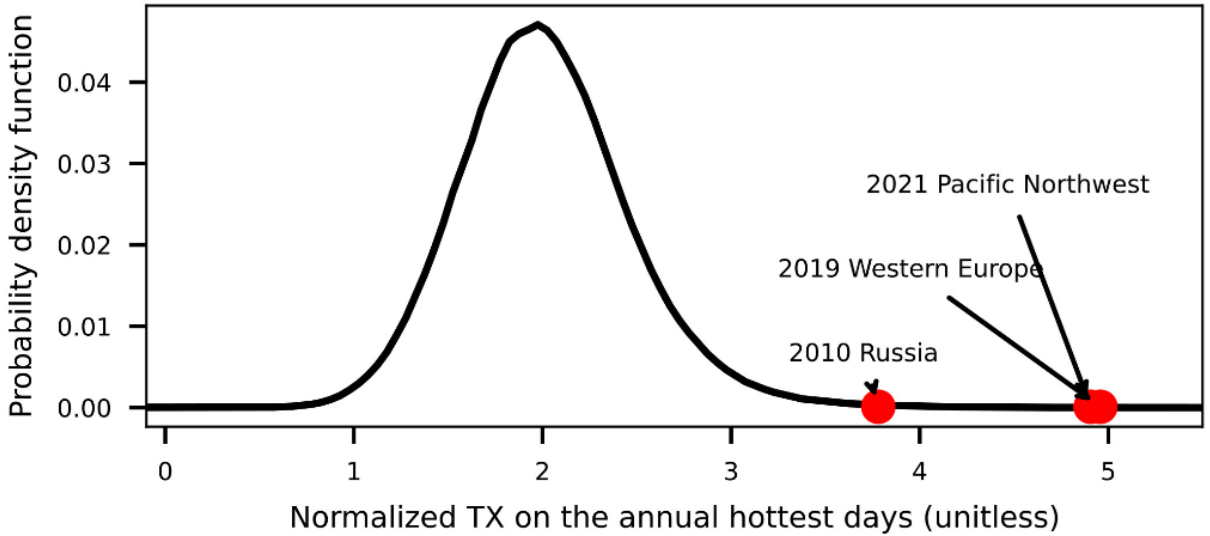
Generating Huge Ensemble Weather Forecasts with Spherical Fourier Neural Operators (SFNO)

Ankur Mahesh, William Collins, Boris Bonev, Noah Brenowitz, Yair Cohen,
Peter Harrington, Karthik Kashinath, Thorsten Kurth, Joshua North, Travis A. O'Brien,
Michael Pritchard, David Pruitt, Mark Risser, Shashank Subramanian, Jared Willard

Lawrence Berkeley Lab, NVIDIA, NERSC, University of California, Berkeley
Indiana University, University of California, Irvine

Low-Likelihood, High-Impact Heatwaves

Extreme heatwaves set temperature records 3+ standard deviations beyond the mean of annually hottest daily maximum temperatures.

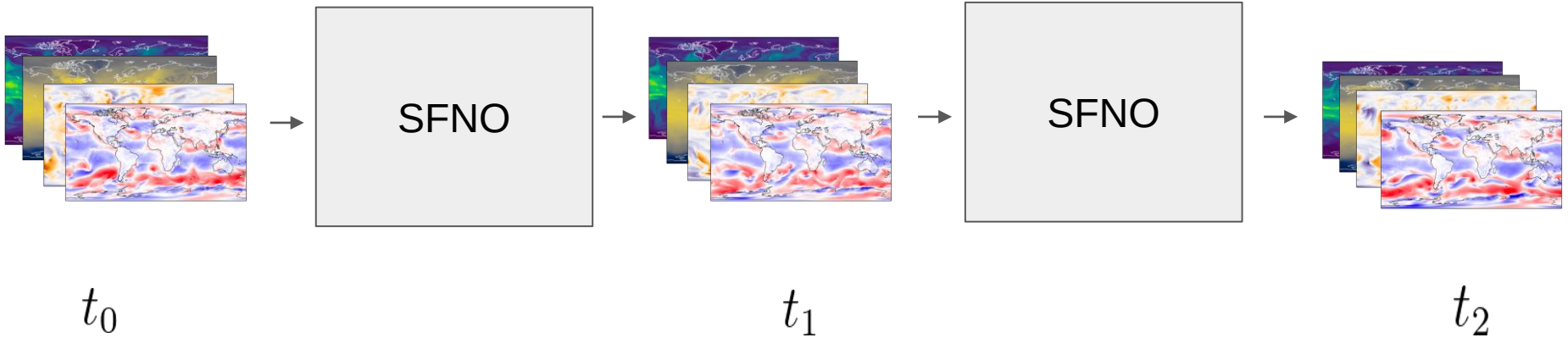


Zhang and Boos, 2023

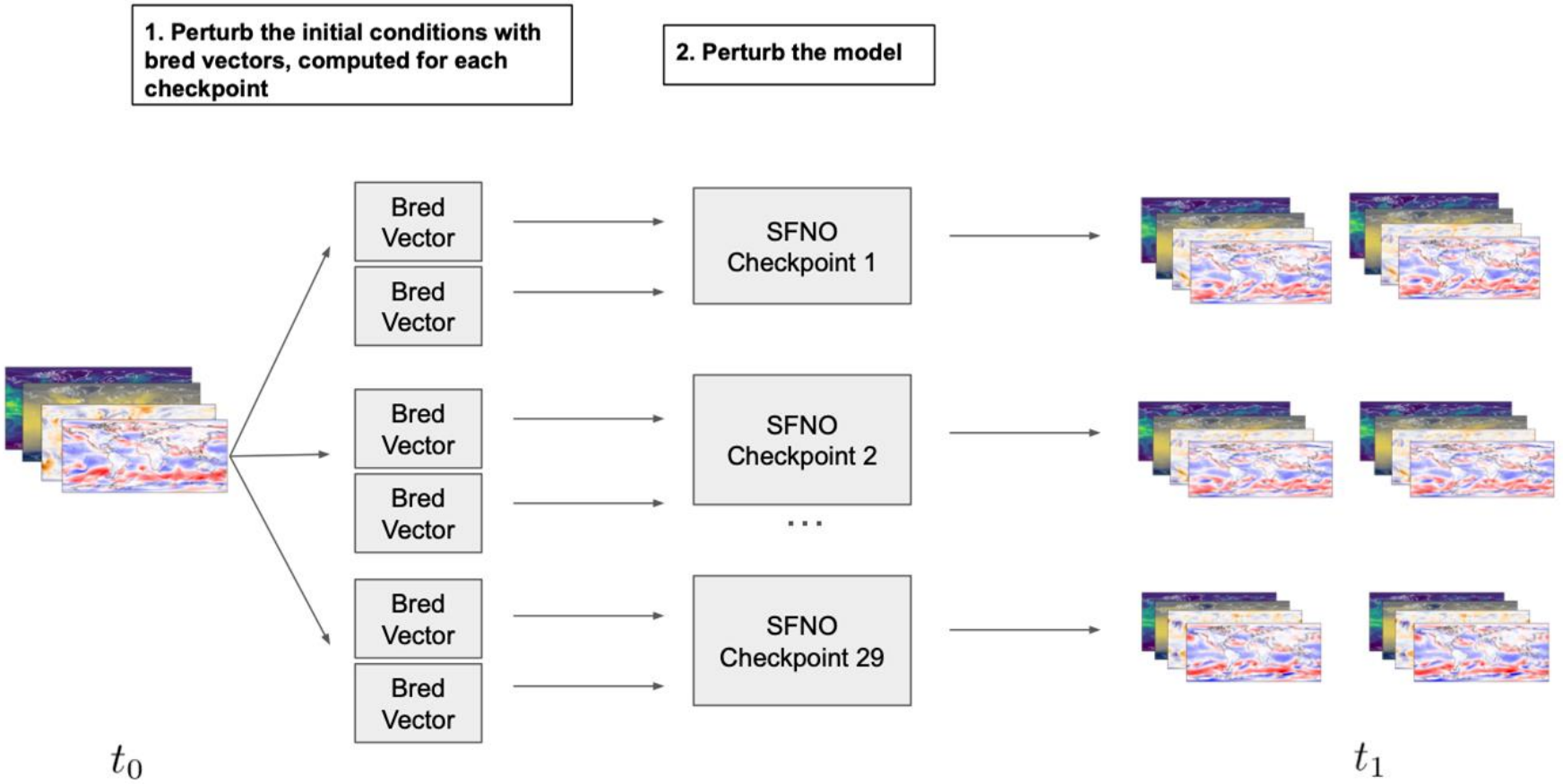
Forecasts from SFNO

Characterizing these extreme statistics and drivers requires large sample sizes.

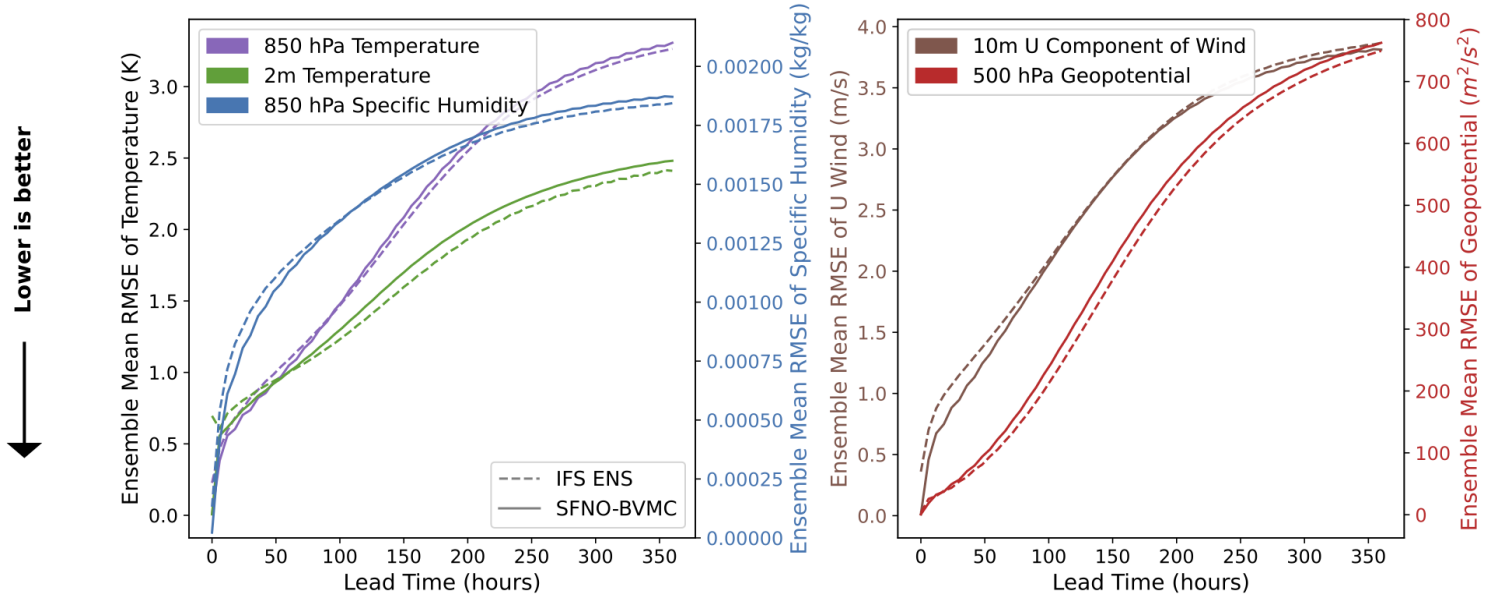
SFNO is a machine learning emulator used for weather prediction. It is ~3 orders of magnitude faster than its numerical counterparts.



Designing ML Ensemble Weather Forecasts

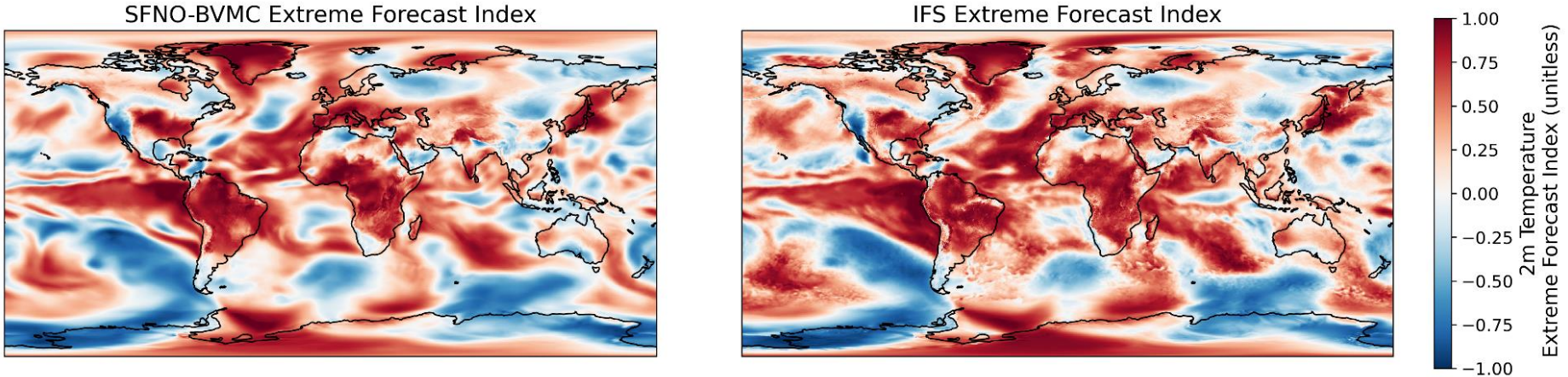


Diagnostics Pipeline: Ensemble Mean RMSE



The root-mean squared error (RMSE) is shown for the SFNO ensemble and IFS, the operational ensemble weather forecasting model at ECMWF.

Diagnostics Pipeline: Extreme Forecast Index



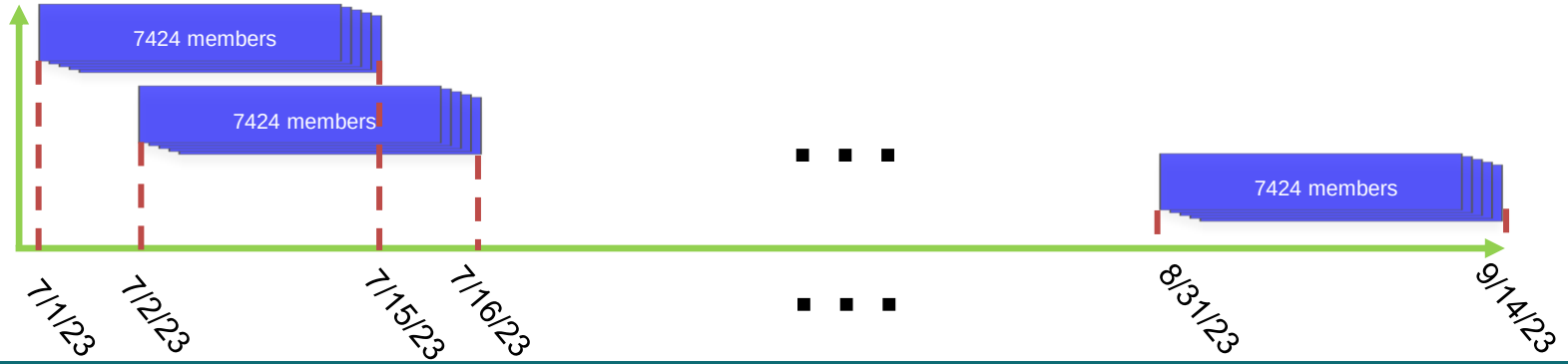
The Extreme Forecast Index is the basis for ECMWF's *Supplemental Score on Extremes*.

This score is a unitless quantity that indicates how extreme a given forecast is. From -1 (anomalously cold) to 1 (anomalously hot), it measures the distance between a given forecast and the model climatology.

Construction of Huge Ensembles (HENS)

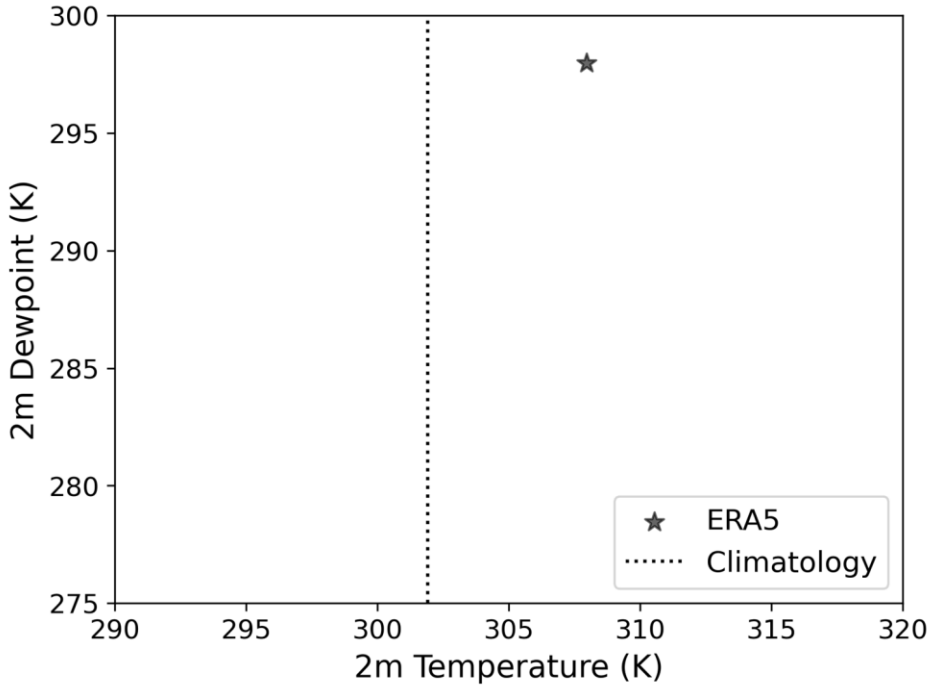
HENS consists of 29 * 256 = **7,424** ensemble members and 28,050 years of simulation.

Number of perturbed models	Number of perturbed initial conditions
29	256



Demo of Huge Ensembles

On August 23, 2023, Kansas City had an extreme heatwave, with 95 °F air temperature, 56% relative humidity, and a heat index of 109 °F.



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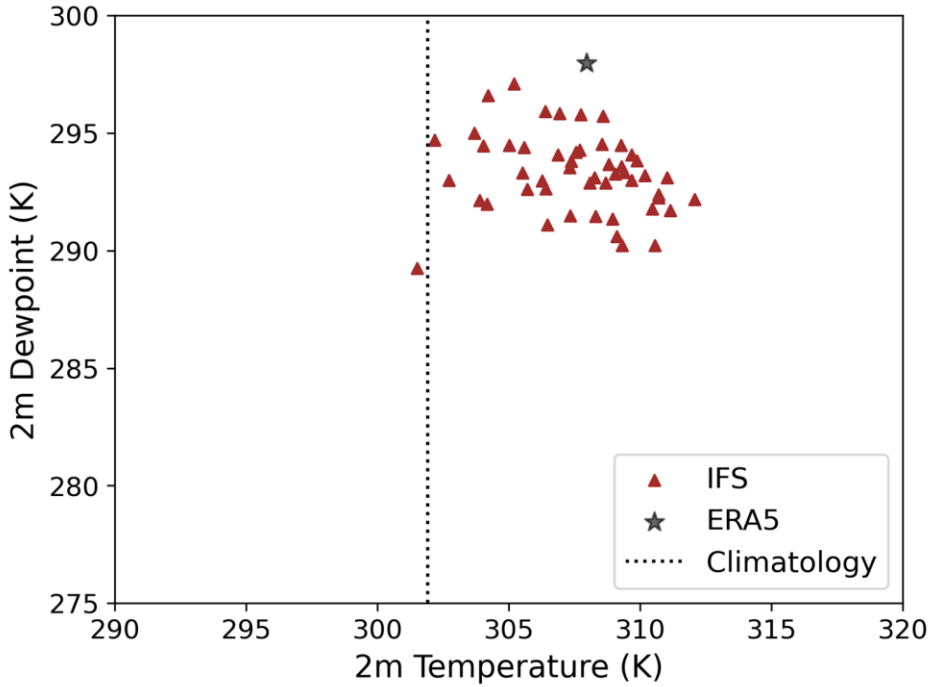
The 10-day IFS ensemble forecasts predicted warmer than average temperatures, but no members captured the combined magnitude of surface heat and humidity.



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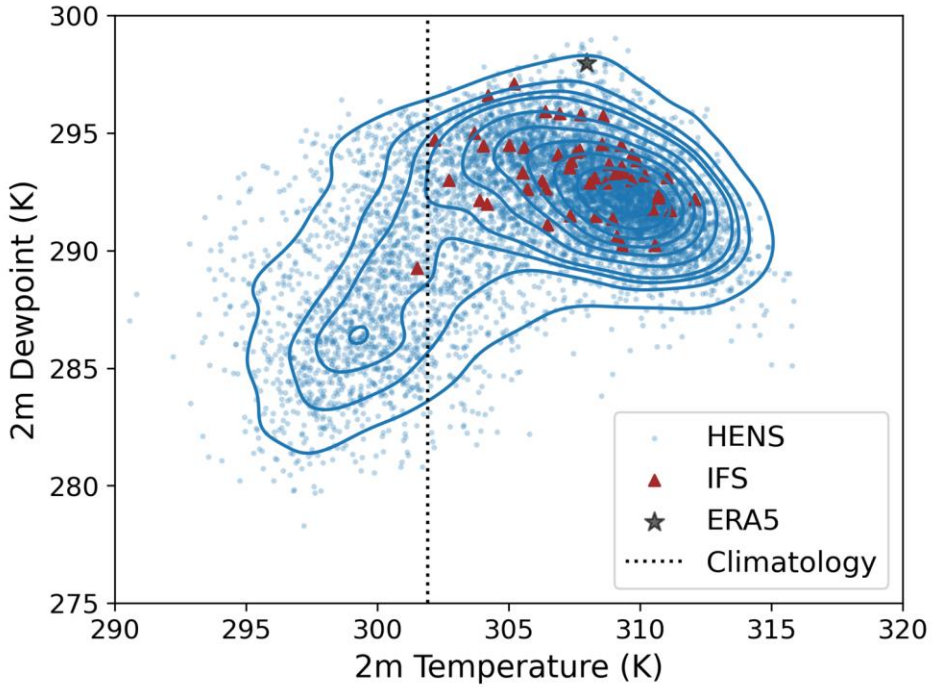
HENS samples the tails of the forecast distribution and is able to capture the magnitude of the event.



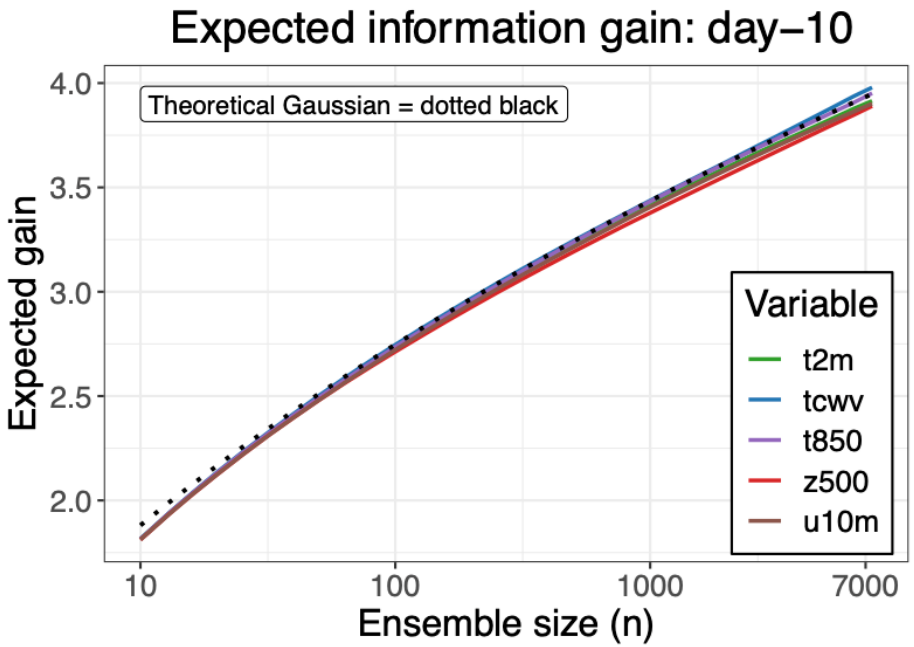
Information Gain from Huge Ensembles

The gain is *the maximum number of standard deviations away from the ensemble mean* that can be sampled by the ensemble.

$$G_n = \max_{i=1,\ldots,n} \frac{|X_i - \overline{X}_n|}{S_n}$$

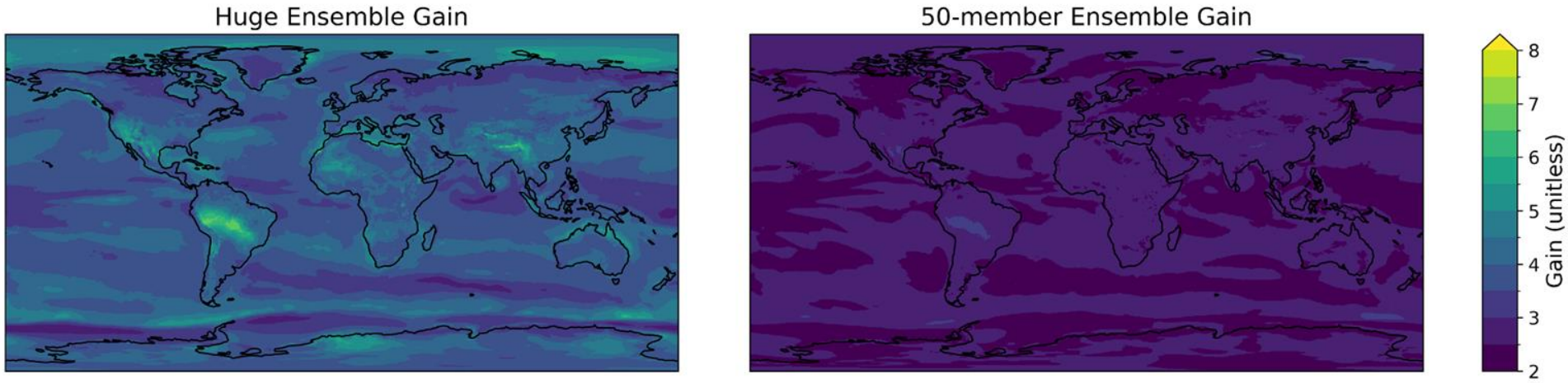
where X_i is an ensemble member, S_n is the ensemble standard deviation, and $\bar{X}_n$ is the ensemble mean.

HENS is large enough to have at least one member that is 4 standard deviations away from the ensemble mean.



Information Gain from Huge Ensembles

The information gain at each grid cell is shown below, for huge ensembles and traditional ensemble sizes.



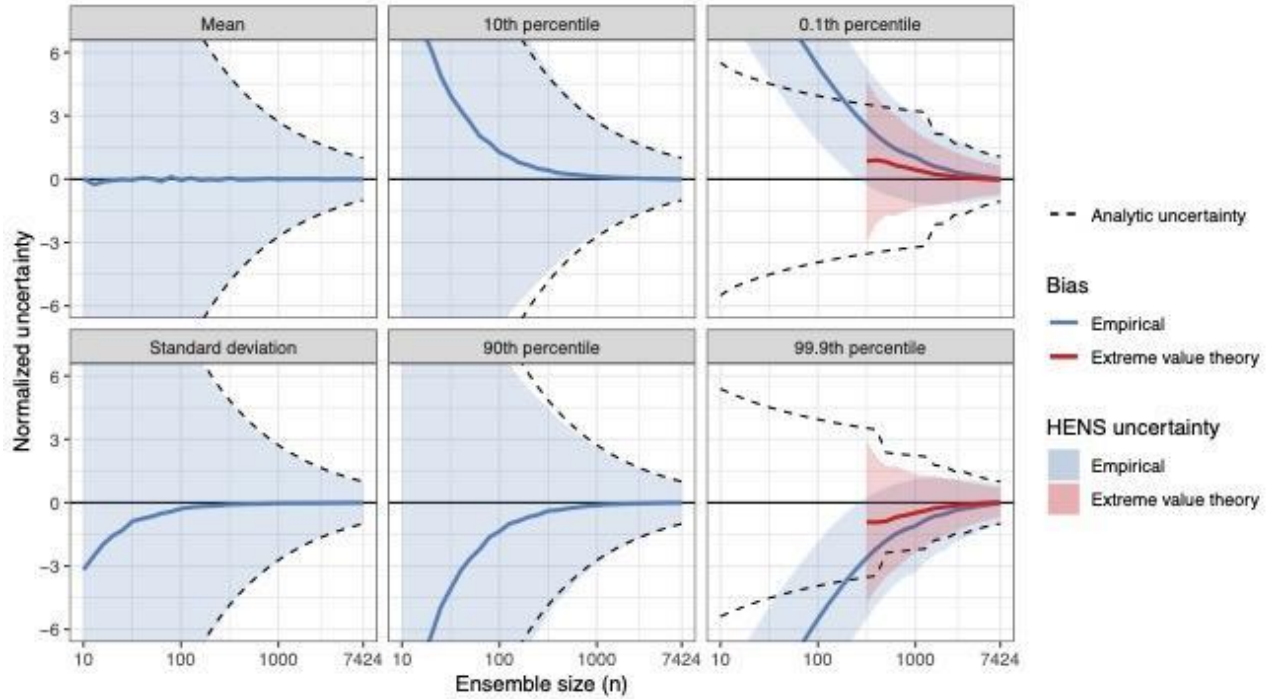
Thank you!

CASCADE
CALIBRATED & SYSTEMATIC CHARACTERIZATION, ATTRIBUTION, & DETECTION OF EXTREMES

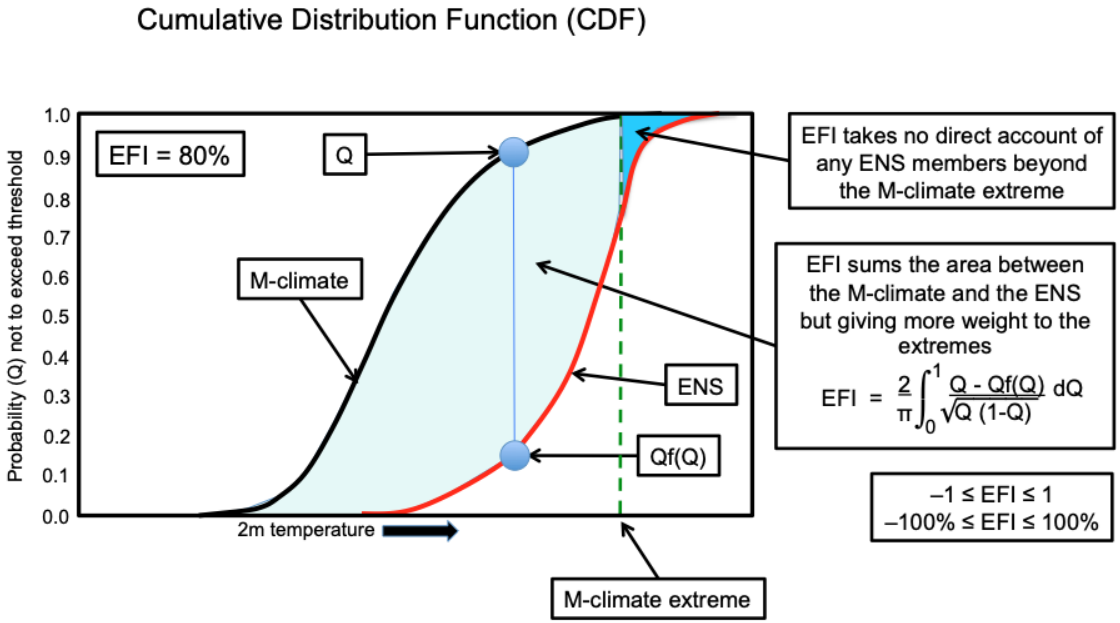
Huge Ensembles Part I:
https://arxiv.org/abs/2408.03100

Huge Ensembles Part II:
https://www.arxiv.org/abs/2408.01581

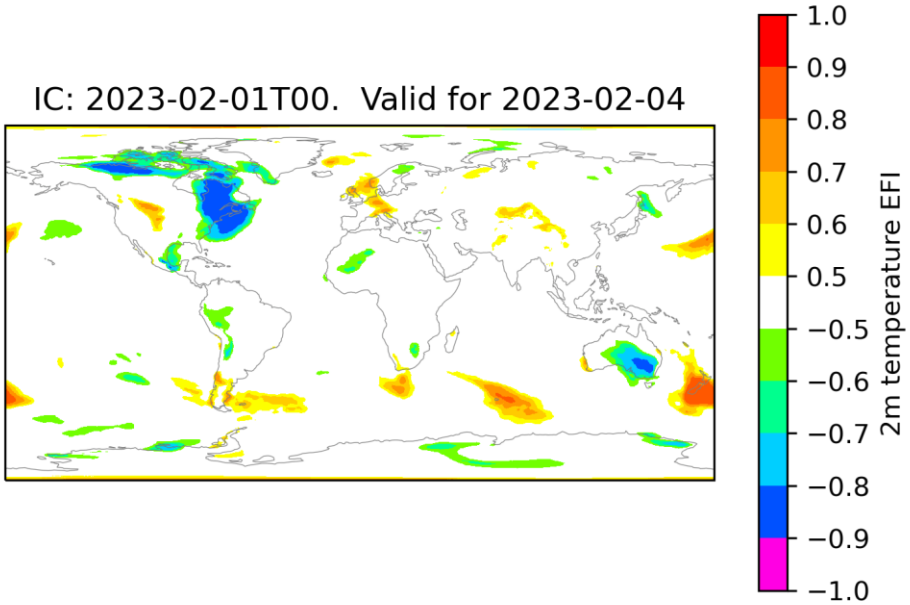
Characterizing the Huge Ensemble

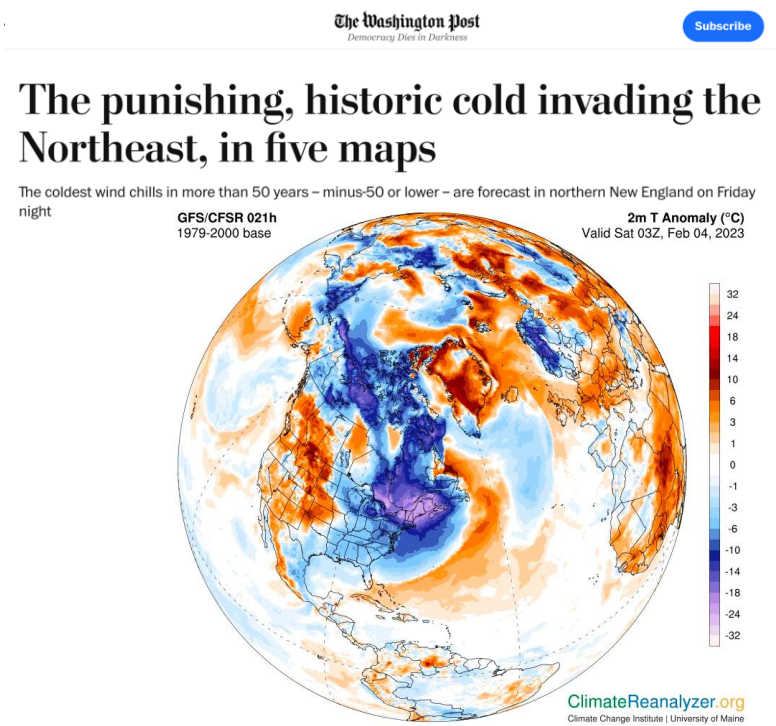


Validation 4: Distance between Ensemble & Climatology



Extreme Forecast Index in FourCastNet





Extreme Forecast Index in SFNO