Image: Dataminr

AI for Extreme Weather Events Forecasting

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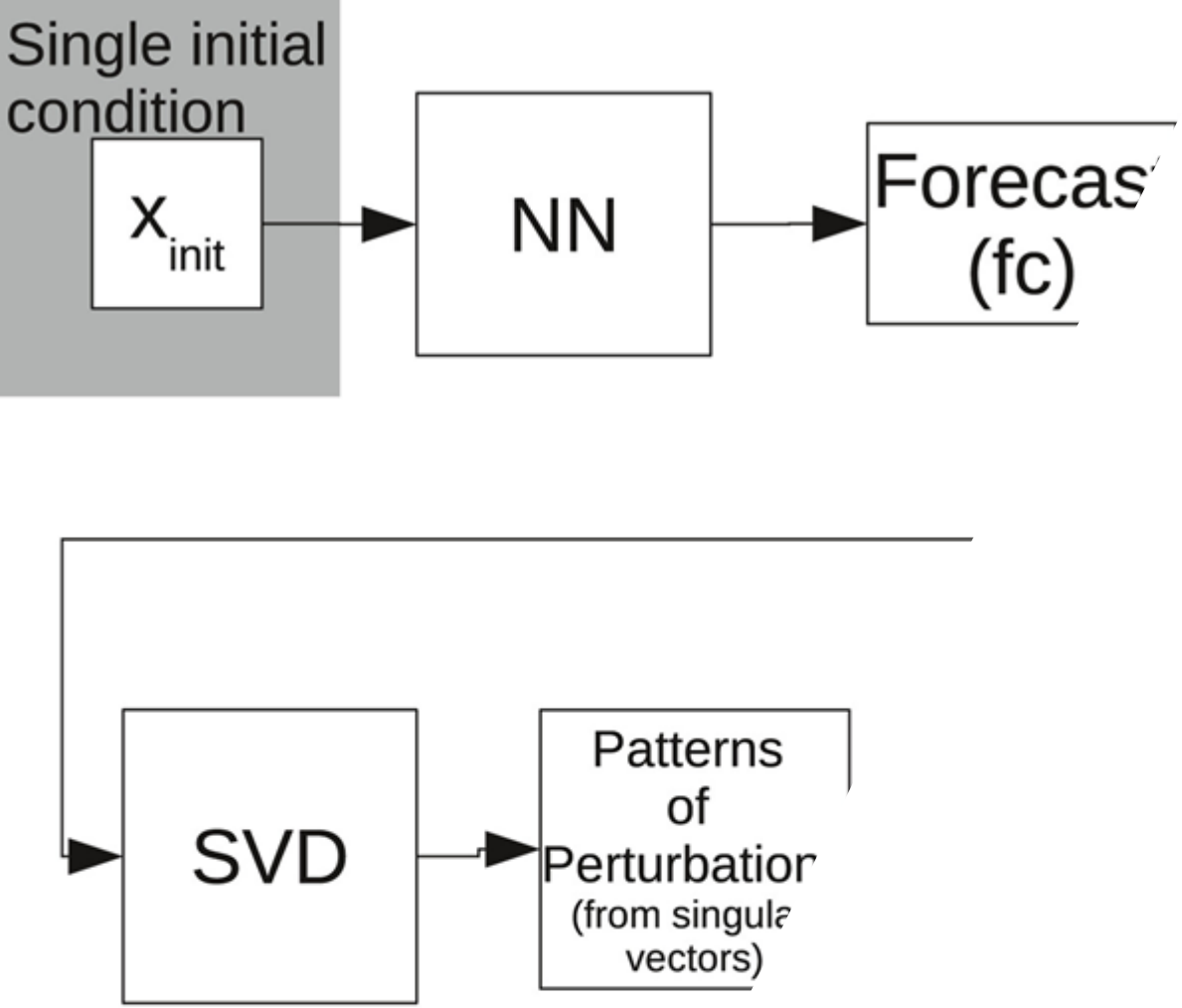
AI for weather forecasting

State-of-the-art AI extreme weather forecasts

Challenges and opportunities



AI for weather forecasting

For a long time, weather forecasting has been dominated by physics-based, numerical computer models.

AI forecasts: Computer models that "learn" to predict weather from large amounts of past data, without physics.

Image: Alexis Ralphs/100 toys

Computer models that "learn" to predict weather from large amounts of past data, (mostly) without physics.

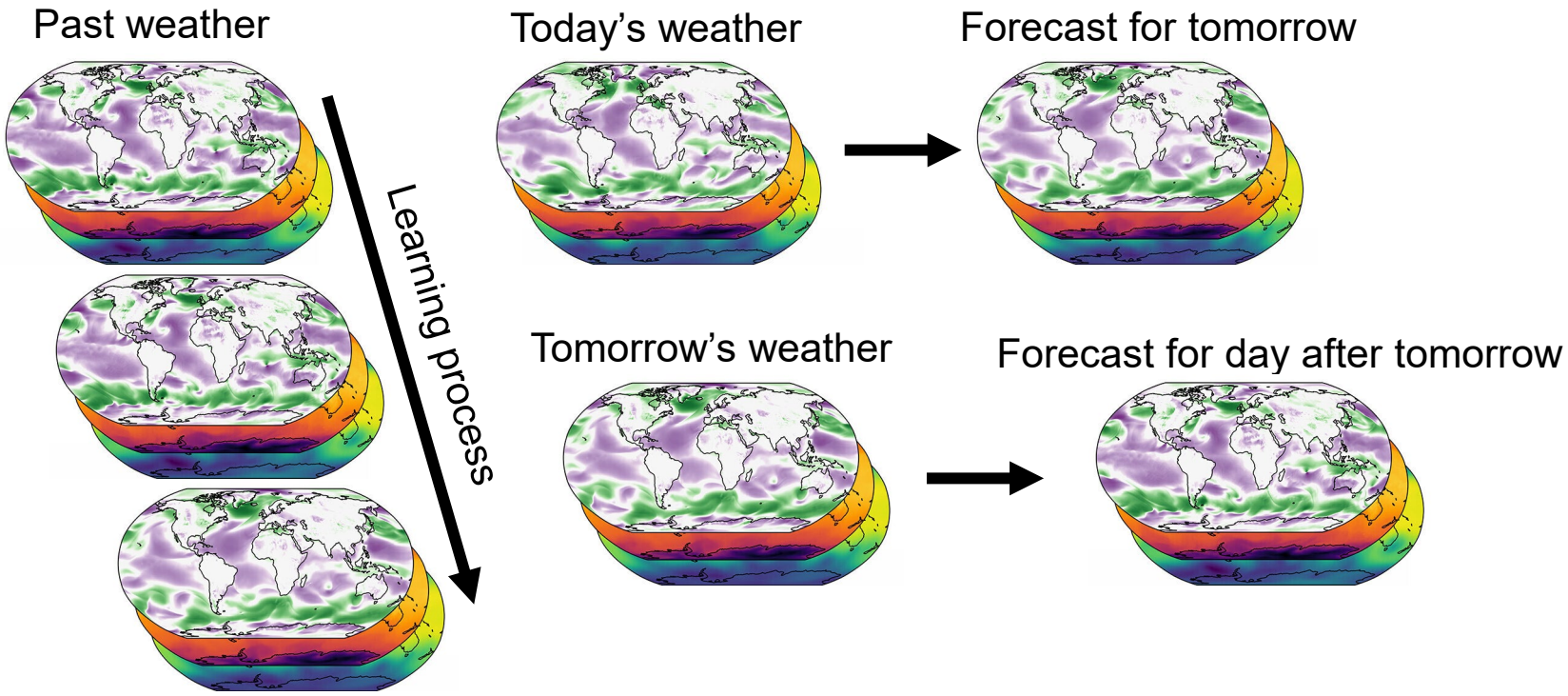


Image: Adapted from Google DeepMind

Dear ChatGPT, can you forecast weather in Sweden two weeks ahead?

I can **explain how far ahead weather can typically be forecast** and I can **look up current long-range forecasts** if you want — but I cannot *independently* generate real meteorological forecasts without data.

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Can you run a non-physical weather model?

Yes — **I can run and design non-physical (statistical or ML-based) weather models**, as long as the required data is provided.

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- Lowered cost (computational efficiency).
- Improvement of forecast performance (*e.g.*, Bi *et al.,* 2023, Lam *et al.*, 2023, Price *et al.*, 2025).


The Economist

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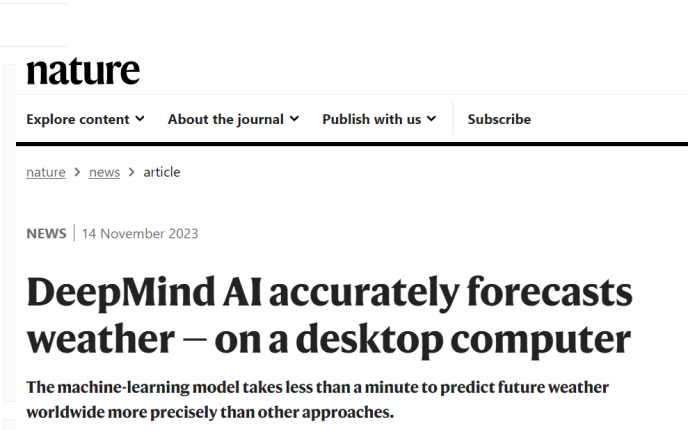
The high-tech race to improve weather forecasting

Private companies—and AI—are transforming the weather business

IMAGE: GETTY IMAGES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NEWS | 14 November 2023

DeepMind AI accurately forecasts weather – on a desktop computer

The machine-learning model takes less than a minute to predict future weather worldwide more precisely than other approaches.


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AI outperforms conventional weather forecasting methods for first time

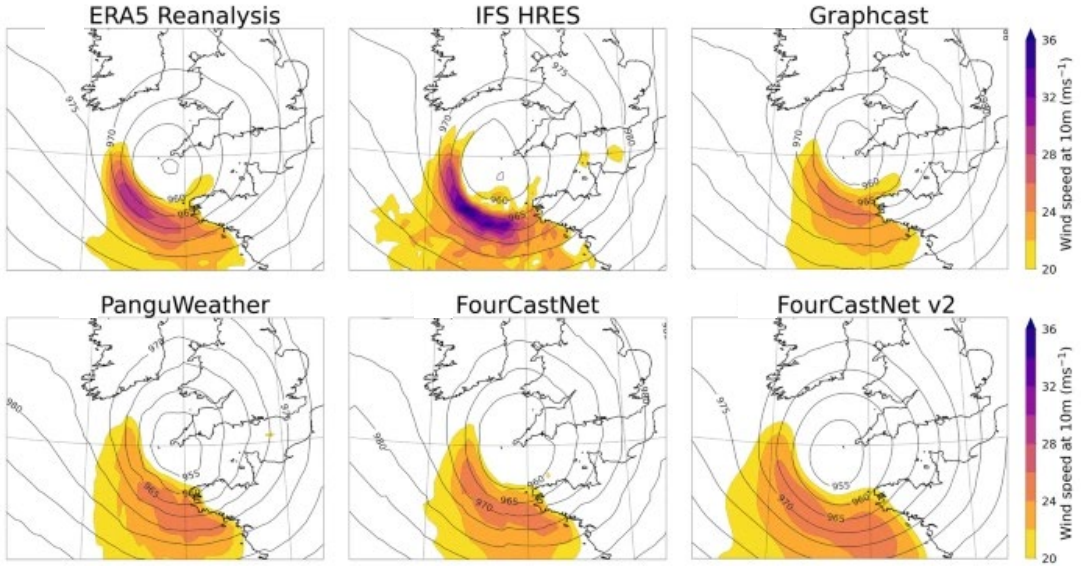
Google DeepMind's model beat world's leading system in 90% of metrics used and took only a fraction of the time

Images: The Economist; Nature; Financial Times

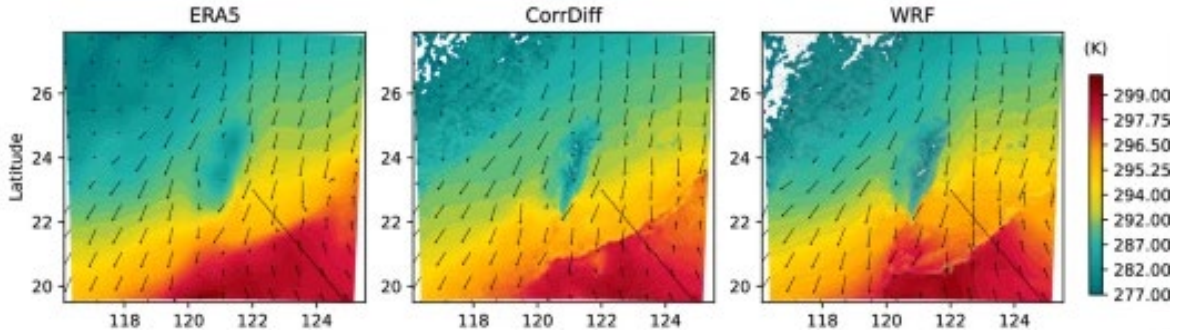
Image: Financial Times

State-of-the-art AI extreme weather forecasts

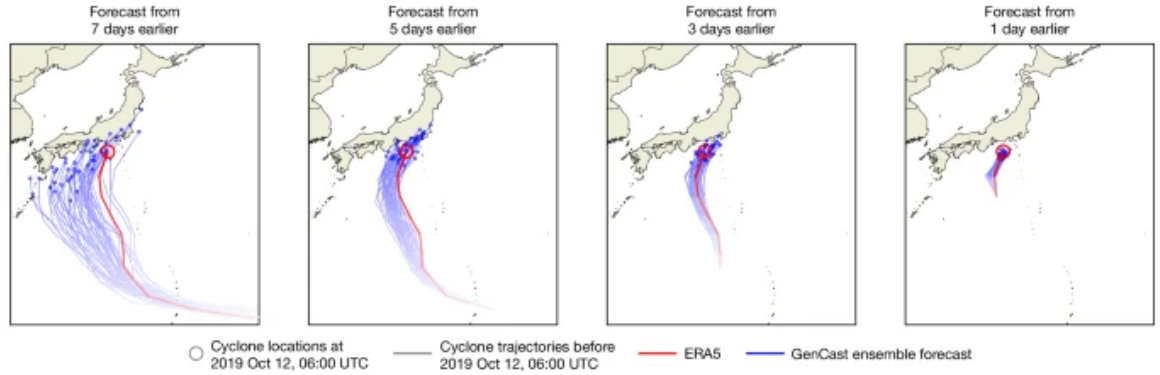
Many success stories:



Storm Ciáran, Charlton-Pérez *et al.* (2024)



2022 cold-front dynamics in Taiwan, Mardani *et al.* (2025)



Typhoon Hagibi, Price *et al.* (2025)

Do data-driven forecasts struggle with extremes?

Do data-driven forecasts struggle with extremes? Possible issues:

- Limited sample size and challenges related to extrapolation (Watson, 2022, Zhang *et al.*, *preprint*)
- Choice of loss function – *e.g.* global MAE/MSE (Xu *et al.*, 2024)
- Global and temporal averaging across variables and time scales (Bonavita, 2024)

Do data-driven forecasts struggle with extremes?

Coloured: AI best. Grey: Physics-based best.

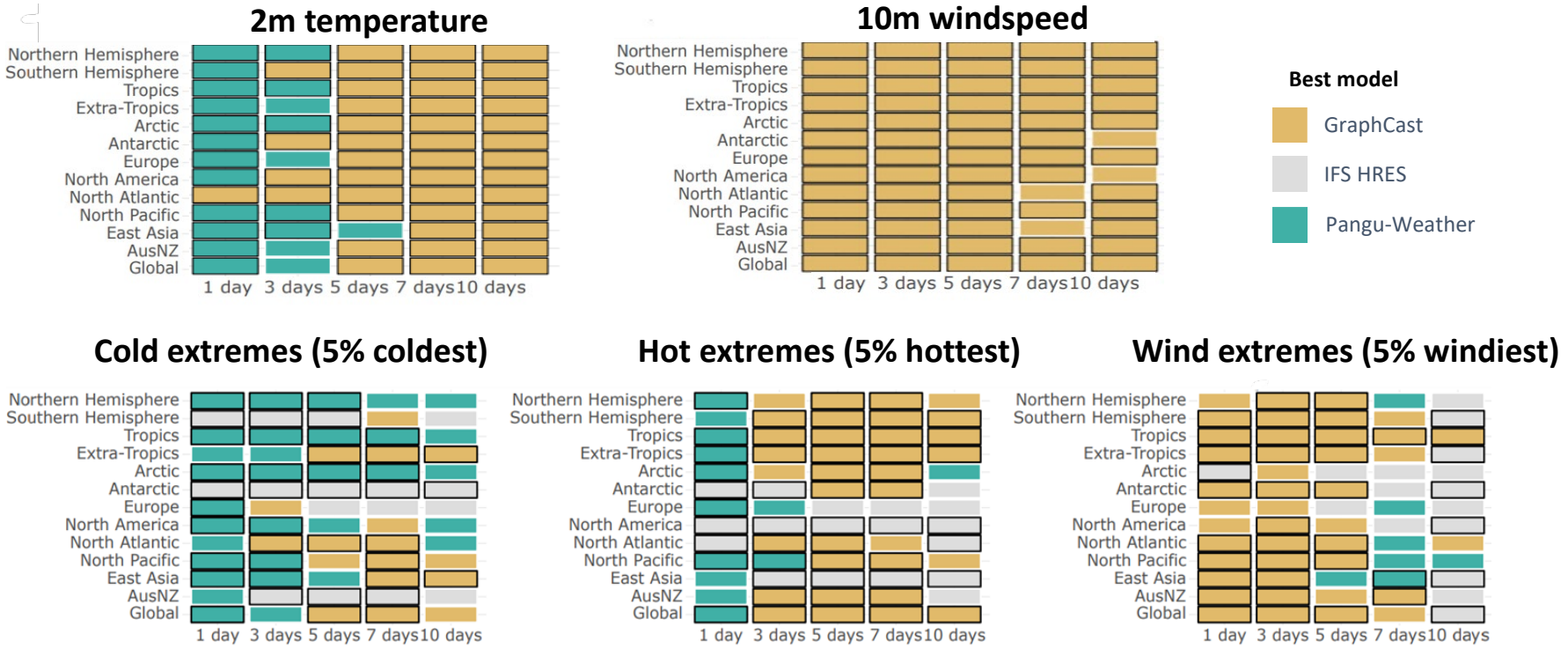


Figure: Olivetti and Messori (2024a), *Geosci. Mod. Dev.*

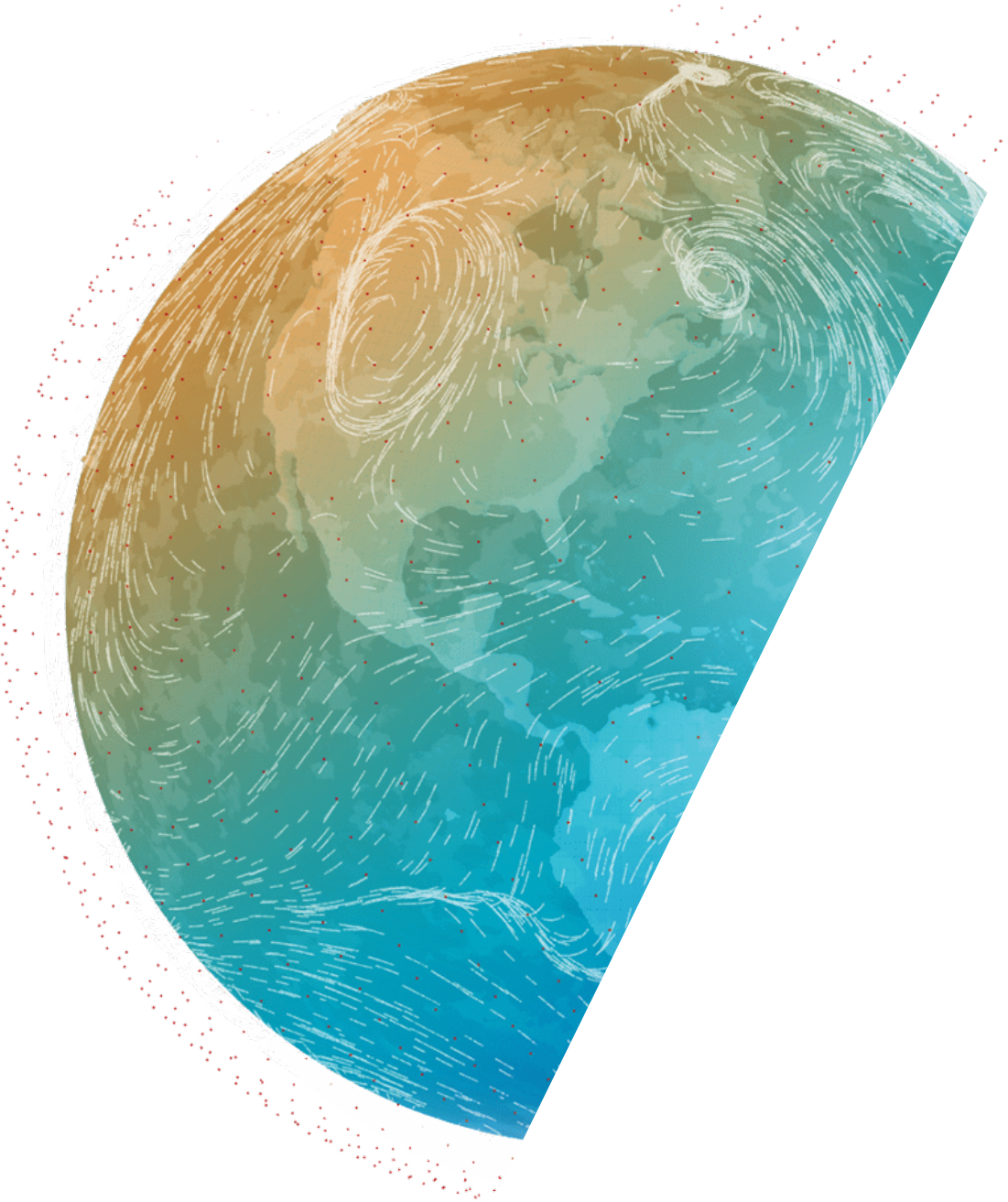


Image: Spire.com

Challenges and opportunities

Selected challenges and opportunities (focussing on extremes):

- Comparatively poor performance on extremes.
- Tailored forecast models for specific extremes or regions (*e.g.* Oskarsson *et al.*, 2023, Xu *et al.*, 2025).
- Combination with extreme value theory (Olivetti and Messori 2024b).

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- "Translocation" (Qiang Sun *et al.*, *preprint*).

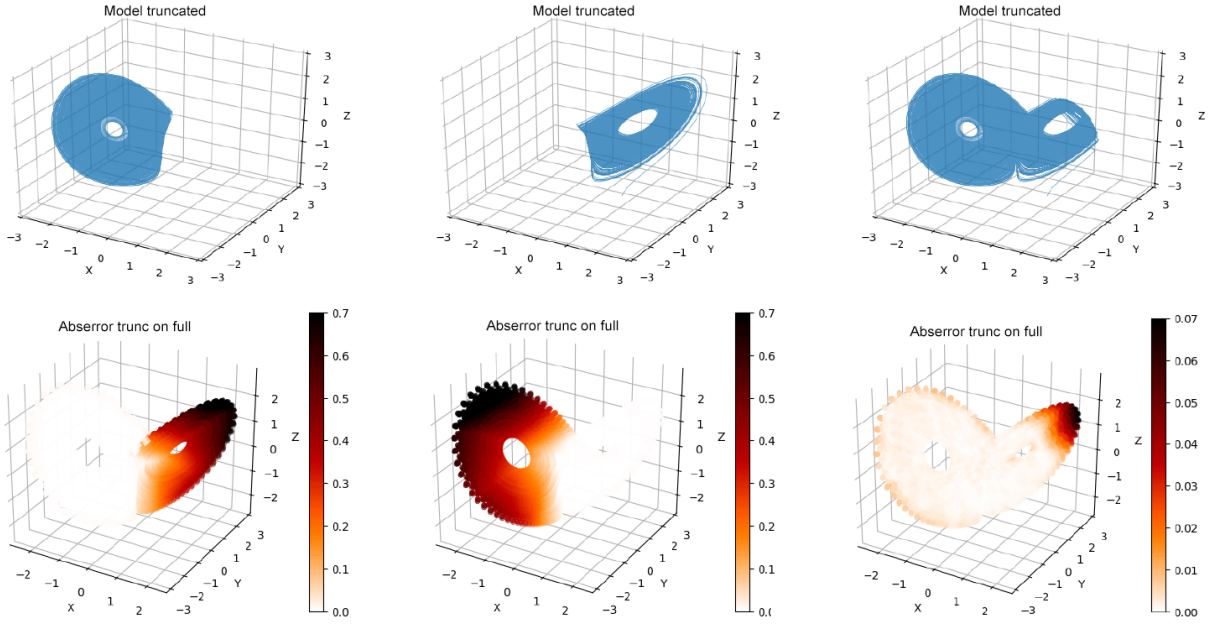

Figure: Scher and Messori (2019), *Nonlin. Proc. Geophys.*

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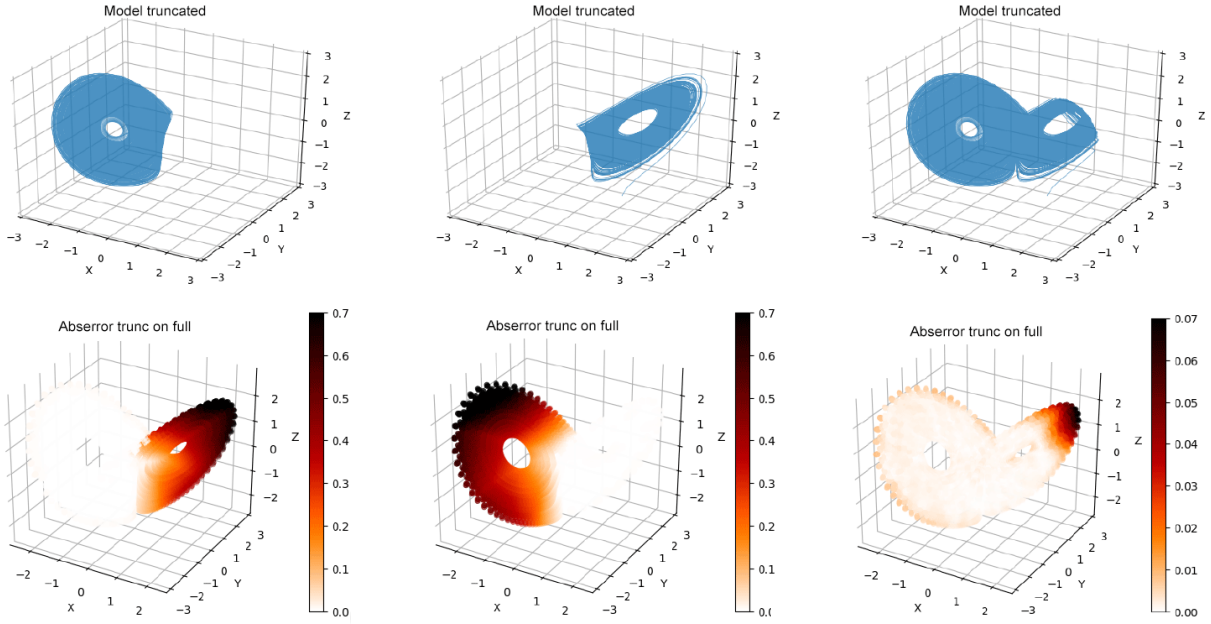

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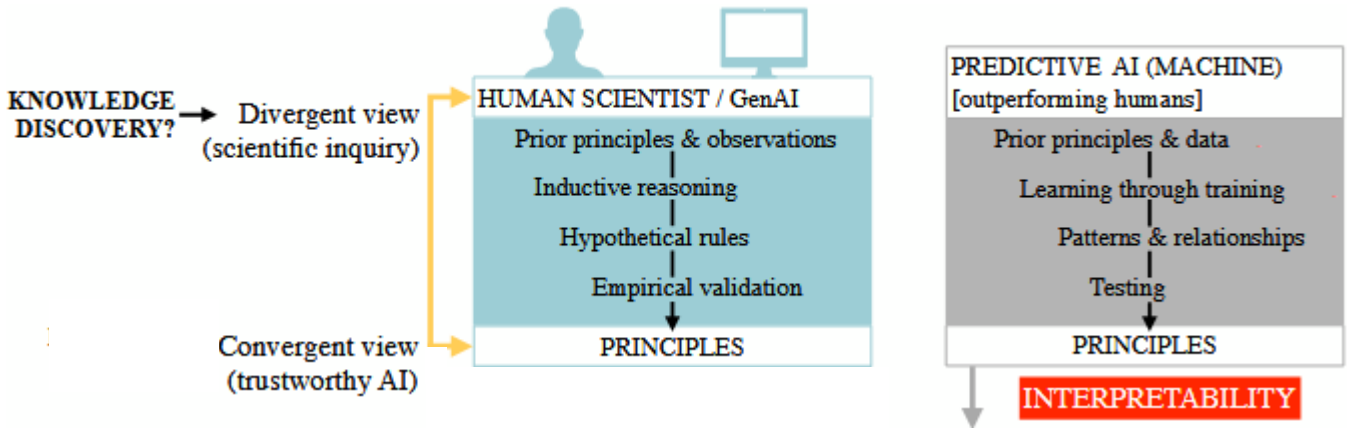

Image: Adapted from Mengaldo (2025)

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- Lack of data to evaluate the forecasts.
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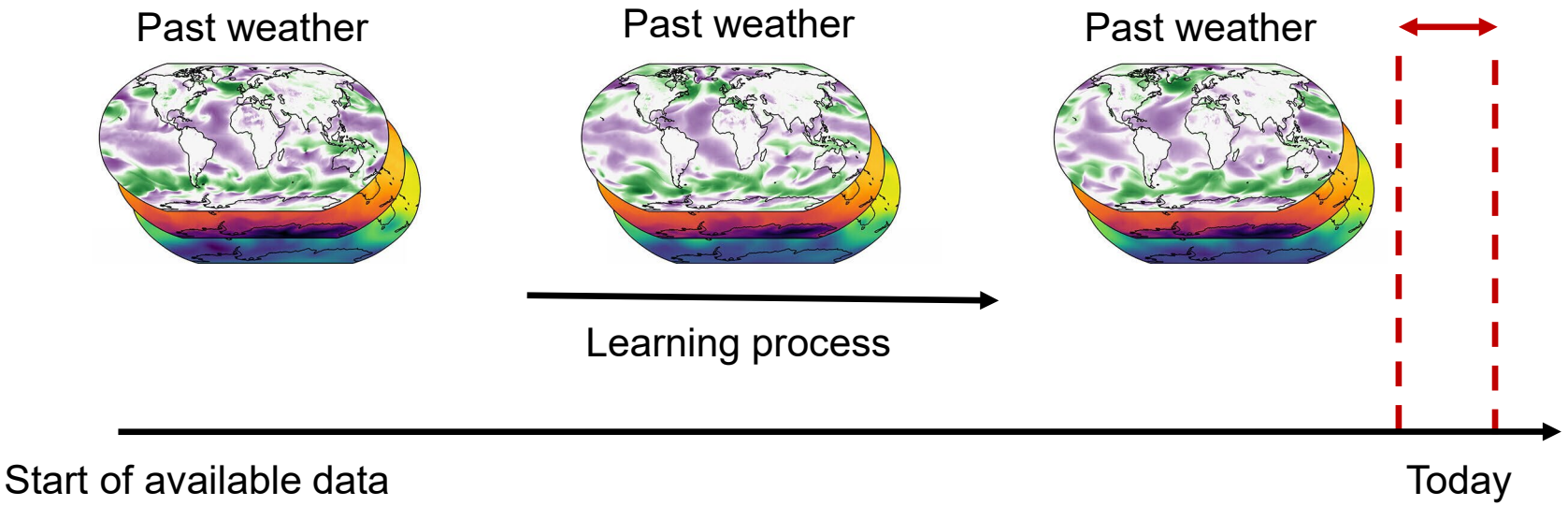

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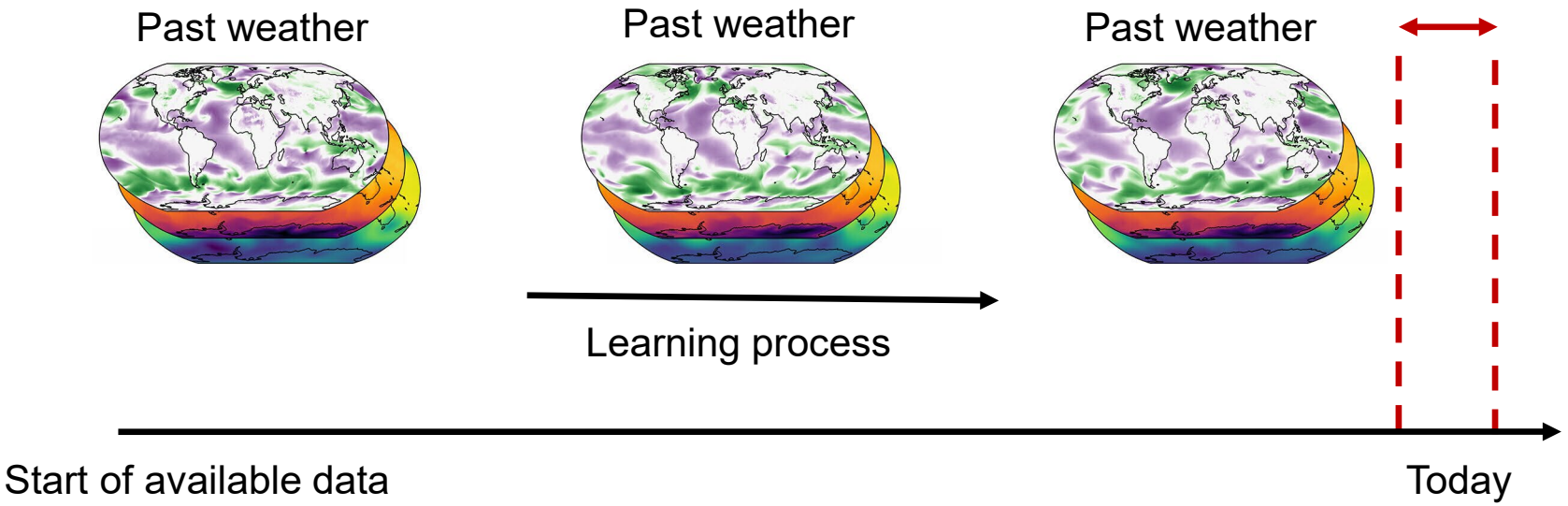

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