U.S. Department of Energy | Office of Science

HYPERFACETS

A Framework for Improving Analysis and Modeling of Earth System and Intersectoral Dynamics at Regional Scales

Project Overview

U.S. DEPARTMENT OF ENERGY
Office of Science

UC DAVIS UNIVERSITY OF CALIFORNIA | Stony Brook University | Cornell University | Iowa State University | Pacific Northwest National Laboratory | UCLA | PennState | Lawrence Livermore National Laboratory | Argonne National Laboratory | University of Wyoming | CUNY The City University of New York | Utah State University | Berkeley Lab Lawrence Berkeley National Laboratory | NCAR

Our Motivation

We want to objectively address the questions:

How much can we trust climate models and data for actionable climate science?

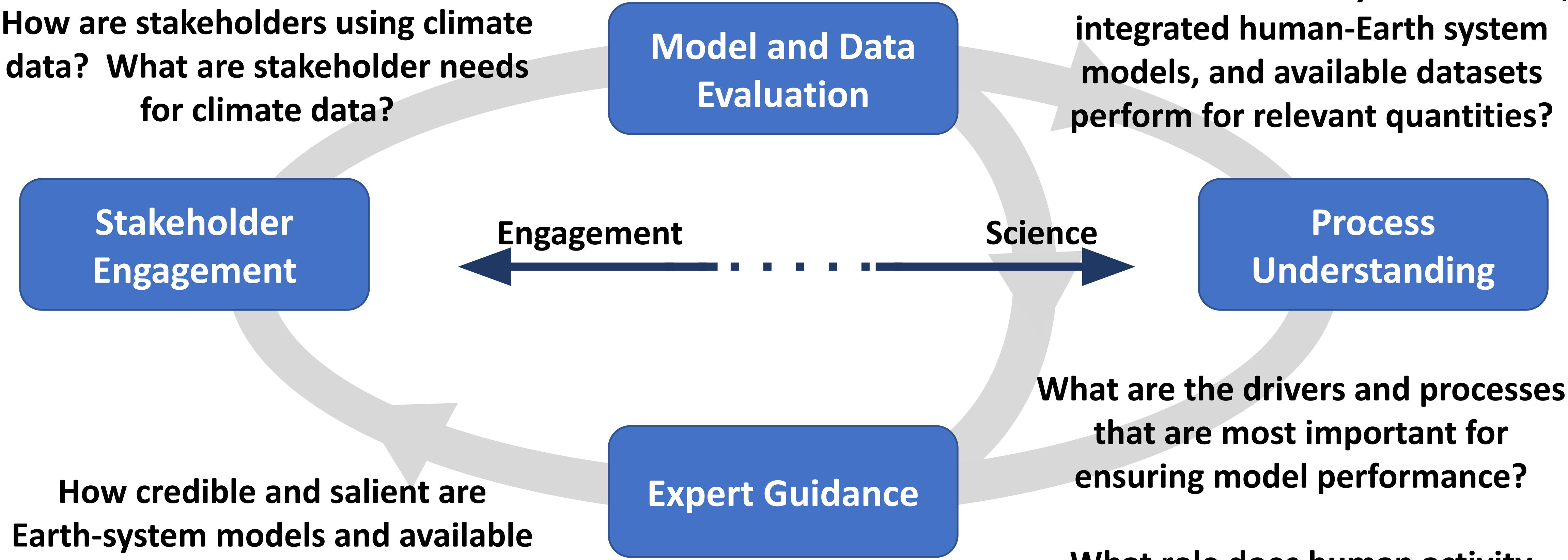
How can we effectively communicate uncertainty in climate projections?

Our efforts rely heavily on **continuous engagement** and **co-production**: developing close collaborations between **stakeholders** and **scientists** so as to ensure the salience of our work.

Achieving Project Goals via Continuous Engagement

How are stakeholders using climate data? What are stakeholder needs for climate data?

How well do Earth-system models, integrated human-Earth system models, and available datasets perform for relevant quantities?



How credible and salient are Earth-system models and available datasets for stakeholder need?

What are the drivers and processes that are most important for ensuring model performance?

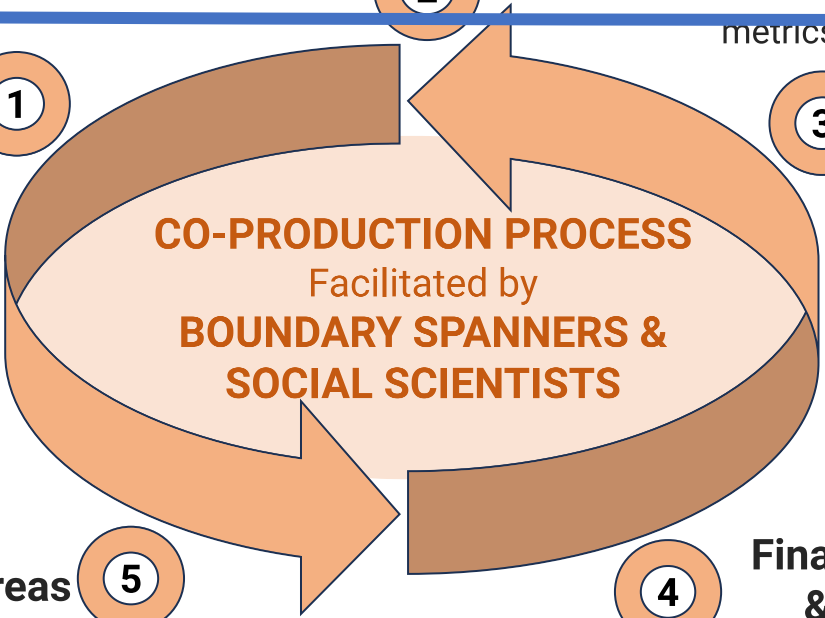
What role does human activity (GHG emissions vs. land-use) play in affecting these quantities?

Co-Production Approach

PRACTITIONERS
(~ 30 Water, Energy, Land Managers from management agencies across US)
- Identify climate-related decision-contexts
- Identify scientific knowledge gaps for practice

1 Co-produce research plan
Identify research topics, broad questions & decision-relevant outputs

2 Refine research questions & approach
Choose models, scales, decision-relevant metrics



3 Iterate on approach & results
Prioritize key results for further analysis

4 Finalize results & outputs
Share results & outputs
Identify decision-applications for results

5 Identify further areas of research
Feedback on other topics to investigate

RESEARCHERS
(~ 40 Climate scientists, Earth system sci, Social sci, Hydrologists, etc.)
- Identify broad research goals and scope
- Identify skills, available datasets and methodologies

HyperFACETSv3 Leadership

Erwan Monier (PI)
Multisector dynamics
Interdisciplinary methods
Extreme weather impacts

Paul Ullrich
Global climate modeling
Model evaluation
Feature identification / characterization

Lai-Yung Ruby Leung
Water cycle and hydroclimate
Modeling across scales
Climate change impacts

Andrew Jones
Stakeholder outreach
Uncertainty quantification
Characterizing decision-making

Melissa Bukovsky
Land-use land-cover change
Weather and climate impacts
Climate change scenarios

Sara Pryor
Wind and wind power generation
Statistical downscaling
Global change and variability

William Gutowski
Regional climate modeling
Coupled land-atmosphere hydrologic cycles
Climate change

Leveraging Broad Expertise

Not pictured here: A cohort of very active and productive graduate students and postdocs.


Rachel McCrary


Kevin Reed


Richard Grotjahn


Simon Wang


Alan Rhoades


Linda Mearns


Seth McGinnis


Zhe Feng


Colin Zarzycki


Xiaodong Chen


David Yates


Alex Hall


Chaopeng Shen


Naresh Devineni

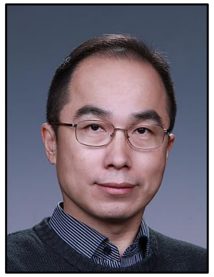

Jiwen Fan


Donovan Finn

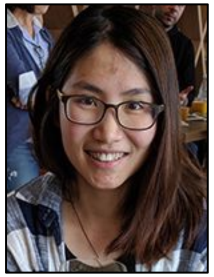

Yoshimitsu Chikamoto


Stefan Rahimi Esfarjani


Abhishekh Srivastava

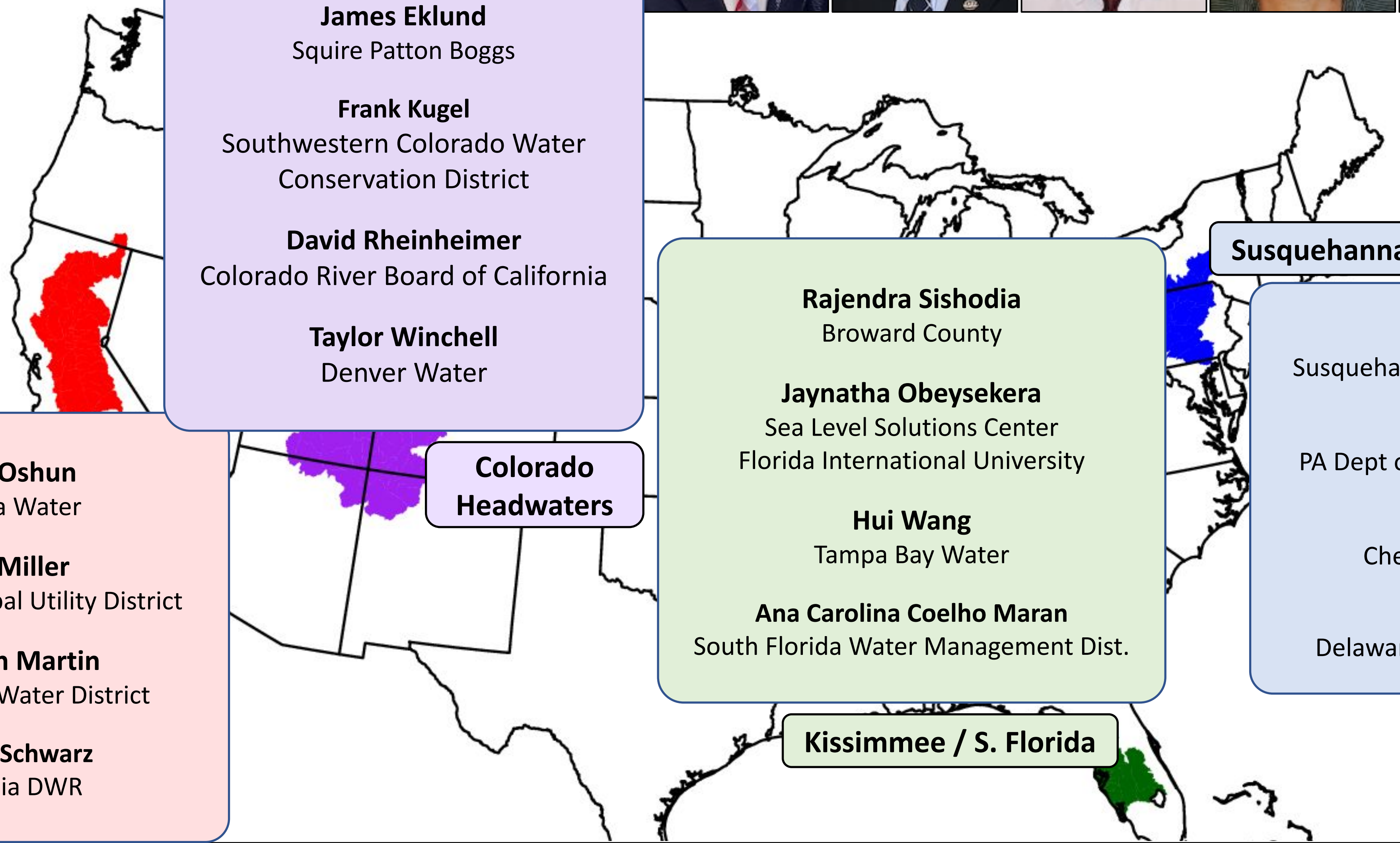

Yun Qian


Kripa Jagganathan


Sally Wang


Rebecca Barthelmie

Our Stakeholders



Colorado Headwaters

James Eklund
Squire Patton Boggs

Frank Kugel
Southwestern Colorado Water Conservation District

David Rheinheimer
Colorado River Board of California

Taylor Winchell
Denver Water

Sacramento-San Joaquin

Molly Oshun
Sonoma Water

Katie Miller
East Bay Municipal Utility District

Maureen Martin
Contra Costa Water District

Andrew Schwarz
California DWR

Kissimmee / S. Florida

Rajendra Sishodia
Broward County

Jaynatha Obeysekera
Sea Level Solutions Center
Florida International University

Hui Wang
Tampa Bay Water

Ana Carolina Coelho Maran
South Florida Water Management Dist.

Susquehanna

John Balay
Susquehanna River Basin Commission

Hoss Liaghat
PA Dept of Environmental Protection

Gary Shenk
Chesapeake Bay Program

Amy Shallcross
Delaware River Basin Commission

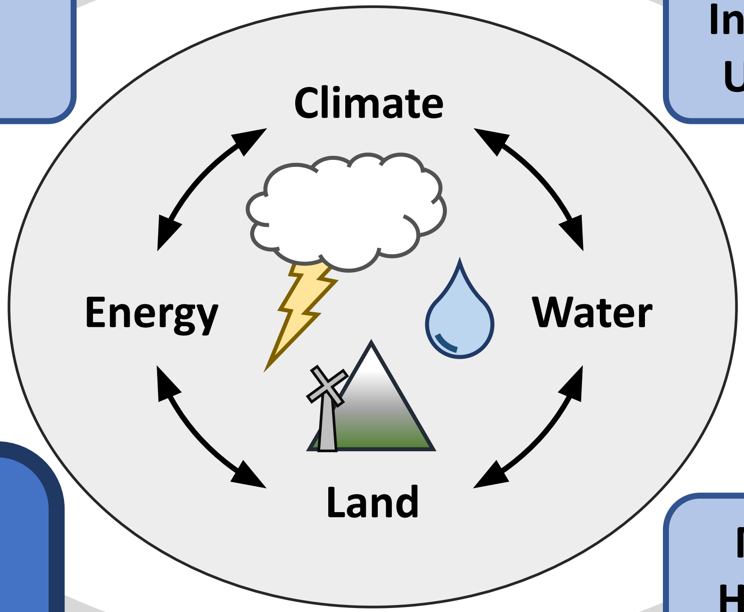
HyperFACETS v3 Themes

Concurrent extremes
Sequential extremes
Preconditioned systems

Compound Extremes

Infrastructural + Urban Impacts

Urban flooding
Energy/water systems
Environmental justice

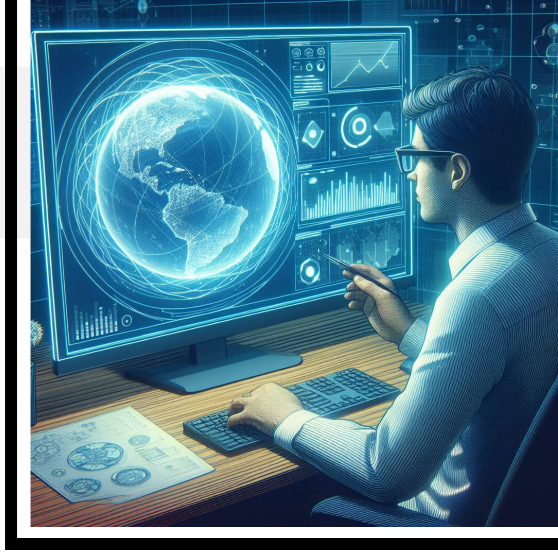


Mountainous Hydroclimate + Wildfires

Water availability
Wildfires
Human-natural system interactions

Scientifically, we aim to deepen understanding of the climate-energy-water-land nexus across the contiguous U.S.

Storylines and Storyline Anthologies



Stakeholder decisions and policy are often guided by **events or periods of significant impact (aka storylines)**.

Storylines are also useful for assessing the performance of models **far from the mean**.

Key Questions

- Do models accurately represent storyline events?
- …and their key meteorological, climatological, hydrological, and decision-relevant drivers?
- …and their impacts?
- How will the character and frequency of storyline events change in the future?

Storyline Anthologies: Multiple storylines that are closely related to one another, either because of geography, process drivers, or phenomenological outcomes.

Storyline Anthologies in HyperFACETSv3

Wildfire in the Western US (1, 2, 3)

Drought and Megadrought in the Colorado River Basin (2, 3)

Integrated Hydroclimate in California (1, 2, 3)

Winter Windstorms (1, 2)

North American Derechos and Convective Winds (1, 2)

Urban Flooding in the Northeast Corridor (2)

Freezing Rain and Icing (1, 2)

Compounding Effects from Tropical Cyclones (1, 2)

Worst-Case Hurricane Tracks (1)

<u>Project Themes</u>

1 Compound Extremes

2 Infrastructural and Urban Impacts

3 Mountainous Hydroclimate and Wildfires

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Examples from Storyline Research

Wildfire in the Western US

Motivation

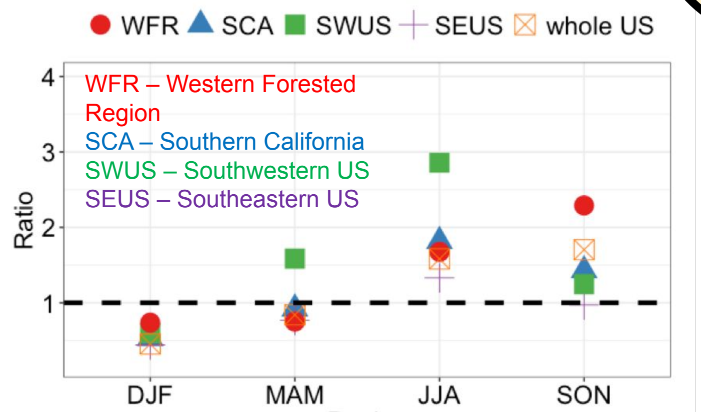
Understand the drivers of future changes in western US wildfire

Methodology

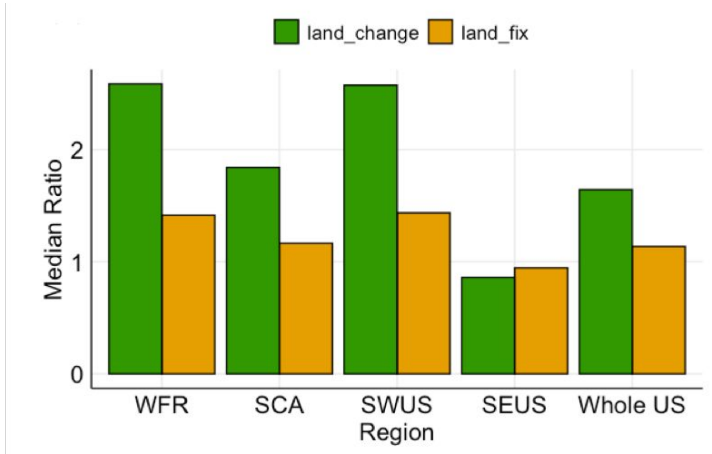
- **ML models** to predict **monthly wildfire emissions** ($PM_{2.5}$) over CONUS at 0.25° resolution
- Drive the ML prediction models using CMIP6 historical and future projections of meteorology and vegetation to project future changes in fire emissions across CONUS

Insights Gained

- Comparing fire $PM_{2.5}$ emissions in 2050-2065 to 2000-2014, fire emissions increase by 60-180% in the western US due to reduced soil moisture and warmer temperature
- Accounting for land use and land cover change further increases fire emissions by ~50% due to increased vegetation cover with warming



Ratio of future to present day fire emissions in different regions and seasons showing larger changes in summer and autumn



Ratio of future to present day fire emissions in different regions with (green) and without (brown) land use and land cover change

Colorado Megadrought

Motivation

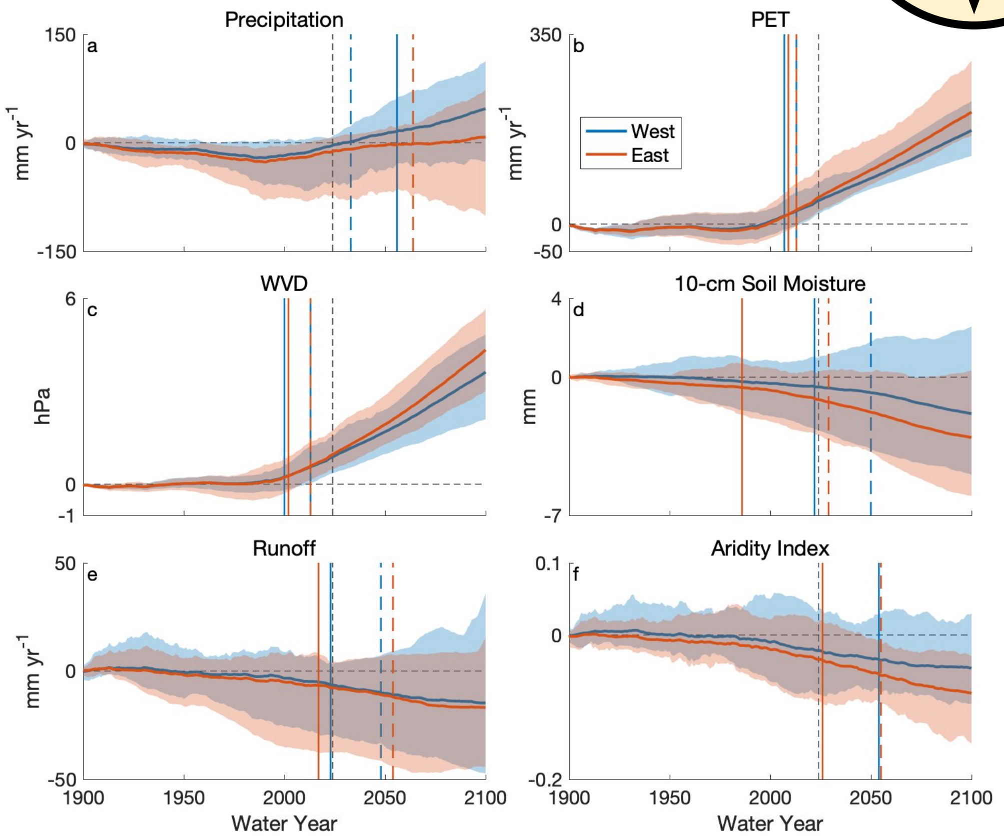
In the recent Colorado megadrought, stakeholders are asking "To what extent will the region recover from this drought, and how much permanent aridification should we expect as a result of climate change?"

Methodology

- Use ten CMIP6-era single-model initial-condition large ensembles over the six headwaters basins in Colorado.
- Explore the time-to-emergence of fundamental shifts in water cycle, including aridity.

Insights Gained

- Fundamental shifts in precipitation, water vapor deficit, runoff, potential evapotranspiration, soil moisture and aridity are found.
- In many cases **fundamental shifts have already occurred**, or will occur by mid-century.



Climatological changes in hydrometeorological variables for the East and West side of the continental divide in Colorado. Horizontal lines indicate the time to emergence of fundamental climate changes

California-Nevada 1997 New Year’s Flood

Motivation

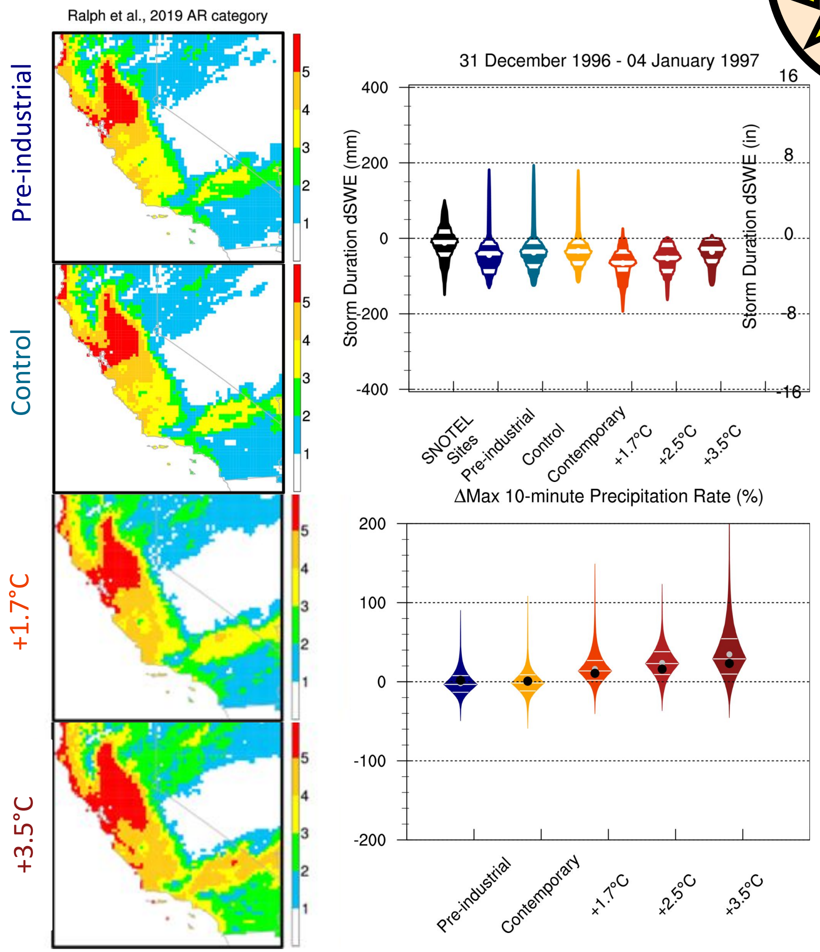
The **1997 California-Nevada New Year's flood** caused over a $1B in damages and is a 1-in-100 year design storm. Extreme precipitation, snowmelt, and saturated soils produced heavy runoff and caused widespread inundation in the Sacramento Valley.

Methodology

- Use regionally refined E3SM to recreate the 1997 flood drivers at different resolutions and forecast lead times.
- Then reforecast the flood event in past and future climates using Betacast.

Insights Gained

- A maxima in the potential for hazardous RoS events was projected at +1.7-2.5°C and includes more intense short-duration rainfall.



The 1997 flood drivers differentially respond to warming. The atmospheric river becomes more hazardous, snowpack systematically decreases, and short duration, high intensity rainfall increases (exceeding theoretical scaling expectations).

Urban Flooding in the Northeast Corridor

Motivation

Understand the risk of **Hurricane Ida's** record-breaking intensity in New York City historically and project its risk in the near- to medium-term future.

Methodology

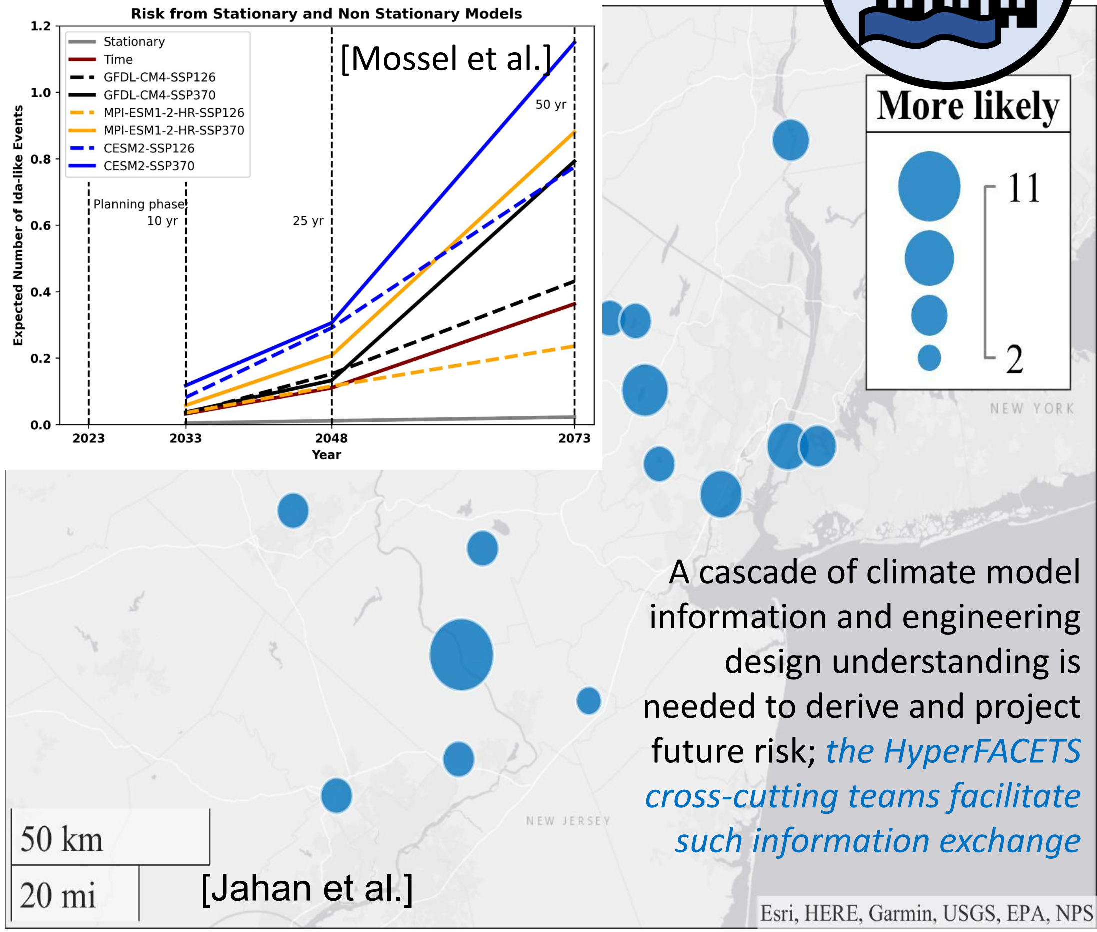
- Develop a climate change-informed nonstationary method based on the Generalized Extreme Value statistics to project the risk of exceedance or manifestation of another event of Ida's magnitude.

Insights Gained

- Hourly Intensity: The anticipated 50-year risk is as high as 115% under the CESM2 high-emission climate model scenario.
- Daily Intensity: Ida-like extreme rainfall is 2~11 times more likely to happen by 2100 in the high-sensitivity model (SSP585).

On-going

- Utilizing these projections with storm water models to generate details urban flood maps



A cascade of climate model information and engineering design understanding is needed to derive and project future risk; *the HyperFACETS cross-cutting teams facilitate such information exchange*

Changes in the extreme daily rainfall probabilities from high sensitivity SSP585 scenario. Inset: Expected number of Ida-like hourly rainfall events in the near- to long-term future.

Freezing Rain and Icing

Motivation

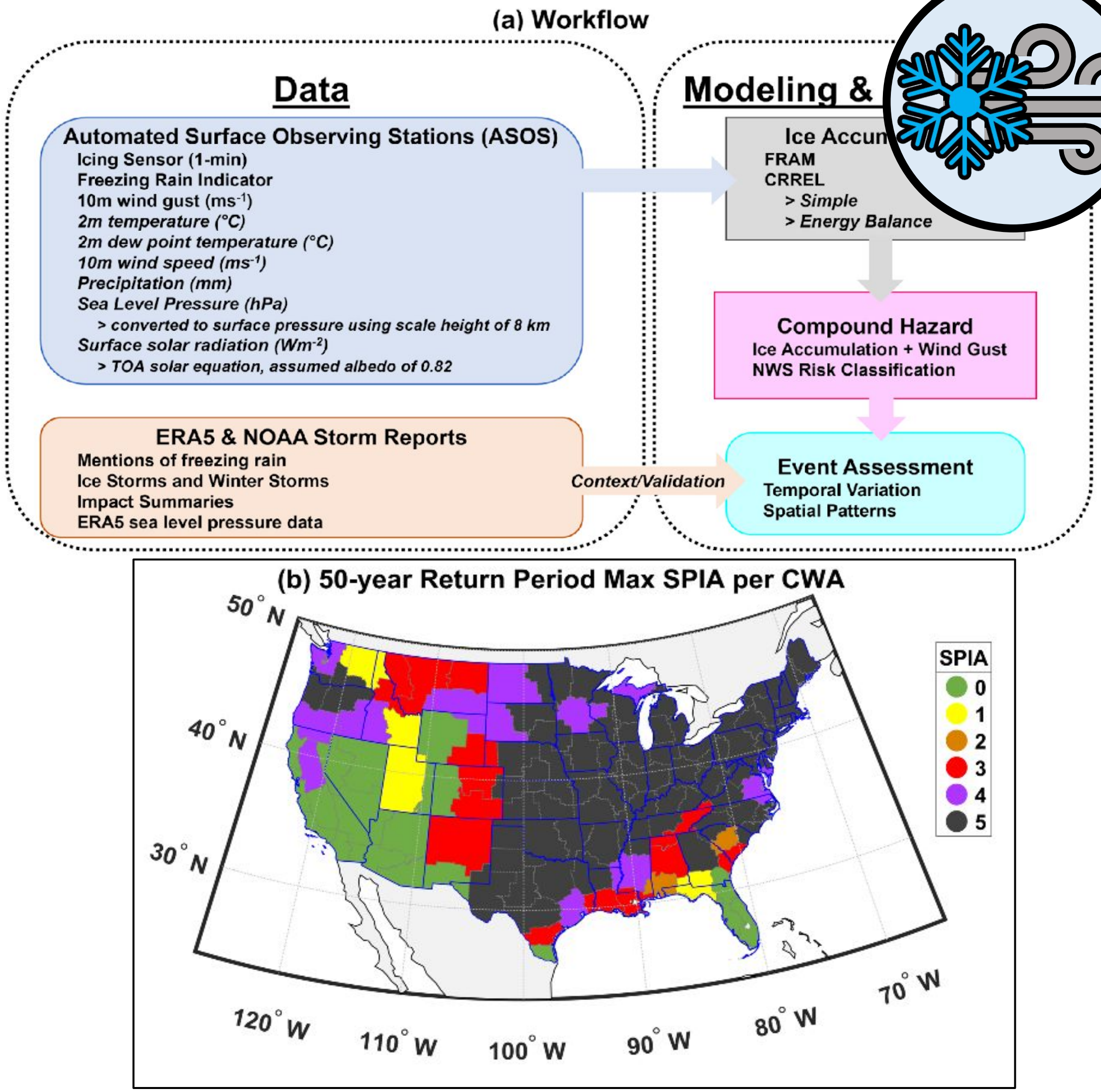
Co-occurrence of freezing rain, ice accumulation + wind gusts (FZG) lead to significant hazard but quantification challenged by lack of ice accumulation measurements.

Methodology

- Ice accumulation modeled at 883 ASOS stations.
- Produced geospatial atlas of Sperry–Piltz Ice Accumulation Index (SPIA) & 50 yr return period event intensities.

Insights Gained

- 1-3 FZG events yr^{-1} occur in an arc from Texas over the Midwest into the Northeast
- 50 yr Return Period values with maximum ice thickness of 3–5 cm and wind gusts > 30 ms^{-1} over much of eastern USA
- Storylines of FZG identified. Found along frontal boundaries of transient midlatitude cyclones or amplification of Rossby waves and associated cold air outbreaks.



Workflow and 50-yr RP SPIA by County Warning Area.
From: Coburn, Barthelmie & Pryor 2024 Environ. Res. Lett. 19 044016

North American Derechos and Convective Winds

Motivation

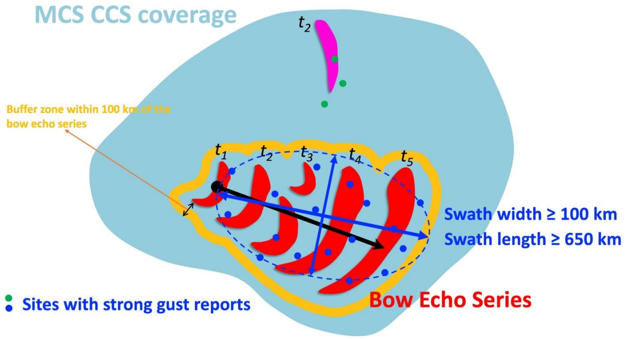
Understand the spatial extent, spatiotemporal variations and associated environments of U.S. derechos.

Methodology

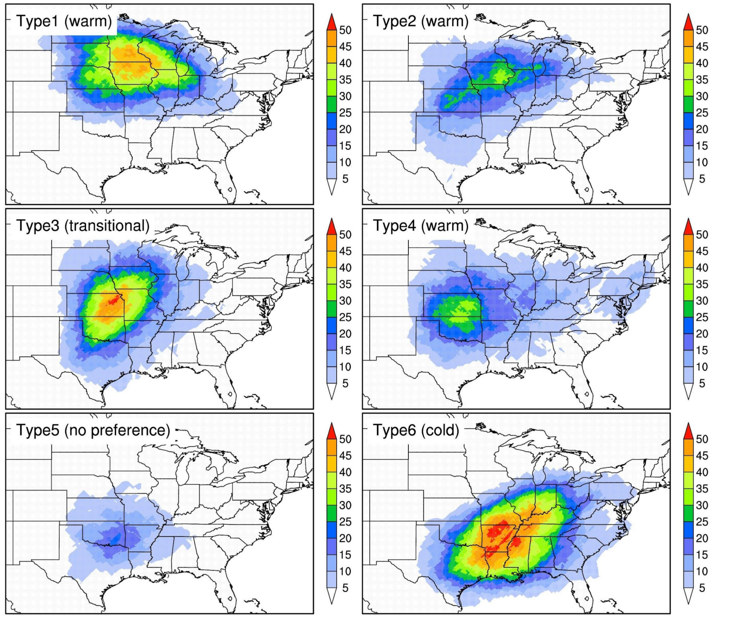
- Develop an automated algorithm to detect derechos based on machine learning (ML) identification of bow echoes over 2004-2021.
- Integrate the new derecho database with reanalysis data to examine environmental factors distinguishing derechos from mesoscale convective systems (MCSs).

Insights Gained

- Derechos have a peak occurrence in the Great Plains and Midwest during the warm seasons.
- About 20% of damaging gust (> 25.93 $m\ s^{-1}$) reported east of the Rocky Mountains were produced by derechos during 2004-2021.
- Compared to MCSs, derechos initiate in an environment with larger CAPE and warmer surface, larger 0-6 km wind shear, and stronger low-level convergence and moisture advection from the Gulf of Mexico.



An automated derecho detection algorithm based on ML identification of bow echoes (Li et al. in review)



Number of different types of derechos in 2004-2021

Worst-Case Hurricane Tracks

Motivation

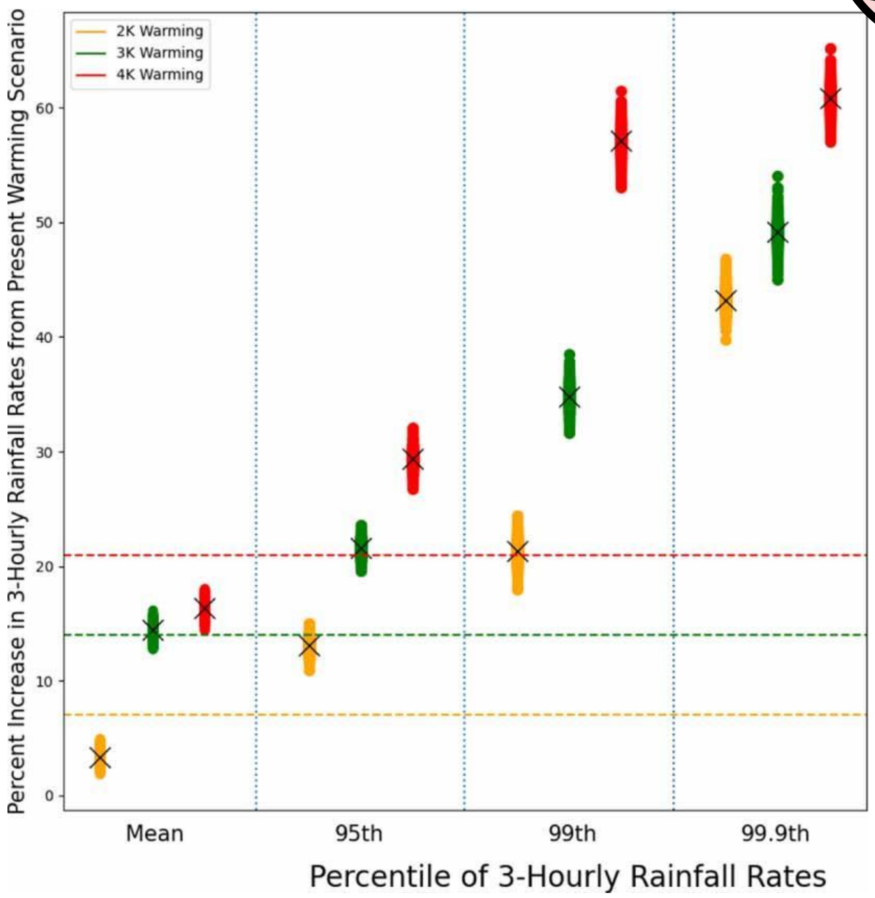
Understand the impact of future climate change on Hurricane-induced rainfall associated with individual hurricane tracks.

Methodology

- ESM simulations are initialized at specific times in advance of hurricane landfall (example Irma) and large ensembles are used to calculate large-scale thermodynamic conditions for future climates to add to initial and boundary conditions.

Insights Gained

- Mean 3-hourly rainfall rates in the simulated storms increase by 3–7%/K compared to present.
- This change increases in magnitude for the 95th and 99th percentile 3-hourly rates, which intensify by 10–13%/K and 17–21%/K, respectively.



Percent increases in Hurricane Irma's 3-hourly precipitation rates in the 2 K (yellow), 3 K (green), and 4 K (red) warming scenarios compared to the present warming scenario.

Summary

- Since 2016, the HyperFACETS project has been working to identify effective pathways for developing **actionable science** through engagement with the climate stakeholder community.
- **Storylines** provide an effective mechanism for framing conversations between scientists and stakeholders, and develop deeper insights into high-impact events.
- Over the coming decade, we expect **HyperFACETS** will continue its **leadership in co-production of science**, and providing that necessary bridge between scientists and stakeholders.

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Thanks!

http://hyperfacets.ucdavis.edu

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Northeast Windstorms

Storyline Overview

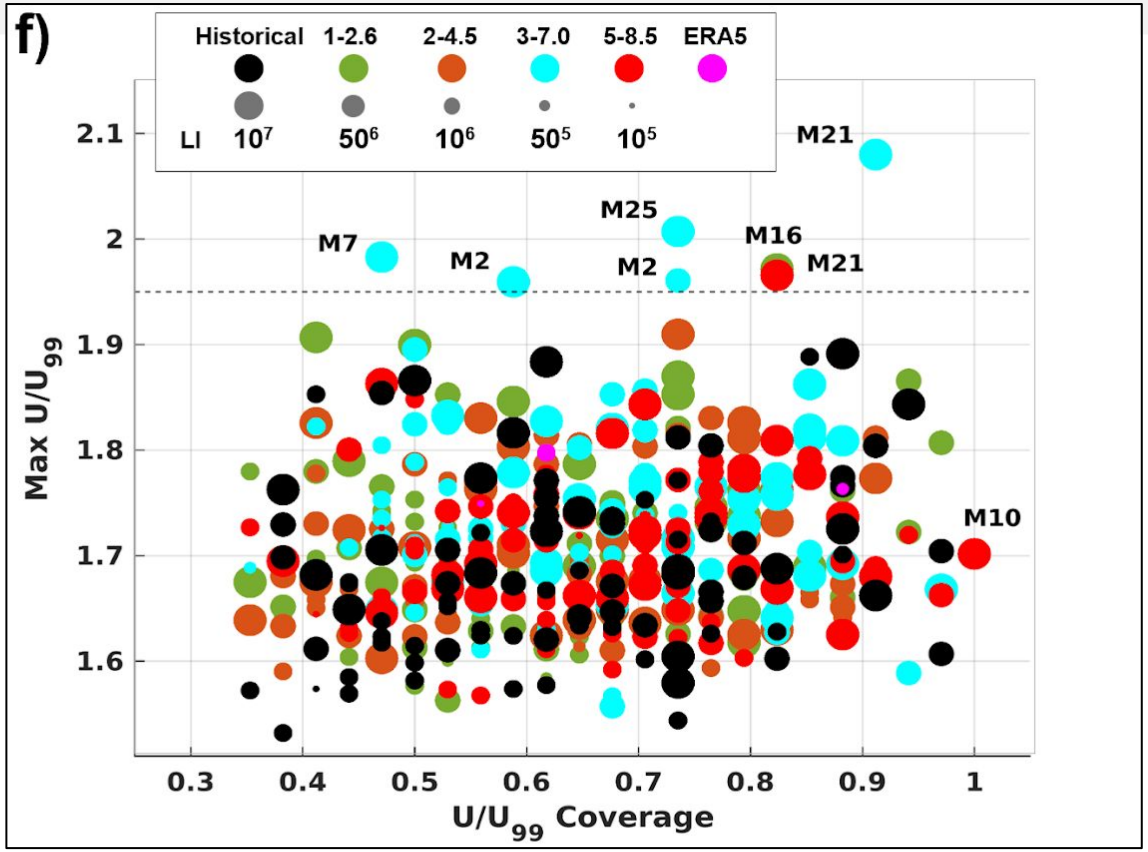
- 13 NE states: 6% of CONUS land area. > 20% of population & high-value assets
- Top-10 Windstorms (1979-2018): > 34 billion US$2020 damage.

Methodology

- Storyline simulations w/WRF @ convection permitting scales, coupled with TGW perturbation experiments ± coupled (ocean-wave-atmosphere) model simulations
- Analyses of transient, moderate resolution regional simulations performed within multiple ESMs
- Analyses of ESM large ensemble to investigate possible emergence of 'black swan' windstorms

Insights Gained

- SSP3-7.0 assumes unprecedented deforestation of NE ∴ substantial inc. of 99th percentile wind speeds & windstorm intensity
- Multiple SSP3-7.0 members evolve windstorms that are unprecedented in historical members



Top-3 NE windstorms from each of 150 members of MPI large ensemble: 30 in Historical, & 30 each in 4 SSP's. $MaxU/U_{99}$ = mean ratio of wind speed to local 99th percentile U (i.e. intensity). U/U_{99} coverage = fraction of NE with extreme winds (i.e. spatial scale)

Coburn J., Barthelmie R.J and Pryor S.C.: Changing Windstorm Conditions for the US Northeast in a Large Ensemble *In review*

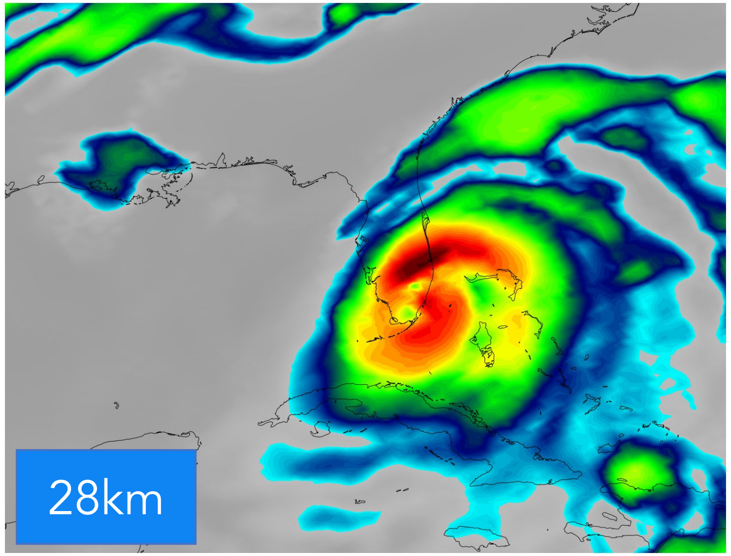
Compound Effects of Tropical Cyclones

Storyline Overview
Evaluating compound extremes that haven't occurred, but are plausible in current or future climates, that are of relevance to stakeholder planning and operations.

Methodology
We leveraged a medium ensemble of tropical cyclone-permitting simulations completed under Hyperion to subselect TCs in consultation with stakeholders that *would* have operational impacts.

Insights Gained
Out of more than 13,000 TCs in the current climate, we found ~10 that stakeholders deemed equal to or worse than their existing "benchmarks" from an hourly precipitation standpoint.

PennState



The same "synthetic" TC simulated in 28km CAM-SE and 3km CAM-MPAS flagged by a South Florida stakeholder as "impactful"