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Extending Aila variable selection: a multi-decoder approach for variable expansion

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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.

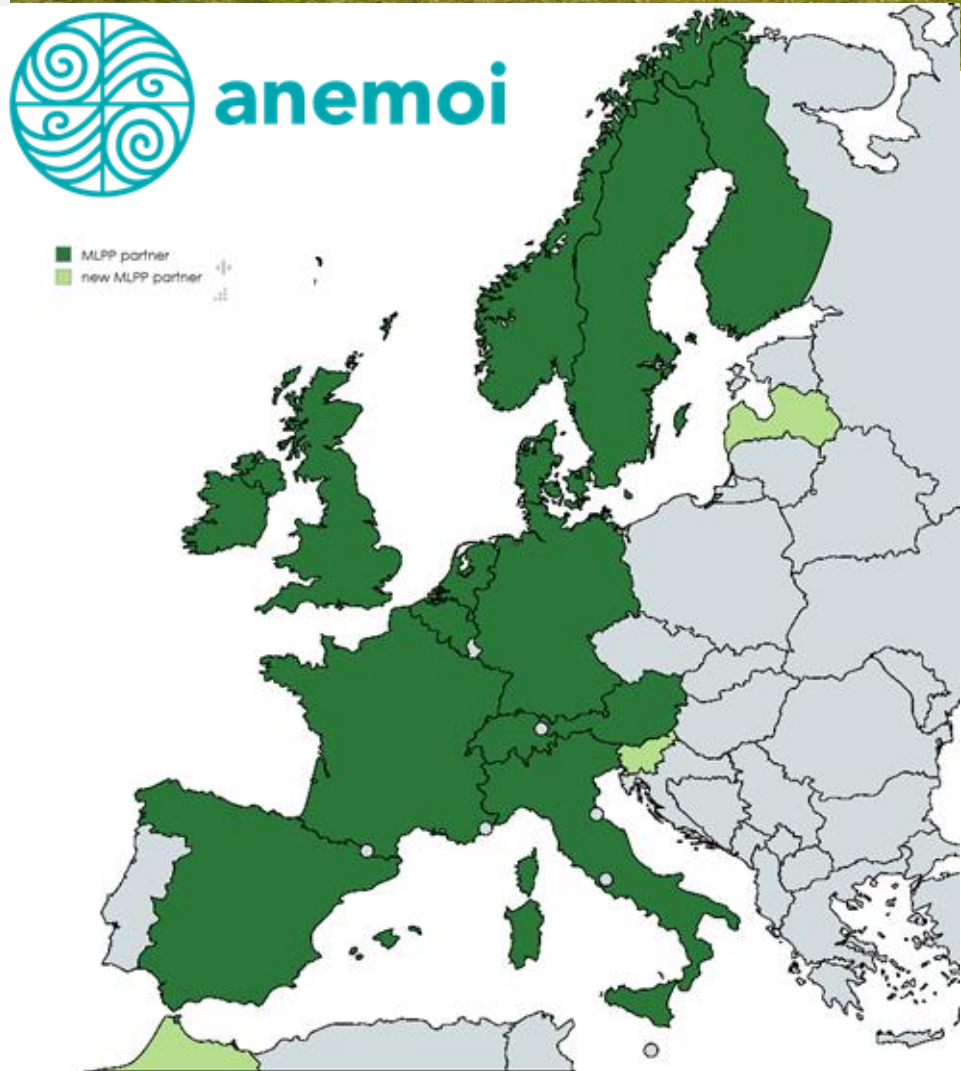
Duration: mid-2024 - mid-2029 = 5 years

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.

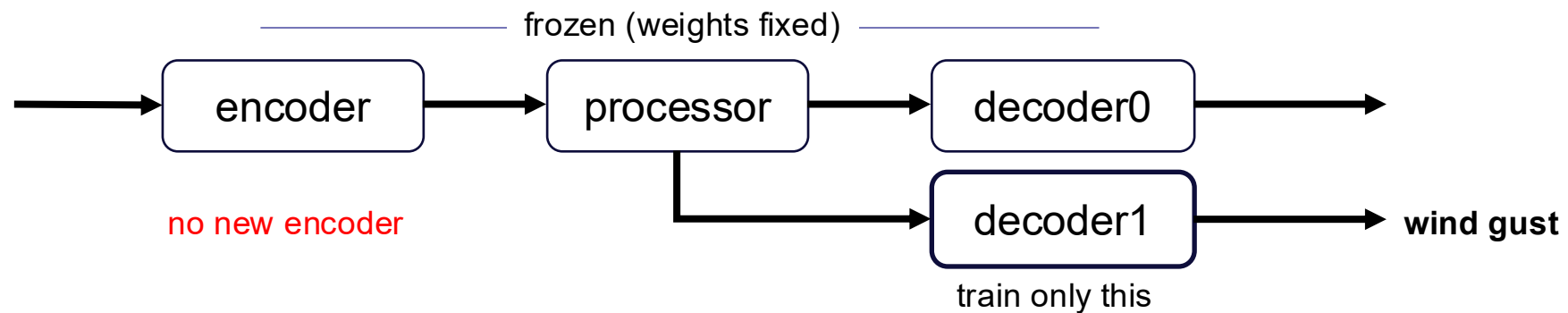


Extending ML weather models for operational use

- ML models produce accurate forecasts of core weather variables
- Operational workflows require additional derived variables, which limits usability
- Examples: wind gust, precipitation type, visibility
- **Need a way to add new variables efficiently**

Multi-decoder: extending the model efficiently

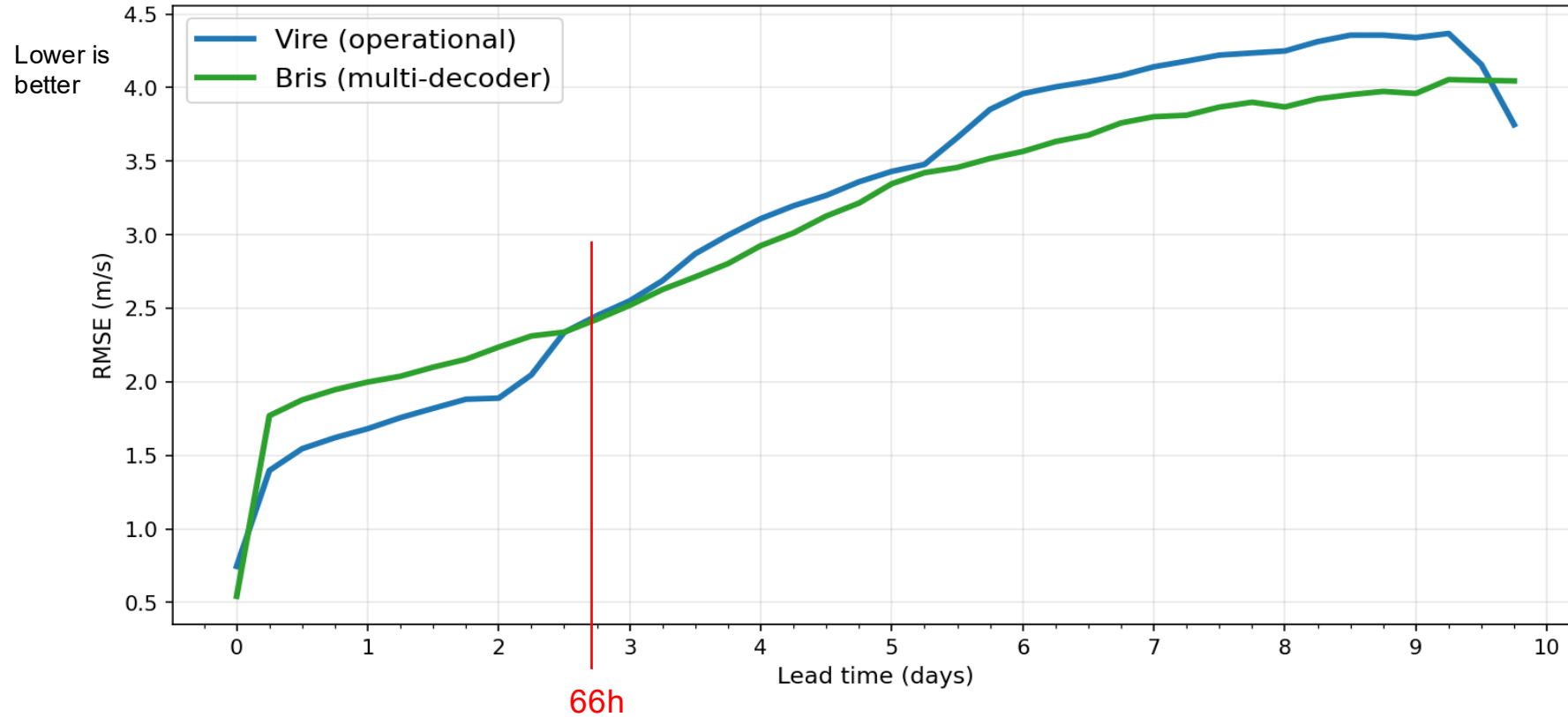
- Attach new prediction heads to a frozen model to add new variables



- Why this approach?
 - Avoids retraining the full model
 - Supports flexible outputs (variable selection, resolution, diagnostics)
- Aila: deterministic stretched-grid model centered over Scandinavia
 - Results shown for Bris ensemble*: Aila ensemble training ongoing

* Nordhagen et al: High-Resolution Probabilistic Data-Driven Weather Modeling with a Stretched-Grid
(<https://arxiv.org/html/2511.23043v1>)

Forecast skill across lead times



TRAINING DETAILS

Train data: 2020-2024
2.5km resolution obs-corrected wind gust from NWP analysis

Test data: Jan-Sep 2025,
~30 Finnish stations

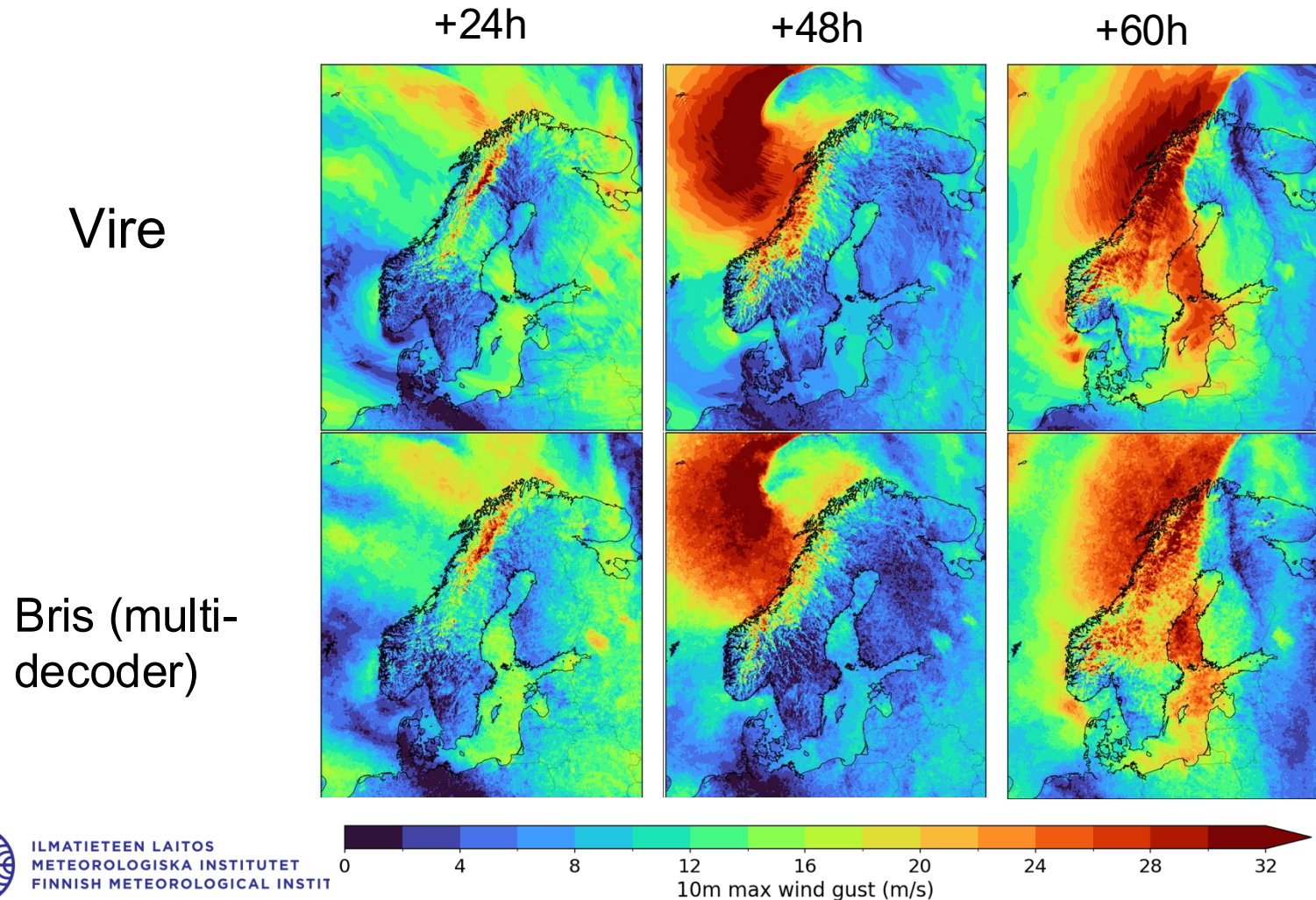
Train two members using CRPS loss function

Decoder structure matches core model

- Vire: deterministic NWP, Bris: single ensemble member
- Slightly degraded skill compared to operational model up to 66h; improved skill at longer lead times
- Vire is post-processed in short range 0-66h, not beyond

Forecast evolution for storm Hannes

Wind gust forecast issued at 25 Dec 2025 00 UTC



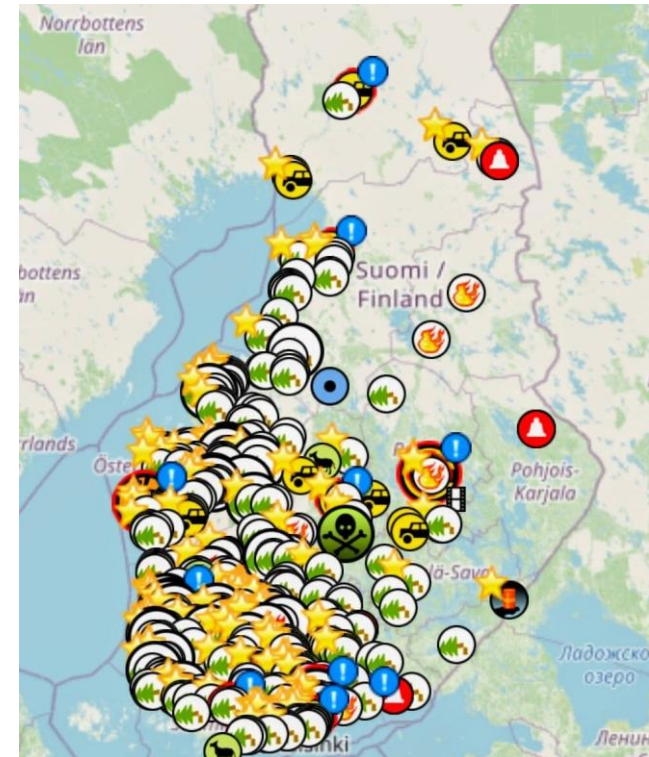
Key observations

- Peak intensity captured similarly
- Slightly noisier texture (Bris)

Case study: storm Hannes

- Major winter storm in western Finland on 27 Dec 2025
- Peak gusts up 31 m/s in populated coastal areas
- Significant societal impact
 - Power outages for 180,000 households
 - 4 million m³ of forest felled
 - Flights cancelled or diverted
- Weather warning issued three days ahead

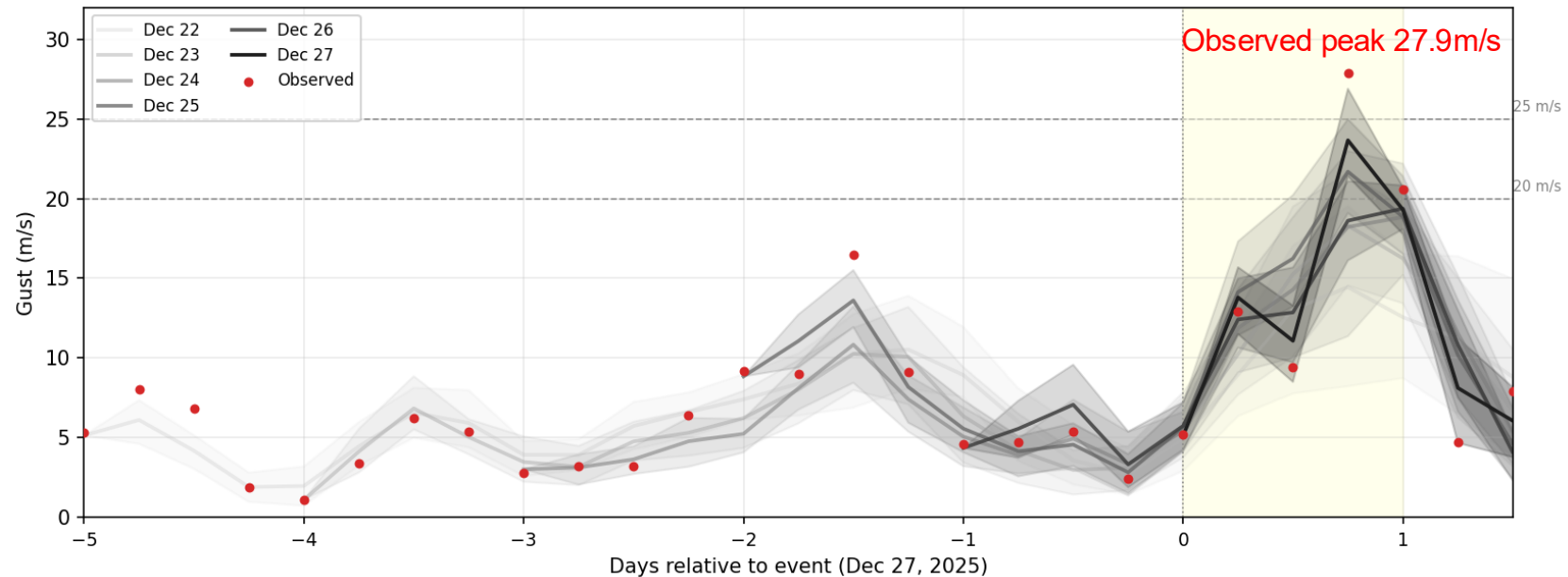
source: Elmeri Nummi



Source: lakeudenmaanpuolustaja.fi

Hannes: peak predicted several days in advance

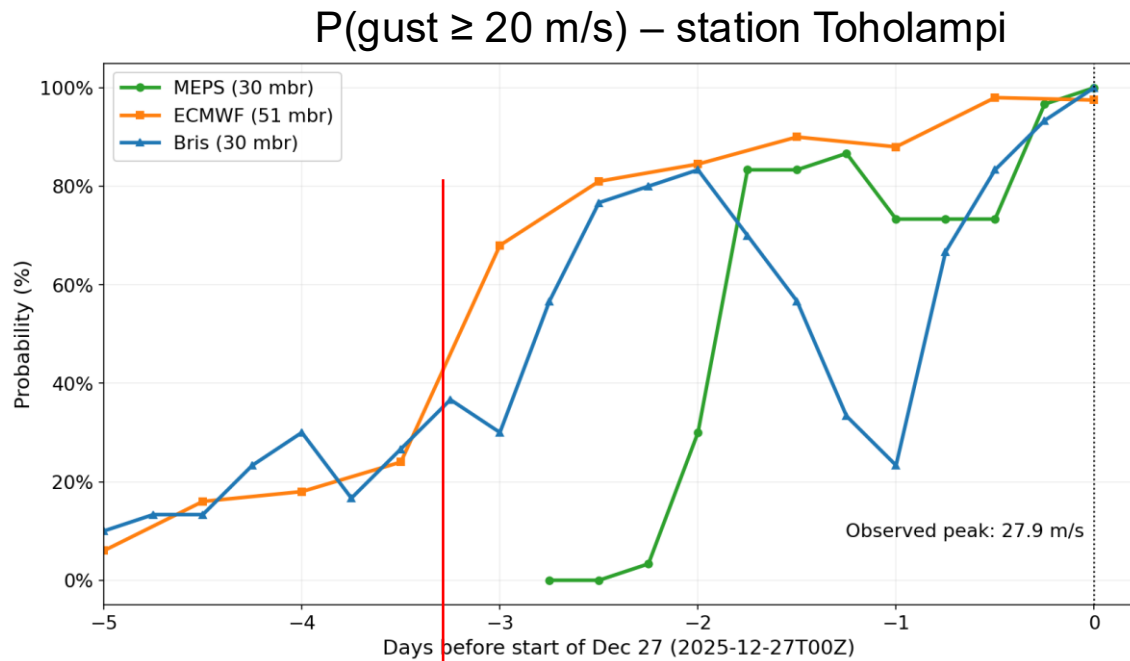
Station Toholampi (western Finland) – ensemble forecasts initialized 1-5 days ahead



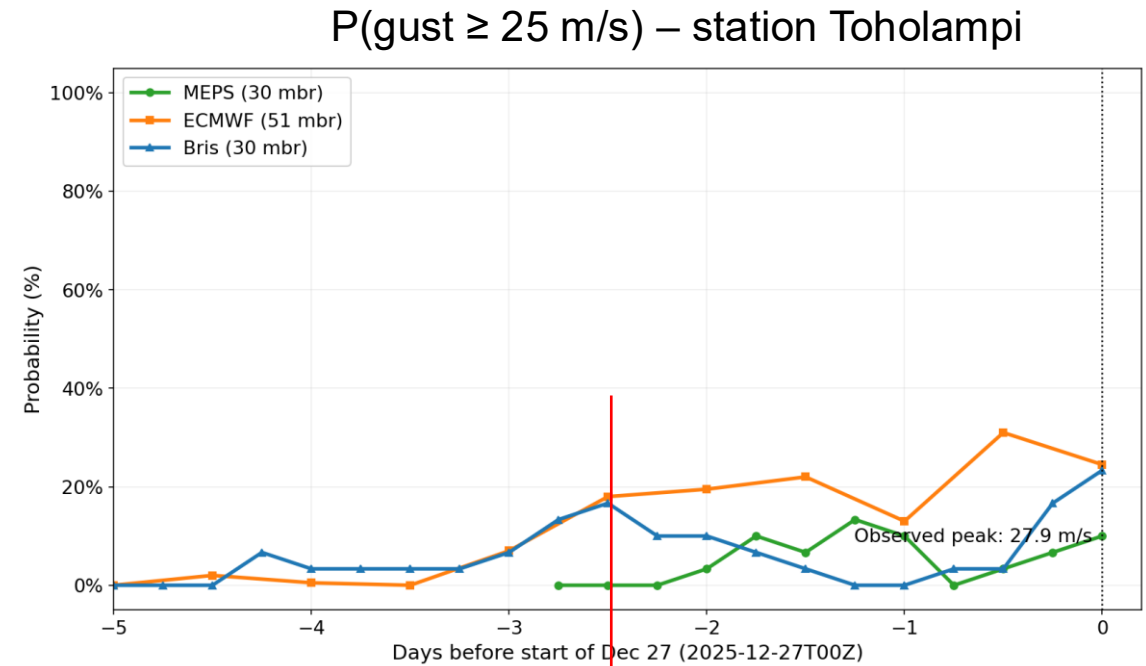
- Peak timing captured across lead times; magnitude improves closer to the event
- Ensemble spread slightly underdispersive

Early warning signal from probabilistic forecasts

Strong gust signal appears several days in advance



Early signal from Bris and ECMWF



Weak signal emerges closer to event



- Elevated probabilities (≥ 20 m/s) appear 3-4 days ahead, consistent with warning timing
- Higher thresholds (≥ 25 m/s) emerge closer to the event but remain weak

Summary

- Multi-decoder extends pre-trained models to new variables
- Adds new variables through separate decoders, keeping the core model unchanged
- Gust decoder shows **promising skill and early warning signal**

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