



# Weather Modelling activities at DMI

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## Introduction and operational framework

The Danish Meteorological Institute (DMI) was founded in 1872 and is responsible for providing weather and climate forecasts for Denmark and Greenland. The Weather Models unit, part of the Weather Research department, currently features 27 scientists working on a variety of core-funded and externally-funded numerical weather prediction (NWP) projects.

DMI issues weather forecasts with continuous cycling on the DINI (Northern Europe) and IG (Iceland-Greenland) domains at 2km resolution through co-production within UWC-W framework, as well as on three smaller domains TAS, SGL, and NUUK in Greenland at 750m resolution.

In addition, forecasts are triggered on three additional Greenland domains when certain thresholds on average wind values corresponding to storm conditions are exceeded (Figure 1 and Table 1). Specifically, observed values at stations located inside the on-demand domains are checked as well as model output on the IG runs at 12UTC and 18UTC on the previous day.

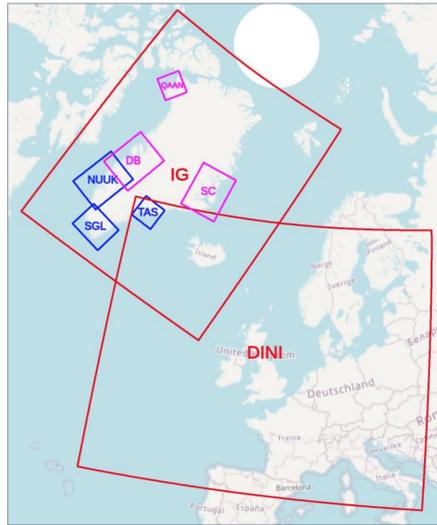


Figure 1: Operational forecast domains at DMI.

Run name	Area coverage	Type of model	Mesh	Grid size (m)	Launch (Z)	Forecast Leadtime (h)	Time step (s)	OBS threshold (m/s)	MODEL threshold (m/s)
DINI-EPS	DINI20A, Northern Europe	Continuous cycling	1920x1620x90	2000	Hourly	60	50	-	-
IG	IG20A, Greenland/Iceland	Continuous cycling	1350x1600x90	2000	00-21:03	72	60	-	-
TAS	TAS11AQ, Tasilaq	Continuous cycling	400x400x90	750	00-18:06	60	15	-	-
SGL	SGL750, South Greenland	Continuous cycling	600x480x90	750	00-18:06	60	15	-	-
NUUK	NUUK750, Nuuk	Continuous cycling	600x800x90	750	00-18:06	60	15	-	-
DB	DB1000, Diskobugt	On-demand triggered	480x600x90	1000	00-18:06	60	25	15	20
SC	SC1000, Scoresbysund	On-demand triggered	480x600x90	1000	00-18:06	60	25	18	20
QAAN	QAAN, Qaanaaq	On-demand triggered	400x400x90	750	00-18:06	60	25	18	18

Table 1: Run names and parameters for operational weather forecasts at DMI.

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## On-demand sub-km extreme weather modelling

DMI is technical coordinator of the Destination Earth On Demand Extremes Digital Twin project, leads the development and operation of the workflow, and co-leads work on data-driven (AI) uncertainty quantification.

The project is part of the European Union's Destination Earth initiative and involves the cooperation of a large number of European NHMs, with the aim of providing a technical framework for running different flavours of the ACCORD forecast models at hectometric scale. The forecasts are expected to be triggered on demand for high-impact weather events such as heatwave, flooding, storm and for the energy (solar/wind) sector.

The novel DEODE Workflow infrastructure (Figure 2) features an on-demand High Resolution (HR) NWP system, running the limited-area forecast models HARMONIE-AROME, AROME, and ALARO at sub-km scale on DTF-suggested domains. The HR NWP simulations run on EuroHPC facilities and use Lateral Boundary Conditions (LBC) from the ECMWF operational deterministic model (9km resolution) or the Global Digital Twin (4.4 km resolution).

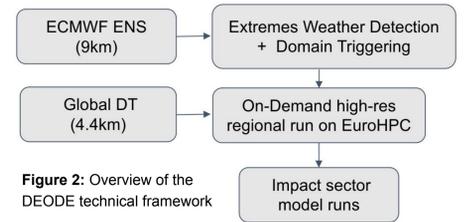
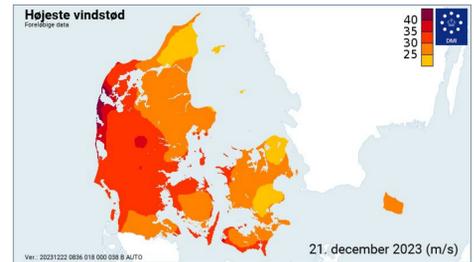


Figure 2: Overview of the DEODE technical framework

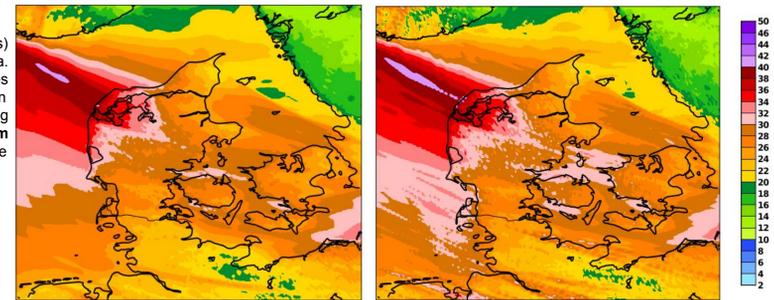
### Case study: Storm Pia, 20-22 December 2023

Storm Pia was named by DMI on 20 December 2023 and brought hurricane-force winds, storm surges, and widespread flooding and travel disruption across North-West Europe. In Denmark, sustained winds of over 30 m/s were recorded along coastal areas, making Pia the strongest windstorm to hit Denmark in 8 years. Maximum wind gusts exceeded 40 m/s on the western coast of Jutland, and even at inland stations in Jutland, the strongest gusts reached hurricane force.



The HARMONIE-AROME model was run using the DEODE Workflow at 2km (current operational resolution, 60 s time step) and 500m resolution (20 s time step), using global DT data at 4.4km resolution for LBC (Figure 3). The 500m run better represents the large values of the maximum wind gust, especially over inland areas of the Jutland peninsula.

Figure 3: 24h maximum gust (m/s) on 21/12/2023 for Storm Pia. Observations (top), simulated values in a HARMONIE-AROME 48h run started at 20/12/2023 00UTC using 2km (bottom left) and 500m (bottom right) resolution using the DEODE Workflow.



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## Machine learning activities

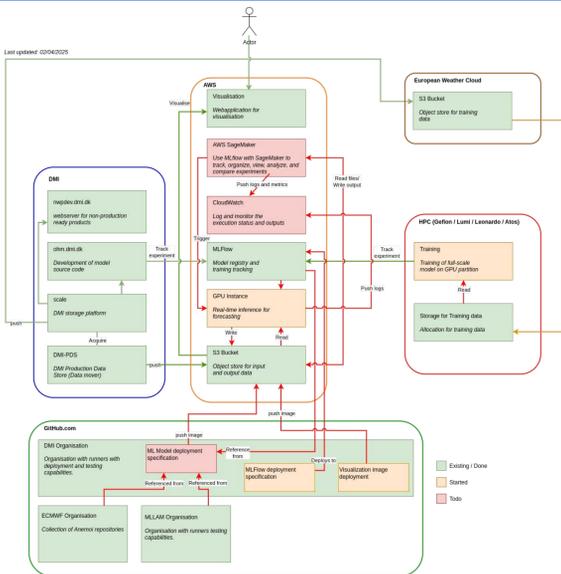


Figure 4: Overview of infrastructure plan and status of deployment of data-driven weather forecasting

### Infrastructure & MLOps

- **NeuralLAM pipeline:** complete workflow from data prep → training → evaluation with DVC for experiment tracking
- **Data versioning:** zarr-based datasets
- **Experiment tracking:** local MLflow on Gefion (air-gapped HPC)
- **Deployment setup:** GitHub runners for automation, visualization partly integrated
- First steps towards a reproducible and operational ML ecosystem at DMI

### Supercomputer Training

**NeuralLAM:** Graph neural network for km-scale forecasts (3-day window). Orders of magnitude faster than NWP, improved uncertainty estimates. Trained on Gefion HPC, requiring roughly 2,500 GPU hours per run on H100 80GB cards, with a total effort on the order of 35K GPU hours across pre-training and fine-tuning cycles.

**LDcast:** Latent diffusion model for precipitation nowcasting critical for flood response (Beredskabsstyrelsen). Multi-GPU scaling on LUMI & Leonardo

Adamov, S. et al. Building machine learning limited area models: Kilometer-scale weather forecasting in realistic settings. arXiv preprint arXiv:2504.09340 (2025).

Leinonen, J., Hamann, U., Nerini, D., Germann, U., & Franch, G. (2023). Latent diffusion models for generative precipitation nowcasting with accurate uncertainty quantification. arXiv preprint arXiv:2304.12891.

### Vision

Our vision is to deliver AI-driven, faster, and more accurate weather forecasts by integrating machine learning models directly into DMI's operational systems, enabling timely and reliable predictions that serve both society and critical infrastructure.

### Next Steps & Collaborations

- Contributing to ECMWF's ANEMOI framework for limited-area models
- **SHADEcast:** Danish retraining planned for solar irradiance nowcasting (15 min-6 h)

Carpentieri, A., Folini, D., Leinonen, J., & Meyer, A. (2024). SHADECast: Enhancing solar energy integration through probabilistic regional forecasts (No. EGU24-5571). Copernicus Meetings.

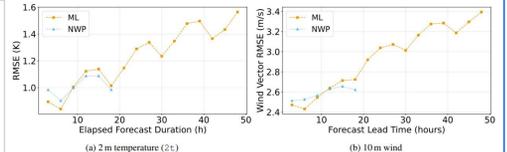


Figure 5: RMSE for the DANRA models compared to station observations.

### Steps Towards Operationalizing LeeWaveNet

LeeWaveNet is being adapted at DMI for the real-time detection of trapped lee waves in the Iceland-Greenland region. Current work focuses on ongoing validation over Norway and preparing integration into DMI's forecasting pipeline with automated data handling and scalable deployment. These steps mark the transition of LeeWaveNet from research towards operational use, supporting aviation safety and hazard awareness in the North Atlantic.

Coney, J. et al. (2023). Identifying and characterising trapped lee waves using deep learning techniques. Quarterly Journal of the Royal Meteorological Society, 150. 10.1002/qj.4592.

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Explore ML-LAM collaboration on GitHub

## DANRA and efficient data extraction

The DANish ReAnalysis (DANRA) is a state-of-the-art 35 year (Sept 1990 - Aug 2024) gap-free, gridded Danish atmospheric reanalysis with 2.5 km grid resolution providing information about weather related variabilities and climate change. A recently developed grib to zarr conversion tool greatly improves efficiency for user access and allows for very fast data extraction and examination (for instance 30 years climate mean calculations are done in minutes). The horizontal grid resolution is 12.4 times as high as ERA-5's 31 km.

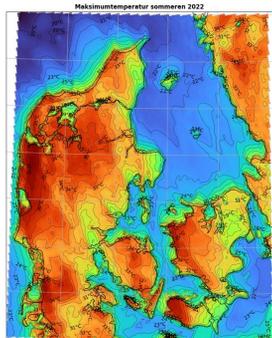


Figure 6: Example output with DANRA data showing highest temperature during the Summer of 2022. The data processing and plotting took ~10 seconds.

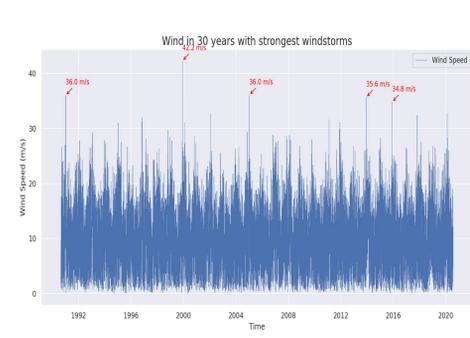


Figure 7: 30 year period of wind climatology near Horns Rev in the North Sea for wind speed at 100 metres height using DANRA data. The five highest wind speed value are annotated. The data processing and plotting took less than 20 minutes.

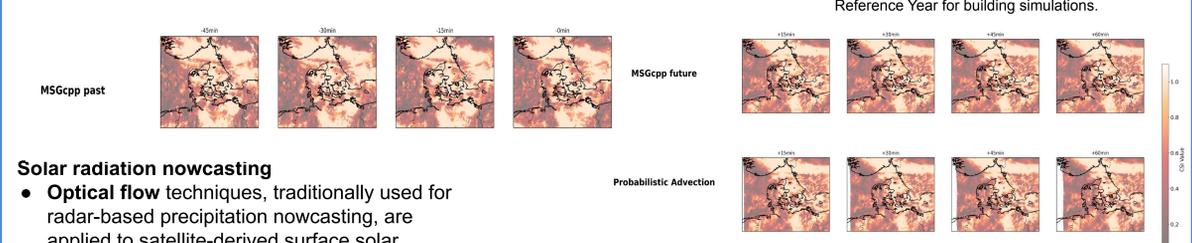
X. Yang, C. Peralta, B. Amstrup, S.B. Thorsen, L. Denby, K.S. Hintz, S. Pelt, M. Schreiner, I.L. Kruse, S.K. Christiansen. DANRA: The Danish Regional Atmospheric Reanalysis, in preparation.

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## EnergyWeather, IEA PVPS Task 16 and Weather2X

With increasing penetration of wind and solar power, accurate forecasts of potential power production are key to the balancing of the electricity grid and for those producing, selling and buying power in advance. In Weather2X DMI, in collaboration leading Danish institutions and power products aims to improve the forecasts of wind and solar radiation.

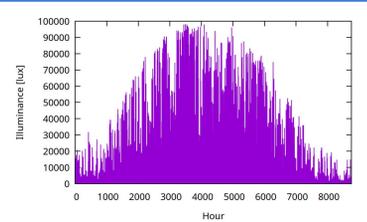
In IEA PVPS Task 16, international experts make recommendations for solar resource assessment and forecasting. DMI here works on satellite nowcasting and forecasting, benchmarking of datasets, and making new meteorological reference years for simulations of energy efficient buildings.



### Solar radiation nowcasting

- **Optical flow techniques,** traditionally used for radar-based precipitation nowcasting, are applied to satellite-derived surface solar radiation.
- Energy sector-driven 15 min-3 h lead times
- Future work: machine learning-based nowcasting model trained on MSGcpp data.

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Global illuminance data in the Danish Design Reference Year for building simulations.

