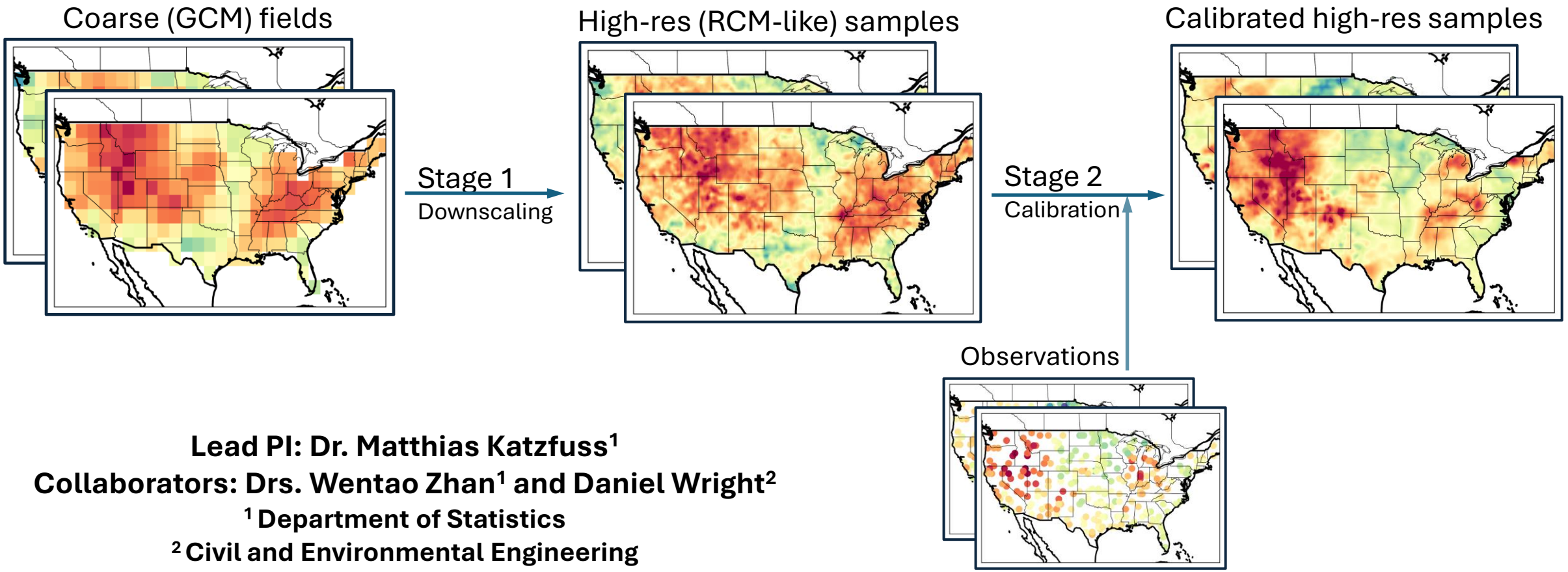
A Framework for Observationally Calibrated Stochastic Wind Event Sets



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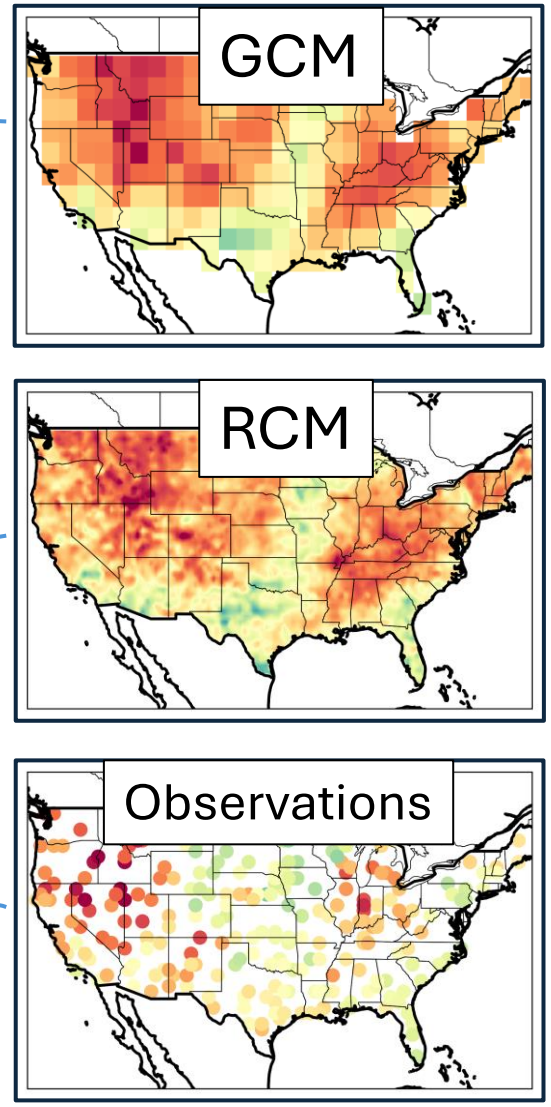
Need and Relevance

- Accurately modeling portfolio risk requires understanding the complex statistical distribution and spatial structure of widespread wind events.
- Existing data sources are all flawed for this purpose:
  - Global circulation models (GCMs): too coarse
  - Regional climate models: expensive and not properly calibrated
  - Observational data: too spatially sparse
- Challenge: Lack of a statistically sound method to fuse these imperfect data sources.
- No reliable way to generate the realistic, high-resolution stochastic event sets needed for accurate pricing and stress-testing.



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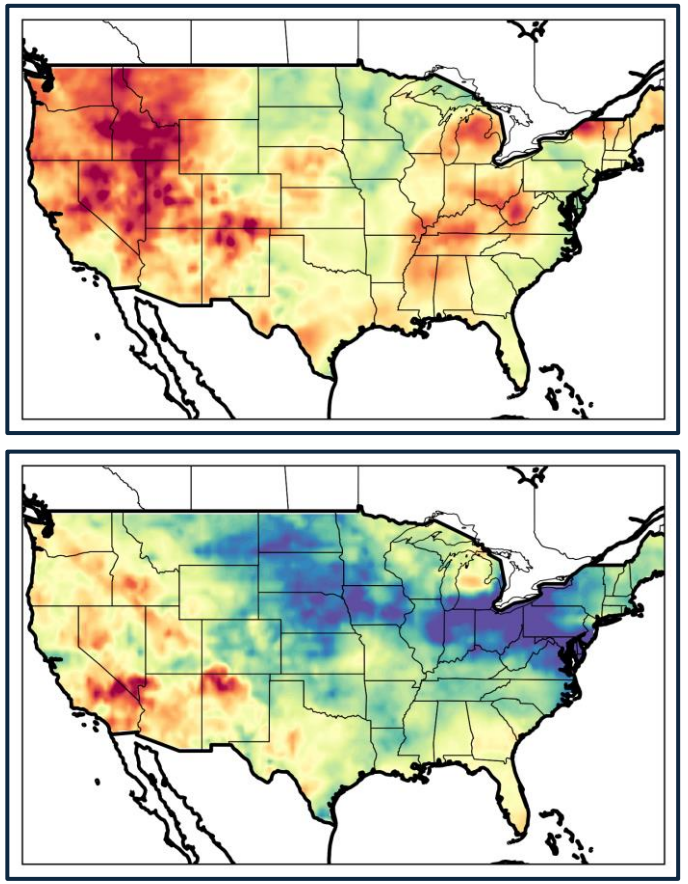
Project Vision

- We will produce observationally calibrated stochastic event sets that characterize the statistical distribution of high-resolution spatio-temporal wind fields.
- We also provide a foundational and extensible statistical framework for model-data fusion.
- CIRCS research pillars: The project uses **Data Science** to **Model** the spatio-temporal **Variability** of wind, a crucial step in characterizing portfolio **Risk** and **Societal Impacts**.

Main Outcome: Event Sets
(Log Wind Speed Over US)



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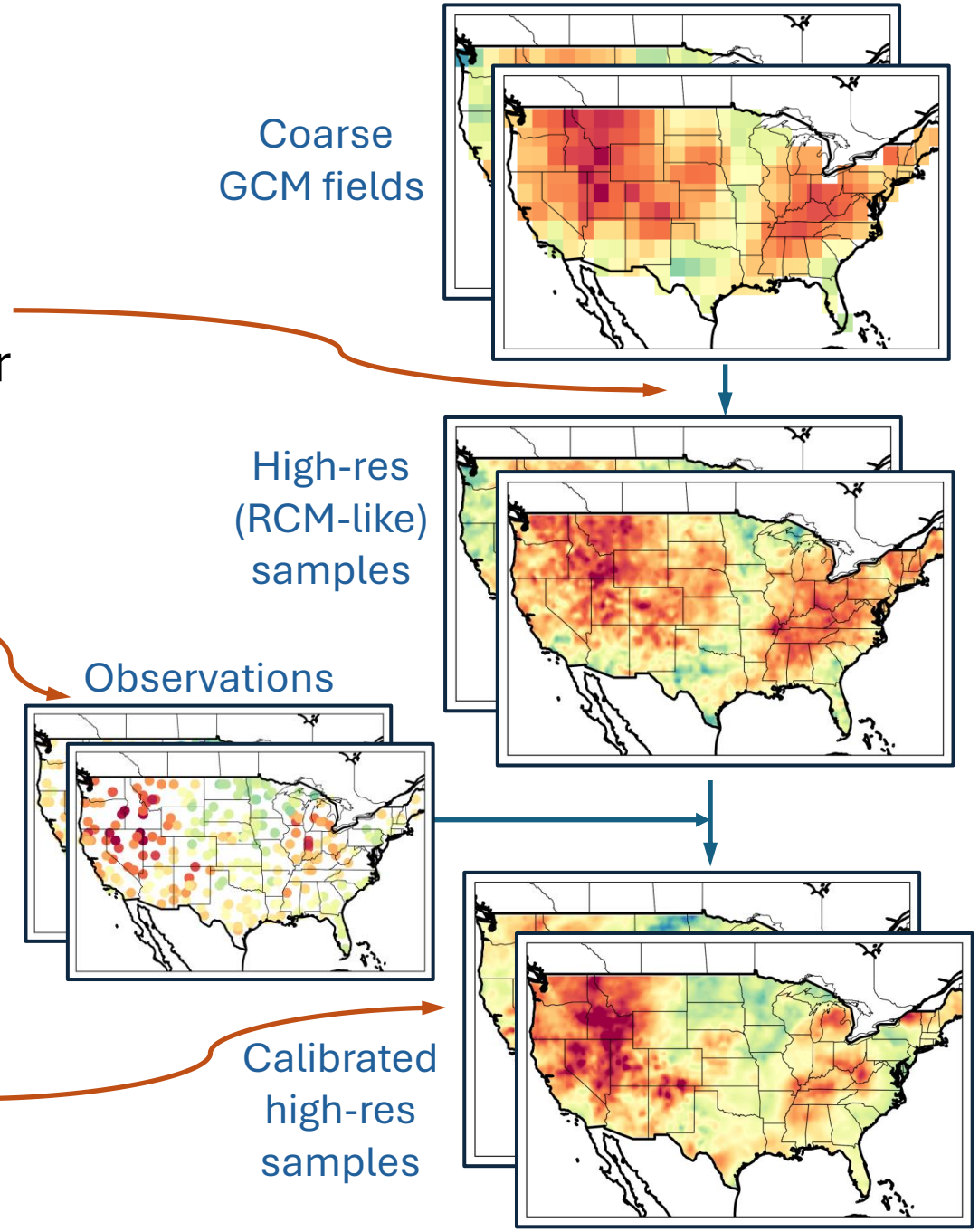
Overview of Approach

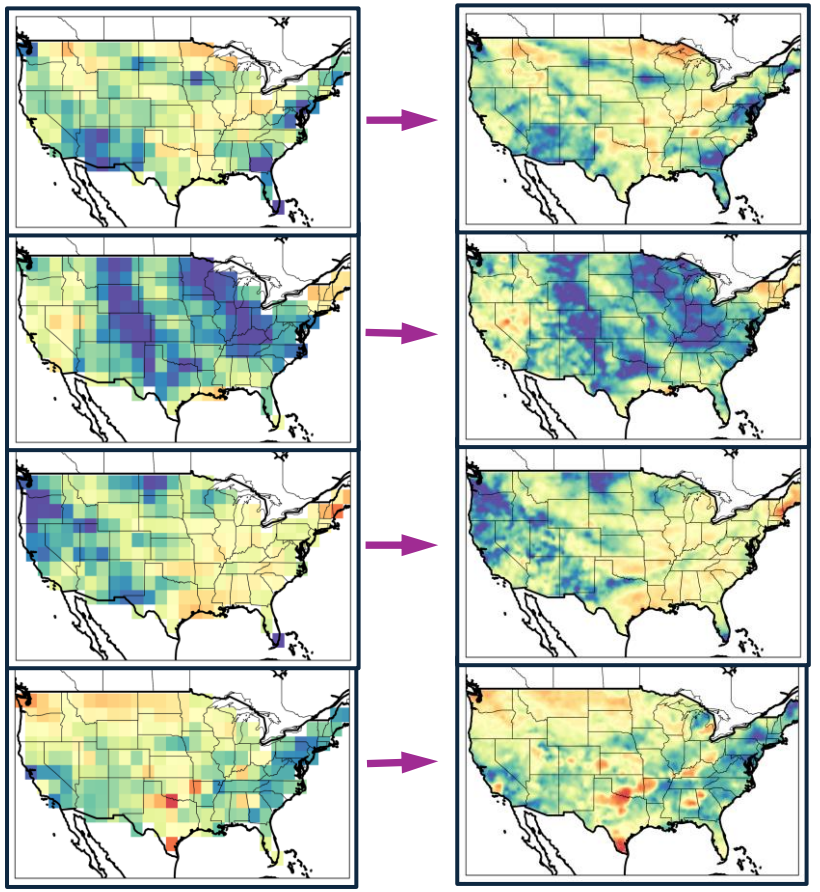
- **Stage 1: Spatial downscaling.** Learn the complex spatial relationship between low-resolution GCM and high-resolution RCM to capture probabilistically how large-scale weather patterns may translate into fine-scale events.
- **Stage 2: Calibration.** Learn the marginal distributions of RCM output and of sparse observational data, to create a calibration map that statistically corrects the RCM fields.
- **Generate realistic event sets**. Use the spatial structure (Stage 1) to generate new, high-resolution wind scenarios and apply our calibration map (Stage 2) to correct them.
- **Result:** A stochastic event set with the realistic spatial structure of the high-res model but the statistical accuracy of real-world observations.



Stage 1: Spatial Downscaling

- **Challenge:** Many different high-resolution storm outcomes (RCM) are possible for a single large-scale weather pattern (GCM).
- **Goal:** Learn the complex relationship between GCM wind patterns and the full range of plausible RCM outcomes.
- **Method:** Build a flexible transport map (using autoregressive Gaussian processes) that learns this nonlinear relationship from limited training data while protecting against overfitting.
- **Result:** A tool to rapidly simulate many spatially realistic, fine-scale hazard possibilities based on limited GCM samples, effectively learning what is possible.

Paired GCM & RCM training data



Learn probabilistic relationship

GCM fields are artificial (coarsened RCM)

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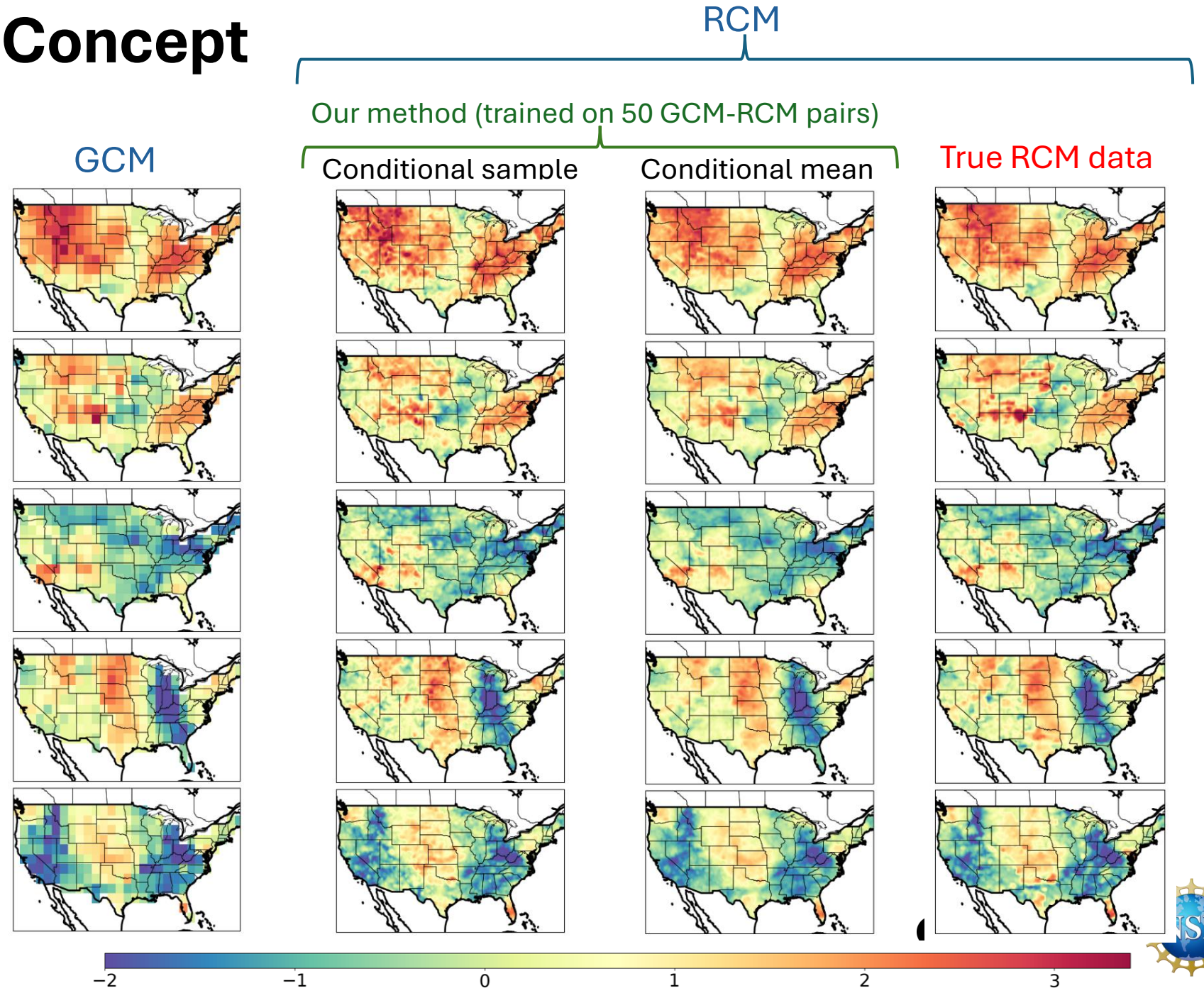
Stage 1: Proof of Concept

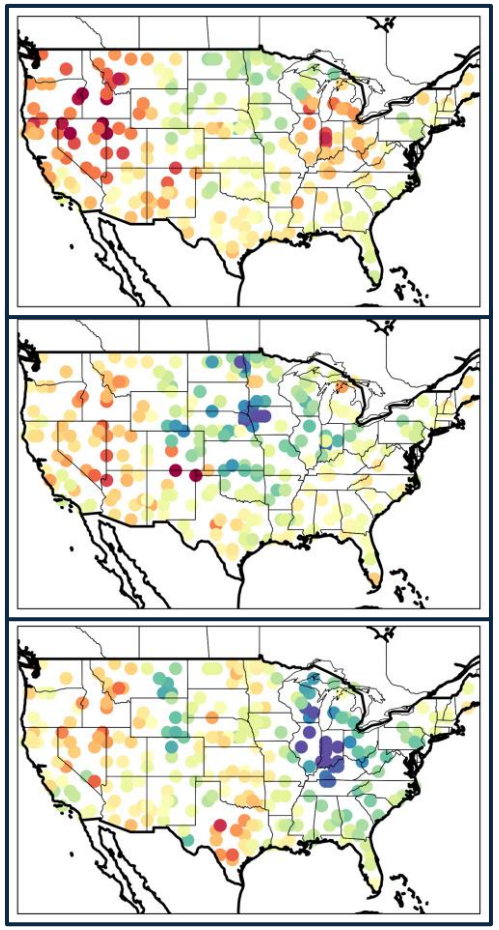
Given held-out GCM fields,
we sample from our learned model
and compare to the true corresponding RCM fields.



Stage 2: Calibration

- **Goal:** Correct the RCM's miscalibration by learning the different statistical properties of the model output and the real-world observations.
- **Challenge:** Observations are sparse, but we must correct the model everywhere on the grid.
- **Method:** Develop spatially smoothed calibration maps that learn the "ground-truth" statistics (including tails) across the entire grid, filling the gaps between observation locations.
- **Result:** The calibration maps will be used to adjust newly sampled fields (from Stage 1) to match real-world statistical properties.

Ground-truth observations (artificial)



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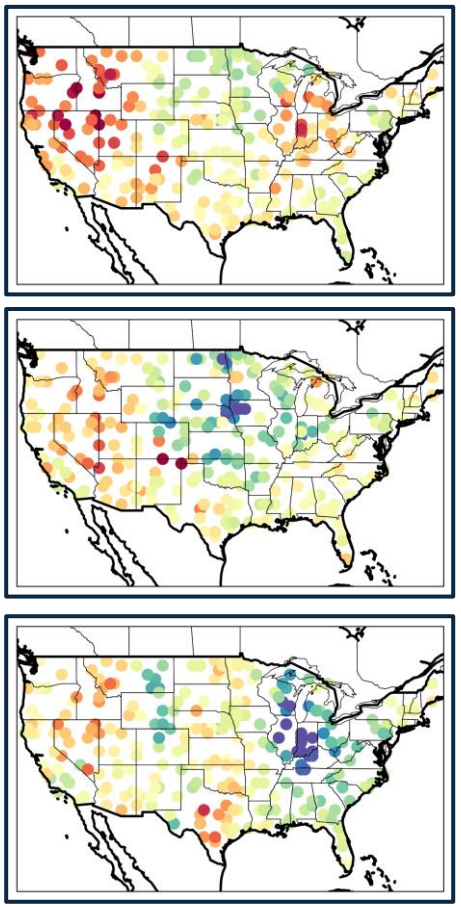
Stage 2: Proof of Concept

(Artificial) Observations



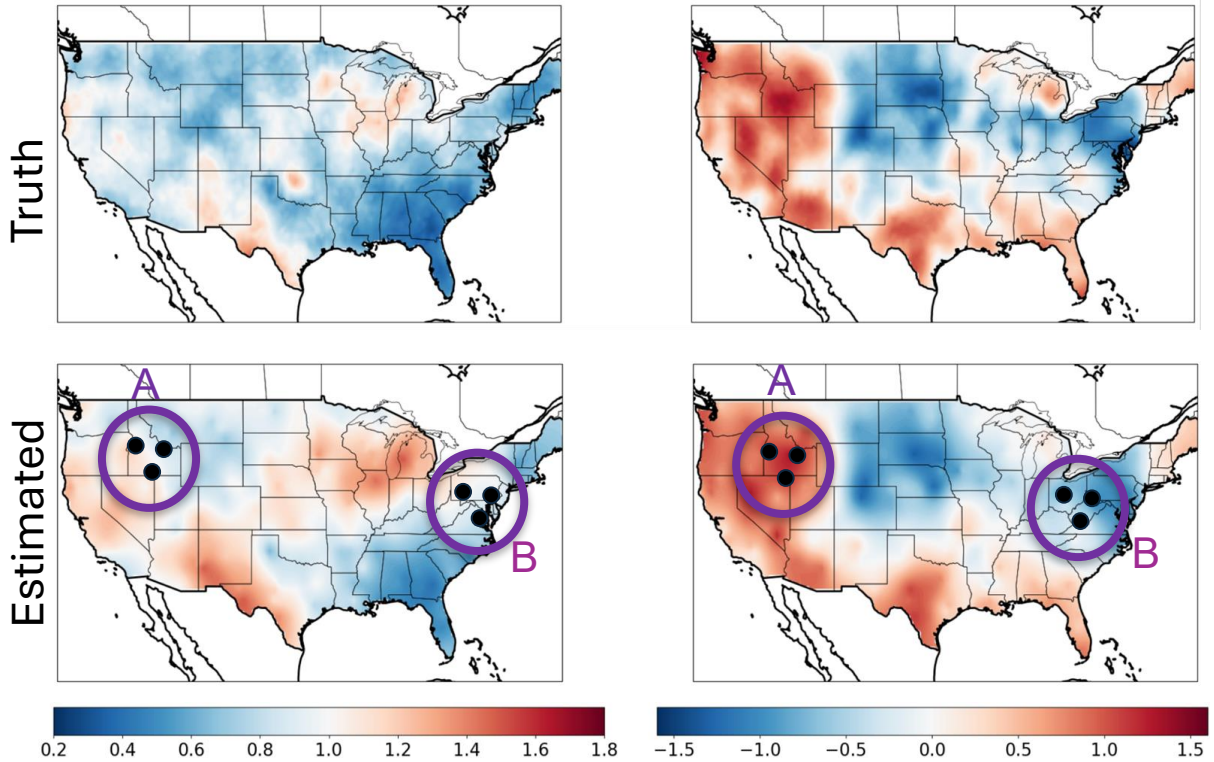
Calibration (estimated from 40 observations at sparse locations)

Relative SD

Mean shift

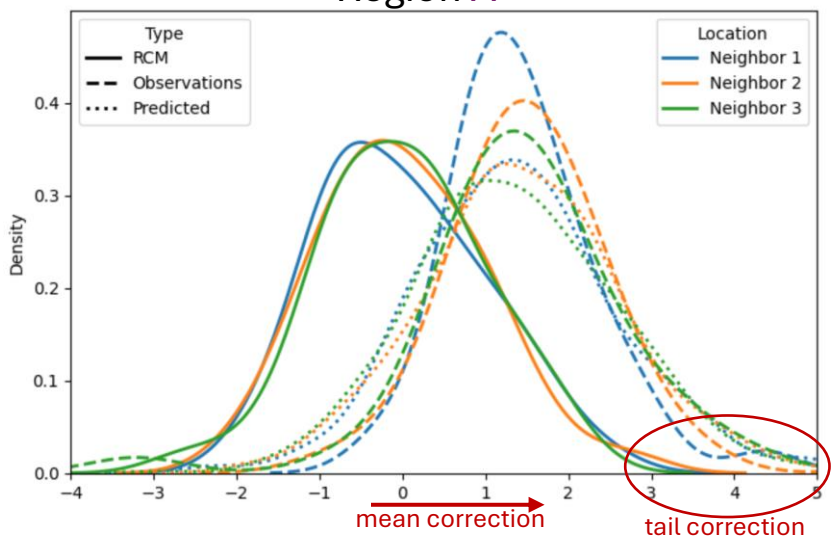
Truth

Estimated

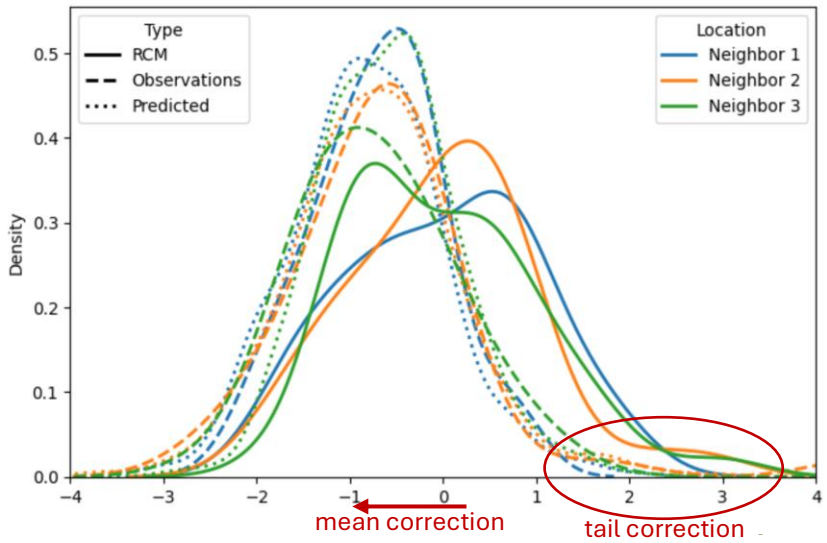


Marginal densities at **unobserved** locations

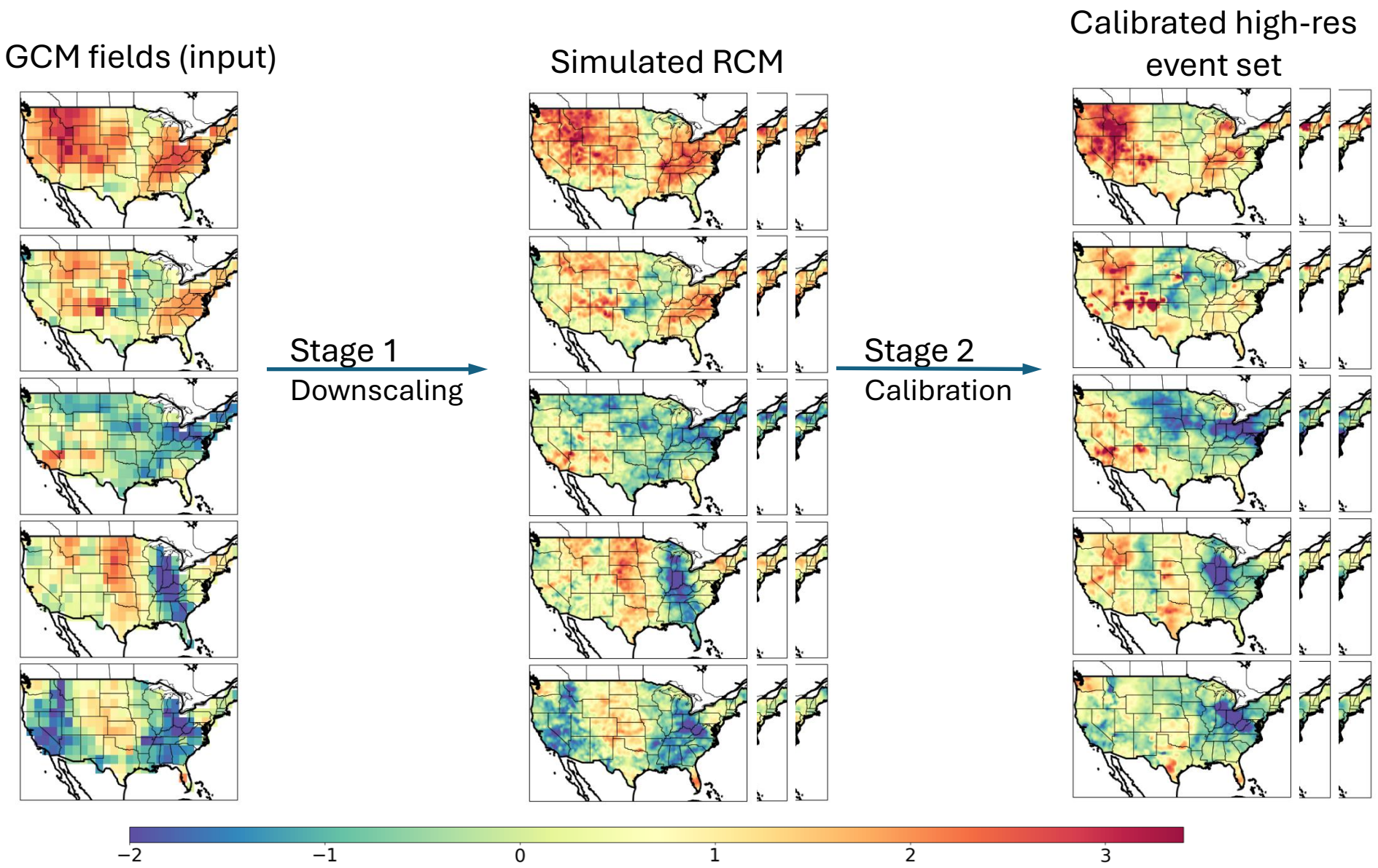
Region A



Region B



Full Pipeline: Proof of Concept



Expected Outcomes / Deliverables

- Observationally calibrated stochastic wind event sets at high (RCM) resolution over the United States.
- Novel general statistical methodology (via tech report) for model-data fusion, combining low-res models, high-res models, and sparse observations.
- Fully documented, open-source software for the entire pipeline, allowing for integration and extension.

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Impact

- Value to insurers:
  - Accurately quantify portfolio risk in the current climate, moving beyond the limitations of obsolete historical claims data.
  - Our "best of both worlds" dataset calibrates high-resolution, spatially-complete model output with sparse observations.
  - Provide a trustworthy stochastic wind event set for reliable stress testing against plausible scenarios, including those that do not exist in the raw data.
- Enabling future CIRCS research:
  - Provides a foundational statistical calibration "engine" for fusing diverse data sources across CIRCS projects.
  - Creates a clear pathway for unlocking multi-peril research (e.g., hail).
  - Reliable event sets can be used as input for Monte Carlo impact studies (e.g., Drs. Strader and Ashley).

Project Timeline

The project period will be calendar year 2026:

- Q1 (Jan-Mar): Stage 1
  - Development of Stage 1 methodology and procurement and analysis of GCM and RCM data
- Q2 (Apr-Jun): Stage 2
  - Development of Stage 2 methodology and procurement and analysis of observational data
- Q3 (Jul-Sep): Full pipeline
  - Combining Stages 1 and 2 and producing wind event sets
- Q4 (Oct-Dec): Final deliverables & reporting
  - Finalizing software documentation and tech report

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Project Budget

- **Personnel: $95,169**
  - PI Katzfuss time
  - Grad student stipend and tuition
- **Travel: $600**
  - PI travel to CIRCS meeting

Total: $95,769