AI activities for NWP applications at CNRM

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Introduction

AI in meteorology is **revolutionizing** how weather forecasting and climate modelling are conducted in diverse meteorological services.

Regarding weather forecasts, application areas of AI models are spread over **the entire workflow** :

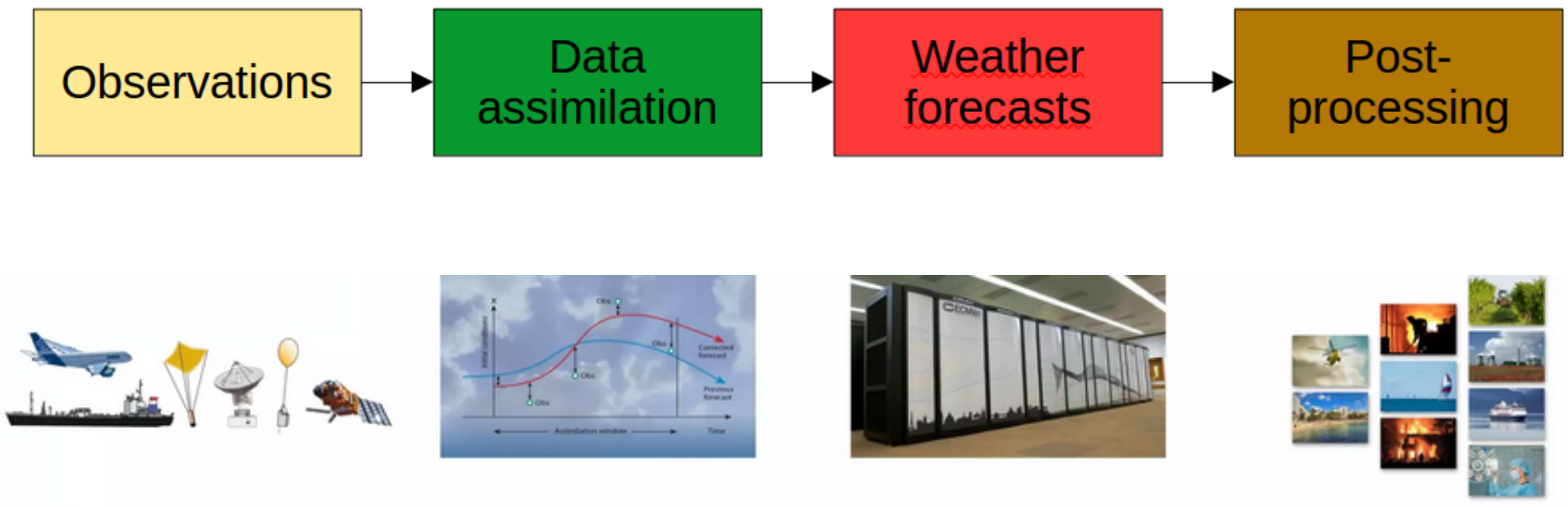


Figure: Weather forecast simplified workflow.

CNRM current AI activities

- **High-resolution regional forecasting models ($\sim$ km scale)** ***(GMAP/PREV)***
- **Downscaling** ***(GMAP/PREV)***
- **Generative ML for ensemble prediction such as GANs or diffusion models** ***(GMAP/PREV)***
- Detection of Bow Echoes (Arnaud Mounier, GMAP/PREV)
- Classification of ensemble forecasts *(Arnaud Mounier, GMAP/PREV)*
- AI models to enhance traditional data assimilation methods *(Vincent Chatbot, GMAP/ASSIM)*

AI-AROME Emulator - Problem overview

ML will emulate the forecasting model:

$$x^{t+dt} = \tilde{M}(x^t) \qquad (1)$$

x^t are generally gridded data of atmospheric variables at different altitudes.

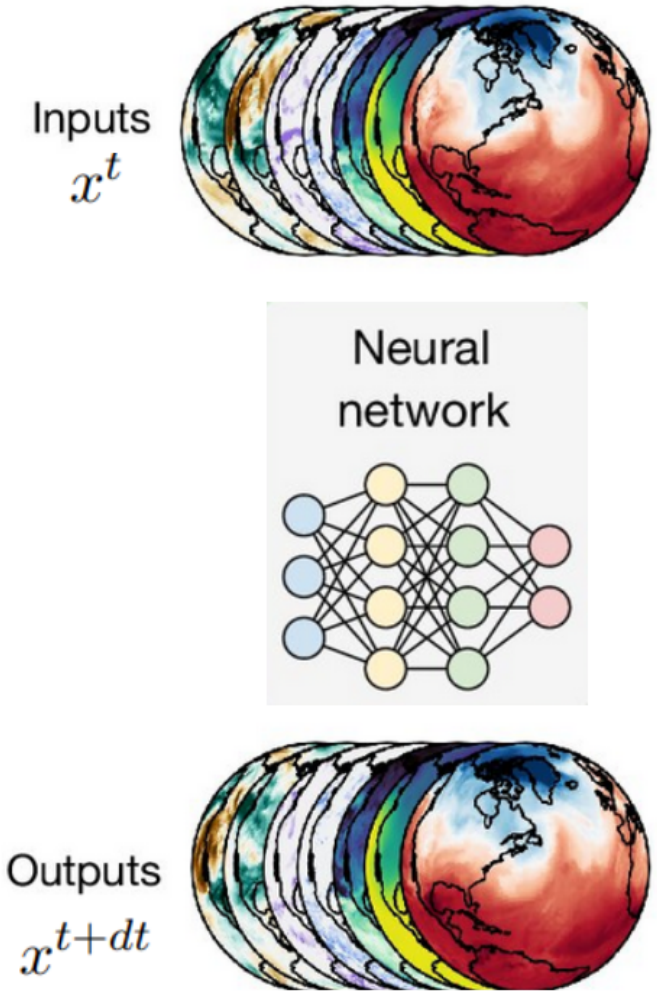


Figure: General approach

AI-AROME Emulator - Anemoi

Aim: Develop a deep learning forecasting system with the aim of providing forecasts of quality equivalent to AROME, both on Western Europe and on the overseas territories.

Anemoi Package

- Collaborative framework developed by ECMWF to develop data-driven weather models.
- Give building blocks to train and deploy AI model based on graph neural networks.
- Open source project: `https://github.com/ecmwf/anemoi-core`

AI-AROME Emulator - Training decomposition

Anemoi model training follows a four-stage procedure.

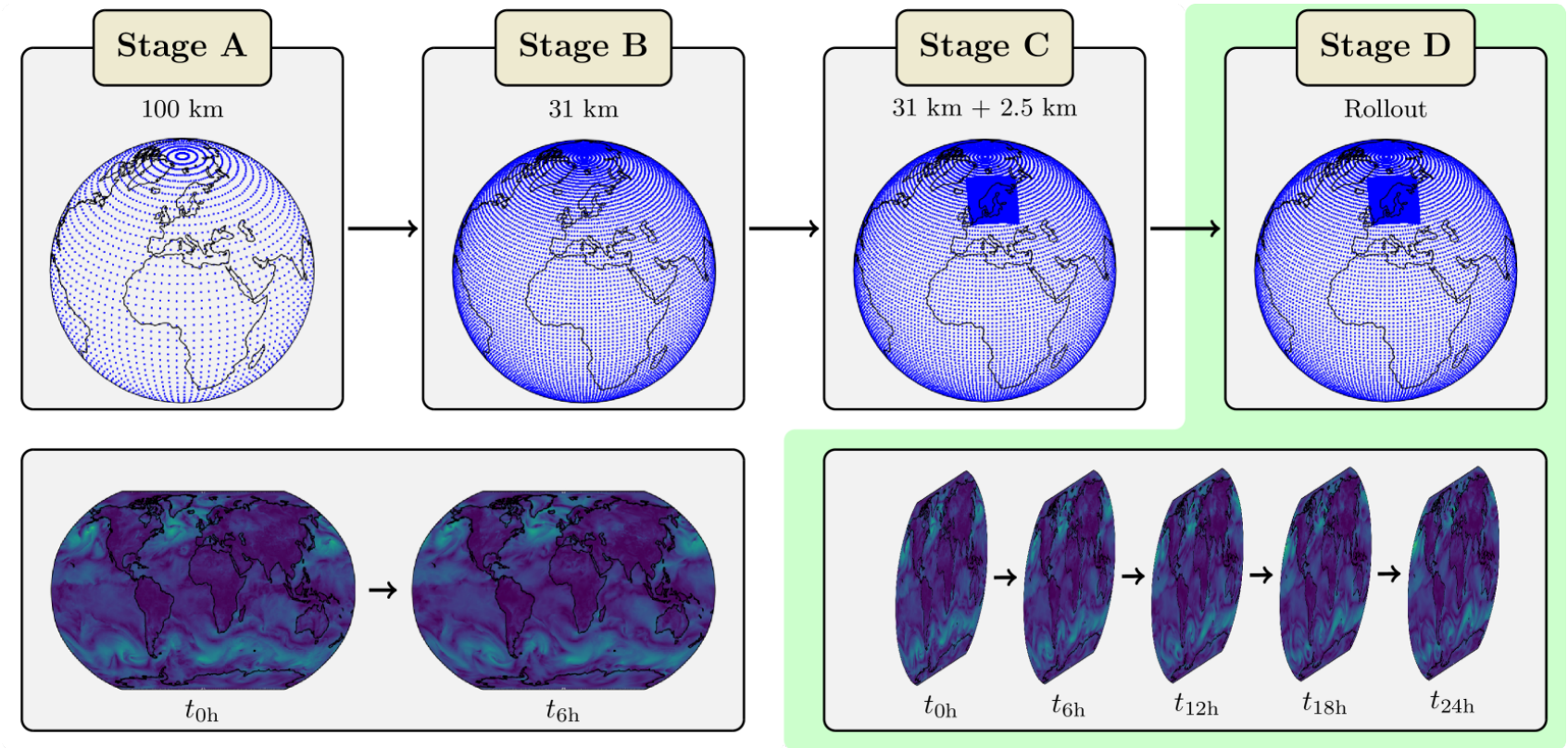


Figure: *Regional data-driven weather modeling with a global stretched-grid (TN Nipen et al · 2024)*

AI-AROME Emulator - Datasets

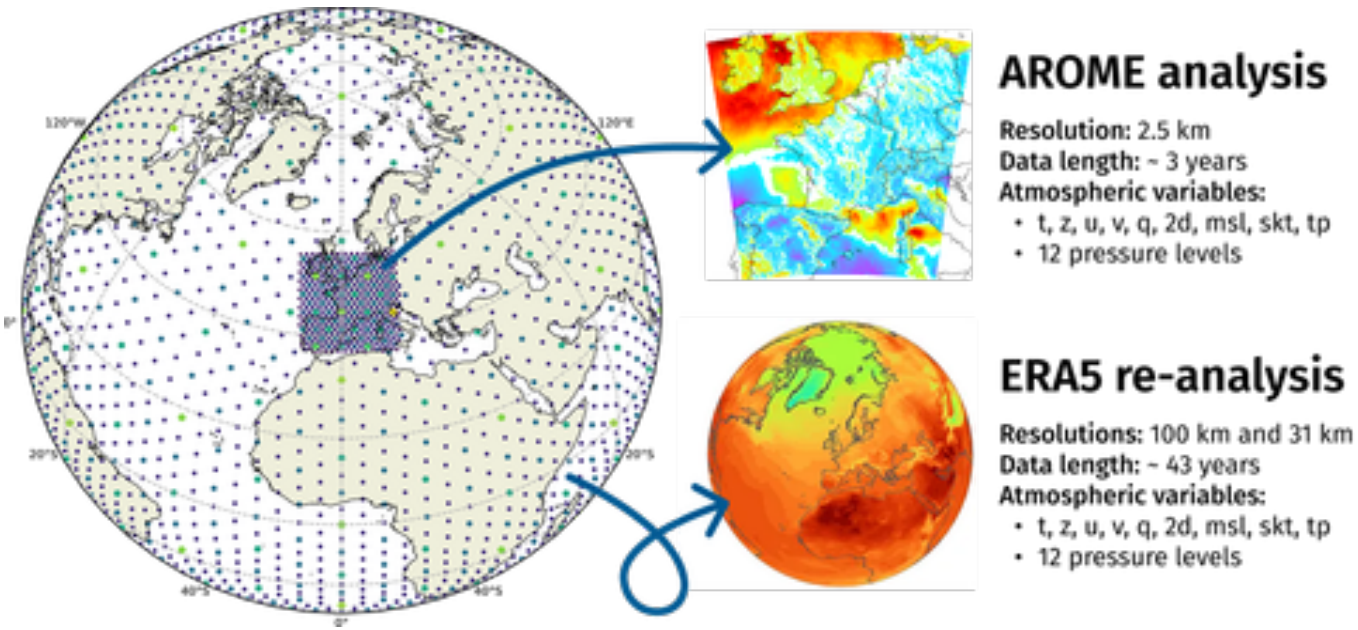


Figure: Representation of the stretch grid used (S. Akodad et al.)

AI-AROME Emulator - First results

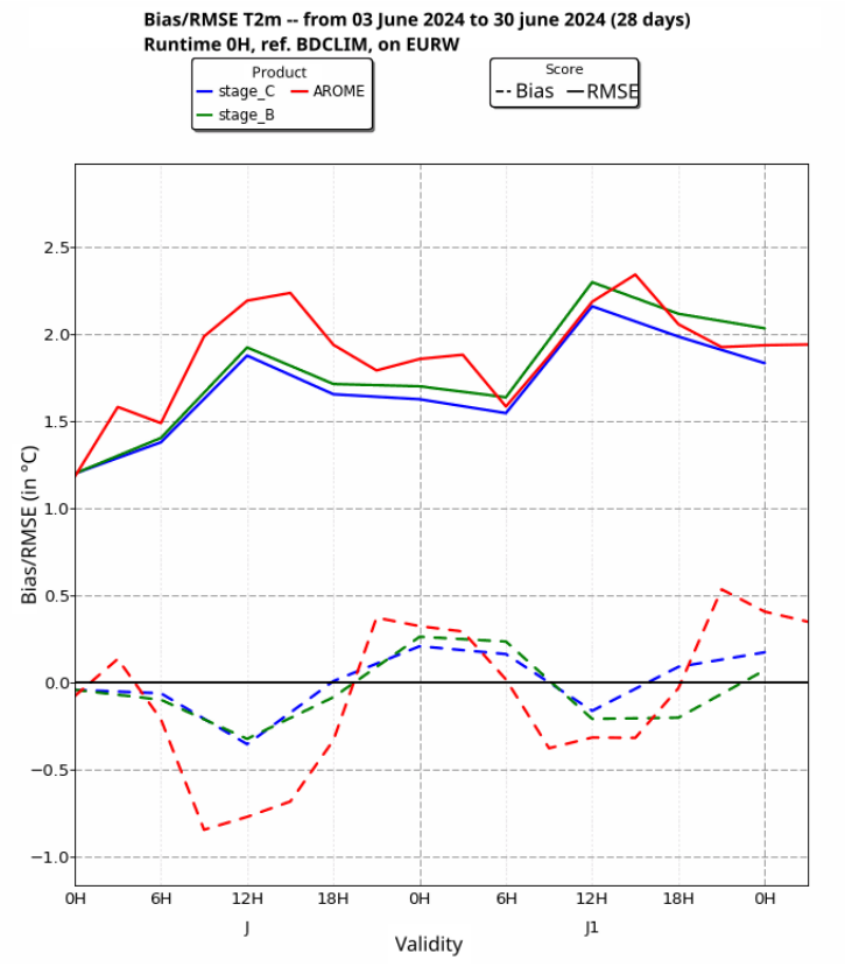


Figure: T2m bias and RMSE comparaison

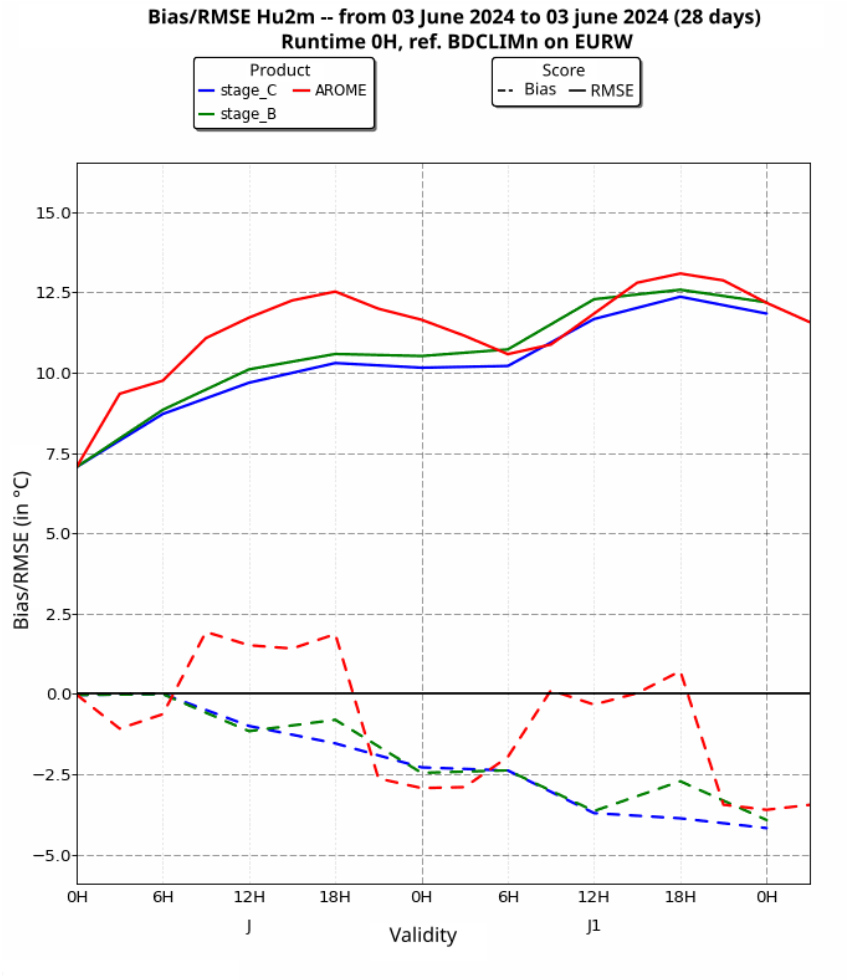


Figure: Hu2m bias and RMSE comparaison

AI-AROME Emulator - Ongoing Work and Perspectives

- Continue evaluation.
- Evaluation of rollout (stage D).
- Include the future ARRA dataset.
- Use global ARPEGE data as the global grid.

Downscaling - Introduction

Main idea

- Starting from low-resolution dataset and applying statistical downscaling to obtain high resolution dataset.
- Diffusion model based.
- Use-case: ERA5 to CERRA.
- Use-case: ARPEGE to AROME.

Downscaling - Diffusion model

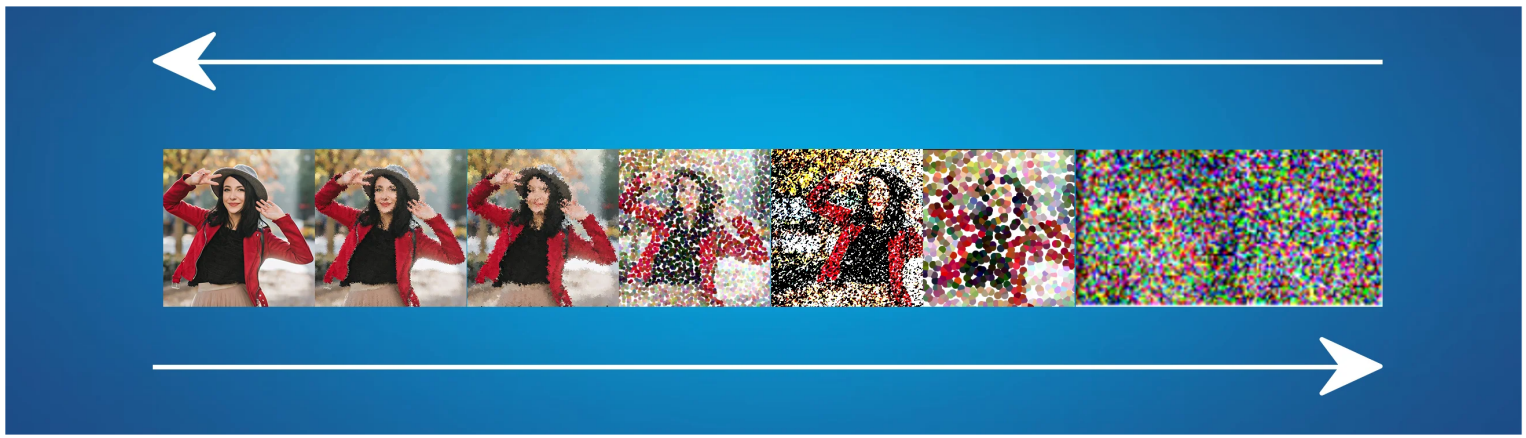


Figure: Main concept of diffusion model

Downscaling - Results ERA5 towards CERRA

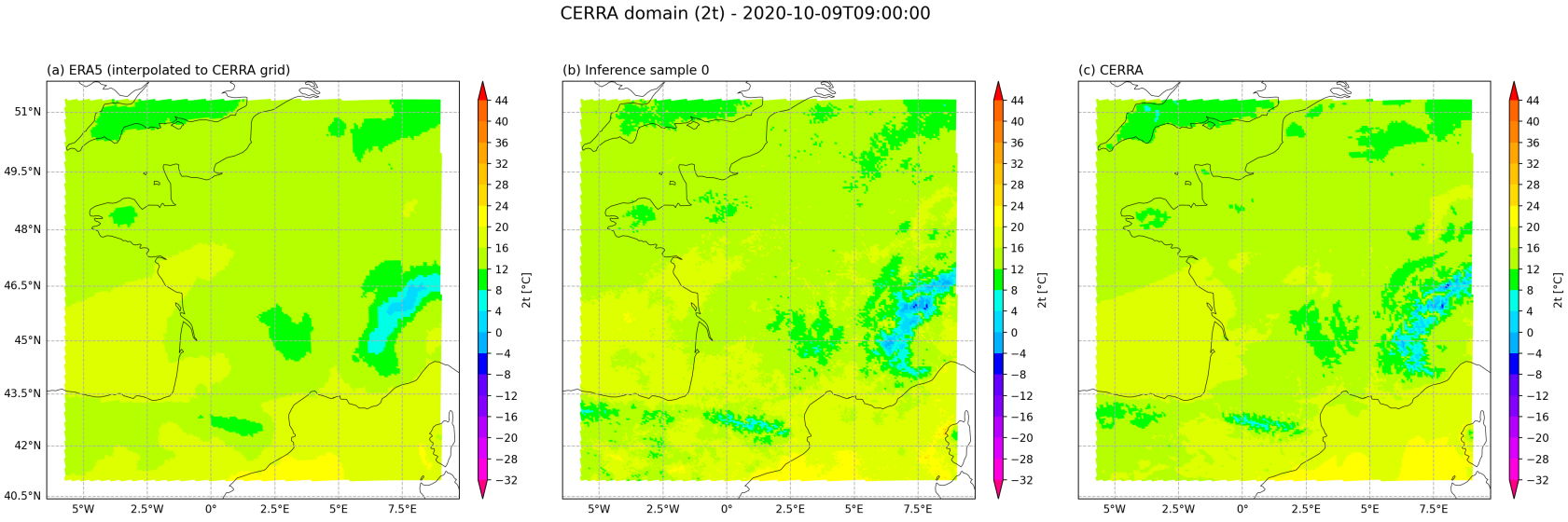


Figure: Comparison between ERA5 (31 km) (left), downscaling's result (middle) and the objectif of CERRA (5.5 km) (right) (Y. ZERAH et al.)

Downscaling - Ongoing Work and Perspectives

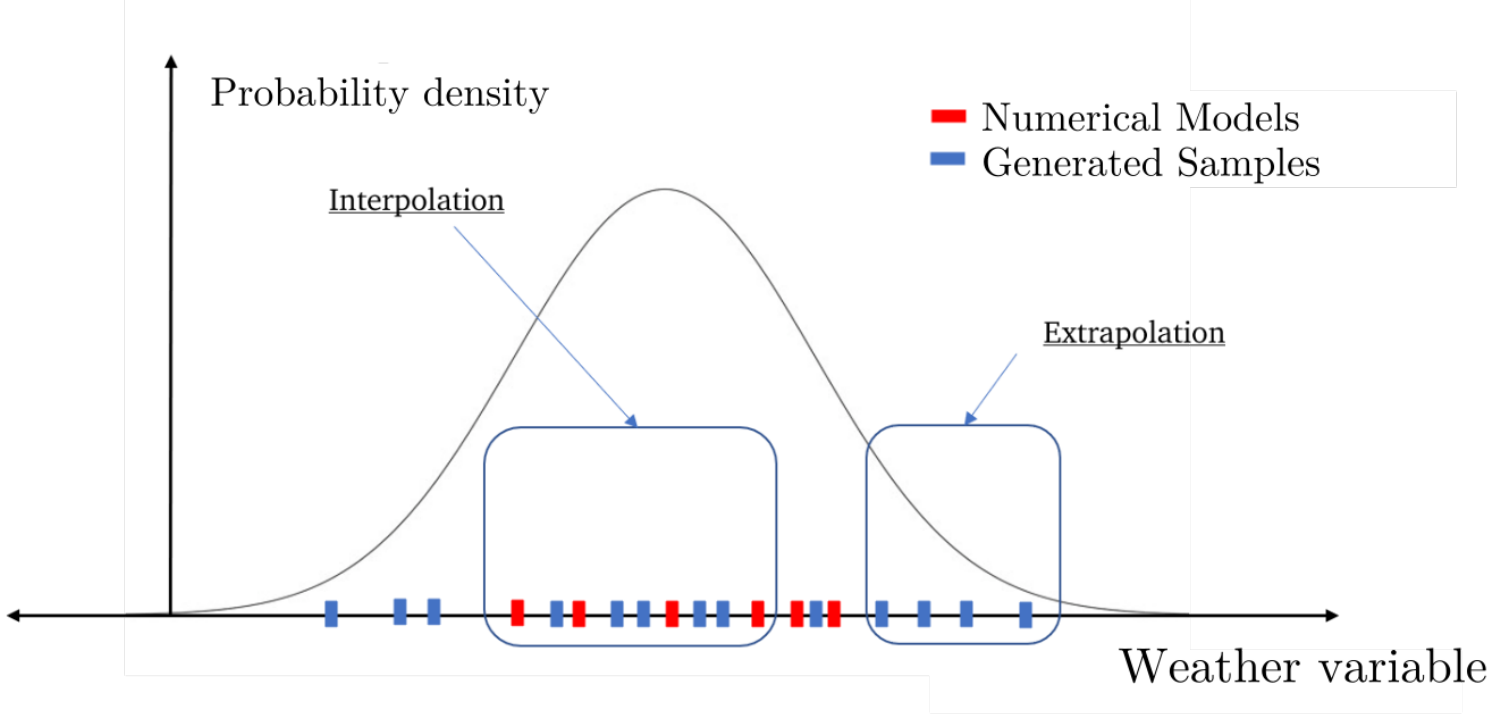
- Quantifying ensemble uncertainty.
- Autoregressive extension:
  $(ERA5_t + CERRA_{t-1} -> CERRA_t)$.
- Operationalization on the Climate Data Store
  (https://cds.climate.copernicus.eu/).

Ensemble generation using diffusion model - Introduction

Main purpose: enrich ensemble approaches

- Physical Model: few members due to operational constraints.
- Main idea: Use generative models such as GANs[a] or diffusion model (SDEdit) to produce more members.

[a] Clément Brochet phD thesis.



Ensemble generation using diffusion model - Results

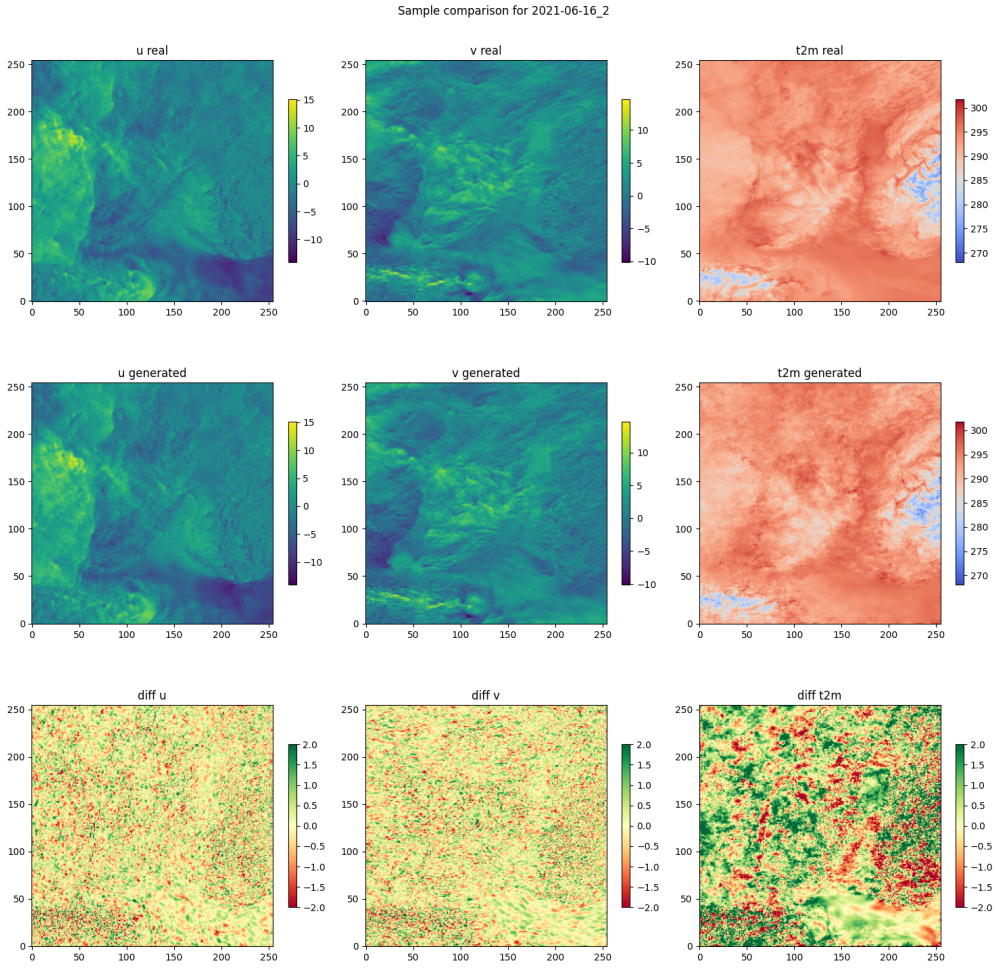


Figure: Generating new members on u, v and t2m. (A. Bonamy et al.)

Ensemble generation - Ongoing Work and Perspectives

- Generate **more meteorological variables** (rain rate, atmospheric pressure, ...).
- Extend the southeast domain to the whole AROME domain using ANEMOI framework on the SDEdit and unconditionnal diffusion.

Conclusions and perspectives

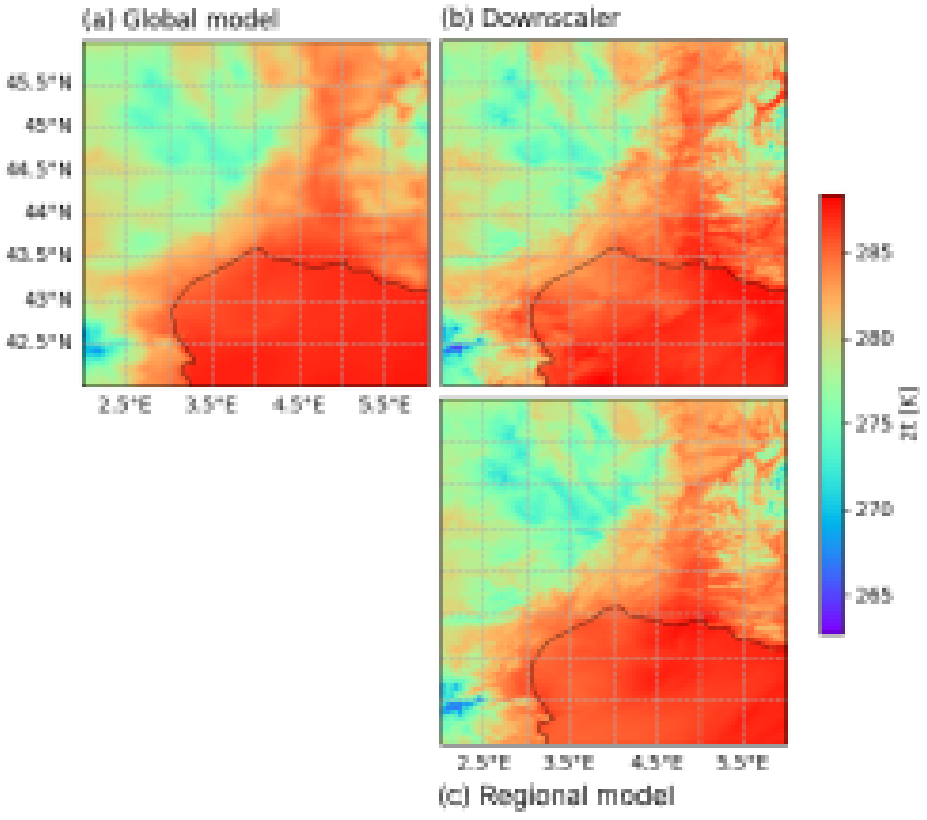
In short

- In the short term, our goal is to develop a **real-time demonstrator** that captures the key variables of interest with a quality comparable to Arome.
- Finish to develop a prototype of **downscaling** and make it operational.
- Using diffusion model to perform **ensemble generation** to help the forecasters.

Thank you for your attention !

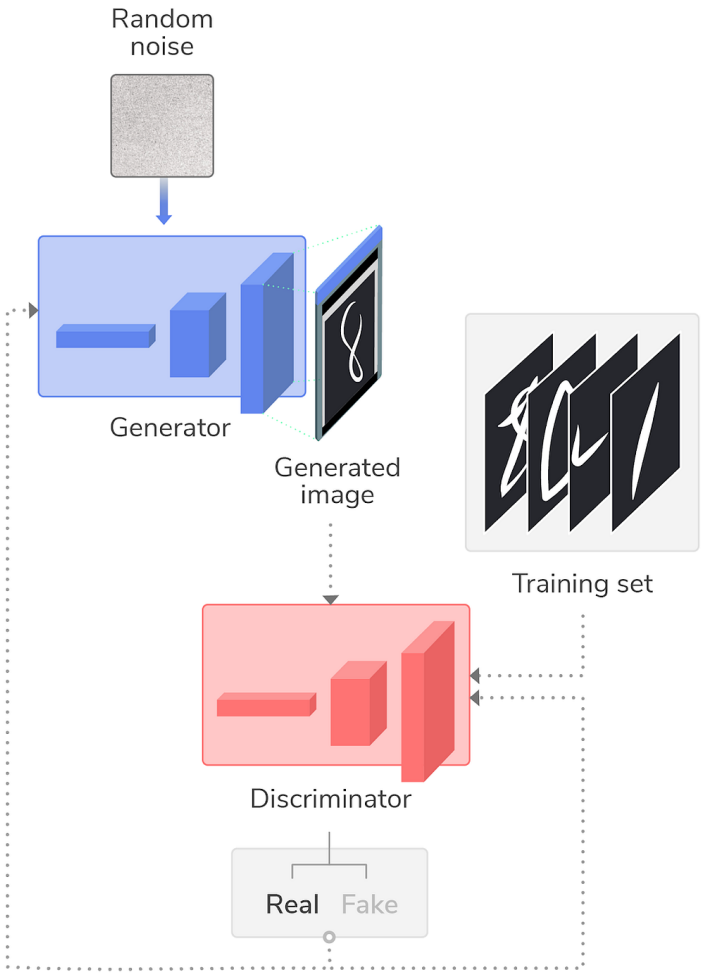
Any questions ?

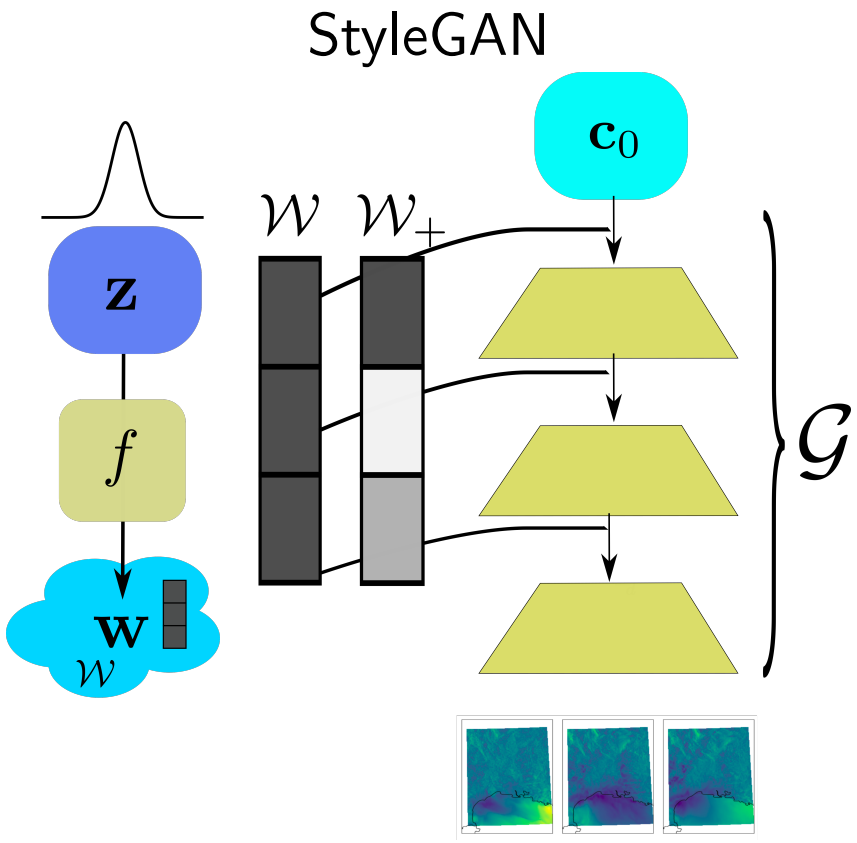
Downscaling - Results ARPGEGE towards AROME



Downscaling from Arpege (10km) to Arome (2.5km), E. LUMET

Appendix - Ensemble generation using GANs





AI-AROME Emulator development - Stretched grid

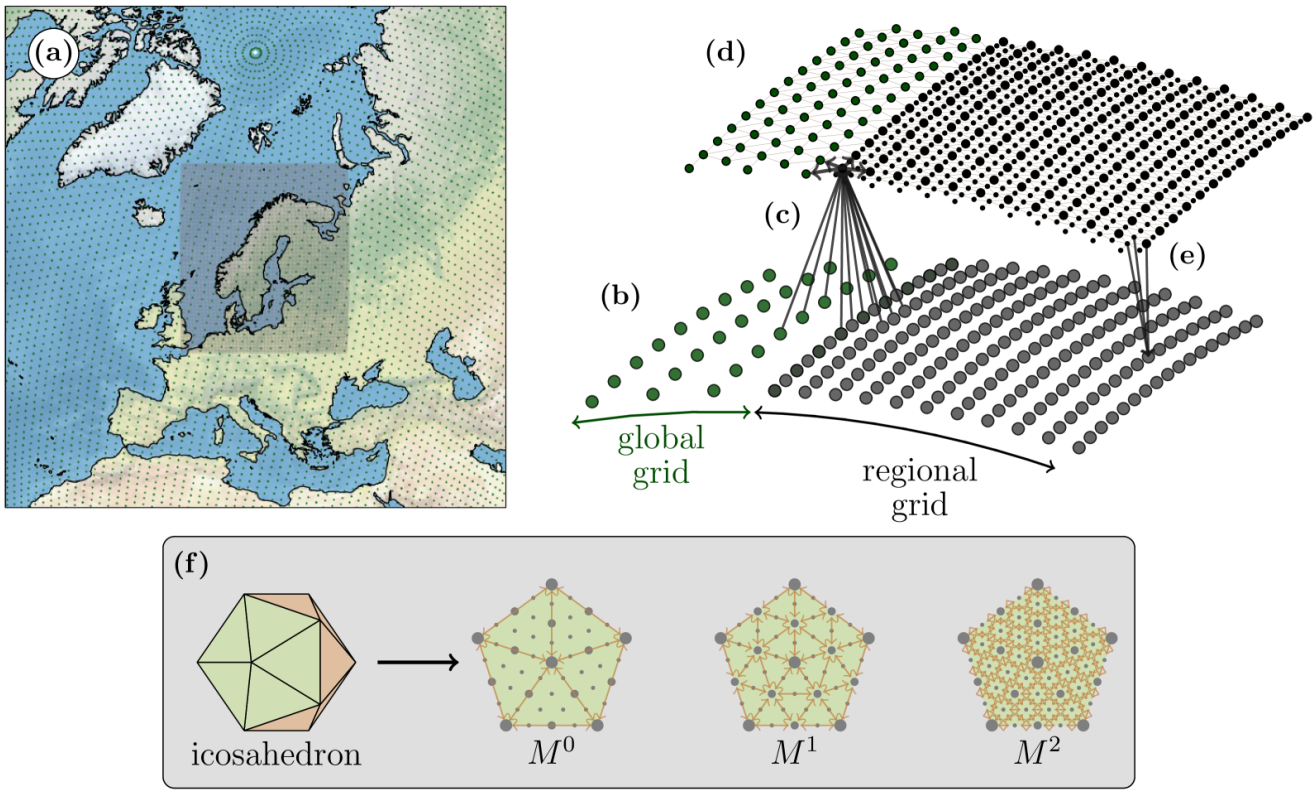


Figure: *Regional data-driven weather modeling with a global stretched-grid (TN Nipen et al · 2024)*

AI-AROME Emulator development - Datasets

AROME - EPS

- Convection-scale
- 1.3km grid-size resolution since 2022
- Dataset used :
  - 17 months of forecasts (1 per day)
  - 16 members for each forecast
  - Lead times up to 51h

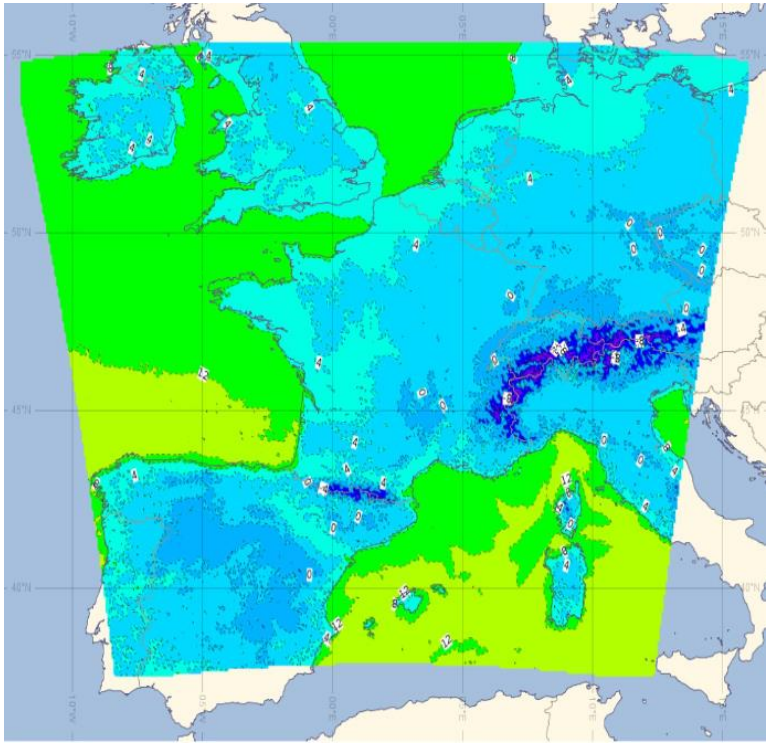


Figure: The AROME domain.

Introduction - It is already here !

From physics-based models to data-driven models:

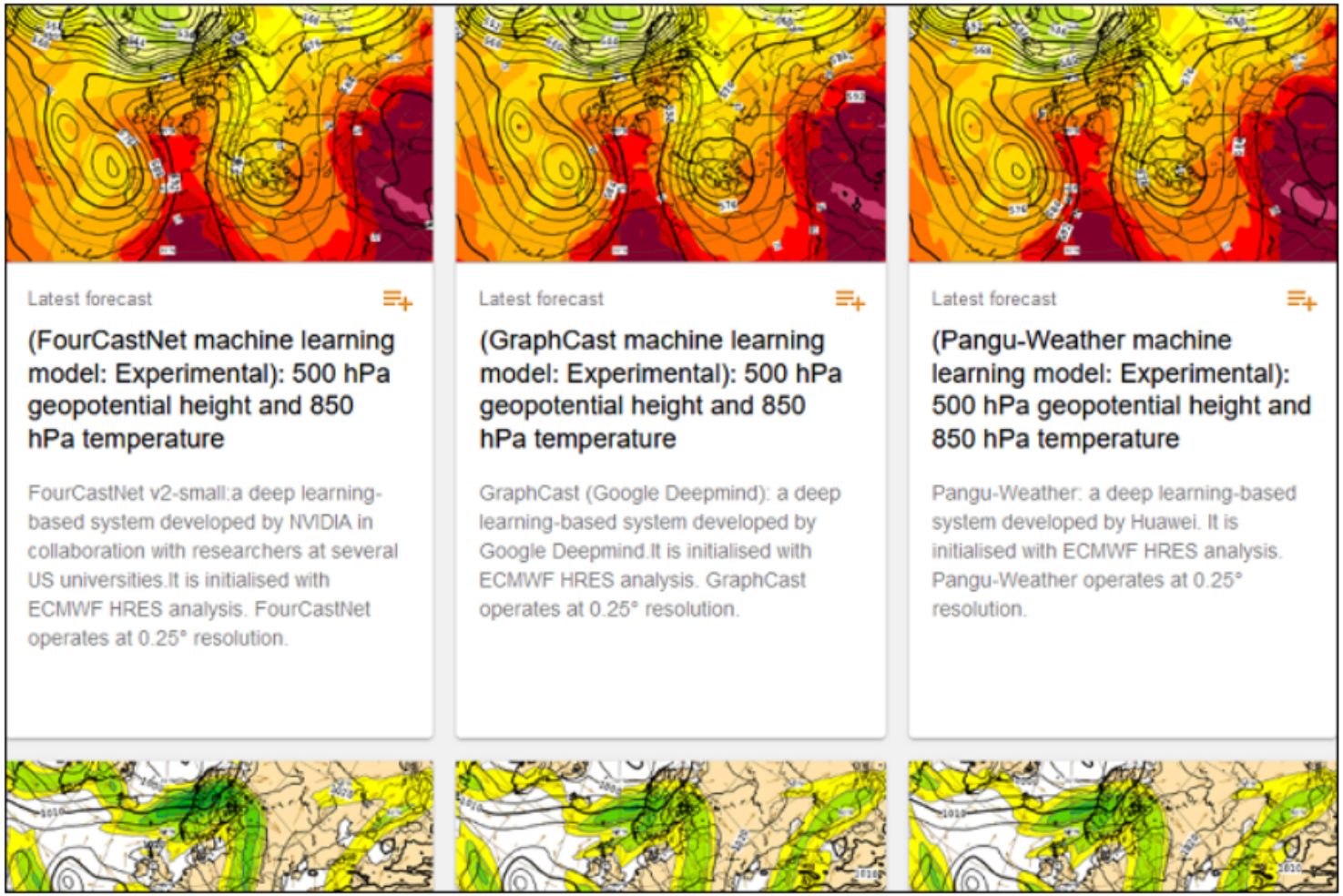


Figure: A showcase of principal data-driven systems created by innovators such as NVIDIA, Huawei and Google DeepMind [1].

Introduction - It is already here !

From physics-based models to data-driven models:

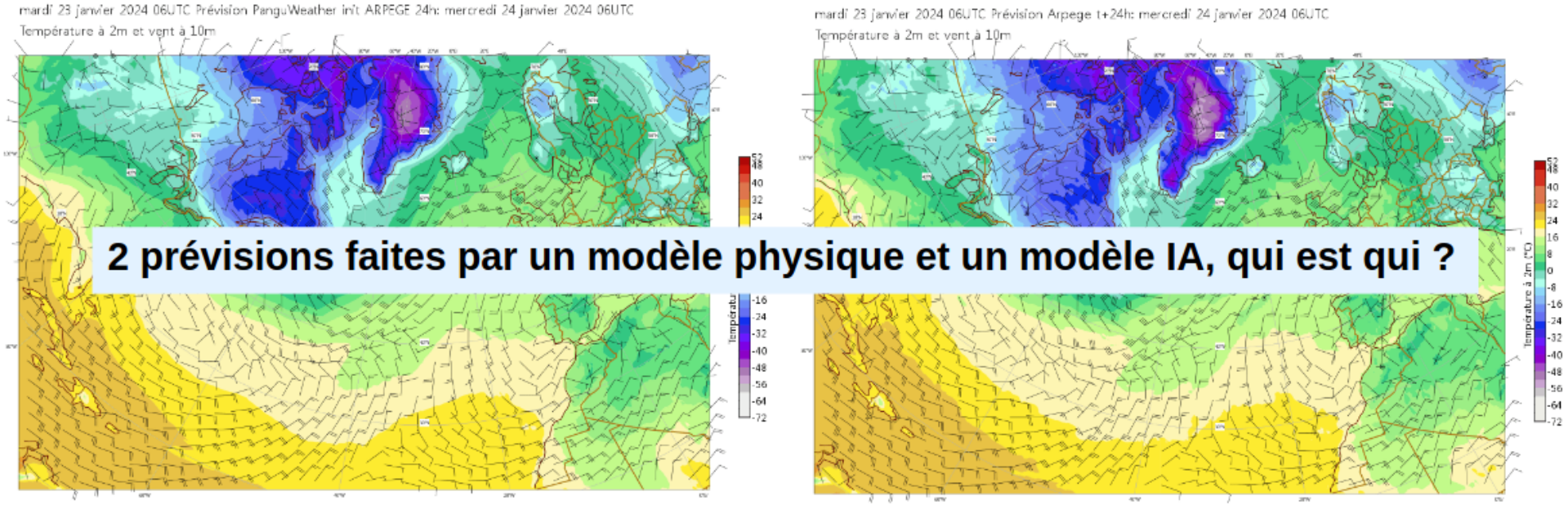


Figure: Two forecasts made by a physics-based model and an AI model [2], who is who ?

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