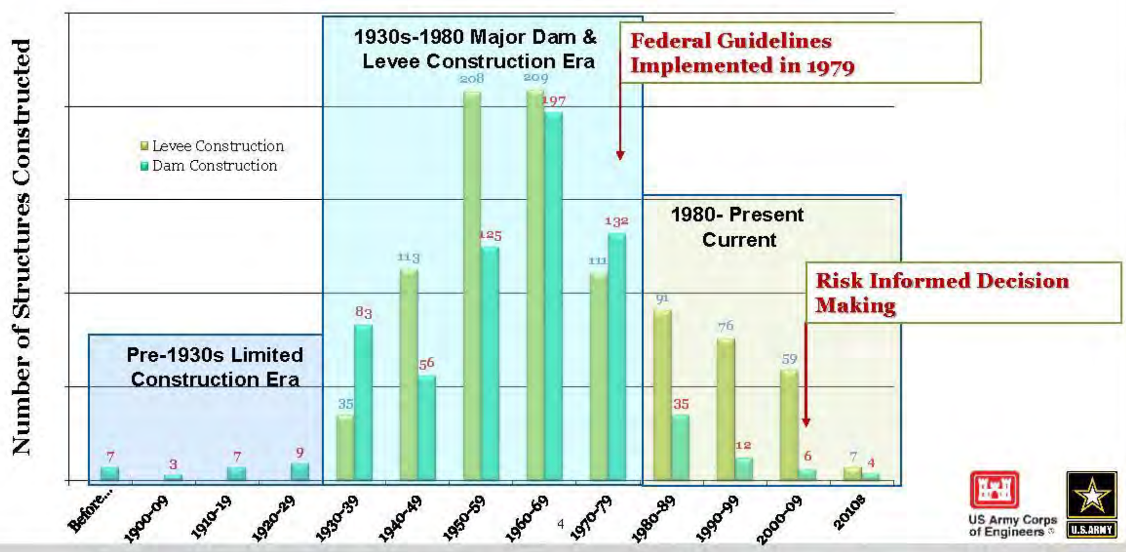
Dams and Levees – Aging Infrastructure



4

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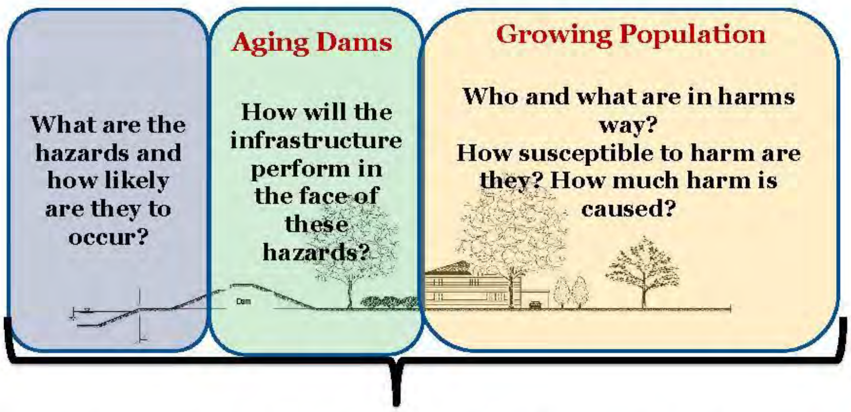
U.S. ARMY

Risk Informed Decisions Making (RIDM)

Risk = f(Hazard, Performance, Consequences)



Infrastructure Safety Program Focused on: People, Performance, and Risks

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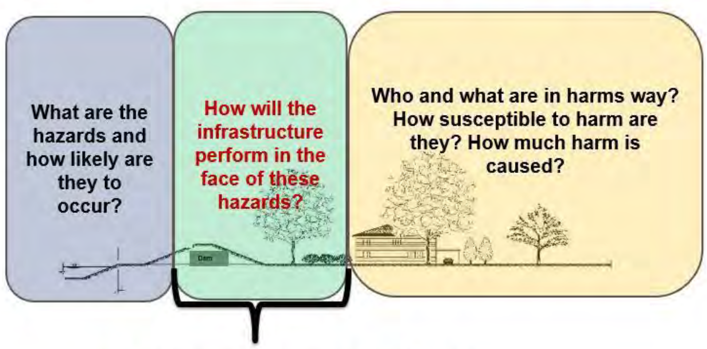
Risk Informed Decisions Making (RIDM)



Instrumentation

- ✓ Quantitative Measurement of Performance
  - ✓ Informs Likelihood of PFM Occurrence
  - ✓ Reduce Uncertainty in Risk Estimate

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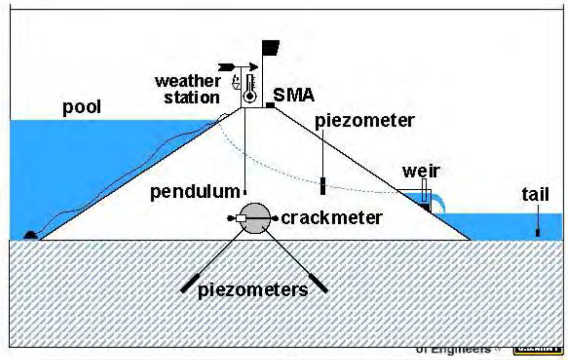
Instrumentation Type overview

- Geotechnical, Survey, Structural, Hydraulic (Quantity/Quality) Monitoring Instruments
  - Piezometers, Inclinometers, Crackmeters, Survey Monitoring Points, Stage gauges, Precipitation, Water Chemistry Sondes, etc.
- Manual and Automated Instruments



Importance of Instrumentation Data

- Used in all Phases: Planning, Design, Construction, Ops,
  - Understand the baseline conditions to inform design
  - Monitor project performance & safety during construction
  - Evaluate short-term & long-term performance of the structure
    - Normal loading and Extreme events (post-seismic, flood, severe storms)

- Amount & Type of Instrumentation at Various Project Varies
  - Parameters Needed to be monitored
  - Frequency of data collection
  - Level of risk/concern associated with the project

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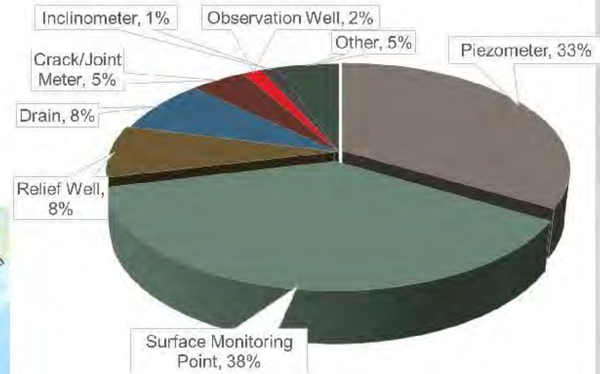
Dam And Levee Instrumentation Inventory

- **> 70,000** Instruments have been inventoried to date
- Average 106 instruments/project
- ~10-15% of all instruments are automated



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Data Volumes

Wolf Creek Dam

247 Piezometers	+6.7 million readings
74 Inclinometers	+360k readings/yr
164 Monuments	719MB; 40MB/yr

J. Percy Priest Dam

130 Active Instruments
+4.3M readings total / ~0.5M readings/yr
423 MB since 1982 / 51 MB last year

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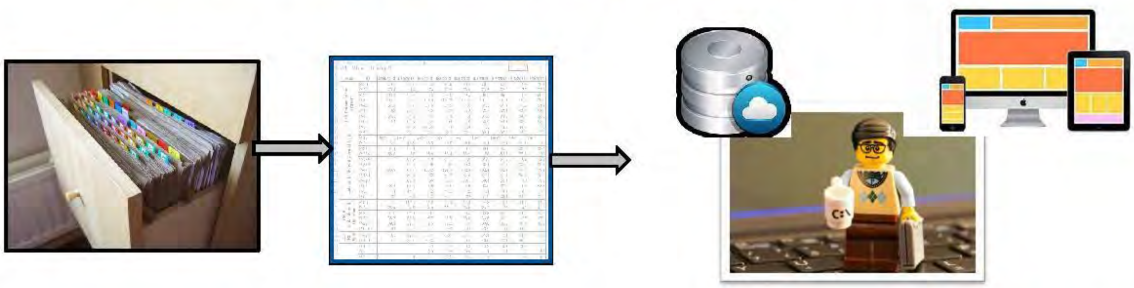
U.S. ARMY

Monitoring Instrumentation Data Acquisition System (MIDAS)



11

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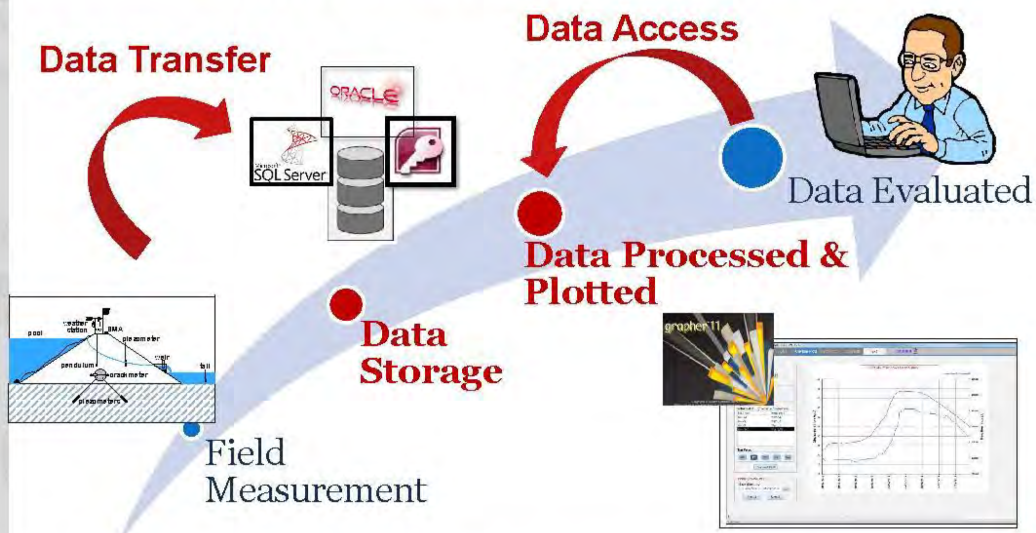
DATA MANAGEMENT – CHALLENGES



Ref: USACE DAM & LEVEE INSTRUMENTATION DATA MANAGEMENT RECOMMENDED IMPROVEMENTS, October 2019

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MIDAS Concept Requirements

- ✓ National/centralized cloud based system
- ✓ **USACE owned, developed, managed**
- ✓ State-of the art tool and ability for **future upgrades/updates**
- ✓ USACE Standardized data model approach
- ✓ Ability to set and broadcast thresholds/alarms;
- ✓ Means of visualization/plotting integral to software/system
- ✓ Ability to assimilate historic data
- ✓ **Web-accessible and meets DOD Security Requirements**
- ✓ **Interoperability with other databases**

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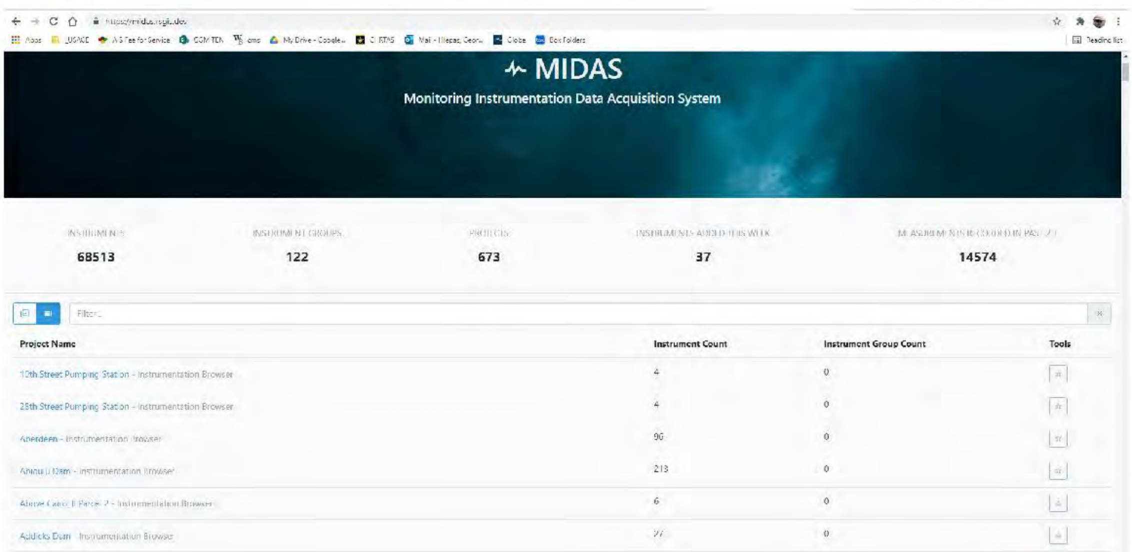

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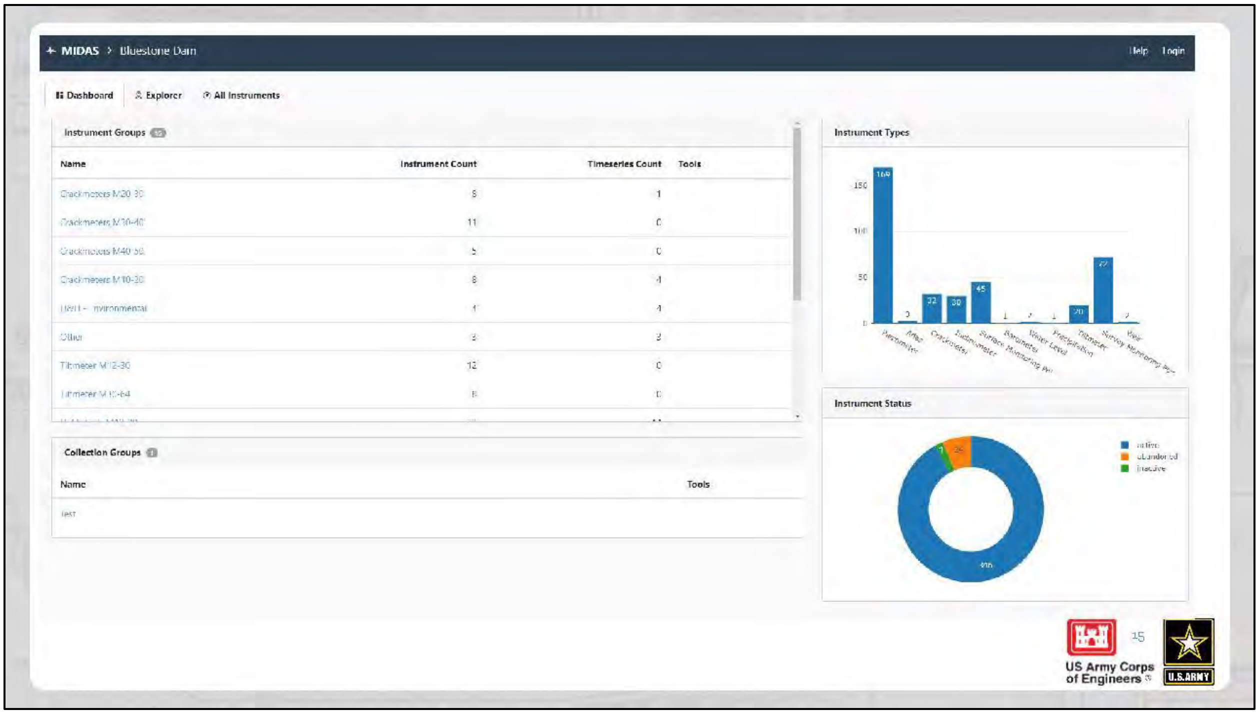

MIDAS > Bluestone Dam
Help Login
Dashboard
Explorer
All Instruments
Instrument Groups
Instrument Types
Instrument Status
Collection Groups
Name
Instrument Count
Timeseries Count
Tools
US Army Corps of Engineers
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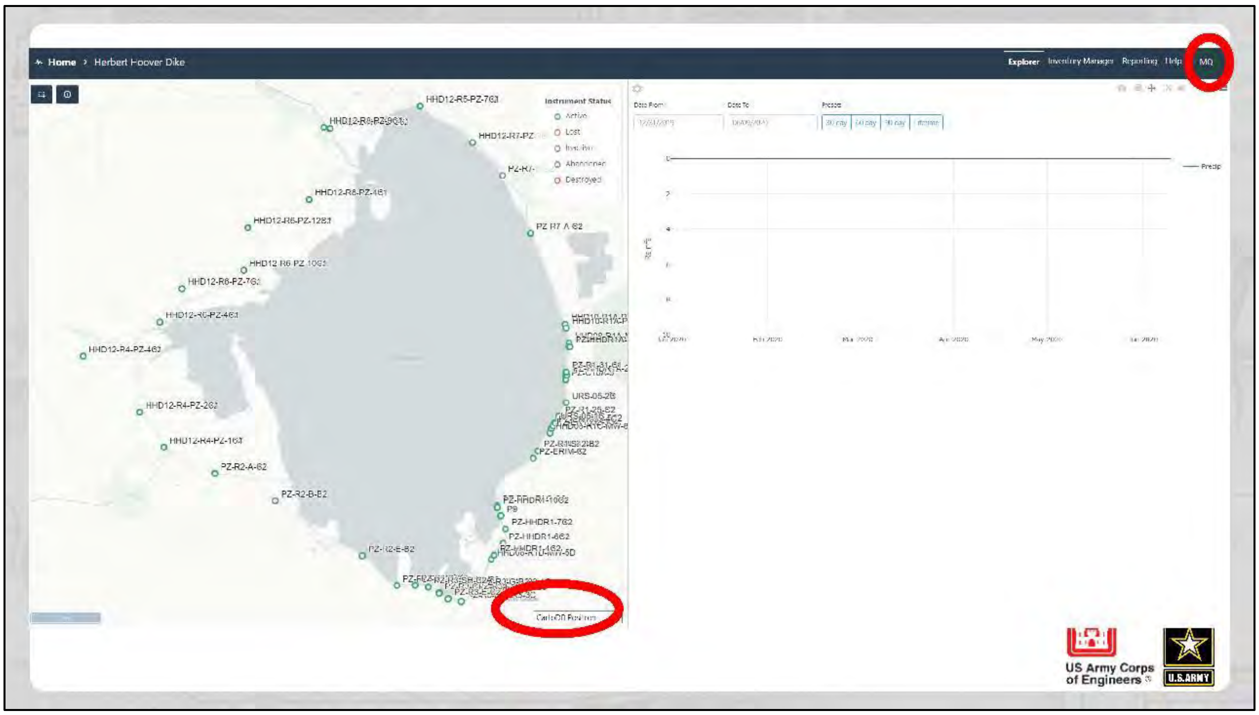
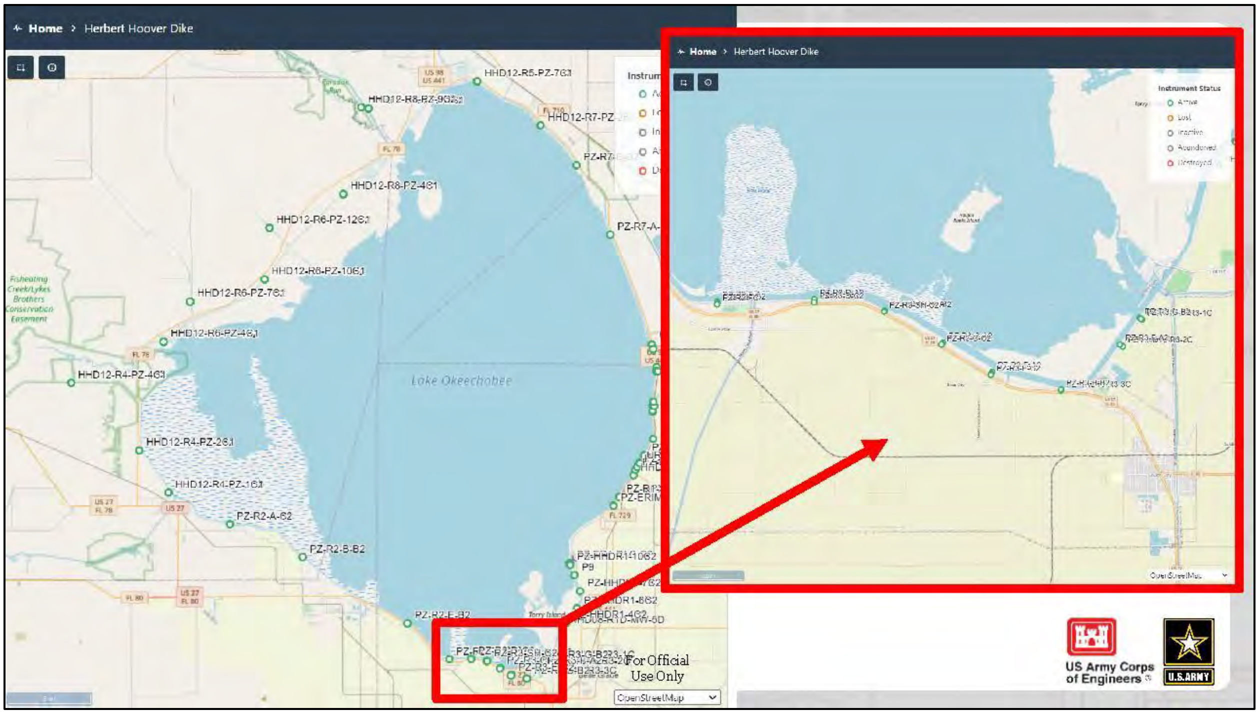


Home > Herbert Hoover Dike
Explorer
Reporting
Help
MQ
US Army Corps of Engineers
U.S.ARMY


Home > Herbert Hoover Dike
Lake Okeechobee
HHD12-R5-PZ-76
HHD12-R8-PZ-90
HHD12-R8-PZ-48
HHD12-R6-PZ-126
HHD12-R6-PZ-106
HHD12-R6-PZ-76
HHD12-R6-PZ-46
HHD12-R4-PZ-46
HHD12-R4-PZ-26
HHD12-R4-PZ-16
PZ-R2-A-B2
PZ-R2-B-B2
PZ-R2-E-B2
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OpenStreetMap
Instrument Status
Active
Lost
Inactive
Abandoned
Destroyed
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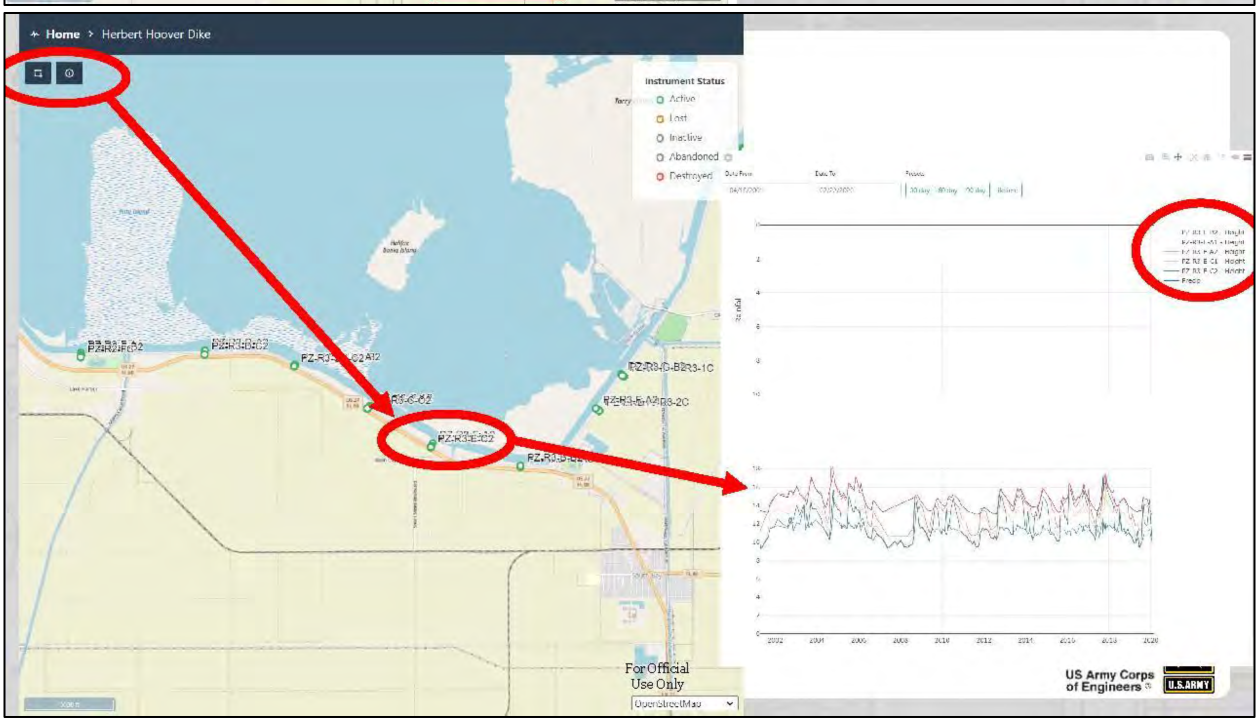
Home > Herbert Hoover Dike
Instrument Status
Active
Lost
Inactive
Abandoned
Destroyed
PZ-R3-D-B2R3-1C
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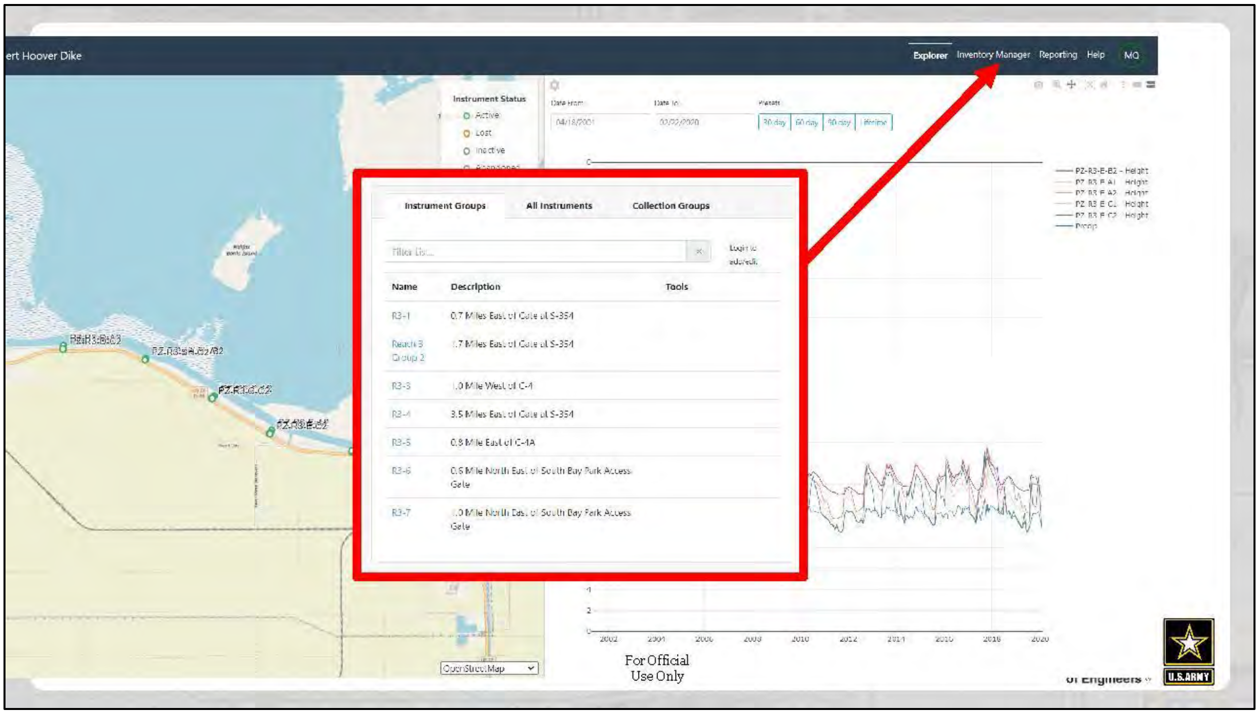
OpenStreetMap
US Army Corps of Engineers
U.S.ARMY


ert Hoover Dike
Explorer
Inventory Manager
Reporting
Help
MQ
Instrument Status
Active
Lost
Inactive
Instrument Groups
All Instruments
Collection Groups
Name
Description
Tools
R3-1
0.7 Miles East of Gate at S-354
Reach 3 Group 2
1.7 Miles East of Gate at S-354
R3-3
1.0 Mile West of C-4
R3-4
3.5 Miles East of Gate at S-354
R3-5
0.8 Mile East of C-4A
R3-6
0.5 Mile North East of South Bay Park Access Gate
R3-7
1.0 Mile North East of South Bay Park Access Gate
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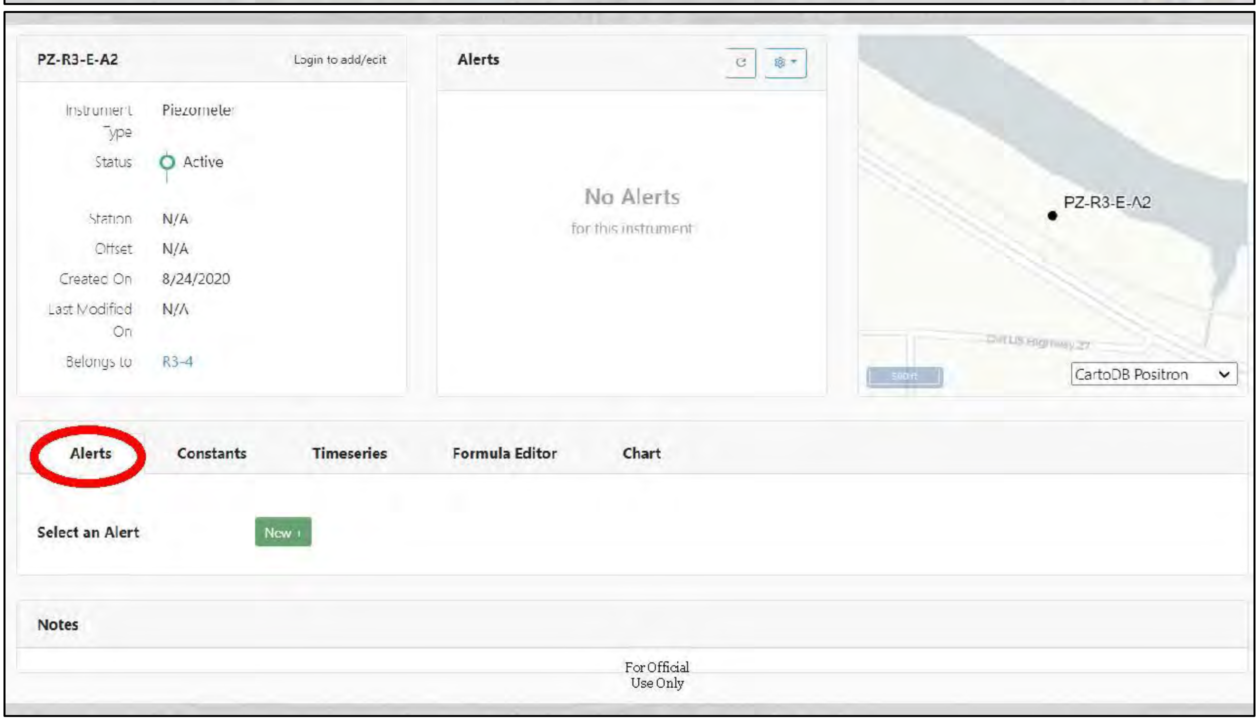
PZ-R3-E-A2
Login to add/edit
Instrument Type
Piezometer
Status
Active
Station
N/A
Offset
N/A
Created On
8/24/2020
Last Modified On
N/A
Belongs to
R3-4
Alerts
No Alerts
for this instrument
PZ-R3-E-A2
CartoDB Positron
Alerts
Constants
Timeseries
Formula Editor
Chart
Select an Alert
New
Notes
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Flood Sensor Program
DHS-USACE

21

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Inter-Agency Agreement

- Assess the functionality of flood sensors for commercial viability
- Provides sensors & technical support

- Provide physical installation, data monitoring & evaluation
- Document effectiveness and provide feedback

22

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- Cellular Data Transmission
- Proprietary data storage and processing
- Sensors
  - Water level (~0.1 in)
  - Temperature
  - Atmospheric Pressure
  - Digital Camera
- Solar Panel
- Integral Battery

23

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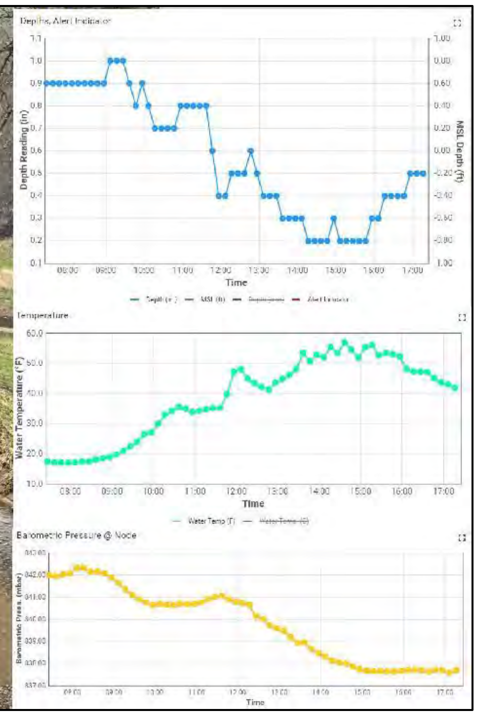
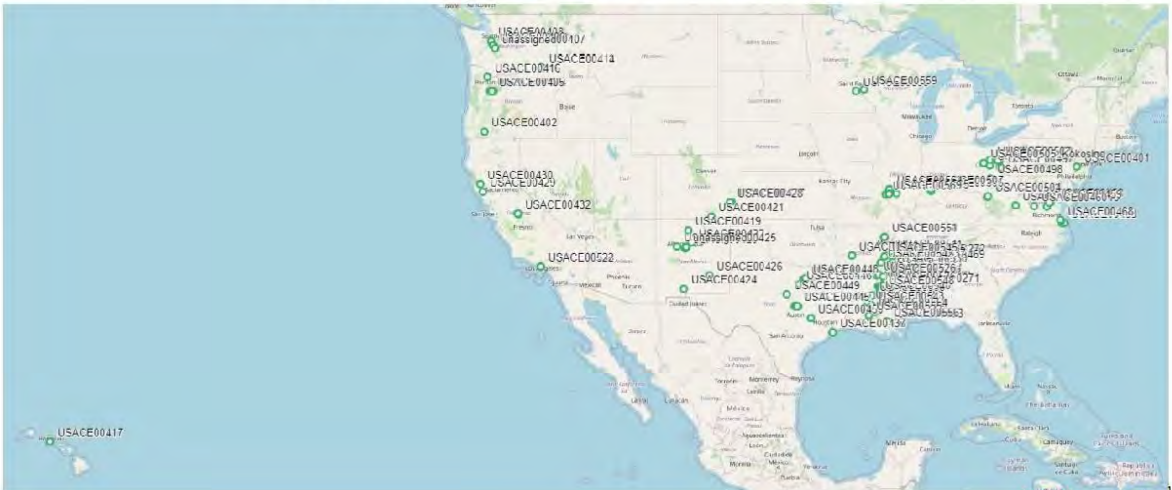


Currently 117 live sensors



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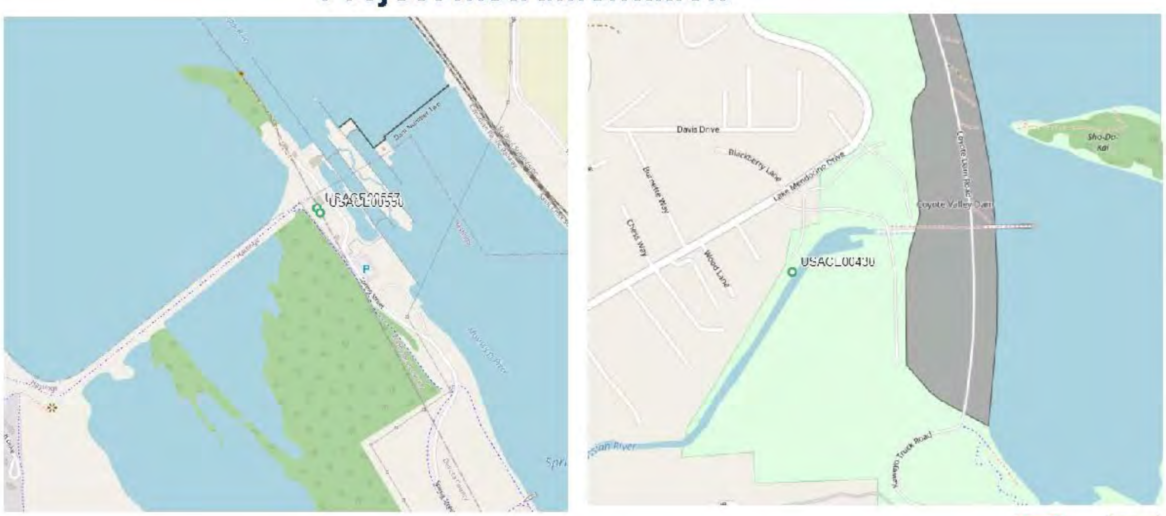
Flood Sensors Supplement USACE Project Instrumentation



26

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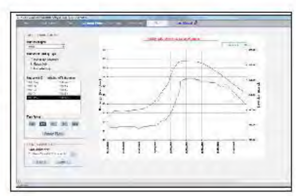
Instrumentation is great, but…

- Where do I install instruments?
- What type do I install?
- How often do I collect/review data?
- When am I concerned?
- How do I manage my data?
- When can I stop monitoring?
- What does the data mean?
- Is my program adequate?

EM 1110-2-1908 and EM 1110-2-4300 Updates

- EM 1908 (2021) Instrumentation of Embankment Dams & Levees
  - Vastly Expanded doc: **SMP, RIDM, Evaluation**, **Data Management**, **Newer Technology**
- EM 4300 (1987) Instrumentation for Concrete Structures
  - Update EM1908 with appropriate concrete structure monitoring guidance
  - Expected Complete end of FY22



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ER 1110-2-103 and ER 1110-2-1802 Updates

- ER 103 Strong Motion Instruments for monitoring and recording earthquake motion **Published 2021** and replaced 1981 doc.
  - Applies to dam, levee, and navigation structures
  - Standardize instrumentation in accordance with USGS state-of-practice
  - Incorporated Risk Informed Decision Making into the site selection process
  - Requires the direct coord. w/ USGS;

- ER 1802 (2017) Reporting Earthquake Effects
  - Remove inconsistency with ER 103
  - Clarification on Reporting Requirements
  - Coordination with Operations
  - Expected Release FY22

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Instrumentation Guide Specification

- Expected Release April 2022
  - for use with construction contracts where performance monitoring instrumentation is required
  - Includes furnishing all labor and equipment for the installation and maintenance of performance monitoring instrumentation through the duration of the contract.
  - Includes instrumentation data management and data interpretation/reporting requirements.



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Federal Guidelines for Instrumentation and Monitoring

- Partnership with FEMA, FHWA, TVA, BoR
- Best Practices Document

U.S. Department of Transportation
Federal Highway Administration

FEMA

TVA

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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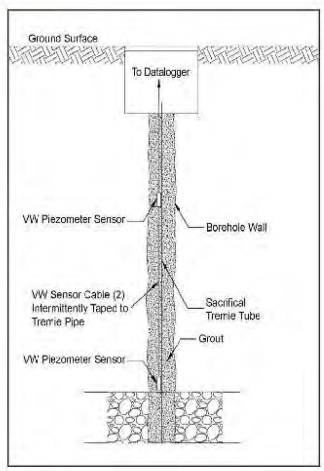
ERDC Research Partnership

- Fully Grouted Vibrating Wire Piezometers
  - Grout Mix Design
  - Appropriate Applications
- FY21
  - Initial Field Install Visits and Numerical Modelling
  - Initial Lab Tests
- FY22-23
  - Continued Lab Tests and Field Testing – FY22



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Instrumentation of Dams and Levees Course

- Georgetown, TX ()
  - ▶ 5-8 May 2022
  - ▶ 7-9 June 2022

- Online Webex (no site visit)
  - ▶ 11-15 July 2022

- Advanced Course (next FY development, pending funding)

https://ulc.usace.army.mil/CrsSchedule.aspx

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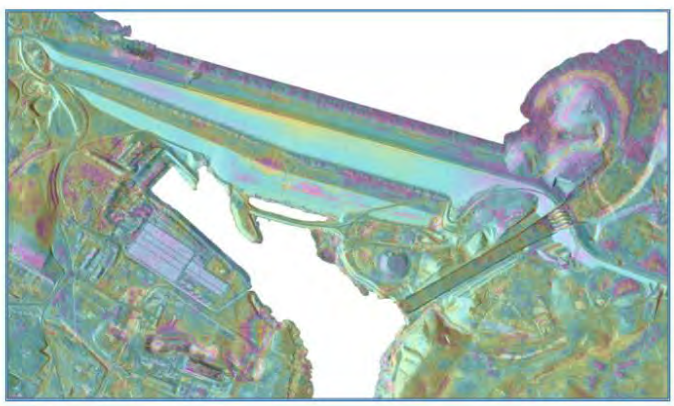
InSAR Data

- Proven at Mosul Dam
- Implementing at multiple projects

- Using TerraSAR-X
  - Hi-Res Spotlight
  - ~0.5m resolution



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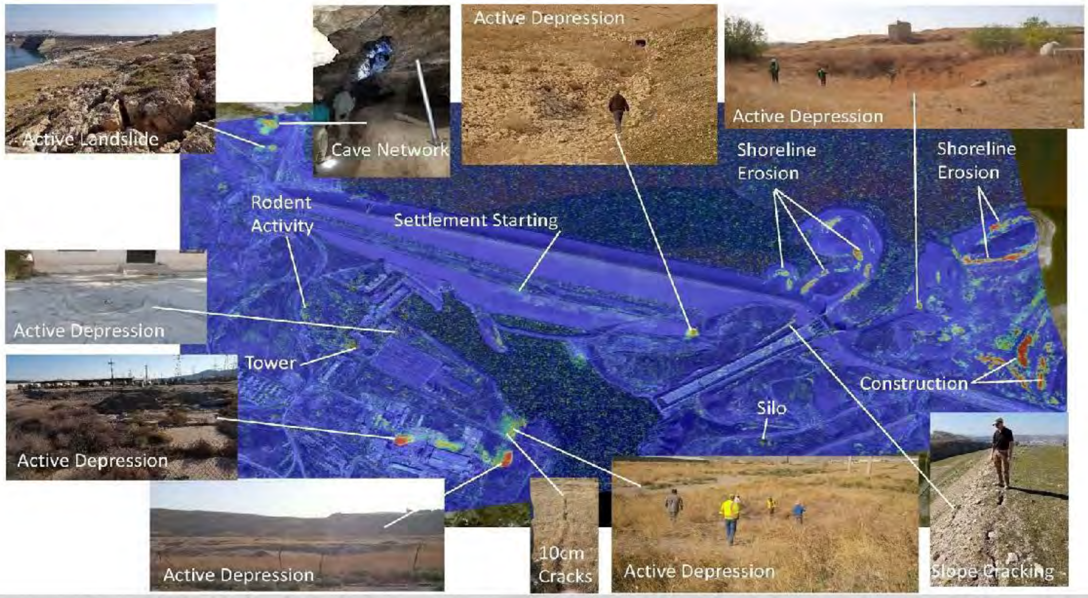
Three Years of Ground Truth



REVOLUTIONIZE

RELEVENT

PREPARED

ENGAGED

READY

WinIDP/Excel → Amazon Cloud/Web-Interface

CHANGE IN CULTURE

US Army Corps of Engineers

U.S. ARMY

3.2.3 Presentation 1B-3: USGS Water Mission Area Observing Systems Research and Development Program

Authors: R. Russell Lotspeich, U.S. Geological Survey

Speaker: R. Russell Lotspeich

3.2.3.1 Abstract

The USGS has a long history of evaluating water technologies for use in monitoring and research applications carried out to characterize the nation's water resources. This is done to verify manufacturer specifications as well as to evaluate technologies for use in new environments and under a range of environmental conditions. Not all technologies are well-suited for all environments and understanding instrument limitations is critical to selecting the best instrument for a given location and to properly interpreting the data generated.

The USGS Water Mission Area (WMA) began receiving congressional appropriations in 2018 to develop a Next Generation Water Observing System (NGWOS) program in select basins across the U.S. This program includes significant investments into evaluating new technologies and transitioning the most promising ones into national operations. Of interest to the program are new and innovative monitoring methods and instrumentation that result in increased efficiencies, accuracy, new data types, and(or) temporal and spatial resolution of water data across networks. Imagery, remote sensing, and artificial intelligence are just a few examples of technologies that are currently being evaluated through the NGWOS program.

The USGS has historically held all the traditional types of water data it provides to the public to a uniform standard for data quality and uncertainty. With advances in technology providing exciting and useful alternative methods for measuring parameters such as water level, water velocity, and water temperature, some of the most promising technologies, unfortunately, do not meet that single standard. Because these data are still of great value to stakeholders and the USGS in defining the temporal and geographic variability in hydrologic conditions, there is a desire to move forward with operational implementation of many of these new systems. So that the new data types and results of new collection methods can be interpreted by end users with as much confidence as the traditional USGS data, the USGS WMA is evaluating systems of data classification that will clearly identify differing levels of quality and uncertainty associated with each new data type, and the NGWOS program is leading this effort.

3.2.3.2 Presentation (ADAMS Accession No. ML22061A132)

USGS WMA Observing Systems Division
Research and Development Program

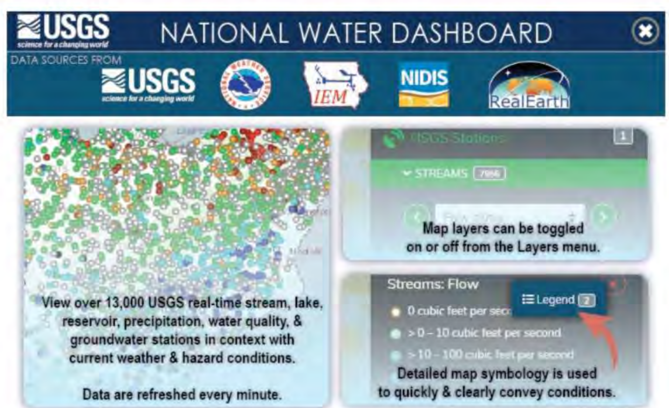
Russ Lotspeich
Research to Operations and Experimental Data Lead
USGS Hydrologic Networks Branch
USACE and NRC Probabilistic Flood Hazard Analysis Workshop
February 15, 2022

USGS science for a changing world R&D Activities in Observing Systems

USGS WMA Observing Systems Division
Research and Development Program

Objectives:

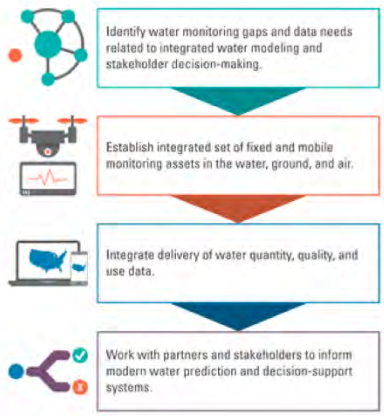
1. Provide overview of USGS Water Mission Area Observing Systems Research and Development
2. Discuss metadata enhancement to data delivery services (Fit-for-Purpose data)
3. Describe collaboration with DHS Science and Technology (S&T) Directorate



https://dashboard.waterdata.usgs.gov/app/nwd/

USGS science for a changing world R&D Activities in Observing Systems

Next Generation Water Observing System (NGWOS)



Characteristics of a Next Generation Water Observing System:

- State-of-the-art measurements
- Dense array of sensors at selected sites
- Increased spatial and temporal coverage
- New technology testing and implementation
- Improved operational efficiency
- Modernized and timely data storage and delivery

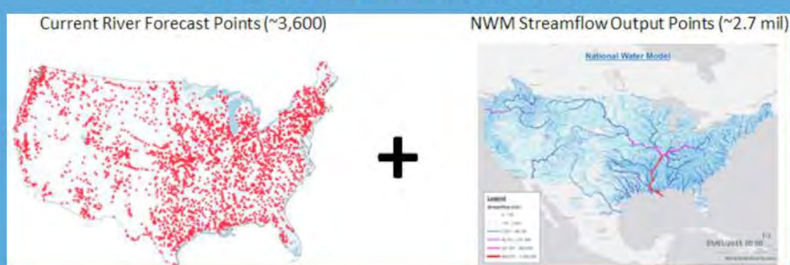
https://www.usgs.gov/mission-areas/water-resources/science/next-generation-water-observing-system-ngwos

USGS science for a changing world

R&D Activities in Observing Systems

Next Generation Water Observing System (NGWOS)

The National Water Model



https://water.noaa.gov/about/nwm

- ✓ **Flood hazard assessment**
- ✓ **Flood protection/mitigation**
- ✓ **Flood risk assessment**

NATIONAL WEATHER SERVICE · NOAA · OWP OFFICE OF WATER PREDICTION

USGS science for a changing world

R&D Activities in Observing Systems

R&D Program - Objectives

1. <u>Evaluate</u> innovative technologies and assess for operational implementation.
2. <u>Engage</u> industry and academia to leverage resources and stay informed
3. <u>Coordinate</u> R&D efforts to improve efficiency, communication, and transparency

USGS science for a changing world

R&D Activities in Observing Systems

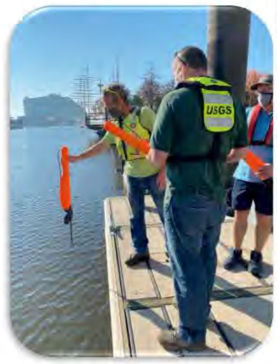
R&D Program - Enhancing Operations

USGS science for a changing world

R&D Activities in Observing Systems

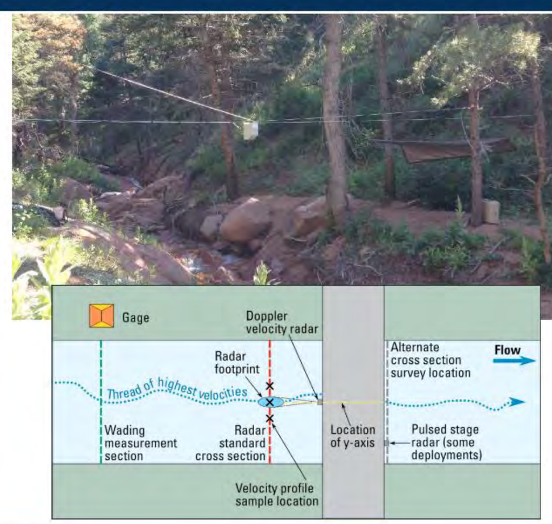
R&D Program - Evaluating New Technology

- Imagery
- IoT Telemetry
- Wireless sensors
- Edge computing
- Smart gages / Smart Cities
- Surface velocity methods
- Artificial Intelligence
- Power systems
- HABs and PFAS samplers
- Autonomous underwater samplers



R&D Program - Evaluating New Technology

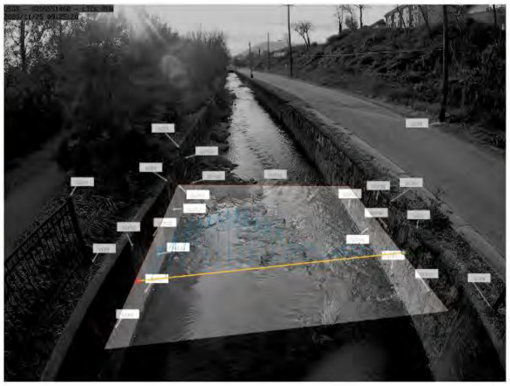
Surface (Doppler) Velocity Radar



USGS science for a changing world
R&D Activities in Observing Systems

R&D Program - Evaluating New Technology

Camera-Based Monitoring



Ground-Penetrating Radar for bathymetry (prototype)

R&D Overview - Engaging Industry

NATIONAL NEWS RELEASE

USGS Partners with UA to Build Hydrologic Instrumentation Facility

By Communications and Publishing

January 20, 2022

TUSCALOOSA, Ala. – The U.S. Geological Survey is partnering with the University of Alabama to construct a new Hydrologic Instrumentation Facility, a science and engineering facility that will support the agency's Water Enterprise observing networks and research.

THE UNIVERSITY OF ALABAMA

Research & Economic Development

Alabama Water Institute

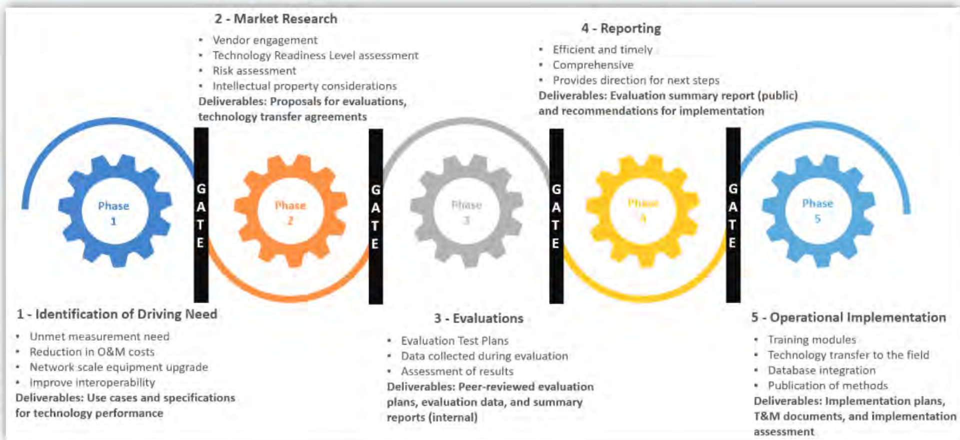
The Alabama Water Institute has been established as a world-class, interdisciplinary research institute that engages in basic and applied research in the topical areas of earth systems science and water resource management, supporting sustainable waterways, ensuring water quality and biological diversity of aquatic systems.

Researchers apply state-of-the art tools and techniques such as hydrological modeling, remote sensing, molecular ecology, hydro-informatics and disaster management.

The University of Alabama (ua.edu)

"Innovation is outpacing acquisition" - Scott Rayder (Director, Alabama Water Institute)

R&D Overview - Technology Transition



R&D Program - Research to Operations

R&D Program - Research to Operations

Experimental and Fit For Purpose Data

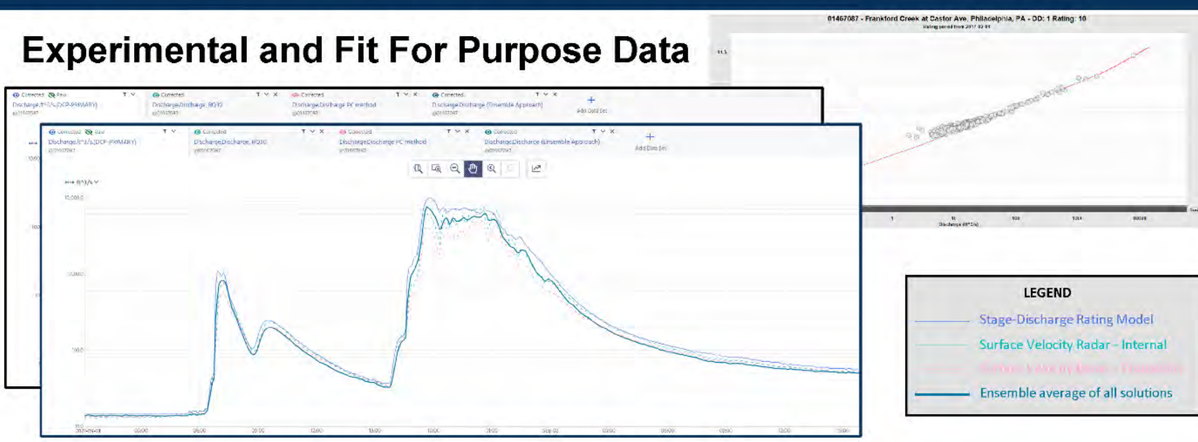
LEGEND

- Stage-Discharge Rating Model
- Surface Velocity Radar - Internal
- Ensemble average of all solutions

Provisional Data – Subject to revision

R&D Program - Research to Operations

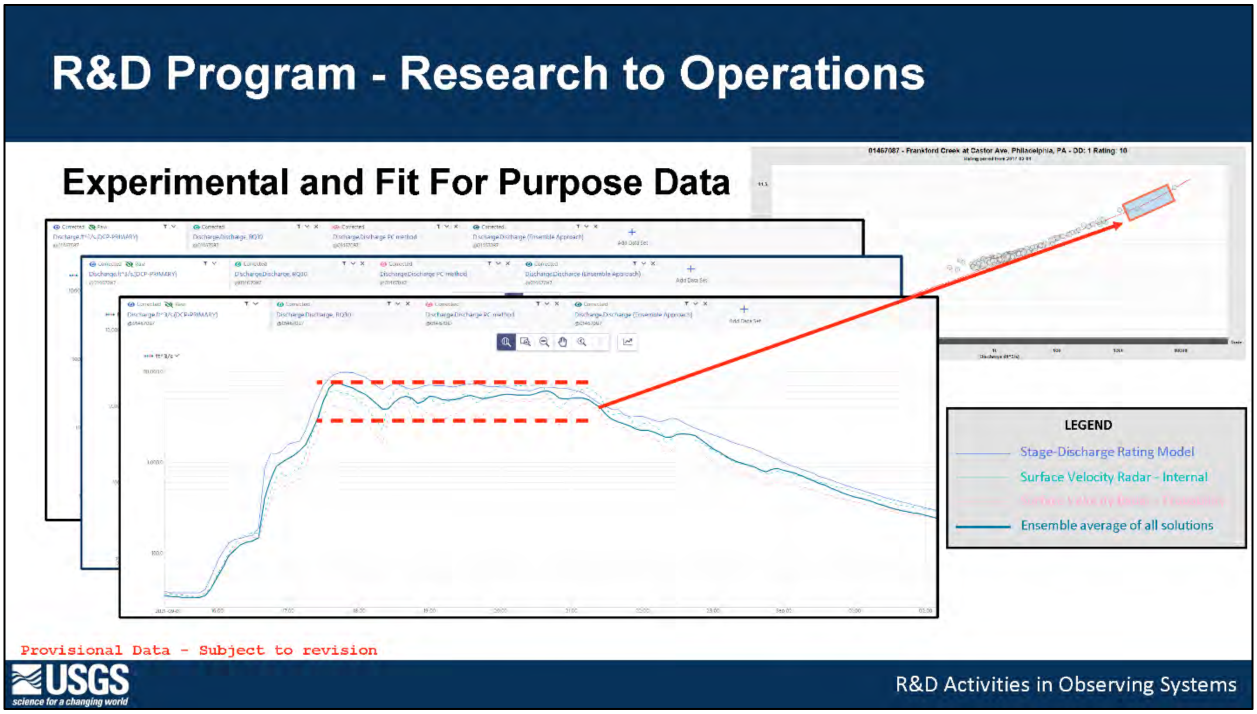
Experimental and Fit For Purpose Data

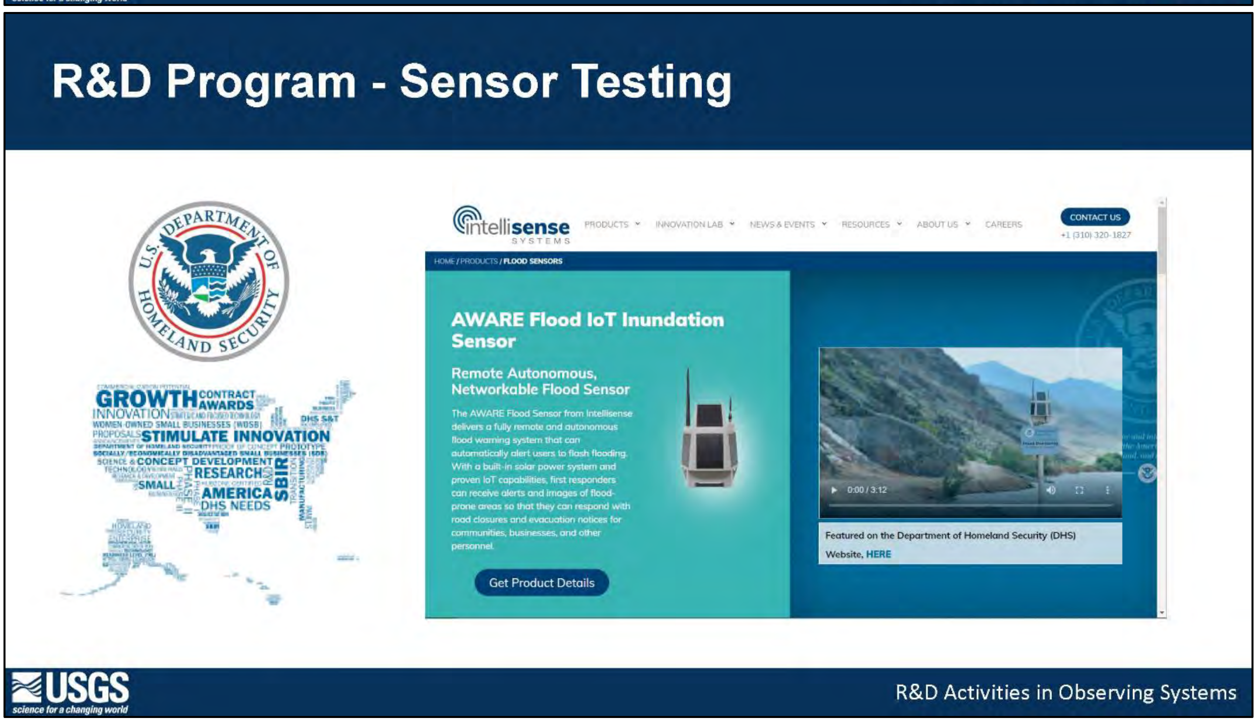


LEGEND

- Stage-Discharge Rating Model
- Surface Velocity Radar - Internal
- Ensemble average of all solutions

Provisional Data – Subject to revision


R&D Program - Research to Operations
Experimental and Fit For Purpose Data
01467087 - Frankford Creek at Castor Ave, Philadelphia, PA - DD: 1 Rating: 10
LEGEND
Stage-Discharge Rating Model
Surface Velocity Radar - Internal
Ensemble average of all solutions
Provisional Data - Subject to revision
USGS
science for a changing world
R&D Activities in Observing Systems


R&D Program - Sensor Testing
U.S. DEPARTMENT OF HOMELAND SECURITY
GROWTH
CONTRACT AWARDS
INNOVATION
STIMULATE INNOVATION
CONCEPT DEVELOPMENT
RESEARCH
AMERICA
DHS NEEDS
SBIR
intellisense SYSTEMS
PRODUCTS
INNOVATION LAB
NEWS & EVENTS
RESOURCES
ABOUT US
CAREERS
CONTACT US
+1 (310) 320-1827
HOME / PRODUCTS / FLOOD SENSORS
AWARE Flood IoT Inundation Sensor
Remote Autonomous, Networkable Flood Sensor
The AWARE Flood Sensor from Intellisense delivers a fully remote and autonomous flood warning system that can automatically alert users to flash flooding. With a built-in solar power system and proven IoT capabilities, first responders can receive alerts and images of flood-prone areas so that they can respond with road closures and evacuation notices for communities, businesses, and other personnel.
Get Product Details
0:00 / 3:12
Featured on the Department of Homeland Security (DHS) Website, HERE
USGS
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R&D Activities in Observing Systems

USGS WMA Observing Systems Division
Research and Development Program

QUESTIONS

Russ Lotspeich
rlotspei@usgs.gov

https://www.usgs.gov/mission-areas/water-resources/science/next-generation-water-observing-system-ngwos

USGS
science for a changing world

3.2.4 Presentation 1B-4: State and Local Experience in Virginia Implementing IoT Sensors and Data Systems

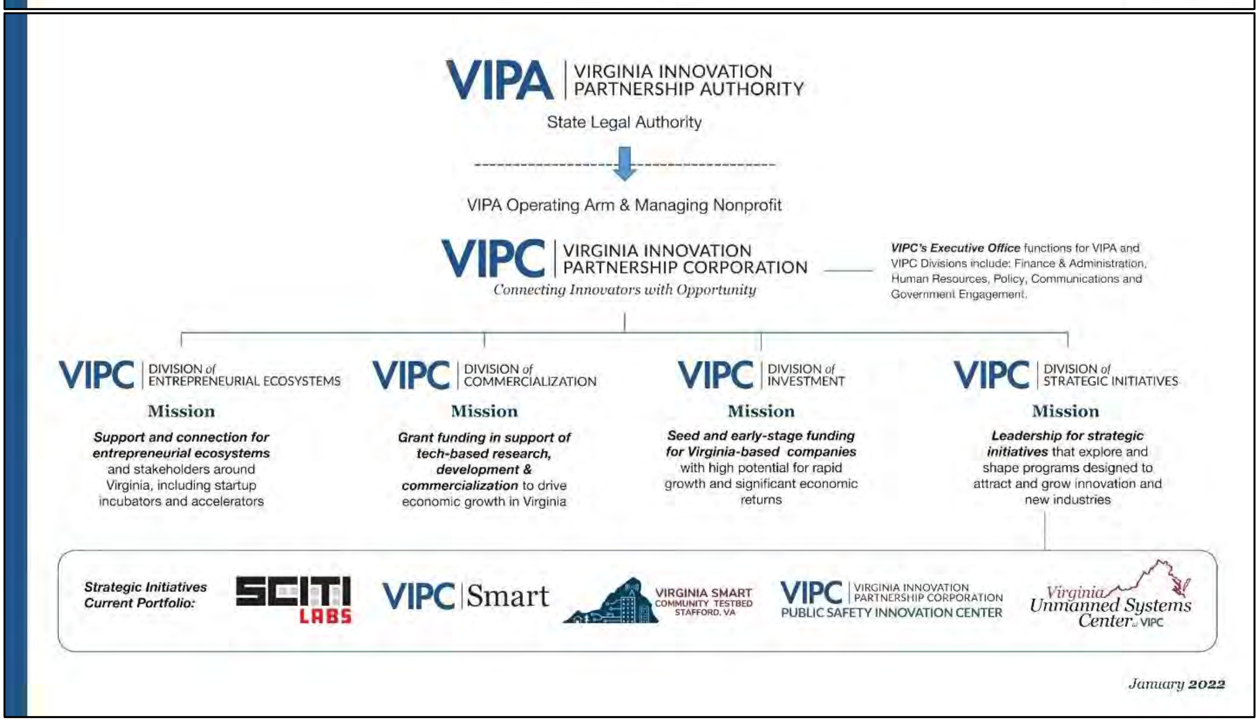
Authors: David Ihrie, Virginia Innovation Partnership Corporation

Speaker: David Ihrie

3.2.4.1 Abstract

The Commonwealth of Virginia and local government partners now have increasing experience implementing IoT sensors such as flood and wildfire sensors, and their related data systems and user facing applications This talk provides a description of the journey, lessons learned, and a look towards the future as these increasingly ubiquitous sensors become a primary driver for situational awareness and delivery of services.

3.2.4.2 Presentation (ADAMS Accession No. ML22061A131)

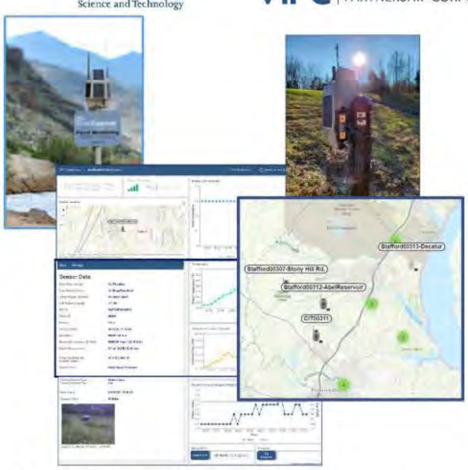


Virginia Smart Community Testbed

Smart Community IoT Flood Sensors

Homeland Security
Science and Technology

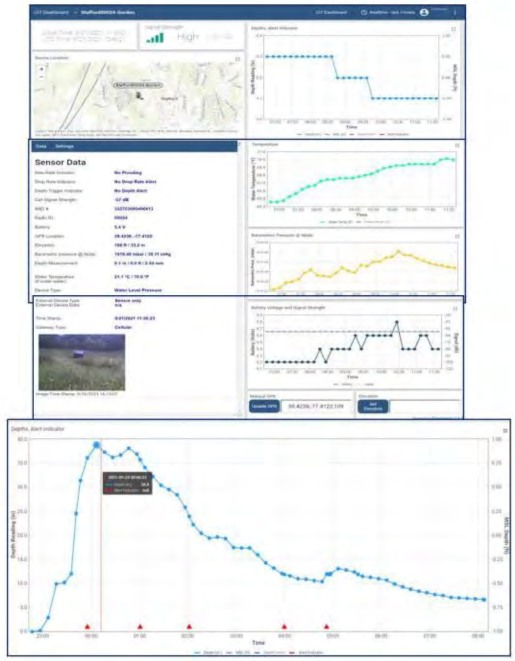
VIPC | VIRGINIA INNOVATION PARTNERSHIP CORPORATION



Stafford County Using Data for Emergency Management of Flooding

Smart Community IoT Flood Sensors

- Stafford lead site for statewide pilot
- Significant uptake from all communities – some buying their own supplements
- Low cost a primary factor
- Advanced uses in discussion for Stafford



Smart Community IoT Flood Sensors

Homeland Security
Science and Technology

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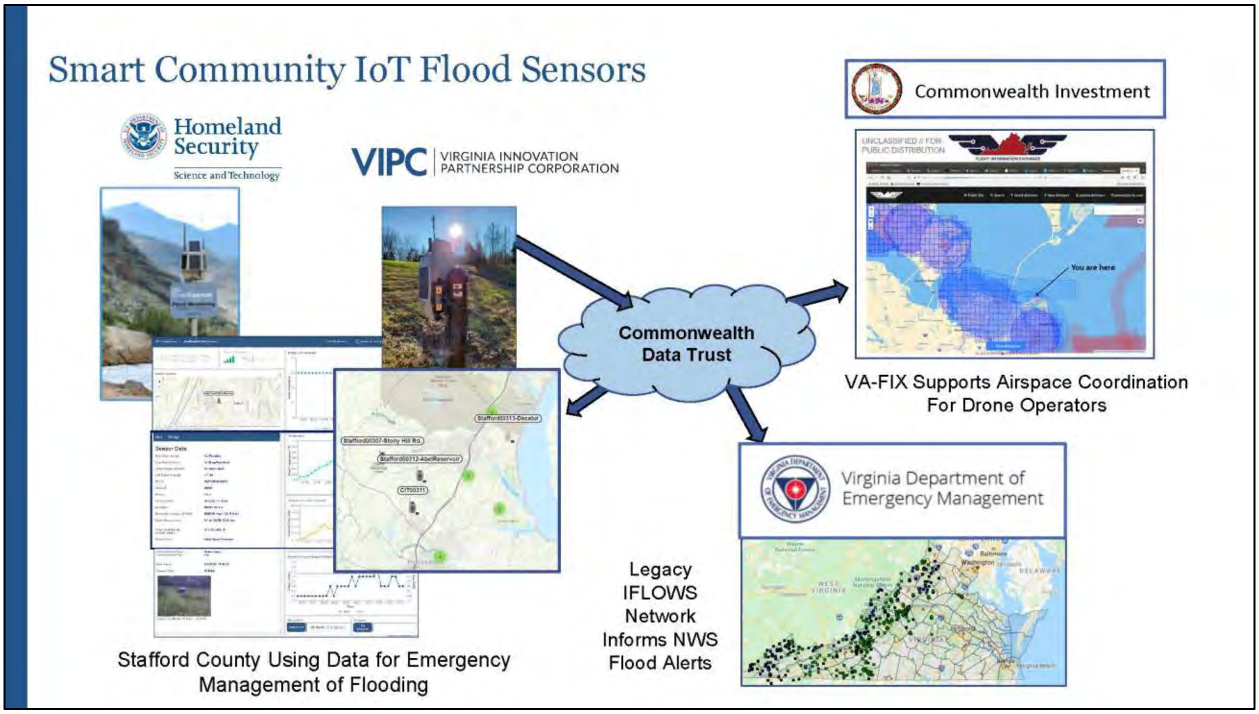
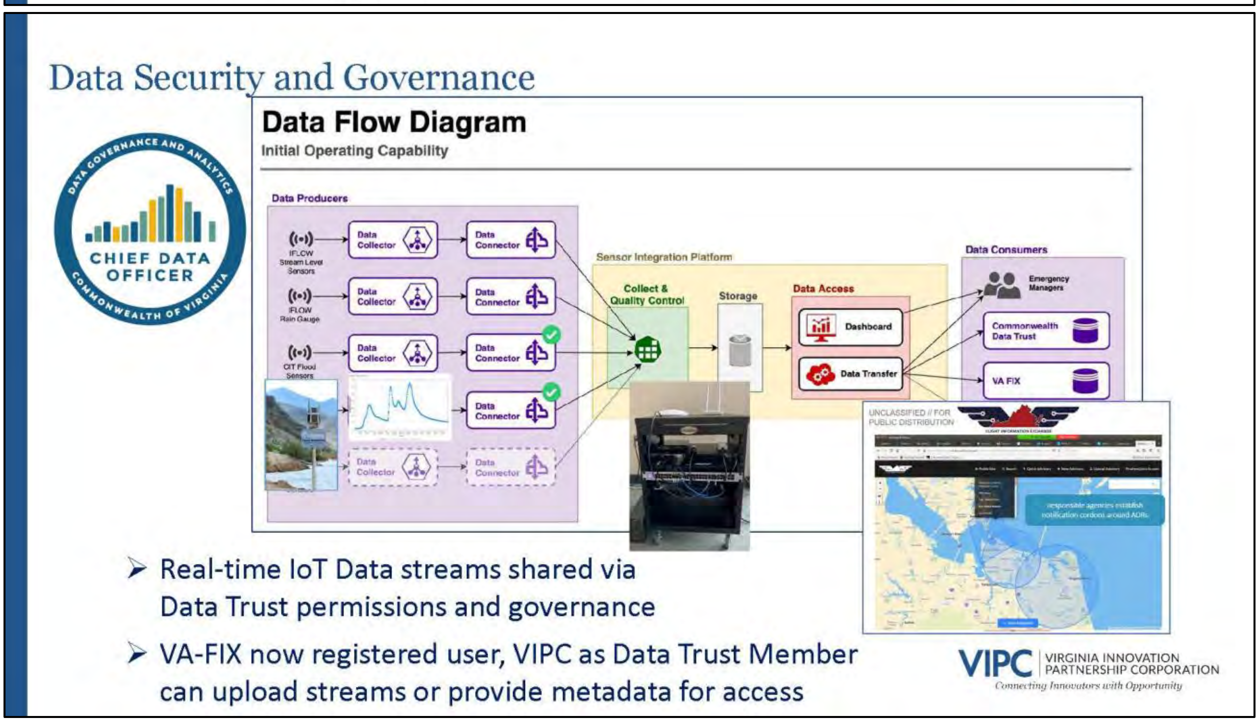
Commonwealth Investment

VA-FIX Supports Airspace Coordination For Drone Operators

Stafford County Using Data for Emergency Management of Flooding


Smart Community IoT Flood Sensors
Homeland Security
Science and Technology
VIPC VIRGINIA INNOVATION PARTNERSHIP CORPORATION
Commonwealth Investment
Commonwealth Data Trust
VA-FIX Supports Airspace Coordination For Drone Operators
Virginia Department of Emergency Management
Legacy IFLOWS Network Informs NWS Flood Alerts
Stafford County Using Data for Emergency Management of Flooding


Data Security and Governance
DATA GOVERNANCE AND ANALYTICS
CHIEF DATA OFFICER
COMMONWEALTH OF VIRGINIA
Data Flow Diagram
Initial Operating Capability
Data Producers
IFLOW Stream Level Sensors
IFLOW Rain Gauge
OIT Flood Sensors
Data Collector
Data Connector
Sensor Integration Platform
Collect & Quality Control
Storage
Data Access
Dashboard
Data Transfer
Data Consumers
Emergency Managers
Commonwealth Data Trust
VA FIX
➢ Real-time IoT Data streams shared via Data Trust permissions and governance
➢ VA-FIX now registered user, VIPC as Data Trust Member can upload streams or provide metadata for access
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Connecting Innovators with Opportunity

IoT Device Security

- "Zero Trust Security"
- Makes groups of IoT devices invisible to hackers
- In place for Stafford Security cameras
- Wider applications demo at Ft. Belvoir for power infrastructure

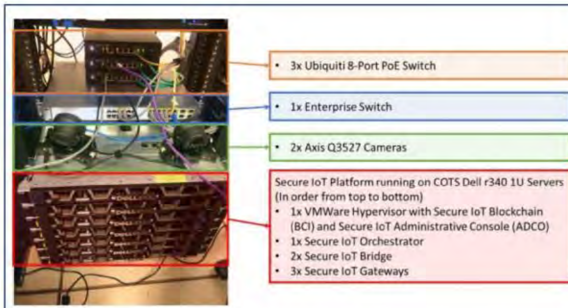
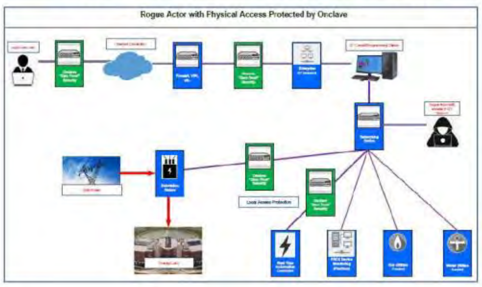
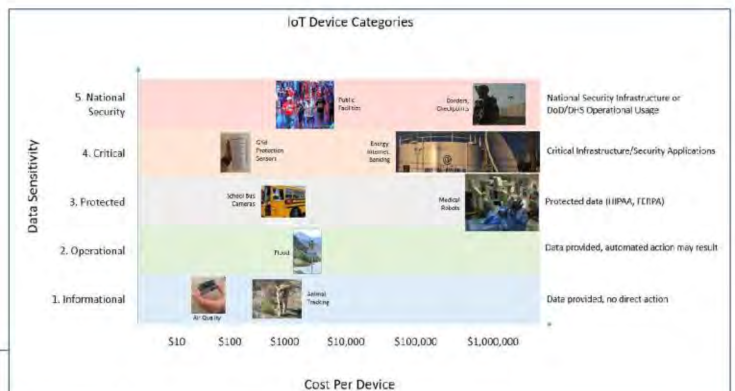


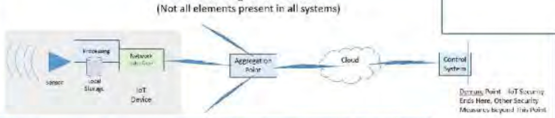
Figure 5: Secure IoT equipment installed at Stafford data center



IoT Device Security



IoT Block Diagram and Threats
(Not all elements present in all systems)



Point of Attack	Threat	Potential Solution	Applicable Device Category
Device	Data Skimming (Theft)	Device Storage Encrypted	3+
	Repurposed Infrastructure	Behavioral Controls on Data Flow	1+
	Rogue Commands	Data Checks	2+
	Corrupted Data	Operational Checks	1+
In Transit	Device Spoofing	Device Validation	2+
	Data skimming (Theft)	End-to-End Encryption	2+
System	Physical Access	Zero Trust	2+
	Data Leakage (Inappropriate Sharing)	Event driven sharing	2+

- Assumes other security procedural controls in place (ie, personnel controls, training, response plans)
- Categories per prior diagram of data sensitivity

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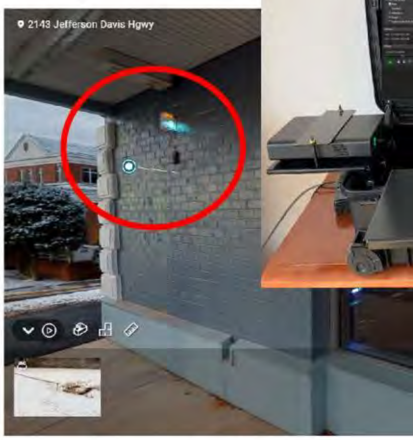
IoT Data Infrastructure Supports Many Types of Sensors



Air Quality/Wildfire

Drone Video/Data

Micro Weather Stations

The MWS®-M625 includes all the same great features as our line of proven line of Micro Weather Stations (MWS®) and adds cloud height measurement and two-way Iridium satellite for more accurate and reliable meteorological reporting.

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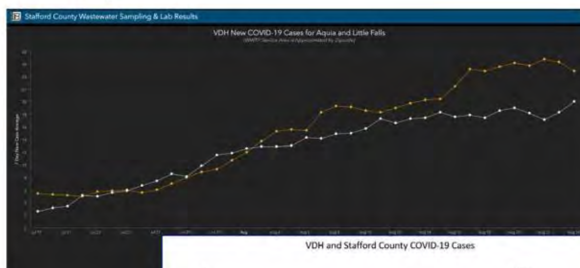
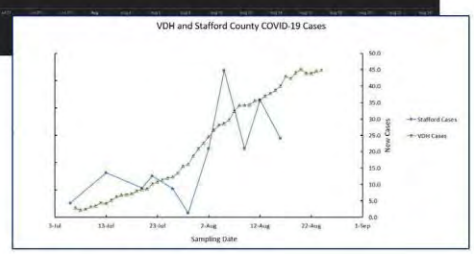
IoT Data Infrastructure Supports Many Types of Sensors





- Wastewater data more accurate than VDH, presents earlier, enables passive monitoring
- Identifies both asymptomatic and pre-symptomatic cases
- Allows potential for more targeted response
- First of its kind testing in U.S.

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Lessons Learned

- ➢ Get Started!
- ➢ Cost Matters
- ➢ Users Are the Best Innovators
- ➢ A secure, integrated architecture is critical for successful adoption
- ➢ Commonwealth Data Trust Provides a Model for Data Governance and Information Sharing

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State and Local Experience in Virginia Implementing IoT Sensors and Data Systems

Presented to: 7th Annual NRC PFHA Research Workshop

Thank You!

Funding for many of the technologies in this presentation has been provided by the U.S. Department of Homeland Security, Science & Technology Directorate, under contract number 70RSAT19CB0000025

UNCLASSIFIED

February 2022

3.2.5 Flood & Fire Sensors for Resilient Communities Panel Discussion (Session 1B-5)

Moderator: Joseph Kanney, NRC/RES/DRA/FXHAB
***Jeffrey Booth**, Department of Homeland Security, Science & Technology Directorate*
***Georgette Hlepas**, U.S. Army Corps of Engineers*
***R. Russel Lotspeich**, U.S. Geological Survey*
***David Ihrie**, Virginia Innovation Partnership Corporation*

Question:

What are your thoughts about the tradeoffs between using cellular communications for these instrumentation systems versus using a different type of communication system, such as the dedicated radio systems used for emergency management? Because cellular networks can get clogged up in emergencies. What are the tradeoffs of how the sensors would communicate with the databases or to be queried and things like that?

David Ihrie:

I think the actual sensing elements are independent of the radio system for the communications. Because there are a number of different potential user communities, my preference would be to have a more general type of communications backhaul rather than a single user, like the emergency management. But however that first hop occurs, our experience has been that the integration of the data on the backend and the sharing of that data is much trickier and it's kind of the critical piece. We've experimented with several different types of radios.

Question:

Can you say a little bit more about what different types of radios you have experimented with?

David Ihrie:

Sure. LoRa is one that is, I think, also pretty popular. We are doing some experimentation in the testbed directly with 5G and several mechanisms to kind of extend off the edge of the 5G network into areas without as much coverage. There has been a look at satellite communications. So, I think just a variety.

Jeff Booth:

For the flood sensors, we have done both cellular and LoRa. We had some challenges with LoRa in very steep terrain, granite hills, etc. So, they have both capabilities, in addition to Iridium satellite. But we are testing the next round of wildland fire sensors that will deploy 20 to 50 sensors with the US Geological Survey and the Feather River in California at LoRa sites that they have deployed for some of their monitoring to get a better sense of both the cell and LoRa comparisons.

Georgette Hlepas:

We often have these discussions with water management and geotech instrumentation. What is the best route? For normal operations cellular works just fine without an issue. Our concern is remote projects and those cellular systems not functioning during emergencies and not being able to know what is happening at our projects. For those more critical projects, more remote projects, a lot of those are using satellite-based data. We transmit through the GOES satellite system. That's more reliable for specific areas.

Russel Lotspeich:

We are also utilizing several different technologies for telemetry. Primarily we utilize GOES. The issue with GOES is the lack of bandwidth for things like imagery. So, we keep getting pushed to cellular for these kinds of higher bandwidth requirement data types. Our focus has been on getting data into our national water information system faster and building better web services and API points, so that people can access the data more readily through our system.

We have added alert radios to our system, so our monitoring stations have the ability to use multiple types of telemetry, much like Jeff was describing. If there is a need by a locality to add one of their local radios to our systems, that is not out of the question, but it creates an issue for us to get the data into our system. That is why we still want to rely primarily on GOES.

Question:

Most of the presentations concentrated on deploying the sensors in some sort of a network ahead of time. I was curious has anyone given a lot of thought or have concrete plans for a use case, which would be more like a campaign in response to an event or an evolving situation? For example, if certain state is in a real drought situation, could there be a campaign to deploy those fire sensors? Or if there has been a particularly wet spring in a certain area and you are worried about snow melt flooding happening in the early summer in a certain area, could there be a campaign to deploy flood sensors?

Jeff Booth:

We have deployed a thousand sensors, mostly flood sensors. And some of our stakeholders did keep several back just for those types of purposes, mostly coastal right now in terms of hurricane and surge. But clearly that is some of what they are concerned about is storm events where they can deploy ahead of time when an unknown event is coming. To follow up after David Ihrie, users are the most creative innovators. One of the more recent use cases with wildland fire sensors was a planned burn or a prescribed burn where one of the performers deployed sensors with a county in Colorado for a prescribed burn just to get some data. They left the sensors there overnight after the fire suppression was performed by the fire department. Later that night, they got triggered on smoke alerts and they actually notified the fire department an hour before the first 911 call that there was a spark up where it went from smolder to ignition. So they were able to redeploy the fire department to suppress it. We are finding more and more use cases. Again, it is the creativeness of the users that is really intriguing. We have got a variety of use cases we never planned on for the flood sensors, and now finding more with the fire sensors as well.

David Ihrie:

Following up on the fire sensors, another recent use case that came to light from one of our fire colleagues was after a small wildfire in an area. Often, they need to deploy people and equipment for the next day or two to make sure it does not flare up again. So the idea was to rapidly deploy a couple of these wildfire sensors, not to detect initial ignition, but to check and help make sure that there is no flare up afterwards.

Georgette Hlepas:

Most of the USACE folks using these sensors are testing in different environments and seeing how they behave and how they react. The great purpose of these is quick deployable when you need something right away and everyone is pretty excited for that use case. We've predetermined, preinstalled these in locations just to see how easy they are to install and how effective they are in different environments, different temperatures, etc. We covered a lot of that in our presentation, but the vast majority of folks agreed that in an emergency this is what we can quickly deploy.

Russel Lotspeich:

We have had what we call a rapid deployment gauge program pretty much since Hurricane Katrina, where we recognized the need to either put out additional monitoring stations during an event. It was primarily focused at coastal events that point in time, but we've also evolved. Now, if a gauge is going to get flooded out due to a flood, we're putting these systems out in advance of that happening to maintain data continuity during the event, especially at forecast points. How those systems have been developed in the past are not very cheap. They are not very easy to install. So, we have been looking at ways to improve on those. We are targeting the Intellisense sensor, as well as some other technologies that are out there, for that purpose, as well as potential fixed continuous monitoring. But certainly, the rapid opportunistic deployment of sensors for various different applications is certainly on our map.

Question:

David, you had a couple of slides that did a good job of talking about the question of data sharing and data ownership, as well as the security aspect of using the sensors and sharing the data. Could I get some comments from the other presenters about how that is being handled in your organizations?

Jeff Booth:

So I can answer for S&T. The unique thing about the Science and Technology Directorate is that we don't own the mission. We are the science edge for identifying gaps in the mission and then applying the technology. So from a data sharing standpoint, we aren't the ones that deploy the sensors or operate them. We're basically trying to find the technology to help the user. So from my standpoint it's not that big of an issue for my mission area.

Question:

Then my question to you Jeff would be: what technology best supports the data security and the data sharing? Are you doing research on that?

Jeff Booth:

David alluded to an effort we're doing right now with the Geological Survey on Cyber IoT security issues. In this case we'll use the Stafford County testbed and look at the flood and fire sensors for cyber vulnerabilities. There's a lot of sensors that are readily deployed because of their price points, but they introduce vulnerabilities for networks. So USGS and DHS have been discussing some of the vulnerabilities with sensor deployments. We have a kick off meeting this week on that effort to look at some of the cyber vulnerabilities for those sensors.

Russel Lotspeich:

I'm sending a link in the chat (https://www.fedramp.gov). Data sharing, access to data, and data ownership have always been a big issue for the USGS to move forward with the use of any third party data services. The key is this Fedramp program and having fully documented, embedded APIs. We're still working through this. We're also looking at zero trust architecture that David mentioned. We have other cyber security projects that are underway looking at this exact question. How do we get data from these IoT based sensors in a way that doesn't violate any of our federal cyber infrastructure rules. If a vendor is Fedramp certified, this currently gives us somewhat of a green light to move forward, because we're moving everything into the cloud anyway. All of our database is moving to the cloud. Once everything is in the cloud, and we can have that handshake, then I think it makes things a lot easier. That has been a significant hurdle up to this point.

Georgette Hlepas:

Security has been a huge concern at the USACE. We had a lot of difficulties trying to find a good way to bring data, especially automated data, from the field into our Corps net. But once we implemented a cloud-based solution, (we have a government owned Amazon cloud system) that's enabled us to do a lot more. We do meet all the government security requirements and make the appropriate handshakes to bring data in. But that cloud-based solution has provided a lot of relief.

We also do work with folks who have to go through the Fedramp certification process, and I chuckle at that because it's a lengthy process. But if there is a third party who is Fedramp certified, it does make it a lot easier, because they have to have met all the security restraints that the DoD has.

3.3 Day 1: Session 1C – Climate

Session Chair: Elena Yegorova, NRC/RES/DRA

3.3.1 Presentation 1C-1 (KEYNOTE): Big Stories from the Historic Winter of 2020/21

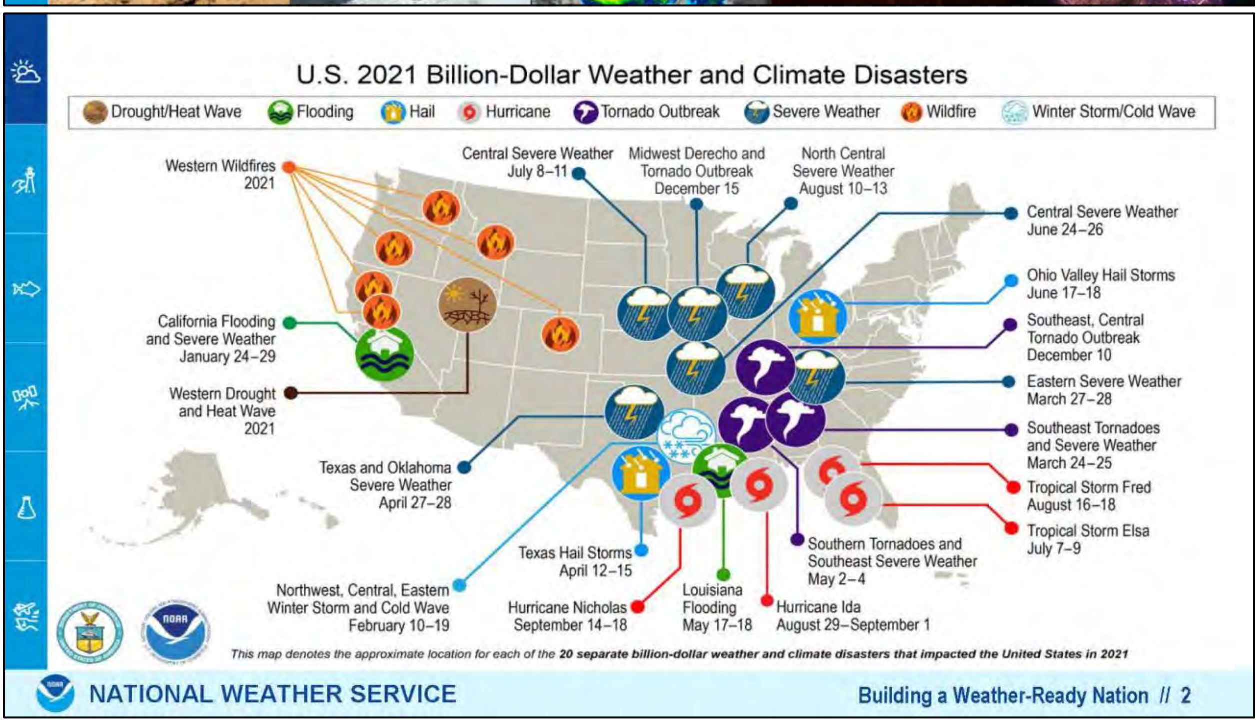
Authors: *David Novak, National Oceanic and Atmospheric Administration, National Weather Service (NOAA/NWS)*

Speaker: *David Novak*

3.3.1.1 Abstract

This review will highlight some of the "big stories" of the 2020-21 historic winter season, including one of the snowiest Octobers on record in the CONUS, an historic early season ice storm in Oklahoma, a December nor'easter with 40" of snow in 15 hours, and most, notably, an historic and devastating February cold wave. Winter dryness over the west foreshadowed a devastating drought for the remainder of 2021. Notable events in the early part of the 21-22 season will also be reviewed. These events will be used to illustrate the impacts of extreme winter conditions on society and the national infrastructure, and the weather enterprise's efforts in building public readiness for such events. Winter 2020-21 will be best known for the February cold wave - the most destructive and costly winter event to affect the United States in recorded history. The event was responsible for 172 deaths and over $20 Billion in direct losses (nearly doubling the inflation-adjusted cost of the 1993 Superstorm). This talk will review the rare meteorological circumstances of the event, which contributed to cascading failures in the power, water, and transportation infrastructure. In reviewing the events of the 2020-21 season, this presentation will also highlight successes and challenges in building industry readiness for winter weather, including new product and messaging innovations.

3.3.1.2 Presentation (ADAMS Accession No. ML22061A130)



The Weather Prediction Center

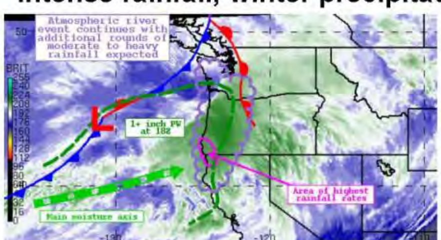
MISSION: Provide national weather situational awareness and precipitation expertise to enable readiness for hazardous weather events

National Weather Situational Awareness

- Heavy Rainfall
- Winter Weather
- Upcoming Hazards

Specialized Meteorological Expertise

Specialized meteorological expertise applied to challenges of intense rainfall, winter precipitation, and upcoming hazards.



Extended Forecast Discussion
NWS Weather Prediction Center College Park MD
159 AM EST Tue Dec 22 2020

Valid 12Z Fri Dec 25 2020 - 12Z Tue Dec 29 2020

...Threat of heavy precipitation and strong winds over parts of the eastern U.S. to extend into Christmas Day...

...Overview and Model Guidance Evaluation/Preferences...

Amplified upper flow late this week, featuring a western ridge and eastern trough, will trend flatter in the mean for the rest of the period but contain moderately amplified troughs that will provide active weather over some areas.

Once southeastern Canada low pressure pushes a sharp cold front through the Northeast on Fri/Christmas Day (GFS still somewhat faster than other guidance by varying degrees), the focus will turn to the West Coast as sharpening shortwave energy likely develops low pressure just off the Washington coast and Vancouver Island. For this system most guidance has been fairly well clustered over the past couple cycles aside from the farther south UKMET. The larger scale shortwave will progress through the West and into the Plains during the weekend. Guidance is showing a decent signal that this energy, along with yet-to-be resolved potential input of northern stream flow from Canada, will support an area of surface low pressure tracking across the central/eastern U.S. Sun-Mon with consolidation into an East Coast or western Atlantic storm by early Tue. At that time the latest GEFS/ECMWF means have been signaling such a system but with enough spread among ensemble members to keep the low fairly weak, while recommending a latitude between the southern ECMWF runs (through 12Z) and northern GFS. The 00Z CMC has come in with a low position close to the 12Z ECMWF mean while the 00Z GEFS mean is a bit more offshore. A preferred model/ensemble mean blend provides a low position closest to the 18Z GEFS/12Z ECMWF means while yielding intermediate depth. Significant change in the new 00Z ECMWF (farther north) highlights the uncertainty that still exists for this system

Heavy Rainfall

Winter Precipitation

Upcoming Hazards

Extreme Weather Forecasts are Inherently Uncertain

- Predictability varies from event-to-event & by scale
- Impacts more difficult to predict than the meteorology
- Results in wide range of lead-time for partner decisions

WEEK TO HOURS

NWS Portland
@NWSPortland

Okay. Enough trying to play catch up with our forecast. Someone in the valley will likely see a FOOT of snow by tomorrow morning.

194 Retweets 274 Likes

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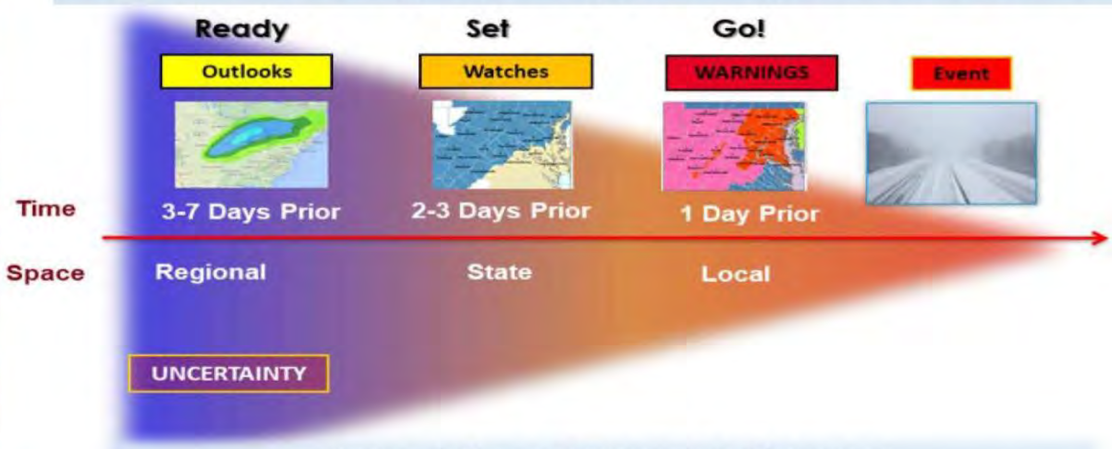
Operational Approach

Products & Language Triggered by Level of Certainty



Impact-Based Decision Support

Adapted from Rothfusz et al. 2018

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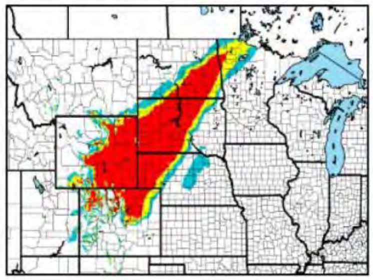
Probabilistic Outlooks Drive National Awareness

Excessive Rainfall Outlooks

Experimental Winter Storm Outlook

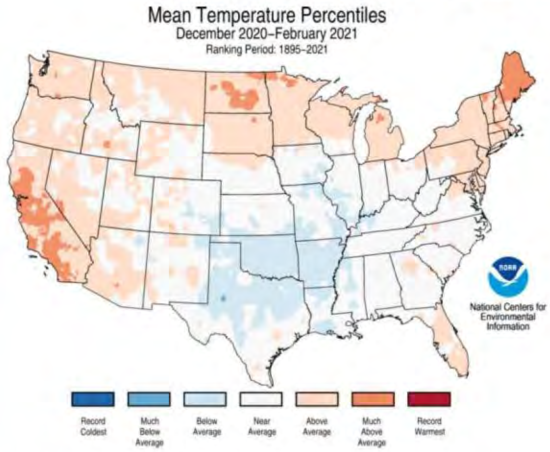


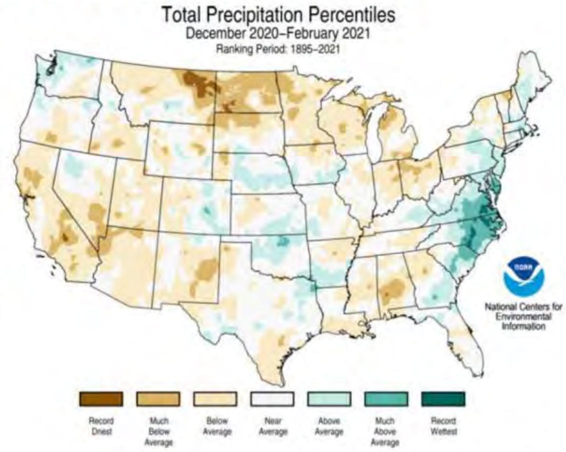
Medium Range Hazards Outlook

Outlooks calibrated to probability of impactful events

Winter of 2020-21

2020-21 Winter Climate Anomalies





- Southern Plains below average
- Much above in CA, ND, and ME

- Drier than average, except coastal Mid-atlantic

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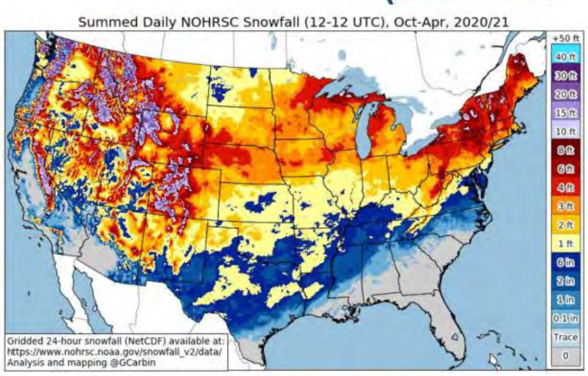
Seasonal Snowfall
(Oct 2020 - April 2021)



- Snow "Drought" across the West and Northern Tier
- Above normal snowfall along the Front Range, and Southern Plains

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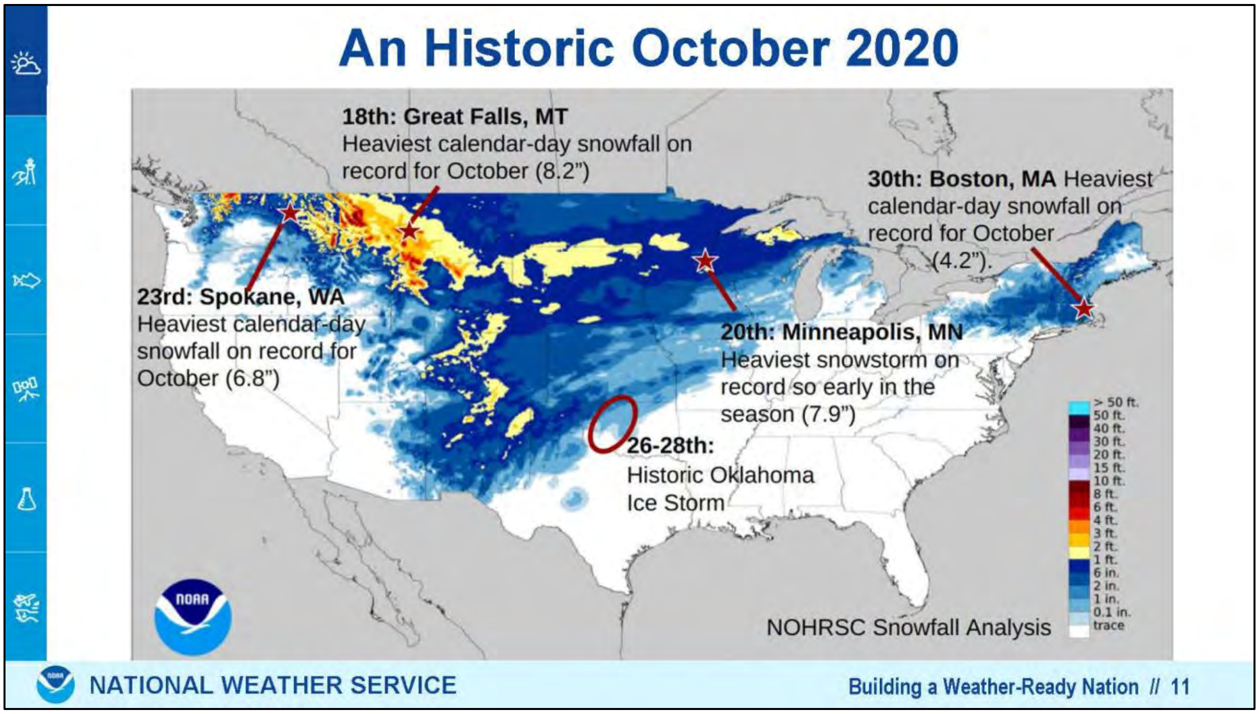

An Historic October 2020
18th: Great Falls, MT
Heaviest calendar-day snowfall on record for October (8.2")
30th: Boston, MA Heaviest calendar-day snowfall on record for October (4.2").
23rd: Spokane, WA
Heaviest calendar-day snowfall on record for October (6.8")
20th: Minneapolis, MN
Heaviest snowstorm on record so early in the season (7.9")
26-28th:
Historic Oklahoma Ice Storm
> 50 ft.
50 ft.
40 ft.
30 ft.
20 ft.
15 ft.
10 ft.
8 ft.
6 ft.
4 ft.
3 ft.
2 ft.
1 ft.
6 in.
2 in.
1 in.
0.1 in.
trace
NOHRSC Snowfall Analysis
NOAA
NATIONAL WEATHER SERVICE
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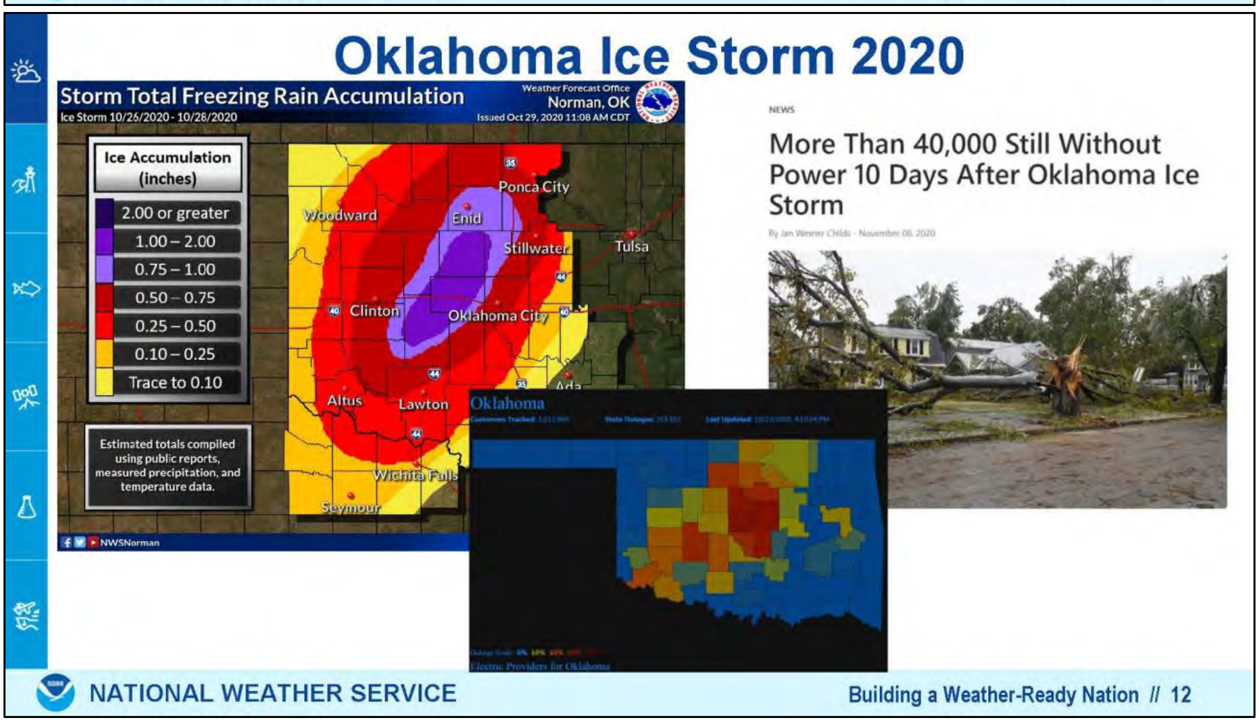

Oklahoma Ice Storm 2020
Storm Total Freezing Rain Accumulation
Ice Storm 10/26/2020 - 10/28/2020
Weather Forecast Office
Norman, OK
Issued Oct 29, 2020 11:08 AM CDT
Ice Accumulation (inches)
2.00 or greater
1.00 – 2.00
0.75 – 1.00
0.50 – 0.75
0.25 – 0.50
0.10 – 0.25
Trace to 0.10
Estimated totals compiled using public reports, measured precipitation, and temperature data.
NWSNorman
Woodward
Ponca City
Enid
Stillwater
Tulsa
Clinton
Oklahoma City
Altus
Lawton
Ada
Wichita Falls
Seymour
Oklahoma
Electric Providers for Oklahoma
NEWS
More Than 40,000 Still Without Power 10 Days After Oklahoma Ice Storm
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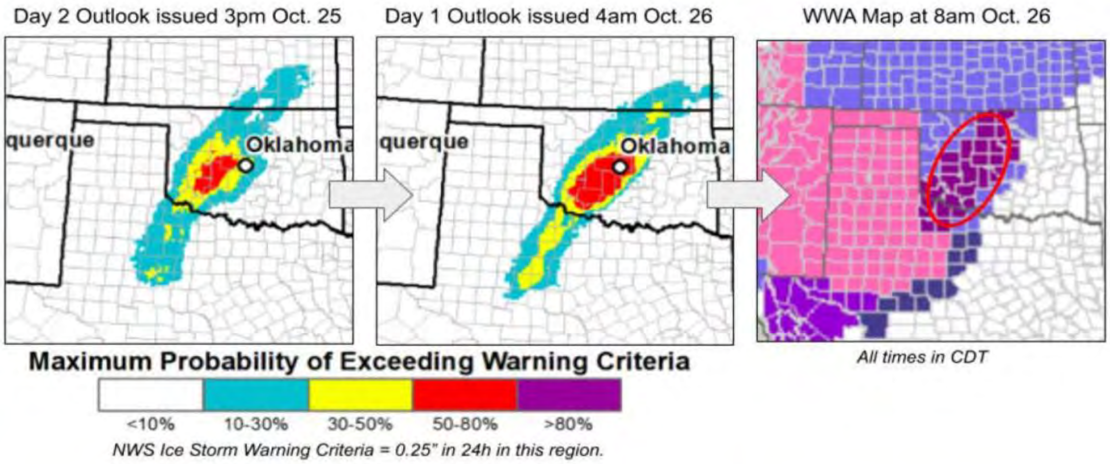
Oklahoma Ice Storm 2020

NWS/WPC Winter Storm Outlooks leading to Ice Storm Warning on Oct. 26, 2020



Historic Southern Plains Arctic Outbreak

The most destructive and costly winter storm to affect the United States in recorded history.

- **172 direct deaths** Source: NOAA Storm Data
- **$20+ Billion in direct losses**

Historic meteorological event

- **Cold**
- **For a long duration of time (~7 days)**
- **With successive snow/ice storms**

Contributed to cascading failures in the power, water, and transportation infrastructure.

A Deadly Week of Winter: Arctic Air Mass and Coast-to-Coast Winter Storms Wreak Havoc

Thursday, Feb. 11, 2021
135-car pile up, I35, north TX
6 dead, dozens injured

Fri-Sat, Feb.12-13, 2021
Major ice storm, NW Oregon

Sat, Feb. 13, 2021
8.9" at SEA, snowiest day since Dec. 1968!

Major ice storm, southwest Virginia

Sun, Feb. 14, 2021
6" of snow in OKC, MaxT 12F

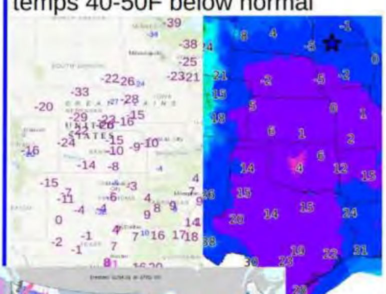
Sun-Mon, Feb. 14-15, 2021
All-time record cold, snow, and ice across Texas.

Houston I45 pile up, millions without power.

A Deadly Week of Winter: Arctic Air Mass and Coast-to-Coast Winter Storms Wreak Havoc

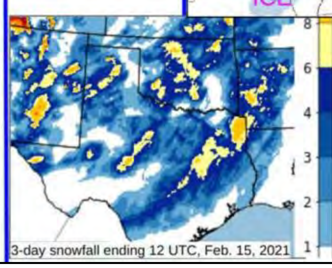
Sun-Mon, Feb. 14-15, 2021
Largest areal coverage of NWS Winter Storm Warnings

Mon, Feb.15, 2021, at least
61 daily record low temps, max temps 40-50F below normal



Mon, Feb. 15, 2021
All-time record snowfall Abilene & San Angelo, Texas (14.8 & 10.1 inches)

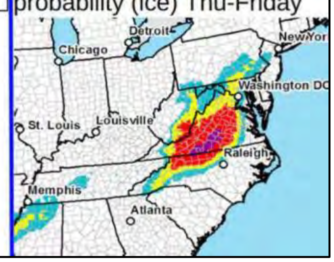
Tue, Feb. 16, 2021

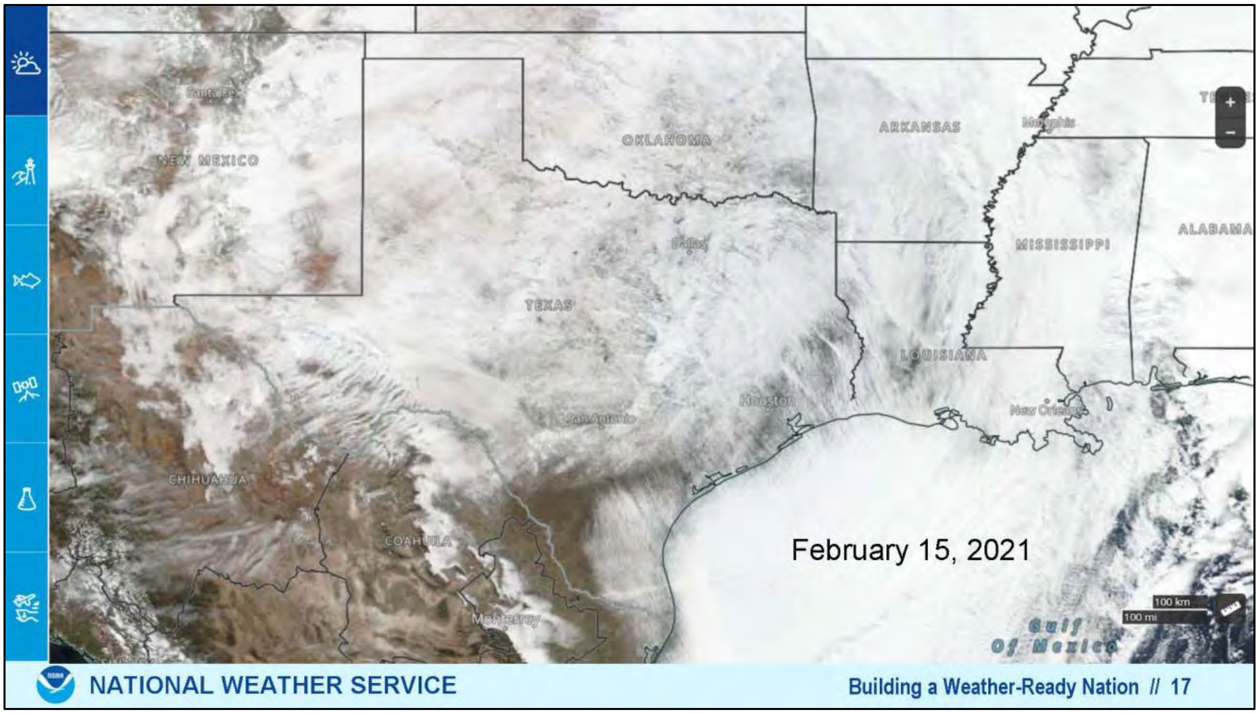


Wed-Thu, Feb 17-18, 2021

2nd snowiest day on record at Little Rock ,AR

WS Warning 24h criteria probability (ice) Thu-Friday




NEW MEXICO
OKLAHOMA
ARKANSAS
Memphis
MISSISSIPPI
ALABAMA
Dallas
TEXAS
LOUISIANA
Houston
San Antonio
New Orleans
CHIHUAHUA
COAHUILA
Monterrey
February 15, 2021
100 km
100 mi
Gulf
Of Mexico
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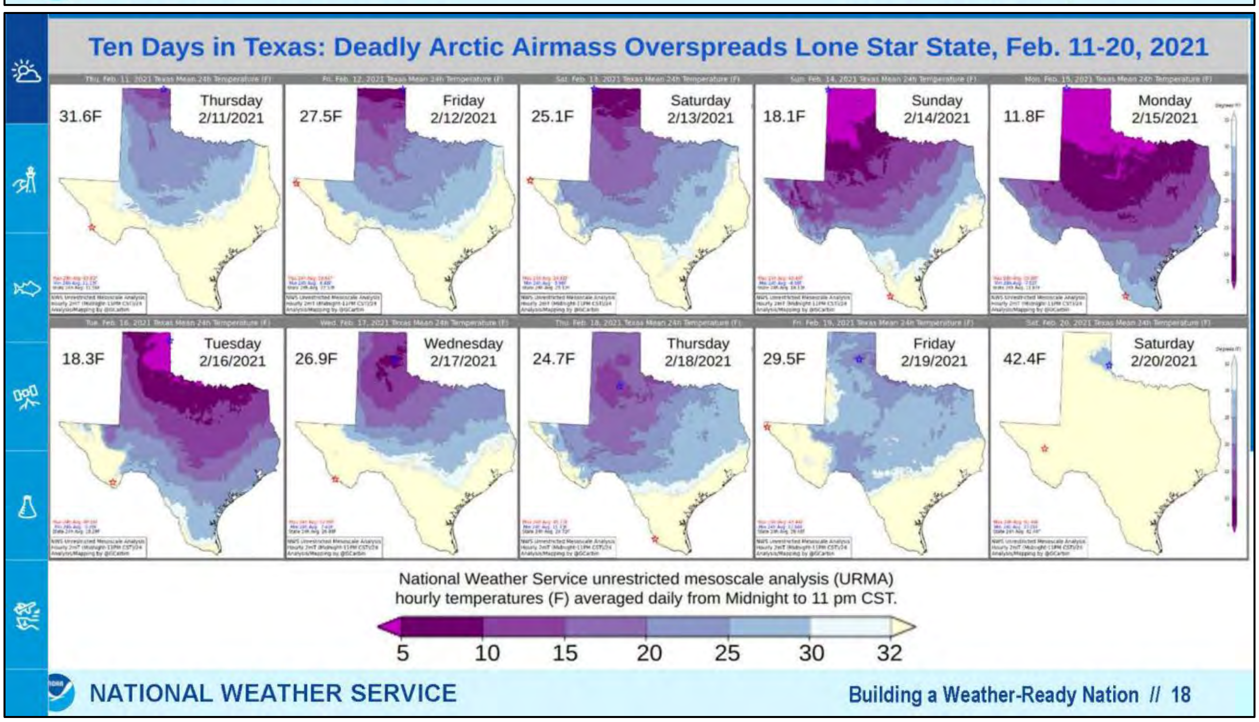
Ten Days in Texas: Deadly Arctic Airmass Overspreads Lone Star State, Feb. 11-20, 2021
31.6F
Thursday 2/11/2021
27.5F
Friday 2/12/2021
25.1F
Saturday 2/13/2021
18.1F
Sunday 2/14/2021
11.8F
Monday 2/15/2021
18.3F
Tuesday 2/16/2021
26.9F
Wednesday 2/17/2021
24.7F
Thursday 2/18/2021
29.5F
Friday 2/19/2021
42.4F
Saturday 2/20/2021
National Weather Service unrestricted mesoscale analysis (URMA)
hourly temperatures (F) averaged daily from Midnight to 11 pm CST.
5 10 15 20 25 30 32
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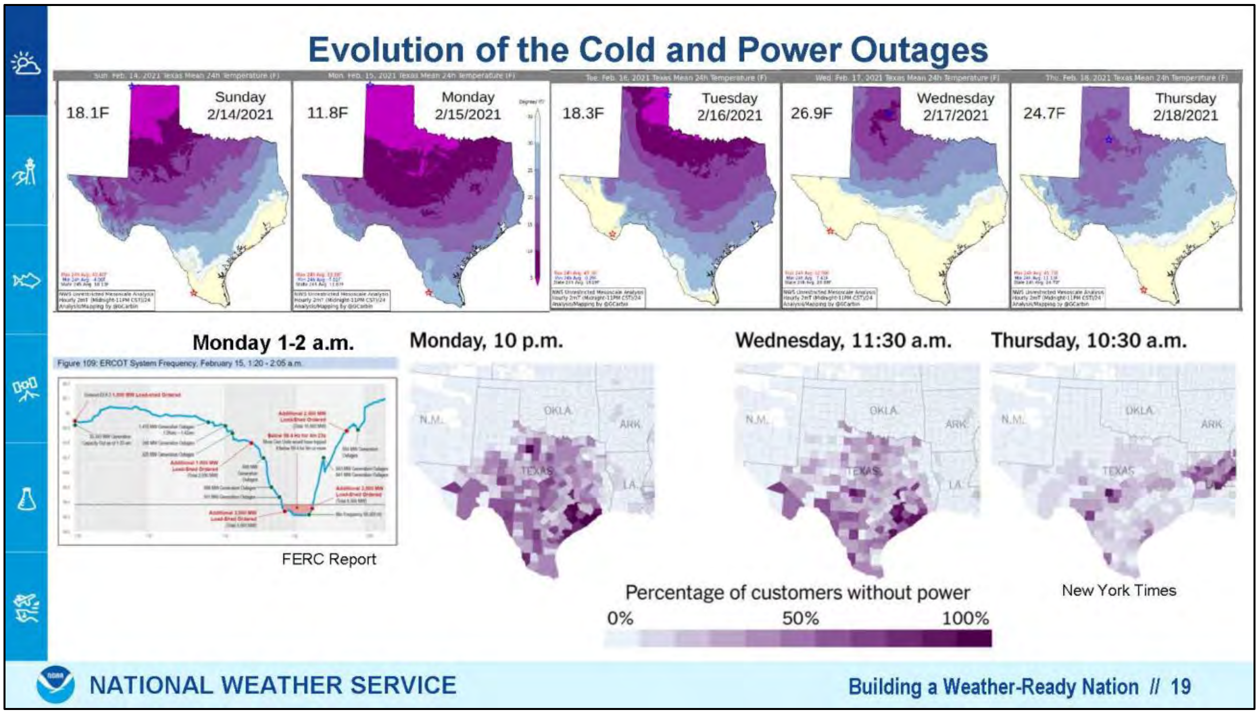
Evolution of the Cold and Power Outages
18.1F
Sunday
2/14/2021
11.8F
Monday
2/15/2021
18.3F
Tuesday
2/16/2021
26.9F
Wednesday
2/17/2021
24.7F
Thursday
2/18/2021
Monday 1-2 a.m.
Monday, 10 p.m.
Wednesday, 11:30 a.m.
Thursday, 10:30 a.m.
FERC Report
Percentage of customers without power
0%
50%
100%
New York Times
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Has it Happened Before?
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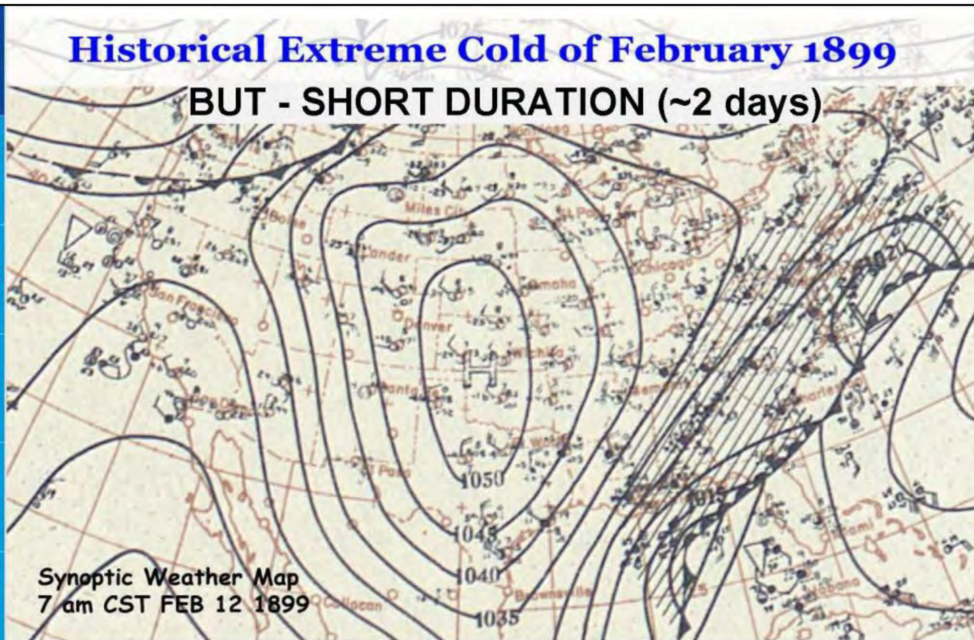
Historical Extreme Cold of February 1899

BUT - SHORT DURATION (~2 days)



Extremely strong high pressure system with central pressure greater than 1055 mb!

Examples of All-time record lows:

Oklahoma City
-17°F

Dallas Ft-Worth
-8°F

Tallahassee, FL
-2°F
(Feb. 13, 1899)

7-day Temperature & Anomalies, Dec. 20-26, 1983 and Feb. 12-18, 2021

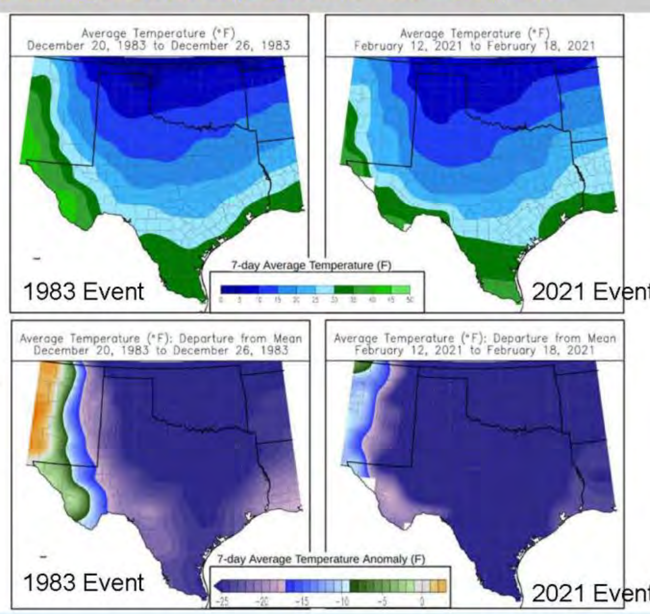
Mean temperature and departure from normal for 7-days centered on the coldest days for Dec. 1983 and Feb. 2021 cold air outbreaks over the Southern Plains. The December 1983 outbreak appears to be a reasonable analog to Feb. 2021.

Anomalously cold air does appear to have spread a bit farther west, south and east in the most recent Arctic outbreak, when compared to 1983.

(Note: Midwest Regional Climate Center (MRCC) online plotter does not go below -25F departure.)

Plots made with Cli-MATE MRCC Applications Tool Environment.

Normals period of record 1981-2010.




Was it Forecast?
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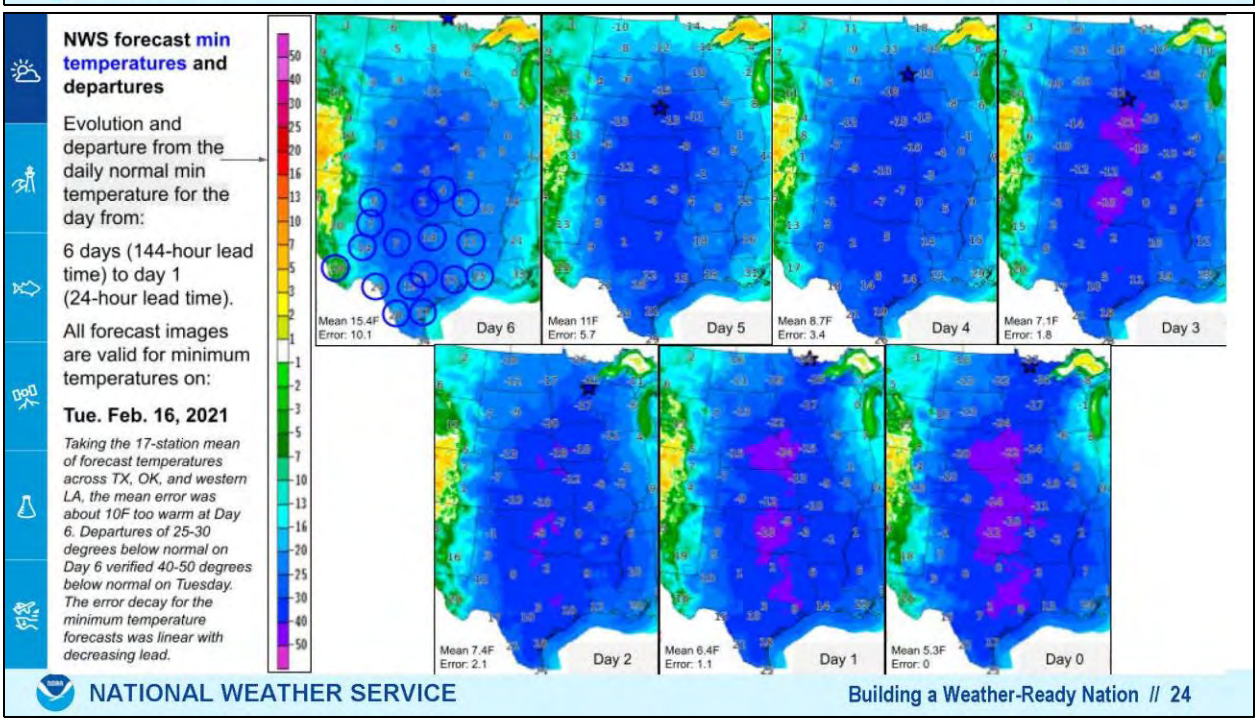
NWS forecast min temperatures and departures
Evolution and departure from the daily normal min temperature for the day from:
6 days (144-hour lead time) to day 1 (24-hour lead time).
All forecast images are valid for minimum temperatures on:
Tue. Feb. 16, 2021
Taking the 17-station mean of forecast temperatures across TX, OK, and western LA, the mean error was about 10F too warm at Day 6. Departures of 25-30 degrees below normal on Day 6 verified 40-50 degrees below normal on Tuesday. The error decay for the minimum temperature forecasts was linear with decreasing lead.
Mean 15.4F Error: 10.1
Day 6
Mean 11F Error: 5.7
Day 5
Mean 8.7F Error: 3.4
Day 4
Mean 7.1F Error: 1.8
Day 3
Mean 7.4F Error: 2.1
Day 2
Mean 6.4F Error: 1.1
Day 1
Mean 5.3F Error: 0
Day 0
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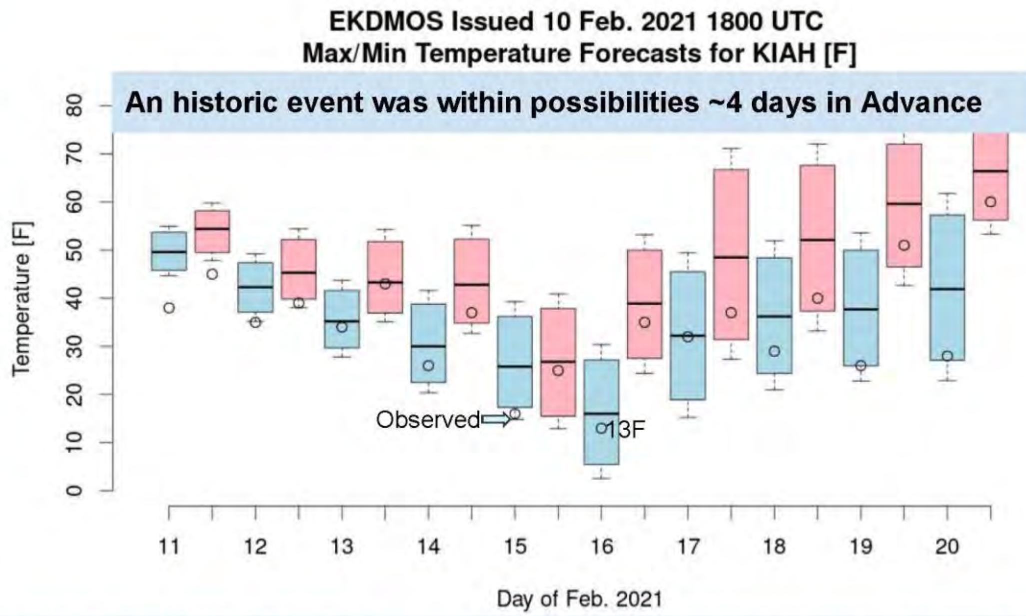
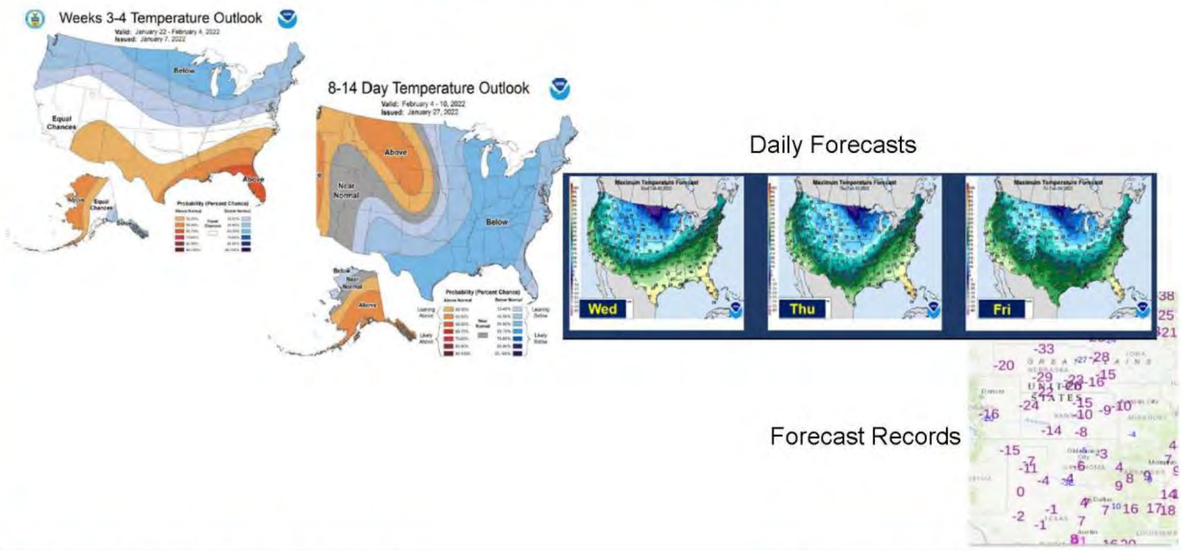


NATIONAL WEATHER SERVICE

A Few NWS Winter Predictive Tools

NATIONAL WEATHER SERVICE

NWS Temperature Forecasts

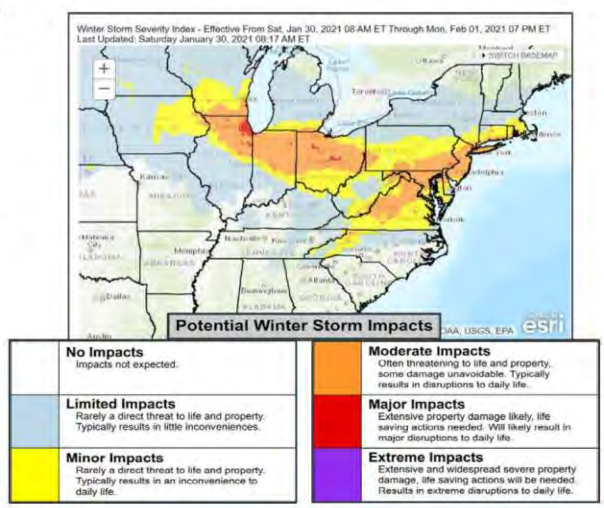


Winter Storm Severity Index (WSSI)

Goal: Forecast the potential severity of community impacts from winter storms, including tree damage, property damage, transportation impacts, and disruptions to daily life

- Impacts relayed in a 5 category scale
    - Relates to rarity of meteorological event
- Algorithms connect official NWS meteorological forecast to general impact categories
- Incorporates non-meteorological factors
    - Population, tree cover, land use

Output available here:
www.weather.gov/wssi



WSSI - Components & Scale

Snow Load
Indicates potential infrastructure impacts due to the weight of snow

Snow Amount
Indicates potential impacts due to the total amount of snow or snow accumulation rate

Ice Accumulation
Indicates potential infrastructure impacts due to combined effects and severity of ice and wind

Ground Blizzard
Indicates the potential travel-related impacts of strong winds interacting with pre-existing snow cover

Flash Freeze
Indicates the potential of flash freezing during or after precipitation events.

Blowing Snow
Indicates the potential disruption due to blowing and drifting snow

Potential Winter Storm Impacts

	No Impacts Impacts not expected.		**Moderate Impacts** Often threatening to life and property, some damage unavoidable. Typically results in disruptions to daily life.
	Limited Impacts Rarely a direct threat to life and property. Typically results in little inconveniences.		**Major Impacts** Extensive property damage likely, life saving actions needed. Will likely result in major disruptions to daily life.
	Minor Impacts Rarely a direct threat to life and property. Typically results in an inconvenience to daily life.		**Extreme Impacts** Extensive and widespread severe property damage, life saving actions will be needed. Results in extreme disruptions to daily life.

Winter Storm Severity Index (WSSI)

Able to show the impacts from different parts of the storm

Snow Amount

Ice Accumulation

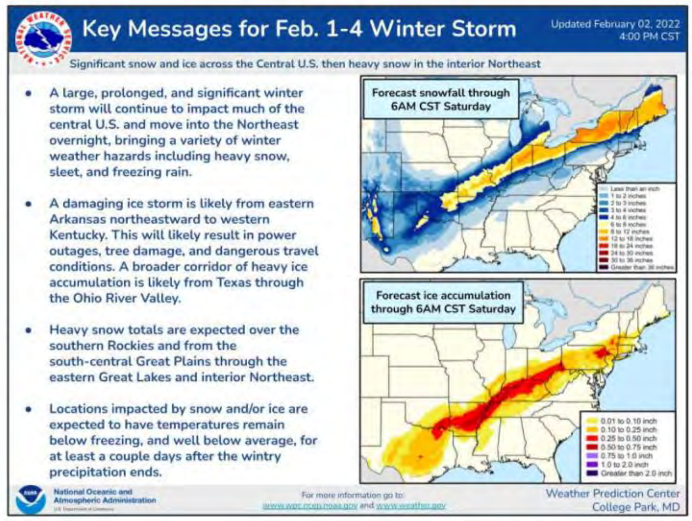
Winter Storm Key Messages

The Purpose

- Galvanize partners and media around consistent, coordinated messages

Specifics

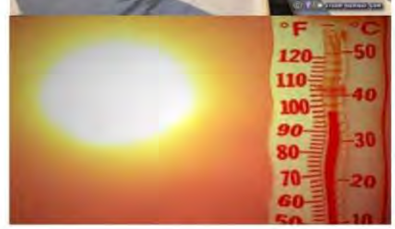
- Used for High-impact storms that are expected to cause travel disruptions or pose a hazard to life and property and/or rare events
- Collaborated among operational units
- Available on WPC homepage and integrated into WFO & WPC messaging



Summary

- Weather extremes are increasing, stressing critical infrastructure
- The winter of 2020-21 was historic
  - The Southern Plains Cold Wave
  - Oklahoma Ice Storm
- The National Weather Service provide critical observations and forecasts essential to public safety

National Weather Service: https://www.weather.gov
Weather Prediction Center: https://www.wpc.ncep.noaa.gov



3.3.2 Presentation 1C-2: Linking Arctic variability and change with extreme winter weather in the US including the Texas Freeze of February 2021

Authors: *Judah Cohen*[1], Laurie Agel[2], Mathew Barlow[2], Chaim Garfinkel[3], Ian White[3]*
[1]Atmospheric and Environmental Research, [2]University of Massachusetts Lowell, [3]Hebrew University of Jerusalem

Speaker: *Judah Cohen*

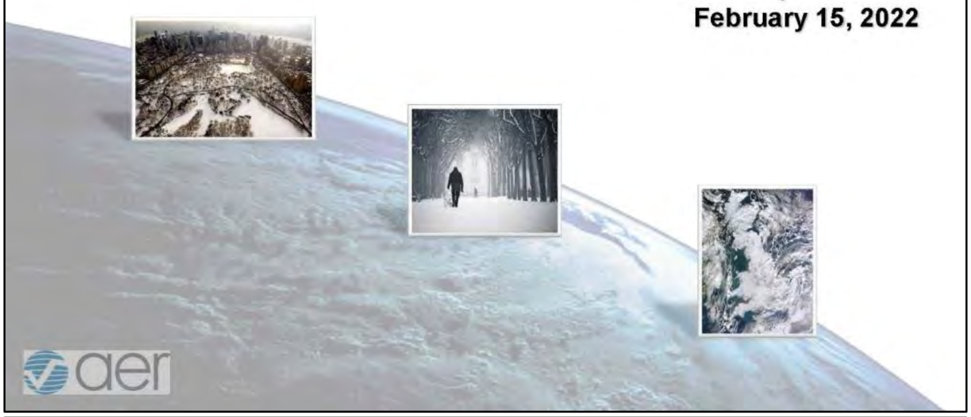
3.3.2.1 Abstract

The Arctic is warming at a rate twice the global average and severe winter weather is reported to be increasing across many heavily populated mid-latitude regions, but there isn't yet agreement on whether there is a physical link between the two phenomena. Here I will present observational analysis to show that a lesser-known stratospheric polar vortex (SPV) disruption that involves wave reflection and stretching of the SPV is linked with extreme cold across parts of Asia and North America, including the recent February 2021 Texas cold wave, and has been increasing over the satellite era (post 1980). I will also present numerical modeling experiments forced with trends in autumn snow cover and Arctic sea ice to establish a physical link between Arctic change and SPV stretching and surface impacts. This phenomenon is also active in January 2022 and if time permits, I will present on the weather of January 2022.

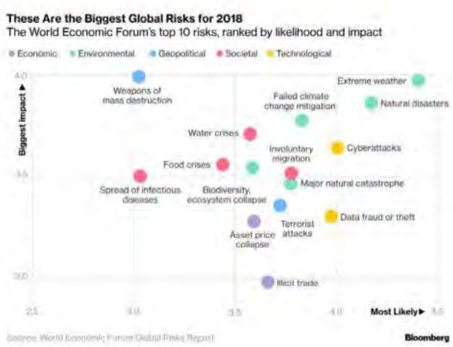
3.3.2.2 Presentation (ADAMS Accession No. ML22061A129)

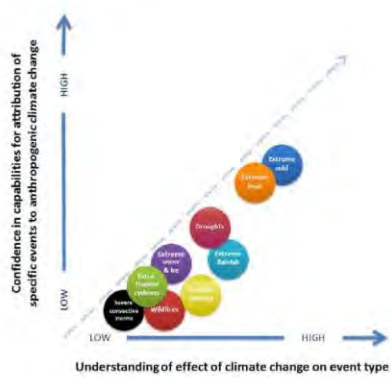
Linking Arctic variability and change with extreme winter weather in the US including the Texas Freeze of February 2021

Judah Cohen
AER/Dept CEE MIT
February 15, 2022



Extreme Weather





-- Extreme weather is the considered by economists to be the biggest global risk

-- The extreme weather climate scientists are most confident will change due to climate change is a decrease in extreme cold

2


National
A winter storm will hit Texas – bringing back memories of last year's power grid failure
U.S.
The New York Times
As Texas braces for a cold snap, officials promise the power grid will hold.
ICY CONDITIONS EXIST
Power lines are seen after winter weather caused electricity blackouts in H
Nakamura/Reuters)
Trucks moved slowly down Interstate 35 in Dallas on Thursday. Jeffrey McWhirter for The New York Times
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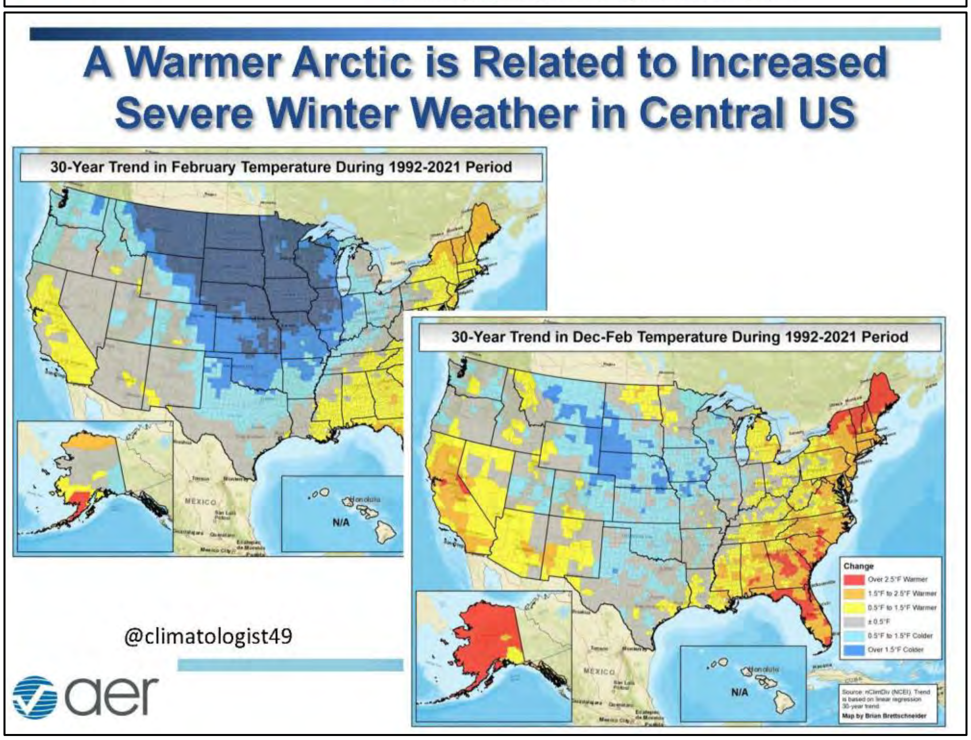
A Warmer Arctic is Related to Increased Severe Winter Weather in Central US
30-Year Trend in February Temperature During 1992-2021 Period
N/A
30-Year Trend in Dec-Feb Temperature During 1992-2021 Period
Change
Over 2.5°F Warmer
1.5°F to 2.5°F Warmer
0.5°F to 1.5°F Warmer
± 0.5°F
0.5°F to 1.5°F Colder
Over 1.5°F Colder
Source: nClimDiv (NCEI). Trend is based on linear regression 30-year trend
Map by Brian Brettschneider
N/A
@climatologist49
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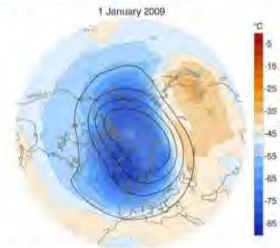
Arctic Oscillation (AO)/Polar Vortex



Atmospheric and Environmental Research (AER)

- Dominant mode of Northern Hemisphere climate variability. Also known as the North Atlantic Oscillation.
- Can be thought of as a metric of how much mixing of air masses is occurring in the atmosphere.
- Positive AO/strong polar vortex – little mixing with strong low pressure/cold air sitting over the pole and higher pressure/warmer air to the south.
- Negative AO/weak polar vortex – strong mixing causes warm air from the south to rush the Pole and Arctic air spills equatorward

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ARCTIC AMPLIFICATION

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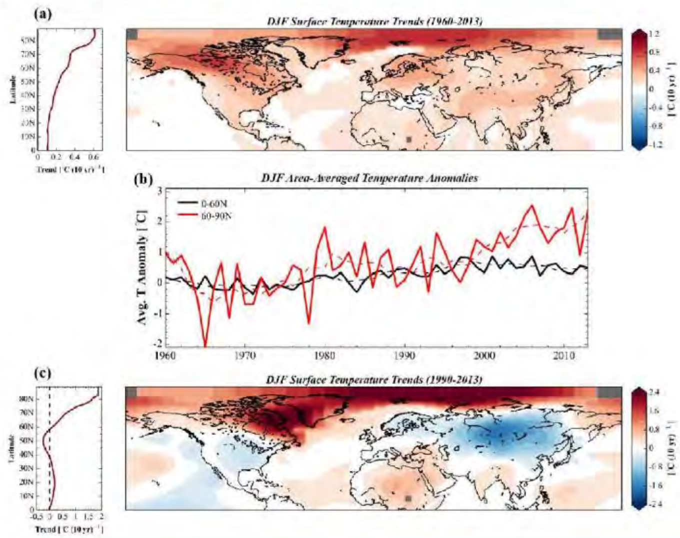
Arctic Amplification



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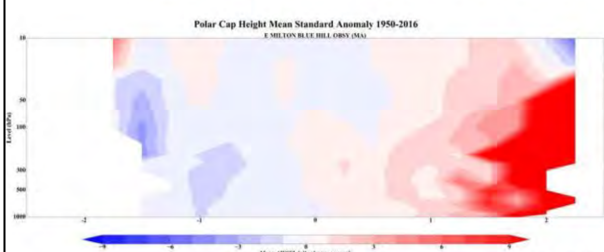
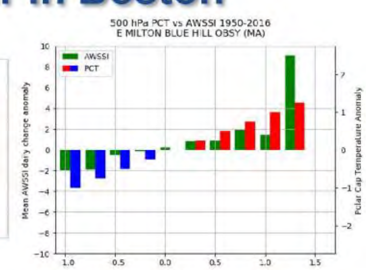
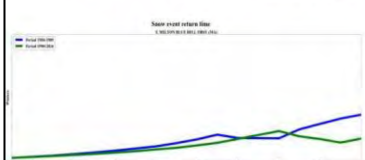
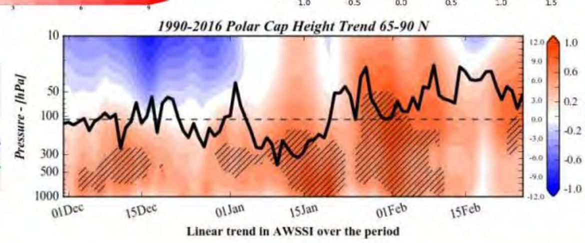
Cohen et al. 2014 Review paper

A Warmer Arctic is Related to Increased Severe Winter Weather in Boston









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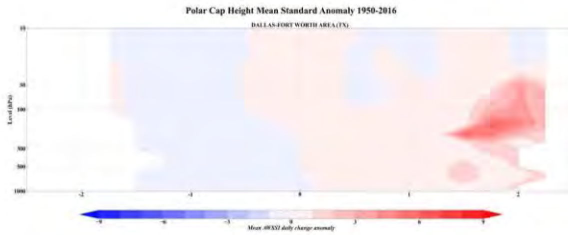
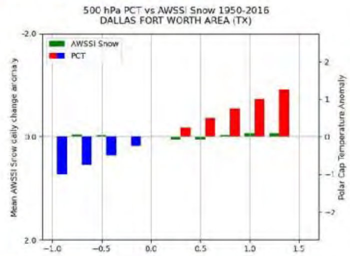
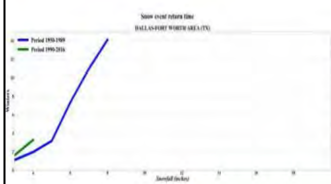
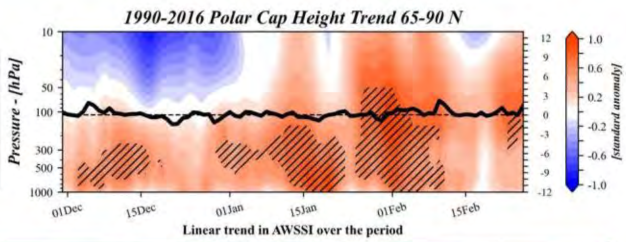
Cohen et al. 2018

A Warmer Arctic is Related to Increased Severe Winter Weather in Dallas









Cohen et al. 2018

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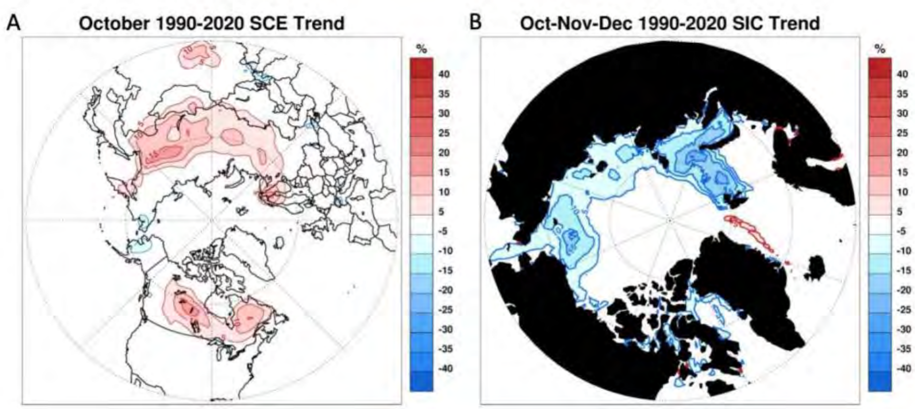
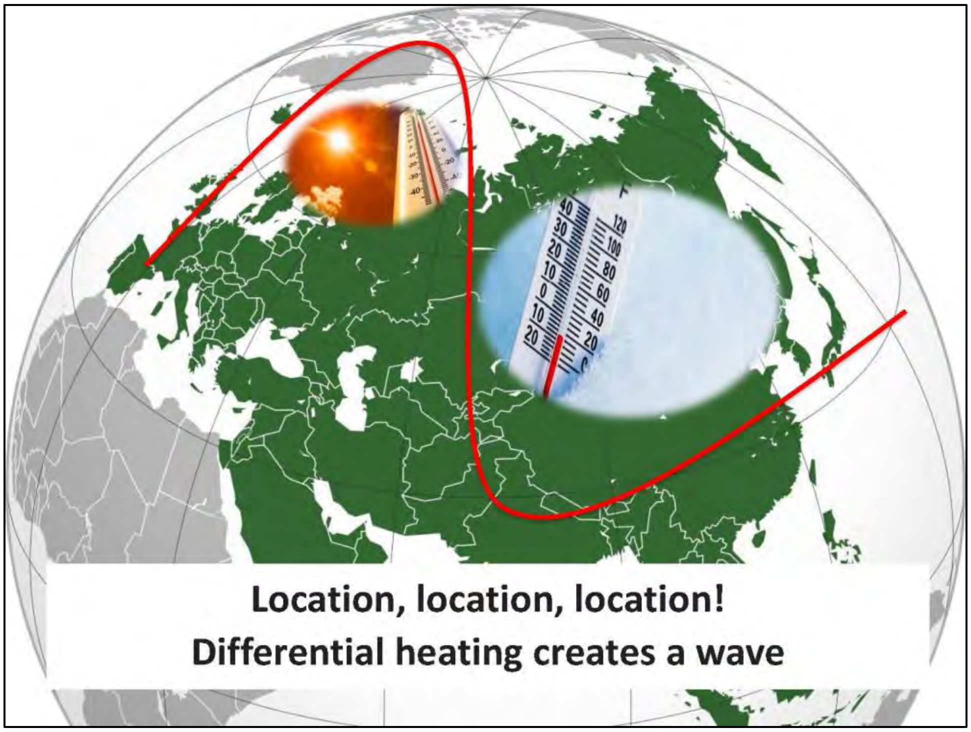
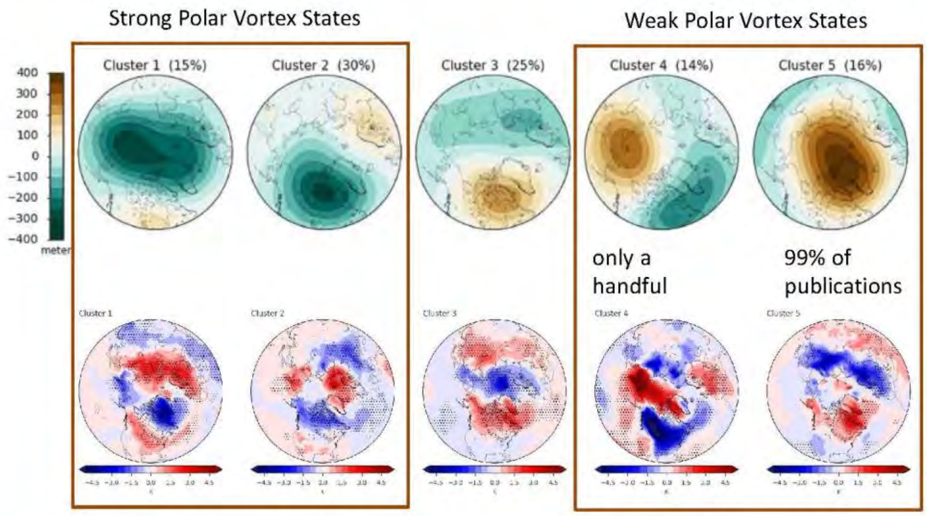
Snow and Sea Ice Trends during Era of Arctic Amplification





STRETCHED POLAR VORTEX

Cluster Analysis of Polar Vortex and Trends



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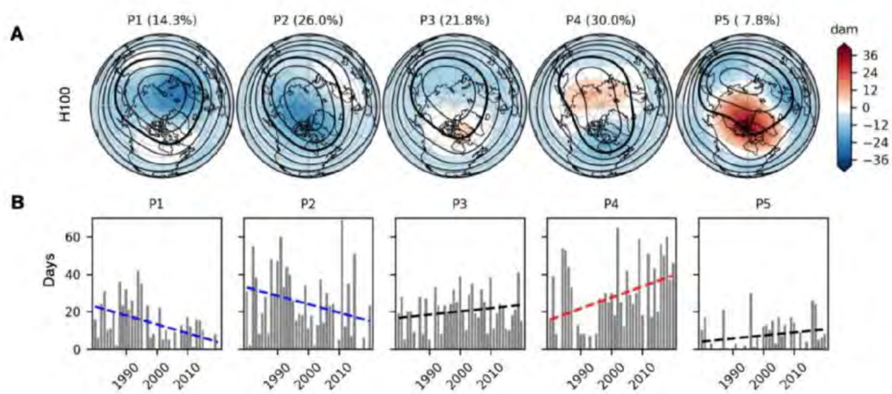
Kretschmer et al (2018)

Trends of five clusters over reanalysis



Cluster 4 i.e., stretched polar vortex shows strongest increasing trend

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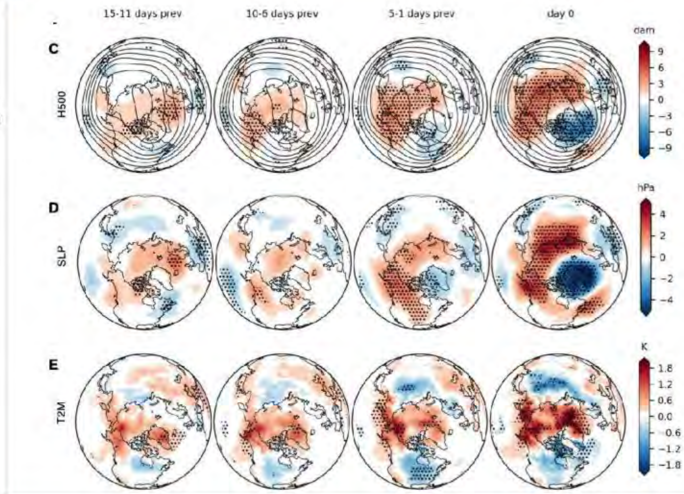
Cohen et al (2021)

Precursors

Ridging across the Arctic
Troughing across East Asia

High pressure across the Arctic

Warm across the Arctic
Cold across Asia then North America



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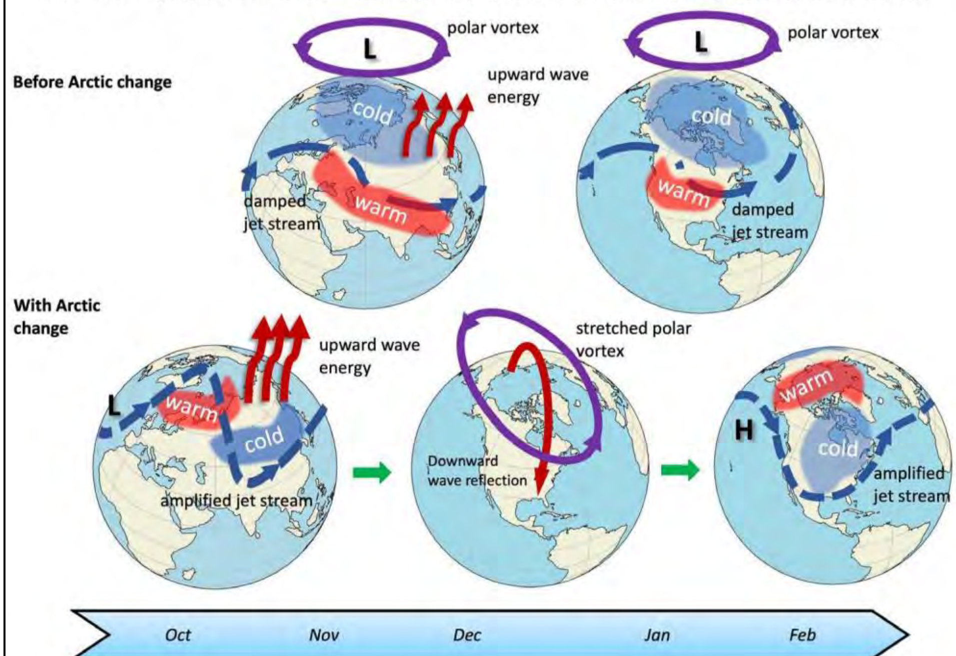
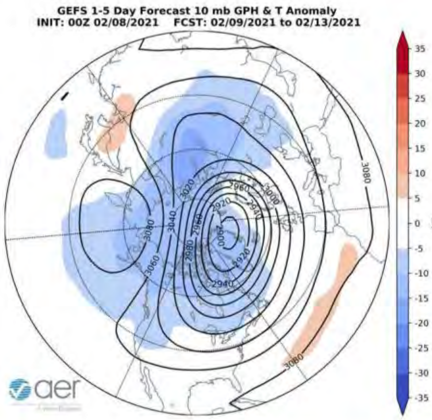
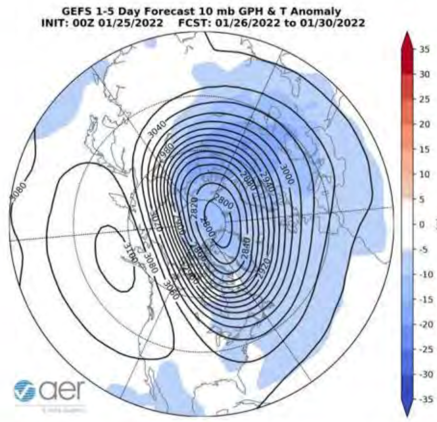
Late fall to early-winter Arctic amplification amplifies the natural standing wave over Eurasia, which leads to mid- to late-winter wave amplification over North America. Wave amplification on both continents favors extreme winter weather.



Stretched polar vortices 2021 and 2022





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Weather Warnings 2021 and 2022

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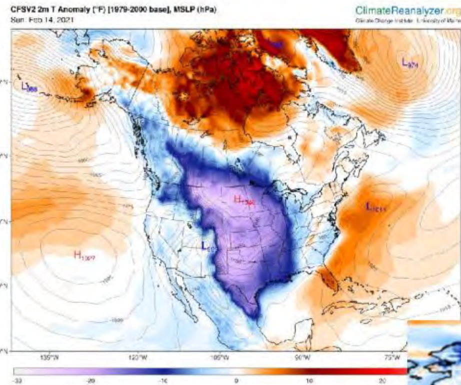
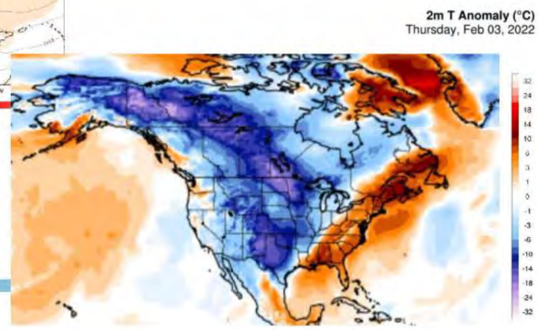
Temperatures 2021 and 2022





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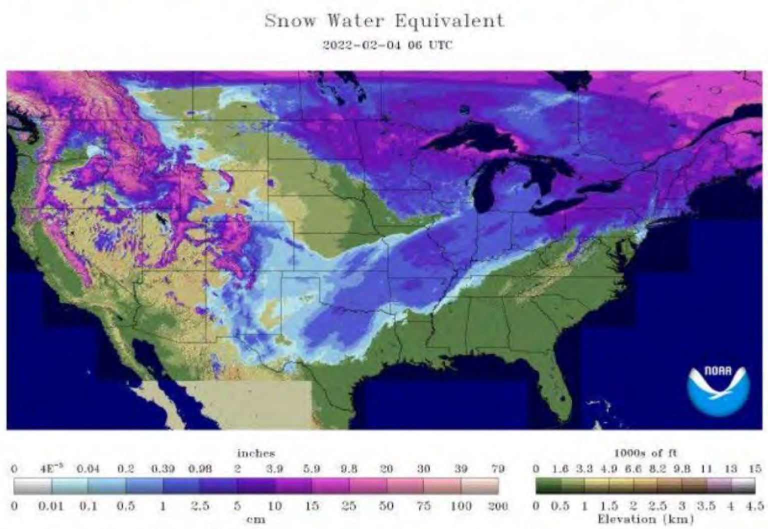
Record snow cover extent in 2021

National Snow Analysis 2020-2021

OWP OFFICE OF WATER PREDICTION



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Summary

- The globe is warming and our climate system is much warmer than even a few decades ago.
- Global warming is not equal everywhere. Over the past three decades the Arctic has been warming the fastest while the mid-latitudes have cooled/no trend (in winter).
- Studies strongly suggests that the warming in the Arctic is related to the cooling in the mid-latitudes and the dynamical link is through the "polar vortex."
- A rather esoteric behavior of the polar vortex is related to extreme winter weather east of the Rockies including Texas where the polar vortex becomes elongated or stretched.
- Winter days where the polar vortex "stretches" have been increasing during the period of accelerated Arctic warming, which can contribute to more severe winter weather.

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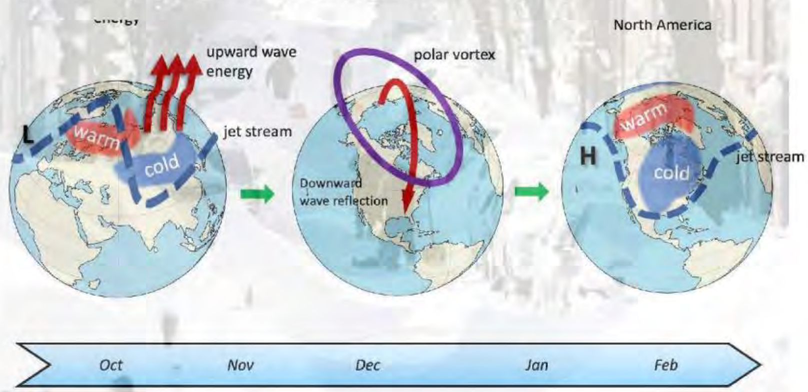
SCIENCE PAPER

Cohen, J., L. Agel, M. Barlow, C. I. Garfinkel, I. White. 2021: Linking Arctic variability and change with extreme winter weather in the US, *Science*, 373 (6559), 1116–1121, DOI: 10.1126/science.abi9167.



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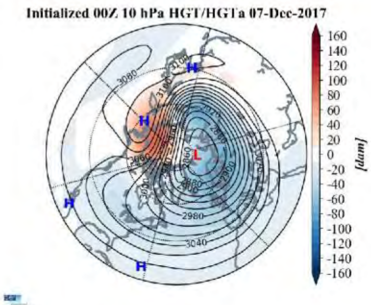
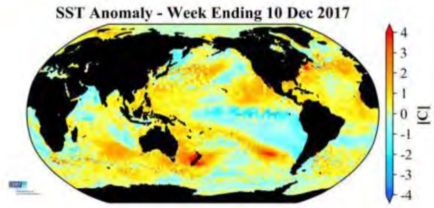
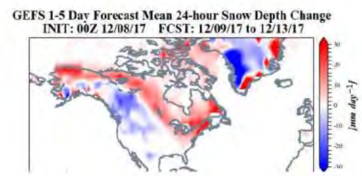
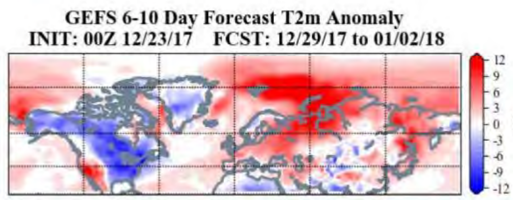
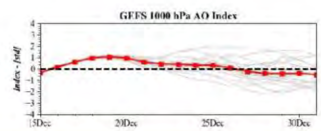
Arctic Oscillation/Polar Vortex Blog











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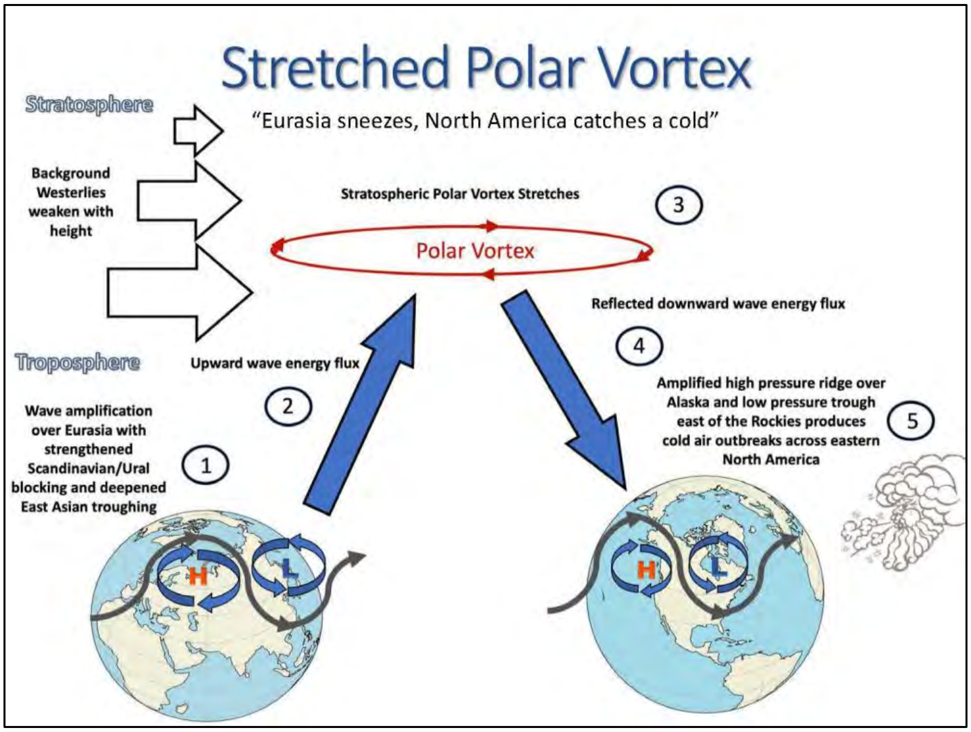
Kretschmer, D. Coumou, L. Angel, M. Barlow, E. Tziperman and J. Cohen. 2018: More frequent weak stratospheric polar vortex states linked to mid-latitude cold extremes, *Bulletin of the American Meteorological Society*, doi:10.1175/BAMS-D-16-0259.1.

Thank you!


Stretched Polar Vortex
"Eurasia sneezes, North America catches a cold"
Stratosphere
Background Westerlies weaken with height
Stratospheric Polar Vortex Stretches
3
Polar Vortex
Reflected downward wave energy flux
4
Troposphere
Upward wave energy flux
2
Amplified high pressure ridge over Alaska and low pressure trough east of the Rockies produces cold air outbreaks across eastern North America
5
Wave amplification over Eurasia with strengthened Scandinavian/Ural blocking and deepened East Asian troughing
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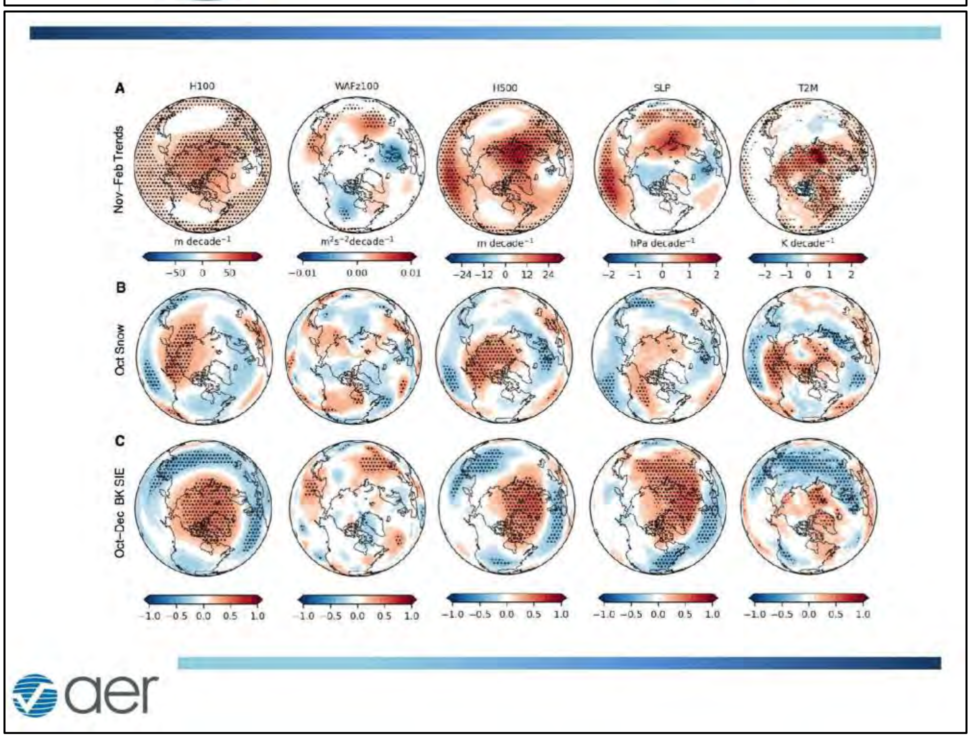
A
H100
WAFz100
H500
SLP
T2M
Nov–Feb Trends
m decade⁻¹
m²s⁻²decade⁻¹
m decade⁻¹
hPa decade⁻¹
K decade⁻¹
B
Oct Snow
C
Oct–Dec BK SIE

Conclusions

- Subseasonal timeframe (2-6 weeks) has exhibited the poorest forecast skill from days to months.
- Land surface influence may just be the sweet spot to provide a signal in the subseasonal timeframe and if the response is long-lived then also in the seasonal timeframe.
- Demonstrated snow cover extent pathway through troposphere-stratosphere coupling make it ideal for subseasonal prediction.
- But challenges remain on the observations snow-AO relationship has decreased over the past decade.
- Models have a difficult time simulating a snow-AO/polar vortex relationship especially free running simulations.
- Still our recent study both observational and modeling (snow forced) confirm snow-polar vortex relationship but not in the traditional SSW-AO pathway but rather a stretched polar vortex-North Pacific Oscillation pathway.

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Outline

- A statistically significant correlation exists between fall Eurasian snow cover extent (SCE) and the dominant mode of Northern Hemisphere (NH) winter climate variability (AO/NAM).
- How SCE influences winter climate can be explained by a six-step process.
- There are challenges though, including most model ensembles and a failing observed AO-SCE relationship.
- However recent studies confirm a snow-troposphere-stratosphere connection but may be independent of the AO.
- That SCE anomalies is a precursor to polar vortex behavior and eventual severe winter weather makes it useful for seasonal to subseasonal prediction.

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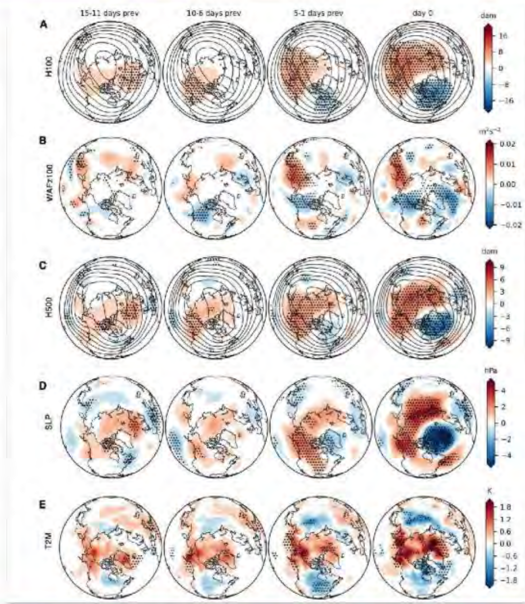
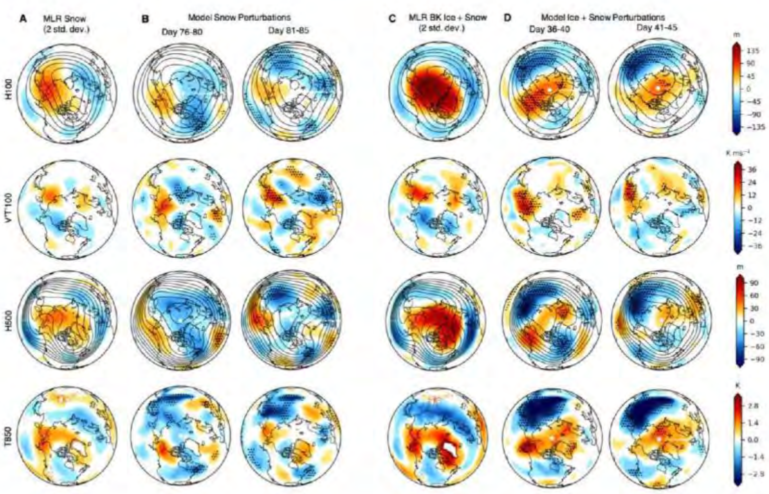
Precursors



Observational and modeling support



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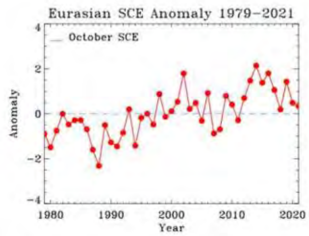
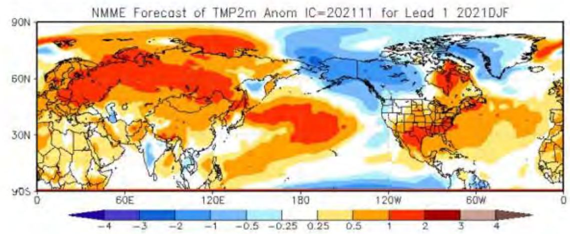
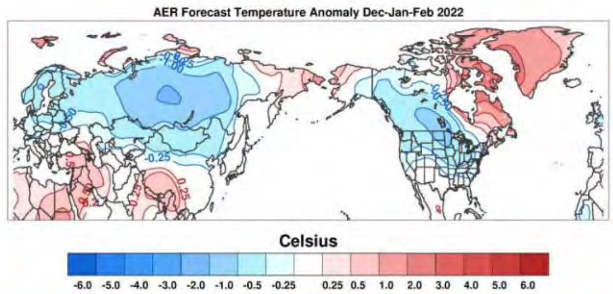
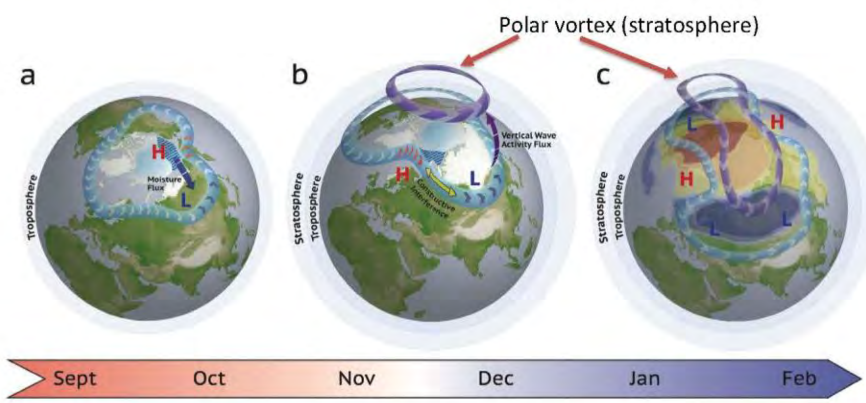
Winter Temperature Forecast



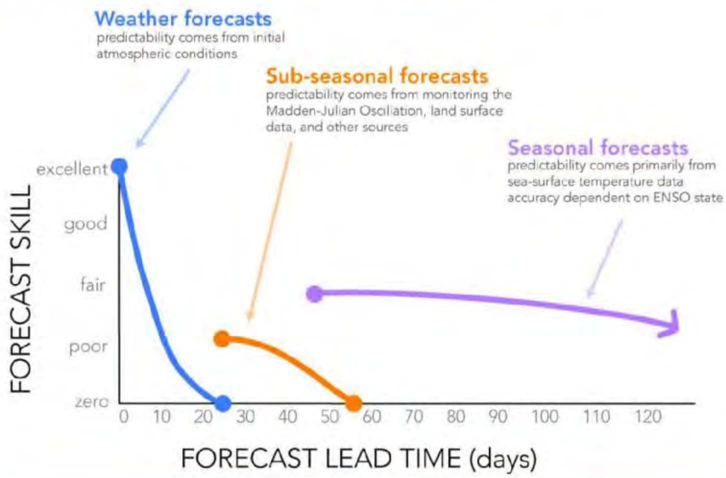




How Accelerated Arctic Warming Impact the Polar Vortex



"It is hard to make predictions, especially about the future." (Yogi Berra, Niels Bohr)



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3.3.3 Presentation 1C-3: 2021 U.S. Billion Dollar Weather and Climate Disasters in Historical Context including New County-Level Exposure, Vulnerability and Projected Damage Mapping

Authors: *Adam Smith, National Oceanic and Atmospheric Administration, National Centers for Environmental Information (NOAA/NCEI)*

Speaker: *Adam Smith*

3.3.3.1 Abstract

NOAA National Centers for Environmental Information (NCEI) released the final update to its 2021 billion-dollar disaster report (www.ncdc.noaa.gov/billions), confirming what much of the nation experienced throughout 2021: another year of frequent and costly extremes. The year came in second to 2020 in terms of number of disasters (20 versus 22) and third in total costs (behind 2017 and 2005), with a price tag of $145 billion. The events included: 1 winter storm/cold wave event (focused across the deep south and Texas); 1 wildfire event (combined impacts of wildfires across Arizona, California, Colorado, Idaho, Montana, Oregon and Washington); 1 drought and heat wave event (summer/fall across western U.S.); 2 flood events (in California and Louisiana); 3 tornado outbreaks (including the December tornado outbreaks); 4 tropical cyclones (Elsa, Fred, Ida and Nicholas); and 8 severe weather events (across many parts of the country, including the December Midwest derecho). The costliest 2021 events were Hurricane Ida ($75 billion), the mid-February Winter Storm / Cold Wave ($24.0 billion), and the Western wildfires ($10.9 billion). Adding the 2021 events to the record that began in 1980, the U.S. has sustained 310 weather and climate disasters where the overall damage costs reached or exceeded $1 billion. The cumulative cost for these 310 events exceeds $2.15 trillion. In broader context, the total cost of U.S. billion-dollar disasters over the last 5 years (2017-2021) is $742.1 billion, with a 5-year annual cost average of $148.4 billion, both of which are new records and nearly triple the 42-year inflation adjusted annual average cost. The U.S. billion-dollar disaster damage costs over the last 10-years (2012-2021) were also historically large: at least $1.0 trillion from 142 separate billion-dollar events. It is concerning that 2021 was another year in a series of years where we had a high frequency, a high cost, and large diversity of extreme events that affect people's lives and livelihoods—concerning because it hints that the extremely high activity of recent years is becoming the new normal. 2021 marks the seventh consecutive year (2015-21) in which 10 or more separate billion-dollar disaster events have impacted the U.S. The 1980–2021 annual average (black line) is 7.4 events (CPI-adjusted); the annual average for the most recent 5 years (2017–2021) is 17.2 events (CPI-adjusted). To better reflect multi-hazard risk – the Billion-dollar disaster site now provides a new mapping tool that provides county-level information on natural disaster hazards across the United States. This interactive NOAA mapping tool provides detailed information on a location's susceptibility to weather and climate hazards that can lead to billion-dollar disasters—such as wildfires, floods, drought and heat waves, tornado outbreaks, and hurricanes. The tool expands upon FEMA's National Risk Index to provide a view of a location's risk for, and vulnerability to, single or multiple combinations of weather and climate hazards for every county and county-equivalent in all 50 states: https://www.ncdc.noaa.gov/billions/mapping In addition, the 2021 annual U.S. billion-dollar disaster report is available here: https://www.climate.gov/news-features/blogs/beyond-data/2021-us-billion-dollar-weather-and-climate-disasters-historical

3.3.3.2 Presentation (ADAMS Accession No. ML22061A128)

NOAA's National Centers for Environmental Information (NCEI) –
Climate Science and Service Division

Statutory mission to describe the climate of the United States and act as the **"Nation's Scorekeeper" regarding the trends and anomalies** of weather and climate.

- As part of this responsibility we also analyze extreme weather and climate events in the U.S. that have **great economic and societal impacts** known as "**U.S. Billion-dollar Weather & Climate Disasters**"
- NCEI's U.S. billion-dollar disaster analysis seeks to bring the best public and private disaster loss data together in a systematic approach. To that end, we maintain a consistent record of weather and climate disasters with costs equaling or exceeding $1 billion in damages (adjusting for inflation) using high-quality data sources and peer-reviewed methods.
- **Period of record: 1980-2021 (Quarterly updates)**
- The U.S. has sustained **310** separate weather and climate disasters since 1980 where overall damages/costs reached or exceeded $1 billion.
- **Total, direct costs exceed $2.15 trillion (CPI-adjusted to 2021).**

To capture losses requires a broad array of **public** and **private** data

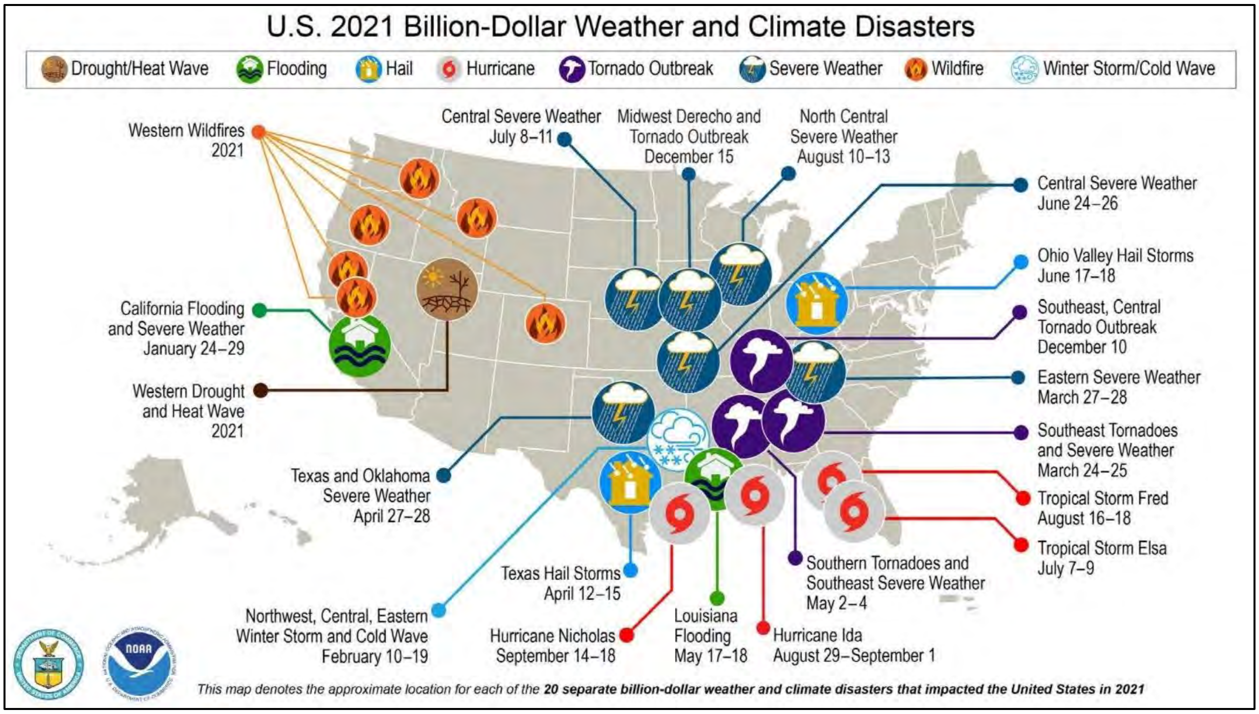
	Hurricanes/ Tropical Storms	Severe Local Storms	Winter Storms	Crop Freeze	Wildfire	Drought / Heat Wave	Inland / Riverine Flooding
Insurance Service Office - Property Claim Services	x	x	x		x		x
FEMA – Presidential Disaster Declarations	x	x	x	x	x		x
FEMA – National Flood Insurance Program	x						x
USDA – Risk Management Agency	x	x	x	x	x	x	x
National Interagency Fire Center					x		
Energy Information Administration	x	x	x		x	x	
US Army Corps of Engineers							x
State Agencies	x	x	x	x	x	x	x

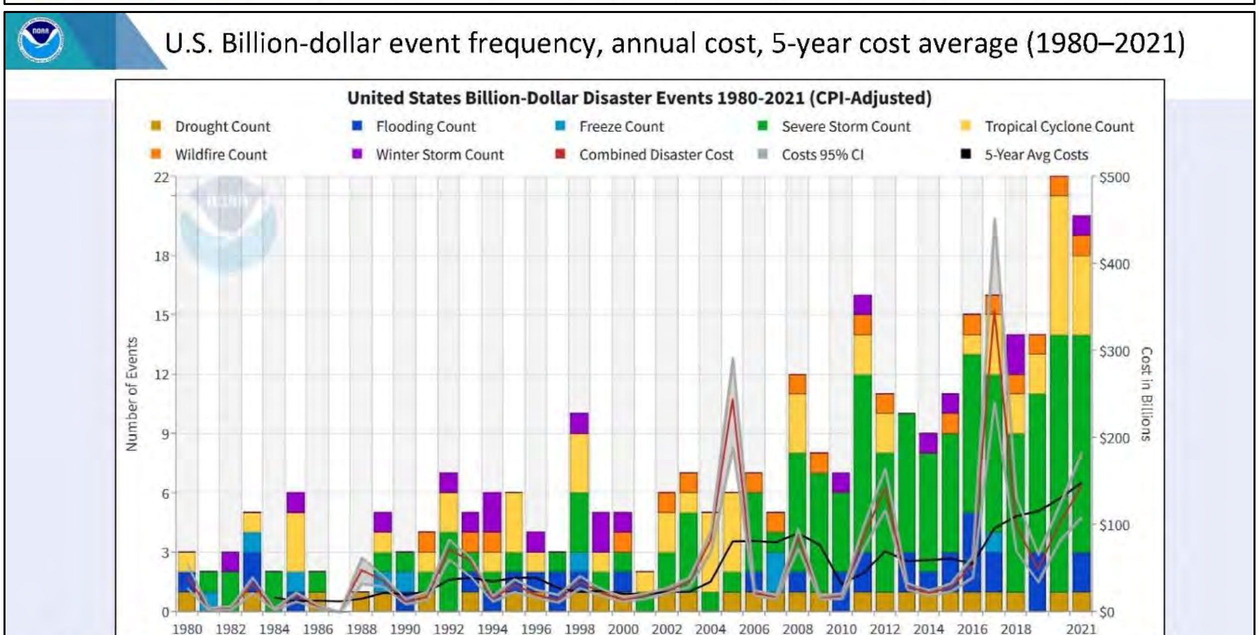
Account for total, direct losses (i.e., **insured** and **uninsured**) for assets including:

- **physical damage** to residential, commercial, and government buildings
- **material assets** (content) within a building
- **time element losses** (i.e., time costs for businesses; hotel costs for loss of living quarters)
- **vehicles, boats, offshore energy platforms**
- **public infrastructure** (i.e., roads, bridges, levees, buildings)
- **Agricultural / forestry assets** (i.e., crops, livestock, commercial timber, wildfire fighting)

We do not account for:

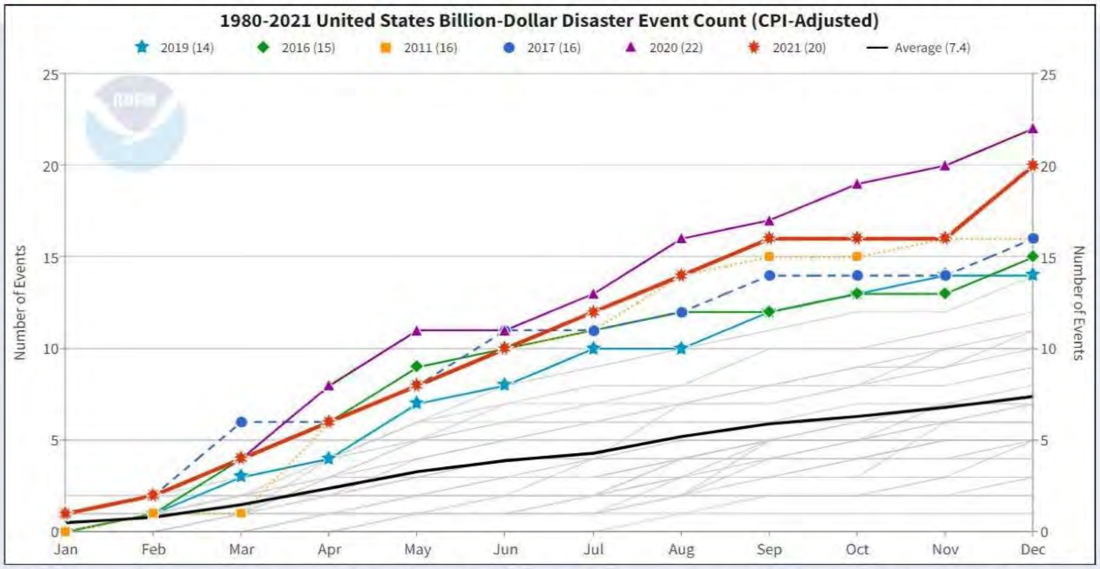
- natural capital/envn. degradation;
- mental or physical healthcare-related costs;
- all downstream (indirect) costs





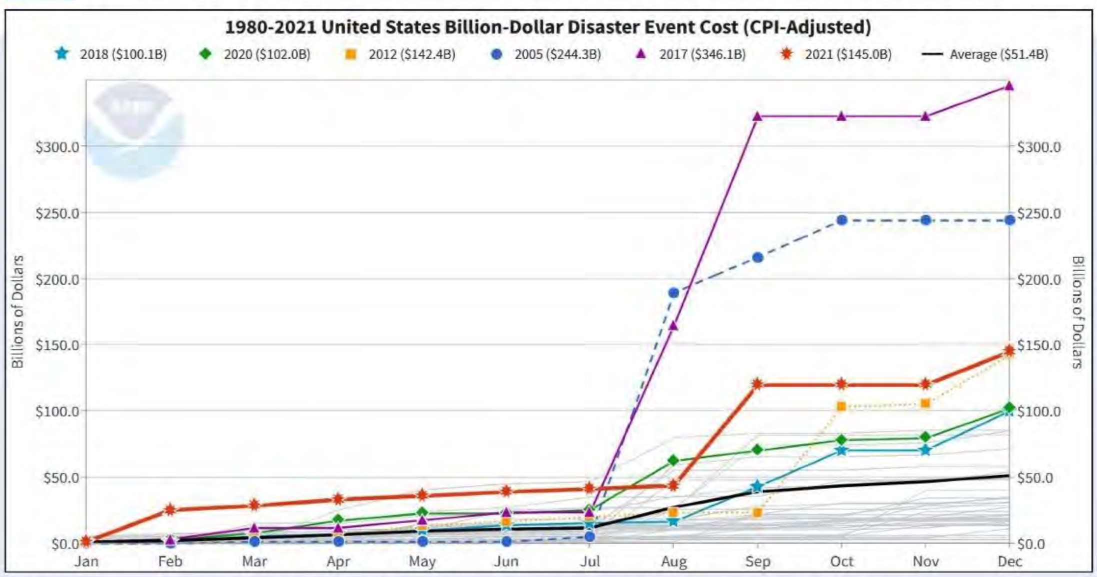
- Western wildfires, severe storms, inland flooding and hurricane costs all on the rise
- **<u>5-year annual cost average</u>** >**$148.4 billion - a record;** costs over **5 years** (2017-2021) **$742 billion - a record**

Cumulative U.S. billion-dollar disaster frequency (year-to-date) for years 1980-2021



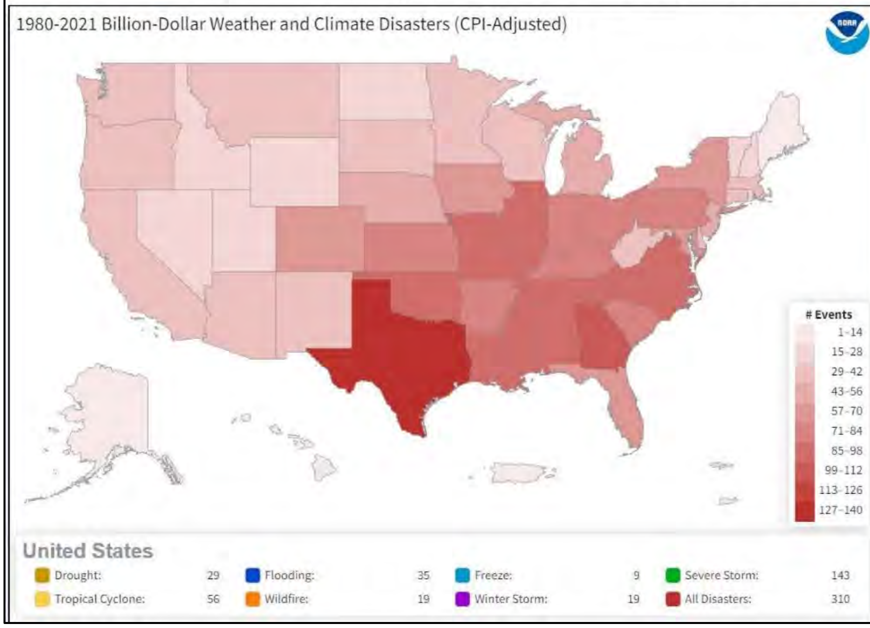
- **1980 – 2021** annual average: **7.4 events** (CPI-adjusted). **2017–2021** 5-year average: **17.2 events** (CPI-adjusted)
- **2021 - 20 events** [11 severe storm events, 4 tropical cyclones, 2 floods, 1 winter storm, drought & wildfire]

Cumulative U.S. billion-dollar disaster cost (year-to-date) for years 1980-2021



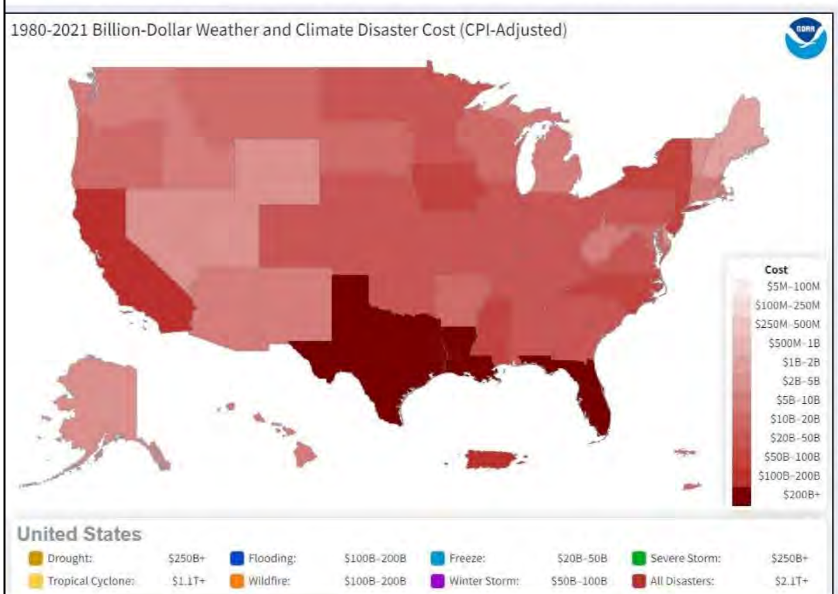
- **2021** cost total (**$145.0 billion – 3rd highest**) vs. the 42-year period of record at **$51.4 billion**
- The **top 3 most costly years** for U.S. - **2017** ($346.1 billion); **2005** ($244.3 billion); **2021** ($145.0 billion)

From 1980–2021, the U.S. **South, Central** and **Southeast** regions experienced a <u>higher frequency</u> of billion-dollar disaster events than any other region



- Reflects the **frequency, diversity**, & **severity** of weather & climate events impacting the regions

From 1980–2021, the U.S. **South, Central** and **Southeast** regions experienced a <u>higher cost</u> from billion-dollar disaster events. CA, NY, NJ, PR and V.I. as well.



- Reflects the **severity** and **vulnerability** of weather & climate events impacting different regions
- The **top 3 most impacted states:**
  - **Texas** ($343 billion)
  - **Louisiana** ($270 billion)
  - **Florida** ($248 billion)
- The <u>relative costs are more acute in Louisiana</u>, as its population and economic size is much smaller than Texas or Florida.
- Louisiana also has a high frequency of disaster events, which can leads to compounding, cascading socioeconomic impacts.

From **1980-2021**, the U.S. has experienced **310** distinct billion-dollar weather & climate events - each causing at least $1 billion in direct losses

- **Total, direct losses** from these **310 events** exceeds **$2.15 trillion** (CPI-adjusted, 2021)

Disaster Type	Events	Events/Year	Percent Frequency	Total Costs	Percent of Total Costs	Cost/Event	Cost/Year	Deaths	Deaths/Year
Drought	29	0.7	9.4%	$285.4B	13.2%	$9.8B	$6.8B	4,139†	99†
Flooding	35	0.8	11.3%	$164.2B	7.6%	$4.7B	$3.9B	624	15
Freeze	9	0.2	2.9%	$32.8B	1.5%	$3.6B	$0.8B	162	4
Severe Storm	143	3.4	46.1%	$330.7B	15.3%	$2.3B	$7.9B	1,880	45
Tropical Cyclone	56	1.3	18.1%	$1,148.0B	53.2%	$20.5B	$27.3B	6,697	159
Wildfire	19	0.5	6.1%	$120.2B	5.6%	$6.3B	$2.9B	401	10
Winter Storm	19	0.5	6.1%	$78.6B	3.6%	$4.1B	$1.9B	1,277	30
All Disasters	**310**	**7.4**	**100.0%**	**$2,159.9B**	**100.0%**	**$7.0B**	**$51.4B**	**15,180**	**361**

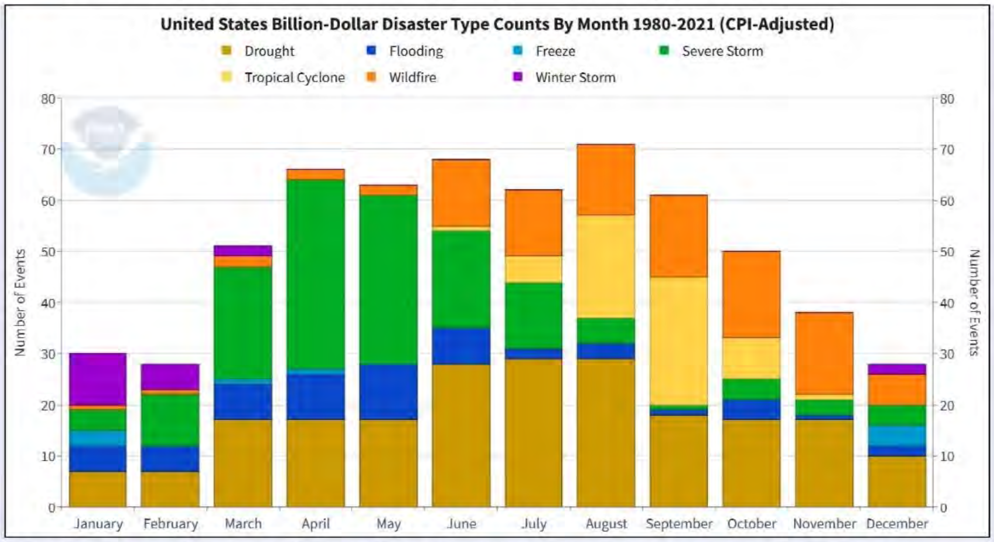
†Deaths associated with drought are the result of heat waves. (Not all droughts are accompanied by extreme heat waves.)
Flooding events (river basin or urban flooding from excessive rainfall) are separate from inland flood damage caused by tropical cyclone events.

Comparison of U.S. Billion-dollar disaster stats over time

Time Period	Billion-Dollar Disasters	Events/Year	Cost	Percent of Total Cost	Cost/Year	Deaths	Deaths/Year
1980s (1980-1989)	29	2.9	$190.2B	8.8%	$19.0B	2,870	287
1990s (1990-1999)	53	5.3	$293.0B	13.6%	$29.3B	3,045	305
2000s (2000-2009)	63	6.3	$556.8B	25.8%	$55.7B	3,091	309
2010s (2010-2019)	123	12.3	$872.9B	40.4%	$87.3B	5,224	522
Last 5 Years (2017-2021)	86	17.2	$742.1B	34.4%	$148.4B	4,519	904
Last 3 Years (2019-2021)	56	18.7	$295.9B	13.7%	$98.6B	994	331
Last Year (2021)	20	20.0	$145.0B	6.7%	$145.0B	688	688
All Years (1980-2021)	**310**	**7.4**	**$2,159.9B**	**100.0%**	**$51.4B**	**15,180**	**361**

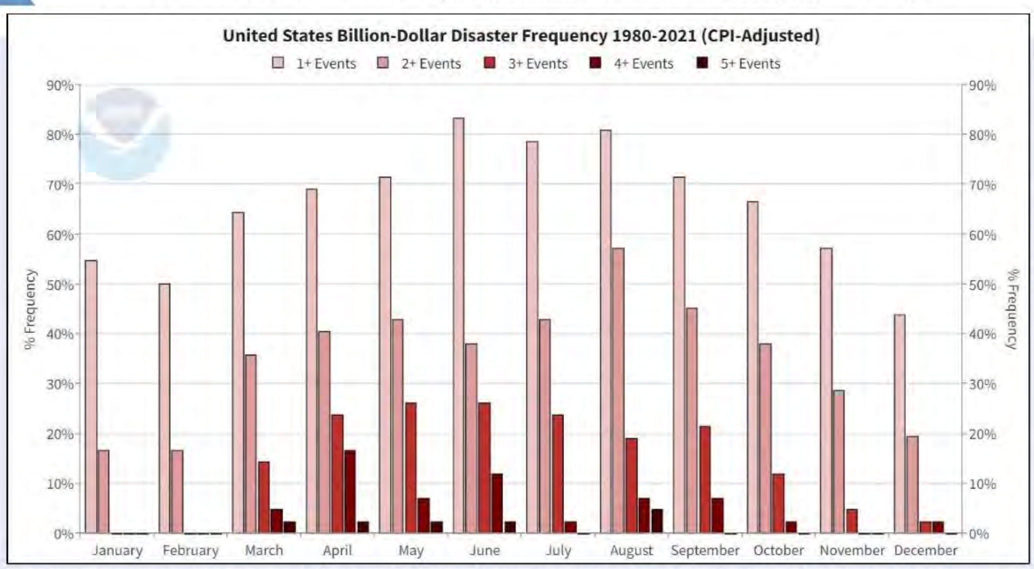
The **number and cost of disasters are increasing over time** due to a **combination of** increased exposure (i.e., values at risk of possible loss), vulnerability (i.e., where we build; how we build) and that climate change is increasing the frequency of some types of extremes that lead to billion-dollar disasters (NCA 2018, Chapter 2)

Severe storm and **inland flooding events** frequent during **Spring** and **Summer** **Wildfires** and **hurricanes** most frequent during **Fall** months.



- Visualizing the 42-year **frequency of climatology of extreme**, damaging events across the Nation.
- A way for decision-makers to understand which types of large events typically occur at what times of year, by region.

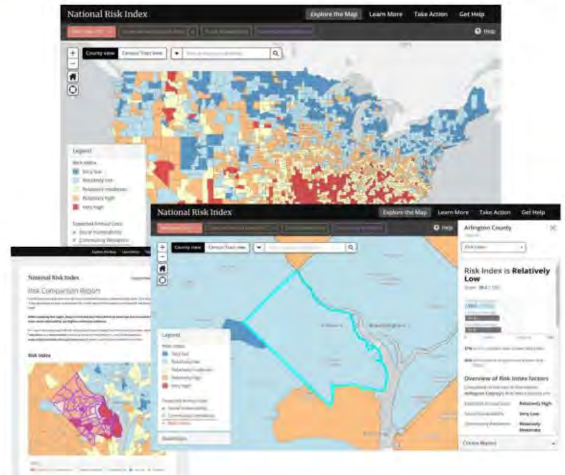
Historic record for multiple, billion-dollar events, by month



As noted in the *Climate Science Special Report* of the *Fourth National Climate Assessment*, "The physical and socioeconomic impacts of compound extreme events (such as simultaneous heat and drought, wildfires associated with hot and dry conditions, or flooding associated with high precipitation on top of snow or waterlogged ground) can be greater than the sum of the parts."

New: Integration & expansion of FEMA National Risk Index within the Billion-dollar disasters platform

- A strategy for reducing cost and eliminating inconsistent risk assessments in planning
- Identifies areas that offer high return on mitigation investment
- Reduces the cost of risk assessment allowing community planners to prioritize action
- Provides pre-calculated, top- down national baseline risk assessment



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Multi-hazard county weather and climate risk mapping

- NCEI worked with & expanded upon FEMA's NRI to enhance the NOAA Billion-dollar disaster website producing **127 new, interactive U.S. county hazard risk maps** for any combination of county-level hazard risk for:

  hurricanes, severe storms (tornado, hail, damaging winds), inland/urban flooding, drought/heat wave, wildfire, winter storms and freeze/cold wave events.

- Importantly, these maps offer more granular information in relation to **exposure, vulnerability and resilience** to weather & climate hazards, at a county scale.

- These new hazard combination maps are useful as we see more focus on **cascading hazard impacts**

  For example: drought-enhanced wildfires produce mountain-side burn scars, which often enhance debris flows from flooding. This is a compound hazard with cascading impacts that we see in California.

Calculating Risk

Risk = **Expected Annual Loss** **x** Social Vulnerability ÷ Community Resilience

where Expected Annual Loss (EAL) =

Annual Frequency		Exposure		Historic Loss Ratio
Rate of occurrence	X	• Property Value • People • Agriculture	X	Percentage of property/people/crop losses
How likely is hazard to occur?		How many people & how much property are potentially at risk?		What percent of property/people have historically been lost from hazard in a given area?

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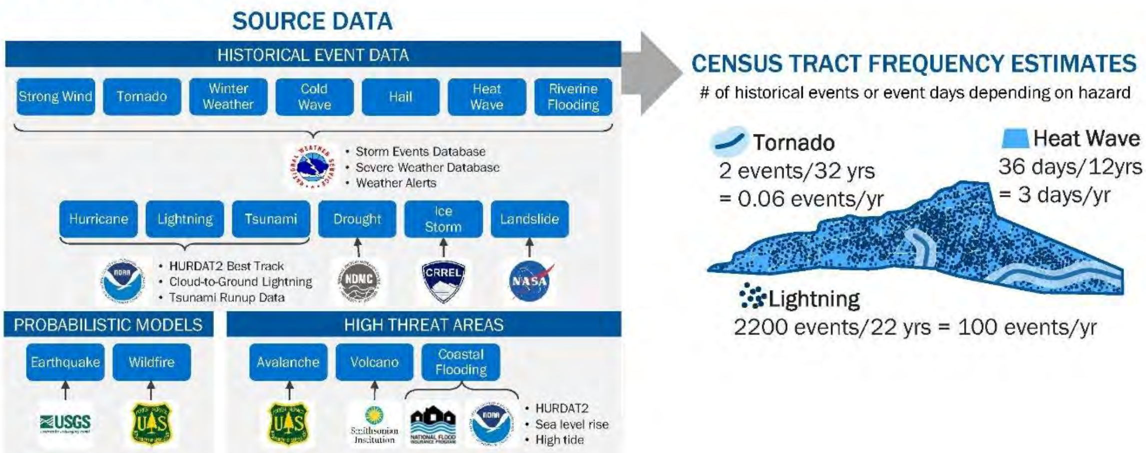
Estimating Annualized Frequency: Rate of hazard occurrence



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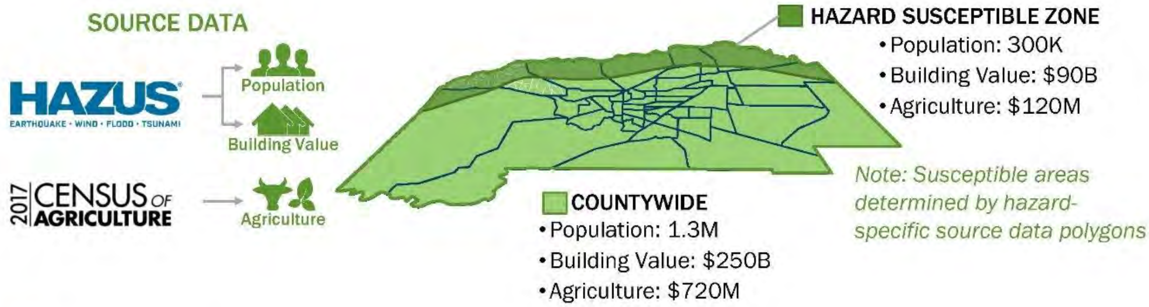
Establishing Hazard Exposure: People/property/ag at risk

Many hazards impact the entire county/census tract while some are limited to susceptible zones



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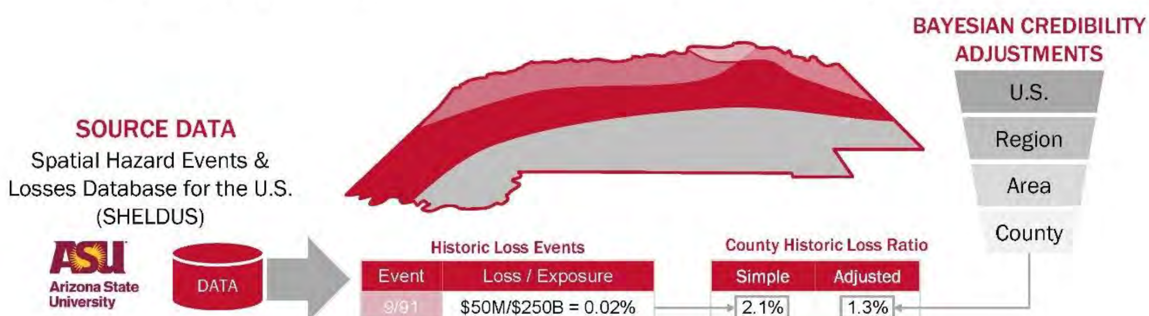
Characterizing Historic Loss Ratios: % of exposure lost in historic events

To address variance & lack of enough events for statistical significance, **county ratios are calculating using Bayesian adjustments informed by averages from multiple geographic levels**



Historic Loss Events

Event	Loss / Exposure
9/91	$50M/$250B = 0.02%
6/07	$300M/$250B = 0.1%
8/14	$15B/$250B = 6%

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Social **Vulnerability** and Community **Resilience**

Social Vulnerability Index: SoVI 2010-2014

- Grouped into **7 components with 29 variables** (SoVI 2010):
  - **Race and class (7 variables), Wealth (5 variables), Elderly residents (6 variables), Hispanic ethnicity (5 variables), Special needs individuals (2 variables), Native American ethnicity (1 variables), and Service industry employment (2 variables)**
- Comparative index at the county & census tract levels
- Positive and negative component loading

FEMA **NRI's "Social Vulnerability and Community Resilience Working Group reviewed multiple top-down and bottom-up indices** and chose to recommend the University of South Carolina's Hazards and Vulnerability Research Institute (HVRI) Social Vulnerability Index (SoVI)."

Baseline Resilience Indicators for Communities: BRIC 2010-2014

- **6 resilience category scores**, plus total score
  - **Social, Economic, Community Capital, Institutional, Infrastructural, Environmental**
- Comparative indicators at the county level
- Indicators analyze the relationship between resilience, vulnerability, and the relative impact of disasters on rural and urban places

HVRI HAZARDS & VULNERABILITY RESEARCH INSTITUTE

UNIVERSITY OF SOUTH CAROLINA

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Risk = Expected Annual Loss x Social Vulnerability / Community Resilience

Illustration of Risk Component Scores

County	Expected Annual Loss	Social Vulnerability	Community Resilience	Risk
County 1	100	45	52	100
County 2	26	94	58	55
County 3	54	48	35	51
County 4	16	92	56	37
County 5	32	36	44	24
County 6	22	45	43	22
County 7	9	69	59	15
County 8	25	21	57	13
County 9	10	44	45	9
County 10	16	4	39	1

All scores are constrained to a range of 0 (lowest possible value) to 100 (highest possible value). To achieve this range, **the values of each component are rescaled using min-max normalization, which preserves their distribution** while making them easier to understand. EAL values are heavily skewed by an extreme range of population and building value densities between urban and rural communities. **To account for this, a cube root transformation is applied before min-max normalization.**

By applying cube root transformation, the National Risk Index controls for this characteristic and provides scores with greater differentiation and usefulness. If the minimum value of the EAL is a nonzero number before normalization, an artificial minimum is set to 99% of that value so that communities expected to experience loss do not receive a 0 EAL score

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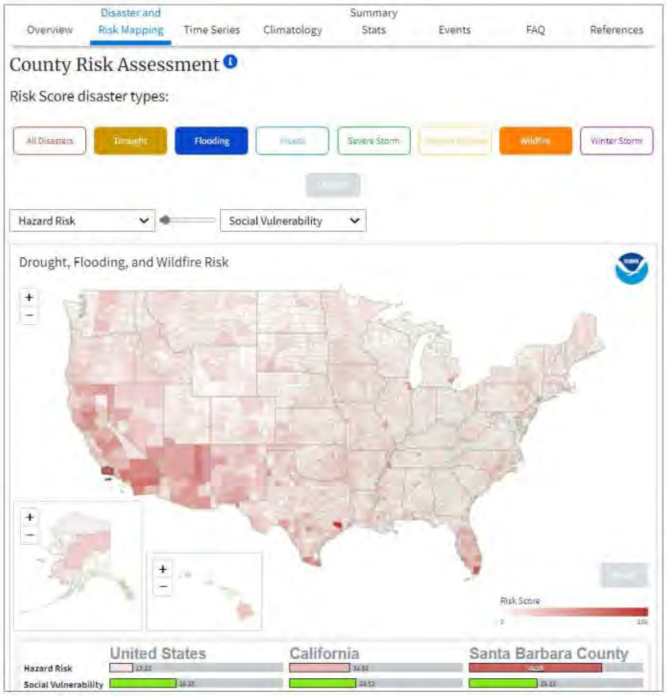

Compound hazard county risk (Drought, Wildfire and Flooding)

Each region faces **unique hazard combinations, which are useful in <u>a new era of more likely cascading hazard impacts</u>** (i.e., drought-enhanced wildfires produce mountain-side burn scars, which often enhance debris flows from flooding.

As noted in National Climate Assessment (2017) **"the physical and socioeconomic impacts of compound extreme events (such as simultaneous heat and drought, wildfires associated with hot and dry conditions, or flooding associated with high precipitation on top of snow or waterlogged ground) can be greater than the sum of the parts."**

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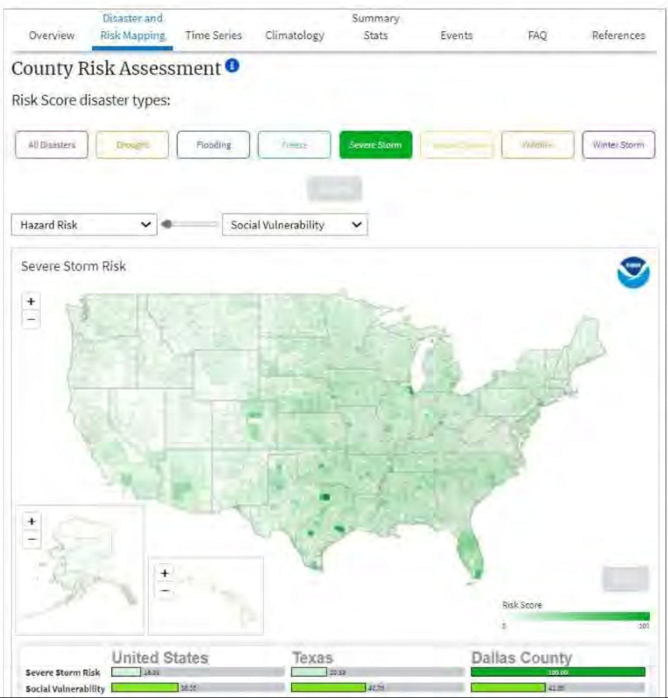
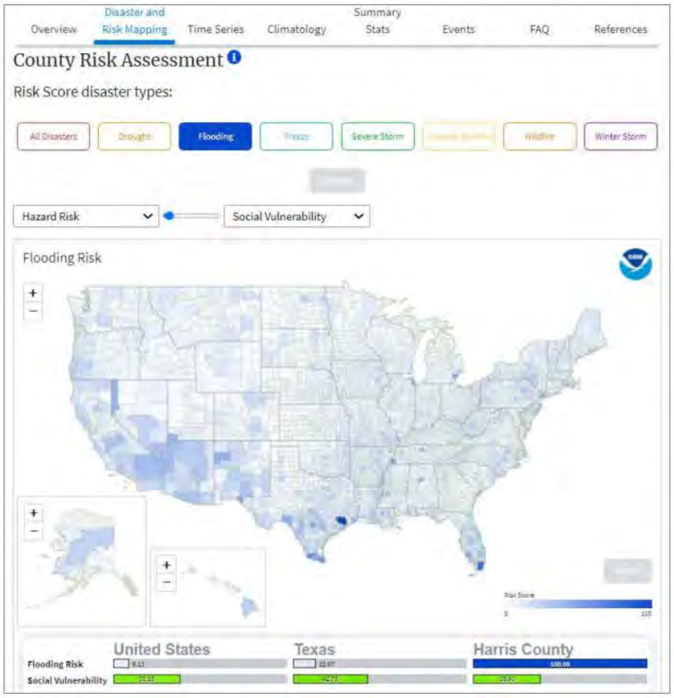


This map provides county risk scores for combined **severe storm events (i.e., tornado, hail, high wind damage)** reflecting a county's annualized hazard frequency; its potential hazard cost related to building value, crop value and population exposure; and its social vulnerability and resilience to recover from hazard impacts based on dozens of socioeconomic variables.

The map highlights that **Dallas County, Texas has a very high score for severe storm risk** due to its historic frequency of being impacted by these events in addition to having a large urban population and valuable exposure, which further increases the damage potential for severe storm impacts and costs.

Dallas County's SOVI score (42.85) is also near the Texas average but is higher than the U.S. county-average score (38.35). A higher SOVI score indicates lower resilience.

24

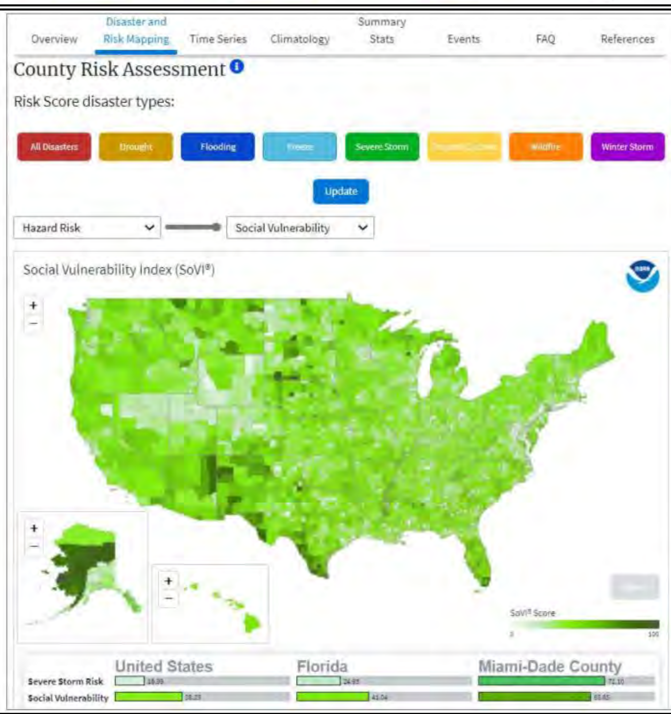


Harris County, Texas - home to **Houston** as America's 4th most populous city - has a very high overall risk from <u>damaging urban flood events.</u>

The Houston area has been **<u>impacted by several 100-year urban flood events</u>** since the year 2015, in addition to **Hurricane Harvey in 2017.**

Harris County's SOVI score (38.90) is **below** (more resilient) than the **Texas county SOVI score average.**

25



The **new mapping interface also provides an interactive control slider** that allows users to compare county hazard risks with county-level vulnerability "to prepare for, respond to, and recover from hazards," via the Social Vulnerability Index (SoVI).

The SoVI is a widely referenced data set that is "a location-specific assessment of social vulnerability that utilizes 29 socioeconomic variables deemed to contribute to a community's reduced ability to prepare for, respond to, and recover from hazards."

The darker colors represent counties with higher scores of socioeconomic vulnerability. The dataset was developed by and is referenced to the University of South Carolina's Hazards and Vulnerability Research Institute (HVRI).

Harris County, TX
Risk Assessment

Historic Risk	Harris County	Texas	U.S.
Drought Risk	20.36	14.32	11.61
Flooding Risk	100.00	12.97	9.13
Freeze Risk	12.05	13.09	15.72
Severe Storm Risk	94.56	20.58	16.99
Tropical Cyclone Risk	100.00	8.63	5.74
Wildfire Risk	11.81	11.28	6.30
Winter Storm Risk	65.33	15.99	13.71
Weather and Climate Combined Risk	100.00	17.19	13.25
Social Vulnerability Index (SoVI®) Score	38.90	42.76	38.35

Harris County, Texas - home to Houston as America's 4th most populous city - has a **very high** overall **risk from damaging urban flood events, severe storm and hurricane impacts**.

The **Houston** area has been impacted by several **100-year urban flood** events since the year 2015, in addition to **Hurricane Harvey in 2017**.

Houston's large population and valuable infrastructure were also damaged from hazards such as the **mid-February 2021 winter storm / cold wave**, which crippled the regional power grid causing widespread damage and disruption.

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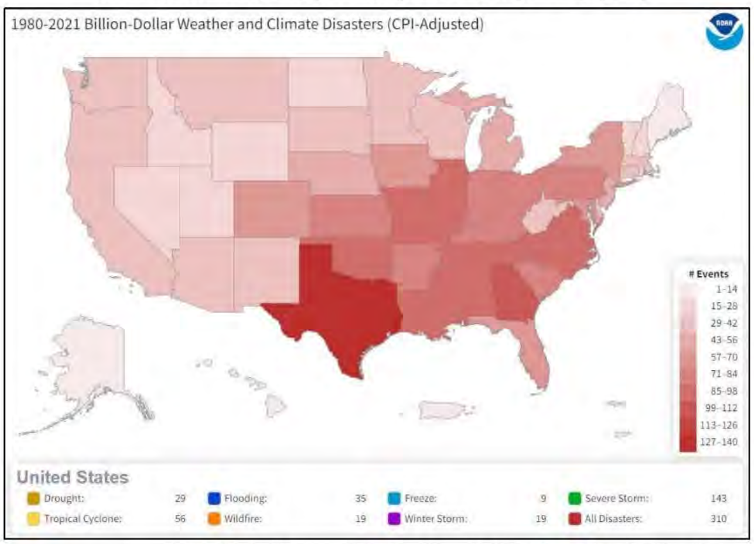
From 1980–2021, the U.S. **South, Central** and **Southeast** regions experienced a **higher frequency** from billion-dollar disaster events. CA, NY, NJ, PR and V.I. as well.

Cumulative Event Frequency (1980-2021) for each state (combined perils)



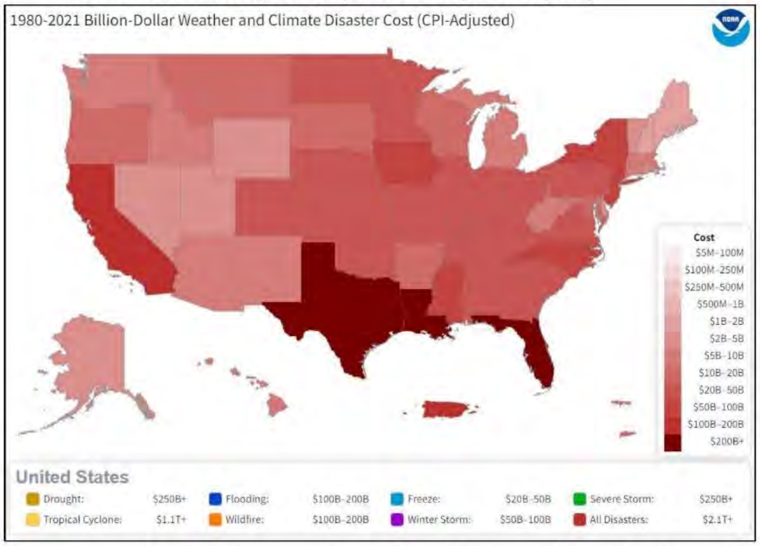
Historically, the U.S. **South, Central & Southeast regions** have experienced the highest frequency and cost from billion-dollar disaster events (see state / event maps on billion-dollar disasters).

The **same U.S. regions** are **projected** to have the **most negative future impacts** across **several socioeconomic metrics**

→ Reflects the **severity** & **vulnerability** of weather & climate events impacting different regions

From 1980–2021, the U.S. **South, Central** and **Southeast** regions experienced a **higher cost** from billion-dollar disaster events. CA, NY, NJ, PR and V.I. as well.

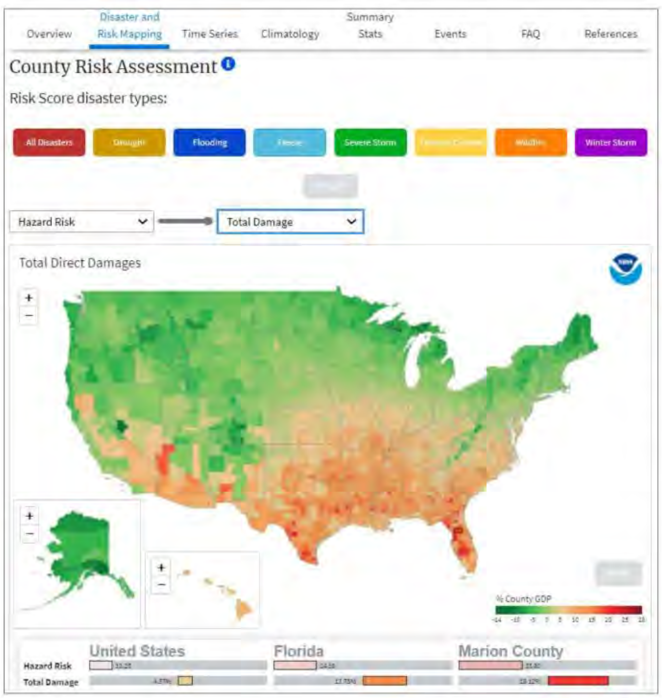
Cumulative Event Cost (1980-2021) for each state (combined perils)



Historically, the U.S. **South, Central & Southeast regions** have experienced the highest frequency and cost from billion-dollar disaster events (see state / event maps on billion-dollar disasters).

The **same U.S. regions** are **projected** to have the **most negative future impacts** across **several socioeconomic metrics**

→ Reflects the **severity** & **vulnerability** of weather & climate events impacting different regions



County-level median total direct economic damage across all sectors as a **% of county GDP** for the combined variables (A)-(H) using a future (2080-2099) high-emission scenario (RCP 8.5). This represents:

(A) Percent change in yields, area-weighted average for corn, wheat, soybeans, and cotton. (B) Changes in all cause mortality rates, across all age groups. (C) Change in electricity demand. (D) Change in labor supply of full-time equivalent workers for low risk jobs where workers are minimally exposed to outdoor temperature. (E) Same as (D) except for high risk jobs where workers are heavily exposed to outdoor temperatures. (F) Change in damages from coastal storms. (G) Changes in violent crime rates. (H) Changes in property crime rates. Source: **"Estimating economic damage from climate change in the United States" (Hsiang et al., 2017)**

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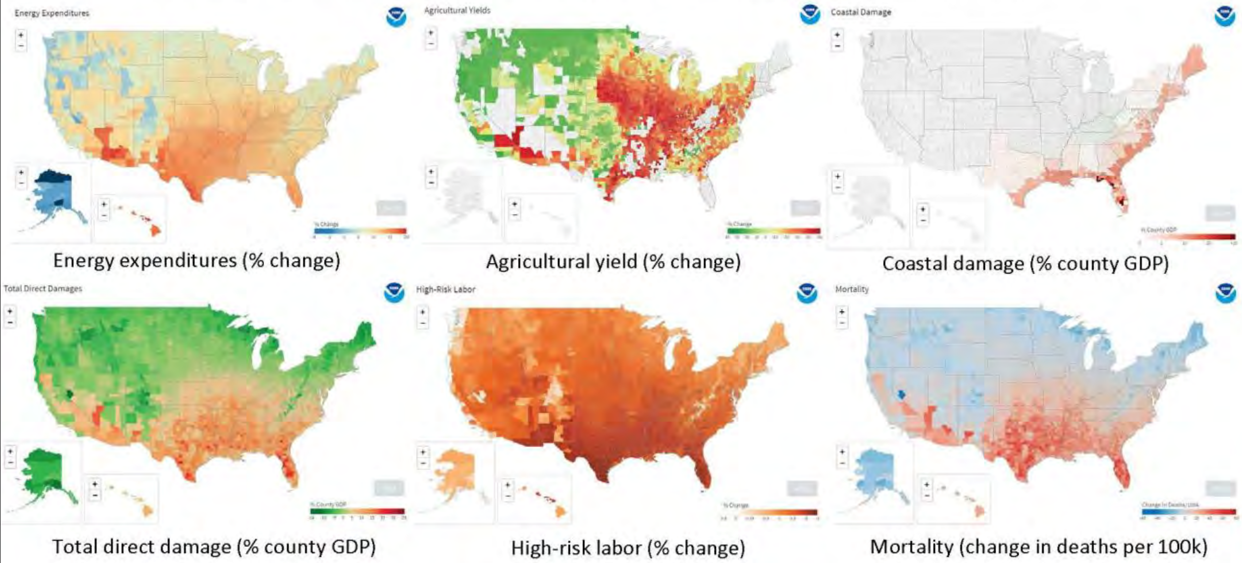
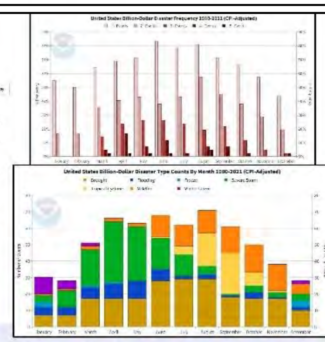
Spatial distributions of projected damages. County-level median values for average 2080 to 2099 RCP8.5 impacts. Impacts are changes relative to counterfactual "no additional climate change" trajectories. County socio-economic risk potential (RCP8.5 projections)



Source: Hsiang, S., Kopp, R.E., Jina, A., Rising, J., Delgado M., Mohan, S., Rasmussen, D.J., Muir-Wood, R., Wilson, P., Oppenheimer, M., Larsen, K., and T. Houser. 2017. **Estimating economic damage from climate change in the United States**. *Science*, 356, 1362-1369

Adam.Smith@noaa.gov

For interactive data, charts, mapping, and disaster summaries (1980-2021):
www.ncdc.noaa.gov/billions



New county hazard risk mapping:
www.ncdc.noaa.gov/billions/mapping

For more detail on disasters, county data, methodology, and uncertainty, see:

NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2022). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73

Zuzak, C., E. Goodenough, C. Stanton, M. Mowrer, N. Ranalli, D. Kealey, and J. Rozelle. 2021. National Risk Index Technical Documentation (fema.gov). Federal Emergency Management Agency, Washington, DC.

Cutter, S., Ash, K., and C. Emrich. 2014. The geographies of community disaster resilience. Global Environmental Change, 29, 65-77.

Hsiang, S., Kopp, R.E., Jina, A., Rising, J., Delgado M., Mohan, S., Rasmussen, D.J., Muir-Wood, R., Wilson, P., Oppenheimer, M., Larsen, K., and T. Houser. 2017. Estimating economic damage from climate change in the United States. Science, 356, 1362-1369

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3.3.4 Climate Panel Discussion (Session 1C-4)

Moderator: Elena Yegorova, NRC/RES/DRA/FXHAB
David Novak, *National Oceanic and Atmospheric Administration, National Weather Service*
Judah Cohen, *Atmospheric and Environmental Research*
Adam Smith, *National Oceanic and Atmospheric Administration, National Centers for Environmental Information*

Question:

Adam, you mentioned that the compound extreme events can be greater than the sum of the parts, so which regions of the country are more prone to the compound extreme events and what kind of events?

Adam Smith:

A few regions of the country have really popped out in recent years and have been really persistent. One would be the Gulf of Mexico, particularly Louisiana, with tropical cyclones, heavy rainfall, flood events, severe convective storm events. Those regions and the economies have really been bombarded by so many events and that lengthens the recovery time. It makes it more difficult to regain the pre-disaster impact status of how efficient the economies and livelihoods were. Certainly that region, but also, as I mentioned in the talk, the Western States, particularly Washington, Oregon, California. There you have got this persistent drought that then links into wildfire seasons. One thing I did not mention during the talk is just the persistent and damaging effects of wildfire smoke as weeks and months pass. That impacts outdoor economies or sensitive health groups. So, you get these chain reactions of hazards and impacts. Those would be the two regions I think that are most profoundly impacted so far in recent analysis.

Question:

Adam, you discussed that the south central and southeast US are experiencing the higher costs of the billion dollar weather events. The paper that you cited is referring to the business as usual scenario - the high emissions scenario. So, should we expect this trend to continue in the changing climate?

Adam Smith:

We also want to put the RCP 4.5 in the mapping. We are working with the authors to get that down scaled to the county level like the RCP 8.5, but what you have seen the data is still the same directional trends in regard to the socioeconomic outcomes, positive or negative, across the same regions. It is just of course more profound at the high emission scenario and it is important to consider. We do not know how policy or technology is going to change over the coming decades, but these are projections that happened to really align surprisingly close to the weather and climate extremes over the last four and a half decades. So I thought that was worth mentioning.

Question:

Judah, in the beginning you showed a figure concerning confidence and attribution of extreme weather to anthropogenic climate change. I really like that figure. It really stresses the importance of not attributing a single extreme weather event to climate change. Can you comment on that?

Judah Cohen:

There is a group that tries to attribute climate change every single weather event. There are people out there who do that. But I do not. The paper that my talk was based on was not trying to argue that winters are getting more severe or were in this cooling trend. I am really trying to argue is that kind of the orthodoxy that global warming only leads to warmer temperatures and less snowfall is an oversimplification of the impact of climate change on our weather in the United States. I try to argue that there is a thermodynamic influence: increasing greenhouse gases lead to warmer temperatures, warmer oceans especially. So there is a huge heat reservoir that can be released in the winter that leads to warmer weather and, if it is warmer, there is less chance of snow. But there's also this dynamic influence that we as scientists did not consider 10-20 years ago. the pattern of climate change is not universal or homogeneous, but it is heterogeneous and can impact the circulation of the atmosphere. My talk really focused on the polar vortex that can lead to more severe winter weather. As I showed my talk, these stretched polar vortices, where they are elongated or take some of this oval shape, are occurring more frequently. And as I showed with the clustering analysis, that extreme cold is more likely, is more probable, when you have one of these stretch polar vortex events and those are increasing. The probability of getting one of these extreme winter weather events associated with these stretch polar vortex is increasing. Again, I'm not trying to argue, that's the only factor or influence to consider. But it's something that was, I believe, ignored or neglected or just not known about how it should be taken into account of in a more complete picture of how climate change can influence our weather. I do not attribute probabilities like saying the Texas freeze was 50% more likely because of climate change or anything like that. But I do think that because these stretched polar vortex events occur more frequently now than they used to, that it does increase the odds of these severe winter weather events.

Question:

Judah, have you looked at what will happen when all this sea ice melts in the Arctic?

Judah Cohen:

That’s an interesting question. The juxtaposition of the anomalies is important. You want to create a wave, that means you cannot have the temperature change equal everywhere. If all the ice melted and the warming became almost like a donut, centered over the North Pole and pretty much the same magnitude, pretty equal cross the entire Arctic Ocean, then I think everything I described in my talk would become irrelevant pretty much. Because of all that ice melting you would have this constant warming across the whole Arctic Ocean like a donut, you would have no wave. Then again, my whole argument hinges on amplifying waves. The mechanism I am describing is really sensitive to sea ice melting in favorable or preferred regions and not throughout the entire Arctic Ocean. I am trying to argue winters are not warming as fast because we are getting this balancing or offsetting influence from the polar vortex. If all the sea ice melted, and that went away, there could be a real acceleration of winter warming.

Adam Smith:

There does not appear to be relief on the way as a nation, in terms of protecting the infrastructure and such. This is going to become more important as we go forward, and you cannot take your ball off the winter weather hazard either. Maybe there was hope that maybe a few of these different hazard extremes would fall off [with climate change], but these extreme weather events and the increased exposure that Adam was talking about have to be taken seriously. On the front lines of the National Weather Service we are working on these extreme events every couple of weeks, it seems like. This is just something we are going to have to work into the national infrastructure.

Question:

David you mentioned that extreme weather forecasts are uncertain. What is the low hanging fruit for reducing this uncertainty?

David Novak:

There was recently a study, commissioned by Congress, called the Priorities for Weather Research Study. It was a one-year study looking at the next 10 years. The unsatisfying answer is there is no silver bullet. There is no one thing that is going to make it all better. That report mentions data assimilation, I think, 251 times. That is taking observations and putting them in a format that numerical weather prediction models can see and use well so that you have a better understanding of the initial state. And then the models can project that out into the future. So, getting the observations right and integrating that into the models is very important, but it does not stop there. Post processing, taking into account the different biases that the models have is also super important. Human forecasters understanding the different biases of the models. Human forecasters working with public safety officials to understand their critical thresholds and providing information in a way that's actionable is also important. So, all along this value chain, we need to make improvements to really prepare for extreme weather events.

3.4 Day 2: Session 2A – Precipitation

Session Chair: Kevin Quinlan, NRC/NRR

3.4.1 Presentation 2A-1: Uncertainty in Precipitation Frequency Estimates Under Current and Future Climate

Authors: *Azin Al Kajbaf, Michelle Bensi, Kaye Brubaker, University of Maryland, Department of Civil and Environmental Engineering*

Speaker: *Azin Al Kajbaf*

3.4.1.1 Abstract

Over the past decades, the intensity of precipitation events in the Northeast of the United States has shown an increasing trend. As climate change continues to affect the characteristics and frequency of rainfall events, it is important to account for these changes in the Intensity/Depth Duration Frequency (IDF/DDF) curves used in engineering design and planning. This study develops model-based precipitation frequency estimates under current and projected future climate in Maryland. Specifically, IDF/DDF curves for selected durations from 15 minutes to 48 hours are developed from statistical analyses of synthetic data from the North American Regional Climate Change Assessment Program (NARCCAP) suite of models. In the NARCCAP suite, 6 regional climate models covering most of North America at a spatial resolution of 50 km are driven by different atmosphere-ocean general circulation models, for a total of 12 climate simulations, both historic and future. NARCCAP synthetic time-series are available at a 3-hour temporal resolution. Machine learning models are used to temporally downscale the NARCCAP time-series to durations as short as 15 minutes. Using the developed time-series, suites of IDF/DDF curves are developed that account for a range of modeling decisions associated with climate model selection and other statistical assumptions. The suites are then used to produce averaged IDF/DDF curves. Graphical tools are developed to comparatively assess the uncertainty associated with climate model selection and the other modeling decisions used to develop IDF/DDF curves. A particular focus is placed on understand differences in drivers of uncertainty under current and future climate conditions.

3.4.1.2 Presentation (ADAMS Accession No. ML22061A127)

Uncertainty in Precipitation Frequency Estimates Under Current and Future Climate

Azin Al Kajbaf, Michelle Bensi, Kaye Brubaker
University of Maryland
Department of Civil and Environmental Engineering

Introduction

Motivation

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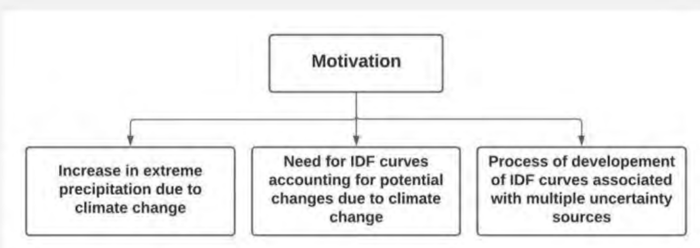

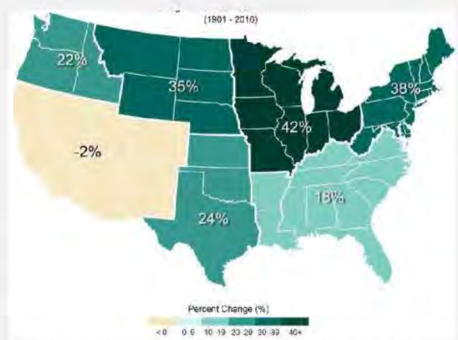

Observed change in total annual precipitation (1901-2016).
Source: globalchange.gov

2

Introduction

Objectives

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This study explores sources of uncertainty associated with the development of IDF curves considering climate change conditions under two main categories:

Uncertainty arising from application of machine learning for temporal downscaling of climate model projections

Uncertainty arising from choice of climate models and statistical modeling choices made in development of IDF curves

ML = Machine Learning

Introduction

Gaps in Studies

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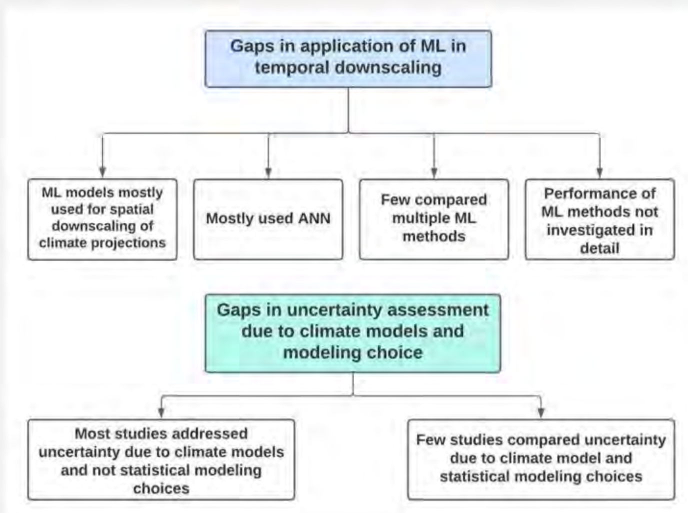
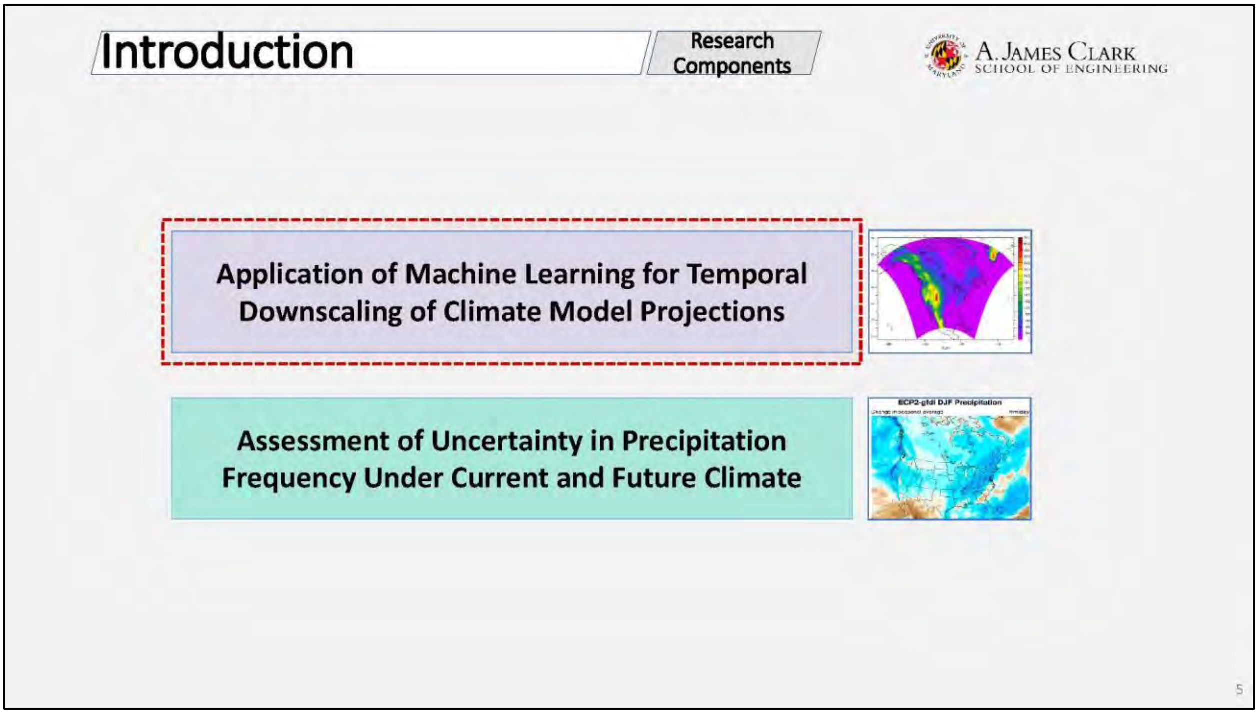
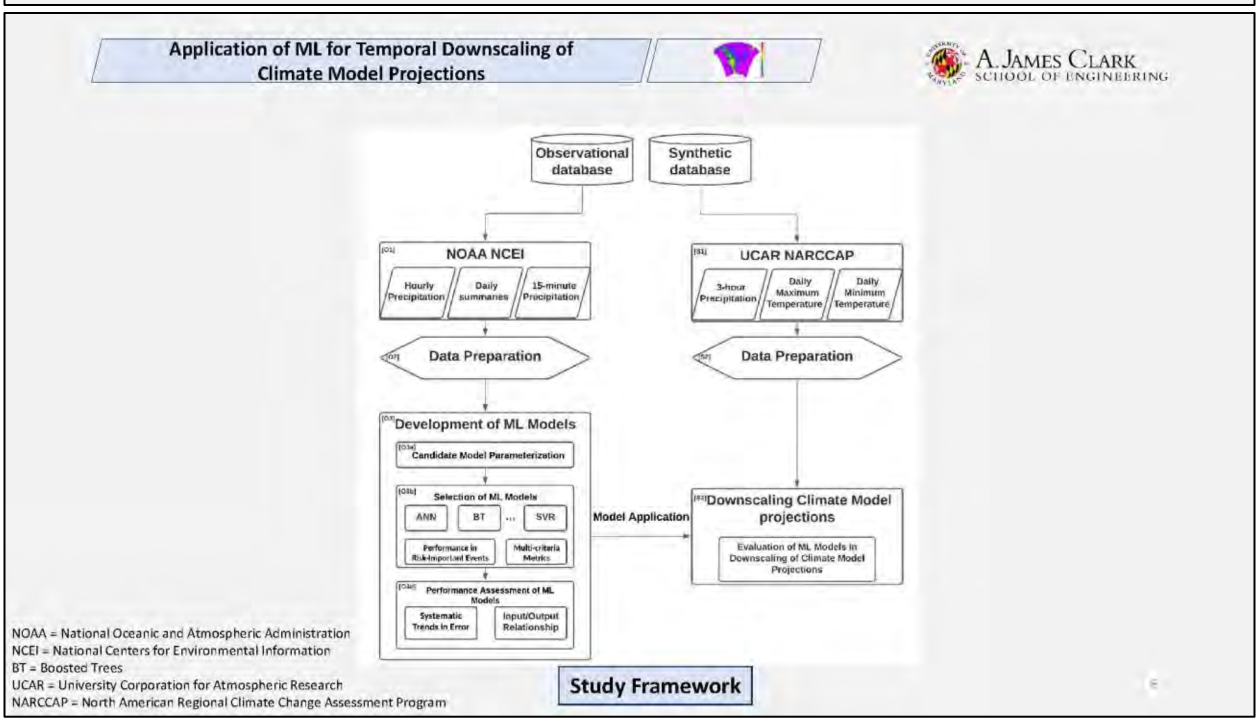


ML = Machine Learning



Introduction
Research Components
A. JAMES CLARK SCHOOL OF ENGINEERING
Application of Machine Learning for Temporal Downscaling of Climate Model Projections
Assessment of Uncertainty in Precipitation Frequency Under Current and Future Climate
ECP2-gfdl DJF Precipitation
5



Application of ML for Temporal Downscaling of Climate Model Projections
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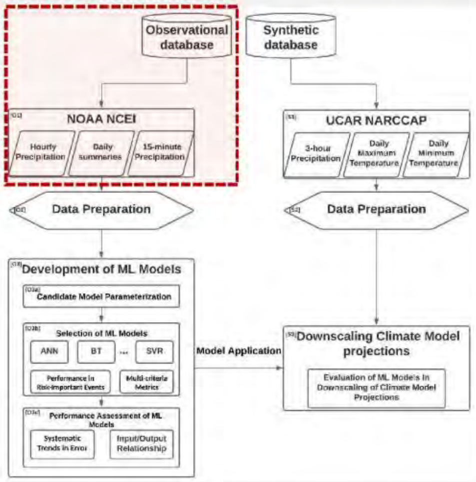
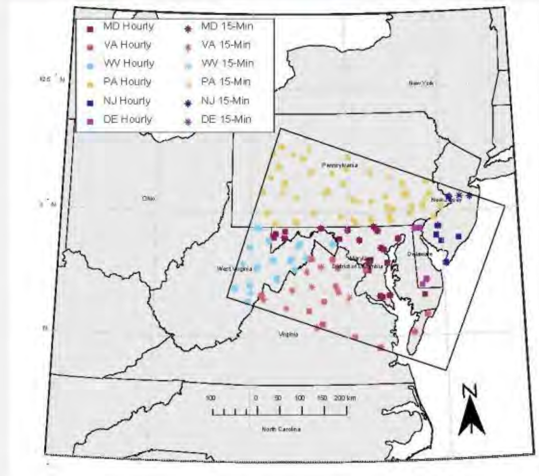
Observational database
Synthetic database
NOAA NCEI
Hourly Precipitation
Daily summaries
15-minute Precipitation
UCAR NARCCAP
3-hour Precipitation
Daily Maximum Temperature
Daily Minimum Temperature
Data Preparation
Data Preparation
Development of ML Models
Candidate Model Parameterization
Selection of ML Models
ANN
BT
...
SVR
Performance in Risk-important Events
Multi-criteria Metrics
Performance Assessment of ML Models
Systematic Trends in Error
Input/Output Relationship
Model Application
Downscaling Climate Model projections
Evaluation of ML Models in Downscaling of Climate Model Projections
NOAA = National Oceanic and Atmospheric Administration
NCEI = National Centers for Environmental Information
BT = Boosted Trees
UCAR = University Corporation for Atmospheric Research
NARCCAP = North American Regional Climate Change Assessment Program
Study Framework

Application of ML for Temporal Downscaling of Climate Model Projections





Location of hourly and 15-minutes stations in the study area

Application of ML for Temporal Downscaling of Climate Model Projections

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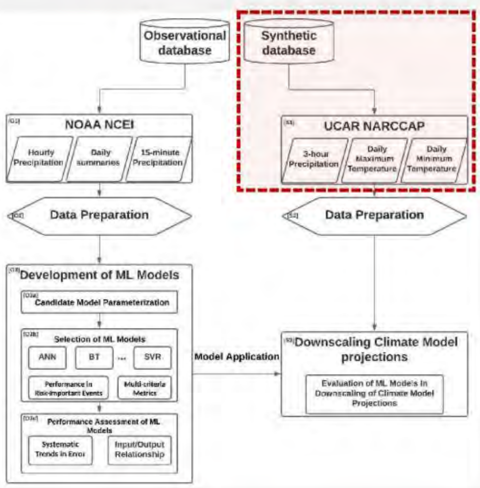

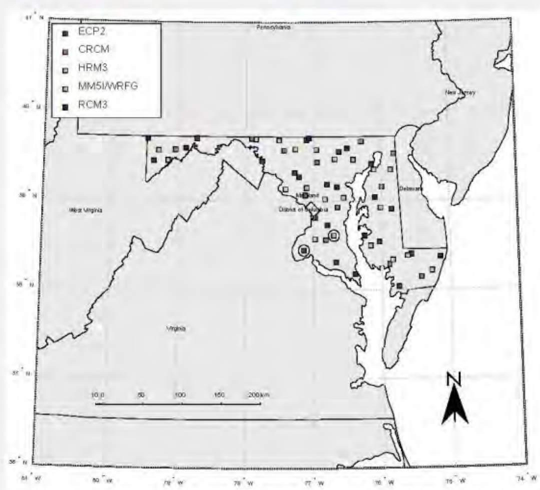

Location of grid centers within Maryland for the six NARCCAP regional models.

CRCM-gfdl	**ECP2**-gfdl	**HRM3**-gfdl	**MM5I**-ccsm	**RCM3**-cgcm3	**WRFG**-ccsm
CRCM-cgcm3	**ECP2**-hadcm3	**HRM3**-hadcm3	**MM5I**-hadcm3	**RCM3**-gfdl	**WRFG**-cgcm3

Application of ML for Temporal Downscaling of Climate Model Projections

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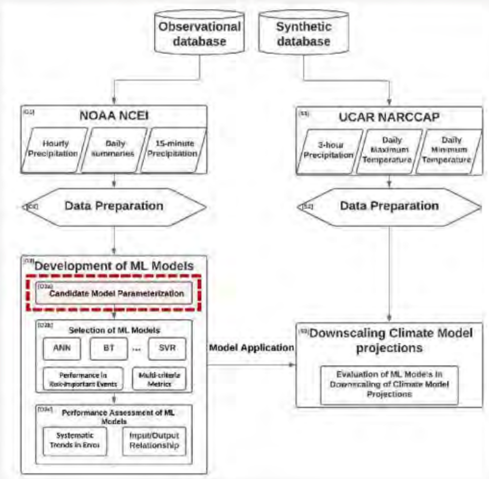

$$P_i = f(P_{i+1}, P_d, T_{max\ d}, T_{min\ d})$$

Input parameters	Target precipitation duration
$P_{3\ h}, P_d, T_{max\ d}, T_{min\ d}$	$P_{2\ h}$
$P_{2\ h}, P_d, T_{max\ d}, T_{min\ d}$	$P_{1\ h}$
$P_{1\ h}, P_d, T_{max\ d}, T_{min\ d}$	$P_{30\ min}$
$P_{30\ min}, P_d, T_{max\ d}, T_{min\ d}$	$P_{15\ min}$

P_i = Downscaled target precipitation $T_{max\ d}$ = Maximum daily temperature
P_{i+1} = Longer duration precipitation $T_{min\ d}$ = Minimum daily temperature
P_d = Daily precipitation

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Application of ML for Temporal Downscaling of Climate Model Projections

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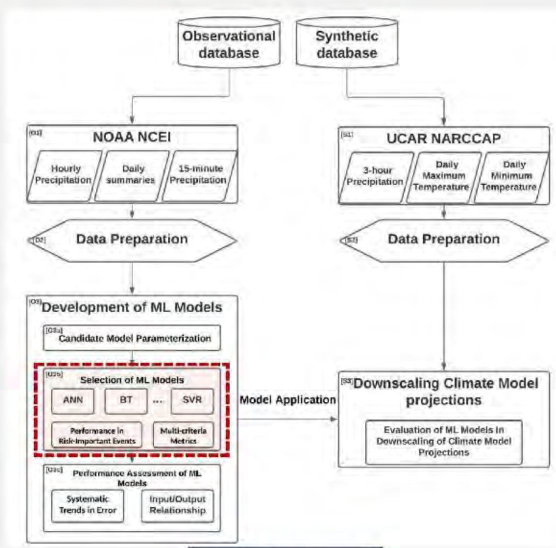

Study Framework

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Application of ML for Temporal Downscaling of Climate Model Projections

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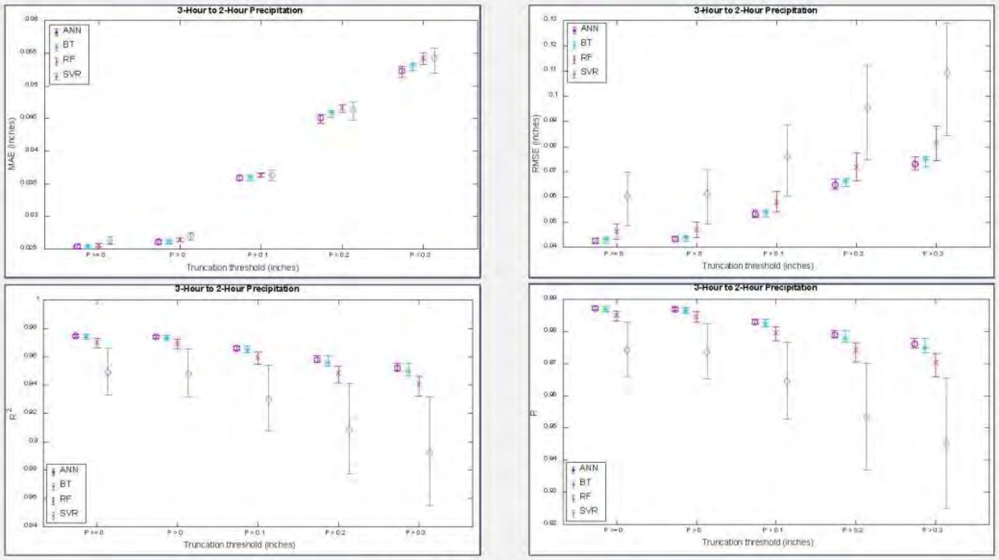

Performance metrics of MAE, RMSE, R and R^2 at different precipitation truncation levels

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Application of ML for Temporal Downscaling of Climate Model Projections

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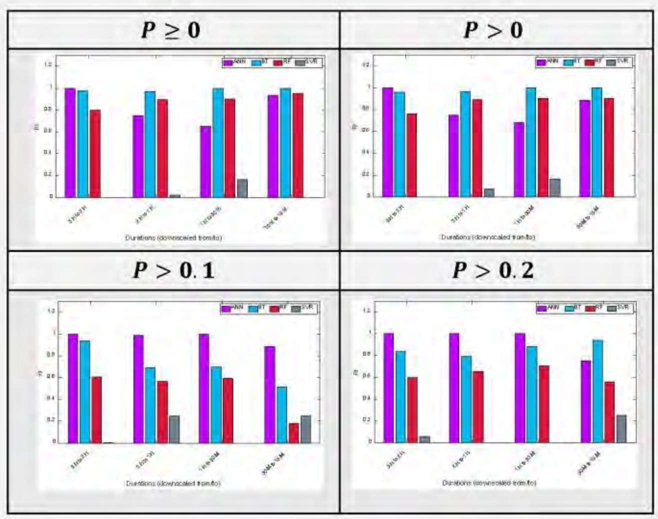
$$x_{norm} = \frac{(x_{max} - x_i)}{(x_{max} - x_{min})};\ x = MAE, RMSE$$

$$x_{norm} = \frac{(x_{min} - x_i)}{(x_{min} - x_{max})};\ x = R, R^2$$

$$RI = \frac{MAE_{norm} + RMSE_{norm} + R_{norm} + R^2{}_{norm}}{4}$$



MAE = Mean Absolute Error
RMSE = Root Mean Squared Error
R = Correlation Coefficient
R^2 = Coefficient of Determination
RI = Reference Index

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Application of ML for Temporal Downscaling of Climate Model Projections

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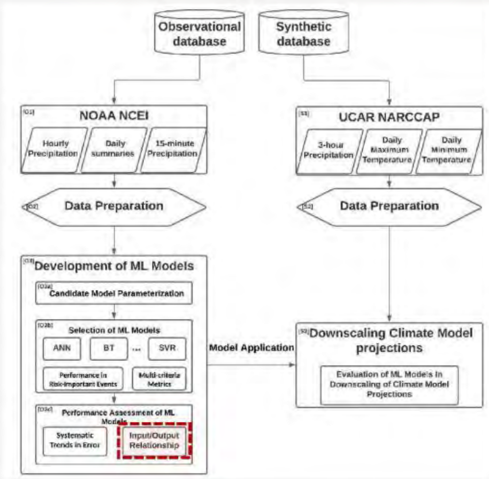
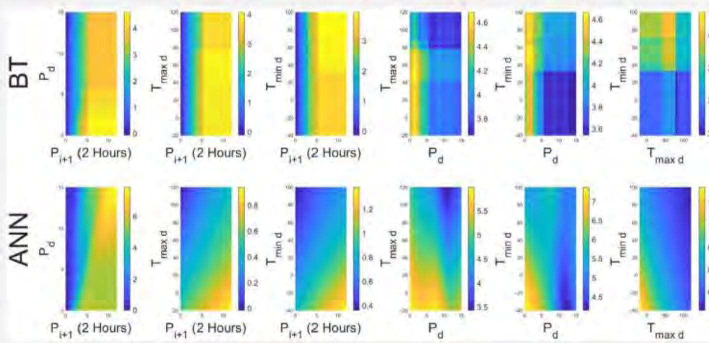


2-Hour to 1-Hour Precipitation



Response Functions

$$P_i = f(P_{i+1}, P_d, T_{max\ d}, T_{min\ d})$$

P_i = Downscaled target precipitation $T_{max\ d}$ = Maximum daily temperature
P_{i+1} = Longer duration precipitation $T_{min\ d}$ = Minimum daily temperature
P_d = Daily precipitation

Application of ML for Temporal Downscaling of Climate Model Projections

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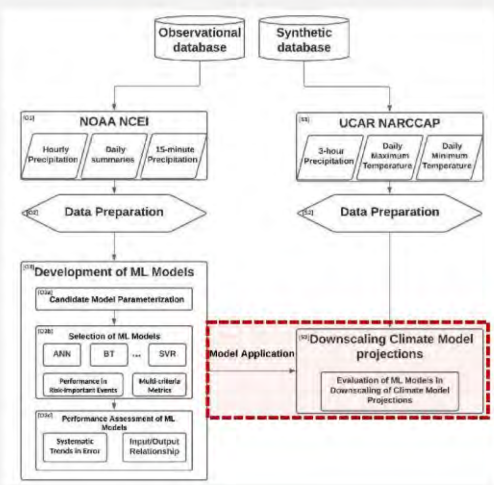

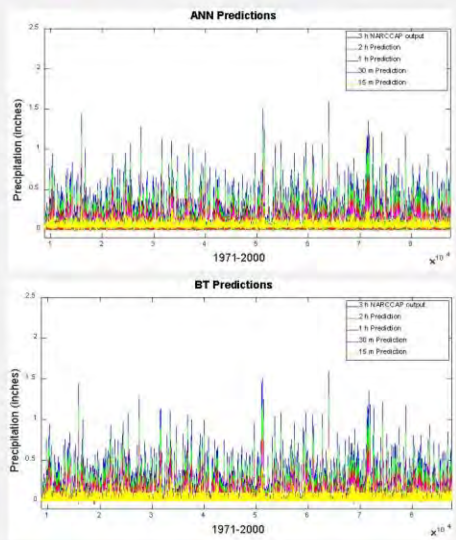

Time-series Predictions

Application of ML for Temporal Downscaling of Climate Model Projections

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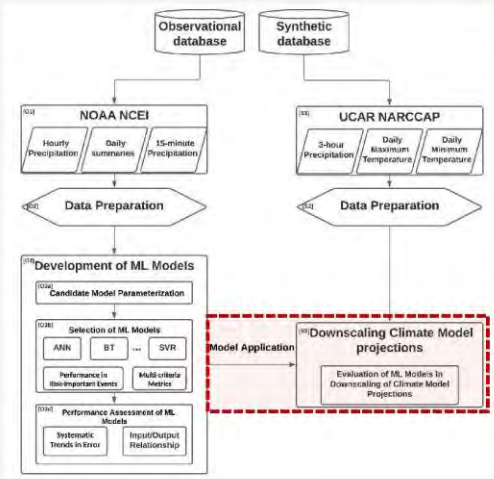

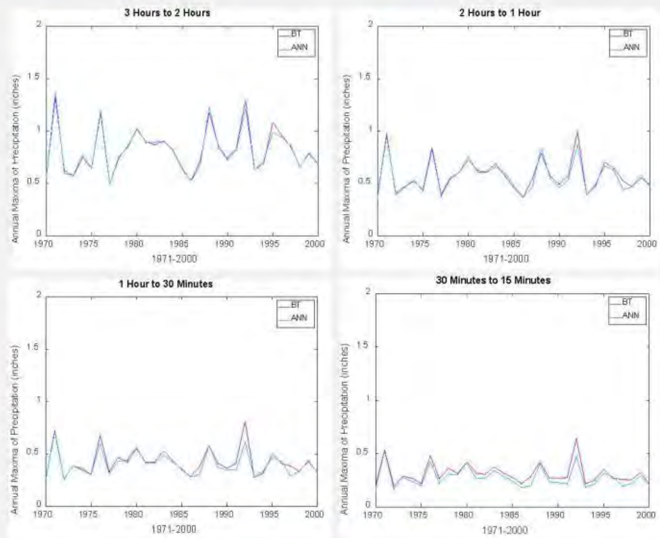

AMS Predictions

Introduction

Research Components

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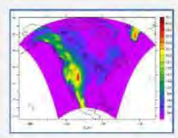
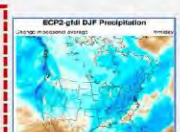
Application of Machine Learning for Temporal Downscaling of Climate Model Projections



Assessment of Uncertainty in Precipitation Frequency Under Current and Future Climate



Assessment of Uncertainty in Precipitation Frequency Under Current and Future Climate

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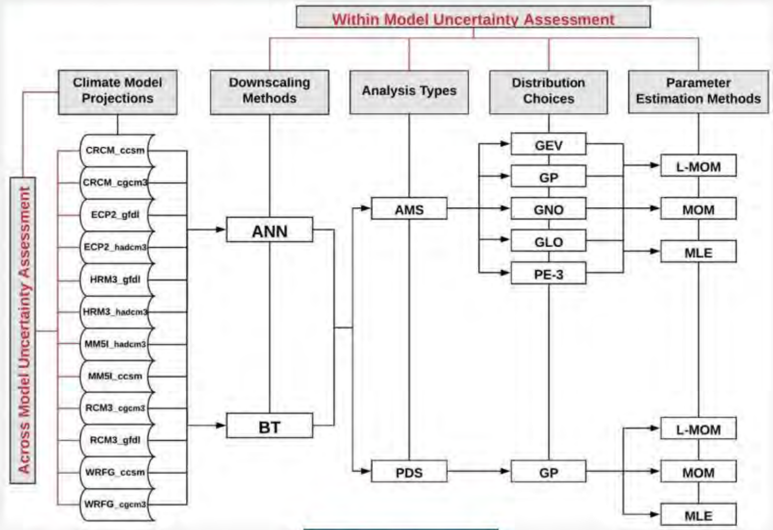

AMS = Annual Maxima Series
PDS = Partial Duration Series
GEV = Generalized Extreme Value
GP = Generalized Pareto
GNO = Generalized Normal
GLO = Generalized Logistic
PE-3 = Pearson type III
L-MOM = L-moments
MOM = Method of Moments
MLE = Maximum Likelihood Estimation

Study Framework

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Assessment of Uncertainty in Precipitation Frequency Under Current and Future Climate

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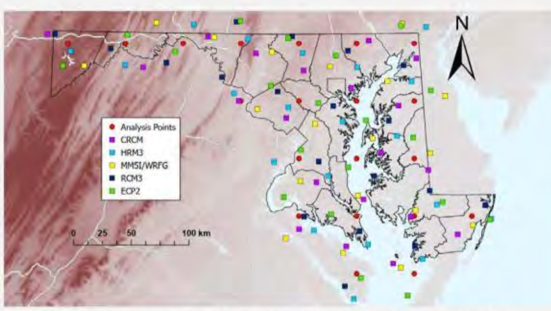
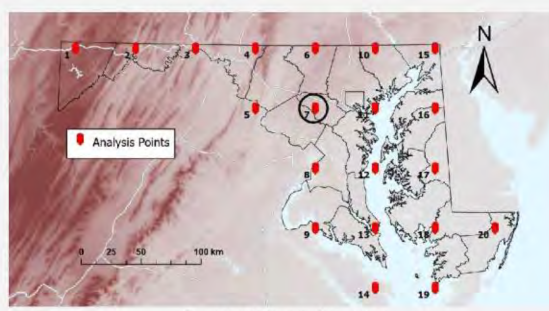
Synthetic data



Location of grid centers within Maryland for the six NARCCAP regional models



Nearest neighbor analysis points

Data Source: NARCCAP

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Assessment of Uncertainty in Precipitation Frequency Under Current and Future Climate

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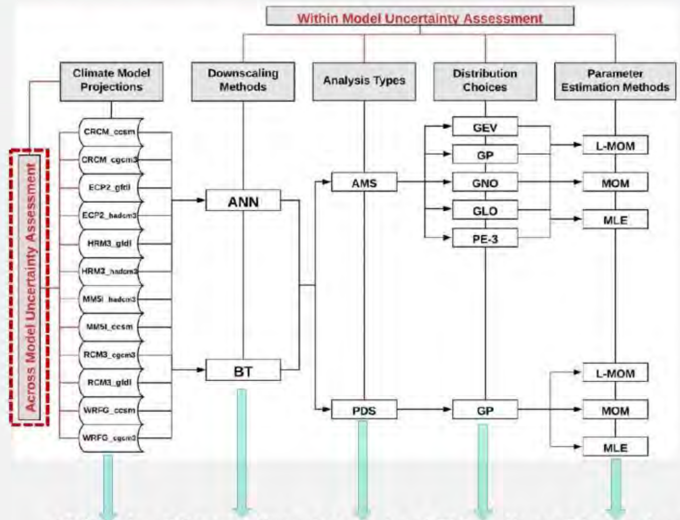

12 Climate Models × 2 Downscaling Methods × 2 Analysis Types × 6 Distributions (AMS(5)+PDS(1)) × 3 Parameter Estimation Methods = 432 Cases

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Assessment of Uncertainty in Precipitation Frequency Under Current and Future Climate

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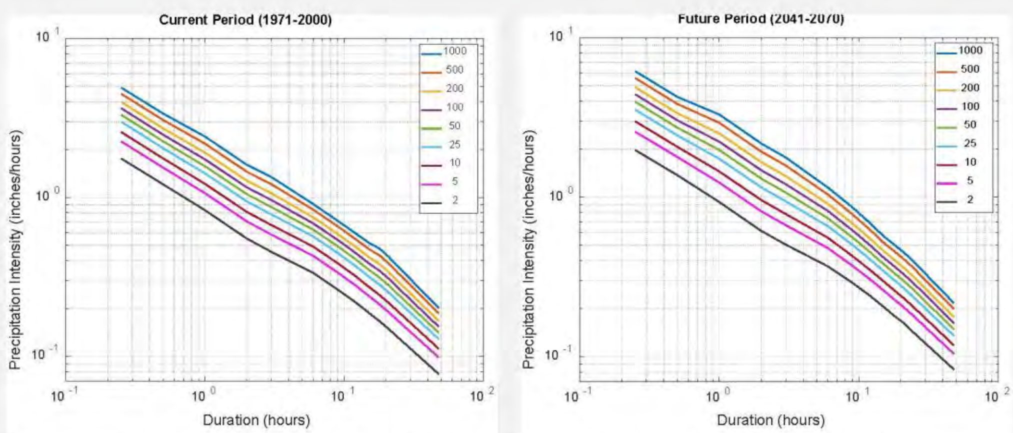

Averaged IDF curves in the current (left) and future (right) periods considering all eligible branches of logic trees for grid point 7

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Assessment of Uncertainty in Precipitation Frequency Under Current and Future Climate

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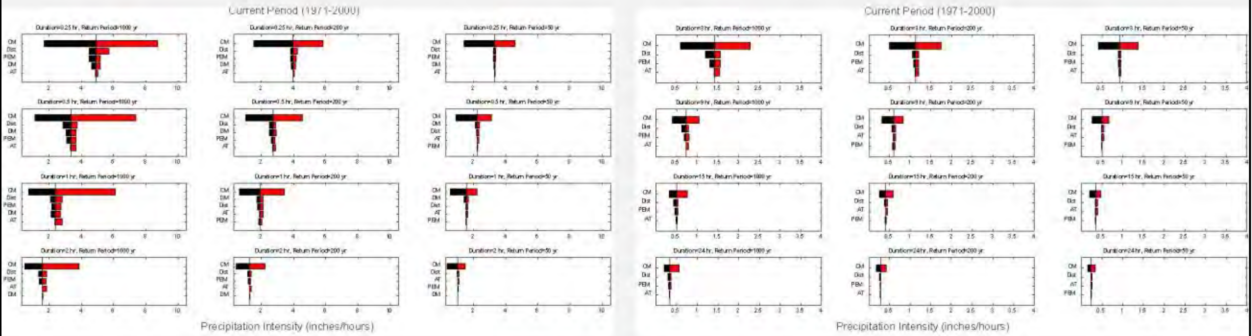
Tornado Plots



Current Period (1971-2000)

CM= Climate Model, DM=Downscaling Method, Dist=Distribution, PEM=Parameter Estimation Method

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Assessment of Uncertainty in Precipitation Frequency Under Current and Future Climate

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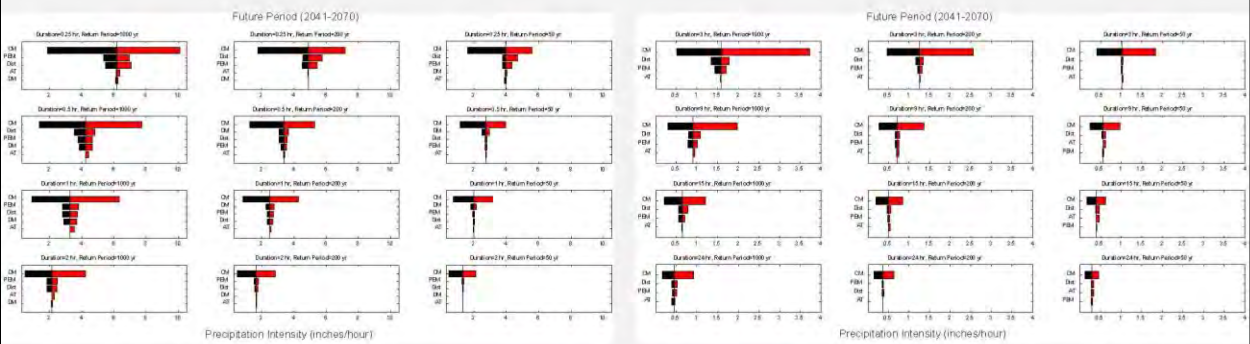
Tornado Plots



Future Period (2041-2070)

CM= Climate Model, DM=Downscaling Method, Dist=Distribution, PEM=Parameter Estimation Method

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Conclusions

Insights

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1. Aggregated error metrics can be modified to provide a more realistic evaluation of the performance of ML models through focusing on important events.
2. Response functions provide valuable insight regarding the behavior of ML models in predicting target response over a wide range of input variables.
3. The choice of the climate model is the dominant contributor to the uncertainty under both current and future climate conditions.
4. The order of importance of the other sources of uncertainty, including distribution, PEM, temporal downscaling method, and analysis type, differs from one duration and return period to the others. The order of the source of uncertainty also differs from the current to the future period.

Acknowledgement

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The authors gratefully acknowledge the support of the Maryland Department of Transportation State Highway Administration (MDOT SHA) under Statewide Planning and Research (SPR) Task Number SHA/UM/5-36 and the Maryland Water Resources Research Center (US Geological Survey Award #G21AP10629).
The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of the funding agency

Thank you

3.4.2 Presentation 2A-2 (KEYNOTE): Gridded Surface Weather Data with Uncertainty Quantification - Daymet V4

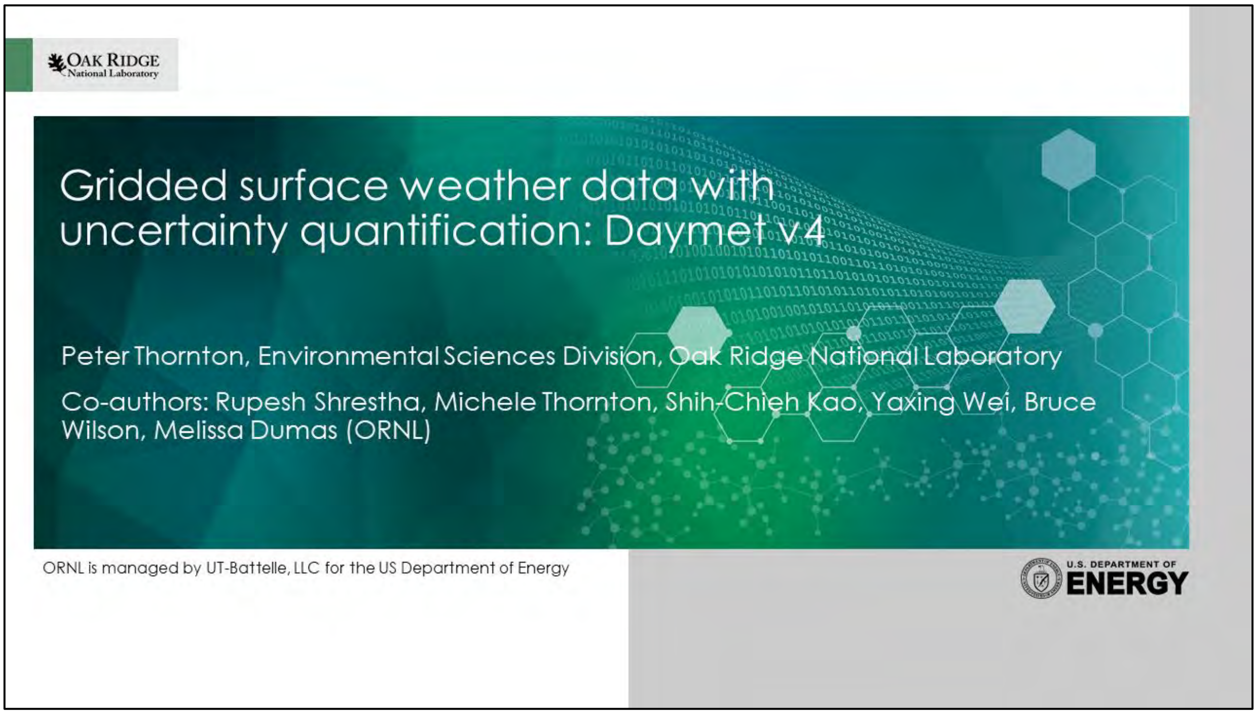
Authors: *Peter Thornton, Oak Ridge National Laboratory*

Speaker: *Peter Thornton*

3.4.2.1 Abstract

Observation-based estimates of surface weather are necessary inputs for many environmental studies and assessments. When uncertainties associated with surface weather estimates can be quantified, researchers and applications specialists can make informed decisions about the utility and appropriateness of data products to meet project requirements. The purpose of the Daymet gridded daily surface weather products is to provide necessary inputs to a broad range of environmental and ecological applications, while also providing the best possible quantification of uncertainty in those products. This presentation will briefly review the history of Daymet development, and will explore the improvements in algorithm and data processing that led to the recently released Daymet v4. The cross-validation metrics for precipitation and temperature will be described, with a focus on statistics for the spatial and temporal distribution of precipitation frequency and event size distributions. The relationship between surface weather and hydrological processes relevant to flooding hazards will also be discussed.

3.4.2.2 Presentation (ADAMS Accession No. ML22061A126)



Overview

- Filling a need for gridded surface weather data
- Following the observations: interpolation and extrapolation
- Truth in advertising: Cross-validation statistics
- Improvements in Daymet v4
- Discussion: applications in hydrology and flood hazard assessment

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Filling a need for gridded surface weather data

- Developed as driver for gridded land ecosystem model
- Daily temperature, precipitation, radiation and humidity
- Free online access to the entire database
- Multiple data access methods
- ~6000 unique users and ~30 million data deliveries per year

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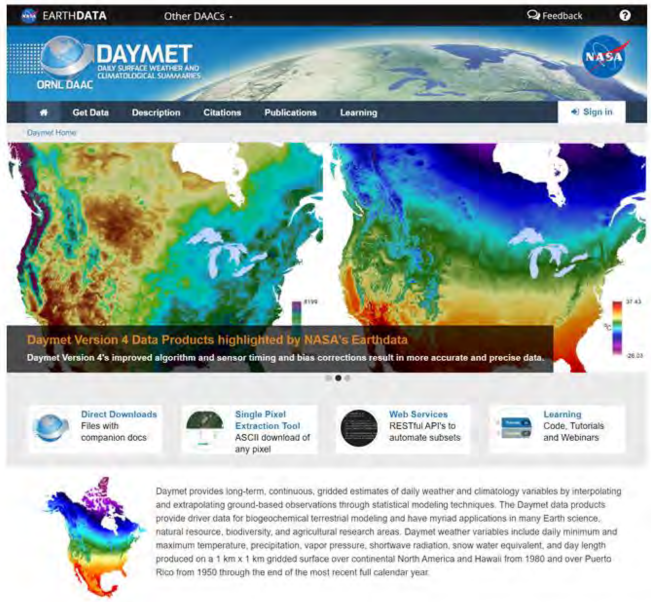
daymet.ornl.gov

- Bulk data access for regional analysis
- Single point data access in CSV file for site-level analysis
- Restful API for automated access to large data subsets
- Deep collection of tutorials, webinars, and user-developed analysis tools



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Following the observations: Interpolation and extrapolation

- Use the data as-observed, but try to eliminate instrumentation biases
- Input from multiple station networks, relying heavily on GHCNd (Menne et al. 2012)
- Objective assessment of vertical and horizontal gradients in temperature and precipitation (3d regression)
- Retain precipitation frequency-intensity distribution
- Retain spatial and temporal structure of extremes

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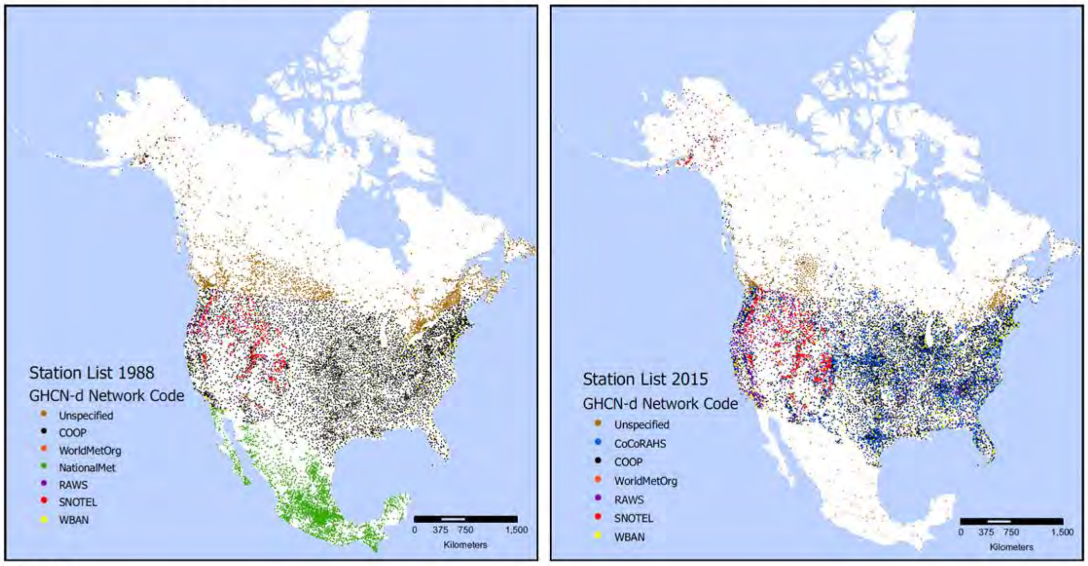
Station networks highly variable in space and time



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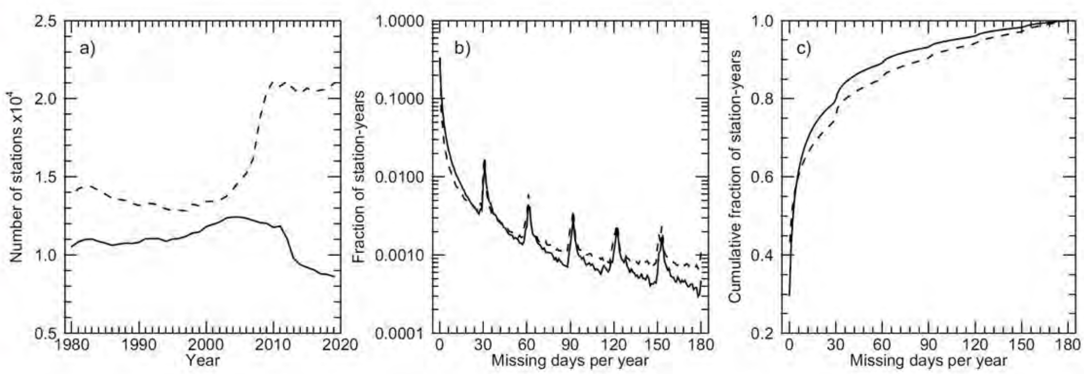
Generous inclusion of stations with missing data



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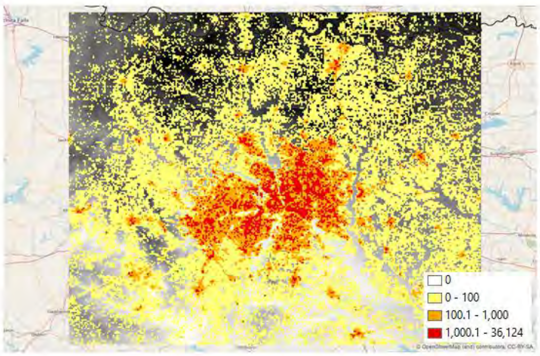
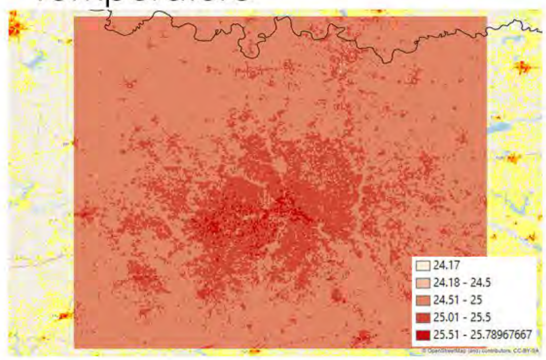
Using the data as-observed reveals real patterns

- Population



- Average Annual Max Temperature



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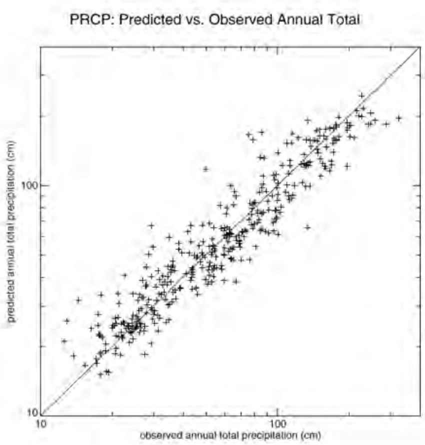
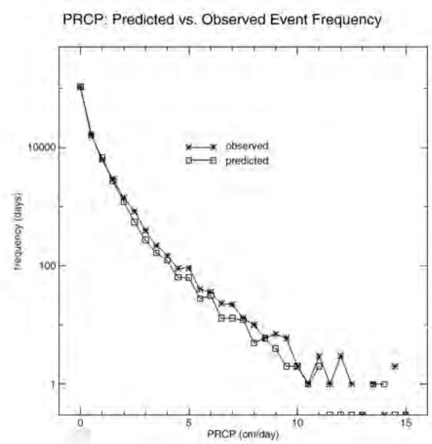
Daymet methods preserve climatology and events: Precipitation examples…





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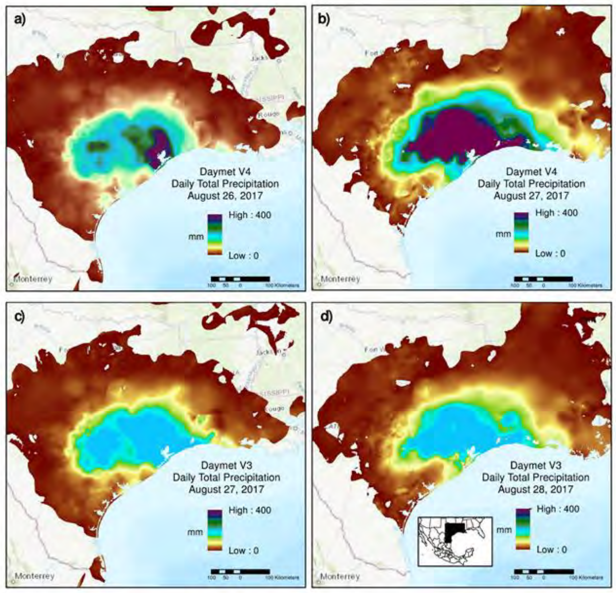
Daymet methods preserve extremes



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Truth in advertising: cross-validation statistics

- Available online for every observed station-day
- Not every dataset is useful for every application: Users encouraged to assess suitability for their specific application
- Provides an objective basis for algorithm improvements
- Can be useful in assessing and correcting instrumentation biases

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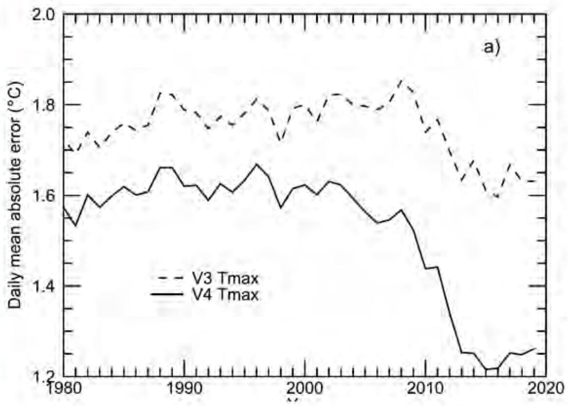
Spatial mean cross-validation data for temperature and precipitation



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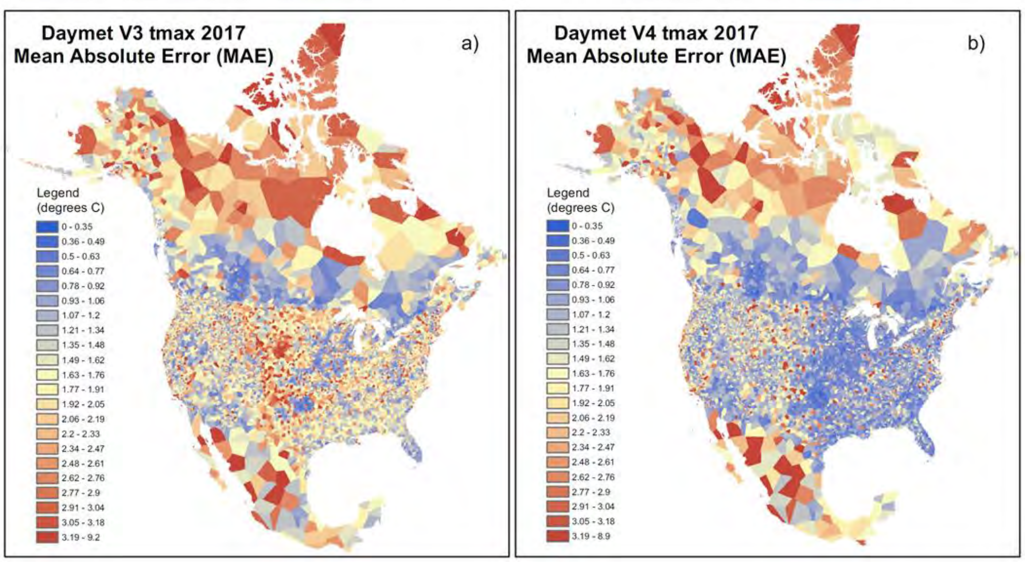
Temporal mean cross-validation statistics for Tmax



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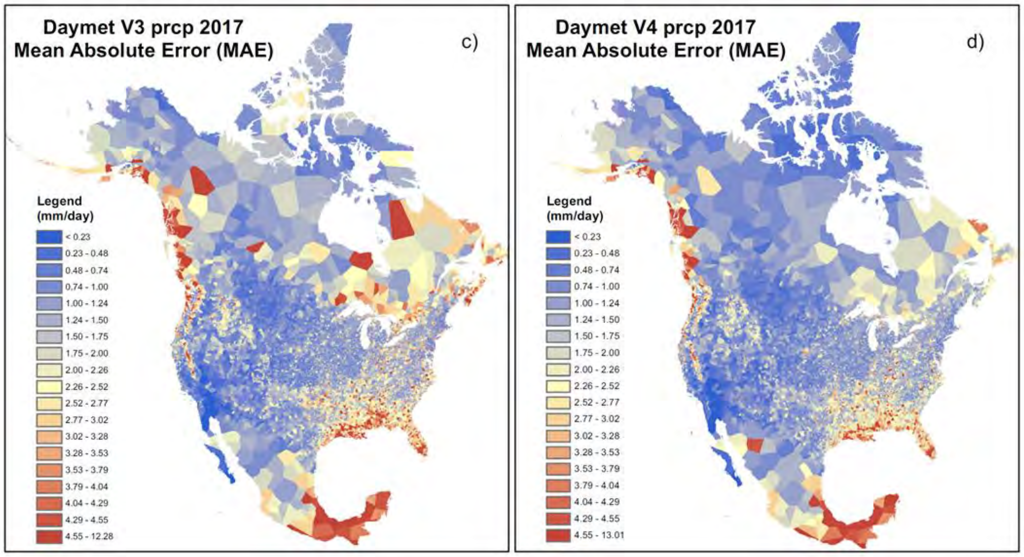
Temporal mean cross-validation statistics for precipitation



Improvements in Daymet v4

- Identify and correct time-of-observation biases
  - Affected maximum temperature and precipitation
- Identify and correct SNOTEL temperature sensor bias
- Removed some previous constraints on extremes

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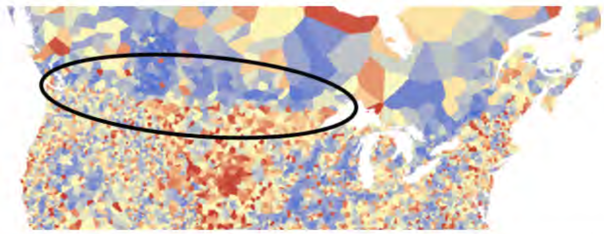
Correcting time-of-observation bias

year	maximum temperature*			precipitation		
	station days	%TOO before noon	% nodata	station days	%TOO before noon	% nodata
1988	1,729,277	49.53	2.26	2,914,822	56.70	11.90
1989	1,742,252	50.46	2.61	2,942,135	56.94	12.42
1990	1,746,314	51.24	2.91	2,937,209	57.26	12.89
2015	1,693,990	74.90	2.03	6,877,546	83.57	5.50
2016	1,676,722	74.90	2.23	6,860,087	84.68	7.87
2017	1,63,5940	74.90	2.40	6,892,927	84.38	7.40

Artefact in V3 cross-validation errors for maximum temperature suggested a problem with the input station data



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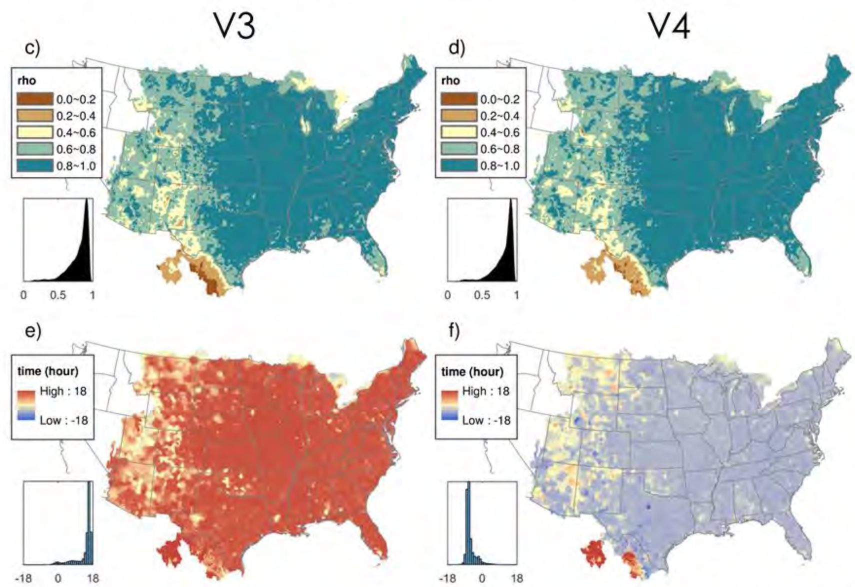
Improved precipitation timing, with a compromise…

Best possible comparison with radar-based Stage IV QPE

Time shift required for best fit to Stage IV QPE



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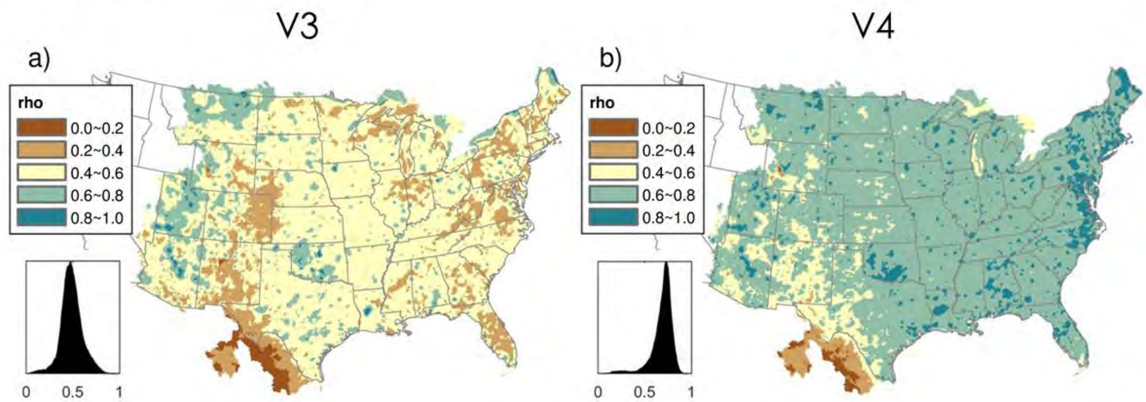
The compromise:

Splitting precipitation across days is better for daily error metric, but ruins the event frequency and raises bias

year	Precipitation (Prcp): Total daily value shift		
year	%change mean dayMAE	%change mean porMAE	%change bias
1988	2.8483	0.6154	0.0000
1989	3.2680	0.9585	4.1667
1990	3.9652	0.8721	4.6512
2015	−8.3990	0.0000	4.5455
2016	−7.9365	0.3861	8.0000
2017	−9.2350	−0.3774	5.1282
year	Precipitation (Prcp): Fractional daily value shift		
	%change mean dayMAE	%change mean porMAE	%change bias
1988	−7.6780	2.4615	87.1795
1989	−8.4967	3.1949	64.5833
1990	−8.0391	2.9070	81.3953
2015	−19.0945	2.6515	14.7727
2016	−17.8744	3.8610	32.0000
2017	−19.2281	2.6415	25.6410

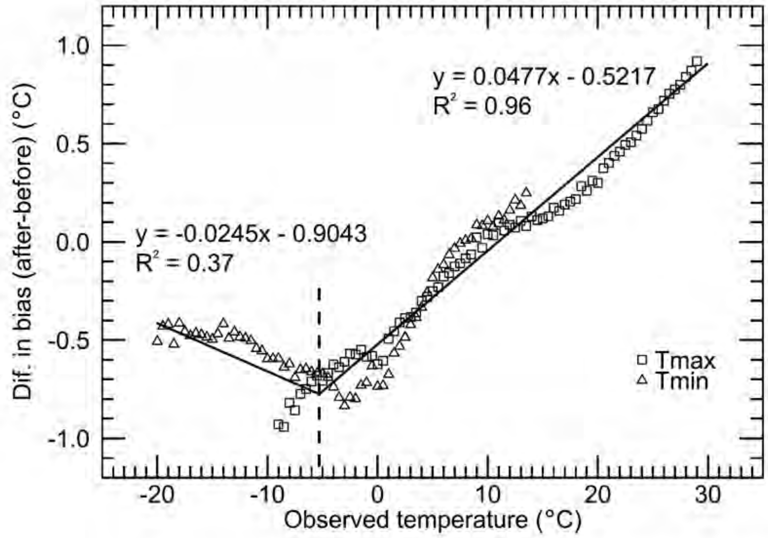
Solution, keep observed daily precipitation intact, but shift by a whole day



End result is improved correlation with Stage IV QPE

Corrected bias related to change in temperature sensors at SNOTEL sites

- Used cross-validation framework to identify bias and design a correction
- Carried out a synthetic bias analysis to verify approach



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Example data and applications

- Continental-scale data resource
- Downscaling climate model output
- Hydrologic modeling

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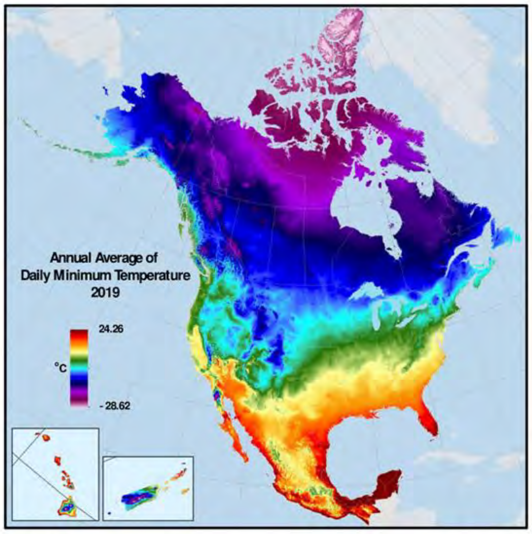
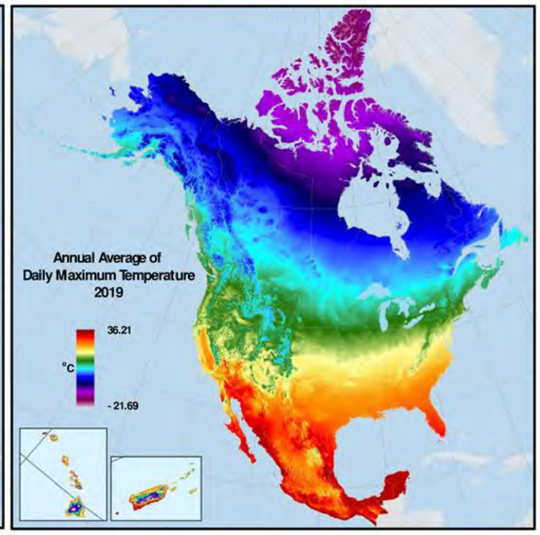
Example continental-scale outputs: temperature





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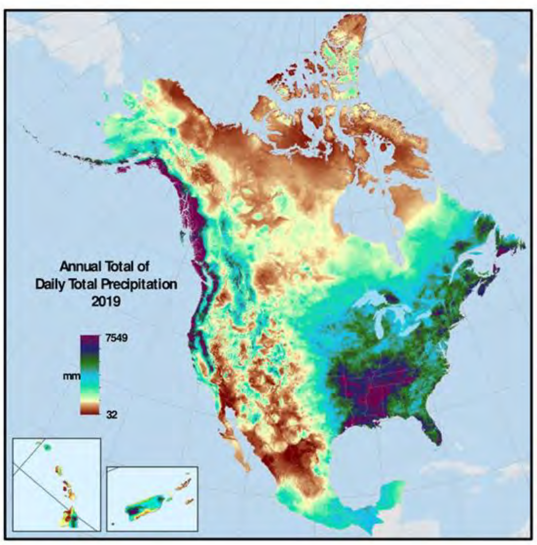
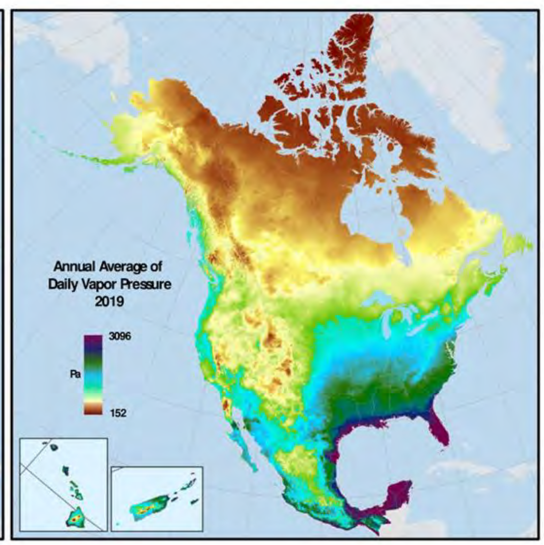
Precipitation and humidity…





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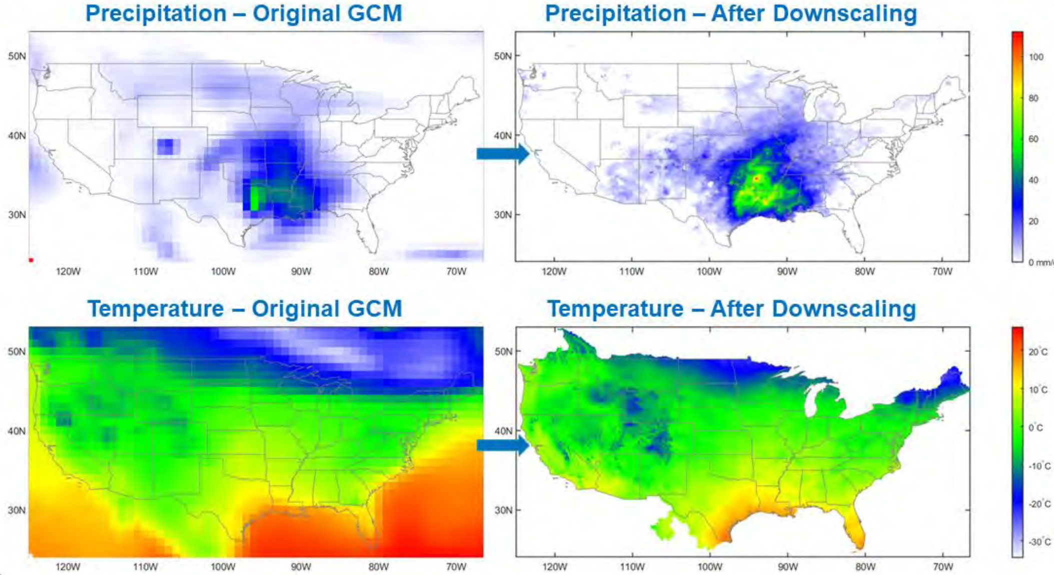
Support climate model downscaling

ACCESS-CM2, January 7th, 2037
DaymetV4 Training Data



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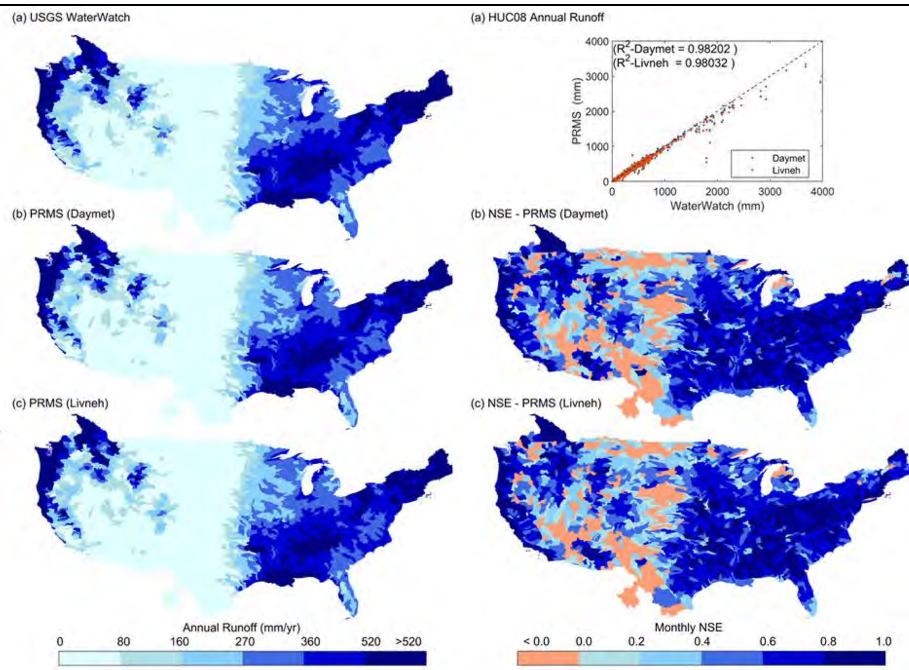
Support hydrologic modeling

- Serve as the driving meteorologic forcing to support hydrologic modeling.
- Can be used to calibrate hydrologic models, and eventually produce historic reanalysis hydrology and streamflow.



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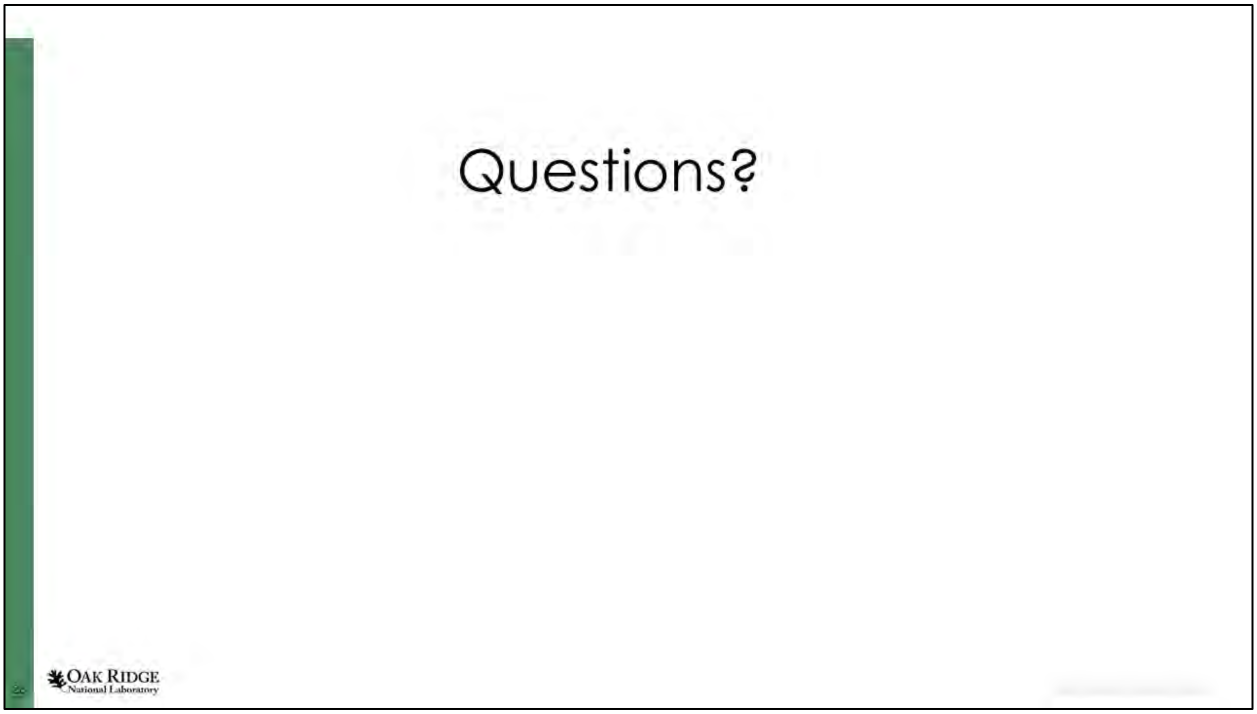

3.4.3 Presentation 2A-3: Utility of Weather Types to Improve Nonstationary Frequency Analysis of Extreme Precipitation

Authors: *Giuseppe Mascaro*, Arizona State University*

Speaker: *Giuseppe Mascaro*

3.4.3.1 Abstract

Theoretical arguments suggest that extreme precipitation (EP) will increase in a warmer climate. Climate projections and, in part, observational studies support these arguments, indicating the need to incorporate nonstationarity in EP frequency analysis. Here, a statistical framework is presented that addresses this need through changes in weather type (WT) occurrence. The framework is based on mixed populations of peak-over-threshold (POT) series of EP associated with the dominant WTs in a given region. The Poisson distribution with time-varying parameters is used to model the WT occurrence, while the Generalized Pareto distribution with constant parameters is adopted to model POT series of EP. The value of the proposed method is demonstrated by focusing on the U.S. Midwest, where it has been recently showed that the occurrence of a dominant WT related to heavy precipitation has been increasing since 1949. It is first showed that the statistical uncertainty of the nonstationary framework is comparable to a stationary approach based on the Generalized Extreme Value distribution fitted to annual precipitation maxima, often used in current engineering design. Next, historical and future climate simulations of a set of general circulation models from CMIP6 are used to quantify projected changes in EP frequency in the region, along with the associated uncertainty.

3.4.3.2 Presentation (ADAMS Accession No. ML22061A125)

Utility of Weather Types to Improve Nonstationary Frequency Analysis of Extreme Precipitation

Giuseppe Mascaro, Arizona State University
gmascaro@asu.edu

Session 1A: Precipitation
7th Annual NRC Probabilistic Flood Hazard Assessment (PFHA) Research Workshop 1

Outline

1. Motivation
2. Nonstationary statistical model of extreme precipitation (EP) based on weather types
3. Application in East North Central U.S.
   a. past climate (reanalysis)
   b. future climate (climate models)
4. Conclusions and future work

Outline

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   b. future climate (climate models)
4. Conclusions and future work

3

Motivation

Extreme precipitation (EP) is one of the most impactful natural hazards

- Primary input of floods and flash floods —> In U.S.A., $137 billion damages and 2640 fatalities from 1990 to 2019 (*Smith*, 2020)
- Impact on public health by degrading water quality (Gershunov et al., 2018) and increasing outbreaks of waterborne diseases (*Cann et al.*, 2013)
- Reduced crop production (*Li et al.*, 2019)

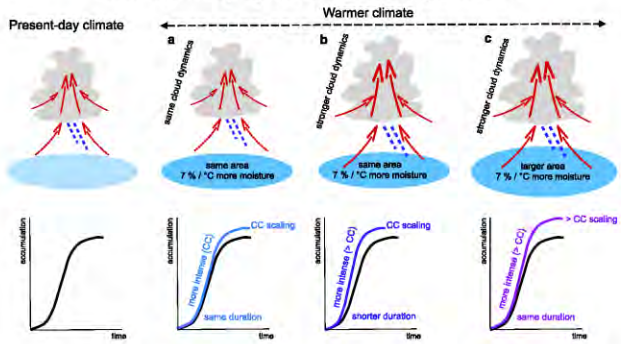
Characterizing EP frequency is key to mitigate these impacts and design infrastructure

4

Motivation

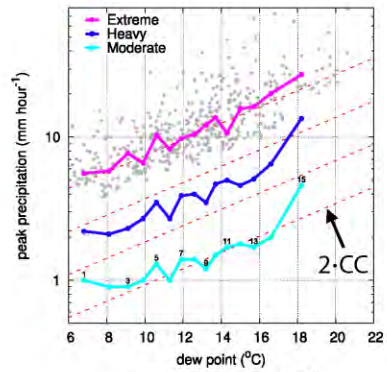
Theoretical arguments suggest that EP frequency and magnitude will change in a future climate

Clausius-Clapeyron (CC) scaling = 7% °C^{-1}



Conceptual diagram from *Westra et al.* (2014)

1-hr EP in the Netherlands

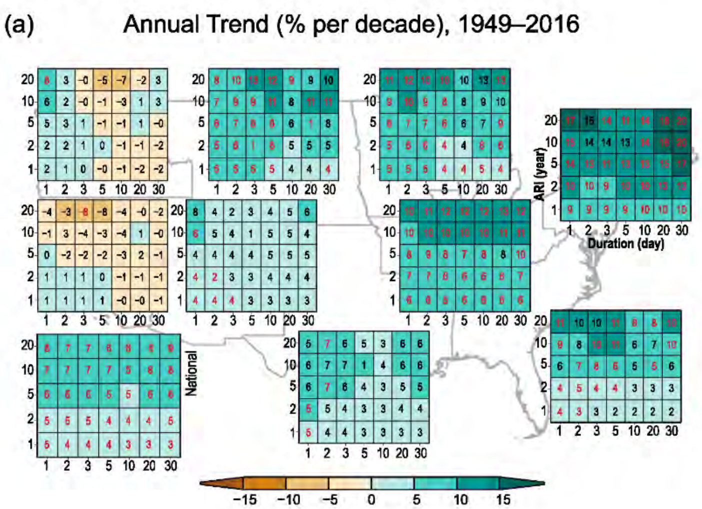


Lenderink et al. (2017)

5

Motivation

Observed increases in global temperature would suggest intensification of observed EP



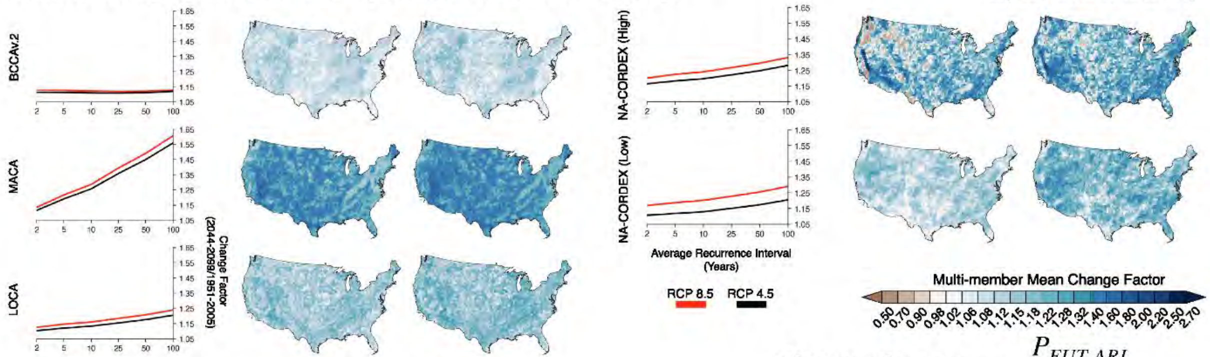
- Increasing frequency of EP in the Midwest and north east
- Constant or decreasing trends in the west
- Link with trends in precipitable water

Kunkel et al. (2020)

Motivation

GCMs project increases in EP, but uncertainties at local scales are still high, even when using statistical or dynamical downscaling

Lopez-Cantu et al. (2020)



$ARI = 25$ years

$$\text{Change factor}_{ARI} = \frac{P_{FUT,ARI}}{P_{HIST,ARI}}$$

7

The direct use of P outputs from GCMs is challenging.
How can we more effectively use information from GCMs to characterize EP?

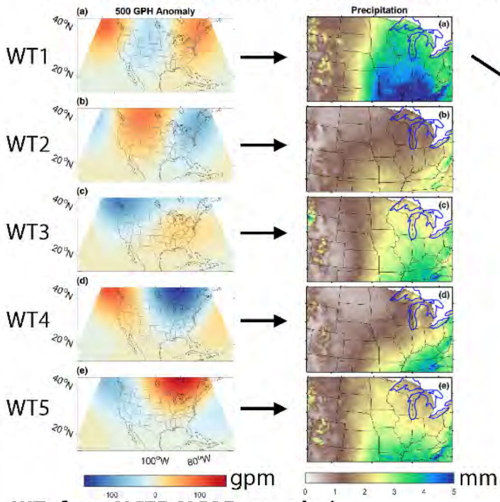
Outline

1. Motivation
2. Nonstationary statistical model of extreme precipitation (EP) based on weather types
3. Application in East North Central U.S.
    a. past climate (reanalysis)
    b. future climate (climate models)
4. Conclusions and future work

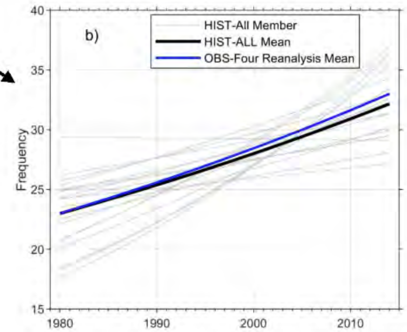
8

Utility of General Circulation Models (GCMs)

GCMs have been shown able to adequately reproduce occurrence of weather types (WTs) or dominant large-scale meteorological patterns controlling weather



WTs from NCEP-NCAR reanalysis



Occurrence of WT1 from reanalysis and historical CMIP6 simulations

Zhang and Villarini (2019; 2020)

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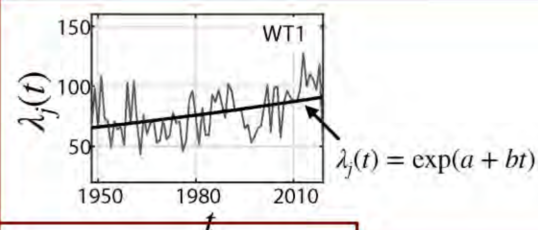
Nonstationary frequency analysis of EP based on WTs

Mixed model of peak-over-threshold (POT) distributions with time-varying frequency

$$F(x) = \sum_{j=1}^{M} p_j \cdot F_j(x \mid \vec{\theta}_j)$$

M : number of generating mechanisms (or WTs)

$$p_j = \frac{n_j}{\sum_{k=1}^{M} n_k} \qquad n_j \sim \text{Poisson}(\lambda_j(t))$$



$\vec{\theta}_j = [\alpha_{0,j}, \xi_j, \zeta_{0,j}]$: parameters of generalized Pareto distribution (GPD) reparameterized for $u = 0$ (*Deidda*, 2010) - Constant in time

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Outline

1. Motivation
2. Nonstationary statistical model of extreme precipitation (EP) based on weather types
3. Application in East North Central U.S.
    a. past climate (reanalysis)
    b. future climate (climate models)
4. Conclusions and future work

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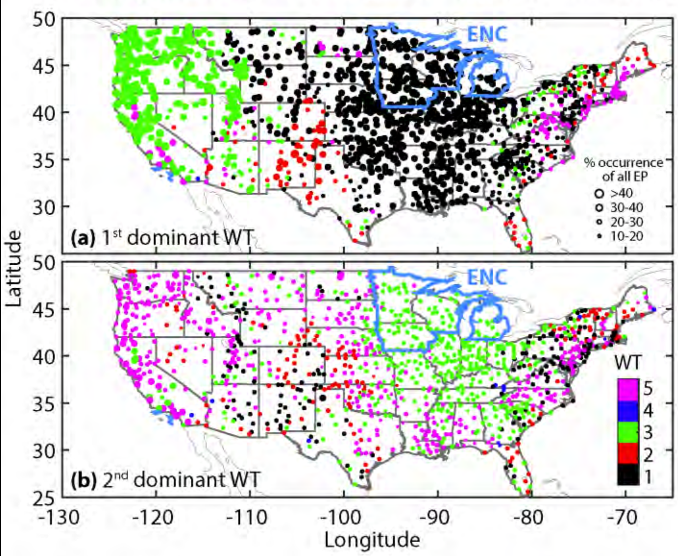
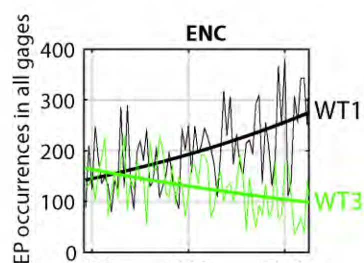
Application in East North Central U.S.

We computed the 5 WTs of Zhang and Villarini (2019) from 1949-2015



- *K*-means cluster analysis on 500 hPa Geopotential height from NCEP-NCAR
- GHNC daily P records
- EP = POT series above 95th quantile
- 1st and 2nd dominant WT in EP



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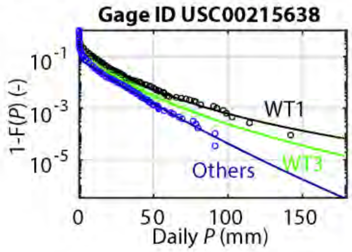
Application in East North Central U.S.

We applied the mixed model to 3 populations

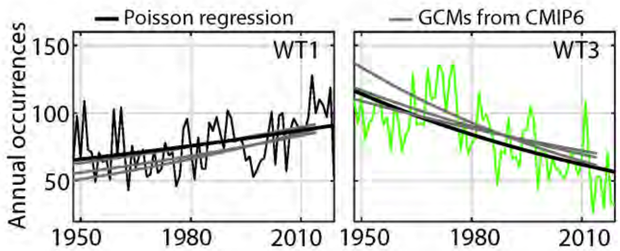
$$F(x) = \sum_{j=1}^{3} p_j \cdot F_j(x \mid \vec{\theta}_j)$$

$$p_j = \frac{n_j}{\sum_{k=1}^{3} n_k} \quad n_j \sim \text{Poisson}(\lambda_j(t))$$



$F_j(x \mid \vec{\theta}_j)$

	$\alpha_{0,j}$	ξ_j	$\zeta_{0,j}$ = Pr{P > 0}
1: WT1	8.55	0.20	0.26
2: WT3	11.07	0.12	0.11
3: Others	11.78	0.03	0.08



$\lambda_j(t) = \exp(a + bt)$

	a	*b*
1: WT1	-4.9	0.0047
2: WT3	24.5	-0.01

- *statistically significant at 0.01 level*
- *t = 1949, …, 2015*

Application in East North Central U.S.

Statistical simulations to compute return levels

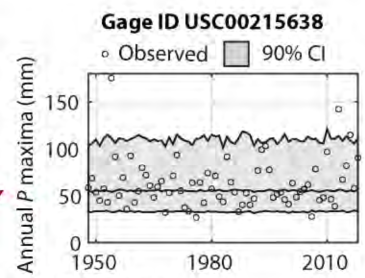
1. For each year, *t* = 1949, …, 2015

WT1—> $n_1 \sim \text{Poisson}(\lambda_1(t))$

WT3—> $n_2 \sim \text{Poisson}(\lambda_2(t))$

Others—> $n_3 = 365 - n_1 - n_2$

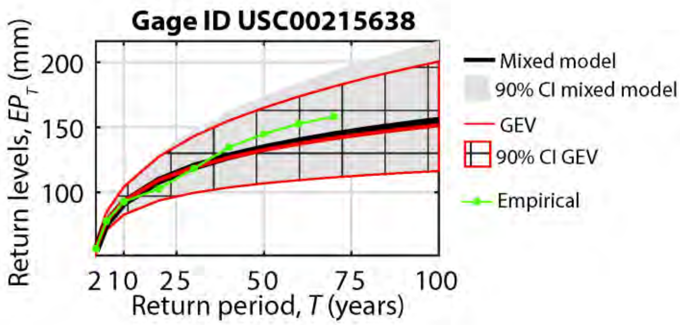
2. Randomly draw n_1, n_2 and n_3 variates from respective GPDs (these include zero P)
3. Repeat for 1-2 all years —> time series of annual P maxima from 1949 to 2015
4. Repeat 1–3 for 10,000 times —> 10,000 time series of annual P maxima

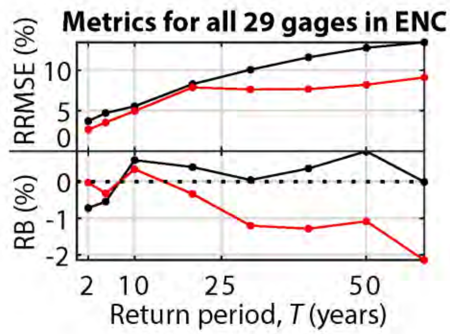


5. Compute return levels, EP_T, from empirical distribution of annual P maxima, along with associated sampling uncertainty

Comparison with models based on annual maxima

We compared return levels of mixed model and Generalized Extreme Value (GEV) distribution



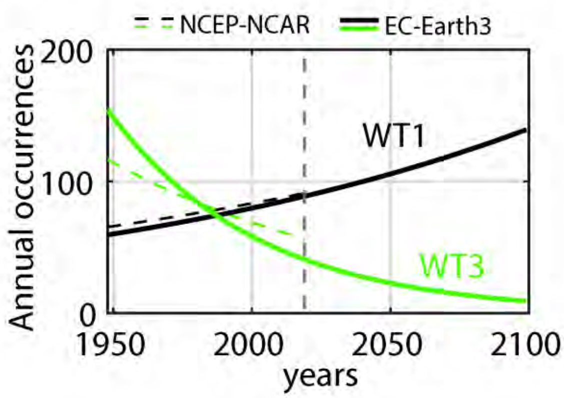


Similar performance with the GEV used in current design standards

Application of the mixed model in future climate

We applied the mixed model with ScenarioMIP simulations of EC-Earth3 for SSP8-8.5

1. We quantified temporal changes in WTs' occurrences and applied the mixed model



- We have applied the mixed model with EC-Earth3-derived:

$$\lambda_j(t) = \exp(a + bt)$$

- Constant GPD parameters
- We have tested other two GCMs with similar results

Application of the mixed model in future climate

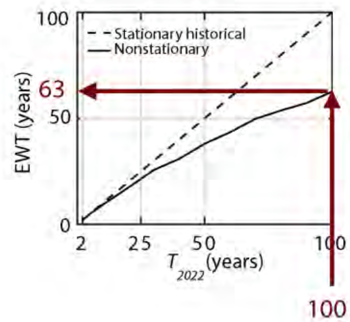
We applied the mixed model with ScenarioMIP simulations of EC-Earth3 for SSP8-8.5

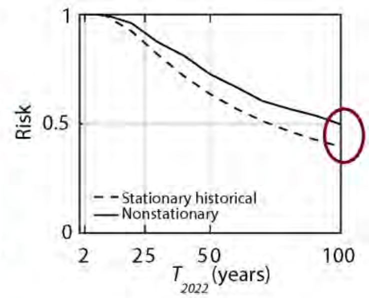
2. We computed metrics accounting for nonstationary frequencies of EP
   - We assumed an infrastructure is built in 2022 with a design life m = 50 years —> T_{2022}, EP_{T2022}
   - We calculated expected waiting time (EWT) and risk of failure —> nonstationary geometric distribution

$$EWT = 1 + \sum_{x=1}^{x_{max}} \prod_{t=1}^{x} (1 - p_t)$$

time varying exceedance probability of EP_{T2022} from the mixed model

$$Risk = 1 + \prod_{t=1}^{m} (1 - p_t)$$





Salas *et al.* (2018)

Outline

1. Motivation
2. Nonstationary statistical model of extreme precipitation (EP) based on weather types
3. Application in East North Central U.S.
   a. past climate (reanalysis)
   b. future climate (climate models)
4. Conclusions and future work

Conclusions and future work

- We have developed a nonstationary statistical model of EP based on mixed populations:
  - ✳Populations identified by WTs, whose occurrence varies with time and is adequately simulated by GCMs
  - ✳GPD with constant parameters modeling P in each population
- Statistical simulations are needed to apply the model. Performances and uncertainty are similar to current approaches based on annual maxima and the GEV distribution
- Preliminary model applications with future climate projections of CMIP6 GCMs suggest increasing intensity of EP in East North Central U.S.
- Future work: thoroughly test the approach in other regions and include a large ensemble of GCMs to characterize the uncertainty of future climate projections.

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Conclusions and future work

Thanks!

For questions: gmascaro@asu.edu

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3.4.4 Presentation 2A-4: Characteristics and Causes of Extreme Snowmelt over the Conterminous United States

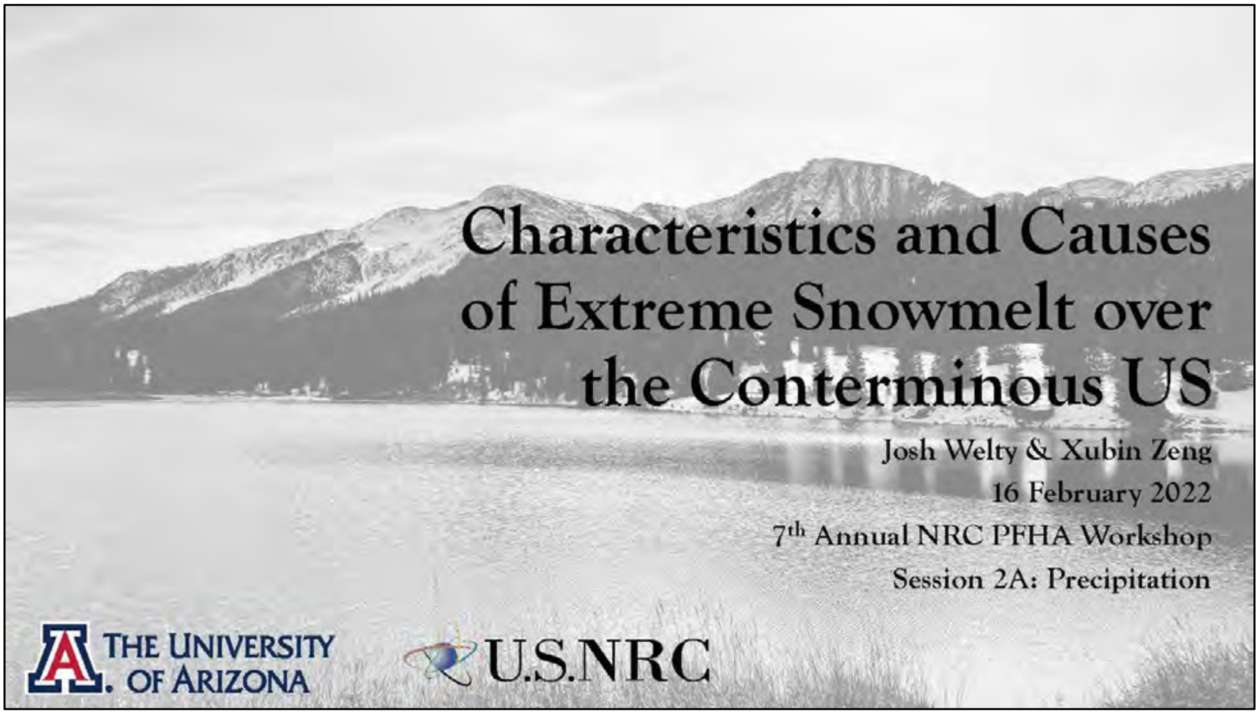
Author: *Joshua Welty*[1], Xubin Zeng[2], [1]U.S. Navy Fleet Numerical Meteorology and Oceanography Center, [2]University of Arizona*

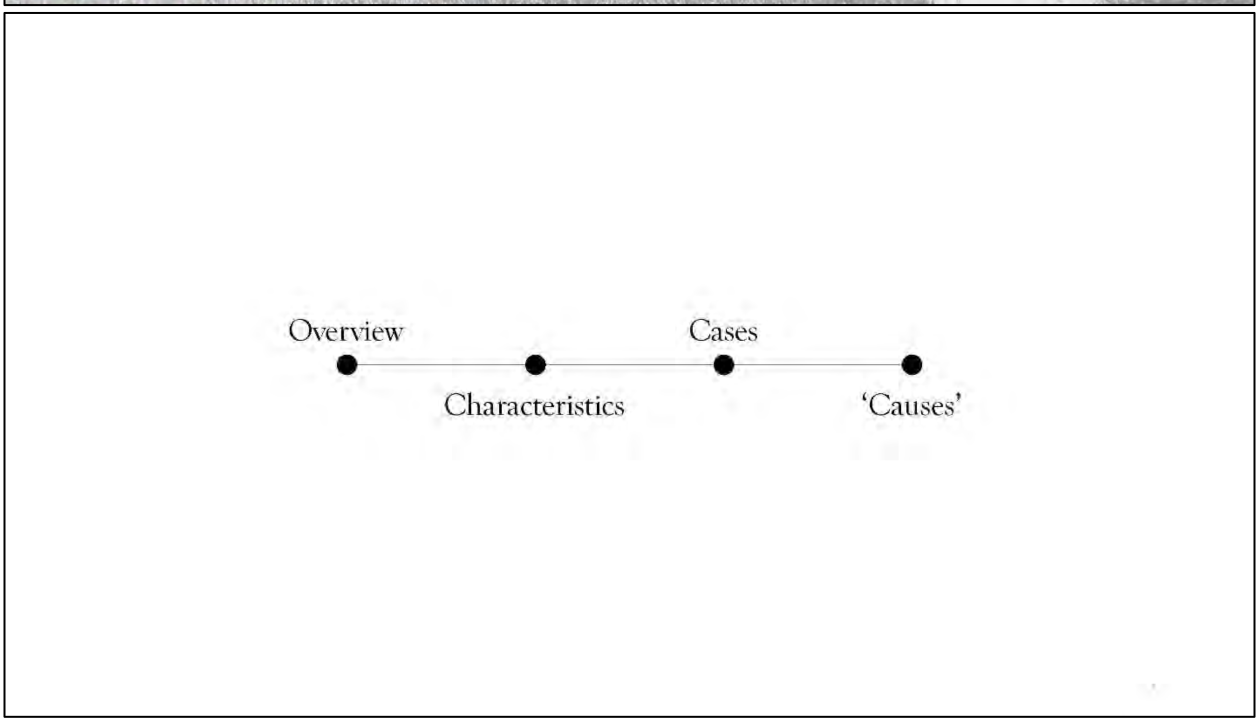
Speaker: *Joshua Welty*

3.4.4.1 Abstract

Snowmelt is an essential process for the health and sustenance of numerous communities and ecosystems across the globe, though it also presents potential hazards when ablation processes are exceedingly rapid. Using 4-km daily snow water equivalent, temperature, and precipitation data for three decades (1988–2017), here we provide a broad characterization of extreme snowmelt episodes over the conterminous United States in terms of magnitude, timing, and coincident synoptic weather patterns. Larger-magnitude extreme snowmelt events usually coincide with minimal precipitation and elevated temperatures. However, certain regions, particularly mountainous regions and the northeastern United States, exhibit greater likelihood of extreme snowmelt events during pronounced rain-on-snow events. During snowmelt extremes, snowmelt rate often exceeds precipitation in many regions. Meteorological patterns and associated water vapor transport most directly connected to extreme events over different regions are classified via a machine-learning technique. Over the 30-yr study period, there is a weakly increasing trend in the frequency of extremes, though this does not necessarily signify an increase in snowmelt magnitudes.

3.4.4.2 Presentation (ADAMS Accession No. ML22061A124)





Overview | Characteristics | Cases | 'Causes'

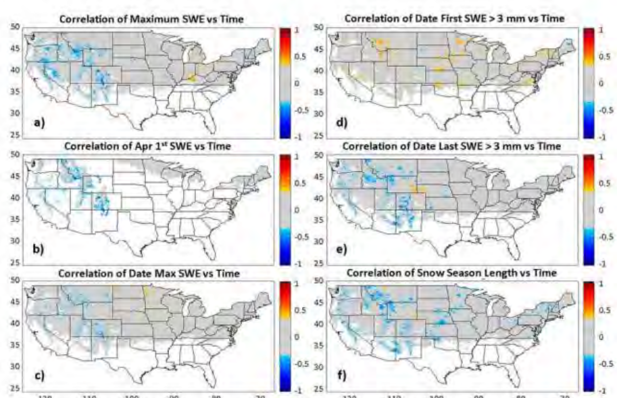
Why is snowpack important?

- Reflects potentially long-term changes in temperature and/or precipitation
- Represent 'water towers' for regions like the drought-prone western CONUS
- Conversely, can prove hazardous when melting process is rapid

Overview | Characteristics | Cases | 'Causes'

What can be done with snowpack data?

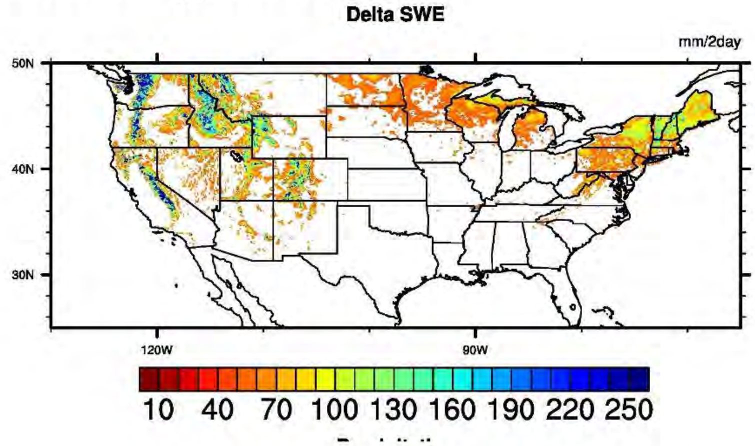
- Spatial representation / heterogeneity of snowpack over the US[1]
- **Long-term trends in snowpack[2]**
- Evaluation of model representation of SWE relationship w.r.t. temperature and precipitation[3]
- Post-processing of near-surface variables for soil moisture and drought monitoring[4]
- Characterization of ablation in terms of magnitude, timing, and synoptic weather conditions[5]



Overview Characteristics Cases 'Causes'

Maximum snowmelt magnitude

- Delta SWE: largest 2-day snow loss for the 30-year period at each pixel
- Largest over high elevations in the western CONUS and portions of eastern CONUS



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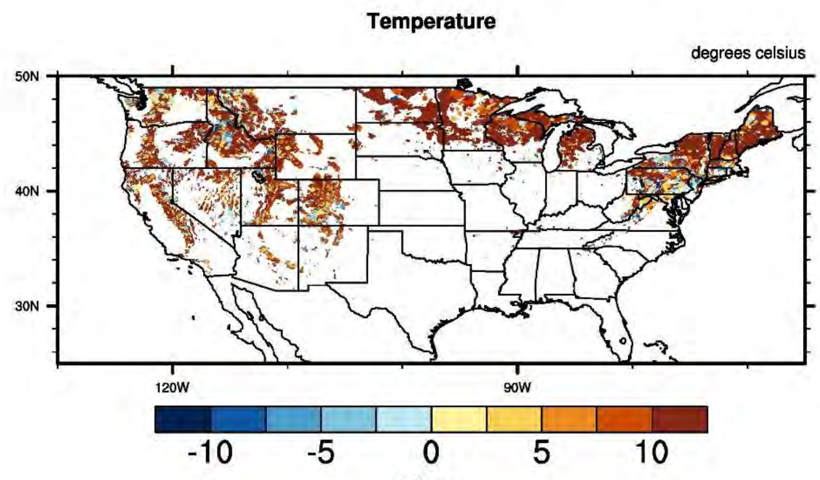
Overview Characteristics Cases 'Causes'



Above-freezing temperatures are most pervasive

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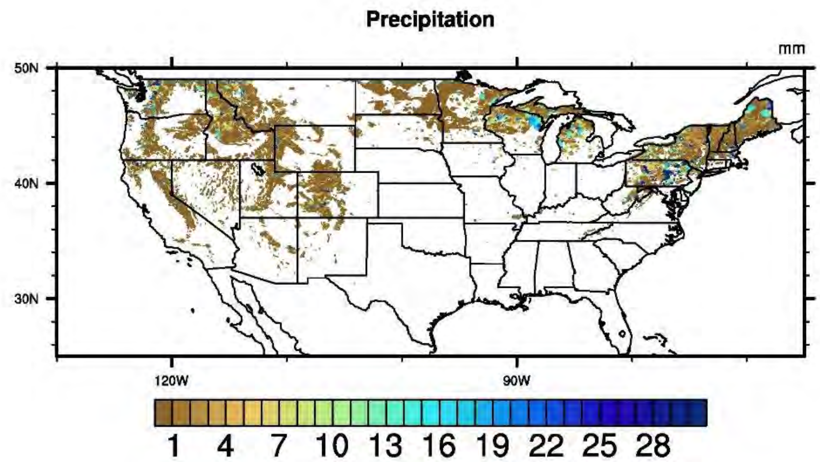
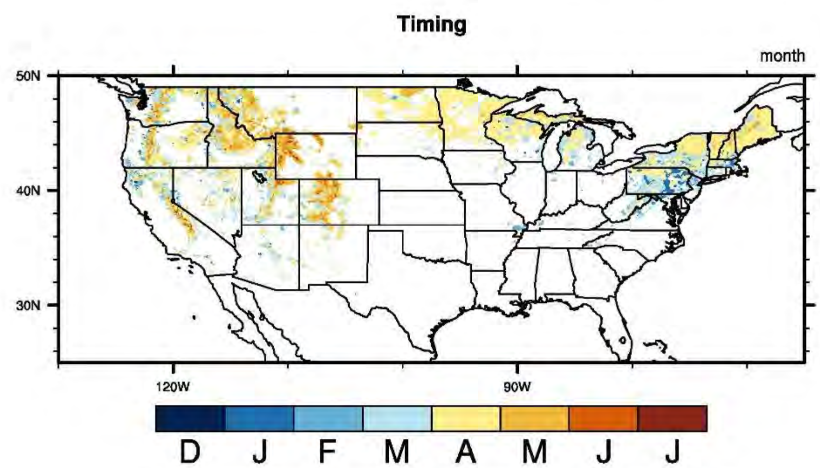
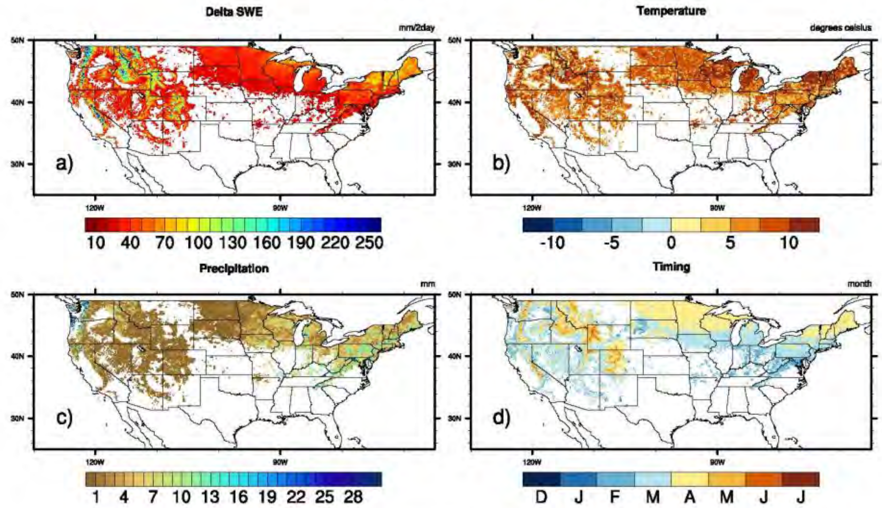


Limited precipitation is associated with snowmelt in most regions



Timing usually during mid- to late spring, though more southerly regions and windward sides of mountains exhibit earlier timing

Overview Characteristics Cases 'Causes'



Analysis also performed for top 10 extreme events at each pixel (mean value for the 10 events at each pixel shown)

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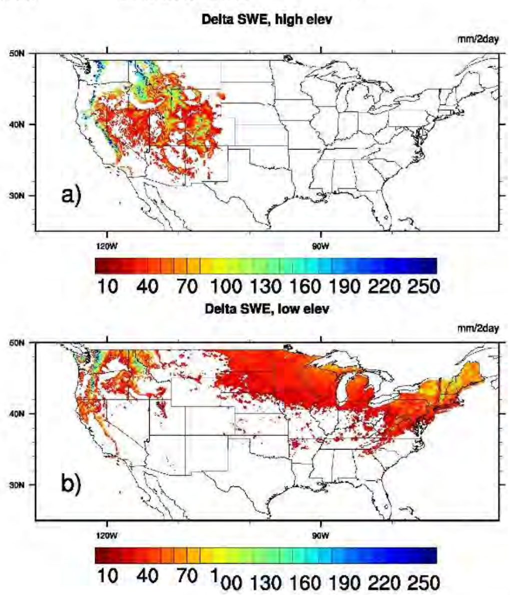
Overview Characteristics Cases 'Causes'

Elevation impacts

- As expected, highest magnitude events tend to occur at higher elevations over western CONUS.
- Distribution is much more heterogeneous over variable topography



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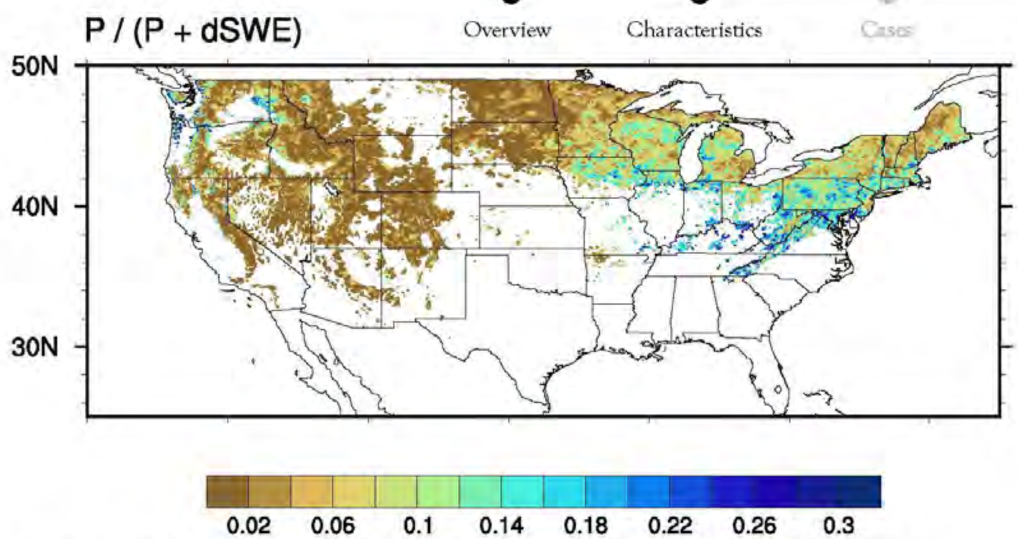
Overview Characteristics Cases 'Causes'



Average contribution of precipitation to runoff potential for the top 10 snowmelt extremes at each pixel. The pattern mirrors climatology, with larger values residing over the Pacific Northwest and the eastern CONUS.

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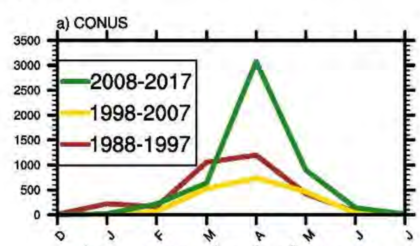
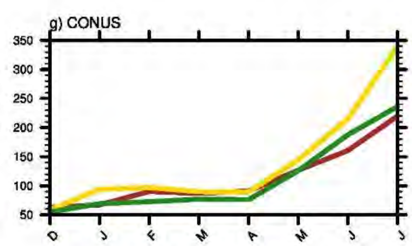
Overview Characteristics Cases 'Causes'

Trends

- There is a positive trend (p=0.25) in the occurrence of snowmelt extremes over the CONUS throughout the period, particularly during the month of May (p=0.03). Also, a positive trend in rain-on-snow occurrence (p=0.19)
- Though there is a weakly positive trend in frequency, no notable pattern for magnitude



Average annual cycle of extreme snowmelt **occurrence** (pixel number) by decade



Average annual cycle of extreme snowmelt **magnitude** by decade

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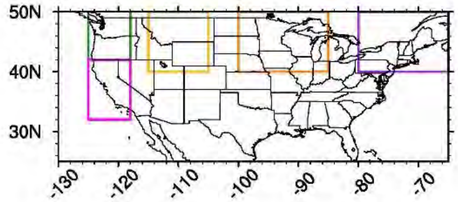
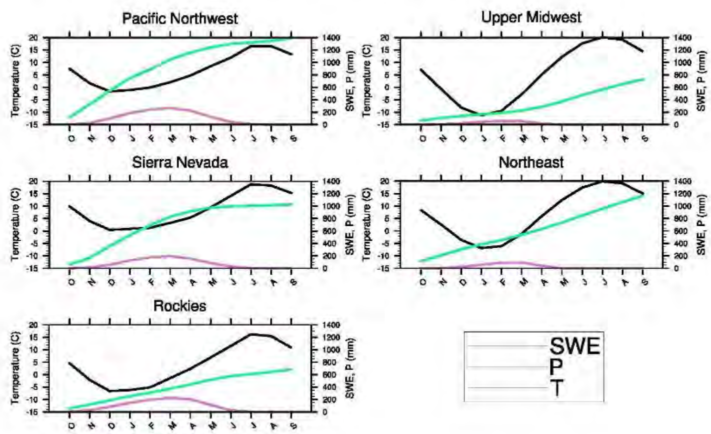
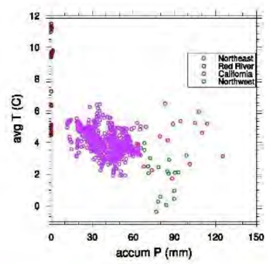
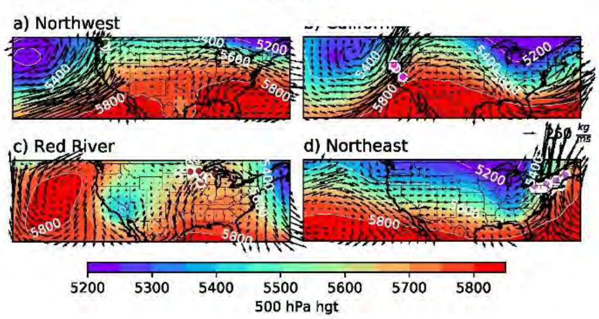
How do snowmelt extremes vary by region?





Overview Characteristics Cases 'Causes'

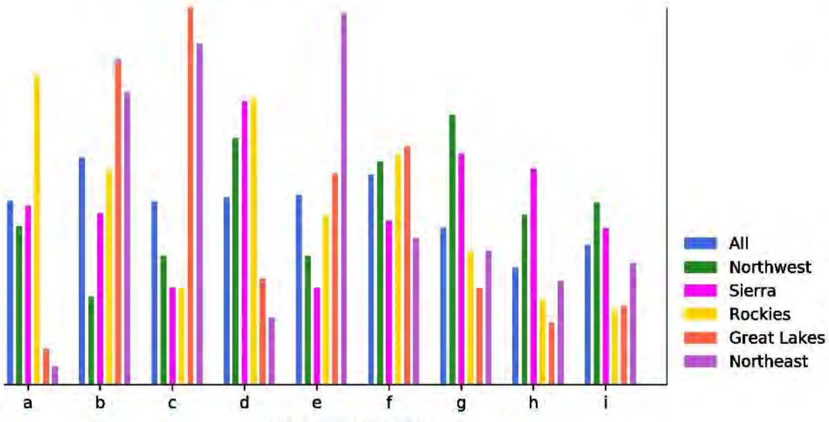




- Four high-impact flooding events over different regions
- In three out of the four case studies (exception being Northwest), dSWE>P contribution to runoff
- In some cases (e.g. Red River, burgundy dots in top, figure 'c' in bottom), dSWE>>P

Overview — Characteristics — Cases — 'Causes'

Weather



- Used self-organizing maps to produce nine dominant patterns associated with extreme snowmelt over the CONUS
- These maps served as template to classify regional snowmelt extremes

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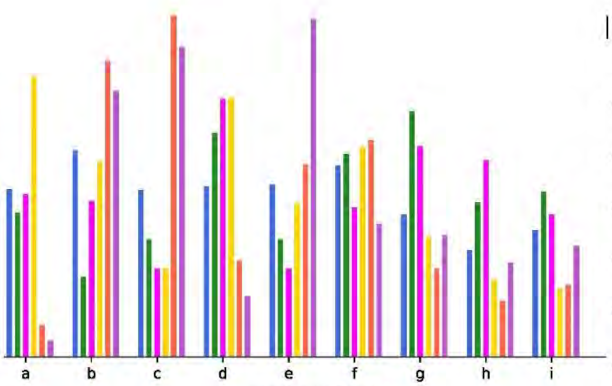
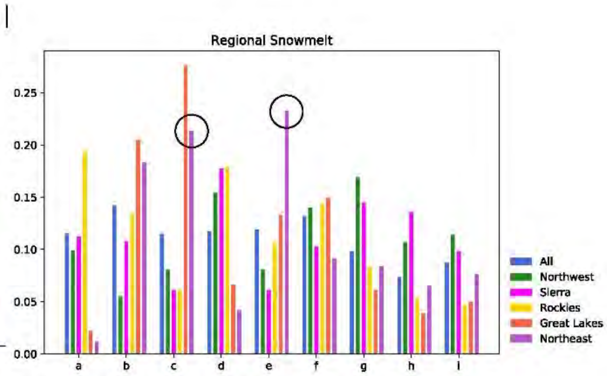
Overview — Characteristics — Cases — 'Causes'





Part of the utility of this approach is that there are more than one 'meaningful' pattern associated with snowmelt over a given region (e.g. maps 'c' and 'e' for the Northeast)

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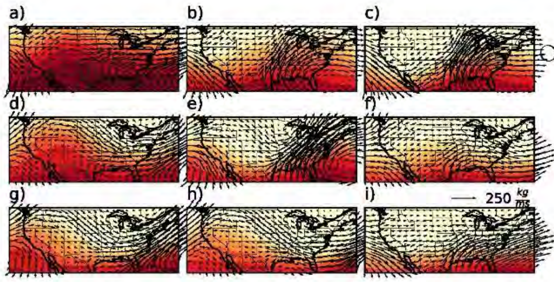
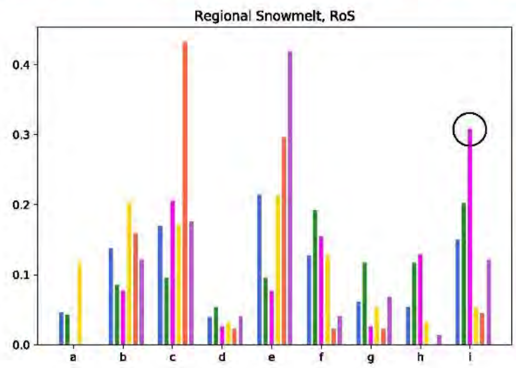
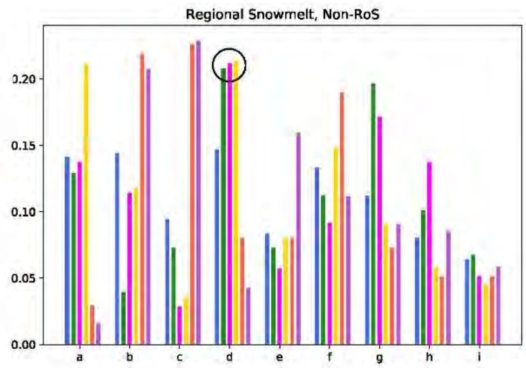


Overview — Characteristics — Cases — 'Causes'

We can also use the maps to classify other specific events, like RoS vs. non-RoS.

For example, majority of Sierra Nevada RoS (non-RoS) events correspond to map 'i' ('d') which exhibit very different synoptic setups.





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Takeaways

- Large variation in the meteorological conditions associated with regional events
  - Over the western CONUS, anomalous high pressure and upstream AR activity
  - Over the eastern CONUS, frontal passage, Gulf warm air advection, and precipitation
- In many cases, SWE loss exceeds the precipitation contribution to runoff
- There is a weakly increasing trend in the frequency of extreme snowmelt events over the US

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Acknowledgments/References

- UA SWE data are available from the National Snow and Ice Data Center (https://nsidc.org/data/nsidc-0719/versions/1). PRISM data can be downloaded from the PRISM Climate Group (https://prism.oregonstate.edu/). MERRA-2 data are available from the Goddard Earth Sciences Data and Information Services Center (https://disc.gsfc.nasa.gov/).

US Army Corps of Engineers

[1]Broxton, P. D., N. Dawson, and X. Zeng, 2016: Linking snowfall and snow accumulation to generate spatial maps of SWE and snow depth. *Earth Space Sci.*, 3, 246–256, https://doi.org/10.1002/2016EA000174

[2]Zeng, X., P. Broxton, and N. Dawson, 2018: Snowpack change from 1982 to 2016 over conterminous United States. *Geophys. Res. Lett.*, **45**, 12 940–12 947, https://doi.org/10.1029/2018GL079621

[3]Brunke, M., Welty, J., & Zeng., X. (2020). Attribution of snowpack error sensitivities to simulated temperature and precipitation in E3SMv1 over the contiguous United States. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021MS002640?af=R

[4]Arévalo, J., Welty, J., Fan., Y., & Zeng, X. (2021). Implementation of Snowpack Treatment in the CPC Water Balance Model and Its Impact on Drought Assessment. https://journals.ametsoc.org/view/journals/hydr/aop/JHM-D-20-0201.1/JHM-D-20-0201.1.xml

[5]Welty, J., & Zeng, X. (2021). Characteristics and Causes of Extreme Snowmelt over the Conterminous United States. https://journals.ametsoc.org/view/journals/bams/aop/BAMS-D-20-0182.1/BAMS-D-20-0182.1.xml

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3.4.5 Presentation 2A-5: LIP PFHA Pilot Study

Authors: *Rajiv Prasad*, Arun Veeramany, Rajesh Singh, Pacific Northwest National Laboratory*

Speaker: *Rajiv Prasad*

3.4.5.1 Abstract

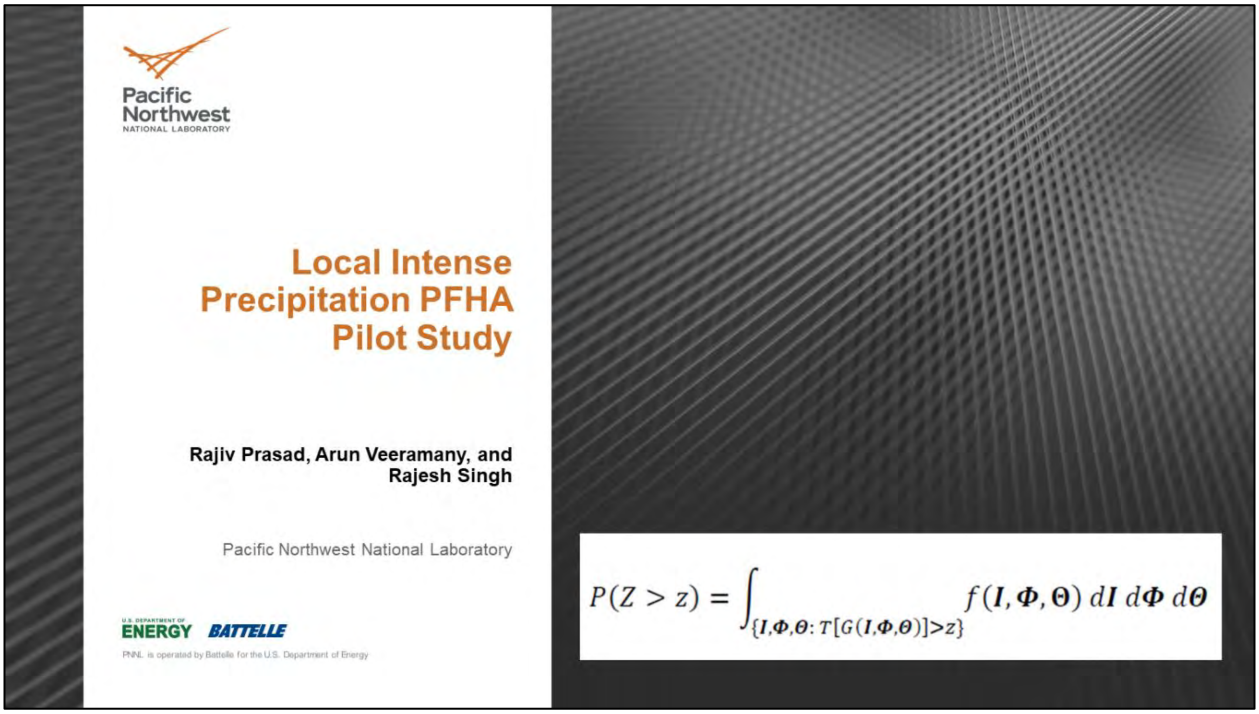
As part of the U.S. Nuclear Regulatory Commission's (NRC's) Probabilistic Flood Hazard Assessment (PFHA) Research Program, the Pacific Northwest National Laboratory (PNNL) is currently performing a pilot study for probabilistic assessment of local intense precipitation (LIP) flood hazards at nuclear power plants (NPPs). The project includes (1) reviewing existing software packages used to perform LIP flood hazard assessments, (2) reviewing aleatory variability and epistemic uncertainty that influence LIP flood event modeling, (3) performing a LIP probabilistic flood hazard assessment (PFHA) for a hypothetical NPP site, and (4) transferring knowledge to the NRC.

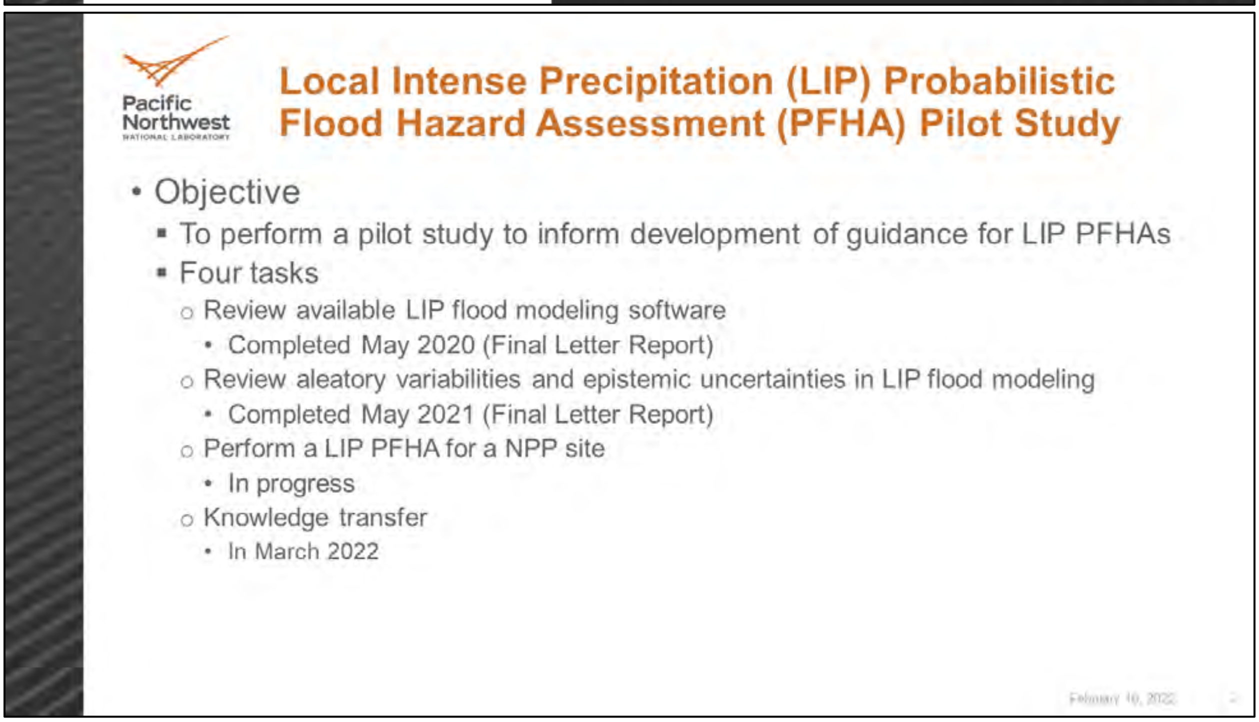
PNNL has completed Tasks 1 and 2 of this project. The findings from these tasks were presented in previous PFHA Workshops. In Task 3, a PFHA was performed for a NPP site. The LIP flood model developed for the post-Fukushima flood hazard reevaluation was leveraged for this study. The LIP flood model was implemented using the FLO-2D™ flood simulation software package. The model was first subjected to a sensitivity analysis to determine the major sources of uncertainty in model predictions. The flood hazards were found to be sensitive to two sources: (1) input precipitation (aleatory variability) and (2) surface roughness (epistemic uncertainty). The flood hazards did not show significant variation with respect to initial soil moisture content, saturated hydraulic conductivity, and presence of storm drains.

LIP PFHA simulations are being performed using a stratified sampling approach. The input precipitation is obtained from the National Oceanic and Atmospheric Administration (NOAA) precipitation frequency data server. Point precipitation frequency estimates for annual maximum precipitation at the site were obtained and extrapolated to an annual exceedance probability of 1×10-6. Storm temporal distributions from NOAA Atlas 14 were used to construct storms of 6, 12, 24, and 96-h durations. The relative frequencies of temporal distribution types (peak intensity in various quartiles) were preserved. The NPP site's spatial distribution of surface roughness (represented by Manning's surface roughness coefficient) were preserved. The epistemic uncertainty in surface roughness was represented by a uniform distribution of multipliers applied to the original spatial distribution.

The model runs for the PFHA simulations are being performed on PNNL's high-performance supercomputer. To this end, the FLO-2D™ software was tested and modified to run under a Microsoft Windows™ emulator on the Linux system. A set of Python scripts are used to sample input parameters, populate input files, perform flood simulations, collect predicted results, and estimate the flood hazard curves. The total probability theorem is applied to estimate the flood hazard curves.

3.4.5.2 Presentation (ADAMS Accession No. ML22061A123)





LIP PFHA for a NPP site

- Task 3: Perform a LIP PFHA for a NPP site
  - Real NPP site selected
  - Characteristics of NPP site used in simulation
    - Buildings, vehicle barrier system, subsurface drainage system
    - Surface characteristics (soil types), surface roughness
  - Scope did not include performing a precipitation frequency analysis
    - Used NOAA Atlas 14 (limited to Annual Exceedance Probability [AEP] of 1×10^{-3} and higher) for precipitation
    - Extrapolated depth-area-duration curves to AEP 1×10^{-6}
  - FLO-2D as the flood simulation software package
    - Implemented on a regular 2-D grid
    - Combined hydrologic and hydraulic model
    - Solves full dynamic wave formulation of 1-D Saint-Venant equations
      - One flow direction at a time
      - Explicit, central finite difference scheme

PFHA

- AEP for a flood hazard

$$P(\boldsymbol{Z} > \boldsymbol{z}) = 1 - P(\boldsymbol{Z} \le \boldsymbol{z}) = 1 - F(\boldsymbol{z}) = \int_{z}^{\infty} f(\boldsymbol{u})d\boldsymbol{u}$$

$\boldsymbol{Z}$: A flood hazard

$\boldsymbol{z}$: A particular magnitude of the flood hazard

$F(\boldsymbol{z})$: The cumulative distribution function for the flood hazard

$$\boldsymbol{Z} = T[G(\boldsymbol{I}, \boldsymbol{\Theta}, \boldsymbol{\Phi})]$$

$\boldsymbol{Z}$ = the set of flood hazards,
G = the flood simulation model,
$\boldsymbol{I}$ = the set of hydrometeorologic input variables,
$\boldsymbol{\Theta}$ = the set of the model parameters,
$\boldsymbol{\Phi}$ = the set of initial and boundary conditions, and
T = any further transformations or analyses needed to estimate the flood hazards from the simulated flood parameters.

PFHA (cont.)

- AEP

$$P(Z > z) = \int_{\{I,\Phi,\Theta:\, T[G(I,\Phi,\Theta)]>z\}} \underbrace{f(I,\Phi,\Theta)}_{\text{Joint PDF of } (I,\Phi,\Theta)}\, dI\, d\Phi\, d\Theta$$

Joint PDF of (I, Φ, Θ)

multi-dimensional integration is taken over this set of (I, Φ, Θ)

- Numerical integration for $P(Z > z)$

$$\hat{P}(z) = \frac{1}{N}\sum_{i=1}^{N} H(z_i - z)$$

$H(z_i - z) = 1$ for $z_i = T[G(I_i, \Phi_i, \Theta_i)] > z$, and $H(z_i - z) = 0$ otherwise

February 10, 2022

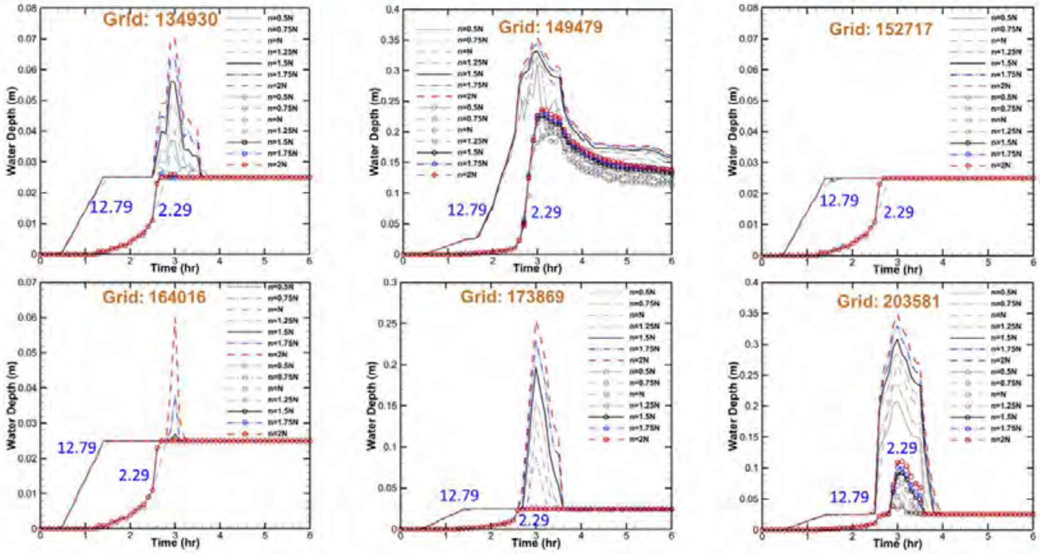
PFHA – Dimensionality and Sensitivity Runs

- Sample from joint PDF of (I, Φ, Θ)
- I: input
  - precipitation (for LIP, primarily rainfall)
- Φ: initial and boundary conditions
  - initial soil moisture content
- Θ: model parameters
  - Manning's roughness coefficient, saturated hydraulic conductivity
- Site configuration
  - Subsurface storm drains

February 10, 2022

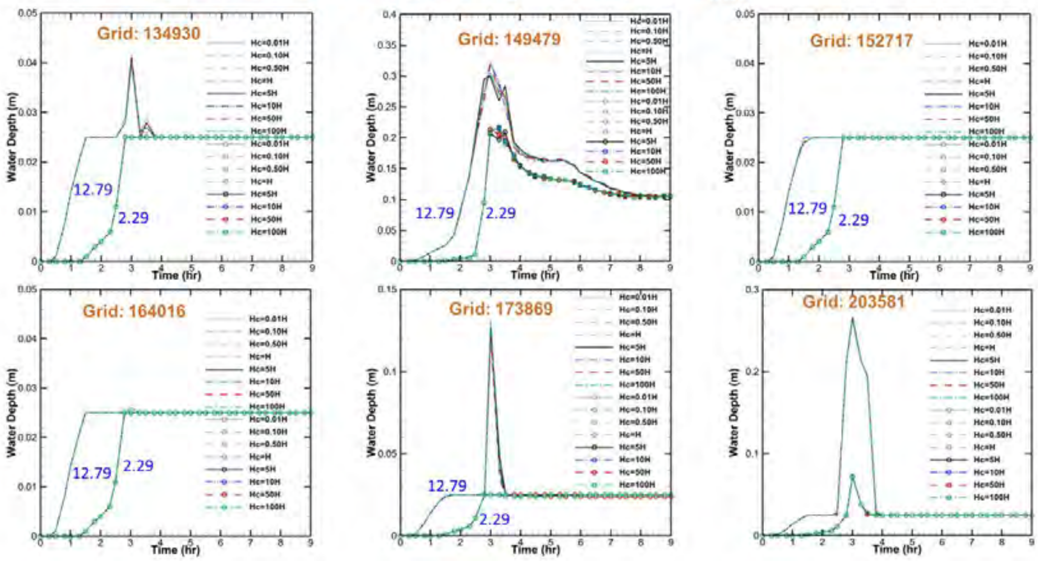
Pacific Northwest NATIONAL LABORATORY

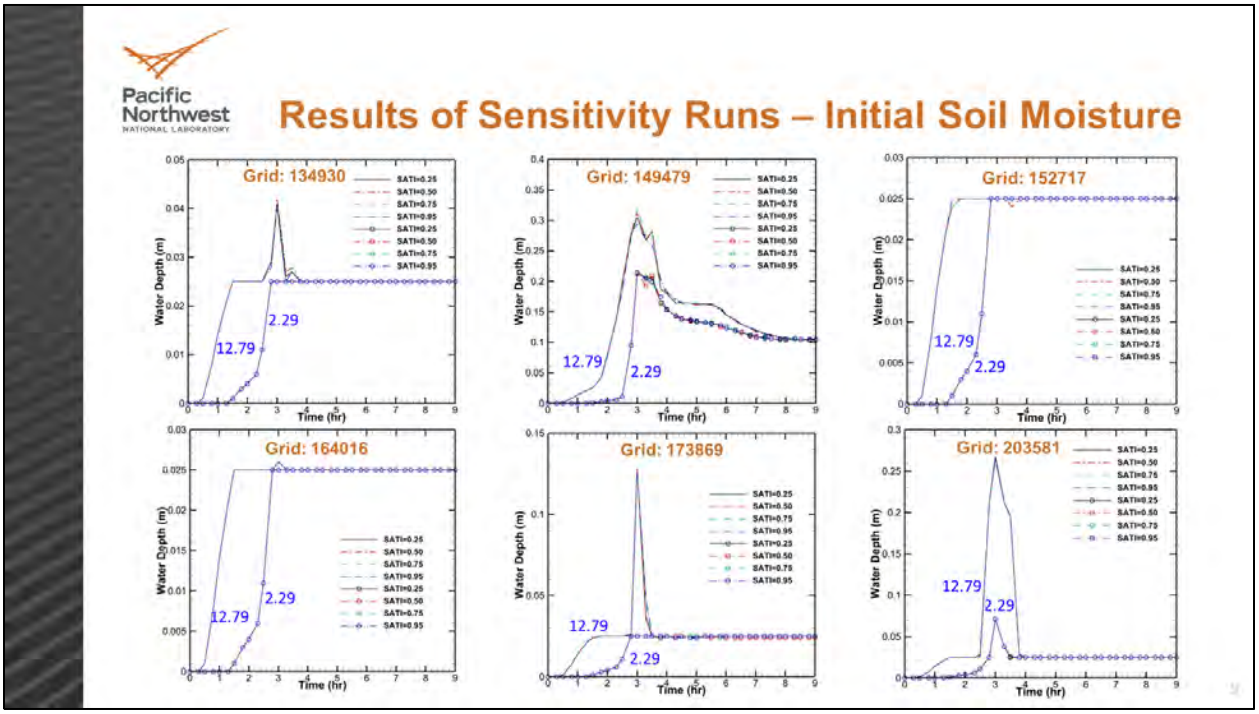
Results of Sensitivity Runs – Manning's n

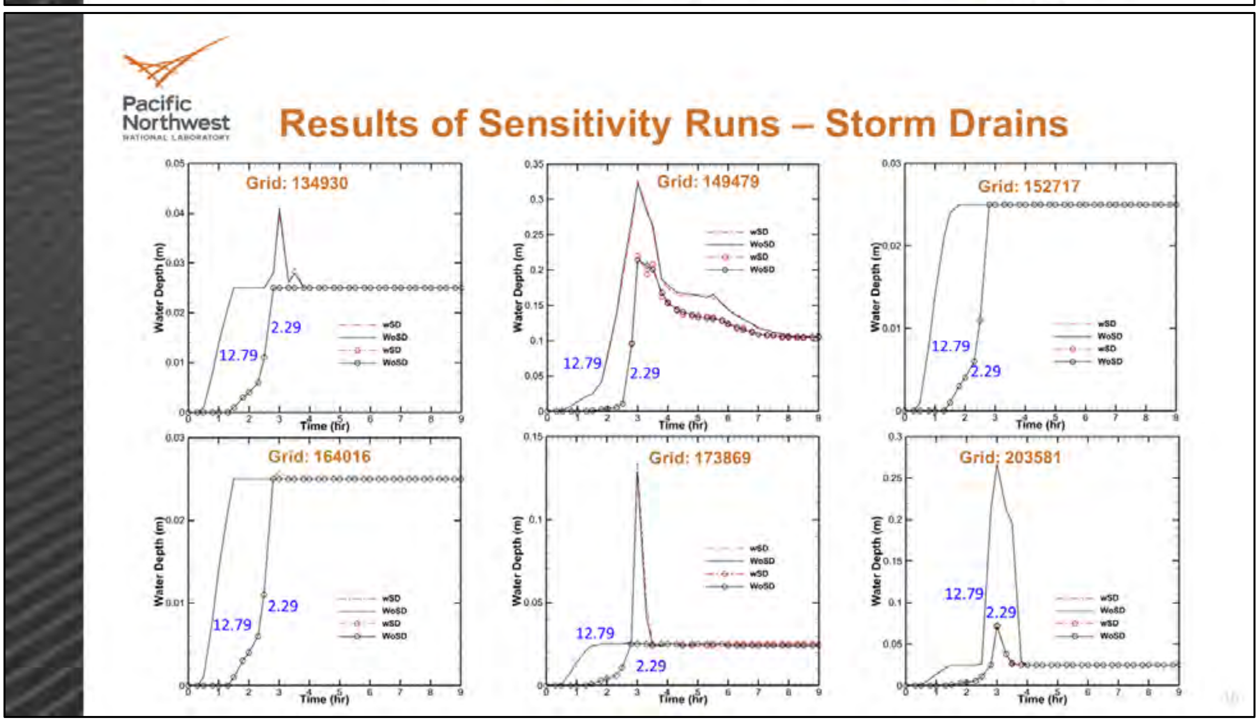


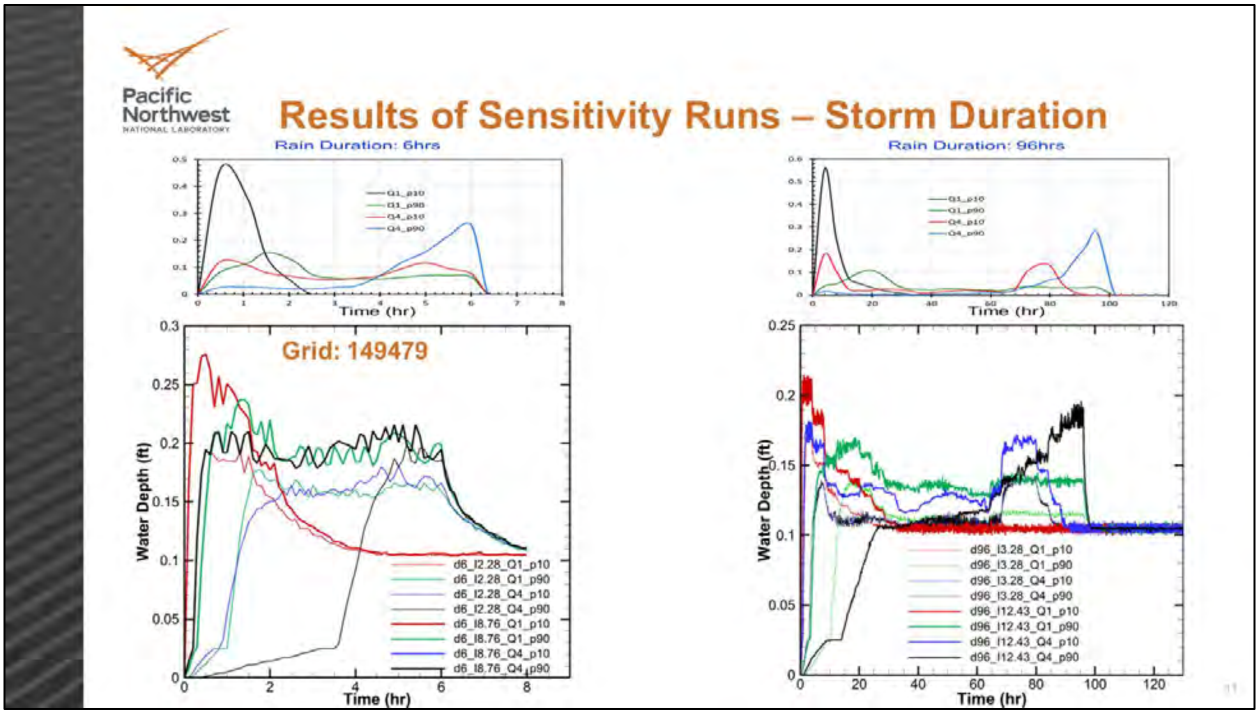
Pacific Northwest NATIONAL LABORATORY

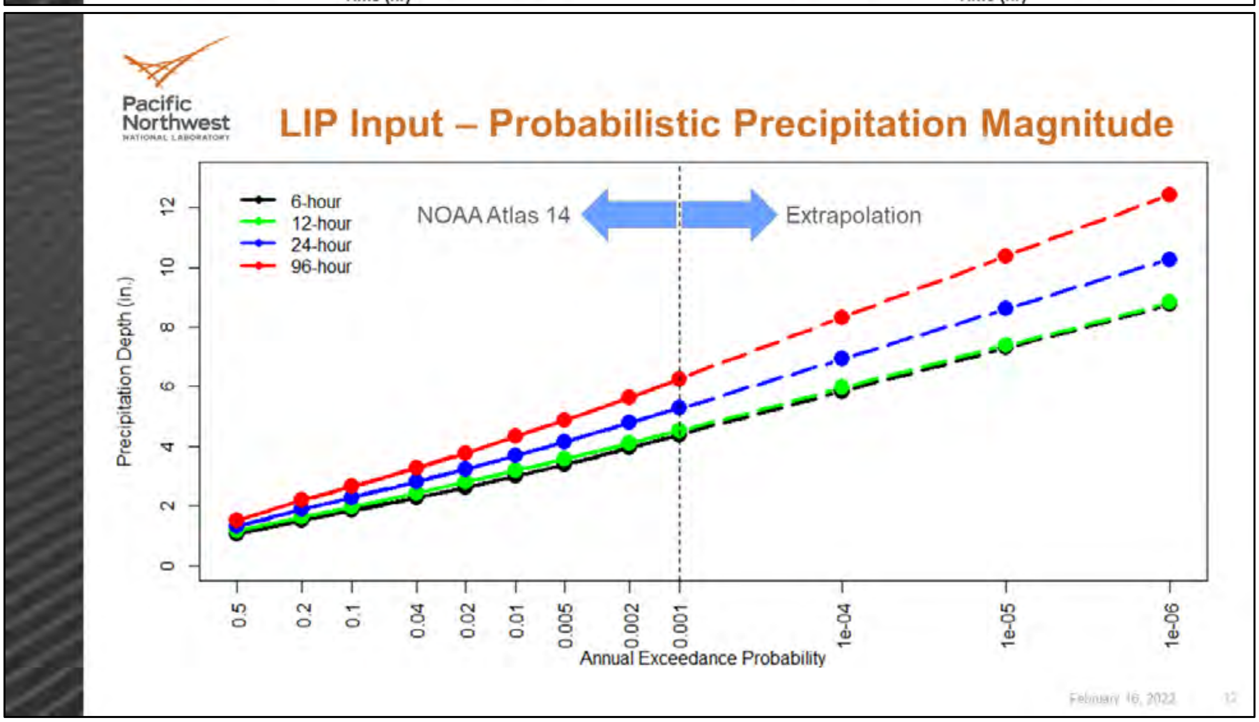
Results of Sensitivity Runs – K_{sat}




Pacific Northwest
NATIONAL LABORATORY
Results of Sensitivity Runs – Initial Soil Moisture
Grid: 134930
Grid: 149479
Grid: 152717
Grid: 164016
Grid: 173869
Grid: 203581
SATI=0.25
SATI=0.50
SATI=0.75
SATI=0.95
12.79
2.29
Water Depth (m)
Time (hr)

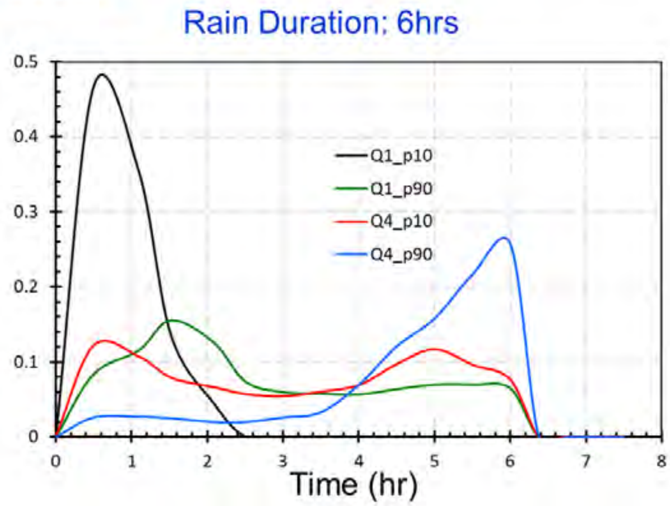

Pacific Northwest
NATIONAL LABORATORY
Results of Sensitivity Runs – Storm Drains
Grid: 134930
Grid: 149479
Grid: 152717
Grid: 164016
Grid: 173869
Grid: 203581
wSD
WoSD
12.79
2.29
Water Depth (m)
Time (hr)


Pacific Northwest NATIONAL LABORATORY
Results of Sensitivity Runs – Storm Duration
Rain Duration: 6hrs
Time (hr)
Rain Duration: 96hrs
Time (hr)
Grid: 149479
Water Depth (ft)
Time (hr)
d6_I2.28_Q1_p10
d6_I2.28_Q1_p90
d6_I2.28_Q4_p10
d6_I2.28_Q4_p90
d6_I8.76_Q1_p10
d6_I8.76_Q1_p90
d6_I8.76_Q4_p10
d6_I8.76_Q4_p90
Water Depth (ft)
Time (hr)
d96_I3.28_Q1_p10
d96_I3.28_Q1_p90
d96_I3.28_Q4_p10
d96_I3.28_Q4_p90
d96_I12.43_Q1_p10
d96_I12.43_Q1_p90
d96_I12.43_Q4_p10
d96_I12.43_Q4_p90


Pacific Northwest NATIONAL LABORATORY
LIP Input – Probabilistic Precipitation Magnitude
6-hour
12-hour
24-hour
96-hour
NOAA Atlas 14
Extrapolation
Precipitation Depth (in.)
Annual Exceedance Probability
February 16, 2022
12

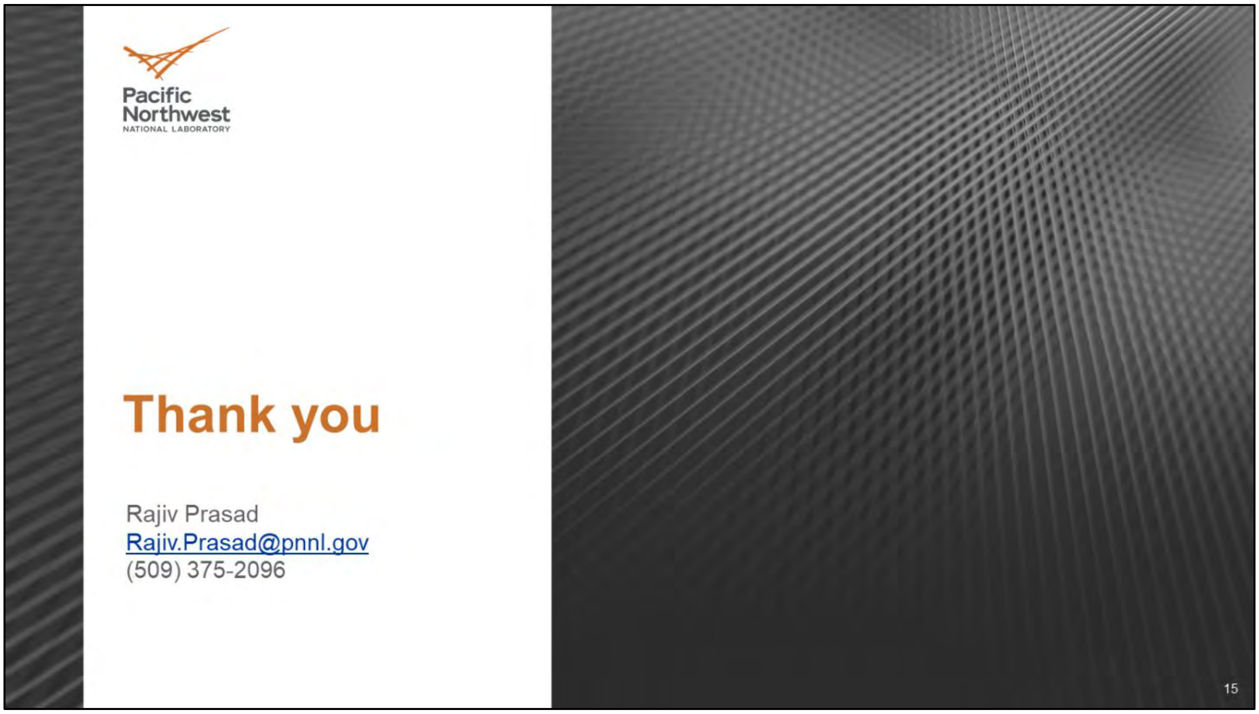
LIP Input – Probabilistic Storm Duration and Temporal Distribution

Duration	Percentage			
	First Quartile	Second Quartile	Third Quartile	Fourth Quartile
6 hr	52	23	16	9
12 hr	51	22	17	10
24 hr	50	19	17	14
96 hr	53	19	14	14



Next Steps

- Python coding
  - Sampling
    - Aleatory: precipitation magnitude, duration, and storm temporal distribution
    - Epistemic: Manning's n
  - Preparing input files
  - Simulation management
  - Numerical integration to estimate hazard curves
    - Flood depth/water surface elevation, flood duration, flood velocity
- Reporting
  - NUREG/CR describing LIP PFHA
  - Webinar – tech transfer
- Archiving
  - All simulations saved


Pacific
Northwest
NATIONAL LABORATORY
Thank you
Rajiv Prasad
Rajiv.Prasad@pnnl.gov
(509) 375-2096
15

3.4.6 Precipitation Panel Discussion (Session 2A-6)

Moderator: Kevin Quinlan, NRC/NRR
Azin Al Kajbaf, *University of Maryland*
Peter Thornton, *Oak Ridge National Laboratory*
Giuseppe Mascaro, *Arizona State University*
Joshua Welty, *U.S. Navy Fleet Numerical Meteorology and Oceanography Center*
Rajiv Prasad, *Pacific Northwest National Laboratory (PNNL)*

Question:

To what degree is the QA/QC of different data sources evaluated and accounted for in Daymet?

Peter Thornton:

For the temperature station observations, we go through a preliminary round of cross validation analysis. We have found that if a station has some questionable quality issues, it tends to stick out as an anomaly in that cross validation approach. So, we have set a pretty generous threshold and we will throw out a station if it exceeds mean absolute error or bias issues in that preliminary cross validation. That ends up being a small fraction of stations that get rejected that way, like less than 1%. We'd like to do something similar for precipitation, but there's so much variability and the daily mean absolute error rates are pretty high for individual precipitation events, which I think anybody familiar with this business is going to understand. So it's been hard to define what those statistics might look like. If you look in our paper, I showed this map of the precipitation mean absolute error as a Thiessen Polygon sort of approach for each station. There are stations even in the heavily instrumented regions in the US that stick out as having particularly high mean absolute error. We have not yet tried to go in and identify those stations and their particular problems. I'm sure that there are some quality issues with individual stations that, NCEI, hasn't found yet that we might be able to identify that way. We haven't gone through that level of analysis yet. We do summarize our statistics by network and so we can see, on average, whether the different networks are providing absolute errors that are higher or lower. That's complicated for precipitation as well, because snow observations are just inherently more uncertain.

Question:

How does the Daymet interpolation method for precipitation relate to PRISM?

Peter Thornton:

The Daymet and PRISM methods have both in the literature and in use widely in the community for a long time. They're fundamentally different, and I think there's real value in having both of those methods out there and in use. The PRISM stands for precipitation regressions on independent slopes, and they tend to have an a priori clustering of the observations on topographic facets. They get some real value out of doing that. We, on the other hand, have this Gaussian kernel filtered approach that includes the X-,Y-, and Z-dimension for the 3D regression that gives us a similar kind of answer. A lot of different analysis have shown that there's a lot of similarity between the two approaches. But there are definitely places with extreme precipitation gradients, in particular along the crest of the Cascades, where PRISM is doing a better job. And there are other places where various analyses have shown that the

Daymet approach is doing better. So, it is kind of a mixed bag there. But I think there is real value in having both approaches out in the community.

Question:

Joshua, for the extreme snow melt was a theoretical maximum melt determined? It would be very interesting to see how close some of those maximum SWE reductions are to a maximum limit.

Joshua Welty:

The simple answer is no, we didn't. I have relatively strong confidence that anywhere approaching the theoretical maximum limit is probably somewhere in the Cascades. If you look at the simple maps we made, a lot of the largest delta SWE magnitudes were generally in the Pacific Northwest, maybe Cascades. That would be the place to start. But no, we didn't identify theoretical maximum limit based on our observational study. But I appreciate the question, that would be really interesting to look at.

Question:

Rajiv, was there any consideration for separating the precipitation aleatory and epistemic uncertainty in the model?

Rajiv Prasad:

A short answer is no. We are only looking at NOAA Atlas 14, for better or worse, for now. But there are epistemic uncertainties related to precipitation. NOAA Atlas 14 basically looks at model parameter estimation errors only. You could extend that in a more comprehensive precipitation frequency analysis that looks at alternative models. For example, you could include alternative statistical distributions that fit extreme precipitation data and then try to look at those in collection as part of the epistemic uncertainty. You could bring that in. Because we are limiting the analysis scope to just the flood at the moment, we did not look at that.

Question:

Regarding precipitation estimates to drive flood hazard assessment modeling, there are several choices: (1) statistical analysis of historical information; (2) mechanistic synthetic approaches such as numerical weather prediction or climate models; and (3) statistical synthetic approaches such as point or multipoint weather generators. What are the strengths and weaknesses of each approach?

Rajiv Prasad:

The way we approach it right now, at least in this project, is to look at NOAA Atlas 14, extrapolated. That is not really satisfactory because NOAA Atlas 14 pretty explicitly says do not do that. Another thing with historical information is that we are, at least in the U.S., limited by record lengths. You can get around that by doing regionalized analysis. The question becomes do we rely on a regional analysis? And how do we translate that back to, at least in the case that we are doing, really, local scale modeling? Are we losing anything in that sense? If we do regionalization, do we lose local features? And how much confidence do we have in those approaches? Synthetic approaches, in terms of weather generators and things like those are becoming more popular. We did review a few of them in our earlier reports. They could be a good approach to get to some of those things. Until we actually do an intercomparison of all of these data sources, I don't know. Maybe putting together a flood model and then try to evaluate the predictions from each of those for sites or watersheds where all of these [precipitation estimates] are available might be a good way of seeing what the strengths and weaknesses might be.

Azin Al Kajbaf:

I just wanted to add that with the historical information there are a lot of challenges. In my work there were a lot of missing data. I think each of the things that you have mentioned have their own weaknesses and challenges to work with. With the historical information there is this uncertainty due to missing data or uncertainty that can come from other sources such as the problems with recordings and things like that. Also, the synthetic models are associated with other sources of uncertainty because they are simplifications of natural processes. So, my opinion is that there are strengths and weaknesses to each one and it should be looked at comprehensively to decide in what situation which one is better to work with based on the limitations that we have.

Question:

What is the latency of the Daymet data? How quickly after the valid date/time is it available? Are the different versions made clear?

Peter Thornton:

Historically we've done this annually and it's taken a few months after the end of the year to get it updated. We've recently moved to a monthly experimental low latency data product which is bringing in updates from NCEI GHCNd dataset monthly and turning that around within, usually, a week of the end of the month. A good question about the marking of those changes in the data set. I might get the details here slightly wrong, but typically, we're storing each of those monthly updates so you can go back and see individual months and then at the end of the year we do a complete reprocessing of the entire year and do an update that would be marked as an extension of the main annual time series data set. So yes, in short, you can track that but there's certainly a lot more iterations with those monthly latency updates.

Question:

Joshua, could one take a climate model or an ensemble of models and using your methods develop future SWE maps? And what would be one of the major challenges to do this?

Joshua Welty:

Presumably, yes. Our approach is flexible, so as long as you have a large enough set of inputs, on the order of maybe 1000+ maps, to train the model this is conceivably an option. I think another benefit of the approach is obviously with self-organizing maps. There's some flexibility in that you can try different number of inputs, different neighborhood functions. You can use 500-millibar heights or 500-millibar height anomalies. So, I think the simple answer to the question is yes. I think the main challenge would be how accurate is the model or suite of models you choose. But I think to answer the question is, conceivably, yes. It's a relatively flexible approach, so that would be the hope.

Question:

Rajiv, there was a question that came in during your presentation about Manning's coefficient and has there been any thought to how that may change with the flood depth, and how that may impact your results?

Rajiv Prasad:

The short answer, when you think about it mechanistically and hydraulically, is yes it can. There are ways in which FLO-2D actually deals with it. They have some empirical ways of adjusting Manning's n when that happens, but I would really like to have a better theoretical understanding of it. The other thing that I haven't seen done, particularly at these local scales industrial Sites, is that you can have the water surface butt up against building walls, etc. So the wetted area as well as the friction on the walls might change, depending on where you are getting inundation. So yes, I think that can be something that we should think about. Surface roughness in this case really applies to all surfaces that the water touches. How do we deal with it? For now, the flood models are implemented in terms the momentum equation formulation that uses Manning's n. Could it be better, or at least can we think about calibrating it better? Yes, we could, but the challenge there is where do you get datasets that allow you to come up with some form of either calibration to look at your site or understanding theoretically how some of these resistance to flow changes might happen? So open question, good question. I don't have a great answer for that.

3.5 Day 2: Session 2B – Riverine Flooding

Session Chair: Joseph Kanney, NRC/RES

3.5.1 Presentation 2B-1 (KEYNOTE): Flood Typing and Application to Mixed Population Flood Frequency Analysis: An Interagency Collaborative Effort

Authors: *Nancy Barth*[*1], Michael Bartles[2], John England[2], Jory Hecht[1], Gregory Karlovits[2], William Lehman[2]; [1]U.S. Geological Survey (USGS), [2]U.S. Army Corps of Engineers (USACE)*

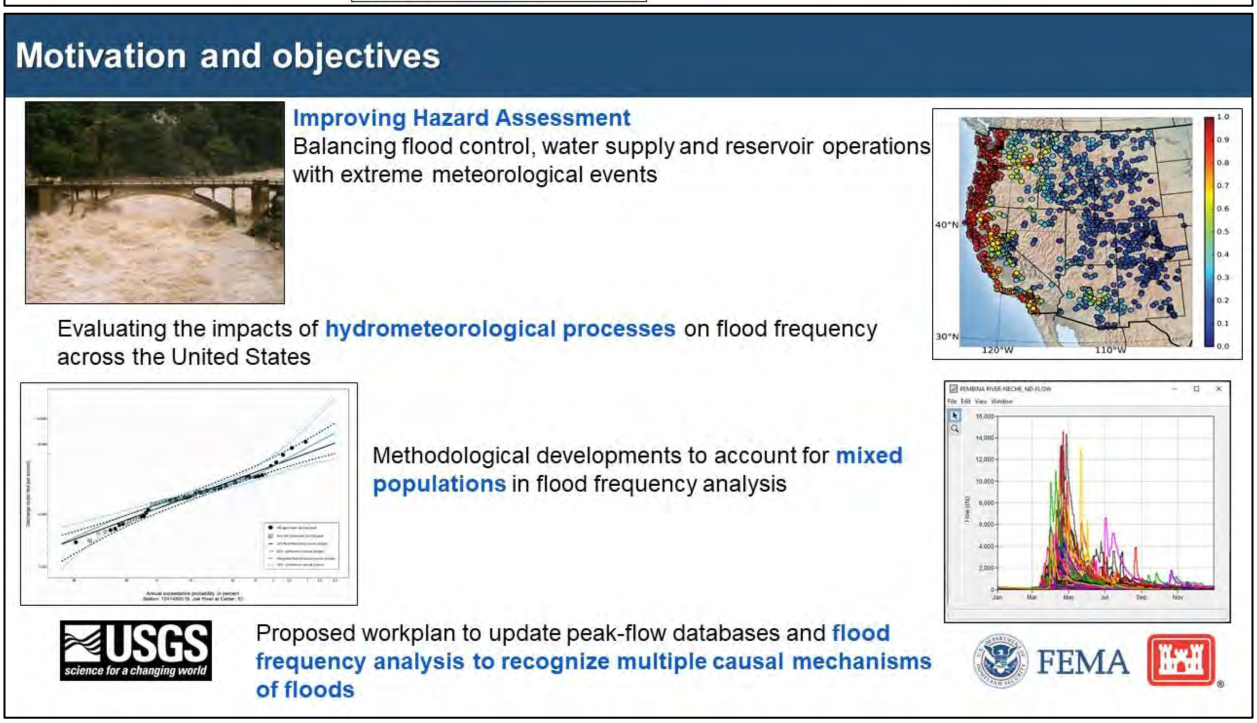
Speaker: *Nancy Barth*

3.5.1.1 Abstract

An improved understanding of the frequency and magnitude of floods is critical for the design of transportation and water-conveyance structures as well as insurance studies and floodplain management. Methods for estimating annual exceedance probabilities (AEPs) (or return intervals) in the United States were recently updated in Bulletin 17C. These methods assume homogeneous flood distributions but acknowledge that floods at a given location can be generated by multiple causal mechanisms, such as snowmelt, intense convective rainfall events, or tropical cyclones, representing a mixed population. Mixed population flood events may not only impact the fit of the flood frequency curve in the range of the observed floods but may also impact the quality of AEP estimates in the upper tail of the flood frequency distribution. The 'Future Studies' section in Bulletin 17C acknowledges shortcomings in the handling of mixed-population

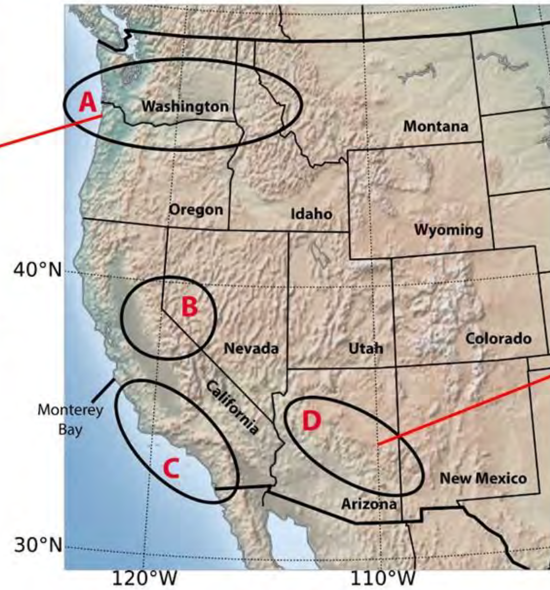
datasets and highlights the need for additional studies before guidance for conducting mixed-population flood frequency analysis can be confidently developed. Classification of individual events by flood generating mechanisms, or flood type classification, might enable a mixed population analysis. The flood type classifications can be defined in terms of both proximal atmospheric causal mechanisms, such as different storm types, as well as antecedent watershed conditions, such as soil moisture storage and snowpack water content. Currently, the largest national database of annual peak flows, the U.S. Geological Survey (USGS) National Water Information System (NWIS) database, contains little information about the flood type classification for each annual peak-flow event. The U.S. Army Corps of Engineers (USACE) and USGS have begun a multi-year collaborative effort to develop methods for efficiently categorizing flood data stored in NWIS by causal mechanisms. In addition, this collaboration includes the design of a database framework for storing peaks-over-threshold (POT) events. This would ensure that all floods taking place in years with multiple large flood events would also be recorded in the database, including information on the mechanisms that generated them. The POT data could be used for mixed population analyses that includes frequency, duration, and volume.

3.5.1.2 Presentation (ADAMS Accession No. ML22061A122)



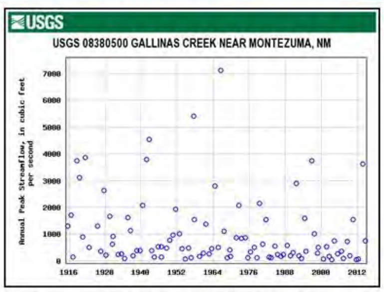
Diverse flood hydrology throughout Western United States

http://exotichikes.com/wp-content/uploads/2014/02/IMG_1449-Large.jpg

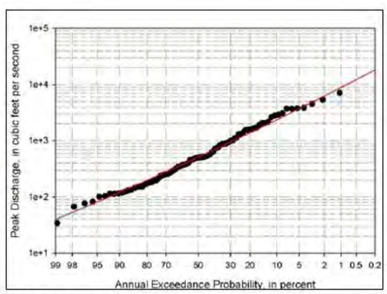


http://verdenews.com/SiteImages/Article/30964a.jpg

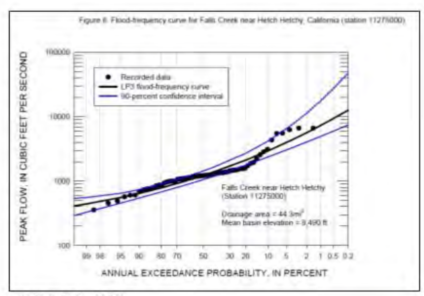
Determining flood frequency at gaged sites—statistical analysis of annual peak discharge



Fit a probability distribution to the sample (recorded) data



Distribution used in the U.S. is the log Pearson Type III (LP3) (described in Bulletin 17B/17C)

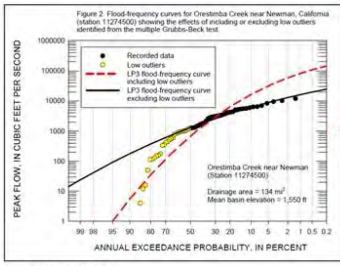


(Parrett et al., 2010)

Mixed population site in California

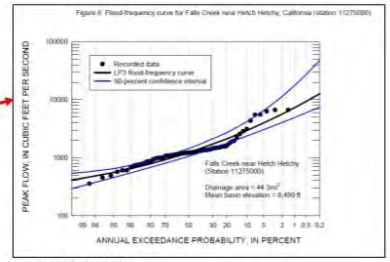
Complicated at-site streamflow data and flood frequency estimates

Mixed Populations:
low flood peaks with influence



(Gotvald et al., 2012)

(Gotvald et al., 2012)



(Parrett et al., 2010)

Mixed Populations:
rain-on-snow flood events

USGS science for a changing world

FEMA

"Future Work" (p.27) Bulletin 17B

1. Selection of distribution and fitting procedures. ✓
2. The identification and treatment of mixed distributions.
3. The treatment of outliers both as to identification and computational procedures. ✓
4. Alternative procedures for treating historic data. ✓
5. More adequate computation procedures for confidence limits to the Pearson III distribution. ✓
6. Procedures to incorporate flood estimates from precipitation into frequency analysis.
7. Guides for defining flood potentials for ungaged watershed and watersheds with limited gaging records.
8. Guides for defining flood potentials for watersheds altered by urbanization and by reservoirs.

(IACWD 1982 B17B)

(England, Jr. et al., 2019)

FEMA

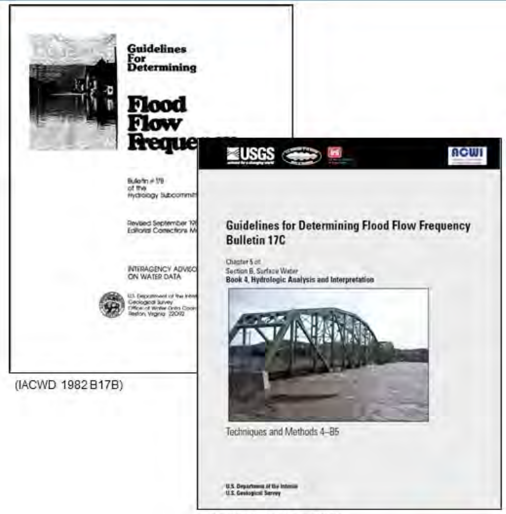
“Future Work” (p.35) Bulletin 17C

1. The identification and treatment of mixed distributions, including those based on hydrometeorological or hydrological conditions;

…

6. Guides for estimating dynamic flood frequency curves that vary with time, incorporating climate indices, changing basin characteristics, and addressing potential nonstationary climate conditions;

…



(IACWD 1982 B17B)

(England, Jr. et al., 2019)

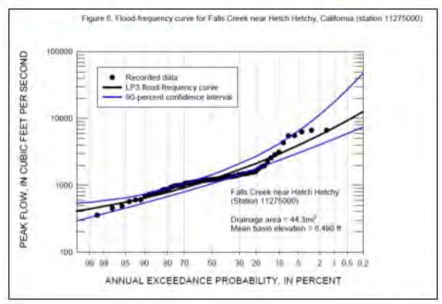
USGS science for a changing world

FEMA

Stochastic hydrology and physical processes

“In some circles, however, the obvious fact that **these [annual peak flow] values represent a response to varying processes in the physical world has tended to become less important than the urge to statistically model flood values** in search of the best fit of the observed data and therefore (ideally) the best predictive capability of future flows…” (Hirschboeck, 1988)

“[T]he main emphasis in stochastic analysis of hydrological processes…has been on the fitting of various preconceived mathematical models to empirical data rather than on arriving at a proper model from the physical nature of the process itself…**Thus what we usually find is not, in fact, statistical hydrology but merely an illustration of statistical and probabilistic concepts by means of hydrologic data**.” (Klemeš, 1974, p.2)



“Major floods occur from at least two independent causes, tropical hurricane storms and extratropical cyclones. Hurricanes are comparatively rare, but produce extreme flows, and therefore cause an upward curvature of the frequency curve of annual maximum flows. **Some improvement in frequency estimates in this region [New England] is attained by segregating hurricane and non-hurricane floods.** However, this apparently does not solve entirely the problem of upward curvature of the frequency curves” (Beard, 1962)

USGS science for a changing world

FEMA

The USACE / USGS / FEMA project proposal staff

U.S. Army Corps of Engineers (USACE)

Mike Bartles
John England, Jr.
Greg Karlovits
Will Lehman

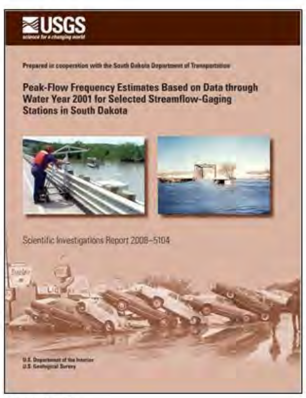
U.S. Geological Survey (USGS)

Nancy Barth
Jory Hecht
Amy McHugh

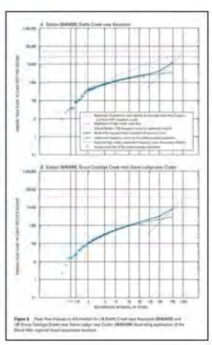
Federal Emergency Management Agency (FEMA)

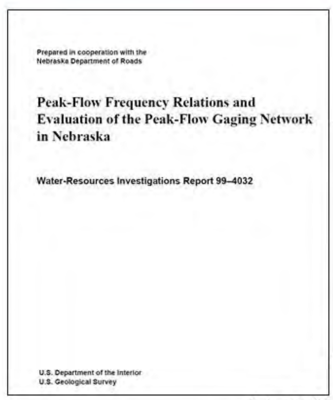
David Bascom
Christina Lindemer
David Rosa

Current and previous studies with potential mixed populations



(Sando et al., 2008)



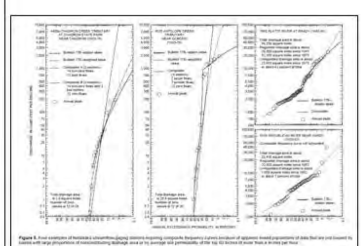

Prepared in cooperation with the
Nebraska Department of Roads

Peak-Flow Frequency Relations and Evaluation of the Peak-Flow Gaging Network in Nebraska

Water-Resources Investigations Report 99–4032

U.S. Department of the Interior
U.S. Geological Survey

(Soenksen et al., 1999)



Recent USACE mixed population applications

Portland District

- *Tides, storm surges, multiple runoff mechanisms*
- Lower Columbia River

St. Paul District

- *Wet/dry cycles, multiple runoff mechanisms*
- Red River at Fargo, ND
- Upper Mississippi River (ongoing)
- Mississippi River / Minnesota River confluence (ongoing)

Omaha District

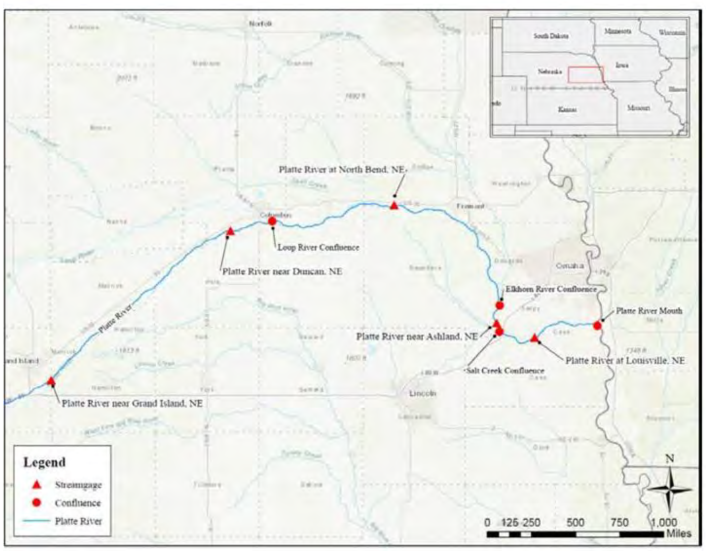
- *Ice jams, multiple runoff mechanisms*
- **Lower Platte River**
- Elkhorn River (ongoing)
- Williston Levee
- Garrison Dam
- Oahe Dam (ongoing)

Philadelphia District

- *Ice jams, tropical storms, rain-on-snow, rainfall-only*
- Lehigh River

USGS science for a changing world — FEMA

Lower Platte River, Nebraska



USGS science for a changing world — FEMA

Lower Platte River, Nebraska: Separating peaks by causal mechanism

Peak caused by rainfall

Accumulated Freezing Degree Days (AFDD)

SWE & Precipitation

Flow

Peak caused by snowmelt

AFDD

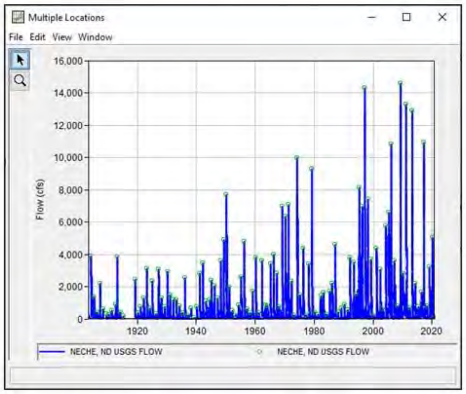
Flow

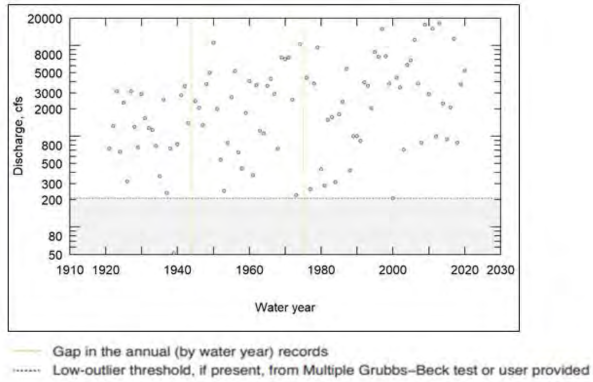
This step can take a lot of time.
We need to make improvements.

USACE mixed population analysis steps

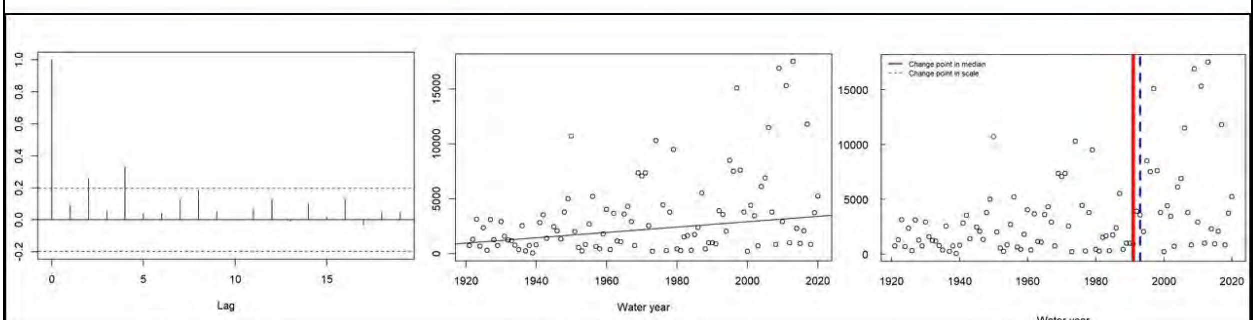
- Engineer Manual 1110-2-1415
- Visualize data
- Identify flood causal mechanisms, different populations, changes in trends, wet/dry periods, etc.
- Extract individual and identically distributed (iid) samples (usually annual maximum series)
- Fit distributions to each sample
- Combine using Probability of Union

Data visualization: Pembina River at Neche, North Dakota





Data visualization: Bulletin 17C analysis--testing stationary assumptions (Pembina River at Neche, North Dakota)



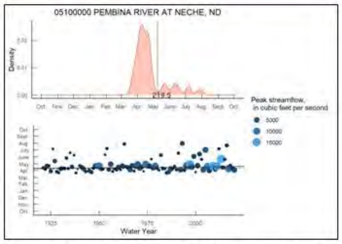
Autocorrelation
AKA
- Serial correlation
- Persistence
- Memory
- Hurst phenomenon

Monotonic trends
AKA
- Gradual trends
- Nonparametric trends

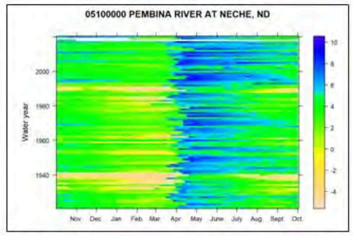
Change points
AKA
- Step trends
  - Median: 1991
  - Scale: 1993

(Preliminary results, USGS from the Transportation Pooled Fund Program)

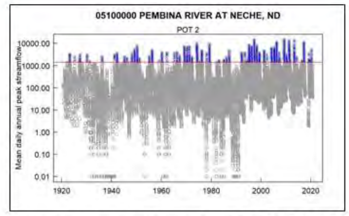
Data visualization: Evaluating potential causal mechanisms of annual peak flow, maxima and peaks-over-threshold



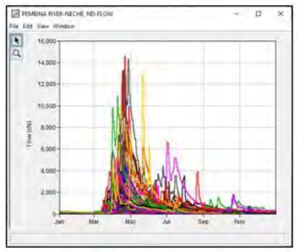
Annual peak-flow timing analysis



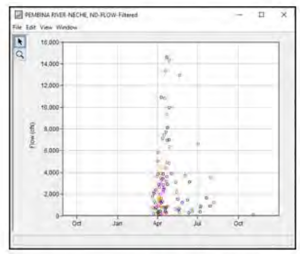
Raster-seasonality analysis



Peaks-over-threshold 2 (POT 2)



Daily average flow



Annual maximum daily average flow

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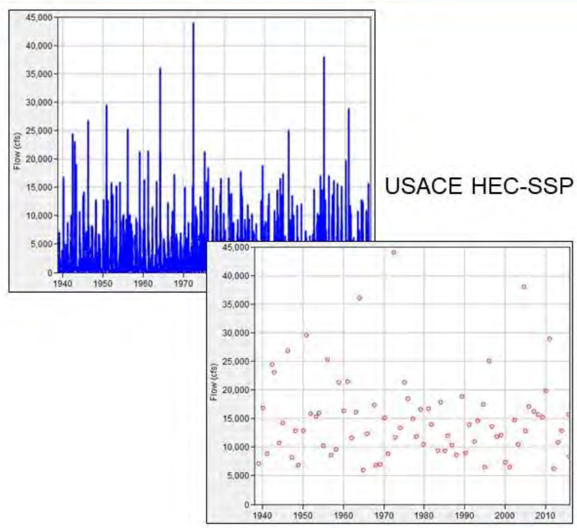
Data filtering to recognize multiple causal mechanisms

Filter data using:

- Time window
- Season
- Min/max threshold
- Duration
- Annual maxima
- POT
- Starting pool stage/elevation



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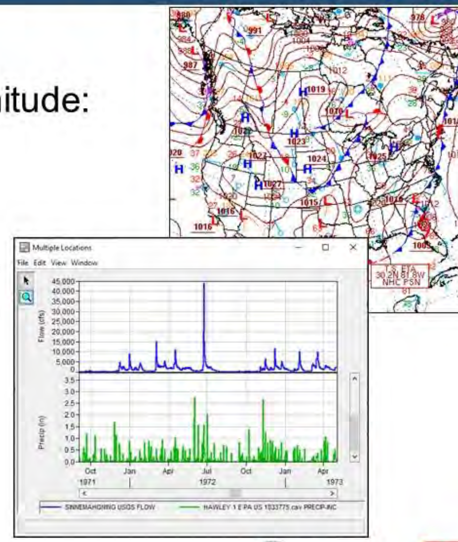
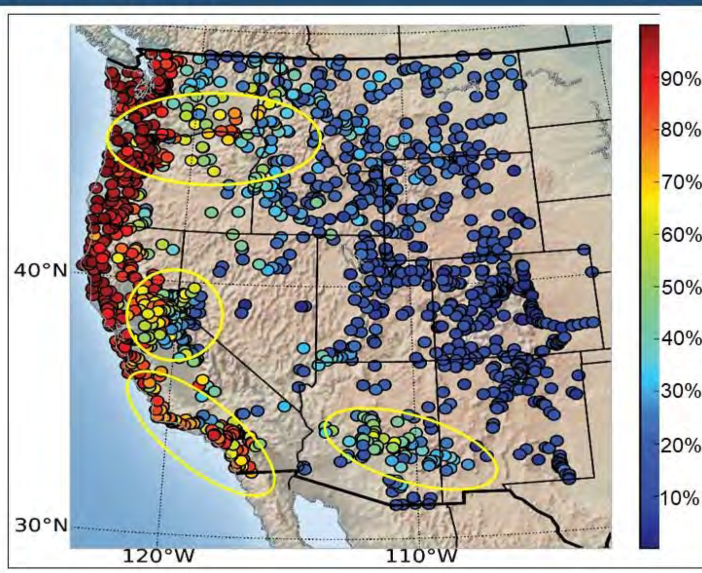
Data filtering enhancements to recognize multiple causal mechanisms

Improve the creation of iid samples

- Use more than just calendar date or magnitude:
  - pressure at one or more altitude,
  - integrated vapor transport (IVT),
  - precipitation (over a duration),
  - temperature,
  - antecedent soil moisture,
  - accumulated freezing degree days,
  - change in SWE, etc.



Example of separating annual peak flows based on causal mechanism in the Western United States

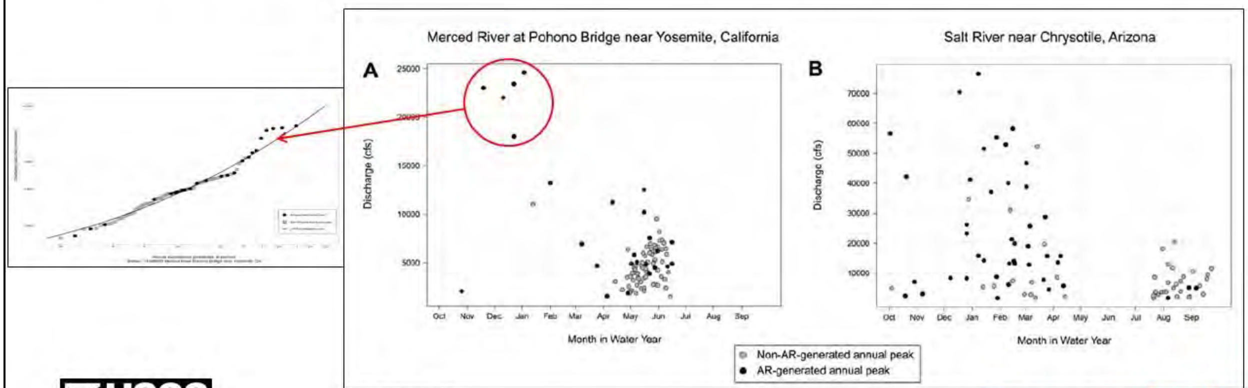


Four smaller regions with a mixture of ~30-70% atmospheric river (AR) and non-AR-generated flood peaks

(Barth et al., 2017)

Methodological developments to account for mixed populations in flood frequency analysis

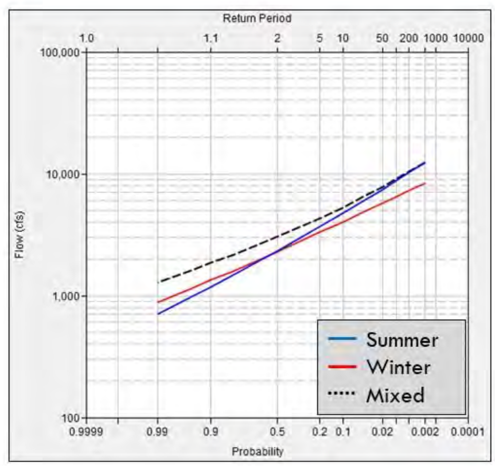
- How do we perform flood frequency analysis by accounting for different flood generating mechanisms?
- What are the improvements in terms of quantile estimates obtained by accounting for mixed populations?



(Barth et al., 2017)

Mixed population analysis

- Combine multiple frequency curves using Probability of Union concept
- $P_{combined} = P_1 + P_2 - (P_1 \; x \; P_2)$
- Results in a frequency curve that correctly reflects the occurrence of more than one type of flood per year



Mixed population analysis: Additional enhancements

- **Compute uncertainty for mixed population curves**
  - (Current) Order stats
  - Probability of Union for input analytical distribution uncertainty
  - Stochastic generation
  - Mixture model
- **Convert from 1-day duration to instantaneous peak**
  - Most continuous, long-term records are daily average flow
  - Need instantaneous peak for most applications

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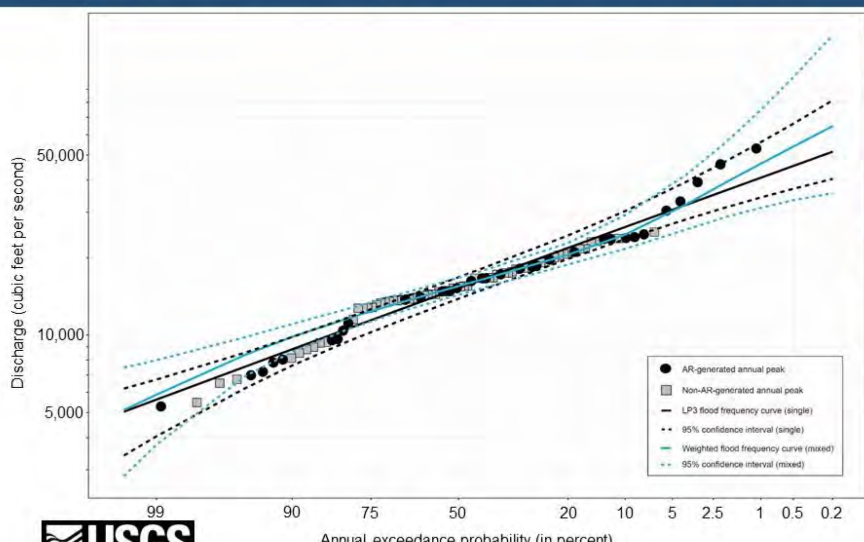
Mixed population analysis can better fit the observations



Station: 12414500
St. Joe River in Calder, ID

Population	Record Length	At-site skew	No. PILF
Single	90	-0.02	0
AR	34	+0.04	0
NonAR	56	-0.25	9

*Potentially influential low floods (PILF)

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Updating peak-flow databases to recognize multiple causal mechanisms of floods from a storm-typing approach

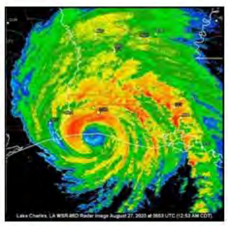
Identification of Storm Type (North America)

Squall Line (MEC)

LS

- Scale
- Seasonality
- Source of moisture
- Nature of uplift
- Location

- Local Storm (LS)
- Mesoscale Storm with Embedded Convection (MEC)
- Tropical Storm and Remnants (TSR)
- Mid-Latitude Cyclone (MLC)



Hurricane (TSR)

MLC

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Updating peak-flow databases to recognize multiple causal mechanisms of floods from a storm-typing approach

Property	LS	MEC	TSR	MLC
Duration	2 hours	6 hours	48 hours	48 hours
Scale	Mesoscale	Mesoscale	Synoptic	Synoptic
Extent	10^1-10^2 km^2	10^2-10^3 km^2	10^3-10^5 km^2	10^3-10^5 km^2
Season	All year	Spring-Summer-Fall	Summer-Fall	Winter-Spring
Uplift/Moisture Source	Convection	Orographic or Convection	Convection/ Tropical	Frontal/Non-Tropical
General Location	Anywhere	Mid-Continent	Below 30°N	30°-60°N

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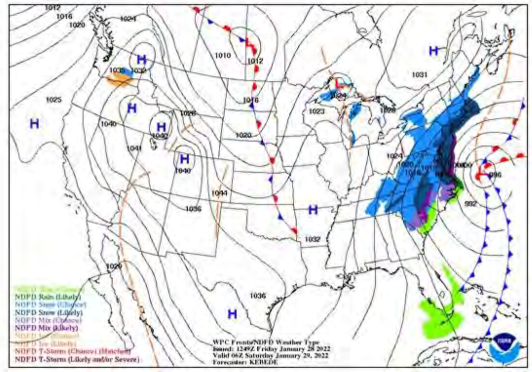
Data-driven identification for storm typing

- Surface analysis/maps
  - Helpful when analyzing a storm type
  - Maps are not as straightforward to interpret by an algorithm
- Gridded precipitation
  - Useful for identifying spatial extent of storm and duration
  - Often first step to identify a storm event
- Reanalysis products
  - Provides information on wind fields, convective activity levels, gradient of pressure fields, etc.
- Track data (IBTrACS)
  - Archive of historical storms tracks primarily for identifying TSRs



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The USACE / USGS / FEMA project proposal staff

Proposed Workplan

Updating peak-flow databases and flood frequency analysis procedures to recognize multiple causal mechanisms of floods

Mike Bartles
John England, Jr.
Greg Karlovits
Will Lehman

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Nancy Barth
Jory Hecht
Amy McHugh

FEMA

David Bascom
Christina Lindemer
David Rosa

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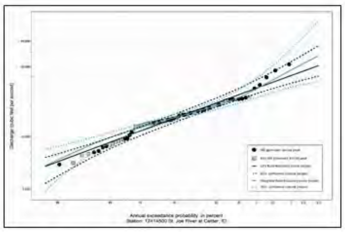
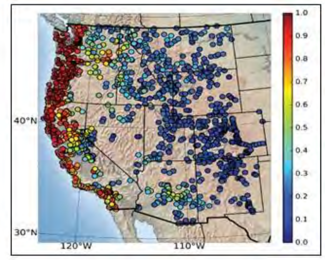
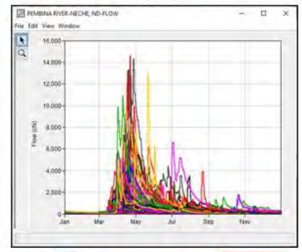
FEMA

Questions?





Thank you
(nabarth@usgs.gov)



3.5.2 Presentation 2B-2: Applying Stochastic Weather Generation and Continuous Hydrologic Simulation for Probabilistic Flood Hazard Assessments

Authors: *Joe Bellini*[1], Bill Kappel[2], Dennis Johnson[2], Doug Hultstrand[2]; [1]Aterra Solutions, [2]Applied Weather Associates*

Speaker: Joe Bellini

3.5.2.1 Abstract

Applied Weather Associates teamed with Aterra Solutions to complete a stochastic weather modeling study to provide long term meteorological realization for hydrologic modeling, flood frequency analysis, and flood recurrence interval analyses. This utilized a multisite stochastic modeling approach using daily observations of precipitation, temperatures, and snow water equivalent (SWE) from 49 sites in the upper Midwest through the Multi-site Auto-regressive Weather GENerator (RMAWGEN)) framework. Stochastic weather generators are statistical models that simulate realistic or plausible random sequences of atmospheric variables. Resulting sequences provide meteorological realizations that can be used for risk evaluations and reliability assessments for various systems such as dams and nuclear generating facilities. Observed precipitation and temperature records were used to calibrate RMAWGEN for the 1949–2019 period. Validation was performed on the calibration period data. Results demonstrate that the model was able to capture spatiotemporal characteristics of observed precipitation and temperature. The model generated 12 iterations of 1,000-years of daily weather sequences of precipitation, temperatures, and SWE. Climate change projections were applied using RCP 4.5 and 8.5 to generate 12 iterations of 1,000-years of future sequences of precipitation, temperatures, and SWE. Weather outputs were used in a continuous simulation hydrologic model built using HEC-HMS. This was calibrated against 3 different years of daily flow data at locations throughout an 88,000 mi2 basin. Normal, wet, and dry years were used for calibration. The final calibrated model was used to simulate runoff for each 12x1000-year simulations, including the three climate change projections. Uncertainty analyses, using a Monte-Carlo framework within HMS, bracketed potential outflow possibilities based on variability in hydrologic inputs identified in the calibration phase. Annual maximum flows were used to characterize probabilistic flood hazards (to as low as a 10-6 annual exceedance probability), considering a wide range of event parameters such as snow accumulation, spring melt patterns, and rainfall. Results will be used in safety assessments and seasonal flood operation planning.

3.5.2.2 Presentation (ADAMS Accession No. ML22061A121)

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Applying Stochastic Weather Generation and Continuous Hydrologic Simulation for Critical Infrastructure Design

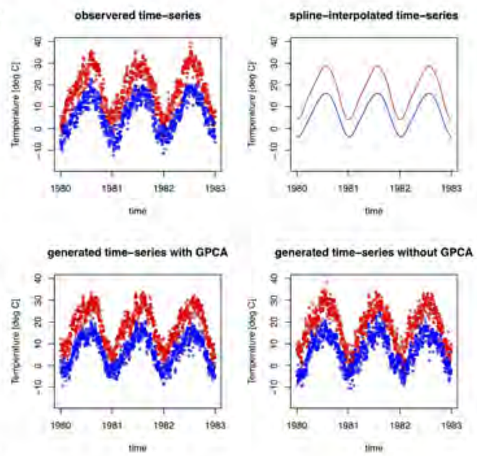
Joe Bellini, PE, PH, D.WRE, Vice President/Principal Engineer, Aterra Solutions
Dennis Johnson, PhD, Senior Hydrologist, Aterra Solutions
Doug Hultstrand, PhD, Senior Hydrometeorologist, AWA
Bill Kappel, President/Chief Meteorologist, AWA

Background

- Purpose: Conduct a PFHA to characterize annual exceedance probabilities for a broad spectrum (to very low)
- Location: Site along the Upper Mississippi River
- Approach:
  - Stochastic weather modeling using daily observations of precipitation, min/max temperatures, snow-water equivalent, and two climate-change projections
  - Continuous hydrologic modeling for 12-1,000-year traces (seamed together) for 3 climate scenarios
  - Monte Carlo simulations performed to quantify uncertainty in hydrologic inputs
  - Other uncertainty factors considered

Stochastic Weather Generator

- A weather generator produces meteorological time series with the same statistical patterns of the observed
- Attempt to reproduce the spatial and temporal dynamics and correlation structures of the variables of interest
- Simulate realistic or plausible random sequences of atmospheric variables such as temperature, rainfall, wind speed, snow
- Synthetic sequences provide a set of alternate realizations that can be used for risk and reliability assessment

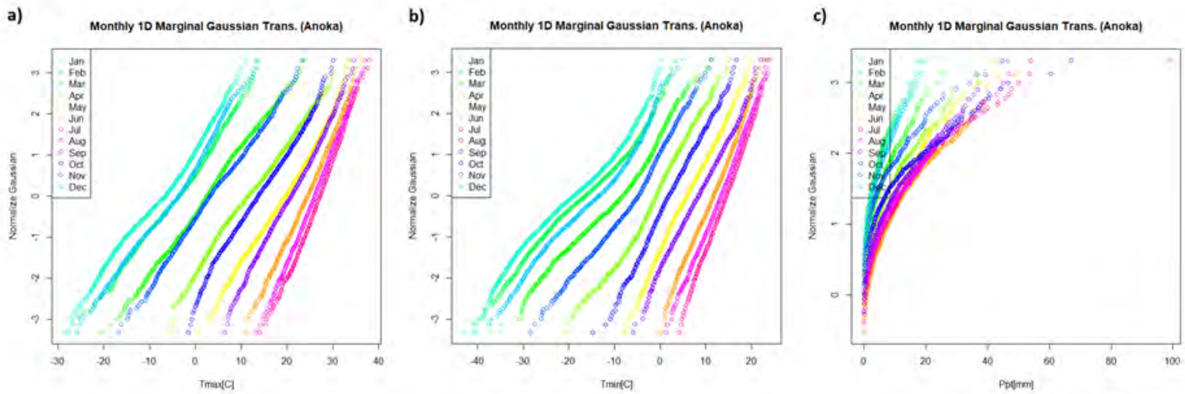


Stochastic Weather Model-RMAWGEN

- RMAWGEN because it can maintain temporal and spatial correlations among stations
- 49 locations selected to calibrate the model
  - Daily precipitation generated for the reference period 1949-2019
- Coupled with monthly mean weather variables to generate stochastic daily scenarios
- Account for seasonally changing weather variables, monthly or season time frame
- Calibrated model simulated twelve 1000-years of daily precipitation, maximum temperature, and minimum temperature
- Daily time series data used as input into SnowMelt model

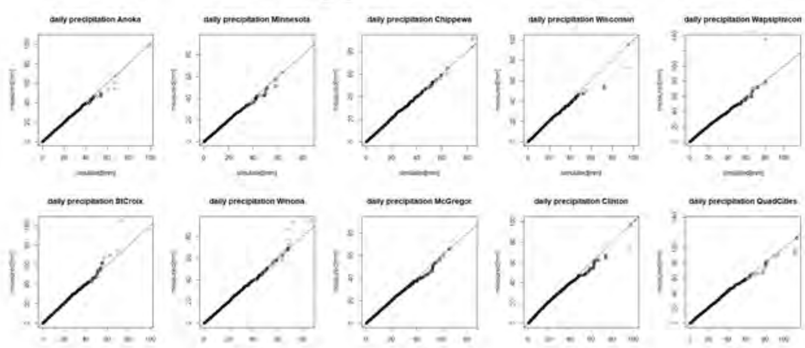
Precipitation and Temperature Seasonality

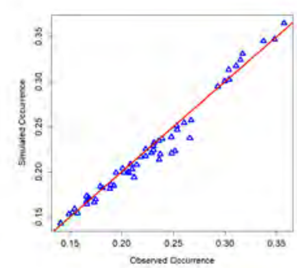
- Account for seasonally weather variables of precipitation, maximum temperature, and minimum temperature



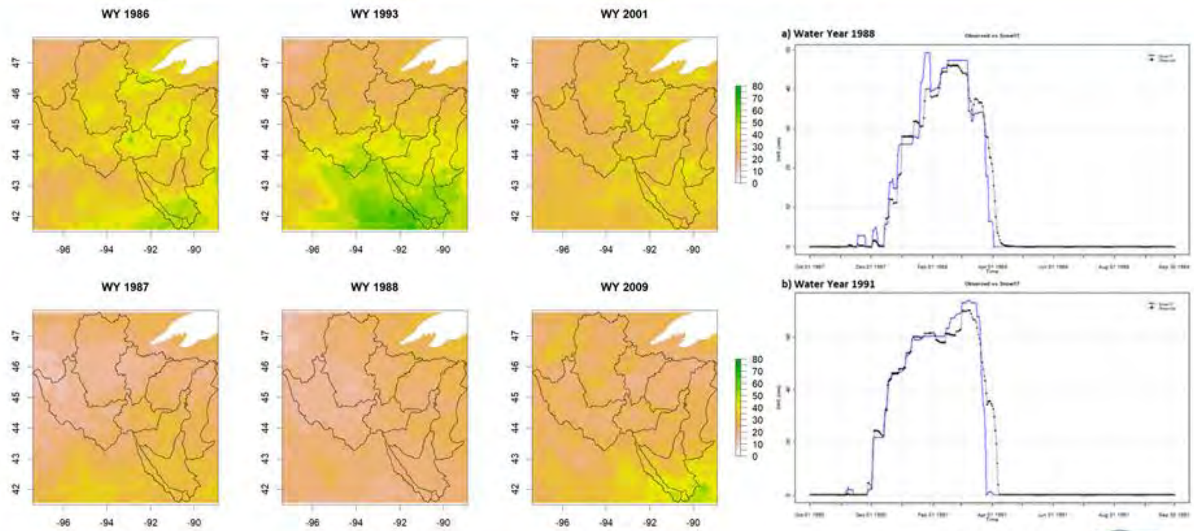
Precipitation and Temperature Simulation

- Calibrated VAR precipitation, maximum temperature, minimum temperature models compared to the observed and simulated data
- Observed vs simulated data were compared at quantiles from 0.1 to 0.99
- Average correlation among the observed and simulated values were excellent with all station's correlation being greater than 0.98

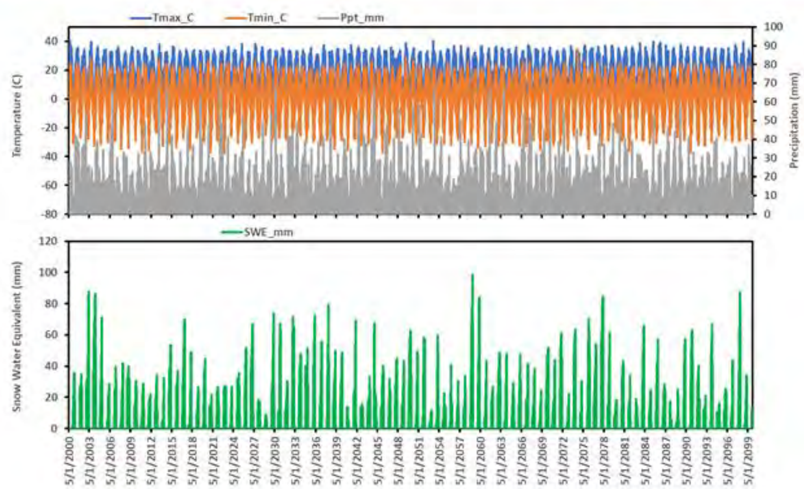




Snow Water Equivalent Simulation

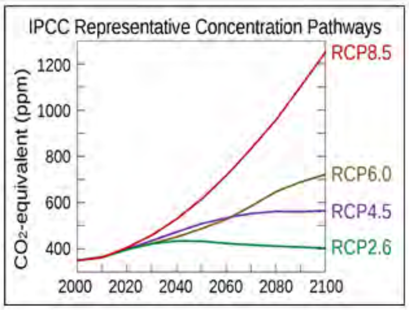


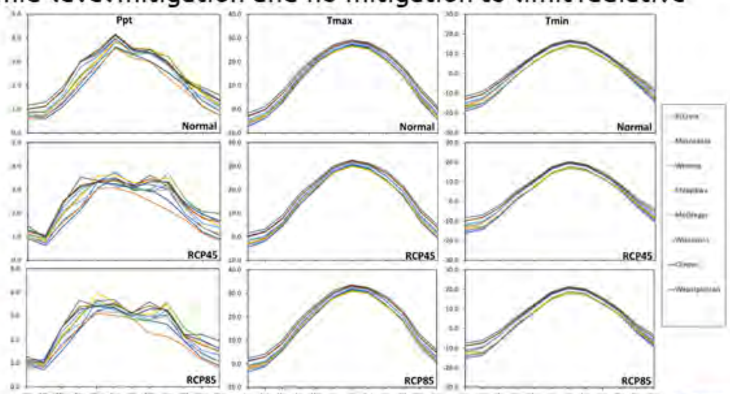
Example Daily Simulation for 100-year Period



Climate Change

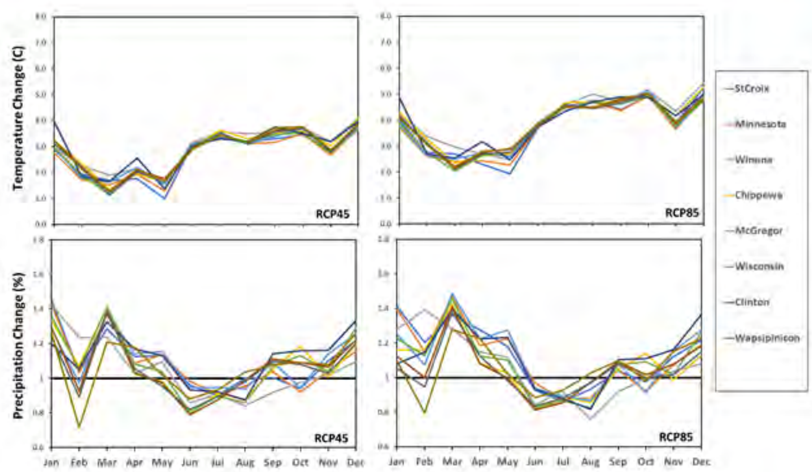
- Projections utilized regional downscaled model output driven by RCP45 and RCP85 from CMIP5 global climate model output
- RCP45 and RCP85; represent a mid-level mitigation and no mitigation to limit radiative





Climate Change

- Increase in monthly mean temperatures
- Increase and decrease in monthly mean precipitation



Hydrologic Modeling Overview

- Hydrologic model (HEC-HMS) developed for 8 sub-watersheds using the following modeling methods:

Element/Method	Chosen Method
Canopy Method	Simple Canopy
Surface Method	Simple Surface
Infiltration / Loss	Deficit & Constant
Transformation	Clark Unit Hydrograph
Baseflow	Linear Reservoir (3 Reservoirs)
Reach Routing	Muskingum

- Model calibrated for three 1-year continuous simulations (dry, normal, and wet) climatology – years chosen, 1988 (dry), 1991 (average), and 1993 (wet)
- Simulated daily data for three climate scenarios : i) current climate, ii) RCP45 climate projection, and iii) RCP85 climate projection

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Study Area

Sub-Basin	Area (Sq. Miles)
Minnesota	17,065
Chippewa	9,079
St. Croix	7,727
Anoka	19,905
Wapsipinicon	2,333
McGregor	7,882
Winona	5,969
Clinton	7,892
Wisconsin	10,419

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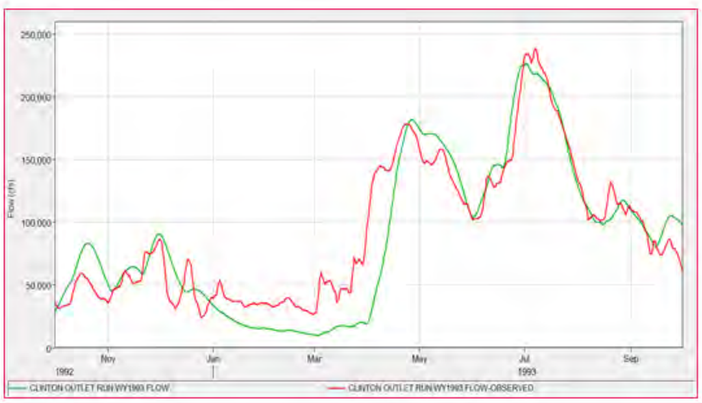
Hydrologic Modeling Approach

- Single vs **Continuous** Model
  - Deficit & Constant Method
  - Canopy, Surface, Infiltration, Transformation, Baseflow, Reach Routing
- Calibration
  - Select representative years
  - Develop MAP's & MAT's
- Apply to Long Term (1,000 year) Simulations
- Flow Frequency Analysis on computed annual maximum flows

Typical Calibration – Wet Year



Long Term (1,000 year) Simulations

- 12 unique "traces" of 1,000 years generated
- 3 Different climate scenarios
  - *Normal* (or current) climate, *RCP45*, and *RCP85*
- 36 Unique traces

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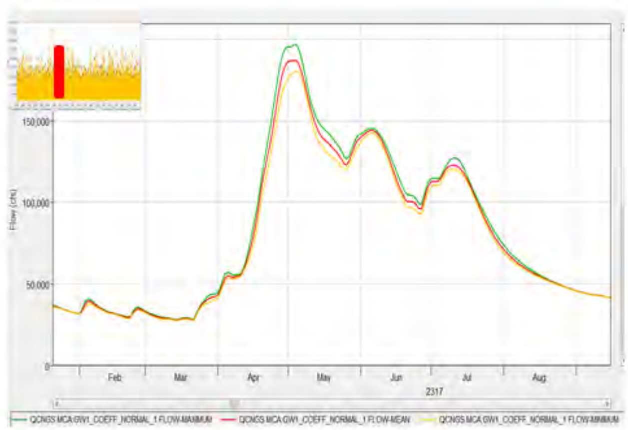
Hydrologic Model Uncertainty Analysis

Parameter	Sub-Basin Component
Groundwater Coefficient 1	Baseflow
Groundwater Coefficient 2	Baseflow
Groundwater Coefficient 3	Baseflow
Constant Loss Rate	Loss (Deficit & Constant)
Maximum Deficit	Loss (Deficit & Constant)
Percent Impervious	Loss (Deficit & Constant)



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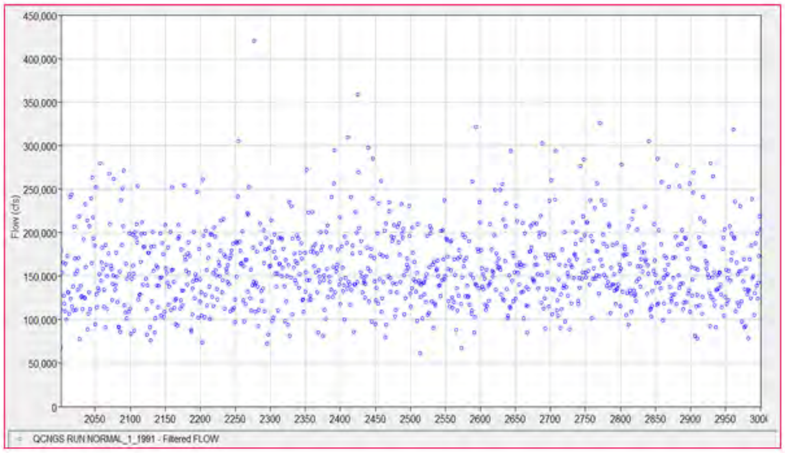
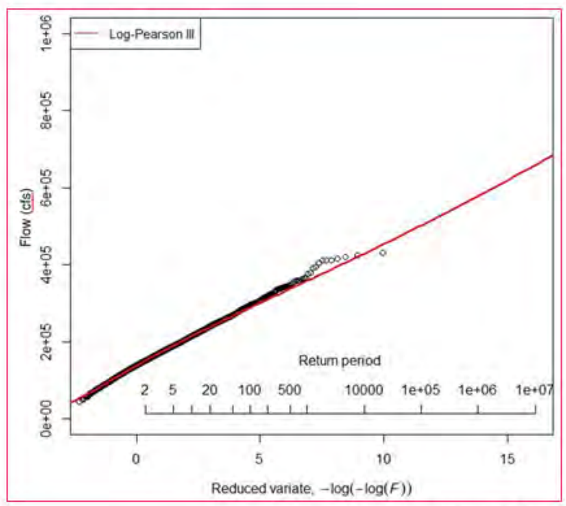
Annual Maximum Flows for Each Trace Extracted



Log-Pearson III Output
Normal Climate Scenario – 12,000 years

Return Period	AEP	Flow (cfs)
2	0.5	151,321
50	0.02	267,341
100	0.01	288,652
200	0.005	309,714
500	0.002	337,411
1,000	1E-03	358,376
10,000	1E-04	428,924
100,000	1E-05	501,931
1,000,000	1E-06	578,283



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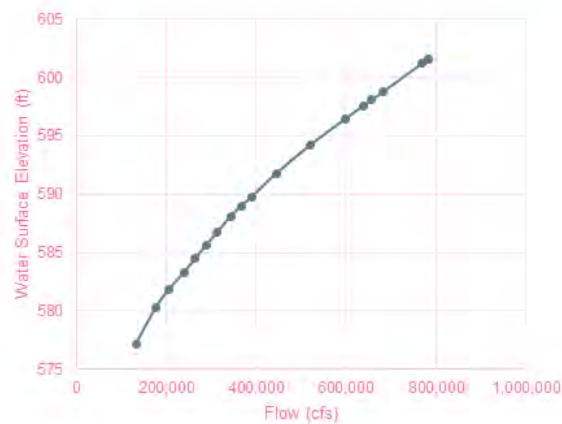
Unsteady River Flow Model – Rating Curve

Return Period (YR)	AEP	NORMAL WSEL (ft)
2	0.5	578.4
50	0.02	584.6
100	0.01	585.6
200	0.005	586.6
500	0.002	587.8
1,000	1E-03	588.7
10,000	1E-04	591.2
100,000	1E-05	593.6
1,000,000	1E-06	595.9



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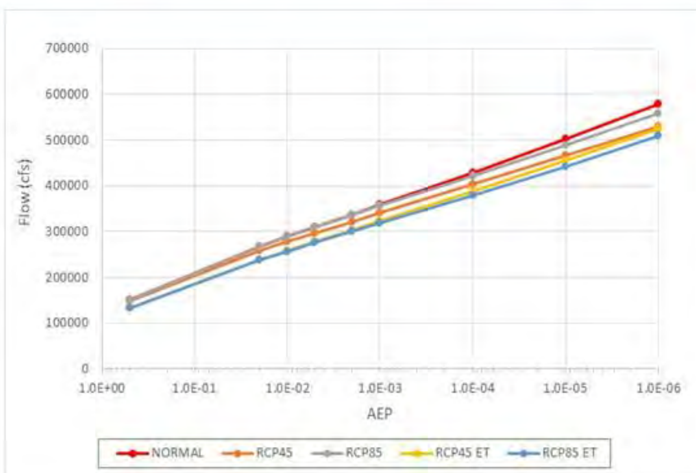
Final Results – Enhanced ET Analysis



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Comparison with 17C Analysis for Higher AEPs

Return Period	AEP	Flow (cfs) from Current Study	Flow (cfs) from Bulletin 17C Analysis	Difference (%)
2	0.5	151,321	143,000	5.5
50	0.02	267,341	257,000	3.9
100	0.01	288,652	274,000	5.1
200	0.005	309,714	290,000	6.4
500	0.002	337,411	309,000	8.4

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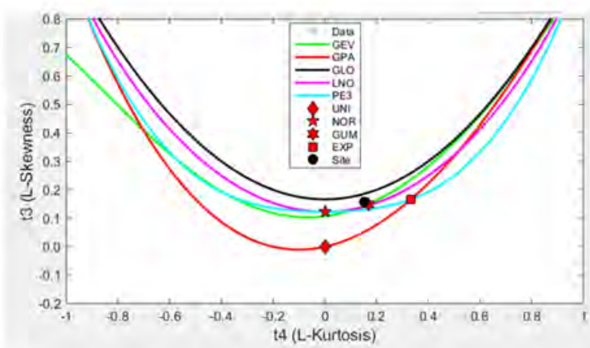
Summary of Uncertainties

- Climate change
- Variability in hydrologic inputs (Monte Carlo)
- Natural variation in river system
- Land use changes
- Probability distribution function (LPIII)
- Potential error in stage-discharge
- Event combinations



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3.5.3 Presentation 2B-3: IWRSS Flood Inundation Mapping for Flood Response

Authors: *Robert Mason*[1], Julia Prokopec*[1], Adam Barker*[2], Cory Winders*[3], Darone Jones*[4]*
[1]U.S. Geological Survey, [2]Federal Emergency Management Agency, [3]U.S. Army Corps of Engineers, [4]National Weather Service

Speaker: *Julia Prokopec*

3.5.3.1 Abstract

Traditionally, flood predictions and forecasts have focused on communicating near-term outlooks for flood-peak stages (water-elevations) and flow rates. But modern geospatial and hydrodynamic modeling techniques permit the rapid conversion of such information into flood inundation maps (FIMs) that communicate fair more effectively the expected area extent and timing of a flood and the physical resources and community populations that will be impacted. Many agencies at the Federal, State, and local levels have evolved these techniques such they are now deployed routinely, and the resulting maps distributed to emergency management agencies.

Sometimes a diversity of approaches, assumptions, or inputs made by the modelers can result in divergent maps that can confuse users. In 2018, the Integrated Water Resources Science and Services (IWRSS; a consortium of the Federal Emergency Management Agency (FEMA), National Ocean and Atmospheric Administration (NOAA), U.S. Army Corps of Engineers (USACE), and the U.S. Geological Survey (USGS)) was tasked with developing a process for coordinating Federal, event-based FIMs and establishing an authoritative source for communication of the coordinated FIM to FEMA. The process was codified in a draft "playbook" that has been exercised and further developed through several recent floods. This presentation will describe the iFIM vision, the evolving playbook, agency roles and products, and efforts to develop a truly integrated and authoritative FIM for the Federal emergency management community.

3.5.3.2 *Presentation (ML22061A120)*

Integrated Water Resources Science and Services (IWRSS) Integrated Flood Inundation Mapping (iFIM)

Julia Prokopec, USGS and Casey Zuzak, FEMA

NOAA / USACE / USGS / FEMA
February 16, 2022

1

Integrated Water Resources Science and Services

- 2011 - Established by MOU between the USACE, USGS, and NOAA
  - Originally focused on "Operational Hydrology"
    - Systems Interoperability and Data Synchronization
    - Flood Inundation Mapping
- 2016 - Renewed and expanded with the addition of FEMA
  - Support flood impact assessments
- 2018 - Hurricane Season
  - Multiple event-based inundation maps produced and distributed caused confusion
  - Science for Disaster Reduction (part of OSTP/CEQ/NSC committee structure) convened review that resulted in request to IWRSS to develop integrated playbook for coordinated production of Federal flood-inundation maps
  - **Integrated Flood Inundation Mapping (iFIM)**
- 2021 – New IWRSS MOU includes BOR, FWS, EPA, DOE, and USDA and expanded scope
  - **Agencies and iFIM development and buildout**
  - Flood Risk Data
  - Integrated science test basins and community model test beds
  - Drought
  - Waters of the US (WOTHUS)

2

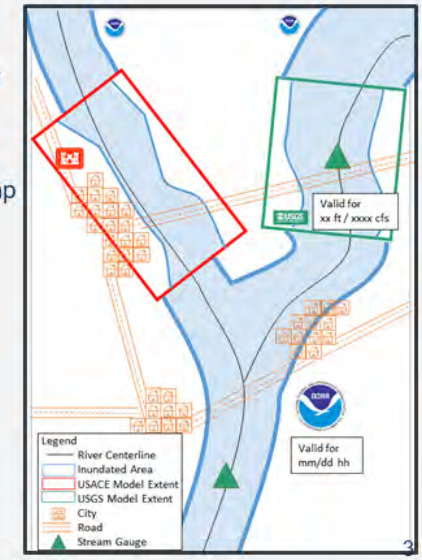
IWRSS iFIM Concept

The proposed concept maintains NOAA/NWS National Water Model maps as a background layer across the CONUS, with other maps slotting in to form the integrated map

- Enabled through a decision tree to identify the best available map given a variety of factors

The iFIM could be enabled through investment in either shared cloud computing and storage environment or "bring your own" infrastructure model.

- Additional details on these technical solutions are being developed



3

Agencies Contribution to IWRSS iFIM (USGS)

United States Geological Survey (USGS)

USGS Flood Inundation Mapping Program

- 140 of USGS streamgages have a FIM library
- Library polygons and depth grids available to download from the mapper
- Partnered with FEMA and have Hazus results for all current libraries

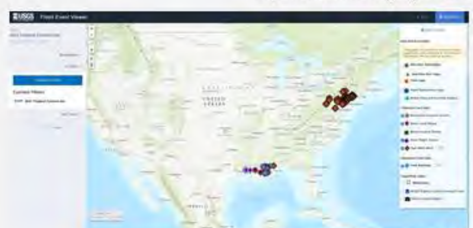
USGS Flood Event Viewer

- Short-term networks, rapid deployment gages, and high-water marks on event-based deployments

USGS Remotely Sensed Flood Inundation Maps

- Goal is to produce near-real time maps with enough spatial detail to be used in response
- In collaboration with NASA, NGA, University of Illinois and University of Alabama

https://fim.wim.usgs.gov/fim/



https://stn.wim.usgs.gov/FEV/

4

Agencies Contribution to IWRSS iFIM (USACE)

United States Army Corps of Engineers (USACE)

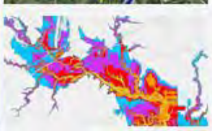
- Library with multiple products
  - 500+ dam break inundation products
  - 180+ watershed models
  - Inundation from major floods and hurricanes since 2011
  - Some misc. inundation products such as local Silver Jackets projects by Districts
- Available models include: 1D HEC-RAS, 2D HEC-RAS, HEC-HMS, HEC-ResSim
- Library contains both inundation shapefiles and depth grids
- Model reports available for some products
- Library of products publicly available through USACE FIM Viewer

5

Agencies Contribution to IWRSS iFIM (NOAA/NWS)

Static

FIM Libraries - Static maps at ~ 200 RFC forecast locations: water.weather.gov. Maps derived from engineering scale hydraulic models. **< 1,000 miles**

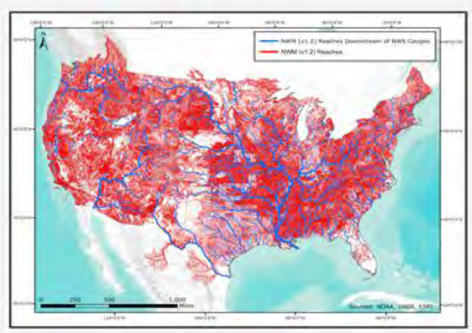


NWS Flood Categorical HAND FIM Libraries - Static maps at ~3,000 RFC forecast locations. Maps derived from 10-m HAND solution. **~ 30,000 miles**

Dynamic

Forecast NWS River Forecast Center Flood Maps - Dynamic maps downstream of ~ 3,600 RFC forecast locations. Maps derived from RFC forecast and 10-m HAND solution. **~ 100K miles**

Forecast National Water Model Flood Maps - Dynamic maps along NHDPlus reach locations. Maps derived from NWM forecast and 10-m HAND solution. **~ 3.4M miles**



6

Agencies Contribution to IWRSS iFIM (FEMA)

Federal Emergency Management Agency (FEMA)

- Primary user of iFIM. Leveraged for integration and action for Event Response and Recovery
- Basis for flood inundation mapping through Risk MAP Program – including investing in LiDAR
- Call for actions for flood mapping community through Risk MAP Program Future of Flood Risk Data
- Risk assessment and loss estimation capabilities through FEMA's Hazus software and future OpenHazus application

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iFIM Initial Development Strategy

- Creation of iFIM at NOAA/NWS National Water Center
  - Provide user interface to NWC operations for review and selection of multiple-sourced FIM during events
  - Allows for NWC forecaster to be "in the loop"
  - Sources initially include USACE, USGS, and NWS FIM
  - Manual output of "best available" FIM after evaluation of multiple-sourced FIM
- Dissemination of iFIM
  - Establish basic service for integrated FIM visualization for near real-time events in 2023
  - Publish ad-hoc updates for internal IWRSS awareness

8

2020 & 2021 Hurricane Seasons Coordination

- Record breaking Atlantic Basin 2020 season - 30 named systems
- Followed the iFIM Playbook both seasons to coordinate forecasts/activities to ensure understanding of FIMs being created and consistency of the message between agencies
  - Held iFIM Coordination Calls for 16 storms impacting CONUS
  - Call structure (15-30 minutes):
    - NWS provided situational awareness weather & water briefing, systems/service issues, NWS FIM considerations
    - FEMA provided mission updates and taskings
    - USACE provided project considerations and simulation information
    - USGS provided field deployment information and systems/service issues

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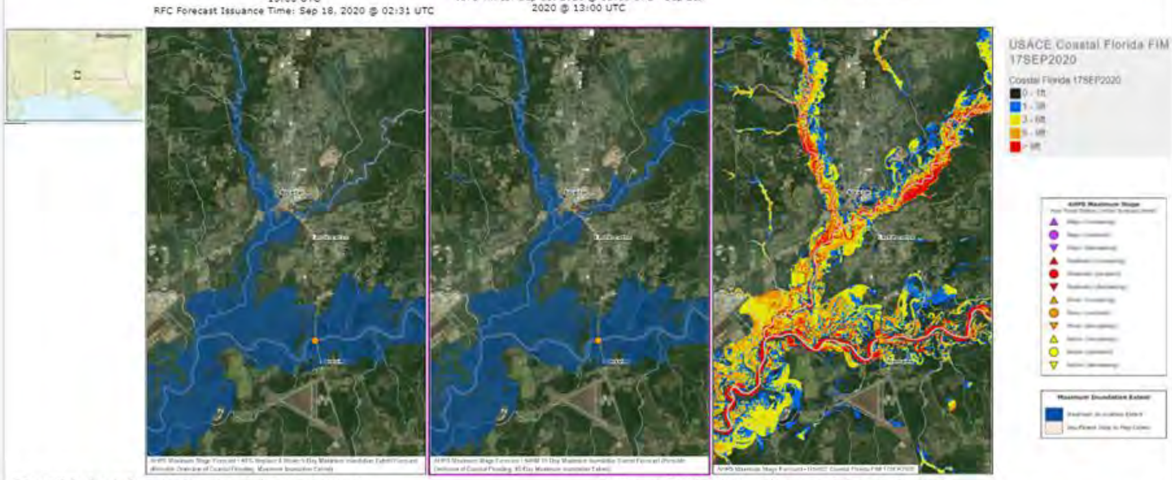
NWS Flood Inundation Mapping (Prototype)

5-Day RFC Replace & Route Maximum Inundation Extent Forecast	10-Day NWM Maximum Inundation Extent Forecast	USACE Inundation Extent Forecast
Valid Times: Sep 18, 2020 @ 15:00 UTC - Sep 23, 2020 @ 15:00 UTC RFC Forecast Issuance Time: Sep 18, 2020 @ 02:31 UTC	Reference Time: Sep 18, 2020 @ 06:00 UTC Valid Times: Sep 18, 2020 @ 13:00 UTC - Sep 28, 2020 @ 13:00 UTC	Issued: Sep 17, 2020



5-Day RFC Replace & Route Maximum Inundation Extent Forecast
Depicts expected maximum inundation extent derived from the official RFC forecast routed through the National Water Model (v2.0) stream network downstream of AHPS gauges (Replace & Route). Shown are the areas expected to be inundated at some point over the next 5 days. Inundation extents are derived using the Height Above the Nearest Drainage method.

18-Hour and 10-Day NWM Maximum Inundation Extent Forecast
Depicts expected maximum inundation extent derived from the operational National Water Model (NWM) (v2.0) short range and medium range forecasts, respectively. Shown are areas that are expected to be inundated sometime over the 18-Hours and 10 days. Inundation extents are derived using the Height Above the Nearest Drainage method; stage heights are interpolated from NWM (v2.0) discharges using synthetic rating curves. Interpolated stage heights are rounded up to the nearest foot, and corresponding pre-computed inundation extent polygons are displayed.

Prototype visualization, for guidance use only. Does not take into account coastal flooding or storm surge. May not reflect the official forecast. Visit water.weather.gov for the official forecast.

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IWRSS iFIM Next Steps

- IWRSS iFIM Team to draft an After-Action Report (AAR) on 2021 coordination (Q2 FY22)
  - Make adjustments to the iFIM Playbook ahead of 2022 season
- IWRSS iFIM Technical Team will be reinvigorated to explore data standards, management and accessibility to enable iFIM (data interoperability).
- Resume bi-weekly meetings, and conduct face-to-face workshops at the NWC
- Workshop Goals:
  - Review and exercise each IWRSS members data and services
  - Review and exercise the iFIM playbook
  - Provide a demonstration of how each IWRSS members data and services and the iFIM playbook culminate in a joint IWRSS inundation map.
  - Document the current iFIM capability, the necessary steps moving forward, and other pertinent information.

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Questions?

- NOAA/NWS - Darone Jones (darone.jones@noaa.gov)
- USACE - Cory Winders (Robert.C.Winders@usace.army.mil)
- USGS - Julia Prokopec (jprokopec@usgs.gov) and
  Robert Mason (rrmason@usgs.gov)
- FEMA – Casey Zuzak (casey.zuzak@fema.dhs.gov) and
  Adam Barker (adam.barker@fema.dhs.gov)

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Backup Slides

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NOAA/NWS FIM Development Opportunities

NWM Enhancements (e.g. hydrology and hydraulics)

Terrain Models (e.g. HAND based solution)

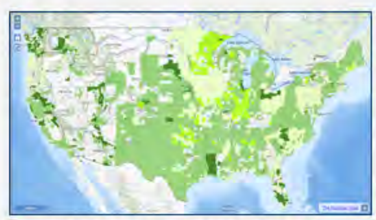
- LiDAR derived 1-m and/or 3-m Digital Elevation Models (DEMs)
- FY19 demonstration of LiDAR HAND FIM capabilities

Hydraulic Models

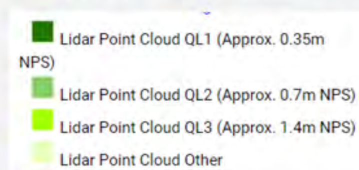
- HEC-RAS derived libraries at reach scale
- Additional model derived libraries at reach scale

Service Enhancements

- FIMpact: Intersection of forecast FIM with infrastructure
- Probabilistic: NWM ensembles, parameter sensitivity analysis



USGS 3DEP LiDAR Availability



NPS = Nominal Pulse Spacing

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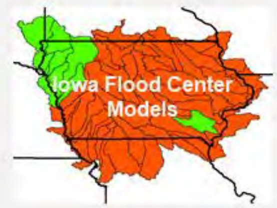
NOAA/NWS Evaluation of FIM Capabilities

- **Benchmark Datasets**
  - **Point FIM Evaluations:** AHPS & USGS FIM library locations
  - **Watershed FIM Evaluations:** FEMA Base Flood Elevation (BFE) models and Iowa Flood Center HEC-RAS models

InFRM = Interagency Flood Risk Management



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NOAA/NWS FIM Evaluation Services

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NOAA/NWS Opportunities to Expand FIM Evaluations

- **Benchmark Data**
  - Rating Curves
  - Depth
- **Event Verification**
  - High water marks
  - Remote sensing
  - UAV
  - NWS FIM Reviewer

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3.5.4 Presentation 2B-4: Using HEC-WAT for NRC's PFHA Process

Authors: William Lehman*, Gregory Karlovits, David Ho, Leila Ostadrahimi, Brennan Beam, Sara O'Connell, Julia Slaughter

U.S. Army Corps of Engineers Hydrologic Engineering Center

Speaker: William Lehman

3.5.4.1 Abstract

This presentation describes the application of the Nuclear Regulatory Commission's (NRC) Probabilistic Flood Hazard Analysis (PFHA) process through the Hydrologic Engineering Center Watershed Analysis Tool (HEC-WAT). PFHA provides a quantitative relation between of the probability of occurrence (or frequency) and magnitude for various flood hazards. The modeling framework includes hydrologic processes such as infiltration, runoff, discharge routing, reservoir operations, and near-field hydraulic processes. A comprehensive flood hazard assessment comprised probabilistic modeling of individual processes as well as composite modeling of coincident and/or correlated processes. The result is computed flood hazard frequency curves described with uncertainty bounds at various sites across the watershed for many informative variables. HEC-WAT was applied to a pilot watershed to provide a concrete demonstration of methodology to produce the outputs required for PFHA. This pilot project is focused on inland flood riverine flooding mechanisms including upstream dam breaching that may impact Nuclear Power Plants (NPPs).

3.5.4.2 Presentation (ADAMS Accession No. ML22061A119)

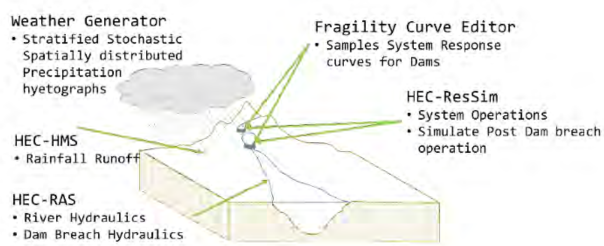
Using HEC-WAT for PFHA

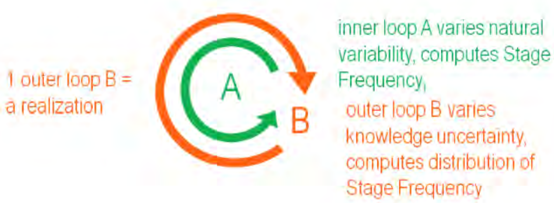
Will Lehman
USACE Hydrologic Engineering Center

US Army Corps of Engineers®

Overview of HEC-WAT

- **Plugin Architecture**
  - Supports Integration of any water resources software
- **Watershed Systems Approach**
  - Model Linking
- **Risk Analysis**
  - Nested Loops



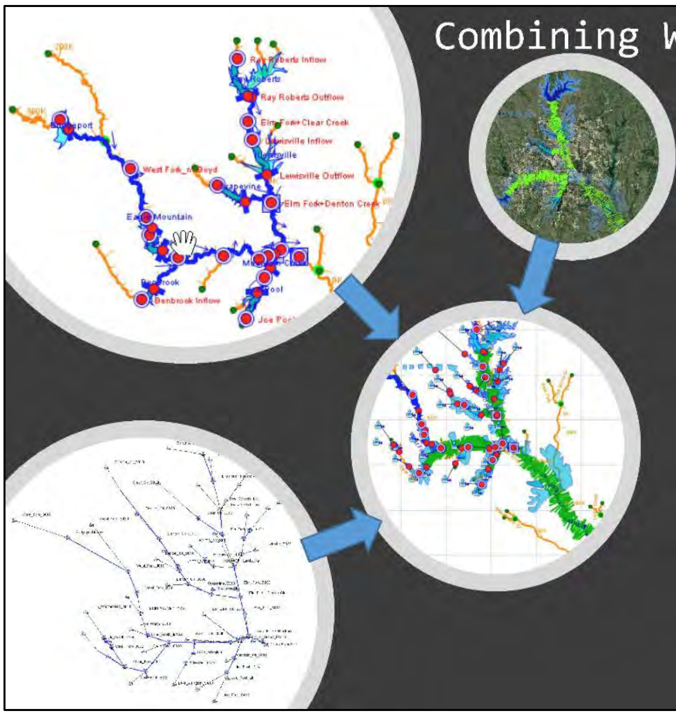


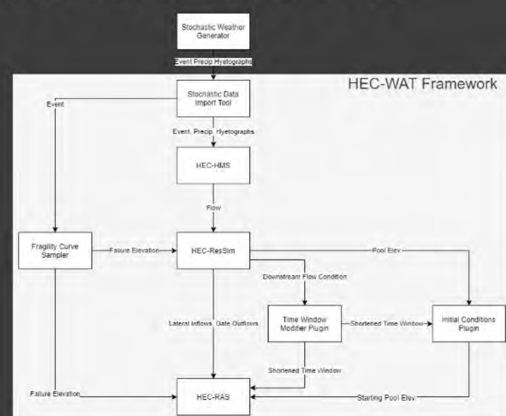
Customized Plugins

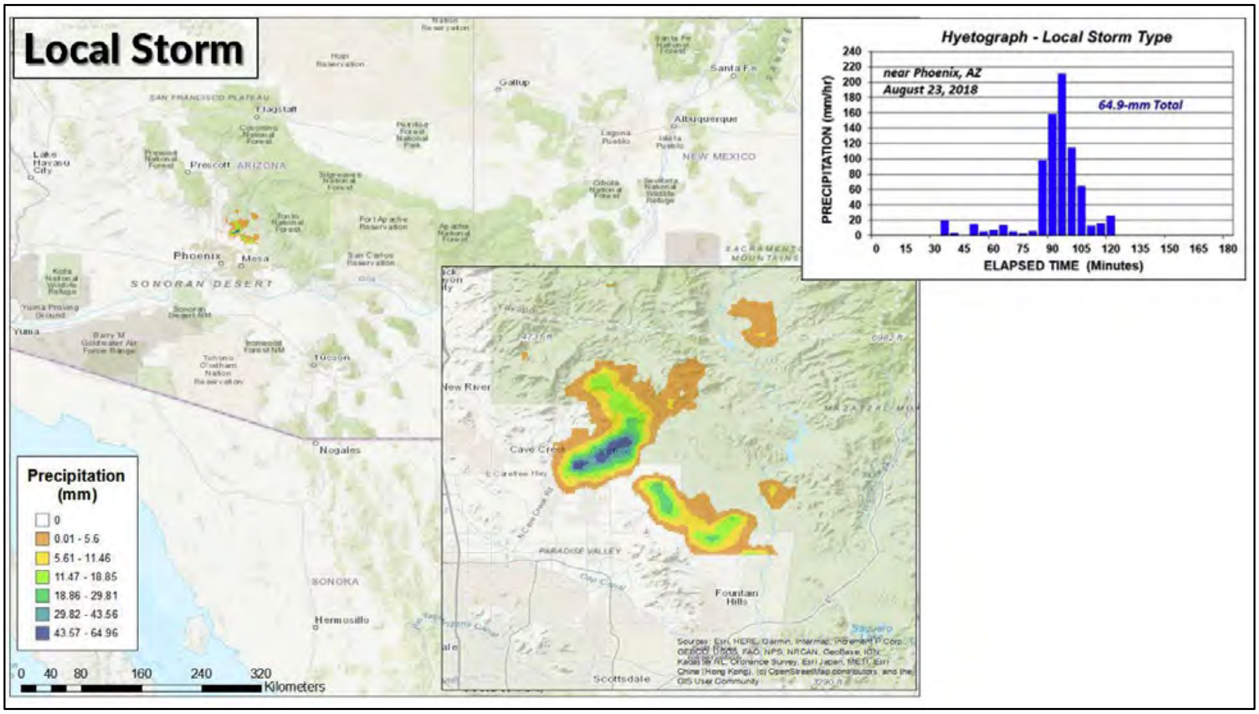
A Plugin allows us to manipulate inputs and outputs during a simulation

- RAS Max XS plugin
- Confidence Builder Plugin
- Improvements to Initial Conditions Plugin
- Improvements to Fragility Curve Plugin
- Improvements to HEC-ResSim Plugin
- Improvements to Duration Plugin

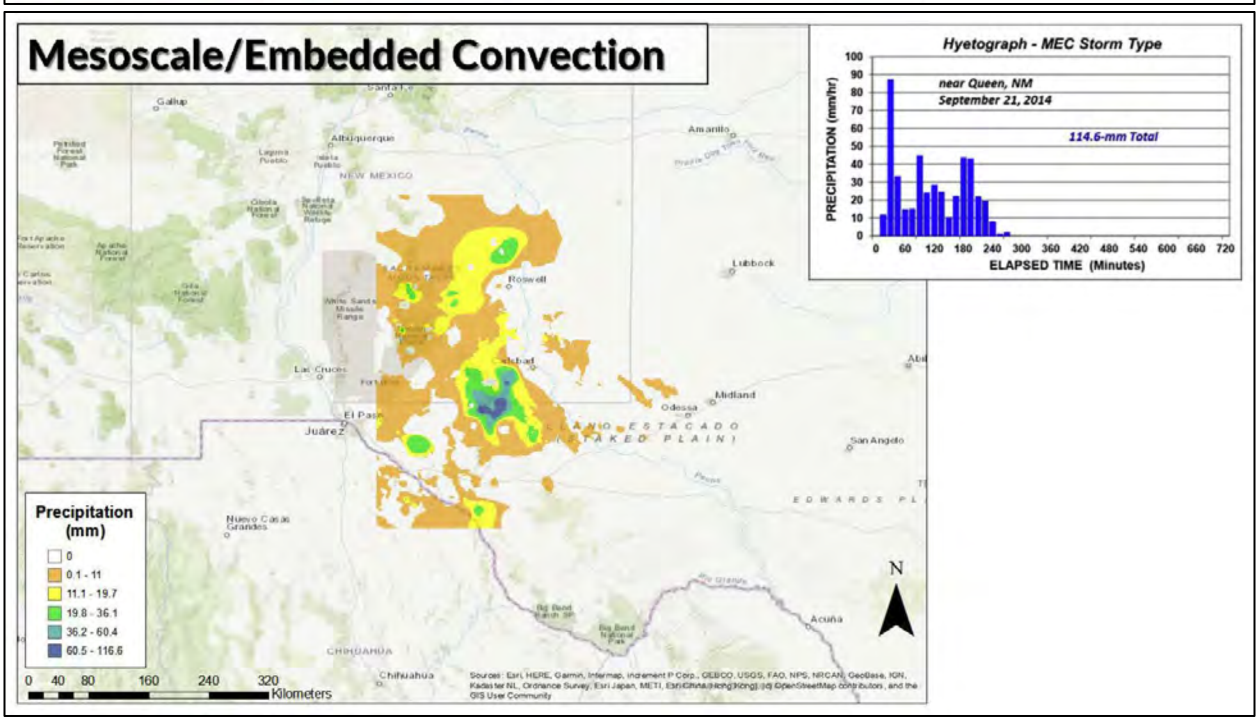
Combining Watershed Processes



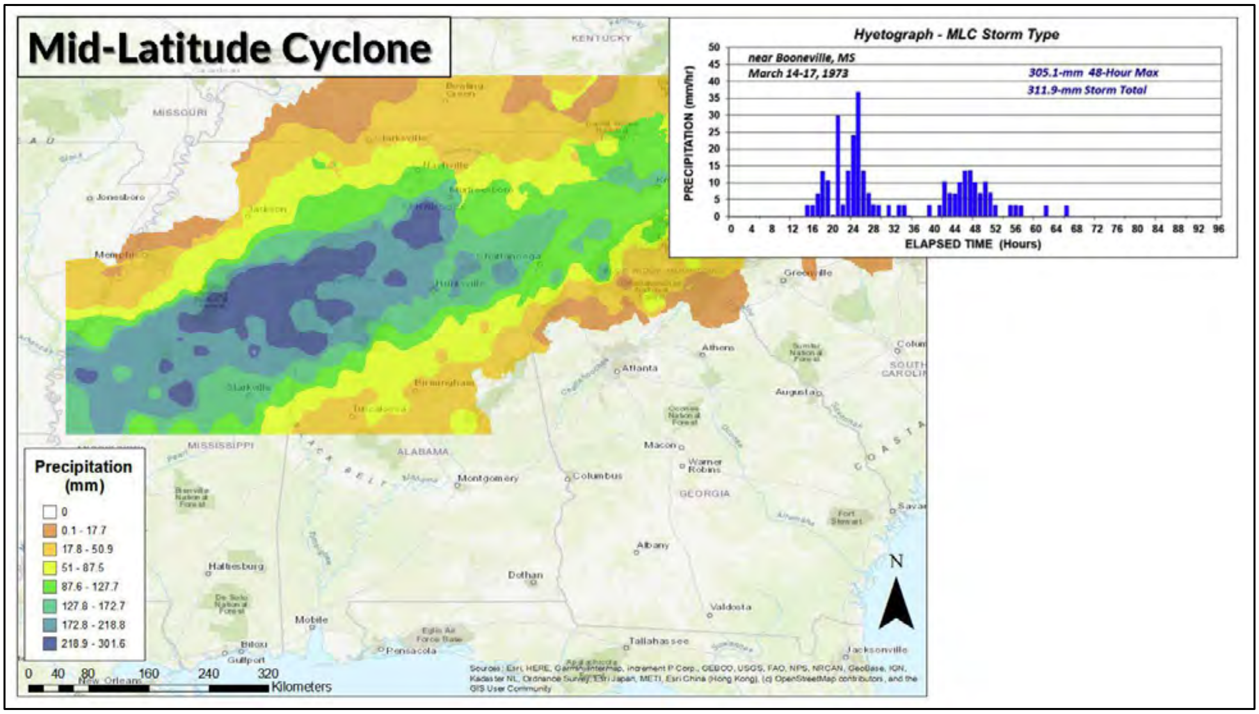


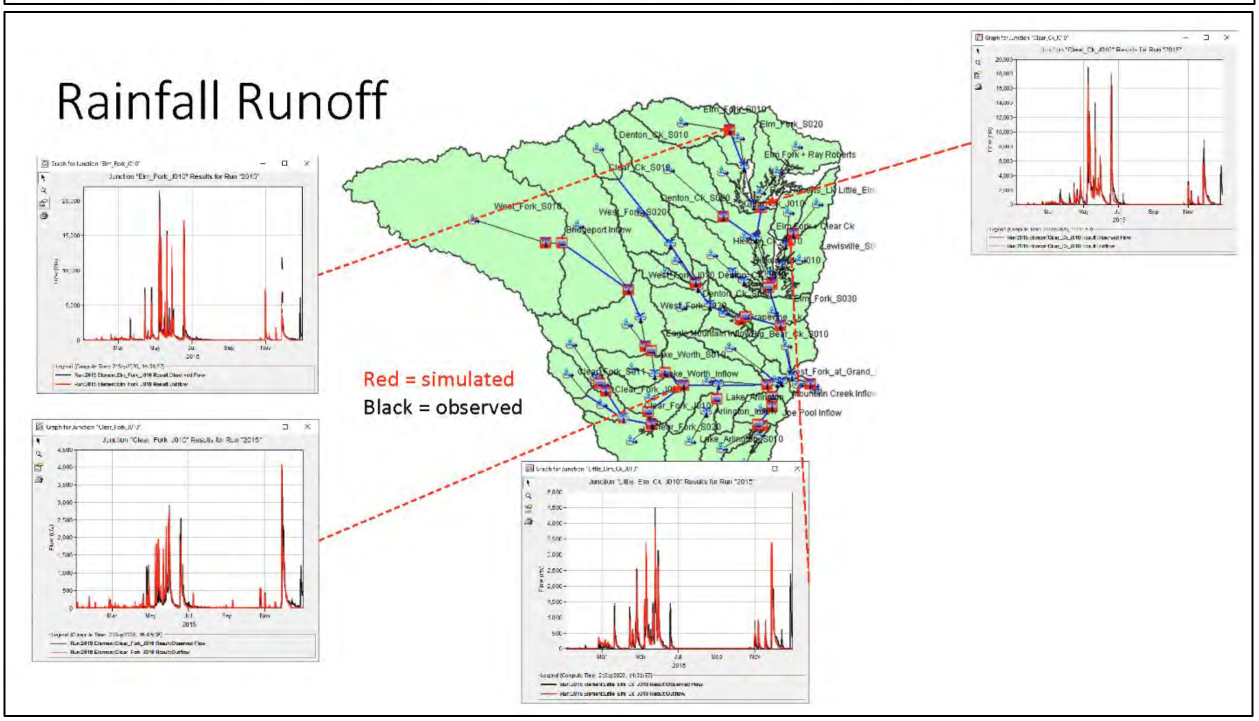


Local Storm
Hyetograph - Local Storm Type
near Phoenix, AZ
August 23, 2018
64.9-mm Total
PRECIPITATION (mm/hr)
0 20 40 60 80 100 120 140 160 180 200 220 240
0 15 30 45 60 75 90 105 120 135 150 165 180
ELAPSED TIME (Minutes)
Precipitation (mm)
0
0.01 - 5.6
5.61 - 11.46
11.47 - 18.85
18.86 - 29.81
29.82 - 43.56
43.57 - 64.96
0 40 80 160 240 320
Kilometers
Phoenix
Mesa
Flagstaff
Prescott
Gallup
Albuquerque
Santa Fe
Tucson
Nogales
Hermosillo
Yuma
Cave Creek
Fountain Hills
Scottsdale

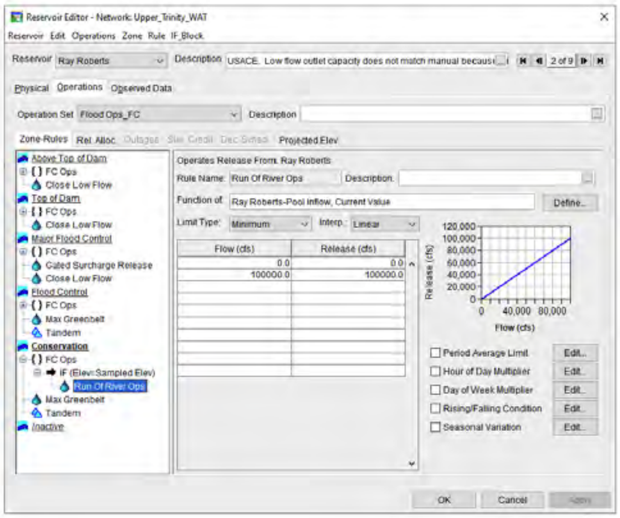


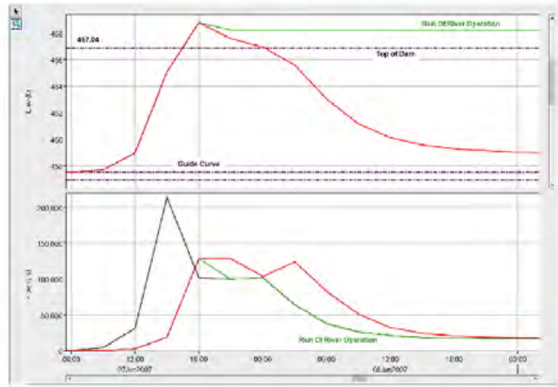
Mesoscale/Embedded Convection
Hyetograph - MEC Storm Type
near Queen, NM
September 21, 2014
114.6-mm Total
PRECIPITATION (mm/hr)
0 10 20 30 40 50 60 70 80 90 100
0 60 120 180 240 300 360 420 480 540 600 660 720
ELAPSED TIME (Minutes)
Precipitation (mm)
0
0.1 - 11
11.1 - 19.7
19.8 - 36.1
36.2 - 60.4
60.5 - 116.6
0 40 80 160 240 320
Kilometers
N
Albuquerque
Amarillo
Lubbock
Roswell
Las Cruces
El Paso
Juarez
Midland
Odessa
San Angelo
Chihuahua

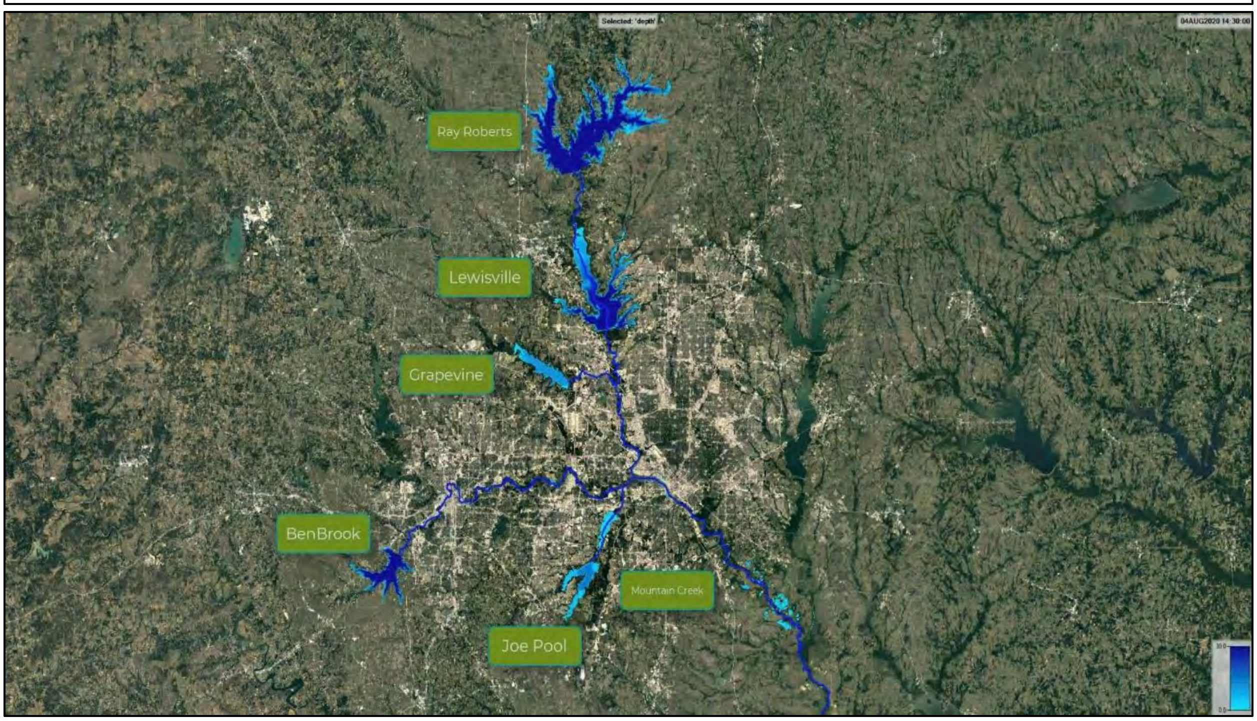

Mid-Latitude Cyclone
Hyetograph - MLC Storm Type
near Booneville, MS
March 14-17, 1973
305.1-mm 48-Hour Max
311.9-mm Storm Total
PRECIPITATION (mm/hr)
ELAPSED TIME (Hours)
Precipitation (mm)
0
0.1 - 17.7
17.8 - 50.9
51 - 87.5
87.6 - 127.7
127.8 - 172.7
172.8 - 218.8
218.9 - 301.6
0 40 80 160 240 320 Kilometers
N


Rainfall Runoff
Red = simulated
Black = observed

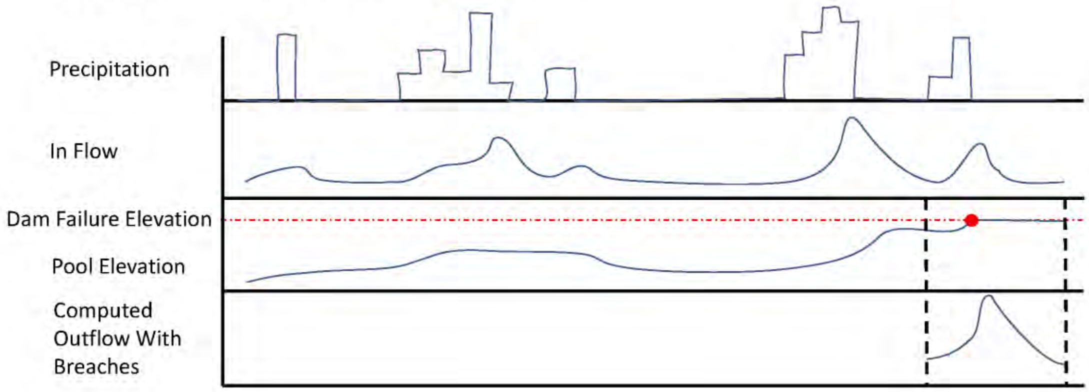
Reservoir Operation



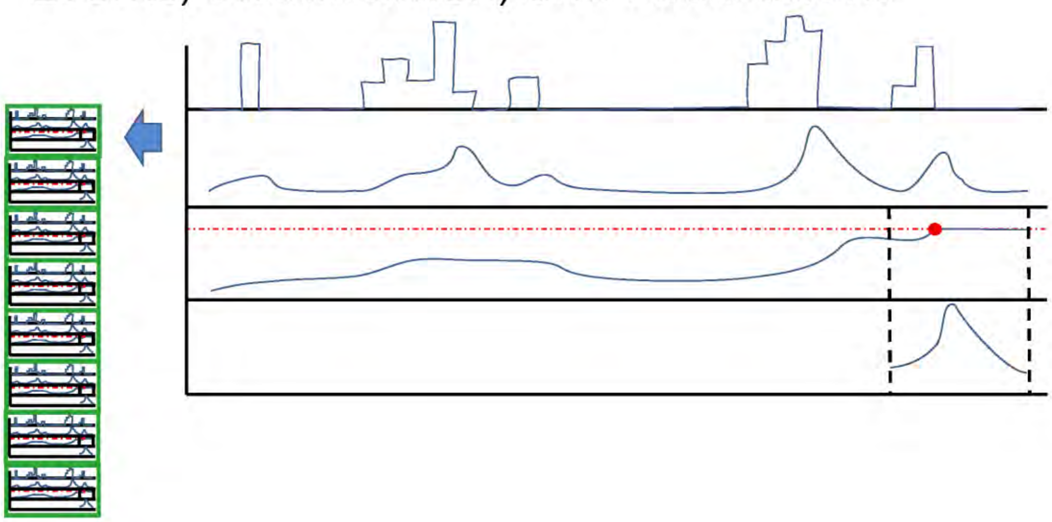




Data Flow Animation

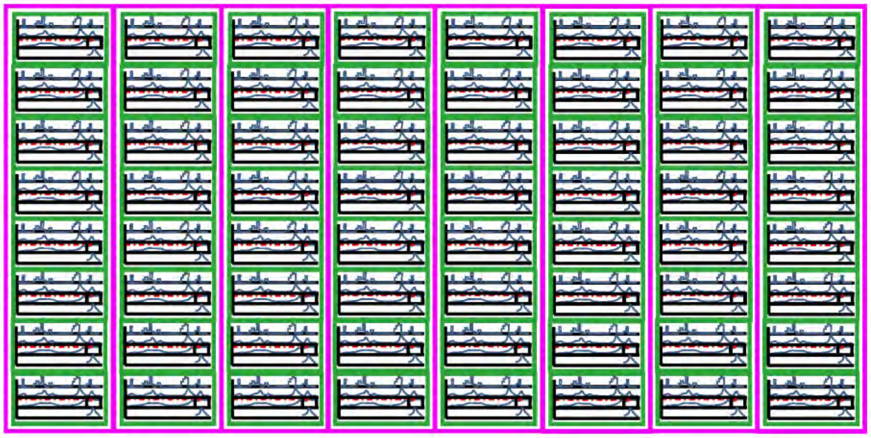


Events, Stratification, and Realizations



Events, Stratification, and Realizations

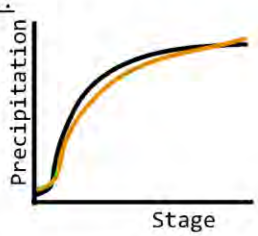
Each Event in a Stratification bin has the same incremental likelihood (defined by the stratification bin).

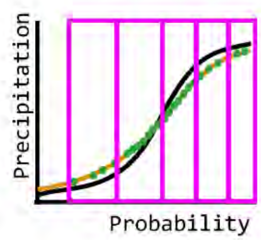


Each Stratification bin has a different incremental likelihood and represents a different range of frequency.

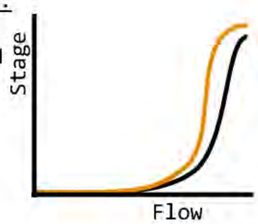
Precipitation to Hazard Frequency

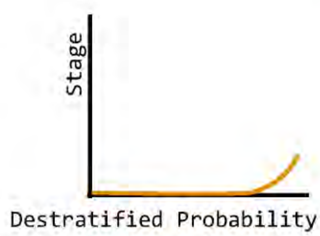
Uncertainties:
- Basin wetness
- Reservoir Operations



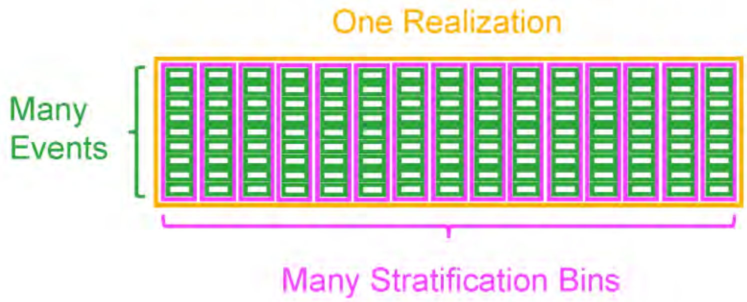


Uncertainties:
- Breaches
- Manning's N

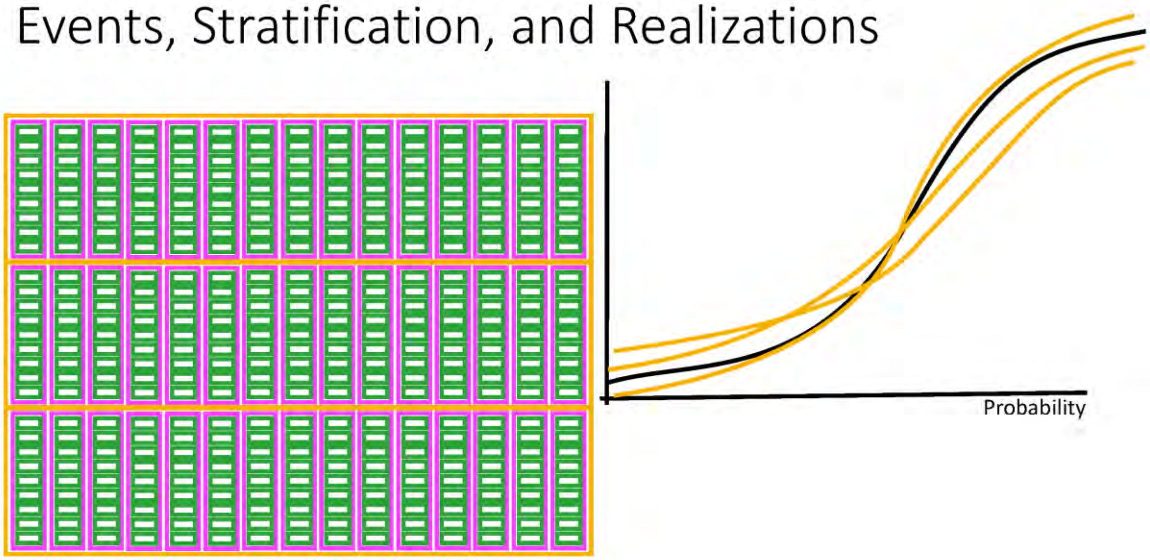




Events, Stratification, and Realizations

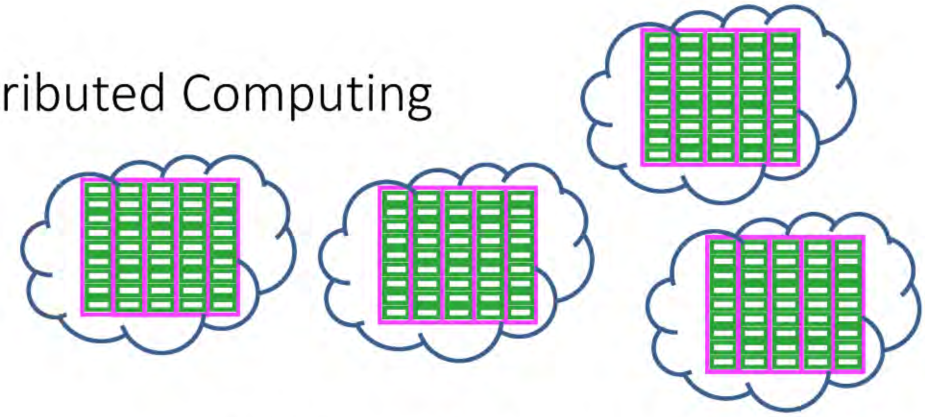


Events, Stratification, and Realizations

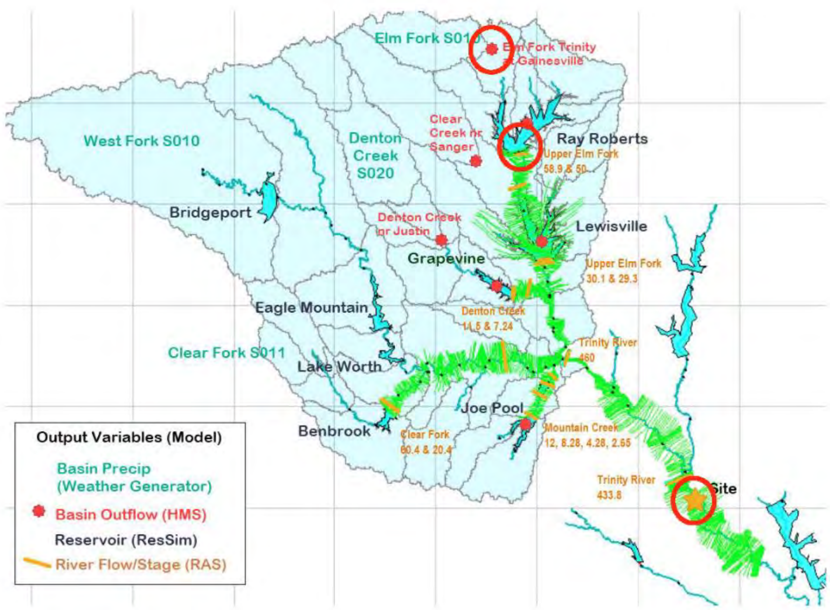


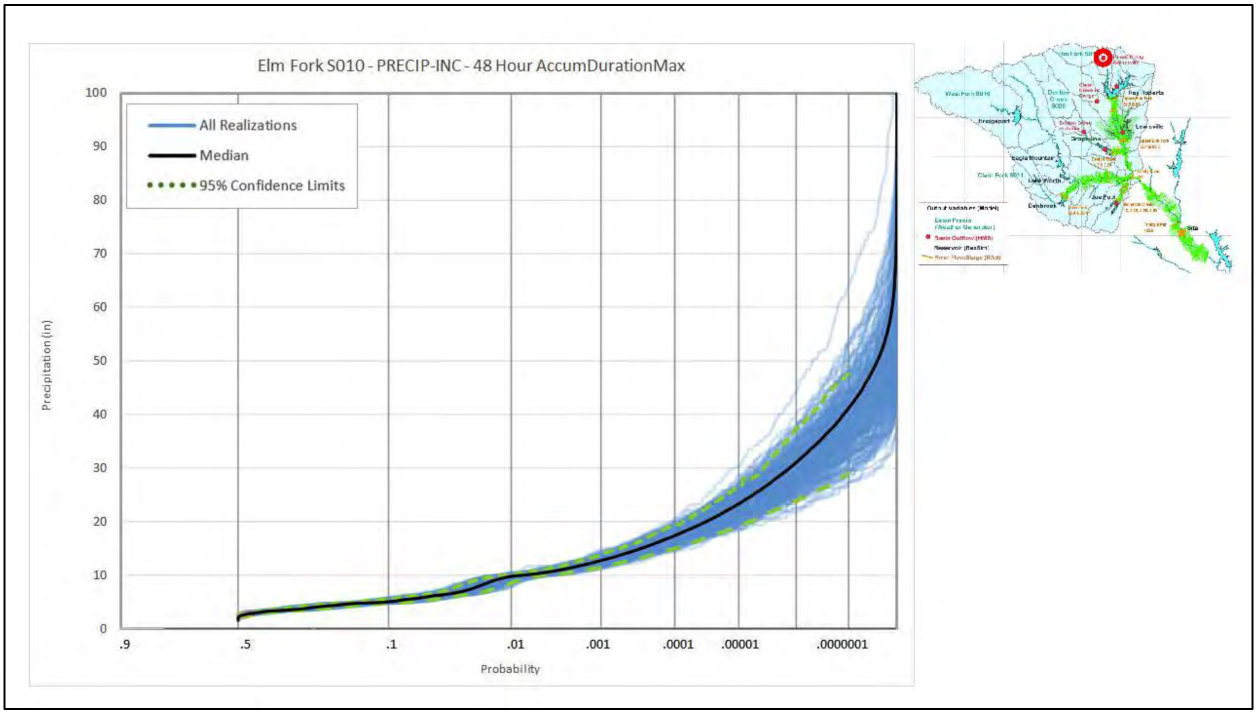
Each Realization represents a sample of Knowledge Uncertainty and can create a Frequency Curve

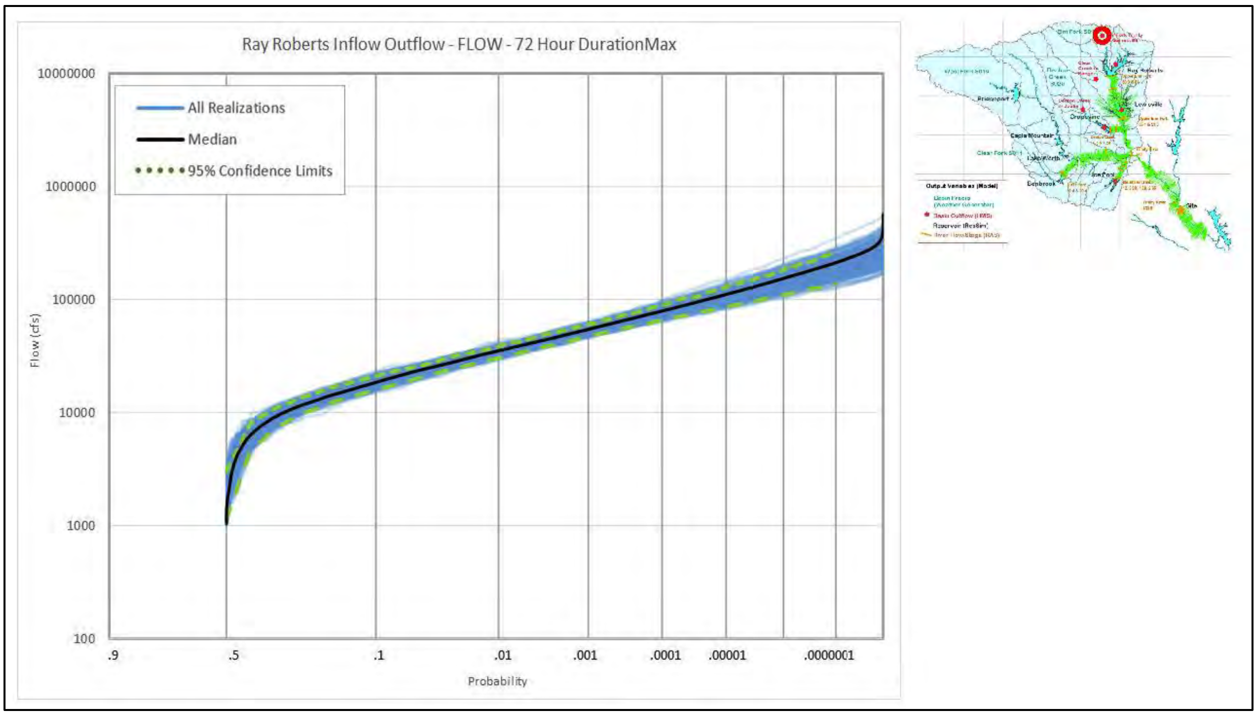
Distributed Computing

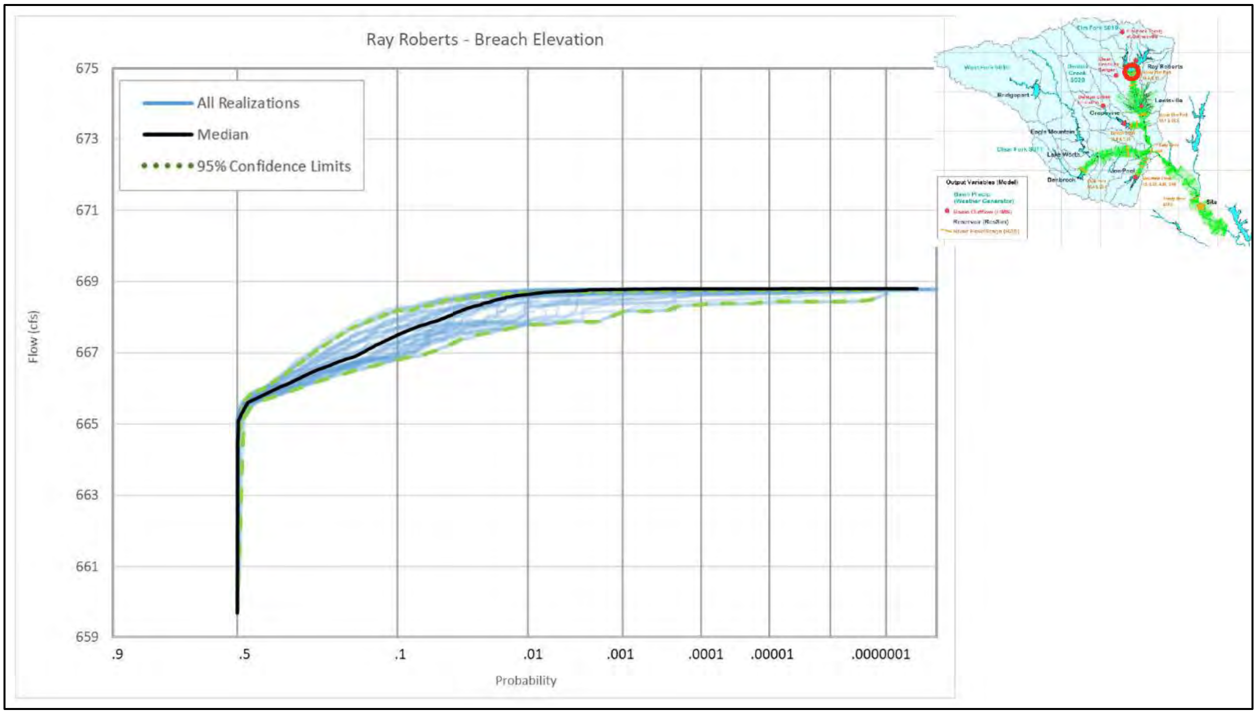


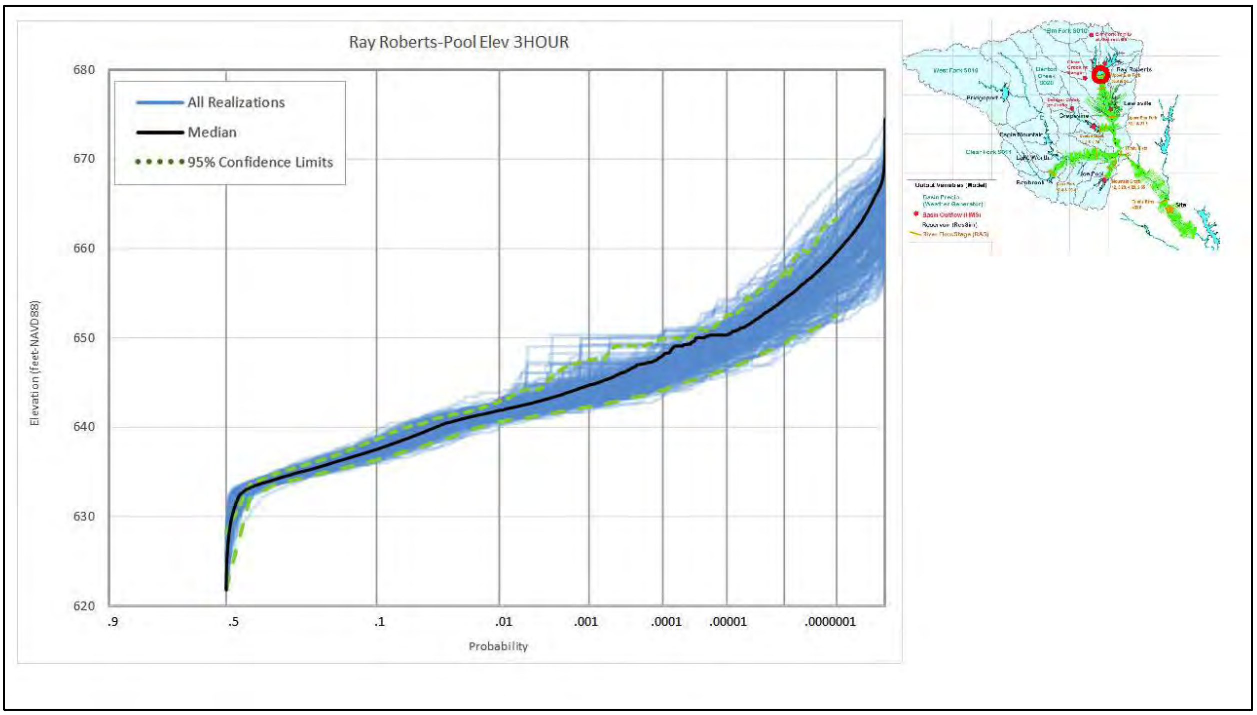
- We leveraged four compute clusters of 25 nodes each
- This could be done via AWS instead of on local infrastructure like we used.

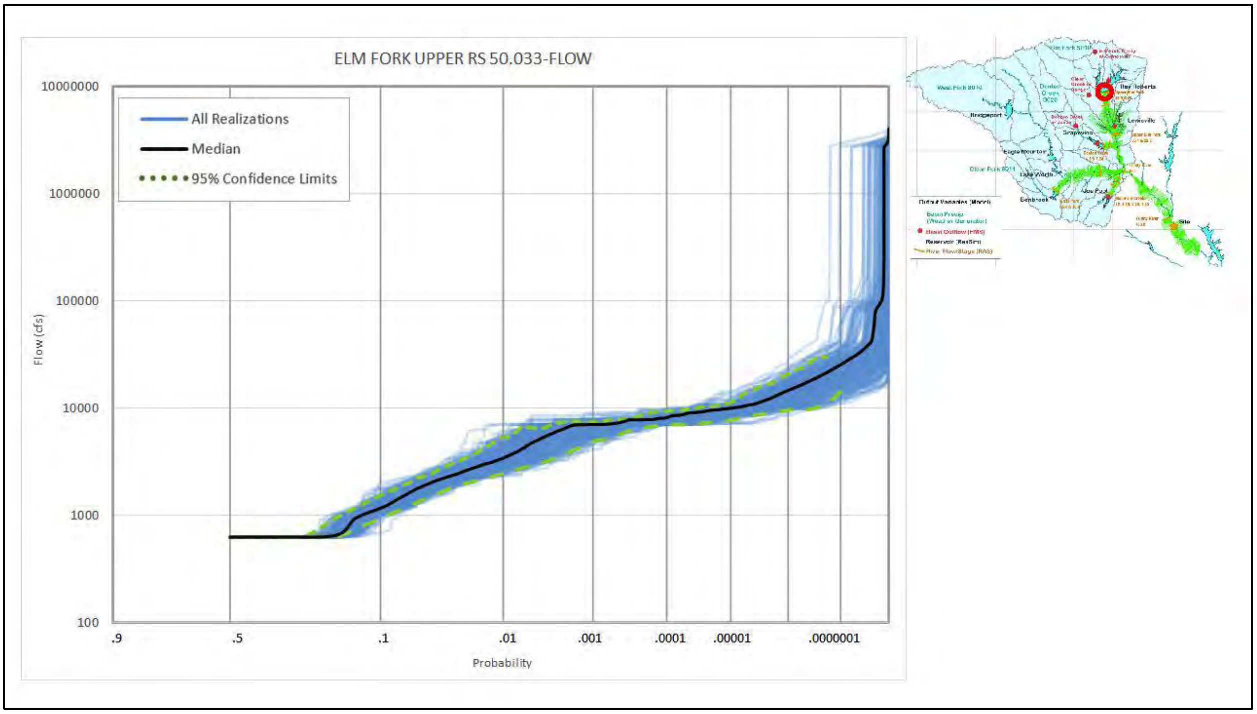


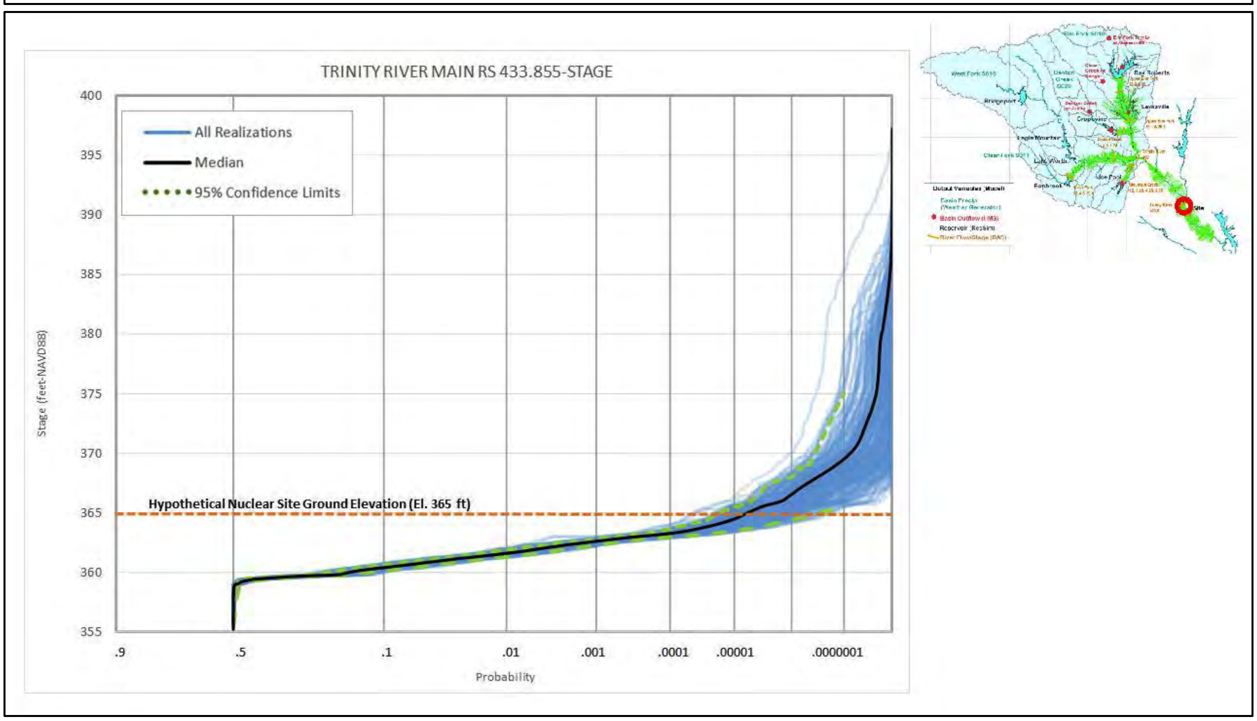

Elm Fork S010 - PRECIP-INC - 48 Hour AccumDurationMax
All Realizations
Median
95% Confidence Limits
Precipitation (in)
Probability
100
90
80
70
60
50
40
30
20
10
0
.9
.5
.1
.01
.001
.0001
.00001
.0000001


Ray Roberts Inflow Outflow - FLOW - 72 Hour DurationMax
All Realizations
Median
95% Confidence Limits
Flow (cfs)
Probability
10000000
1000000
100000
10000
1000
100
.9
.5
.1
.01
.001
.0001
.00001
.0000001


Ray Roberts - Breach Elevation
All Realizations
Median
95% Confidence Limits
Flow (cfs)
675
673
671
669
667
665
663
661
659
.9
.5
.1
.01
.001
.0001
.00001
.0000001
Probability


Ray Roberts-Pool Elev 3HOUR
All Realizations
Median
95% Confidence Limits
Elevation (feet-NAVD88)
680
670
660
650
640
630
620
.9
.5
.1
.01
.001
.0001
.00001
.0000001
Probability


ELM FORK UPPER RS 50.033-FLOW
All Realizations
Median
95% Confidence Limits
Flow (cfs)
10000000
1000000
100000
10000
1000
100
.9
.5
.1
.01
.001
.0001
.00001
.0000001
Probability


TRINITY RIVER MAIN RS 433.855-STAGE
All Realizations
Median
95% Confidence Limits
Hypothetical Nuclear Site Ground Elevation (El. 365 ft)
Stage (feet-NAVD88)
400
395
390
385
380
375
370
365
360
355
.9
.5
.1
.01
.001
.0001
.00001
.0000001
Probability

Questions?

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3.5.5 Riverine Panel Discussion (Session 2B-5)

Moderator: Joseph Kanney, NRC/RES/DRA/FXHAB
Nancy Barth, U.S. Geological Survey
Joe Bellini, Aterra Solutions
Robert Mason*,* U.S. Geological Survey
William Lehman*,* U.S. Army Corps of Engineers
Bill Kappel, Doug Hulstrand, Applied Weather Associates

Question:

Nancy, it seemed that from the scope of your presentation that the combinatorics could get out of hand very quickly when you start to combine nonstationarity and the idea of these mixed types. The mixed type could be from different types of storms or it could be coming from changes in the in the watershed over time even if the storm types are the same over a 40-year period. And if the watershed is changing, then you would also need some sort of a mixed model for that. How do you to prioritize or have some sort of target on the number of different mixed types that you think you might tackle?

Nancy Barth:

What we're trying to do is address the question from the highest-level flood attribution for causation. So, we look at those peaks that are directly attributed to atmospheric rivers or snowmelt, the more common primary attributions rather than getting muddied into challenges in the watershed changes. We are trying to keep to more primary causes, more attributable to actual storm typing to get to flood type attributions.

Question:

This question is for Joe Bellini and colleagues. What steps were taken to account for extremes? For example, such as physically possible storms that weren't seen in the record that was used for calibration. There are certainly plausible physical mechanisms for generating an extreme storm, but it just wasn't there on the record. What sort of steps were taken to account for things like that in the weather generator?

Doug Hultstrand:

To account for events that are not in the observed data itself, we rely on the probabilistic side in that we can sample a storm event, look at its rarity and artificially insert that into the time series. The methodology we follow is the SCHADEX methodology, which is common in European countries, where you're taking storms that have occurred in and around the basin that are considered to be transpositionable, and transposing those storms based on a frequency realm from where they occurred to the new storm center location. So that's the method. We ultimately selected several big events with 1000+ year return periods, just south of the basins in the Canadian Rockies and transpositioned them just to the north for several locations.

And when I say transposition, we are transposing the storm in probability realm. Then we can artificially insert that precipitation timeseries into the observed timeseries for the proper season. In this case, they are all June-time events. You can insert those and use the calibrated stochastic model to simulate those upper tail frequency precipitation events. There it becomes an issue. How do you insert?

Bill Kappel:

The bottom line is that it is a plug and play. Of course there are a lot subjective choices that are made in what storms to move, what values to replace, and where in the time frame to replace. But in the end, it's basically replacing an observed event with a much larger event and rerun the time series with that the larger event as if it had occurred there versus what was observed.

Question:

This question is for all panelists. Have you ever been able to confirm the predicted extreme statistical events by some other independent data?

Doug Hulstrand:

In the realm of looking at extreme events, we do an independent analysis when we're trying to quantify the annual exceedance probability of PMP. We do the regional frequency analysis, which is one independent method, and the second is a storm stochastic storm transposition which is a different method. We do these independently and see how the two methods kind of come together to estimate that probability or exceedance probability.

Joe Bellini:

This may address part of the question, at least for the study we did. As I mentioned in the presentation, we did look at an observed annual maximum flows. We developed the frequency curve using Log-Pearson III, sing observed data, not just stochastic data for higher probability frequencies. That might help address that question.

Question:

Any perspective on the use of paleoflood information in the types of flooding analysis that you're doing?

Joe Bellini:

For our study, prior to the stochastic analysis, we used the Bulletin 17 C method. There were some regional paleoflood studies. We incorporated them as basically historical floods. You set the flow ranges and apply the expected moment algorithm to add to the systematic record. In that case, we had about 150 years of systematic record, and we had some additional historical flood records. We used some regional paleoflood data to set some maximum flows for specific periods of time (approximately 600-1200 CE and 1200-1800 CE), before the historic and systematic record began. That informed the statistical analysis of the annual maximum series, which was independently compared to the stochastic analysis we presented on.

Question:

If someone looks at the different talks in this session in terms of riverine flooding, you notice that there are basically three broad use cases: (1) forecasting; (2) real time event response; and (3) prediction and design. Is there any way that we could sort of integrate these together and have a common set of tools that could be used for all these different use cases? Could you see a community model that could address all these uses? Something analogous to the Weather Research and Forecasting (WRF) model developed by the atmospheric sciences community.

Robert Mason:

I don't know that we have a community model that addresses all of the uses, but increasingly we're seeing more and more powerful models that can address multiple uses. It's entirely possible now to do simulations that are for design as well as prediction, and to really use essentially the same chassis, the same elements of the model may be run with slightly different data, but the models are very much the same. We're having conversations within IWRSS about trying to integrate agency models and to do that from two perspectives: one being sort of a design and the other being sort of focus on operations/ forecasting.

William Lehman:

I believe that the community will prevail at some point, and I hope and pray for that day. But you know, everybody has got their turf wars that they live and breathe by. I think that there will always be room for innovation, which means there might be branches and what we need to figure out is how to merge the trunk. The Army Corps of Engineers Watershed Analysis Tool (WAT) and the Corps Water Management System (CWMS) share a common framework for how we sequence events with the WAT being more for planning/design like you were saying and CWMS being more for the real-time response. One thing I will say though is that models are as good as the project that they're built for the reason that they are built. The level of scrutiny on a response or a map to help someone evacuate might be different than a map that is one of 300,000 in a very large uncertainty analysis. What I find is that the scale associated with getting enough events to describe uncertainty sufficiently may be different than getting a really good map for an evacuation. So, to some degree, the models/software themselves may be the same, but the resolution that the model is developed at may differ between applications.

Bill Kappel:

This is always something the public private partnership and being able to utilize and leverage the great work that each these individual agencies and private companies are doing and try to consolidate that into one usable format would be ideal. It’s always a matter of how it’s done. Everybody has different objectives and agendas, but there certainly should be an overarching framework that can consolidate all this into one aspect and usability. This is a multi-agency thing, right? You have meteorology, climatology and hydrology. All these different aspects trying to solve the same types of problems from different angles. It seems obvious that there should be some kind of overarching, all-encompassing aspect to put all these pieces together and to make them usable for everybody.

Joe Bellini:

In the private sector we've had a variety of entities that we support. It ranges from the dam safety community, to dam owners, to communities with levies, to insurers. Both forecasting and combined tools that can increase the ability for forecasting.
When we write an emergency action plan (EAP) or emergency operation plan for a levee system for operating gates and closure structure and so forth, we do link those plans to tools that are available from the federal agencies. And then also closing the gap between pluvial and fluvial (we work mostly in the realm of interior flooding), there's not a lot of tools available for localized flooding. So there are gaps to be filled, not only for design work, but also for helping

communities to improve their forecasting ability to take action well in advance of a flood occurring.

Bill Kappel:

We've obviously had lots of conversations and the conversations continue about how to make these things integrate. There's so much work being done, and in so many different areas. Sometimes there's overlap. Sometimes the work is done in "silos" where we're doing something and somebody else is doing something, and they might not know about it, and vice versa. If there was collaboration between those processes, it would be a much better outcome. For example, just a couple weeks ago during the American Meteorological Society meeting, I was listening to a presentation on some great work being done by UCAR on numerical modeling of PMP estimates and how to bring those together with the deterministic side and the things that have been done over the years by the Weather Service and the Corps of Engineers and private industry. It always comes down to having some leadership and the right people to recognize all the pieces that are out there and figuring out a way to put all the pieces together in a way that's most efficient and usable for the widest range of communities, versus a bunch of work being done individually, and not leveraging off of each otherwhere it makes sense. I don't know the answer to that, but certainly we all recognize it and we have to figure out a way to put those pieces together.

Robert Mason:

I just wanted to mention that even on Monday we had a discussion with NOAA about coupling of our models. The PowerPoint was titled "Coupling Our Models" and the point of the discussion was not just to say we'll take NWS rainfall and add it to a USGS model.It was that we will take an element of a particular model and try to put that element, perhaps with another element from another agency or yet another supplier. I don't know that we will have a single model, but I think that we will see greater integration of them as we go forward.

Moderator:

So, if I paraphrase your answer to say that maybe interoperability is a more reasonable or maybe a preferable goal than a community model. Would that be a fair statement?

Robert Mason:

I won't say that it's preferable, but I say that it's achievable.

3.6 Day 3: Session 3A – Poster Session

3.6.1 Poster 3A-1: Flood Fragility Function Methodology for a Conceptual Nuclear Power Plant

Authors: *Joy Shen*, Michelle Bensi, Mohammad Modarres*; *University of Maryland*

Presenter: Joy Shen

Abstract: Fragility functions quantify the probability that a structure or component will be damaged or fail at a certain intensity measure (IM) of hazard severity (e.g., flood height). Due to limited experience in external flooding probabilistic risk assessment (PRA) in the nuclear energy sector, flooding fragility function development has not been a practical priority for nuclear power plants (NPPs). As a result, there is a gap in the literature related to flooding fragility assessments to support NPP PRAs. However, recent flooding events at Fukushima Daiichi NPP, Fort Calhoun NPP, and other facilities have highlighted the importance of advancing this field. The poster will present a conceptual, illustrative example of an emergency diesel generator (EDG) building with flood barrier components that act as protective measures during an external flood. In addition, this poster will include a brief description of the fragility function development for flood barriers such as penetration seals, doors, floodgates, and louver covers. The data gathered from a literature review and the conservative deterministic failure margin (CDFM) method is used to derive fragility parameters. This information is then used to determine damage states and their associated leakage rate as the external flood enters the building as a result of varying degrees of flood protection damage. Leakage rates and internal flood heights are generated from illustrative geometry and representative hazard characteristics.

Poster Material (ML22061A118):

Flood Fragility Function Methodology for a Conceptual Nuclear Power Plant

Joy Shen, Dr. Michelle Bensi, and Dr. Mohammad Modarres
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College Park, MD 20742
jshen132@umd.edu; mbensi@umd.edu; modarres@umd.edu

Introduction

- Risks of external flooding events are increasingly relevant
  - Climate change affecting flooding patterns
- Flood fragility functions are not robustly developed in current literature
- External flood PRAs are conservative

- Objectives:
  - Develop external flood fragility methodology
  - Convert external to internal flood height

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Overview of Fragility

$$\Pr[g_k(\boldsymbol{X}, \boldsymbol{\theta}) \leq 0 | S = s]$$

- $g_k(\boldsymbol{X}, \boldsymbol{\theta})$: Limit State Function comprised of demand and capacity
- $\boldsymbol{X}$: Vector of random variables representing capacity and demand
- $\boldsymbol{\theta}$: Vector of parameters of limit state function
- S: Hazard Intensity/Severity Measure

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Overview of High-Confidence-Low-Probability-of-Failure (HCLPF)

- Assume lognormal distribution
- Mean fragility curve can be estimated using HCLPF capacity
  - HCLPF Capacity can find the median capacity of a component

$$C_{50\%} = C_{HCLPF} e^{2.326\beta_C}$$

  - Composite standard deviation is the combination of aleatory and random uncertainty
  - Given by ASCE standard for SSC design in NPPs for this case study

$$\beta_C = \sqrt{\beta_R^2 + \beta_U^2}$$

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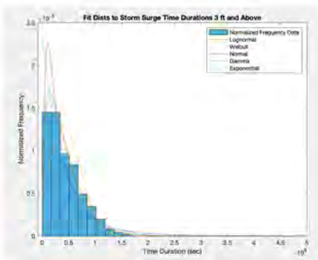
Converting External to Internal Flood Height

$$(h_{2in} - h_{1in}) = \frac{\left(\sqrt{2g(h_{2ext} - h_{1ext})}A_f\right) * \left(\boldsymbol{T}(\boldsymbol{h_{2ext}} > \boldsymbol{h})\right)}{l_{in} * w_{in}}$$



Obtained flood duration from NACCS study

Example Conversion of External to Internal Flood Height		
External Flood Height	Volumetric Flow Rate	Internal Flood Height
$h_2 = 0ft$	$Q = 0\frac{ft^3}{s}$	$0ft$
$h_2 < 3ft$	$Q = 0\frac{ft^3}{s}$	$0ft$
$h_2 < 4ft$	$Q = 1.44\frac{ft^3}{s}$	$61092\ ft$
$h_2 < 7ft$	$Q = 2.89\frac{ft^3}{s}$	$97869.85\ ft$
$h_2 < 15ft$	$Q = 5.00\frac{ft^3}{s}$	$61000\ ft$
$h_2 < 18ft$	$Q = 5.60\frac{ft^3}{s}$	$0\ ft$

Future Work

- Develop fragility functions for internal components
- Use fragility functions to inform Bayesian networks
- Develop 3D fragility and hazard surfaces with flood duration and flood height
- Correlations
  - Among components
  - Between flood height and flood duration

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Conclusion

- Flood Fragility Methodology
  - Demonstrated external flood fragility development using HCLPF capacity
  - Developed a conversion of external to internal flood height

The authors acknowledge and appreciate research support received from the A. James and Alice B. Clark Foundation. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of the funding organization.

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3.6.2 Poster 3A-2: Quantifying Uncertainty in Hurricane Warning Times to Inform Coastal Hazard PRA

Authors: *Somayeh Mohammadi*, Michelle Bensi; University of Maryland*

Presenter: *Somayeh Mohammadi*

Abstract:

Nuclear power facilities and other critical infrastructure are often located in coastal regions exposed to the effects of tropical cyclones (e.g., hurricanes and tropical storms). These facilities may employ response strategies that involve actions to install temporary protection or mitigation features. The effectiveness of response strategies may be adversely affected by hardware failures. In addition, there is also a possibility that actions will be unsuccessful due to delayed organizational decision-making, human errors, and differences between the predicted and experienced coastal hazard characteristics. Accurate coastal hazard probabilistic risk assessments for critical infrastructure such as nuclear power facilities must include human reliability assessments that quantify the probabilities that protection and mitigation actions will be unsuccessful. These probabilities depend on the information available to support decisions and the environmental conditions under which actions are performed. A critical input to the human reliability assessment is the time available to perform actions. However, this estimated time is subject to uncertainty due to uncertainty in hurricane and tropical storm forecasts. This study seeks to quantify the uncertainty in the time available to execute actions that are triggered based on storm advisories. Uncertainty assessments are developed using NOAA GIS datasets related to advisory/forecast and observed storm track data from 2012 to 2020. Specifically, the differences between advisory forecasted track data (e.g., predicted landfall locations and times) at various time points are compared against the final observed track. This provides insights into the likelihood that the time available to perform proceduralized actions triggered by advisory information will be longer or shorter than assumed.

Poster Material (ML22061A117):

Quantifying Uncertainty in Hurricane Warning Times to Inform Coastal Hazard PRA

Somayeh Mohammadi, Michelle Bensi

University of Maryland, College Park
Department of Civil and Environmental Engineering,
College Park, MD, United States

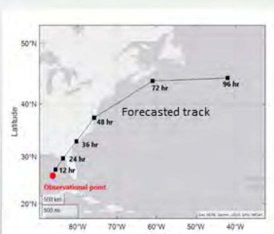
7th Annual NRC PFHA Research Workshop
(February 15-18, 2022)

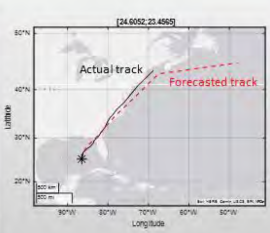
Motivation

Context/assumption:

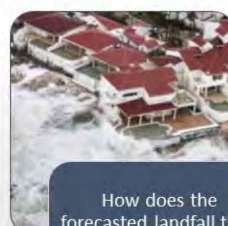
When a hurricane is being monitored, plants will typically initiate proceduralized actions when a storm is forecasted to make landfall in the vicinity of a plant within x hours (e.g., 48 hours)

This "trigger" for action determines the assumed "time available" to complete actions (e.g., for use in HRA/PRA).



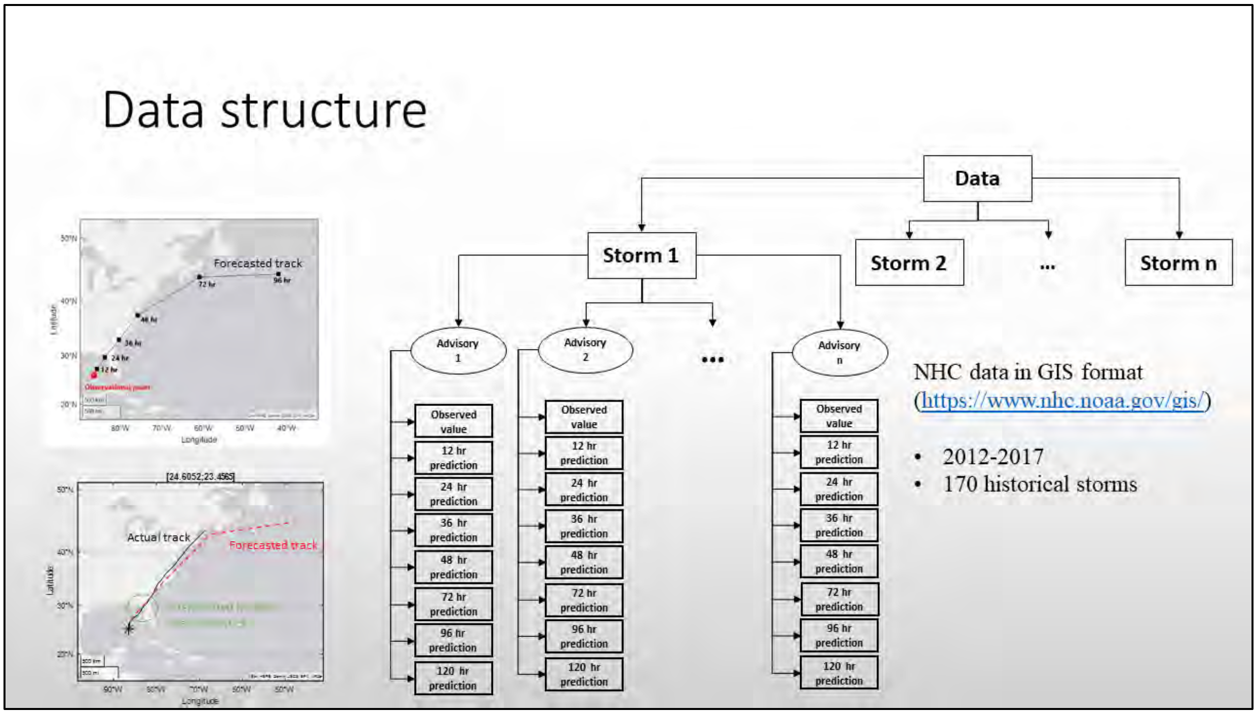


Storm is predicted to make landfall in 12/24/48/72/96/120 hours.



How does the forecasted landfall time differ from actual landfall time?

What is the uncertainty in time available to complete actions?


Data structure
Data
Storm 1
Storm 2
...
Storm n
Advisory 1
Advisory 2
Advisory n
Observed value
12 hr prediction
24 hr prediction
36 hr prediction
48 hr prediction
72 hr prediction
96 hr prediction
120 hr prediction
NHC data in GIS format (https://www.nhc.noaa.gov/gis/)
• 2012-2017
• 170 historical storms
Forecasted track
Actual track
Forecasted track
[24.6052,23.4565]
Latitude
Longitude

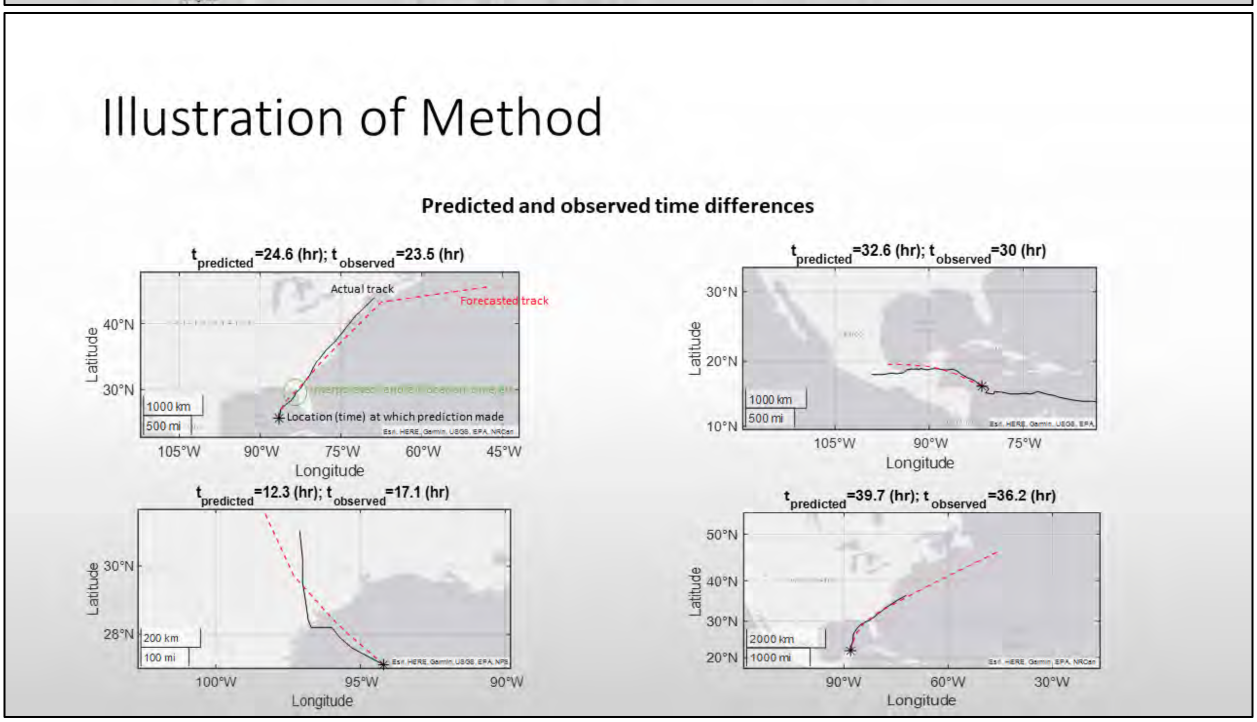
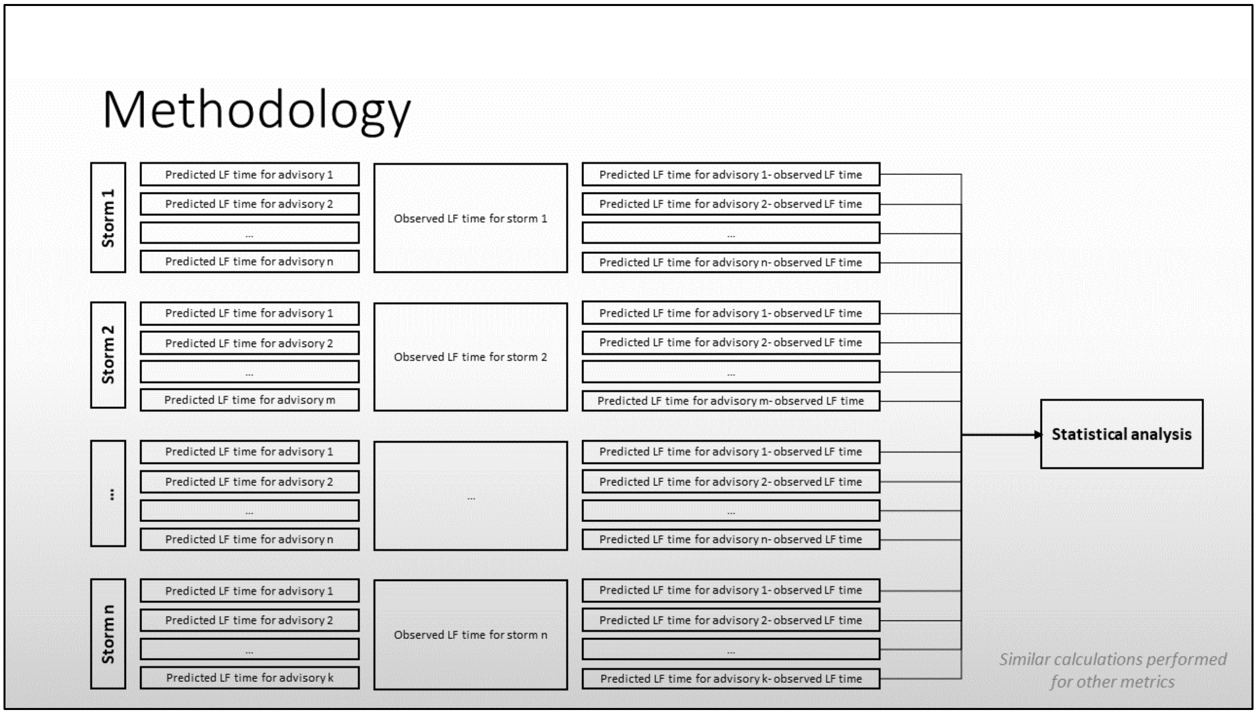
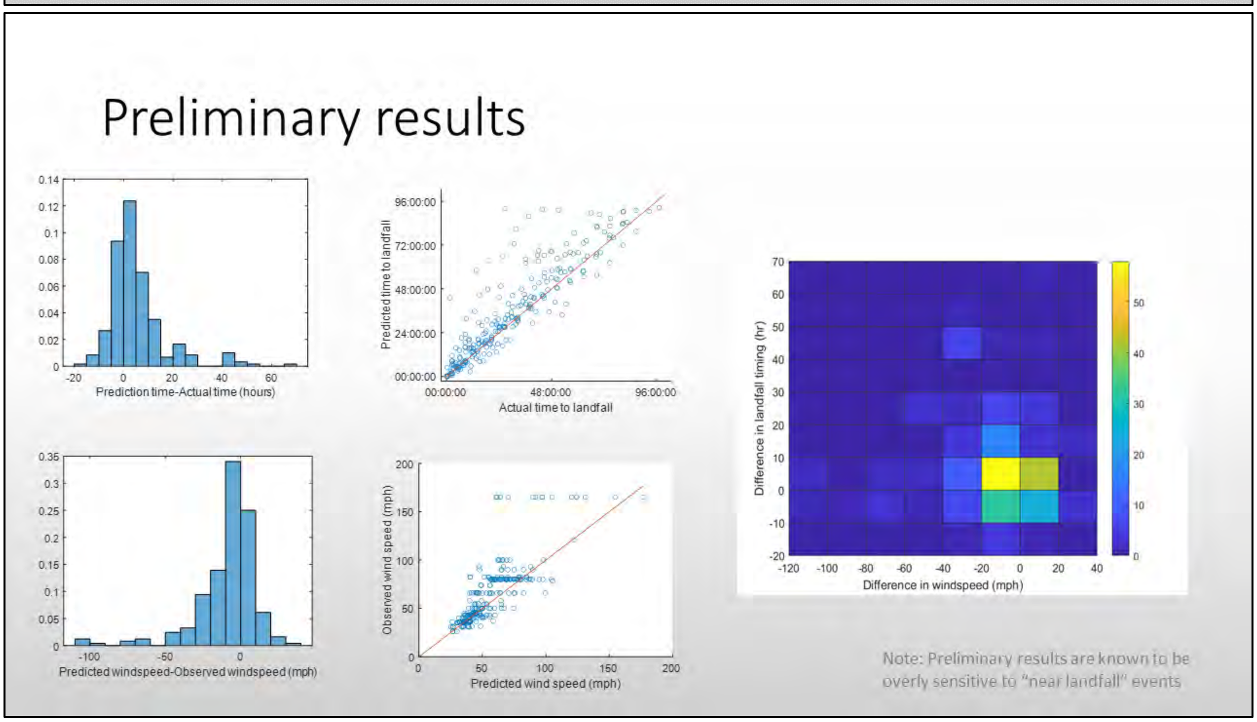
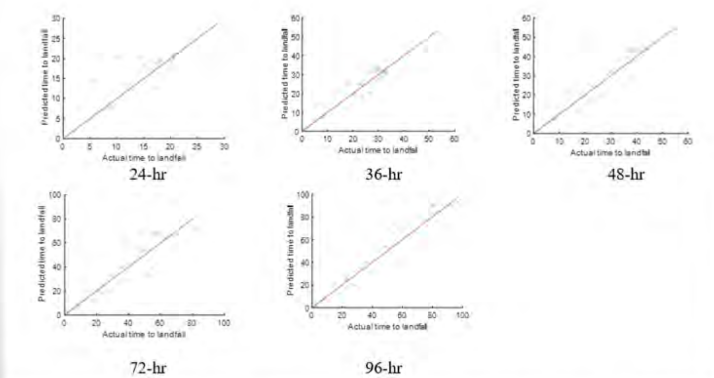


Illustration of Method
Predicted and observed time differences
t predicted =24.6 (hr); t observed =23.5 (hr)
Actual track
Forecasted track
Location (time) at which prediction made
t predicted =32.6 (hr); t observed =30 (hr)
t predicted =12.3 (hr); t observed =17.1 (hr)
t predicted =39.7 (hr); t observed =36.2 (hr)
Latitude
Longitude


Methodology
Storm 1
Predicted LF time for advisory 1
Predicted LF time for advisory 2
...
Predicted LF time for advisory n
Observed LF time for storm 1
Predicted LF time for advisory 1- observed LF time
Predicted LF time for advisory 2- observed LF time
...
Predicted LF time for advisory n- observed LF time
Storm 2
Predicted LF time for advisory 1
Predicted LF time for advisory 2
...
Predicted LF time for advisory m
Observed LF time for storm 2
Predicted LF time for advisory 1- observed LF time
Predicted LF time for advisory 2- observed LF time
...
Predicted LF time for advisory m- observed LF time
...
Predicted LF time for advisory 1
Predicted LF time for advisory 2
...
Predicted LF time for advisory n
...
Predicted LF time for advisory 1- observed LF time
Predicted LF time for advisory 2- observed LF time
...
Predicted LF time for advisory n- observed LF time
Storm n
Predicted LF time for advisory 1
Predicted LF time for advisory 2
...
Predicted LF time for advisory k
Observed LF time for storm n
Predicted LF time for advisory 1- observed LF time
Predicted LF time for advisory 2- observed LF time
...
Predicted LF time for advisory k- observed LF time
Statistical analysis
Similar calculations performed for other metrics


Preliminary results
Prediction time-Actual time (hours)
Predicted time to landfall
Actual time to landfall
Difference in landfall timing (hr)
Difference in windspeed (mph)
Predicted windspeed-Observed windspeed (mph)
Observed wind speed (mph)
Predicted wind speed (mph)
Note: Preliminary results are known to be overly sensitive to "near landfall" events

Preliminary results

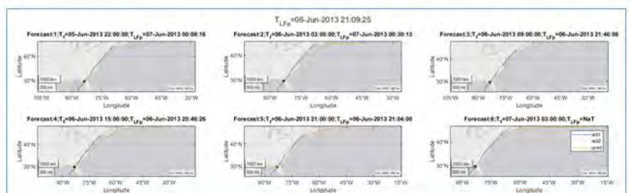


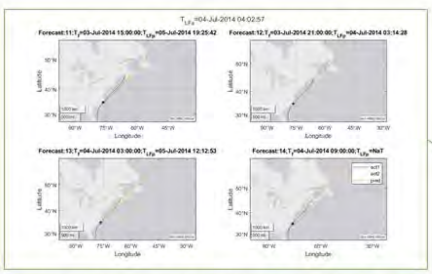
Scatter plot of predicted time to landfall and actual time to landfall for different target times to take protective actions

Target time periods	Correlations
24-hr	70%
36-hr	73%
48-hr	78%
72-hr	82%
96-hr	84%

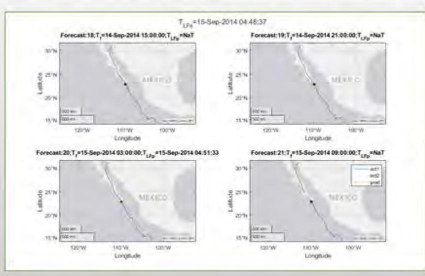
Correlation between predicted time to landfall and actual time to landfall for different target times

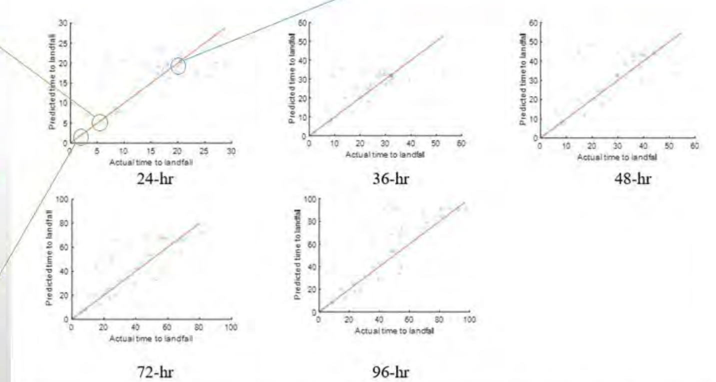
Note: Preliminary results are known to be overly sensitive to "near landfall" events





Challenge: Results are overly sensitive to "near landfall" events

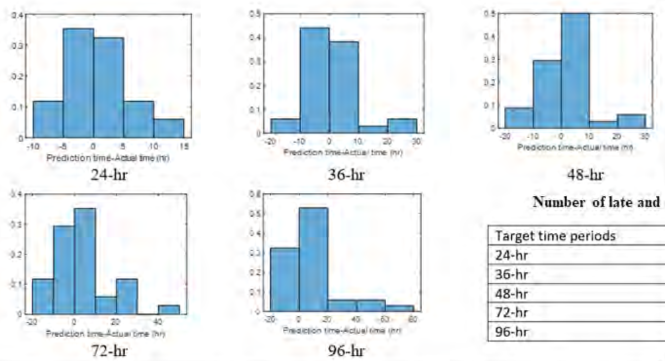




Scatter plot of predicted time to landfall and actual time to landfall for different target times to take protective actions

Preliminary results

Estimated difference between the first predicted and observed landfall times for different procedure "trigger" times



Histogram of time differences between predicted and observed landfalls for different target time periods

Number of late and early predictions for landfalling storms for different target times

Target time periods	Late predictions	Early predictions	Total predicted landfalls
24-hr	17 [51.5%]	16 [48.5%]	33
36-hr	16 [48.5%]	17 [51.5%]	33
48-hr	20 [60.6%]	13 [39.4%]	33
72-hr	19 [57.6%]	14 [42.4%]	33
96-hr	23 [67.6%]	11 [32.4%]	34

Note: Preliminary results are known to be overly sensitive to "near landfall" events

Next steps

- Modify geospatial algorithm to address issues with sensitivity to "near landfall" events
- Extend the analysis beyond "centerline analyses" to consider wind radii and forecast cone of uncertainty
- Conduct the analysis for longer duration of data
- Develop distributions for the uncertainty in time available to perform actions as well as other storm characteristics
- Analyze the uncertainty related to other storm parameters including:
  - Central pressure deficit
  - Storm forward velocity
  - Heading direction

Thank you

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The authors acknowledge and appreciate research support received from The Department of Energy, Nuclear Energy University Program. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of the funding organization.

3.6.3 Poster 3A-3: HEC-WAT Interface and Set Up for the Trinity River PFHA Pilot Project

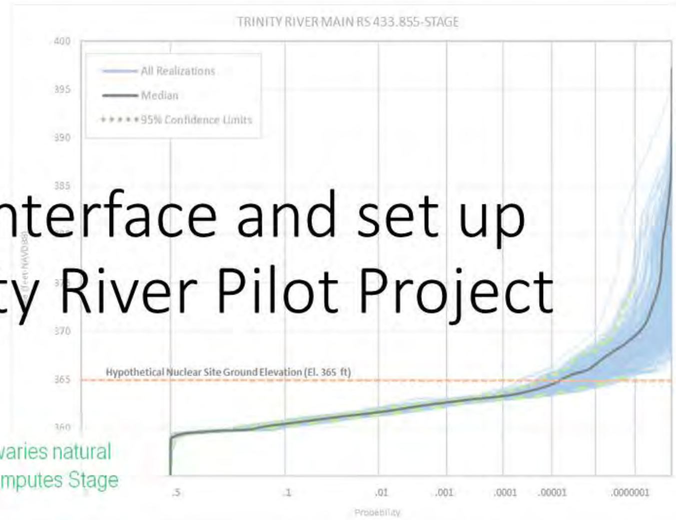
Author: David Ho*, William Lehman, Brennan Beam, Sara O'Connell, Leila Ostadrahimi
U.S. Army Corps of Engineers, Hydrologic Engineering Center

Presenter: David Ho

Abstract: The Nuclear Regulatory Commission's (NRC) Probabilistic Flood Hazard Analysis (PFHA) utilized Hydrologic Engineering Center Watershed Analysis Tool (HEC-WAT) to provide a quantitative relationship between of the probability of occurrence (or frequency) and magnitude for various flood hazards. HEC-WAT was applied to the Trinity River watershed to demonstrate a method of producing stochastic outputs required for the PFHA. The modeling effort required a number of different applications or "plugins" to perform the PFHA analysis. This poster will show the Trinity River HEC-WAT interface, how the project was set-up for the modeling, which plugins were added, and how the model order was selected.

Poster Material (ML22061A116):

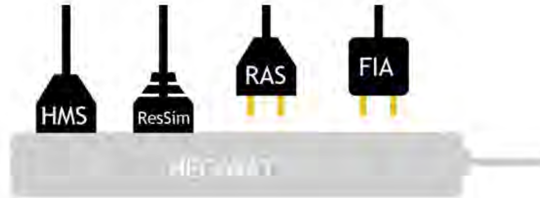
HEC-WAT Interface and set up for the Trinity River Pilot Project



Story Map

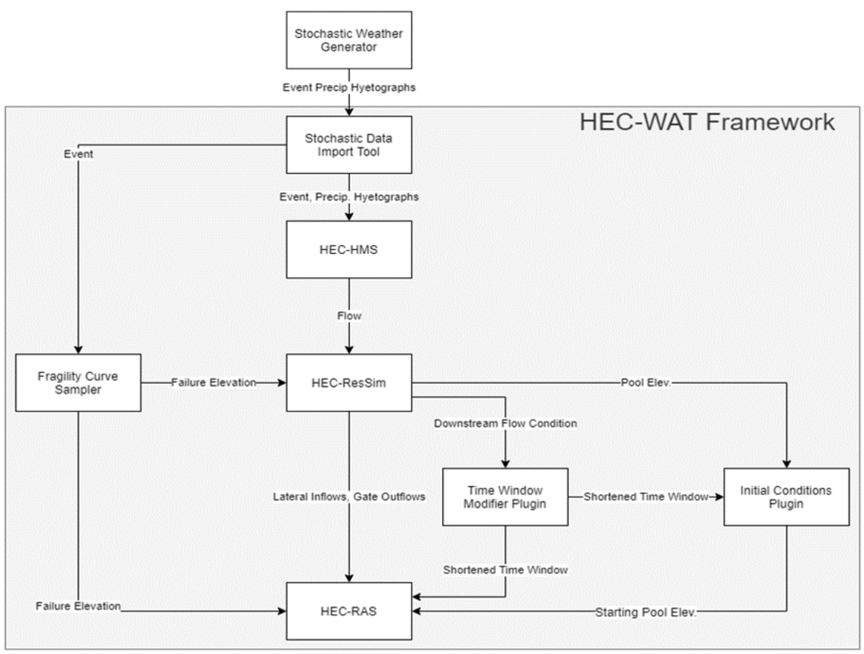
- https://storymaps.arcgis.com/stories/1f1242cf6f834cef9662aa420dc1b14e

Plugin Architecture



- Plugins during Compute
  - Stochastic Data Importer
    - Take in the weather generator data and pass to hydrologic model
  - HEC-HMS
    - Hydrologic Model to generate hypothetical flows
  - Fragility Curve
    - Probability of dam failure for a given elevation
  - HEC-ResSIM
    - Reservoir simulation model to compute regulated flows
  - Time Window Modifier
    - Changes the time window of the simulation for RAS model
  - Initial Conditions
    - Link the starting pool and outflows assumptions between HEC-RAS and HEC-ReSIM
  - HEC-RAS
    - Hydraulic Model for computing dam breaks, flood stages and river velocities
  - RASCAL
    - Troubleshooting RAS results
  - RasXSMAX
    - Extracted the maximum depth and velocity from RAS HDF output and set as an output variable
  - Duration
    - Computes max average duration, max accumulated duration, stage/flow/velocity over threshold

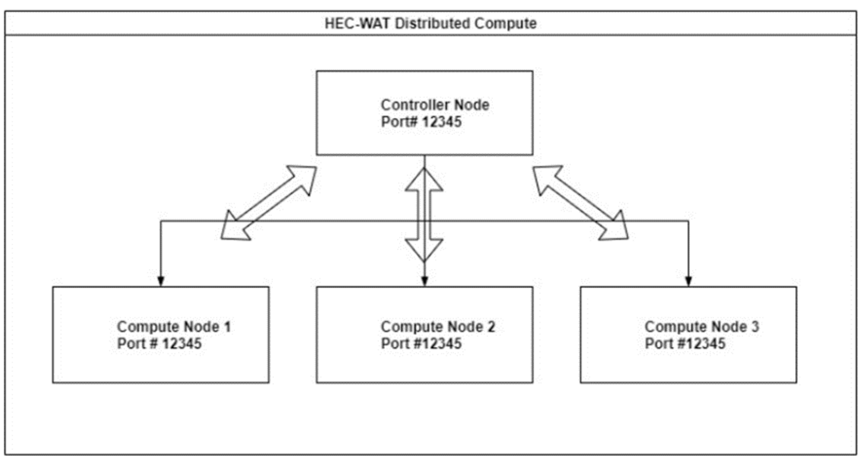
https://www.hec.usace.army.mil/confluence/display/WATPlug/HEC-WAT+Plugin+Development+Guide

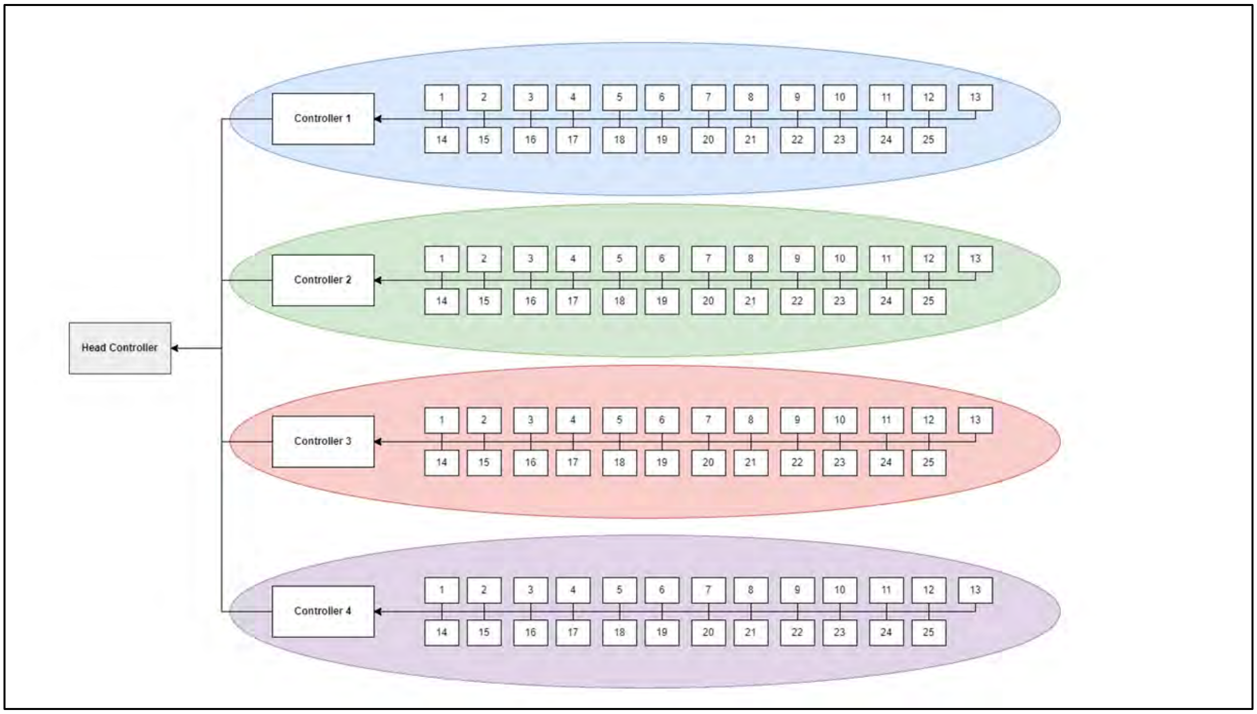


Plugin Architecture

- Post Processing Plugins
  - Confidence Builder
    - Computes user defined confidence intervals, de-stratifies output variables, simplifies plotting using Ramer-Douglas-Peuker algorithm
  - DCInvestigator
    - Reviews computed simulation dss file for missing lifecycles and/or events
  - Merger
    - Merge files computed from distributed compute into a single dss

Distributed Compute




Head Controller
Controller 1
Controller 2
Controller 3
Controller 4
1 2 3 4 5 6 7 8 9 10 11 12 13
14 15 16 17 18 19 20 21 22 23 24 25

3.6.4 Poster 3A-4: Riverine Flooding HEC-WAT Pilot Project Dam Break Modeling

Authors: *Brennan Beam*, William Lehman, Sara O'Connell, David Ho, Leila Ostadrahimi*
U.S. Army Corps of Engineers, Hydrologic Engineering Center

Presenter: *Brennan Beam*

Abstract:

This poster describes how the Hydrologic Engineering Center's Watershed Analysis Tool (HEC-WAT) is being used to include dam failure in their probabilistic flood hazard assessment (PFHA) process. The technical details associated with viewing a system wide dam failure for a single event using HEC-RAS and HEC-ResSim is the primary focus of the poster.

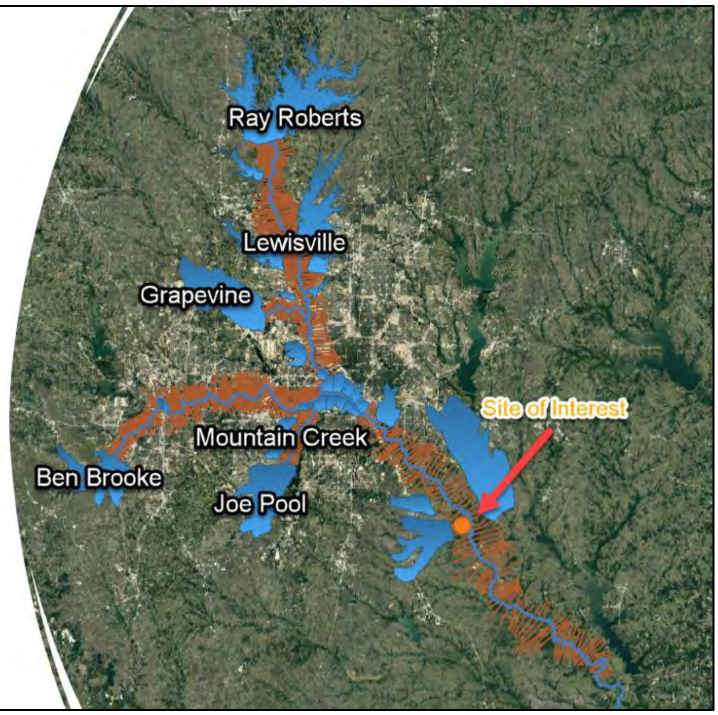
Poster Material (ML22061A115):

HEC-WAT Hydraulics for PFHA

Brennan B. Beam PE, CFM
USACE Hydrologic Engineering Center

Hydraulic Model

- Trinity River Watershed
- Dallas, TX
- Six Breaching Dams
- Two Sets in Series



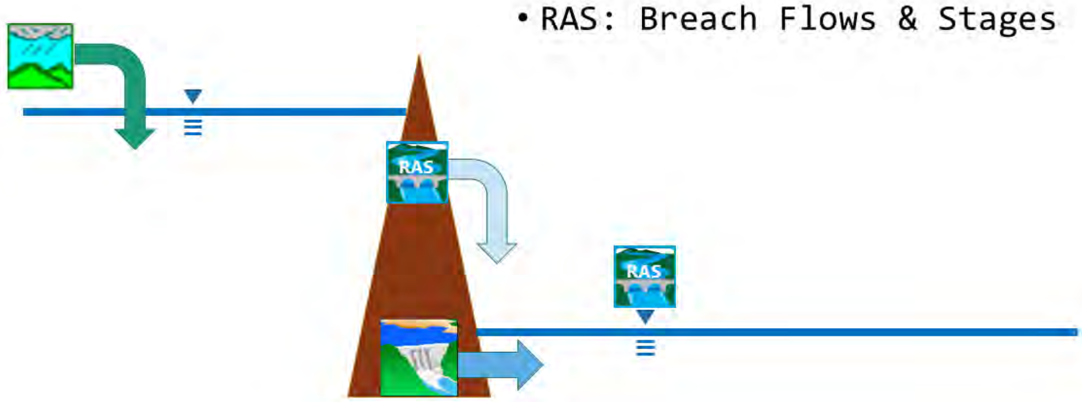
Unique Challenges

- Reservoirs are modeled in two different software (ResSim & RAS)
- Model must remain stable, appropriate, and efficient for a wide range of events.

3

The Overview

- HMS: Inflows
- ResSim: Operations
- RAS: Breach Flows & Stages



4

Shared Modelling of Reservoirs

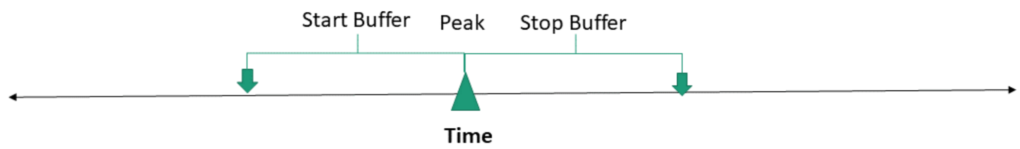
ISSUES

- How do we set the Time window for RAS?
- How do we set the initial condition in RAS?

5

Defining the Time window

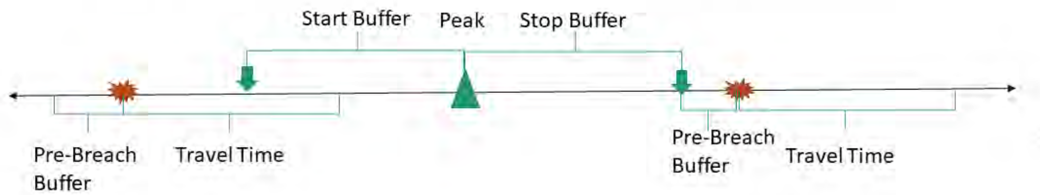
- Define the anchor point. We want to extend the time window out from the Peak Flow in Dallas calculated in the ResSim model.
- Define a generous window around this.
  - START: Capture pre-event flows
  - STOP: Account for the difference in ResSim routing flows, and RAS's hydraulic solution.



6

Defining the Time Window (2)

- Ensure we capture all dam breaches
  - START: Capture any Dam Breach occurring prior to the peak, plus a buffer.
  - STOP: Capture any Dam Breach after the peak, and it's travel time

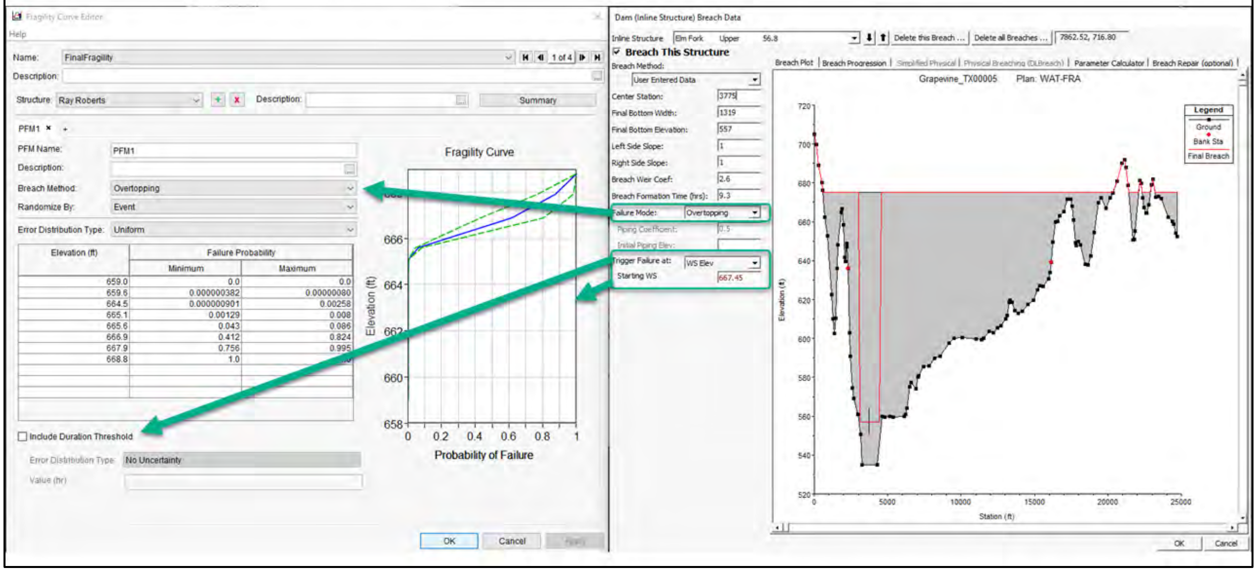


Setting Initial Conditions

- Set by the Initial Conditions Plugin
- Mines Values from the Starting timestep in the RAS Adjusted Time window.
- Need to set
  - Initial Flows out of Reservoirs
  - Initial Elevations of both US Cross Section and Storage Areas for Reservoirs
- The initial stream profile in the RAS Model is set by running the initial flows to steady state before beginning the actual timeseries simulation.

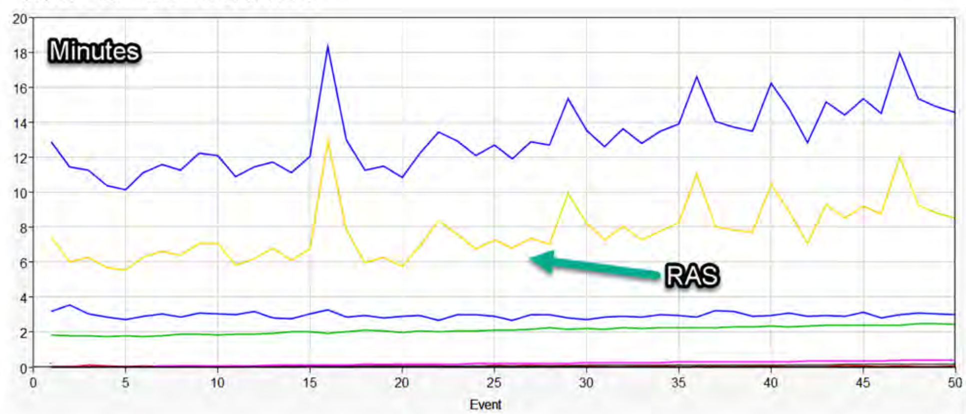
8

Modelling Breaches in HEC-RAS



A Moment of Panic

- First 2 Realizations take 20hrs instead of 10.
- Who’s to blame?



10

Building for Stability

- Modelling Decisions
  - Represent overbanks as Storage Areas instead of 2D
  - Removing Bridge decks and represent as XS
  - Adjust XS Spacing / Computational Timestep
  - Ensure Smooth Volume Elevation Curves
- Computational Options
  - Adjust Output Timestep
  - Adjust Solution Tolerances
  - Adjust Stability Coefficients
  - Change Solver

11

Paradiso vs Gaussian Solver

- Gaussian is the RAS default. Runs on a single core of your processor.
- Pardiso is less efficient but runs on multiple cores.

Solver	LC20-20 Compute Time	LC520-20 Compute Time
Gaussian	3:43	2:31
Pardiso (2-Core)	4:43	2:46
Pardiso (4-Core)	NA	2:49

12

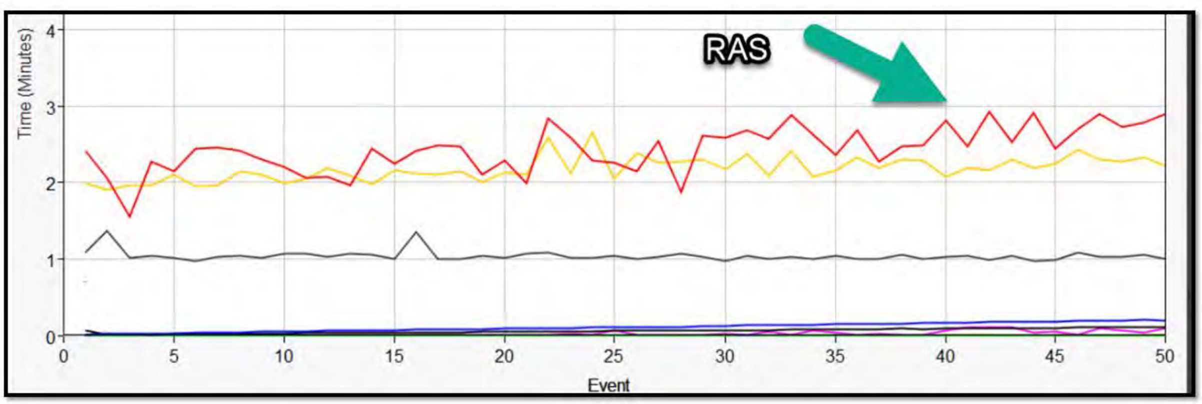
Inline Structure Stability

As this coefficient increases, it dampens the first guess of the computation engine projecting an upstream energy slope. Increasing it theoretically increases computation time in stable locations, but can stabilize difficult inline structures, resulting in less instability.

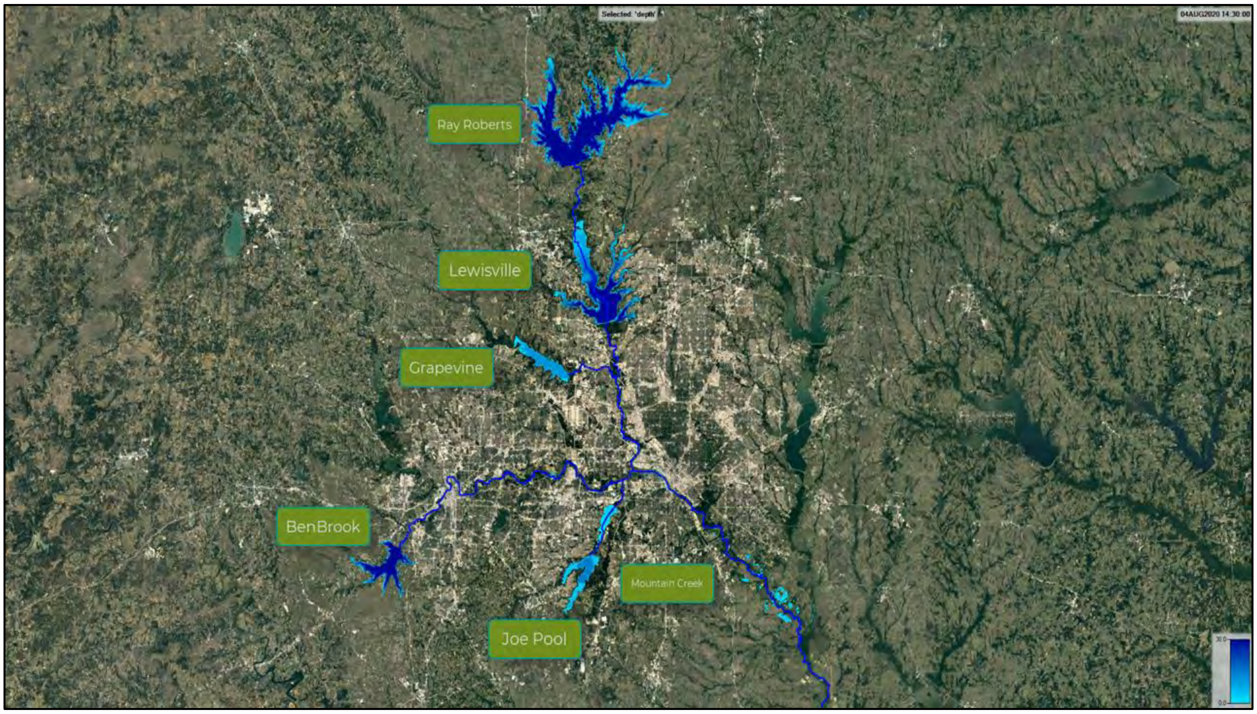
Stability Factor	LC20-1 Compute Time
1	8:57
3	5:58

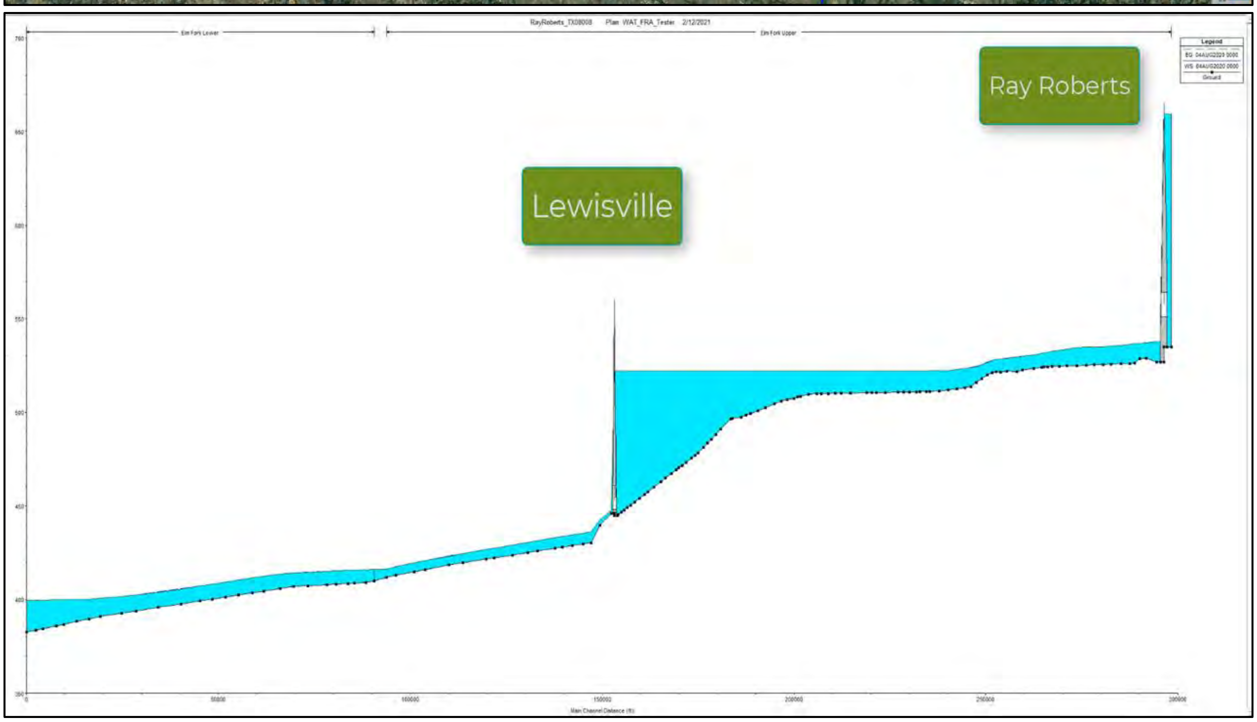
13

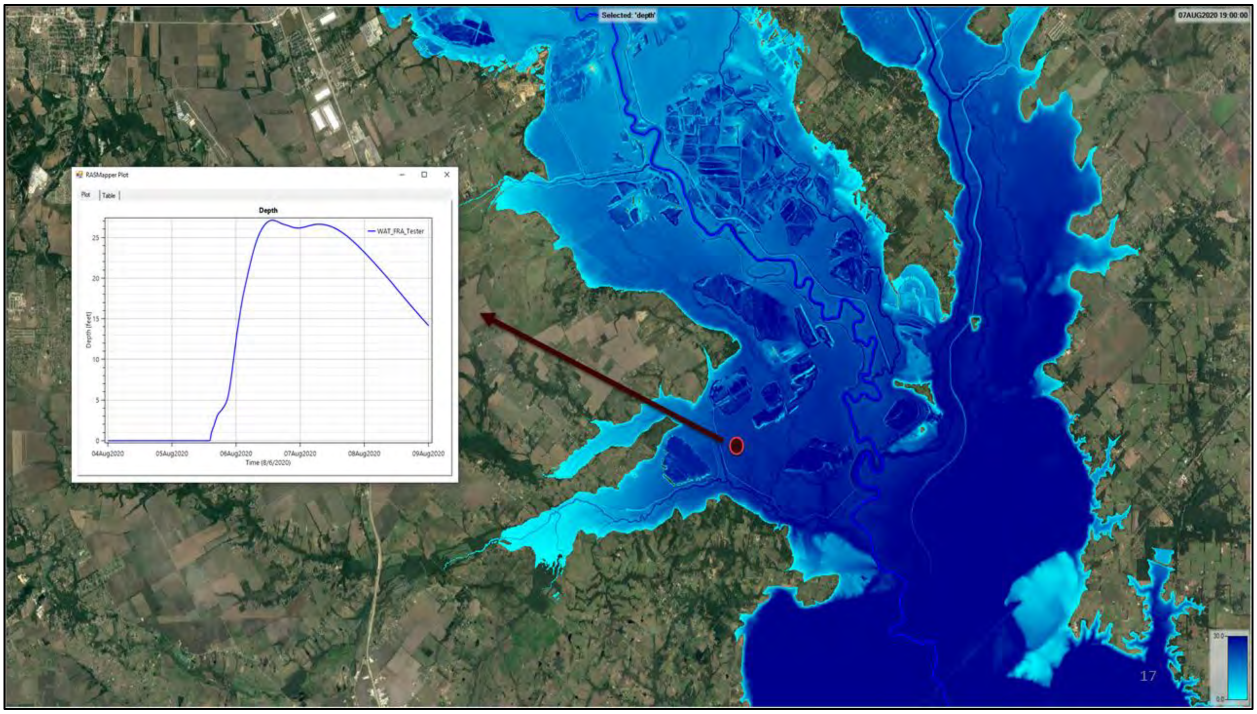
SUCCESS!



14


Ray Roberts
Lewisville
Grapevine
BenBrook
Mountain Creek
Joe Pool


Lewisville
Ray Roberts


Selected: "depth"
07AUG2020 19:00:00
RASMapper Plot
Plot
Table
Depth
WAT_FRA_Tester
Depth (feet)
0
5
10
15
20
25
04Aug2020
05Aug2020
06Aug2020
07Aug2020
08Aug2020
09Aug2020
Time (8/6/2020)
17

3.6.5 Poster 3A-5: Flooding from Below – The Groundwater Emergence Hazard

Author: *Kevin M. Befus*[1], Patrick L. Barnard[2], Peter W. Swarzenski[2], Clifford Voss[2]*
[1]*University of Arkansas,* [2]*U.S. Geological Survey*

Presenter: *Kevin M. Befus*

Abstract:

Shallow groundwater levels create hidden flood hazards via 'groundwater emergence'. In such areas, thin vadose zones could accentuate compound flooding events, and rising water tables could reach the ground surface and flood low lying areas. Even without groundwater emergence, a shoaling groundwater table can reduce the effectiveness and lifespans of coastal urban and rural infrastructure, such as storm drains, shoreline armoring, and other buried assets, as well as potentially remobilize soil contaminants. Wetter regional climate, more frequent and intense storms, focused urbanization and projected sea-level rise are just a few processes that will likely expand future zones of groundwater emergence in some regions. Downstream coastal communities and associated infrastructure are most at risk to the compounded effects of prolonged or chronic groundwater emergence. Numerical simulations of the California coastal region illustrate the expansive extent and nuances of shoaling and groundwater emergence hazards today and predict a substantial increase in groundwater-flooded areas with future sea-level rise. Low-lying areas are most vulnerable to flooding hazards from below due to groundwater emergence, as well as to episodic marine overland flooding and quasi-permanent inundation. Overall, societal exposure to shallow and emergent groundwater with rising sea levels was projected to be 6-9 times higher than overland flooding by the end of the century for coastal California. Thus, responsive flood protection policy and infrastructure should account for not only marine overland flooding but also for groundwater flooding from below. Ongoing work will extend these simulations to coastal aquifers across the southeastern United States.

Poster Material (ML22061A114):

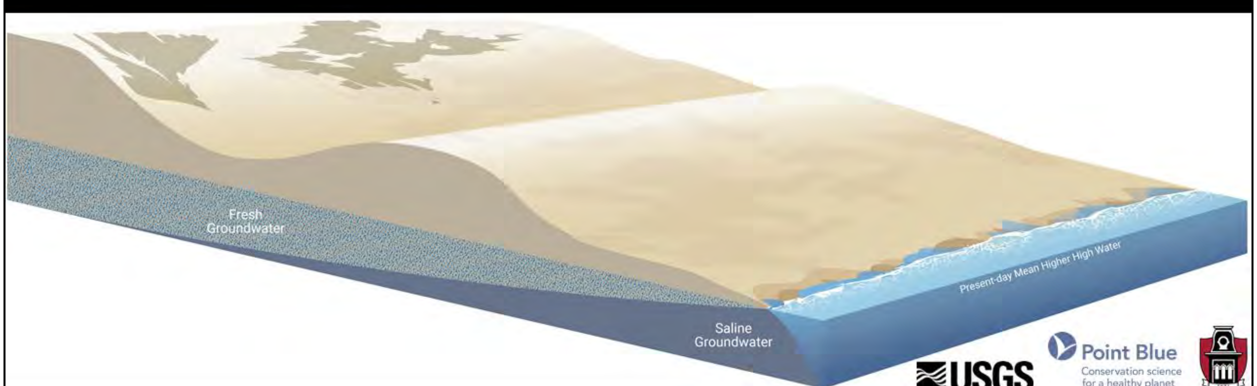
Flooding from below – the groundwater emergence hazard

PFHA 2022
WS7

Kevin M. Befus[1], Patrick L Barnard[2], Peter W. Swarzenski[2], and Cliff Voss[3]

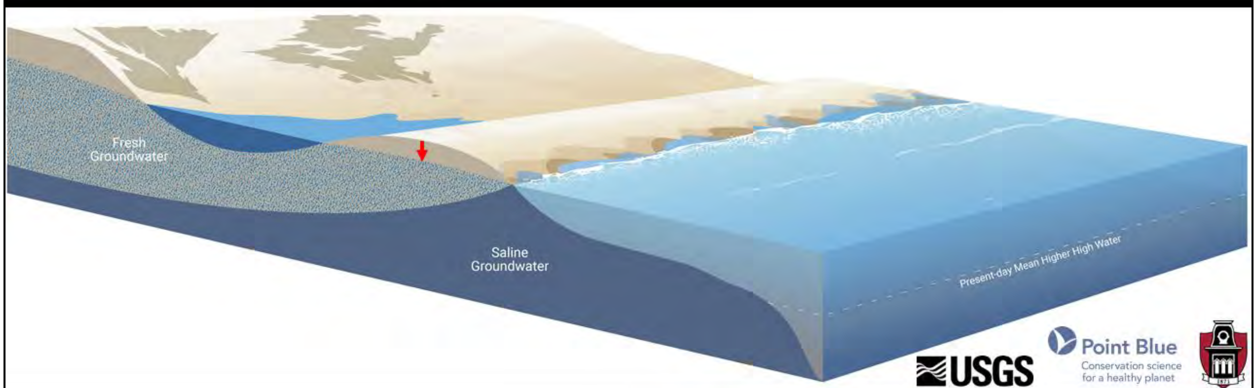
[1]University of Arkansas
[2]USGS Pacific Coastal and Marine Science Center
[3]USGS Water Science Mission Area, Emeritus

How sea-level rise affects the groundwater table



How sea-level rise affects the groundwater table

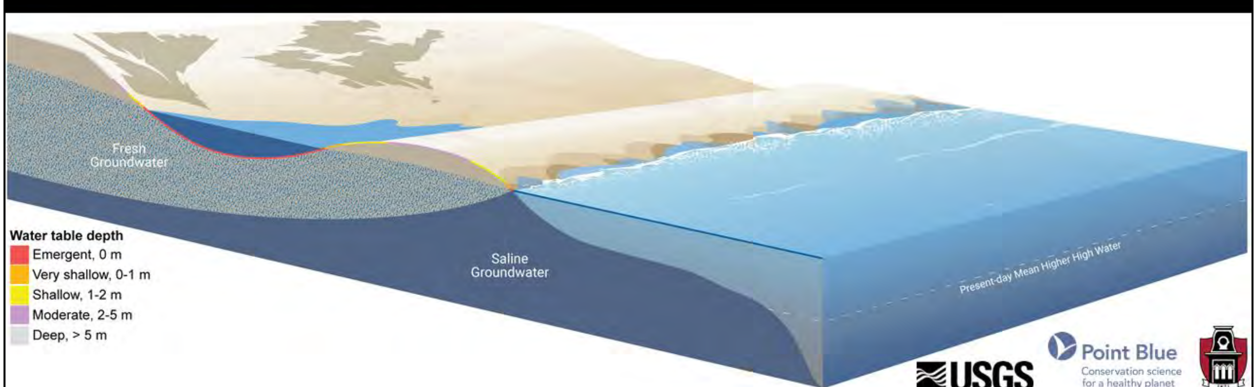
[redacted]



[redacted]

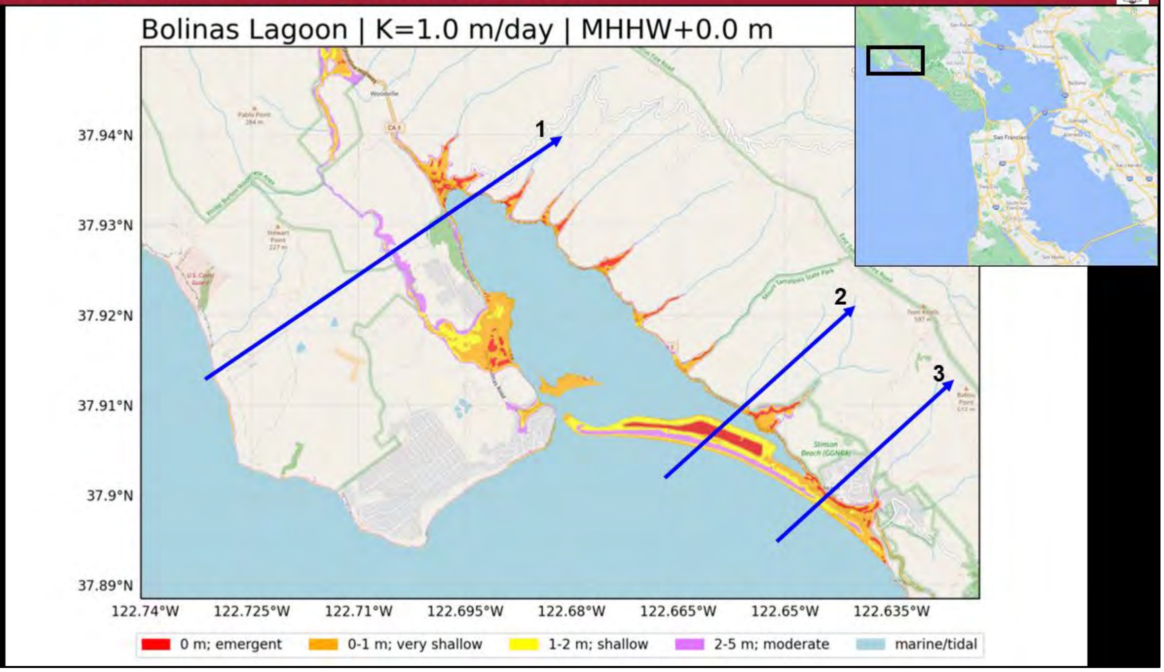
Depth to the groundwater table

[redacted]

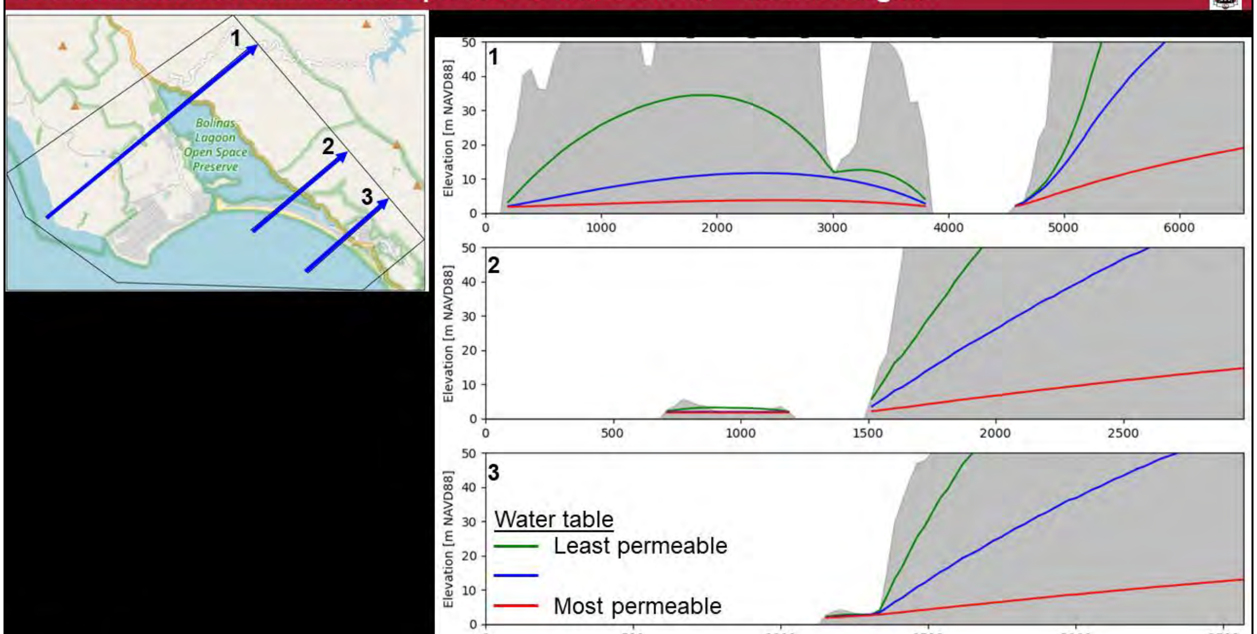


[redacted]

Water table depths for Bolinas Lagoon/Stinson Beach,

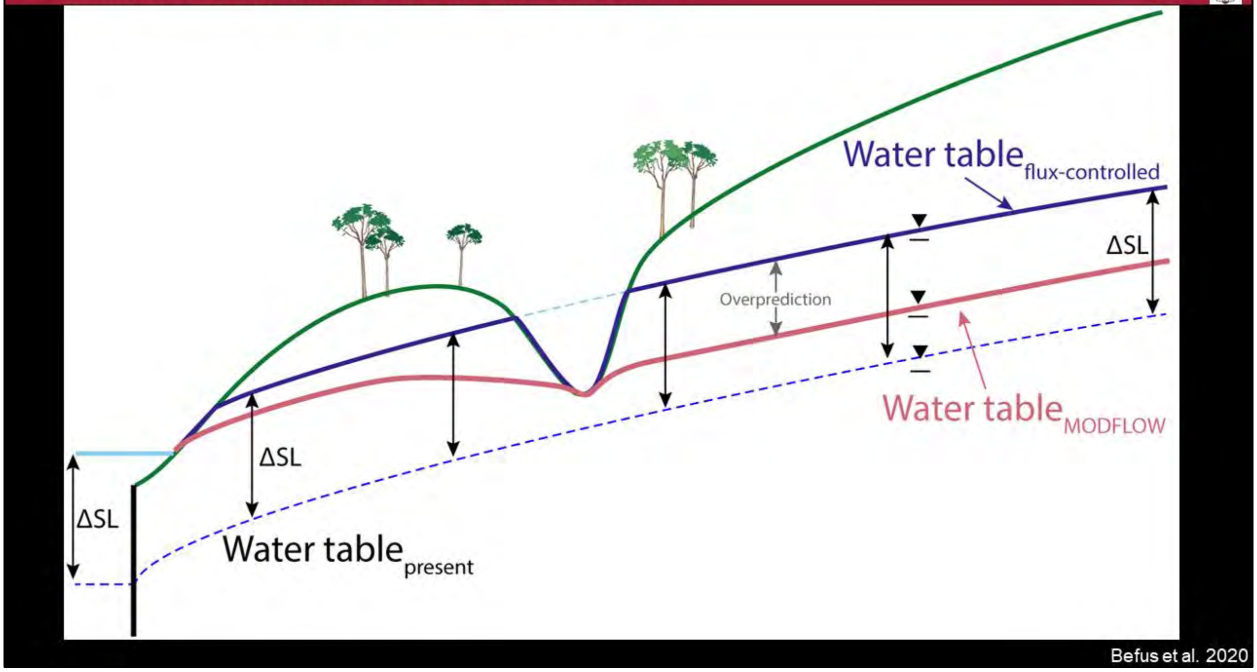


Cross sections of water table responses to sea-level rise – Bolinas Lagoon

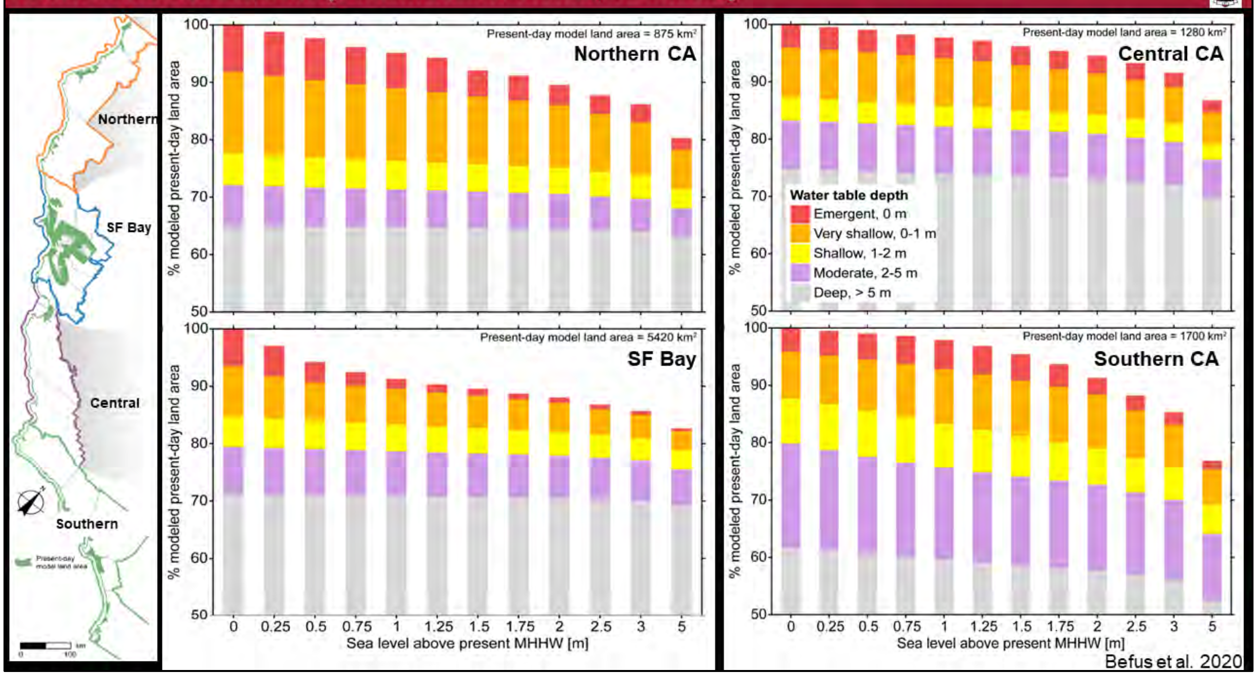


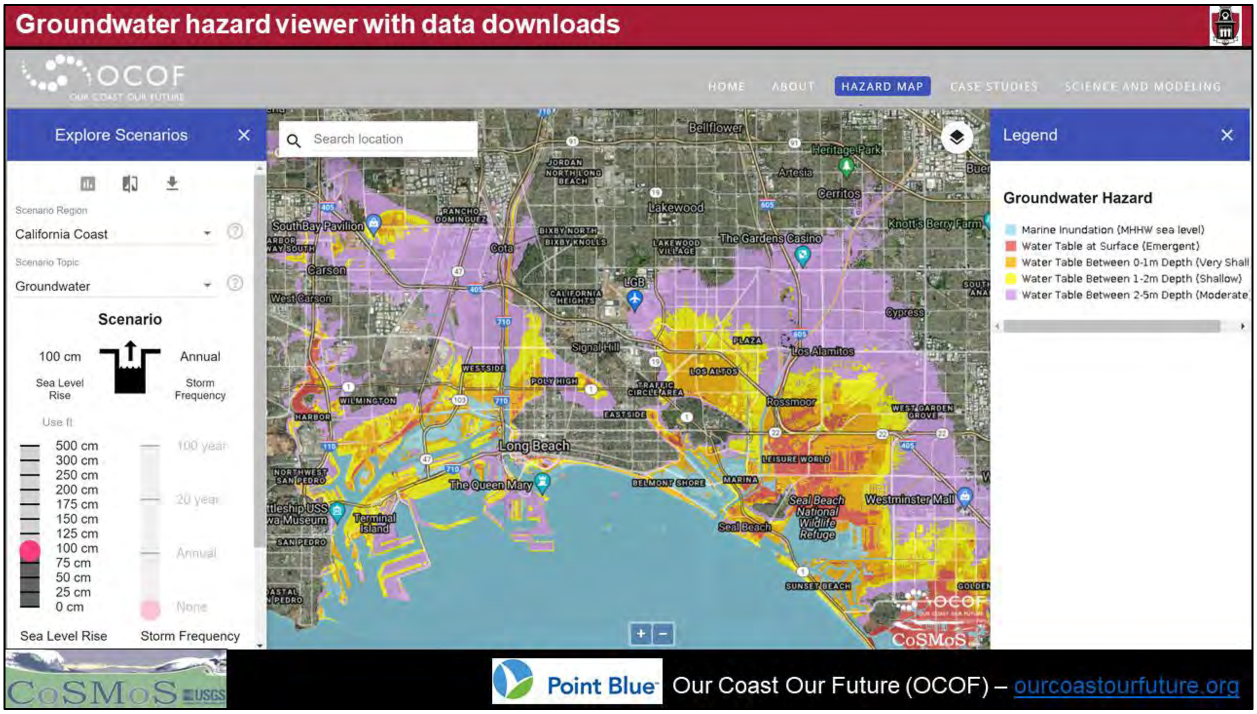
Befus et al. 2020

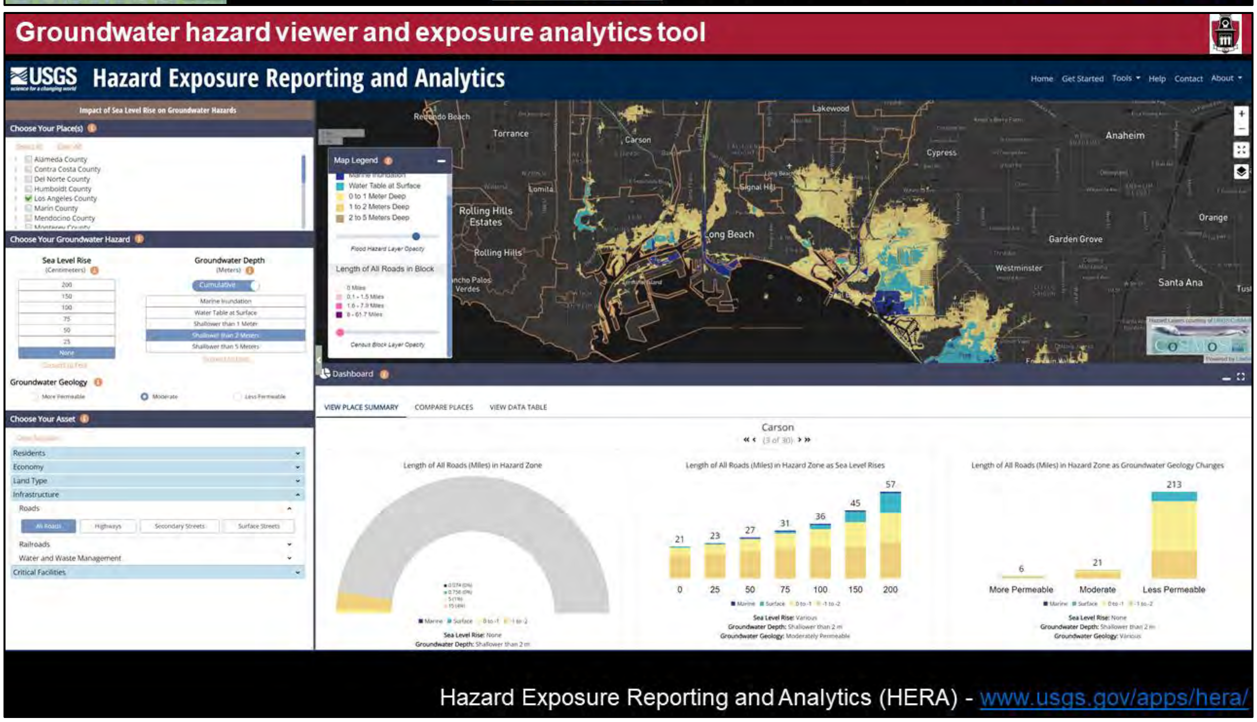
How much does a water table rise with sea-level rise?



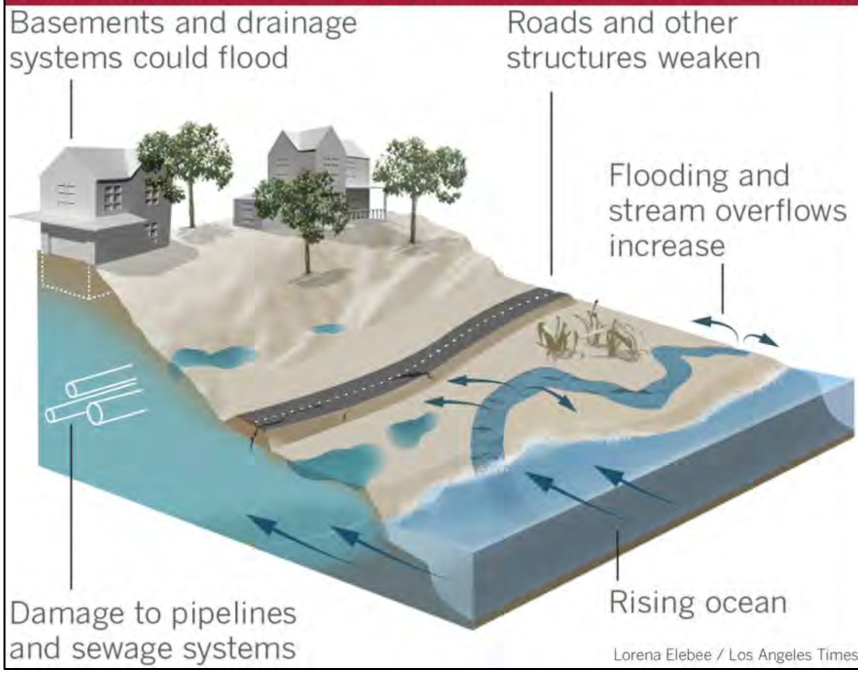
Water tables become deeper with sea-level rise, K=1 m/day




Groundwater hazard viewer with data downloads
OCOF
HOME
ABOUT
HAZARD MAP
CASE STUDIES
SCIENCE AND MODELING
Explore Scenarios
Scenario Region
California Coast
Scenario Topic
Groundwater
Scenario
100 cm
Sea Level Rise
Annual
Storm Frequency
500 cm
300 cm
250 cm
200 cm
175 cm
150 cm
125 cm
100 cm
75 cm
50 cm
25 cm
0 cm
100 year
20 year
Annual
None
Sea Level Rise
Storm Frequency
Search location
Long Beach
Legend
Groundwater Hazard
Marine Inundation (MHHW sea level)
Water Table at Surface (Emergent)
Water Table Between 0-1m Depth (Very Shall
Water Table Between 1-2m Depth (Shallow)
Water Table Between 2-5m Depth (Moderate
CoSMoS
Point Blue
Our Coast Our Future (OCOF) – ourcoastourfuture.org


Groundwater hazard viewer and exposure analytics tool
USGS
Hazard Exposure Reporting and Analytics
Home
Get Started
Tools
Help
Contact
About
Impact of Sea Level Rise on Groundwater Hazards
Choose Your Place(s)
Alameda County
Contra Costa County
Del Norte County
Humboldt County
Los Angeles County
Marin County
Mendocino County
Choose Your Groundwater Hazard
Sea Level Rise
Groundwater Depth
Groundwater Geology
Choose Your Asset
Residents
Economy
Land Type
Infrastructure
Roads
Railroads
Water and Waste Management
Critical Facilities
Map Legend
Water Table at Surface
0 to 1 Meter Deep
1 to 2 Meters Deep
2 to 5 Meters Deep
Length of All Roads in Block
Dashboard
VIEW PLACE SUMMARY
COMPARE PLACES
VIEW DATA TABLE
Carson
Length of All Roads (Miles) in Hazard Zone
Length of All Roads (Miles) in Hazard Zone as Sea Level Rises
Length of All Roads (Miles) in Hazard Zone as Groundwater Geology Changes
21
23
27
31
36
45
57
0
25
50
75
100
150
200
6
21
213
More Permeable
Moderate
Less Permeable
Hazard Exposure Reporting and Analytics (HERA) - www.usgs.gov/apps/hera/

Societal impacts from rising groundwater: exposure vs vulnerability

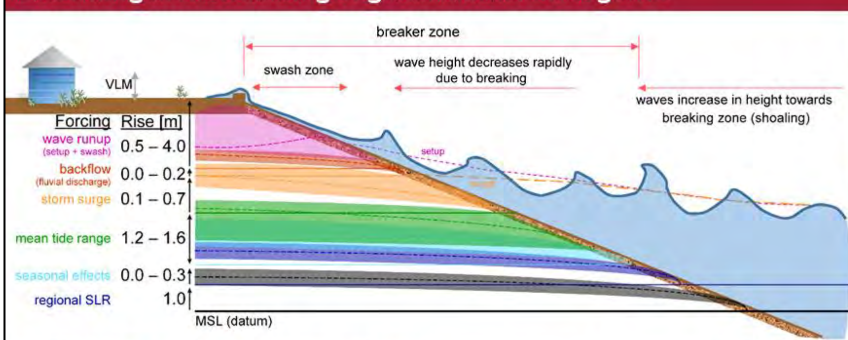


California (2 m of SLR)

- **4 million residents**
- **$1.1 trillion in property**
- **33,000 km of roads**
- **3,000 critical facilities (e.g., schools, police stations, hospitals)**

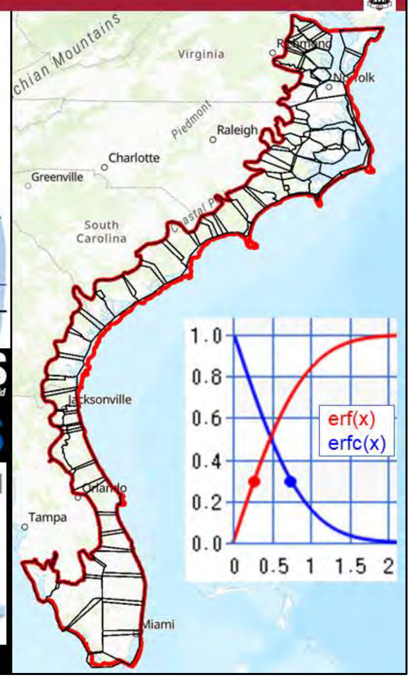
***6-9 times greater exposure then overland flooding**

Extending understanding of groundwater emergence



Point Blue
CoSMoS USGS
green way
Sea Grant University of Southern California
USGS science for a changing world
NOAA NCCOS

after Sutton-Grier et al. 2015 & www.fisheries.noaa.gov/insight/understanding-living-shorelines



Data and code availability

1. Paper
   doi.org/10.1038/s41558-020-0874-1

nature climate change — ARTICLES
https://doi.org/10.1038/s41558-020-0874-1

Increasing threat of coastal groundwater hazards from sea-level rise in California

K. M. Befus[1,2], P. L. Barnard[3], D. J. Hoover[3], J. A. Finzi Hart[3] and C. I. Voss[4]

2. Water table depths and groundwater head data: doi.org/10.5066/P9H5PBXP
   USGS science for a changing world — ScienceBase-Catalog

3. Saline groundwater wedge footprints data: hydroshare.org/resource/1c95059edcf041a0959e0b4a1f05478c/
   HYDROSHARE

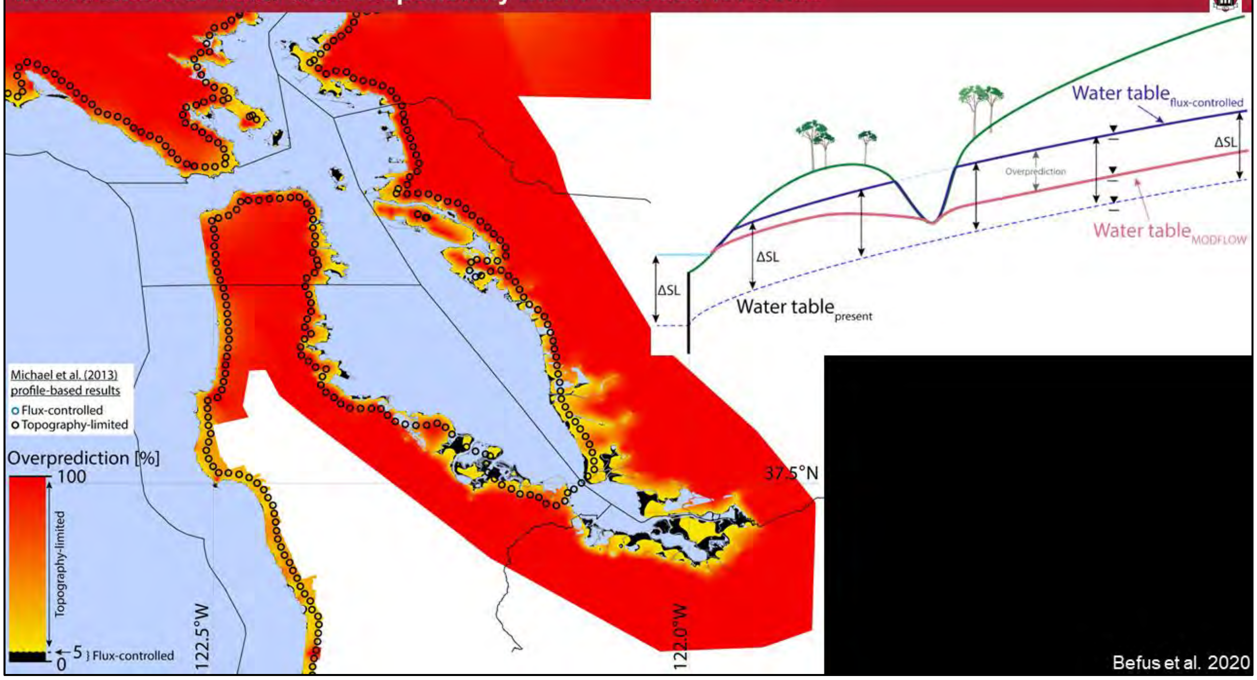
4. Python scripts: github.com/kbefus/ca_gw_slr

5. Interactive web maps and applications:

   Our Coast Our Future (OCOF) – ourcoastourfuture.org
   Hazard Exposure Reporting and Analytics (HERA) - www.usgs.gov/apps/hera/

Funding provided by
OCEAN PROTECTION COUNCIL
USGS

Inland extent of water table responsivity with 1 m of sea-level rise



Befus et al. 2020

3.6.6 Poster 3A-6: External Flooding PRA Guidance

Author: *Marko Randelovic*[1], Raymond Schneider*[2]*
[1]*Electric Power Research Institute (EPRI),* [2]*Westinghouse Company*

Presenter: *Marko Randelovic*

Abstract:

EPRI is currently developing a guidance for performing an external flood PRA for use in the nuclear industry. The guidance establishes a structured framework for treating the spectrum of external flood hazards and provides background materials and examples for the PRA analyst to use. Specifically, the project aids the PRA analyst in:

1) Defining and characterizing the external flood hazard, considering event and plant-specific issues.

2) Estimating external flood hazard frequencies.

3) Developing external flood fragility curves for flood significant Systems, Structures, and Components (SSCs).

4) Preparing an external flood event tree, including consideration of actions preparing the plant for the flood, mitigating the flood hazard, and responding to random and flood-induced failures of initial flood mitigation strategies.

Guidance is being developed to be consistent with expected requirements of the ASME/ANS PRA Standard. To facilitate understanding simple hypothetical example applications illustrate the interface with the probabilistic flood hazard assessment (PFHA), parsing the flood analysis to characteristic event frequencies and the development of various PRA flood event trees and overall quantification overall process. This guidance also includes a potential screening approach for the flood related combined/correlated hazards.

Poster Material (ML22061A113):

External Flooding PRA Guidance

7th Annual Probabilistic Flood Hazard Assessment Workshop

Marko Randelovic - Principal Technical Leader, EPRI
Ray Schneider, Fellow Engineer, Westinghouse

February 17, 2022

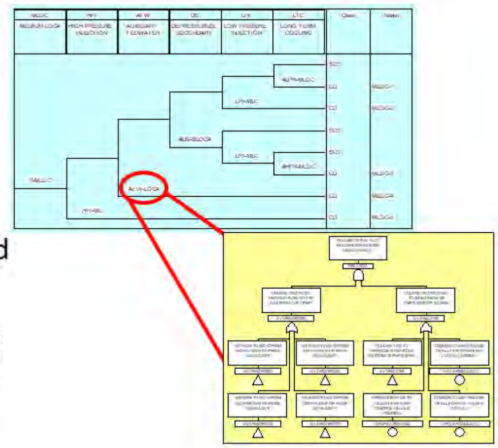
www.epri.com

Background

- Past EPRI projects have provided guidance supporting implementation of the ASME/ANS PRA Standard to assess risks of internal and external hazards.
- The current project expands the external flood PRA effort by integrating available information on external flood modeling to develop a practical methodology for the development of the external flooding PRAs
- Flood related combined/correlated hazards screening methodology is currently being developed and will be captured in the final draft of the External Flooding PRA guidance
- Lessons learned from the past external flood events will supplement the External Flooding PRA guidance and provide practical guidance in preparing for and mitigating external floods at NPPs

External Flood Guidance for Probabilistic Risk Assessment

- Provides a structured roadmap for performing an External Flood PRA (XFPRA) consistent with meeting requirements of the ASME/ANS PRA Standard.
- Includes guidance for:
  - Defining and characterizing the external flood hazard
    - Including estimation of external flood hazard frequencies, severity and associated uncertainties
  - Identifying flood induced failure modes and develop external flood fragility curves for flood significant Systems, Structures, and Components (SSCs).
  - Preparing and quantifying a PRA external flood event tree.



External Flood Guidance for Probabilistic Risk Assessment

- Guidance uses baseline internal events and internal flood PRAs as basis for developing relevant flood-induced failures for the External Flood PRA.
- Guidance is structured consistent with the ASME/ANS PRA Standard
- Guidance builds upon prior relevant EPRI references for hazard screening and example PFHA studies for representative NPPs
- Where available and appropriate USACE and NRC documents and methods are identified to support both PFHA and fragility assessments
- Methodology has been reviewed by EDF and found to be consistent with the EDF external flood PRA process

External Flood PRA Process

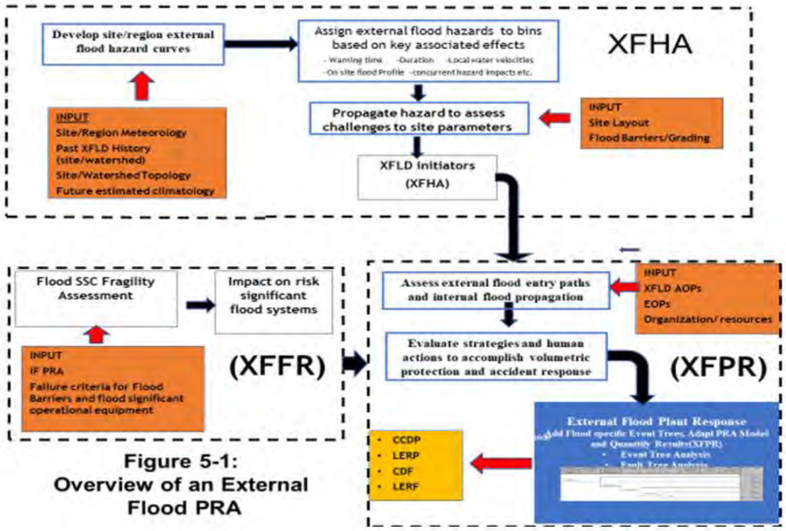


Figure 5-1:
Overview of an External Flood PRA

Flood Related Combined Hazards

- Process extends External Flood Hazard identification and characterization to consider impact of secondary flood and other coexistent hazards
- Provides basis for more realistic treatment of complex flood hazards for External Flood PRAs
- Process uses a framework that extends the EPRI Combined Hazard Screening Process (developed initially in EPRI TR 3002005287)
- Focus on characterization of complex flood hazards by identification of combined hazards and their respective impact on external flood PRA scenarios

Flood Related Combined Hazards

- Approach includes potential for considering multiple coexistent hazards within the External Flood PRA model
- Identifies those coexistent hazards that should be considered within the site-specific external flood hazard including those that may be Correlated, Consequential or Random
- Structured process provides a vehicle for evaluating completeness of primary External Flood PRA characterization; supplemental matrix identifies treatment considerations identified within the matrix

Practical Insights from External Flood Events

- New task to present insights from operational experiences to support development of actionable guidance/ recommendations for developing flood hazard coping and mitigation strategies.
- Focus is on lessons learned from external flood events and findings at Fort Calhoun Station but will also consider insights from regulatory and international experience.
- Guidance supports development, validation, and improved procedural guidance and overall preparedness for responding to external flood challenges.

Major 2022 Project Activities

- Comparison between EPRI and EDF External Flooding PRA methodologies and combined hazards screening approach - In progress (target end of April)

- Final draft available for NRC-RES review – May 2022

- Draft EPRI white paper on the Operating Experience and Lessons Learned – July 2022

3.7 Day 3: Session 3B – Coastal Flooding

Session Chair: Joseph Kanney, NRC/RES/DRA

3.7.1 Presentation 3B-1: An Overview of CSTORM Model Development and Results for the South Atlantic Coastal Study (SACS)

Authors: *Margaret Owensby*[1], Thomas Massey[1], Tyler Hesser[1], Mary Bryant[1], Andrew Condon[2]*
[1]*U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center, Coastal and Hydraulics Laboratory,* [2]*USACE Jacksonville District*

Speaker: *Margaret Owensby*

3.7.1.1 Abstract

The U.S. Army Corps of Engineers (USACE) South Atlantic Division and the Engineer Research and Development Center (ERDC) have been engaged in a large, multi-year project called the South Atlantic Coastal Study (SACS). Following the precedent of other large coastal studies within the USACE, such as the North Atlantic Coastal Comprehensive Study (NACCS), the SACS study was designed to identify and assess coastal hazards risks in the domain of concern on a regional scale and to support future resilience and sustainability efforts in coastal communities. Probabilistic coastal hazards analysis using a state-of-the-art innovative statistical and probabilistic framework for the comprehensive characterization of storm climatology was applied as part of one component of this study. Modeling was performed using the high-resolution Coastal Storm Modeling System (CSTORM-MS), and advanced joint probability analysis of atmospheric forcing and primary storm responses, including associated aleatory and epistemic uncertainties, was conducted. The study was broken into three domains: 1) the southern U.S. East Coast ranging from the border of North Carolina and Virginia to the southern tip of Florida, 2) the Gulf Coast from the southern tip of Florida to the Mississippi and Louisiana state boundary, and 3) Puerto Rico and the U.S. Virgin Islands. The focus of this presentation is on the South Atlantic (SA) and Gulf of Mexico (GoM) domains, for which 1700 unique synthetic tropical storm events, 15 historical tropical storms, and 70 historical extratropical events were simulated for present-day sea level as well as two sea level rise scenarios. An overview of the CSTORM model development and validation process for the two domains will be given, along with details about the storm suite and water levels. A summary of the modeled results and their inclusion in the Coastal Hazards System (CHS) will also be presented.

3.7.1.2 Presentation (ADAMS Accession No. ML22061A112)

AN OVERVIEW OF CSTORM MODEL DEVELOPMENT AND RESULTS FOR THE SOUTH ATLANTIC COASTAL STUDY

Margaret Owensby,
Chris Massey,
Ty Hesser, Mary Bryant, and Norberto Nadal
USACE-ERDC
Coastal & Hydraulics Laboratory

Andrew 'Drew' Condon
USACE Jacksonville District

Probabilistic Flood Hazard Assessment Research Workshop
February 17, 2022

ERDC
DISCOVER | DEVELOP | DELIVER
US Army Corps of Engineers
COASTAL & HYDRAULICS LABORATORY
U.S.ARMY

SACS

The South Atlantic Coastal Study was authorized by Section 1204 of WRDA 2016. Guidance was issued on Nov. 16, 2017, requiring the study to follow planning guidance for watershed assessments. Public Law 115-123 provided Federal funding in the amount of $16M to cover 100% of the Study costs.

Study Goals

- Provide a Common Operating Picture of Coastal Risk
  - Provide decision-makers at all levels with a comprehensive and consistent regional assessment of coastal risk.
- Identify High-Risk Locations/Focus Current and Future Resources
  - Enable resources to be focused on the most vulnerable areas.
- Identify and Assess Risk Reduction Actions
  - Assess actions that would reduce risk to vulnerable coastal populations.
- Promote and Support Resilient Coastal Communities
  - Ensure a sustainable coastal landscape system, considering future sea level rise scenarios and climate change. Provide information to stakeholders to optimize existing efforts to reduce risk.
- Promote Sustainable Projects and Programs
  - Develop and provide consistent foundational elements to support coastal studies and projects; regionally manage projects through Regional Sediment Management and other opportunities.

BUILDING STRONG®
Owensby, Massey, Hesser, Bryant, Nadal, Condon, USACE 2
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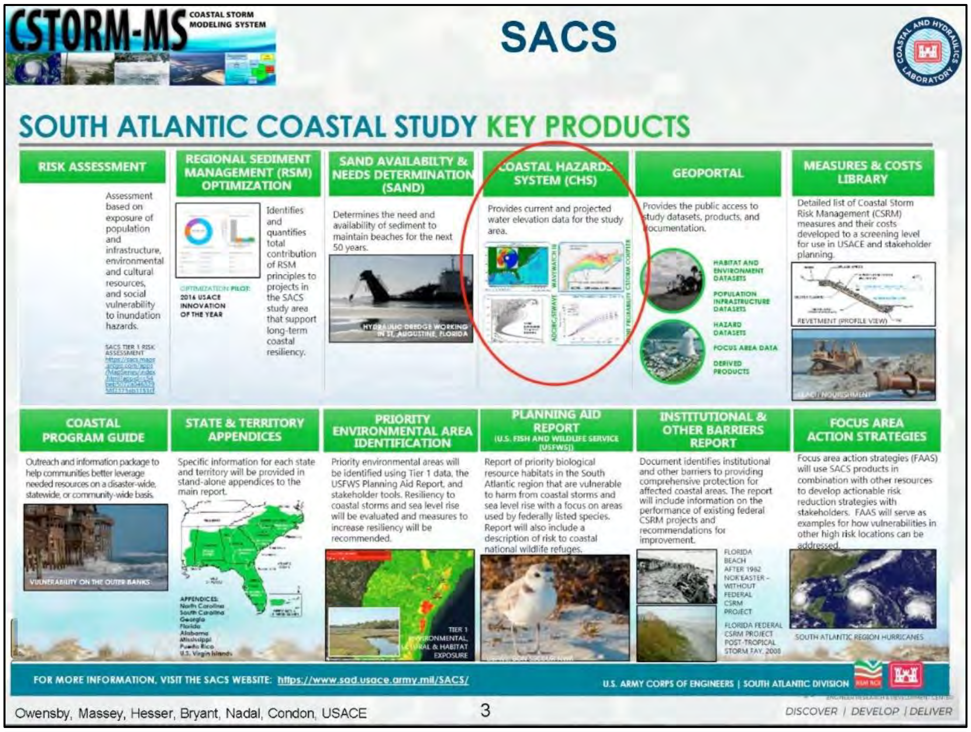
CSTORM-MS COASTAL STORM MODELING SYSTEM
SACS
SOUTH ATLANTIC COASTAL STUDY KEY PRODUCTS
RISK ASSESSMENT
Assessment based on exposure of population and infrastructure, environmental and cultural resources, and social vulnerability to inundation hazards.
REGIONAL SEDIMENT MANAGEMENT (RSM) OPTIMIZATION
Identifies and quantifies total contribution of RSM principles to projects in the SACS study area that support long-term coastal resiliency.
SAND AVAILABILTY & NEEDS DETERMINATION (SAND)
Determines the need and availability of sediment to maintain beaches for the next 50 years.
COASTAL HAZARDS SYSTEM (CHS)
Provides current and projected water elevation data for the study area.
GEOPORTAL
Provides the public access to study datasets, products, and documentation.
MEASURES & COSTS LIBRARY
Detailed list of Coastal Storm Risk Management (CSRM) measures and their costs developed to a screening level for use in USACE and stakeholder planning.
COASTAL PROGRAM GUIDE
Outreach and information package to help communities better leverage needed resources on a disaster-wide, statewide, or community-wide basis.
STATE & TERRITORY APPENDICES
Specific information for each state and territory will be provided in stand-alone appendices to the main report.
PRIORITY ENVIRONMENTAL AREA IDENTIFICATION
Priority environmental areas will be identified using Tier 1 data, the USFWS Planning Aid Report, and stakeholder tools. Resiliency to coastal storms and sea level rise will be evaluated and measures to increase resiliency will be recommended.
PLANNING AID REPORT (U.S. FISH AND WILDLIFE SERVICE (USFWS))
Report of priority biological resource habitats in the South Atlantic region that are vulnerable to harm from coastal storms and sea level rise with a focus on areas used by federally listed species. Report will also include a description of risk to coastal national wildlife refuges.
INSTITUTIONAL & OTHER BARRIERS REPORT
Document identifies institutional and other barriers to providing comprehensive protection for affected coastal areas. The report will include information on the performance of existing federal CSRM projects and recommendations for improvement.
FOCUS AREA ACTION STRATEGIES
Focus area action strategies (FAAS) will use SACS products in combination with other resources to develop actionable risk reduction strategies with stakeholders. FAAS will serve as examples for how vulnerabilities in other high risk locations can be addressed.
FOR MORE INFORMATION, VISIT THE SACS WEBSITE: https://www.sad.usace.army.mil/SACS/
U.S. ARMY CORPS OF ENGINEERS | SOUTH ATLANTIC DIVISION
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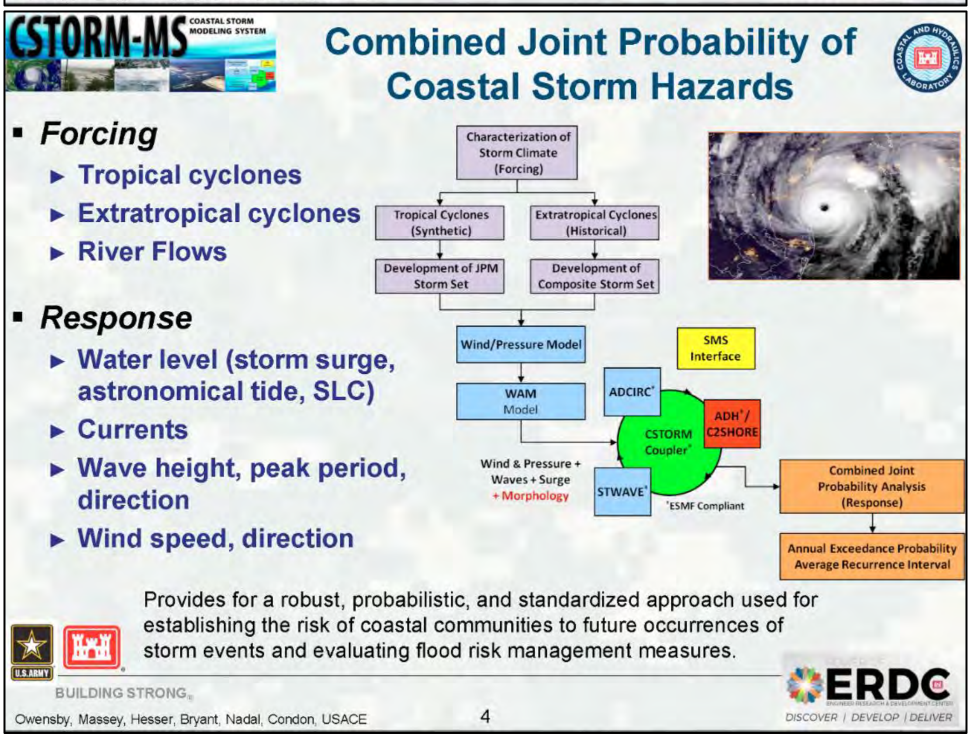
CSTORM-MS COASTAL STORM MODELING SYSTEM
Combined Joint Probability of Coastal Storm Hazards
Forcing
Tropical cyclones
Extratropical cyclones
River Flows
Response
Water level (storm surge, astronomical tide, SLC)
Currents
Wave height, peak period, direction
Wind speed, direction
Characterization of Storm Climate (Forcing)
Tropical Cyclones (Synthetic)
Extratropical Cyclones (Historical)
Development of JPM Storm Set
Development of Composite Storm Set
Wind/Pressure Model
SMS Interface
WAM Model
ADCIRC*
ADH*/ C2SHORE
CSTORM Coupler*
STWAVE*
*ESMF Compliant
Wind & Pressure + Waves + Surge + Morphology
Combined Joint Probability Analysis (Response)
Annual Exceedance Probability Average Recurrence Interval
Provides for a robust, probabilistic, and standardized approach used for establishing the risk of coastal communities to future occurrences of storm events and evaluating flood risk management measures.
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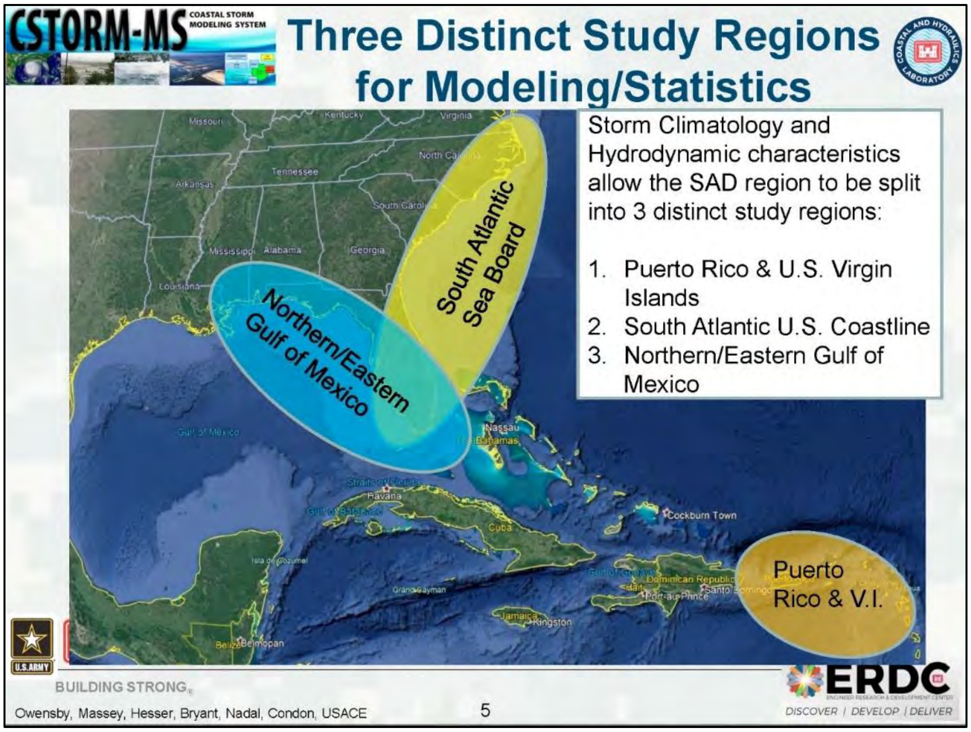
CSTORM-MS COASTAL STORM MODELING SYSTEM
Three Distinct Study Regions for Modeling/Statistics
Storm Climatology and Hydrodynamic characteristics allow the SAD region to be split into 3 distinct study regions:
1. Puerto Rico & U.S. Virgin Islands
2. South Atlantic U.S. Coastline
3. Northern/Eastern Gulf of Mexico
South Atlantic Sea Board
Northern/Eastern Gulf of Mexico
Puerto Rico & V.I.
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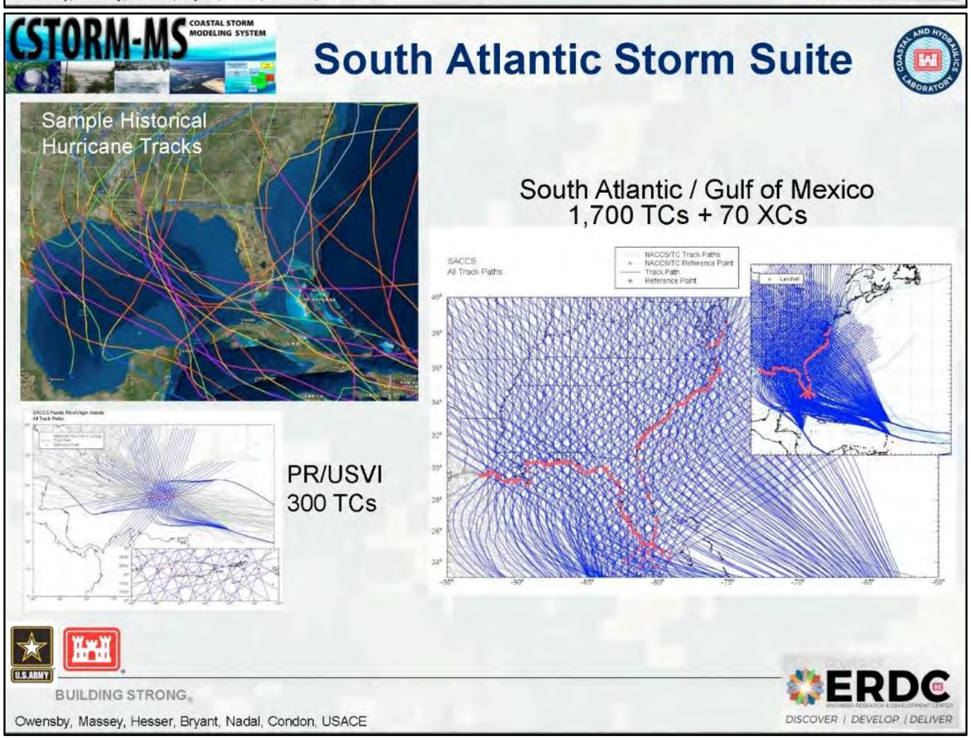
CSTORM-MS COASTAL STORM MODELING SYSTEM
South Atlantic Storm Suite
Sample Historical Hurricane Tracks
South Atlantic / Gulf of Mexico
1,700 TCs + 70 XCs
PR/USVI
300 TCs
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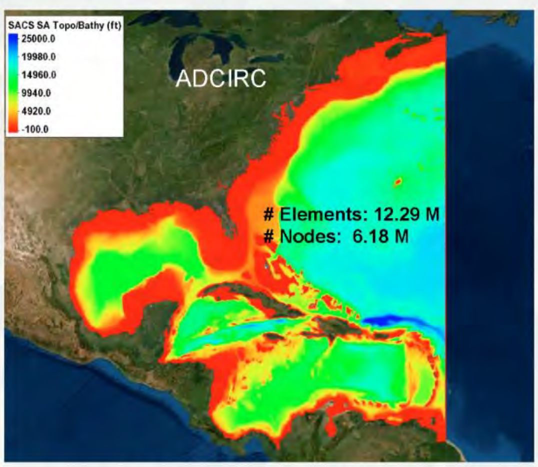
CSTORM-MS COASTAL STORM MODELING SYSTEM

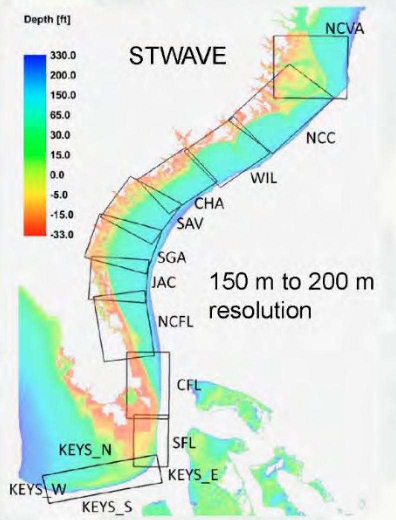
Modeling Scenarios

- Sets of Modeling and PCHA results for CHS South Atlantic:
  1. Puerto Rico & U.S. Virgin Islands ~ 300 Storms
     - Storm surge + waves
     - Storm surge + waves + SLC 1 (2.33 ft)
     - Storm surge + waves + SLC 2 (6.95 ft)
  2. South Atlantic (North Carolina to South Florida) ~1200 Storms
     - Storm surge + waves
     - Storm surge + waves + astronomical tides
     - Storm surge + waves + SLC 1 (2.73 ft)
     - Storm surge + waves + SLC 2 (7.35 ft)
  3. Gulf of Mexico ~ 1200 Storms
     - Storm surge + waves
     - Storm surge + waves + SLC 1 (2.72 ft)
     - Storm surge + waves + SLC 2 (7.35 ft)

CSTORM-MS COASTAL STORM MODELING SYSTEM

ADCIRC & STWAVE South Atlantic Domain



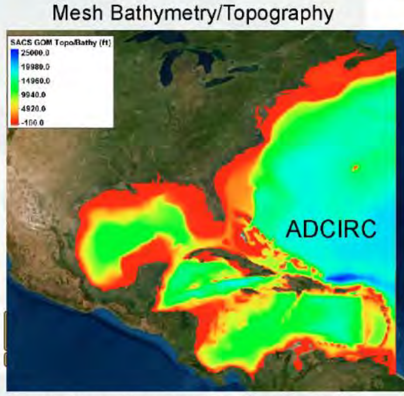


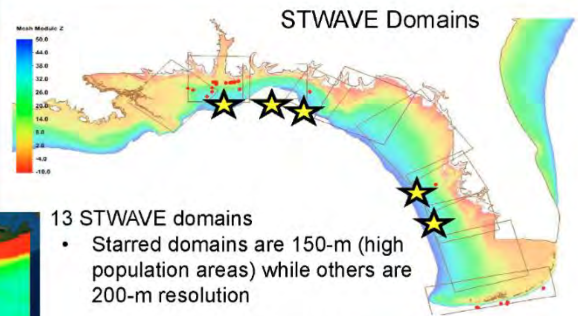
Dr. Joannes Westerink and team at Notre Dame constructed this mesh using Oceanmesh2D software

ADCIRC & STWAVE Gulf of Mexico Domain

- ADCIRC mesh built by Scott Hagen and Matt Bilskie
- Approximately 7.8 M nodes, 15.6 M elements

Mesh Bathymetry/Topography



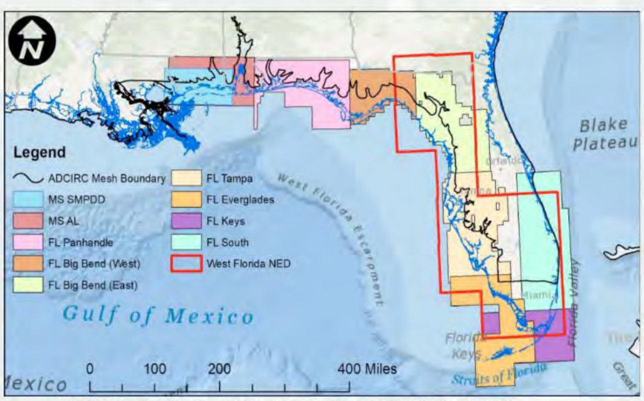


13 STWAVE domains

- Starred domains are 150-m (high population areas) while others are 200-m resolution
- extended from at least 35 m depth contour to 10 m topographic contour
- Red dots indicate location of buoys for validation

Regional Topo/Bathy Data Sources

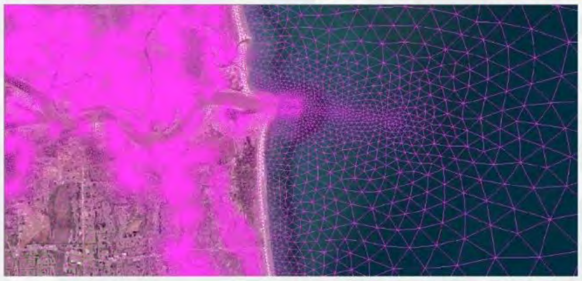
- Topography/bathymetry data taken from 3-m resolution DEM developed by JALBTCX (USACE), as well as SRTM, USGS, NOS, FEMA datasets



Example is from GoM area and is likewise for SA areas.

Image courtesy of Scott Hagen and Matt Bilskie

Closer View of ADCIRC South Atlantic Domain



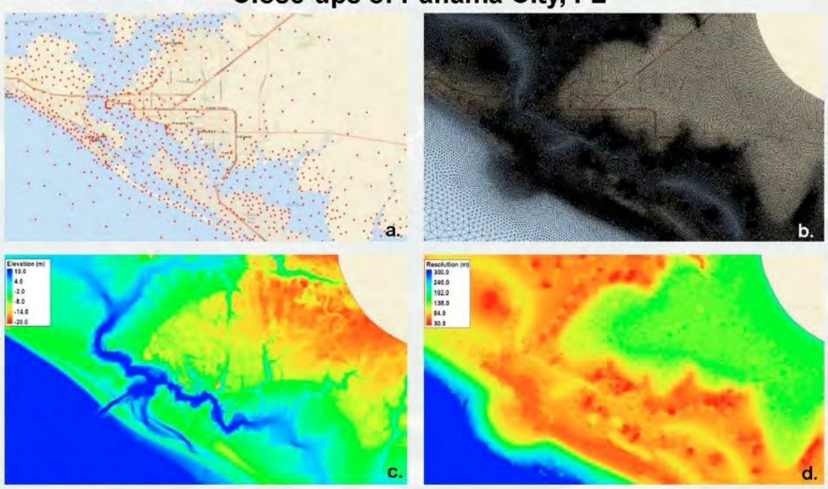
View of SACS SA ADCIRC mesh elements in the Jacksonville, FL area.

Similar inland resolution to FEMA RISK Map Mesh

Same view of ADCIRC mesh elements from NOAA's HSOFS mesh.

GOM Domain ADCIRC Mesh

Close-ups of Panama City, FL



a. Map with save point locations
b. Image of mesh elements
c. Image of mesh topography/bathymetry
d. Color-map image of mesh resolution

CSTORM-MS COASTAL STORM MODELING SYSTEM

Save Point Locations

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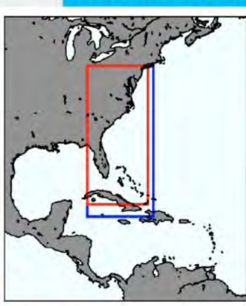
WaveWatch III v5.16: SACS South Atlantic Domain Setup

- Fully Parallel phase-averaged spectral wave model developed by the NOAA National Centers for Environmental Prediction
- Runs in both structured and unstructured grids and has the option for explicit and implicit (not ready for primetime) solvers
- Presently being used by the Wave Information Study for the Atlantic and Pacific wave hindcasts.

WW3 will use two way coupling at the boundaries of 3 grids with nesting



Grid	Longitude (W deg)	Latitude (N deg)	Resolution (deg)
Basin_L1	-99.0, -55.0	5.0, 47.0	0.2 x 0.2
EC_L2	-84.0, -72.0	19.0, 41.0	0.1 x 0.1
EC_L3	-84.0, -73.0	21.0, 41.0	0.05 x 0.05

Similar setup used for Gulf of Mexico

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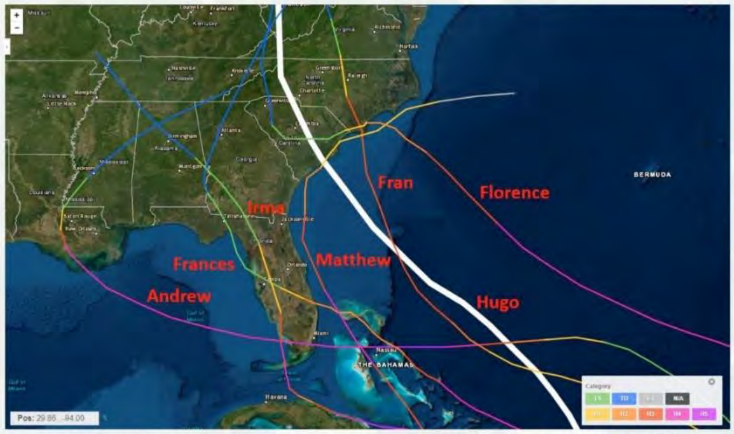
Validation Storms for South Atlantic Domain



The paths of the seven historical storms used to calibrate and validate ADCIRC, STWAVE, and WaveWatch III simulations for the South Atlantic domain (Image Source: NOAA's Historical Hurricane Tracks website)

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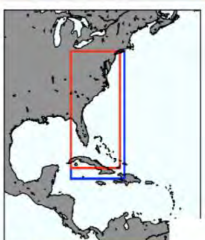
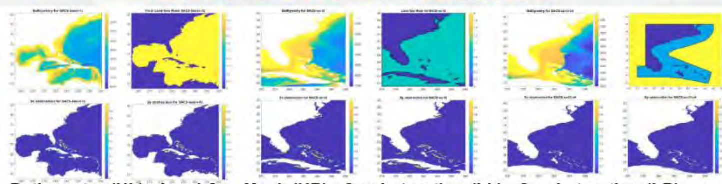
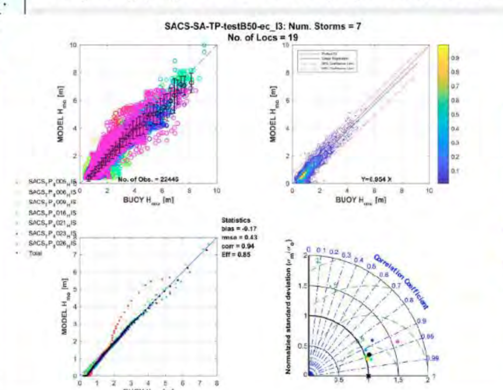
WW3 Validation for Historical Hurricanes: Atlantic





Bathymetry (UL) : Land-Sea Mask (UR) : Sx obstruction (LL) : Sy obstruction (LR)

Storms
Andrew
Florence
Fran
Frances
Hugo
Irma
Matthew



Statistic	TestB50 (meters)
Bias	-0.17
RMSE	0.43
Corr	0.94
Eff	0.85

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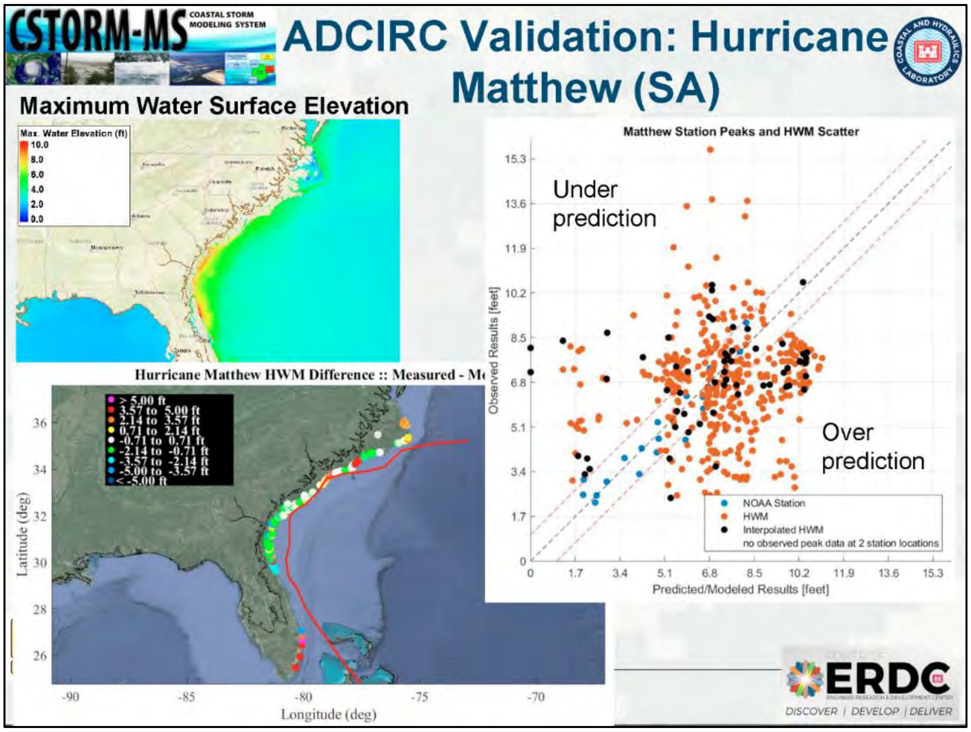
CSTORM-MS
COASTAL STORM MODELING SYSTEM
ADCIRC Validation: Hurricane Matthew (SA)
Maximum Water Surface Elevation
Max. Water Elevation (ft)
10.0
8.0
6.0
4.0
2.0
0.0
Hurricane Matthew HWM Difference :: Measured - M
> 5.00 ft
3.57 to 5.00 ft
2.14 to 3.57 ft
0.71 to 2.14 ft
-0.71 to 0.71 ft
-2.14 to -0.71 ft
-3.57 to -2.14 ft
-5.00 to -3.57 ft
< -5.00 ft
Latitude (deg)
Longitude (deg)
Matthew Station Peaks and HWM Scatter
Under prediction
Over prediction
Observed Results [feet]
Predicted/Modeled Results [feet]
NOAA Station
HWM
Interpolated HWM
no observed peak data at 2 station locations
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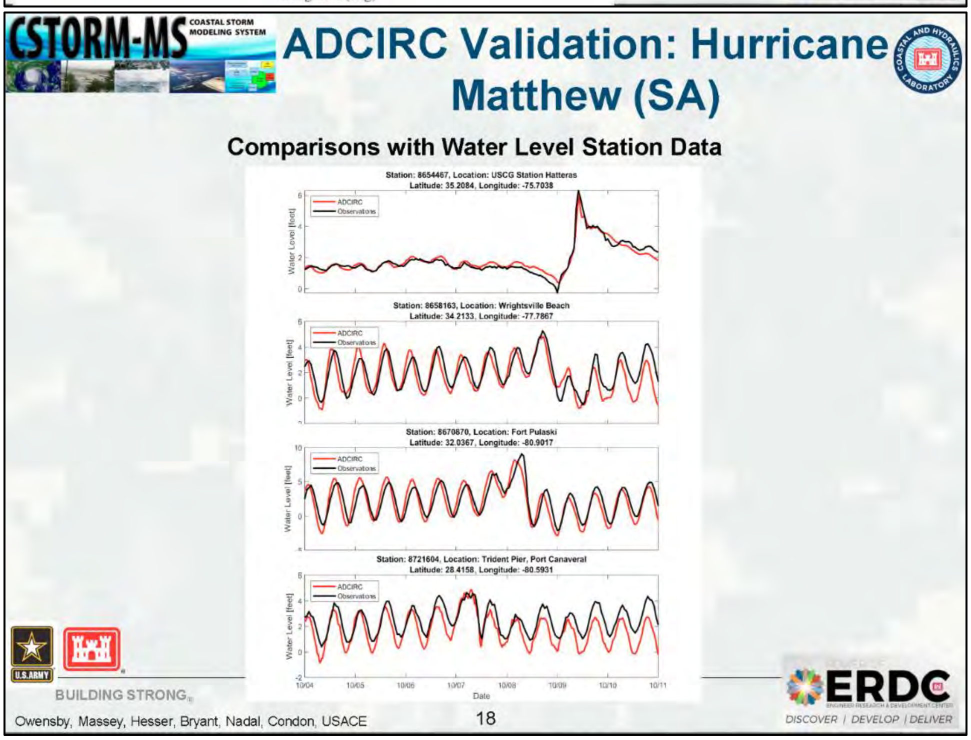
CSTORM-MS
COASTAL STORM MODELING SYSTEM
ADCIRC Validation: Hurricane Matthew (SA)
Comparisons with Water Level Station Data
Station: 8654467, Location: USCG Station Hatteras
Latitude: 35.2084, Longitude: -75.7038
Station: 8658163, Location: Wrightsville Beach
Latitude: 34.2133, Longitude: -77.7867
Station: 8670870, Location: Fort Pulaski
Latitude: 32.0367, Longitude: -80.9017
Station: 8721604, Location: Trident Pier, Port Canaveral
Latitude: 28.4158, Longitude: -80.5931
ADCIRC
Observations
Water Level [feet]
Date
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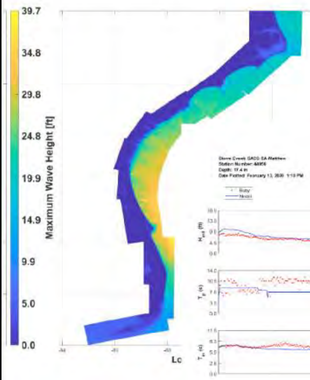
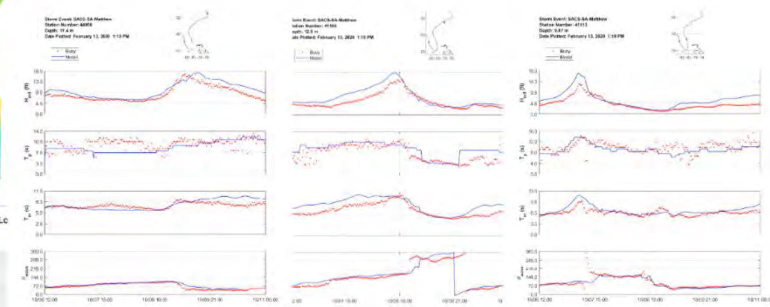
STWAVE Validation: Hurricane Matthew

CSTORM-MS COASTAL STORM MODELING SYSTEM

Maximum Significant Wave Height



Time Series at Wave Buoys



Station 44056 **Station 41108** **Station 41113**

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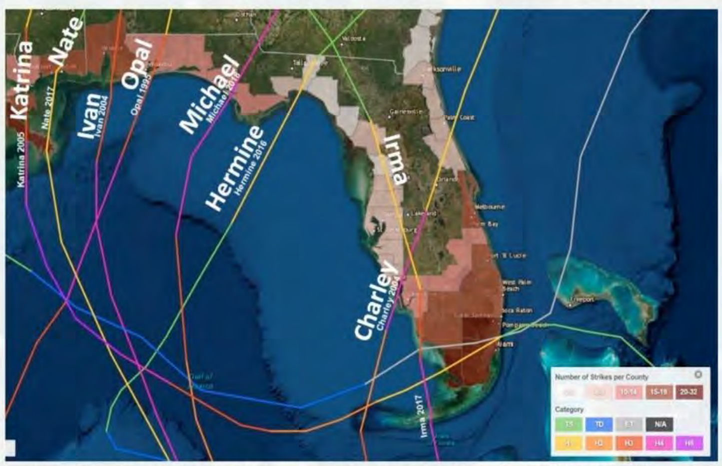
Validation Storms for Gulf of Mexico Domain

CSTORM-MS COASTAL STORM MODELING SYSTEM



The paths of the eight historical storms used to calibrate and validate ADCIRC, STWAVE, and the CSTORM coupled ADCIRC+STWAVE simulations for the Gulf of Mexico domain (source: NOAA's Historical Hurricane Tracks website)

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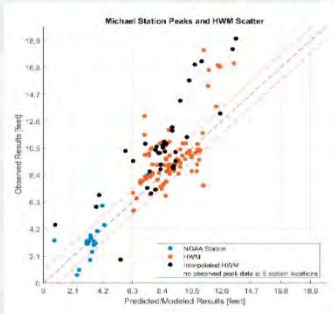
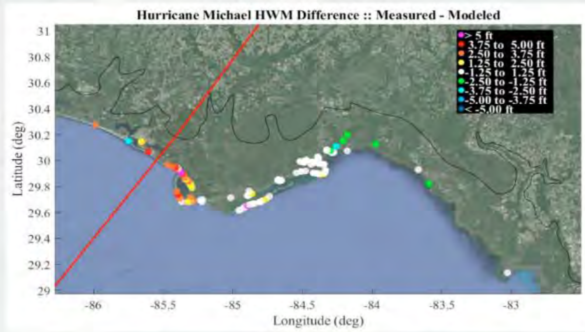
Hurricane Michael Results

HWM & Gauge Data vs. Model Scatter Plot



Model data comparison at gauges and for most high water marks is very good, although there is underestimation for the most extreme HWM's.

HWM Difference Plot



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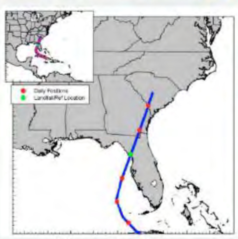
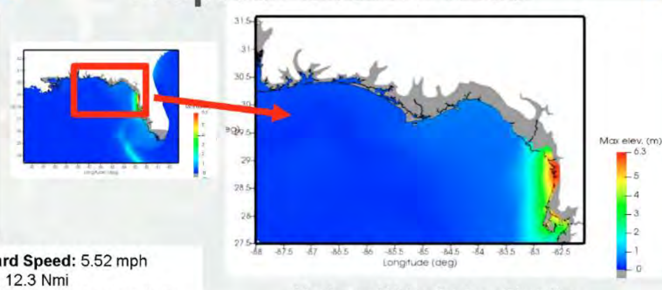
Sample Results – Synthetic Tropical Storm 1230



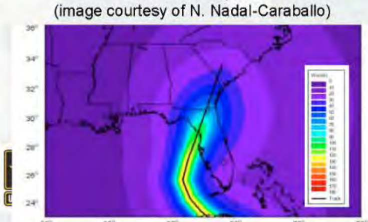
Storm Track
(image courtesy of N. Nadal-Caraballo)



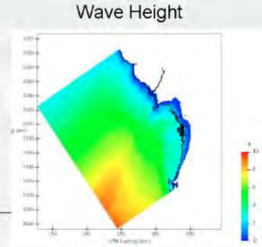
Maximum Water Surface Elevation

Forward Speed: 5.52 mph
RMW: 12.3 Nmi
Max. Wind Speed at Landfall: 117.01 mph (Cat. 3)
Min. Pressure: 865 mb

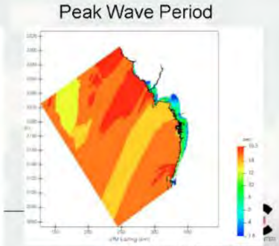
Max. Wind Speed
(image courtesy of N. Nadal-Caraballo)



Max. Significant Wave Height



Peak Wave Period



CSTORM Production System

- The **CSTORM Production System** (CSTORM-PS) makes use of standard Linux/Unix tools (bash scripting) and readily available open source software, Python
- The production system allows for
  - Rapid preparation of input files (Reduces chances for human error)
  - Execution of the simulation and post processing (Optimized CPU usage)
  - Efficient hierarchical storage and archival of results
  - Project design condition evaluations enabled

CSTORM Production System

Setup Simulation → Prep ADCIRC for Parallel → Execute CSTORM → Visualize & Stats → Compress Outputs → Tar Results Together → Archive Results

Onyx	Jim *	Thunder	Conrad
Cray XC40/50	**SGI Ice X**	**SGI Ice X**	**Cray XC40**
6.06 PFLOPS	4.66 PFLOPS	5.62 PFLOPS	2 PFLOPS
4,810 nodes, 44 cores/node	3,456 nodes, 36 cores/node	3,216 nodes, 36 cores/node	1,523 nodes, 32 cores/node
211,640 processors	124,416 processors	115,776 processors	48,736 processors

*Pay for Use

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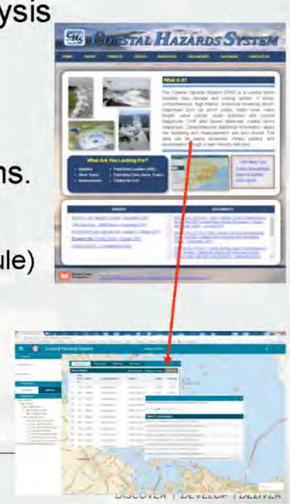
Coastal Hazards System (CHS)

- The CHS is the only national database and web-based data mining and visualization tool for probabilistic coastal hazard analysis (PCHA) results.
- Based on high-resolution / high-fidelity probabilistic, atmospheric and hydrodynamic modeling of coastal storms.
- Directly supports:
  - SMART planning/feasibility studies (3x3x3 rule)
  - PED, stochastic-forcing structure design
  - Hazard analysis and risk assessments



https://chs.erdc.dren.mil

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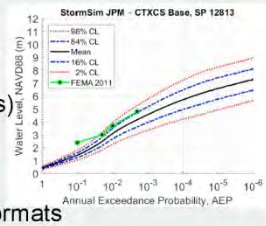
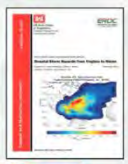
Coastal Hazards System (CHS)

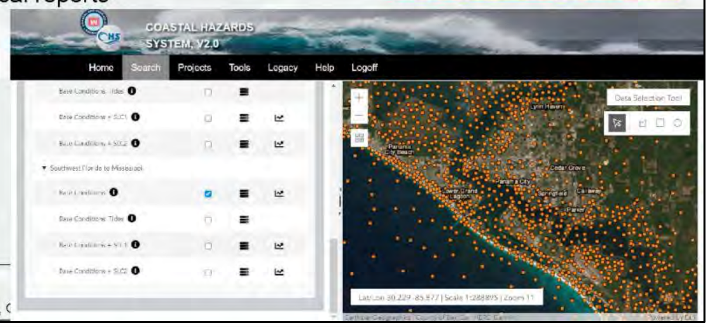
PCHA results and deliverables:



- Response Hazard Curves: surge, water level, waves, wind, currents
- Annual Exceedance Probability values: 1 to 10000 (1/years)
- Confidence Limits: 2%, 16%, 84%, 90%, 98%
- Uncertainty quantification & SLC nonlinear residuals
- Peaks and time series files for all storms in NetCDF/CSV formats
- Atmospheric and hydrodynamic model inputs
- Model grids, technical reports

https://chs.erdc.dren.mil





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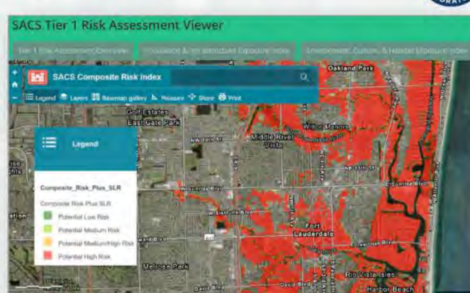
SACS Findings To-Date

Significant Risk

- Tier 1 & 2 identified 700+ high risk locations
- Back bay storm surge inundation is a key driver
- Sea level rise will non-linearly increase surge in some areas: San Juan vicinity, St. John, St. Croix, throughout the back bays of the Atlantic Coast
- Further understanding/application of compound flooding impact is needed
- Significant need for follow-on efforts to address complex risk related to combined inland/coastal flood risk and ecosystem restoration



Support Joint Responsibility

- Follow-on Corps studies (feasibility, CAP, etc.)
- Actions within current authorities (RSM, EDRs, Planning Assistance to States, Silver Jackets, etc.)
- Shared tools support actions within expanding at-risk areas

"Coastal storm risk management is a shared responsibility, and we believe there should be shared tools used by all decision makers to assess risk and identify solutions."
Commanding Officer (2015)
U.S. Army Corps of Engineers
North Atlantic Division

Slide Courtesy of Drew Condon, USACE-SAJ

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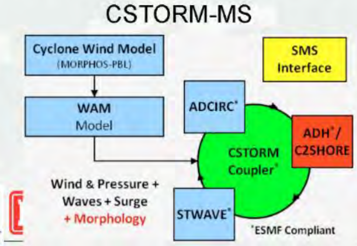
Summary

The SACS CHS and CSTORM products will provide valuable data, both oceanographic and storms, in support of the Corp missions and those of other agencies and communities for many years to come, in order to:

- understand the likelihood and extent of present and future storm surge and storm waves
- design more reliable engineering projects and effective coastal storm damage solutions to reduce wave attack, provide flood protection, and create robust environments (Eng. w/ Nature) that can provide a buffer to coastal flooding
- allow communities to prepare for the future

CSTORM-MS

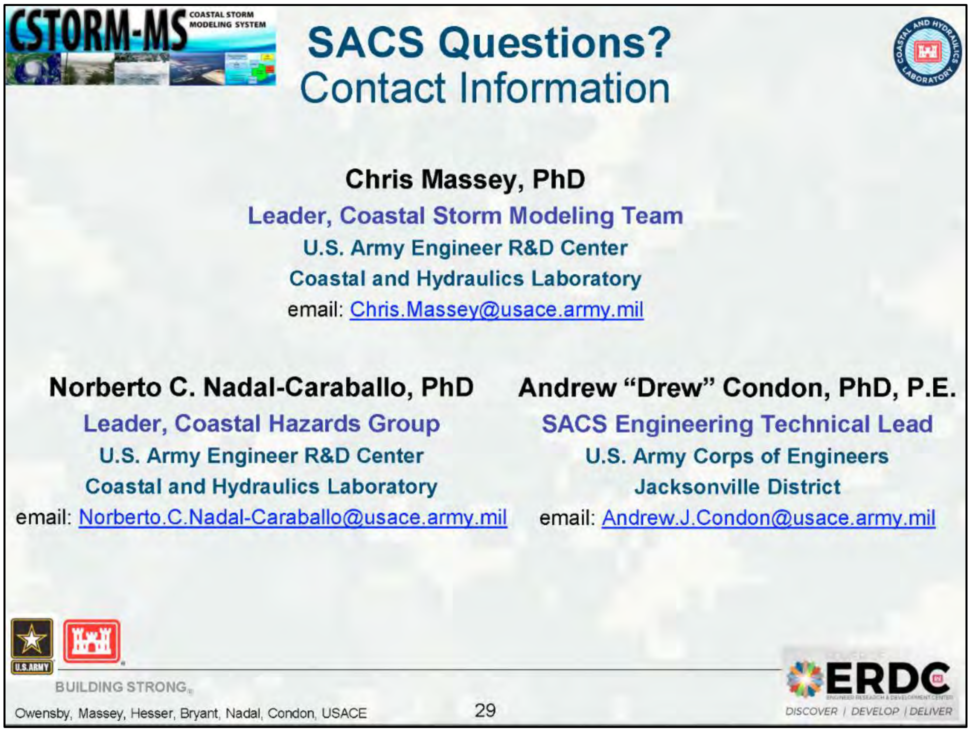


Coastal Hazards System

https://chs.erdc.dren.mil

Team Acknowledgements

- USACE South Atlantic Division (SACS) Project Team
- Chris Massey – (CSTORM Modeling Team Lead)
- Norberto Nadal-Caraballo – (CHS Team Lead)
- Tyler Hesser and Al Cialone – (Deep Water Waves)
- Mary Bryant and Catie Dillon – (Nearshore Waves)
- Margaret Owensby, Leigh Provost, Amanda Tritinger, John Goertz, Fatima Bukhari, Abi Wallace, and Yan Ding – (Production Modeling Team)
- Victor Gonzalez, Madison Campbell, Debbie Green, Efrain Ramos-Santiago, Marissa Torres, and Jeff Melby - (Hazards Team)
- ERDC DSRC – (HPC Access)
- JALBTCX – (DEMs)
- Andy Cox of OceanWeather Inc. - (Storm Climatology & Storms Support)
- Joannes Westerink and Team at Univ. of Notre Dame - (Mesh)
- Scott Hagen of LSU and Matt Bilskie of UGA – (Mesh)


CSTORM-MS COASTAL STORM MODELING SYSTEM
SACS Questions?
Contact Information
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Norberto C. Nadal-Caraballo, PhD
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Andrew "Drew" Condon, PhD, P.E.
SACS Engineering Technical Lead
U.S. Army Corps of Engineers
Jacksonville District
email: Andrew.J.Condon@usace.army.mil
BUILDING STRONG
Owensby, Massey, Hesser, Bryant, Nadal, Condon, USACE
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3.7.2 Presentation 3B-2: Compound Flood Hazard Assessment using a Bayesian Framework

Somayeh Mohammadi[1], Michelle Bensi[1], Shih-Chieh Kao[2], Scott DeNeale[2], Joseph Kanney[3], Elena Yegorova[3], Meredith Carr[4]*

[1]Univeristy of Maryland, [2]Oak Ridge National Laboratory, [3]U.S. Nuclear Regulatory Commission, [4]U.S. Army Corps of Engineers Engineer Research and Development Center Coastal and Hydraulics Laboratory

Speaker: *Somayeh Mohammadi*

3.7.2.1 Abstract

Compound flooding is a topic that has received high attention recently. These types of flood events are caused by the occurrence of more than one flood mechanism, such as storm surge, precipitation, and tides. Compound flood events can cause more severe impacts on societies and the built environment than flood events caused by just a single flood mechanism. In this way, a probabilistic assessment of compound flood hazards is necessary for a realistic assessment of flood hazards. This study focuses on the probabilistic assessment of compound flood hazards caused by the simultaneous occurrence of hurricane-induced surge, precipitation, tide, and antecedent river flow. A Bayesian framework is developed to include these flood drivers in the probabilistic flood hazard assessment for a case study on the Delaware River in Trenton. The inputs to this model include storm parameters (i.e., central pressure deficit, forward velocity, heading direction, radius to maximum wind and landfall location), antecedent river flow, and predicted tidal levels. A series of predictive surrogate models are developed to estimate total river discharge accounting for hurricane-driven surge, antecedent flow, and tides. The proposed model can be used to generate a probability distribution for total river discharge at the time of the storm occurrence in the study area. Furthermore, the model can be used to generate a hazard curve representing the annual exceedance frequency of total river discharge caused by the hurricane-induced flood mechanisms mentioned earlier.

3.7.2.2 Presentation (ADAMS Accession No. ML22061A111)

Multi-Mechanism Flood Hazard Assessment in Coastal Areas

Somayeh Mohammadi[1], Michelle Bensi[1], Shih-Chieh Kao[2], Scott DeNeale[2], Elena Yegorova[3], Joseph Kanney[3] and Meredith L Carr[4]

(1) University of Maryland College Park, Department of Civil and Environmental Engineering, College Park, MD, United States
(2) Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, TN, United States
(3) Nuclear Regulatory Commission, Rockville, MD, United States
(4) U.S. Army Corps of Engineers, ERDC/CHL, Vicksburg, MS, United States

7th Annual NRC PFHA Research Workshop
(February 15-18, 2022)

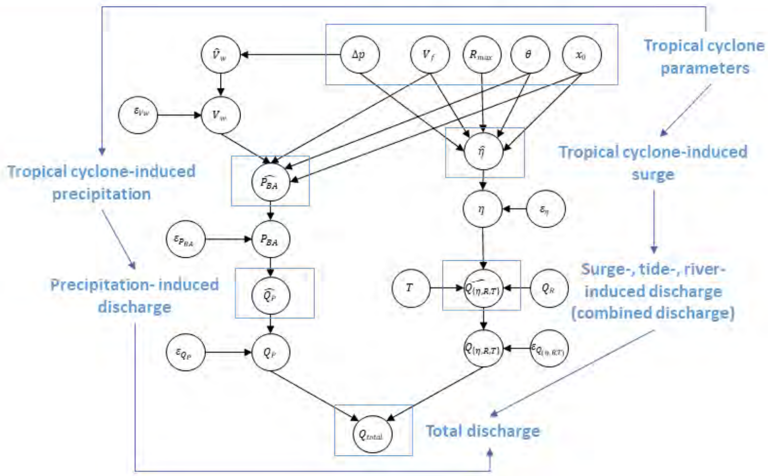
Research objective

Develop a Bayesian-motivated approach for probabilistic assessment of flood hazard due to simultaneous occurrence of storm surge, precipitation, tides and river flow.

1

Bayesian-Motivated Approach

Bayesian network

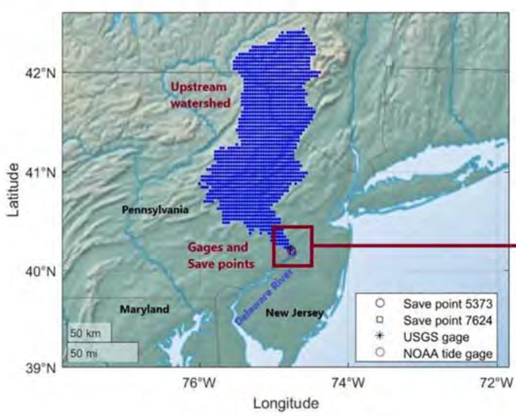


2

Case study location and data sources

- **USGS gage 01463500**
- **NOAA tide gage 8539993**
- **CHS Save points (5373 &7624)**

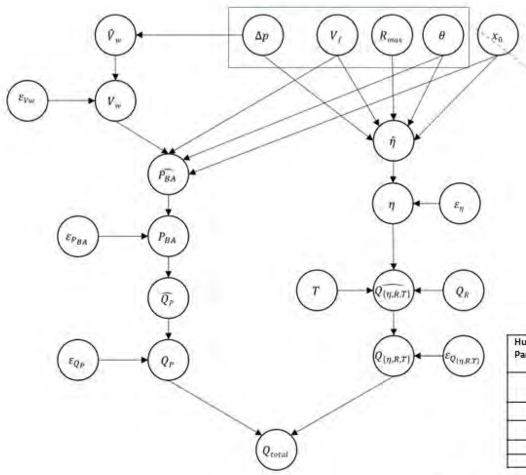
Delaware River at Trenton

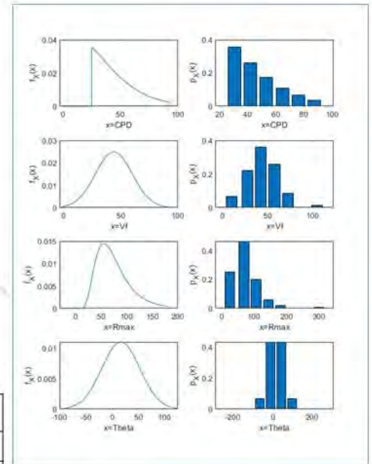


3

4

Tropical cyclone parameters





Hurricane Parameter	Distribution
Δp	Doubly truncated Weibull distribution (DTWD)
R_{max}	Lognormal distribution
V_f	Normal distribution
θ	Normal distribution
x_0	Uniform distribution

Source: North Atlantic Coast Comprehensive Study (NACCS), Nadal-Caraballo et al. 2015

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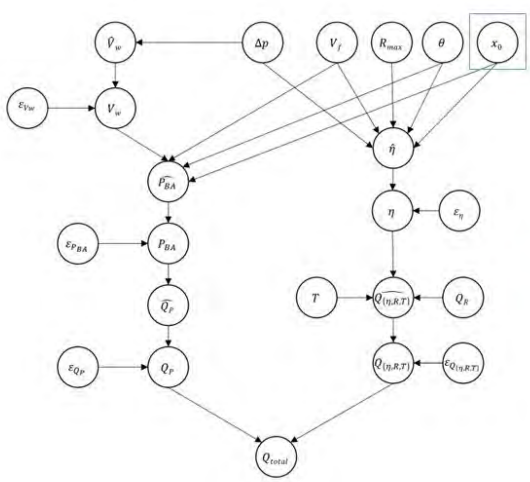
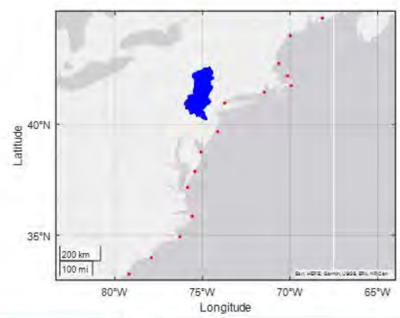
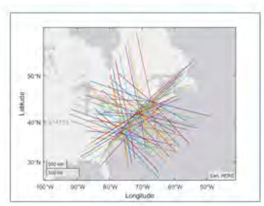
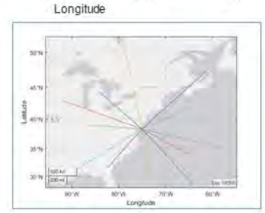
Tropical cyclone parameters



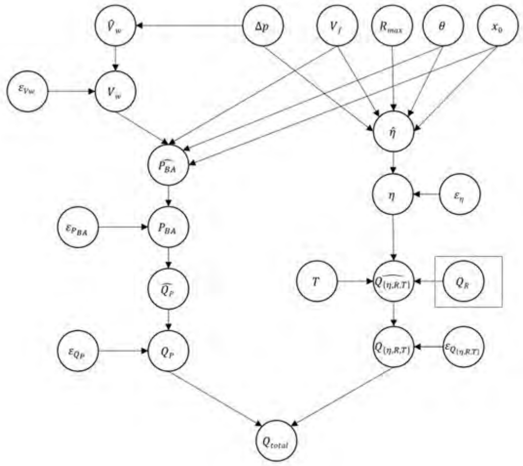


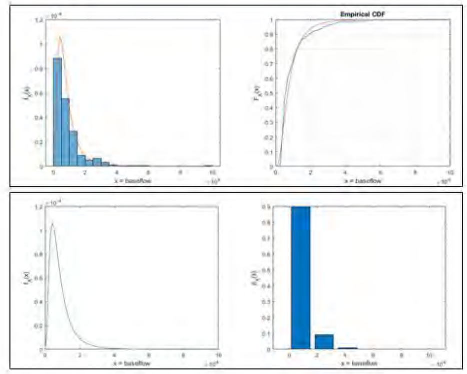




Statistical analysis of river flow

- Gather daily discharge time-series
- Remove hurricane event dates from record
- Randomly sample a subset of data
- Perform statistical assessment to define distribution
- Lognormal distribution as the best fit distribution





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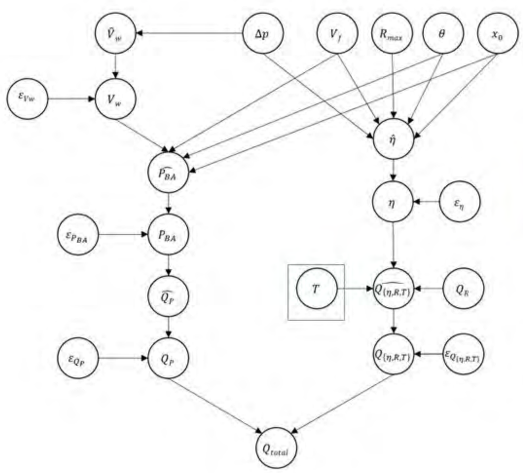
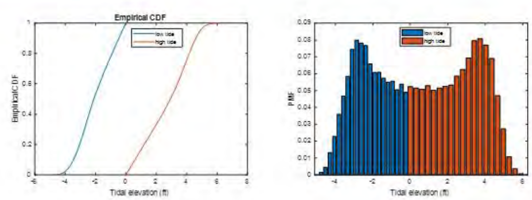
Statistical analysis of tides

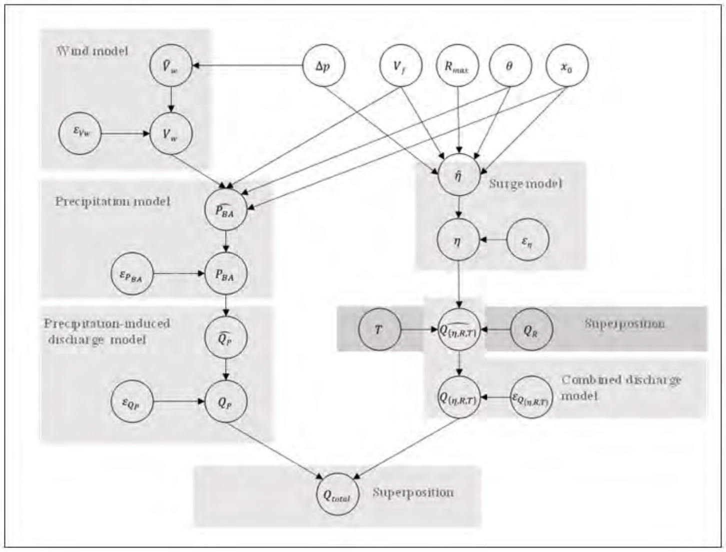


Data:

NOAA tide gage 8539993



Predictive models



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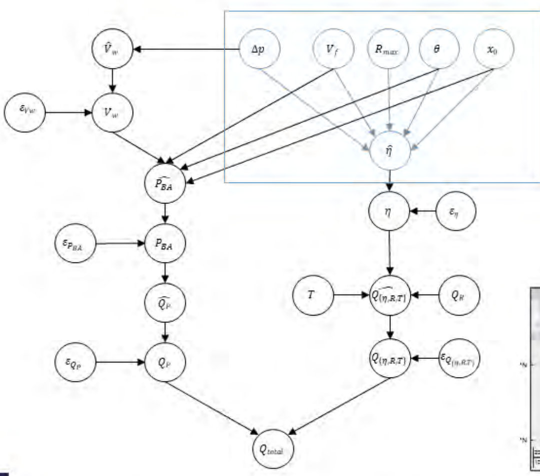
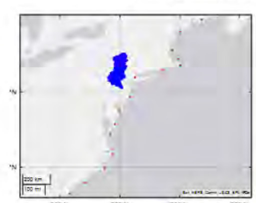
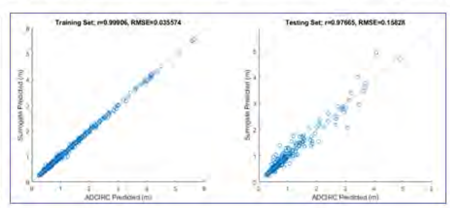
Surge model



Hurricane Parameter	Distribution	Functional forms	Distribution Parameters
Δp	Doubly truncated Weibull distribution (DTWD)	$P[\Delta p > x] = \frac{\exp\left[-\left(\frac{x}{U}\right)^k\right] - \exp\left[-\left(\frac{\Delta p_2}{U}\right)^k\right]}{\exp\left[-\left(\frac{\Delta p_1}{U}\right)^k\right] - \exp\left[-\left(\frac{\Delta p_2}{U}\right)^k\right]}$	$\Delta p_1 = 25$ hpa $\Delta p_2 = 93$ hpa $U = 35.77$ $k = 1.41$
R_{max}	Lognormal distribution	$f(x) = \frac{1}{x\zeta\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{\ln(x)-\lambda}{\zeta}\right)^2\right]$	$\lambda = 4.215, \zeta = 0.45$
V_f	Normal distribution	$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$	$\mu = 44.05, \sigma = 16.06$
θ	Normal distribution	$f(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$	$\mu = 16.48, \sigma = 36.17$
x_0	Uniform distribution	n/a	n/a





Data source: https://chswebtool.erdc.dren.mil/ Savepoint: 5373

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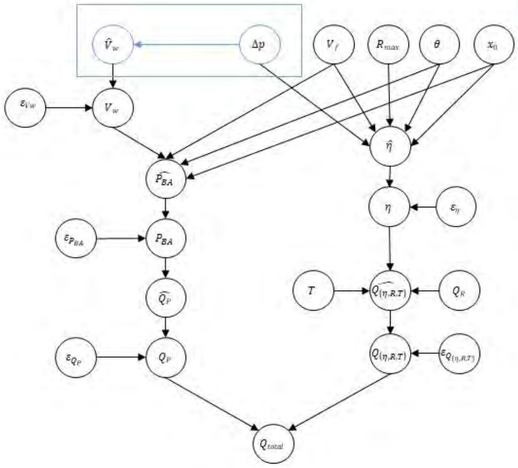
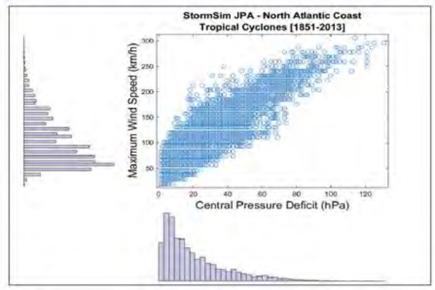
Wind model



$$V_w = 42.4807 - 0.0084\,CPD^2 + 2.9752\,CPD$$

$$\sigma_{V_w} = 18.66$$



Source: North Atlantic Coast Comprehensive Study (NACCS), Nadal-Caraballo et al. 2015

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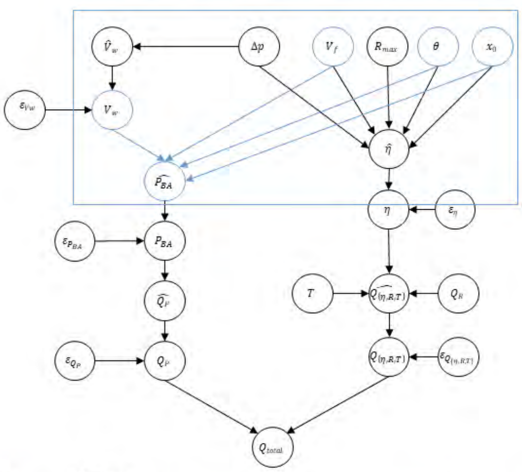
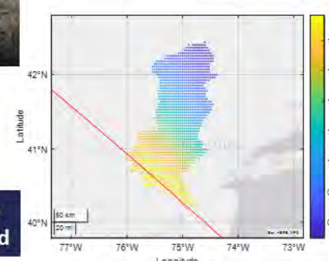
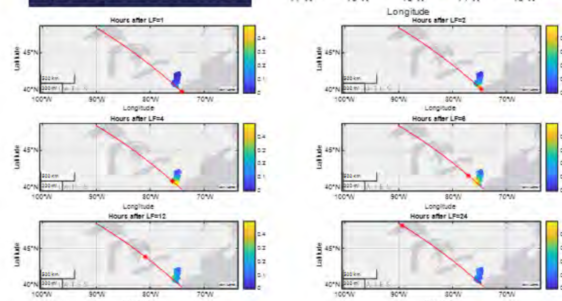
Precipitation model



Basin average daily rainfall

1862 grid points in upstream watershed





Source:
- Tropical Rainfall Measuring Mission (TRMM) rain rates (TRR) model (https://journals.ametsoc.org/view/journals/wefo/22/1/waf972_1.xml)
- "On the Decay of Tropical Cyclone Winds after Landfall in the New England Area.", Kaplan, J., and Demaria, M. (2001).

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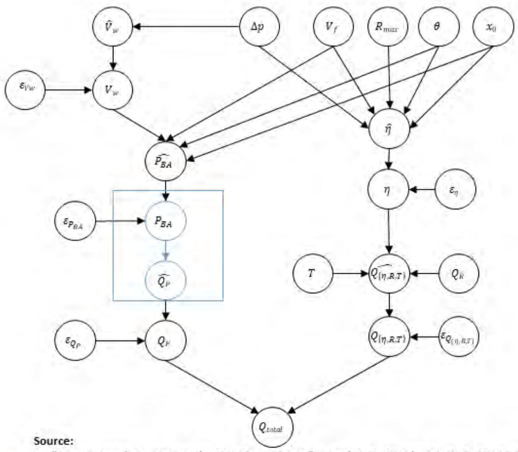
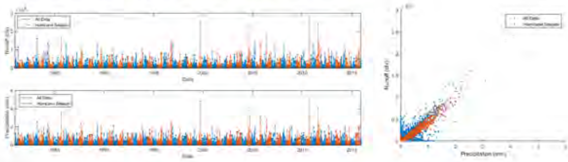
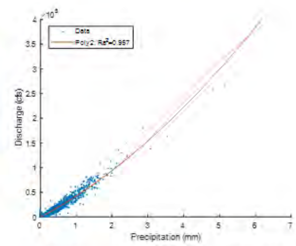
Precipitation-induced discharge model





Data :

Simulated 1980-2015 daily runoff and streamflow by the VIC-RAPID model



Correlation = 0.9831; RMSE_Test = 3.0915e+03 (cfs)

Source:
- "River Network Routing on the NHDPlus Dataset.", David, C. H., Maidment, D. R., Niu, G.-Y., Yang, Z.-L., Habets, F., and Eijkhout, V. (2011).
- "A large-scale, high-resolution hydrological model parameter dataset for climate change impact assessment for the conterminous United States.", Oubeidillah, A. A., Kao, S.-C., Ashfaq, M., Naz, B., and Tootle, G. (2013).

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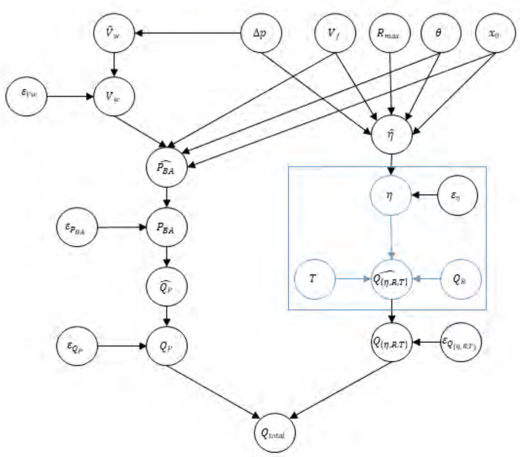
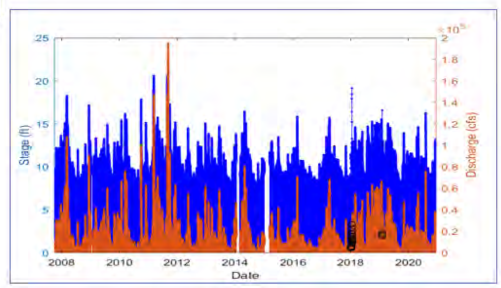
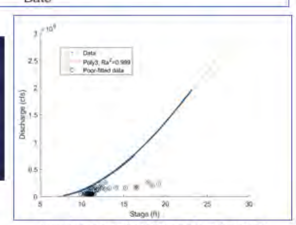
Combined discharge model





Data:

15 minute data from USGS (Discharge and Water level) Station number: 01463500



Correlation = 0.9831; RMSE_Test = 3.0915e+03 (cfs)

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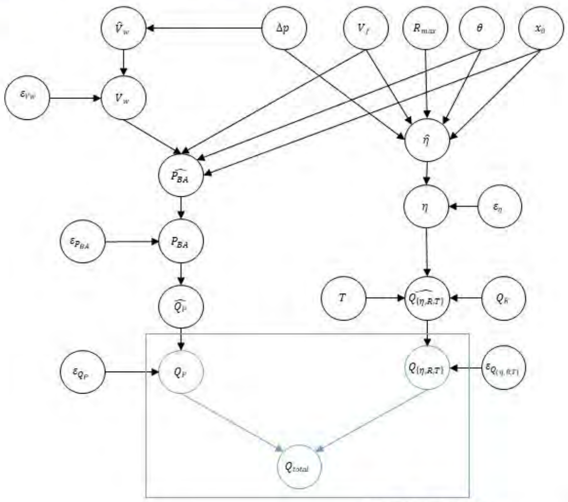
Compute total discharge (Q)



Superposition:

$$Q_{Total} = Q_P + Q_{T,\eta,R}$$

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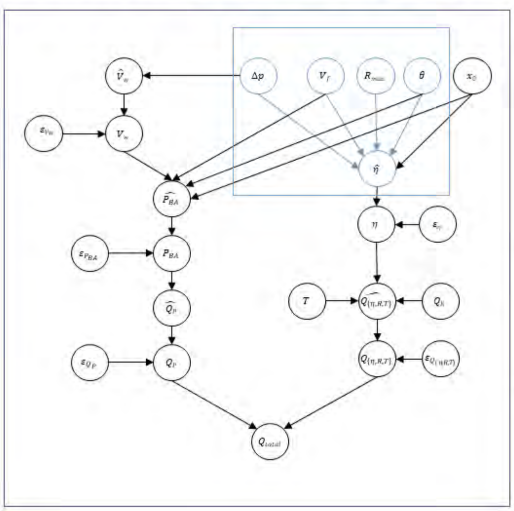
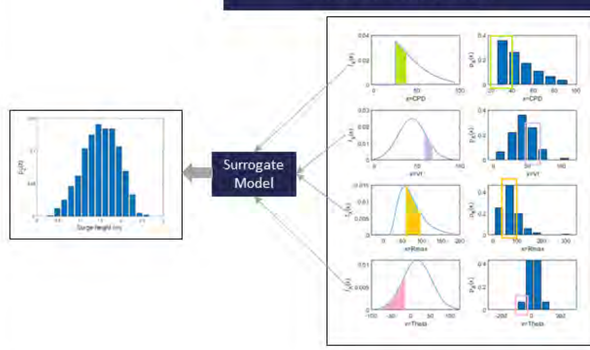
Decrease discretization error



Monte Carlo simulation
- **Generating conditional probability tables (CPTs)**
- **Reducing the impact of discretization error**



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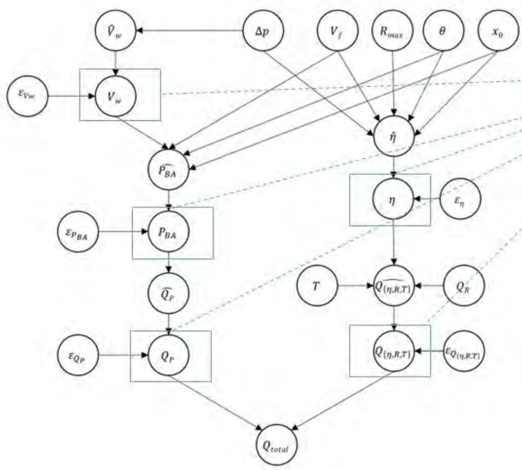
Inclusion of modeling error (epistemic uncertainty)



For all models:

- **Normal distribution assumed for error**
- **Error discretized in to 9 bins**

Correct predicted response variables:

$$X = X_{pred} + \epsilon_X$$

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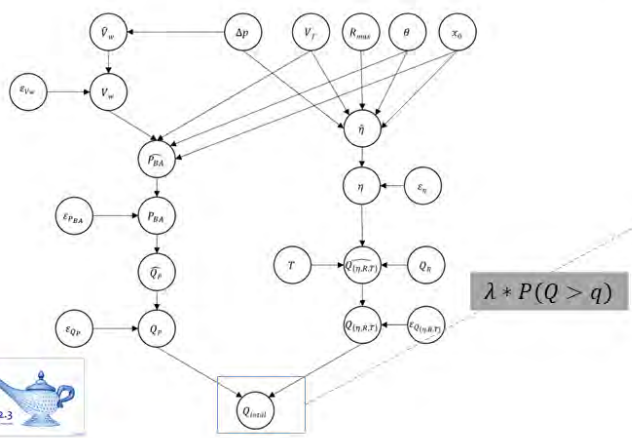
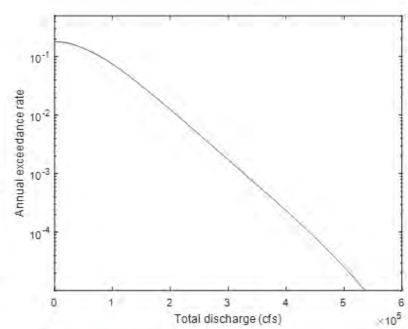
Estimate annual exceedance frequency





"Representative" hazard curve

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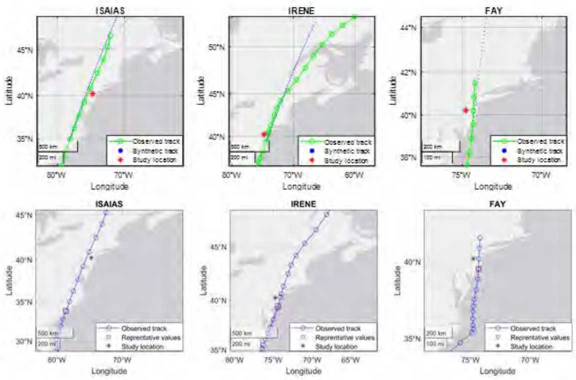
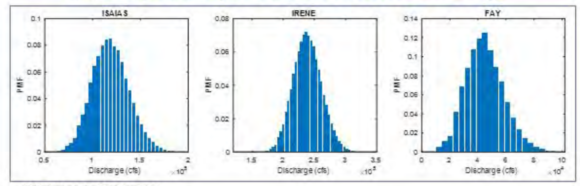
Assessment of the model performance



Modeled probability distributions for total river discharge



PMF: Probability Mass Function

Name of the storm	Time	LAT	LON	ΔP (hPa)	V_w (km/h)	θ (degree)	V_f (km/h)	R_{max} (km)	Tide at peak WL (ft)	Q_b (cfs)	USGS Q (cfs)	Modal bin[1] of PMF for discharge (cfs)
ISAIAS	8/4/2020 0:00	33.7244	-78.5834	25.25	138	19	37	37	4.56	4,000	75,800	118,465-122,550
FAY	7/10/2020 18:00	39.5473	-74.3161	15.25	92	7	25	166	-1.86	4,500	19,000	44,935-49,020
IRENE	8/28/2011 9:00	39.1783	-74.49	55.25	111	20	42	185	5.25	15,000	146,000	236,930-241,015

[1] Bin associated with the highest probability mass

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Next steps

- Consider the non-linearity between surge induced and precipitation induced discharge in the analysis
- Conduct the analysis using other methods (for comparison)
  - Copula based
  - Direct estimation of the joint distribution
- Inclusion of uncertainty in storm parameters

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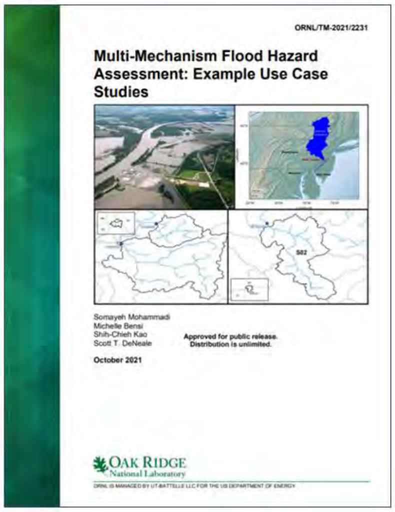
Publications


ORNL/TM-2021/2231

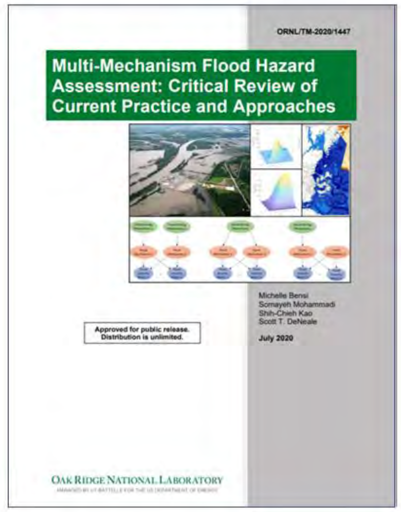
Multi-Mechanism Flood Hazard Assessment: Example Use Case Studies

Somayeh Mohammadi
Michelle Bensi
Shih-Chieh Kao
Scott T. DeNeale

Approved for public release.
Distribution is unlimited.

October 2021

OAK RIDGE National Laboratory


ORNL/TM-2020/1447

Multi-Mechanism Flood Hazard Assessment: Critical Review of Current Practice and Approaches

Michelle Bensi
Somayeh Mohammadi
Shih-Chieh Kao
Scott T. DeNeale

July 2020

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Thank you

Somayeh@terpmail.umd.edu
mbensi@umd.edu

3.7.3 Presentation 3B-3: Coastal Flooding PFHA Pilot Study

Authors: *Victor M. Gonzalez*, Meredith L. Carr, Karlie Wells, Norberto C. Nadal Caraballo U.S. Army Corps of Engineers, Engineer Research and Development Center, Coastal and Hydraulics Laboratory (USACE/ERDC/CHL)*

Speaker: *Victor M. Gonzalez*

3.7.3.1 Abstract

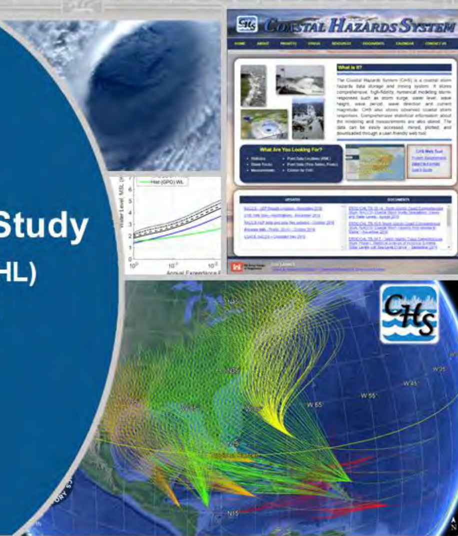
Inundation due to the compound effects of storm surge and rainfall associated with coastal storms can produce widespread damage to coastal infrastructure. A coastal probabilistic flood hazard assessment (PFHA) pilot study is being conducted to demonstrate the application of PFHA to external flooding at a hypothetical nuclear power plant (NPP) location on the Lower Neches River watershed in Texas. Compound flooding hazards being assessed in this study include storm surge, astronomical tide, waves, rainfall, and coincident riverine flooding along with associated uncertainties. The assessment requires the characterization of storm climatology for tropical cyclones (TCs) using the U.S. Army Corps of Engineers' (USACE) Coastal Hazards System (CHS) data based on its Probabilistic Coastal Hazard Analysis (PCHA) framework. The PCHA is a probabilistic framework for quantifying coastal storm hazards that includes storm climatology characterization, high-resolution, high-fidelity numeric atmospheric, hydrodynamic, and wave modeling, and advanced joint probability analysis of atmospheric forcing to develop storm hazard curves and uncertainty. The compound probabilistic modeling approach being implemented here incorporates rainfall within the PCHA framework though the use of a physics-based parameterized tropical cyclone rainfall (TCR) model driven by the same atmospheric forcing, allowing concurrent characterization of the compound flooding hazard and associated uncertainties. Simulation of both coastal and riverine processes driven by TCs will be completed using hydrologic, hydraulic, and hydrodynamic models: synthetic TC rainfall will be applied to a HEC-HMS model of the Neches Watershed and the flow output routed through the inland-coastal boundary through the use of a 2D HEC-RAS model. The compound hazards will be assessed through the application of a loosely coupled HEC-RAS and ADCIRC modeling framework and quantified through the integration of the combined responses, including uncertainty. As the coupled inland and coastal models are being implemented, the impacts of several modeling options are being explored including: precipitation-based infiltration parameters, antecedent flow conditions, precipitation in the hydraulic model, boundary condition geometry and additional runs of hydrodynamic models for multiple riverine flow conditions.

3.7.3.2 Presentation (ADAMS Accession No. ML22061A110)

7th Annual Probabilistic Flood Hazard Assessment Research Workshop
US Nuclear Regulatory Commission

Coastal Compound Study PFHA Pilot Study

- Presenter: Victor M. Gonzalez, PE (USACE ERDC-CHL)
- Meredith Carr, PhD, Karlie Wells, Norberto C. Nadal Caraballo, PhD (USACE ERDC-CHL).
- 17 February 2022



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Presentation Outline

- Project Objectives
- Probabilistic Storm Surge Hazard Modeling
- Compound Flooding Hazard Approach
- Synthetic Tropical Cyclone Rainfall Assessment and Bias Correction
- Hydrologic Modeling and Antecedent Flow
- Hydraulic Modeling Approach

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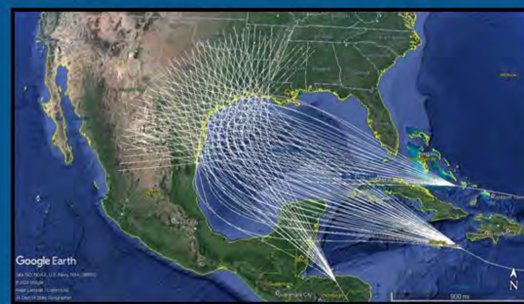
Study Objectives

Demonstrate the application of PFHA to external flooding at a hypothetical location in a coastal setting.

- Leverage existing data and models characterizing the hydrology, hydraulics, and hydrodynamics of the region.
- Primary region: Texas Coast
  - Available H&H data and models offered through SWG.
  - CTXS* results through ERDC-CHL.
- Apply the Coastal Hazards System's (CHS) Probabilistic Coastal Hazard Analysis (PCHA) framework developed by ERDC-CHL.
  - Extended to include precipitation-induced riverine flooding.



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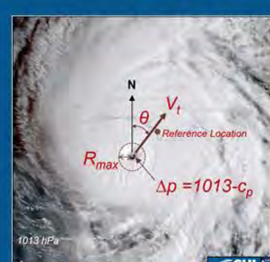
*USACE Coastal Texas Study

Probabilistic Storm Surge Hazard Modeling

- Approach dependent on type of cyclonic exposure:
  - Tropical Cyclones (TC): Joint probability analysis of TC forcing parameters.
    - Development of synthetic TCs through sampling of joint probability distribution of TC parameters.
    - Development of synthetic TCs wind and pressure fields and hydrodynamic modeling of response.
  - Extratropical Cyclones (XC): extreme value analysis of atmospheric and hydrodynamic modeling response of historical XCs wind and pressure fields.



Standard TC parameters

Track position
(reference location, x_0).
Track angle
(heading direction, θ).
Intensity
(central pressure deficit, Δp).
Size
(radius of maximum winds, R_{max}).
Translational speed
(V_t)

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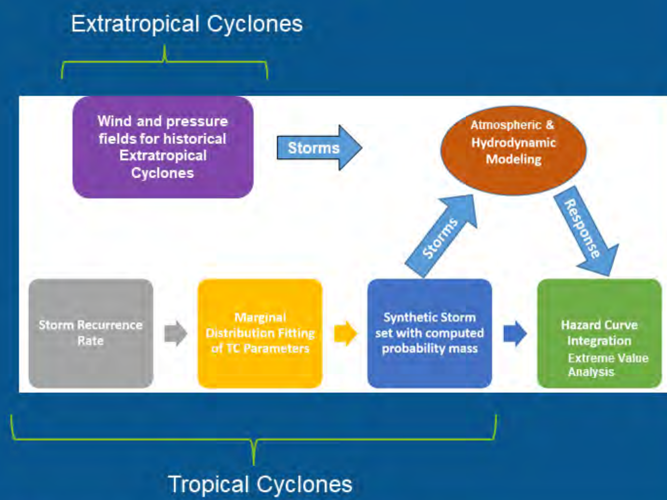
Probabilistic Storm Surge Hazard Modeling

JPM Integral

$$\lambda_{r(\hat{x})>R} = \lambda \int P[r(\hat{x}) + \varepsilon > r|\hat{x}, \varepsilon] f_{\hat{x}}(\hat{x}) f_{\varepsilon}(\varepsilon) d\hat{x} d\varepsilon$$

$$\approx \sum_i^n \lambda_i P[r(\hat{x}) + \varepsilon > r|\hat{x}, \varepsilon]$$

where:
$\lambda_{r(\hat{x})>R}$ = AEF of TC response R due to forcing vector $\hat{x}$
$\hat{x} = f(x_o, \theta, \Delta p, R_{max}, V_t)$
λ = SRR (storms/yr/km)
$\hat{\lambda}_i$ = probability mass (storms/yr) or λp_i, with p_i=product of discrete probability and TC track spacing (km)
$P[r(\hat{x}) + \varepsilon > r|\hat{x}, \varepsilon]$ conditional probability that storm i with parameters $\hat{x}_i$ generates a response larger than r
ε = unbiased error or aleatory uncertainty of r



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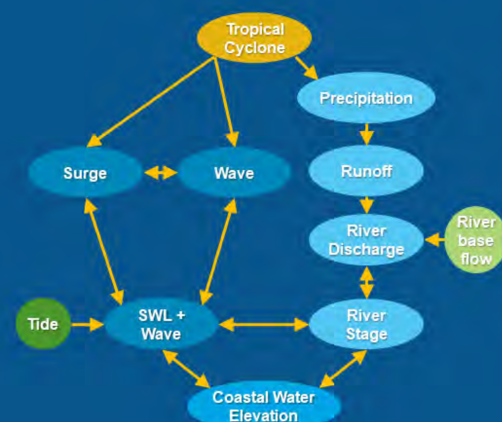
Compound Flooding

- Until recently, coastal probabilistic flood hazard studies have mainly focused on surge and wave climate components of the flooding hazard.
- Concurrent riverine flooding effects have typically been addressed in the hydrodynamic modeling through assignment of baseline flows representing a particular level of hazard.
- Hurricane Harvey brought to the forefront the risk of compound flooding, in particular rainfall generated flooding.



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Compound Flooding Hazard Approach

Study approach:

- **Incorporate rainfall within the PCHA framework though the use of a physics-based parameterized tropical cyclone rainfall (TCR) model.**
- **Hazard driven by the same atmospheric forcing than drives surge hazard (i.e. synthetic TCs).**
- **Concurrent characterization of the compound flooding hazard and associated uncertainties.**

Storm → Responses

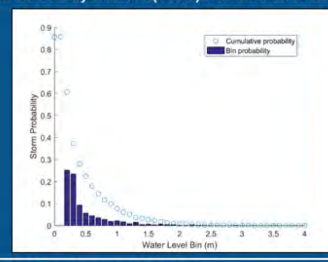
TC 1 Probability Mass 1 (PM_1) → **WL_1, Precipitation$_1$, PM_1**

⋮

TC n* PM_n → **WL_n, Precipitation$_n$, PM_n**

*n = TC number

Probabilities of water level bins and construction Complementary Cumulative Density Function (CCDF) -> AEP hazard curve.



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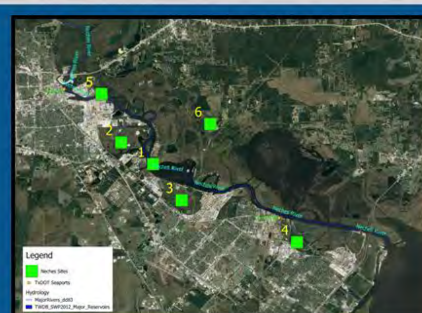
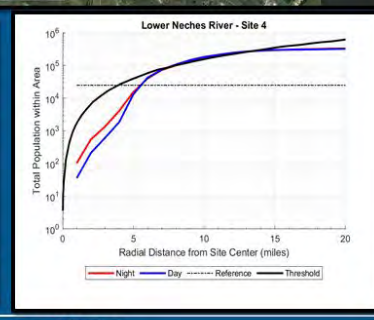
Site Location

- **Evaluated locations within the Lower Neches River.**
- **Selected location labeled Site 4.**
- Surge levels vary from:
  - $1x10^{-2}$ AEP ~10 ft
  - $1x10^{-6}$ AEP: ~20 ft
  - Developed area, industrial (petrochemical) and residential zones.
  - All locations affected by riverine and storm surge flooding and within H&H modeling domains.





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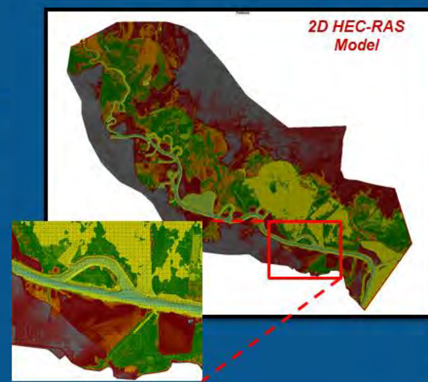
Existing Site Information

- LiDAR Topography
  - 70 cm resolution (SWG)
- 2019: Fort Worth District completed the Lower Neches Riverine Flooding Analyses (LNRFA) (Mosser et al. 2019)
  - Evaluation of riverine flooding along both Sabine and Neches Rivers
- HEC-HMS and HEC-RAS models have been made available to ERDC-CHL through the SWG



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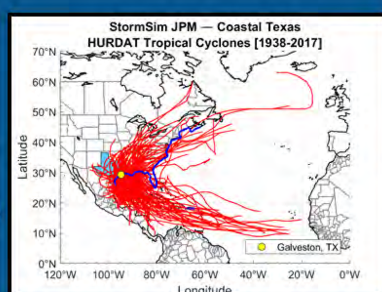
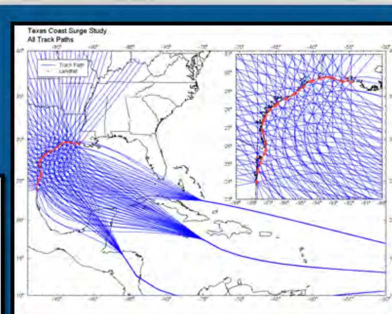
Existing Site Information

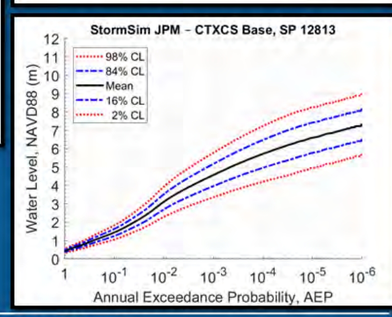
Coastal Texas Study

Storm response and statistical analysis for entire coastal Texas region

- Characterization of storm climate
- 660 unique storms
- High-fidelity storm surge and wave computations
  - 18,000 savepoints
- AEP and average recurrence interval







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Compound PCHA Development

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Compound PCHA

Existing Models & Data

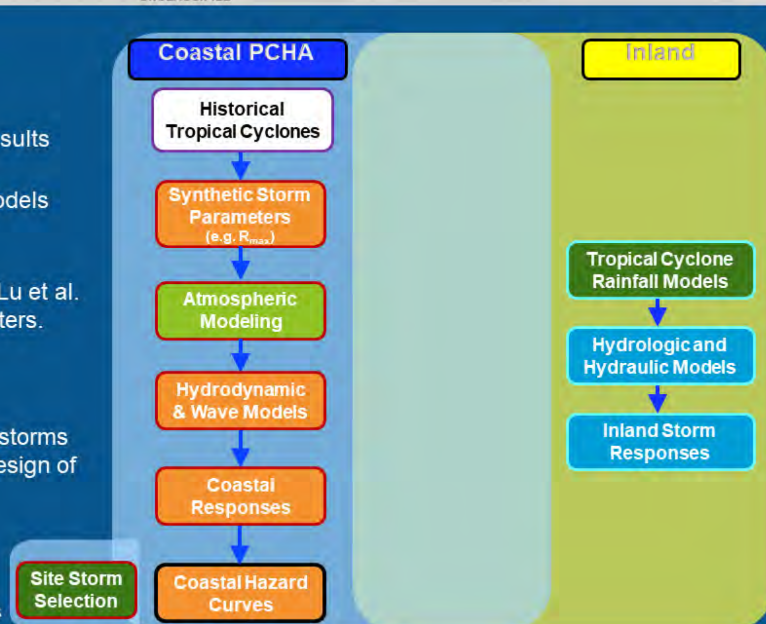
- PCHA based on Coastal Texas results
- ADCIRC and STWAVE models
- HEC-HMS & HEC-RAS inland models

Link by Joint Effects

- Tropical Cyclone Rainfall Model (Lu et al. 2018) using synthetic TC parameters.
- Boundary conditions for inland hydraulic and coastal hydrodynamic models.
- Storm Selection of subset of 150 storms using Genetic algorithm-based Design of Experiments (DoE) approach.

Uncertainty

- JPM
- H&H Modeling (e.g antecendent flows Manning n's)



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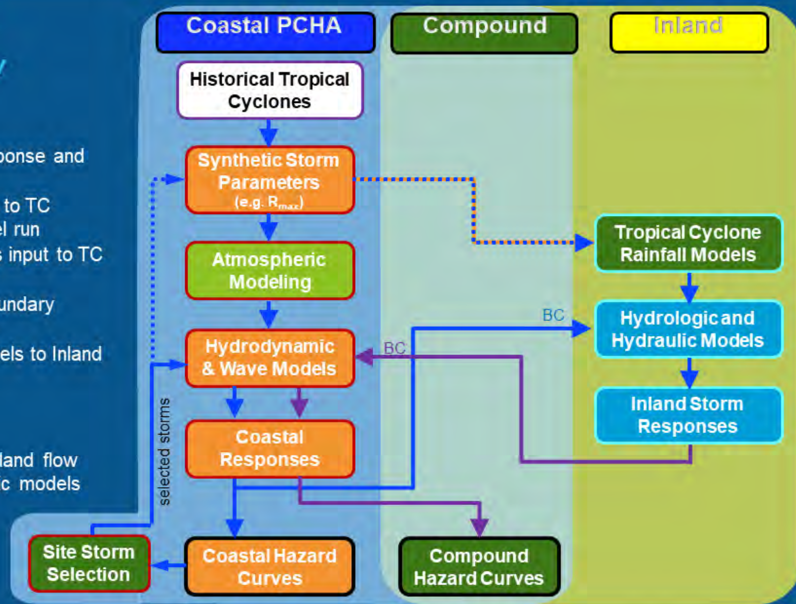
Compound PCHA

Loose Coupling under Review

- **1st Loop in BLUE**
  - Step through PCHA to Coastal Response and Hazard Curves
  - Storm selection from PCHA Results to TC Rainfall Model and next surge model run
  - Synthetic storm parameters used as input to TC Rainfall Model
  - Coastal Response elevations as boundary condition (BC) for hydraulic model
  - Step through TC Rainfall, H&H Models to Inland Response
- **2nd Loop in PURPLE**
  - From hydraulic model, distributed inland flow used as BC for coastal hydrodynamic models
  - Coastal responses:
    - Used to develop compound hazard curves (or):
    - Coupling can be repeated



Tropical Cyclone Rainfall (TCR) Analysis

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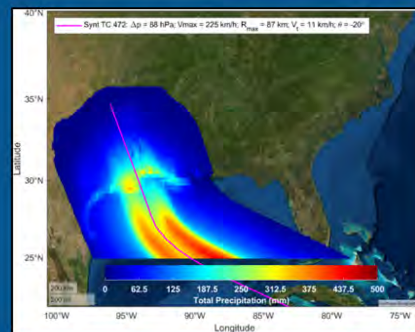
Tropical Cyclone Rainfall

Synthetic Rainfall Modeled from CHS Storms

- Parametric Tropical Cyclone Rainfall Model (TCRM, Lu et al. 2018)
  - Physics-based model with rainfall estimated by upward vapor flux
    - Accounts for major rainfall-generating mechanisms: frictional, topographic, baroclinic, vortex stretching
    - Produces gridded time-series data based on evolution of synthetic storm parameters (Wmax, Rmax, lat/lon)
    - 0.1 x 0.1 degree spatial resolution (nominal 10 km); 1-hour temporal resolution
  - *Limitations:* Like other TCR models, does not well account for storm outer rainbands or interaction with other meteorological features.



Example of TCRM Output (Event Total Rainfall)

Collaboration for TC Rainfall

- Princeton University
  - Dazhi Xi, PhD student
  - Ning Lin, Associate Professor
  - *Natural hazards & risk analysis, focus on hurricanes*

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Coastal Hazards Group

Evaluation of TCRM results

- Assessment at three grid locations within the Neches River watershed representing lower, middle and upland areas and three rain gages (Beaumont, Rusk, and Jasper gages).
- Ability to model individual historical storms.
- TCRM precipitation frequency assessment at grid locations comparing with NOAA Atlas 14 and gage extreme value analysis.
  - **IMPORTANT:** NOAA Atlas 14 consists of mixed storm populations.
  - TCs found to be a primary driver of precipitation at lower Neches.

ARI (years)	NOAA Atlas 14 24-hr Rainfall (mm)	GPD fitted 24-hr TC rainfall (mm)
50	368	350.4
100	442	431.0
500	666	688.6

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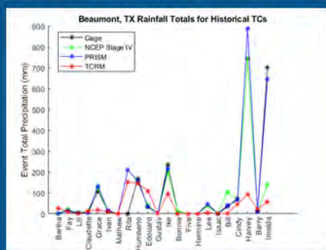
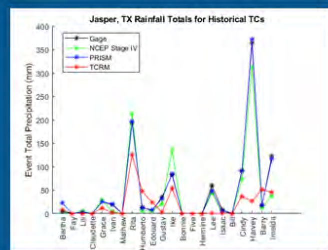
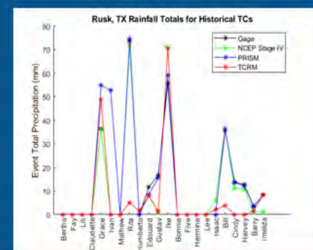
Evaluation of TCRM results

- Comparisons of TCRM results with gage, NCEP Stage IV, and PRISM data for the three gage locations.







- The model underpredicted precipitation for various historical storms, particularly for storms with larger event total precipitation.

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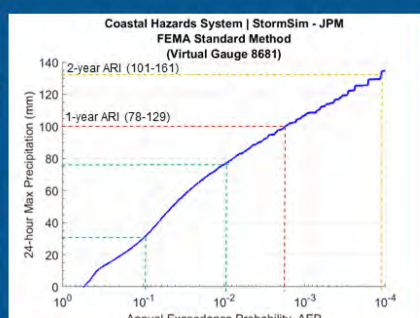
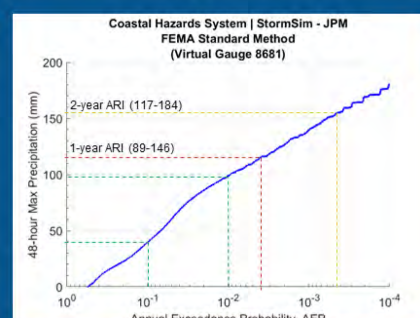
Comparing to NOAA Atlas-14 – Lower Neches River Watershed

- Lower Neches





PDS-based precipitation frequency estimates with 90% confidence intervals (in millimeters)

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
24-hr	100 (78-129)	133 (101-161)	179 139-226)	223 (172-289)	291 (218-390)	350 (255-482)	420 (296-590)	501 (343-722)	626 (413-935)	733 (472-1121)
2-day	114 (89-146)	154 (117-184)	209 (163-262)	263 (204-339)	347 (262-463)	422 (309-578)	510 (361-711)	611 (419-873)	764 (506-1133)	895 (578-1357)

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TCR Bias Correction

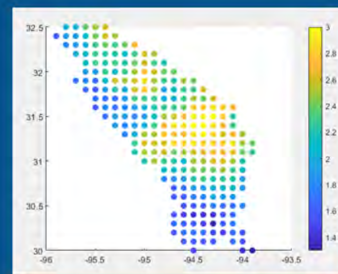
- Focused on tuning dominant physical parameters of the TCRM (q_s, C_d)
- Bias correction using total rainfall:
  - Run TCRM for suite of historical storms
  - Compute observed rainfall totals for historical storms from PRISM dataset (when storm is within 300km of point of interest)
- For each point, minimize the error between the distributions of total rainfall for observations/TCRM simulations

Main Equation Driving the TCRM

$$P_{rate} = \epsilon_p \frac{\rho_{air}}{\rho_{liquid}} q_s (w_f + w_h + w_t + w_s + w_r)$$

Saturation specific humidity

Friction, $w_f = f(C_d)$



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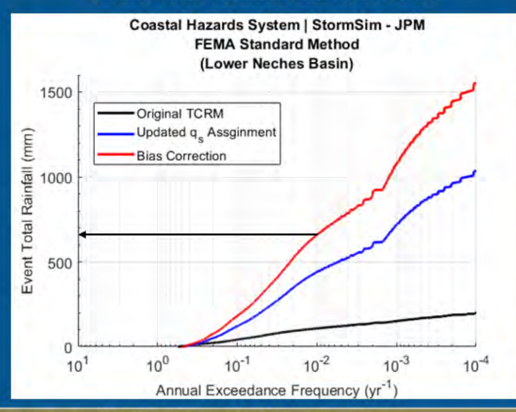
Results of Bias Correction

- **Lower Neches**

Event Total Rainfall Hazard Curve



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Hydrologic Modeling and Antecedent flow estimation for TCs

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Automating HEC-HMS

- Dynamically create input files and run HMS (without the GUI) for desired storms
- Loss rates for each subbasin assigned based on storm frequency
  - Original HMS model used NOAA Atlas-14 rainfall estimates
  - Compare TCR totals from synthetics to NOAA Atlas-14 to assign storm frequency & calibrated loss

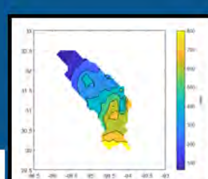
Pre HMS calculations: Prep Storms and ARI estimate

Storm Selection

Precipitation Hyetograph in dss file format

Freq. Estimation Determine the frequency of the event in TC only rain space, convert to Atlas 14 ARI for basin file creation

Basin File Creation Select Initial and Constant Loss Rates for storm according to storm frequency



Total Rainfall from Synthetic Storm 472

Identify Storm Name based on storm number

Create New Met File From template, change title, basin name, precip grid name

Create new .grid file From template, change grid name, dates and times, DSS Path, DSS filename

Create New Control File From template, change title, dates and times

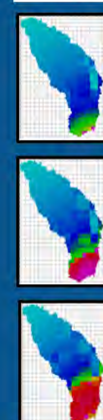
Create New .run file From template, add run name, log and dss output file name, date and time, basin name, Met file name, Control file name

Create New .hms file From template, change project name and attach submodel names in HMS for met model, basin model and control file

Run HEC-HMS

Flow Output for HEC-RAS

TCR within HEC-HMS at hourly timesteps



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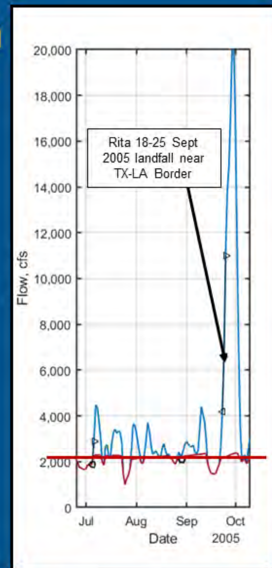
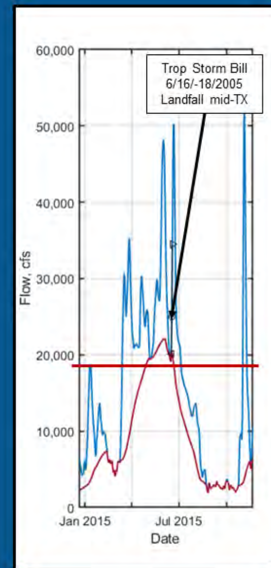
Antecedent Flow Approach

- Early parameter sensitivity analysis for hydrologic parameters were conducted early in the work
- Antecedent flow parameters were assessed for
  - increasing baseflow +/ 10% & +/- 50%
  - little change implied insensitivity
- Later, gage records for storm precursor flows demonstrated sensitivity
  - Tidally filtered data at USGS gage at the Neches River Saltwater Barrier
  - 2003-2021





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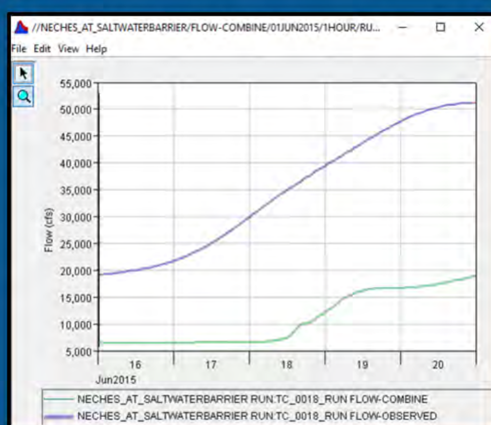
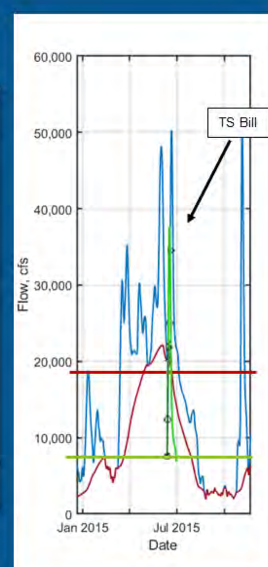
Antecedent Flow

- HMS model runs showed we were often underestimating precursor flows
- Considered solutions to the apparent sensitivity to antecedent flows





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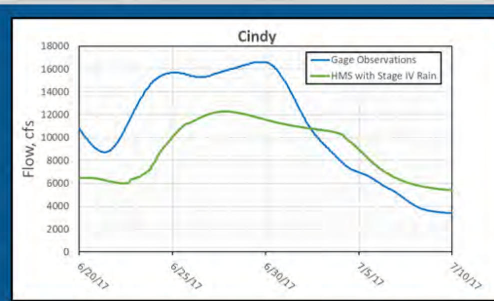
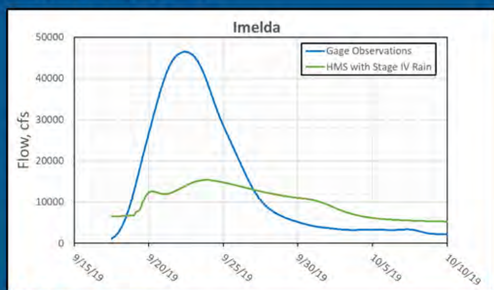
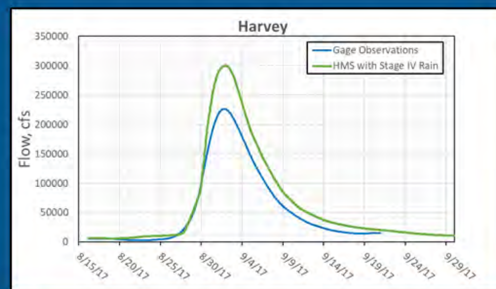
Antecedent Flow

- The difference in antecedent flows was inconsistent, sometimes too large and sometimes too small
- To select values for the synthetic storms, we needed a probabilistic approach to selecting an antecedent flow







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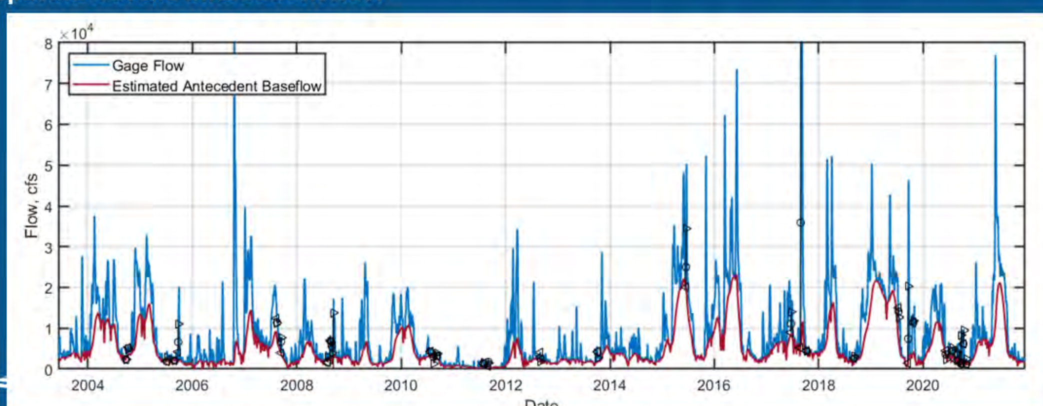
Developing an Antecedent Flow Approach

- First step was to determine an antecedent flow for the gage time series
- Used a simple baseflow filter (Lynn and Holick with alpha = 0.955 and 3 passes) to separate out the antecedent flow



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Standard approach shown in Ladson, A. R., R. Brown, B. Neal and R. Nathan (2013). "A standard approach to baseflow separation using the Lyne and Hollick filter." Australian Journal of Water Resources 17(1): 173-180.

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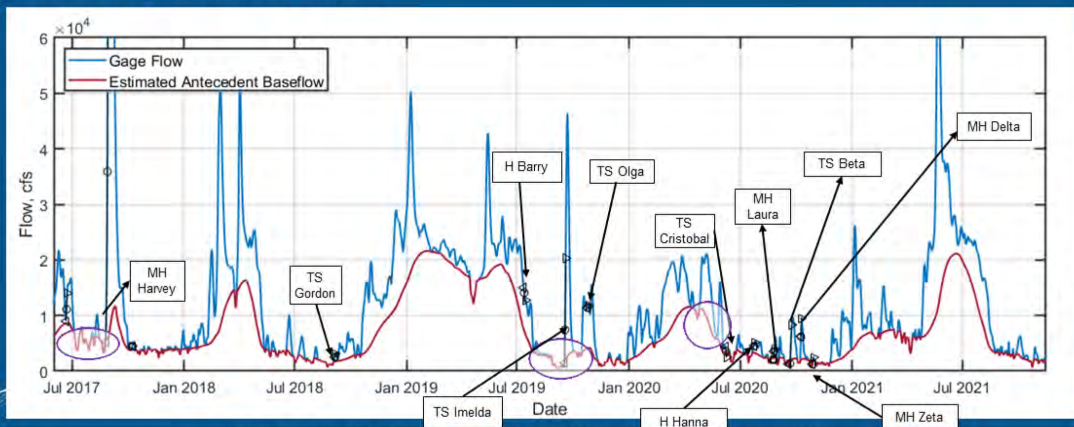
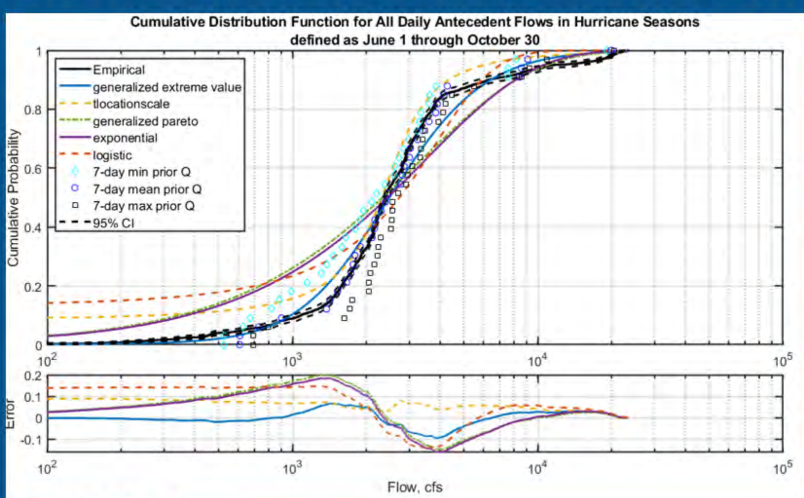
Developing an Antecedent Flow Approach

- **Reviewed Tropical Storms Events and Antecedent Flow Series at USGS Gage Saltwater Barrier**

Period: 2017-2022



Fit Distributions to the Daily Flows During Hurricane Seasons



- **The black curve is the mean fit of the daily summer flows.**
- **The point values are for the min, max and mean flows in the 7 day prior to historical TCs**
- **Curves were ranked by AIC (Aikake Importance Criterion), a goodness of fit parameter**

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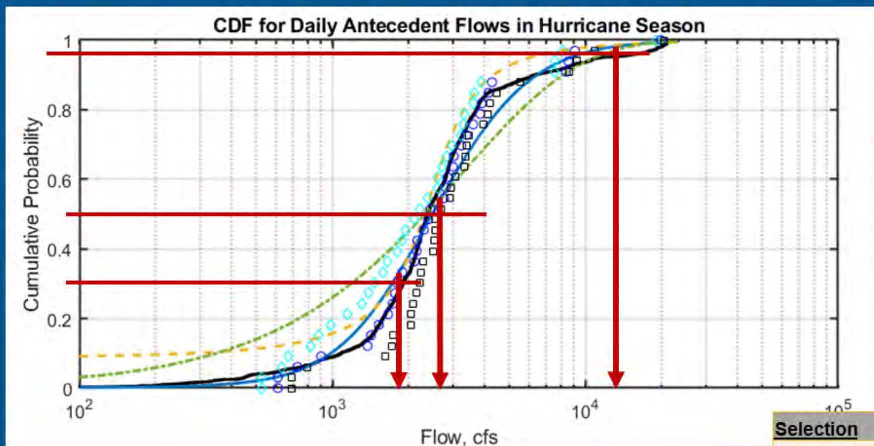
Selecting Antecedent Flows from the Distribution for Pilot



- Estimate 3 antecedent flows to test to capture the range
- Will carry out a sensitivity analysis to make sure these antecedent flows are capturing effects
- Later, during model production, can decided how to weigh those flows

- Recommended Values

Selection	Reason	Approx Q (cfs)
32%nd percentile	-1σ	1800
50% percentile	median	2500
95%th percentile	+2σ	8,700

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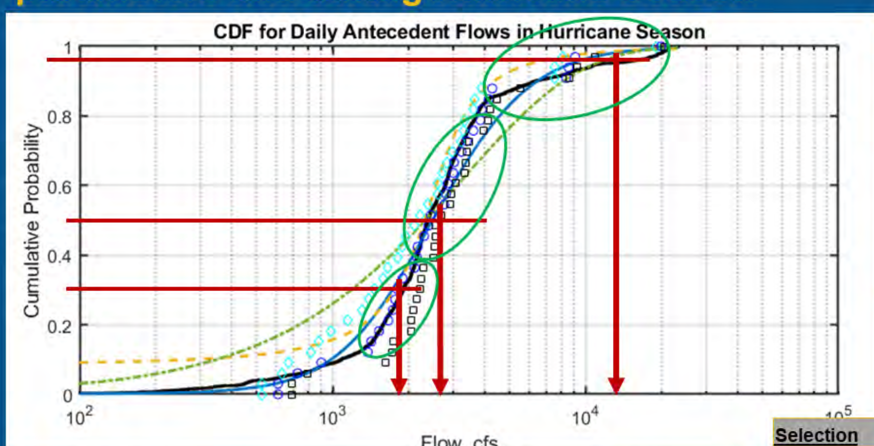
Distributions found for the selected antecedent flow parameters and during Hurricane Season



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Hydraulic Modeling Approach

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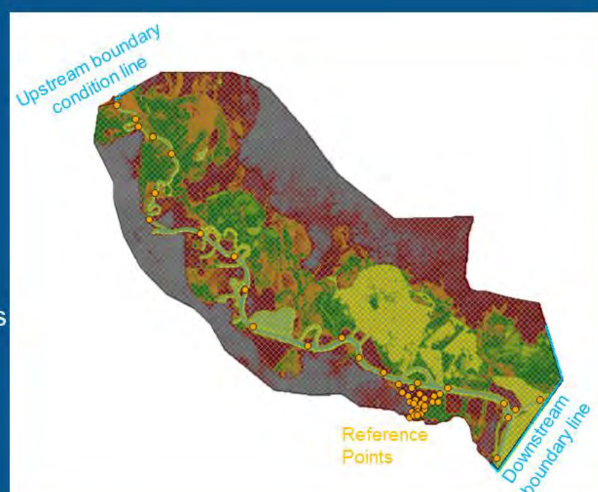
HEC-RAS Model

- 2D HEC-RAS Model
- Upstream boundary condition
  - Flow Hydrograph from HMS outputs
- Downstream boundary condition
  - Stage Hydrograph from ADCIRC outputs
- Added precipitation and infiltration parameters to calculate rainfall runoff within domain
- Added Reference Points at locations of interest – written to results hdf5 file



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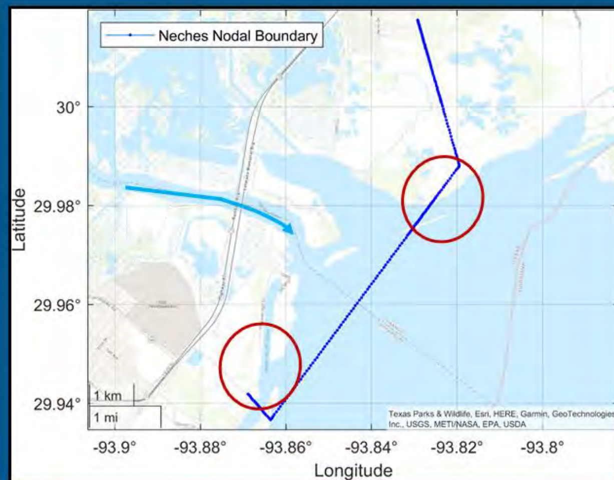
HEC-RAS Boundary condition

- One-way coupled HEC-RAS - ADCIRC boundary
  - Testing boundary condition discretization, currently focused on physical characteristics (channels, swamp, etc.)
- Automate HEC-RAS:
  - Input file generation
  - "rascontrol" in python environment
  - Data extraction for necessary outputs



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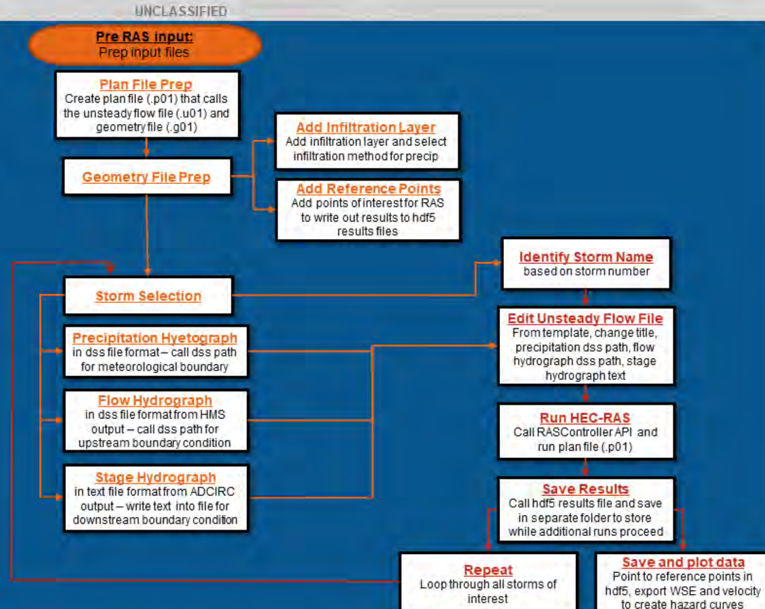
Automating HEC-RAS

- Dynamically create input files and run RAS (without the GUI) for desired storms
- Pull data of interest from output files and store elsewhere to use to create hazard curves and then overwrite results within RAS to run next scenario
  - Allows for one model/project file to run all scenarios (using individual plan files would limit each model version to 99 runs)



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Next Steps

- Hydraulic Modeling of synthetic storms
- Execute "loosely-coupled" framework with hydrodynamic model
- Compute combined hazard curves

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3.7.4 Presentation 3B-4: Probabilistic Wave Height Hazard Assessment Method at the NPP Site Considering Storm Surge

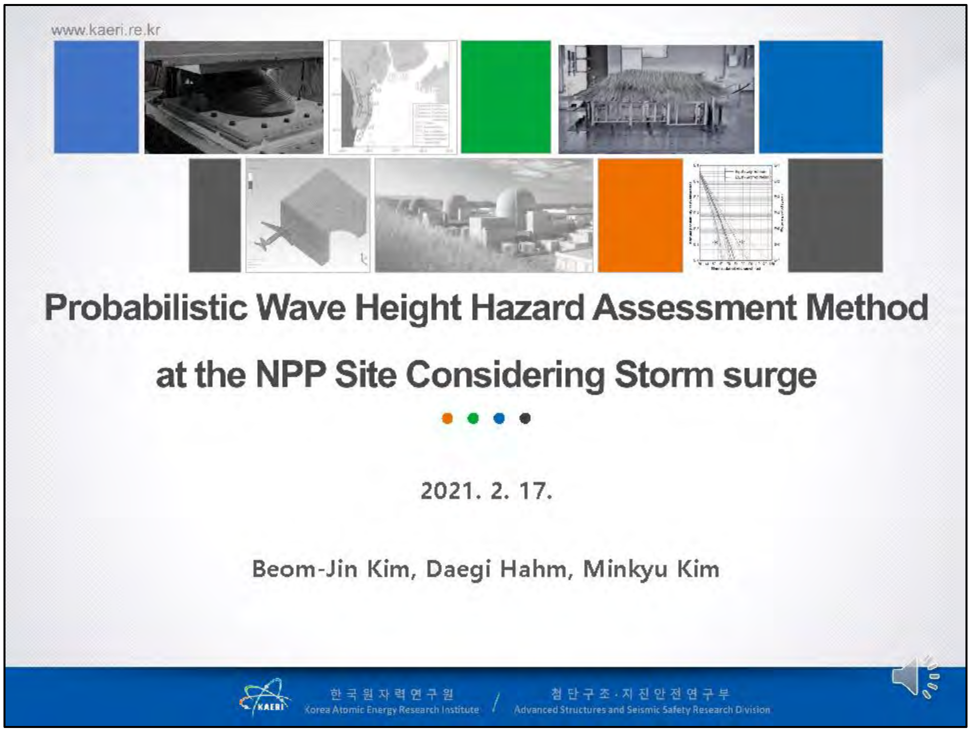
Authors: *Beom-Jin Kim*, Daegi Hahm, Minkyu Kim*
Korea Atomic Energy Research Institute (KAERI)

Speaker: *Beom-Jin Kim*

3.7.4.1 Abstract

Due to the influence of recent climate change, typhoon invasions of the Korean Peninsula with extreme rainfall frequently occur. Between August and September 2020, three typhoons, Bavi, Maysak, and Haishen, attack to the Korean Peninsula, and the resulting heavy rains that fell caused flood damage. As typhoons Maysak and Haishen passed east of Korea, the local nuclear power plants were automatically shut down. In order to analyze the wave height, wave period, and wave direction characteristics in the front of the nuclear power plant site, the SWAN model was built in the near sea area through nesting technique. First, based on the data presented in the Deepwater design waves report, wave height, period, and sea wind were estimated according to the return period. Second, the SWAN model was established through SMS and GIS programs based on the sea-depth data around the nuclear power plant site. Finally, a probability distribution was applied based on the wave height data, the result of the SWAN model for each return period. Based on the result, the probabilistic wave height hazard assessment (PWHA) of the sea around the nuclear power plant site was estimated. The results of this study are expected to be the basis for the waterproofing design of nuclear power plant sites and the planning of various flood prevention measures caused by the combination of external hazard such as local intense precipitation (LIP) and storm surges.

3.7.4.2 Presentation (ADAMS Accession No. ML22061A109)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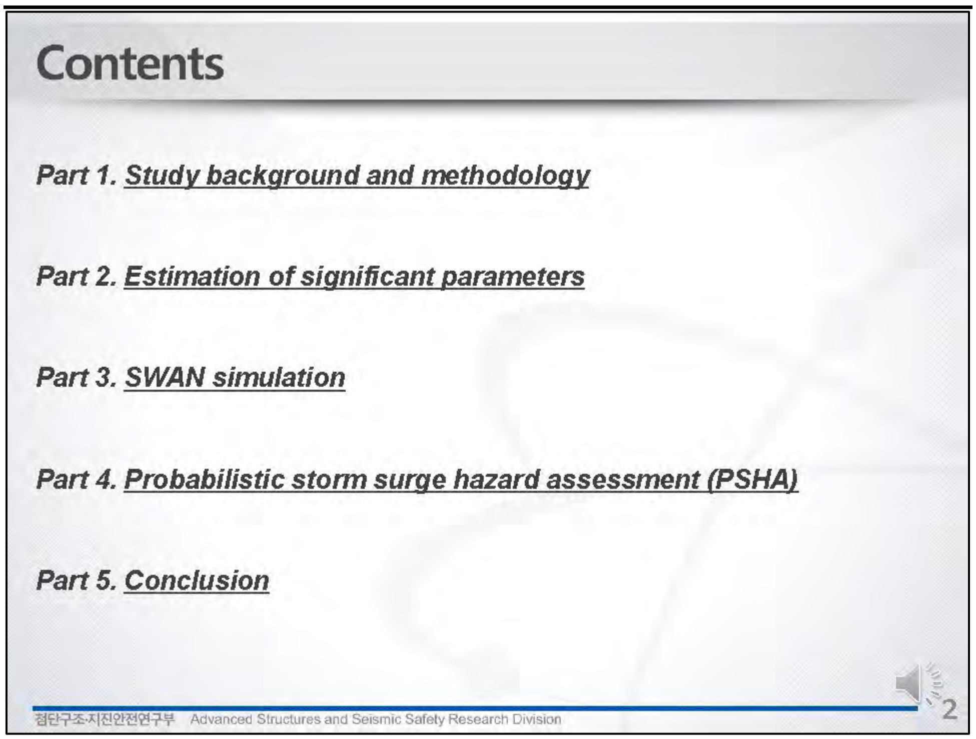
Probabilistic Wave Height Hazard Assessment Method
at the NPP Site Considering Storm surge
2021. 2. 17.
Beom-Jin Kim, Daegi Hahm, Minkyu Kim
한국원자력연구원
Korea Atomic Energy Research Institute
첨단구조·지진안전연구부
Advanced Structures and Seismic Safety Research Division


Contents
Part 1. Study background and methodology
Part 2. Estimation of significant parameters
Part 3. SWAN simulation
Part 4. Probabilistic storm surge hazard assessment (PSHA)
Part 5. Conclusion
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2

Part 1. Study background

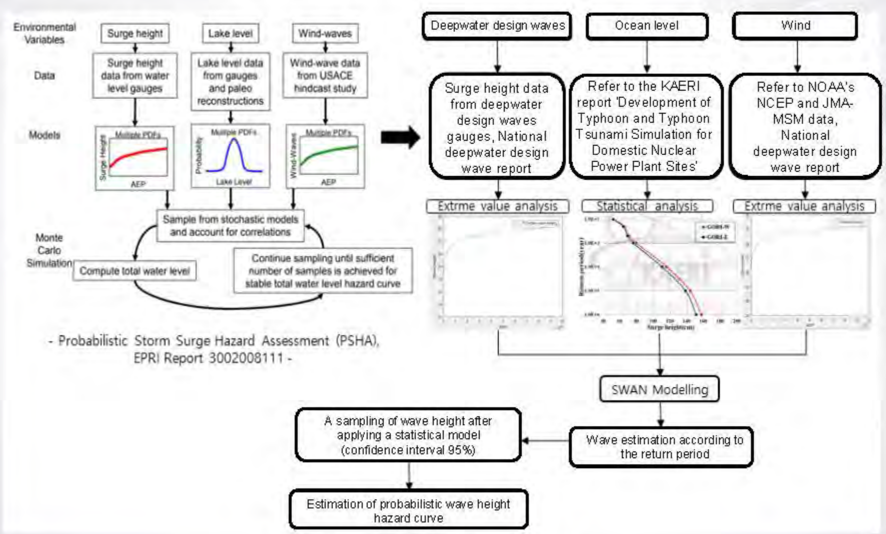
- Due to the influence of recent climate change, typhoon invasion of the Korean Peninsula with extreme rainfall frequently occur. Between August and September 2020, three typhoons, Bavi, Maysak, and Haishen, attack to the Korean Peninsula, and the resulting heavy rains that fell caused flood damage. As typhoons Maysak and Haishen passed east of Korea, the local nuclear power plants were automatically shut down.
- Such as flooding can cause core damage to nuclear power plants. Therefore, it is necessary to analyze hazards in advance and take measures to prevent them.

< Typhoon Maysak >

< Typhoon Bavi >

< Typhoon Haishen >

Part 1. Methodology

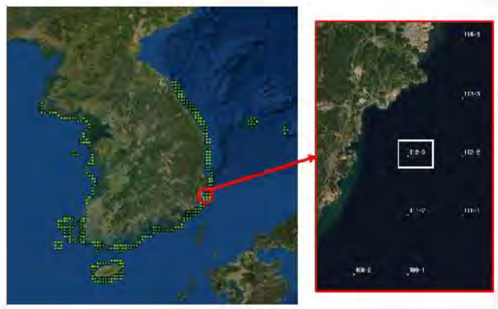


< Study flow>

Part 2. Estimation of significant parameters

➢ *Deepwater design wave estimation*

- Currently, there are 535 design wave height points in the ocean of the Korean Peninsula.
- In this study, analysis was conducted based on the ocean of the Gori nuclear power plant.
- The design wave height point in the Ocean near the Gori nuclear power plant is No. 112-3.



< Fig. 1 Deepwater design wave height points near Gori NPP>

Part 2. Estimation of significant parameters

- One design wave height is divided into 16 directions (S, SSE, SE, SEE, E, ENE, NE, NEN, N, NNW, NW, NWW, WSW, SW, SWS). In addition, data of deepwater wave height (m), period (sec), and wind speed (m/s) are included.
- The 'National Deepwater Design Wave Report (2019)' was referred to predict the Gori Nuclear Power Plant waves. In the case of typhoons, 193 typhoons that affected the Korean Peninsula among typhoons that occurred between 1959 and 2017 were selected when calculating the deepwater design wave.
- Extreme value analysis was performed on the selected typhoon.
- As a result, the Weibull distribution was selected for the typhoon data.

< Table. 1 Parameter estimation >

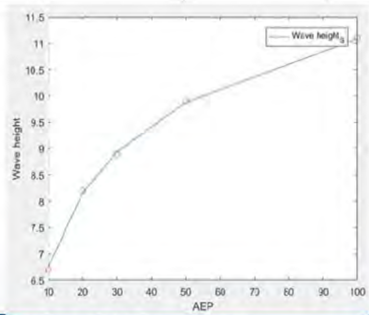
	Parameters (No. 112-3)															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
location	-	-	-2.4	-1.6	-0.5	0.1	-0.7	-	-0.6	-3.7	-	-	-	-	-	-
scale	-	-	6.0	5.5	3.6	0.8	3.3	-	4.2	7.7	-	-	-	-	-	-
shape	-	-	3.9	2.9	1.9	0.9	1.4	-	1.5	5.4	-	-	-	-	-	-

Part 2. Estimation of significant parameters

- After estimating the wave height according to the return period based on the calculated parameters, the wave height of 10 years, 20 years, 30 years, 50 years, and 100 years presented in the 'National Deepwater Design Wave Report (2019)' were compared and verified.

< Table. 2 Validation of wave height >

Return period (y)	10	20	30	50	100
Report Hs (m)	6.7	8.2	8.9	9.9	11.1
Estimation Hs (m)	6.7481	8.1638	8.9408	9.8770	11.0846



Part 2. Estimation of significant parameters

- By applying the validated parameters, wave heights (Hs) corresponding to return periods of 200 years to 1 million years were estimated.

< Table. 3 Wave height estimation according to return period >

Return period (y)	Estimation Hs (m)
200	12.2328
500	13.6766
1000	14.7219
2000	15.7327
5000	17.0229
10000	17.9684
20000	18.8904
50000	20.0769
100000	20.9523
200000	21.8102
500000	22.9199
1000000	23.7422

Estimation of significant parameters

➤ *Period estimation*

- The period according to the wave height was calculated by applying the robust regression curve formula.

$$T_p = a(H_s)^b \ (0.2 \le b \le 0.8)$$

- Here, a and b are variables, and the parameters are estimated by applying the Solver function according to the range of the variable b.
- As a result, 'a' was calculated as 4.940527 and 'b' as 0.428656. By applying to the calculated parameters, the period according to the wave height was calculated and compared and verified with the values of the previous report as shown in <Table 4>.

< Table. 4 Verification of the period>

Return period (y)	Hs (m)	Report Tp (s)	Calculation Tp (s)
10	6.7	11.2	11.2
20	8.2	12.2	12.2
30	8.9	12.6	12.6
50	9.9	13.2	13.2
100	11.1	13.9	13.9

Part 2. Estimation of significant parameters

- By applying the verified parameters to the robust regression curve formula, the period for the wave height corresponding to the return period of 200 years to 1 million years was estimated.

< Table. 5 Period estimation according to return period (Tp) >

Return period (y)	Estimation Hs (m)	Estimation Tp (s)
200	12.2328	14.5
500	13.6766	15.2
1000	14.7219	15.6
2000	15.7327	16.1
5000	17.0229	16.7
10000	17.9684	17.0
20000	18.8904	17.4
50000	20.0769	17.9
100000	20.9523	18.2
200000	21.8102	18.5
500000	22.9199	18.9
1000000	23.7422	19.2

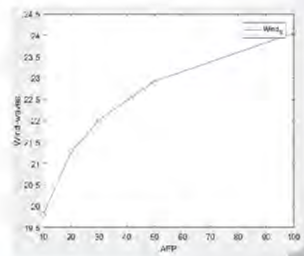
Part 2. Estimation of significant parameters

➢ *Ocean level and wind estimaton*

- The sea level was based on the Korea Atomic Energy Research Institute report 'Development of Typhoon and Tsunami Simulation for Domestic Nuclear Power Plant Sites (2017)'.
- The sea wind data used the NCEP wind data of NOAA (National Oceanic and Atmospheric Administration) from 1979 to 2017. After that, the same method as the deepwater design wave estimation method was applied.
- The estimated sea wind data were compared and verified with the values presented in the previous report.

< Table. 6 Verification of Sea wind >

Return period (y)	10	20	30	50	100
Report Hs (m)	19.8	21.3	22.0	22.9	24.1
Estimation Hs (m)	19.8091	21.2575	22.0238	22.9239	24.0519



Part 2. Estimation of significant parameters

- The sea wind corresponding to the return period of 200 years to 1 million years was estimated by applying the verified parameters.
- Finally, the results of estimating wave height, period, sea wind and sea level height according to the return period are as follows.

< Table. 7 Results of major parameter estimation>

Return period (y)	Estimation Hs (m)	Estimation Tp (s)	Estimation Wind (m/ss)	Estimation Sea level (m)
200	12.2328	14.5	25.09	1.1705
500	13.6766	15.2	26.37	1.2220
1000	14.7219	15.6	27.27	1.3010
2000	15.7327	16.1	28.12	
5000	17.0229	16.7	29.19	
10000	17.9684	17.0	29.95	1.6560
20000	18.8904	17.4	30.69	
50000	20.0769	17.9	31.63	
100000	20.9523	18.2	32.31	1.9365
200000	21.8102	18.5	32.97	
500000	22.9199	18.9	33.81	
1000000	23.7422	19.2	34.43	2.0680

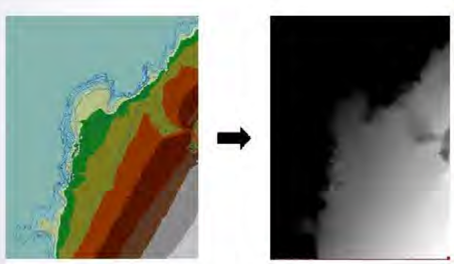
Part 3. SWAN simulation

➢ *SWAN(Simulation Waves Nearshore) modeling*

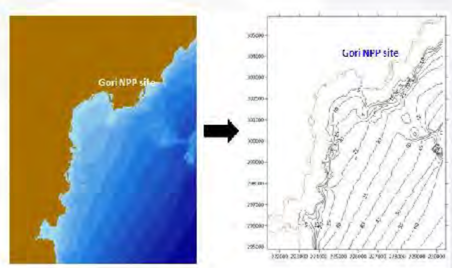
- The Simulation Waves Nearshore (SWAN) model was selected as the model applied to the storm surge simulation.
- The SWAN model can highly calculate wave deformation such as wave refraction, diffraction, wave dissipation due to wave breaking, and bottom friction according to the change in water depth. It can calculate waves in coastal areas, lakes, and rivers downstream.

Part 3. SWAN simulation

- Triangulated Irregular Network (TIN) was generated for the ocean of the Gori nuclear power plant based on the ocean depth data.
- Based on the generated TIN, a digital elevation model (DEM) was created to extract the Gori nuclear power plant area's ocean depth (Z). Also, based on the generated DEM, the sea depth was extracted to determine the suitability of this topographical data.



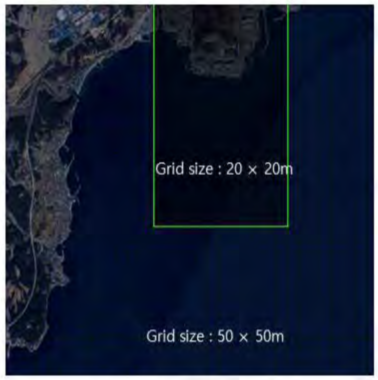
< Fig. 2 TIN to DEM>



< Fig. 3 Sea depth of the Gori NPP >

Part 3. SWAN simulation

- The nesting function of SWAN is used to analyze the wave height of the Gori nuclear power plant.
- A 50 × 50 m grid was constructed in the distant ocean of the nuclear power plant, and a 20 × 20 m grid was constructed in the ocean near the nuclear power plant.

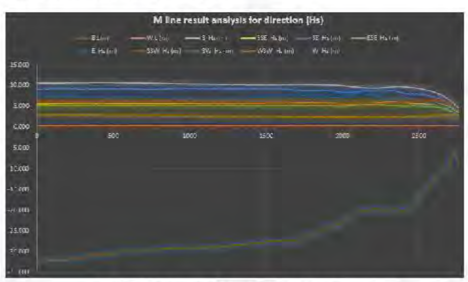


< Fig. 4 Grid for Gori NPP >

Part 3. SWAN simulation

➢ *Sensitivity analysis of SWAN model*

- After constructing the SWAN model, the optimal model was selected through sensitivity analysis of variables.
- As a result of analyzing the SWAN model for wave conditions (16 directions) at the deepwater wave point (No. 112-3), the wave height in the S direction was the largest.
- Therefore, in this study, the direction for wave height analysis by storm surge was determined to be the S direction.



< Fig. 5 Sensitivity analysis for SWAN>

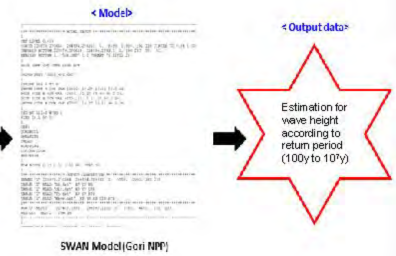
Part 3. SWAN simulation

➢ *SWAN simulation*

- According to the return period, wave height analysis was analyzed through SWAN using estimated data of wave height, period, and wind, as shown in the figure below.

< Input data >

No.	112-3				
Direction	S	Hs (m)	Tp (sec)	Wind (m/s)	Sea level (m)
RETURN	EXCEEDANCE	Weibull	Robust	Weibull	KAERI Rport
10	0.1	5.7	11.2	19.81	
20	0.05	8.2	12.2	21.25	
30	0.03	8.9	12.6	22.02	
50	0.02	9.9	13.2	22.92	
100	0.01	11.1	13.9	24.05	1.0455
200	0.005	12.2	14.5	25.09	1.1705
500	0.002	13.7	15.2	26.37	1.2220
1000	0.001	14.7	15.6	27.27	1.3010
2000	0.0005	15.7	16.1	28.12	
5000	0.0002	17.0	16.7	29.19	
10000	0.0001	18.0	17.0	29.95	1.6550
20000	0.00005	18.9	17.4	30.69	
50000	0.00002	20.1	17.9	31.63	
100000	0.00001	21.0	18.2	32.31	1.9365
200000	0.000005	21.8	18.5	32.97	
500000	0.000002	22.9	18.9	33.81	
1000000	0.000001	23.7	19.2	34.43	2.0580
2000000	0.0000005	24.6	19.5	35.03	
5000000	0.0000002	25.6	19.8	35.80	
1E+07	0.0000001	26.4	20.1	36.35	



< Fig. 7 Wave height analysis method>

Part 3. SWAN simulation

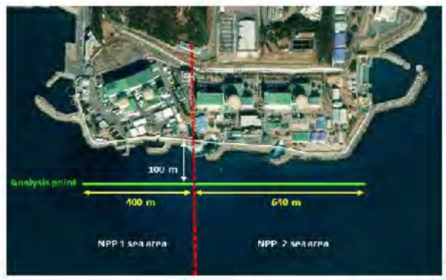
➢ *SWAN results*

- SWAN simulations were performed based on the estimated input data for wave height conditions in the 100 to 1 million year return period.
- As a result, the wave height generated in the ocean near the nuclear power plant was estimated according to the return period.

< Fig. 8 SWAN simulation results (Wave height, Hs >

Part 4. Probabilistic storm surge hazard assessment

- Probabilistic Storm Surge Hazard Assessment (PSHA) is a preliminary step for probabilistic flood risk assessment due to storm surge at the Gori nuclear power plant site.
- For the probabilistic analysis of the storm surge wave height according to the return period, the ocean of the Gori nuclear power plant were classified for each power plant.
- In addition, the verification process of the probability distribution type was conducted by deriving the wave height of the analysis point at intervals of 10 m through the SWAN result for each return period.



Part 4. Probabilistic storm surge hazard assessment

- The maximum wave height, minimum wave height, mean, and standard deviation were calculated for each return period in the ocean area of each power plant, and the probability distribution was verified through AIC verification by return period.

< Table. 8 Apply to probabilistic distribution (NPP 1) >

Return period (y)	Max Hs (m)	Min Hs (m)	Average (m)	Std.	AIC Distribution	Parameter (a)	Parameter (b)
100	3.81	1.96	2.71	0.47	Invguss	2.71	92.32
200	3.98	2.06	2.89	0.48	Gamma	36.25	0.08
500	4.07	2.11	2.98	0.49	Gamma	37.80	0.08
1000	4.18	2.18	3.09	0.51	Gamma	37.10	0.08
10000	4.58	2.47	3.56	0.57	Weibull	7.65	3.79
100000	4.86	2.69	3.90	0.64	Pert	4.58	4.87
1000000	4.97	2.80	4.05	0.68	Pert	4.81	4.97

< Table. 9 Apply to probabilistic distribution (NPP 2) >

Return period (y)	Max Hs (m)	Min Hs (m)	Average (m)	Std.	AIC Distribution	Parameter (a)	Parameter (b)
100	9.05	3.11	5.27	1.40	Pearson5	19.13	95.34
200	9.48	3.21	5.48	1.47	Pearson5	18.98	98.27
500	9.88	3.29	5.61	1.56	Pearson5	18.02	95.15
1000	10.08	3.35	5.74	1.58	Pearson5	18.19	98.29
10000	10.56	3.12	6.11	1.67	Loglogistic	5.78	7.50
100000	10.81	3.45	6.36	1.68	Pearson5	18.37	110.29
1000000	10.83	3.89	6.47	1.66	Pearson5	20.46	[illegible]

Part 4. Probabilistic storm surge hazard assessment

- The @RISK program was used to estimate the hazard curve of the probabilistic wave height caused by the storm surge.
- After applying the Latin hypercube sampling method to the wave height according to the return period, statistical analysis was performed with a 95% confidence interval through 50,000 iterations.
- Based on the results, wave heights of 5%, Mean, Median, Mode, and 95% were estimated according to the return period of each power plant.

< Table. 10 Probabilistic wave height estimation results (NPP 1) >

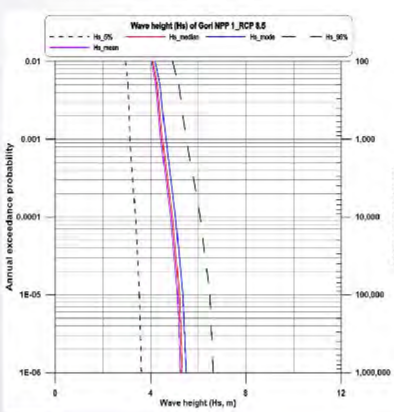
Return period	Exceedance	Hs(m)_5%	Hs_(m)_mean	Hs_(m)_median	Hs_(m)_mode	Hs_(m)_95%
100	0.01	2.94	4.04	4.09	4.19	4.93
200	0.005	3.05	4.22	4.28	4.40	5.18
500	0.002	3.11	4.34	4.40	4.53	5.35
1000	0.001	3.13	4.43	4.49	4.64	5.50
10000	0.0001	3.36	4.84	4.91	5.05	6.08
100000	0.00001	3.53	5.13	5.21	5.35	6.48
1000000	0.000001	3.62	5.25	5.33	5.50	6.62

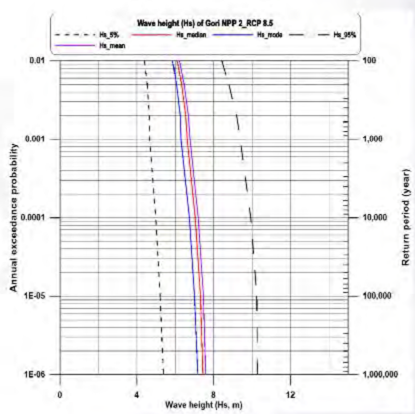
< Table. 11 Probabilistic wave height estimation results (NPP 2) >

Return period	Exceedance	Hs(m)_5%	Hs_(m)_mean	Hs_(m)_median	Hs_(m)_mode	Hs_(m)_95%
100	0.01	4.40	6.21	6.09	5.87	8.43
200	0.005	4.54	6.45	6.32	6.05	8.80
500	0.002	4.65	6.66	6.53	6.25	9.18
1000	0.001	4.67	6.76	6.61	6.29	9.37
10000	0.0001	4.99	7.19	7.04	6.73	9.92
100000	0.00001	5.22	7.46	7.31	7.00	10.24
1000000	0.000001	5.39	7.56	7.44	7.17	10.26

Part 4. Probabilistic storm surge hazard assessment

- Finally, the probabilistic wave height hazard curves for power plants 1 and 2 by storm surge were estimated through statistical analysis using a probability distribution.





Part 5. Conclusion

- This study analyzed the probabilistic wave height caused by the storm surge according to climate change.
- A detailed sea bottom topography was constructed for the storm surge simulation. In addition, the parameters were estimated by applying the probability distributions for the deepwater wave height and wind caused by storm surge.
- Also, the SWAN model is linked with the nesting technique to analyze the characteristics of wave height, period, and wave direction by frequency in the front ocean of the Gori nuclear power plant.
- Based on the results of the SWAN model, statistical analysis was applied to calculate the probability distribution for the possible wave heights in the ocean in front of the nuclear power plant.
- A probability distribution model presented the possible wave heights of the ocean in front of the nuclear power plant according to the return period.
- Based on the results of this study in the future, it will be used as input data for the EurOtop model, and it is judged that valuable data will be utilized for the analysis of flooding caused by the overtopping of the nuclear power plant site.

Thank you for listening to my presentation

If you have any questions at any time, please contact me by my email.

beomjin88@kaeri.re.kr

3.7.5 Presentation 3B-5: Comparative Assessment of Joint Distribution Models for Tropical Cyclone Atmospheric Parameters in Probabilistic Coastal Hazard Analysis

Authors: *Ziyue Liu*[1], Michelle Bensi[1], Meredith Carr[2], Norberto Nadal-Caraballo[2]*
[1]University of Maryland, [2]U.S. Army Corps of Engineers Engineer Research and Development Center Coastal and Hydraulics Laboratory

Speaker: *Ziyue Liu*

3.7.5.1 Abstract

The United States Army Corps of Engineers (USACE) has developed the Probabilistic Coastal Hazard Analysis (PCHA) framework to extend and advance the joint probability method, which has been used to establish probabilistic coastal hazard curves over the past decade. The PCHA framework requires characterization of the joint distribution of tropical cyclone (TC) atmospheric parameters (i.e., central pressure deficient, forward velocity, radius of maximum wind, and heading direction). While the assumptions made in developing this joint distribution have changed over the years, the current PCHA framework uses a meta-Gaussian copula (MGC) to characterize the dependence among TC atmospheric parameters. However, the MGC has limitations associated with modeling of circular variables such as storm heading direction as well as the degree to which it can capture tail dependence. This research investigates the performance of a series of joint distribution models, including the MGC and alternative models. A particular emphasis is placed on characterizing the dependence between linear and circular variables. Specifically, a von Mises kernel function (VKF) is proposed as an alternative to the Gaussian kernel function (GKF) typically in the calculation of the directional storm recurrence rate (DSRR) representing the probability model of heading direction. This study then builds a series of joint distribution models based on assumptions ranging from independence to full dependence models that consider a range of copula models (e.g., MGC and vine copulas combining linear-circular copulas with Gaussian or Frank copulas). The sensitivity of coastal hazard curves to different joint distribution models is assessed for selected locations around New Orleans, LA (USA). The stability of hazard curves generated using an MGC assumption related to the selection of the zero-degree convention is assessed, along with a comparison of tail dependence between copula models.

3.7.5.2 Presentation (ADAMS Accession No. ML22061A108)

Comparative Assessment of Joint Distribution Models for Tropical Cyclone Atmospheric Parameters in Probabilistic Coastal Hazard Analysis

7th Annual NRC PFHA Research Workshop

Speaker: Ziyue Liu, Ph.D. Candidate (UMD)

Co-authors:

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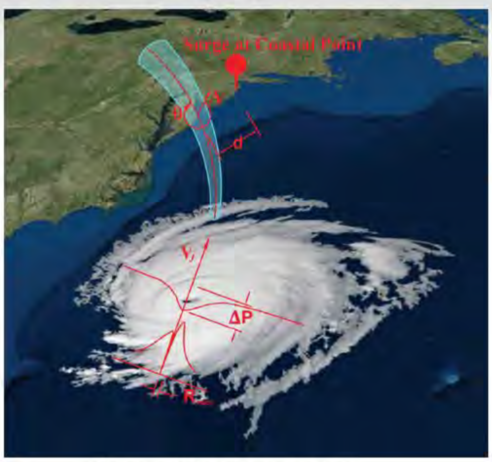
Introduction



TC Atmospheric parameters

Image source: *Al Kajbaf, A. and Bensi, M., 2020.*

Research Need:

JPM is used as the primary methodology for coastal hazard frequency analysis.

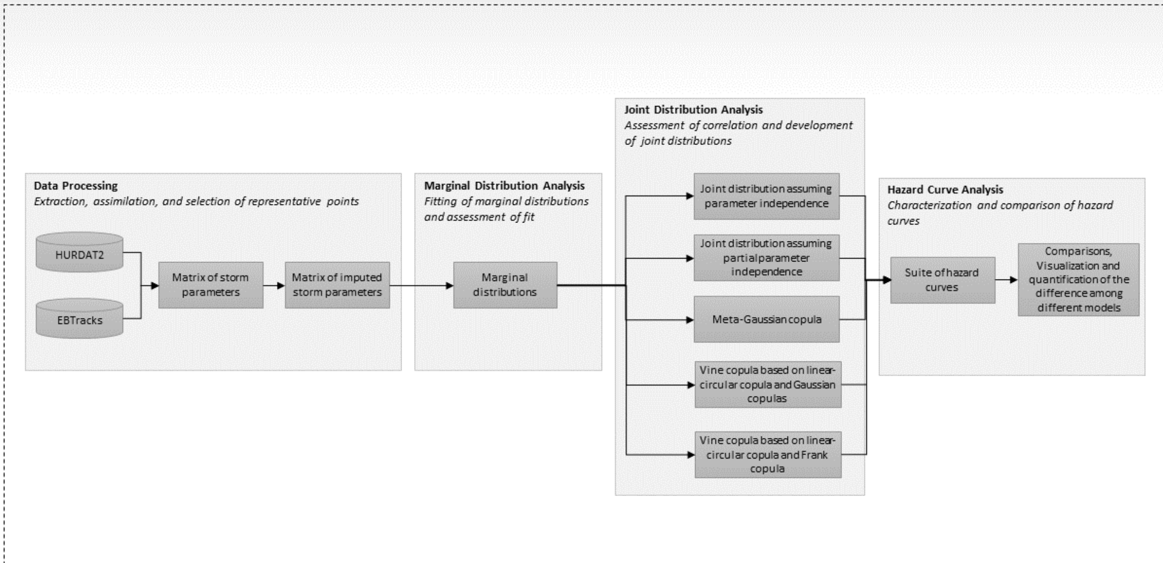
USACE implemented meta-Gaussian copula (MGC) in the latest PCHA framework.

PCHA results may be sensitive to the assumed joint distribution model.

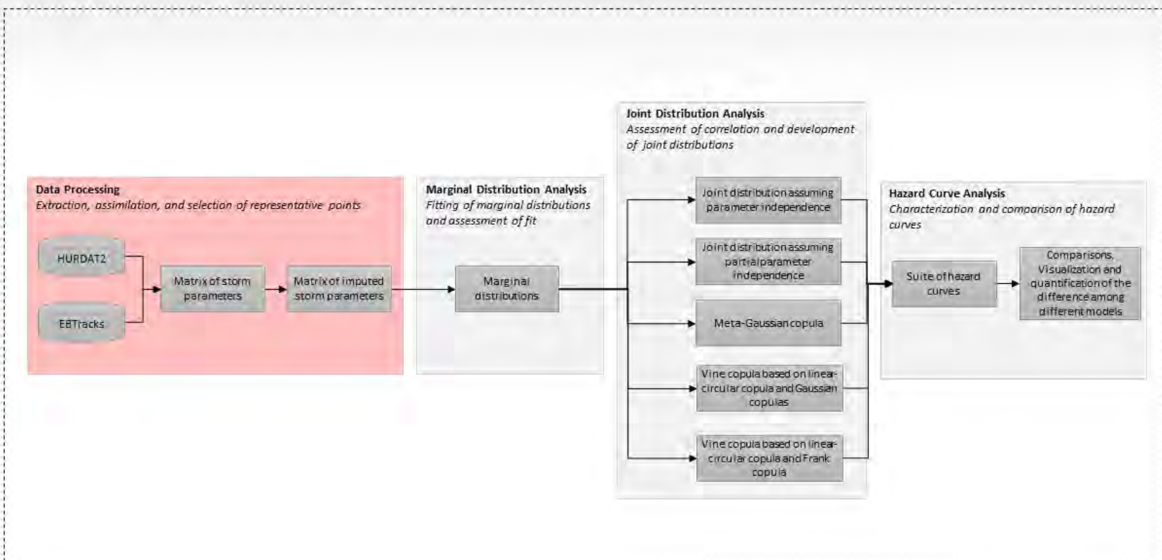
Research Objective:

Investigate performance of different joint distribution models for TC parameters.

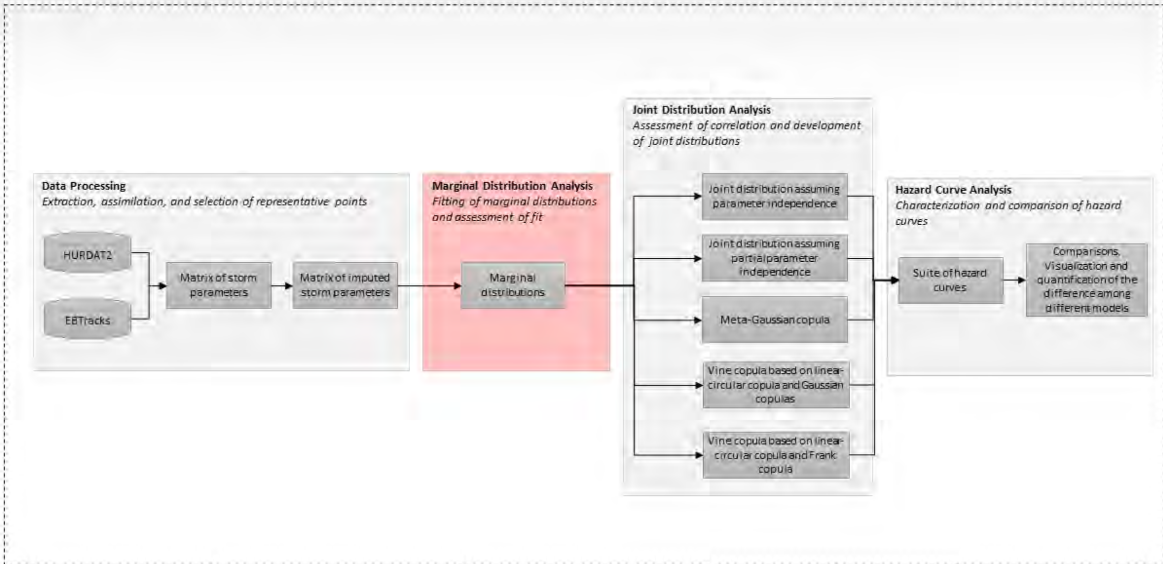
Study Flow Chart



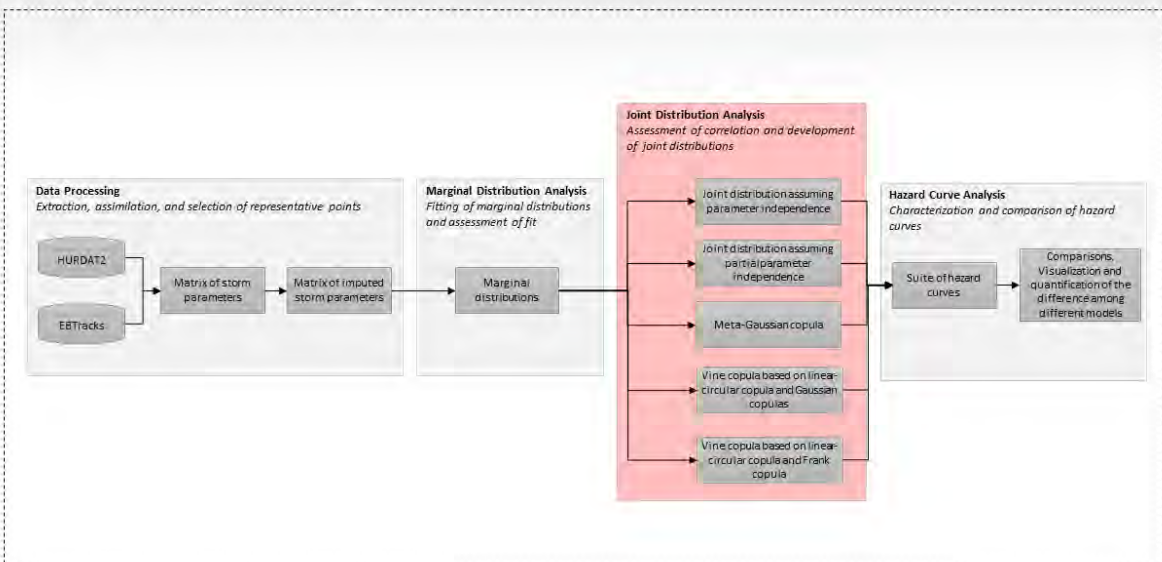
Study Flow Chart



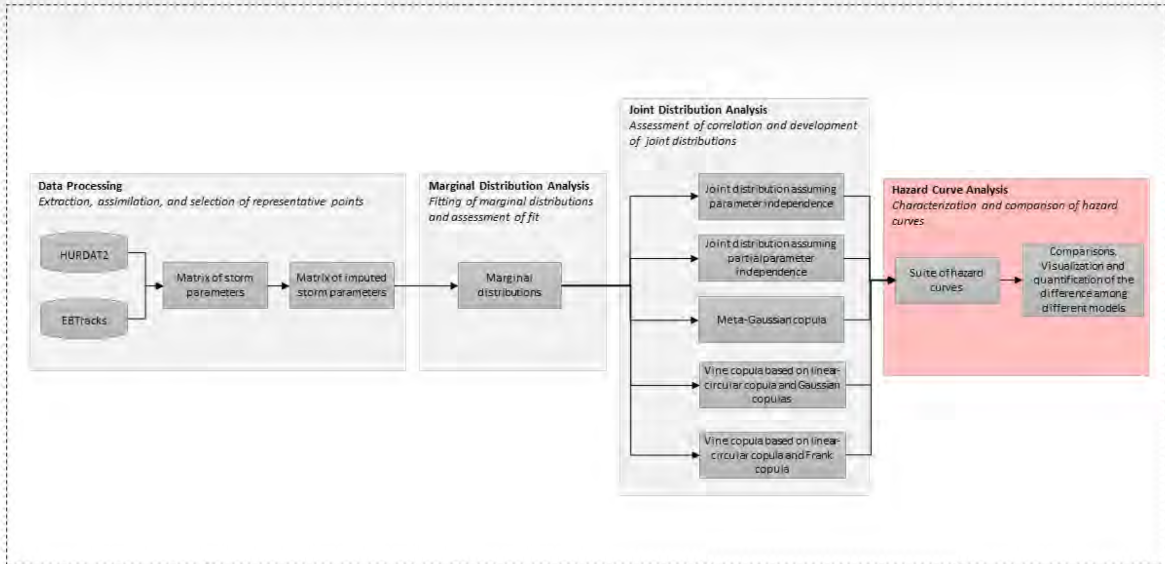
Study Process



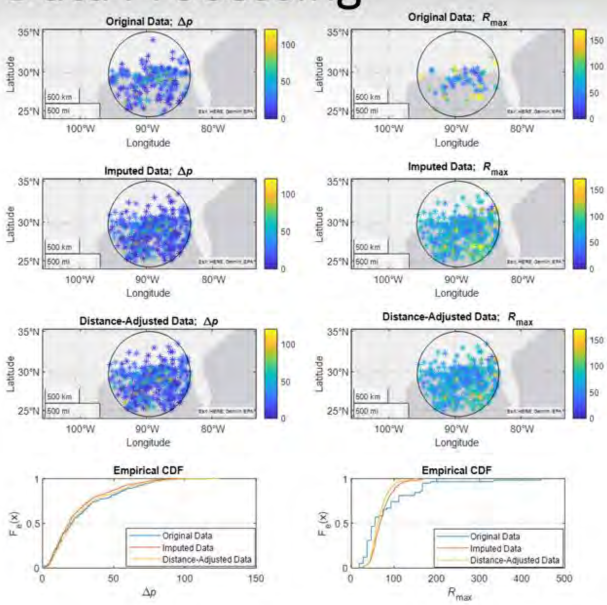
Study Flow Chart



Study Flow Chart



Data Processing



Historical Data Resource:

HURDAT2 and EBTRK.

Data imputation:

Estimate missing p_c and R_{max} using GPR model.

Optimal sampling location:

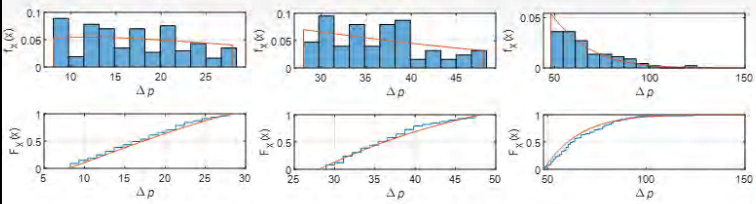
Select a coastal reference location (CRL) and extract optimal sampling locations.

Distance-weight adjustment:

Adjust data based on its distance to reference location.

Preliminary Results

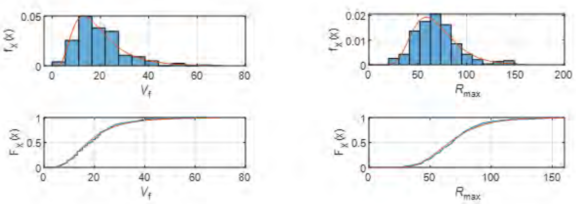
Marginal Distribution Analysis



Central pressure deficit (Δp):

Truncated Weibull distribution:

$$f(x) = \frac{b}{a}\left(\frac{x}{a}\right)^{b-1} \exp -\left(\frac{x}{a}\right)^{b} \qquad x \geq 0$$



Forward velocity (V_f) and radius of maximum wind speed (R_{max}):

Lognormal distribution:

$$f(x) = \frac{1}{x\sigma\sqrt{2x}} \exp\left(-\frac{(\ln x-\mu)^2}{2\sigma^2}\right) \qquad x > 0$$

Marginal Distribution Analysis

Marginal of heading direction (θ):

Probability model based on Directional storm recurrence rate:

$$\lambda_\theta = \frac{1}{T}\sum_{i}^{n} w(d_i)\, w(\theta_i - \theta)$$

Use von Mises kernel function (VKF) to replace GKF

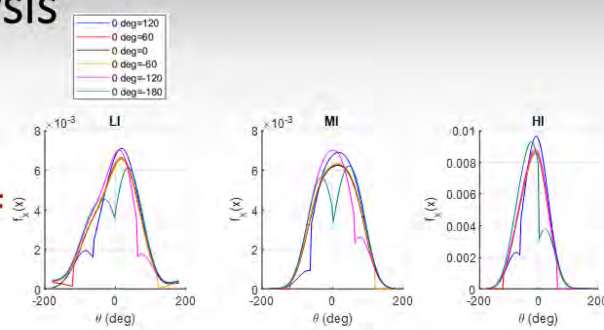
GKF:

$$w(\theta_i - \theta) = \frac{1}{\sqrt{2\pi}h_\theta} exp\left[-\frac{1}{2}\left(\frac{\theta_i - \theta}{h_\theta}\right)^2\right]$$

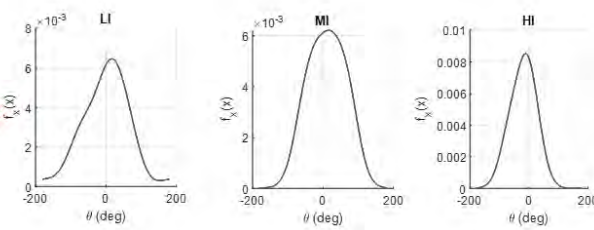
VKF:

$$w(\theta_i - \theta) = \frac{1}{2\pi I_0(\kappa)} \exp[\kappa \cos(\theta_i - \theta)]$$

GKF



VKF



Joint Distribution Models

Independence model:

$$f(\Delta p, V_f, R_{max}, \theta) = f_{\Delta p}(\Delta p) * f_{V_f}(V_f) * f_{R_{max}}(R_{max}) * f_\theta(\theta)$$

Partial dependence model:

$$f(\Delta p, V_f, R_{max}, \theta) = f_{R_{max}|\Delta p}(R_{max}|\Delta p) * f_{\Delta p}(\Delta p) * f_{V_f}(V_f) * f_\theta(\theta)$$

Joint Distribution Models

Meta-Gaussian copula model:

Skalar's theorem: $H(x_1, \dots, x_n) = C(F_1(x_1), \dots, F_n(x_n))$

Expression of Gaussian copula CDF: $C_R^{Gauss}(u) = \Phi_R(\Phi^{-1}(u_1), \dots, \Phi^{-1}(u_n))$

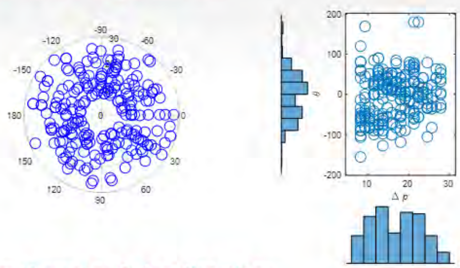
$$R = \begin{pmatrix} 1 & \rho_{1,2} & \cdots & \rho_{1,n} \\ \rho_{2,1} & 1 & \cdots & \rho_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{n,1} & \rho_{n,2} & \cdots & 1 \end{pmatrix}$$

Dependence measurement: $\rho = \sin \frac{\tau\pi}{2}$

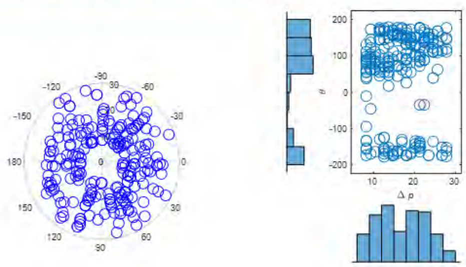
$$f(\Delta p, V_f, R_{max}, \theta) = c(F(\Delta p), F(V_f), F(R_{max}), F(\theta)) * f_{\Delta p}(\Delta p) * f_{V_f}(V_f) * f_{R_{max}}(R_{max}) * f_\theta(\theta)$$

Dependence between Linear Variable and Circular Variable

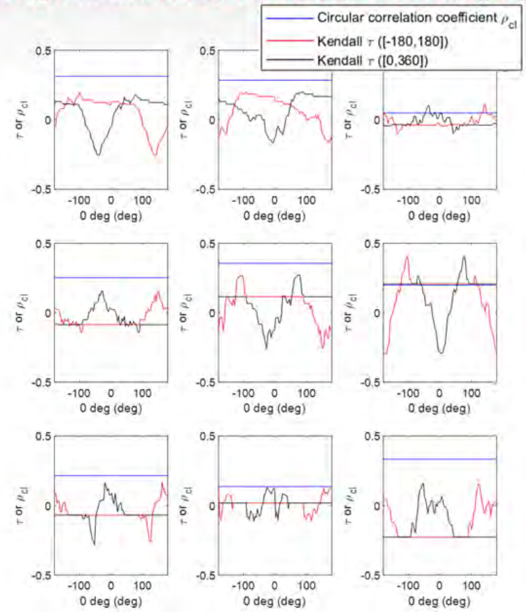
Use North as 0-deg direction:



Use Southwest as 0-deg direction:



Change in measured dependence with shift of 0-deg direction:



Linear-circular Copula

A joint distribution of linear variable x and circular variable θ; provided by Johnson and Wehrly :

$$f(\theta, x) = 2\pi g(\xi) f_\Theta(\theta) f_X(x)$$

$$\xi = \begin{cases} 2\pi(u-v), u \geq v \\ 2\pi(u-v+1), u < v \end{cases}$$

PDF of a mixture of two von Mises distribution

$$u = F_\Theta(\theta);\ v = F_X(x)$$

Apply skalar's theorem: $f(\theta, x) = c(F_\Theta(\theta), F_X(x)) f_\Theta(\theta) f_X(x)$

$$c(u, v) = 2\pi g\big(2\pi(u-v)\big)$$

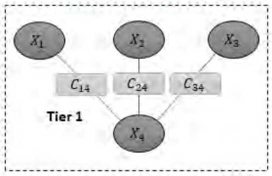
$$C(u, v) = \int_0^u \int_0^v 2\pi g\big(2\pi(u-v)\big) du dv$$

Joint Distribution Models

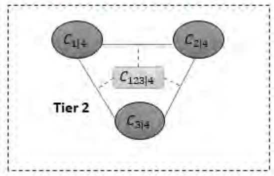
Linear-circular Gaussian vine copula (LCGV) model:

$$X_1 = \Delta p; X_2 = V_{\mathrm{f}}; X_3 = R_{\max}; X_4 = \theta$$

Fitting linear-circular copula



Fitting Gaussian copula



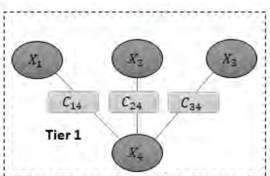
$$f(x_1, x_2, x_3, x_4) = c_{123|4} c_{14} c_{24} c_{34} f(x_1)\, f(x_2)\, f(x_3) f(x_4)$$

Joint Distribution Models

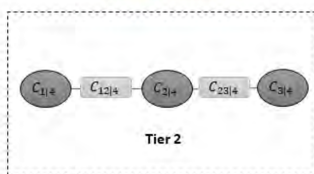
Linear-circular Frank vine copula (LCFV) model:

$$X_1 = \Delta p; X_2 = V_{\mathrm{f}}; X_3 = R_{\max}; X_4 = \theta$$

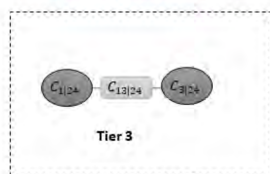
Fitting linear-circular copula



Fitting Frank copula

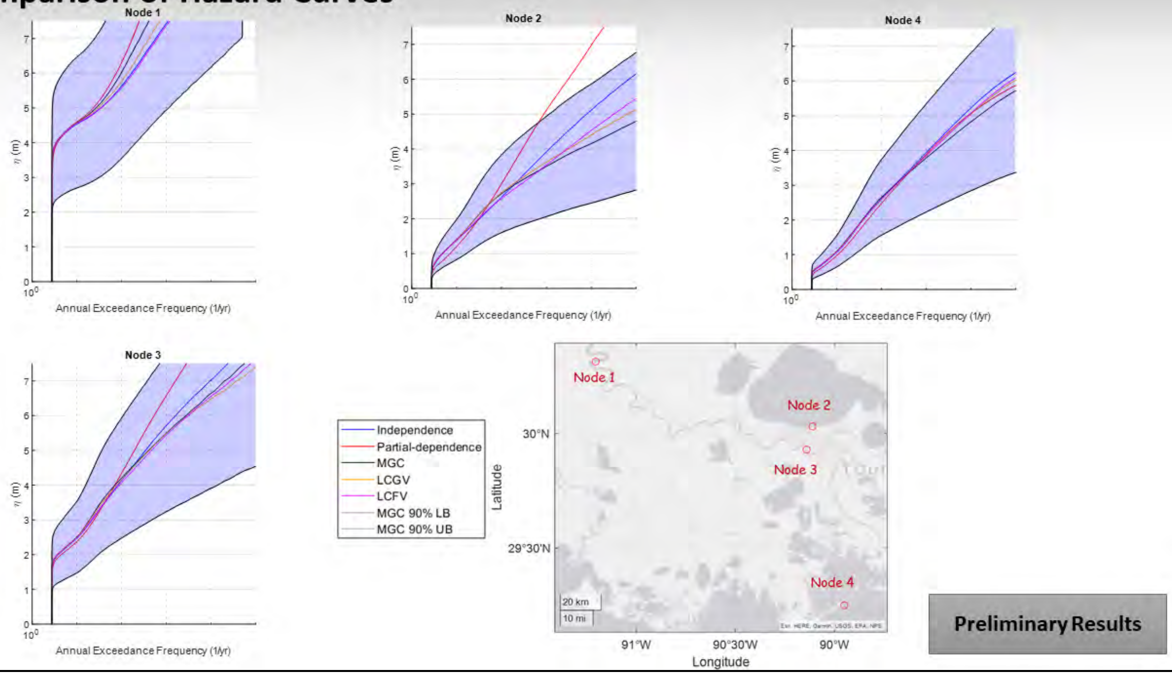


Fitting Frank copula

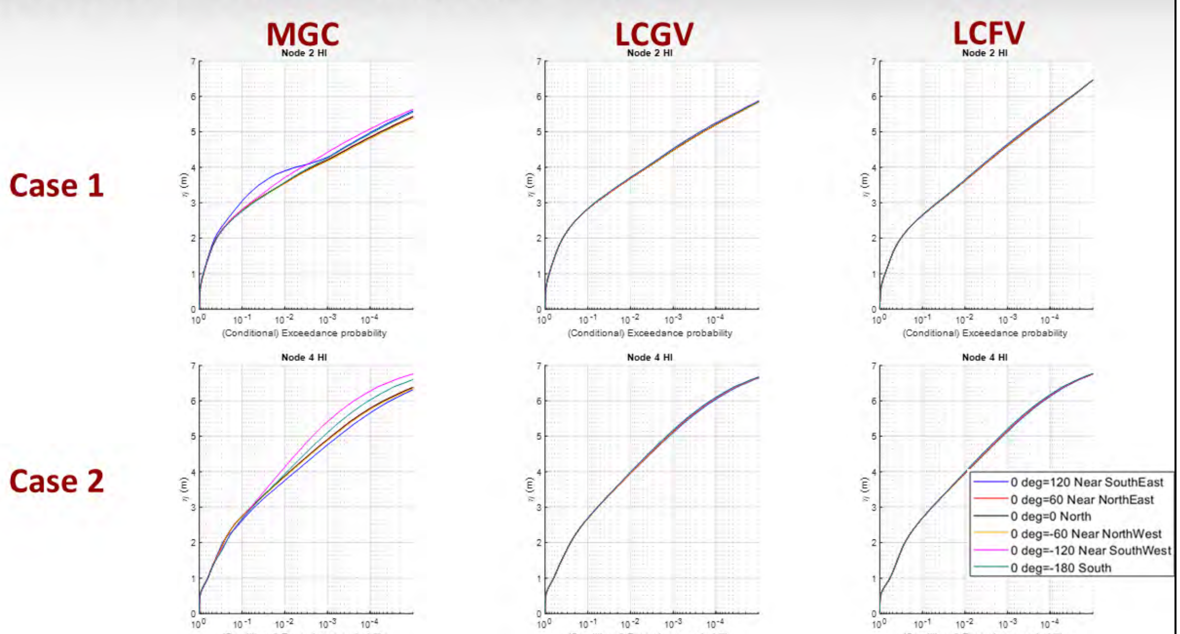


$$f(x_1, x_2, x_3, x_4) = c_{13|24} c_{12|4} c_{23|4} c_{14} c_{24} c_{34} f(x_1)\, f(x_2)\, f(x_3) f(x_4)$$

Comparison of Hazard Curves



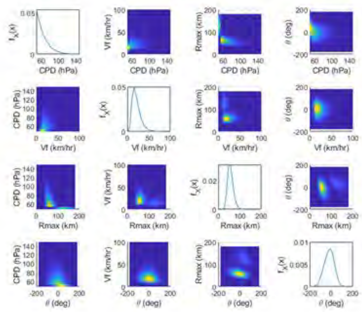
Robustness of MGC Hazard Curve



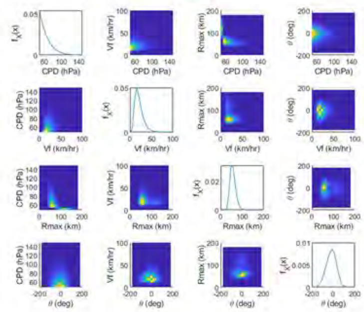
Comparison of Full Dependence Models

Pair-wise joint pdf :

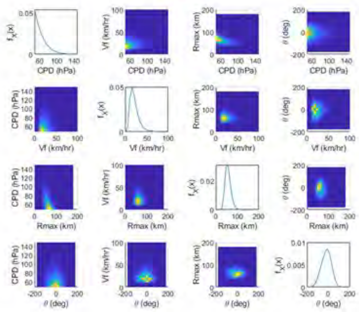
MGC



LCGV

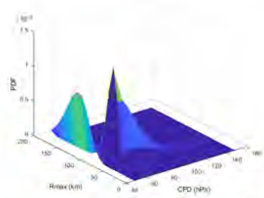


LCFV

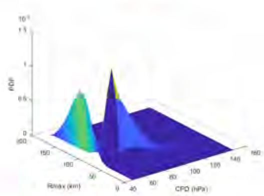


Comparison of Tail Dependence

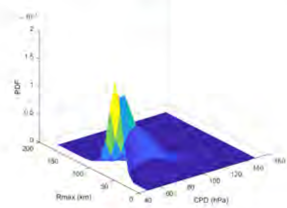
MGC



LCGV



LCFV



Upper tail dependence between Δp and $R_{\max}$:

$$\lambda_U = P(R_{\max} \geq R_{\max}^{+} | \, \Delta p \geq \Delta p^{+})$$

	$\Delta p^{+} = 132.21\ hpa;$ $R_{\max}^{+} = 151.58\ km$	$\Delta p^{+} = 137.47\ hpa;$ $R_{\max}^{+} = 161.05\ km$	$\Delta p^{+} = 142.74\ hpa;$ $R_{\max}^{+} = 170.53\ km$
MGC	$\hat{\lambda}_U$ =6.4e-11	$\hat{\lambda}_U$ =3.9e-12	$\hat{\lambda}_U$ =2.1e-13
LCGV	$\hat{\lambda}_U$ =9.8e-10	$\hat{\lambda}_U$ =9.5e-11	$\hat{\lambda}_U$ =8.4e-12
LCFV	$\hat{\lambda}_U$ =1.4e-06	$\hat{\lambda}_U$ =3.9e-7	$\hat{\lambda}_U$ =9.5e-8

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3.7.6 Coastal Panel Discussion (Session 3B-6)

Moderator: Joseph Kanney, NRC/RES/DRA/FXHAB
Margaret Owensby, U.S. Army Corps of Engineers
Somayeh Mohammadi, University of Maryland
Victor Gonzalez, U.S. Army Corps of Engineers
Beom-Jin Kim, Korea Atomic Energy Research Institute
Ziyue Liu, University of Maryland

Question:

For different applications, one might choose different balance between the use of surrogate models versus the use of high-fidelity models. What's the optimum mixture or balance for the types of coastal hazard assessments that you're involved in?

Margaret Owensby:

It really just depends on what you're trying to accomplish with the particular study. The results from the South Atlantic Coastal Study were being used to develop flood maps for different regions and identify risk over a wide regional area. Your approach to that problem would be best assessed probably with high fidelity modeling. But if you're looking at some other problem, you're probably better off using surrogate models.

Question:

Somayeh, do you see any areas in your particular study where you could benefit from a high-fidelity model?

Somayeh Mohammadi:

I should mention that if we want to know where the best balance for use of surrogate and high fidelity models is, we have a limitation because in our case we also were trying to decrease the computational effort. However, there are not always data available that we can use for training a surrogate model. We just could use it for the surge model and For example, our target variable was total river discharge and there was some interactions that could be captured with physical models between precipitation-induced river and discharge and surge. For these types of things we didn't have much data. For surrogate model we need more than 1000 data points and we didn't find this type of data for the area under study. That was one limitation in balancing our work with more surrogate model. But yes, in our work we have made some simplified assumption and were some parts of our work that for sure can be improved by using a high-fidelity model. To capture interactions between precipitation induced discharge and tides and also surge induced discharge since the flow is going different direction, I believe that we can have a very more reliable result if we use more expensive and high-fidelity models.

Victor Gonzalez:

We use surrogate modeling in PCHA to make sure we cover probability space and finely discretize the parameter space of the synthetic storms. This of course allows us to incorporate in a more rigorous way the uncertainty when we generate the hazard curves for the uncertainty.

Even the probability mass comes from your storms without having to rely on other methods. I think another beneficial aspect of these surrogate models is on the downstream end of your analysis. Once you do a regional study and you need to do a study that is more location based. Then you would use the surrogate models to help you reduce the number of storms that you need to use. And there are many applications that you want to apply a response-based approach. For example, in computing the response on a per-storm basis, the surrogate modeling can help a great deal. I will end by saying that in the quantification of uncertainty in our study, where we were looking at the logic tree approach to estimating epistemic uncertainty, it would not have been possible to generate as many branches in the logic tree without the use of surrogate models.

Beom-Jin Kim:

High fidelity modeling should come first. Then based on the high fidelity models, I think it is important to create and analyze a simpler model, because high fidelity models can take a long time to simulate. I think simpler models are good in terms of time.

Question:

Has anyone thought about doing a meta study to mine the entire body of simulations that are in the Coastal Hazard System (CHS)? For example to investigate different approaches for modeling the error term or to evaluate different surrogate modeling approaches. Does anyone have any thoughts about that?

Margaret Owensby:

I haven't heard of any efforts to try to use all the data as a whole. I definitely think that's something that could be useful for people to do to use all the different data from the different studies that's available on the coastal hazard system.

Victor Gonzalez:

I think that would be a good idea. I would add that the CHS has been developed across time. It was started after hurricane Katrina. Then there was the Great Lakes Study, then the North Atlantic Study. Some of these studies have evolved over time and there are some differences in the different applications. Methods have evolved over time. One effort that is going on is redoing some of the old studies to have them all apply the same methods. Then that would lend itself well to a meta-analysis type of approach.

Question:

Somayeh**,** do you have any thoughts about applying some of the machine learning techniques you used in your work to the CHS?

Somayeh Mohammadi:

As much as I could in my work, I tried to. use the CHS. But the critical parts of my work was simultaneous occurrence of different flood mechanism. Related to capturing those physical interaction, I couldn't take that much advantage. For or the surge model. I could.

Question:

From the presentations and discussions on might conclude that for the compound hazard assessment perhaps we need to do more work on the rainfall.
So, for anyone who's sort of been involved in that aspect, do you have any thoughts about avenues of research that we should be looking at to improve on the rainfall model and how we incorporate it into the compound a flood hazard assessment for coastal regions?

Victor Gonzalez:

I think a first step is applying these models over a regional extent. We are starting to look at this for example, in the Texas region. But with all the issues we've encountered with bias correction and the representativeness of the model, we should probably have a good grasp first of how it applies across the several regions representative of the of the US coastline. There is more research needed in this area.

Question:

Do you think this might be an area where we may want to go to a higher fidelity model? There are some high-fidelity numerical weather prediction models used for forecasting tropical storm rainfall. That would be one more really big, computationally intensive high-fidelity model. But do you think that might be a viable approach.

Victor Gonzalez:

It could be, but the synthetic storms might be an issue, the parameterized synthetic storms. So, yes, if there are better models out there that can be linked to the synthetic storms in a reasonable way, it probably would be worthwhile to pursue.

Somayeh Mohammadi:

Based on the experience that I had in my work, precipitation effects could be from two different aspects. One is estimation of precipitation itself and the other is how precipitation is converted to runoff. For the second part, we always need distributed models for converting precipitation to runoff because we need land characteristic such as different curve numbers. I think that it is really difficult to have surrogate model for this type of distributed models which can give us runoff for precipitation based on precipitation. But the other part which is estimation of precipitation itself. One of the challenges that I had in my work was with that. I also saw that there was a gap for more refined physical based modeling. Again in this part there are two problems. One is related to developing physical models which are showing the relationship between precipitation and different parameters and the other is availability of a training database. Because in probabilistic work we usually did need a big sample of data, a database related to parameters which are showing the physical relationship between its storm parameters and precipitation. Even the database I think is not easily available and having these data sources and more developed physical models that can show the relationship will be helpful.

3.8 Day 4: Session 4A – Duane Arnold Derecho Operational Experience

Session Chair: Joseph Kanney, NRC/RES/DRA

3.8.1 Presentation 4A-1: Duane Arnold Energy Center (DAEC) Loss of Offsite Power (LOOP) Due to Derecho

Authors: *Terry Brandt*******, Nextera Energy*

Speaker: *Terry Brandt*

3.8.1.1 Abstract

This presentation will give you the initial conditions, timeline of events, and operator actions associated with the Duane Arnold Derecho Event.

3.8.1.2 Presentation (ADAMS Accession No. ML22061A107)

Duane Arnold Energy Center (DAEC) Loss of Offsite Power (LOOP) Due to Derecho

Terry Brandt
Fleet Online Director
NEXTera ENERGY

DAEC Overview

BWR/4 -

An early BWR/4, the “B” loop of RHR is half of RHR (B+D pumps)

Mark I Containment

HPCI (3,100 gpm) & RCIC (425 gpm)

Core Spray and RHR

Rated Thermal Power 1,912 MW(t)

Rated Net Electric Power ~615 MW(e)

368 Fuel Bundles in the Core

SRVs setpoints:

1 SRV 1,110 psig	2 SRVs 1,130 psig
1 SRV 1,120 psig	2 SRVs 1,140 psig

Two safety valves (SVs) discharge directly to the DW airspace at the RPV pressure of 1,240 psig

2

DAEC Plant Status - Monday August 10th, 2020

1. DAEC was operating at ~80% power due to coasting down to end of cycle (EOC). This power was selected to limit the cycling of a turbine control valve (TCV4) that would have occurred around ~84% power
2. Diesel Driven Fire Pump (DFP) is inoperable due to maintenance
3. LPCI B train was inoperable due to testing prior to the event, it was not being tested during the event and was available for use if needed
4. Two control rods are fully inserted to suppress a fuel leaker
5. Dry cask storage campaign under way in the spent fuel pool; time to boil is 64 hours

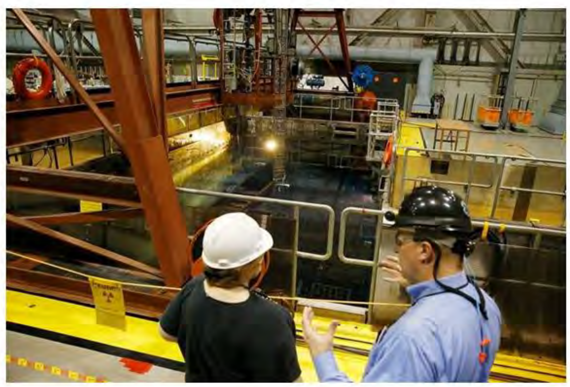
Initial conditions:
Power= 80.2% RTP
Gross Electric power = 493.5 MWe
RPV water level = +189.5"
RPV pressure = 1,009.57 psig

SP Temperature = 83.7 °F
DW Pressure = 0.5 psig
SC Pressure = 0 psig
DW Temperature = ~123 °F

3

DAEC Plant Status - Monday August 10th, 2020

- 11:38 A severe Thunderstorm watch is declared
- DAEC entered the Abnormal Operating Procedure (AOP) for Severe Weather and began performing their preparation actions
- 12:02 The Watch is upgraded to a Severe Thunderstorm Warning
- Shift Manager (SM) directed that fuel handling be placed in a safe condition and secured



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August 10, 2020 Monday 12:30-12:35

- 12:30 Multiple alarms received due to grid issues
- 12:35 Grid perturbation occurs which causes the Emergency Diesel Generators (EDGs) to start but not tie on. The EDGs remain running
- Wind speeds > 100 mph with onsite peaks between 100 mph & 130 mph

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August 10, 2020 Monday 12:35-12:49

12:49 Loss of offsite power due to sustained strong winds (> 100 mph) causes:

- Generator load reject, tripping the turbine and causing the Reactor to scram
- EDGs tie onto the safety buses A and B
- Recirculation pumps trip due to loss of power

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August 10, 2020 Monday 12:49-12:51

- 12:49 All control rods fully insert
- RPV pressure rises quickly causing 2 SRVs to lift on low-low Set when pressure rose above 1,055 psig and initiation of an SRV on its setpoint (1,110 psig)
- 12:49 Ops enters EOP-1 on low level (+170" and lowering). RPV pressure 960 psig and steady. RPV Water level +135 and slowly lowering
- 12:50 Ops directed an initial level control band of 135" to 211"
- 12:51 RPV water level lowers to L2 (+119.5") due to loss of feedwater

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August 10, 2020 Monday 13:00 – 24:00

- **Continued Cooldown**
- **Level maintained high to facilitate natural circulation, in accordance with plant procedures.**
- **Restored Systems to facilitate plant reliability:**
  - Reactor Water Cleanup System
  - Fuel Pool Cooling System
  - Well Water to keep pressure applied to the Fire System
  - General Service Water for equipment cooling
  - Set up DAEC Switchyard for emergent repairs

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August 11, Tuesday

- 02:30 Ops established cold shutdown conditions using SDC
- 11:26 The 161kV Vinton line is restored to the switchyard restoring off-site power
- 12:15 Startup transformer is reenergized from off-site power
- 13:12 Safety Bus A is reenergized from off-site power
- 13:34 Safety Bus B is reenergized from off-site power
- 16:00 The NOUE is terminated
- Storm damage found on roof of the North FLEX building. FLEX function maintained by South FLEX Building equipment
- Forced draft Cooling towers severely damaged

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August 17, 2020 Tuesday 12:49

- All six off-site power lines are restored

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Interstate Transmission Company's (ITC) Off Site Heroes

Restoration of DAEC Off Site Power

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DAEC - LOOP Insights

ESW Availability following the increase in dP of the strainer:

- The ESW strainer did not start "clogging" until the Torus Cooling was maximized later in the day with the operation of the HPCI System:
  - DAEC procedures required that maximizing of Torus Cooling with the operation of HPCI
  - This was also done to maintain the Torus under EOP-2 required temperatures
- The ESW system dPs remained low throughout the event
- The high strainer dP came into existence after shutdown cooling was placed in service

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3.8.2 Presentation 4A-2: The NRC's Regional Response to the Duane Arnold Derecho

Authors: *John Hanna*, U.S. Nuclear Regulatory Commission*

Speaker: *John Hanna*

3.8.2.1 Abstract

This presentation, as part of the greater panel on the Duane Arnold derecho, will address Region 3's response to the event including the aspects of immediate event response by the inspection staff, the Management Directive 8.3 event assessment and other regional actions taken. Additionally, risk insights from this event will be shared.

3.8.2.2 Presentation (ADAMS Accession No. ML22061A106)

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The NRC's Regional Response to the Duane Arnold Derecho

John David Hanna
Senior Reactor Analyst
US Nuclear Regulatory Commission, Region III Office
Division of Reactor Projects

February 18, 2022

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Overview of the Presentation

- General Information
- Regional response to the event
  - Immediate event response
  - Management Directive 8.3 assessment
  - Other regional actions
- Risk insights from this event
- Comments/Questions

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General Information

- My Background and Experience

3

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Duane Arnold derecho

- 10 August 2020 storms/high winds hit large sections of Midwest US with little warning
- Widespread destruction including damage to the electrical grid occurred

4

DAEC Immediate Event Response

- Operators performed well
- NRC inspectors responded to the site
  - On-site within 1 hour
  - Rapid assessments of immediate actions, plant stability, SM, DID, etc.

- Rapid risk assessment was done to inform the inspectors event response, i.a.w., what should they review?
- Initial response to the site was supplemented with regional inspectors with EP and Ops expertise
- The storm had impacts on IE and MS and lesser effects on BI and EP

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Duane Arnold (continued)

Illustration by Dennis Cain

6

DAEC Management Directive 8.3 Assessment

- RIII immediately realized the PRA risk from the event was very high.
- CCDP was approx. 2E-4 to 2E-3 range.
- MD 8.3 process was entered.
- RIII performed a focused baseline inspection under IP 71153 and supplemented the RIO with other inspectors (ML20314A150), but did not perform a Special Inspection.

Estimated CCDP				
CCDP < 1E-6	1E-6 –> 1E-5	1E-5 –> 1E-4	1E-4 –> 1E-3	CCDP > 1E-3
No Additional Inspection				
	SI	SI		
		AIT	AIT	
			IIT	IIT

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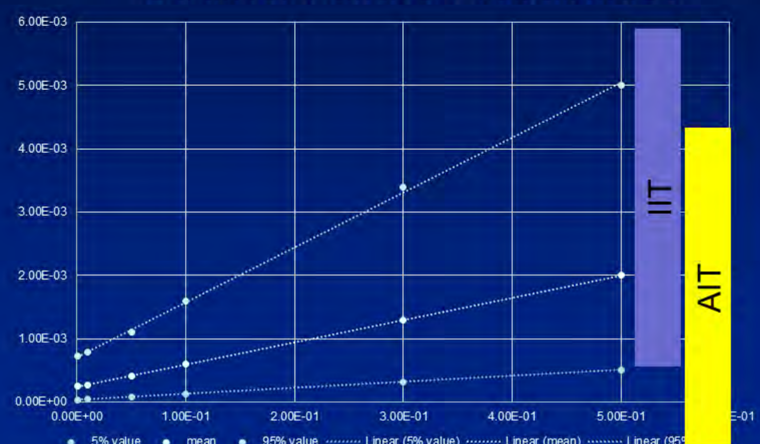
MD 8.3 Assessment - Continued

ICCDP Results Given Various 'B' ESW Strainer Failure Probabilities



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Regional Response – Miscellaneous Items

- Requested that the LIC-504 “Integrated Risk-Informed Decisionmaking Process for Emergent Issues” process be entered
- Risk analysis paper written looking at commonalities between several events involving external hazards, including DAEC
- Supported the ongoing revisions to the MD 8.3 and IMC-0309, “Reactive Inspection Decision Basis for Reactors”

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Risk Insights – what are these events “telling us?”

- “Sunny day” events can happen with little warning but relatively high-risk impact
- Synergistic effects are non-trivial
- Operator actions may be required in order to respond to the event which will initially INCREASE the risk during the event
- Small changes in the weather could have had disproportionately large impacts on the event

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Questions or Comments?

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Backup Slides

12

References & Additional Material

- Paper "Characterizing Previously Unknown Dependencies in Probabilistic Risk Assessment Models of Nuclear Power Plants," ML21103A355
- NRC Inspection Report - ML20314A150
- MD 8.3 assessment document ML21022A415
- Non-Concurrence document ML21022A418
- John Hanna – John.Hanna@nrc.gov

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Back up slides – DAEC

Storm damage from the derecho – State of Iowa, 10 August 2020

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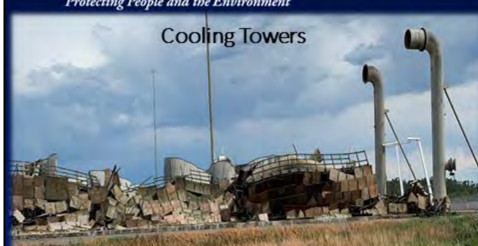
Back up slides – DAEC

Pictures of damage to Duane Arnold Energy Center due to derecho – 10 August 2020

15

Back up slides – DAEC



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Back up Slides – DAEC Plant Automatic Response

- **Immediate Response**
- Generator Trip, Turbine Trip, Rx Scram
- Diesel output breakers immediately closed to safety related busses; no loss of RPS; no Group I Isolation
- 2 Safety Relief Valves lifted for approximately 10 sec
- Reactor Water Level decreased to Level 2, Lo-Lo Level
- HPCI and RCIC started
- Reactor water level restored to Level 8, High Level Trip
- HPCI and RCIC Tripped (as designed)

- **Two Minutes Later:**
- Plant parameters were stable
- ‘A’ and ‘B’ EDGs supplying power to their respective safety busses

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Back up Slides – how do these events compare to others?

Risk Significance of DAEC Derecho compared to other High Profile US Events since 2000 (Conditional Core Damage Probabilities)

- 2002 Davis Besse vessel head leakage: $6x10^{-3}$
- 2020 Duane Arnold Derecho: $8x10^{-4}$
- SWGR Fires (2010 Robinson, 2011 Fort Calhoun): $4x10^{-4}$
- Earthquake induced LOOP (2011, North Anna Unit 1): $3x10^{-4}$
- Trans. & breaker failure induced LOOP (2012 Byron): $1x10^{-4}$

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Where is LOOP/SBO risk highest and/or where does FLEX make the most difference?

- Single unit sites
- Fewer EDGs +/or no SBO EDG
- No crosstie capability at multi-unit sites
- Absence of low leakage RCP seals
- Small DC batteries
- Higher LOOP likelihood
- Higher (LOOP/SBO or electrical) risk from internal events

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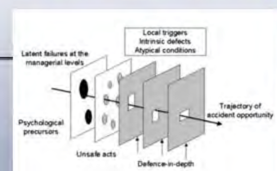
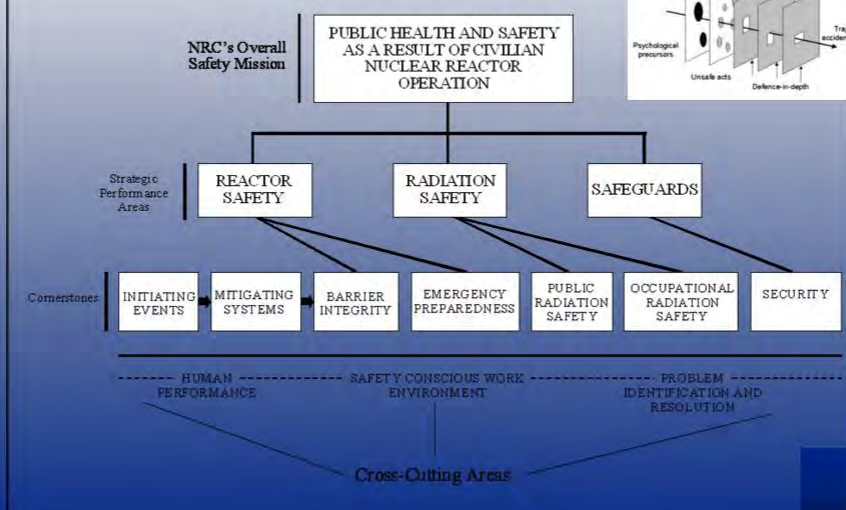
General Info- Reactor Safety Cornerstones





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3.8.3 Presentation 4A-3: Why the Risk of the Extended Loss of Offsite Power Was Almost a Significant Precursor?

Authors: *Christopher Hunter*, U.S. Nuclear Regulatory Commission*

Speaker: *Christopher Hunter*

3.8.3.1 Abstract

On August 10, 2020, a severe storm with heavy rains and very strong straight-line winds (called a derecho) resulted in an extended loss of offsite power (LOOP) at Duane Arnold Energy Center (DAEC). The National Weather Service later estimated wind speed peaks were likely near 130 mph, which resulted in extensive damage to offsite power lines and a number of plant structures including the reactor, turbine, and FLEX buildings, and nonsafety-related cooling towers. In addition, the high winds led to an ingress of debris into the essential service water that challenged the system strainers and required operator intervention to maintain adequate cooling to one of the two emergency diesel generators. This presentation will cover the important assumptions, results, and key risk insights from the accident sequencer precursor (ASP) analysis. In addition, a comparison with other recent LOOP precursors due to severe weather will show why the event at DAEC had substantially higher risk that these other events.

3.8.3.2 Presentation (ADAMS Accession No. ML22061A105)

Why the Risk of the Extended Loss of Offsite Power Was Almost a Significant Precursor?

Chris Hunter

Office of Nuclear Regulatory Research
Division of Risk Analysis
Performance and Reliability Branch

Event Overview

- On August 10, 2020, a derecho moved through Iowa and other parts of the Midwest.
  - The most extreme winds were estimated to be near 110 mph, wind gusts of 80–100 mph were common.
- Duane Arnold experienced a grid perturbation that caused the emergency diesel generators (EDGs) to automatically start, but initially ran unloaded.
- Approximately 15 minutes later, the main generator tripped resulting in a loss of offsite power (LOOP) and subsequent reactor trip.
  - The two EDGs automatically loaded to their respective safety buses.
- The licensee declared a Notice of an Unusual Event.

Additional Event Details

- Prior to the event, the licensee was loading fuel into a spent fuel canister.
- North FLEX building was damaged and equipment within was declared inoperable.
- The main steam isolation valves remained open, allowing operator to align main steam-line drains.
- Approximately 10 hours into the event, the essential service water (ESW) strainers started to get plugged due an ingress of debris.
- A small tear was discovered in the reactor building resulted in secondary containment being declared inoperable.

Accident Sequence Precursor (ASP) Evaluation

Initial ASP Information

- Initial ASP analysis started within a few days of the event and showed that the event was potentially a significant precursor.
- Focused on early sequence results to determine which modeling/event assumptions that needed to be evaluated further.
  - FLEX modeling
  - Stuck-open SRV scenario modeling
  - ESW strainer challenge
- Provided some initial high-level information during ASP presentation to international precursor community.

SPAR Model Changes

- MELCOR calculations were performed to determine timing information for postulated stuck-open SRV scenarios.
  - Based on these calculations and discussions with the licensee revealed that operators would have enough time to connect and initiate either firewater or FLEX reactor makeup.
- Credit for FLEX mitigation strategies was applied.
  - Modified FLEX hardware reliability data based on initial data evaluation (3× multiplier was used).
- Modified ESW Strainer common-cause failure (CCF) parameters to use environmental causal alpha factors.
  - Added operator action to bypass clogged strainers to SPAR model, which largely mitigates significant CCF potential.
- Additional Changes
  - Eliminated some assumptions deemed needlessly conservative (72-hour AC power recovery requirement).
  - Removed EDG repair for scenarios where ELAP is declared due to potential for load shed activity precluding recovery.

Preliminary ASP Analysis

- The preliminary ASP analysis resulted in a mean conditional core damage probability (CCDP) of 1×10^{-3}.
  - Risk dominated by station blackout (SBO) scenarios.
  - Offsite power recovery credit not provided within 24 hours.
- Identified several key uncertainties.
  - Performed sensitivities to evaluate the impact of these uncertainties.
- Sent the preliminary ASP analysis to the licensee for a 60-day review per Regulatory Issue Summary 2006-24.

Industry Comments

- NextEra provided comments on the preliminary ASP analysis on February 9, 2021 (ADAMS Accession No. ML21042A079).
  - In addition, the Pressurized-Water Reactor Owners Group provided comments.
- Offsite power was available to be restored to the safety buses approximately 22.6 hours after the event started.
  - This change resulted in mean CCDP decreasing to 8×10^{-4}.
- The PWROG showed that the rate for EDG failures to run (FTR) could be reduced from 1.4×10^{-3} per hour to 8.4×10^{-4} per hour.
  - Idaho National Laboratory performed an updated calculation that was only slightly smaller than current estimate and, therefore, no changes were made.
- A significant conservatism is that FTR events are assumed to occur at the start of the event.
  - The treatment of FTR events in the SPAR models is consistent with the current state-of-practice.

ASP Comparison

Brunswick LOOP during Hurricane Isaias

- Storm-generated debris resulted in a LOOP to Unit 1 in August 2020.
  - The LOOP lasted approximately 14 hours.
- Electrical Design Elements
  - Each unit has two EDGs and share an SBO EDG that can crosstied to the other unit.
- The mean CCDP was 2×10^{-5}.
  - LOOP transient scenarios dominated risk; SBO risk was minimal.
  - FLEX credit provided minimal risk reduction.

Pilgrim LOOP during Winter Storm Juno

- LOOP caused by flashover of the switchyard insulators as a result of snowpack and salt spray in January 2015.
  - Offsite power was restored in ~60 hours.
- Electrical Design Elements
  - Unit has two EDGs and an SBO diesel.
  - A separate 23kV offsite power source remained available.
- The mean CCDP was 4×10^{-5}.
  - Risk equally distributed between transient LOOP sequences and postulated SBO scenarios.
  - FLEX mitigation strategies not credited.

3.8.4 Presentation 4A-4: The NRC's Response to the Duane Arnold Derecho Event using the LIC-504 Process

Authors: *Matthew Leech*, U.S. Nuclear Regulatory Commission*

Speaker: *Matthew Leech*

3.8.4.1 Abstract

When the NRC saw that the risk of the Duane Arnold derecho event was high, the decision was made to perform a LIC-504 analysis to determine if a safety issue risk existed to other power plants in the fleet. The LIC-504 is a risk informed process that the NRC uses to disposition emergent safety issues. This presentation will discuss how the NRC evaluated the risk to a number of other power plants if they experienced a similar event, it will discuss the key insights, and recommendations from the LIC-504.

3.8.4.2 Presentation (ADAMS Accession No. ML22061A104)

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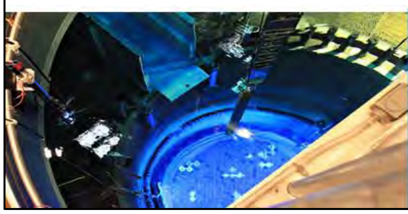
Duane Arnold Derecho

PFHA Research Workshop - 2022

Matthew Leech
Reliability and Risk Analyst
Office of Nuclear Reactor Regulation
Division of Risk Assessment



Overview

- ✓ Re-cap of the event and its risk significance
- ✓ Description of the LIC-504
- ✓ Risk Insights and Sharing the Operating Experience (OE)

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Re-cap of the Event

- A Loss of Offsite Power Occurred – and was not restored for 23 hours
- The plant scrammed offline and shutdown safely, power was provided by their EDGs until offsite power was restored
- Cooling towers were destroyed (non-safety)
- Transmission towers knocked down and damage occurred to a standby transformer in the switchyard – complicated offsite power recovery
- One FLEX building was damaged, but equipment inside remained functional.
- Secondary containment was damaged.
- Hours later ESW was challenged by debris clogging the strainers, one train of ESW and it's EDG was declared INOP but still functional

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Risk Significance of DAEC event – Why was the risk so high?

- Single unit site without the ability to crosstie power from another unit
- No Station Blackout diesel
- It took about 24 hours to restore offsite power
- Ultimate Heat Sink and Service Water Intake were vulnerable to debris generated by derecho
- Another insight was that the risk was significantly improved due to FLEX.

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LIC-504

- The NRC's LIC-504 process is a risk-informed decisionmaking process that the NRC uses for emerging issues.
- One of the recommendations from regional feedback of the DAEC event was that the NRC should evaluate the event for any generic implications to the nuclear fleet.
  - Is there a population of plants that could have unacceptable risk?
  - Are there risk insights that would be useful to share?
- The NRC decided to perform a LIC-504 in October of 2020.

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The LIC-504 Analysis vs the ASP

ASP

Conducted by Office of Research focuses on examining the risk from the specific event for the Duane Arnold Plant.

LIC-504

Conducted by the office of Nuclear Reactor Regulation (NRR) examined several plants by running a similar scenario to the one Duane Arnold experienced during the derecho and examining the risk results.

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LIC-504 in Two Main Steps

- The first step of the LIC-504 analysis is to determine if the risk from the issue warrants any immediate action:
  - Do any plants need to be shutdown immediately?
  - Are there any immediate compensatory actions or orders that need to be issued?
- The second step involves a more detailed analysis to assess the risk and develop recommendations.
- It's also used to formally document how the NRC arrives at a decision.

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Getting Started with the LIC-504

- To get started the NRC took a population of plants that had the same generic traits as DAEC.
  - Single unit sites
  - No station blackout diesels
  - Potentially vulnerable ultimate heat sinks*
- Plants were chosen to gain a representative look at the overall fleet vulnerability to a similar derecho using the characteristics identified as being risk significant from the event at DAEC.
- First step concluded that there was no immediate safety issue.

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Second Step of the LIC-504

- Eight different plants were chosen for the analysis.
- They were a representative population of plants: PWR Westinghouse, PWR Combustion Engineering, BWR4 plants, and a BWR6.
- They were evaluated for the same conditions present during the DAEC derecho:
  - A weather-related loss of offsite power that was not recoverable for 24 hours
  - Challenge to the ESW system

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Second Step of the LIC-504 (Cont.)

- The second analysis differs from the first in that it was a more detailed analysis and designed to increase accuracy and reduce conservatism.
  - Provided credit for FLEX actions and equipment
  - More scrutiny and detail looked at each plants service water modeling
  - Lessons learned from the DAEC ASP analysis was applied to this phase of the analysis.

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LIC-504 Risk Insights

- When the risk analysis for the LIC-504 was completed some common plant design attributes were found to have an impact on plant risk.
  - Plants with extra diesel generators not dependent on service water cooling had significant benefit
  - Plants that had the ability to bypass a degraded strainer had improved risk
  - Some plants have alternate cooling strategies to their diesel generators in case ESW isn't available (like fire protection water for instance) and that helps risk
  - Plants that have ESW traveling screens on an emergency power source that will still be available during a loss of offsite power have improved risk
  - FLEX equipment and strategies, demonstrated a significant safety benefit from this type of event

LIC-504 Follow Up Actions

Held a public webinar with the industry to discuss the ASP, the LIC-504 and the results.

Issued internal OE communication with more information, including updated risk insights from the LIC-504.

Issued an Information Notice to share the OE, the results of the ASP & the LIC-504 & share the risk insights with the industry.

References and Contact Info

- Duane Arnold Derecho ASP Analysis: ML21056A382
- The Duane Arnold Energy Center LIC-504 recommendations: ML21078A127
- Information Notice 2021-03: ML21139A091

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(301) 415-8312

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3.8.5 Duane Arnold OpE Panel Discussion (Session 4A-5)

Moderator: Joseph Kanney, NRC/RES/DRA/FXHAB
Terry Brandt, *Nextera Energy*
John Hanna, *NRC/Region 3*
Christopher Hunter, *NRC/RES*
Matthew Leech, *NRC/NRR*

Question:

Chris, snowpack and salt spray were mentioned for the Pilgrim event. Was there a distinction between what the two weather-related events contributed to the analysis? Seems like for a near-shoreline event that the presence of accumulated salt spray would dominate.

Christopher Hunter:

To be quite frank, I don't know. If you follow Pilgrim, they've had a lot of these ice storms and a lot of these kind of issues where they've gotten these winter storms. They had one just a couple years previously for Winter Storm Nemo. So they had this continual experience. If you look at the history of Pilgrim they have had the most losses of off-site power, I think, of any any plant in the fleet and the majority of them were due to that their switch yard wasn’t necessarily fully protected from ice and salt spray. But I can't tell you wehter the salt spray or ice events were the worst.

Question:

Chris, were any reactive inspections done for the ASP analysis shown or for the Waterford hurricane event?

Christopher Hunter:

For Brunswick an MD 8.3 [incident investigaiton] was done, but there were no deterministic questions answered as ‘yes’, and so they determined not to perform a special investigaiton (SIT) because none of the questions were answered ‘yes’. Even though they weren't required, they did a risk evaluation that came up with a 2 e-5 [CDF], which is basically the same answer that I got because, as I mentioned, the loop transient risk is dominant. At Pilgrim they did an MD 8.3 but they did do an SIT. They they did answer some of the deterministic questions ‘yes’. I think it had to do with the repeated switchyard issues, the fact that they they kept on getting these winter ice storm loops. But they also had some additional complications with some of the equipment so they answered yes and so they did do an SIT. With the Waterford event that just occurred, I'm currently working on the ASP analysis now. They did not do an MD 8.3 so there was no SIT performed for that.

Question:

Specific to Duane Arnold, what is the approximate size of debris that can pass through the river water system to the stilling basis? What is the approximate size of the openings for the ESW suction strainers? Was there any indication of suction issues for other pumps that take suction from that stilling basin?

Christopher Hunter:

At Duane Arnold during the event they had this late inrush of debris. Initially the traveling screens, that are powered by safety-related power, were not not running because they didn't need to. Then they transitioned from not running to slow speed to fast speed. So what happened during the event was debris comes in, and then the traveling screens start to pick up, but already debris is either getting overtopped or bypassed. Eventually the traveling screens were in fast speed and caught up and was preventing debris for coming down and loading the strainers. You can kind of see that from the the differential pressures on the strainers. Train B reached its differential pressure limit of 15 PSID. But the train A strainer peaked at 11 PSID and stopped there. So to me that kind of indicates that it seemed like the traveling screens finally, were going at a fast enough speed to handle the debris. But another issue is the fact of bypassing. I don't know the size of the strainers, but there could be potential issues of bypassing the strainers. You're sending dirty water downstream that could plug heat exchangers or could cause equipment issues. We didn't see any of that during the event, and I think it's kind of an open question on whether that was because the traveling screens caught up and it was no longer sending dirty water down there, and so the amount of debris being bypassed was kind of minimized because the traveling screens are caught up? Or was that just because the debris was small enough to where it wasn't really causing any issues with running the train B diesel generator? So it's an interesting question that we don't really know the anwer, but obviously potentially a more severe event could have led to issues. You know, just bypassing the diesel generator is not necessarily a cure all and it could have caused some problems. But it didn't for Duane Arnold. I don't know if Terry and John or Matt want to jump in on that.

Terry Brandt:

The river water supply system allowed for larger debris to be filtered through. It was not uncommon to see sand pumped by the river water supply pumps into the stilling basin and we had a preventive maintenance that would clean out sand from the bottom of the stilling basin and the openings of the individual heat exchangers in the individual components and the ESW system. I think the opening of the systems were commiserate with the strainer design as to what would be strained out. We did have a procedure that allowed us to to monitor the differential pressure and we had instrumentation that's permanently installed, so we monitored that throughout the event. But I can't give you a design specs of each one of those. I'd have to go back and do some research to find those numbers.

Matthew Leech:

I'd also point out that what I learned during the LIC 504 analysis is all plants are different. They all have slightly different designs for their strainers, traveling screens, and even in terms of the openings, how big the traveling screens and their screens are. And in the design of the strainers, some are self backwashing, some are basket type strainers. All plants have slightly different types of straining systems.

John Hanna:

Terry, several hours into the event, things maybe have stabilized a little bit, but before 24 hours or when offsite power was restored, I think we had asked the station about whether there was an intent to pre stage any FLEX equipment. Given that, in our opinion, we thought the threat had really passed, the derecho had gone by and we were thinking maybe pre staging FLEX equipment would be advantageous. Specifcally, the phase two equipment because if you had a diesel failure or other equipment issues then it's less time to get that equipment and activate it and use it. But we heard back that there was not a desire or there was no plan to do that. Can you talk about the rationale, the mindset behind the decision not to go that path? To give a little bit of context, especially for those that are not in the industry, when the Fukushima orders came out and we required every licensee to be able to mitigate a Fukushima-type event and institute equipment and procedures, we did hear from the industry that there was a lot of desire to credit that equipment for a non-beyond-design-basis event. Whether it be for flexibility and refueling or maybe flexibility with taking other equipment out of service, that there was a general desire to credit that equipment for non-beyond-design-basis events. So we thought this was an event that FLEX equipment might have been used or credited or pre staged. But for whatever reason Duane Arnold didn't go down that path. Terry, could you speak to the mindset in the decision making there?

Terry Brandt:

We actually had a significant amount of discussions early on in the event with regard to the pre staging of FLEX equipment. If you go back to the initial conditions, we did have a diesel fire pump that was out of service in order to perform some preventive maintenance and we had some testing in progress. A couple of the small, and I would say minor, equipment issues that happened required operator response too. The Duane Arnold staffing at the time allowed for outside of the control room three equipment operators and we maintain a fire brigade with the maintenance organization also. So the FLEX assumptions assume that we have just those people on site. Now we weren't in FLEX assumption. It wasn't 2:00 o'clock in the morning on a Saturday night. It was a normal day shift, so we did have people on site. But the discussions that we had, were, you know, given the fact that we had both CSTs available, that they were undamaged as a suction source with both of our steam driven turbines being operational and in operation, maintaining level and maintaining the core covered very well. Our level was up above 214 inches to facilitate our natural circulation. We felt the need to get our operators out in the field and recover the plant. That would allow us to continue to use plant equipment first and then we could further evaluate the FLEX equipment afterwards. So the discussion initially was regarding maintaining the equipment or getting the equipment back to what we need. And then we go back further. So that was the background of why that decision was made in order to get some of the plant equipment back into a standby readiness state before we further evaluated that.

Question:

If Duane Arnold had not shut down, which of the model modifications that you made might have been rolled into the SPAR model? Or were all the changes you were making just really specific to the particular questions you were trying to get at in the ASP analysis?

Christopher Hunter:

Whenever we're doing this type of analysis there's going to be certain changes made just to support the analysis. There's other changes because we notice issues with the models. So for example, if Duane Arnold would have continued operating, one item that should have went in the model was the ability to initiate fire water in time to support a stuck open relief valve in SBO. That's the diesel driven fire water pump that Terry was mentioning. Although it was initially inoperable due to maintenance, they could have restored that in pretty short order. Because if you just open up the SPAR model from scratch, and ou run a long duration loop, that was what was dominating. So that would be an item that should be accounted for and changed in the permanent model record. Now, some of the other things such as FLEX, we're kind of in a kind of a grey area with FLEX. We still have all the FLEX models turned off, so I don't know if the FLEX modeling would stay in there, but some of that stuff would make sense. Because, whenever you're opening it, and reviewing the FLEX, the final integrated plan, and it would make sense that you would, even if the FLEX credit is turned off, that some of those changes, would be made, so you're not losing that effort. So, next time someone comes in and uses the model, they don't have to make those changes and we're maybe more consistent across our analysis.

Matthew Leech:

During the the LIC-504 analysis when I was working with a group of plants, I did discover some modeling issues that you'll discover when you go in depth into an analysis. Some of them might be very specific just to that one analysis you're doing. But some of the things I found did require changing in the base model of record, not necessarily for derecho. But I found some errors in how service water was modeled or something that could be better modeled in the models. I did feed that back to our vendor, Idaho National Labs, which maintains the model, and I know that upgrades or updates were made to those based on some of those things that we found. So throughout the process we did update some models of record.

Question:

Terry, you mentioned a very early in your talk about monitoring the weather forecast and the watches and the warnings. Where are you getting your weather alerts and watches from? Are you getting specialized forecasts from an enitity geared toward your industry? Or relying on forecasts avaialble to the general public?

Terry Brandt:

We did not have any specific program that would allow us to monitor the weather. So I subscribe to National Weather Service warnings on my cell phone and we had designed our communication such that a cell phone on airplane mode with Wi-Fi was allowed to be used inside of our control room. So I got the weather warnings on my cell phone. That's just being a good steward. What behavior that we would see on site is if a warning or a watch would be issued we'd typically get about two dozen phone calls in the control room to ask us whether or not we were taking actions out of our abnormal operating procedure. So the monitoring from a local weather station, National Weather Service in our case, out of the Quad Cities is what we use to determine the watches and warnings.

Moderator:

A derecho is an example of meso scale convective system where you have large scale organization, more than just a single isolated thunderstorm. You have many thunderstorms that line up together in a large system. There is a convective outlook, produced by the Weather Service Storm Prediction Center. I think they go as far out as maybe four days in advance. These don't have the same level of definitiveness in terms of a warning. It's a long range view of weather systems of interest that may be coming up. The condvective outlook would be something that would be useful to have somebody subscribing to so you would have some advance warming that the conditions are ripe for things like, large thunderstorms, tornadoes, derecho's and things of that nature.

Terry Brandt:

Thinking back to it, we did carry the emergency response pagers. Those were subscribed, so we would typically get a page. Wwhether or not it was timely, I can't remember, but we would get a page on the pagers if we had a watch or warning also. We had a couple different methods to be able to get informed of this. In this case, if I remember right, the two-day outlook was fairly clear with not a lot of chance of storms. So this was, to John's point earlier, that this was very fast moving and with very little warning of a storm.

John Hanna:

Terry, following the Robinson event and I'm not sure if you're familiar with that one. It was a major fire, a very risk-sgnificant event. There was an augmented inspection team (AIT) . During the restoration of power to get off the diesels and restoring normal lineup, they actually caused a second event, a high energy arc fault, to occur. Following that event, can you speak towhat's changed in terms of offsite power restoration, the care and precautions you take before re-energizing buses? If you're not aware of what the industry overall is doing, maybe what changes Duane Arnold might have made.

Terry Brandt:

I can tell you that during our restoration we reviewed, did a pre job brief and took a very slow and very cautious approach to the restoration, because we knew that we were very stable where we were at with both diesels operating. We took a very cautious approach, used our normal procedures in order to restore power, and actually followed the recommendation of the transmission company, in this case ITC (International Transmission Company), to warm up the transformers and have breakers closed and wait a period of time. In our case we waited 15 minutes just to make sure that everything was going right. We were very stable at that point. The other point that they [ITC] wanted to make with us, and on which we had very close conversations, is we just had a very significant event. They had just rebuilt some of our lines and they wanted to make sure that they weren't going to introduce anything to the lines by closing the breakers too. So, the Robinson event was not in the forefront of my mind. What was in the forefront of my mind was what we had built into the program from the Robinson event: (1) make sure you understand what you are doing; and (2) make sure you know where your fault is so that you don't reintroduce a fault by re-energizing the exact bus that you had a fault with.

Question: What's the timeline for ASP analysis and the LIC-504 process? How long after the event were these two processes completed?

Christopher Hunter:

For ASP, the normal process is to start when we get the Licensee Event Report (LER) and complete the analysis in about two months after receiving the LER. For Duane Arnold we started pretty early. We were waiting on the LER before we sent the preliminary analysis out. We completed the final analysis a little over 5 months from the event date.

Matthew Leech:

LIC-504 started a couple months after the event. We didn't act immediately. The recommendation to do the LIC-504 came in, management looked at it and discussed it and said yes, let's go ahead and do it. There is one time metric for the first step of the LIC-504, where we have to decide whether or not we need to take immediate action or prompt action as it's worded. Do we need to shut the plant down? Do we need to issue some other type of order that would improve safety? There's a time frame for that, usually we want to get that done within 30 days. We did meet that goal for Duane Arnold. Once that was finished and there was a little bit less urgency, it took us about three more months before the LIC 504 was in a finished status. That’s due to the fact that were not looking at one plant. We were studying about 8 different plants and running that analysis. It took a little bit longer. But I will say there was one thing that the NRC did do in the interim before the ASP and LIC-504 was finished. As we had some information from a risk standpoint from Region III when this event occurred, we did issue some internal operating experience so that our inspectors would know initially what happened and some risk type information to focus on.

3.9 Day 4: Session 4B – ASCE-7 Tornado Wind Loads

Session Chair: Elena Yegorova, NRC/RES/DRA

3.9.1 Presentation 4B-1: Introduction to Tornado Loads in the New ASCE 7-22 Standard - Including Long Return Period Tornado Hazards Maps with Applications to Nuclear Facilities

Authors: *Marc Levitan*, National Institute of Standards and Technology*

Speaker: *Marc Levitan*

3.9.1.1 Abstract

The American Society of Civil Engineers ASCE 7 Standard on Minimum Design Loads and Associated Criteria for Buildings and Other Structures is the national standard referenced in model building codes for determination of dead loads, live loads, and loads caused by environmental hazards such as earthquakes, floods and windstorms. This standard has not included loads caused by tornadoes – until now. The 2022 edition of ASCE 7 has a new chapter with requirements for consideration of tornado loads in the design of certain buildings and other structures. The tornado hazard maps and load methodology in ASCE 7 are the result of a decade of research and development led by the National Institute of Standards and Technology (NIST). Key to the tornado load provisions is a new generation of tornado hazard maps. These maps incorporate advances in the understanding of tornado climatology and regional properties of tornadoes, tornado wind fields, tornado wind speeds, and the very significant effects of target size (and shape) on wind speed risk. The Standard includes a series of 48 maps with design tornado speeds for six return periods (from 1,700 to 10 million years) at eight target sizes each (from point targets to 4 million square feet). The map development process included consideration of epistemic (modeling) uncertainties, with support from the Nuclear Regulatory Commission. This presentation provides an overview of the tornado load requirements in ASCE 7-22 and their development. Tornado maps are a main focus of the talk, including introduction of Appendix G (Long Return Period Tornado Hazard Maps) and the ASCE 7 Hazard Tool, which provides site-specific values for all environmental hazards (including tornadoes) through a webGIS application.

3.9.1.2 Presentation (ADAMS Accession No. ML22061A103)

Introduction to Tornado Loads in the New ASCE 7-22 Standard

Including Long Return Period Tornado Hazards Maps with Applications to Nuclear Facilities

PFHA Workshop
Feb. 17, 2022

Marc L. Levitan, Ph.D.
Lead Research Engineer, National Windstorm Impact Reduction Program

NIST National Institute of Standards and Technology
U.S. Department of Commerce

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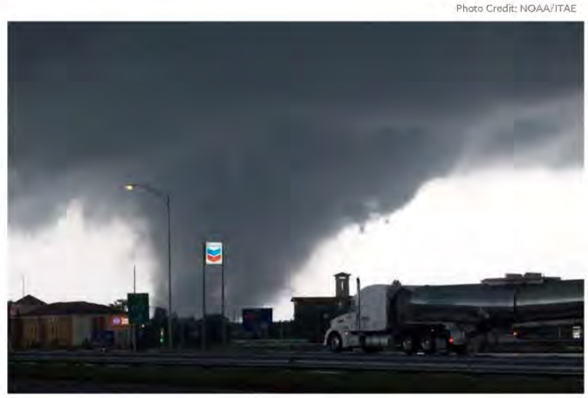
Why Haven't We Considered Tornadoes in Conventional Engineering Design?

NIST

Common Misperceptions

- Too rare
- Losses from tornadoes are small compared to other hazards
- Nothing we can do about them
- Inadequate knowledge
- Buildings would all have to be concrete bunkers
- Too expensive

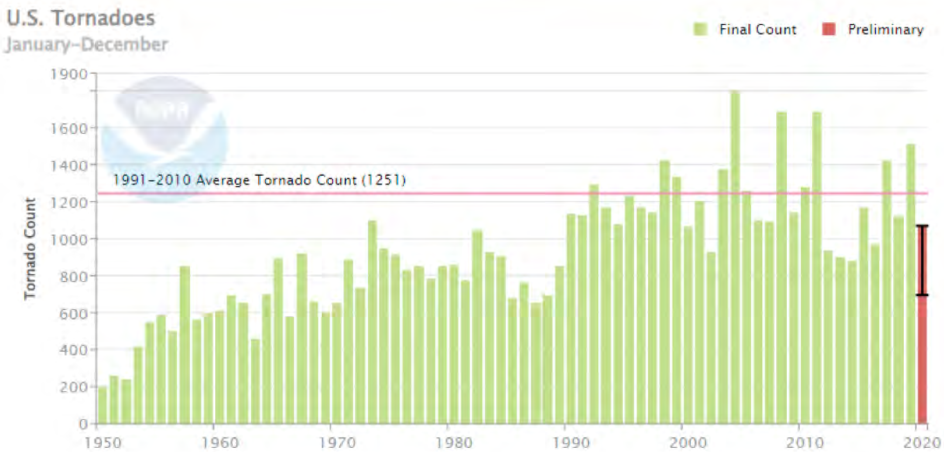
Photo Credit: NOAA/ITAE



Perceptions may be shaped by the few violent tornadoes per year that make the headlines

How Rare are Tornadoes?

Source: NIST, from NOAA data

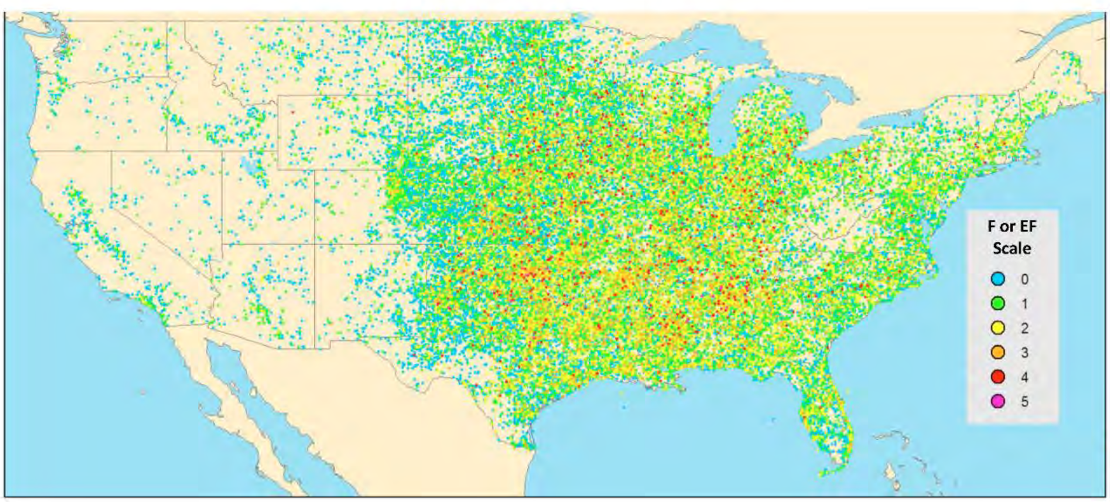


This plot shows the number of *reported* tornadoes per year.
Many tornadoes go unreported.

Where do Tornadoes Occur?

Source: NIST, from NOAA data

U.S Tornadoes: 1995-2016



How Many Lives are Lost in Tornadoes?

NIST

Tornadoes kill more people per year in the U.S. than hurricanes and earthquakes combined

Tornado fatalities overwhelmingly occur inside buildings.

High Tornado Death Toll

5,600 killed (1950 – 2011)

Average deaths/year:

Tornadoes:	91.6
Hurricanes:	50.8
Earthquakes:	7.5

Moore OK Tornado – 2013. Damage to the hallway and classrooms of the new main classroom building (complete loss of roof and many walls) where the 7 fatalities occurred (most of the debris has already been removed). This hallway area was a "designated area of safety." NIST SP 1164 (2013)

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Storm Shelters for Life Safety Protection

NIST

We *can* design for mother nature's worst

FEMA Safe Rooms are designed for 'near-absolute' life safety protection, ICC 500 Storm Shelters have almost identical requirements

- **250 mph tornado winds**
- **Impact of 15-pound 2x4 traveling at 100 mph**
- **No reported failures of safe rooms or shelters constructed to FEMA or ICC 500 requirements**

In-Residence Safe Room
Joplin, MO, May 22, 2011

Source: FEMA

Winston County Commission Community Safe Room
Arley, AL, November 30, 2016

How Much Damage do Tornadoes Cause?

NIST

INSURANCE INFORMATION INSTITUTE

Over the 20-year period, 1997 to 2016, events involving tornadoes, including other wind, hail and flood losses associated with tornadoes made up **39.9%** of total catastrophe insured losses, adjusted for inflation.

Hurricanes and tropical storms were a close second largest cause of catastrophe losses, accounting for **38.2%** of losses

https://www.iii.org/article/spotlight-on-catastrophes-insurance-issues#:~:text=Hurricanes%20and%20tropical%20storms%20were,winter%20storms%20(6.7%20percent)

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Isn't Most Damage Caused by the Big Tornadoes?

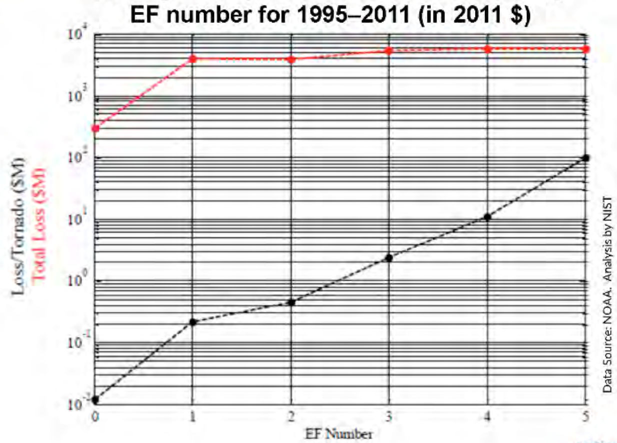
NIST

Property damage and resulting losses per *individual* tornado (black curve) increase dramatically with EF rating

However, *aggregate* losses for all tornadoes per EF number (red curve) are of the same magnitude (except EF0)

- because there are so many more tornadoes with lower intensities

Average loss per tornado and total loss by EF number for 1995–2011 (in 2011 $)



Source: NIST (2014)
https://doi.org/10.6028/NIST.NCSTAR.3

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Opportunity for Tornado Loss Reduction

EF SCALE	
EF #	**3-s Gust (mph)**
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	Over 200

We don't *have* to design everything to withstand the most violent tornadoes in order to significantly reduce tornado damage

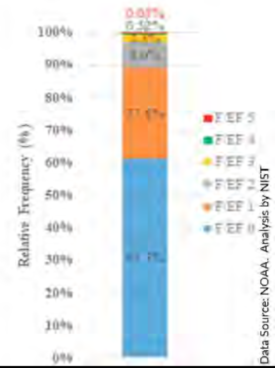
From 1995-2016, of the over 1,200 tornadoes/year

*** 89.1% were EF0-EF1, 97.1% were EF0-EF2**

Most of the area impacted by a tornado does not experience the greatest winds, e.g., in the 2011 EF-5 Joplin Tornado (NIST, 2014)

*** 72% of area swept by tornado experienced EF0-EF2 winds**

*** 28% experienced EF3-EF5 winds**



Paradigm Shift Needed

NIST

Ignoring tornado hazards in the design of our built environment is not an appropriate response

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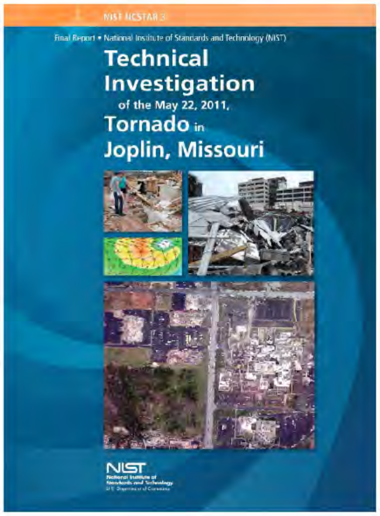
Genesis of Tornado Loads in ASCE 7-22



http://dx.doi.org/10.6028/NIST.NCSTAR.3

The first tornado study to include storm characteristics, building performance, emergency communication and human behavior together - with assessment of the impact of each on fatalities

16 recommendations for improving:

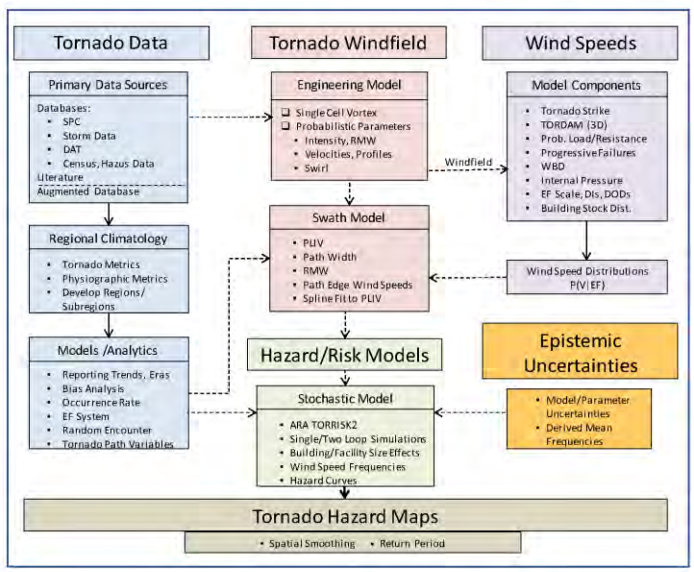
- Tornado hazard characterization
  - R3 - develop new tornado hazard maps considering spatial estimates of tornado hazard
- Design and construction of buildings and shelters in tornado–prone regions
  - R5 - develop performance-based tornado-resistant design standards
  - R6 - develop tornado design methodologies
- Emergency communications that warn of threats from tornadoes

NOTE: Summaries of the recommendations are provided in this presentation for context. The complete recommendations are available in the final report, available through the link shown at left.

Tornado Hazard Maps

Map Development Overview

- Tornado Risk Mapping Project Components
- Six year effort, working with Applied Research Associates, Inc. (ARA) under contract to NIST, led by Dr. Larry Twisdale
- The US Nuclear Regulatory Commission supplemented NIST funding to include the analysis of epistemic uncertainties



Consideration of Uncertainty

- Epistemic Uncertainties are often called "modeling uncertainties"
- Aleatory Uncertainties are often referred to as "randomness"
- Many epistemics in modeling tornado wind speeds
- Approach:
  - Modeled numerous random variables, many regionally, to capture randomness.
  - Modeled epistemic uncertainties in 5 key areas characterized by:
    - Significant uncertainties in mean values
    - Uncertainties in models/parameters
    - Expert judgment
- 12 Implementations
- The modeling philosophy for the uncertainty modeling was "best-estimate."

Group	Epistemic Topic	Model/Parameter Uncertainty
1	Tornado Regionalization	Region-Subregion Boundaries
2	Tornado Occurrence Rates	Region/Subregion Occurrence Rates
3	Tornado Intensity and Path Variables	a. EF-Scale
		b. Path Length
		c. Path Width
4	Tornado Windfield and Swath Model	a. Windfield
		b. Swath
5	Damage Modeling/EF Wind Speed Analysis	a. Engineering Interpretation in EF DODs Descriptions
		b. Structural Quality Factor
		c. DOD to EF Distribution
		d. House DOD 9-10 Model
		e. Bayesian Prior Wind Speed Distribtuion

Target Size Effects

Tornado risk and tornado speeds are a function of building or facility size and shape (effective plan area)

- Tornado strike probabilities increase with increasing plan area of the target building or structure (target size)
- For a given return period (i.e., mean recurrence interval), tornado speeds increase with increasing target size

Effects of building or facility plan area on tornado strike probability

"Does the Flap of a Butterfly's Wings in Brazil Set off a Tornado in Texas?"
Edward U. Lorenz, Sc.D.
Professor of Meteorology
Massachusetts Institute of Technology, Cambridge

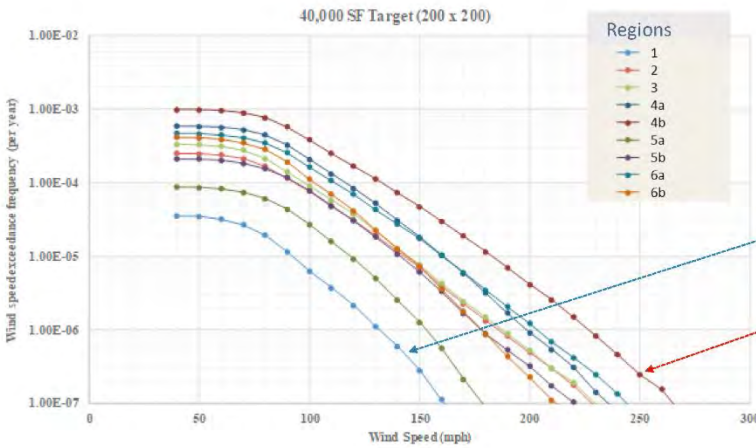
https://www.ias.ac.in/article/fulltext/reso/020/03/0260-0283

Tornado Hazard Maps

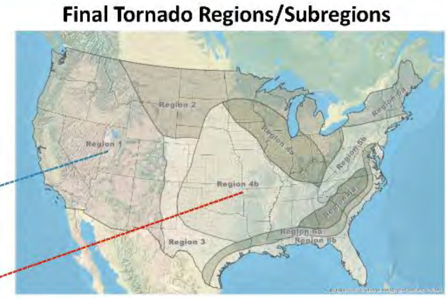
NIST

Windspeed Exceedance Frequencies (WEFs)

WEFs developed for each region and subregion, for a range of target sizes



Final Tornado Regions/Subregions



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Tornado Hazard Maps

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Target Size Effects

- The effects of target size depend on the Region and the tornado wind speed
- The effect of target size is reduced for high return periods
- The effects of target size are greater in regions with lower wind hazard, such as Region 1, since the tornadoes are smaller and the impact of increasing target size has a more dominant effect on the resulting risk.

Target Size Effects for Regions 1 (West) and 4b (Center)

Note: Return Period (also referred to as mean recurrence interval or MRI) is the inverse of the annual exceedance frequency

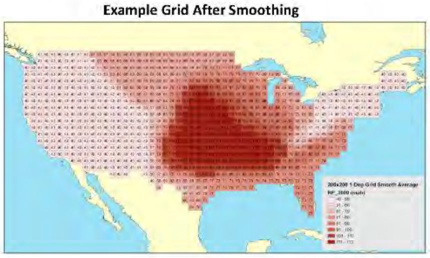
Tornado Hazard Maps

NIST

Map Development Process

1. A six step process is used to develop maps.
2. The grid wind speeds for a given Return Period and Target Size were smoothed using Gaussian smoothing.
3. The Kriging was performed in ArcGIS with default parameters, similar to the current ASCE 7 non-tornadic maps.

Example Grid After Smoothing



1. Hazard Curve WEFs (Given Target Size)
2. Interpolate Windspeeds to Return Periods
3. Input Windspeeds to Region/Subregion Grid Cells
4. Gaussian Smoothing
5. ArcGIS Kriging
6. PAEK Smoothing & Hand Adjustments for Final Maps

Regional Boundary Uncertainties

Region Boundary	Mean Distance (mi)	Approx. Number of 1 Deg. Cell Widths
Region 1- Region 2	166	2.8
Region 1 – Region 3	125	2.1
Region 2 - Region 3	416	6.9
Region 4 – Region 2	217	3.6
Region 4 – Region 3	130	2.2
Region 4 – Region 5 (West of Appalachians)	85	1.4
Region 4 – Region 5 (South and East of Appalachians)	177	3.0
Overall Mean	**188**	**3.1**

Gaussian Smoothing Weights

0.0099	0.0239	0.0320	0.0239	0.0099
0.0239	0.0575	0.0770	0.0575	0.0239
0.0320	0.0770	0.1031	0.0770	0.0320
0.0239	0.0575	0.0770	0.0575	0.0239
0.0099	0.0239	0.0320	0.0239	0.0099

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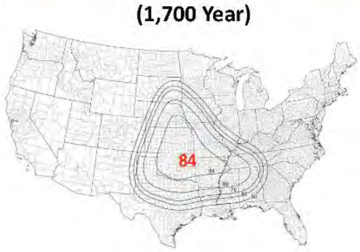
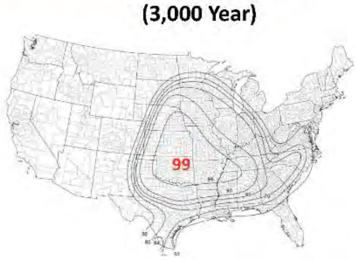
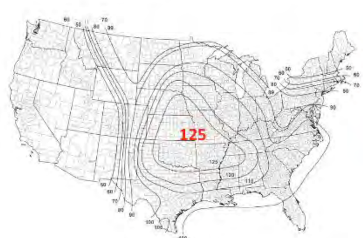
Tornado Hazard Maps - Examples

NIST

Effective Plan Area, A_e (ft^2)	Risk Category III (1,700 Year)	Risk Category IV (3,000 Year)
10K		
1M		

Tornado speeds are 3-s peak gusts in mph at 33 ft (10 m) height

8 mapped effective plan area sizes (target sizes), from 1 to 4M sq ft

- 1 (Geometrical Point)
- 2,000 (45' x 45')
- 10,000 (100' x 100')
- 40,000 (200' x 200')
- 100,000 (316' x 316')
- 250,000 (500' x 500')
- 1,000,000 (1,000' x 1,000')
- 4,000,000 (2,000' x 2,000')

Mapped values are available through the ASCE 7 Hazards Tool, free of charge
https://asce7hazardtool.online/

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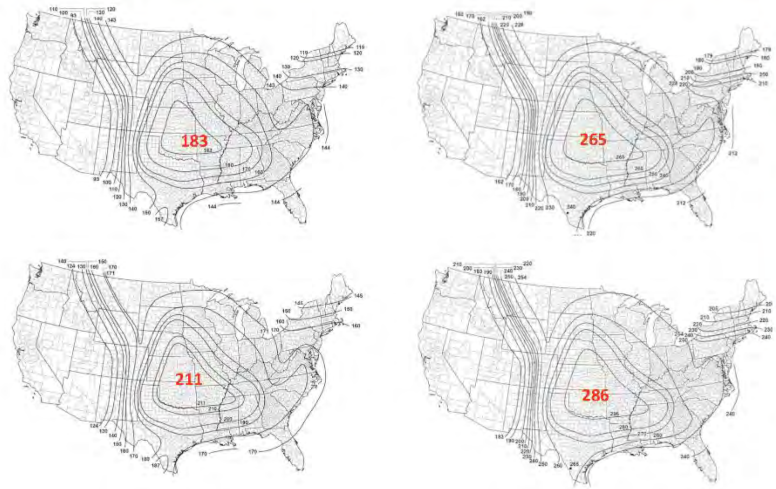
Tornado Hazard Maps – Long Return Periods

Effective Plan Area, A_e (ft²) | **100,000 Year** | **10,000,000 Year**

40K

4M



Tornado speeds are 3-s peak gusts in mph at 33 ft (10 m) height

More information on the long return period maps was presented at 2021 RIC – Session T11

Mapped tornado speeds for longer return periods at each of the 8 sizes are provided in ASCE 7-22 Appendix G

- 10,000 years
- 100,000 years
- 1,000,000 years
- 10,000,000 years

ASCE 7-22 also includes a new Appendix F with longer return period *wind speed* maps

Tornadic Wind Characteristics

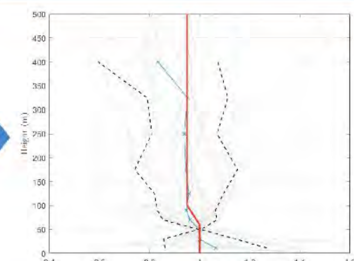
Very different from straight-line winds

- Short duration
- Rapidly changing speeds and directions
- Strong updrafts
- Decreasing speed with height above ground
- Atmospheric Pressure Change

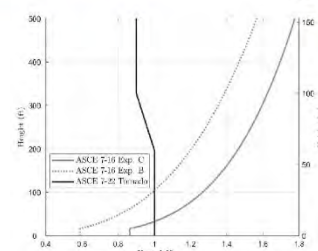
Worked closely with mobile radar community

- analyzed radar-measured tornado wind speeds
- developed tornado velocity pressure profiles

Source: NSF



Normalized Tornado Velocity Profiles



ASCE 7-22 Velocity Pressure Profiles for Tornadic and Straight-Line Winds

Tornadic Wind-Structure Interaction

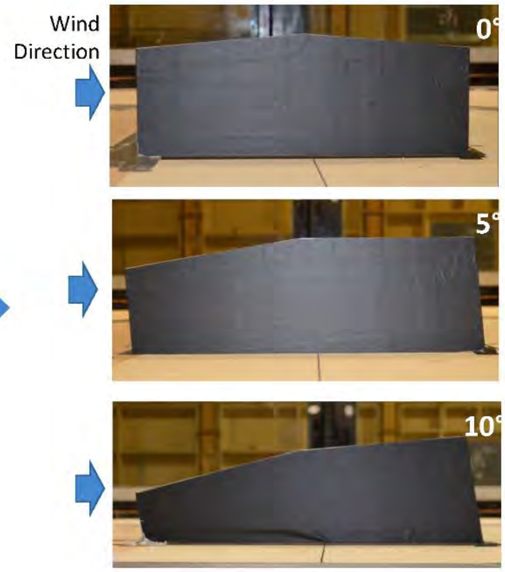
NIST

Very different from straight-line winds

- Short duration
  - Changes to gust effect factor
- Rapidly changing speeds and directions
  - Changes to directionality factor
- Strong updrafts
  - Addition of new factor to account for increase in uplift pressures on roofs

Conducted wind tunnel tests to simulate the effective change in wind angle at the leading edge of the roof

- Decreasing speed with height above ground
  - Changes to velocity pressure exposure coefficient
- Atmospheric Pressure Change
  - Changes to internal pressure coefficient to account for contributions of APC



engineering laboratory

ASCE/SEI 7-22
Tornado Provision Highlights

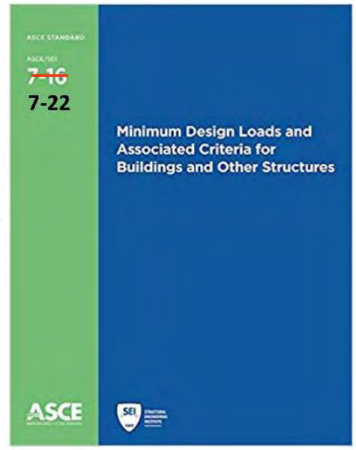
Marc Levitan

Chair
ASCE 7-22 Tornado Task Committee

SEI STRUCTURAL ENGINEERING INSTITUTE ASCE

Tornado Loads - New in ASCE 7-22

NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory (NSSL).



Tornado Loads: Placement in 7-22

Red indicates differences from ASCE 7-16

- **Chapter 1: General**
  - Add Tornadoes to Risk Categorization Table 1.5-1
- **Chapter 2: Load Combinations**
  - Add Tornado Loads to load combinations
- **Chapter 26: Wind Loads**
  - Add requirement to check Tornado Loads per Ch. 32
- **New Chapter 32: Tornado Loads**
  - Complete provisions to determine Tornado Loads
- **New Appendix G: Tornado Hazard Maps for Long Return Periods**
  - Tornado speed maps for longer return periods, in support of tornado PBD and other applications

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Tornado, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life	III
Buildings and other structures designated as essential facilities Buildings and other structures, the failure of which could pose a substantial hazard to the community Buildings and other structures required to maintain the functionality of other Risk Category IV structures	IV

Ch. 32: Tornado Loads

- Built on ASCE 7 wind load procedures framework
  - Designed to provide similar look and feel with the wind provisions for improved ease of use
- Most wind load coefficients and equations are modified to account for differences in tornadic wind and wind-structure interaction
- Despite similarities in procedures, tornado loads are treated separately from wind loads

CHAPTER 32
TORNADO LOADS

32.1 PROCEDURES

32.1.1 Scope Buildings and other structures classified as Risk Category III or IV and located in the tornado-prone region as shown in Figure 32.1-1, including the main wind force resisting system (MWFRS) and all components and cladding (C&C) thereof, shall be designed and constructed to resist the greater of the tornado loads determined in accordance with the provisions of this chapter or the wind loads determined in accordance with Chapters 26 through 31, using the load combinations provided in Chapter 2.

User Note: The tornado loads specified in this chapter provide reasonable consistency with the reliability delivered by the existing criteria in Chapters 26 and 27 for MWFRS, and therefore are only required for Risk Category III and IV buildings and other structures (see Return Period discussion in Section C32.5.1 for more information). The tornado loads are based on tornado speeds using 1,700- and 3,000-year return periods for Risk Category III and IV, respectively (which are the same return periods used for basic wind speeds in Chapter 26). The tornado speed at any given geographic location will range from approximately Enhanced Fujita Scale EF0 – EF2 intensity, depending on the risk category and effective plan area of the building or other structure (see Section C32.5.1). Options for protection of life and property from more intense tornadoes include construction of a storm shelter and/or design for longer-return-period tornado speeds as provided in Appendix G, including performance-based design. A building or other structure designed for tornado loads determined exclusively in accordance with Chapter 32 cannot be designated as a storm shelter without meeting additional critical requirements provided in the applicable building code and ICC 500, the ICC/NSSA *Standard for the Design and Construction of Storm Shelters*. See Commentary Section C32.1.1 for an in-depth discussion on storm shelters.

32.1.2 Permitted Procedures The design tornado loads for buildings and other structures, including the MWFRS and C&C elements thereof, shall be determined using one of the procedures as specified in this section and subject to the applicable limitations of Chapters 26 through 32, excluding Chapter 28.

An outline of the overall process for the determination of the tornado loads, including section references, is provided in Figure 32.1-3.

32.1.2.1 Tornado Loads on the Main Wind Force Resisting System Tornado loads for the MWFRS shall be determined using one or more of the following procedures, as modified by Chapter 32:

1. Directional Procedure for buildings of all heights as specified in Chapter 27 for buildings meeting the requirements specified therein;
2. Directional Procedure for Building Appurtenances (such as rooftop structures and rooftop equipment) and Other Structures (such as solid freestanding walls and solid freestanding signs, chimneys, tanks, open signs, single-plane open frames, and trussed towers) as specified in Chapter 29 for buildings meeting the requirements specified therein; or
3. Wind Tunnel Procedure for all buildings and all other structures as specified in Chapter 31 for buildings meeting the requirements specified therein.

32.1.2.2 Tornado Loads on Components and Cladding Tornado loads on the C&C of all buildings and other structures shall be determined using one or more of the following procedures, as modified by Chapter 32:

1. Analytical Procedures as specified in Parts 1 through 5, as appropriate, of Chapter 30, for buildings meeting the requirements specified therein; or
2. Wind Tunnel Procedure for all buildings and all other structures as specified in Chapter 31, for buildings meeting the requirements specified therein.

32.1.3 Performance-Based Procedures Tornado design of buildings and other structures using performance-based procedures shall be permitted subject to the approval of the Authority Having Jurisdiction. The performance-based tornado design procedures used shall, at a minimum, conform to Section 1.3.1.3 and be documented and submitted to the Authority Having Jurisdiction in accordance with Section 1.3.1.3.

32.2 DEFINITIONS

The following definitions apply to the provisions of Chapter 32. Terms not defined in this chapter shall be defined in accordance with Chapters 26 through 31, as appropriate, excluding Chapter 28.

ASCE TORNADO DESIGN GEODATABASE: The ASCE database (version 2020-1.0) of geocoded tornado speed design data.

OTHER STRUCTURES, SEALED: A structure that is completely sealed or has controlled ventilation such that tornado-induced atmospheric pressure changes will not be transmitted to the inside of the structure, including but not limited to certain tanks and vessels.

TORNADO-PRONE REGION: The area of the conterminous United States most vulnerable to tornadoes, as shown in Figure 32.1-1.

Minimum Design Loads and Associated Criteria for Buildings and Other Structures 353

Scope

- Risk Category III and IV buildings and other structures
- Located in the tornado-prone region
- Design of MWFRS and C&C
- Must resist the greater of tornado loads or wind loads, using load combinations in Chapter 2

32.1 PROCEDURES

32.1.1 Scope Buildings and other structures classified as Risk Category III or IV and located in the tornado-prone region as shown in Figure 32.1-1, including the main wind force resisting system (MWFRS) and all components and cladding (C&C) thereof, shall be designed and constructed to resist the greater of the tornado loads determined in accordance with the provisions of this chapter or the wind loads determined in accordance with Chapters 26 through 31, using the load combinations provided in Chapter 2.

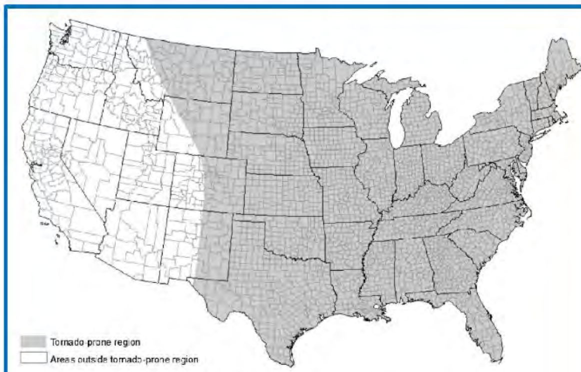


Figure 32.1-1. Tornado-prone region.

User Note

- Highlights key features/ explanations of tornado load provisions
- Design tornado speeds range from 60-138 mph, approximately EF0-EF2 intensity,
  - Dependent on Risk Category, geographic location, and effective plan area (target size)
- Return periods for Risk Category III and IV are 1,700 and 3,000 years, respectively (the same as used for wind loads)
- Options for protection from more intense tornadoes include storm shelters and PBD
- Tornado shelters cannot be designed solely using Chapter 32 – pointers to commentary

User Note: The tornado loads specified in this chapter provide reasonable consistency with the reliability delivered by the existing criteria in Chapters 26 and 27 for MWFRS, and therefore are only required for Risk Category III and IV buildings and other structures (see Return Period discussion in Section C32.5.1 for more information). The tornado loads are based on tornado speeds using 1,700- and 3,000-year return periods for Risk Category III and IV, respectively (which are the same return periods used for basic wind speeds in Chapter 26). The tornado speed at any given geographic location will range from approximately Enhanced Fujita Scale EF0 – EF2 intensity, depending on the risk category and effective plan area of the building or other structure (see Section C32.5.1). Options for protection of life and property from more intense tornadoes include construction of a storm shelter and/or design for longer-return-period tornado speeds as provided in Appendix G, including performance-based design. A building or other structure designed for tornado loads determined exclusively in accordance with Chapter 32 cannot be designated as a storm shelter without meeting additional critical requirements provided in the applicable building code and ICC 500, the ICC/NSSA *Standard for the Design and Construction of Storm Shelters*. See Commentary Section C32.1.1 for an in-depth discussion on storm shelters.

Where Tornado Loads are Likely to Control

Tornado loads are more likely to control at least some element(s) of the wind load design for structures that

- are located in the central and southeast US (except near the coast where dominated by hurricanes)
- are Risk Category IV
- are designated as Essential Facilities
- have large effective plan areas
- are located in Exposure B
- have low mean roof heights
- are classified as enclosed buildings for wind loads

Nursing Home
Caddo County, Oklahoma
August 19, 2007

Credit: FEMA

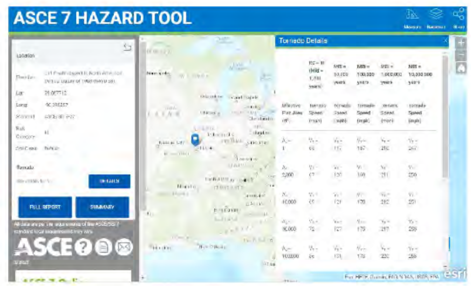
Tornado loads can control over wind loads when tornado speeds are as little as half of the basic wind speeds

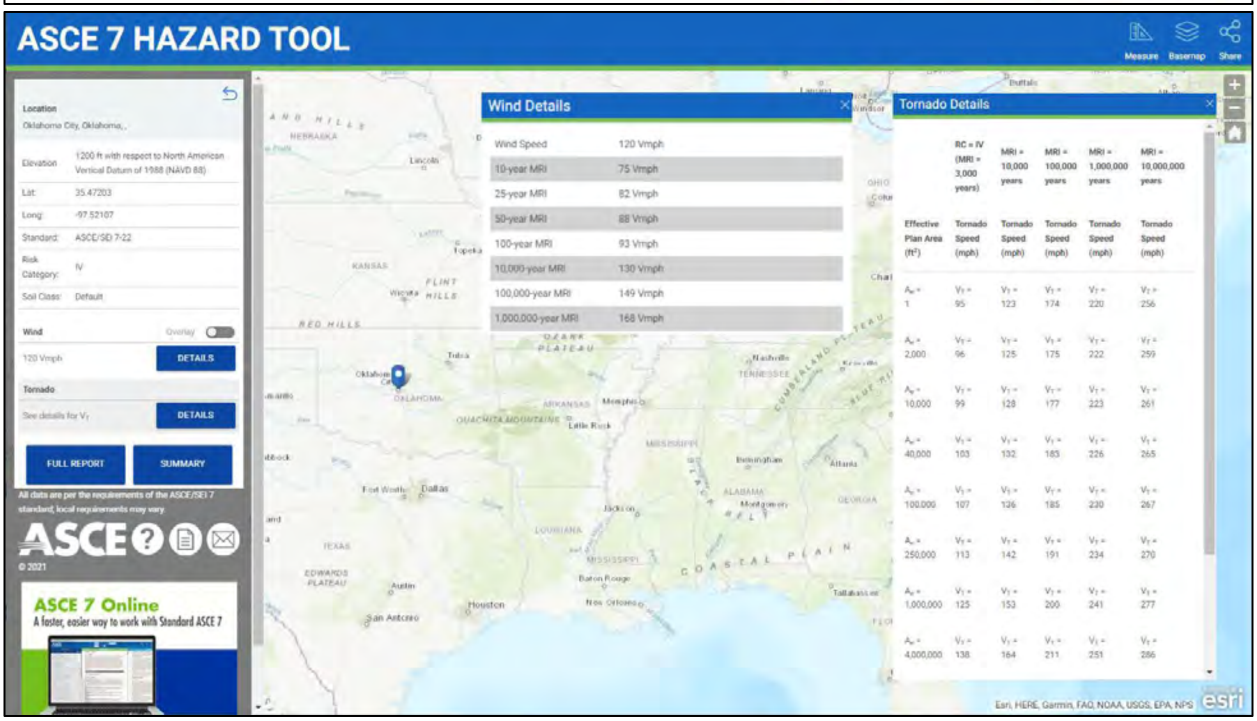
Where tornado loads control, design uplift pressures on roofs will typically increase. This will help reduce the most common tornado and other windstorm failures.

CURRENT STATUS OF ASCE 7-22

- **Public Comment Draft was published in June for 45-day review period**
- **Published December 1, 2021**
  - In e-book (pdf), paperback, and online versions

- ASCE 7 Hazard Tool - Available to the public
  https://asce7hazardtool.online/

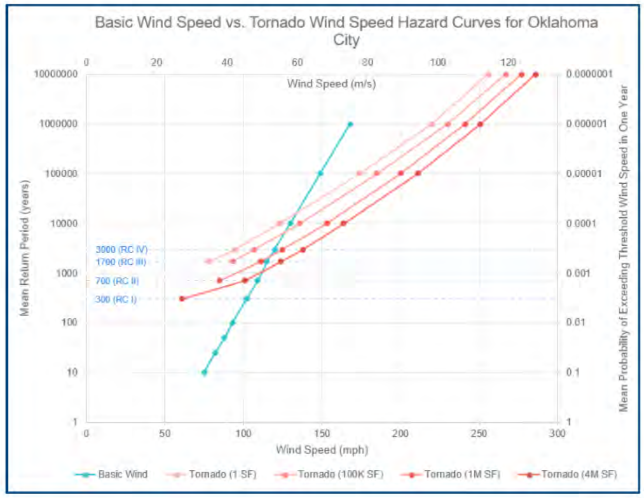




Hazard Curves for Tornadic and Other Winds

ASCE 7 Hazards Tool provides data that can be used to construct site-specific wind speed hazard curves for

- Design tornado speeds for range of target sizes
- Design wind speeds all other windstorm types combined ('basic wind speeds')



Introduction to Tornado Loads in the New ASCE 7-22 Standard

Including Long Return Period Tornado Hazards Maps with Applications to Nuclear Facilities

Marc L. Levitan
Marc.levitan@nist.gov

Questions?

PFHA Workshop
Feb. 17, 2022

National Institute of Standards and Technology
U.S. Department of Commerce

engineering laboratory

3.10 Day 4: Session 4C – USACE Dam and Levee Database Updates

Session Chair: Joseph Kanney, NRC/RES/DRA

3.10.1 Presentation 4C-1: National Inventory of Dams

Authors: *Becky Ragon****,** *U.S. Army Corps of Engineers*

Speaker: *Becky Ragon*

3.10.1.1 Abstract

The National Inventory of Dams (NID), a congressionally authorized database, has served as a central repository of information on dams in the U.S. and its territories since the 1980s. The site has been updated to make it easier to find and share dam-related data. The U.S. Army Corps of Engineers (USACE) maintains the NID and works in close collaboration with federal and state dam safety agencies to obtain accurate and complete information about dams in the database. The new NID allows agencies to update data in-real time – users can expect fresher data that can be downloaded and shared at any time. The NID also features new information for some dams. USACE is sharing flood inundation maps for its dams in the NID as well as narrative summaries about what their dams do, benefits they provide and risks they pose, and planned and ongoing actions to manage dam risks.

3.10.1.2 Presentation (ADAMS Accession No. ML22061A102)

NATIONAL INVENTORY OF DAMS

Becky Ragon
NID Manager

Probabilistic Flood Hazard Assessment
Research Workshop

Feb 18, 2022




U.S.ARMY

US Army Corps of Engineers®

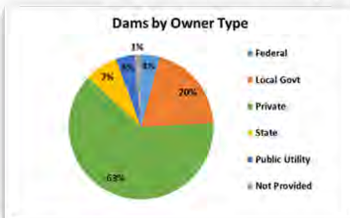
2

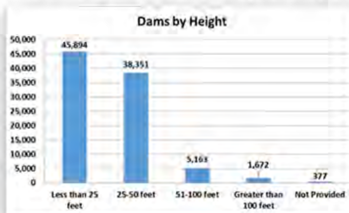
PRESENTATION OUTLINE

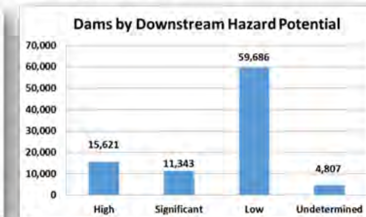
- National Inventory of Dams Overview
- What's New in the NID?
- Why is USACE Publicly Sharing Inundation Maps?
- NID Map Viewers
- NID Live Demonstration
- Questions

NATIONAL INVENTORY OF DAMS (NID)

- Congressionally authorized database documenting dams in the United States and its territories
- Includes dams owned and operated by federal agencies, the military, states, territories, tribes, local governments, public utilities and private entities
- Contains information about dam's location, size, purpose, type, last inspection and regulatory facts
- Data provided by state and federal dam safety agencies
- Maintained and published by U.S. Army Corps of Engineers







WHAT'S NEW IN THE NID?

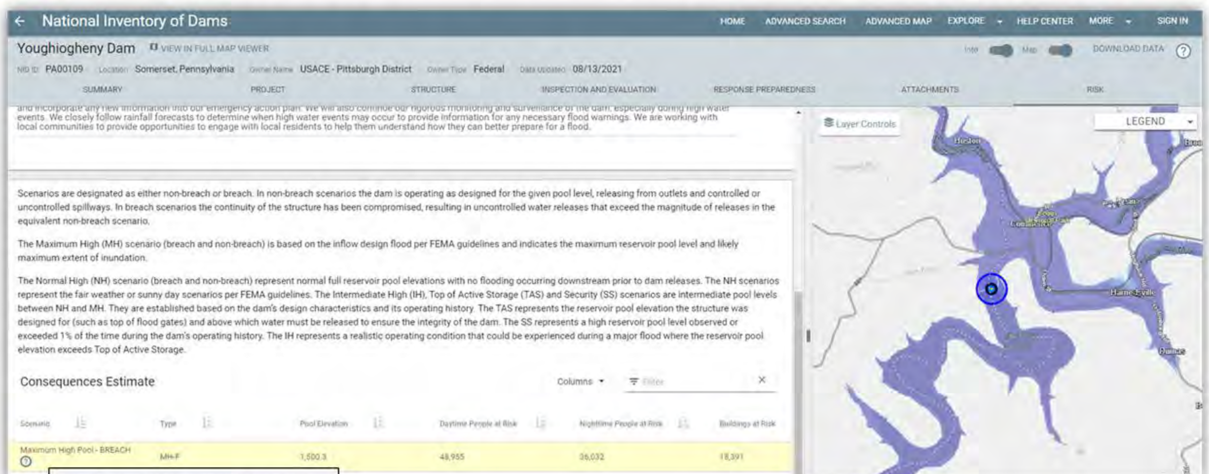
What's New in the NID?

- Public sharing of dam flood inundation maps (initially USACE only)
- Real-time data input and download
- User-friendly search functions
- Learning center for additional dam-related resources
- Additional information to explain benefits and risks of USACE dams
- https://nid.sec.usace.army.mil/#/

WHY IS USACE SHARING INUNDATION MAPS AND RISK INFORMATION?

- Increases public understanding of dam flood risk
- Empowers the public to prepare for and respond to potential floods, better managing (their own) risk
- Helps the public at risk and risk managers to "visually" see how flooding from a dam may impact their community

NID PROJECT MAP VIEWER FOR USACE DAM

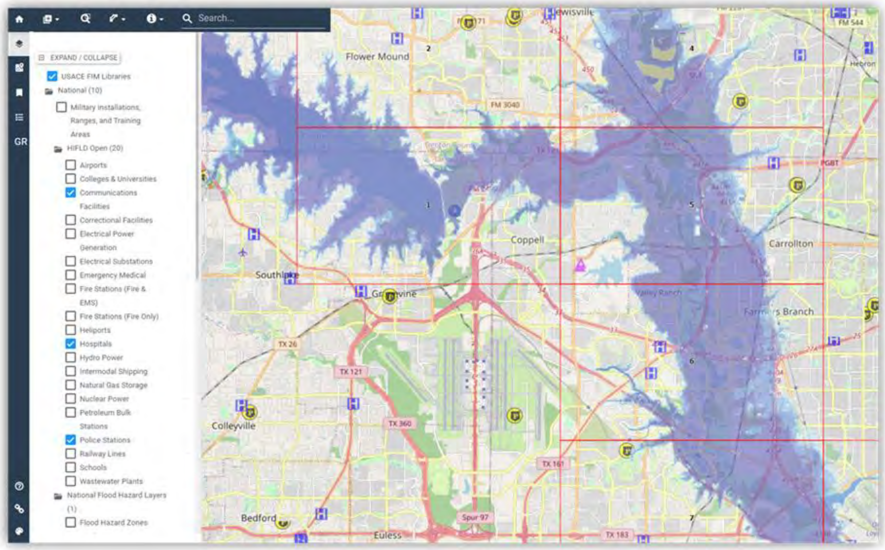


A Max High pool is the pool level near the top of dam resulting from water flowing into the reservoir from heavy rainfall, snowmelt, or other significant high-water events.

The Max High with breach pool scenario typically results in the greatest flooded area, depth of downstream flood waters, and life safety and economic consequences.

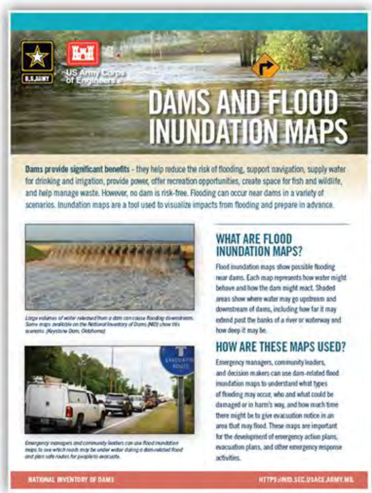
- Descriptions are included to explain the different scenarios
- Scenarios include breach and non-breach

NID ADVANCED MAP VIEWER FOR USACE DAM



- Add other map layers
- Customize with your own data
- Share the data with others
- Download or use the web services

NID – ADDITIONAL RESOURCES


US Army Corps of Engineers

DAMS AND FLOOD INUNDATION MAPS

Dams provide significant benefits - they help reduce the risk of flooding, support navigation, supply water for drinking and irrigation, provide power, offer recreation opportunities, create space for fish and wildlife, and help manage waste. However, no dam is risk-free. Flooding can occur near dams in a variety of scenarios. Inundation maps are a tool used to visualize impacts from flooding and prepare in advance.

WHAT ARE FLOOD INUNDATION MAPS?

Flood inundation maps show possible flooding near dams. Each map represents how water might behave and how the dam might react. Shaded areas show where water may go upstream and downstream of dams, including how far it may extend past the banks of a river or waterway and how deep it may be.

HOW ARE THESE MAPS USED?

Emergency managers, community leaders, and decision makers can use dam-related flood inundation maps to understand what types of flooding may occur, who and what could be damaged or in harm's way, and how much time there might be to give evacuation notice in an area that may flood. These maps are important for the development of emergency action plans, evacuation plans, and other emergency response activities.

NATIONAL INVENTORY OF DAMS HTTPS://NID.SEC.USACE.ARMY.MIL

Welcome to the NID (Exploring Our Nation's Dams)

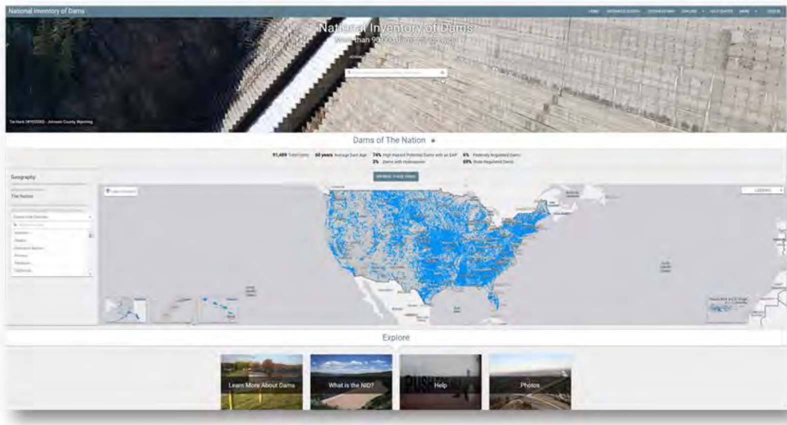
Visualizing Dams - Routine Dam Operations

Tour the NID

Visualizing Dams - Operational Flood Risk

NID DEMONSTRATION

- https://nid.sec.usace.army.mil/#/
- For additional information, contact Becky Ragon at rebecca.ragon@usace.army.mil.



3.10.2 Presentation 4C-2: National Levee Database

Authors: *Brian Vanbockern******, *U.S. Army Corps of Engineers*

Speaker: *Brian Vanbockern*

3.10.2.1 Abstract

The National Levee Database (NLD), developed by the U.S. Army Corps of Engineers (USACE), is the focal point for comprehensive information about our nation's levees. The database contains information to facilitate and link activities, such as flood risk communication, levee system evaluation for the National Flood Insurance Program (NFIP), levee system inspections, flood plain management, and risk assessments. The NLD continues to be a dynamic database with ongoing efforts to add levee data from federal agencies, states, and tribes.

3.10.2.2 Presentation (ADAMS Accession No. ML22061A101)

NATIONAL LEVEE DATABASE

NLD AND LEVEE SAFETY TOOLBOX

Brian VanBockern

February 2022

US Army Corps of Engineers

U.S.ARMY

TOPICS

- NLD history
- NLD data holdings
- NLD and its expanded toolbox
- The National Levee Safety Program

US Army Corps of Engineers

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NATIONAL LEVEE DATABASE HISTORY

- Authorized in WRDA 2007 due to Hurricane Katrina findings
- Started primary as a USACE levee database focused on federal projects
- Expanded in 2015 to include thousands of non-federal projects in cooperation with FEMA
- FEMA now uses NLD as sole source of levee data

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NLD GOALS

1. Identifying the most critical levee safety issues;
2. Understanding the true cost of maintaining levees;
3. Quantifying the Nation's flood risk exposure; and
4. Focusing priorities for future funding.

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NLD DATA HOLDINGS

- 7000 levee systems
  - Inundation areas for each system
- Risk Assessment data for over 2000 systems and growing
- Detailed Inspection data for over 2000 systems and growing
- 500 Channel projects added as part of Flood Risk Management collaboration
- 90% of data is publicly retrievable

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KEY NLD CAPABILITIES

- Robust data exploration tools
- Ability to download data individually or in bulk in multiple formats
- Online data management for users
  - Includes Inspection and Risk assessment tools
- Inundation areas – overtopping scenarios/worst case
- Capability to track multiple spatial features and hundreds of attributes with an in-depth data model.
- Access to current FEMA accreditation data

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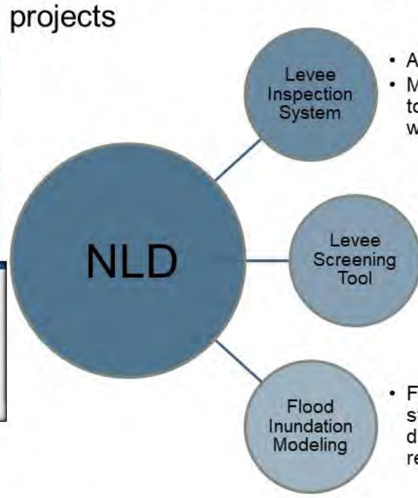
THE TOOLBOX

The NLD consists of a linked set of tools to aid users in compiling inventory, inspection and risk data for their projects



- Assess condition
- Mobile tool linked to NLD with NLD web report building

- Risk Assessment tool
- Web tool linked to NLD to assign risk and consequences

- Flood event and study model tool to display and share results

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FUTURE PLANS

- The new National Levee Safety Program will drive some change to the database.
  - www.leveesafety.org
- Focus currently is on non-federal projects where less is known on the levees
- Assisting states/tribes and other groups in levee safety data management.
- Provide a comparable basic risk measure across all levees in the National Levee Database.
- Use a scalable approach for data collection

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LIVE Demo

National Levee Database: https://levees.sec.usace.army.mil/#/

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U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

RIL 2022-10

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International Atomic Energy Agency

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Moffatt & Nichol

Kevin Coyne
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5 SUMMARY AND CONCLUSIONS

5.1 Summary

This report includes the agenda and presentations for the Seventh Annual PFHA Research Workshop, including all presentation abstracts and slides and abstracts for submitted posters. The workshop was virtually attended by members of the public; NRC technical staff, management, and contractors; and staff from other Federal agencies and academia. Public attendees over the course of the workshop included industry groups, industry members, consultants, independent laboratories, and academic institutions.

5.2 Conclusions

As reflected in these proceedings, PFHA is a very active area of research for the NRC and its international counterparts, other Federal agencies, industry, and academia. Readers of this report will have been exposed to current technical issues, research efforts, and accomplishments in this area within the NRC and the wider research community.

The NRC projects discussed in these proceedings represent the main efforts in the first phase (technical basis phase) and second phase (pilot studies) of the NRC's PFHA Research Program. This technical basis phase is nearly complete, and the NRC has initiated a second phase (pilot project phase) that synthesizes various technical basis results and lessons learned to demonstrate development of realistic flood hazard curves for several key flooding phenomena scenarios (site-scale, riverine, and coastal flooding). The third phase (development of selected guidance documents) is an area of active discussion between RES and NRC user offices. The NRC staff looks forward to further public engagement on the second and third phases of the PFHA research program in future PFHA research workshops.

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