Encroachment of the severe weather season on late winter

Emerging high-impact events

PIs: Andrea L. Lang (UW), Jonathan E. Martin (UW), Victor Gensini (NIU)

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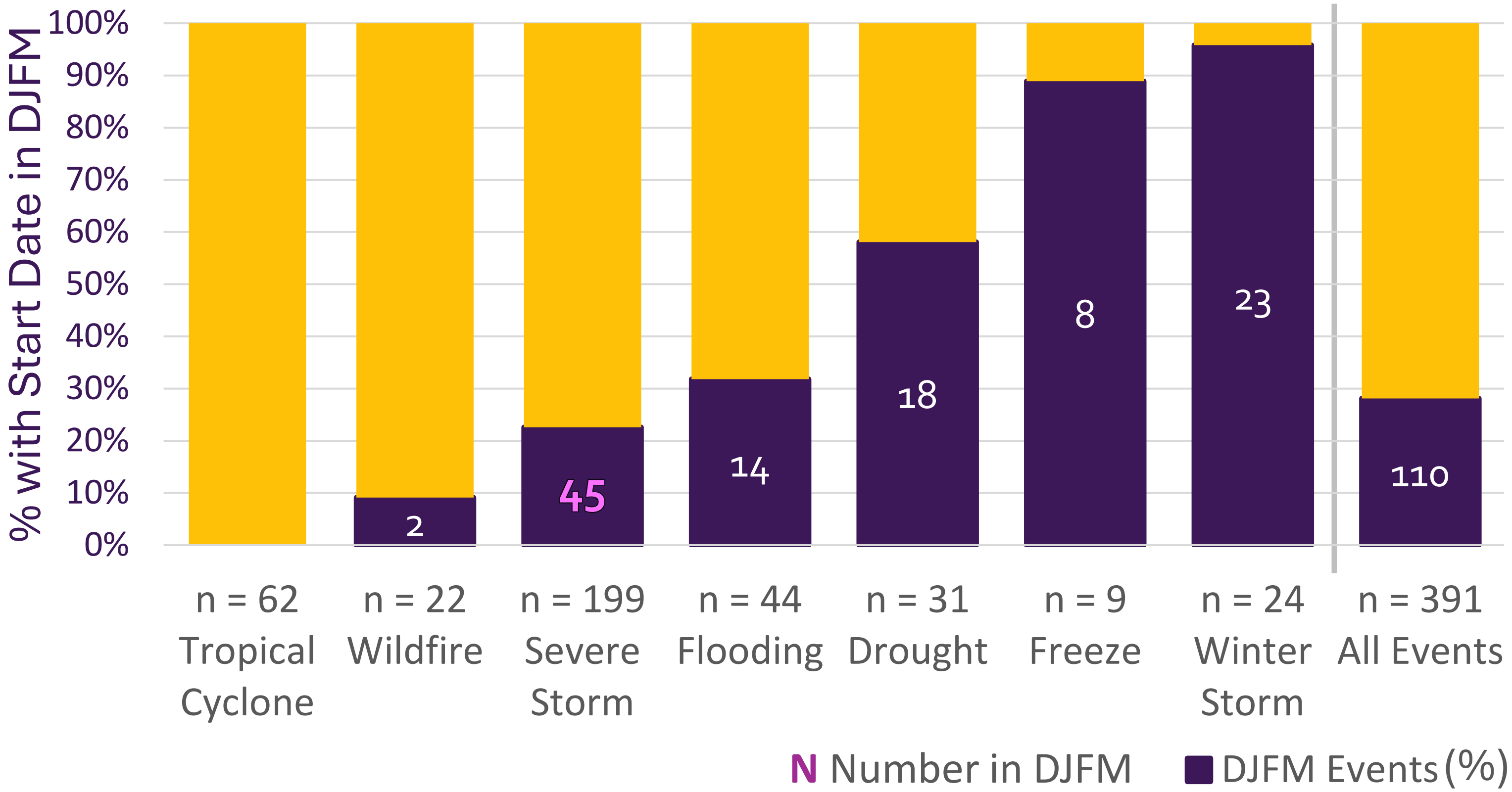
Need and Industry Relevance

Feb. 9, 2024, A confirmed EF2 tornado northwest of Evansville, Wis. (Anthony Wahl//The Janesville Gazette, AP)

EVANSVILLE, Wis. (AP) — The first tornadoes ever recorded in Wisconsin in the usually frigid month of **February** caused more than **$2.4 million** in damage, officials said Wednesday.



NOAA National Centers for Environmental Information (NCEI)
U.S. Billion-Dollar Weather and Climate Disasters (2024)
https://www.ncei.noaa.gov/access/billions/

Severe convective storms are #1 type of U.S. billion-dollar disaster in DJFM

An under-researched problem

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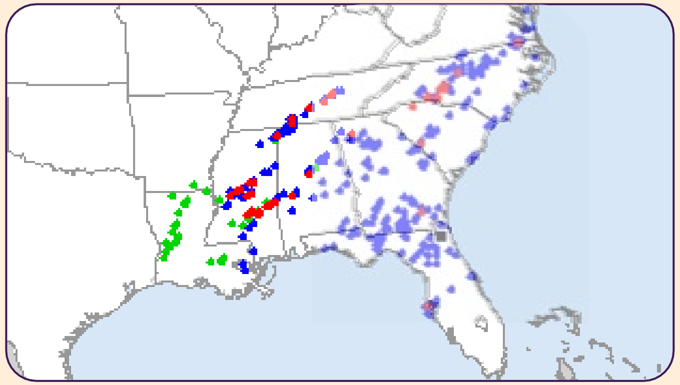
Project Goals

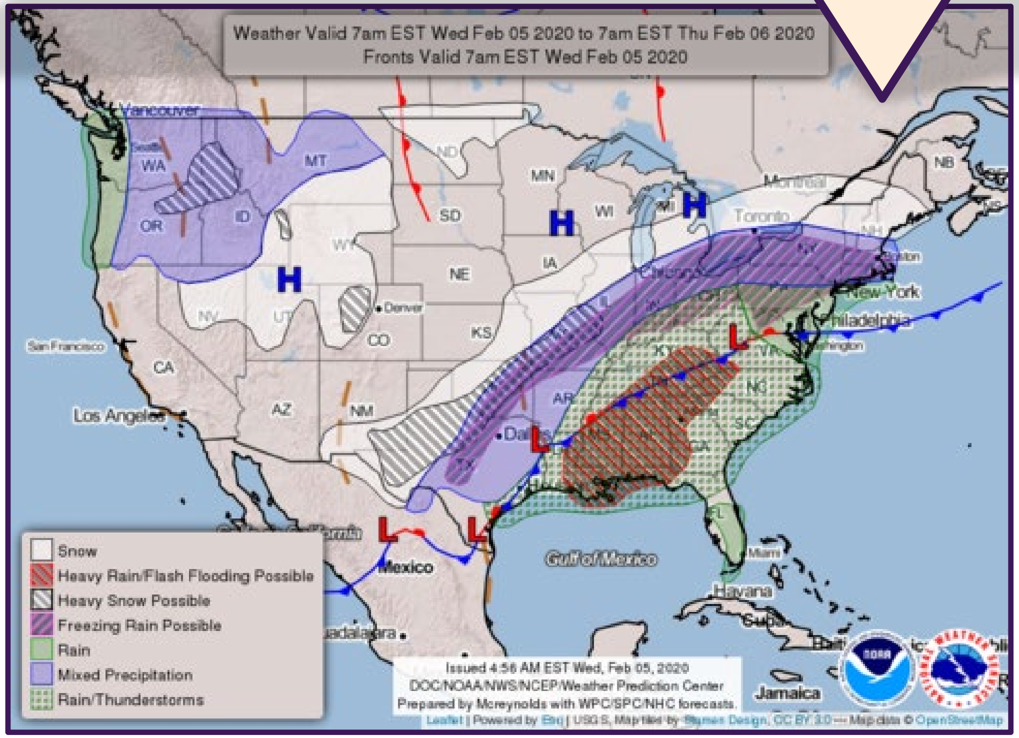
1) Establish a detailed climatology of cold-season SCS events and compound events.
2) Better understand the climate variability and trends associated with the processes that conspire to produce the growing winter SCS and compound event threat.
3) Explore the probability and uncertainty in the potential for SCS and compound events in winter at various prediction timescales to inform outlooks and decision making.

February 5-7, 2020:
Severe Weather Outbreak

- 66 confirmed tornados
- 38 severe hail reports
- >300 severe wind reports
- $1.5 billion in losses
- 3 deaths



NOAA/SPC Storm Reports, Feb 5–6 2020



NOAA/WPC Weather Hazards Map valid Feb 5–6 2020

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Objectives

1) Create an accessible database of historic winter SCS events and assess frequency and trends in compound hazards.

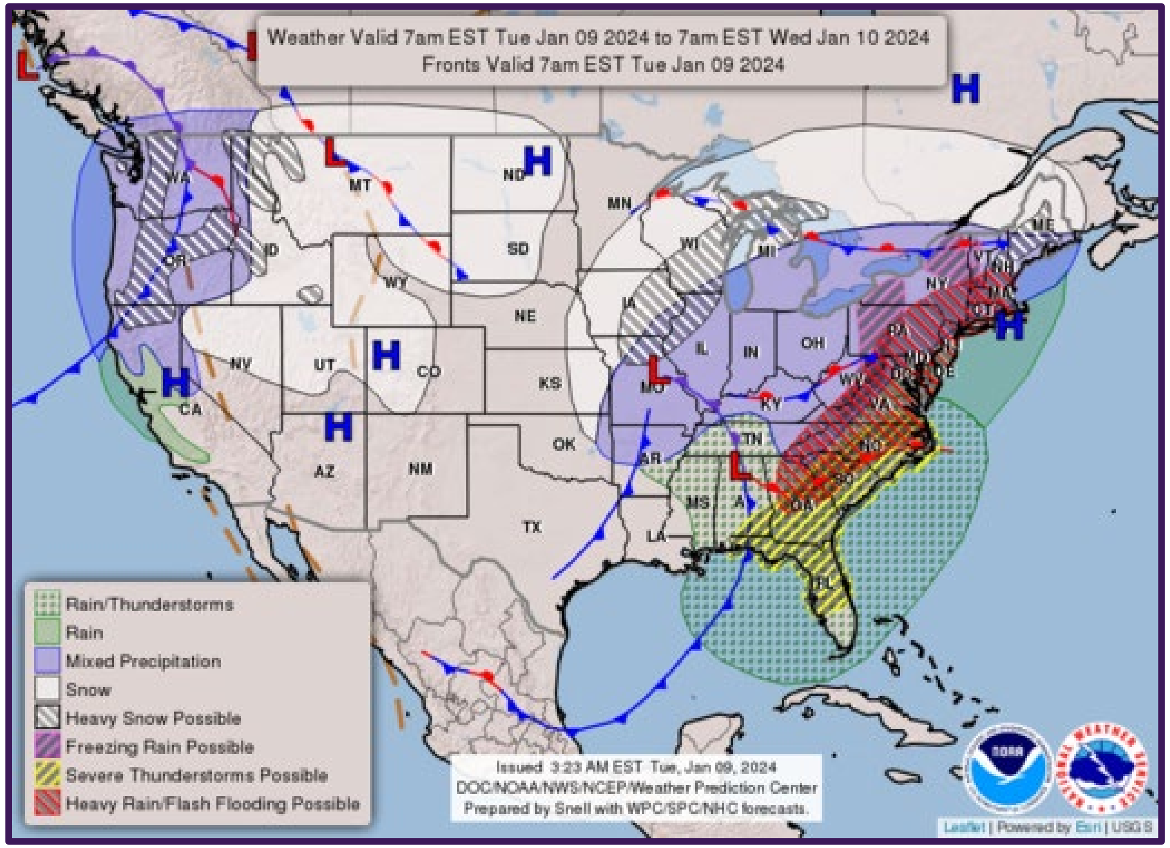
   (Liaise with industry to better capture high-impact events)

2) Assess the synoptic environment, climate variability, and trends to better understand the processes that conspire to produce the growing winter SCS threat.

   (Inform interannual assessments)

3) Quantify changes in probability and uncertainty in the synoptic-environment, climate variability, and trends in SCS and compound events in winter to better understand future events.

   (Assess historic and projected events)



NOAA/WPC Weather Hazards Map valid Jan 9–10 2024
$2.8 billion in insured losses from SCS
39 Tornados | 411 Severe Hail | 17 Severe Wind

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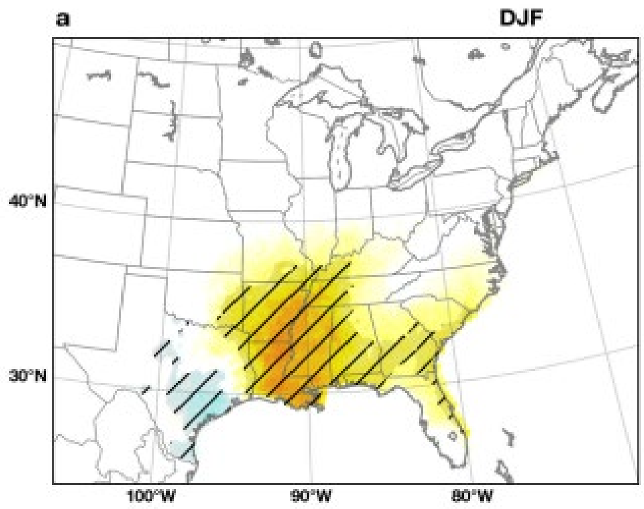
Approach

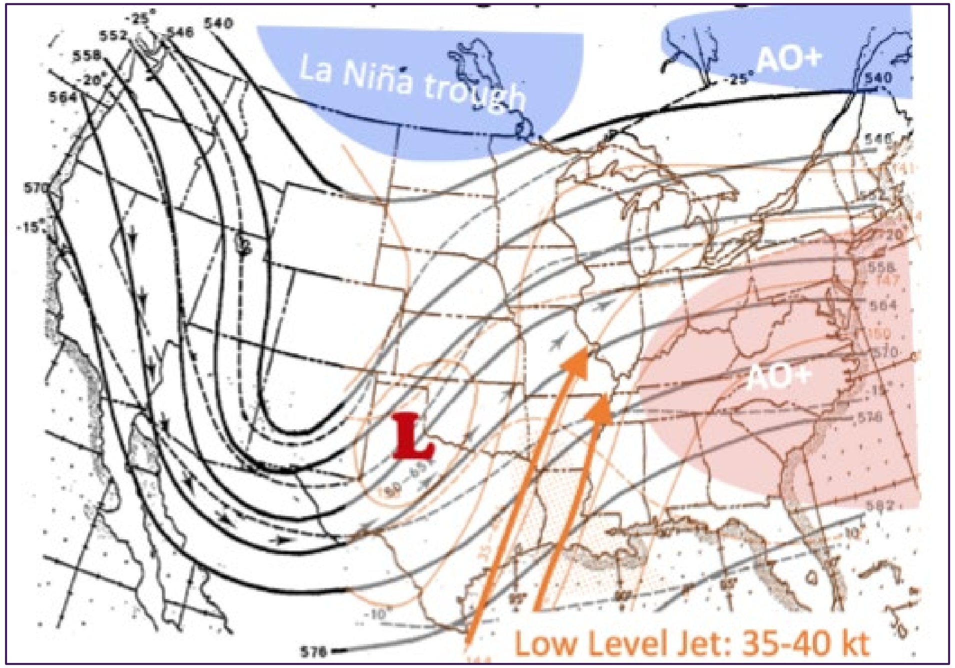
Key point: Unlike the majority of warm season SCS events, most winter SCS events in the U.S. are associated with low-CAPE/high-shear conditions, along with high-amplitude flow at upper levels and an active low-level jet.

- Consider how environments of winter SCS differ compared to warm season events.
- Assess variability and trends separate from warm season diagnostics.
- Analyze key winter SCS and compound event ingredients in historic and projected data.



Trend of DJF tornado frequency
Gensini & Brooks (2018)

Significant increases
Significant decreases



DJF composite map of southcentral U.S. tornado outbreaks
Geopotential height & winds at 500 hPa (**black**) & 850 hPa (orange)

Annotated regions indicating typical 500-hPa geopotential height anomalies (negative & positive) during La Niña and AO+ conditions.

Adapted from Galway & Pearson (1981)

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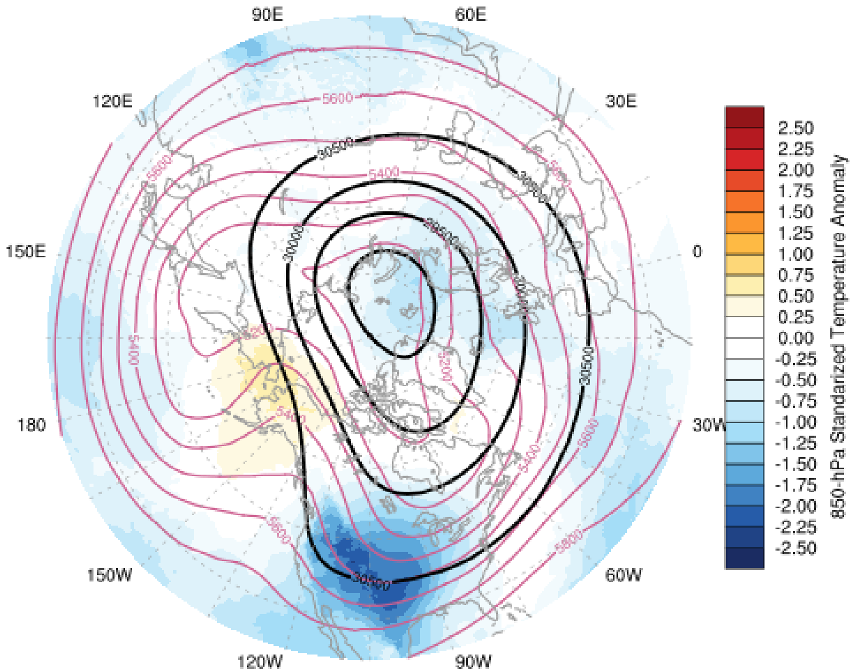
Approach

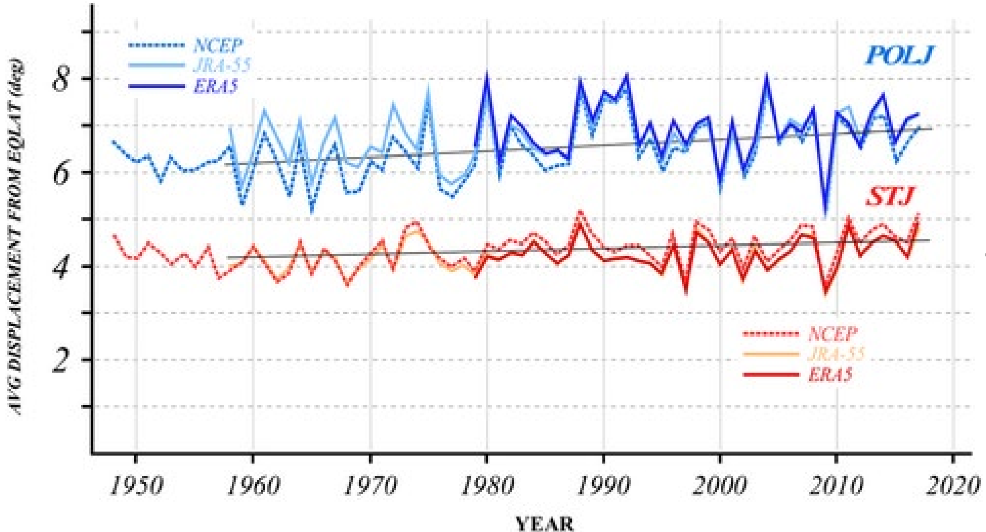
Related work:

- Winter climate change signal: DJF jet stream waviness is increasing (Martin 2021) and can impact flow amplitude and high-shear regions.
- Cold season tornado frequency: more closely linked to extratropical variability (Arctic Oscillation) than ENSO.
- Other winter extremes: Cold air outbreaks are linked to large-scale variability in the stratospheric polar vortex. A type of variability that does not exist in the warm season.

The strength of the climate signal in the stratospheric polar vortex is an open area of research



The 850-hPa standardized temperature anomaly (**fills**) and geopotential height at 500 hPa (**pink**) and 10 hPa (**black**) for a composite of 57 cold air outbreaks between 1959-2021.



Timeseries of the "waviness" of the polar and subtropical jet streams in different reanalysis datasets.

Martin (2021)

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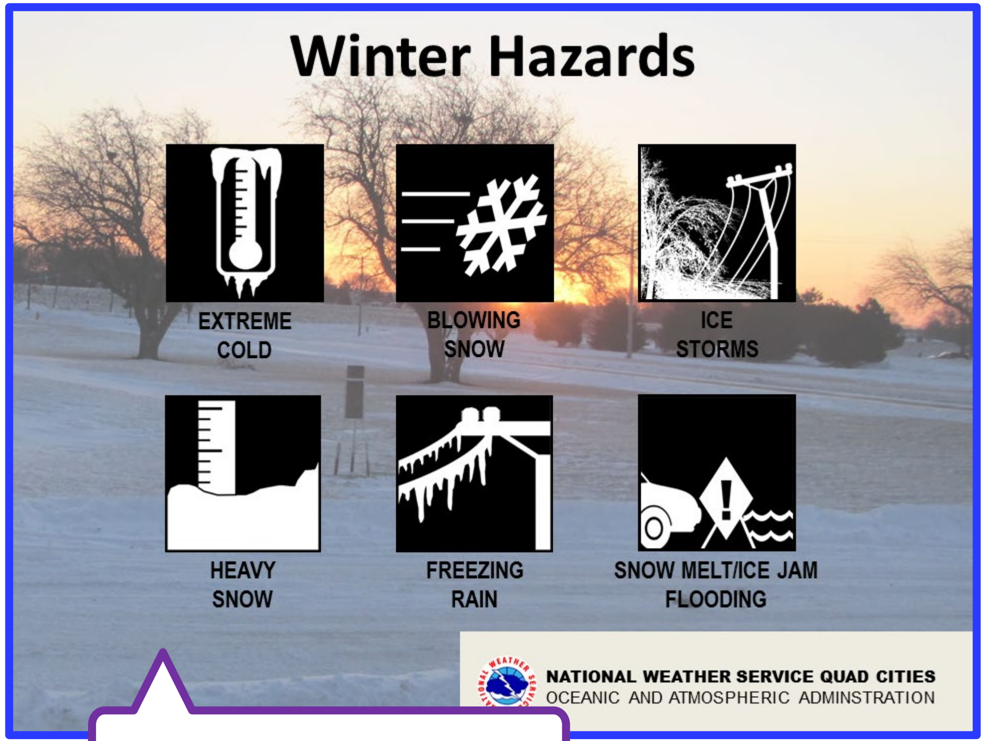
Outcomes and Deliverables

- Adaptable work plan with input from industry members.
  - Prioritize historic events in Y1
  - Goals for assessing projections as future work/Y2.
- Open-source events dataset.
  - Catalogue of events including relevant weather & climate diagnostic indices.
  - Catalogue of events including population & impact vulnerability metrics.
  - Composites of similar events and impact frequency maps in the context of weather & climate diagnostic indices.
- Open-source code.
  - Sample workflows and documentation of code and data.
- Dissemination of results.
  - At workshops, conferences, and peer-reviewed publication.

Impacts

- A thorough assessment of winter SCS and compound events from a climatological perspective.
  - Address an under-researched topic with high impacts
- A focused analysis and diagnosis of the wintertime trends of SCS and compound event ingredients.
  - Opportunity for new insights
- The development of an accessible database of events, documentation, and code for further analyses.
  - Generate a new dataset of future work

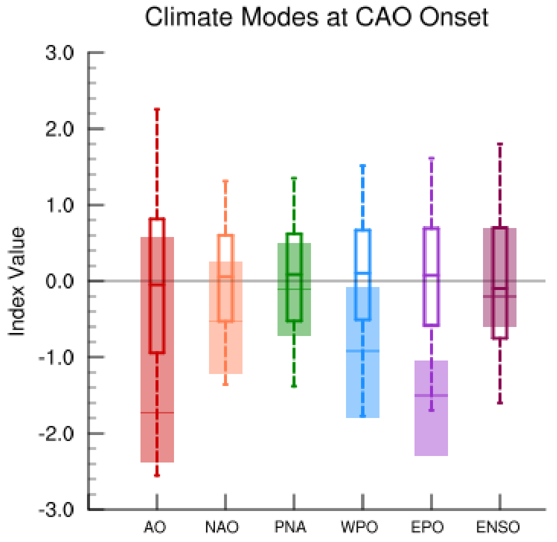


Emerging Hazard? Severe Wx

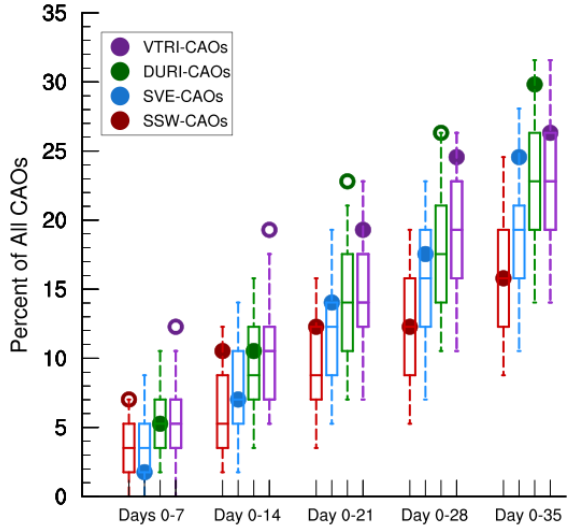
Project Duration & Proposed Budget

Timeline:

- **Year 1** (historic perspective):
  - Semester 1 – Hire graduate student build winter SCS and compound event database.
  - Semester 2 – Assess synoptic and large-scale variability of events in database. Build accessible dataset.
  - Summer – Assess trends in variability of historic cases
- **Year 2** (climate projection perspective / optional)
  - Semester 1 – Assess projected winter SCS and compound events in select HiResMIP model runs.
  - Semester 2 – Assess synoptic and large-scale variability of events in model ensembles.
  - Summer – Assess trends in variability of projected cases



Example analysis from work on Cold Air Outbreak events



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Season-ahead Prediction of Severe Convective Storms in the US

Lead PI: Paul Block (UW-Madison)

Co-PIs:
Steve Vavrus, Dan Wright, Peng Shi (UW-Madison)
Victor Gensini, Alex Haberlie (NIU)

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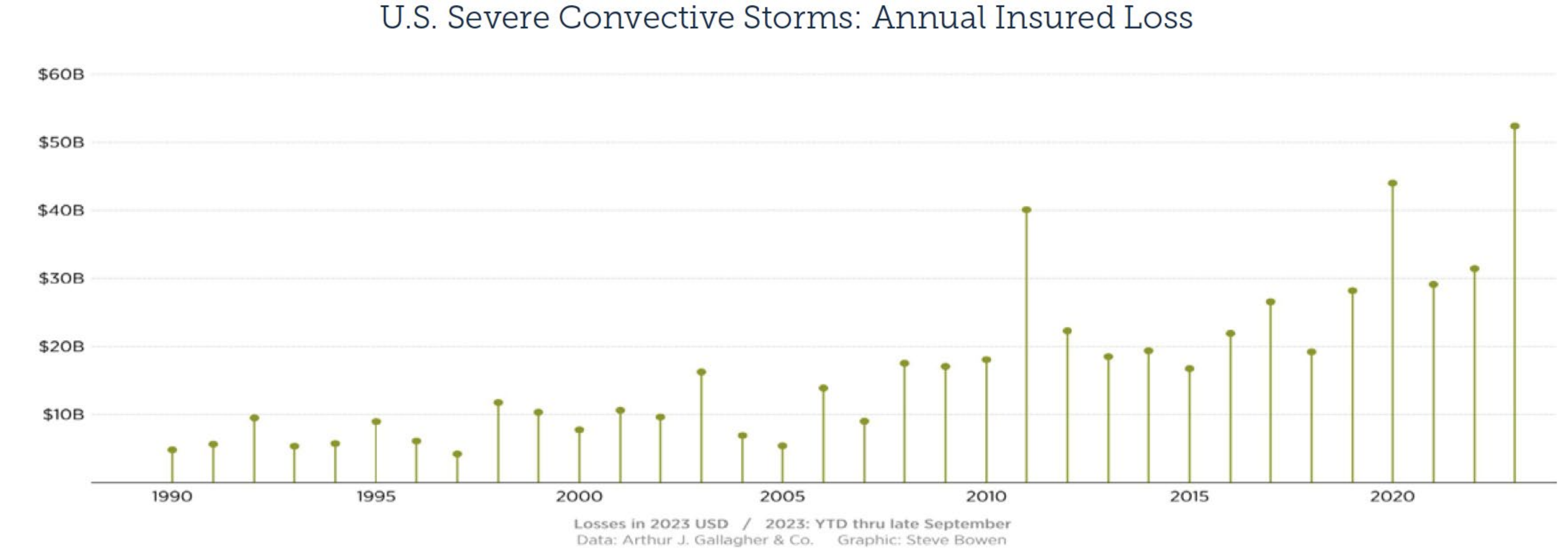
Need and Industry Relevance

- The number and intensity of summertime SCS varies from year to year
- Losses can vary spatially by cause of damage (winds, hail, etc.)
- Predictions at season-ahead scales can foster preparedness



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Project Goals

1. Understand the role of large-scale climate features on seasonal SCS variation
2. Forecast SCS season conditions (e.g., active year) and potential damages/losses
   - Geographic variation
   - Lead time (1-, 3-, 6-month lead time)
3. Inform insurance industry demands (for future projects)
   - Pricing annual re-insurance contracts or parametric insurance products
   - Pre-season budgeting, loss reserving, capital management
   - Geographically-specific advertising and underwriting
   - Signal to insured to take preparedness action

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Objectives

1. Characterize historical SCS seasons
   - Spring and summer seasons
   - Number, type, location (NOAA record)
   - Damages/losses (insurance records)
   - Regional clustering (storm catalog, Haberlie)
   - Attribution: how much of the recent increase in SCS damages is a result of the storms themselves vs. enhanced vulnerability

2. Evaluate the predictability of various SCS related targets at seasonal leads
   - Number of SCS across the summer
   - Property damage / losses
   - Lead time vs model performance
   - Statistical vs dynamical modeling approaches

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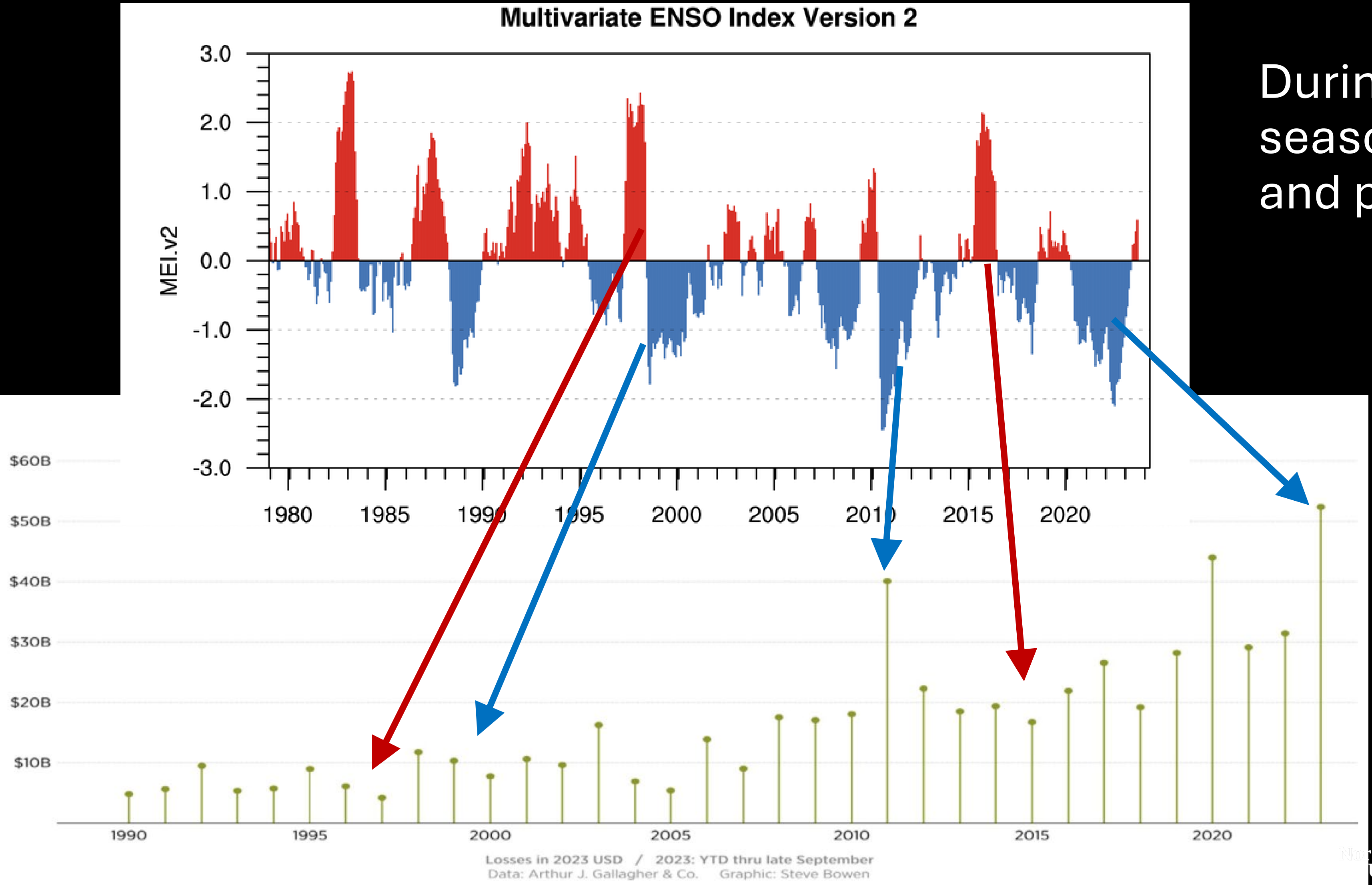
Approach (Research Methods)

Large-scale climate features (e.g. ENSO) partially control the number of seasonal SCSs



During La Niña, the SCS season typically starts *earlier* and produces *more* events

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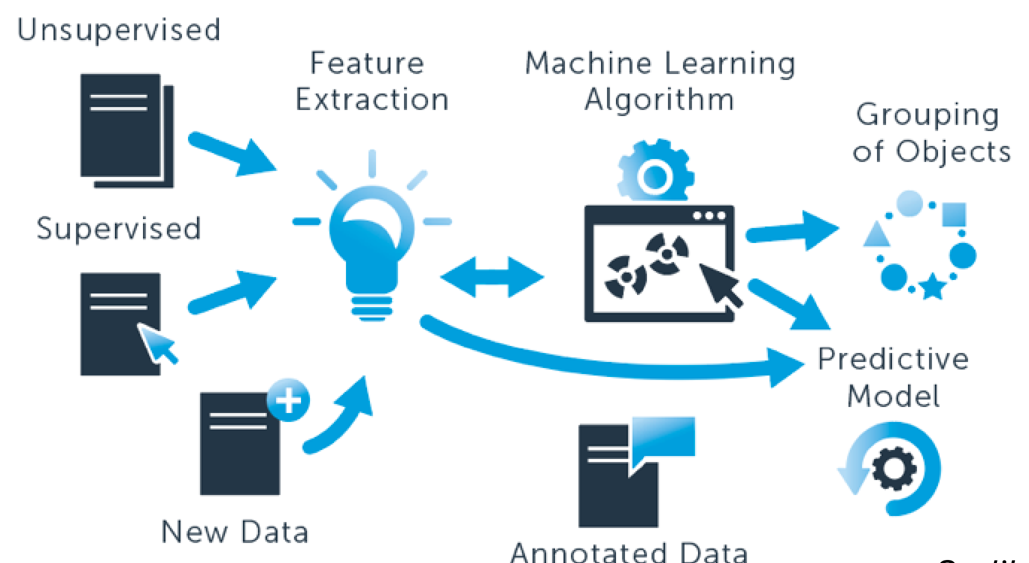
Approach (Research Methods)

- Construct statistical (ML) prediction models conditioned on large scale and local scale ocean and atmosphere variables for targets of interest (#SCSs, losses, etc.)
- Compare with high-resolution, dynamical models
- Extend to cool season, leveraging Lang and Martin project
- Analyze how SCS seasonal characteristics may evolve in the future (e.g., with CESM)



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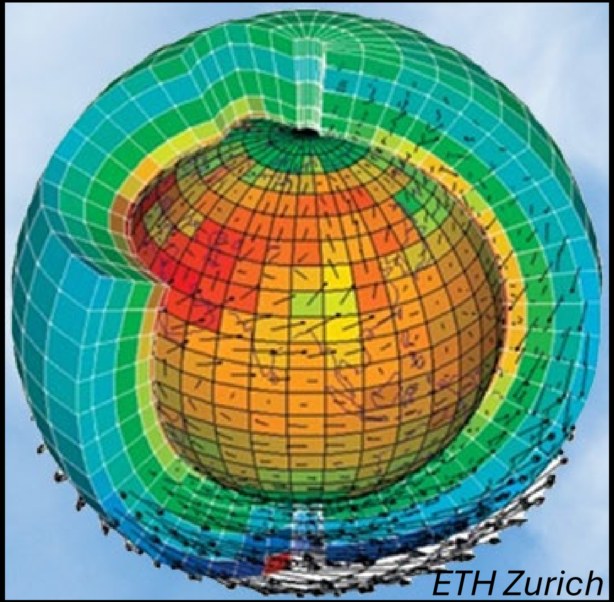
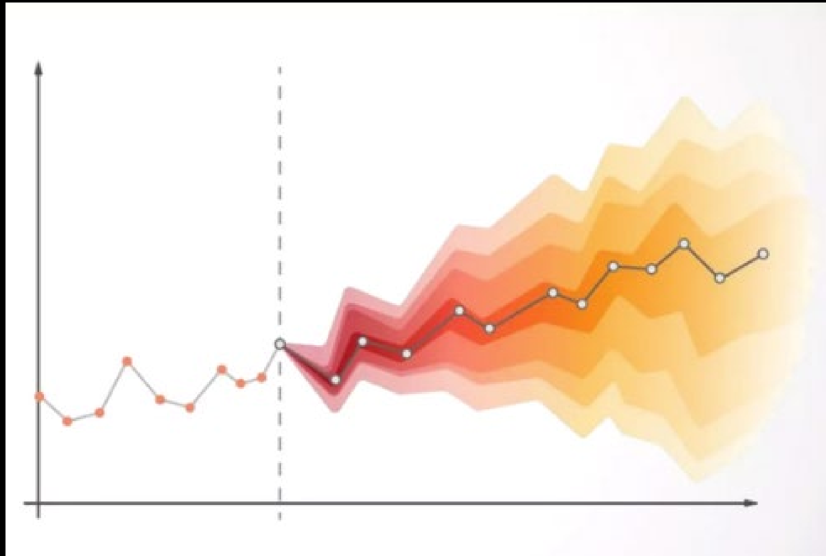


ETH Zurich



Slideshare

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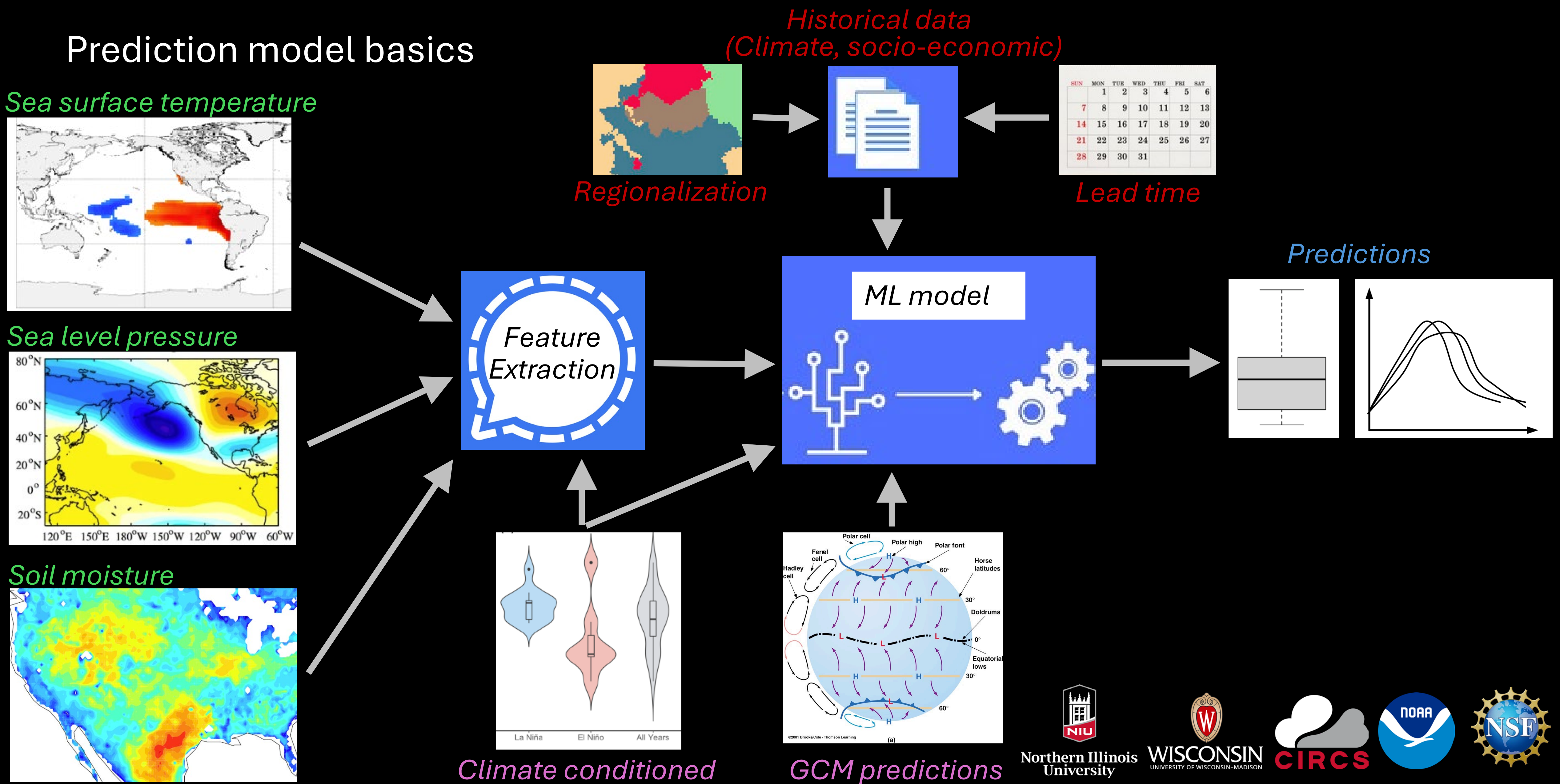
Approach (Research Methods)

Prediction model basics



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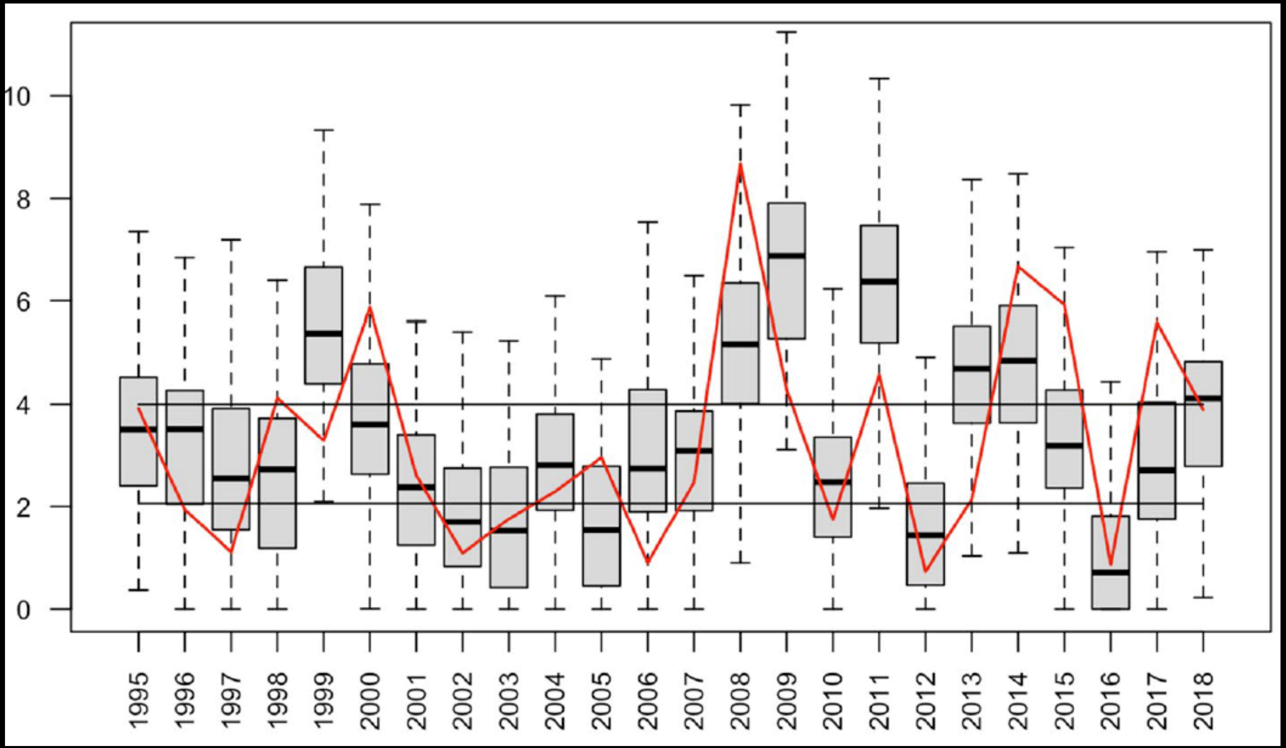
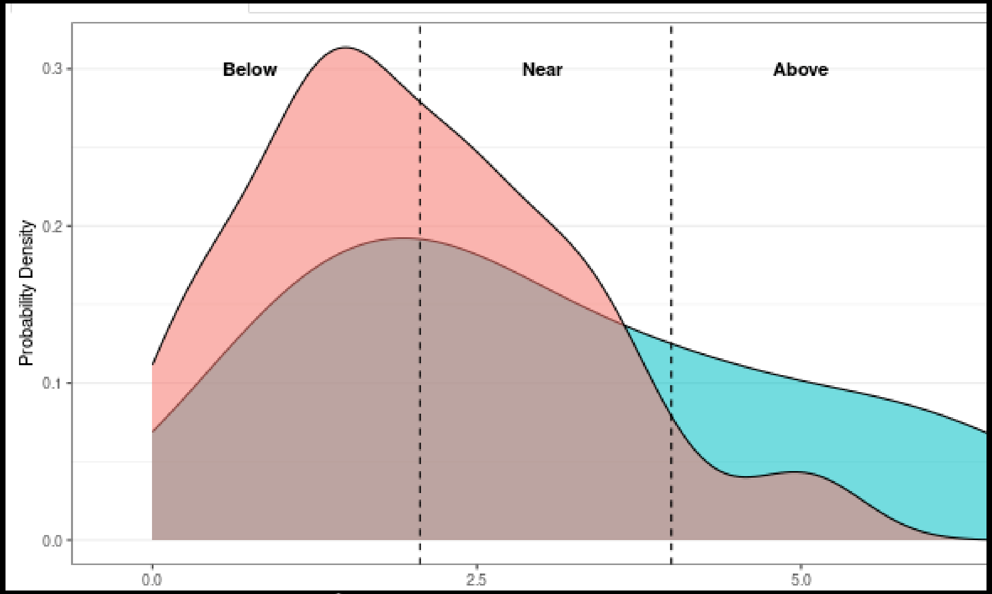
Outcomes / Deliverables

1. Hindcast of model performance
   - Predictions of SCS seasonal characteristics
   - Predictions of seasonal damages/losses
2. Open-source code, documentation, and examples (e.g., Github)
3. Define future directions with input from industry members





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Impact

- Basis for developing SCS tailored prediction tools
- Implications for insurance agencies: pricing, pre-season budgeting, underwriting, etc.

Project Duration

- Timeline: 1-2 years (advanced PhD student or postdoc)

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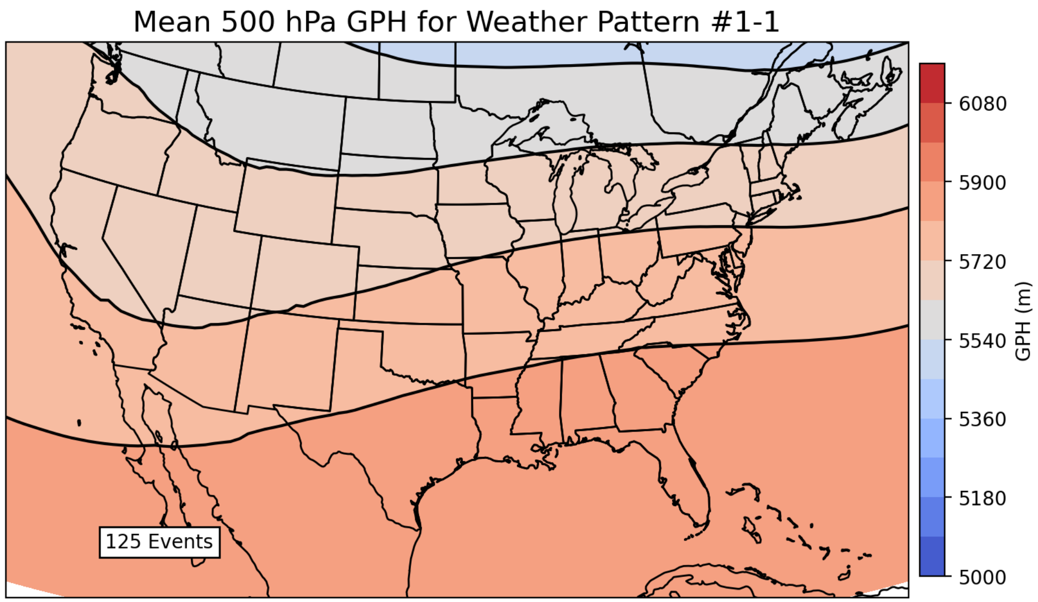
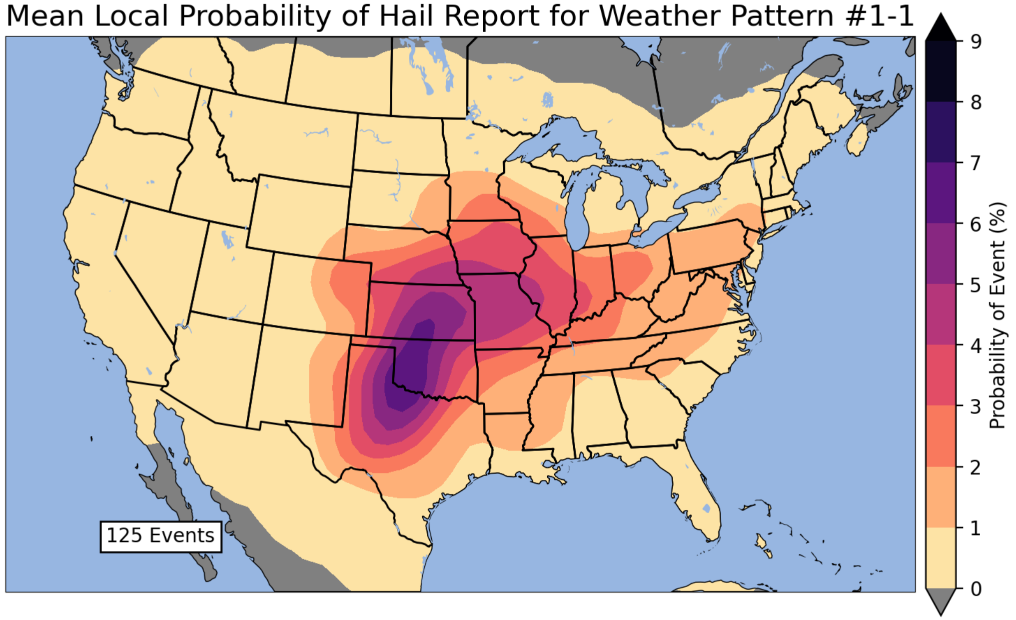
Connecting Weather Patterns to Thunderstorm Hazard Exposure using Data-driven Methods





Lead: Dr. Alex Haberlie[1]

Collaborators: Drs. Allison Michaelis[1], Victor Gensini[1], Andrea Lang[2], Jon Martin[2], and Stephen Strader[3]

[1] Northern Illinois University; [2] University of Wisconsin; [3] Villanova University

NIU Northern Illinois University

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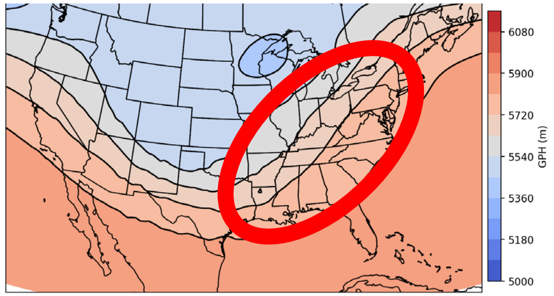
Need and Industrial Relevance

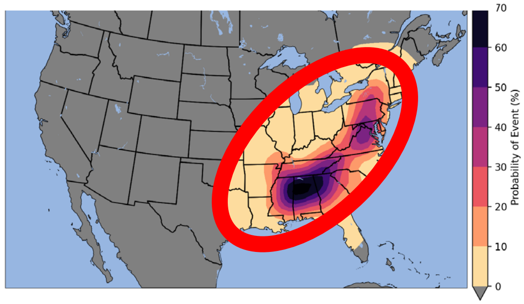
- **Reduce uncertainty** by examining a curated dataset of large-scale weather patterns for thousands of HCW events and associated estimates of local risk
- **Challenge**: Extracting actionable insights from immense weather datasets requires specialized domain knowledge and the use of data-driven methods

Large-scale weather patterns drive ***small-scale*** weather patterns that can produce hazardous convective weather (HCW)

Large-scale Weather Pattern



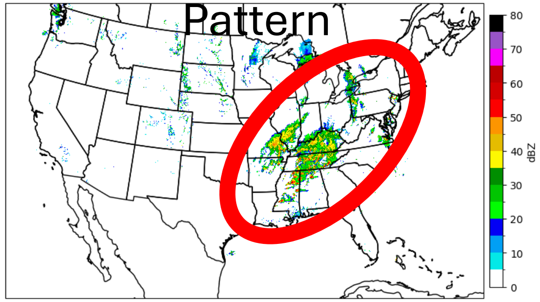
Local HCW Risk



Conditional

Thunderstorms develop in favorable areas within the large-scale weather pattern

Small-scale Weather Pattern



Conditional

Thunderstorms produce hazards

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Need and Industrial Relevance

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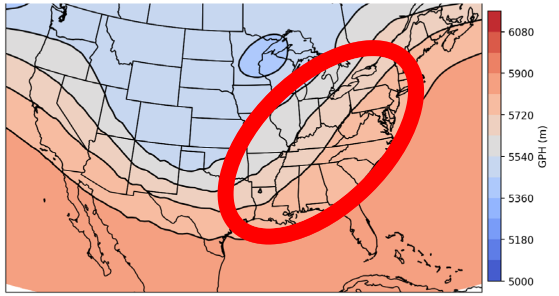
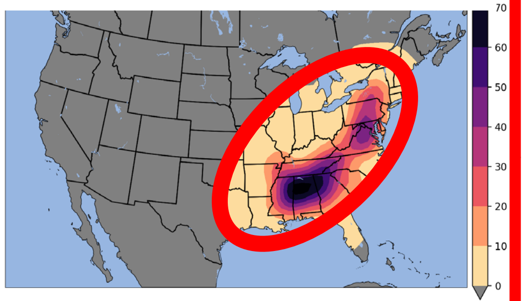
Large-scale Weather Pattern



Develop statistical relationships

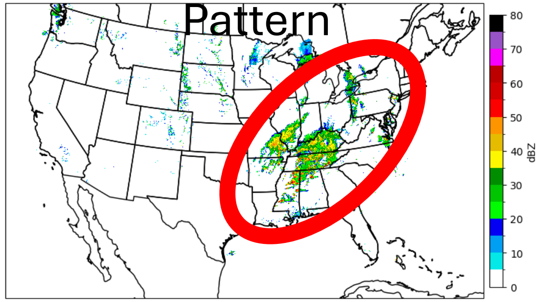
Local HCW Risk



Conditional

Thunderstorms develop in favorable areas within the large-scale weather pattern

Small-scale Weather Pattern



Conditional

Thunderstorms produce hazards

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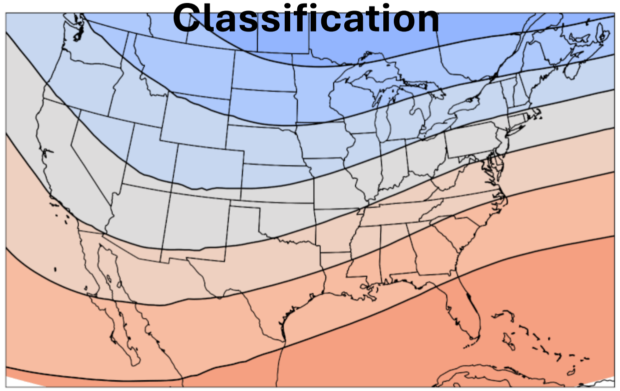
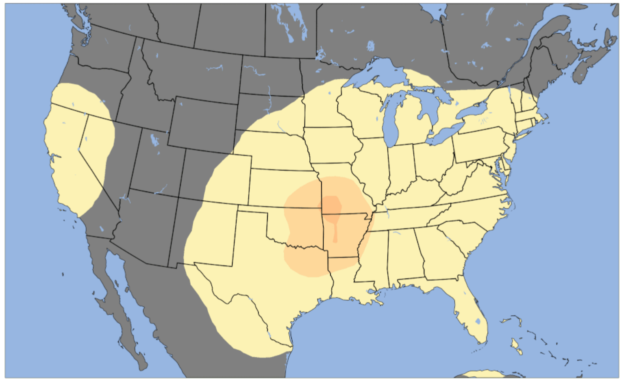
Project Goals

- Generate a catalog of spatiotemporally-relevant weather variables and risk information associated with large-scale weather patterns:
  - Event date, location, spatiotemporal HCW risk, building and population exposure estimates, and weather pattern classification
  - Data-driven representation of reanalysis variables
- Assess the skill and utility of the data-driven methods
- Provide examples of using the catalog

Weather Pattern Classification



Mean Historical HCW Risk



Data-driven Methods: Self-organizing Maps

```
current model configuration
{'input_len': 12141, 'random_seed': 42, 'sigma': 1, 'x': 3, 'y': 3}
current training configuration
{'data': array([[-0.25137576, -0.2717395 , -0.2910666 , ..., -1.6829596 ,
        -1.665843  , -1.6458105 ],
       [-2.0890706 , -2.1046786 , -2.120379  , ..., -1.0175054 ,
        -1.096332  , -1.1508251 ],
       [ 0.49144065,  0.47642753,  0.46079248, ..., -2.0563104 ,
        -2.0083194 , -1.9515929 ],
       ...,
       [-0.50235075, -0.47209135, -0.44347998, ..., -0.55323505,
        -0.49988458, -0.43796992],
       [-1.3113967 , -1.2605388 , -1.2157547 , ..., -0.21857356,
        -0.21897714, -0.21436653],
       [-1.0604217 , -1.0745479 , -1.0869249 , ..., -0.36559248,
        -0.38636723, -0.39592484]], dtype=float32),
 'num_iteration': 10000,
 'random_order': True,
 'verbose': True}
 [ 10000 / 10000 ] 100% - 0:00:00 left
 quantization error: 67.78098845737615
```

```
defaultdict(list,
            {(2,
              2): [array([-0.25137576, -0.2717395 , -0.2910666 , ..., -1.68
                      -1.665843  , -1.6458105 ], dtype=float32), array([ 0.0
                      -1.340683  , -1.3228278 ], dtype=float32), array([-1.4
                       0.26972488,  0.22519572], dtype=float32), array([ 0.6
                      -1.2464058 , -1.231093  ], dtype=float32), array([1.44
```

```
prefs = {'var': 'z500',
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         'som_config': {'x': 3, 'y': 3,
                        'sigma': 1, 'random_seed': 42},
         'som_train': {'num_iteration': 10000,
                       'random_order': True,
                       'verbose': True}}
```

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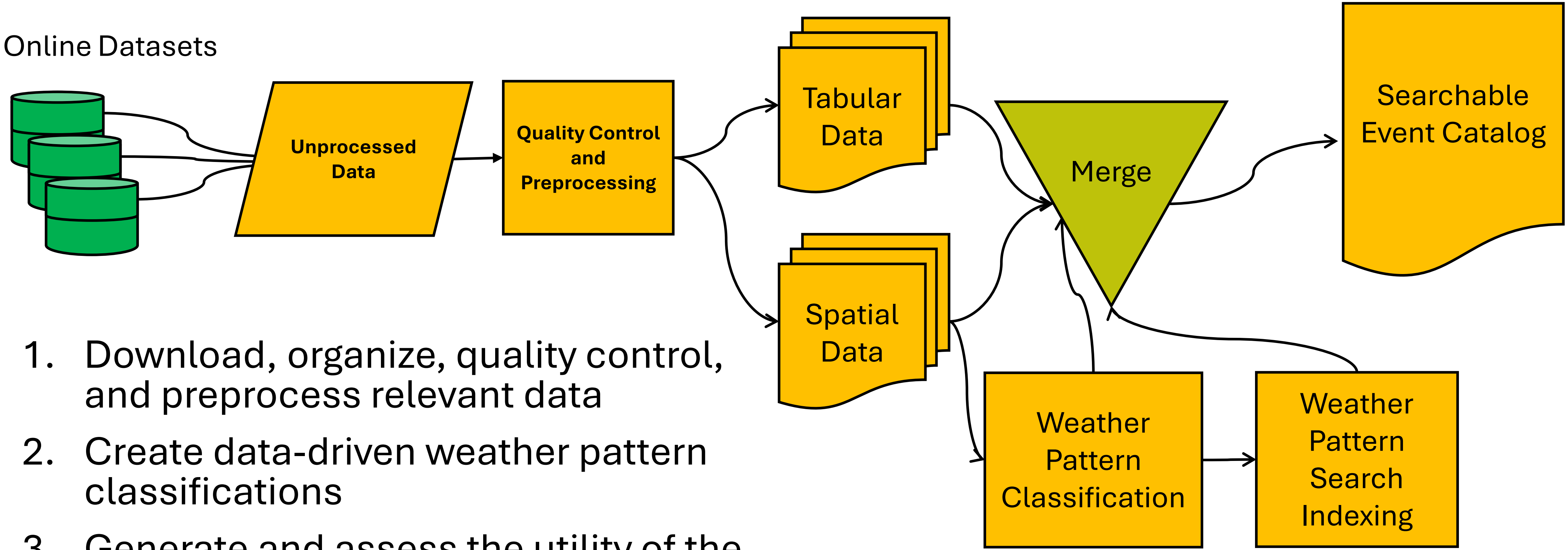
Project Objectives

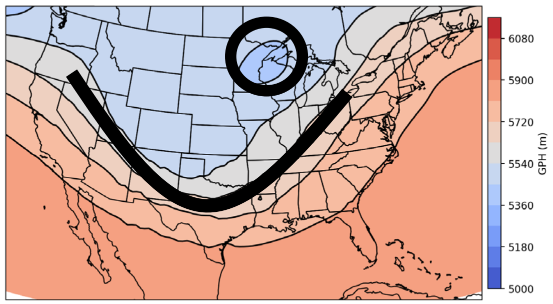


1. Download, organize, quality control, and preprocess relevant data
2. Create data-driven weather pattern classifications
3. Generate and assess the utility of the catalog
4. Demonstrate “real-time” applications of the catalog

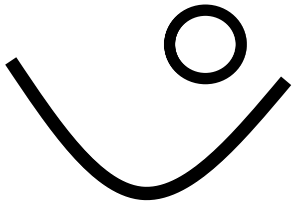
Weather Pattern Classification

- Atmospheric data will be used to inform the data-driven weather pattern identification process:
  1. Above-surface and surface variables
  2. Derived variables
  3. Spatiotemporal context variables
- Spatiotemporal patterns will be indexed using feature detection to allow “smart” searching
- Self-organizing maps and other clustering approaches will be explored

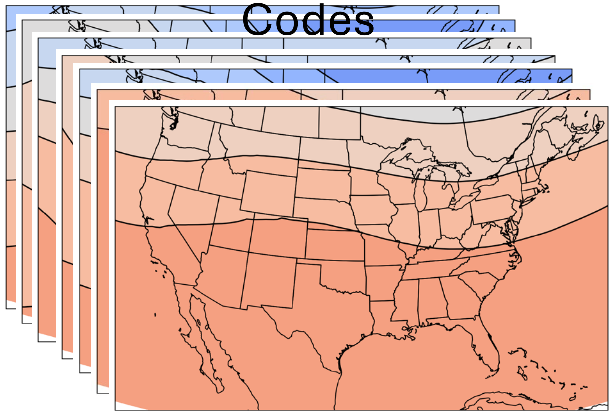
Original Data



Automatically Identify Pertinent Spatial Features



Use Spatial Features to Generate and Assign Weather Pattern Codes



Save Numerical Representation (Index) in Catalog

Searchable Event Catalog

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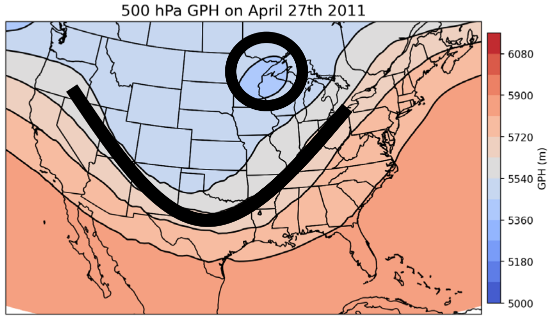
Searchable Catalog Creation

- The catalog will include 4 different types of data:
    1. Spatiotemporal information (coordinates, time, etc.)
    2. Indexed spatiotemporal patterns
    3. Local HCW risk (tornado, large hail, etc.)
    4. Exposure estimates (e.g., buildings, population, etc.)
- Exposure information will be based on publicly-available data and overlap with probabilistic HCW risk that exceeds pre-defined thresholds:
    - High-resolution population dataset
    - Building footprints dataset
    - Other sources of exposure information

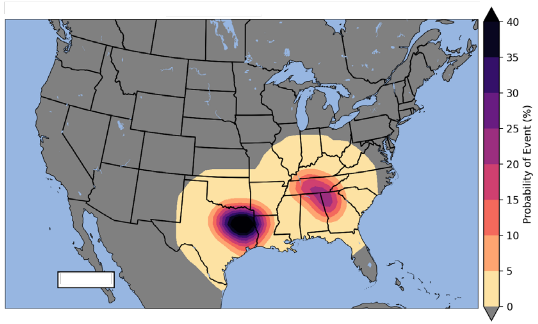
Spatiotemporal data

st	stf	stn	mag	inj	fat	...	f3	f4	fc	init_date
TX	48	2	1	1	0	...	0	0	0	1996-01-17-22:33:00
TX	48	8	1	0	0	...	0	0	0	1996-01-17-22:50:00
TX	48	9	1	0	0	...	0	0	0	1996-01-17-23:00:00
MO	29	1	1	0	0	...	0	0	0	1996-01-18-08:05:00
TN	47	1	0	0	0	...	0	0	0	1996-01-18-08:55:00

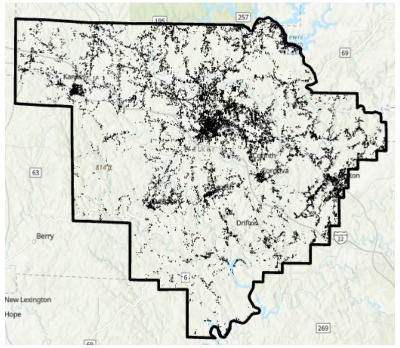
Indexed spatiotemporal patterns



Local HCW risk



Exposure estimates



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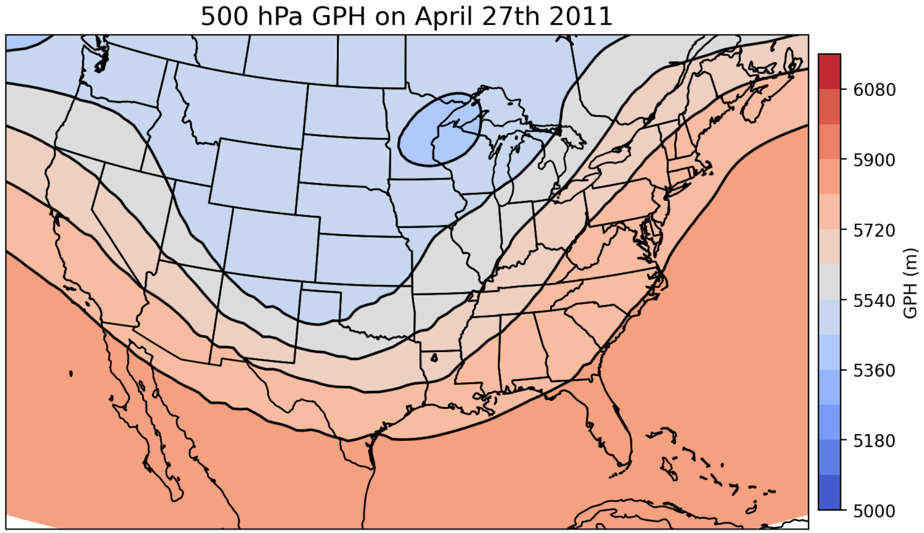
Search Example

Find the most similar catalog entries for this high-cost event



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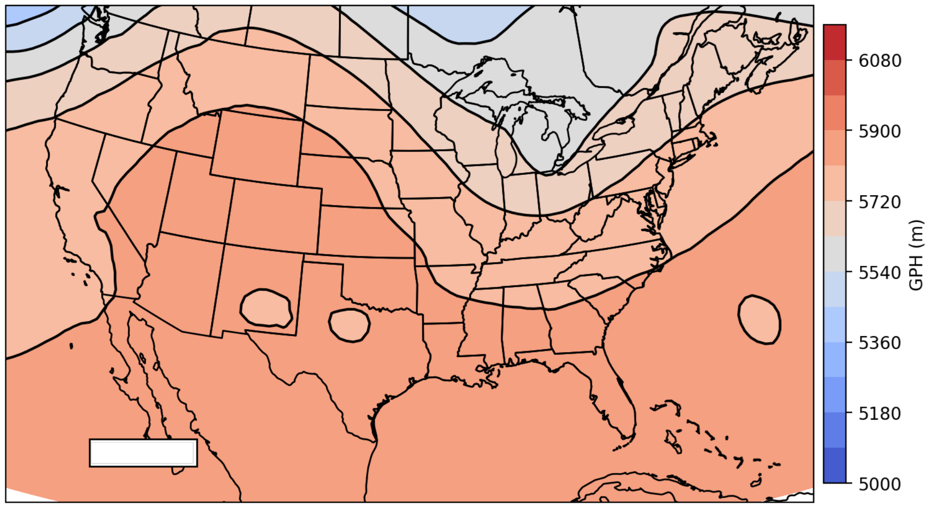

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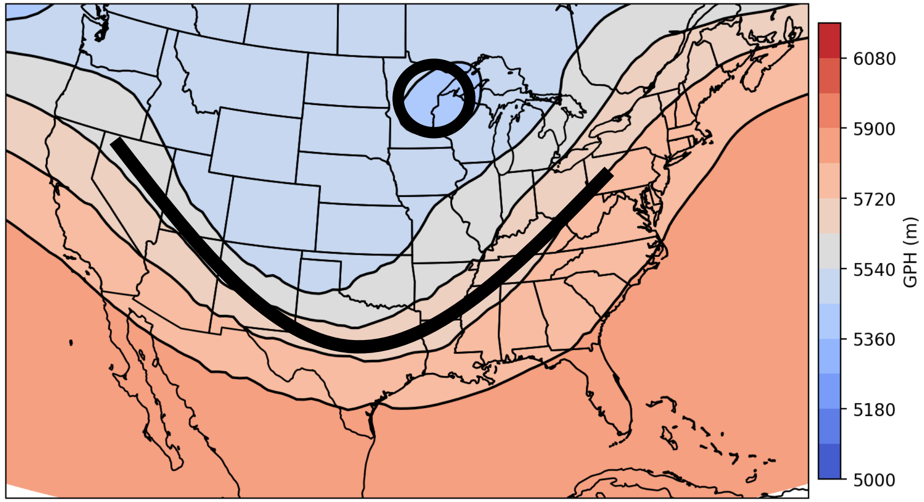
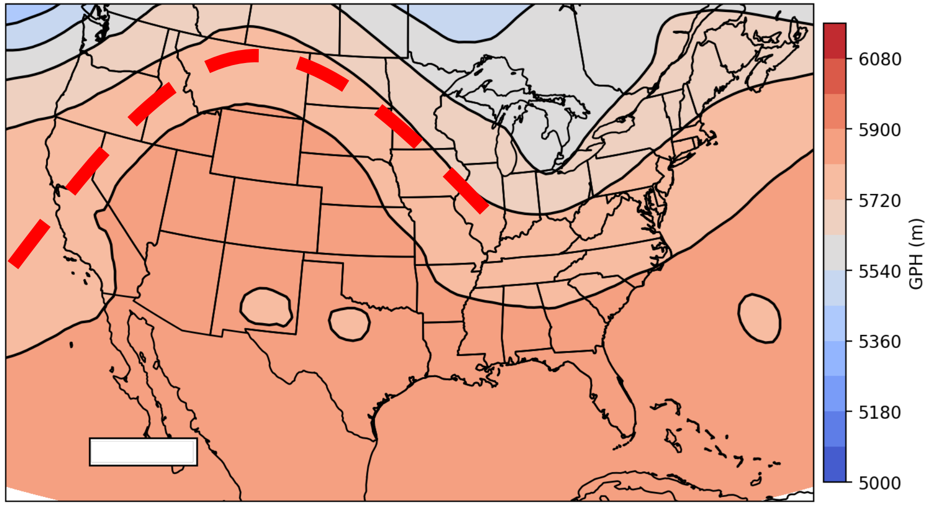
Find the most similar catalog entries for this high-cost event

500 hPa GPH on April 27th 2011



Access Spatial Index

Catalog entry to check for similarity



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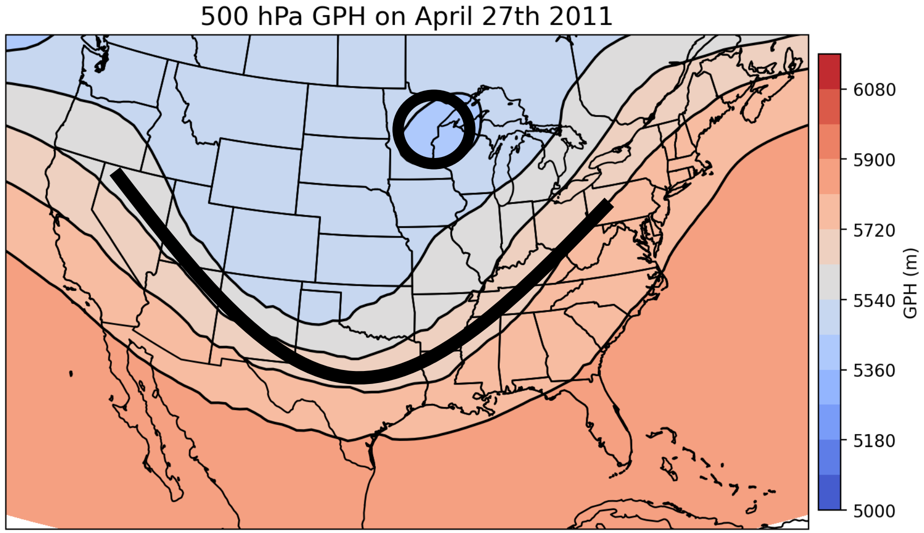

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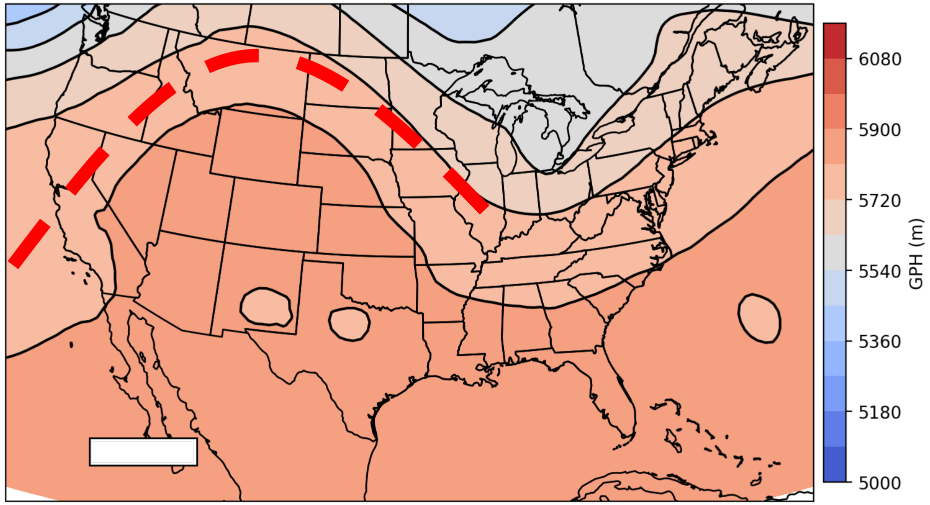

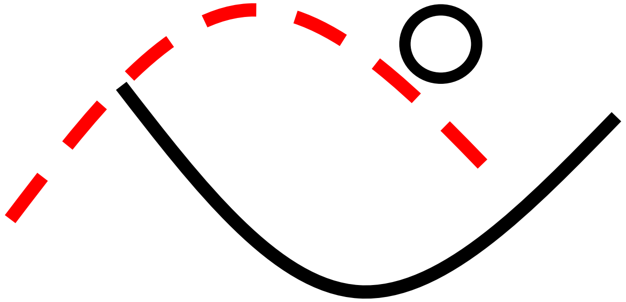

Compare Spatial Indexes

Poor Match

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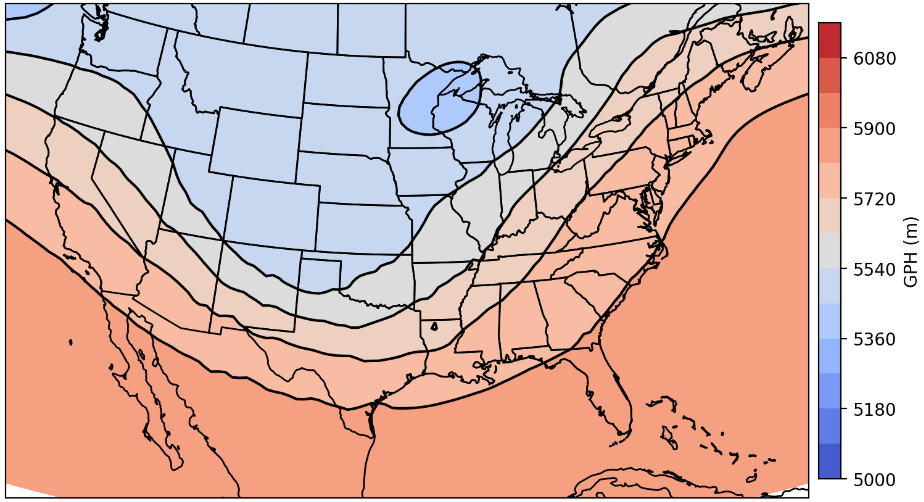
Search Example

Find the most similar catalog entries for this high-cost event

500 hPa GPH on April 27th 2011



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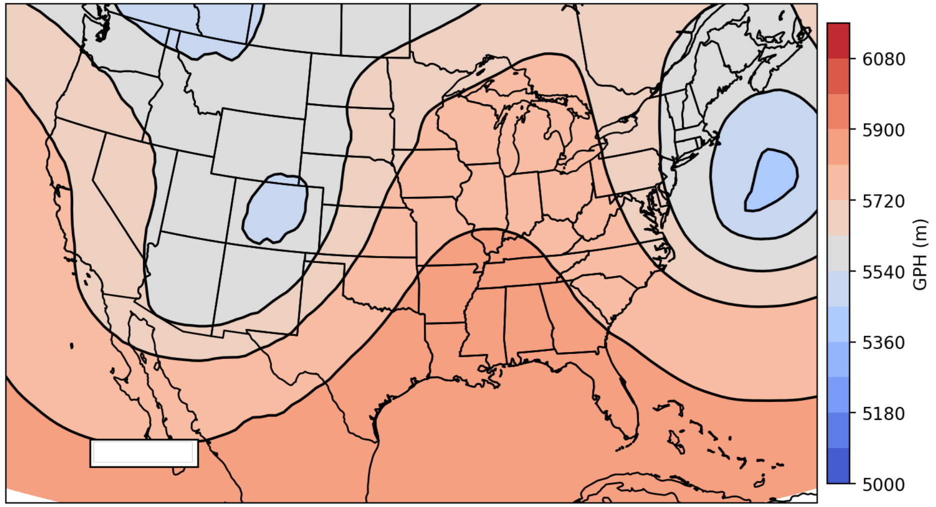

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Search Example

Find the most similar catalog entries for this high-cost event

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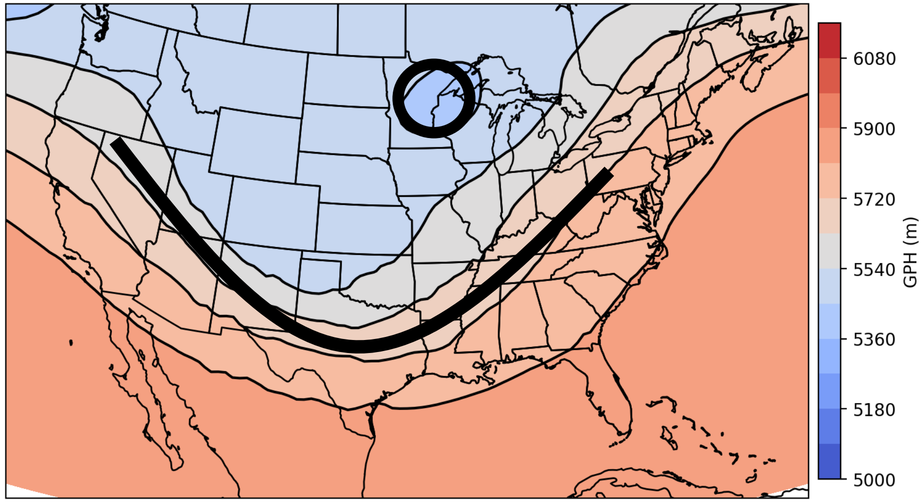

Access Spatial Index

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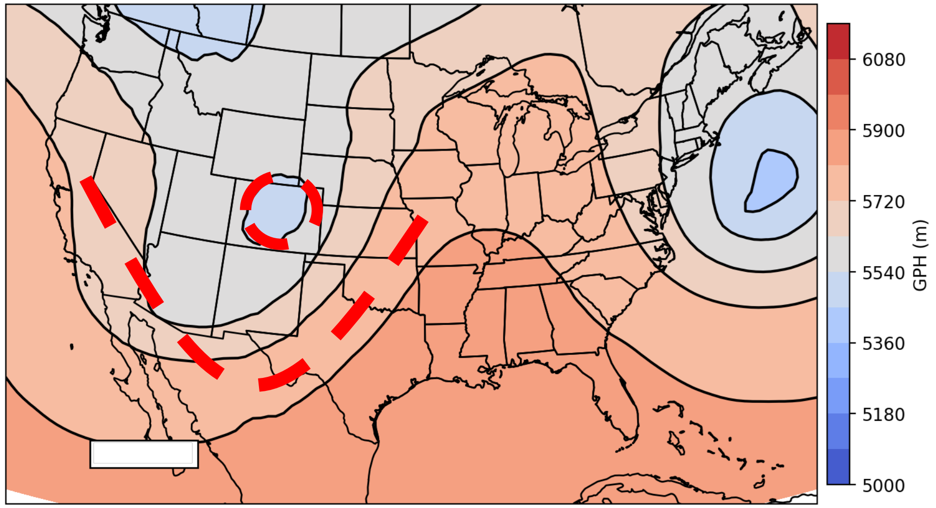

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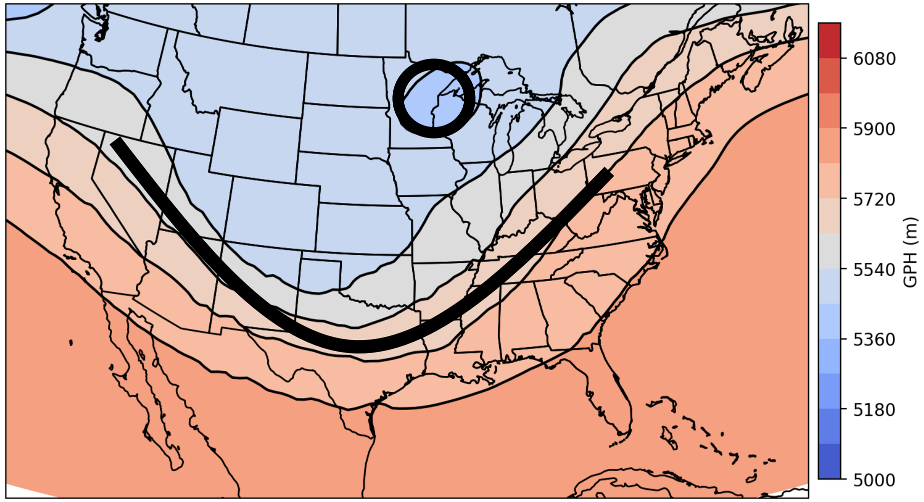

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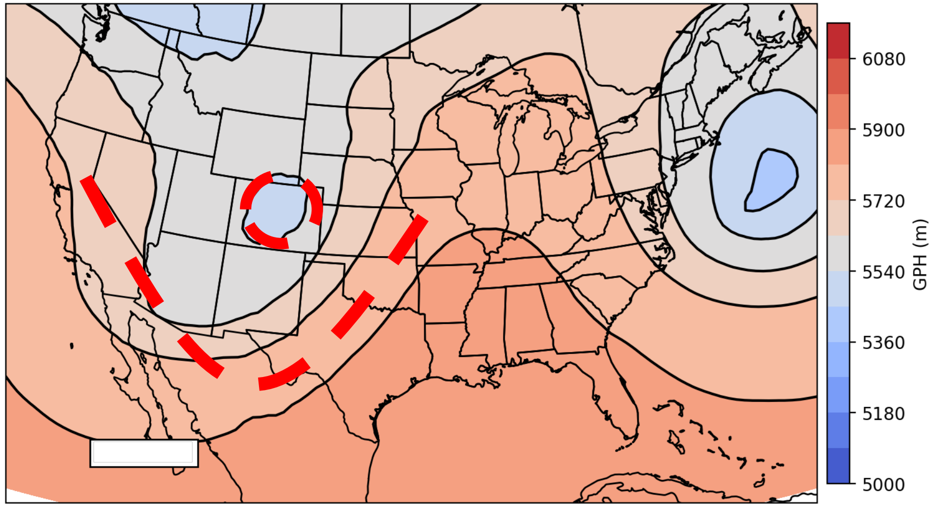

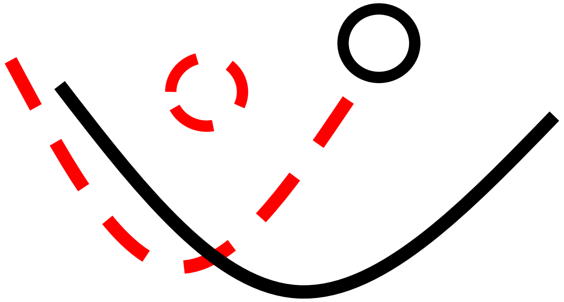

Compare Spatial Indexes

Good

Match

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Project Outcome / Deliverables

- The overall outcome of this project will be a pre-competitive catalog of relevant and “plug-and-play” data to be used in statistical and/or dynamical risk models
- Specifically, the deliverables are as follows:
  1. Catalog of spatiotemporally-relevant weather variables and risk information associated with synoptic regimes:
     - Event date, location, spatiotemporal HCW risk, building and population exposure estimates, and synoptic regime classification
     - Data-driven representation of reanalysis variables
  2. Report of prediction skill based on catalog data at various lead times
  3. Examples of applications

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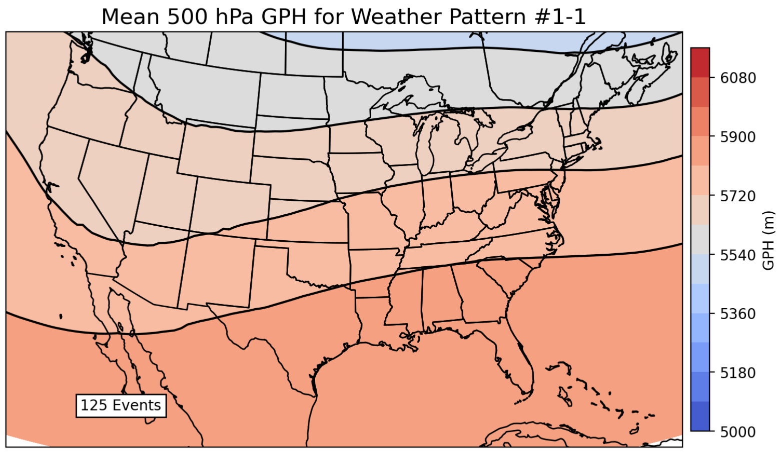
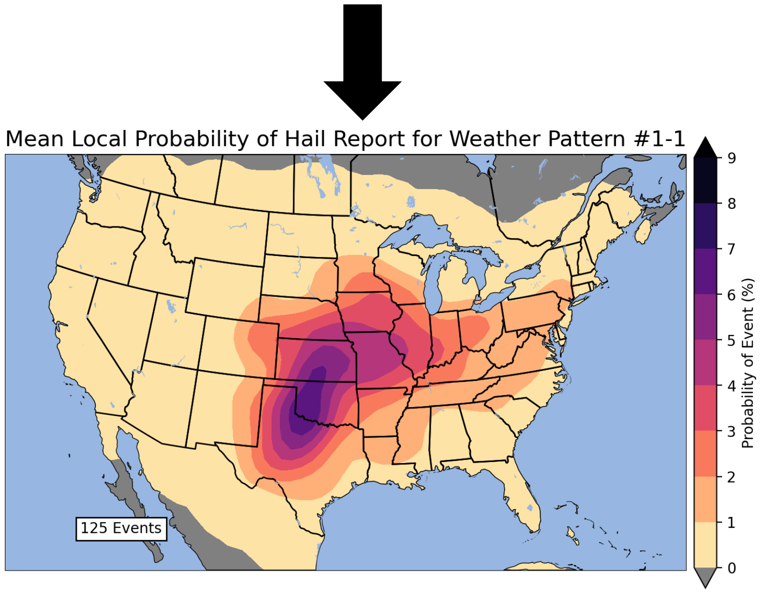
Project Impact

- The intended impact of this project is to provide a catalog of HCW events and pertinent information to be used in decision models
- Reduced uncertainty would reduce near- and long-term losses through informed mitigation strategies
- Searchable spatial indexing simplifies the process of scenario simulation





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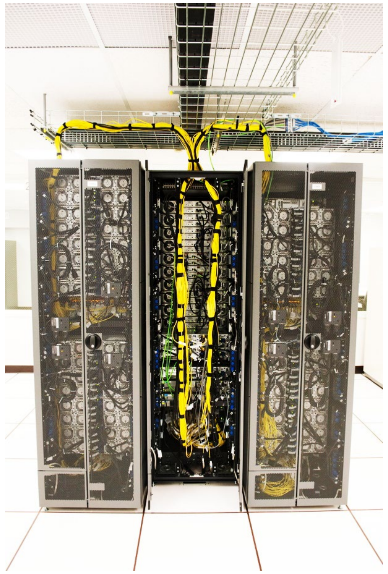
Project Duration

- **We anticipate the project will take 1 year to complete:**
  - Data procurement: January 2025
  - Data preprocessing: February 2025 – April 2025
  - Data-driven analyses: April 2025 – August 2025
  - Finalize catalog and assess utility: May 2025 – December 2025



NIU Computing Resources

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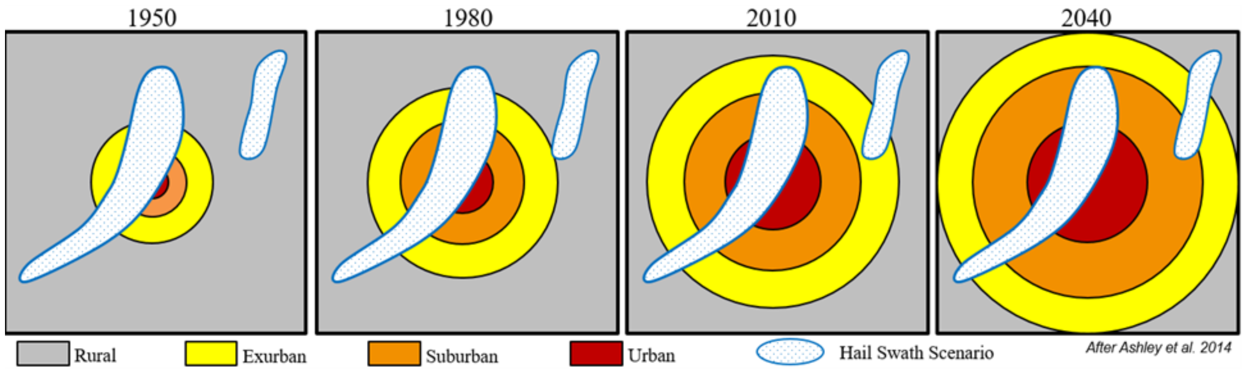
Simulating Historical and Potential Future Hail Impacts on Exposure Surfaces



Stephen M. Strader, Ph.D.; Associate Professor; Villanova University

Walker S. Ashley, Ph.D.; Professor; Northern Illinois University

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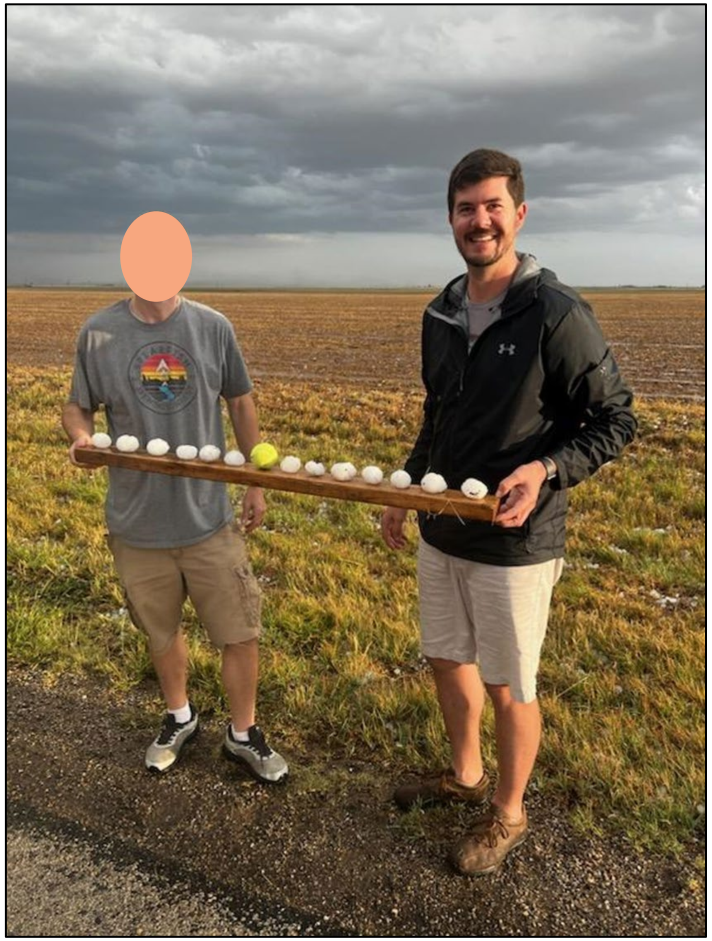
The Emerging and Escalating Challenge of SCSs

- **70%** of global insured losses driven by SCSs (Aon)
- SCS losses are increasing at an annual rate **of 9 to 10%,** which is more than double all perils (Aon, Insurance NewsNet)
- In 2022 and 2023, **$60 billion** in SCS losses with **hail comprising over 50% of those losses** (Insurance Information Institute, Gallagher Re)
- **Hail the costliest** of SCSs (Zurich)



Is hail really a *secondary* loss?

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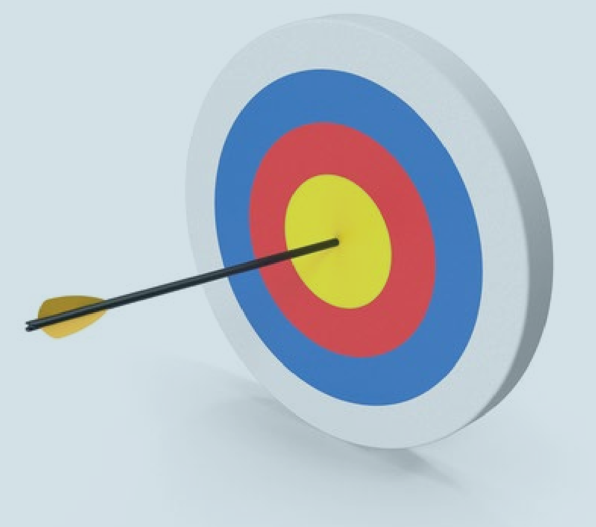
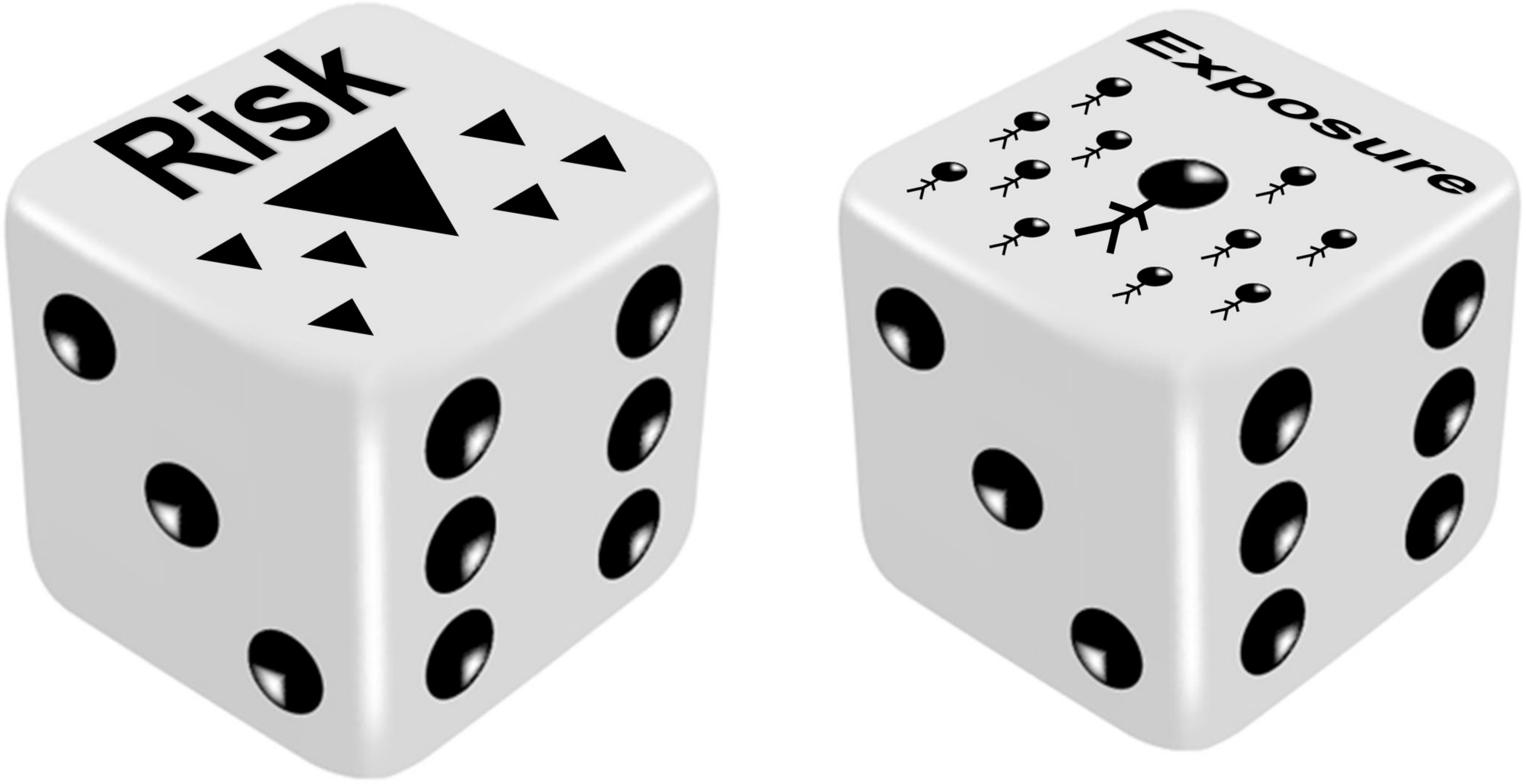
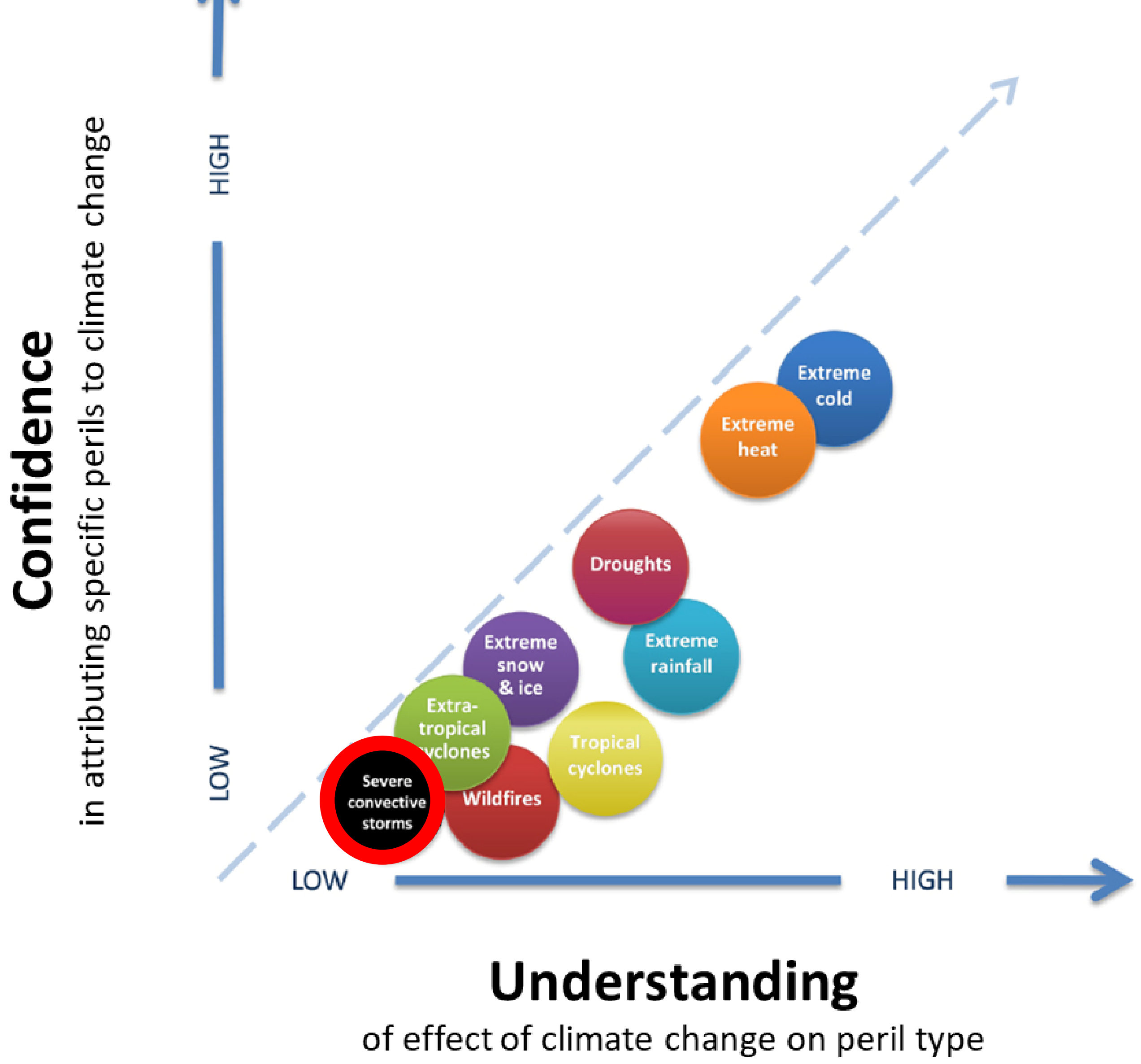
Root Causes



Need and Relevance





After Kunkel et al. 2013; NAS 2016

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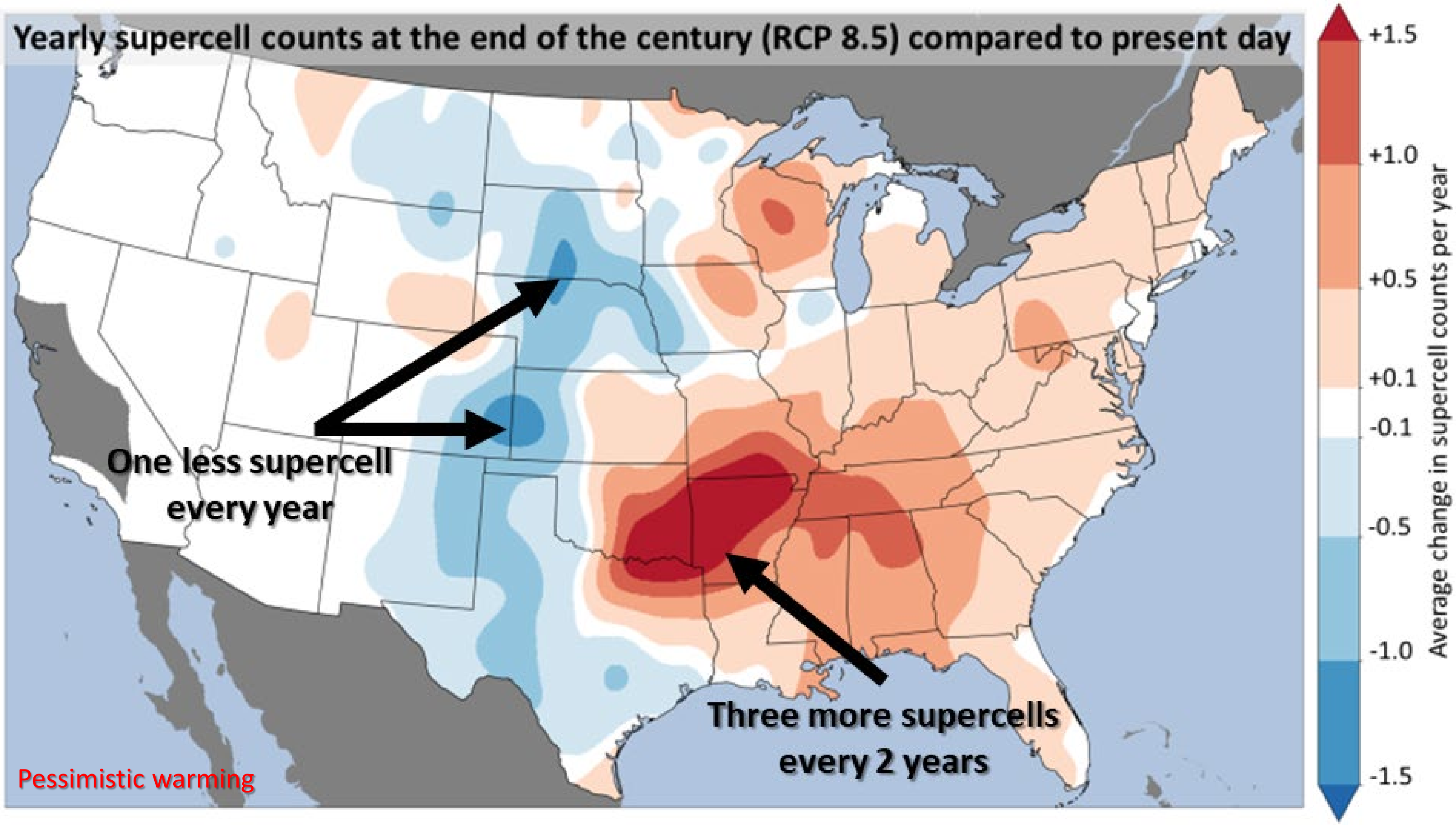
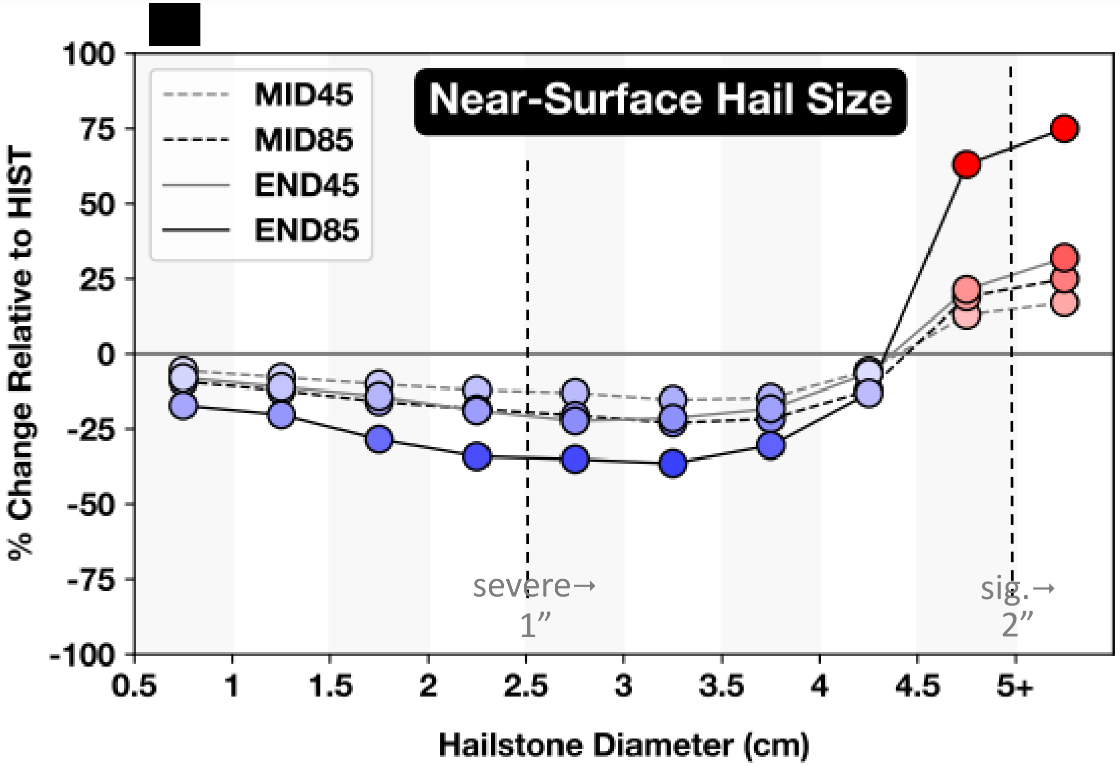
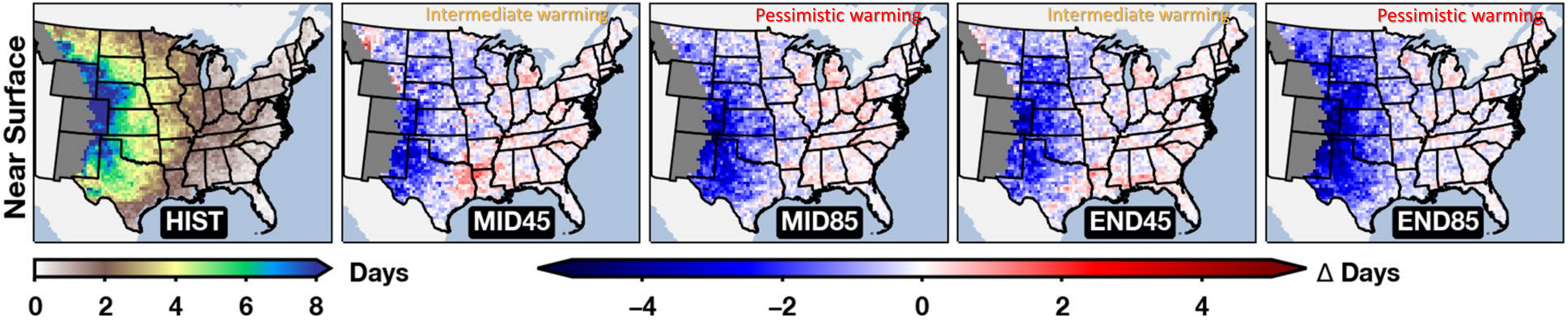


Ashley et al. 2022: *BAMS*

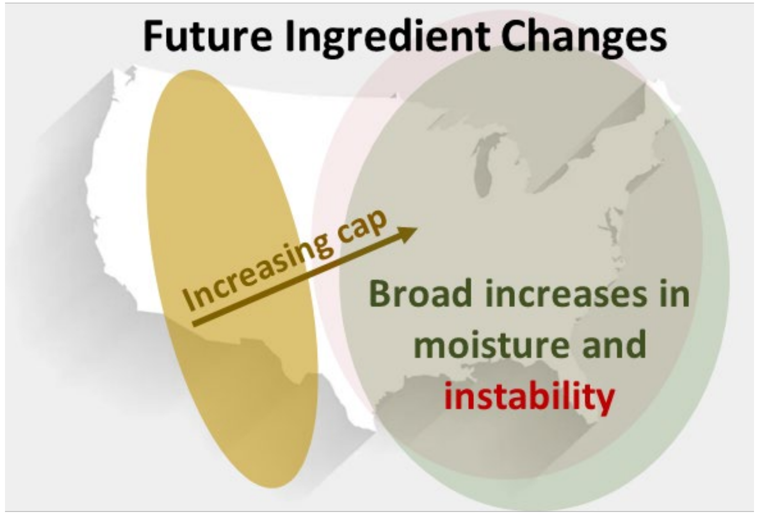


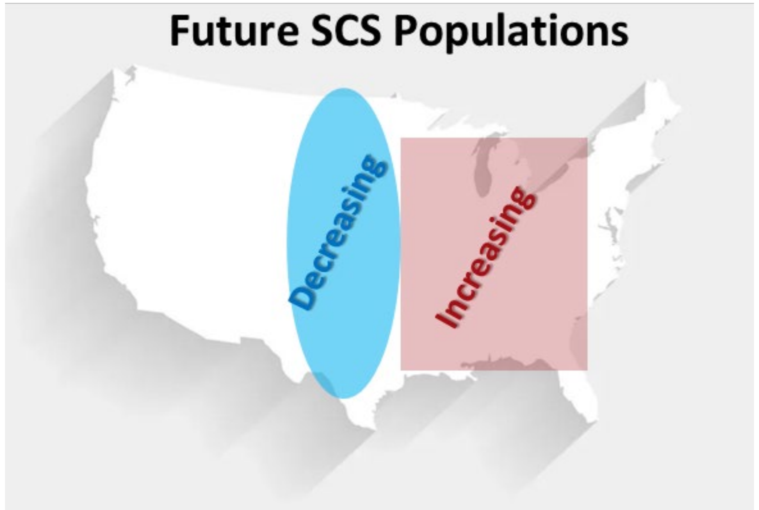
Changes in Annual Near-surface Severe (>1”) Hail Days: Historical (HIST) vs. MID and END of 21st century



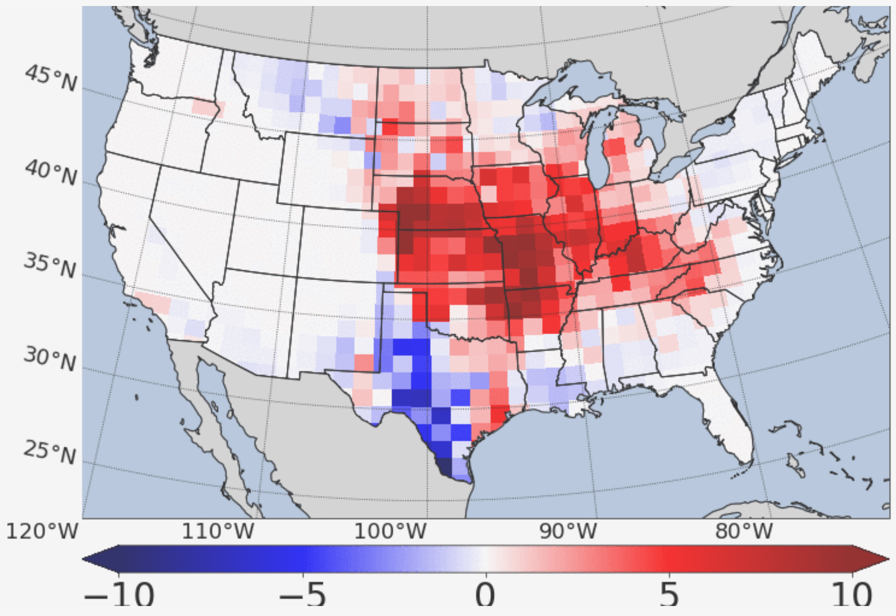
Gensini et al. 2024: *npj Climate and Atmos. Sci.*

Need and Relevance





Projected **Annual** # Days Supportive of 2” **Hail**



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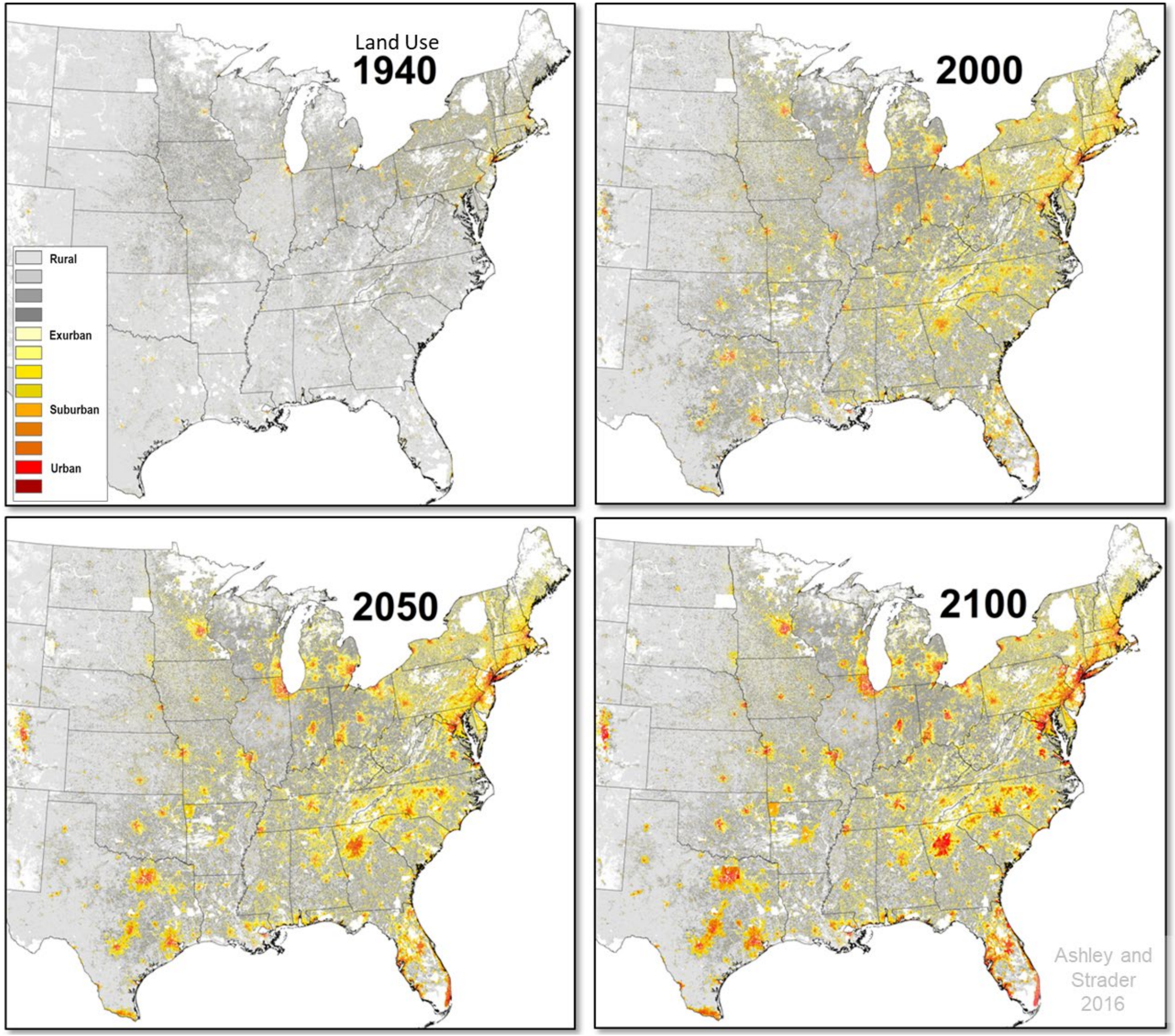
Population more than doubled the past 80 years

Since 1950, housing increased nearly 350%

Transitioned development character

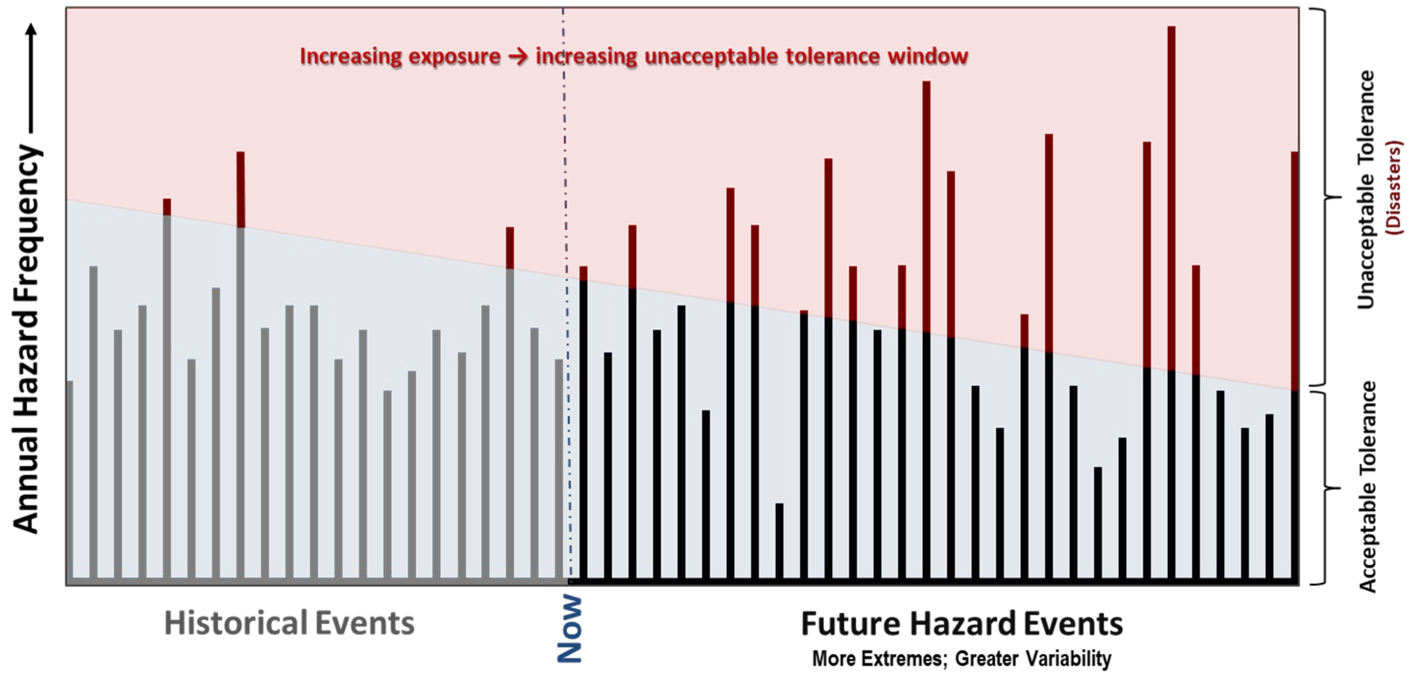
Urban footprint 5X

in 1940, 2.5% of land developed; by 2100, 18%



Project Goals

- Leverage existing (and new!) tools and datasets—e.g., Monte Carlo tool and weather simulation outputs—to understand how the hail disaster landscape will change
- Explore how changes in climate system *and* built-environment will shape future hail losses **over different time horizons**



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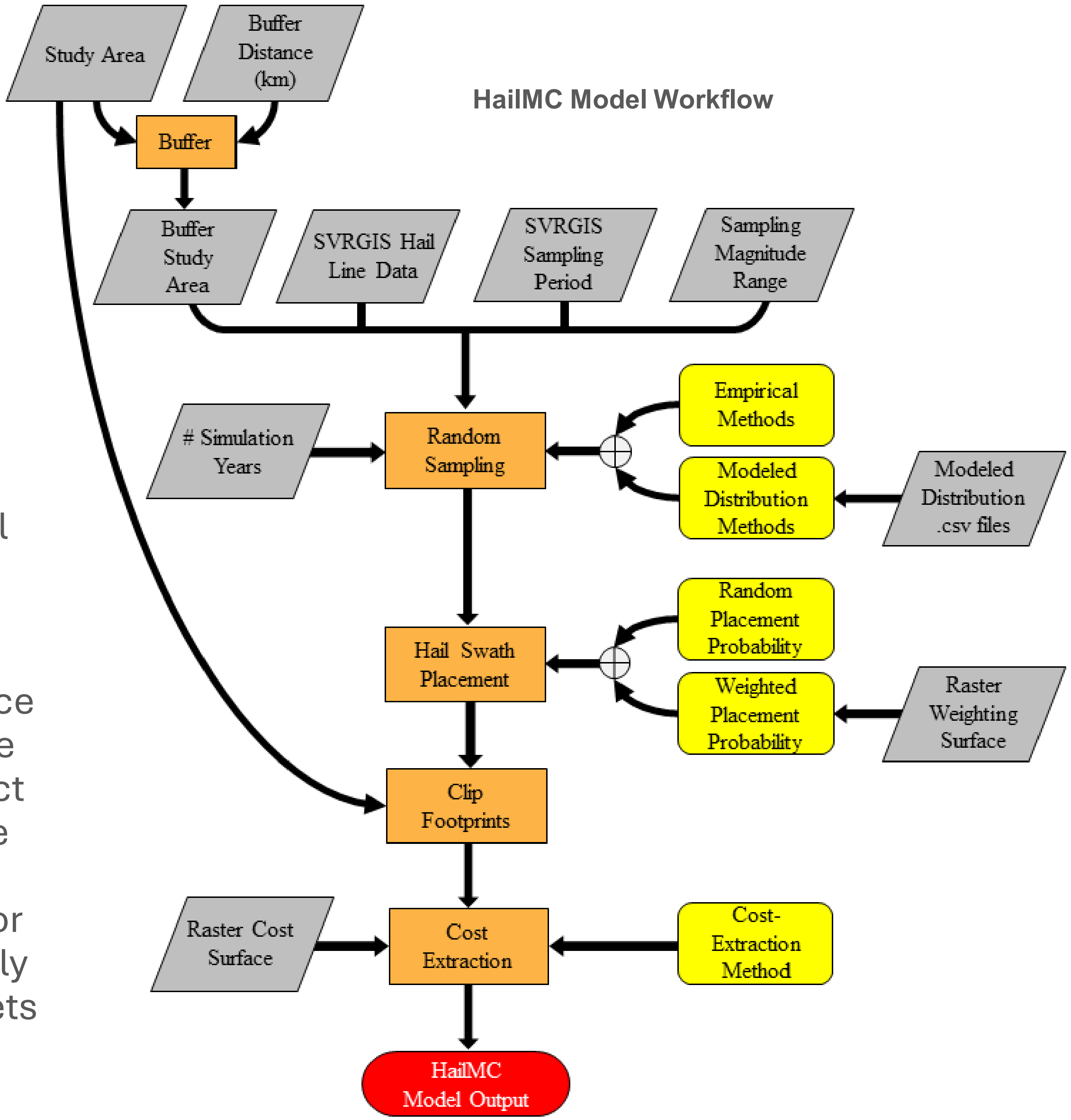
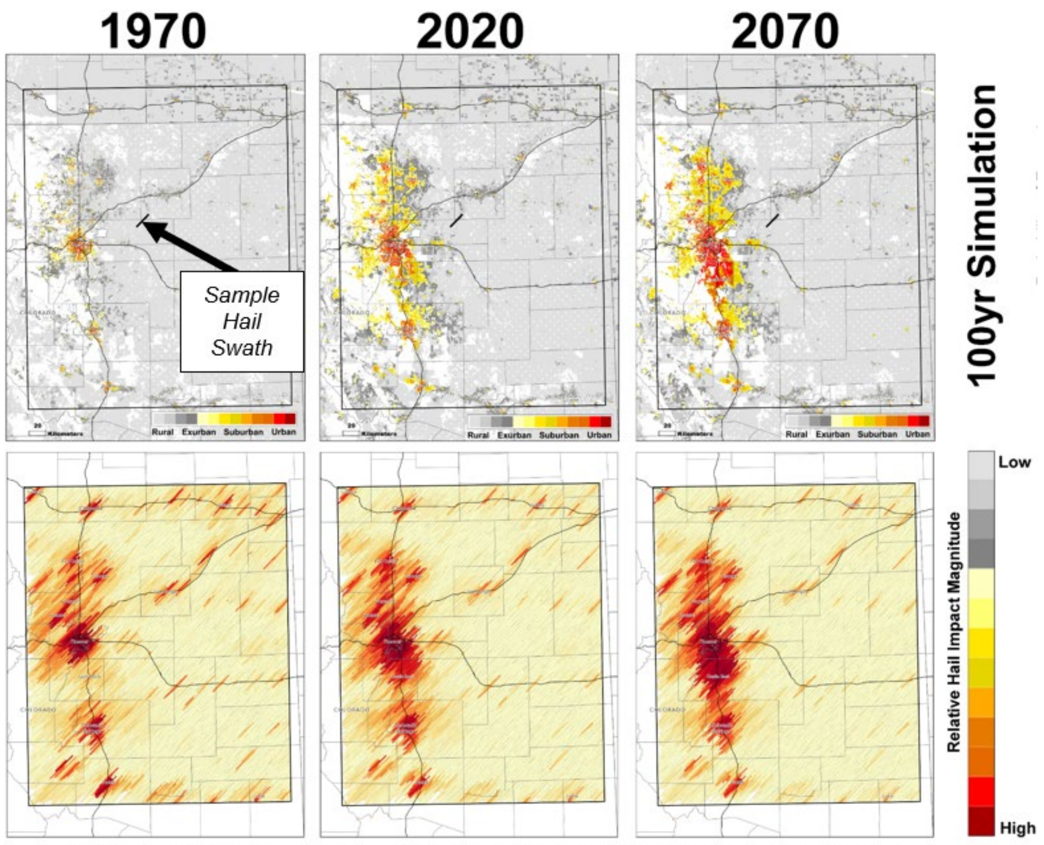
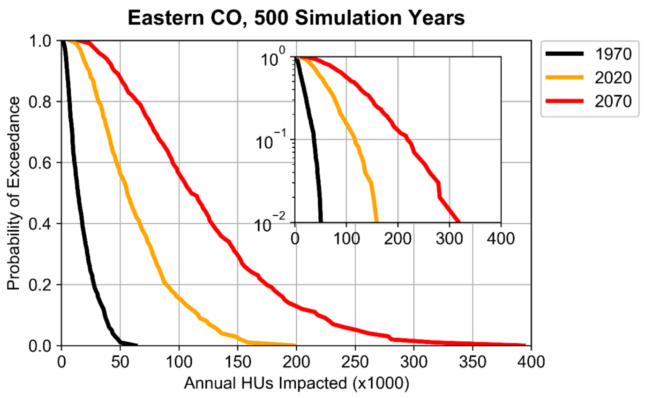
Hail Impact Monte Carlo Model

Simulates hail events atop a user-defined domain and exposure surface to estimate the possible impact on people, the built-environment, or other potentially vulnerable assets





Sample HailMC simulations atop housing unit density for 1970, 2020, and 2070.



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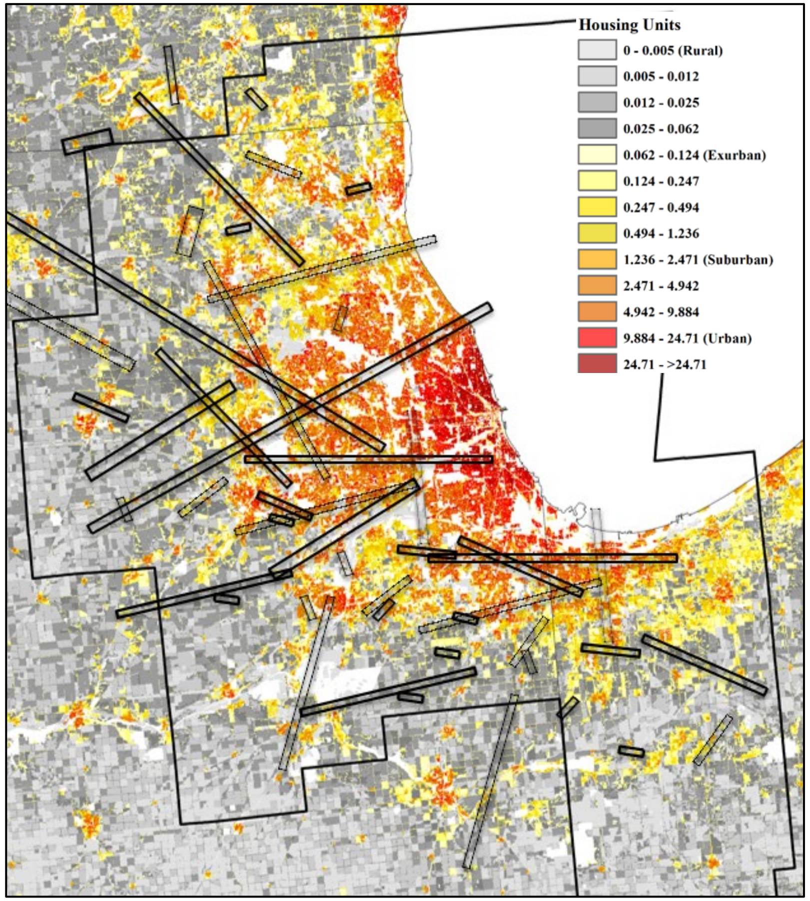
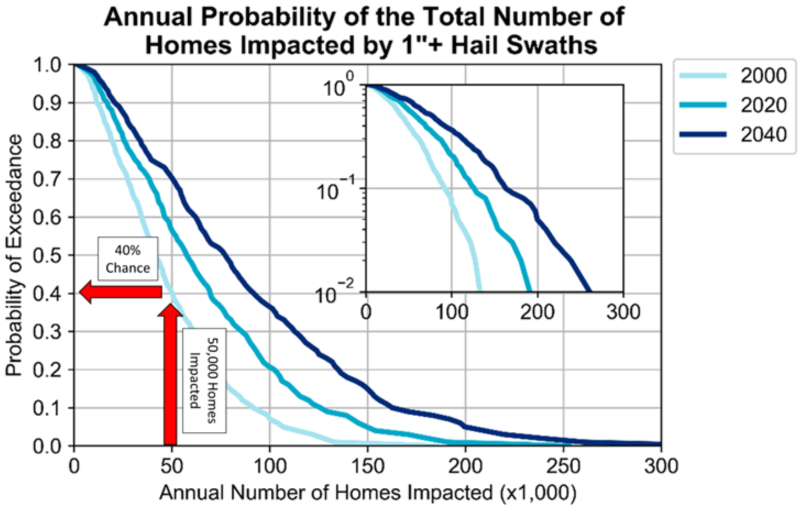
Objectives

1. Assess the influence and possible consequences of a **changing climate** on hail impact potential across region of interest
2. Assess the influence and possible consequences of a **changing built-environment or other exposure surface** on hail impact potential
3. Develop a more complete understanding of how hail disasters have and may potentially change in the upcoming decades across region of interest

Sample Study Domain





Modeled total annual number of homes (housing units; x1,000) affected by 1"+ hail swaths by development year

Impact Year	Median	Mean	Std. Dev.	95th Percentile	99th Percentile
2000	64.1	68.4	60.1	187.2	234.3
2020	75.9	80.5	50.8	200.9	245.7
2040	80.3	85.2	70.7	228.0	310.6

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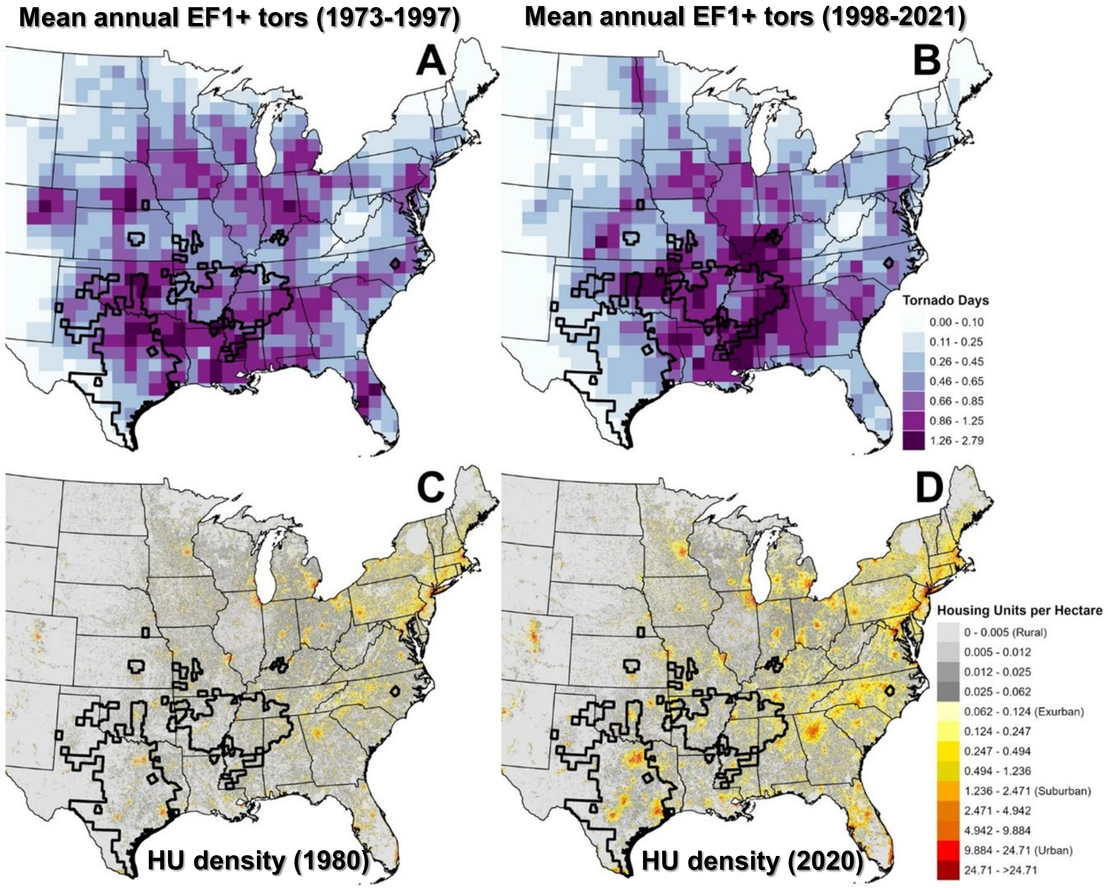
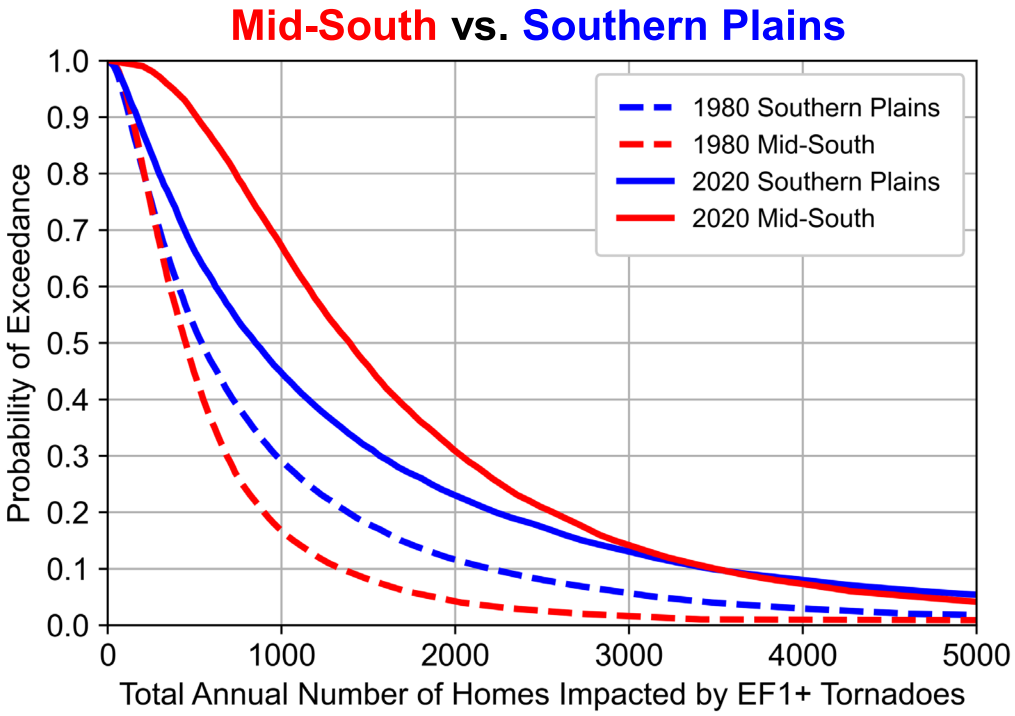
Sample Results from TorMC

What's driving regional losses? Climate or exposure shifts





Strader et al. 2024 *npj Natural Hazards*

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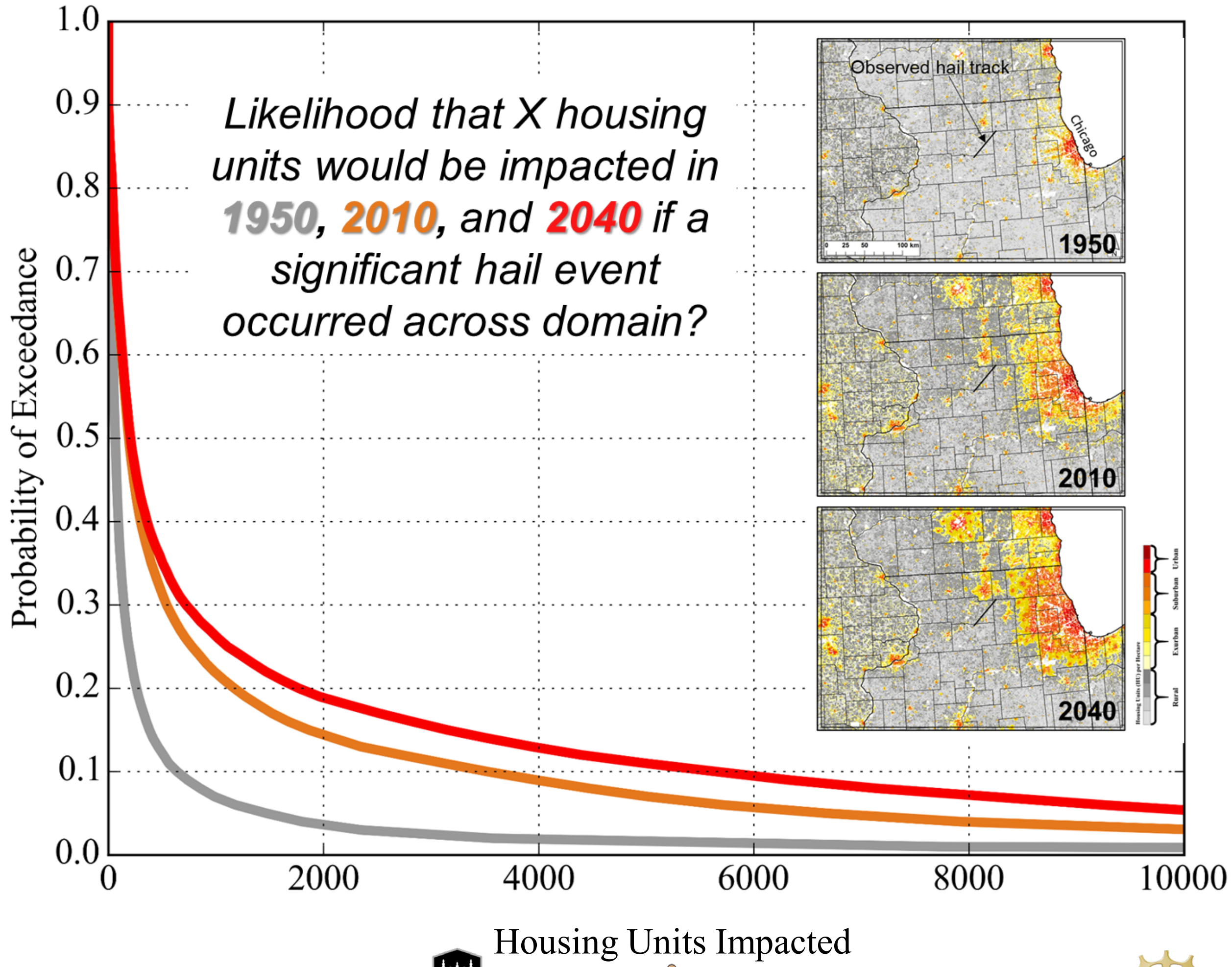
Project Outcomes and Deliverables

- Difference: Our focus is on **change**, not a singular slice in time; not a black box; can modify to examine user-defined hypotheticals

- Outcomes:
  - Employ existing exposure datasets to assess a user's current exposure and potential **future** exposure should book change
  - Ultimately, generate a better understanding of drivers of hail losses … i.e., **who is in the driver seat: climate or exposure?**
  - Determine geographies where hail impact potential has and will change the most in the future

- Products: POE curves, maps of disaster variables, statistics on potential exposure and losses, etc. You dream it, we can deliver it.



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Impact

- **Incorporate** both climate mode/change-driven effects and societal growth
- **Quantify** future hail loss potential on a variety of exposed entities
- **Identify** areas where resilience building efforts are in need
- **Adjust** policies, exposure, premiums, etc., to reduce potential impacts on bottom line

- Expected project duration is 1 year depending on research questions, geographical extent(s), and existing inputs

- Work could be expanded to other perils:
  - Tornado Impact Monte Carlo Model (TorMC)
  - Wind Impact Monte Carlo Model (WindMC)
  - Wildland Fires
  - Flooding
  - Tropical Storms

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Stochastic Modeling of Convective Hazards for Uncertainty Quantification and Climate Projection

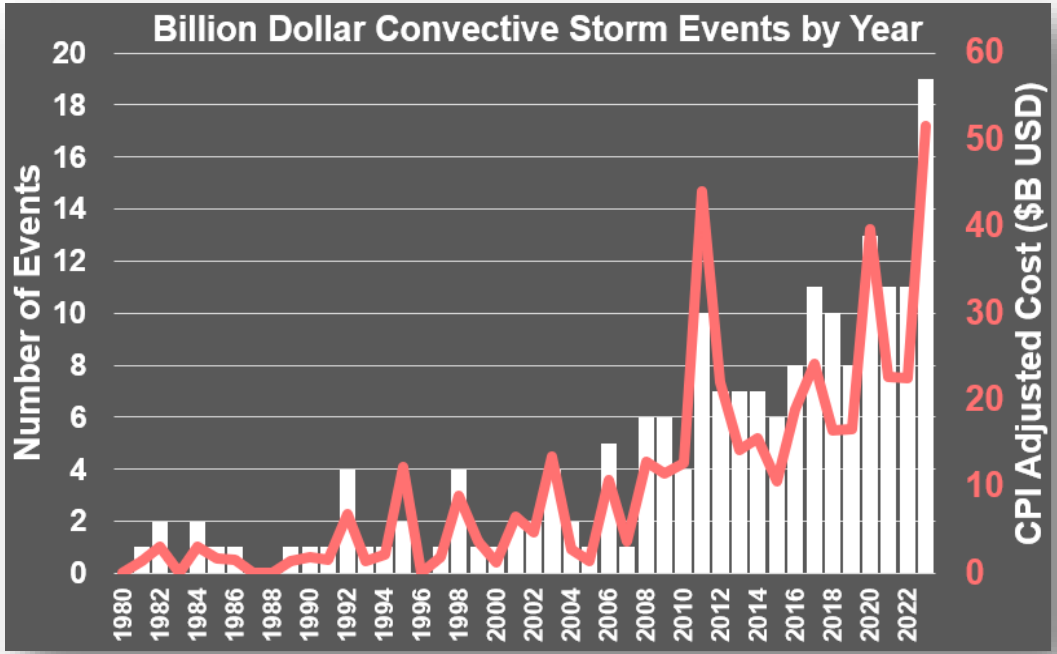
Lead PI: Daniel Wright (UW-Madison)

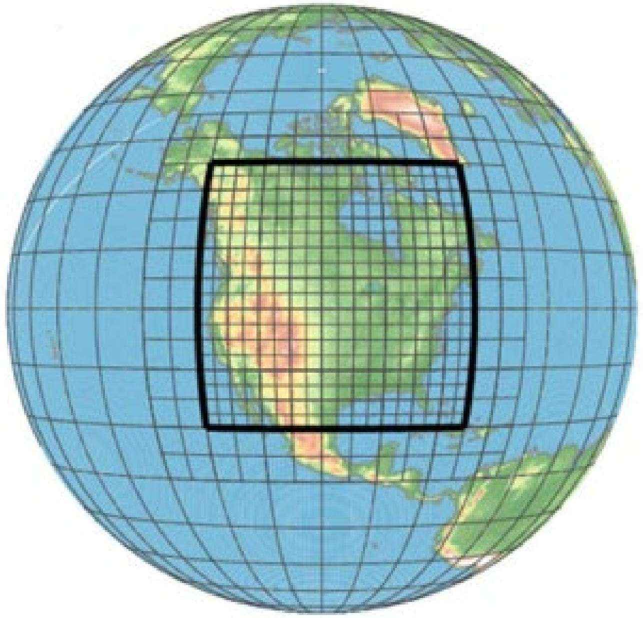
Co-PIs:

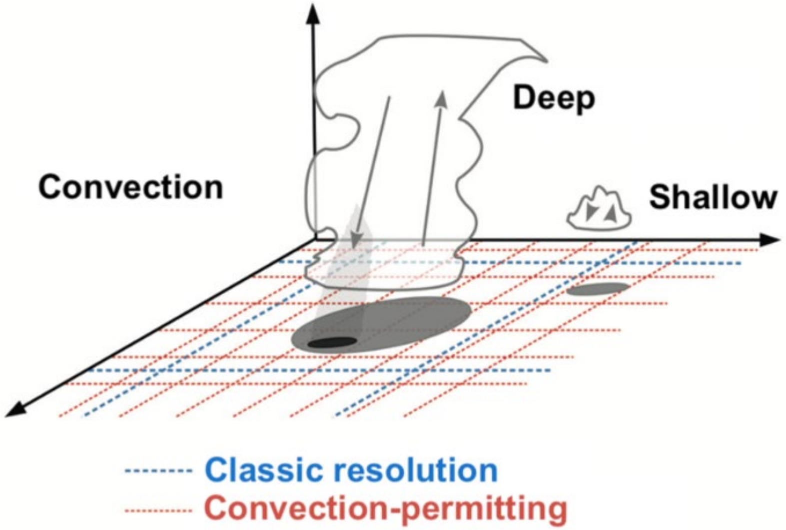
Angela Rowe, Kyle Cranmer (UW-Madison)

Victor Gensini, Walker Ashley (NIU)

Need and Industrial Relevance







Climate and changes in the human environment are driving up losses from convective storms

- Assessing & pricing risk based on historical experience is becoming more problematic
- Insights from physical science-based models are increasingly important for lead times of hours to decades
- Despite rapid improvement, these models have considerable uncertainties, high computational costs, and/or coarse resolution

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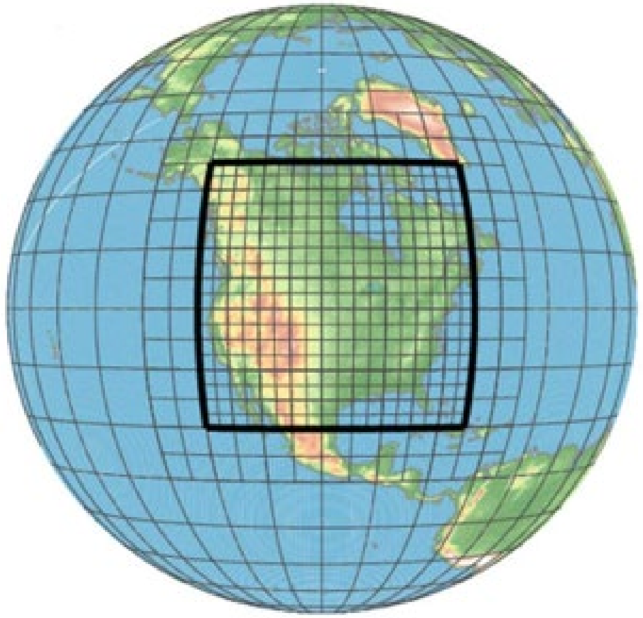
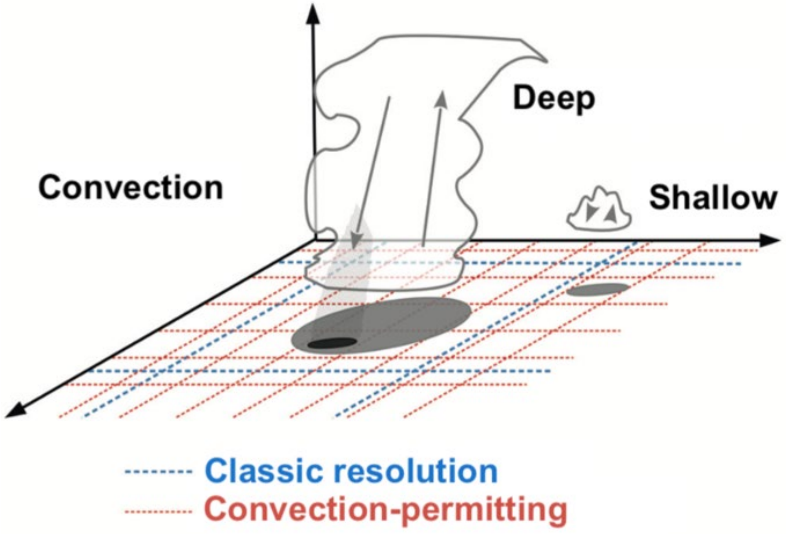
Project Goals



1. Create **<u>fast</u>** uncertainty quantification (UQ) and stochastic downscaling framework for convective hazards **<u>at decisionmaking scales</u>**
2. Better understand strengths and weaknesses of coarse, intermediate, and high-resolution weather/climate models for prediction of rainfall, hail, and winds
3. Help meet other CIRCS projects' data needs



NOTE: Seed funding has been provided by American Family Insurance via their funding partnership with UW-Madison's Data Science Institute

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Objectives

1. Enhance hazard predictive capability across model resolutions and types; **working with center members to prioritize**:
   - Areas/resolutions of interest: e.g., global vs. USA
   - Hazards of interest: e.g., rainfall vs. hail
   - Applications: short-term forecasts vs. seasonal or long-term climate projections
2. Adapt existing open-source StormLab software* to maximize flexibility across applications
3. Support other center projects with UQ and large **“synthetic event sets”**

*Liu, Y., Wright, D. B., & Lorenz, D. J. (2024). A nonstationary stochastic rainfall generator conditioned on global climate models for design flood analyses in the Mississippi and other large river basins. *Water Resources Research;* https://github.com/lorenliu13/StormLab

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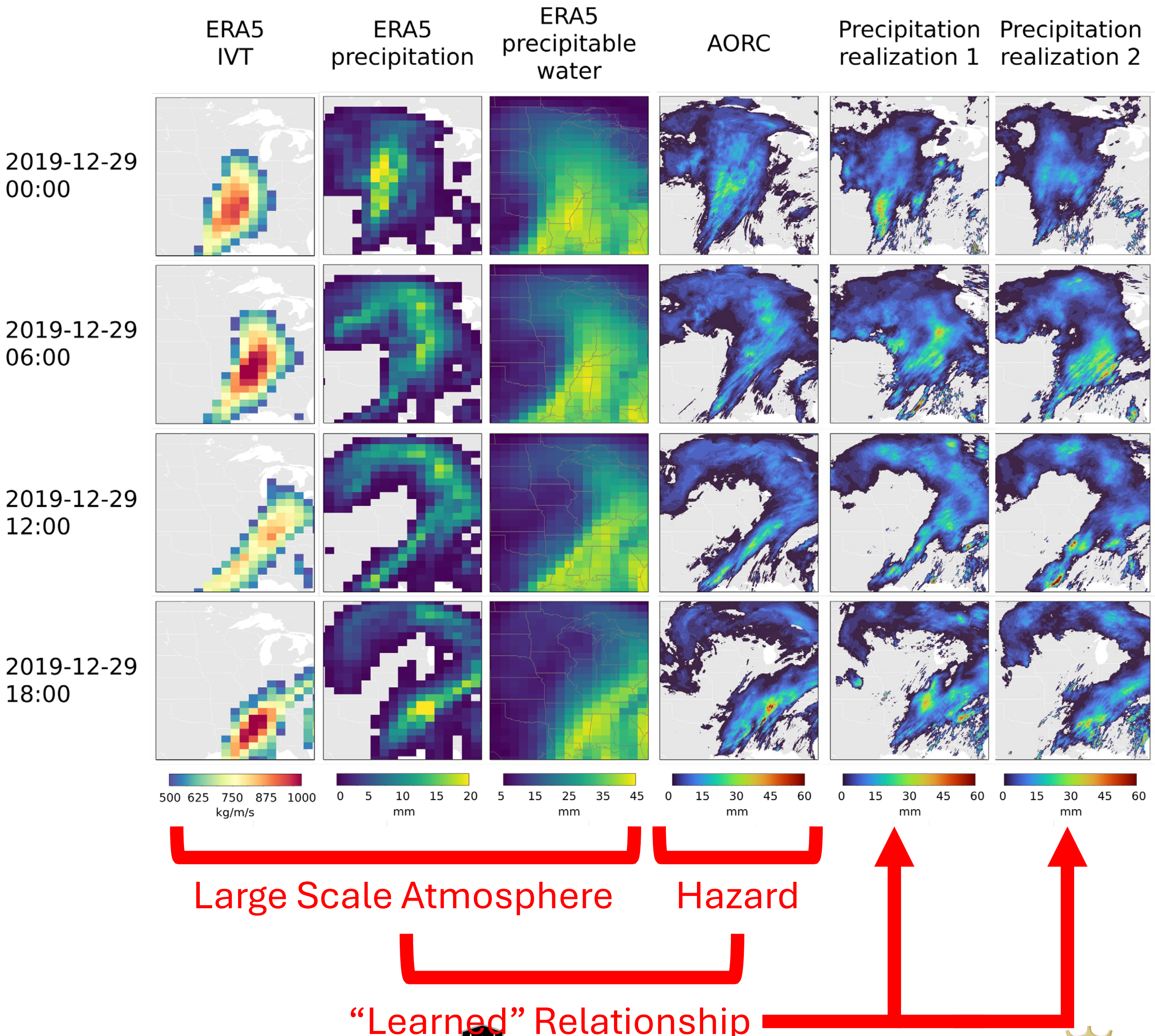
Approach

Key point: Convective hazards are fine-scale phenomena embedded in larger-scale atmosphere

- Large scale provides important but insufficient info on fine-scale hazards
- Multiple fine-scale outcomes are possible for a given large-scale condition
- By "learning" what is possible, we can **quickly simulate many plausible fine-scale hazard possibilities** based on large-scale model predictions



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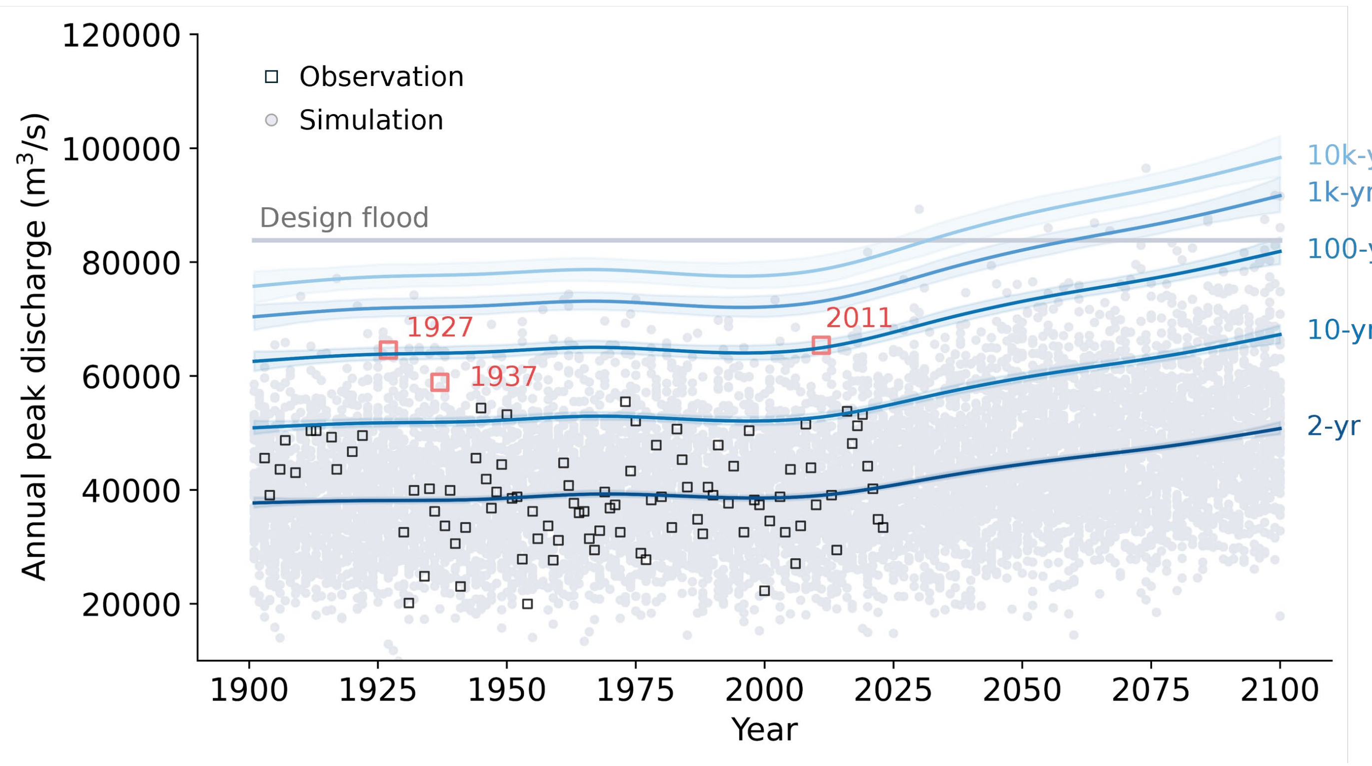
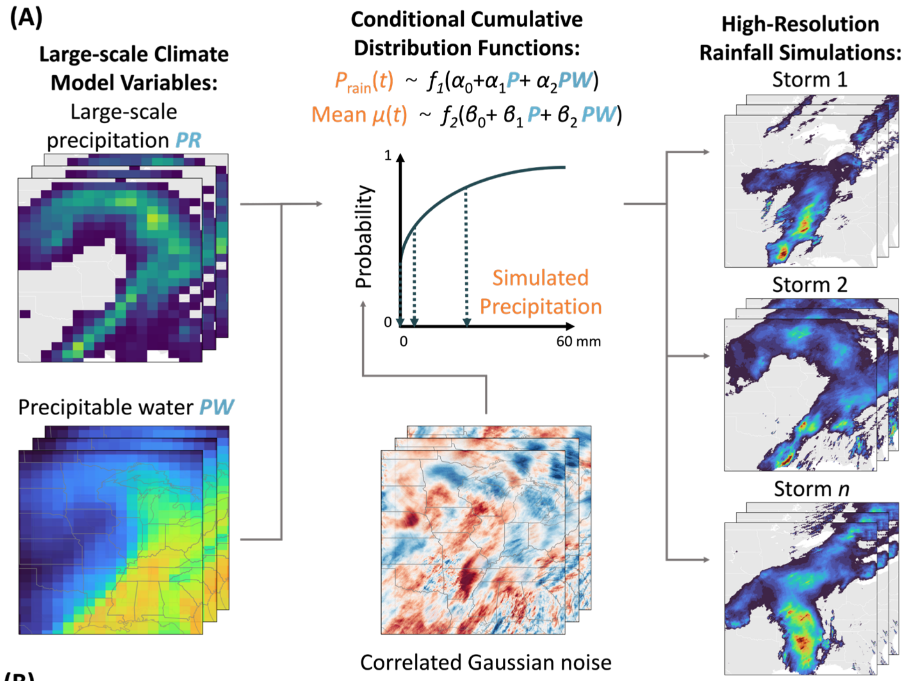
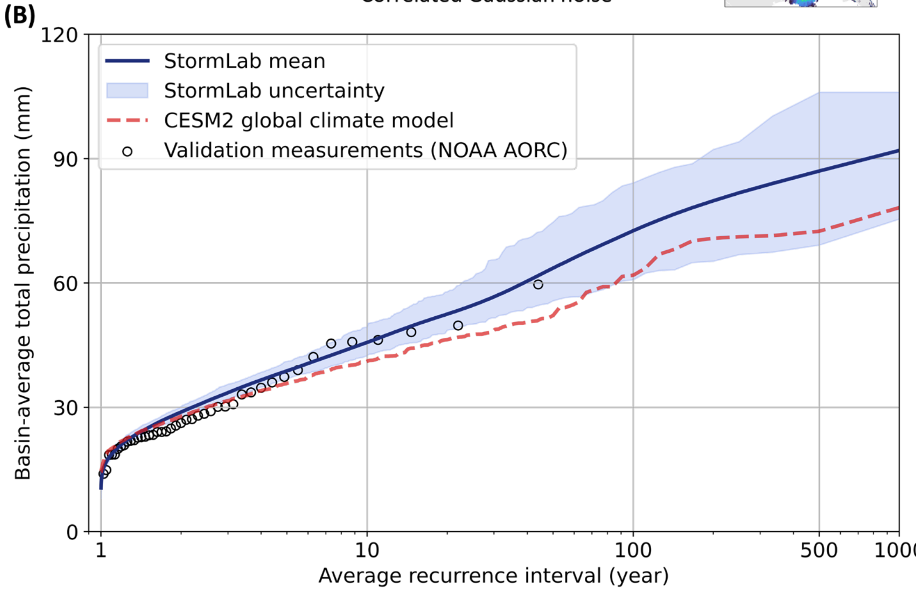
Approach

Recent work: estimating past/present/future rainfall and flood return periods for Lower Mississippi River based on a large archive of climate model projections

(a)







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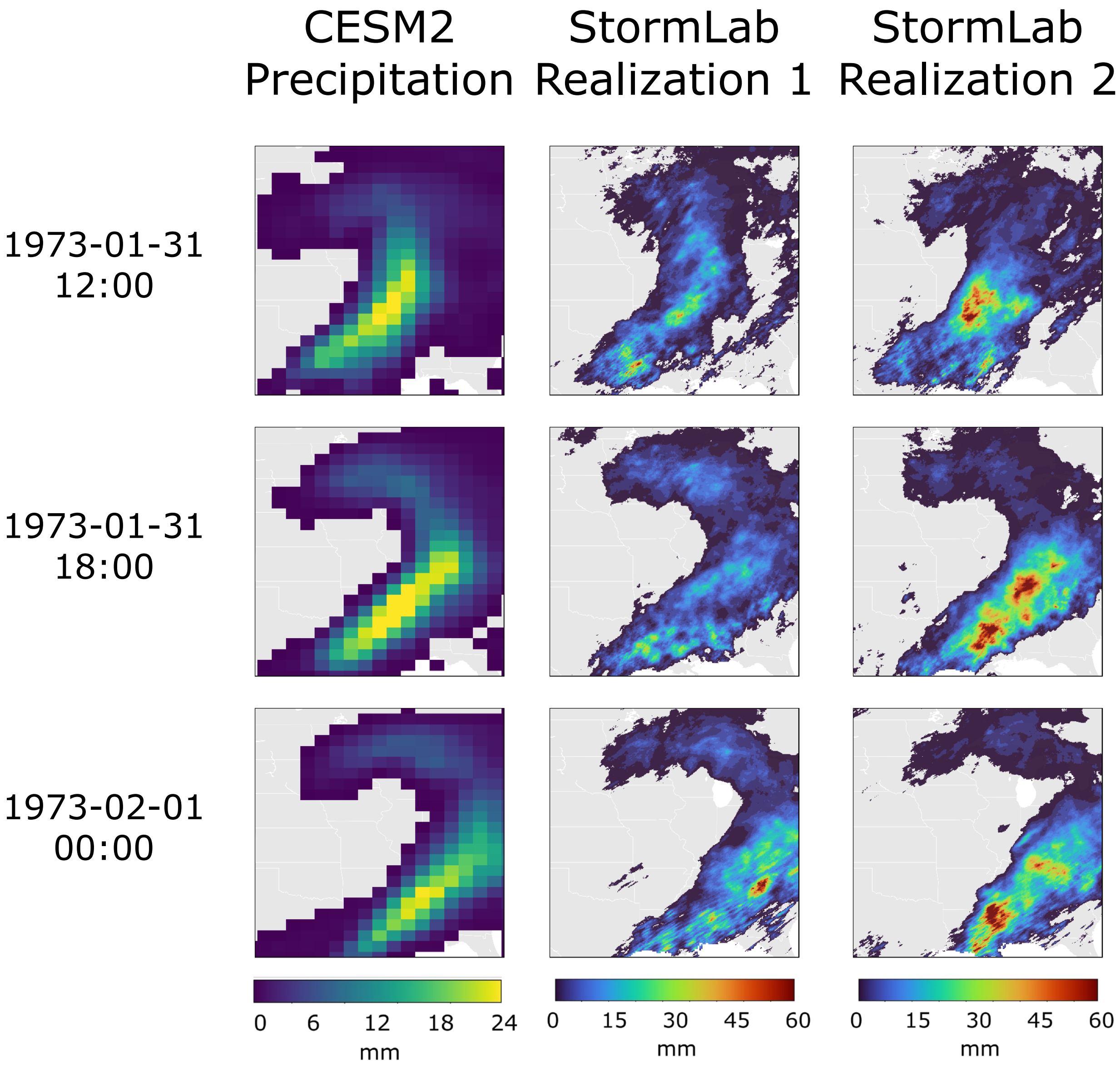
Outcomes/Deliverables

1. **Large synthetic event sets for priority hazards & regions**
   →Support member initiatives and other CIRCS projects
2. **Open-source codebase (Github repository) with examples and documentation**
   →Members and CIRCS PIs can apply in new contexts
3. **Better understanding of the SCS “information content” in a range of weather/climate models**
   →Work w/ Data Science Institute on opportunities for AI/ML enhancement



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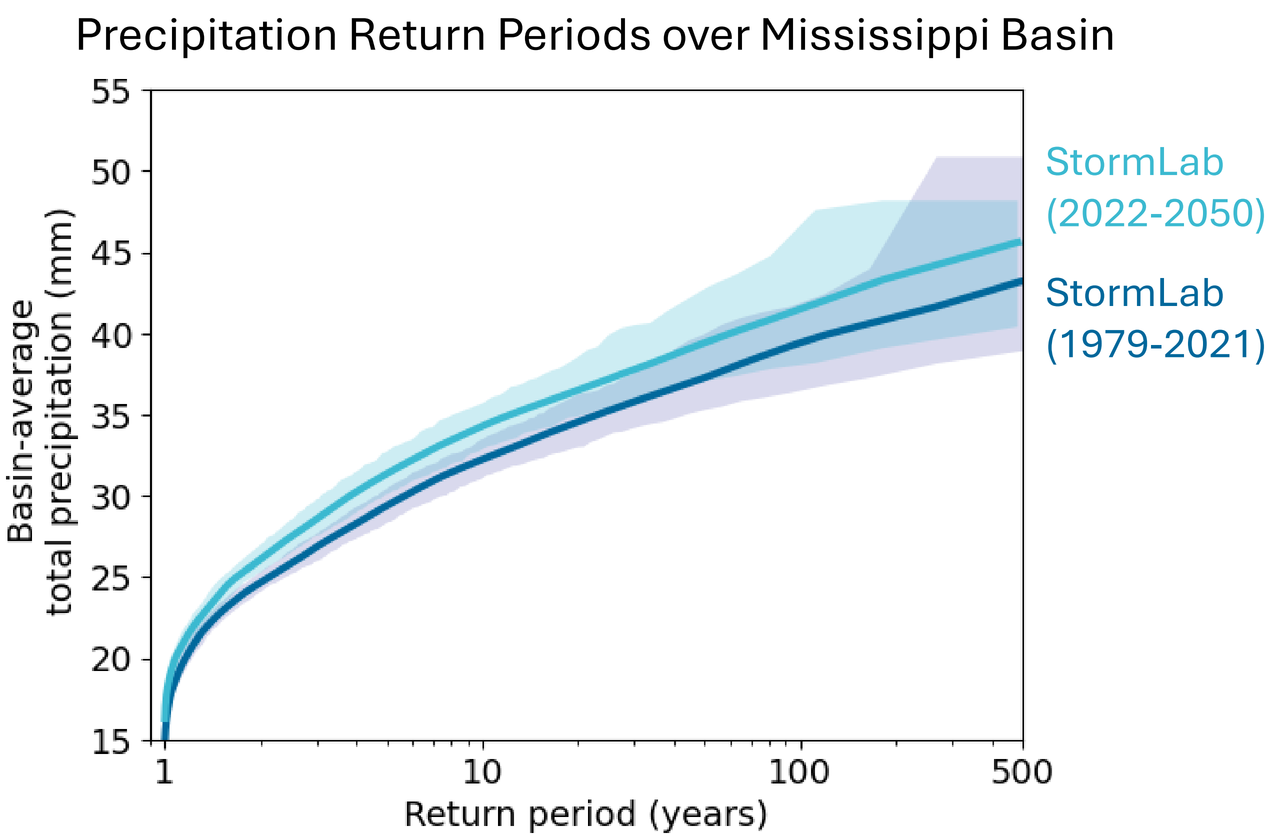
Impact

1. **Flexible, computationally lightweight tool for members & broader community**
   - **Examples:**
     - Estimating changing return periods of rainfall/floods
     - Enriching National Weather Service short range forecasts by enhancing resolution, expanding forecast "envelope", or both
     - Lowering parametric insurance basis risk through better uncertainty quantification
2. **Enabling other CIRCS research**
   - **Examples:**
     - Predicting current/future variability in spatially-correlated hail losses (Dr. Shi)
     - Connecting large-scale weather regimes to portfolio exposure (Dr. Haberlie)
     - Supporting Monte Carlo impact simulation (Drs. Strader and Ashley)



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Project Duration & Timeline

Timeline: 1 year (Research Scientist) or 2 years (graduate student)

Months 0-3: refine work plan with industry members; adapt StormLab code

→

Months 3-6: adapt StormLab code; prepare input data

→

Months 6-9: conduct analysis

→

Months 10-12: finalize analysis and share results; assessing future directions (including AI/ML); followup with industry members

Thanks for your time and input!

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High-Resolution Modeling Catalogue of Historical Extreme Convective Events

Lead: Dr. Allison Michaelis[1]

Collaborators: Drs. Alex Haberlie[1], Victor Gensini[1], Walker Ashley[1], Daniel Wright[2], Angela Rowe[2], Peng Shi[2]

[1]Northern Illinois University

[2]University of Wisconsin-Madison

Need and Industrial Relevance

- Losses from hazardous convective weather are often concentrated over limited areas and associated with a specific event or outbreak
- It is informative to understand the historical context and peril footprints of specific events and their associated impacts

Kirkland tornado (August 2021)

Kirkland tornado damage (August 2021)

https://www.weather.gov/lot/2021aug09

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Need and Industrial Relevance

- Losses from hazardous convective weather are often concentrated over limited areas and associated with a specific event or outbreak
- It is informative to understand the historical context and peril footprints of specific events and their associated impacts
- The high-resolution modeling and the pseudo-global warming (PGW) approach is an effective way to perform impact attribution studies tailored to the needs of CIRCS members for critical events of interest
    - What would have been the actualized losses of the Palm Sunday 1965 tornado outbreak?
    - If the 1927 Mississippi Flood occurred today, how would portfolios be impacted?
- Creating a workflow for high-resolution simulations of historical extreme convective events fills a critical gap to assessing event significance and projection onto today's losses

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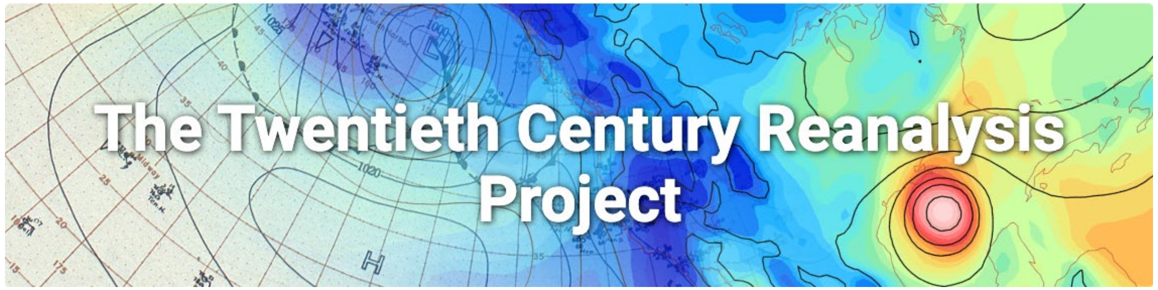
Phase I Project Goals & Objectives

- Create an event-based catalogue of simulated extreme convective events of interest to CIRCS members and actualized footprints of their perils
- Establish a workflow for conducting ensemble high-resolution simulations for historical events identified by CIRCS members
  - Taking an ensemble approach will facilitate assessment of uncertainty



Provides data from 1836–2015

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Phase I Project Goals & Objectives

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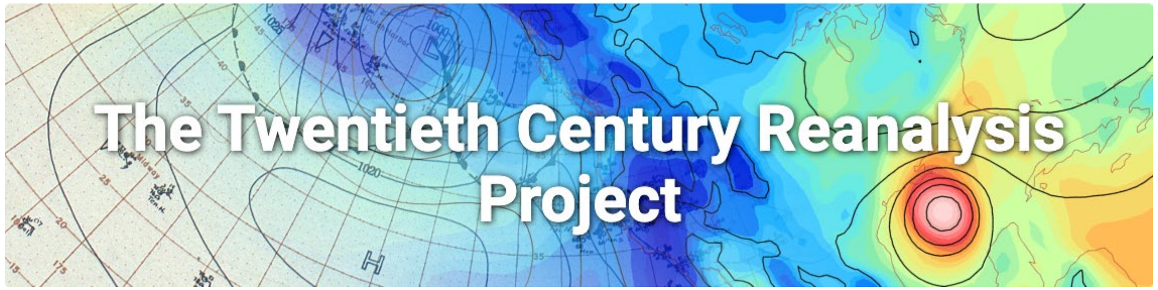
- Establish a workflow for conducting ensemble high-resolution simulations for historical events identified by CIRCS members
  - Taking an ensemble approach will facilitate assessment of uncertainty
- Create summative statistics and graphics to illustrate findings
  - Assess potential losses from historical hazards in today's world:
    - What is the footprint of flooding rainfall of the 1927 Mississippi flood and how does it project onto today's coverage?



Provides data from 1836–2015

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The Twentieth Century Reanalysis Project

Phase I Approach

Simulated Tornado Tracks for the 1925 Tri-State Tornado Outbreak

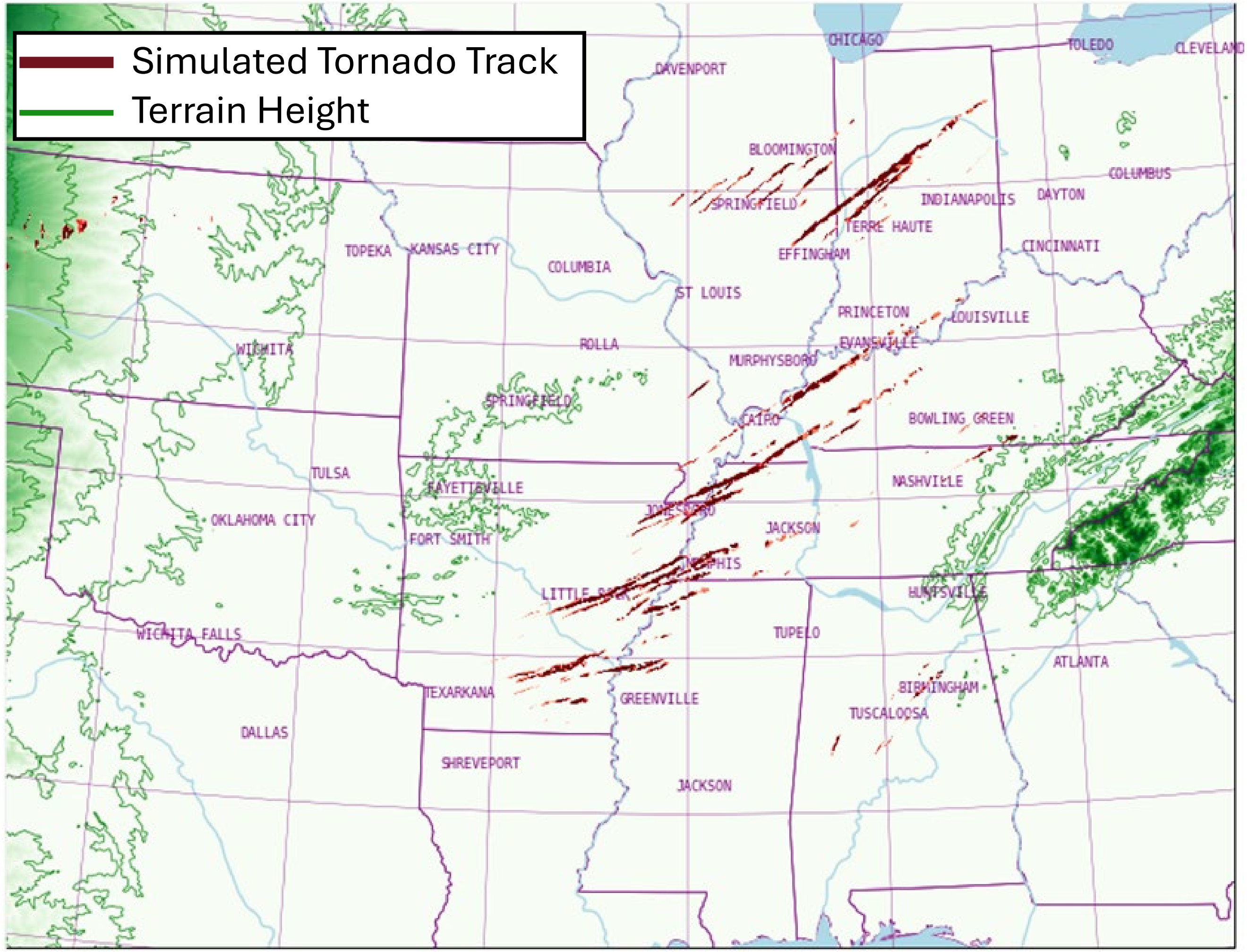

Figure courtesy of Kyle Pittman (NIU)

Observed Tornado Tracks and Hail Reports

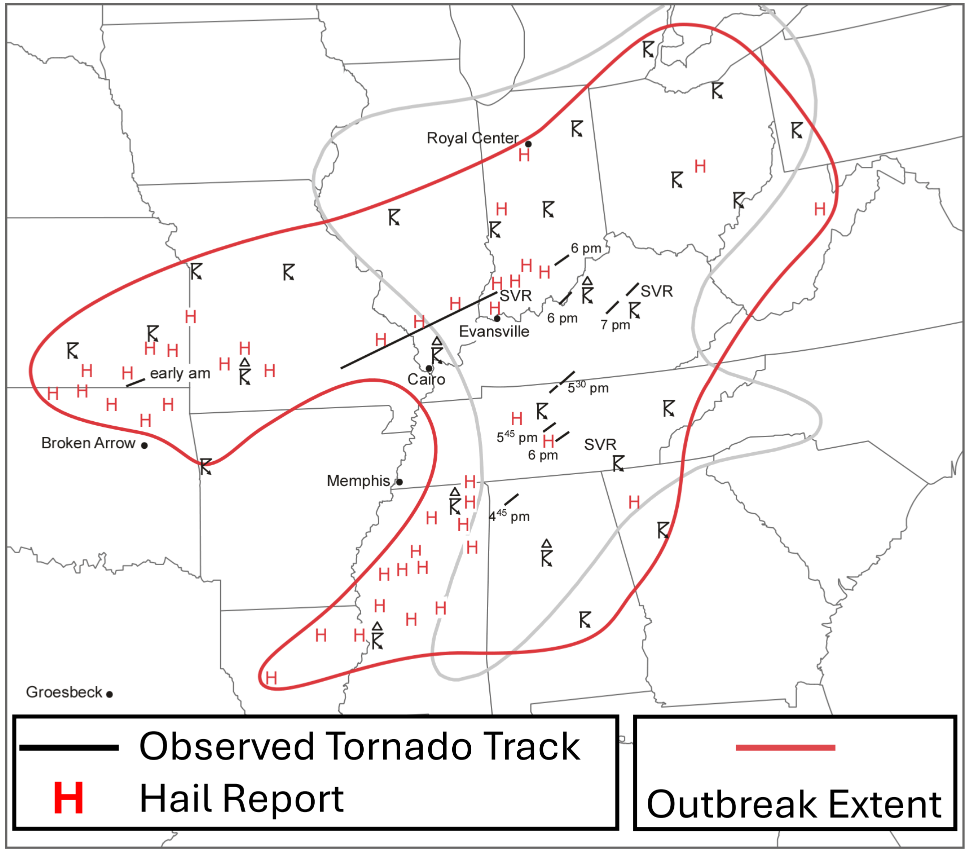

Figure 6 of Maddox et al. (2013), *Severe Storms Meteorology*

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The Twentieth Century Reanalysis Project

Phase I Approach

Simulated Tornado Tracks for the 1925 Tri-State Tornado Outbreak

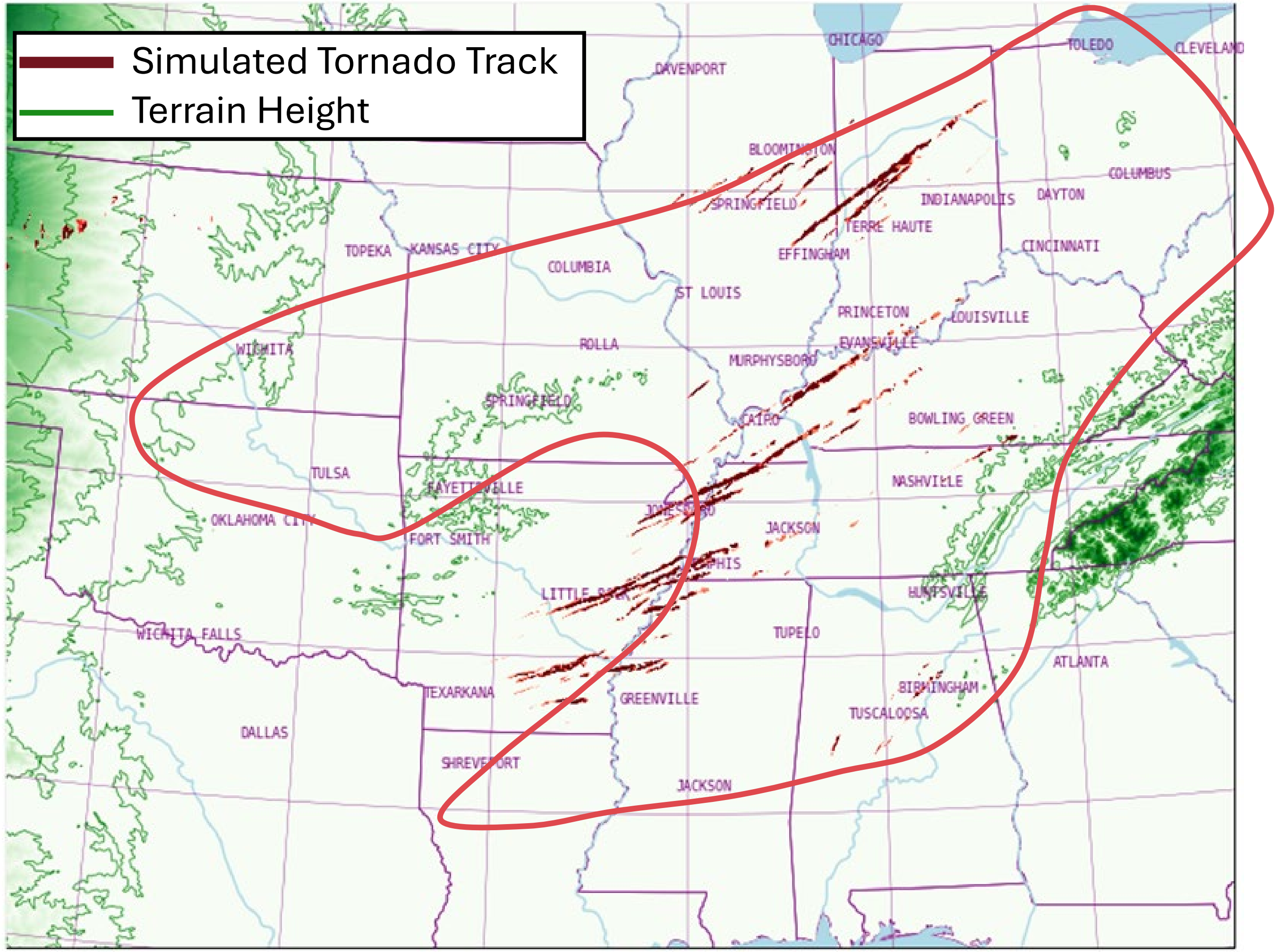

Figure courtesy of Kyle Pittman (NIU)

Observed Tornado Tracks and Hail Reports

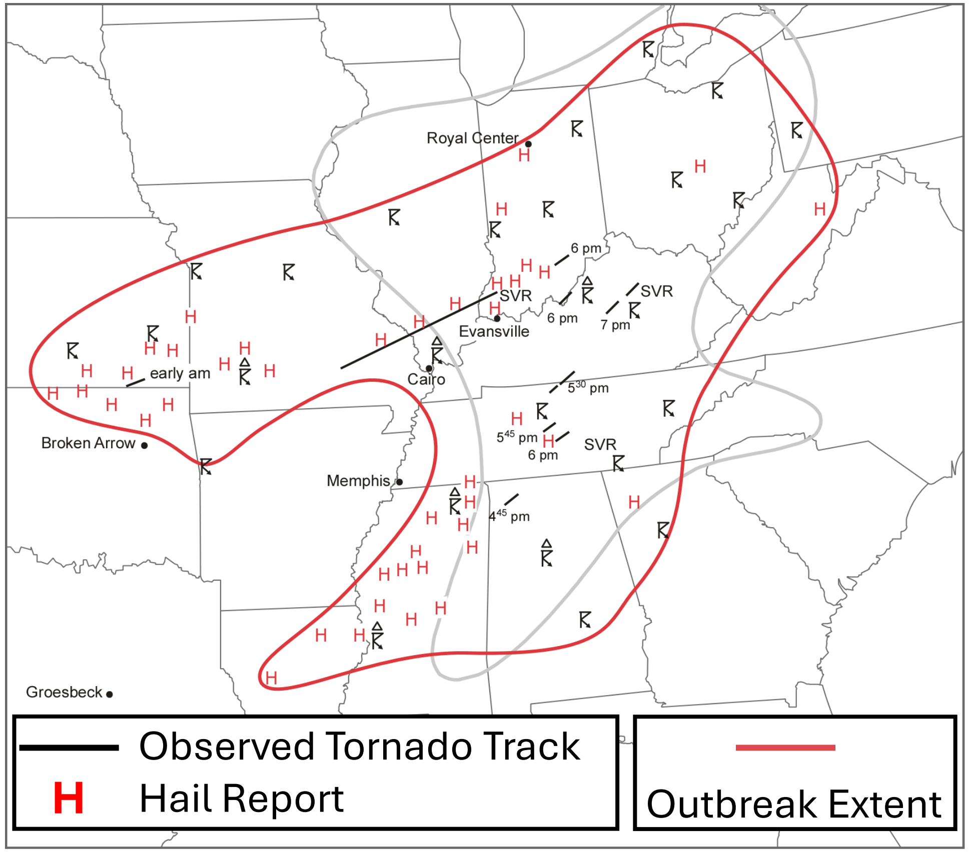

Figure 6 of Maddox et al. (2013), *Severe Storms Meteorology*

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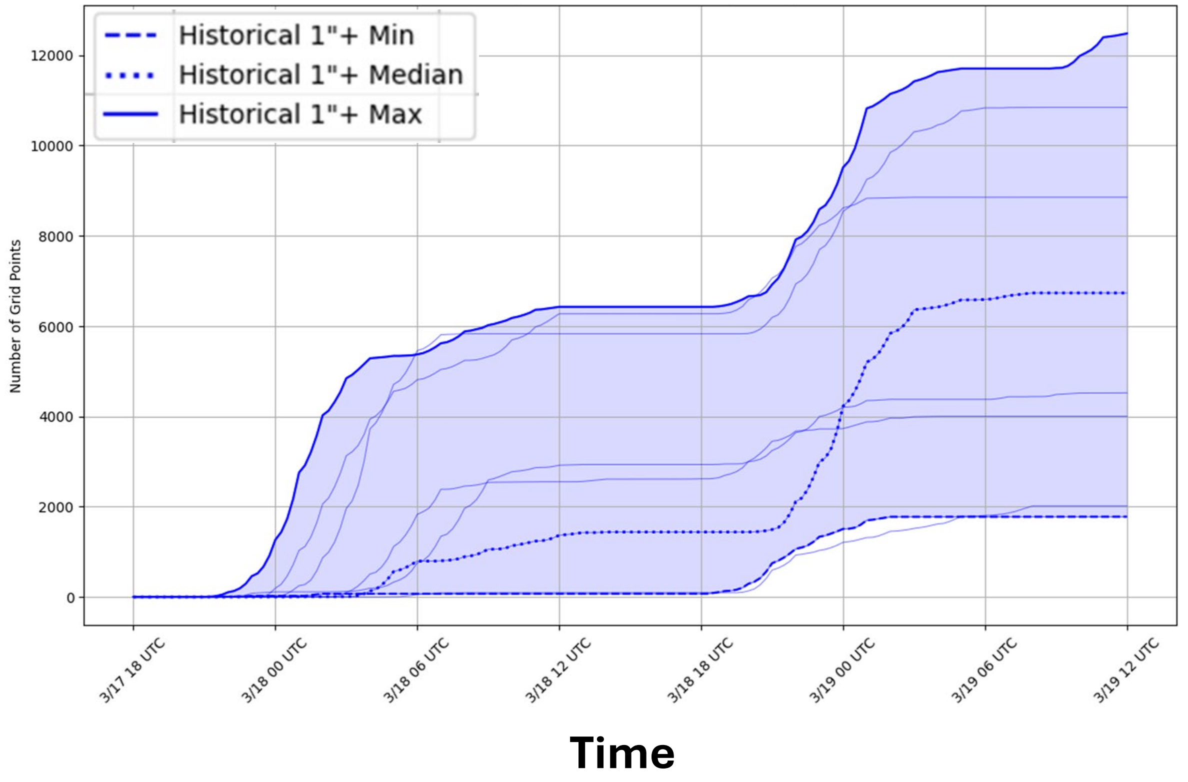
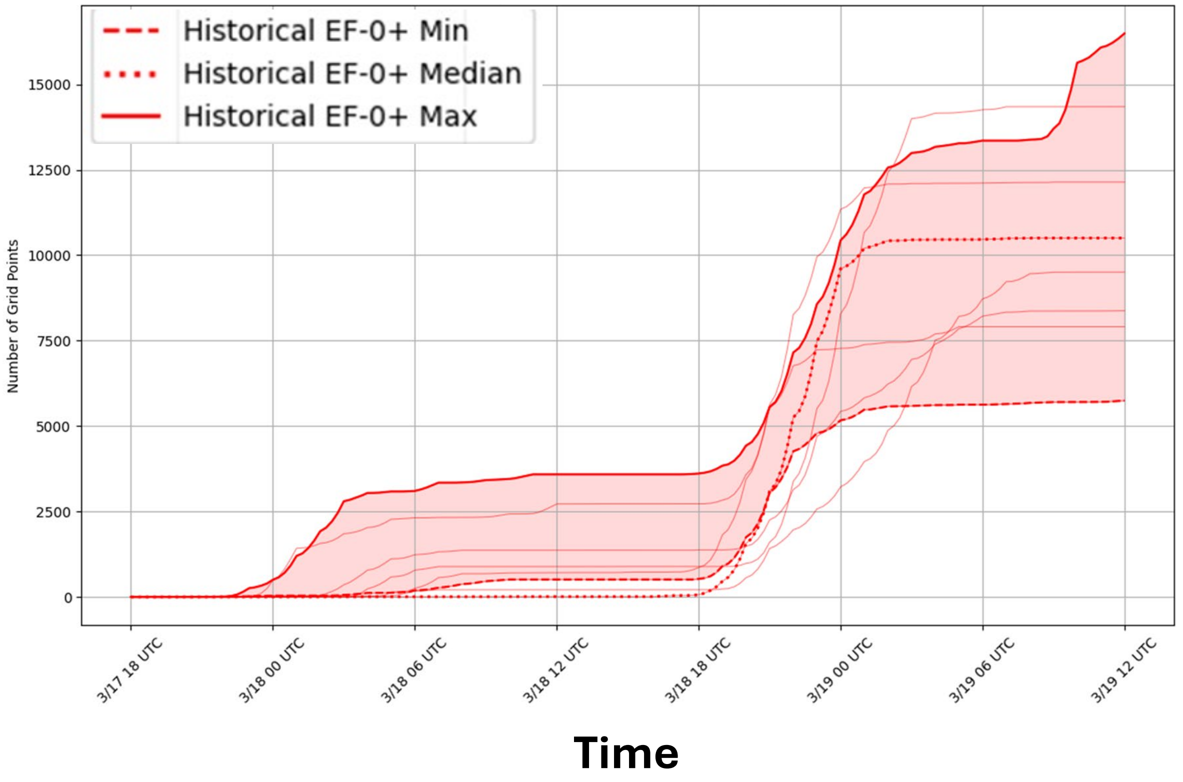
Phase I Approach

Cumulative Frequency of Hail ≥ 1"



Cumulative Frequency of Tornado Occurrences



Phase II Project Goals & Objectives

- Extend event-based catalogue of extreme convective events to the modern era (e.g., post-1970s) and quantify footprints of their perils
- Utilize established workflow for conducting ensemble high-resolution simulations for additional modern-day events identified by CIRCS members
  - Taking an ensemble approach will facilitate assessment of uncertainty
- Create summative statistics and graphics to illustrate findings
  - Assess potential losses from hazards in alternative scenarios:
    - How would potential losses change if the August 2020 derecho initially formed farther south?

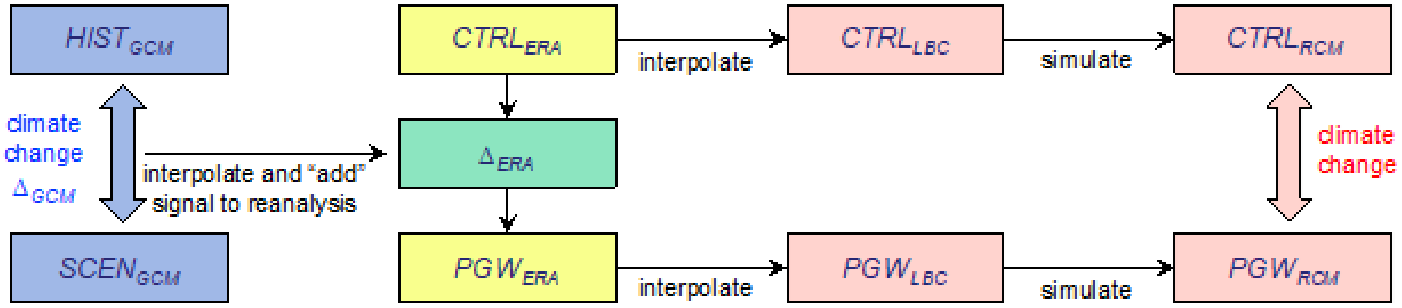
ECMWF Reanalysis v5 (ERA5)

Provides data from 1950–present

Phase III Project Goals & Objectives

- Extend event-based catalogue of extreme convective events to alternative environmental scenarios and quantify footprints of their perils
- Utilize established workflow for conducting ensemble high-resolution simulations for additional modern-day events identified by CIRCS members
  - Taking an ensemble approach will facilitate assessment of uncertainty
  - Compute a suite of "delta" fields for various environmental scenarios to facilitate PGW studies

Figure courtesy of Brogli et al. (2023)



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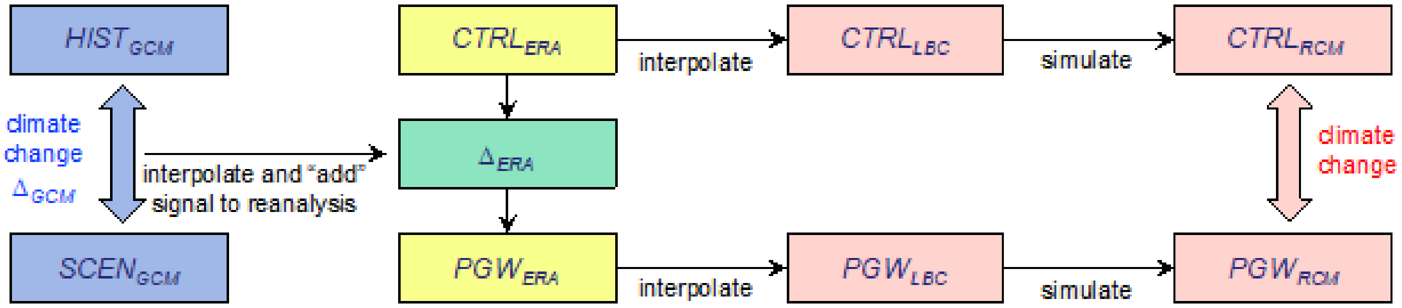
Phase III Project Goals & Objectives

- Extend event-based catalogue of extreme convective events to alternative environmental scenarios and quantify footprints of their perils
- Utilize established workflow for conducting ensemble high-resolution simulations for additional modern-day events identified by CIRCS members
  - Taking an ensemble approach will facilitate assessment of uncertainty
  - Compute a suite of "delta" fields for various environmental scenarios to facilitate PGW studies
- Create summative statistics and graphics to illustrate findings
  - Attribute differences in event evolution and peril footprint to environmental changes:
    - How would the areal extent of damaging winds from the 1933 Midwest derecho change under warmer environmental conditions?

Figure courtesy of Brogli et al. (2023)



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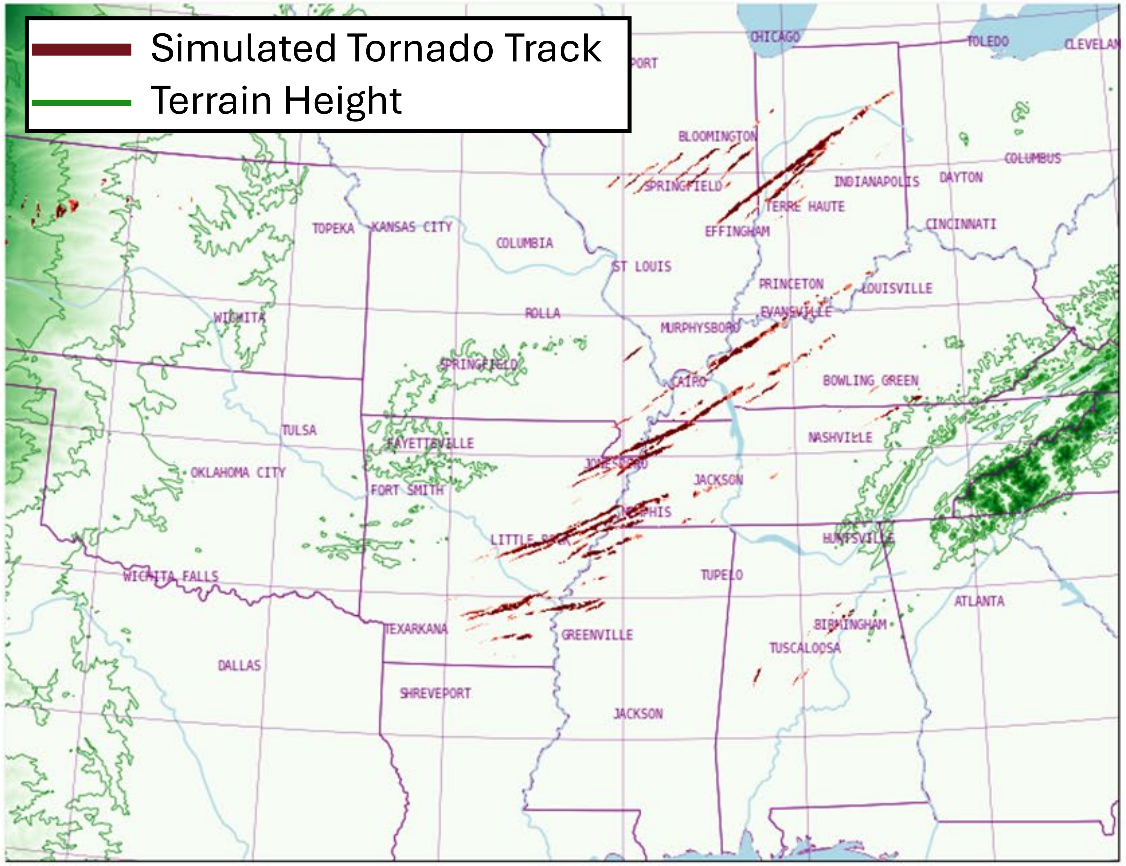
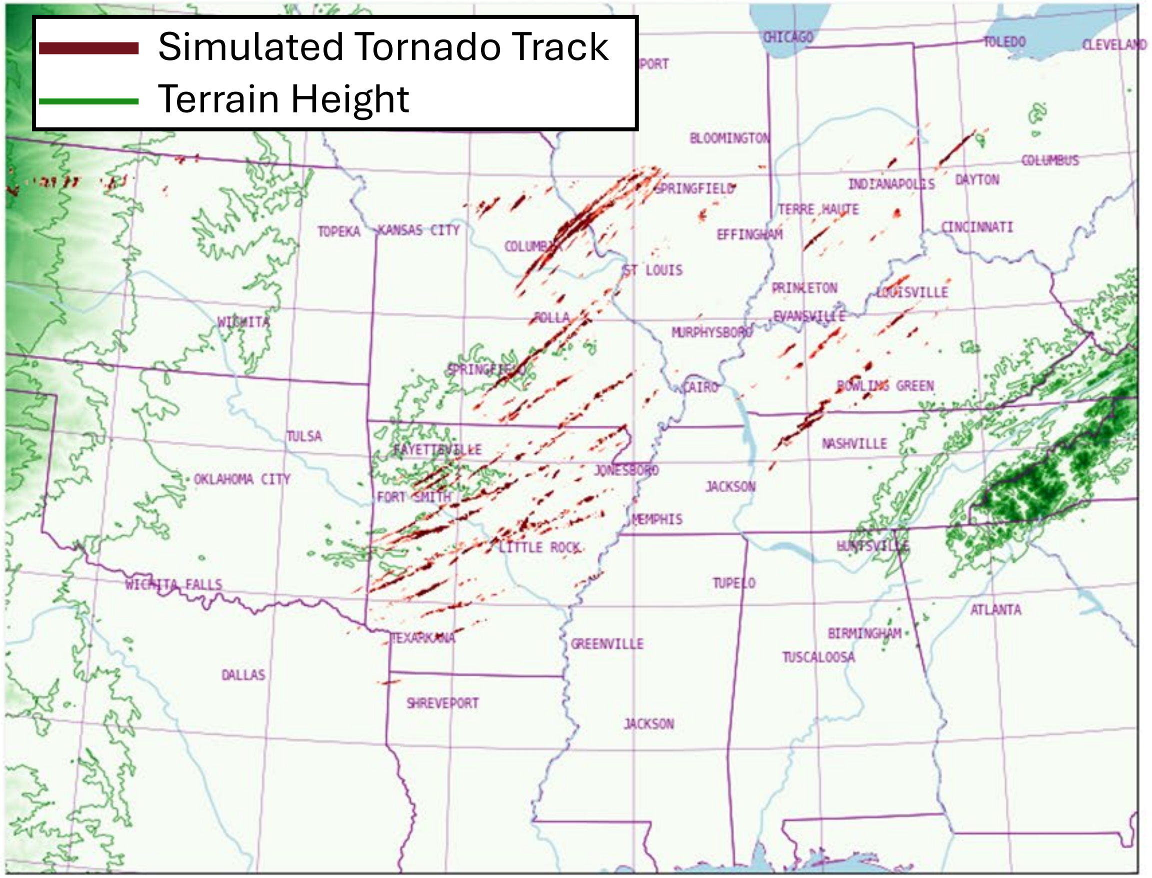
Phase III Approach

1925 Tri-State Tornado Outbreak

Historical Tornado Tracks



Projected Future Tornado Tracks



Figures courtesy of Kyle Pittman (NIU)

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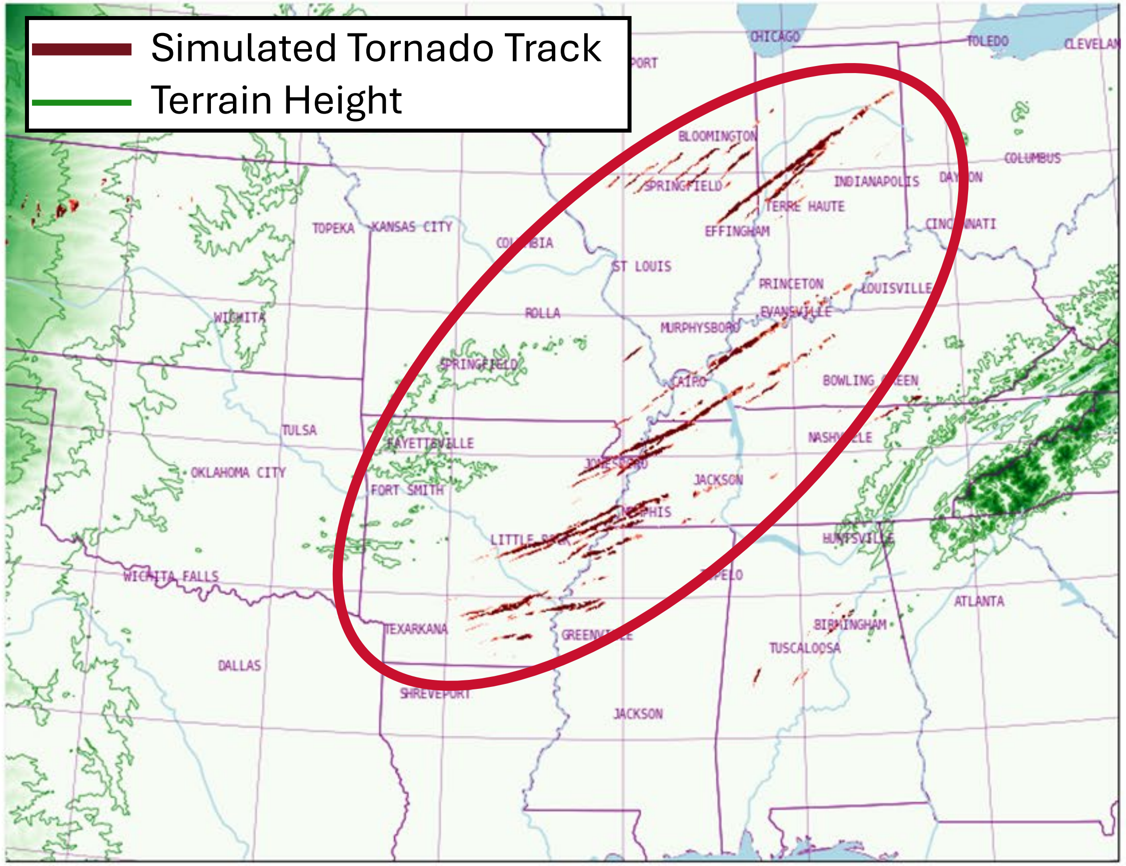
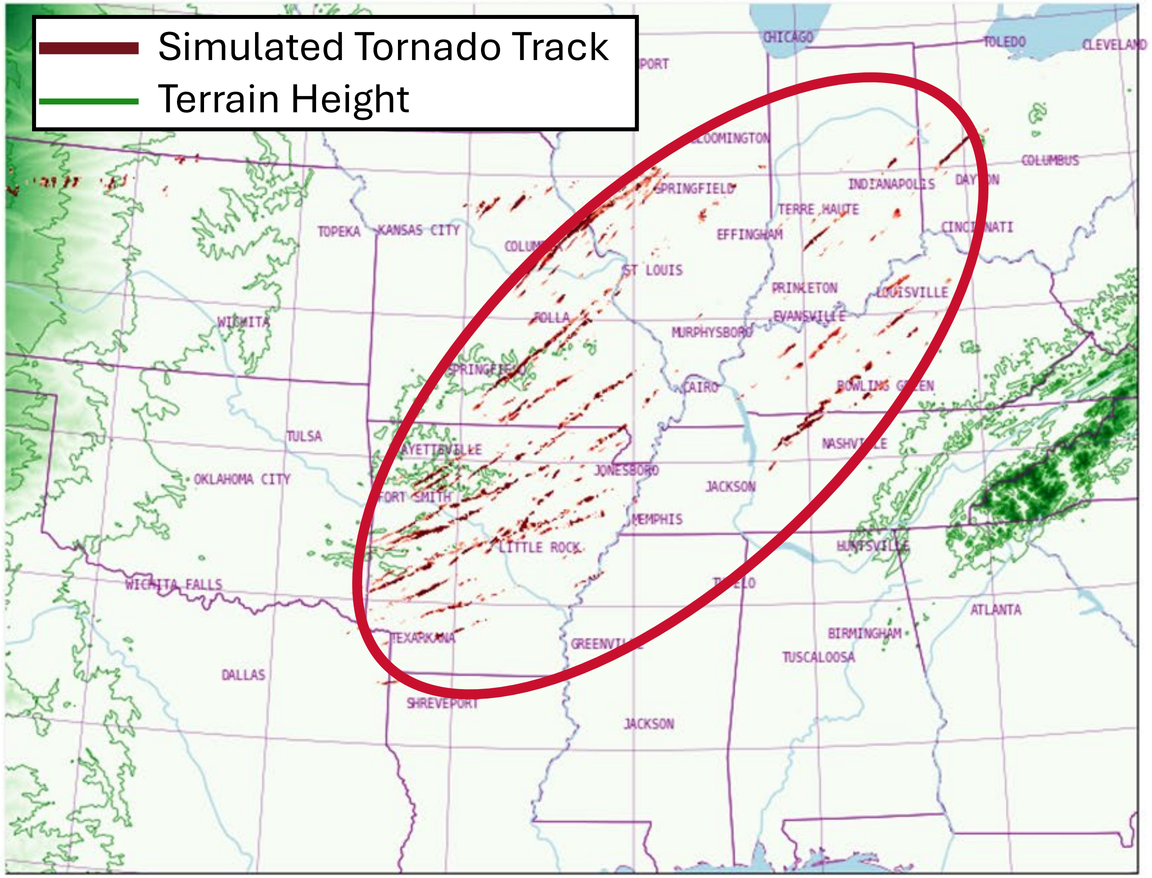
Phase III Approach

1925 Tri-State Tornado Outbreak

Historical Tornado Tracks



Projected Future Tornado Tracks



Figures courtesy of Kyle Pittman (NIU)

Outcomes and Deliverables

- CIRCS members will be provided with:
  1. Event set of historical (e.g., pre-satellite era) and contemporary extreme convective events of interest
  2. Searchable catalogue of simulated historical, contemporary, and future storms
     - Model output will be provided with in raster and/or vector formats
     - Model output can be used in collaboration with other CIRCS projects (e.g., exposure analysis
  3. Summative products communicating results for locations and variables tailored to the needs of CIRCS members
     - e.g., industry white papers, web-based viewing platforms, peer-reviewed publications

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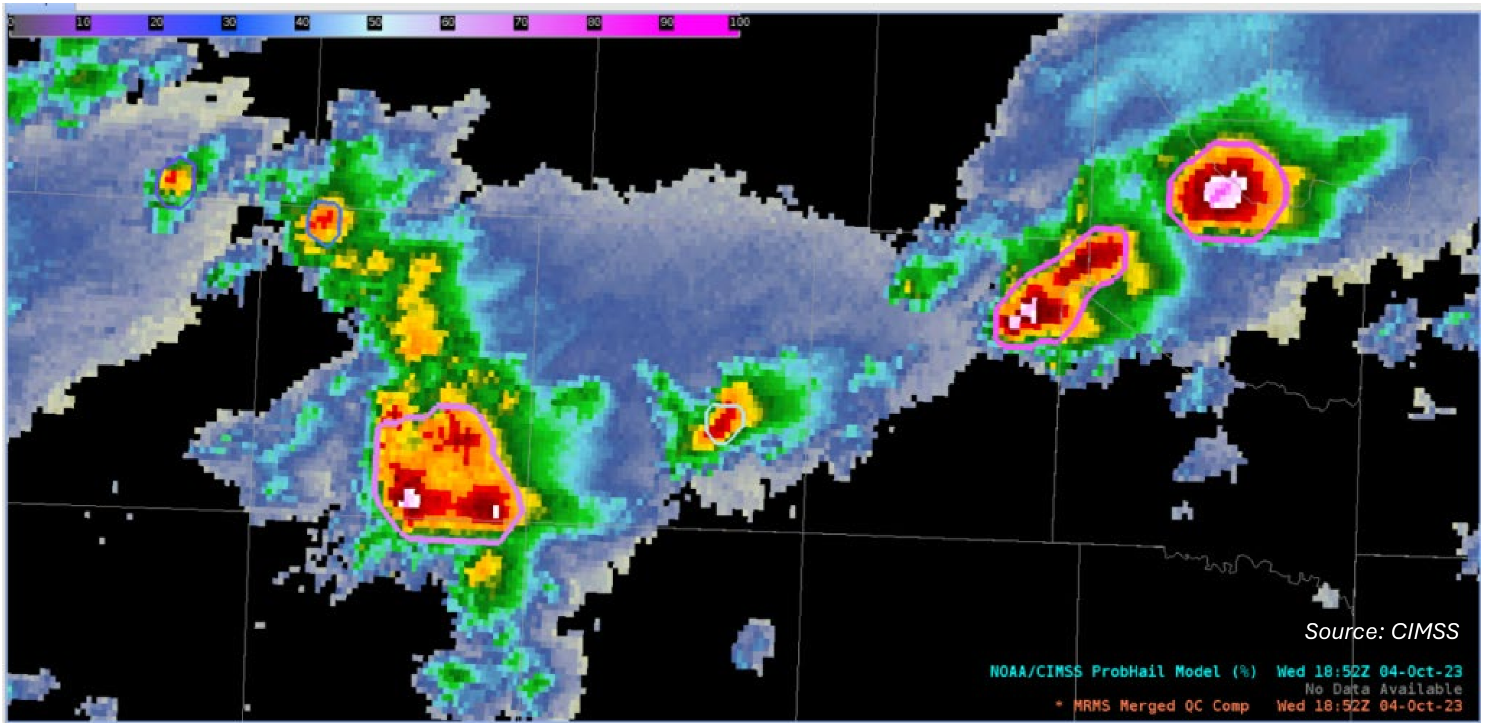
Project Road Map and Timeline

Create a catalogue of extreme convective events to quantify peril footprints and assess potential losses in today's world

Create catalogue of historical events	Expand catalogue to include more modern-day events	Quantify changes in peril intensity/footprint due to environmental changes
Establish workflow for downloading data and conducting simulations	Utilize established workflow for simulating additional events	Compute "delta" fields for various environmental scenarios
Produce summative products for industry-specific applications	Produce summative products for industry-specific applications	Utilize established workflow for re-simulating events
		Produce summative products for industry-specific applications

Timeline for each project phase is about 1 year

Remote Sensing-Based Hail Probabilities



Lead: Dr. Angela Rowe[1]

Collaborators: Drs. Tristan L'Ecuyer[1], John Cintineo[1], Victor Gensini[2], Stephen Strader[3], Peng Shi[1]

[1]University of Wisconsin-Madison, [2]Northern Illinois University, [3]Villanova University

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Need and Industrial Relevance

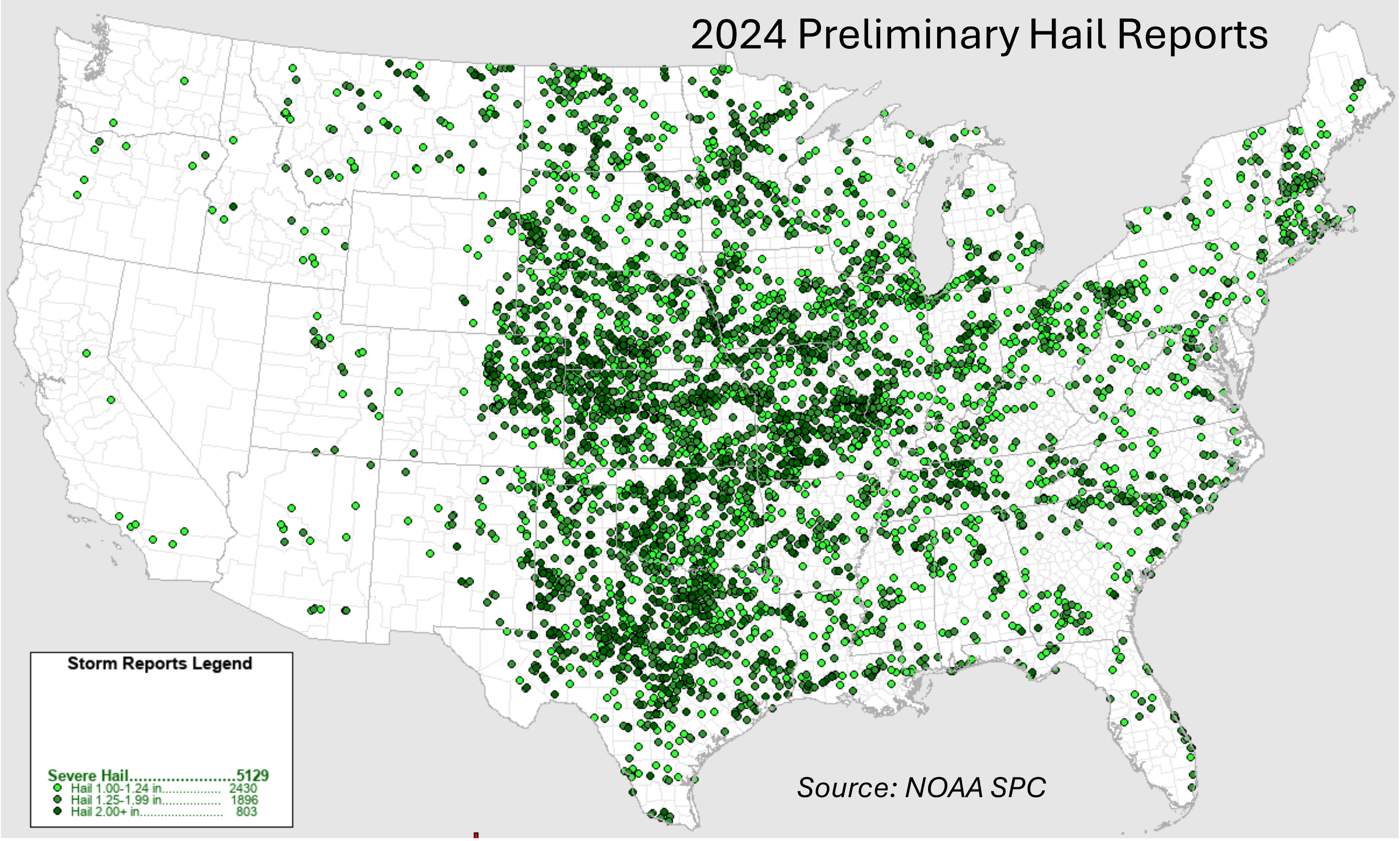
When and where <u>did</u> it hail?

- ➢Known limitations in storm report databases
- ➢Remote sensing valuable tool for inferences

When and where <u>will</u> it hail?

- ➢Probabilities

When and where are these datasets most reliable?



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ProbHail

Probability that a storm will produce severe hail in the near term (0-60 min)

❖**UW-Madison:** AOS + NOAA Cooperative Institute for Meteorological Satellite Studies (CIMSS)

❖NOAA-CIMSS **ProbSevere**: machine learning-based statistical model to nowcast probability of severe hail (**ProbHail**), severe wind, and tornadoes

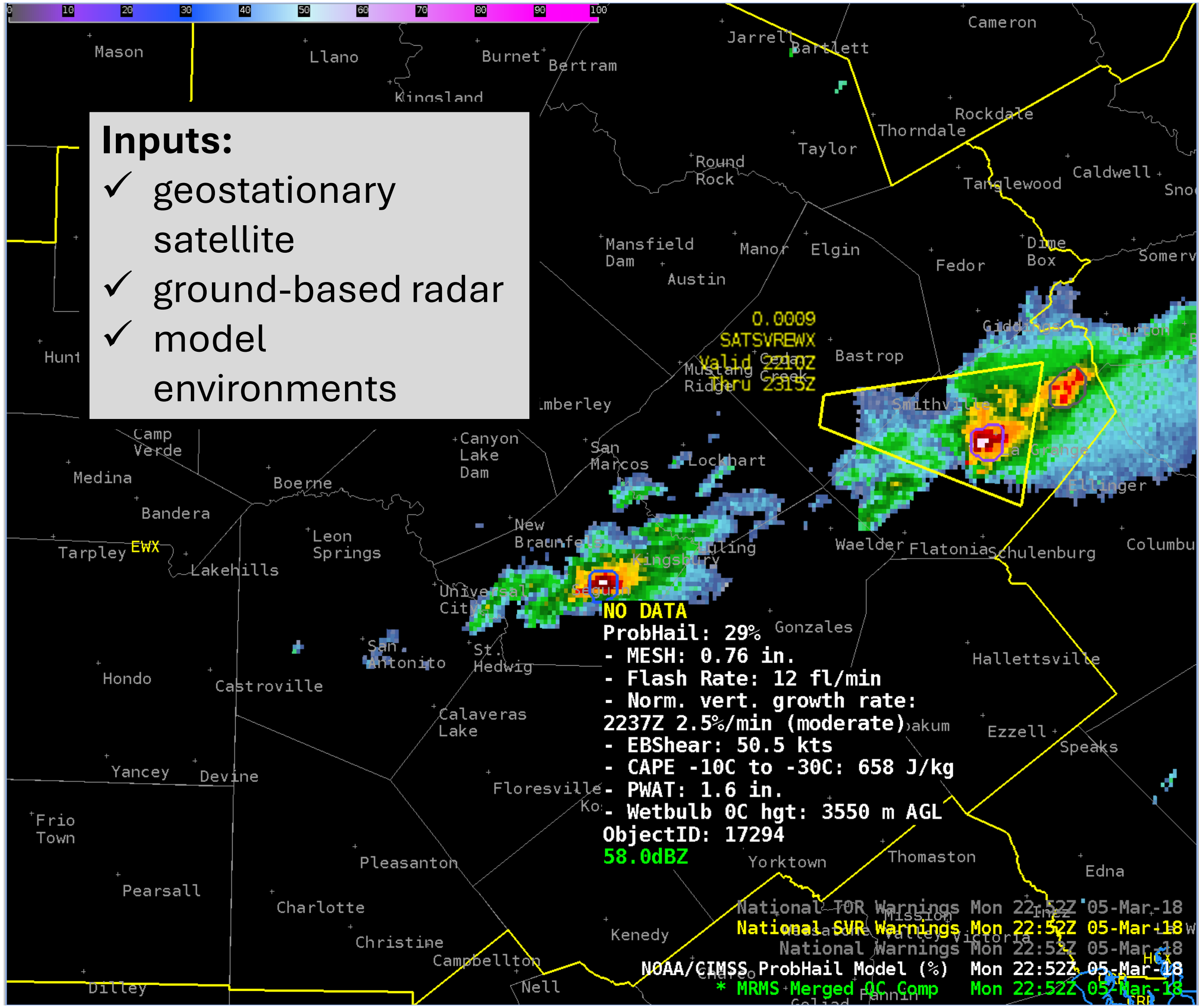
❖Probabilities are a function of environment and observations

Inputs:

✓ geostationary satellite

✓ ground-based radar

✓ model environments



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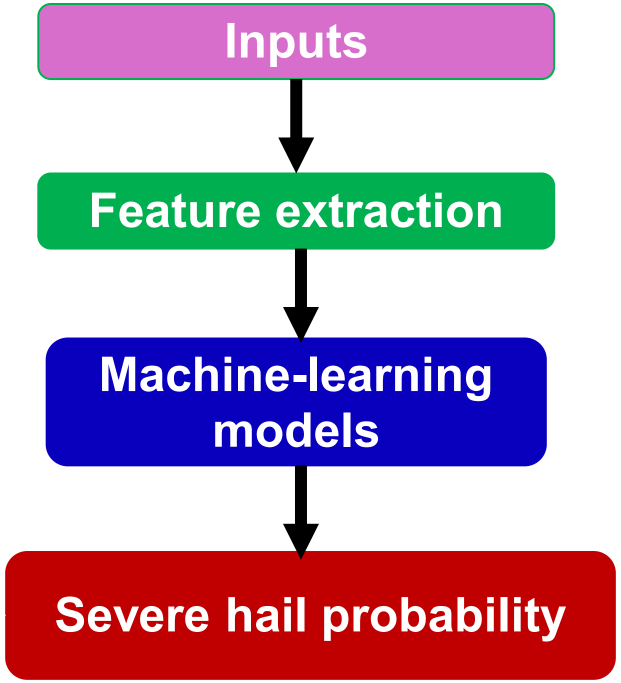
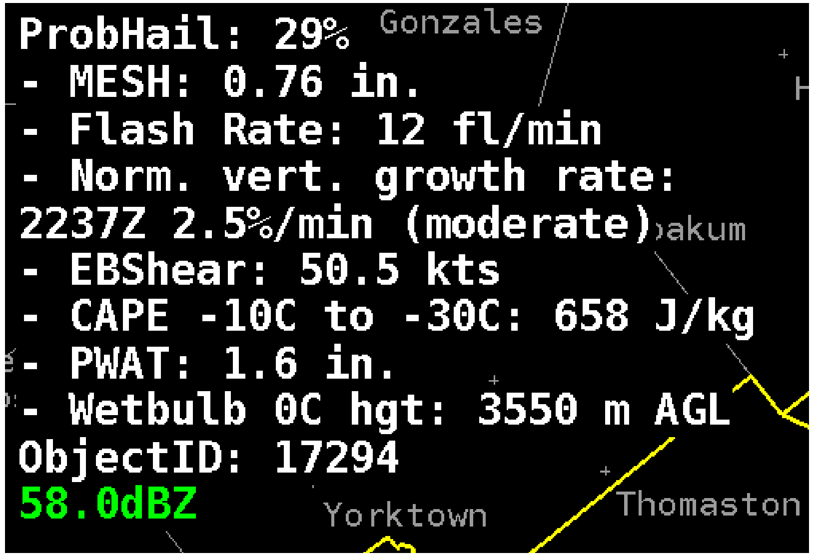
ProbHail

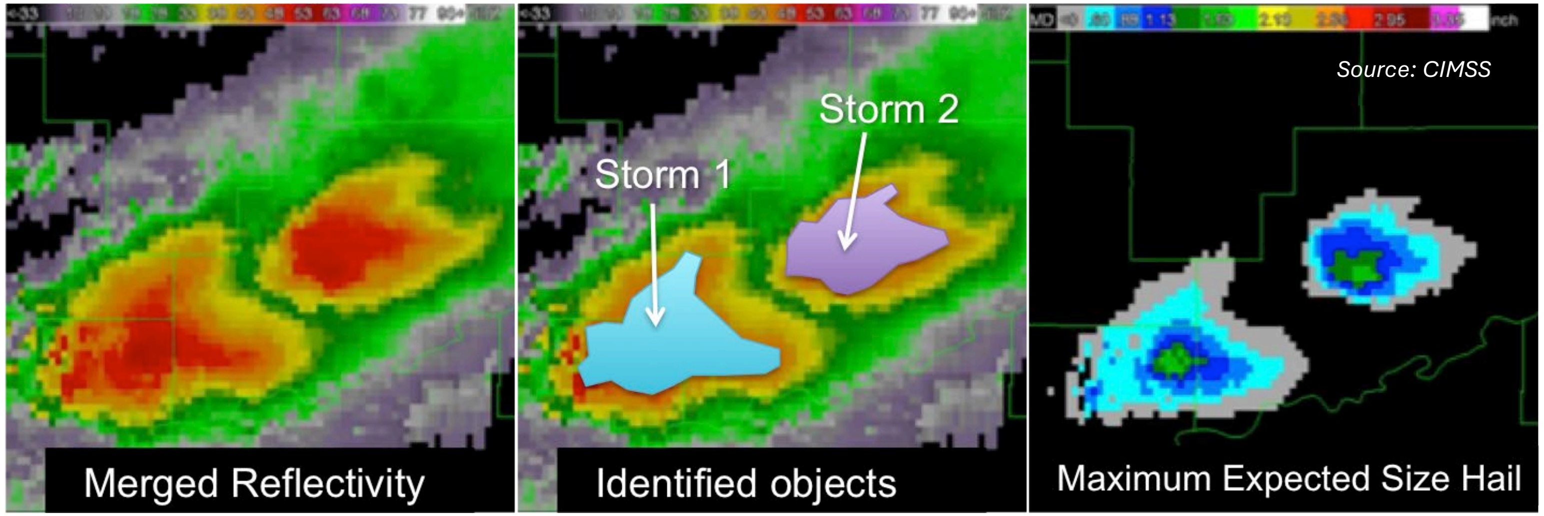
- Outputs shapefiles contoured around radar storm cells (but can be overlaid on any field) with model predictability and each model predictor

- Increased performance with each version, including reduced FAR (current: V3)

- Performance linked to:
    - Known issues in input
    - Storm tracking
    - Machine learning techniques
    - Storm types/regions (e.g., low-topped storms, summer "pulse" storms remain a challenge)







Project Goals

- ➢Broaden the ProbHail userbase

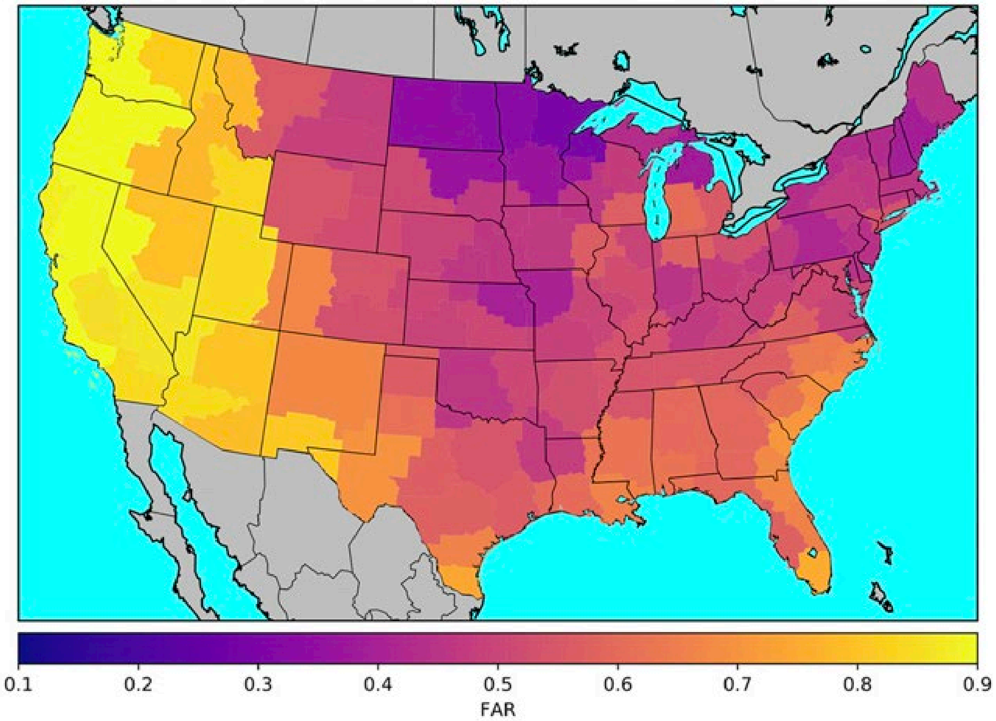
forward-looking probabilities →
probabilistic verification database

- ➢Assess ProbHail V3 performance

→ *where/when it doesn't do well*

- ➢Improvements on input

→ *Radar (MESH, polarimetric variables)*



False Alarm Rates for all ProbSevere
[Cintineo et al. 2020]

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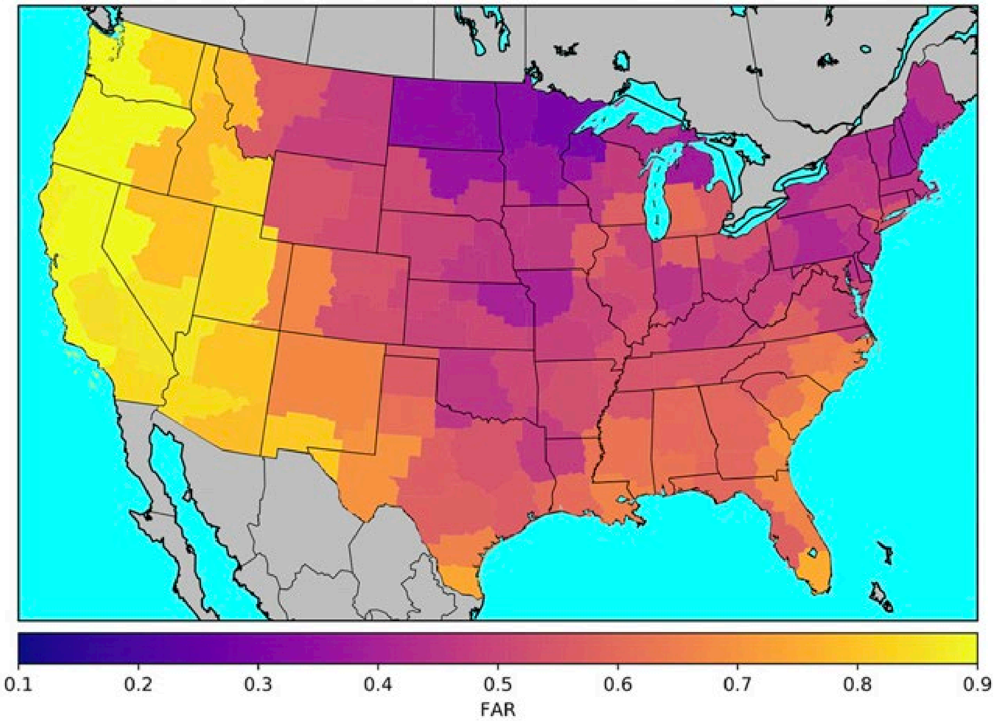
Objectives

1. With industry members, refine focus:
   - How to incorporate ProbHail into decision-making process (usability) or risk assessments?
   - Priority performance (Regional? Seasonal? Storm types?)
2. Evaluation of performance beyond storm report database (industry evaluation?)
3. Pathway to longevity for further ProbHail performance improvements (radar-based input products)
4. Train students in probabilistic remote-sensing applications and evaluation toward industry needs
5. Connecting ProbHail to other industry-relevant products



False Alarm Rates for all ProbSevere

[Cintineo et al. 2020]

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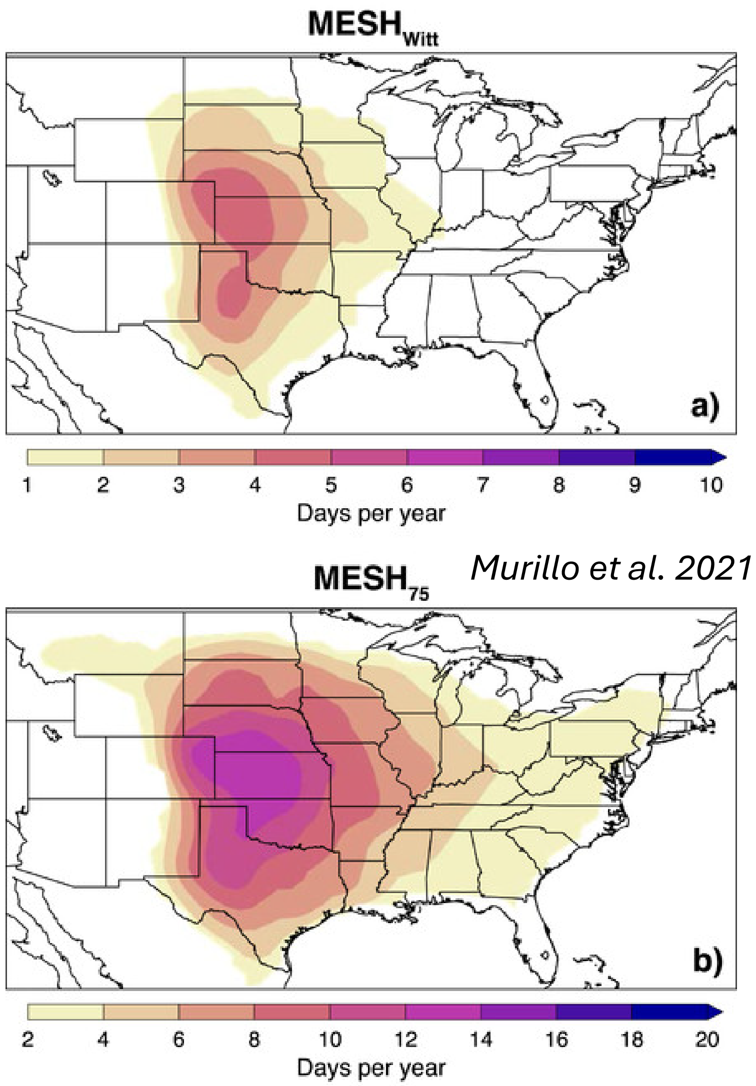
Radar-based estimate of Maximum Expected Hail Size (MESH)

- Multi-Radar Multi-Senser (**MRMS**) merges operational radar network data, gridded
- **MESH:** Known issues in underestimating hail (highly tilted storms, left-moving supercells, low-density dry hailstones) + known deficiencies of model temperature input + empirical relationship sensitivity
- Underutilized dual-polarization radar hail inferences

Empirical fits compared to hail reports



Murillo et al. 2021

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Project Outcomes

✓**Probabilistic hail database** across the U.S., day and night, all year with context-based evaluation

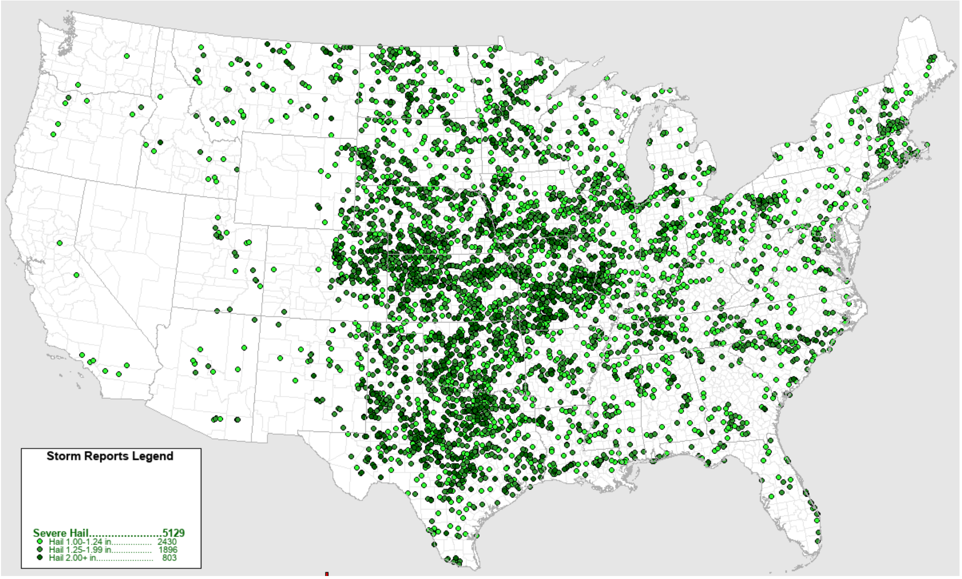
→*Applying in new contexts, supporting other projects*

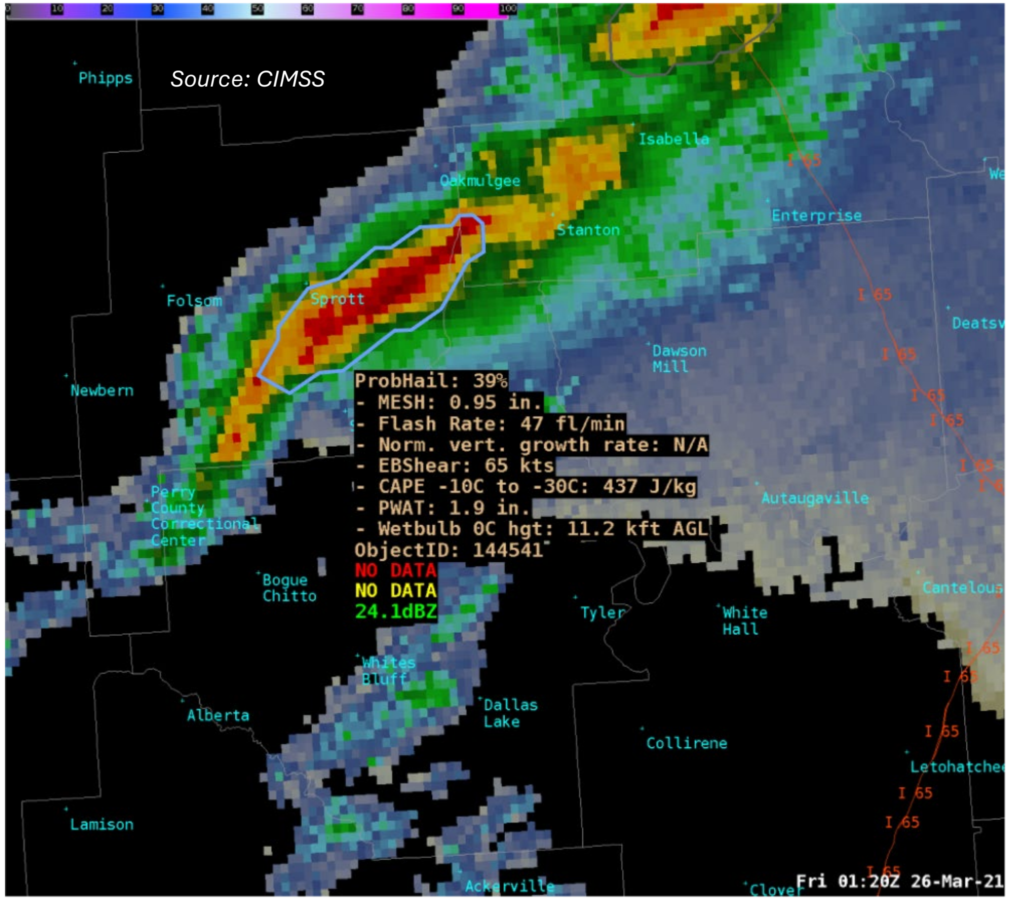
✓Quantifiable improvements in performance based on adjustments to radar-based input

→*Opportunities to expand on which inputs to prioritize for continued improvements*

******We are open to working with others in the center to define project directions with this database******

Project Impact





- **Probabilistic-based hail verification** with greater reliable coverage
- Better understanding of conditions under which **hail probabilities most reliable**
- Valuable database for **supporting other CIRCS research**

Project Duration

- **A 1-year project**: Assessing usability of ProbHail for broader user base
  - Months 0-1: discuss data needs with industry members; student acquires and familiarizes with ProbHail code with CIMSS collaborator
  - Months 2-4: Run code on existing V3 database to iteratively assess output in context of industry needs
  - Months 5-6: Run code on historical period of interest in coordination with industry partners to assess output usability and assessment
  - Months 6-12: Iterative assessment of cases/periods/regions of interest and utility
- **A 2-year project**: Allows for evaluation of performance with incremental updates to radar-based input

Severe Convective Storm Risk Management: Post-Event Property-level Assessment and Prediction

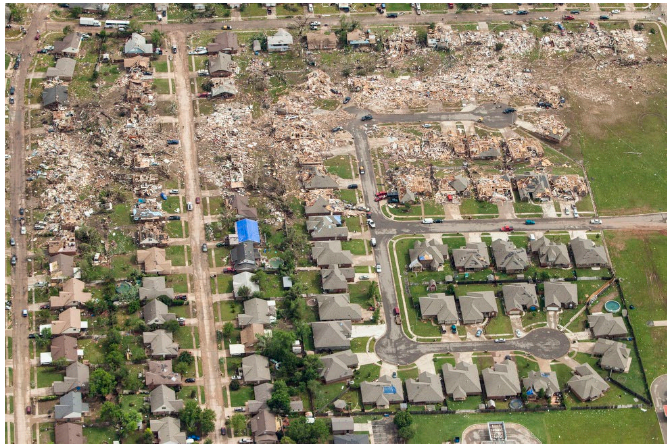
Lead: Peng Shi[2]

Collaborators: Drs. Daniel Bauer[2], Victor Gensini[1], Philip Mulder[2], Angela Rowe[2], Justin Sydnor[2], Daniel Wright[2]

[1]Northern Illinois University, [2]University of Wisconsin

Need and Industrial Relevance

- Rising severe convective storms (SCS) change the risk landscape of the insurance industry:
  - Between 1990 and 2022, SCS increased at an annual rate of 8.9%
  - Severe convective storms caused $35 billion — nearly 70% — in insured losses worldwide in the first half of 2023 (Swiss Re Institute report)
- Fast and accurate prediction of losses immediately following SCS events at the granular property-level would help:
  - Prioritize claims adjustment, customer service, etc.
  - Exercise loss control and minimize further damage
  - Improve claim management, e.g. fraud detection
  - Understand risk exposure
  - Design alternative risk management solutions



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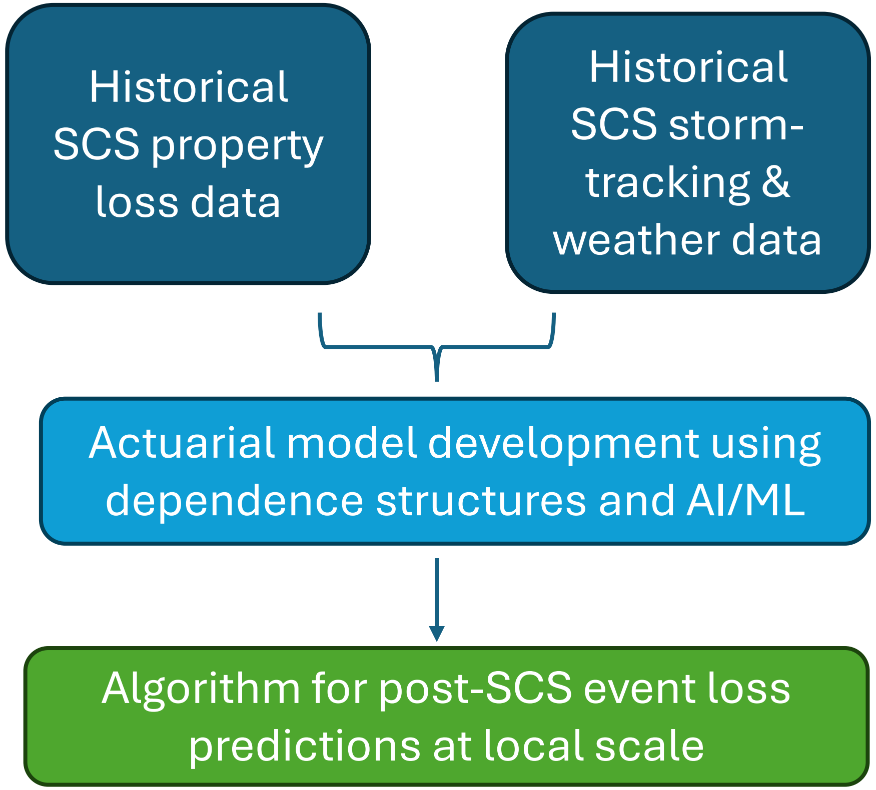
Project Goals

1. Develop a probabilistic framework to perform post-SCS-event risk assessment at granular property-level
2. Integrate storm-tracking data and models into actuarial models to improve insurance and risk management practice
3. Understand, model, and quantify the dependence pattern of SCS-induced property losses
4. Use AI/ML to augment traditional actuarial models with complex and multi-modality data sources



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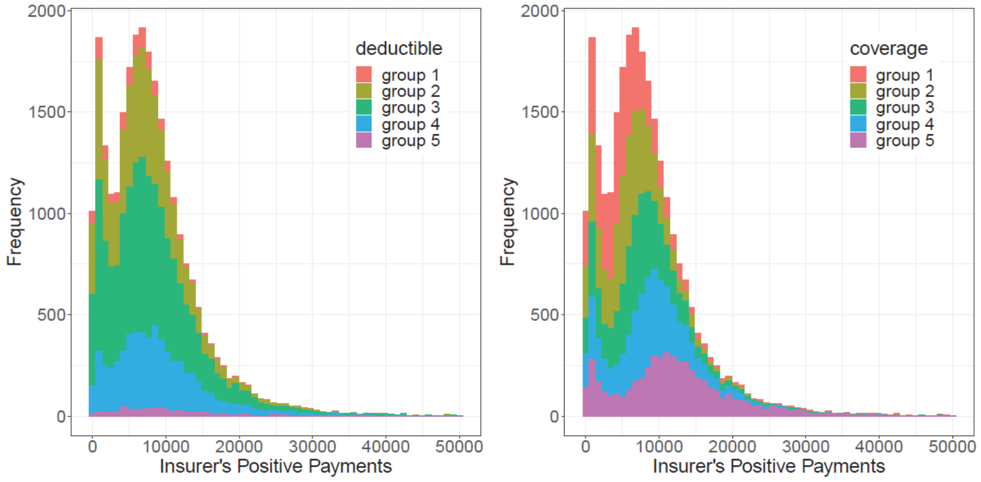
Objectives

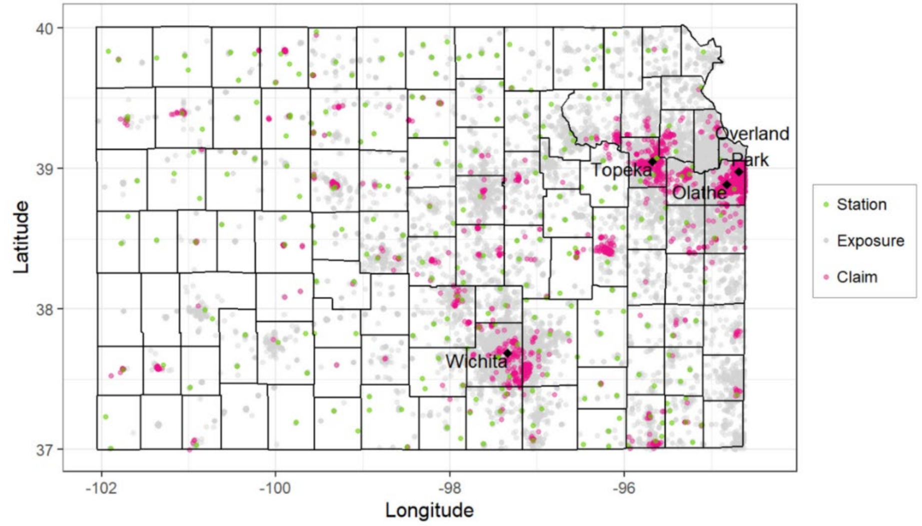
1. Design, implement, and validate a probabilistic prediction model using historical property loss data from industry partners paired with weather readings from SCS events.
2. Identify key dependence patterns among property-level losses and analyze their implications on loss prediction and uncertainty quantification for
   - individual properties
   - group of properties in a geographical region
3. Test the AI/ML-augmented models against traditional models, measuring improvements in predictive accuracy
   - Incorporate relevant weather models
   - Identify auxiliary information, e.g. aerial imagery

Approach (Research Methods)

A distributional probabilistic prediction model that features:

- Accommodate complex characteristics of loss distribution, e.g. extremal events
- Incorporate auxiliary information-both structured and unstructured-to enhance existing predictors
- Incorporate spatial dependence among property losses into the model
- Quantify the uncertainty in the prediction and its implications in risk management practice





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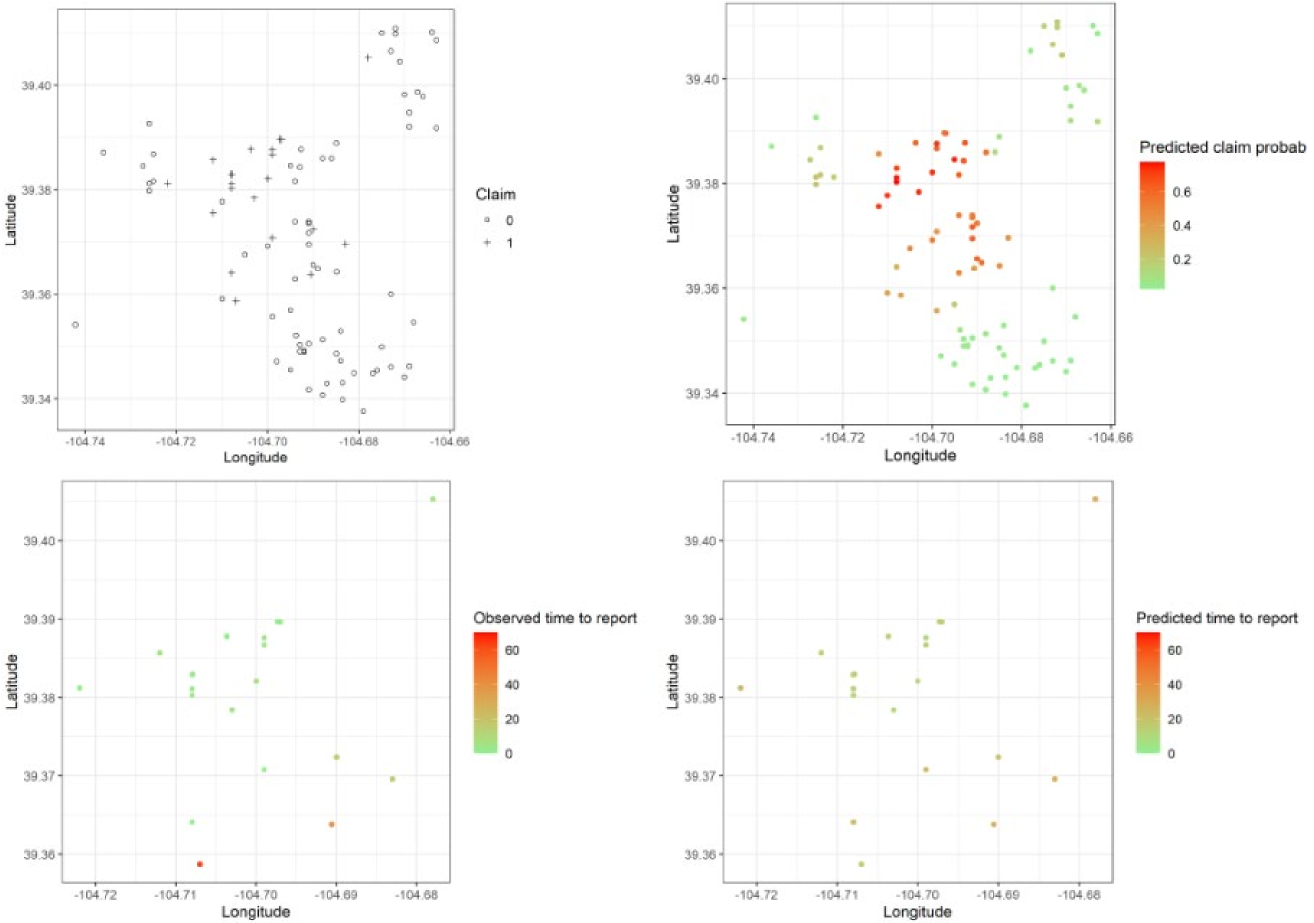
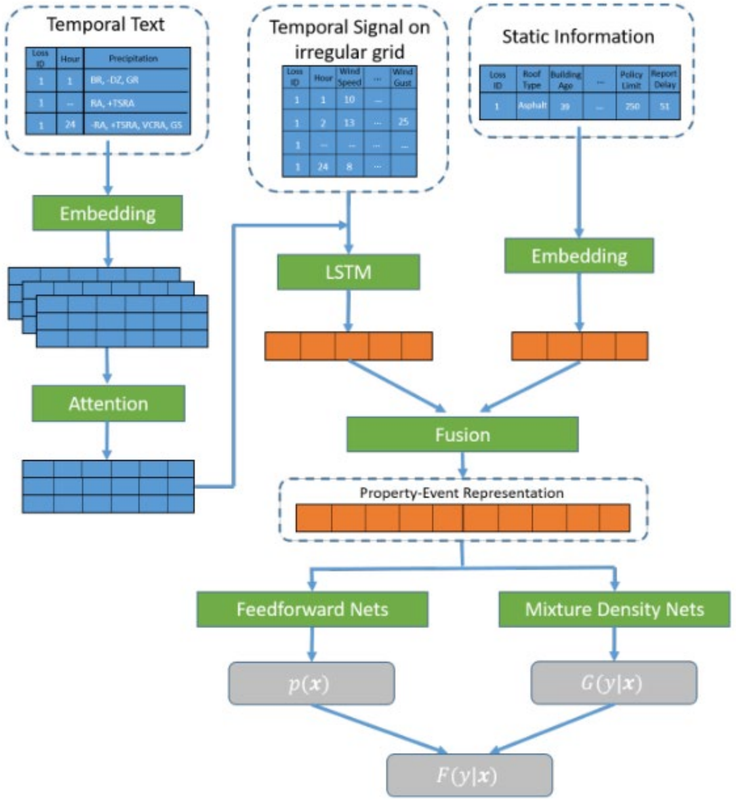
Approach (Research Methods)

Some recent work on hail storms:

- Quantify spatial-temporal dependence and update loss prediction



- Leverage weather dynamic information to enhance claims prediction and triage



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Outcomes/Deliverables

- **Industry White Papers:** Develop and disseminate white papers that summarize the approach, findings, and implications for industry stakeholders.
- **Web-Based Application:** Subject to additional funding, design and launch a web-based application to implement the approach, providing users with a practical tool to apply the developed methodology.
- **Conference Presentations:** Deliver presentations to industry practitioners at professional conferences, e.g. SOA and CAS meetings
- **Case Studies:** Create case studies for both professional education and academic classroom use, illustrating the application of the methodology in real-world scenarios.
- **Peer-Reviewed Publications:** Publish an article in a high-impact peer-reviewed journal, detailing the methodology, analysis, and significant results.
- **Educational Webpage:** Subject to additional funding, develop a dedicated webpage to host educational materials, including tutorials, resources, and supporting documentation for broader dissemination.

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Impact

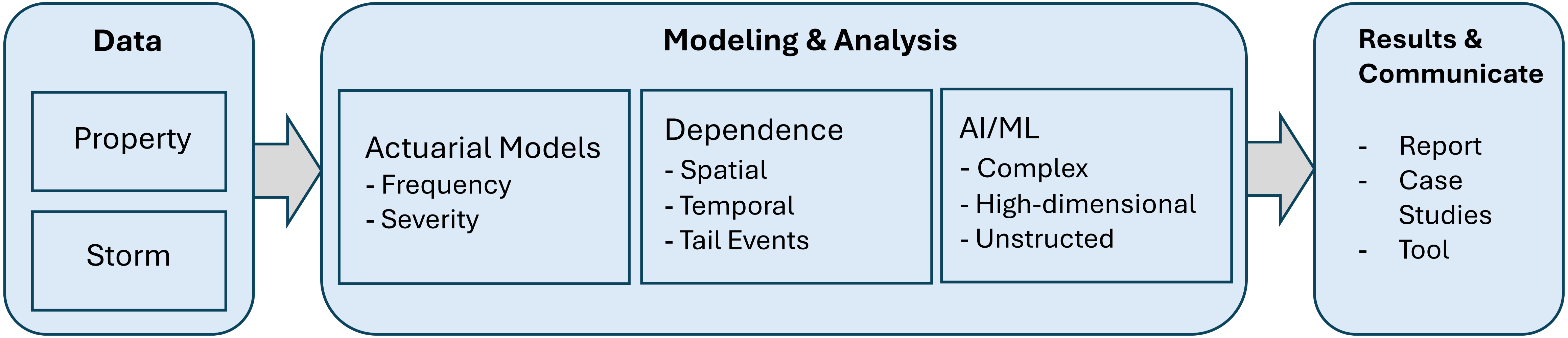
- Provide a practical tool to assist post-event claim management, examples are
  - Triage - prioritize resources allocation (e.g. claim adjusters)
  - Fraud detection
  - Set case reserves and facilitate reinsurance claims

- Longer-run potential impact: when coupled with outputs from other CIRCS projects that can simulate future SCS events, this approach can help to:
  - Better understand the risk exposure due to SCS and quantify its financial impact, including the impact on capital requirements due to correlated losses
  - Better design alternative risk management solutions such as parametric insurance, cat bonds, etc.

Project Duration

Timeline: ~1 year

- Months 0-3: finalize work plan and prepare data needed for analysis
- Months 3-6: develop methodology and refine models
- Months 6-9: perform simulation and conduct data analysis
- Months 10-12: summarize findings and outline future directors



The Effect of Improved Information about Risk on Flood-Insurance Take-up

Lead: Dr. Philip Mulder[1]
Collaborators: Drs. Peng Shi[1], Justin Sydnor[1], Daniel Wright[1]
[1]University of Wisconsin

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Need and Industrial Relevance

- As of 2019, nearly 6 million homes with elevated flood risk were located outside the official 100-year FEMA floodplain (Weill 2024*)
- Increasing prevalence of Severe Convective Storms (SCS) raises risks of heavy-rain induced flooding for properties without flood insurance.
- Awareness is low:
  - Many wrongly believe home insurance policies would cover flood damage.
  - Past experience of no flooding may not align with evolution of risk due to climate change and development in new areas.

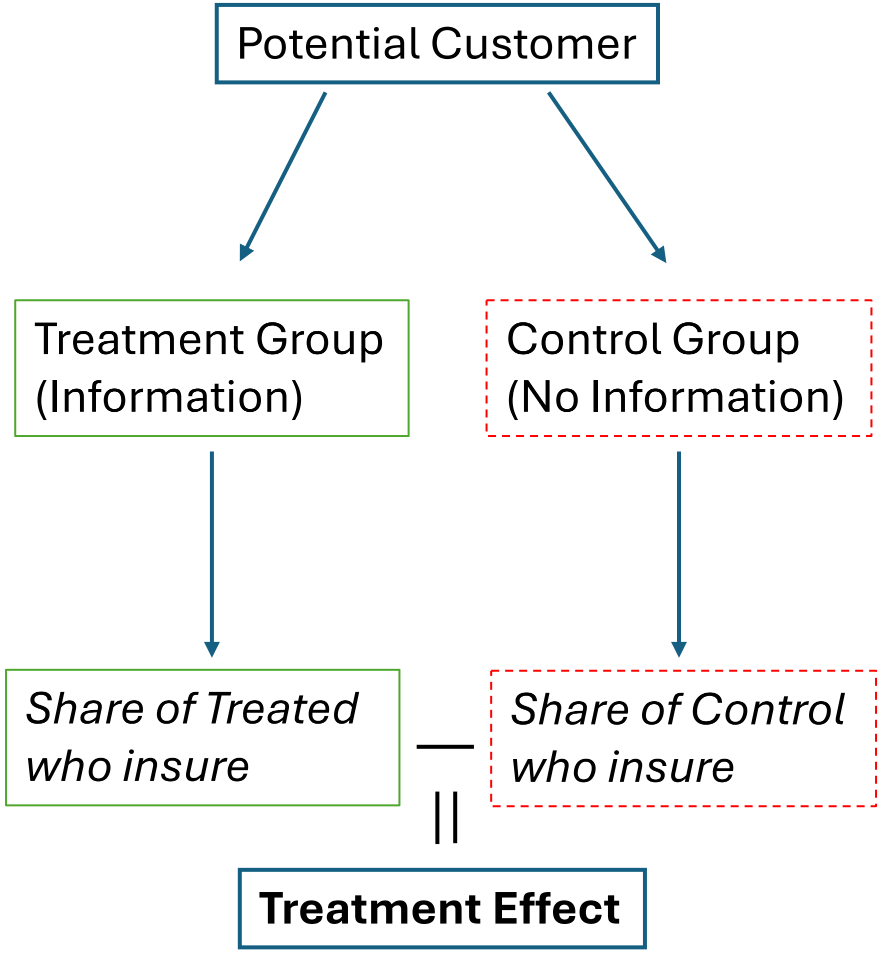
*Weill, Joakim A. (2023) "Flood Risk Mapping and the Distributional Impacts of Climate Information." Federal Reserve System Finance and Economics Discussion Series Working Paper.

Project Goals

1. Partner with industry members to conduct a randomized test of the impact of providing improved information about flood risk on the take-up of flood insurance (NFIP and/or private-market products).

2. Test whether the reaction to information about elevated flood risk is stronger when information about current flood risk is coupled with information about how that risk is changing over time.

Randomization Protocol



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Objectives

1. Partner with industry member(s) to identify properties without flood insurance coverage.
2. Leverage UW access to First Street Foundation (FSF) modeling data and relationships with FSF research staff to identify uninsured properties with elevated flood risk outside FEMA flood plain.
3. Use FSF model data to identify areas where flood risk is changing most. Collaborate with climate-science colleagues that these estimates are in line with climate models.
4. Pilot test and refine risk-communication strategies in survey experiments using the UW BRITE Lab.
5. Partner with industry member(s) to conduct a randomized field test of information outreach campaigns to improve awareness of flood risk.
6. Evaluate the impact of the information campaigns on uptake of flood-insurance policies using administrative data from industry partners.

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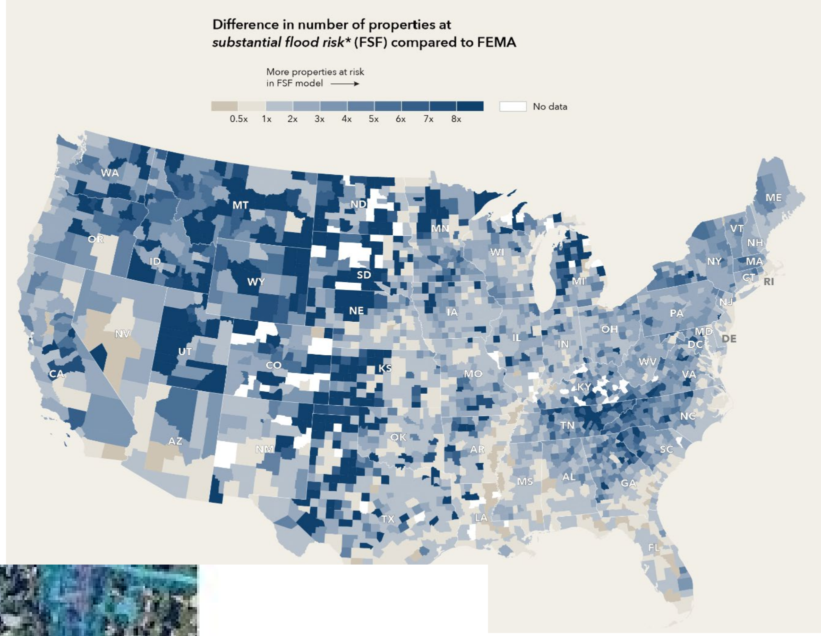
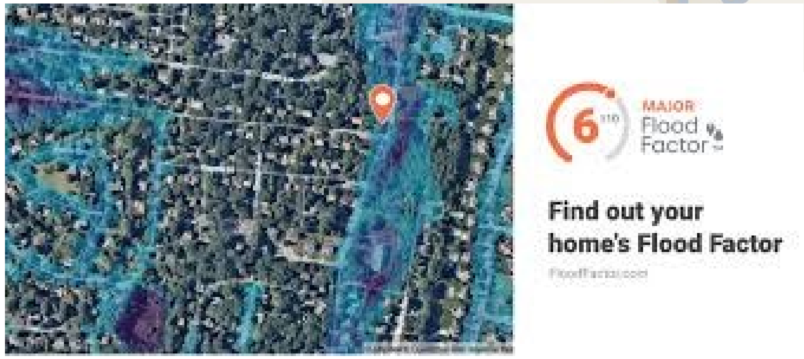
Approach (Research Methods)

Key point: Innovations in modeling, such as those by First Street Foundation, make it possible to provide property-level risk information.

- Important to test whether access to this information affects insurance decisions.
- We will use expertise in behavioral science to test ways of best conveying risk. Specifically focusing on potential to address overconfidence from limited experience with floods by providing information about how risk profiles have changed over time.





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Outcomes/Deliverables

- White paper and draft communications informed by the study results that industry members can use in materials informing customers about flood risk (with implications for communicating about broader risks).
- Estimate of the impact of risk-clarification outreach campaigns (ROI estimate).
- Academic journal article and conference presentations disseminating the results.

Impact

- Estimates of impact of risk communication on insurance take-up.
  - Informs industry/gov investments in risk communication.
  - Benefits of increased take-up of flood insurance products:
    - Reducing issues with uncovered claims after flood events.
    - May support further development of private-market flood insurance products.

- Understanding of importance of conveying changes in risk.
  - Informs the “how” and “who” of targeting information about risk.

Project Duration

Timeline: 1 year to launch the field experiment plus 6 months of continued data collection (needs industry partners)

- Months 0-3: identify uninsured properties
- Months 3-6: analyze FSF data for risk communication
- Months 6-9: develop and pilot test risk communications
- Months 10-11: finalize and deliver field experiment with industry partners
- Months 12-18: analyze administrative data on flood insurance take-up for experiment targets; write final reports