

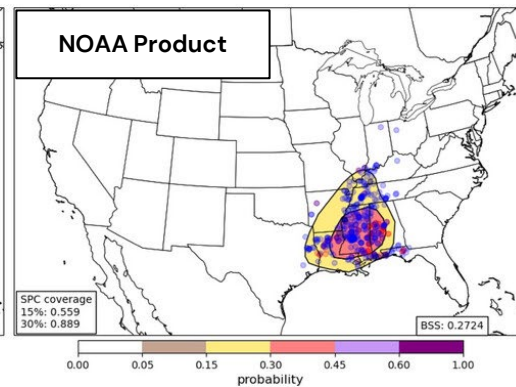
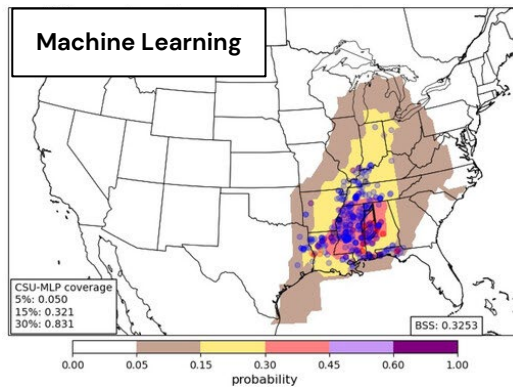
AI Development and Implementation for Earth System Prediction & Attribution

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Colorado State University

NASEM Extreme Event Attribution Information Gathering Session
March 11, 2025

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AI for tailored predictions
[e.g. single learning tasks]



Severe Hazards Forecasts

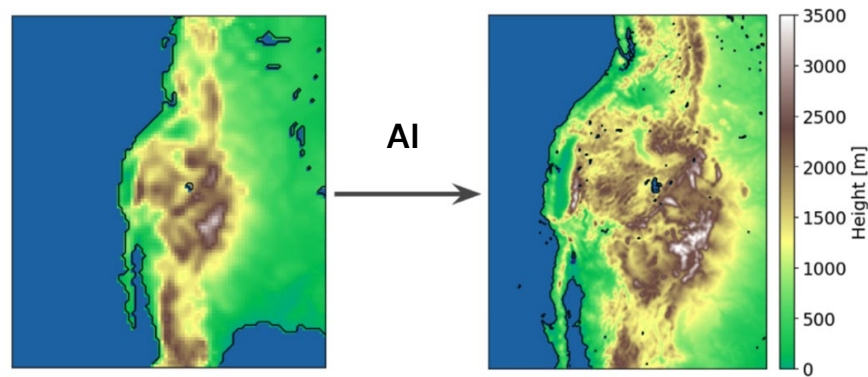
e.g. Lagerquist et al. (2020); McGovern et al. (2023); Vonich & Hakim (2024); Hill et al. (2023)

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AI for tailored predictions
[e.g. single learning tasks]

1

AI for post-processing
[e.g. corrections, compression, downscaling]



Downscaling Weather & Climate Data

e.g. Watt & Mansfield (2024); Schmude et al. (2024); van der Meer et al. (2023);
Lopez- Gomez et al. (2024)

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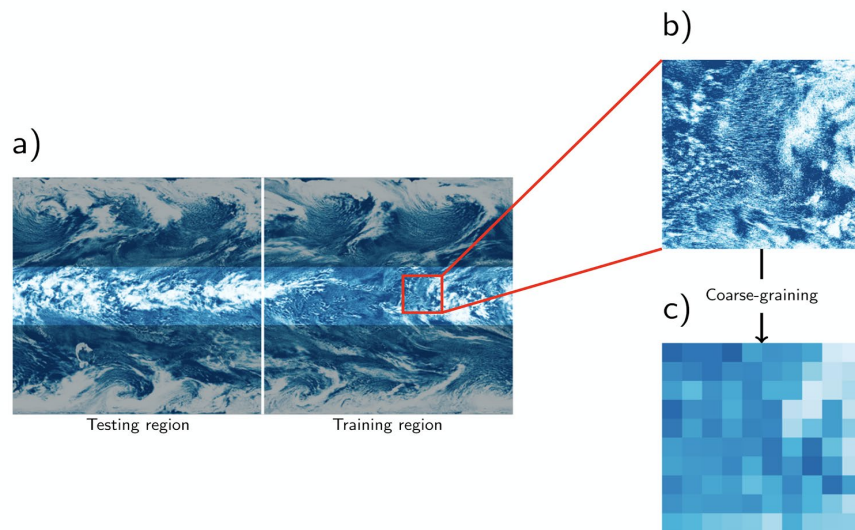
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AI to improve physics-based models
[e.g. parameterizations]



Improve Model Parameterizations

e.g. Rasp et al. (2018; PNAS); Schneider et al. (2017; GRL); O’Gorman and Dwyer (2018);
Beucler et al. (2020; PRL); Dagon et al. (2020); *Brenowitz and Bretherton (2018)*

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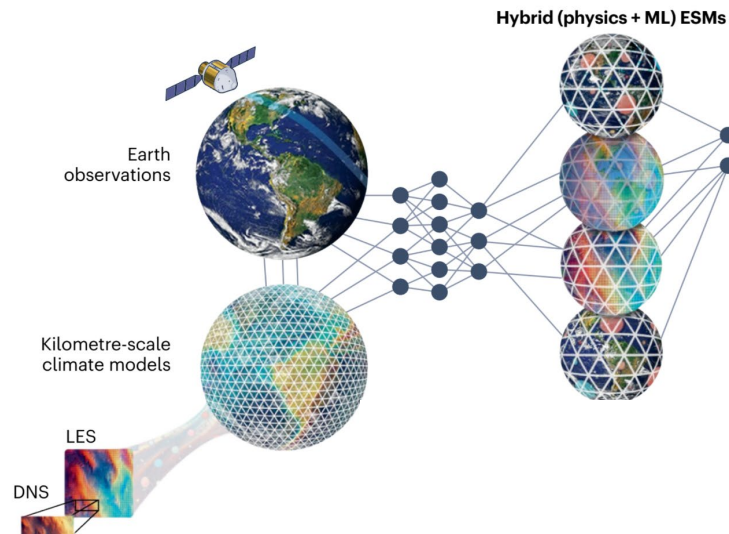
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AI to improve physics-based models
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3

**Merging observations and model data to reach
the end user [e.g. fine tuning, data assimilation]**



Observations Integration & Fine-Tuning

e.g. Ham et al. (2019); Barnes et al. (2024); Mayer et al. (2024); Immorlano et al. (2024);
adapted from Eyring et al. (2024)

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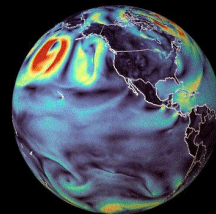
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Deep-learning weather/climate emulators
and foundation models [e.g. GraphCast, Aurora,
ACE2, DLESyM]

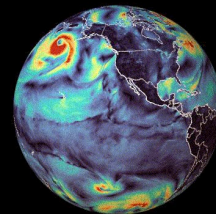
2024

- Watt-Meyer et al. [preprint]: [ACE2](#)
- Ling et al. [preprint]: [FengWu-W2S](#)
- Schreck et al. [preprint]: [WxFormer](#)
- Guan et al. [preprint]: [LUCIE](#)
- Gong et al. [preprint]: [WeatherFormer](#)
- Cressworraell-Clay et al. [preprint]: [DLESyM](#)
- Schmude et al. [preprint]: [Prithvi WxC](#)
- Basetti et al. [preprint]: [DiffESM](#)
- Chattopadhyay et al.: [OceanNet](#)
- Zhong et al. [preprint]: [FuXi 2.0](#)
- Flora & Potvin [preprint]: [WoFSCast](#)
- Met Office Press Office [blog]: [FastNet](#) [link not stable]
- Zhong et al. [preprint]: [FuXi-ENS](#)
- Wang et al. [preprint]: [CAS-Canglong](#)
- Sun et al. [preprint]: [FuXi Weather](#)
- Pathak et al. [blog]: [StormCast](#)
- Chen et al.: [FuXi](#)
- McNally et al. [preprint]: [ECMWF transformer for data-driven weather forecasts](#)
- Fuchs et al.: [TorchClim](#)
- Kochkov et al.: [NeuralGCM](#)
- Addison et al. [preprint]: [CPMGEM](#)
- Meuer et al. [preprint]: [Latent Diffusion Models for Generating Ensembles](#)
- Cachay et al. [preprint]: [Emulation of a Global Climate Model with Spherical Dyffusion](#)
- Wang et al. [preprint]: [Ola](#)
- Lang et al. [preprint]: [ECMWF AIFS](#)
- Couiaron et al. [preprint]: [ArchesWeather](#)
- Bodnar et al. [preprint]: [Aurora](#)
- Li et al. [preprint]: [CaFA](#)
- Gan et al. [preprint]: [EWMoE](#)
- Willard et al. [preprint]: [Swinv](#)
- Willard et al. [preprint]: ["Large](#)
- Verma et al.: [ClimODE](#)
- Li et al.: [Generative emulation](#)
- Vaughan et al. [preprint]: [Aard](#)
- Cheon et al. [preprint]: [KARIN](#)
- Ramavajjala [preprint]: [HEAL](#)
- Windborne [blog]: [WindBorne](#)
- Han et al. [preprint]: [FengWu-](#)

2018-01-08



SFNO

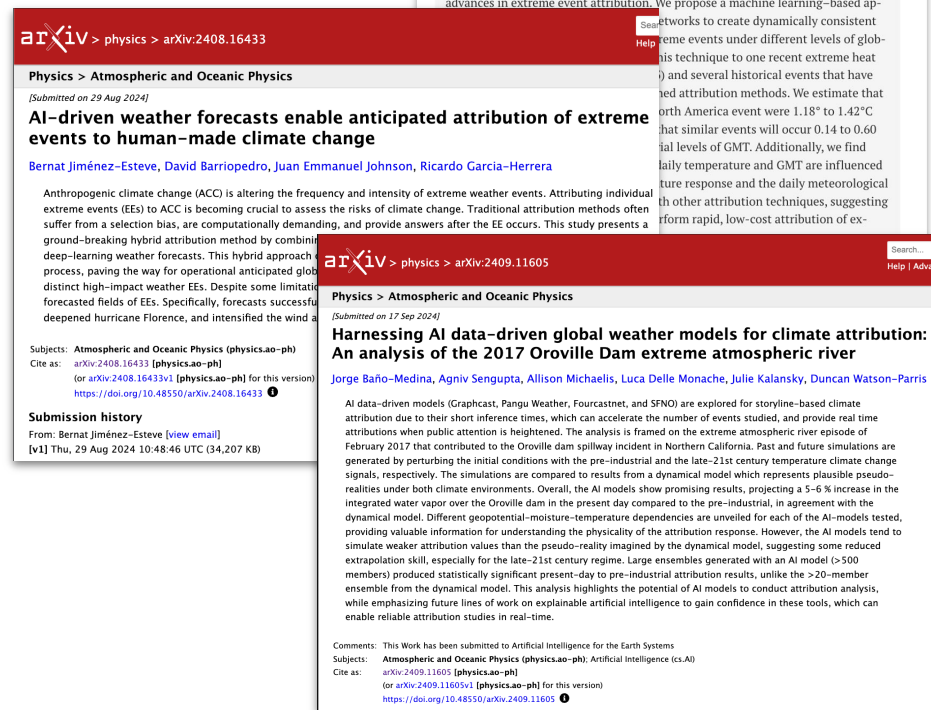


Ground truth

Created by NVIDIA [link]

New Frontiers

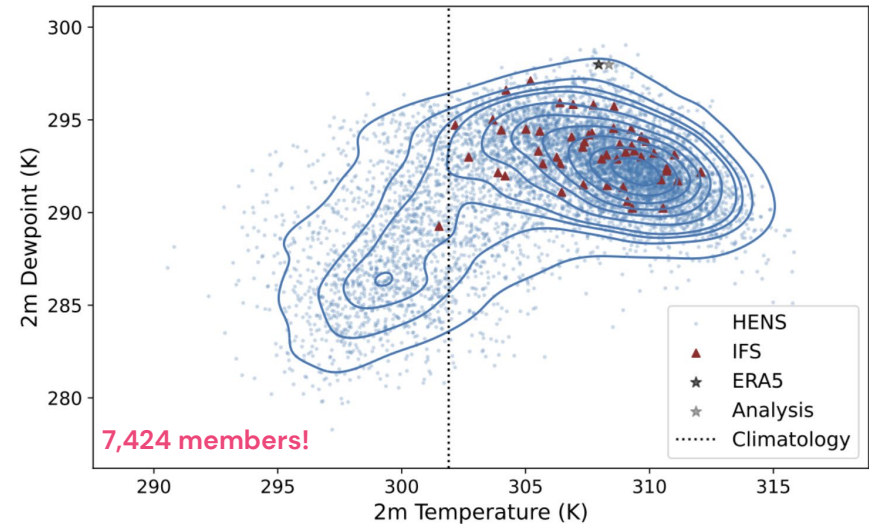
1. Deep-learning extreme event attribution is already being attempted.



New Frontiers

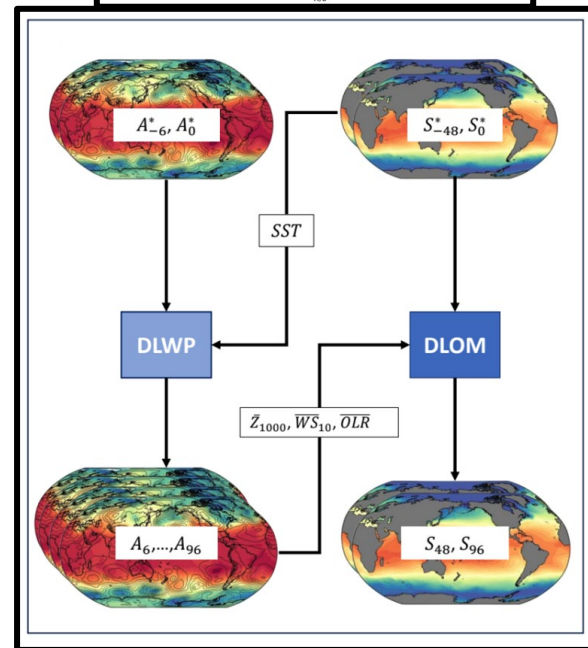
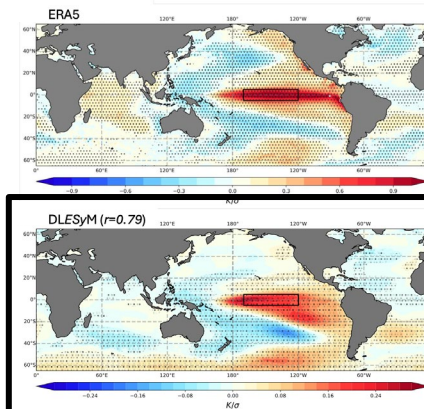
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2. Speed and low cost could allow for large ensembles in minutes, supporting uncertainty quantification.

10 day forecast for Kansas City, Missouri Verifying August 23, 2023 @ 18 UTC



New Frontiers

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2. Speed and low cost could allow for large ensembles in minutes, supporting uncertainty quantification.
3. Coupled AI-emulators are just coming online now.



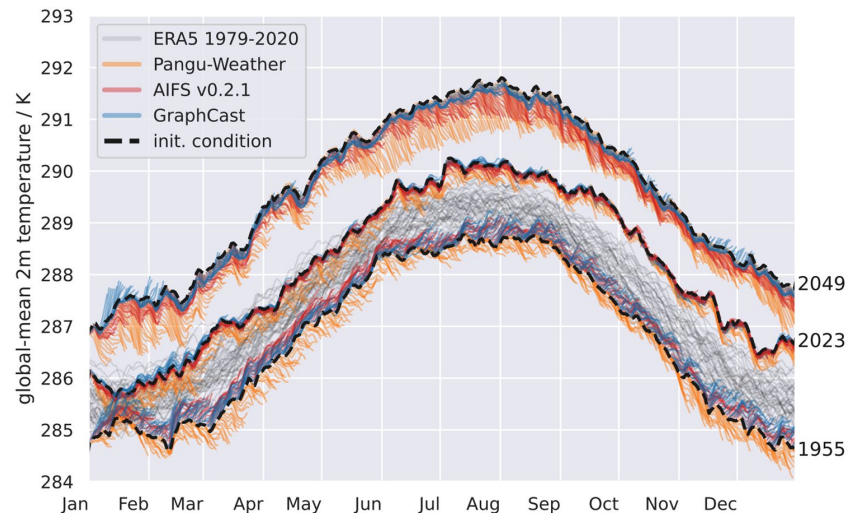
Are they fit for purpose?

How will we know?

Unlike weather forecasting models, Earth system models need to be credible when external factors are very different from history. This poses a challenge for purely data-driven emulators.

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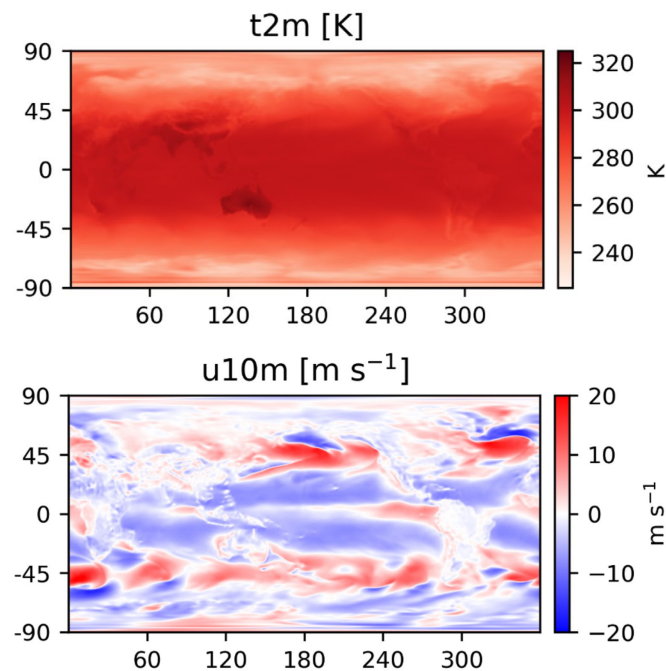


Model drift is evident when predicting the weather in future and past climates.

This has major implications for attribution applications.

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SFNO model 10 days after initialization of an idealized, no topography, baroclinic wave test.

The outlines of the continents demonstrate the difficulty in using these models out-of-sample.

Priorities for AI Applications for Attribution Studies

1. **Rigorous evaluation of weather/climate emulators;** this requires both agreeing on what tests are necessary, as well as implementing them
2. **Assess and understand how these models behave under realistic climates out-of-distribution;** determine strategies for improving performance in these instances (e.g. training on climate model data, building hybrid AI-physics models)
3. **Leverage a wide range of datasets to support the full pipeline from earth system simulation to final impact** (e.g. monetary, health, etc.)