Climate-Change Projections of Hazardous Convective Weather Using an Environment-Informed, Convection-Permitting Dynamical Downscaling Methodology (96)

S. Wang, R. Trapp, University of Illinois; **J. Allen, D. Gopalakrishnan**, Central Michigan University; **E. Robinson**, Aon, Inc.

ILLINOIS

CMU CENTRAL MICHIGAN UNIVERSITY

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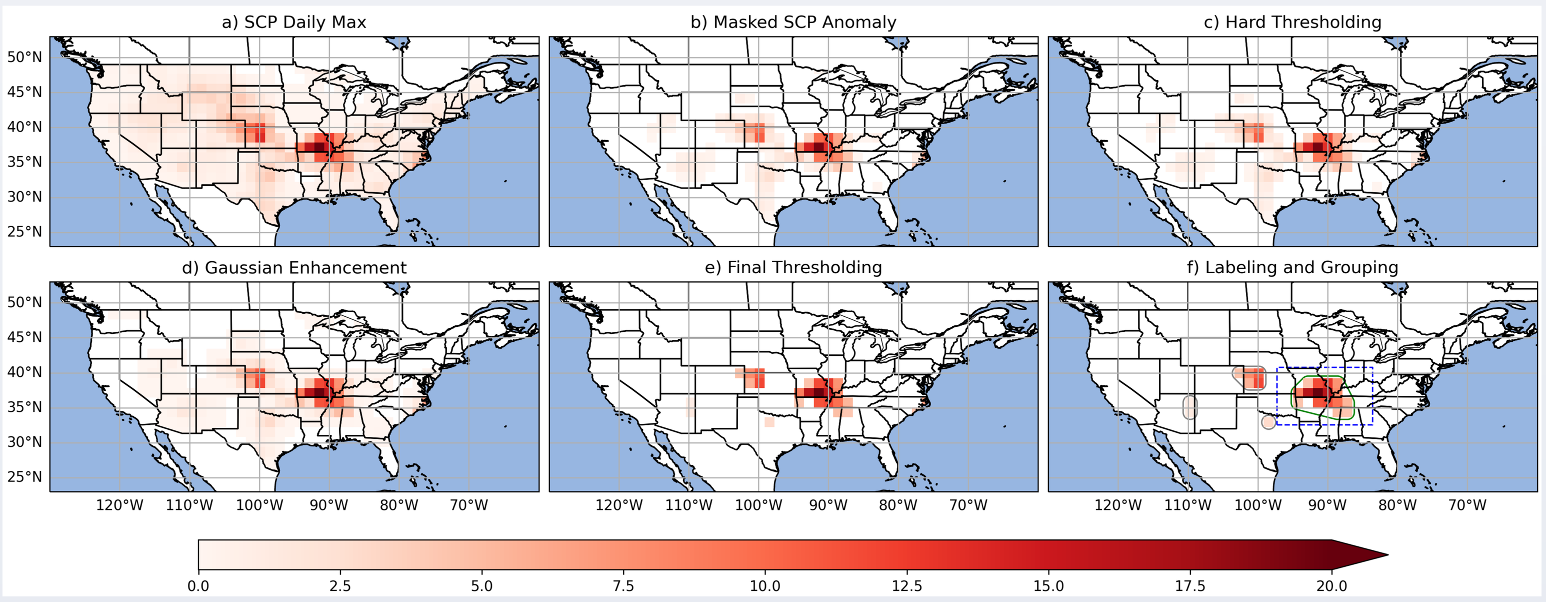
Motivation

- Studies of hydro-climate extremes benefit from application of ***convection-permitting dynamical downscaling*** **(CPDD)**
  - ***e.g., storm-scale generators of locally heavy precipitation, tornadoes, hail, and severe winds (HCW) are explicitly represented with few-kilometer grid spacings***
- The scope of CPDD studies, however, tend to be more computational–resource limited than GCM studies, which imposes limitations on:
  - ***integration lengths, computational domain size, number of different GCM drivers, etc.***
- Such studies have have tended to downscale a single GCM (or GCM composite), and thus are absent of uncertainty measures otherwise determined with an ensemble of simulations via an ensemble of GCMs
  - ***exceptions include Kendon et al. (2020) and Coppola et al. (2018)***
- With our **"environment-informed"** approach, only a subset of days/geographical domains are downscaled, therefore eliminating unnecessary model integrations: **This allows us to downscale multiple GCMs, providing HCW projections with more confidence.**

Methodology

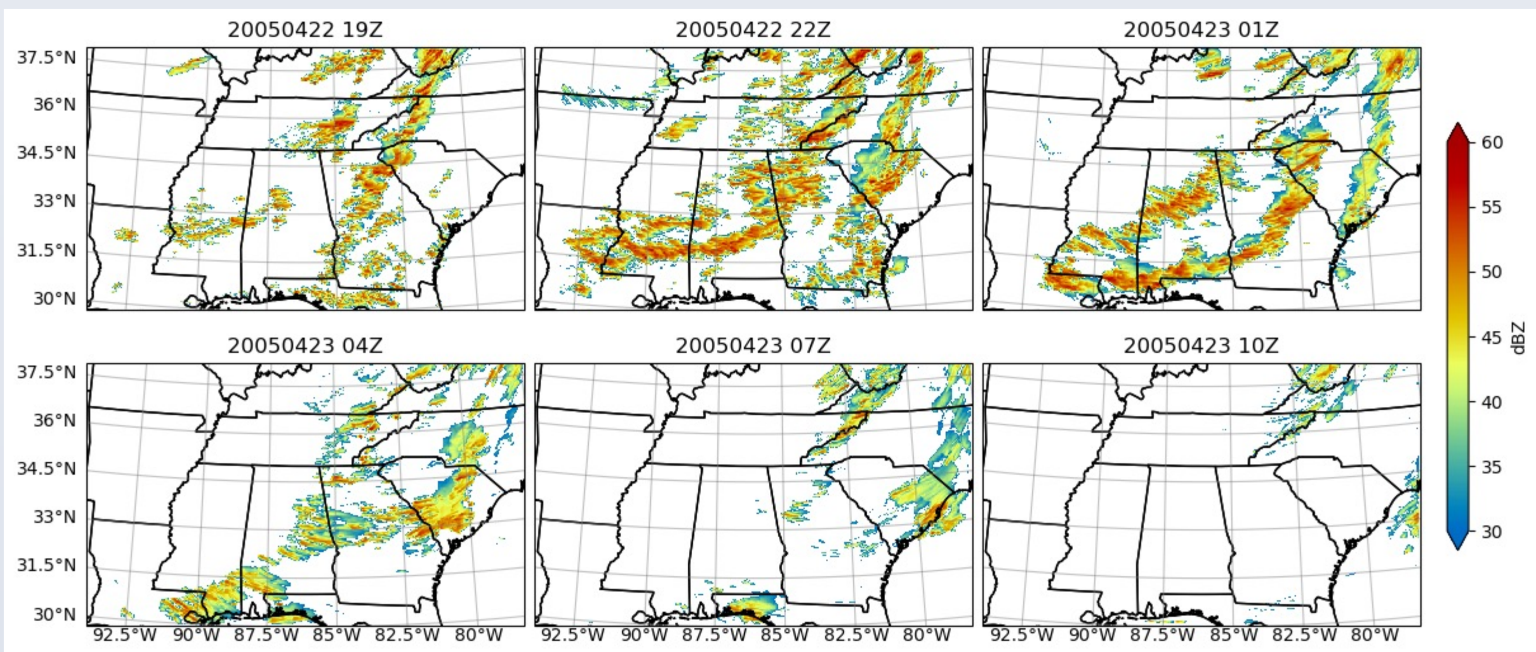
1. Environment screening using *supercell composite parameter* (SCP):

$$\mathrm{SCP}=\begin{cases}\left(\frac{\mathrm{MUCAPE}}{1000\ \mathrm{J\ kg^{-1}}}\right)\left(\frac{0-3\ \mathrm{km\ SRH}}{100\ \mathrm{m^2\ s^{-2}}}\right)\left(\frac{\mathrm{S06}}{20\ \mathrm{m\ s^{-1}}}\right), & \mathrm{MUCIN}\le 125\ \mathrm{J\ kg^{-1}}\\ 0, & \mathrm{MUCIN}>125\ \mathrm{J\ kg^{-1}}\end{cases}\qquad(1)$$

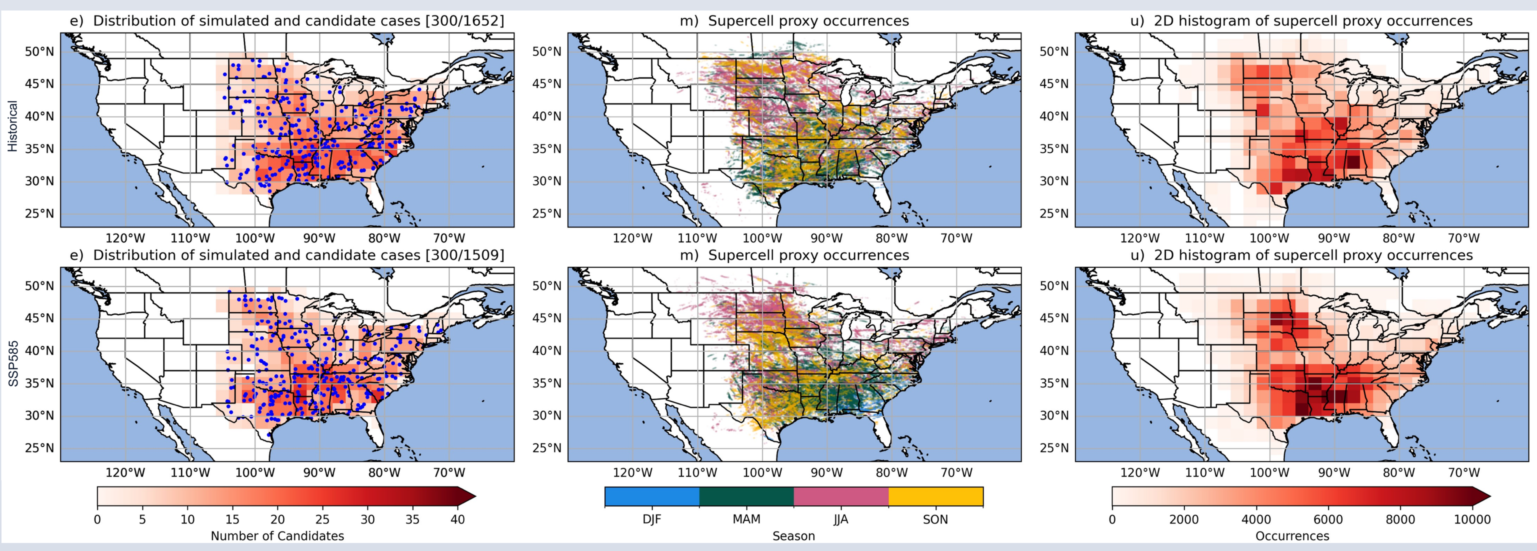


2. WRF simulation for sampled cases:

Domain size & resolution	500×300 grid points, 3 km gridpoint spacing
Vertical level & model top	50 levels, 50 hPa
Iteration time & time step	24 hours, 12 seconds



3. Collect candidate cases and sample 300 cases for dynamical downscaling:



4. Repeat for 8 GCMs from CMIP6:
   - BCC-CSM2-MR, CanESM5, CESM2, CNRM-ESM2, MIROC6, MPI-ESM1-2-HR, MRI-ESM2-0, NorESM2-MM.
   - Historical (1995-2014), SSP585 (2040-2059):

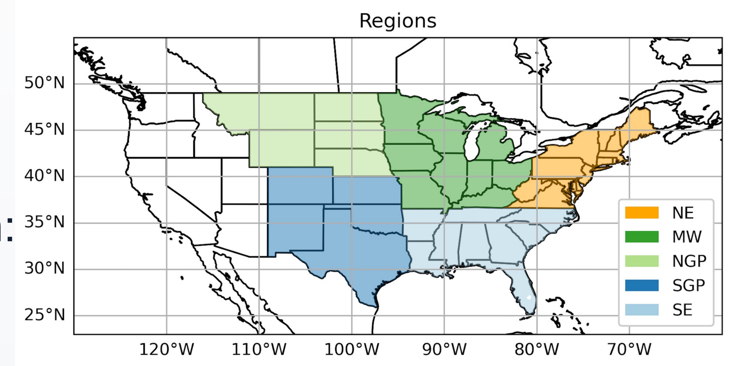
Notes on Approach

This "environment-informed" (EI) approach, which is used to generate a CPDD ensemble:

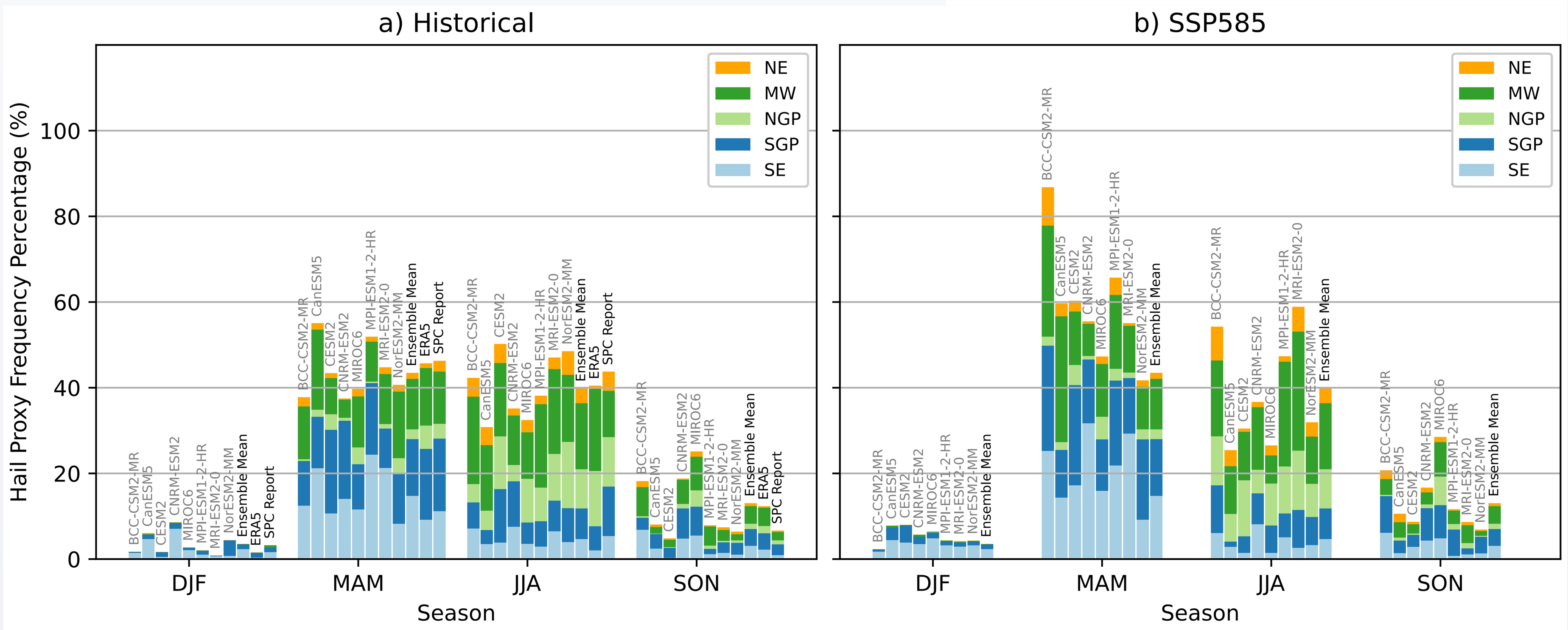
\+ offers flexibility: one could repeat a given set of runs with different physics, refined resolution, different downscaling models/versions;
\+ can be done using fairly modest HPC resources;
\+ is adaptable for different applications;
\+ is also adaptable for different scenarios, time periods, etc.;
– is not suitable for problems involving feedbacks (e.g., land-atmosphere) on multi-day or longer periods;
– is not suitable to study the water cycle

Results from CPDD Ensemble

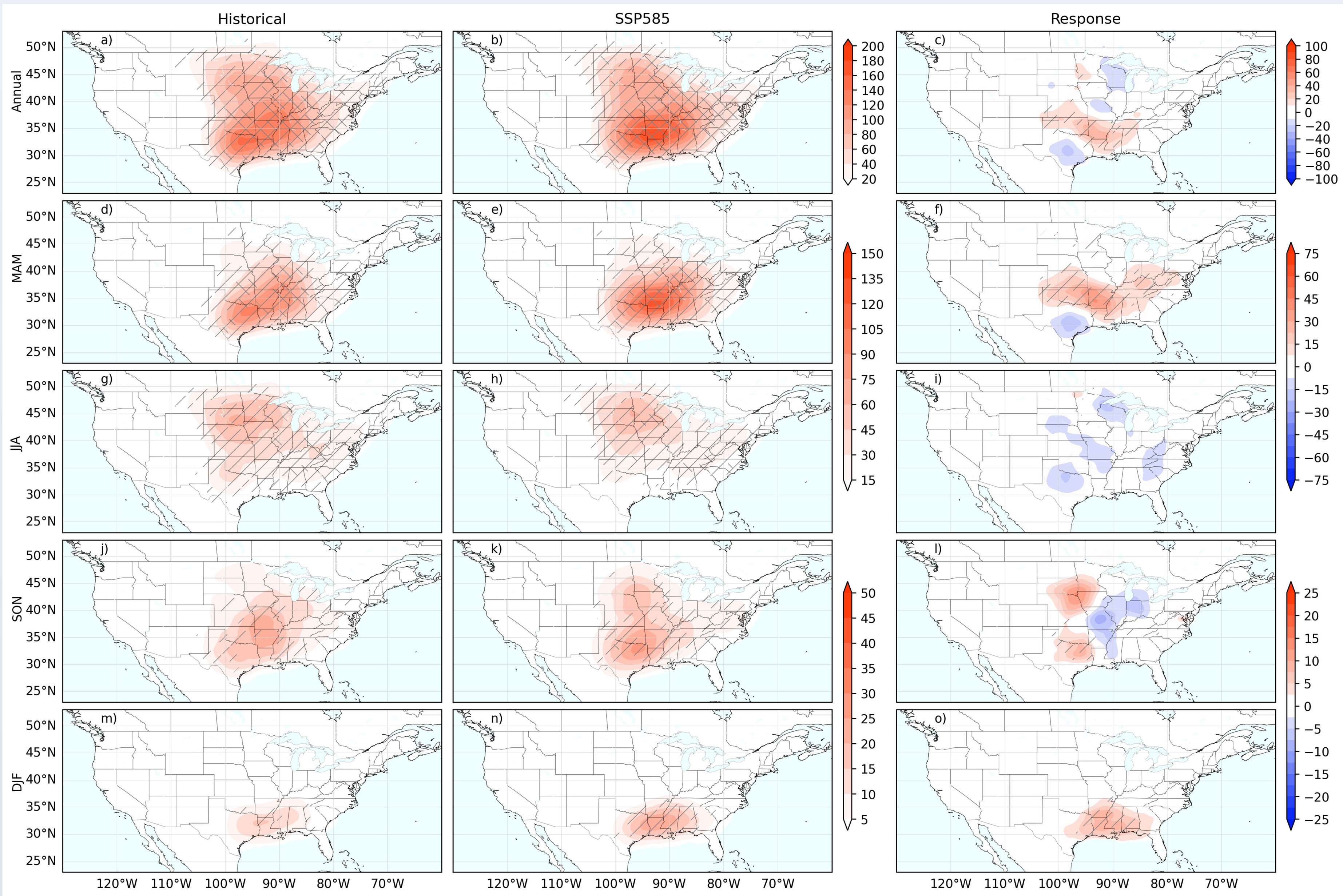
Hail proxy: HAIL_MAXK1>1.8 cm & WUP>20 m/s & REFD_MAX>55 dBZ



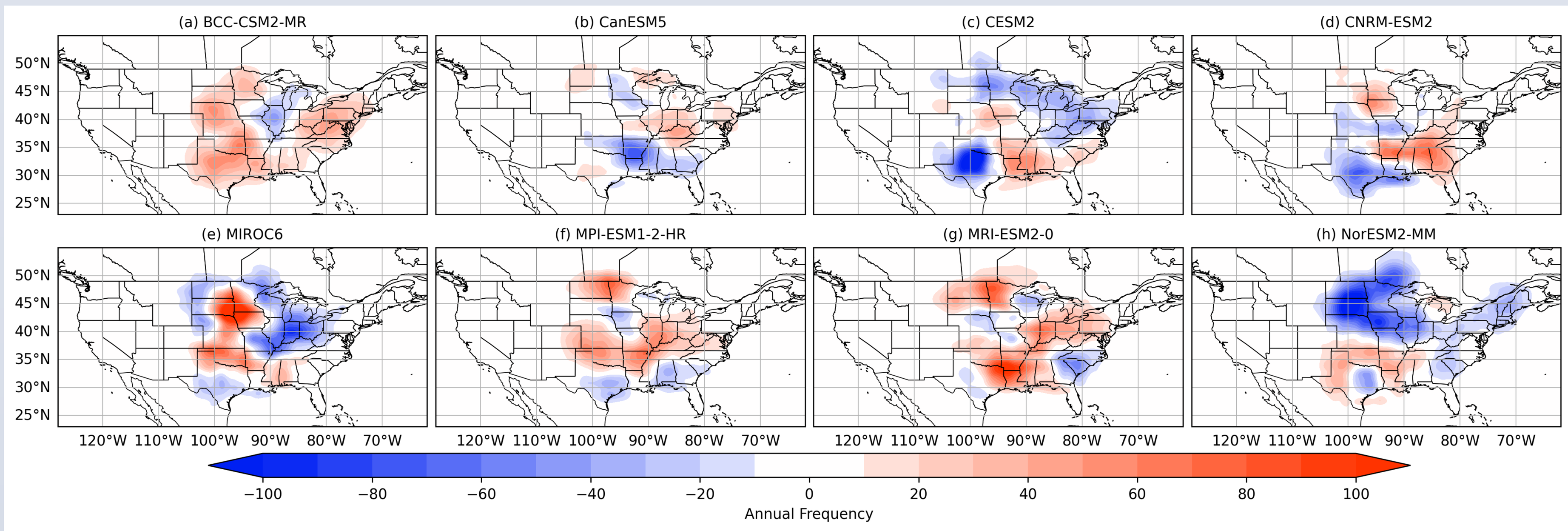
1. Hail proxy occurrence stratified by region and season:
   - Similar seasonal and regional distribution among GCMs, ERA5, and historical hail reports.



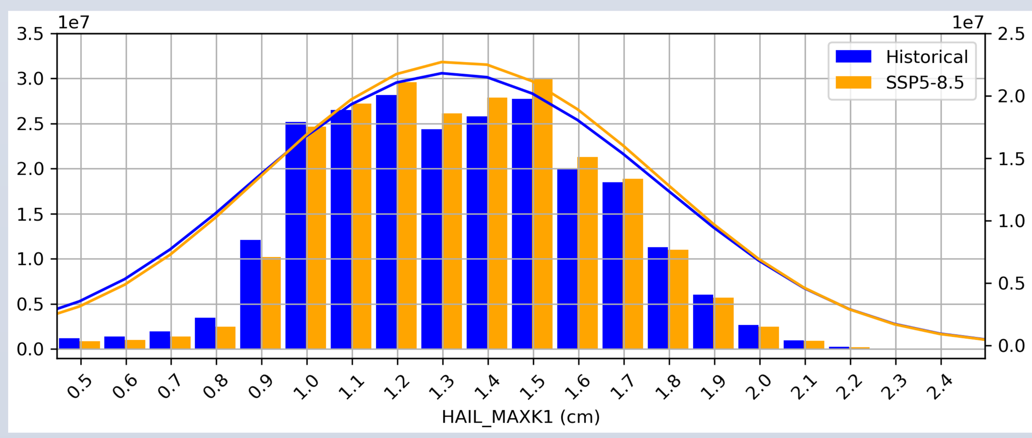
2. 2D hail proxy occurrence with robustness/significance:
   - Consistent with observed climatology, the center of hail occurrence moves northwards during summer, while in winter is confined to the coast of the Gulf of Mexico.
   - Hail increases in the future in the region extending from Oklahoma to Tennessee-Alabama border.
   - Spring is the season that contributes the most to hail occurrence in the historical and future; the climate change response is largest in spring as well.
   - The historical and future occurrence is robust among the ensemble (Mean>Std).
   - The response of hail occurrence is significant only in limited regions. (T-test: P<0.10)



3. Ensemble spread and GCM biases:
   - GCM biases, etc. contribute to different responses in future hail occurrence across the ensemble.
   - The spread in this response shows the value of a multi-GCM ensemble.



4. Hail size distribution across the ensemble:
   - Hail between 1–1.75 cm tends to increase in the future; hail larger/smaller than this decreases.
   - The future distribution of hail size has larger mean and smaller variance.



Ongoing Work

- Future projection of tornado and severe wind activity.
- Upscaling: machine learning methods to build the relationship between large-scale environment and convective storm activity.

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