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Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

AI-Based Weather Forecasting for Switzerland

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Data-driven forecasting for the Alps

Build a data-driven forecasting system leveraging machine learning methods within the Anemoi framework for weather prediction.

- High-resolution on the Alpine domain
- High-frequency updates
- Seamless forecasting from minutes to days

We call this system **Varda** (Alpine dialect for “watching”, “looking”)

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The ECMWF Machine Learning Pilot Project (MLPP)

Goal: Integration of **machine learned weather forecasting** into operational value chain of **national weather services,** based on the **Anemoi** software ecosystem.

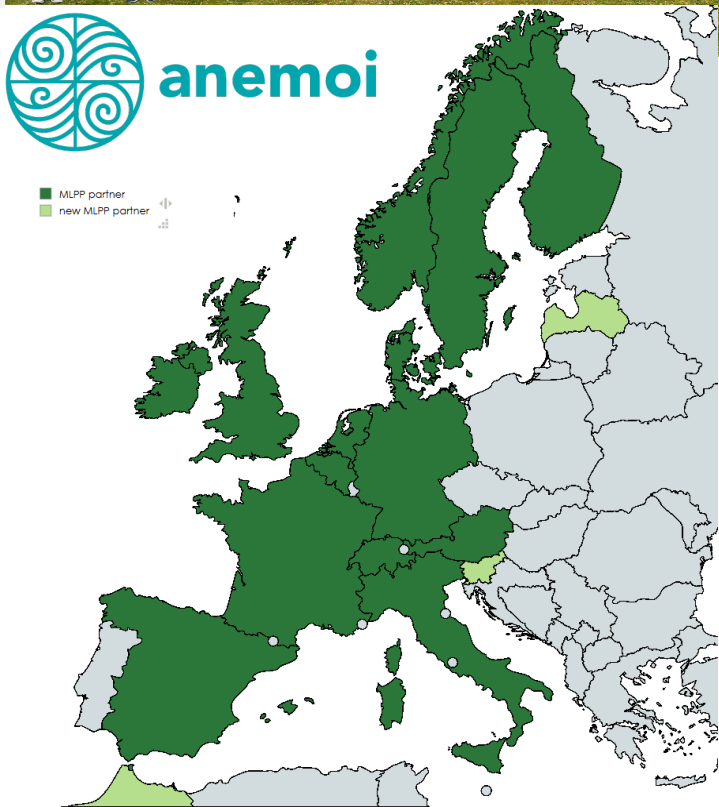
Duration: mid-2024 - mid-2029 = 5 years

Partners: 18 (17 ECMWF Member/Co-operating States)

Funded by ECMWF, but **driven** by the partners

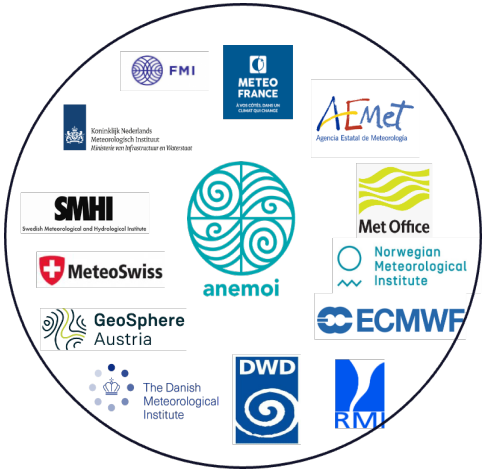
Covers the full forecasting chain: ML models, ensembles, data assimilation, operations and infrastructure

MLPP is not a single ML lab or model — it is a shared European effort to build ML into the forecasting system.



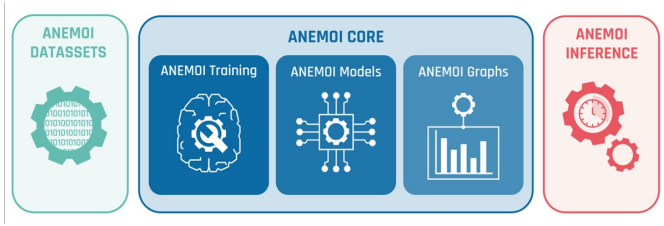
Anemoi framework

- A shared platform for data-driven weather models
- End-to-end framework for building operational models
- Dataset generation to operational inference
- Shared code, but individual national models



Develop in and for Anemoi

- Actively contribute to the Anemoi codebase
- Work lives in Anemoi so it's shared, maintainable, and aligned with the wider community



Lang, Simon, et al. "AIFS – ECMWF's Data-Driven Forecasting System." arXiv, 2024

Outline

- Current real-time emulator based on 2km COSMO NWP dataset
- Real-time inference
- New 1km ICON NWP dataset (REA-L-CH1)
- First preliminary results of the 1km emulator

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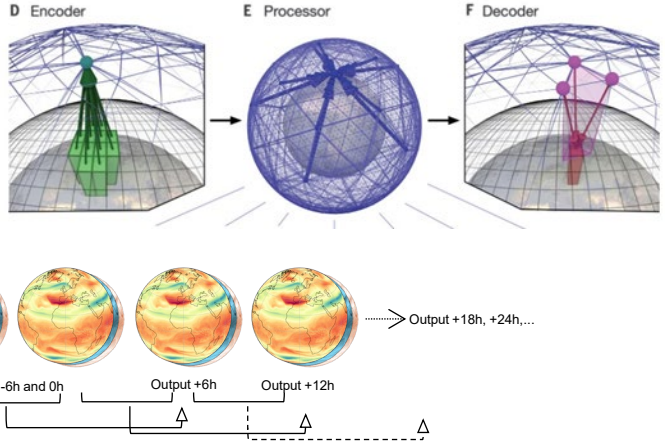
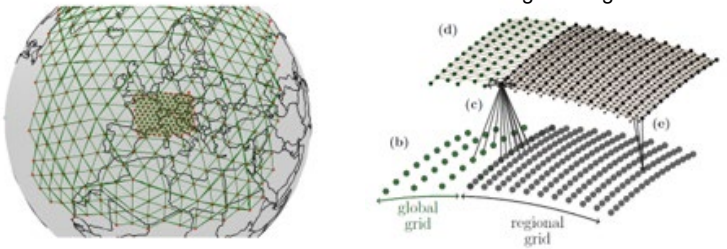
Model setup

- **Graph-based**: use graph neural networks to encode and process input data in a flexible way.
- **Autoregressive**: rollout forecast iteratively, currently with 6h steps.
- **Stretched-grid**: high-resolution over a localised domain of interest and lower resolution elsewhere with seamless information passing across boundaries.

Lam et al. (*Nature,* 2023), Learning skillful medium-range global weather forecasting, "GraphCast"



Nipen et al. (2025), Regional data-driven weather modeling with a global stretched-grid

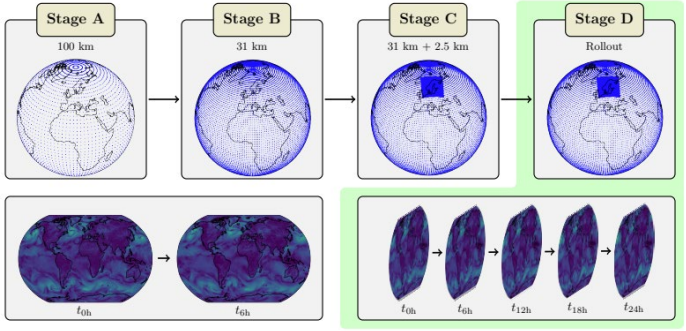


Multi-stage training, COSMO emulator

Transfer learning
- sequentially adapt the model to more complex tasks
- gradually refine the model, allowing it to reach local minimum

↪ Pre-training with **global** ERA5 n320
↪ Fine-tuning with global ERA5 n320 and **Europe-domain** CERRA
↪ Fine-tuning with global ERA5 n320 and **regional, operational COSMO/KENDA 2km analysis** (5y)
↪ Rollout

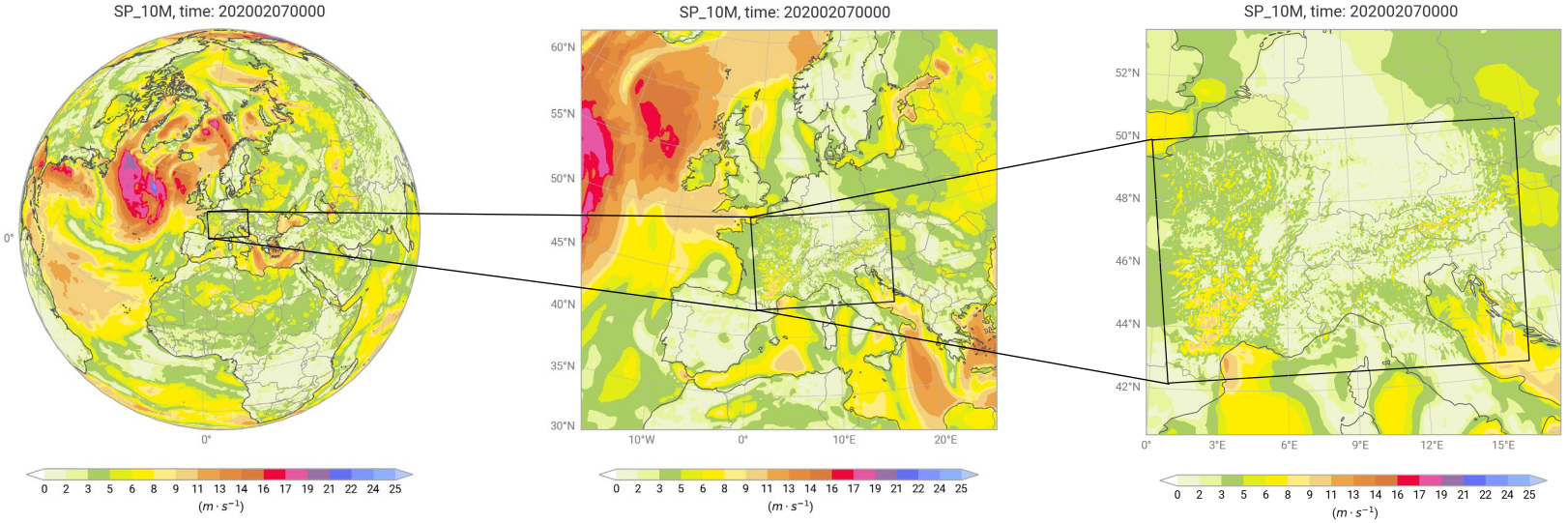
- 6h forecaster + 1h interpolator



Nipen et al. (2025), Regional data-driven weather modeling with a global stretched-grid

Global context with regional detail

Showcase Storm Ciara/Sabine, February 2020



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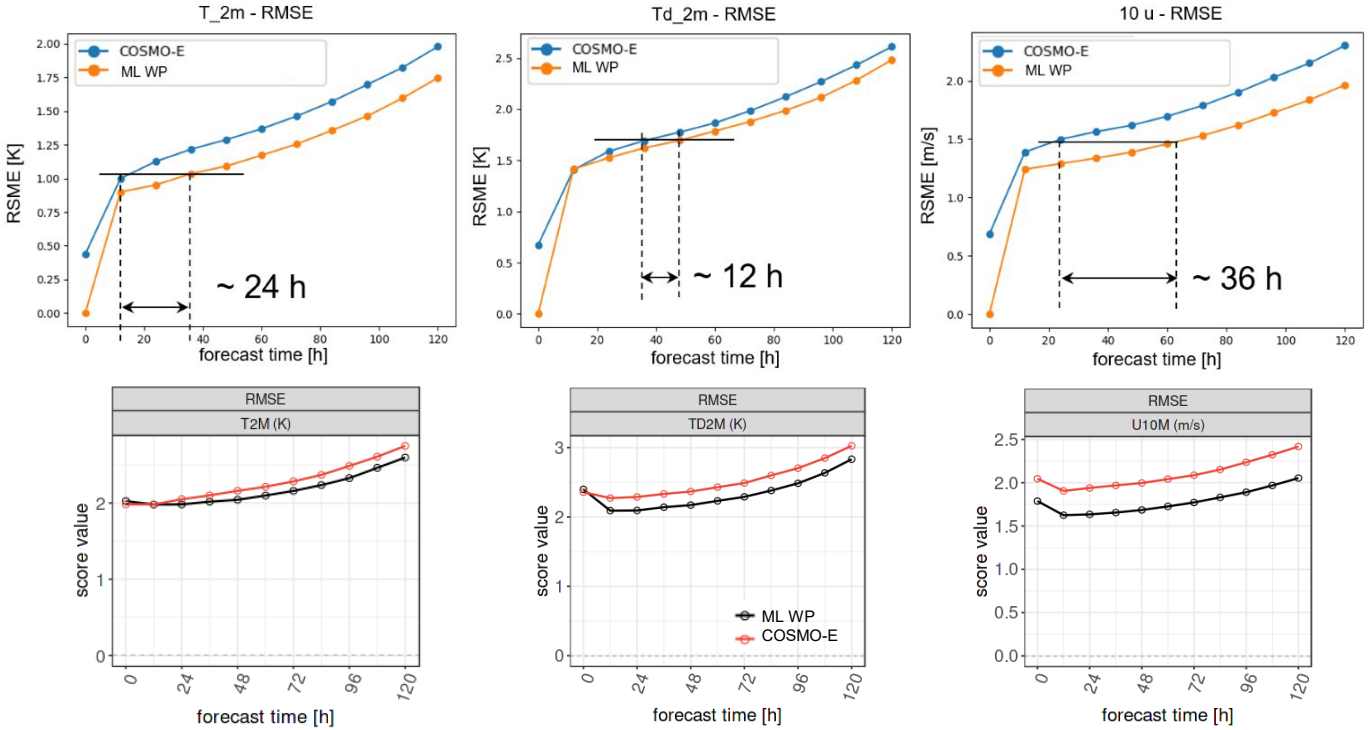
6h forecaster verification

Comparison (RMSE) for 2020 with:

the operational NWP COSMO forecast

observations



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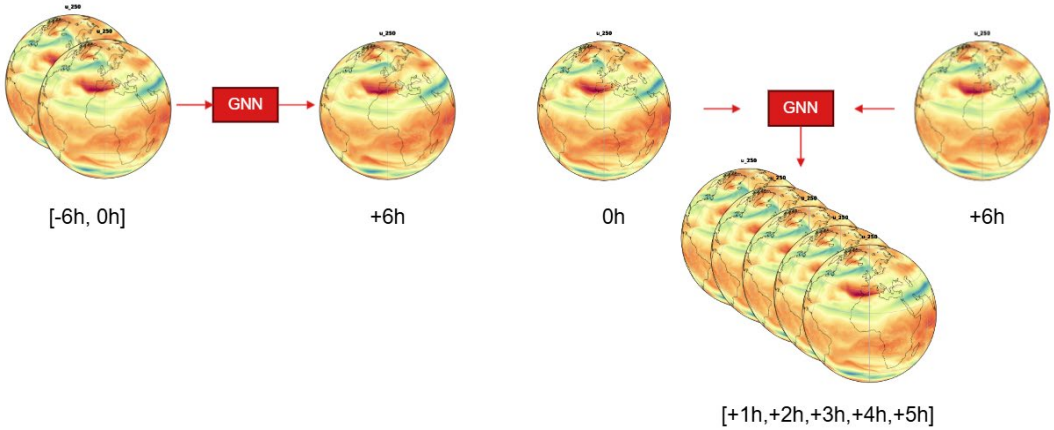
Time interpolator between 6h steps

- **Avoid compounding error growth** from training a model at 1h steps during long autoregressive rollouts
- Time interpolation allows to progressively produce finer temporal resolution forecasts while **maintaining model skill at long lead times**



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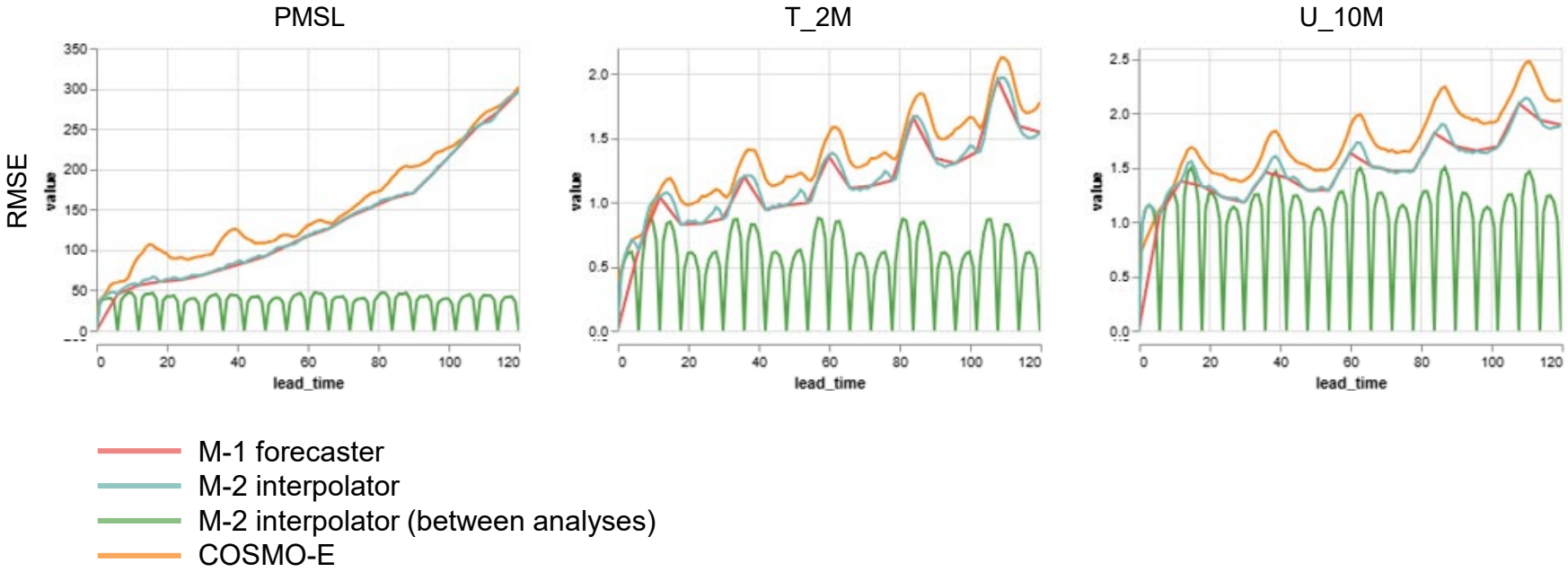
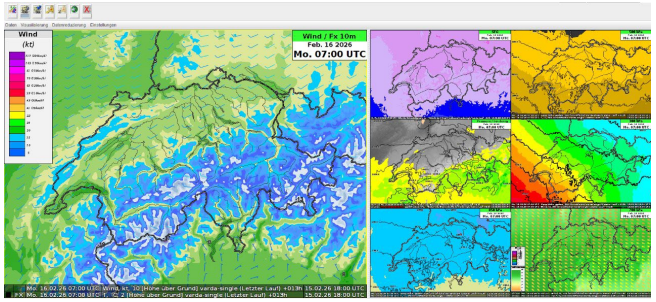
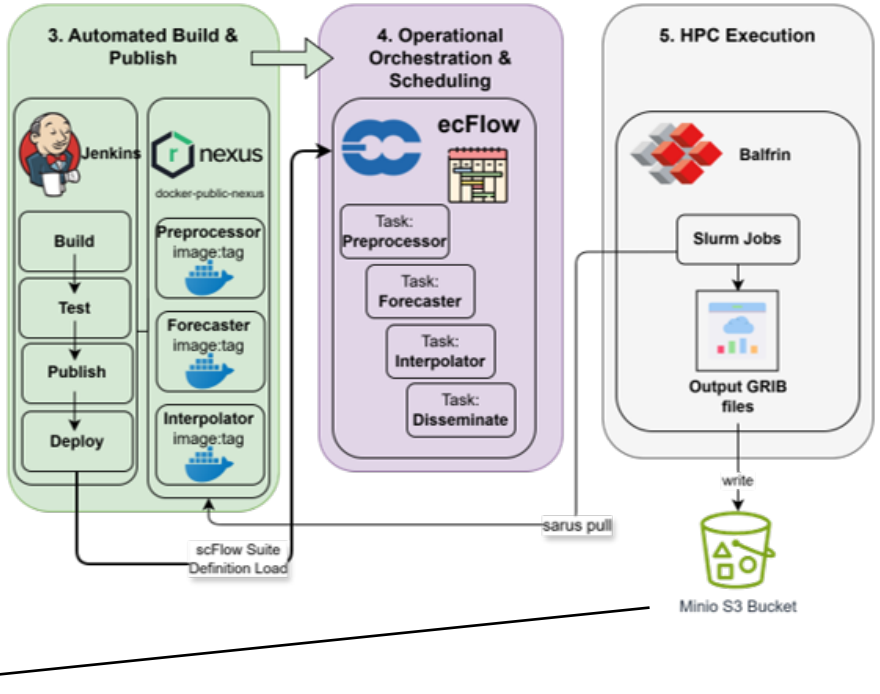
Time interpolator verification



Orchestration and dissemination

- Ecflow server on a dedicated HPC machine login node for orchestration and scheduling of **real-time inference pipeline**
- Tasks are containerised
- **Dissemination** of products (visualisation in NinJo) to forecasters for evaluation





ICON reanalysis dataset at 1km (REA-L)

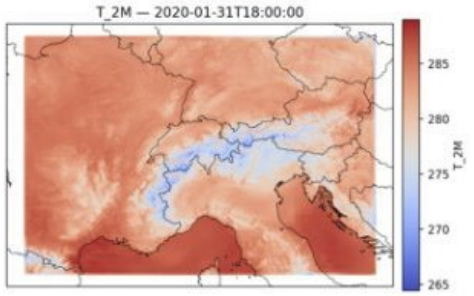
20 years of high resolution (1km, 10') deterministic downscaling with ICON over the alpine domain.

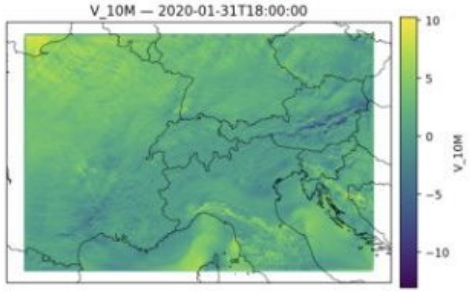
A **deterministic downscaling**

- with ICON model on the Alpine region (CH1 domain)
- using **ERA5 at the lateral boundaries**
- and **Latent Heat Nudging** (online; based on radar surface precipitation estimates) and a standalone **snow analysis**

Quality compared to operational analysis:

- STDE larger (except precipitation and wind)
- Bias comparable





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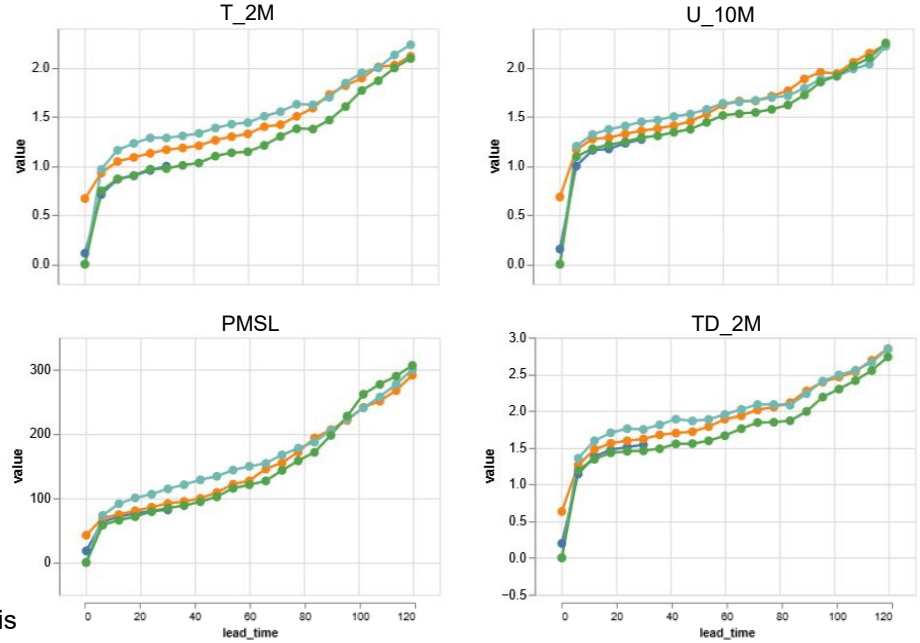
Multi-stage training, ICON emulator

- Pre-training with **global** ERA5 n320
- Fine-tuning with global ERA5 n320 and **regional downscaling REA-L** (1km, 15y)
- Fine-tuning with global ERA5 n320 and **regional operational analysis data** (1km, 1y)

- 6h forecaster + 1h interpolator

Preliminary evaluation agains opr NWP analysis (January-June 2025), RMSE



Next steps

- Further **evaluation and improvements of the 1km emulator** (6h forecaster and 1h interpolator), investigating e.g.:
  - The impact of the length of the 1km dataset
  - The benefit of adding subgrid-scale orography
  - Different graph connectivity configurations
  - Testing hierarchical meshes

  } Publication in progress

- Focusing on **nowcasting applications**
  - Rapid refreshes
  - Sub-hourly forecasts: extend interpolator to 10min steps
  - Include observations: as additional channels and direct observation prediction
  - Probabilistic emulator

Thank you for your attention :)

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