AIFS

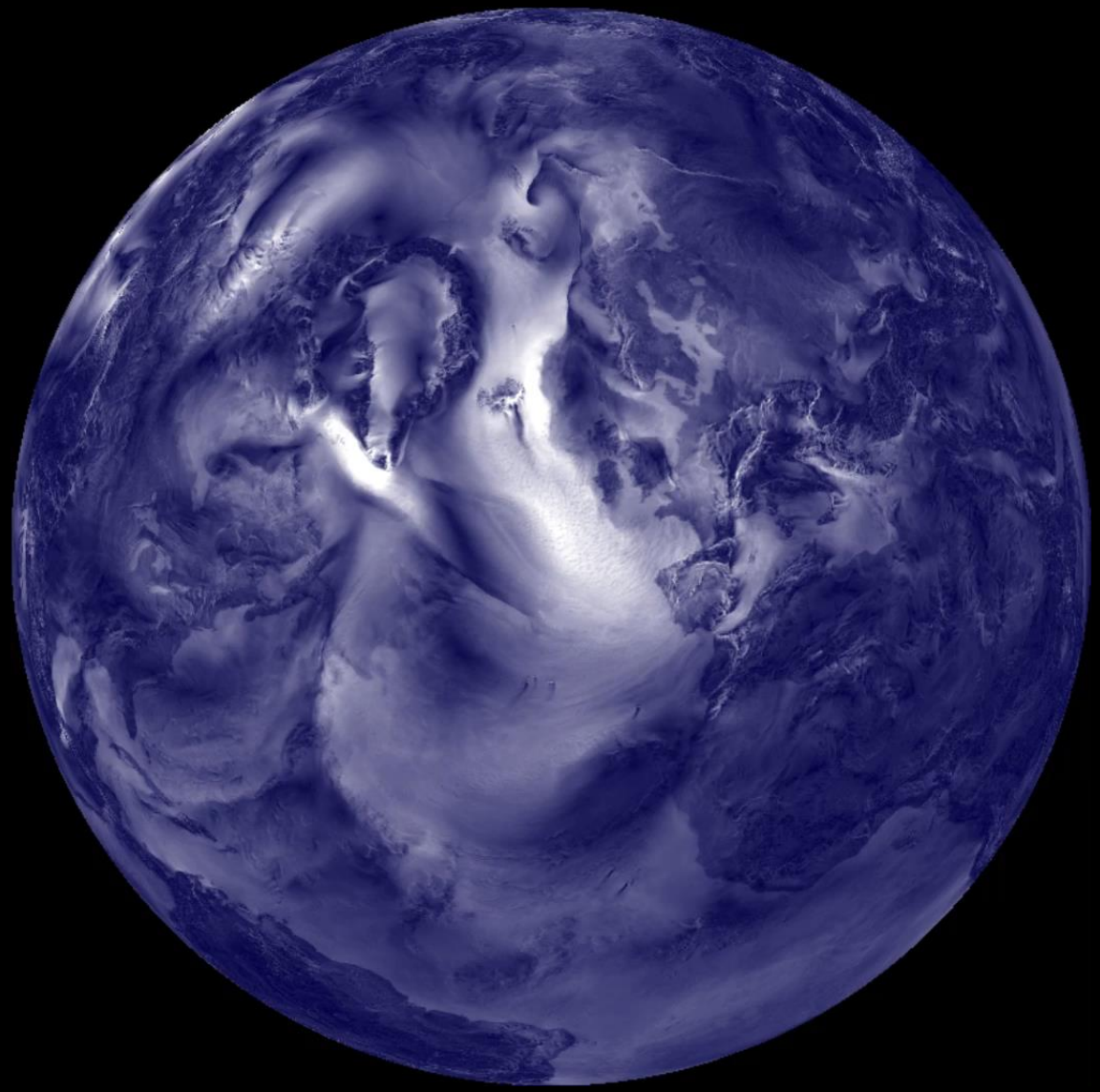
ECMWF's data driven forecast model

Simon Lang
Simon.lang@ecmwf.int

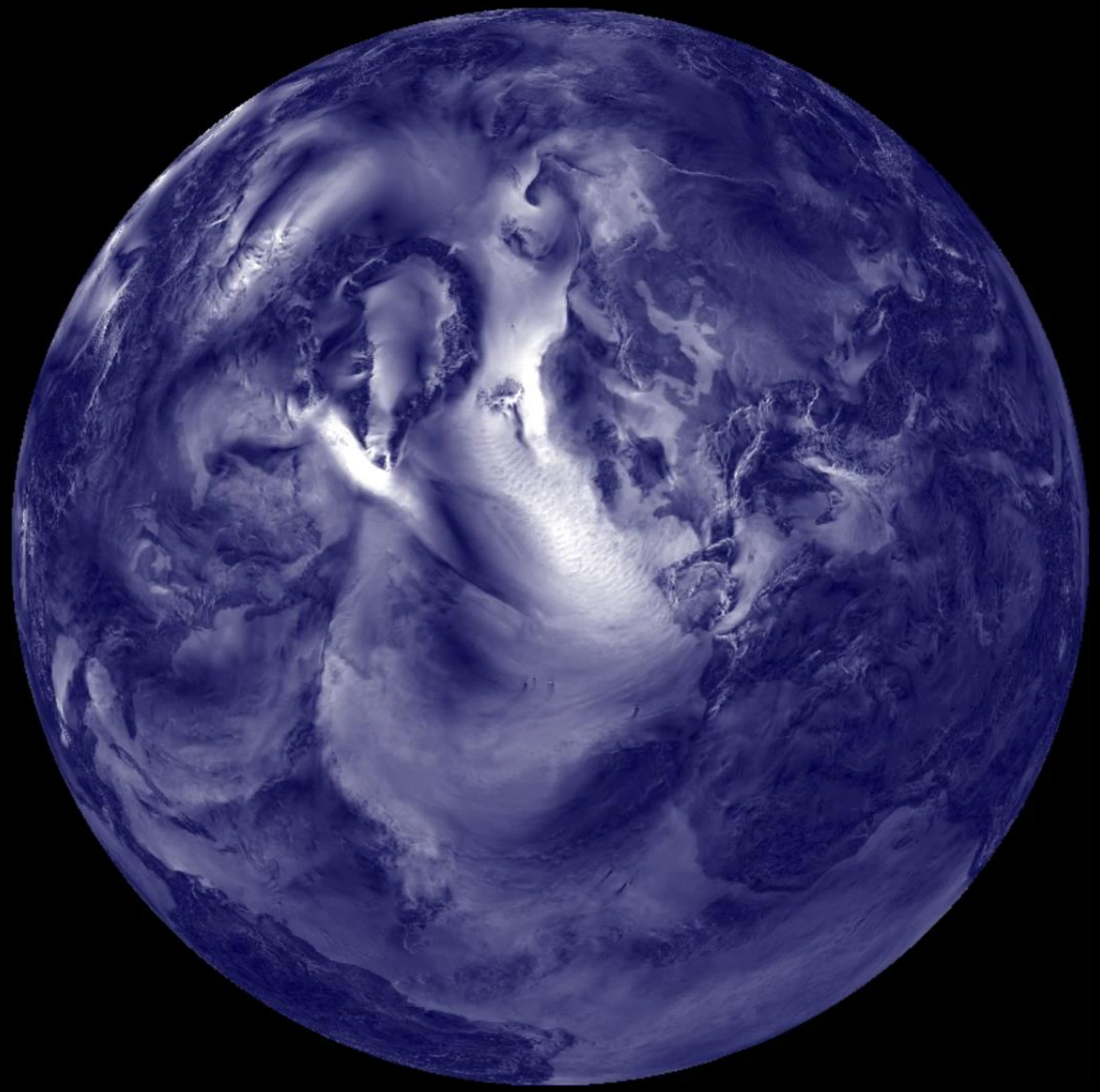
Mihai Alexe, Matthew Chantry,
Jesper Dramsch, Florian Pinault, Baudouin Raoult, Zied Ben Bouallegue, Linus Magnusson, Mariana Clare, Christian Lessig, Ana Prieto Nemesio, Steffen Tietsche, Michael Maier-Gerber, Cihan Sahin, Martin Leutbecher, Peter Dueben

ECMWF

IFS 10m wind gusts, 2020-12-04 00 UTC 720h forecasts, 9 km spatial resolution



Control Member

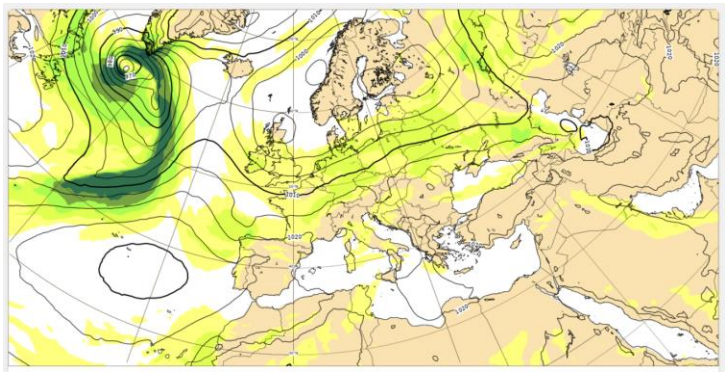


Perturbed member 1

Weather Forecasts – NWP? Data Driven?

Traditionally weather forecasts are generated by running NWP model – computer code that has been designed to represent the physical processes governing the evolution of the atmosphere. But can you produce a forecast without a NWP model?

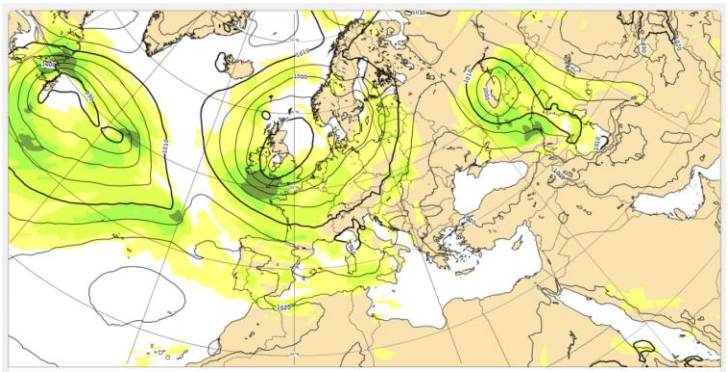
Analysis



Fusion of short-range forecast with latest observations

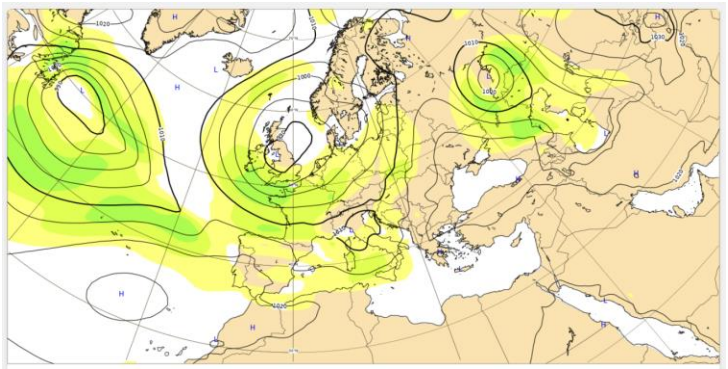
NWP Model

Forecast



Data Driven Model

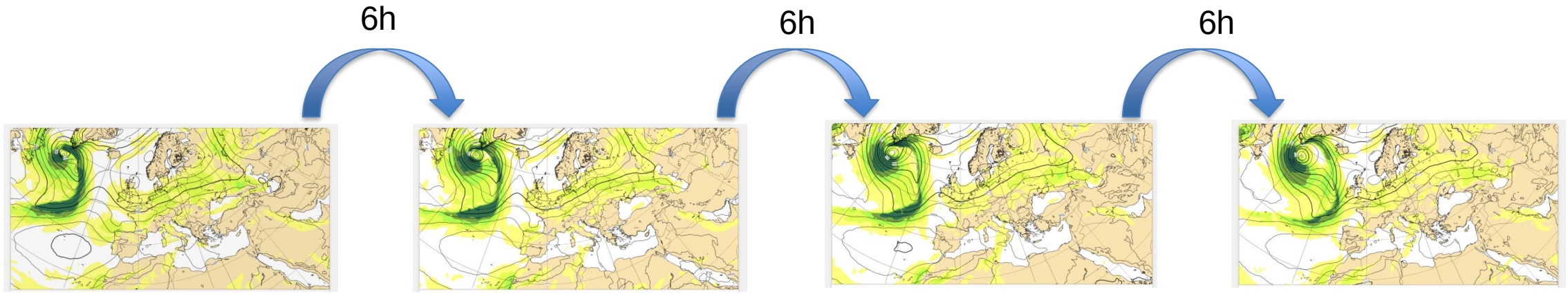
Learned from 40 years of analyses



Weather Forecasts – NWP? Data Driven?

Recent advances by individuals and tech companies and individuals show that this is possible (e.g. NVIDIA, Keisler, Deepmind, Huawei, … and others)

Here, the models learn from ca. 40 years of ERA5 re-analysis data, stepping e.g. 6h from analysis to analysis



The forecast is then autoregressively stepping 6h into the future $x_n = f(x_{n-1})$ …

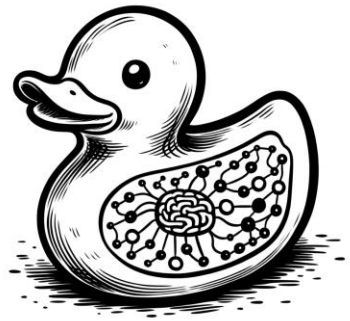
If we want to build a model, we have to choose an architecture …

- Vision transformers
- Graph neural networks
- Convolutions
- ….

AIFS - Artificial Intelligence / Integrated Forecasting System

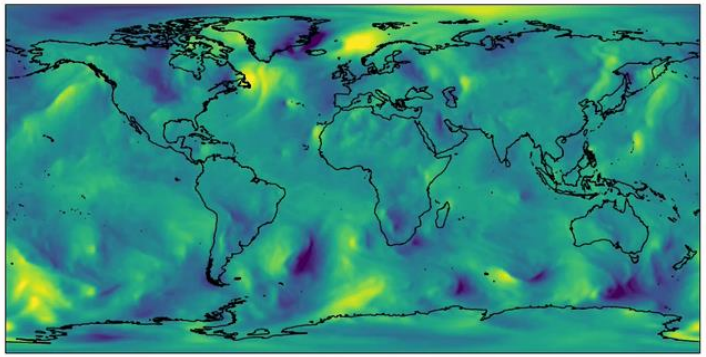
First implementation (~ 1deg resolution) in 2023, following Keisler 2022 and Lam et. al 2022:

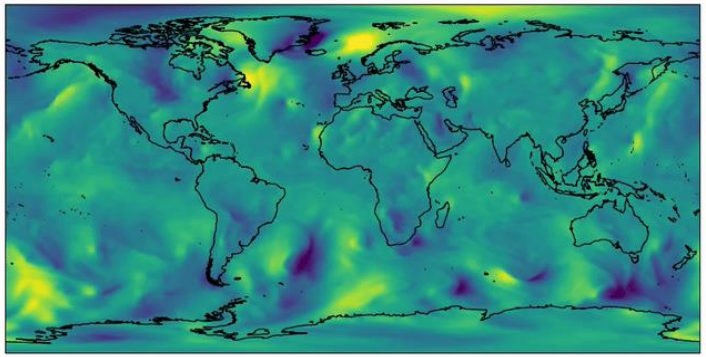
- GNN architecture: Interaction Networks (Battaglia et. al 2016)
- Graph representation, hidden multi-scale mesh, edge features



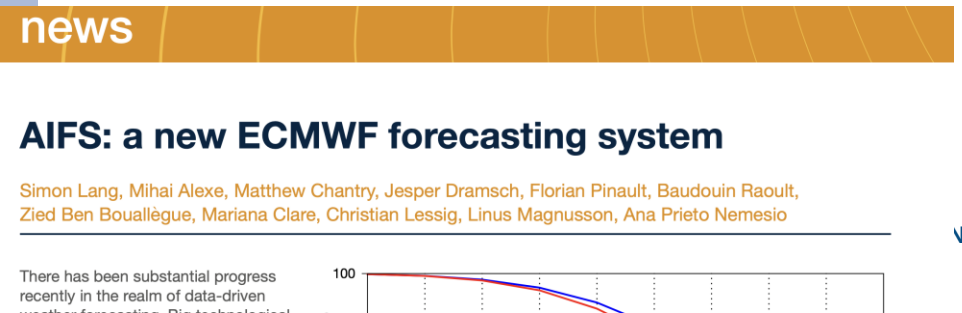
Update beginning of 2024, update to ~ 0.25 deg:

- Attention based GNN for encoder, decoder
- Transformer backbone in processor





Why GNN Encoder / Decoder: can handle arbitrary input / output grids, local and ad hoc grid refinement, changing grids etc. ; attractive for use in earth system science


news

AIFS: a new ECMWF forecasting system

Simon Lang, Mihai Alexe, Matthew Chantry, Jesper Dramsch, Florian Pinault, Baudouin Raoult, Zied Ben Bouallègue, Mariana Clare, Christian Lessig, Linus Magnusson, Ana Prieto Nemesio

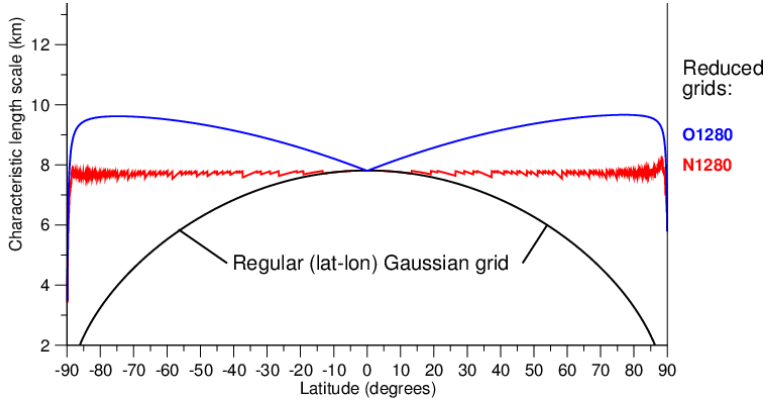
There has been substantial progress recently in the realm of data-driven

100

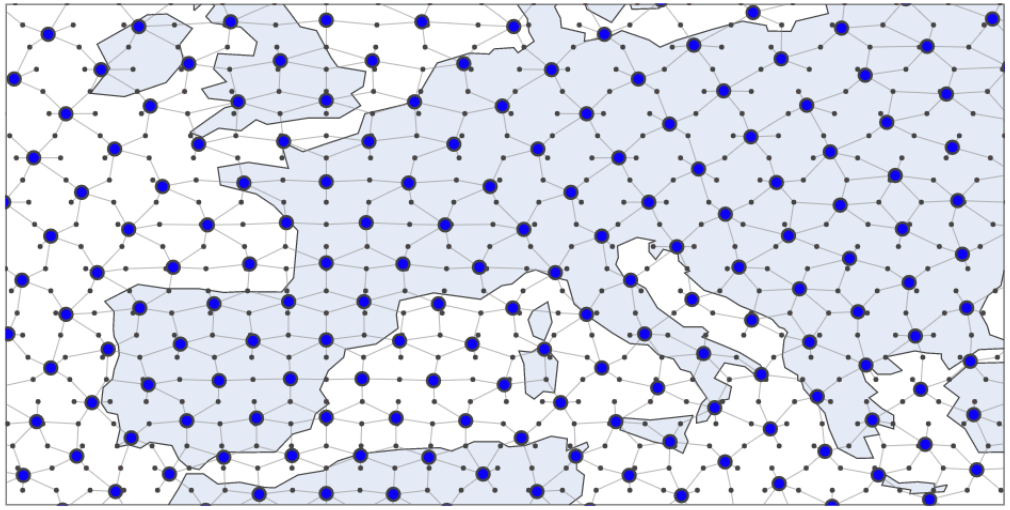
Lang S., Alexe M., Chantry M., Dramsch J., Pinault F., Raoult B., Ben Bouallègue Z., Clare M, Lessig C., Magnusson L., Prieto Nemesio A., 2024. **AIFS: a new ECMWF forecasting system**. ECMWF Newsletter number 178. p4-5. http://dx.doi.org/10.21957/1a8466ec2f

AIFS – Encoder and Decoder

AIFS works with the native IFS reduced gaussian grids ; possible to split model across multiple GPUs to handle large memory requirements



Encoder, GNN



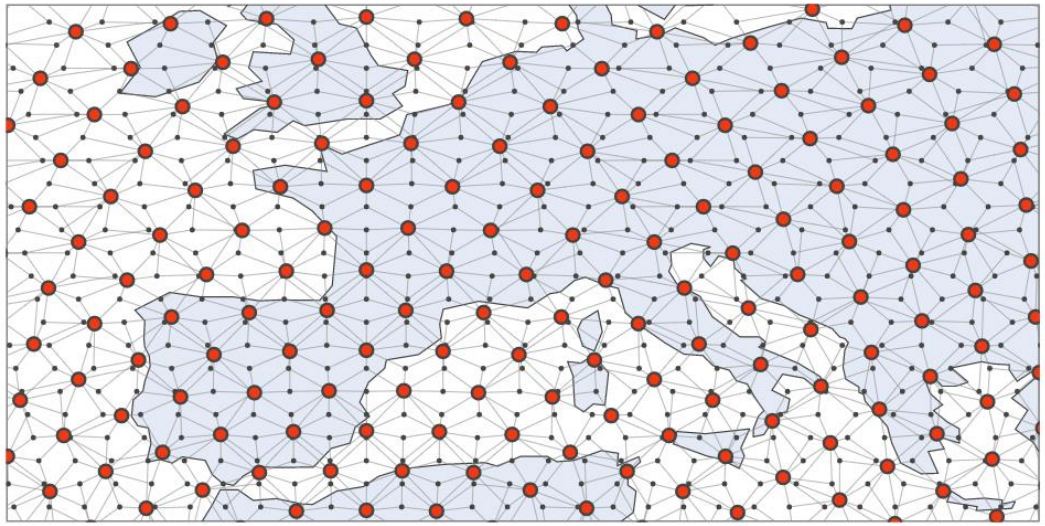
Era5 – n320

~ 540 000 Nodes,
~ 1 Million Edges

16 x Processor
with skip-connections

O96 ~ 40 000 Nodes

Decoder, GNN



Era5 – n320

AIFS – Processor

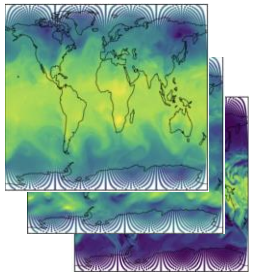
Transformer (like LLMs) that works with a sliding attention window -> attention bands around the globe

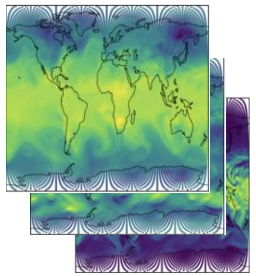
Red: target node
Blue: Nodes target node attends to in one processor layer
Grey: How far information can travel within e.g. 6 processor layers
(here lower resolution processor grid than operational AIFS for visualization)

since February 2024, See AIFS blog:

Lang et al. 2024: https://www.ecmwf.int/en/about/media-centre/aifs-blog/2024/first-update-aifs
Chantry et al. 2024: https://www.ecmwf.int/en/about/media-centre/aifs-blog/2024/its-raining-data

Atmospheric state:
X(t), X(t-6h)





previous
X(t)

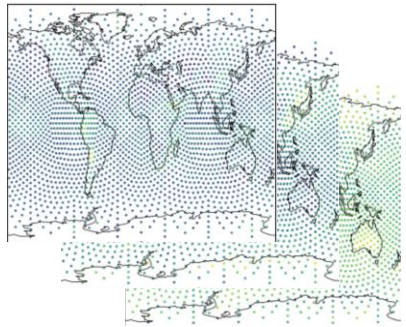
Prediction:
X(t+6h)

$WMSE_{t+6h}$

encoder

decoder

processor:
16 MP rounds



$AIFS_{t \rightarrow t+6h}$

$AIFS_{t+6h \rightarrow t+12h}$

$WMSE_{t+12h}$

AR predictions

…

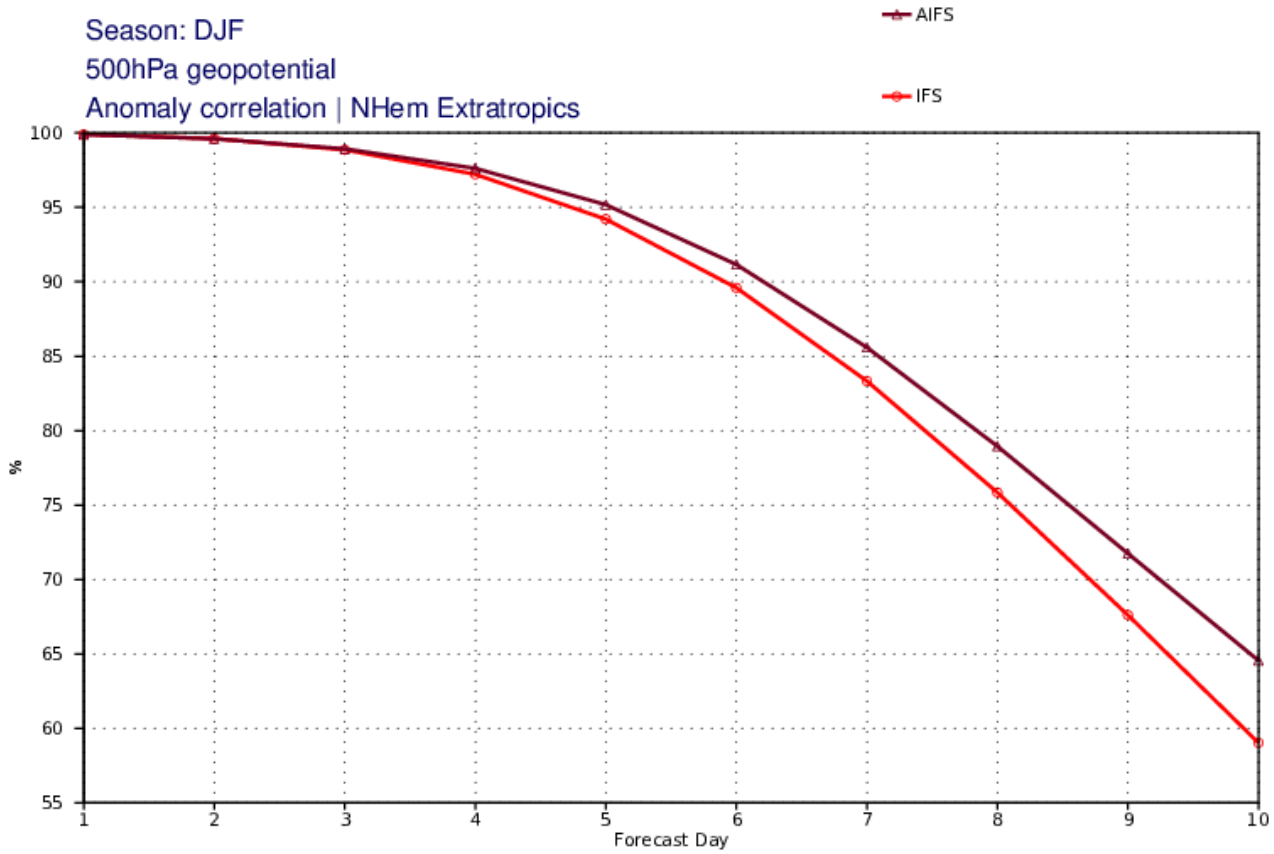
Aggregate
WMSE

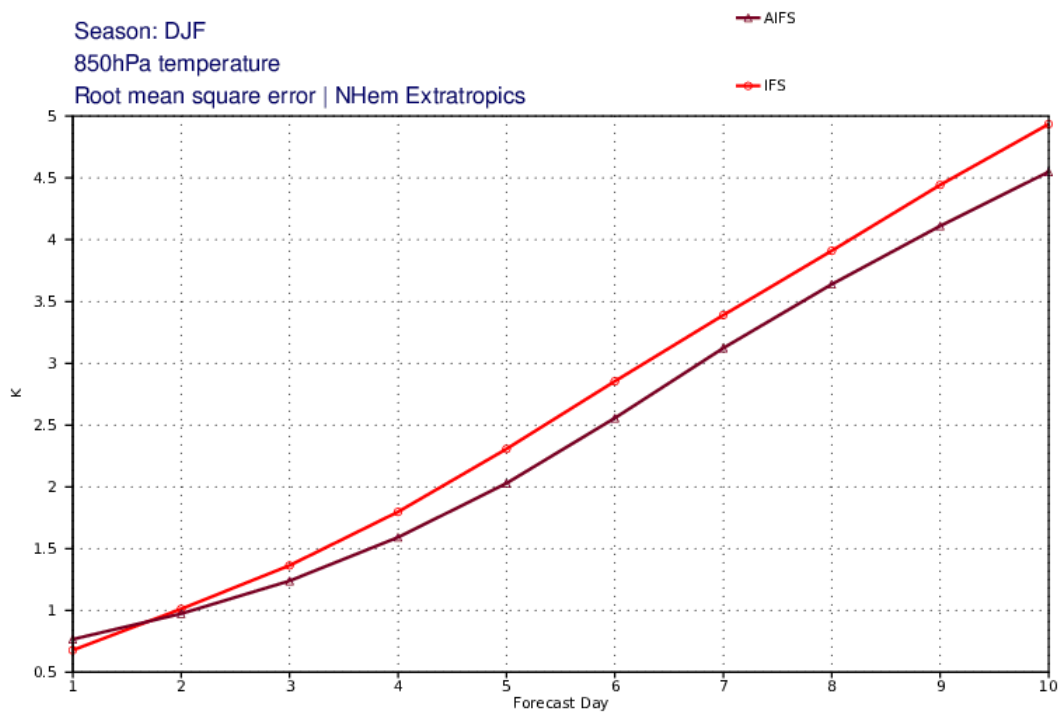
Forecast skill:

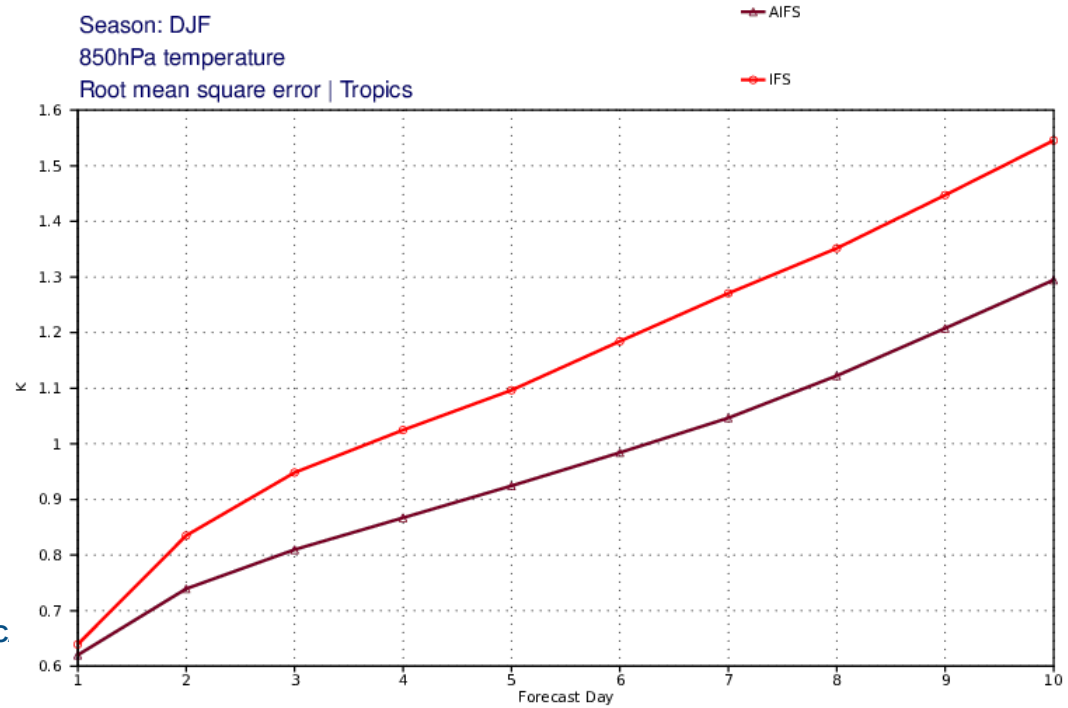
DJF, 2023/2024

AIFS

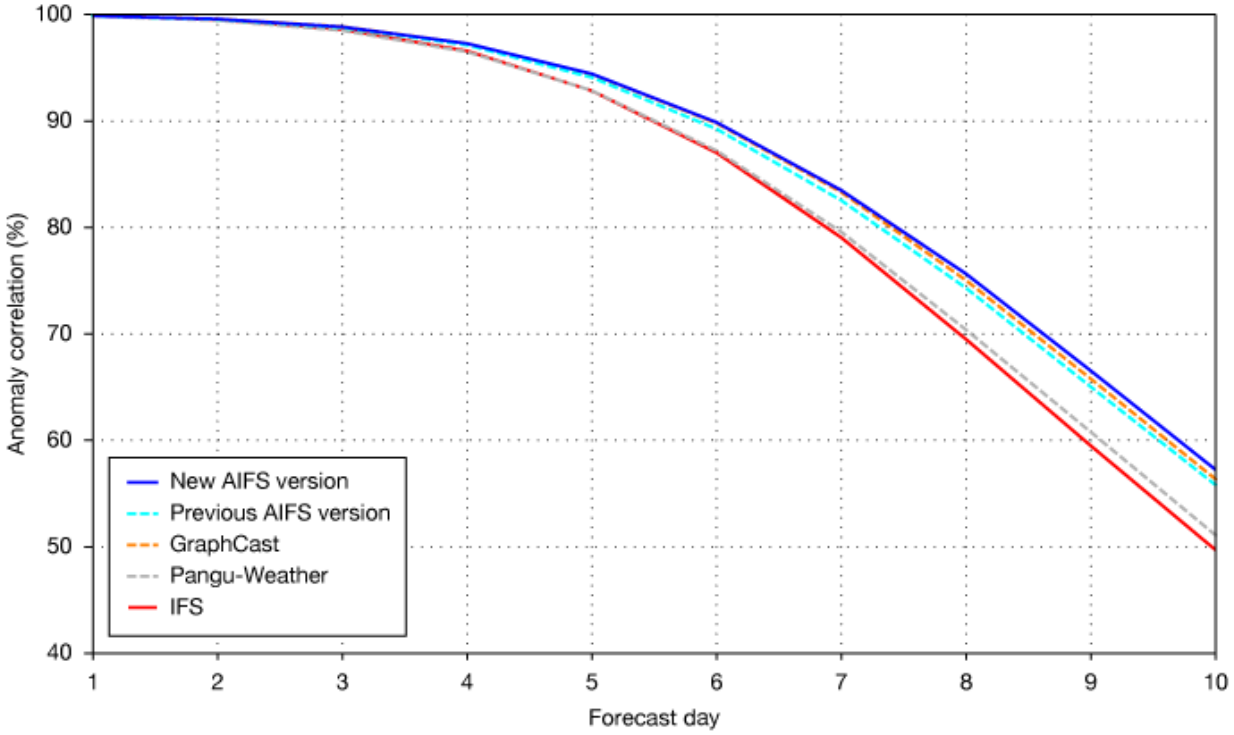
IFS

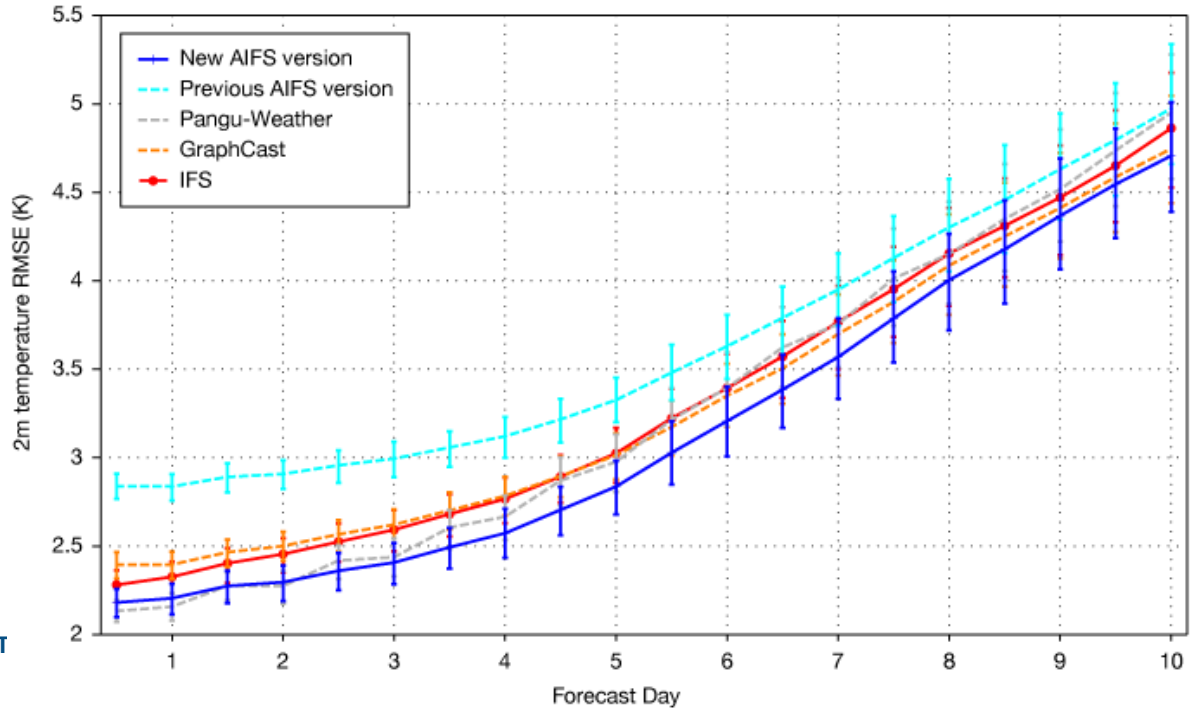






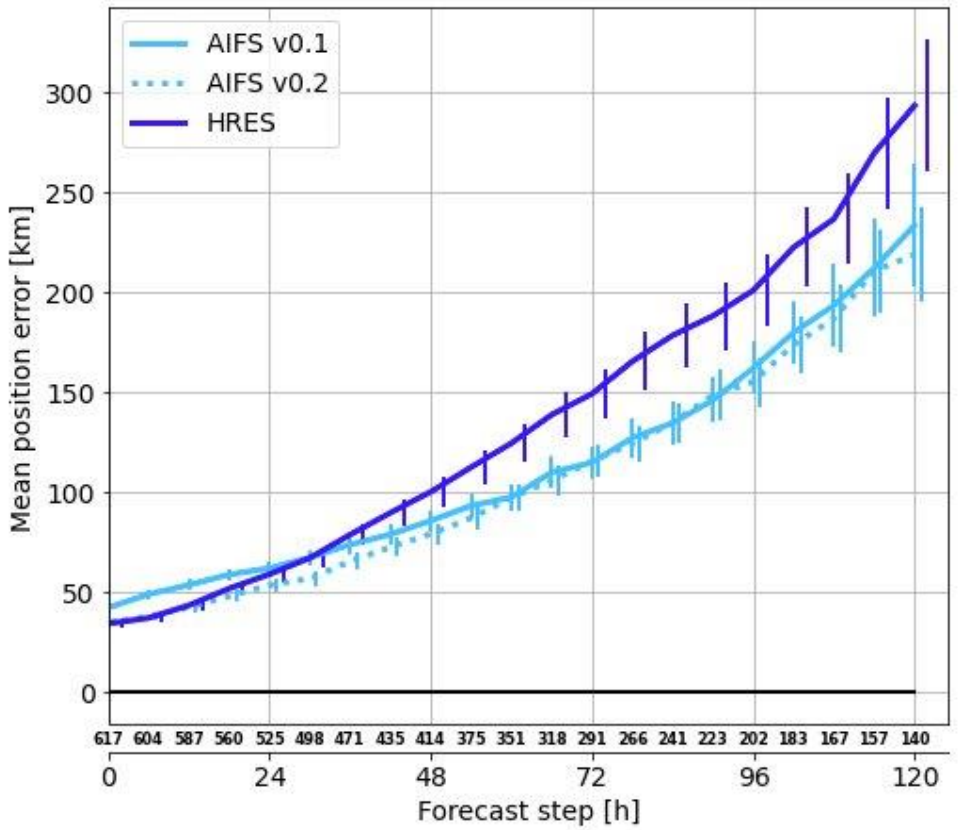
Forecast skill 2022:



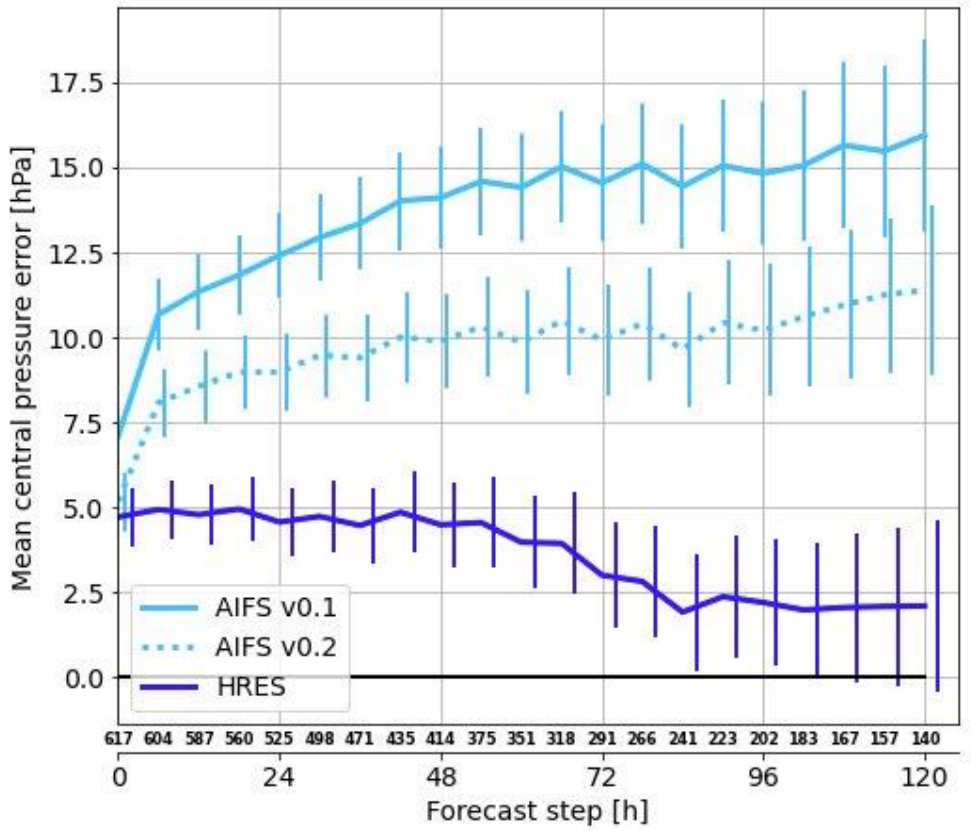


Forecast skill TCs, 2022:

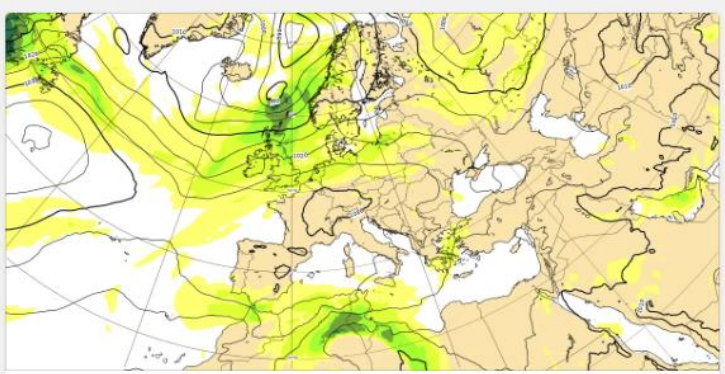
Position error



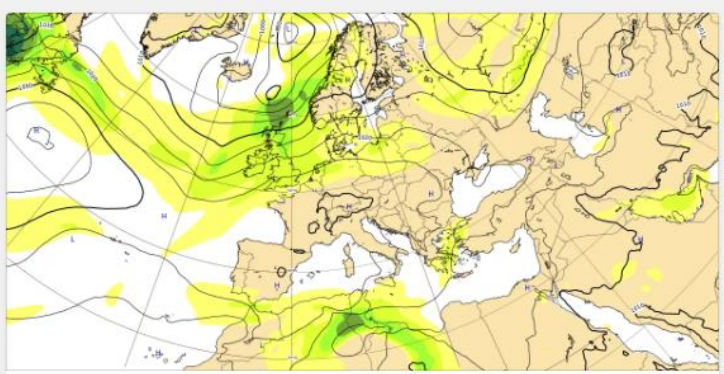
Central pressure bias



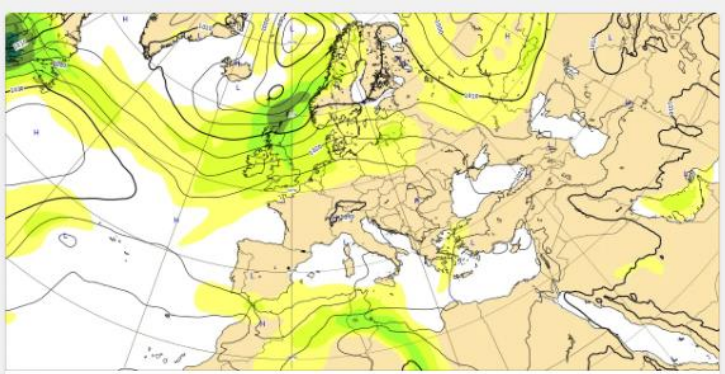
IFS, AIFS and other machine learning models - charts.ecmwf.int:



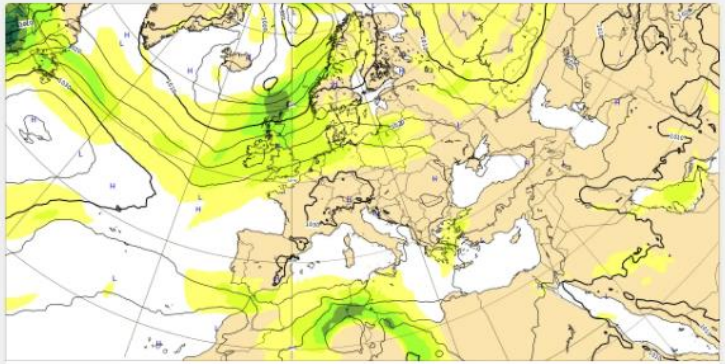
Mean sea level pressure and 850 hPa wind speed



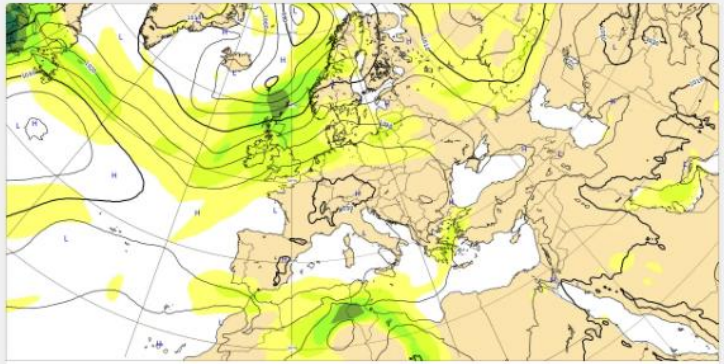
Experimental: AIFS (ECMWF) ML model: Mean sea level pressure and 850 hPa wind speed



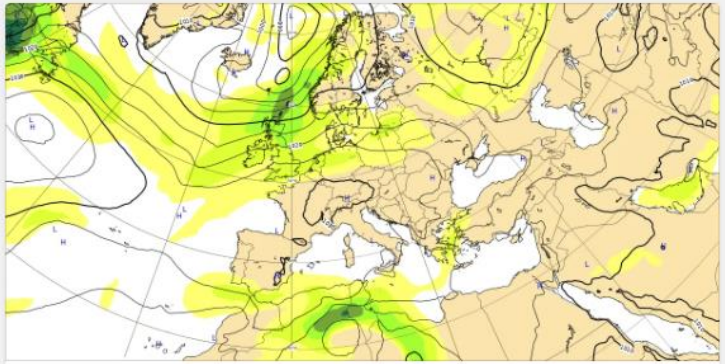
Experimental: FourCastNet ML model: Mean sea level pressure and 850 hPa wind speed



Experimental: FuXi ML model: Mean sea level pressure and 850 hPa wind speed



Experimental: GraphCast ML model: Mean sea level pressure and 850 hPa wind speed



Experimental: Pangu-Weather ML model: Mean sea level pressure and 850 hPa wind speed

Some AI model verification ->

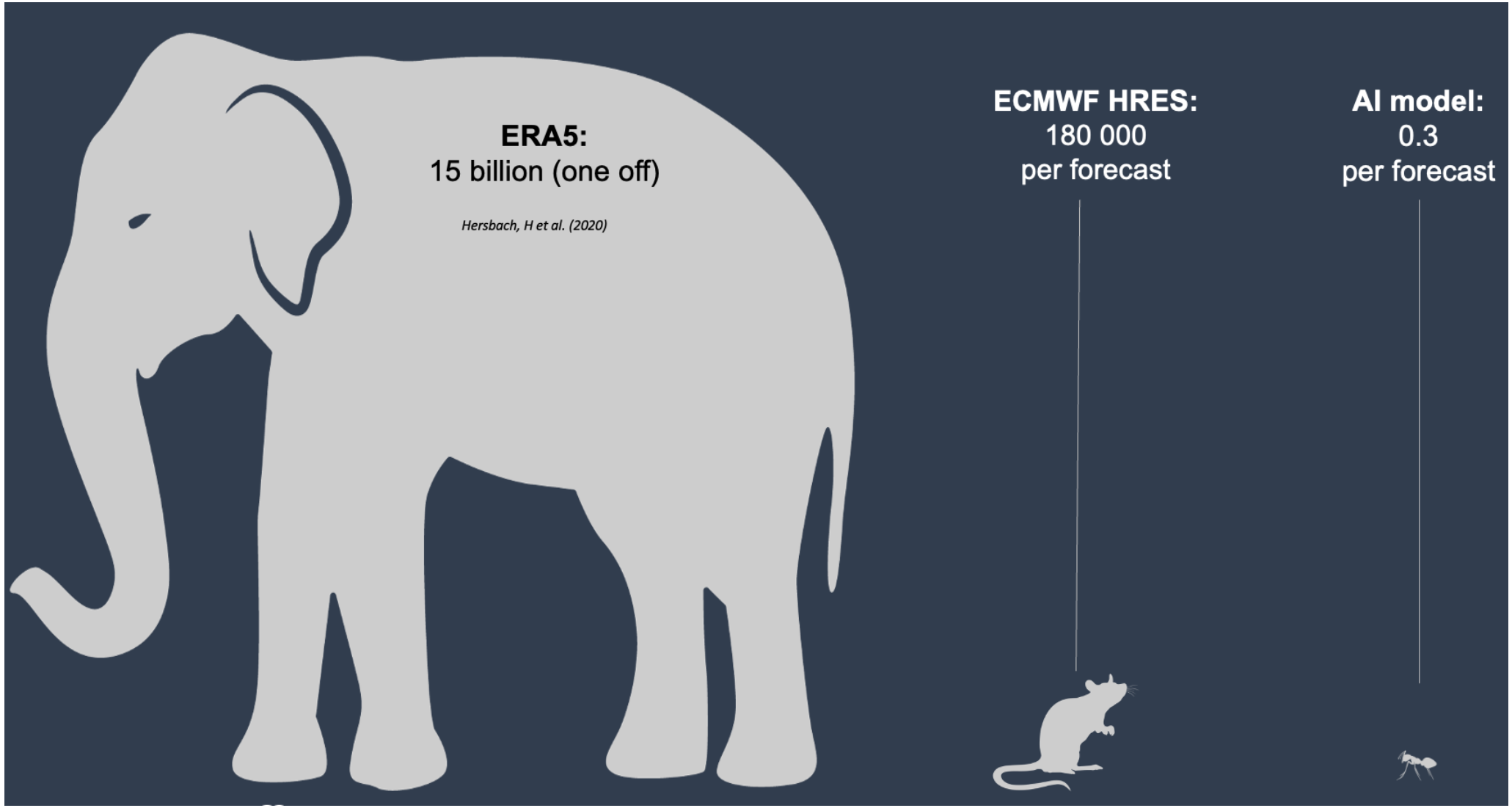
THE RISE OF DATA-DRIVEN WEATHER FORECASTING

A FIRST STATISTICAL ASSESSMENT OF MACHINE LEARNING-BASED WEATHER FORECASTS IN AN OPERATIONAL-LIKE CONTEXT

A PREPRINT V2

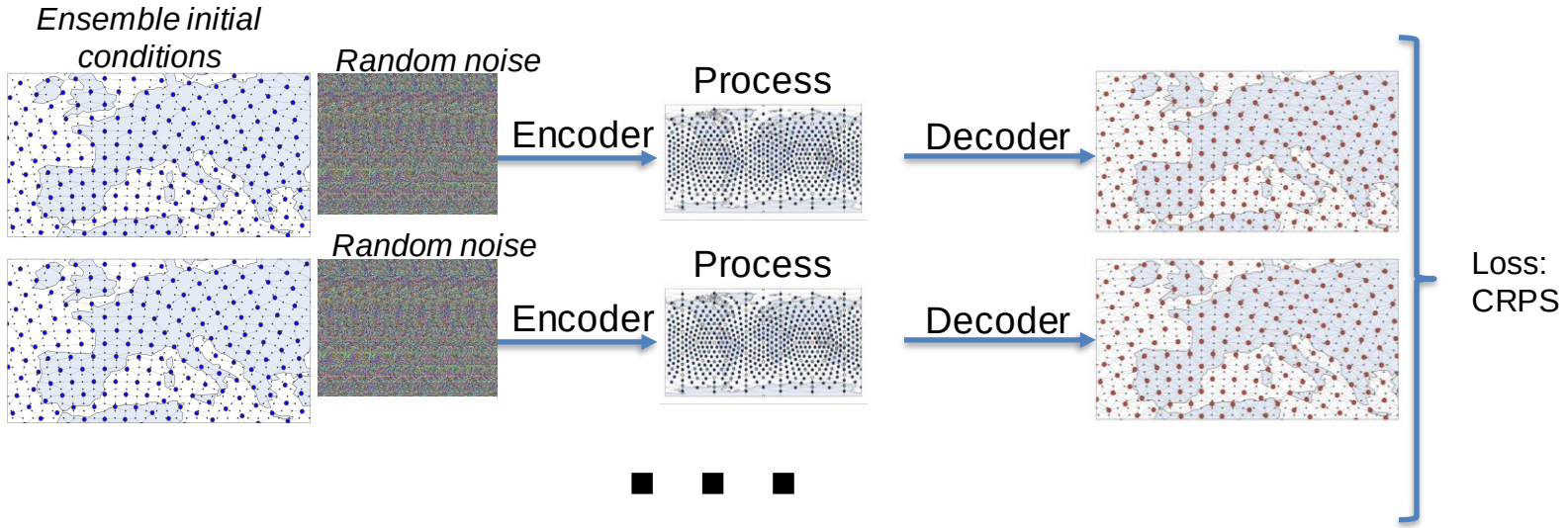
Zied Ben Bouallègue, Mariana C A Clare, Linus Magnusson, Estibaliz Gascón, Michael Maier-Gerber, Martin Janoušek, Mark Rodwell, Florian Pinault, Jesper S Dramsch, Simon T K Lang, Baudouin Raoult, Florence Rabier, Matthieu Chevallier, Irina Sandu, Peter Dueben, Matthew Chantry, Florian Pappenberger

How costly?

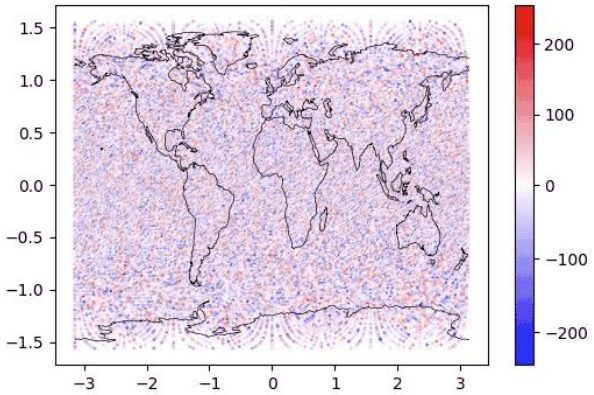

ERA5:
15 billion (one off)
Hersbach, H et al. (2020)
ECMWF HRES:
180 000
per forecast
AI model:
0.3
per forecast

Next? Ensemble forecasts …

Instead of a MSE loss, learn an ensemble via optimizing probabilistic scores



"Generative AI", e.g. create a forecast as de-noising task (diffusion models)



Thank you!