Numerical Weather Prediction 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 within the **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.

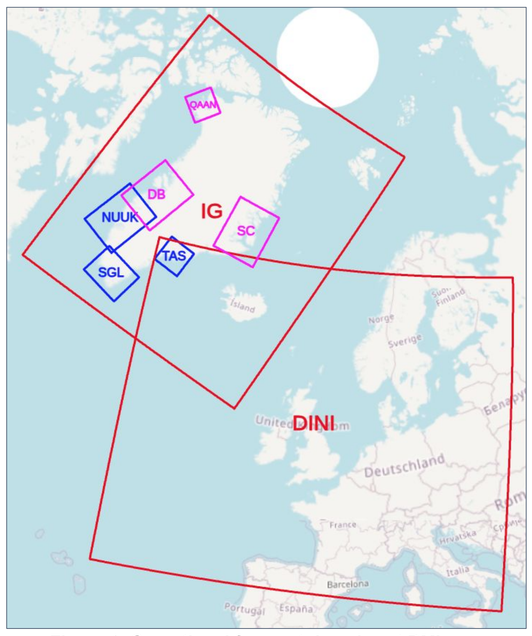

Figure 1: Operational forecast domains at **DMI**.

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	TASIILAQ, Tasiilaq	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, Scores-bysund	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 NHMSs**, 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).

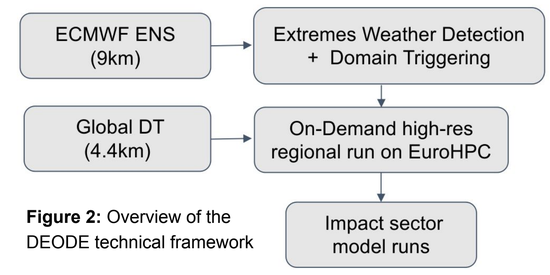
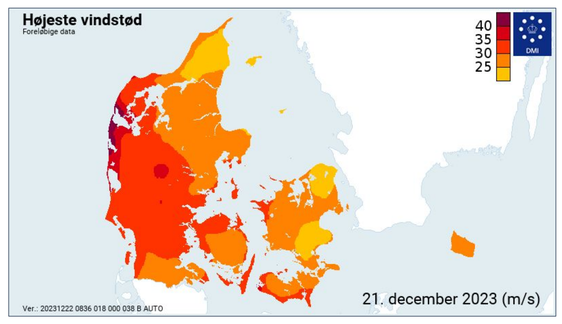


Figure 2: Overview of the DEODE technical framework

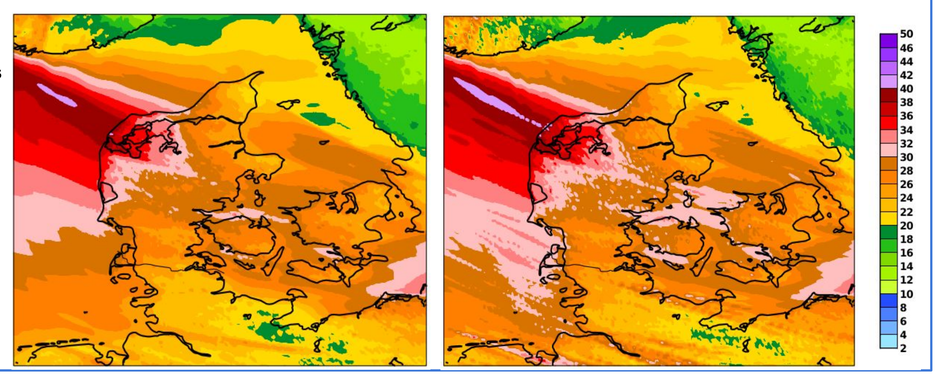
Case study: Storm Pia, 20-22 December 2023

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 modelling activities

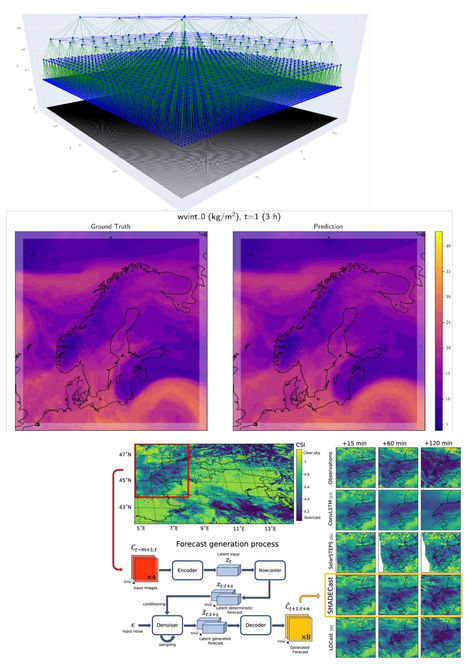

Figure 4: Graph Neural Network **(top),** Neural LAM output **(middle),** SHADEcast workflow **(bottom).**

Project	**Precipitation** and **solar irradiance nowcasting** using existing **latent diffusion** models **SHADEcast** and **LDCast** retrained on Danish data.	**Graph neural network**-based **LAM** using **NeuralLAM** and **ANEMOI** for real-time operations with a **purely data-driven forecasting model**.	**Detection** and **characterisation** of **Trapped Lee Waves** using **U-Net** architecture in the **Iceland-Greenland** Region
Data	Satellite-derived solar irradiance and radar-based precipitation	DANRA 1990-2023 2.5km reanalysis of northern Europe	High-resolution **Harmonie-IG** model output in the Iceland-Greenland region
Use	**Predict (extreme) precipitation events** with **higher accuracy** and **efficiency** than in physics-based NWP. **Nowcast 2D fields** of surface solar irradiance, based on the past 2D fields.	**Produce km-scale forecast for Denmark** over **3-day window**, **orders of magnitude faster** than traditional NWP models.	Real-time detection of trapped lee waves Deployed in a **containerized environment** for operational scalability. Predicts **wavelength**, **orientation**, and **amplitude**
Impact	**Solar nowcasting** (15min - 6 h) for the solar energy field in Denmark. **Provide accurate precipitation amounts** and **locations** in **extreme events**. **Critical for flooding response and prevention** by Danish Emergency Management Agency (Beredskabsstyrelsen)	**Faster forecasts** - current forecasts are hours old when accessed by end-users. **Better uncertainty estimates** - cheaper runs allows for more ensemble members. **Improved process modelling** through learnt process representation for phenomena difficult to model (e.g. clouds and rain)	**Provide forecasters** with **accurate** and **timely wave predictions** leading to enhanced **aviation safety** with proactive turbulence warnings. Potential to **expand to other regions** and predict additional hazardous weather events
Sources	**LDCast** is developed by **MeteoSwiss**, **SHADECast** is developed by Alberto Carpentieri et al. 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. Carpentieri, A., Folini, D., Leinonen, J., & Meyer, A. (2024). SHADECast: Enhancing solar energy integration through probabilistic regional forecasts (No. EGU24-5571). Copernicus Meetings.	**ANEMOI** is ECMWF's framework for GNN models for global and LAM weather models. The **NeuralLAM** model was originally published by Joel Oskarsson et al., and we have contributed to the open source repository under the ML-LAM organization. Oskarsson, J., Landelius, T., & Lindsten, F. (2023). Graph-based Neural Weather Prediction for Limited Area Modeling. arXiv preprint arXiv:2309.17370.	Builds on previous research conducted in the UK, where they developed a deep learning model called **LeeWaveNet**. Coney, J. et al. (2023). Identifying and characterising trapped lee waves using deep learning techniques. Q. J. Roy. Met. Soc. 150. 10.1002/qj.4592.

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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**.

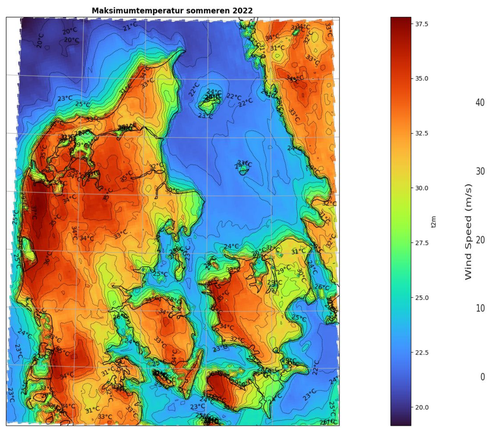

Figure 5: Example **output** with **DANRA data** showing **highest temperature** during the **Summer of 2022**. The **data processing and plotting** took **~10 seconds**.

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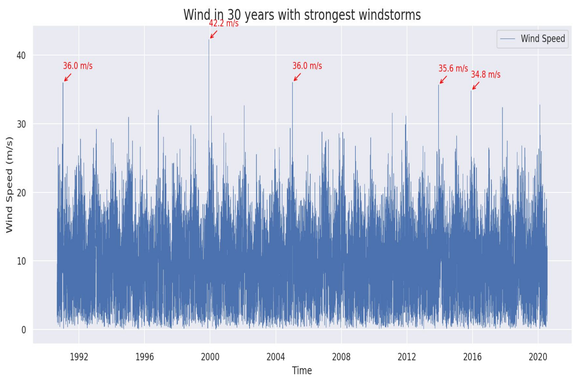


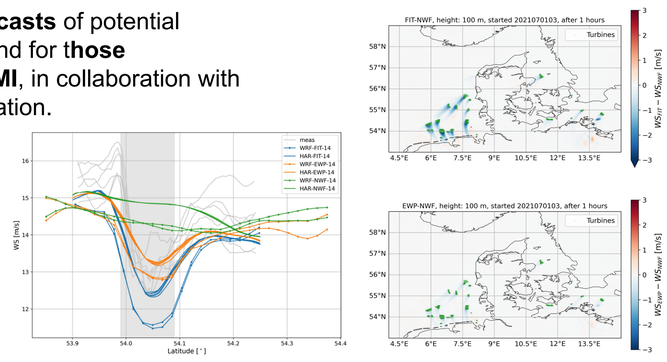
Figure 6: **30 year period of wind climatology** near Horns Rev in the North Sea for **wind speed at 100 metres height** using DANRA data. The five highest wind speed value are annotated. The **data processing and plotting** took **less than 20 minutes**.

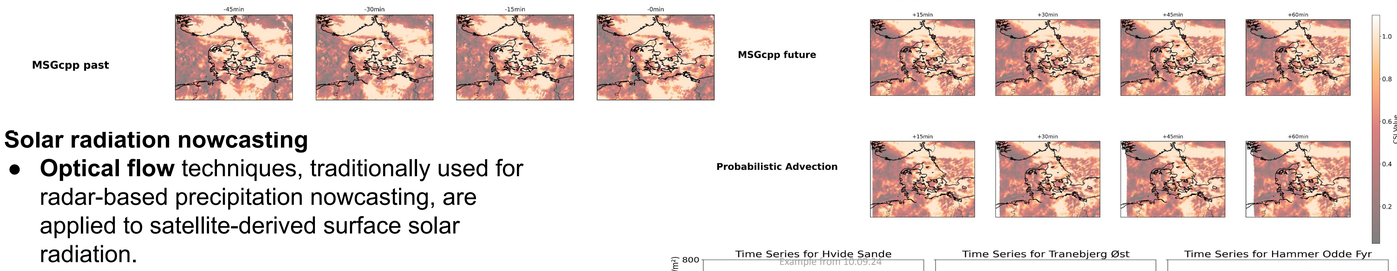
EnergyWeather, IEA PVPS Task 16 and Weather2X

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 t**hose producing, selling and buying power** in advance. In **Weather2X DMI**, in collaboration with **KNMI** and **DTU**, aims to improve the forecasts of wind and solar radiation.

The **Fitch scheme** (FIT) and **explicit wake parameterisation** (EWP) are now included in **HARMONIE-AROME** (Figure 5).

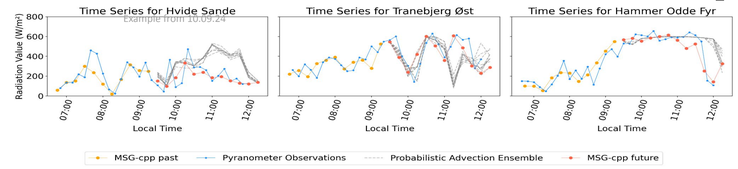
Data from **masts**, **wind turbines** and **lidar** at the heights where wind turbines operate will be available. **Post processing** is then expected to lead to **better forecast skill**.





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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