AI activities for NWP applications at CNRM

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Outline

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** :

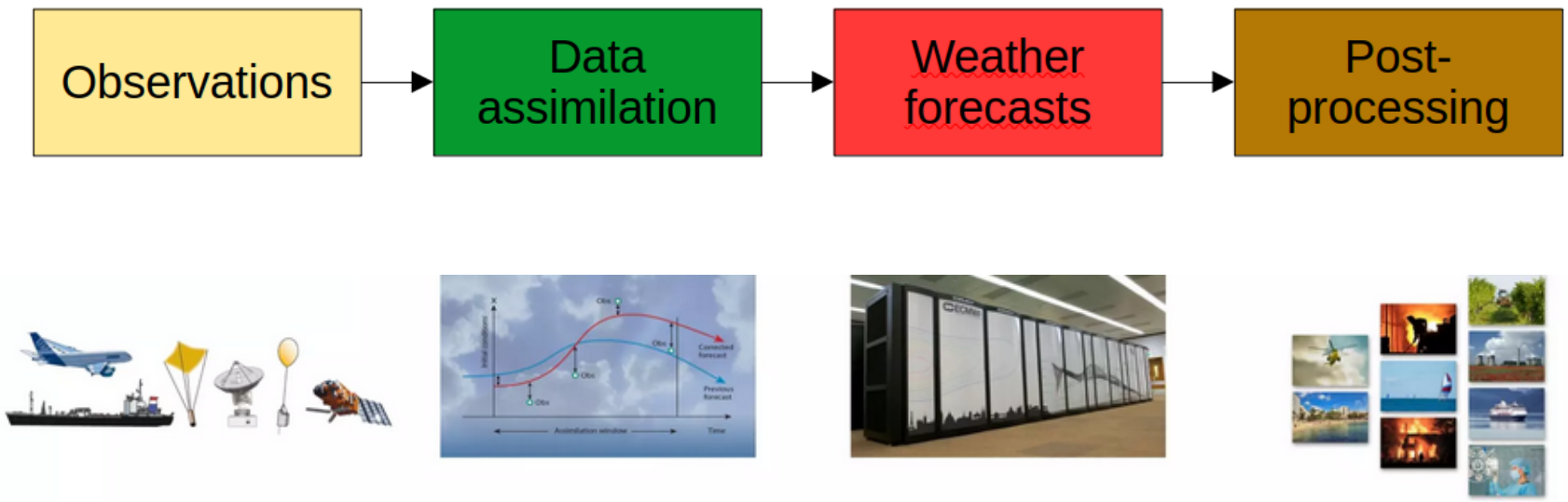


Figure: Weather forecast simplified workflow.

Introduction - It is already here !

From physics-based models to data-driven models:

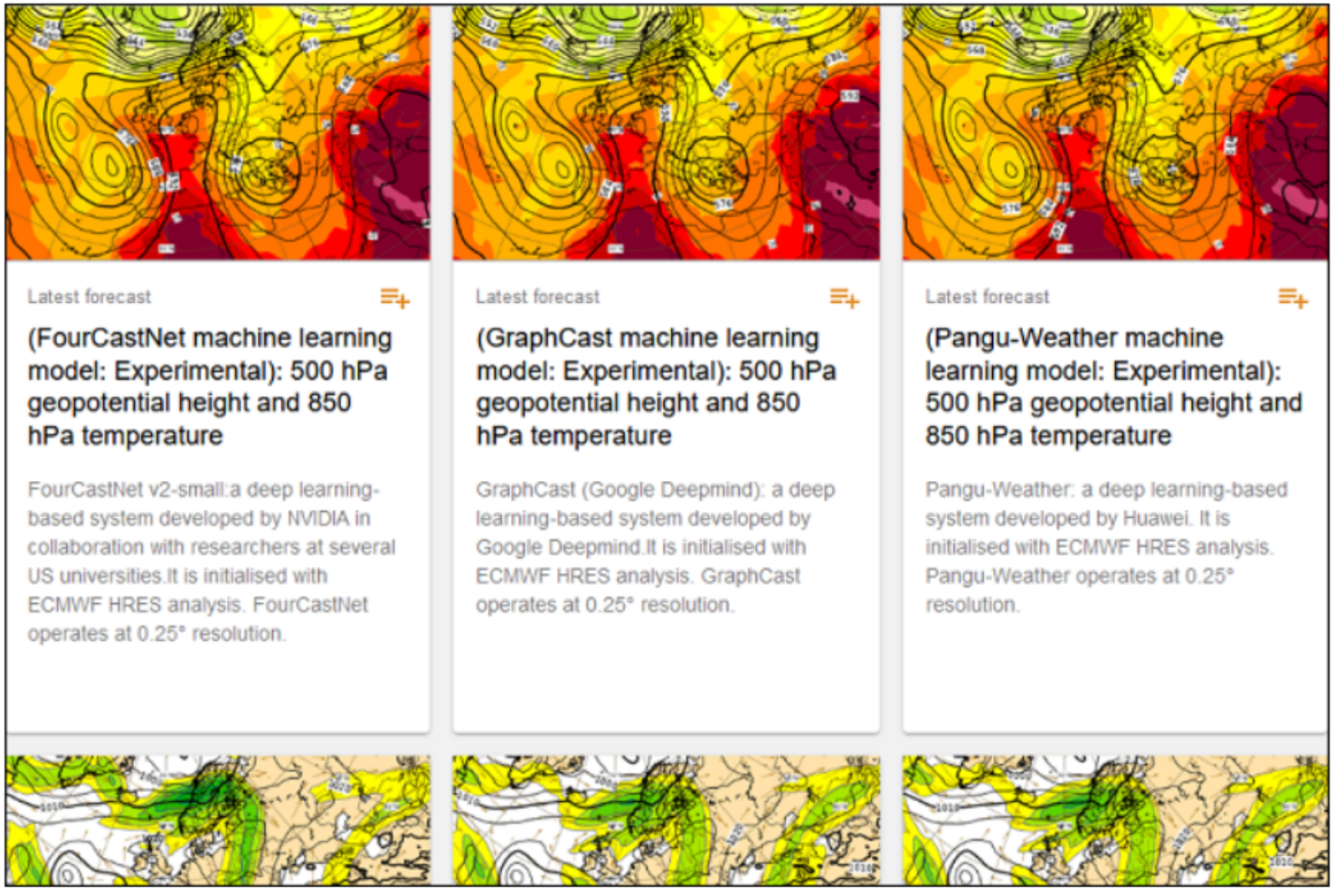


Figure: A showcase of principal data-driven systems created by innovators such as NVIDIA, Huawei and Google DeepMind [1].

Introduction - It is already here !

From physics-based models to data-driven models:

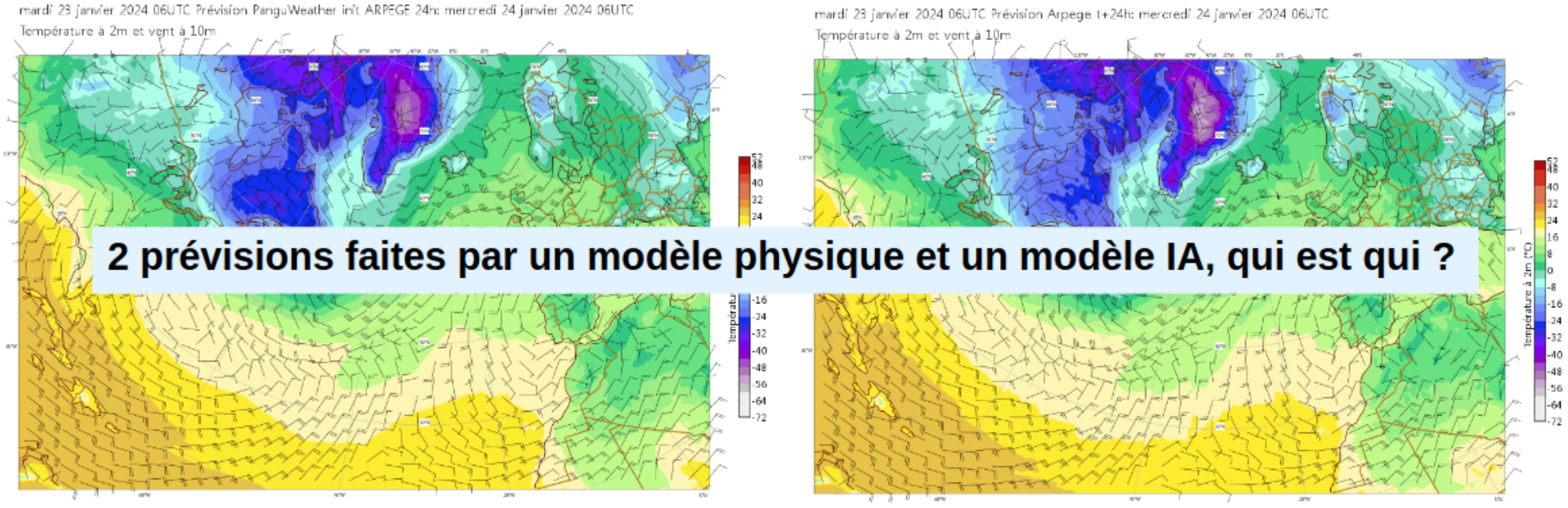


Figure: Two forecasts made by a physics-based model and an AI model [2], who is who ?

CNRM current AI activities

- High-resolution regional forecasting models ($\sim$ km scale) *(GMAP/PREV)*
- Generative ML for ensemble prediction such as GANs or diffusion models *(GMAP/PREV)*
- AI models to enhance traditional data assimilation methods *(Vincent Chabot GMAP/ASSIM)*
- Now-casting using AI *(Nicolat Merlet - AI-lab, GMAP/DIROP)*

AI-AROME Emulator development - Py4cast

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.

Developing an agnostic interface for models and data

- Data-agnostic: Arome forecasts, analyses, etc.
- Model-agnostic: Graph neural networks, Vision transformers, Unets, etc.

Open source framework:
`https://github.com/meteofrance/py4cast`

AI-AROME Emulator development - 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.

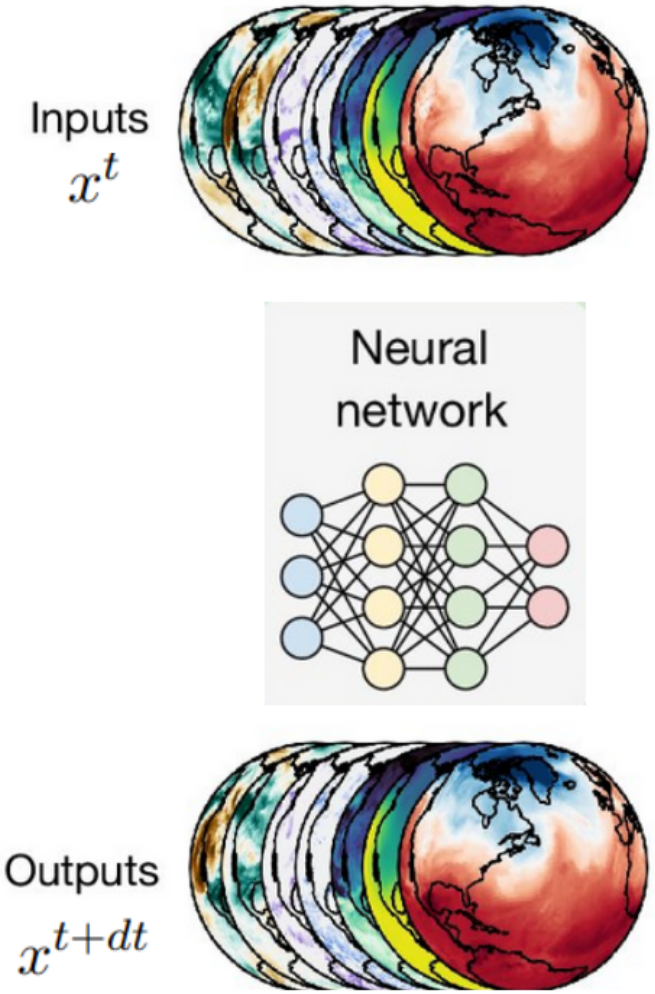


Figure: General approach.

AI-AROME Emulator 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

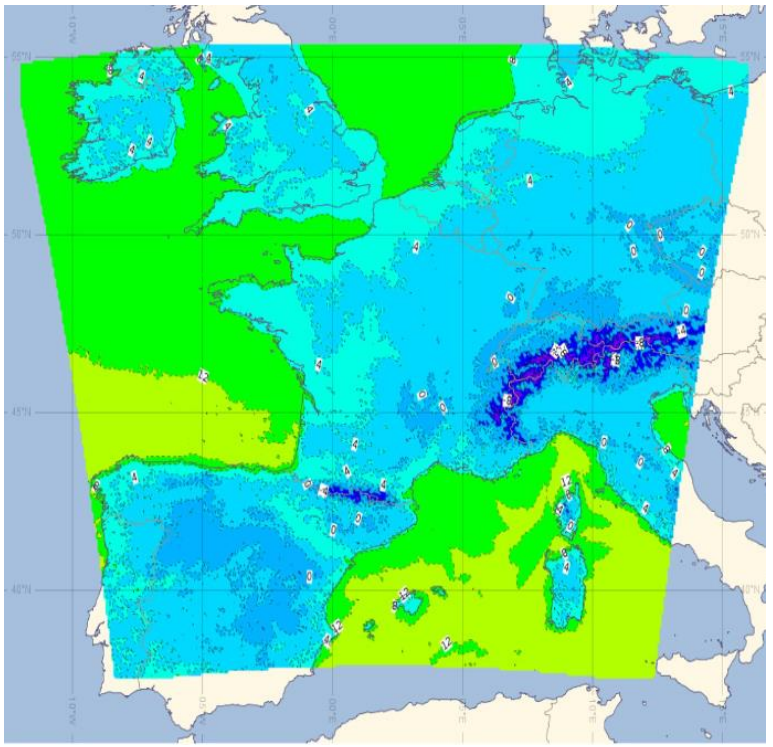


Figure: The AROME domain.

AI-AROME Emulator development - Datasets

Titan dataset

- Analyses from AROME, ANTILOPE and analyses and forecasts from ARPEGE
- 1.3km grid-size resolution since 2022
- Dataset used:
  - 3.5 years depth
  - 1 hour timestep
  - Resolutions :
    Arome (1.3km, 2.5km)
    Arpege (10km)
    Antilope (1km)

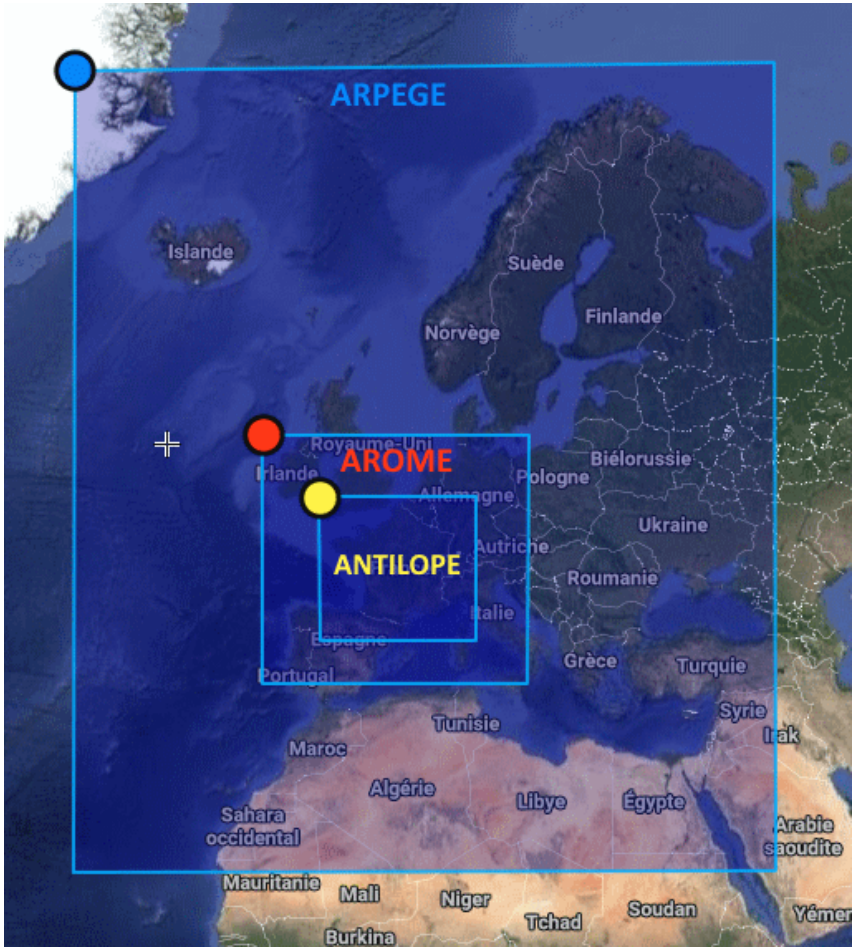
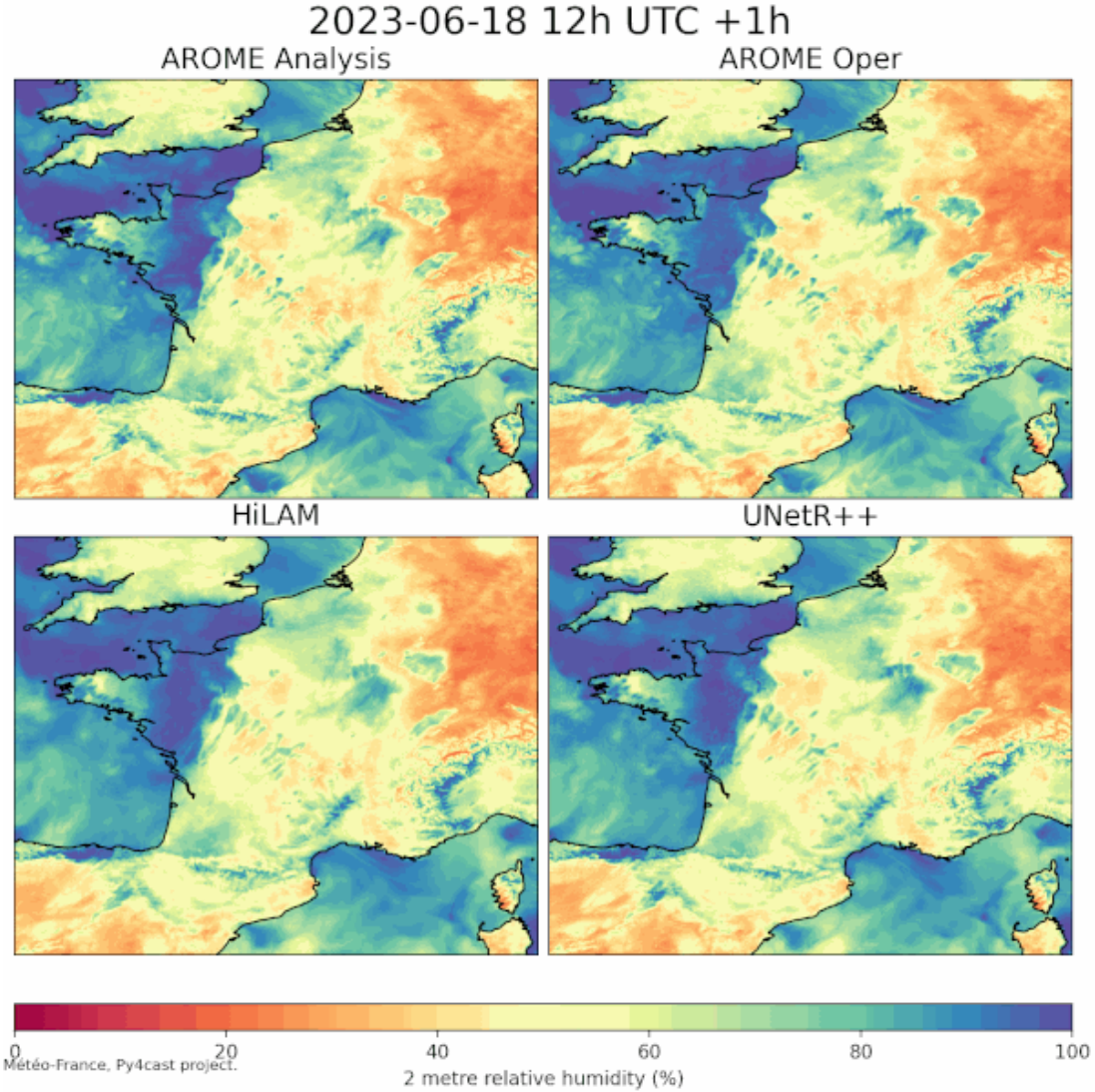


Figure: The Titan domain [3].

AI-AROME Emulator development - Preliminary results

Example of produced forecasts using Hilam and UnetR++ models:



AI-AROME Emulator development - 2025 Perspectives

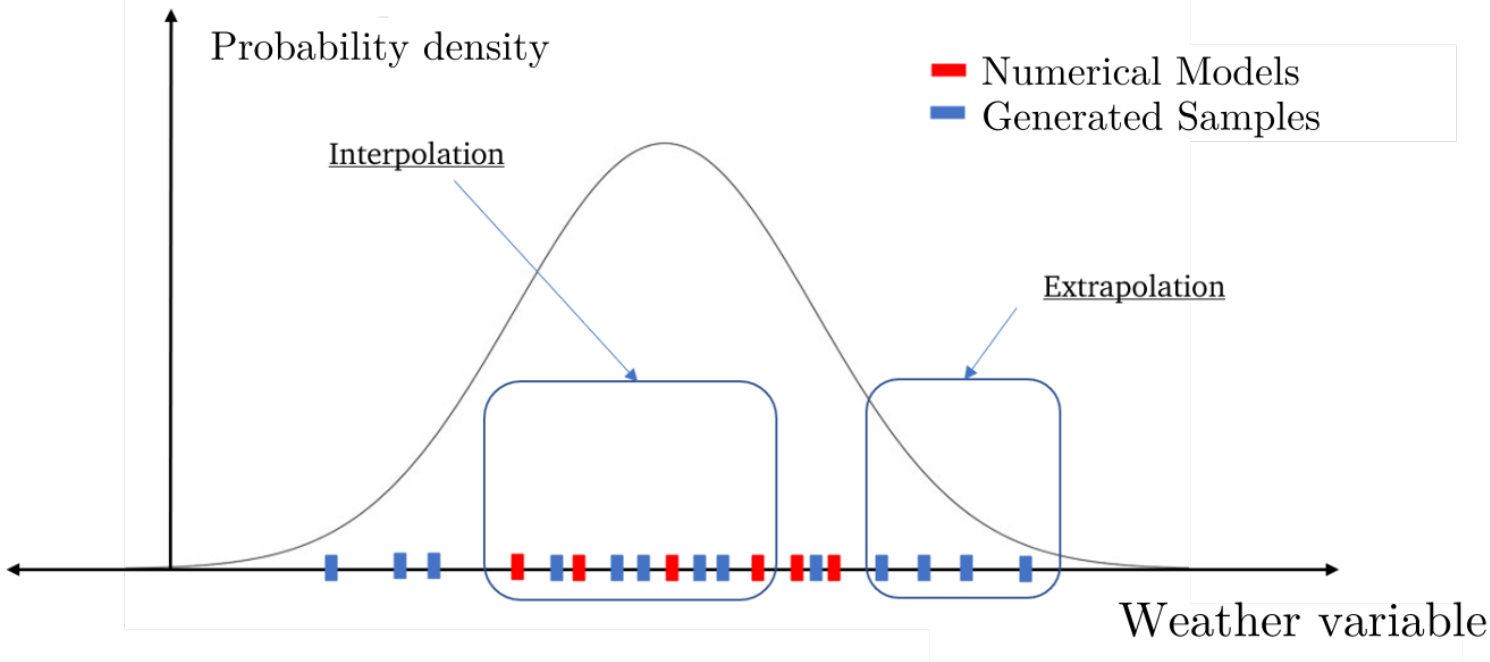
- Building on the current developments, our next steps focus on addressing remaining questions. These include **refining boundary forcing**, identifying **key variables of interest**, and **exploring the design space** [4] of the selected architectures.
- Identify qualification tools (existant metrics, score tables) to conduct **an evaluation phase** of this new system, in terms of **quality and physical consistency**
- Explore issues of **explicability** and use of this type of forecast by the forecasters and other users.
- Instruct on **operationalization** of the developed tools.

Ensemble generation using GANs

Main purpose: enrich ensemble approaches

- Physical Model: few members due to operational constraints.
- Implies sampling errors of the distribution.
- Main idea: Use generative models to produce more members[a].

[a] Clément Brochet phD thesis.



Ensemble generation using GANs

- The Discriminator has to learn to distinguish between real and fake images.
- The Generator has to learn to trick the Discriminator to generate images that could be real.
- Train a GAN to learn the distribution of meteorological variables.

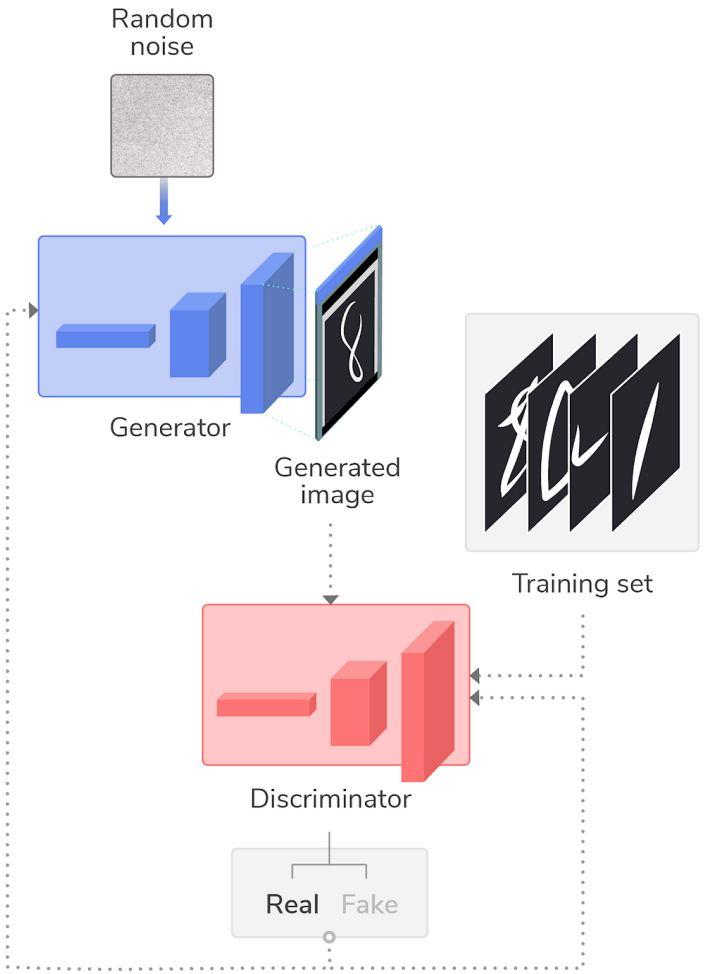


Figure: GAN architecture.
Credit <**empty citation**>

Ensemble generation using GANs - Conditioning

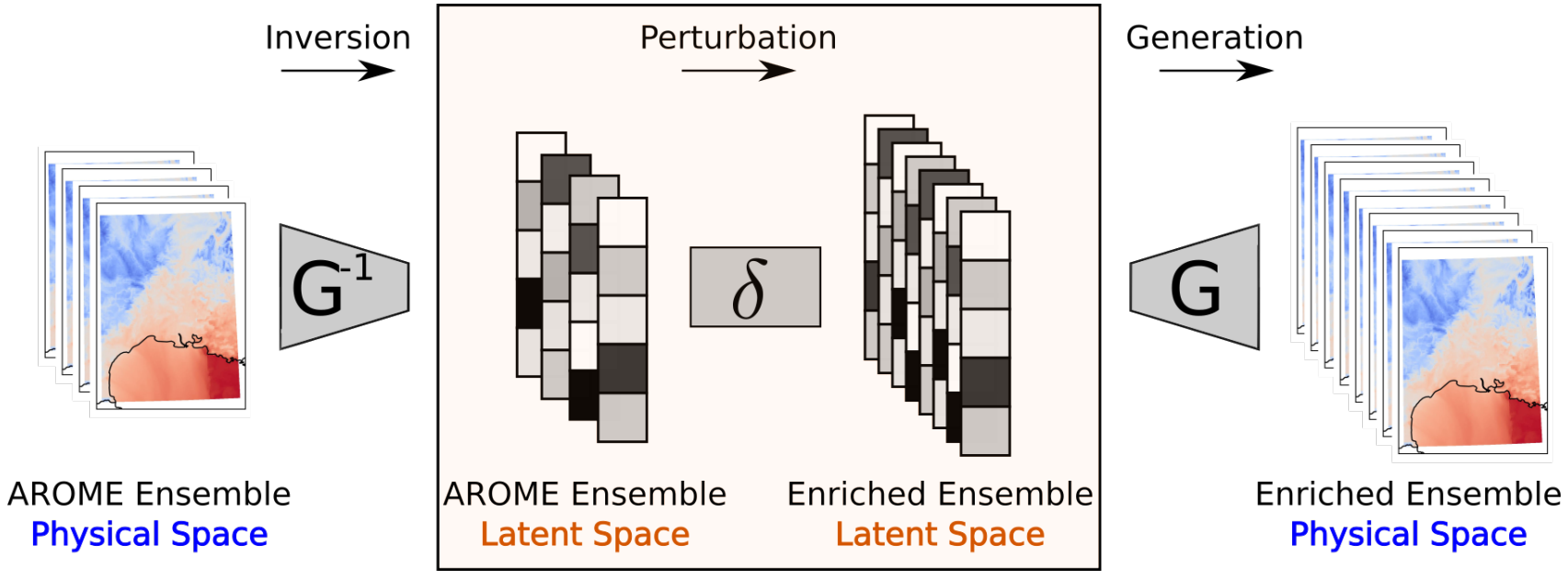


Figure: Conditioning strategy [5].

Ensemble generation using GANs - Preliminary results

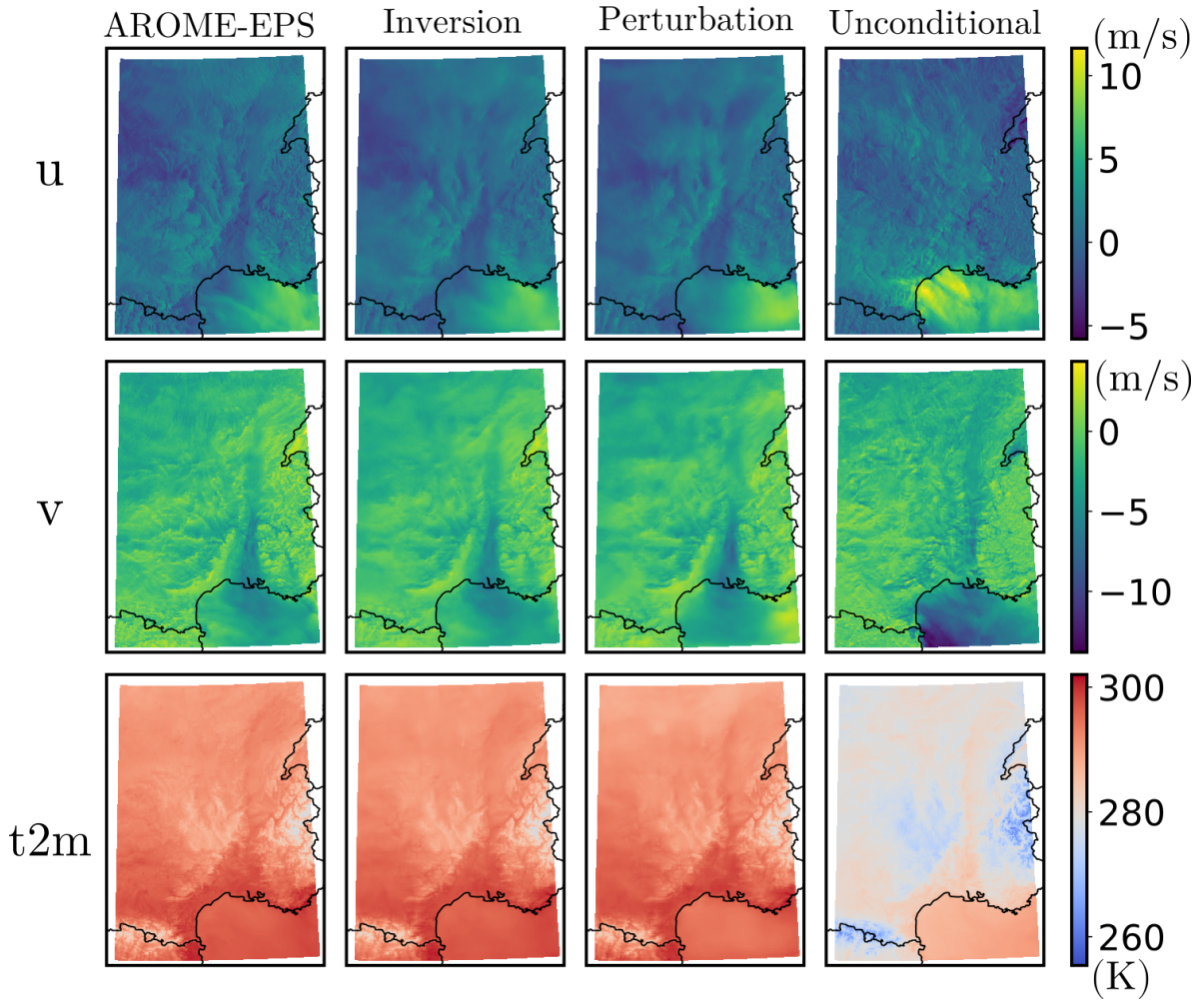


Figure: Comparison of generated samples (*Brochet C. et al. [5]*)

Ensemble generation - Ongoing Work and 2025 Perspectives

- Generate **more meteorological variables** (rain rate, atmospheric pressure, ...)
- Extend the southeast domain to the **whole AROME domain**.
- Draw a comparison with other Generative Models like **Diffusion Models**.

Conclusions and perspectives

Upcoming AI-Dedicated Team

A team dedicated to AI-related activities will be established in the near future.

- 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
- Regarding the approach of generating ensemble members using GANs, the idea behind this hybrid method is to **enhance and build upon existing models**.
- Other topics are also being explored, such as **downscaling**, which in meteorology refers to refining large-scale model data to achieve higher-resolution local forecasts.

AI models in Météo France - Strategic vision

- **Long-term Goals**: We envision AI as an integral component of next-generation weather forecasting systems, enhancing accuracy and operational capabilities.
- **Commitment to Open Science:** collaboration within the scientific community. By sharing our methodologies and findings, we aim to advance the field of meteorology collectively.

Current collaborations

ECMWF and EU weather centers within the **ML Pilot project** and the **WeatherGenerator project**.

Thank you for your attention !

Any questions ?

References I

[1] ECMWF. "How AI models are transforming weather forecasting: a showcase of data-driven systems". In: (2023). URL: https://www.ecmwf.int/en/about/media-centre/news/2023/how-ai-models-are-transforming-weather-forecasting-showcase-data.

[2] Laure Raynaud. "Artificial intelligence for weather forecasting". In: *Encyclopedia of the Environment* (2024).

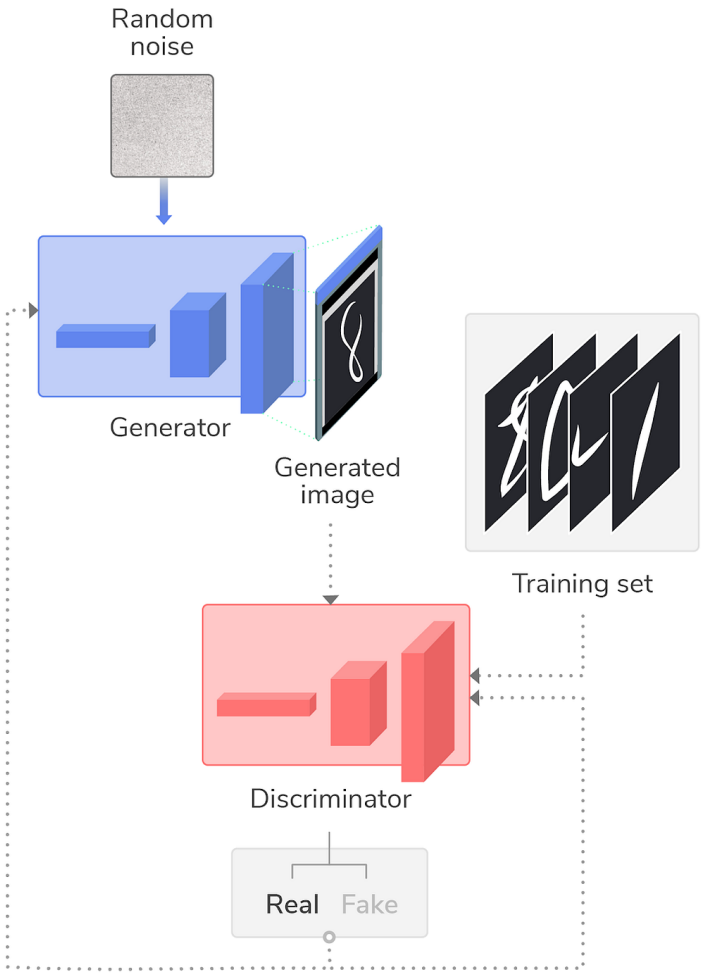
[3] Meteo-France. "Titan documentation". In: *https://git.meteo.fr/dsm-labia/monorepo4ai/-/tree/main/projects/titan* ().

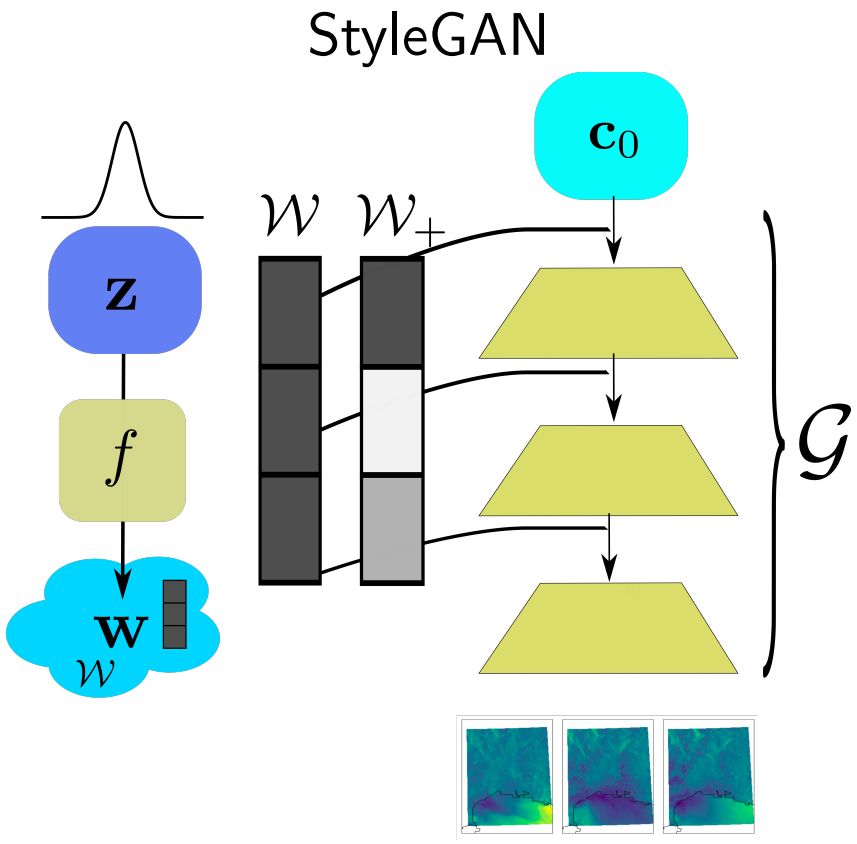
[4] Shoaib Ahmed Siddiqui, Jean Kossaifi, Boris Bonev, et al. *Exploring the design space of deep-learning-based weather forecasting systems*. 2024. arXiv: 2410.07472 [cs.LG]. URL: https://arxiv.org/abs/2410.07472.

References II

[5] Clément Brochet, Laure Raynaud, Nicolas Thome, et al. "Multivariate Emulation of Kilometer-Scale Numerical Weather Predictions with Generative Adversarial Networks: A Proof of Concept". In: *Artificial Intelligence for the Earth Systems* 2.4 (Oct. 2023). DOI: 10.1175/AIES-D-23-0006.1.

Appendix - Ensemble generation using GANs





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