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

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Project Goals

1. Advance our **understanding of processes** at the **atmosphere-water-energy-land interface.**

2. Fundamentally improve our ability to **perform credible climate modeling** of **particular regions** and the **processes relevant to those regions.**

3. **Strengthen stakeholder input** in model development and evaluation. Engage effectively in **co-production:** Together enforcing the science and meeting real needs.

Project Overview

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

Use-Inspired Metrics

How well do models and available datasets perform for relevant quantities?

Stakeholder Engagement

Engagement ⟵ ⋯ ⟶ Science

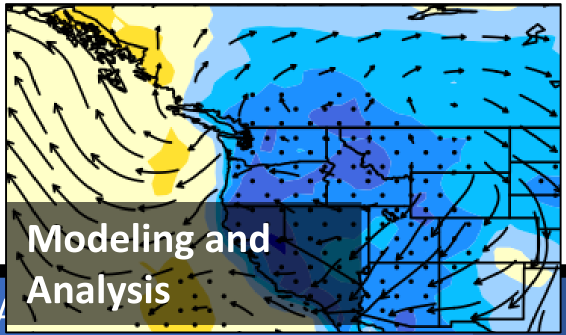
Process Understanding

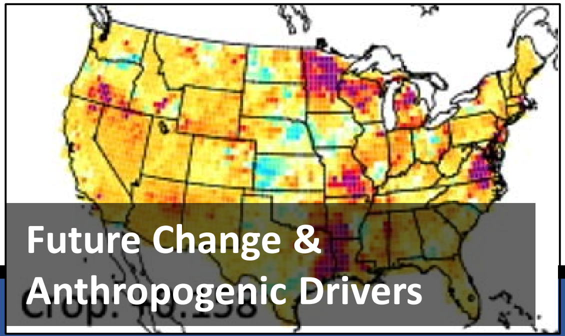
What processes are most relevant to model performance?

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

Expert Guidance

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

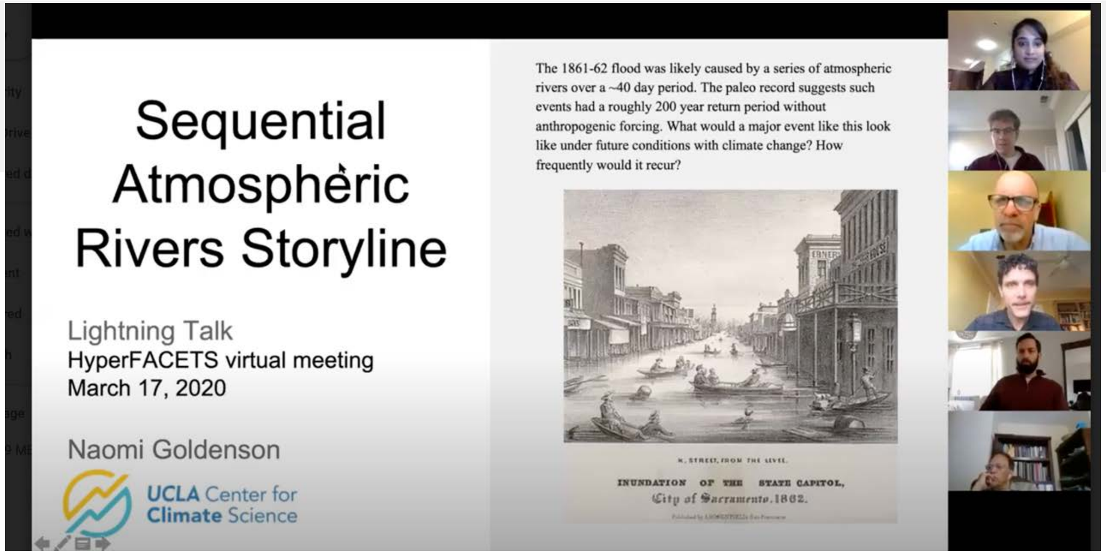




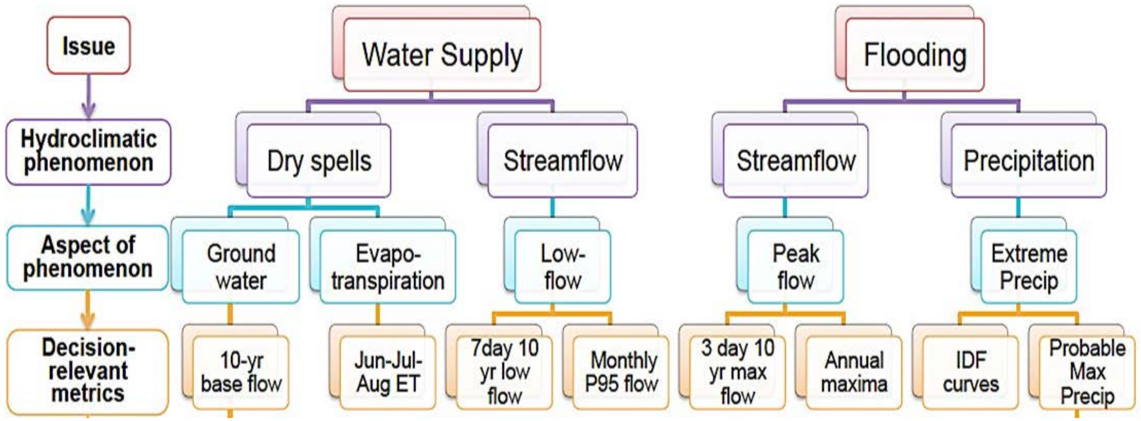
Stakeholder Engagement

- The HyperFACETS project continues to **pioneer methods of stakeholder engagement** to identify fundamental science challenges related to the practical needs of resource managers.

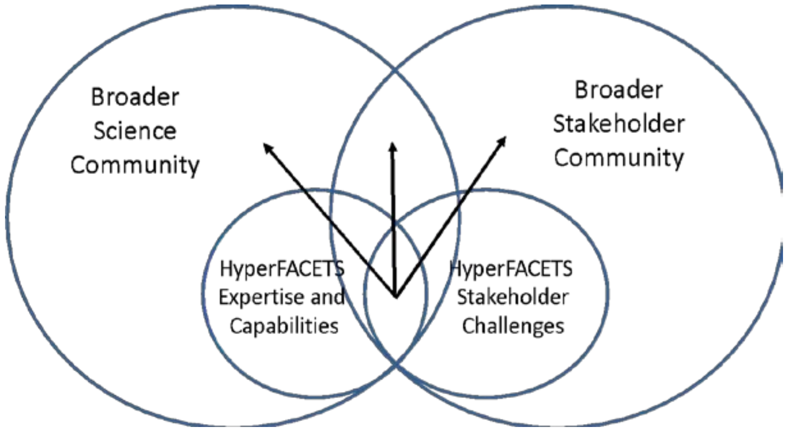
- Current engagement effort focuses on the refinement of science plans for each of the storylines.



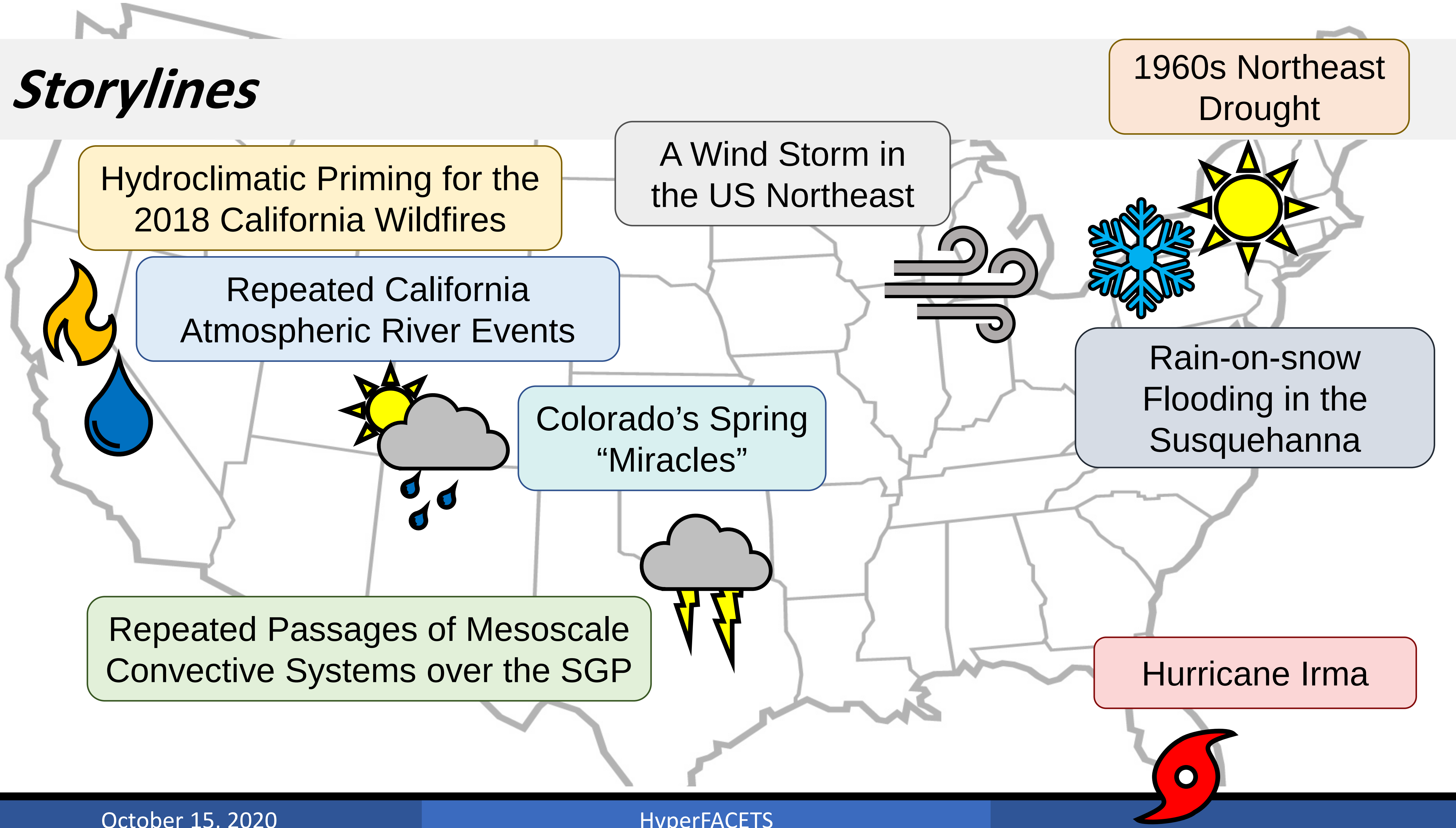
A March 2020 workshop with more than 50 attendees identified fundamental science questions related to practical resource management challenges in each of 6 storylines.



Successfully co-produced decision relevant metrics across 4 case study basins (Jagannathan et al., 2020, BAMS)



Storylines



1960s Northeast Drought

A Wind Storm in the US Northeast

Hydroclimatic Priming for the 2018 California Wildfires

Repeated California Atmospheric River Events

Colorado’s Spring “Miracles”

Rain-on-snow Flooding in the Susquehanna

Repeated Passages of Mesoscale Convective Systems over the SGP

Hurricane Irma

Storylines: Key Questions

1. What were the **upstream drivers** responsible for this event / period, including **regional conditions**, **large-scale meteorological patterns (LSMPs)** and **low-frequency modes of variability**?

2. In terms of **process-based and use-inspired metrics**, how well do Earth system models and available datasets simulate or represent these storylines?

3. How might the **character or frequency** of these events change into the future? What are the **process drivers** responsible for this change?

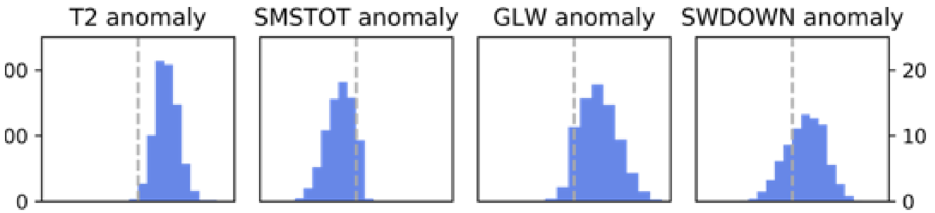
Hydroclimatic Priming of California Wildfires

Goal: Develop a storyline for the 2018 California wildfires to understand the driving factors and how they may unfold in the future.

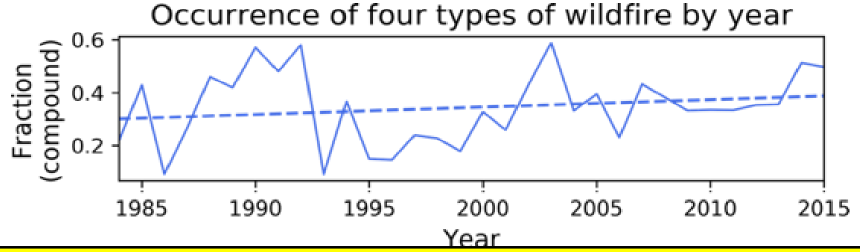
Process-based Understanding: What are the roles of large-scale meteorological and regional hydroclimatic conditions in CA wildfires?

Hydroclimate conditions

ML identified the most dangerous antecedent hydroclimatic conditions for CA wildfires (high temperature, dry soil, strong radiation)

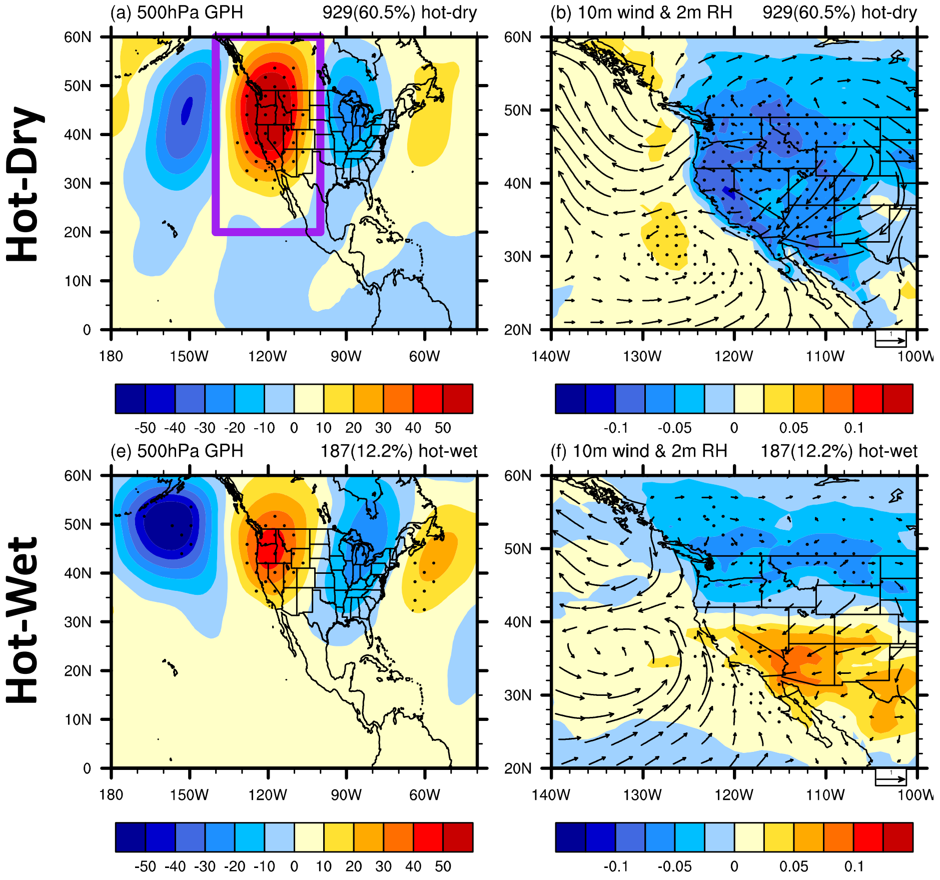


This type of conditions also shows the largest increasing trend in the past 30 years



Large-scale meteorological conditions

About 60% of CA wildfires occur under hot-dry conditions, but hot-wet conditions (12%) also support wildfires through lightning



Lu Dong “Meteorological environments associated with California wildfires and their potential roles in wildfire changes during 1984-2017”

Atmospheric Rivers Storyline

Goal: Understand the conditions that could give rise to extreme precipitation and widespread flooding in California.

Methodology and Results so far:

- Using Self-Organizing Maps (SOMs), LSMPs were found using 500-hPa streamfunction and vertically integrated water vapor on heavy precipitation days from rain-gauge data in Southern California.
- Analysis of individual LSMPs reveals linkages to high-impact storms over Southern California, including not only atmospheric rivers, but also arctic outbreaks and other mid-latitude synoptic variations.

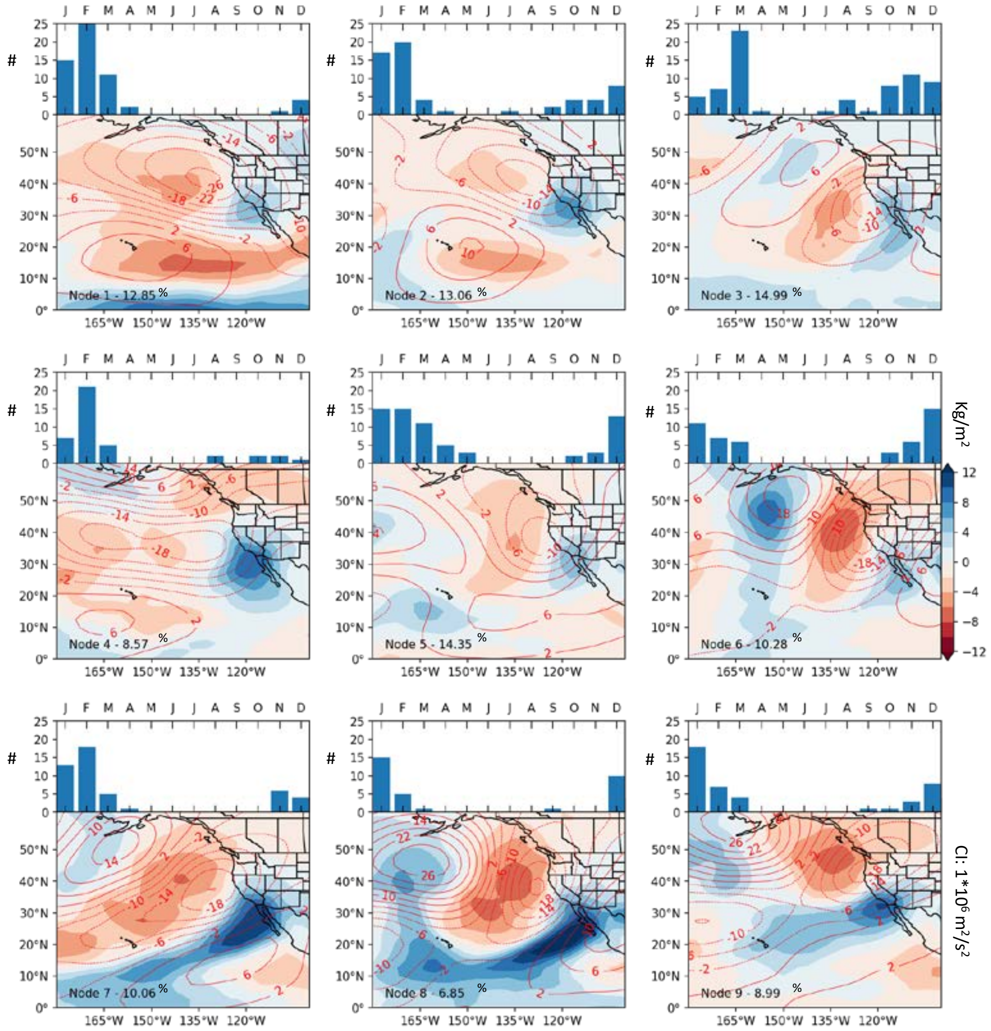


Figure: Types of heavy precipitation events, as revealed by the SOM analysis, based on heavy precipitation days in Southern California. Bars show the seasonal frequency distribution of each type of event.

Naomi Goldenson "Visualizing Drivers Associated with West Coast Atmospheric Rivers using a Deep Learning Framework"

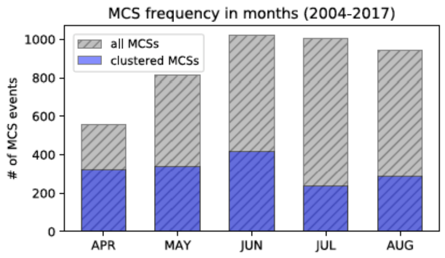
Sequential/Clustered MCS Storyline

Goal: Develop a storyline for the 2015 Texas-Oklahoma flood associated with passages of multiple MCSs to understand the meteorological and climatic context and how the event may unfold in the future.

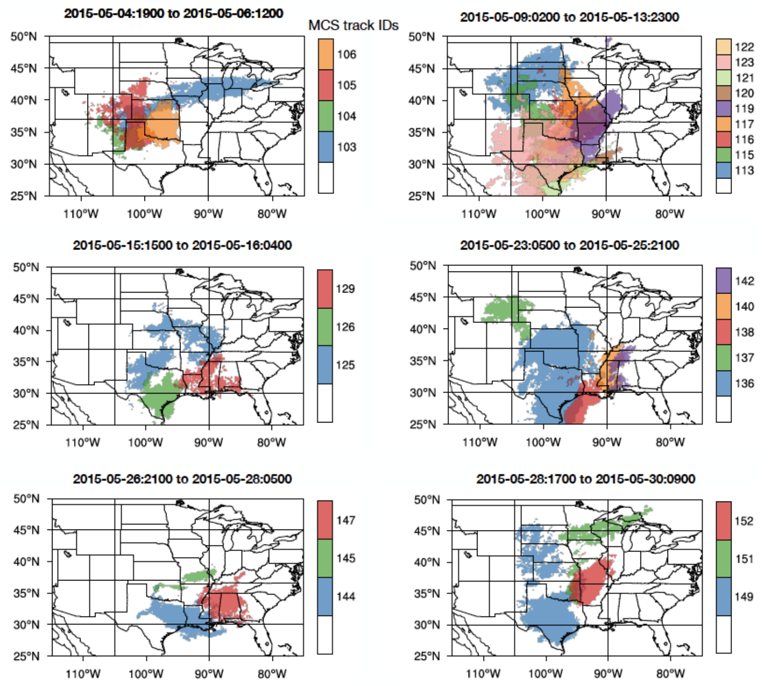
Process-based Understanding: What are the climatological characteristics of sequential/clustered MCSs and their association with hydrologic floods in the US?

Climatological characteristics of clustered MCSs

More clustered MCSs occur in April-June and in the southern states; they have larger rain area and greater rainfall volume per unit area



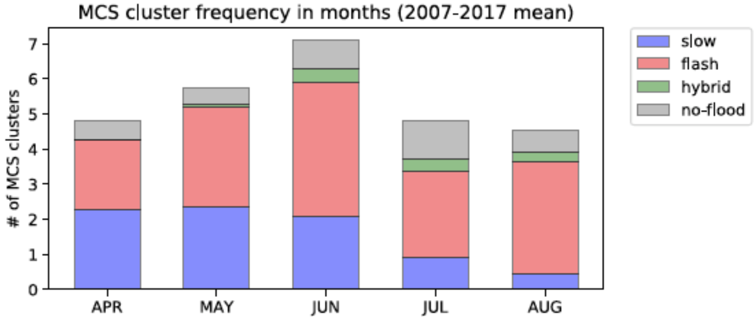
Clusters of MCSs during six periods in May 2015



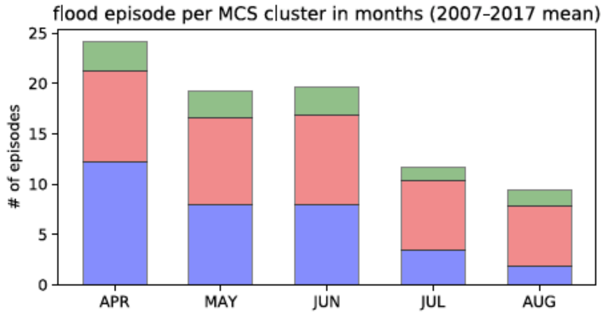
MCS clusters and floods

Analysis of an MCS database and the NOAA storm event database (2007-2017)

86% of clustered MCS area is associated with flooding

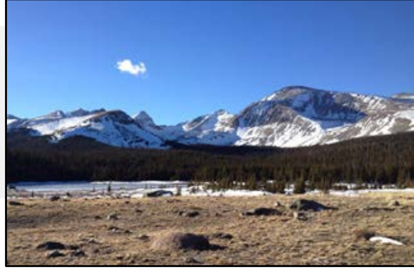


A flood producing MCS cluster results in ~20 flood episodes



Zhe Feng "Evaluation of Mesoscale Convective Systems in Climate Simulations: Methodological Development and Results from MPAS-CAM over the U.S."

“Miracle” Spring Storyline



Goal: Provide a precise quantitative definition of a “Miracle Spring” event. Explain the upstream climate drivers that may be responsible for a “miracle” event that offsets a bad drought.

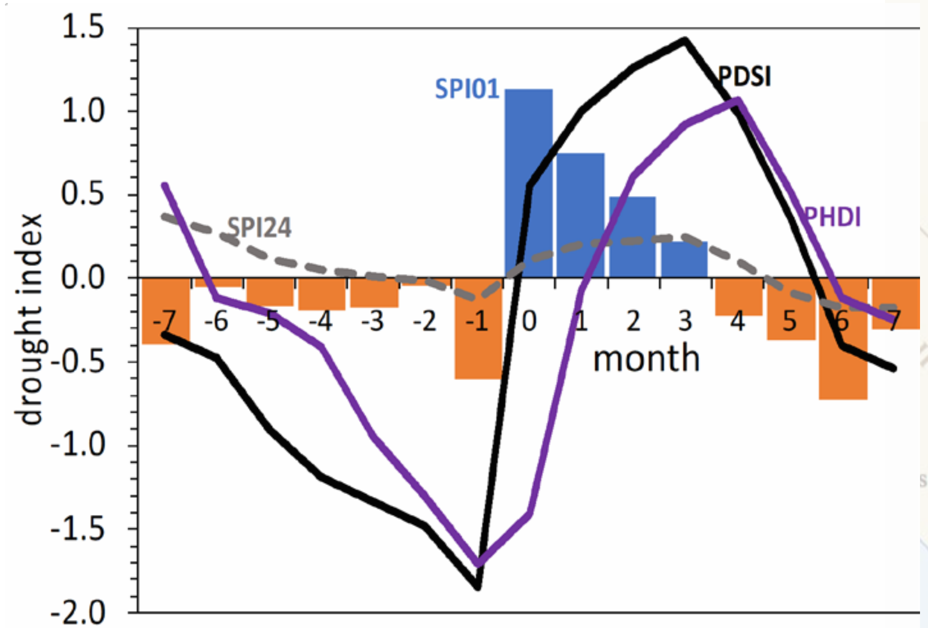


Figure 1: Composite drought indices of different kinds during “miracle” years in Colorado Upper basin, centered at 0 month and compiled from 1895-2019.

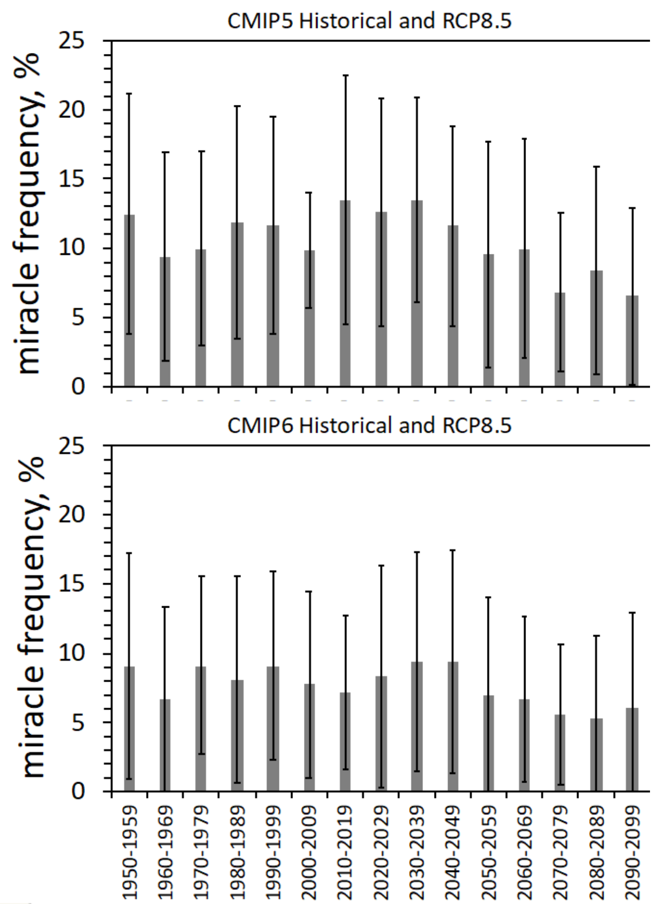


Figure 2: “Miracle” frequency based on monthly precipitation of CMIP5 (upper) and CMIP6 (lower).

Binod Pokharel “Examination of Miracle Spring Precipitation under the warmer climate in Colorado River Basin”

Rain-on-Snow and Rain-instead-of-Snow

Goal: Understand if climate data captures ephemeral RoS/RiS events.

Metric development

- Rain-on-snow periods -> spatiotemporally collocated precipitation, runoff, and SWE changes. Historical verification accurately detects stream gauge spikes.

E3SM storyline simulations

- Betacast ported to E3SM; rapid historical simulations on Cori-KNL
- Evaluate plausible storylines (less snowpack, land use changes)

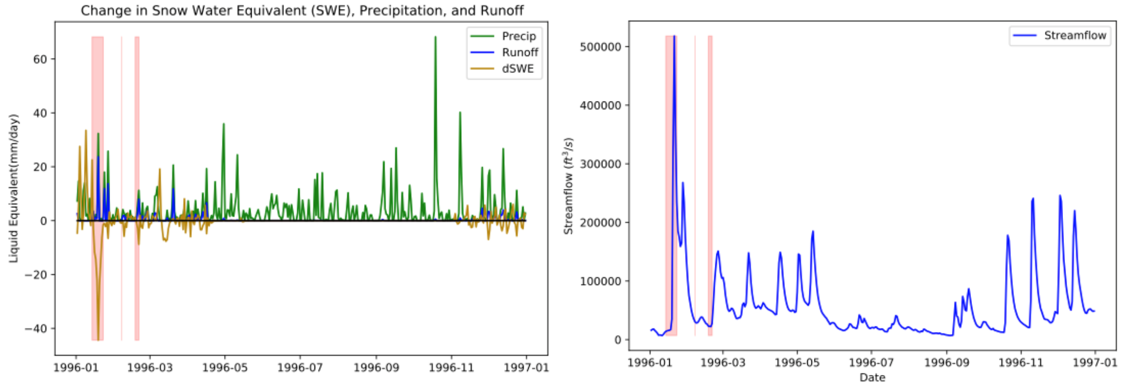


Figure: 1996 Susquehanna Basin precipitation, snow depth change, and surface runoff in JRA-55 (left), observed streamflow (right). RoS events shaded in pink.

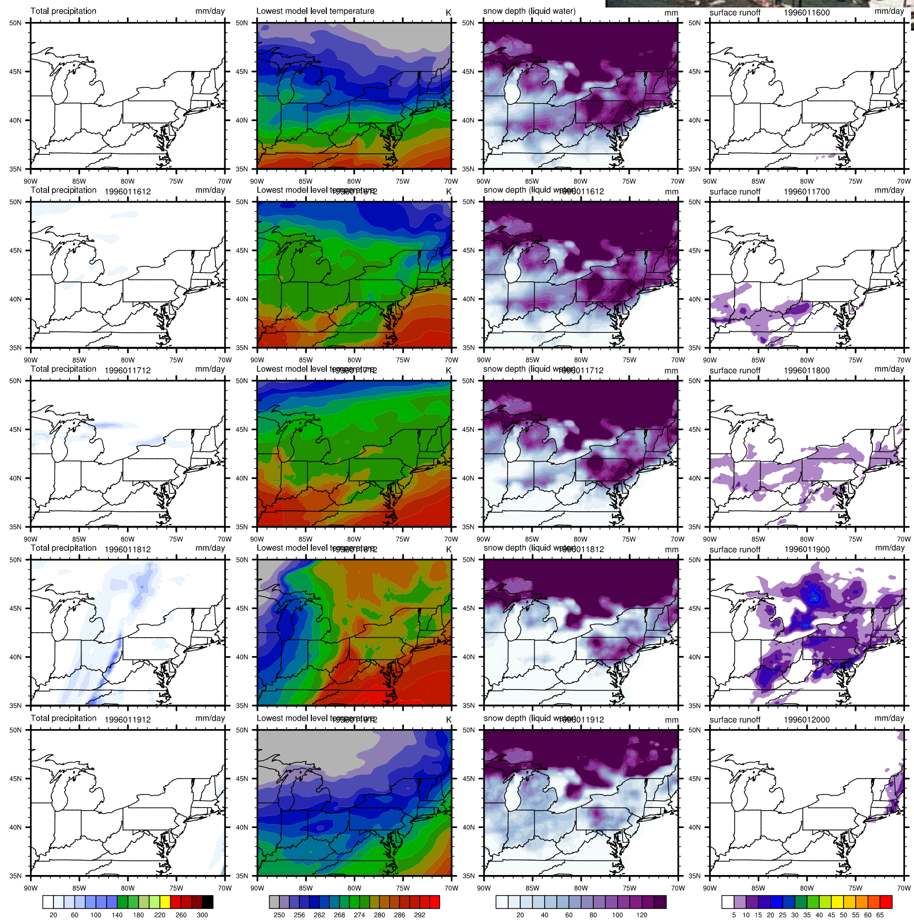


Figure: E3SM hindcast of 1996 Susquehanna flood event. From (L->R), precipitation rate, surface temperature, SWE, surface runoff.

Colin Zarzycki "Hydrological extremes and large-scale meteorological patterns associated with coastal cyclones over the eastern United States"

Rachel McCrary "Multi-year Predictions of Snow Water Equivalent over North America in Global and Regional Climate Models."

Coastal Storms Storyline

Goal: Investigate how coastal storms are affected by their environments.

- Metrics have been built within **TempestExtremes** to extract hurricane size and rainfall.
- These metrics are being used to explore changes in rainfall for **Hurricane Irma (2017)** under different climate scenarios with E3SM.

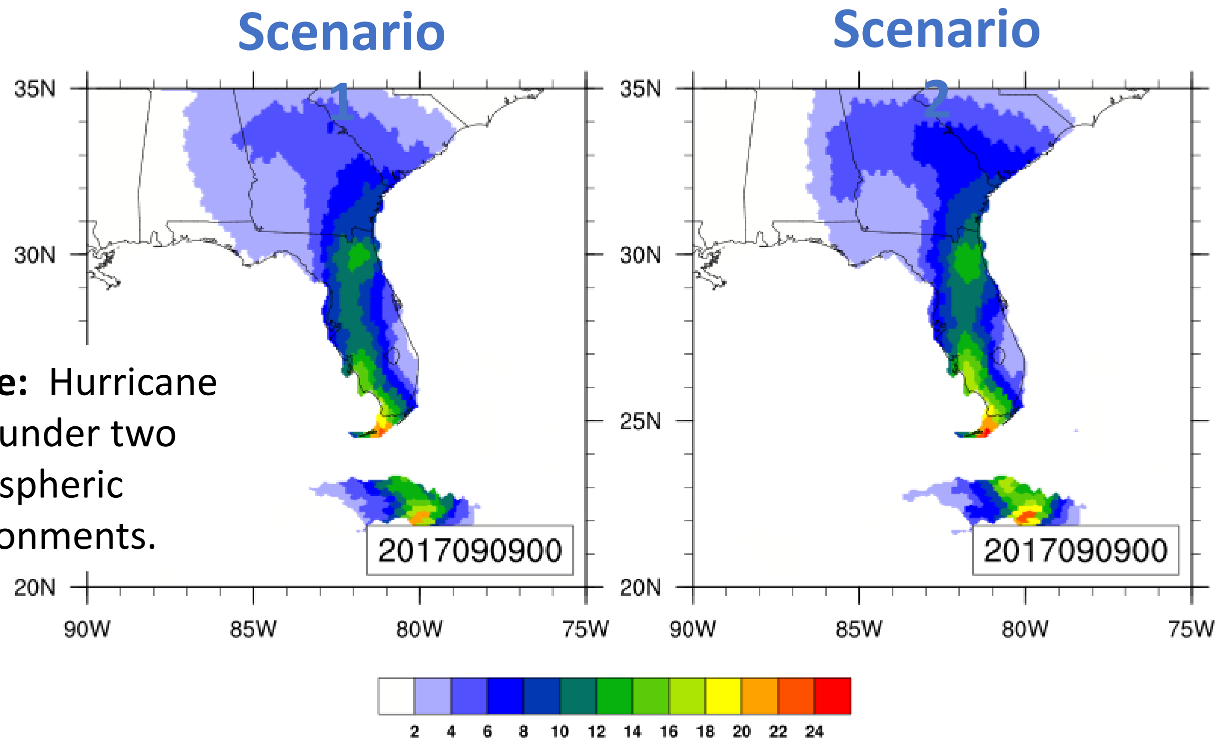
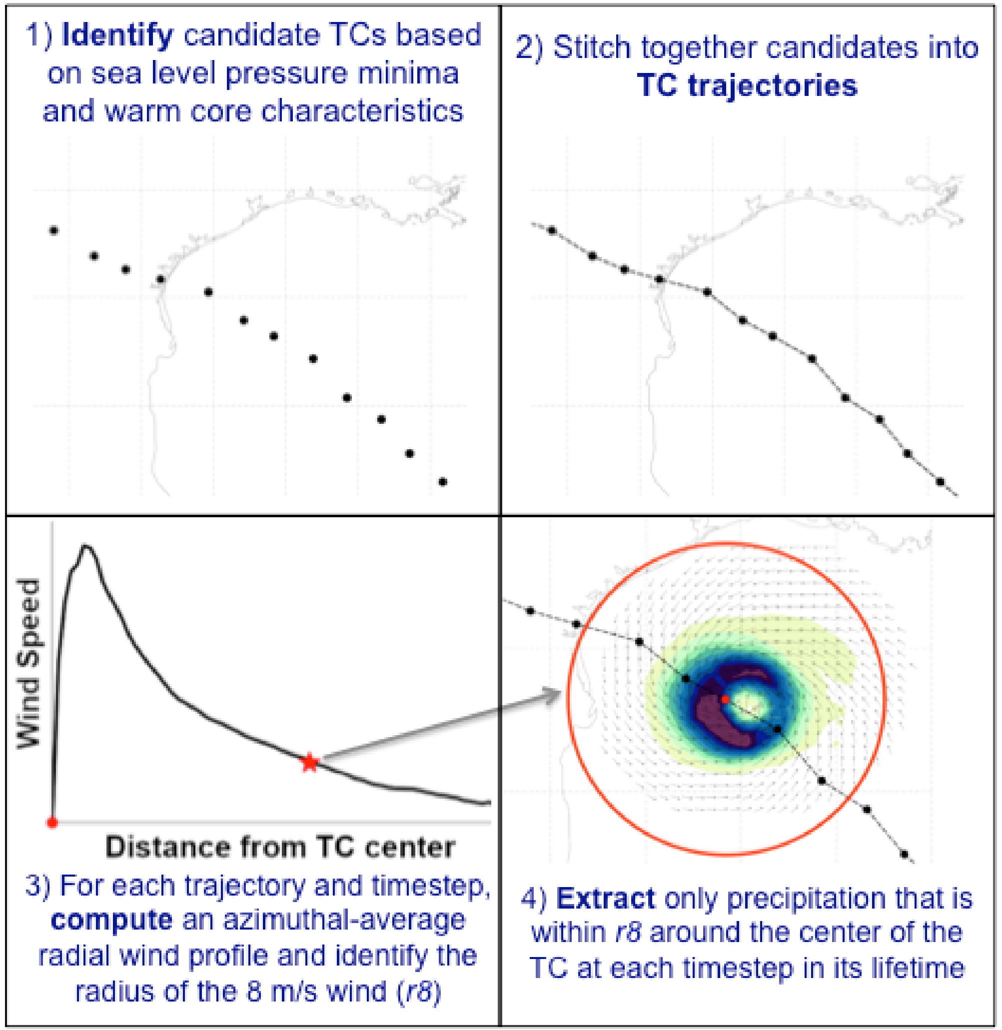


Figure: Hurricane Irma under two atmospheric environments.

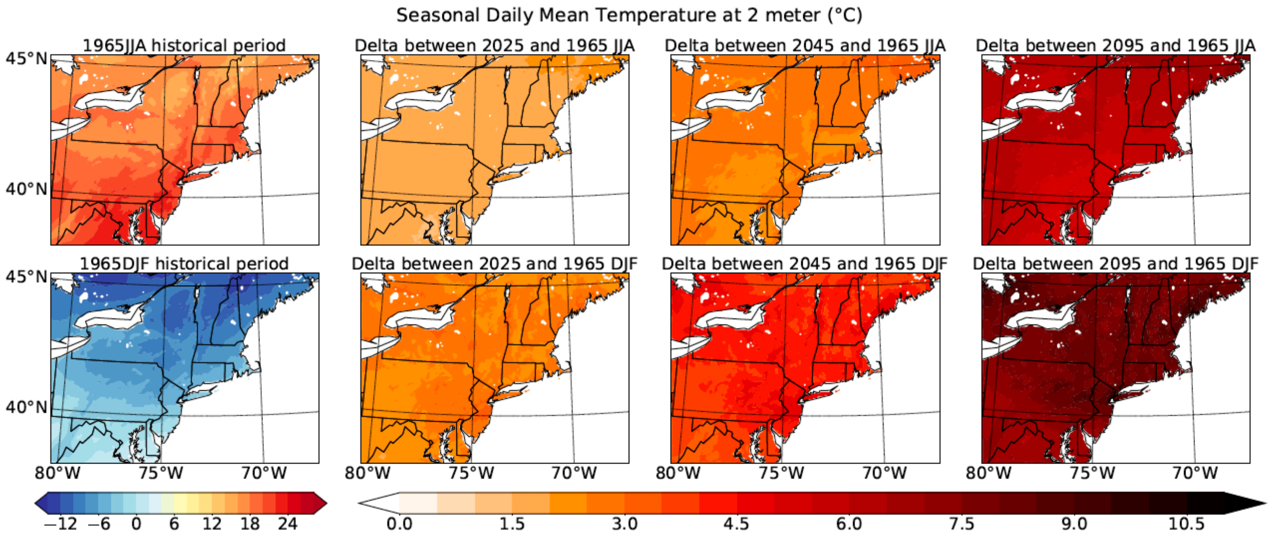


Kevin Reed "Quantifying changes in extreme precipitation associated with future tropical cyclones"

The 1960s Northeast US Drought Storyline

Goal: Characterize and project the 1960s NE US drought.

- **Pseudo-global warming simulations** over the US Northeast using CERA-20C data as driver (matches well with observations).
- By 2040s similar conditions are above the 50th percentile of historical percentile and above the 99th percentile for temperature.
- More **extreme heat**, **more variability**, **more extreme precipitation**, general loss of snowpack and frozen soil.



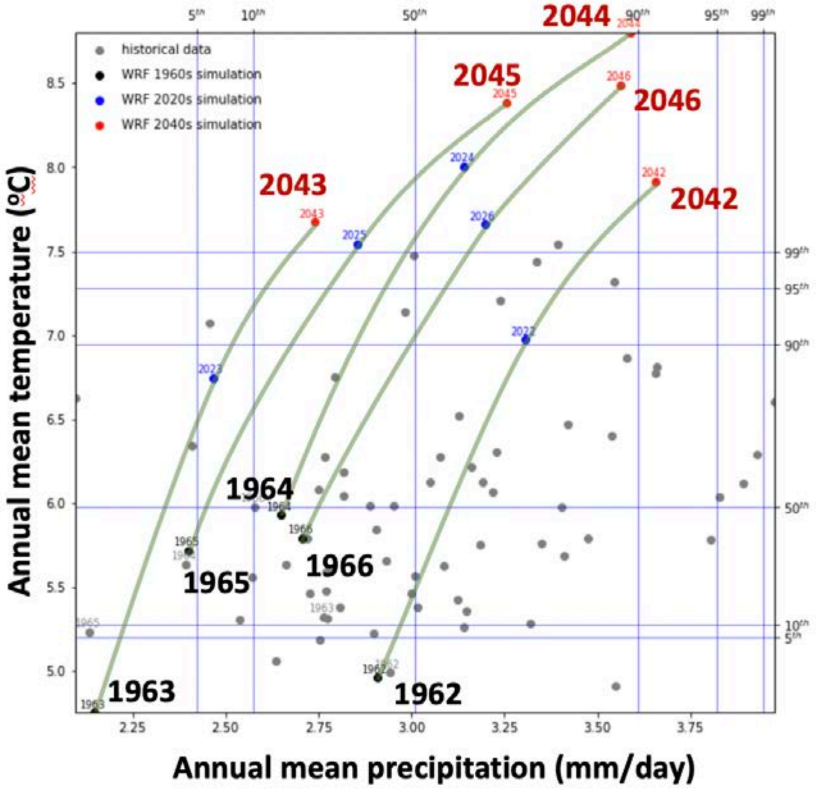


Figure: Simulated temperatures/precipitation from pseudo-global warming simulations versus historical observations from CPC (temperatures) and UDel (precipitation).

Wind Storms

Goal: Characterize severe windstorms across the US and their drivers.

Key Questions:

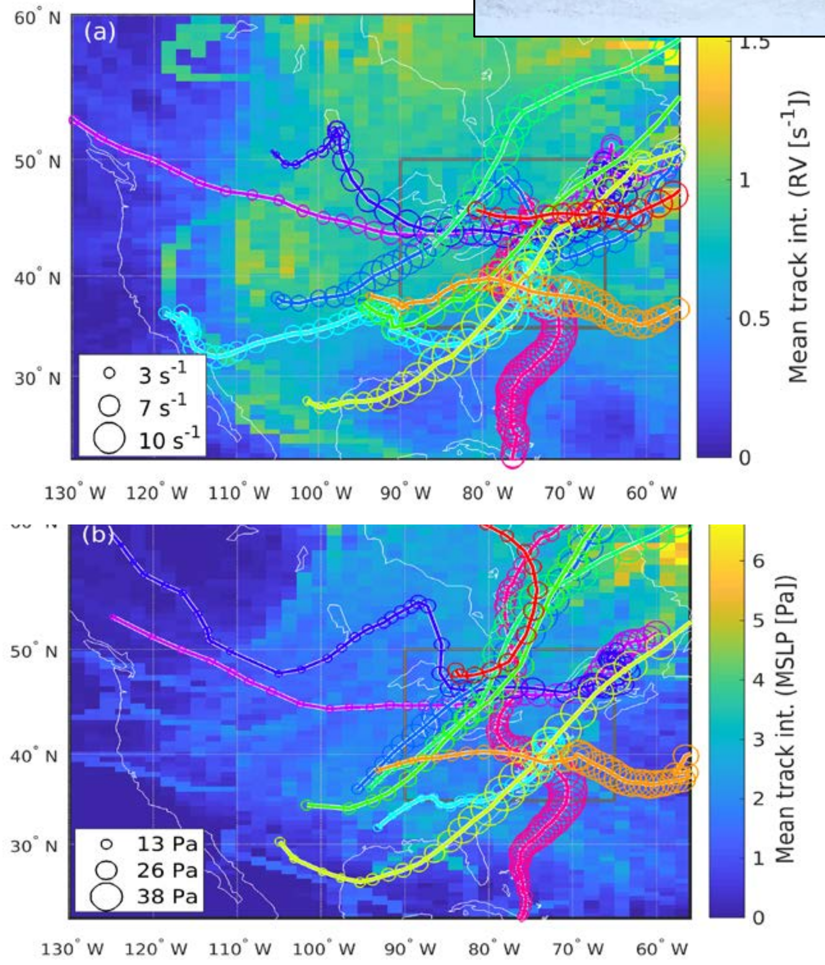
- What are optimal ways to **characterize severe windstorms**?
- How do the associated cyclones differ from climatology?
- What is model (e.g. WRF) fidelity? Does it vary with resolution?
- How might these windstorms change in the future?

Methodology

- Characterize top-10 events using ERA5 & new detection algorithm. Contextualize in cyclone climatology (1979-2018)
- WRF simulations in ERA5 & using pseudo-global warming simulations

Results

- ERA5 windstorm character validated with observations. Local wind speed > 99.9th percentile over 40-60% of land area of NE during wind storms. Windstorm cyclones as climatology but 10x more intense.
- WRF fidelity at 3 km > 5 km. PGW simulations started.



Cyclone intensities top 10 Northeastern windstorms (the symbol diameter scales with intensity) plotted over a heat map of mean cyclone intensities.

Sara Pryor “Windstorms in the Northeastern United States”

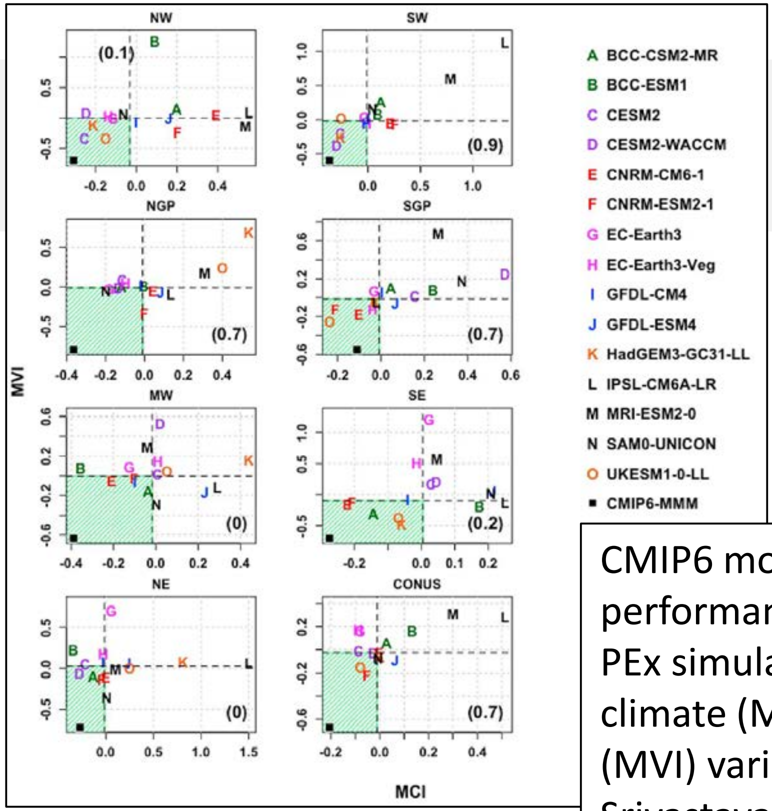
Metrics and Process Drivers

Goal: Understand and **improve model performance** for simulating **extreme precipitation**.

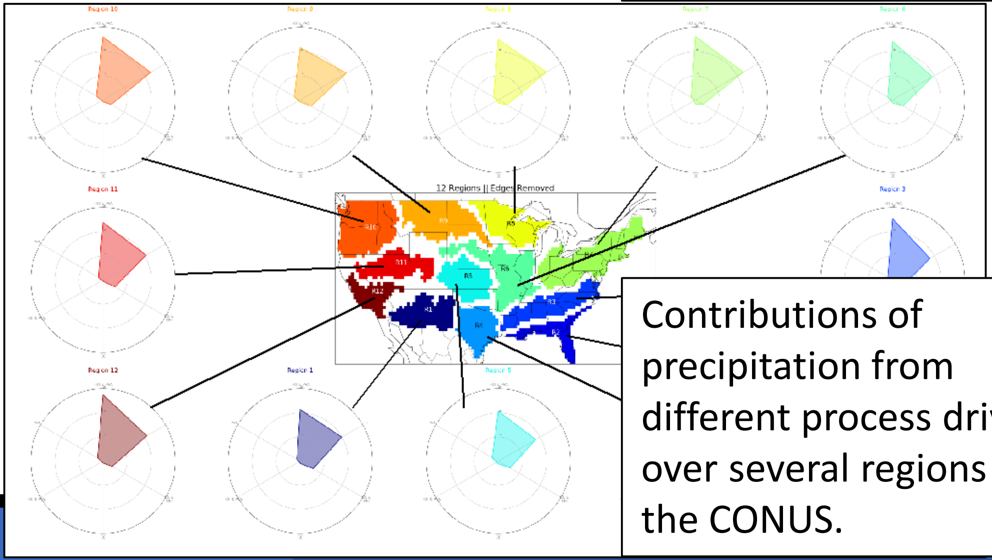
- Assess CMIP6 & CORDEX model simulations of ETCCDI metrics across CONUS and in 7 NCA regions.
- Multimodel technique for reducing uncertainty in climate model estimates of extreme precipitation changes including IDF curves.
- Regional Frequency Analysis techniques for improved IDF curves at stations within homogeneous regions.

Goal: Parse **contributions by various processes** to precipitation extremes over the CONUS.

- Created new metrics to optimize self organizing maps (SOMs) with application to annual precipitation cycle across CONUS.
- “Omega” equation as unified platform to separate and relatively weight 5 processes during PEx events.



CMIP6 models overall performance in ETCCDI PEx simulations of climate (MCI) and time (MVI) variability. Srivastava et al. (2020)



Contributions of precipitation from different process drivers over several regions of the CONUS.

Abhishekh Srivastava “Identification, predictability and future projections of large-scale meteorological patterns associated with extreme precipitation events over the CONUS”

Differential Credibility Analysis (DCA)

Goal: to differentiate across the downscaling methods using process-level analysis. Which changes in climate are most credible?

- Comparison and differentiation across different statistical (SDSM) and dynamical downscaling methods (WRF, RegCM4, MPAS)
- **Variables:** Precipitation, max & min temperature.
- **Location:** Southern Great Plains, for summer.
- Top predictor variables for precipitation for SDSM statistical method: Q700; RH850; U850; V850; Vorticity at 700hpa.
- Evaluate biases in precipitation and temperature in downscaling methods and driving GCM (MPI-LR). Evaluate changes in relevant large-scale variables (those used as predictors in the statistical method), to determine which changes are most credible from dynamical arguments.

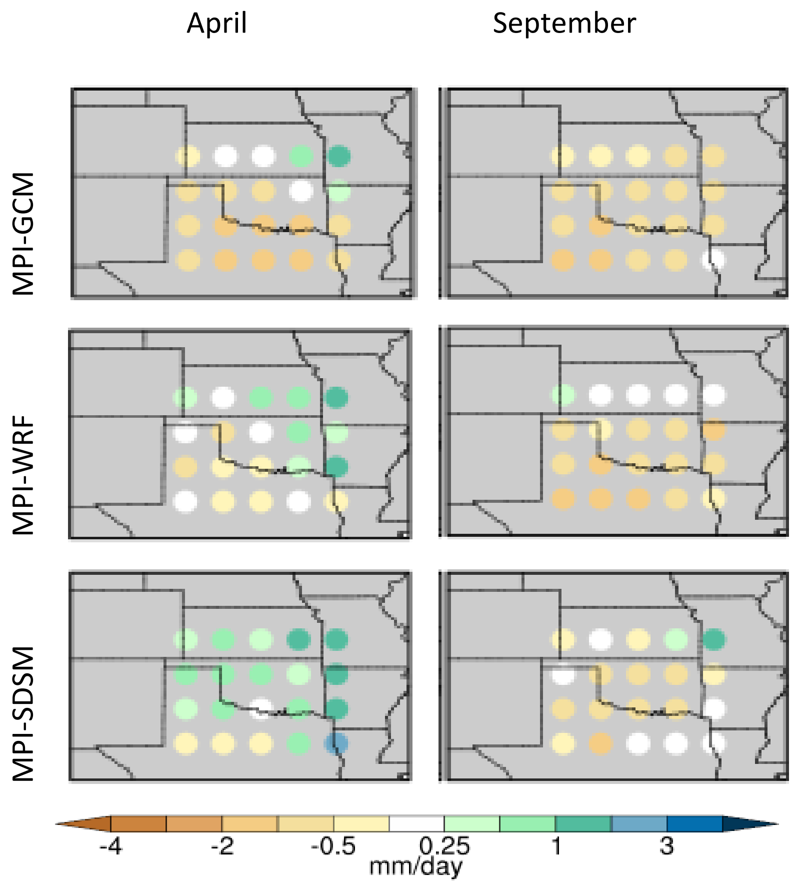


Figure: Future change in precipitation over the Southern Great Plains for the points common to the driving GCM, WRF, and SDSM.

Multi-Sector Interactions

Goal: Understand what **regional impacts** are most important for affecting **climate storylines & stakeholder** decisions.

- What are the relative importance of changes in **GHGs** and **LULC** over 21C?
- What are the relative impacts of changes **urbanization**, **irrigation** & **wind turbines** over 21st century?

Methodologies and Analyses:

- WRF 12-km simulations over 21C periods using RCP8.5 with SSP3 & SSP5
- WRF 4-km simulations (3-5 yr) with changes in urbanization, irrigation and wind farms, esp. over eastern/central US.
- ELM-MOSART-WM and SWAT hydrology simulations driven by our climate simulations.
- Additional analyses: Wind turbine vulnerability, Great Plains LLJ and convective storms, storylines of multi-year drought events (figure).

Brandon Fisel “Using Object-Based Methods to Evaluate 36-Month Drought Events for the Contiguous U.S.A. under Contemporary and Scenario Climates.”
Melissa Bukovsky “SSP-based land use change scenarios: a critical uncertainty in future regional climate change projections”

NE Multi-year Drought Events

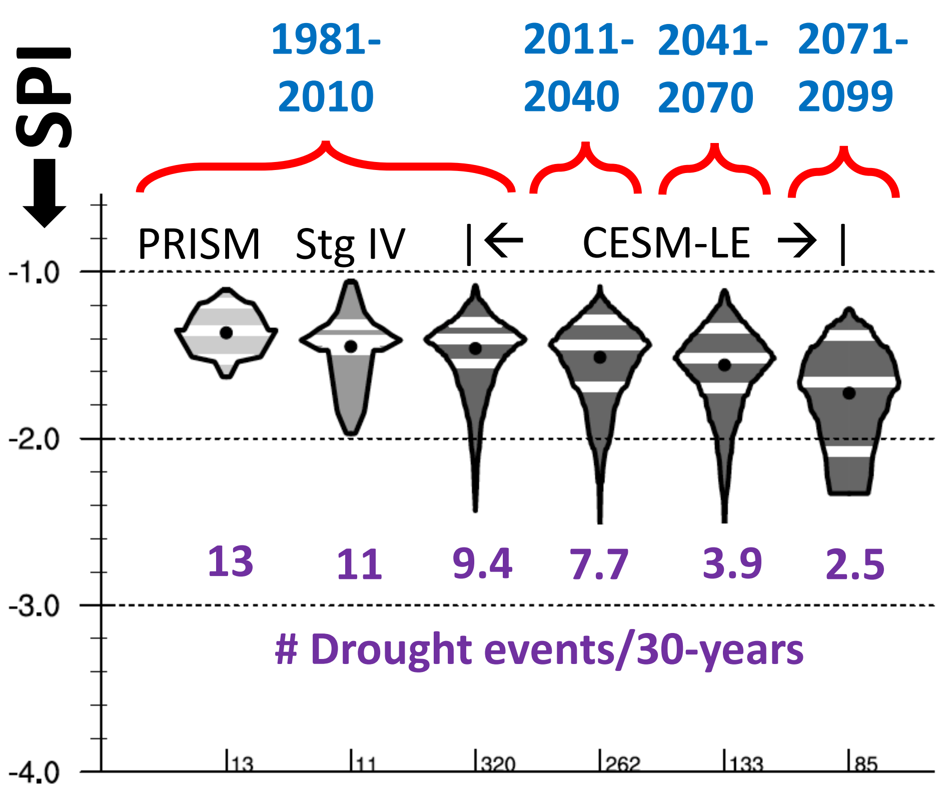


Figure: Intensity of extreme, 3-yr Northeast drought events, from observations (PRISM & Stage IV) and CESM Large Ensemble. Drought estimated from Standardized Precip. Index (SPI). SPI event pdfs shown as violin plots.

TempestExtremes for Feature Tracking *(now in v2)*

- A software toolset for **feature detection, tracking, and analysis** of regional or global Earth-system datasets on structured or unstructured grids.
- Extensive support for **both nodal and areal features**, including tropical cyclones (TCs), extratropical cyclones (ETCs), monsoonal lows and depressions, atmospheric rivers, atmospheric blocking, precipitation clusters and heat waves.

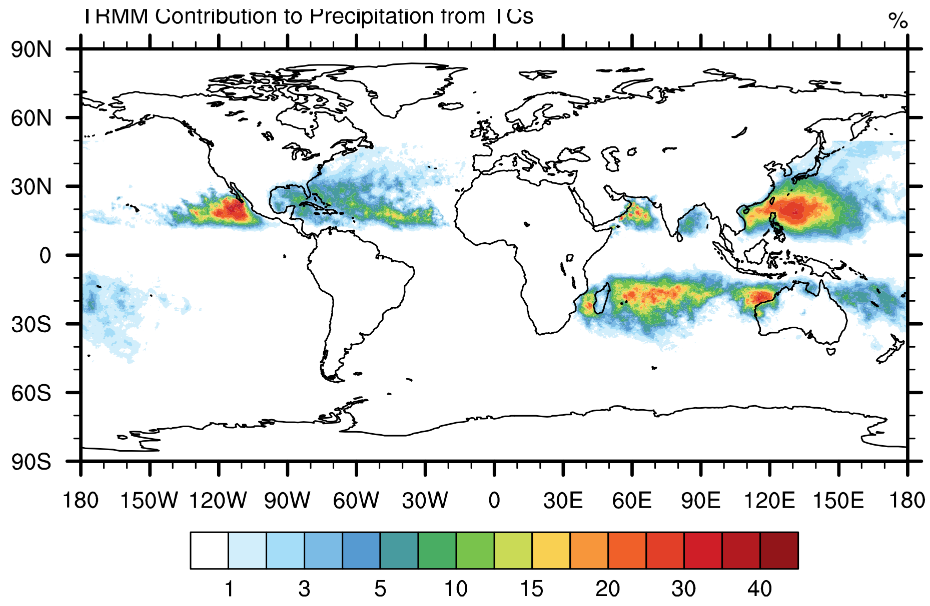


Figure: Percentage of TC precipitation from TRMM (%), where precipitation is associated with a TC if it is within the TC's radius of 8m/s winds (r8). TCs are tracked in ERA5.

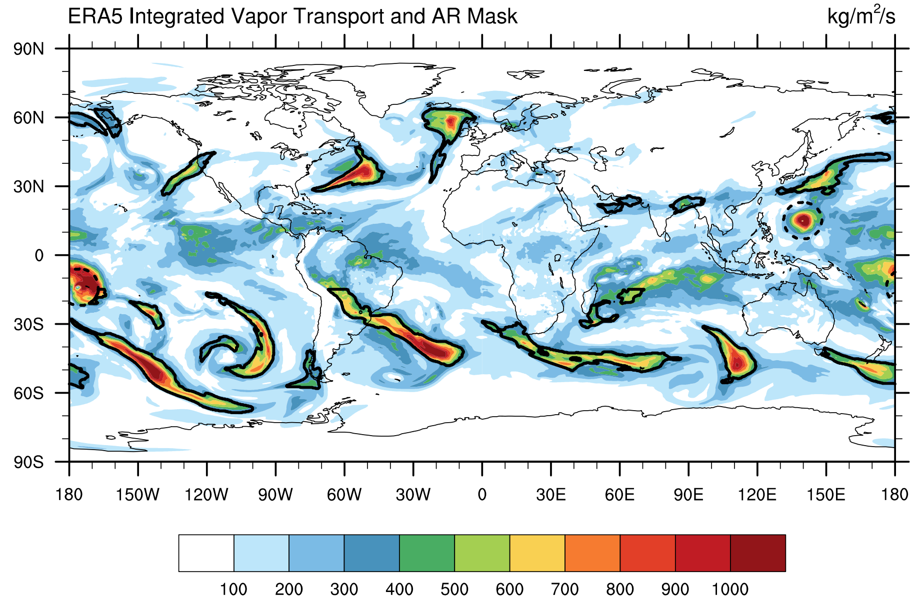


Figure: Atmospheric River Objects identified using the TempestExtremes AR tracking algorithm (with exclusion of tropical storms).

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Thanks!

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