A Primer on AI Weather Models

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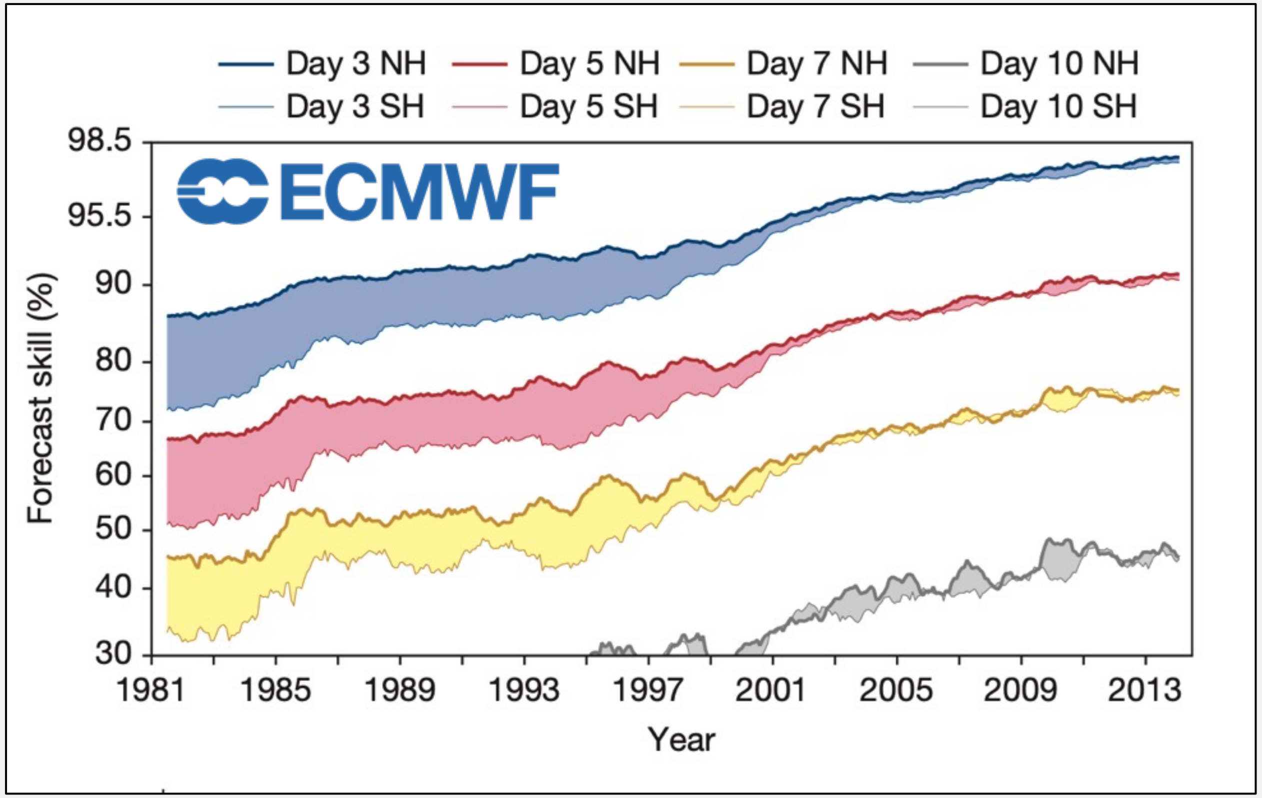
Connecting Models and Observations

The status of weather forecasts

Adapted from Bauer et al. (2015)



Numerical weather forecasts gained about a day of skill per decade

Connecting Models and Observations

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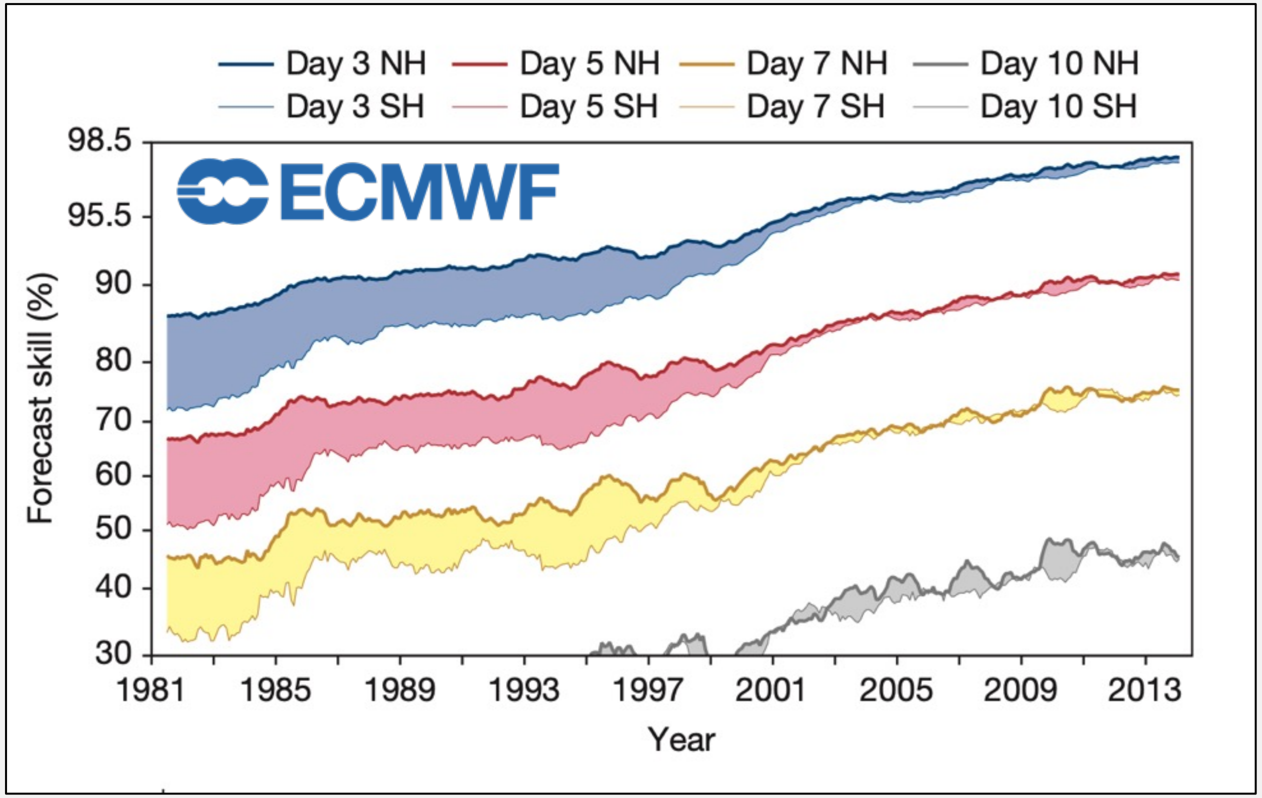
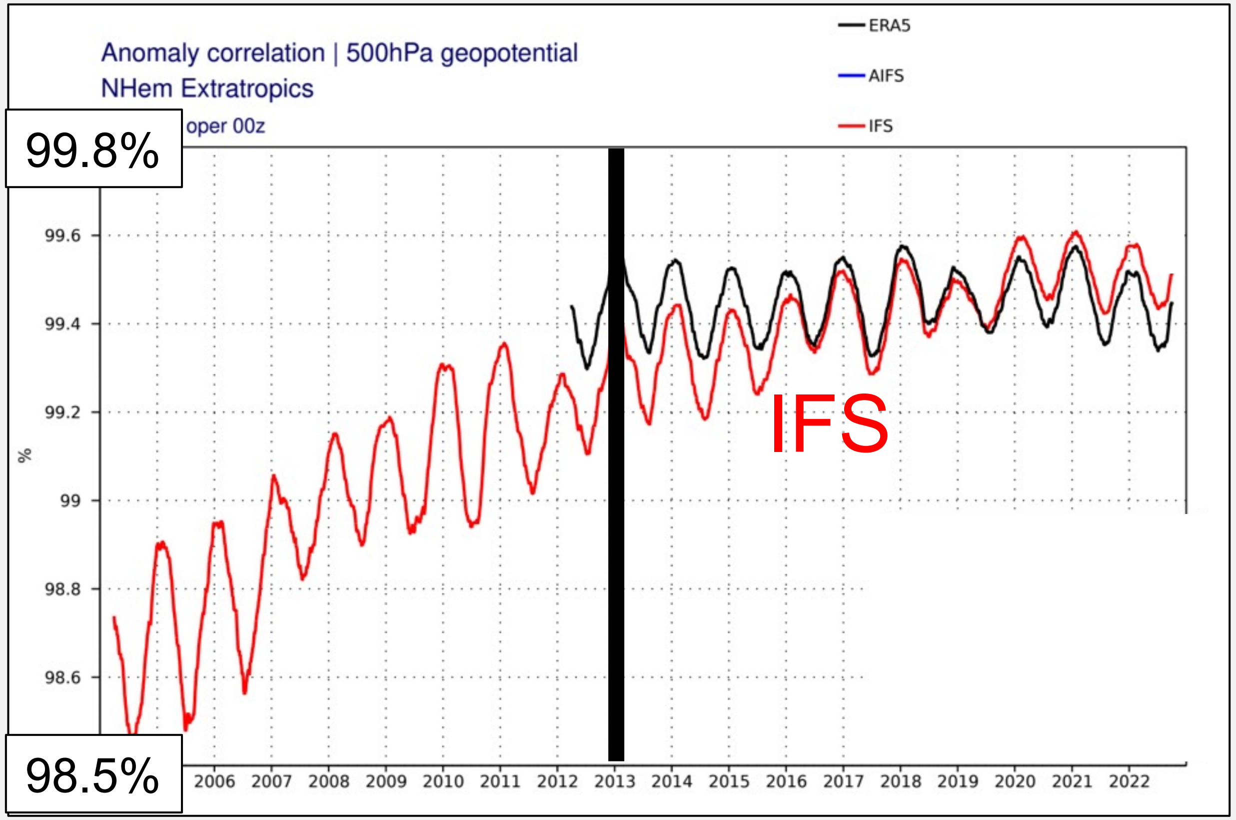


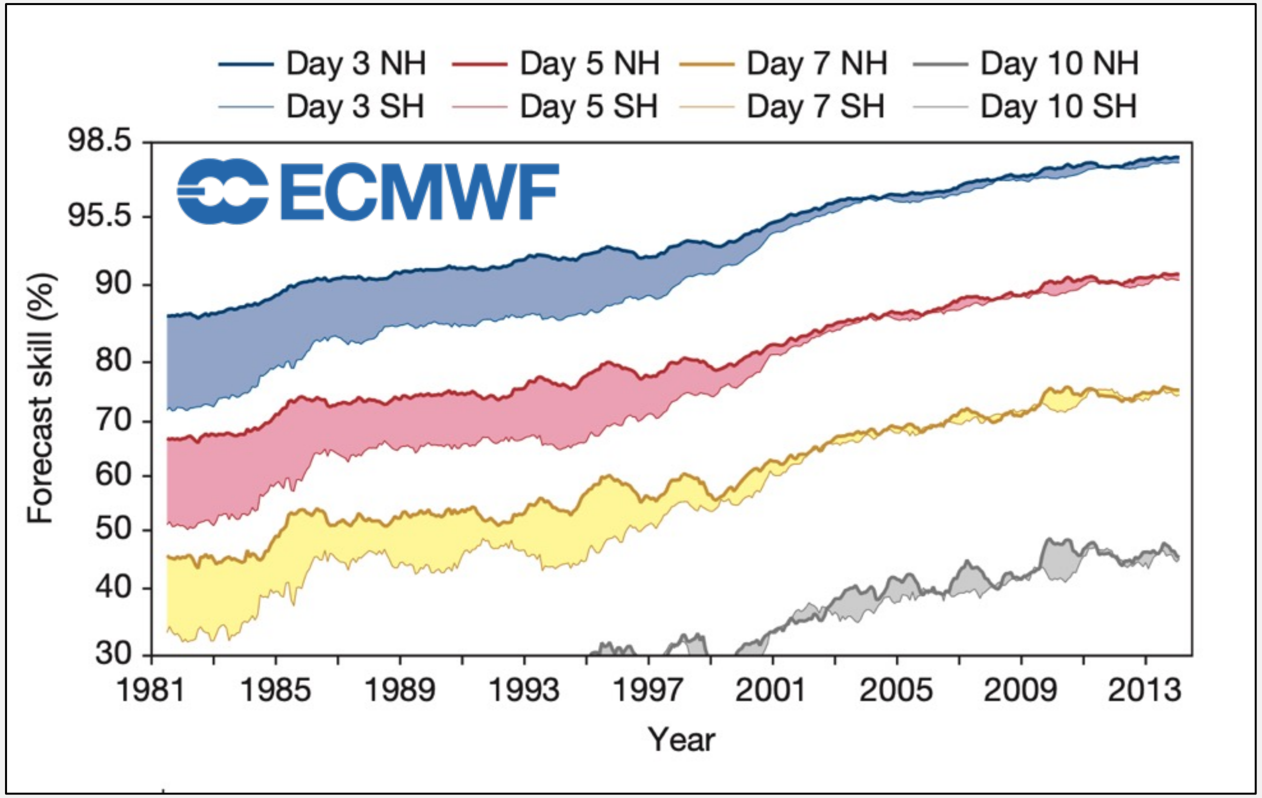
Adapted from Lang et al. (2024)



Physics forecasts gained about a day of skill per decade

The status of weather forecasts

Adapted from Bauer et al. (2015)



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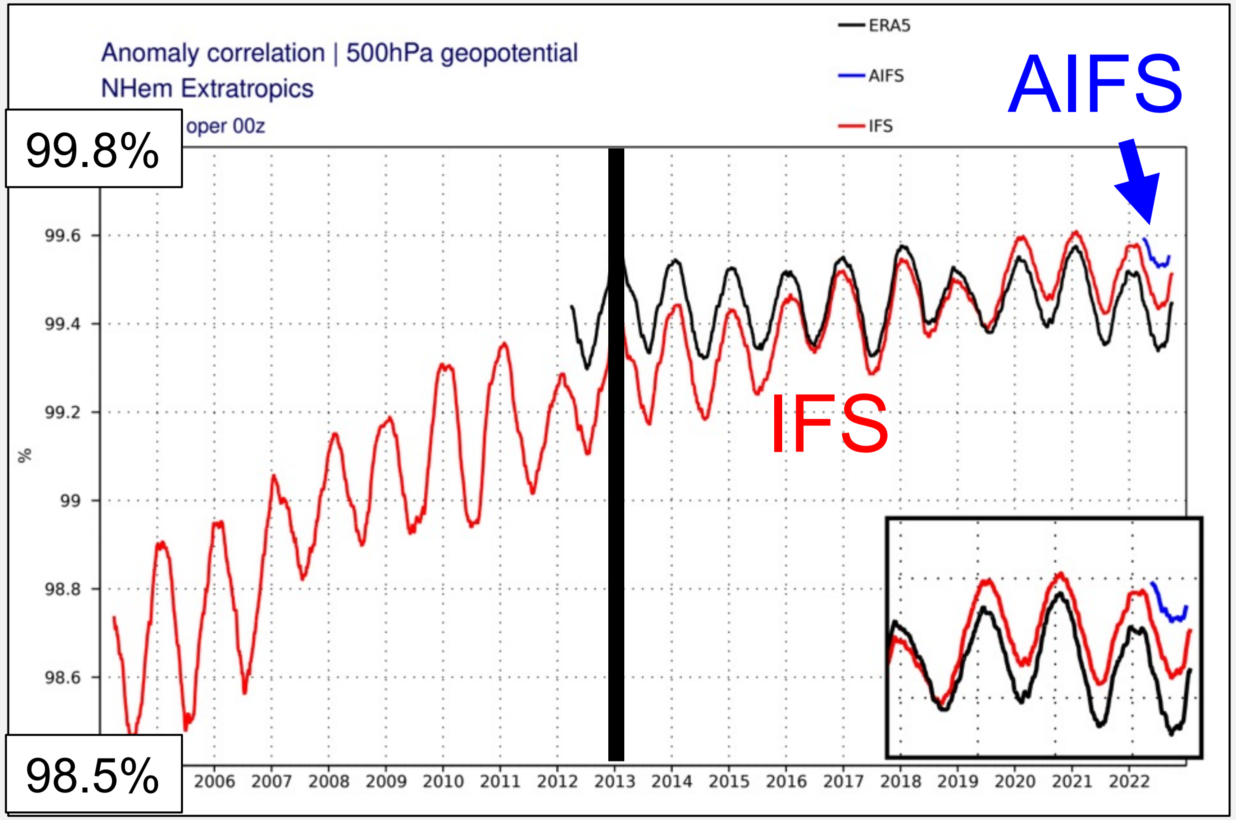

AI forecasts emerged in 2022, outperforming the physics-based methods

The status of weather forecasts

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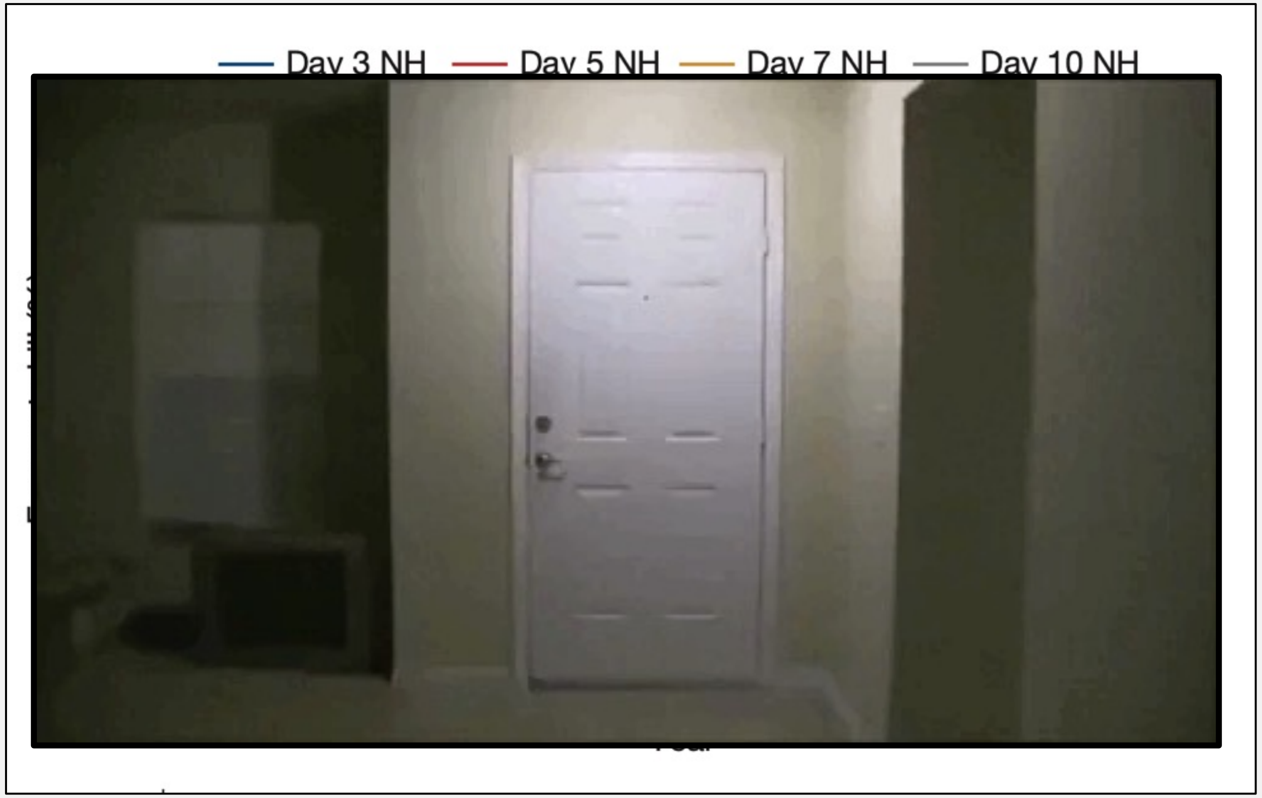

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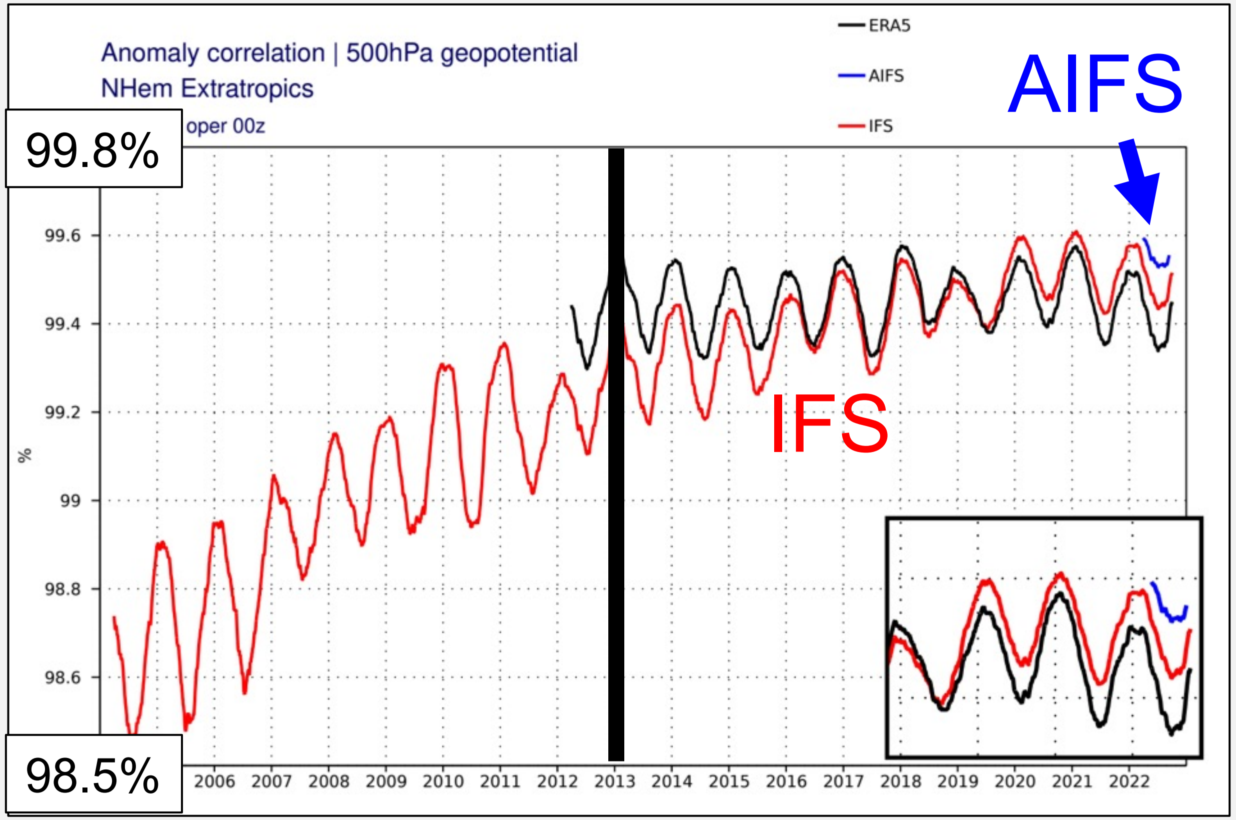

AI forecasts emerged in 2022, outperforming the physics-based methods

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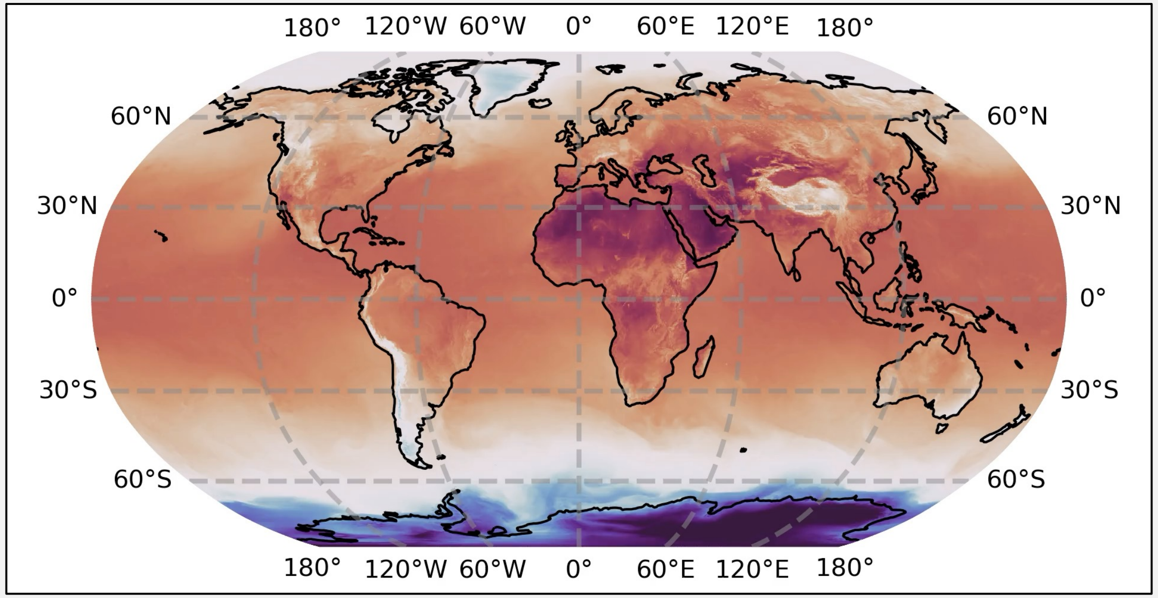
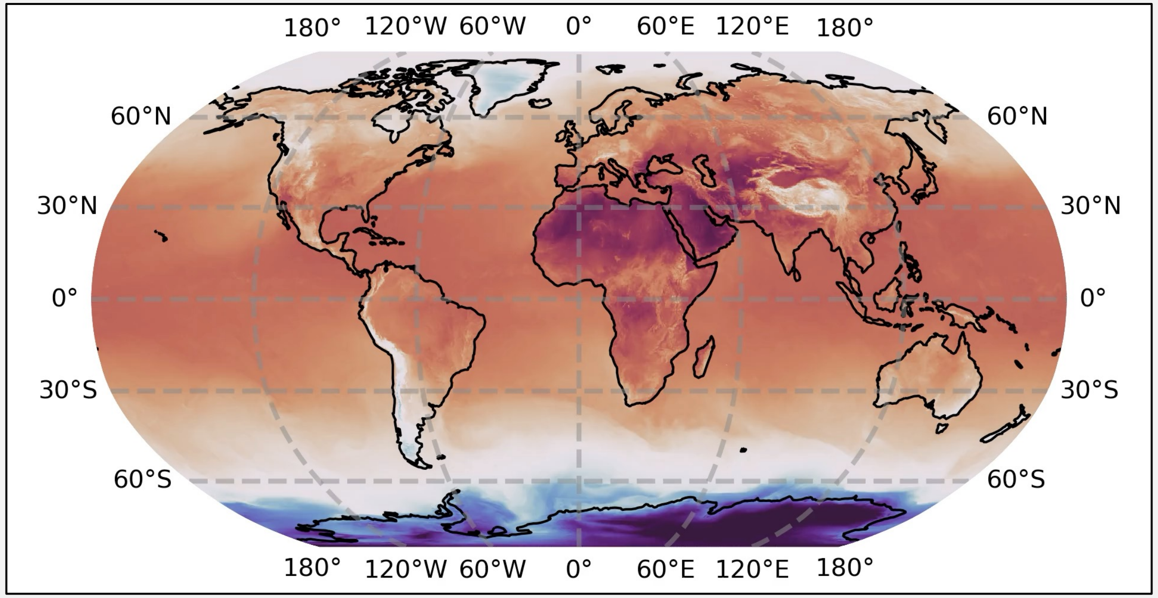
A new age of weather forecasting

One of these are a pure machine learning model…





One of these takes 1 hour to run on a super computer the other 1 min on an 'average' GPU

Thanks to Jacob Radford and Robert DeMaria for running FourCastNet

A new age of weather forecasting

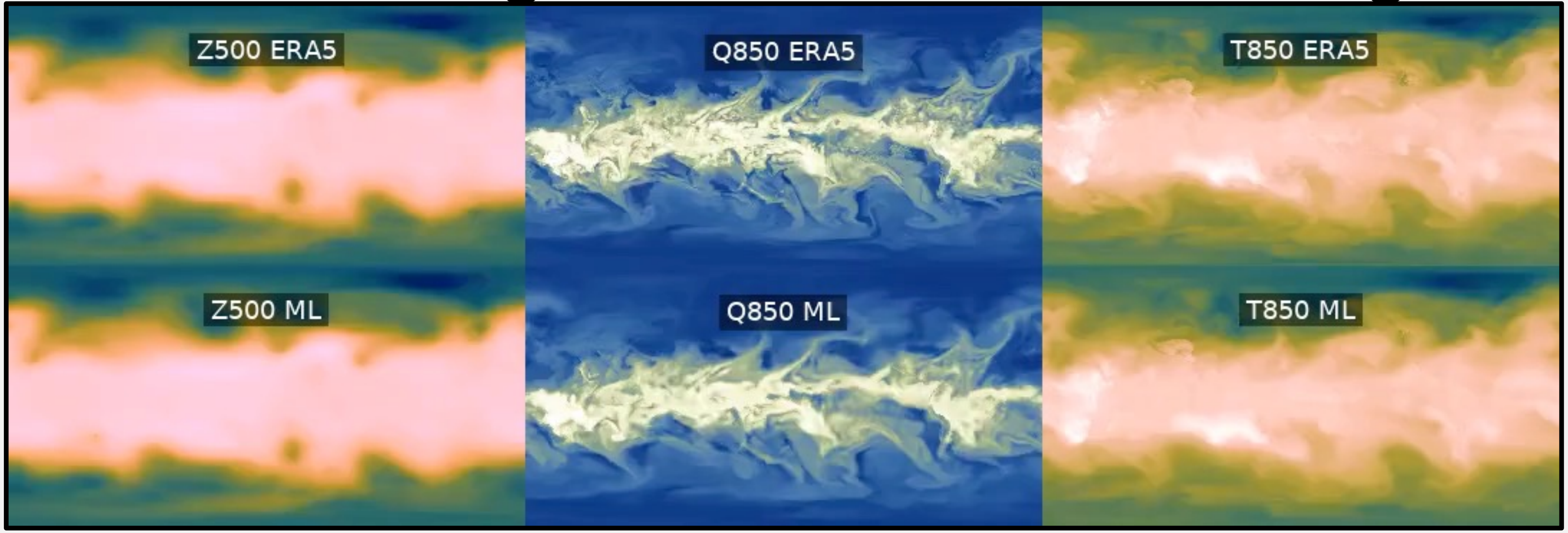
Supercomputer for NOAA (runs GFS etc)

$$$$

1 GPU

$

A new age of weather forecasting



There is a growing body of literature suggesting NWP-like skill from pure machine learning methods:

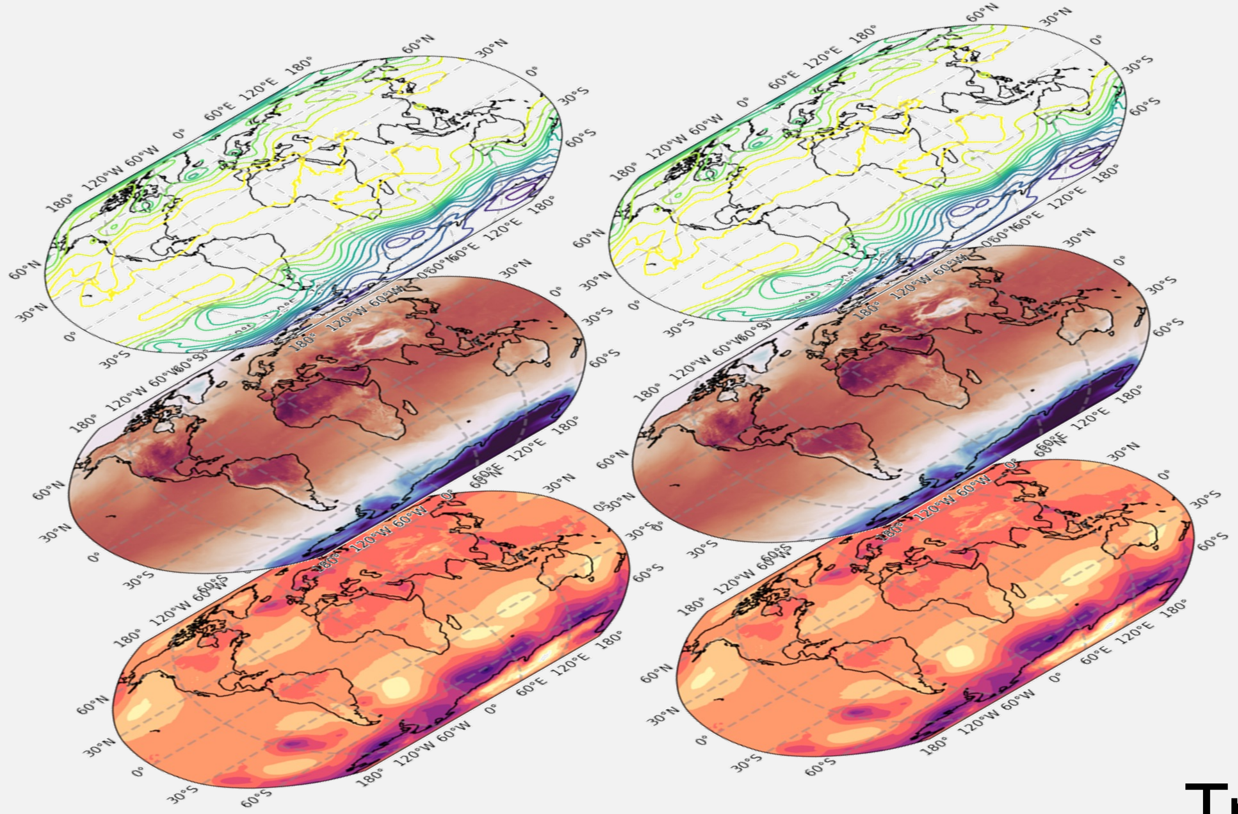
Weyn et al. (2020) [Microsoft]; Rasp et al. (2021); Ravuri et al. (2021) [Google]; Espeholt et al. (2022) [Google]; Keisler (2022*; Figure above); Pathak et al. (2022*) [NVIDIA]; Bi et al. (2023) [Huawei Cloud Computing]; Lam et al. (2023) [Google]; Nguyen et al. (2023*) [Microsoft]; Andrychowicz et al. (2023*) [Google]; Leinonen et al. (2023*) [MeteoSwiss]; Zhang et al. (2023) [Tsinghua University]; Chen et al. (2023*) [University of Science and Technology of China] …. more every few months

*unpublished

CIRA
Connecting Models and Observations

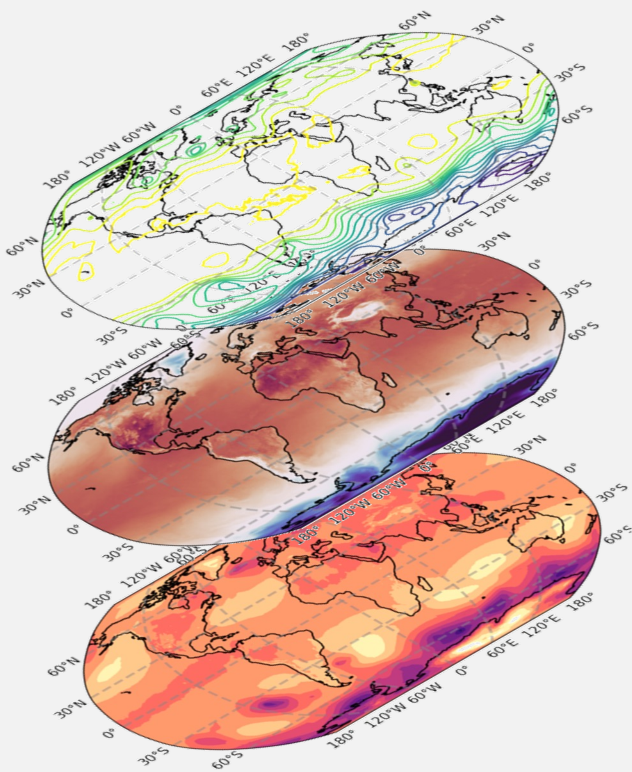
Training the AI4NWP models

ERA-5 at some time t, and t-6



ML model

ERA-5 t+6

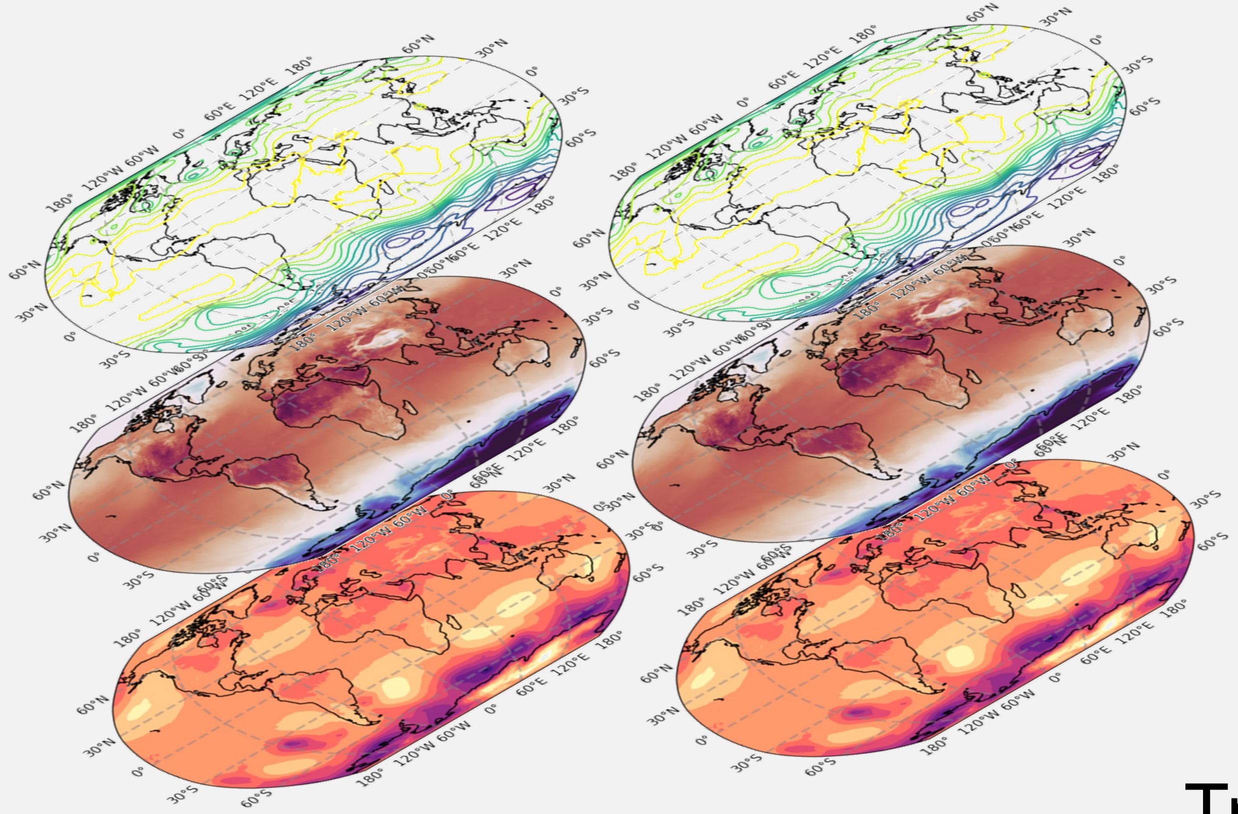


Tend to use:
Transformers, diffusion, or graph neural networks

Training the AI4NWP models

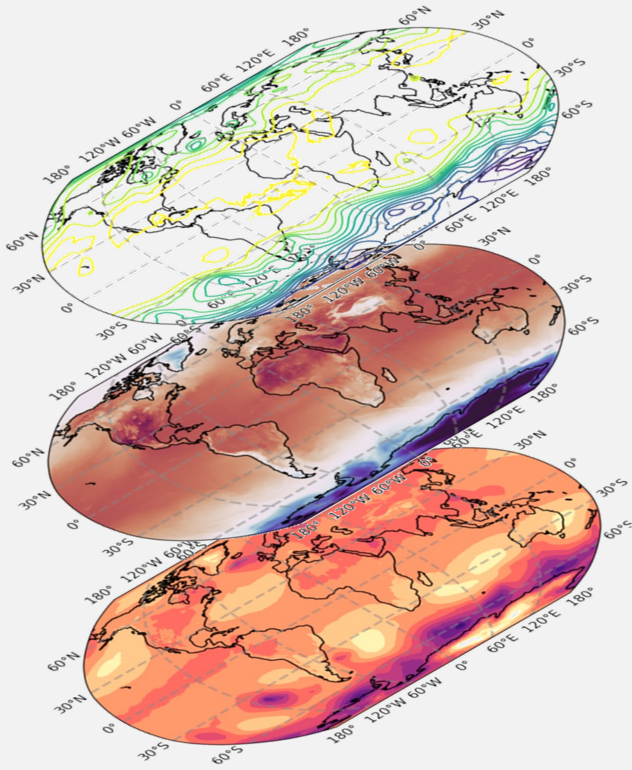
Usually needs DA

GFS or IFS Initialization



ML model

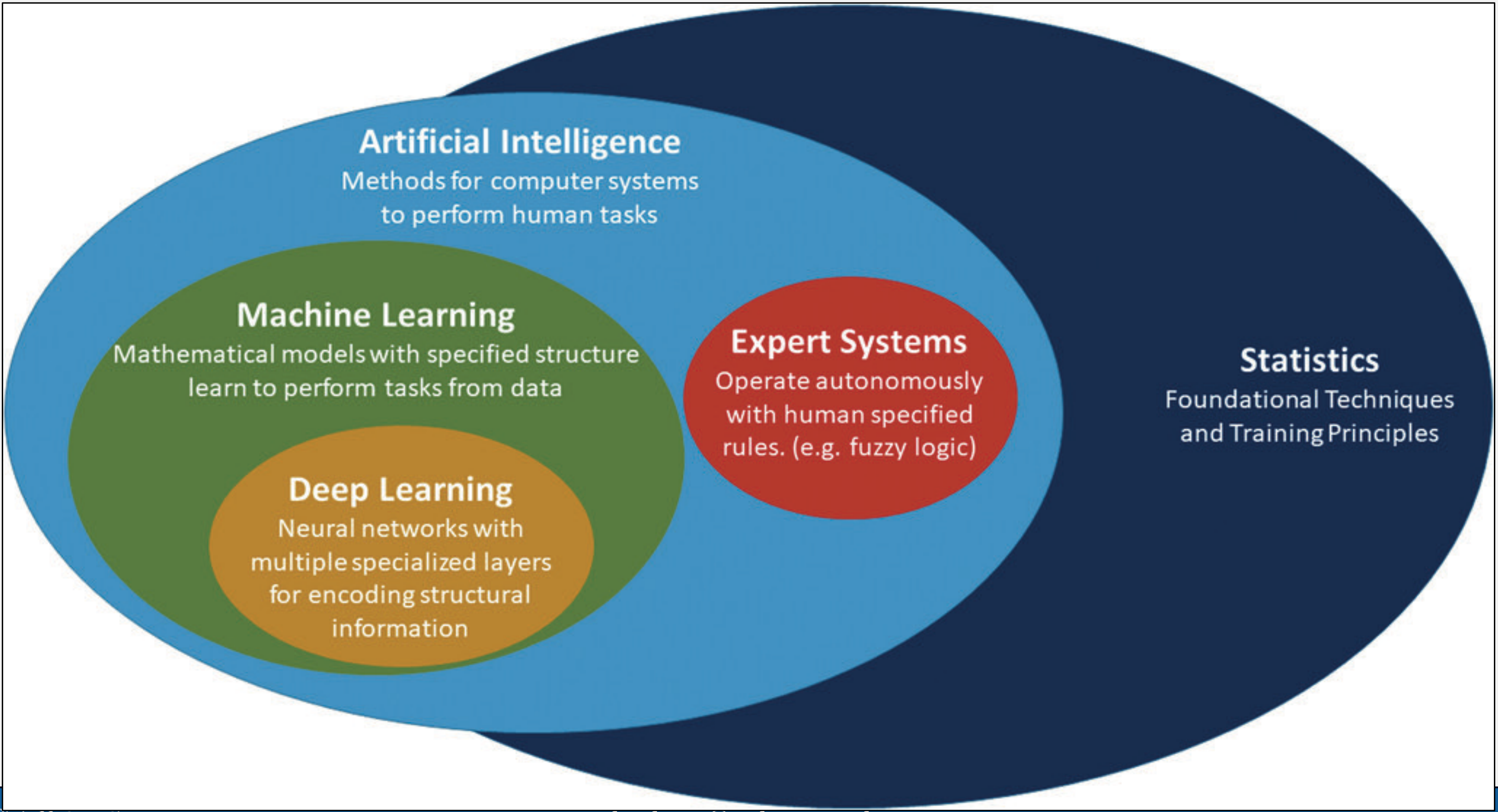
ERA-5 t+6



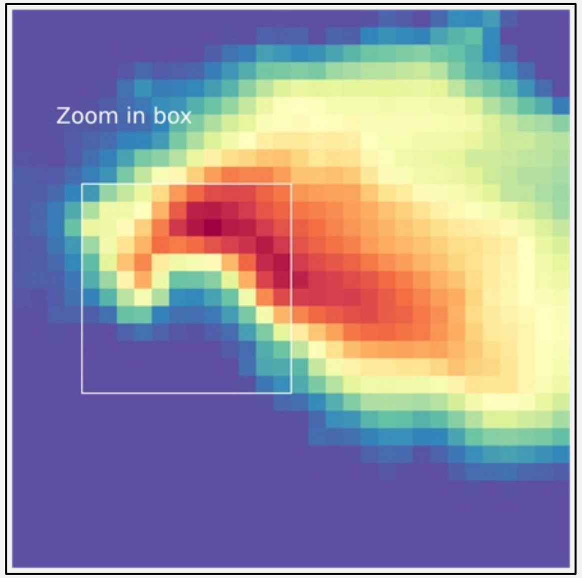
Tend to use:
Transformers, diffusion, or graph neural networks

What is AI and Machine Learning?

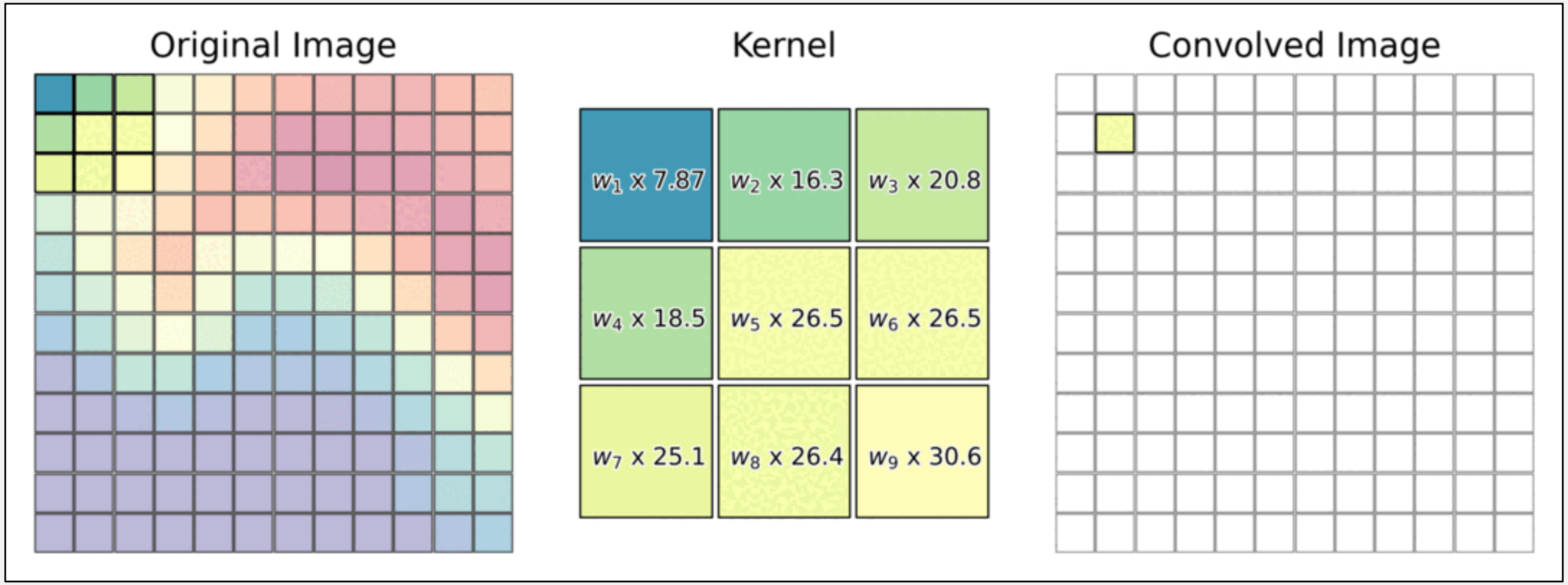
Provided by: Haupt et al. (2022)



Some intuition



Radar hook echo



The methods used to train the models all use calculus (i.e., derivatives) to ***learn*** how to best extract information from the data

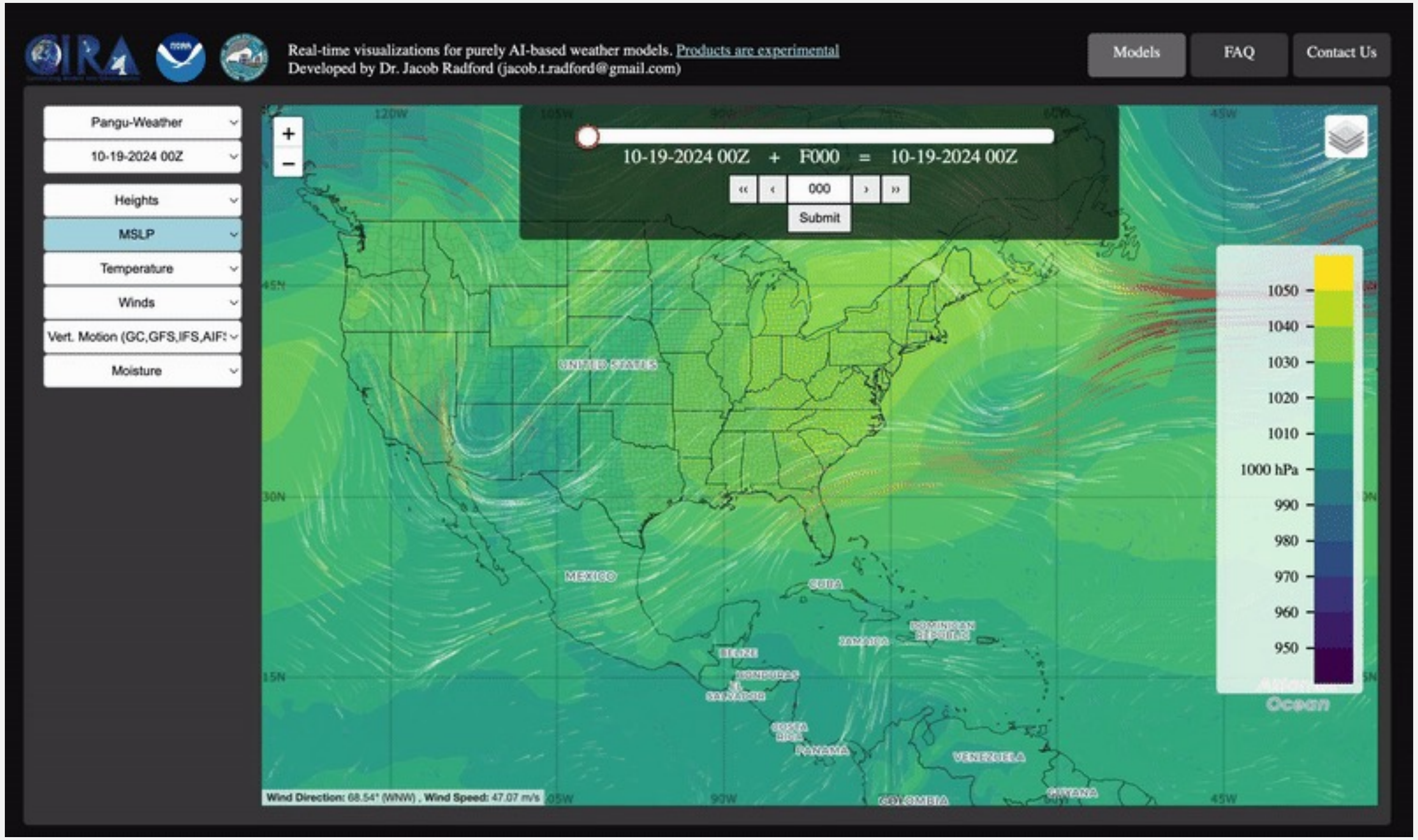
CIRA AI-Weather page

If you are interested in looking at the output of these experimental models check out our CIRA page:

aiweather.cira.colostate.edu

Or ECMWF's charts page:

https://www.ecmwf.int/en/forecasts/charts



Some of the global models

GraphCast

Google DeepMind

Lam et al. (2023)

Pangu Weather

HUAWEI

HUAWEI CLOUD

Bi et al. (2023)

AIFS

ECMWF

Lang et al. (2023)

FourCastNet

NVIDIA

Pathak et al. (2022)

Some Pros

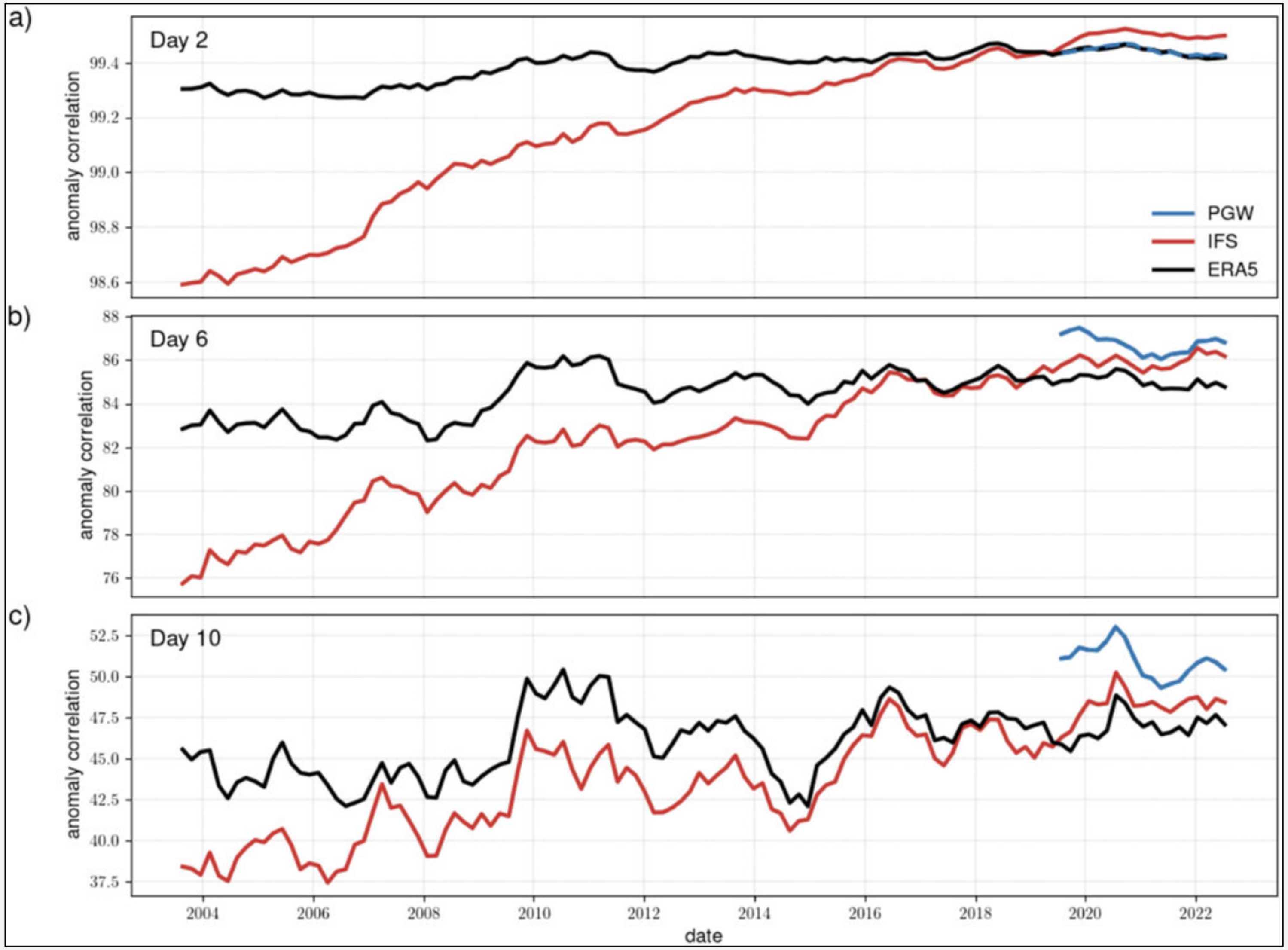
Adapted from Bouallègue et al. (2024)

- Speed:

  Runs in mins on modest hardware

- Skill:

  Based on RMSE and ACC, these models perform similarly to physics-based methods



Some Cons

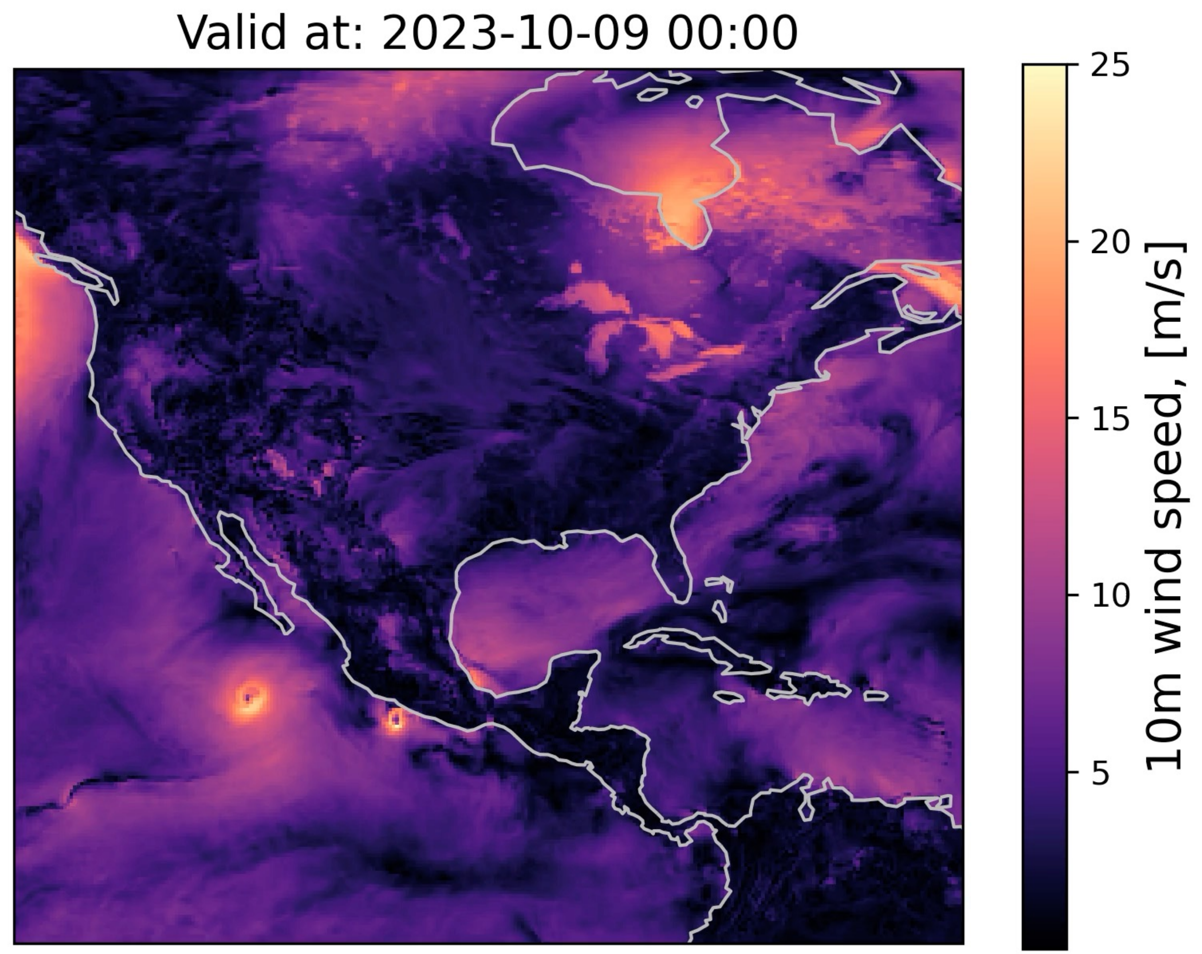
- <u>Resolution:</u>

  Most are at 0.25 deg (i.e., think GFS), underdoes extremes, blurs with time

- <u>Limited variables:</u>

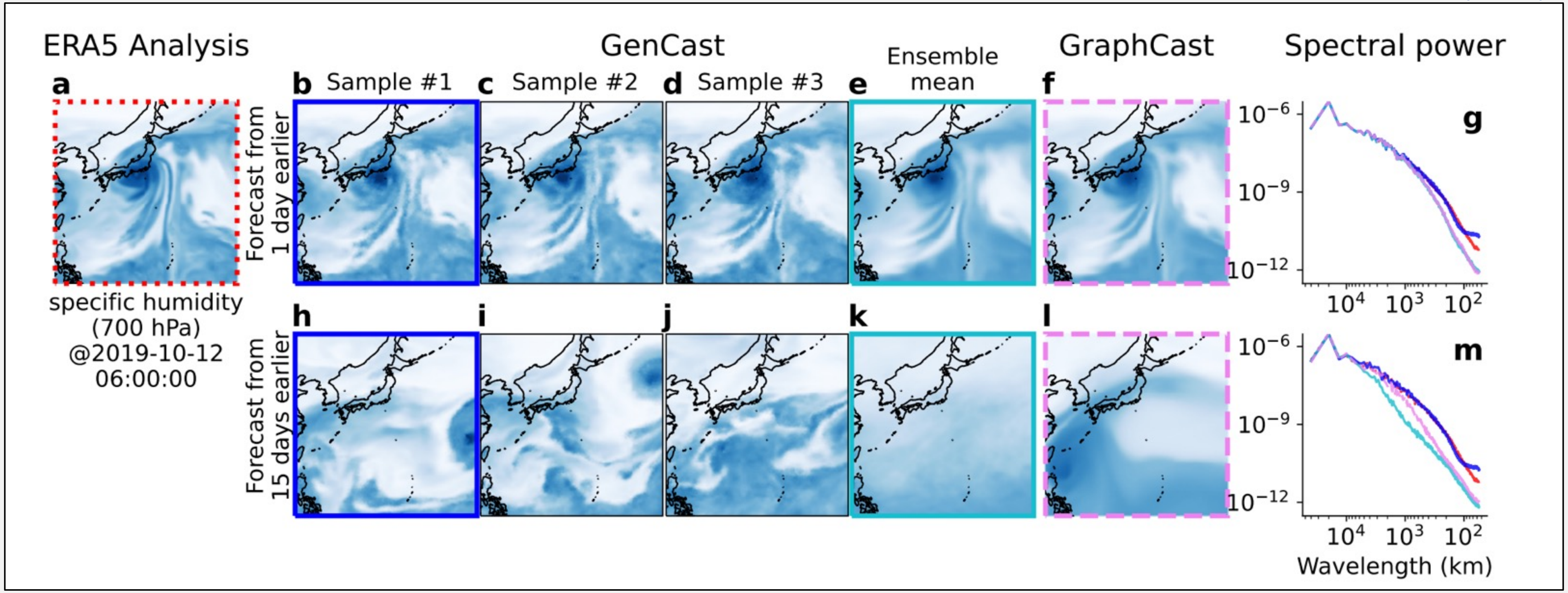
  Most models have about 13 levels and the common state fields

  *Precip has been mostly unsuccessful so far



What's next?

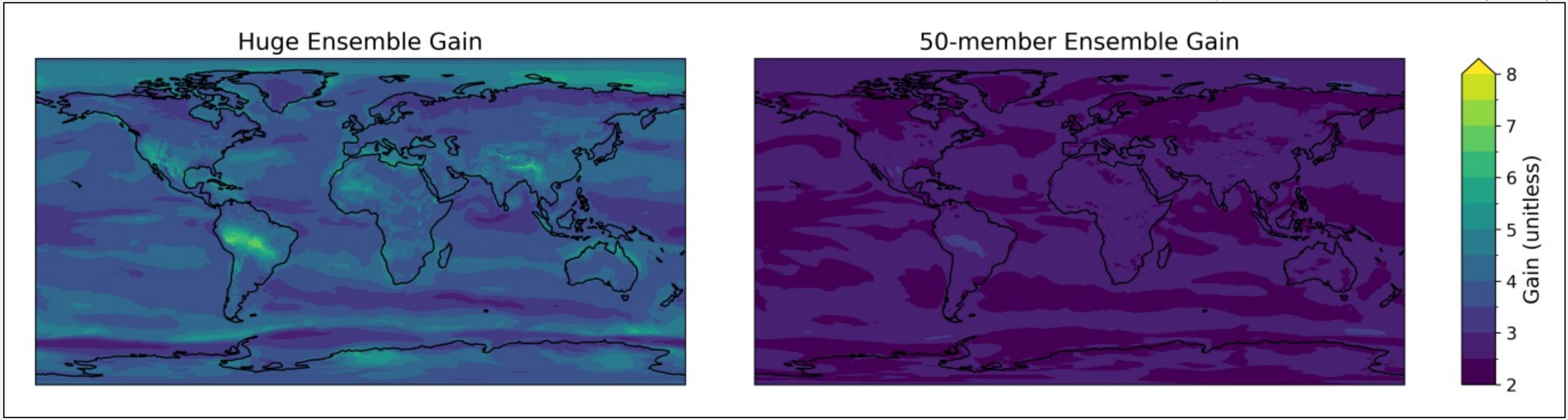
Adapted from Price et al. (2024)



Ensembles: Going beyond the deterministic results in GraphCast, Price et al. (2024) show that ML (named GenCast) can outperform the ECMWF ENS

What's next?

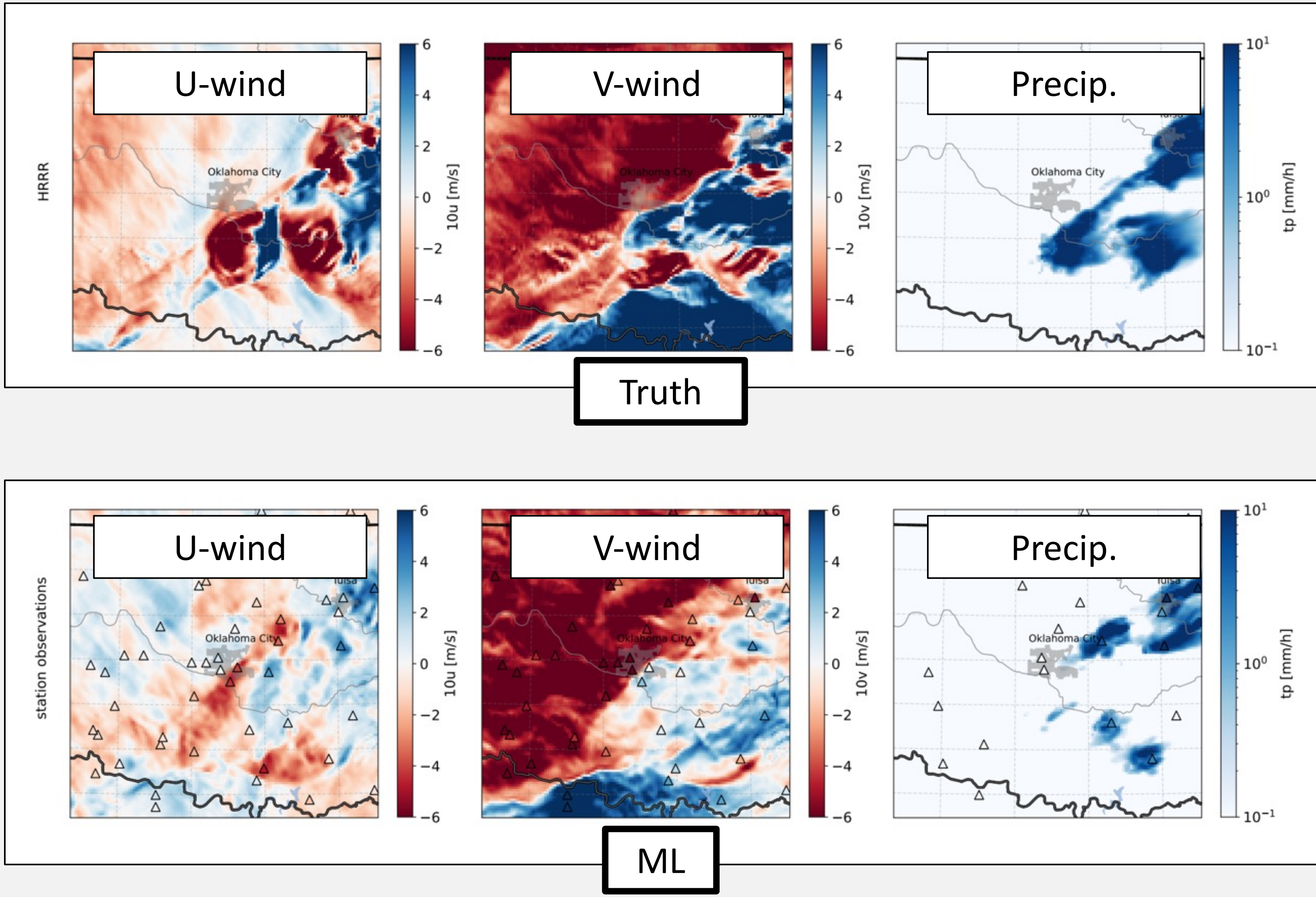
Adapted from Mahesh et al. (2024)



Ensembles: Given the relatively low computational cost, ensembles with members in the 1000s is now possible. Mahesh et al. (2024) show that an ensemble of about **7000 members** can reliably capture more extreme events than the current operational ensembles

What's next?

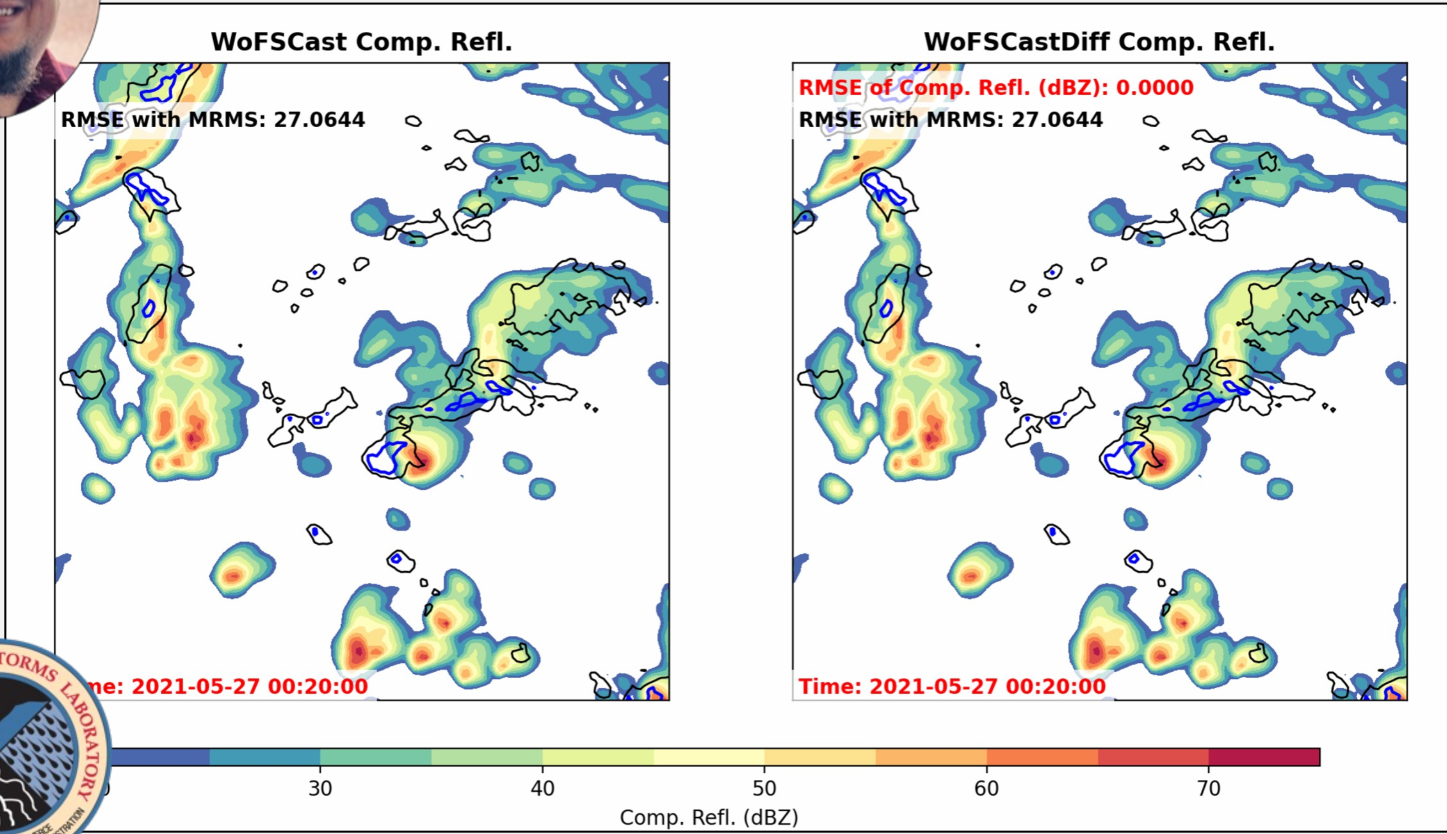
Adapted from Manshausen et al. (2024)



Data assimilation: A lot of the forecast models discussed still need an initial state. But ML based DA is being worked on

What's next?

from Flora et al. *in prep*

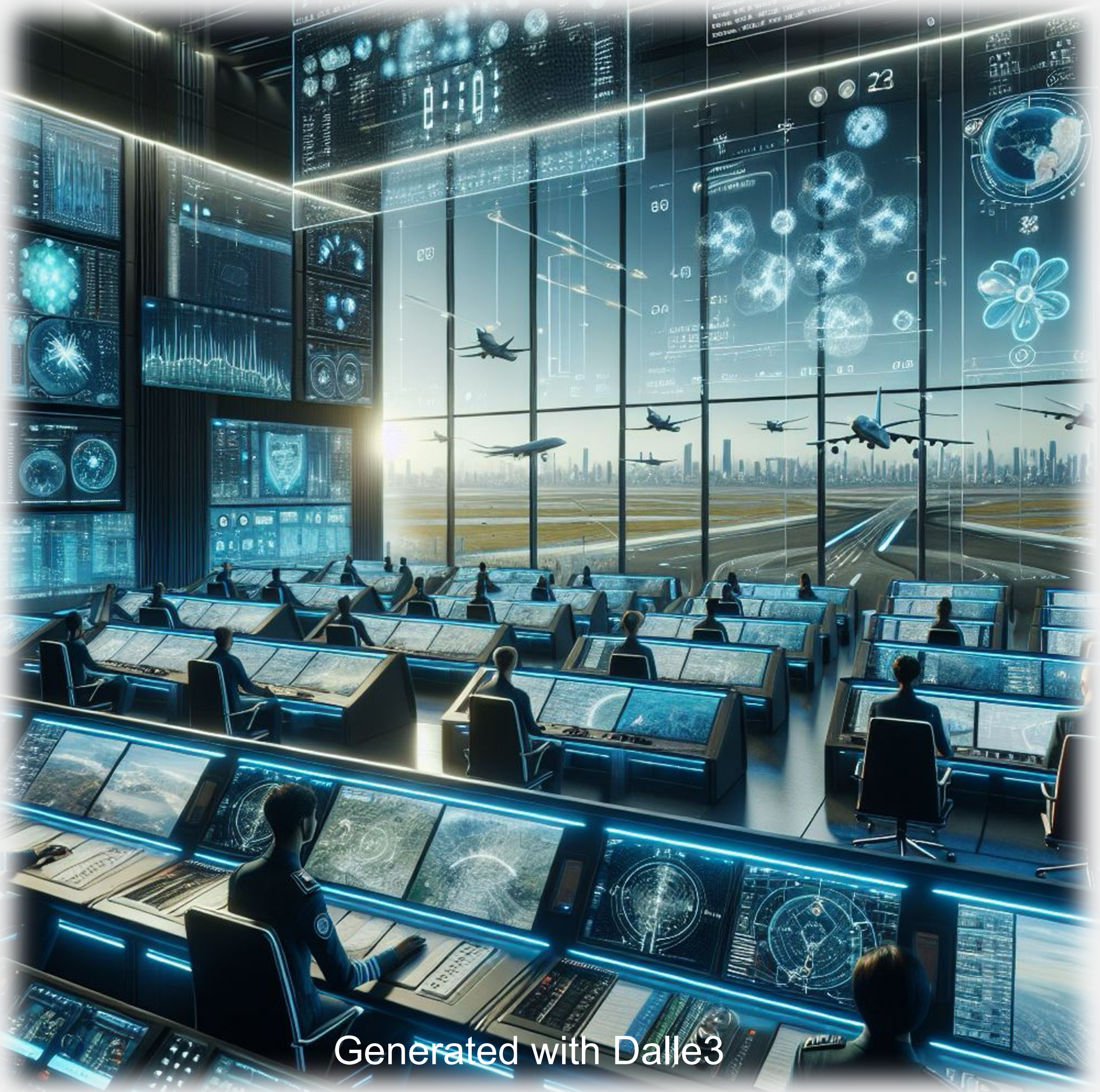


Storm scale: Most success so far has been on the synoptic scale. There are efforts to extend the methods down to the storm scale

WoFSCast: https://essopenarchive.org/users/829074/articles/1223249-wofscast-a-machine-learning-model-for-predicting-thunderstorms-at-watch-to-warning-scales

Imagining the future

Since these forecasts can run so quickly on modest machines, imagine a future where forecasts can be launched on a plane by plane basis (or even on the plane)



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Where can I learn about ML?

Looking to learn about machine learning? We have written 2 *plain language* tutorial style papers

AUGUST 2022 | CHASE ET AL. | 1509

A Machine Learning Tutorial for Operational Meteorology. Part I: Traditional Machine Learning

AUGUST 2023 | CHASE ET AL. | 1271

A Machine Learning Tutorial for Operational Meteorology. Part II: Neural Networks and Deep Learning


Amy McGovern


Gary Lackmann


David Harrison


Amanda Burke

Both Published in WAF, and are open-access