Generative DL for high-resolution regional forecasting : a proof-of-concept

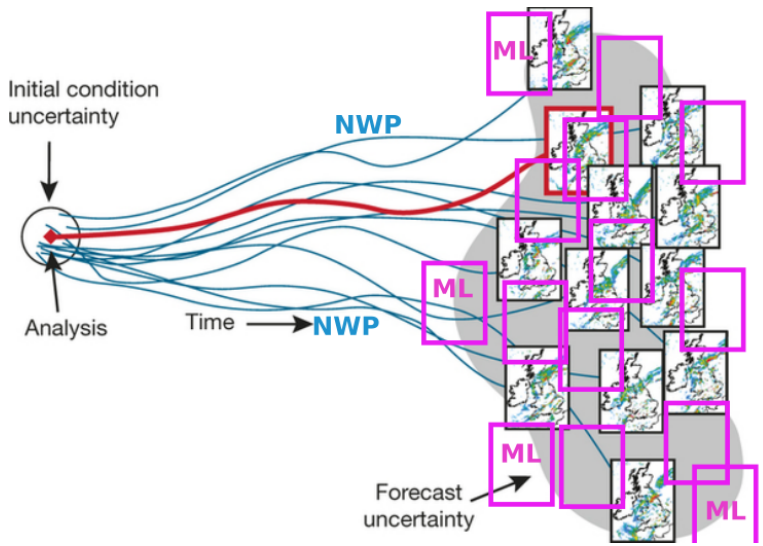
Workshop on Large-scale deep learning for the Earth system
Laure Raynaud and contributors, 5 September 2023

DL for Ensembles

▷ Size and resolution of operational ensemble forecasts are still constrained by computational resources

▷ How to leverage DL to significantly enhance ensemble design ?

- Oversampling of NWP distributions



- Statistical downscaling

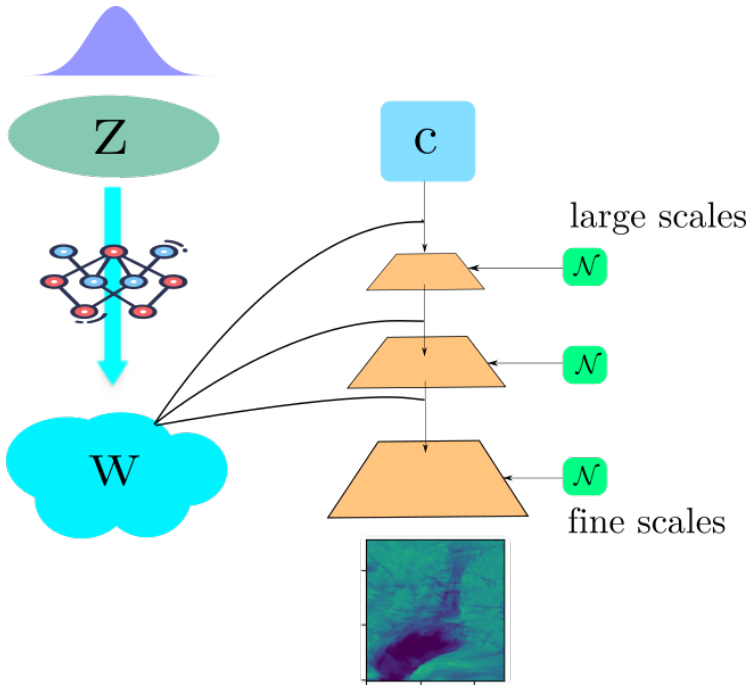
▷ Application to the kilometre-scale Arome forecasts

Plan

1. DL-based ensemble forecasts
2. DL-based statistical downscaling

Step 1 : Generative DL to generate NWP-like samples

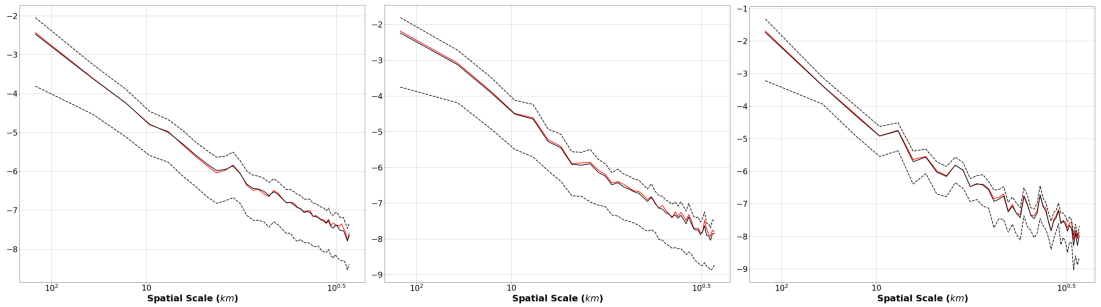
▷ StyleGAN architecture



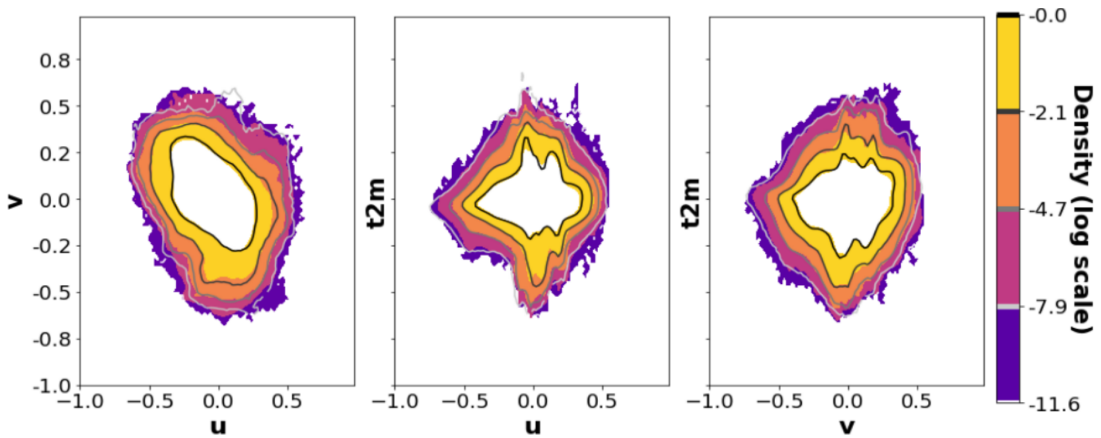
▷ Trained on 18-month of Arome forecasts for 2m-temperature and 10m-wind.

1 - Unconditional generation

▷ PSD Arome (black) vs DL (red) for u10, v10 and T2m



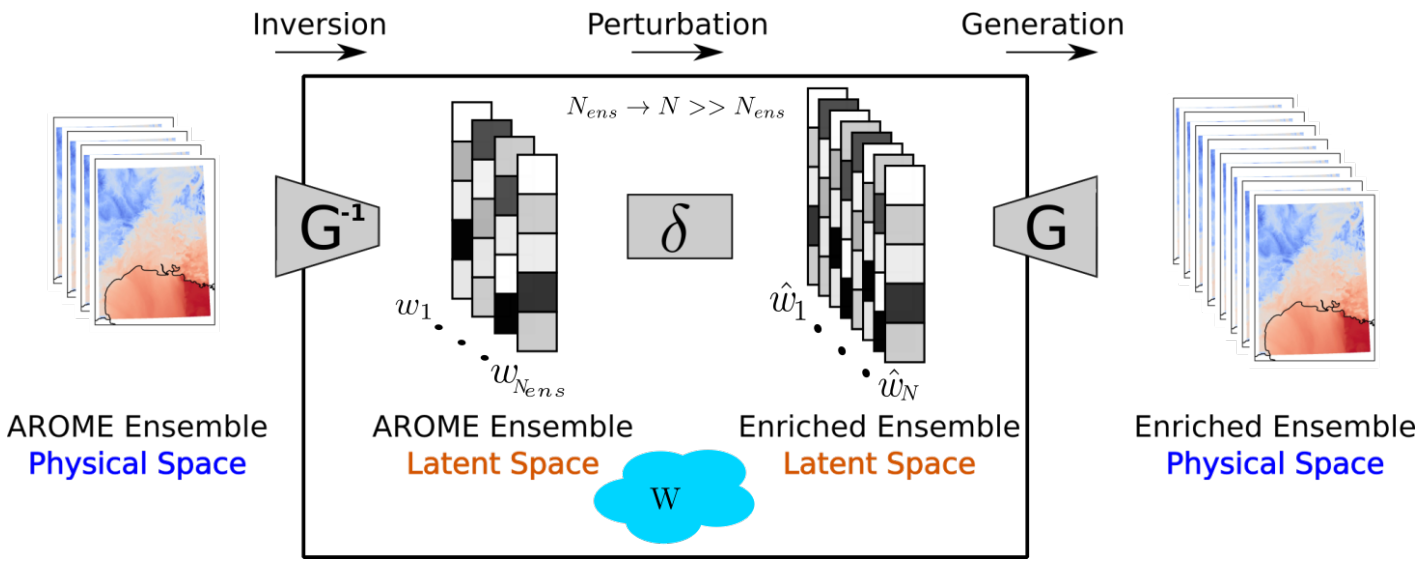
▷ Bivariate distributions Arome (contours) vs ML (color)



- DL properly learns the distribution of Arome forecasts
- DL is able to produce samples with proper physical and spatial consistencies
- Detailed evaluation in Brochet *et al.* 2023.

Step 2 : DL builds on existing NWP forecasts to produce new samples

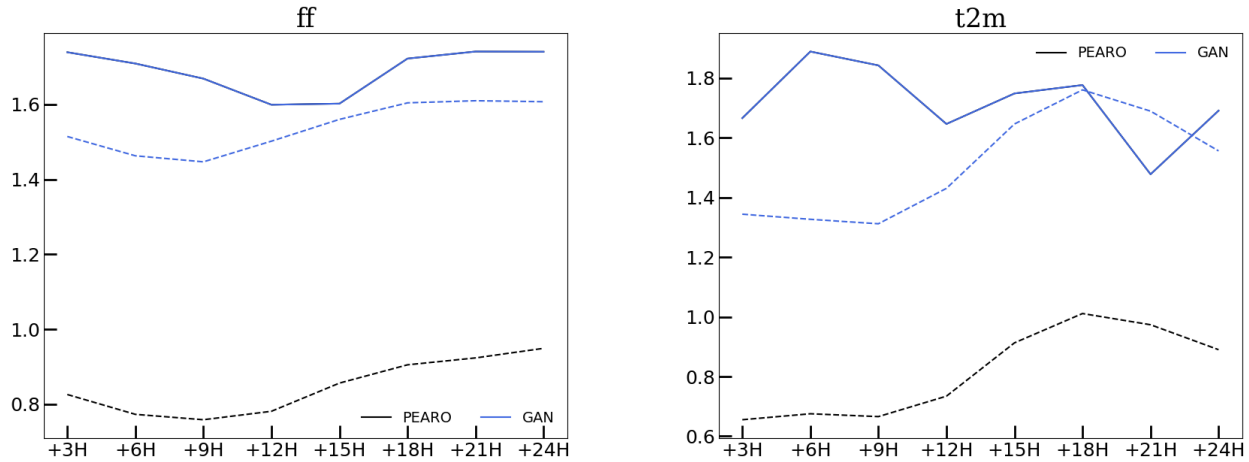
▷ Latent-space sampling : perturb NWP forecasts projected in the GAN latent space
▷ Leverages nice properties of the latent space (small, continuity, disentanglement, ...) and good performances of the generator
▷ Deterministic forecast or ensemble forecasts can be used as input



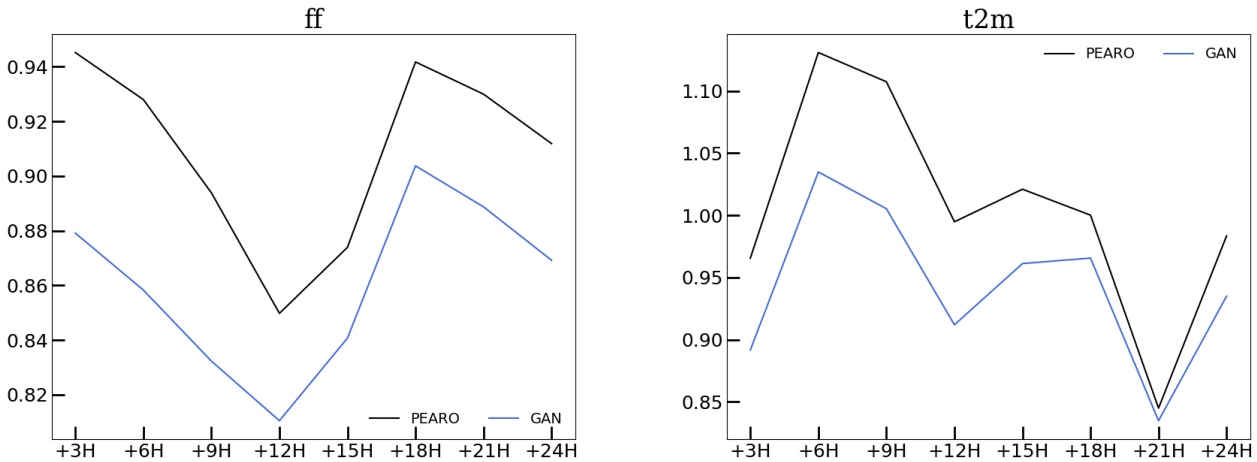
▷ Generate as many members as we want
▷ Latent perturbations can be applied selectively on the most important layers and can be optimized based on probabilistic scores.

1 - Evaluation of large DL ensembles

▷ DL-enhanced ensemble significantly outperforms NWP ensemble
(Courtesy : G. Moldovan)



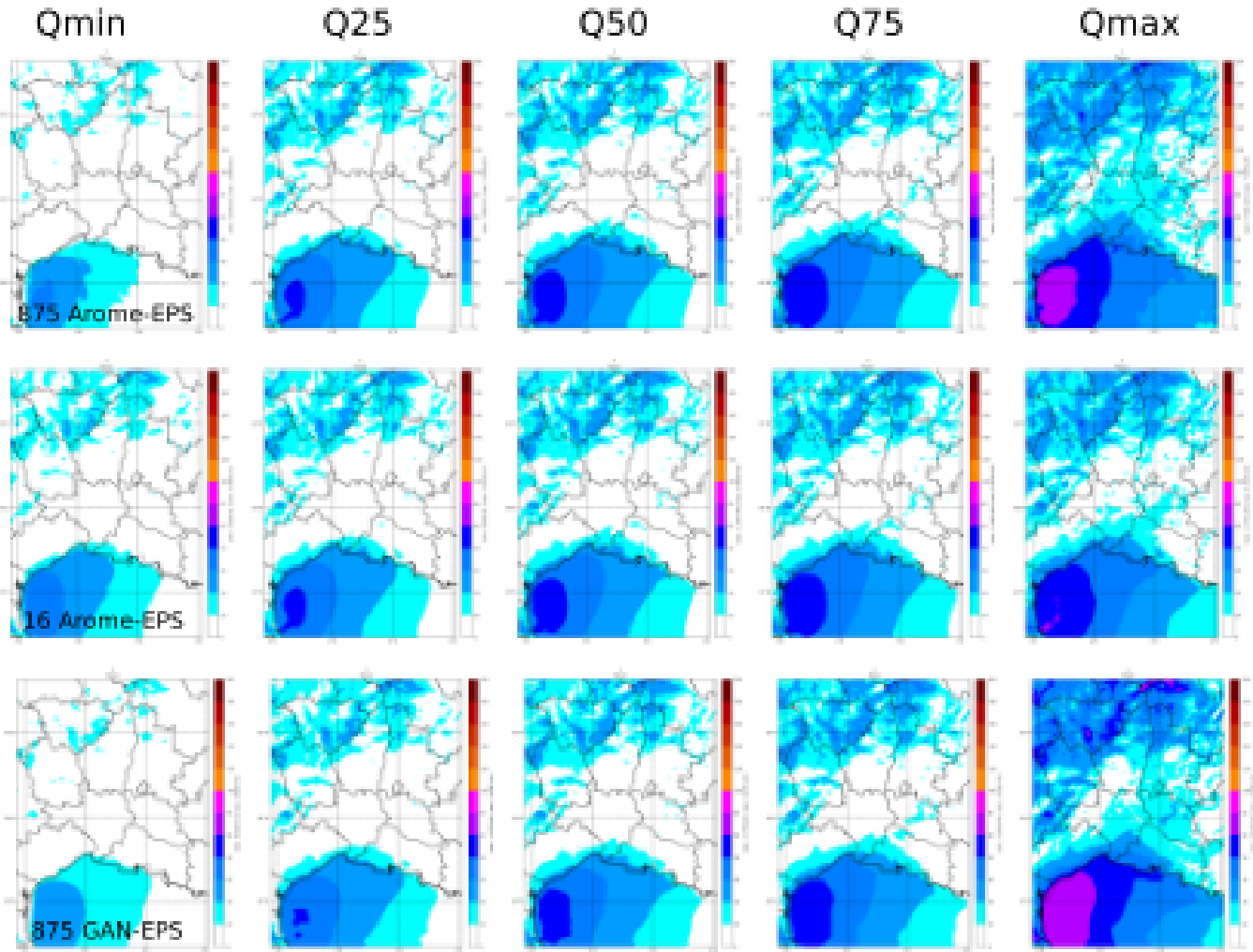
(a) Spread/skill



(b) CRPS

1 - Evaluation of large DL ensembles

▷ DL-enhanced ensemble is close to a large NWP ensemble



▷ The DL ensemble properly extends the tails of the distribution while preserving the main part.

1 - **Future works, challenges and open questions**

▷ The latent-space sampling method provides both **improved performances** and **physically-consistent** members

▷ Its application could be extended to other variables : **precipitation** is under investigation

▷ Benefit of DL ensembles for high impact events to be adressed

▷ The method does not adress bias correction (no obs used), but post-processing methods could be applied to the DL ensembles

▷ Other generative approaches could be used : we found **diffusion models as skillful as GANs** (although much more expensive)

▷ The method could be compared to others, eg,

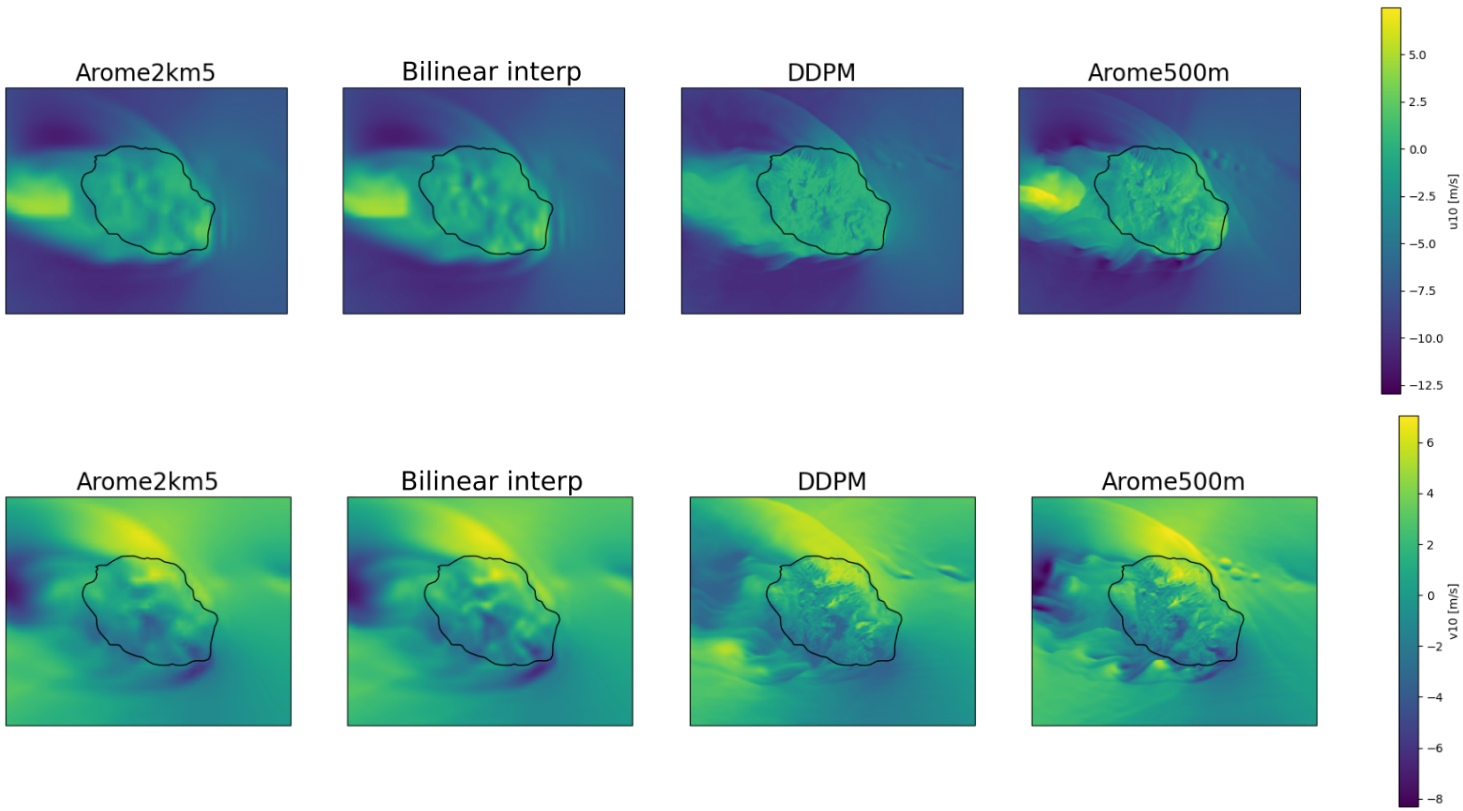
- M. Clare's presentation
- Li *et al.*, 2023 : SEEDS Emulation of Weather Forecast Ensembles with Diffusion Models

Plan

1. DL-based ensemble forecasts
2. DL-based statistical downscaling

2 - DDPM for high-res wind forecasts

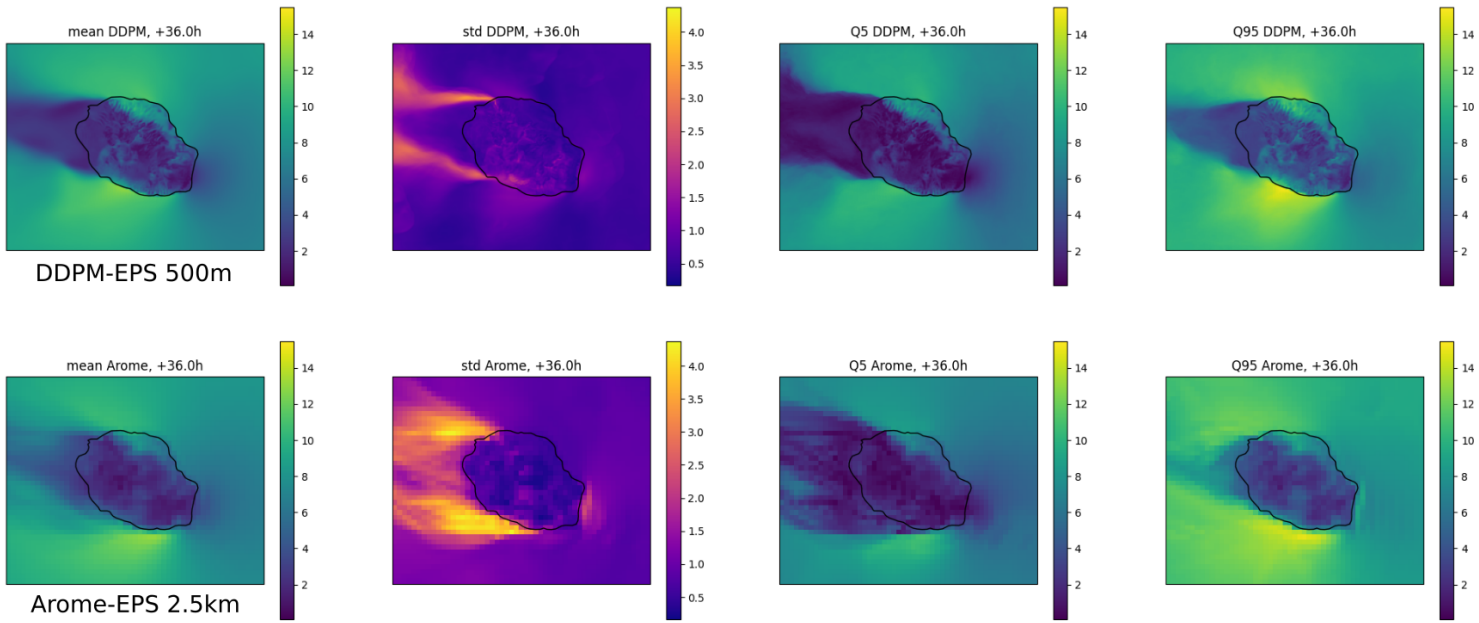
▷ Denoising Diffusion Probabilistic Models (DDPM) can be used for super resolution
▷ Application to downscale wind forecasts from Arome 2.5km to Arome 500m (Courtesy : L. Danjou)



▷ DDPM is better at capturing the spatial structure than the intensity
▷ To be continued.

2 - DDPM for high-res wind ensemble forecasts

▷ Ensembles can be easily generated with DDPM
▷ A 128-mb ensemble of 500m forecasts is generated, conditioned only on the deterministic 2.5km forecast



▷ DDPM spread has some similarity with Arome spread, but it is smaller.