MS/CS “Green Book’ Report 2024

This report relates to Use and Verification of ECMWF products in Member and Co-operating States, since January 2022. Please add your text below under the appropriate headings. Mandatory questions are marked with a ''. Also, **please do include figures/tables wherever you feel they are appropriate**, with figure/table numbers (e.g. “Figure 1”) and explanatory captions underneath. You should aim for the finished report to be 8 pages or less. Once completed it would be help us if you could delete all the ECMWF instructions (in grey italics) such as this paragraph.*

Section 1: Background

* 1.1 Country

Denmark

* 1.2 Author(s)

Henning Gisselø
Sebastian Pelt
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* 1.3 Organisation

Denmark Meteorological Institute

* Section 2: Summary of major highlights

- Since January 2022, we have established an operational co-production arrangement with United Weather Centres-West (UWC-WEST).
- Additionally, we have transitioned to using IFS-ENS (Integrated Forecasting System - Ensemble) as the lateral boundary input for our Limited Area Model - Ensemble Prediction System (LAM-EPS). This change replaces our previous method of utilizing the Scale Lagged Average Forecast (SLAF) approach.

Section 3: Forecast Products

3.1. Direct use of ECMWF forecast products

In each of the following 4 categories please outline what direct use you make of standard ECMWF model products (on ecCharts / OpenCharts / own workstation), for operational duties, (noting that new AI model output should be dealt with separately, in Section 3.4).

a) Medium Range (e.g. for high impact weather forecasting)

ECMWF data are widely used in our daily forecasting. We mainly use our own application system (NINJO) when presenting the data, but we also to some extent use ecCharts and OpenCharts (especially when ECMWF data are not available in our own application system).

We use the data as a second opinion to our own models and beyond 48-54h the ECMWF data are the main source in the forecasting process.
We also use relevant ECMWF data in order to forecast severe weather (mainly precipitation and wind).

DMI operates several 2.5 km NWP model setups for short range limited area NWP models based on HARMONIE-arome for daily weather forecasts of up to 66h over its service areas centred around Denmark, Greenland and Faroe Islands. Apart from conventional short range forecast at deterministic mode, it also includes a novice **CO**ntinuous **M**esoscale **E**nsemble **P**rediction **S**ystem with 25 member ensemble with hourly refresh through time lagging. In addition, a rapidly refreshing system with 3 km resolution, based on HIRLAM forecast system, is run hourly to cover the needs for nowcasting and for road condition forecast in Denmark and Faroe Islands. As the focus of the LAM forecasts are on short range, the model setups at DMI are typically run with 1 to 3h assimilation interval, with a short (0.5 to 1.5 h) observation data cut-off, enabling a frequent and early delivery. All forecast setup runs with 3D-VAR data assimilation with focus on use of radar, mode-s-EHS/aircraft data as well as synoptic and satellite data.

For all of the operational NWP setups at DMI, the operational HRES forecast at ECMWF, including those by the optional boundary condition (BC) forecasts, are used as lateral boundary conditions through direct coupling, normally with a 6 to 9 h time lagging.

Starting April 2024 DMI joins the Netherland meteorological institute (KNMI), Irish meteorological institute (Met Éirann) and Icelandic meteorological office (IMO) for joint operational productions of short-range weather forecasting. This consists of a model set up of hourly 31 member DINI with COntinuous Mesoscale Ensemble Prediction Systems and a deterministic 3-hourly IG model for Greenland and Iceland area. For the DINI set up forecast lead time is 60 hours, while for IG it extends to 72 hours.

Both models operate on a 2.0 km horizontal grid spacing with 90 vertical levels and use IFS forecasts as lateral boundary conditions. For DINI ensemble, the IFS-ENS data is used for lateral boundary perturbations.

Additionally, DMI uses ECMWF data for our extended Fire Weather Index, and similarly for the extended range (+60 hours) storm surge forecast DKSS and wave model, WAM.
ECMWF forecast data is also employed in dispersion modelling at DMI.

* b) Extended Range (monthly)

ECMWF data are very important when making monthly forecast and widely used.

* c) Long Range (seasonal)

ECMWF data are very important when making seasonal forecast and widely used.

* d) CAMS and Fire-related output (ecCharts mainly)

For the moment, we do not use CAMS and Fire-related output very much

3.2. Cycle 48r1

ECMWF cycle 48r1 went live at the end of June 2023. Changes included a much higher resolution medium range ensemble, and much more frequent monthly forecasts. In sub-sections a and b below lease detail any positive or negative impacts of this cycle for your organisation.

*** a) <u>Positive</u> impacts of model cycle 48r1**

Over all we are quite satisfied about the quality of the ECWMF data.

*** b) <u>Negative</u> impacts of model cycle 48r1**

none

c) Systematic changes in forecast output since model cycle 48r1 was implemented

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3.3: Derived Fields

We do currently not use derived fields from ECMWF model output.

3.4: Artificial Intelligence (AI) / Machine Learning (ML) techniques

We are currently exploring the use of ML techniques in data driven LAM-forecasting and in emulation of various components of the LAM-forecast systems.

3.5: Dynamical Adaptation

ECMWF-data is used in on-demand hi-res forecasting for Greenland subregions.

3.6: Data-driven (AI) models

We are currently not using AI-models directly but we are following the activities at ECMWF closely and part of the ML-LAM community building limited-area data-driven forecasting.

*** a) ECMWF's real-time AI model initiative**

Unaware

*** b) Use of AI forecasts for operational purposes**

None

Section 4: Verification

Generally, the forecasts from ECMWF are very accurate and verify well. The standard deviation is small and across a wide range of temperatures nearly identical to HARMONIE.

TEMPERATURE
In the most extreme cases—namely, maximum temperatures in summer and minimum temperatures in winter—we see that our high-resolution model has a slightly better handle on the extremes (Figure 1 and 2).

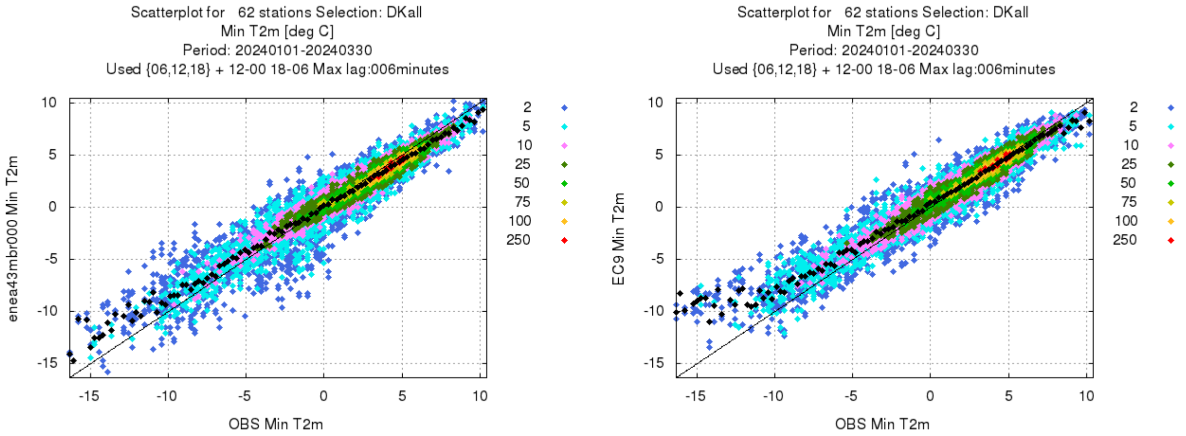

Figure 1: Verification of DMI HARMONIE-NEA (left) and EC-HRES (right) for the minimum temperatures (Min T2m) during the last winter in Denmark.

The analysis reveals that across a broad temperature spectrum, both forecasting models demonstrate similar levels of accuracy, effectively capturing the general trends in minimum temperatures. However, it is noteworthy that at the lower extremes of the temperature spectrum, the HARMONIE-NEA model exhibits a slightly superior performance. These very low temperatures often occur over snow-covered ground where the lowermost part of the boundary layer – the contact layer – near the surface can become extremely stable due to outgoing longwave radiation from the snow surface.

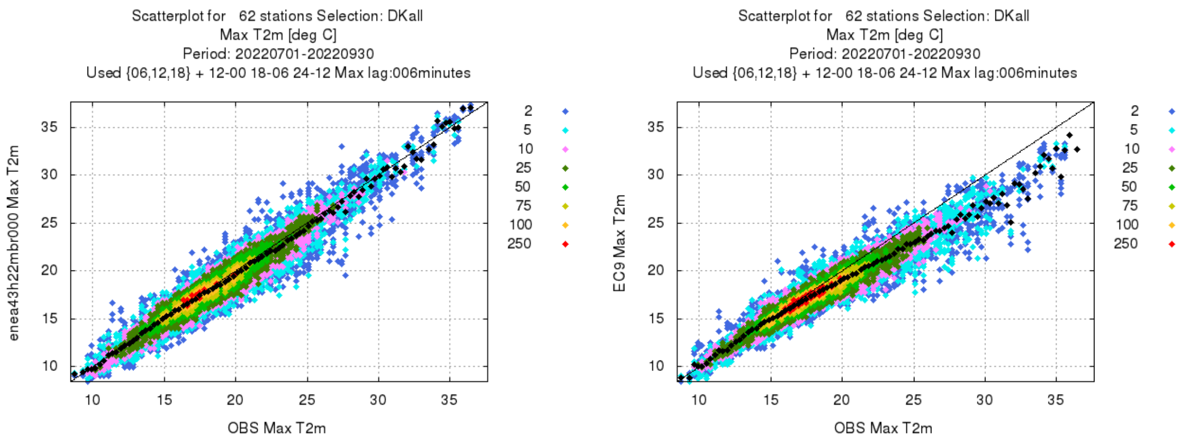

Figure 2: Verification of DMI-HARMONIE NEA (left) and EC-HRES (right) for the maximum temperatures (Max T2m) during the summer of 2022 in Denmark.

Overall, the EC-HRES model performs well across a broad spectrum of maximum temperatures, capturing the general trends effectively and demonstrating robust model reliability under standard summer conditions in Denmark. When forecasting the highest temperatures (above 30-35°C), the HARMONIE-NEA model proves to be slightly superior. The highest temperature recorded in Denmark during the summer of 2022 was 35.9°C in July, marking the highest ever observed in that month and the second highest ever measured in Denmark, just behind the record of 36.4°C on August 10th, 1975.

WIND

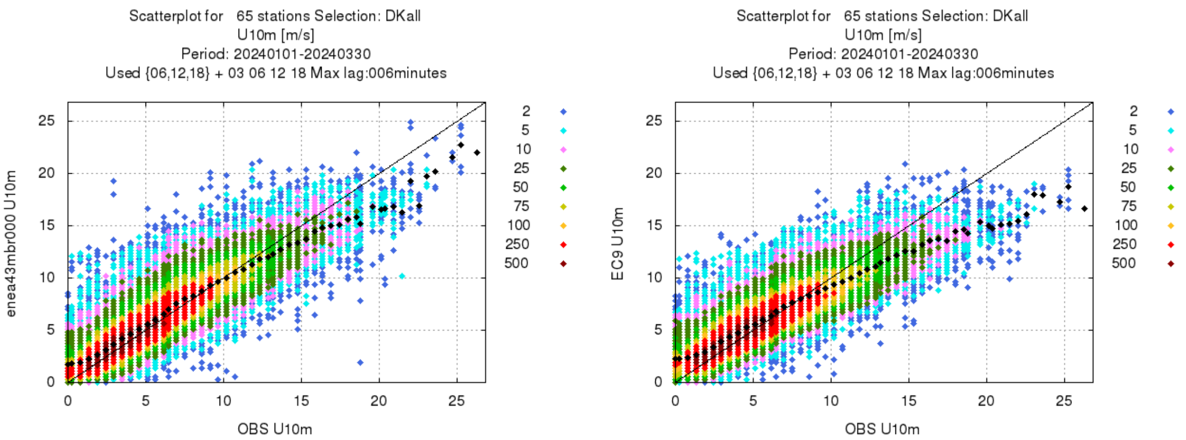

Figure 3: Verification of DMI-HARMONIE NEA (left) and EC-HRES (right) for the 10m-wind speed (U10m) during the last winter time in Denmark.

As was the case considering temperature forecasts, EC-HRES generally performs very well. However, during severe wind episodes, there might be a slight tendency for EC-HRES to underestimate the highest observed wind speeds compared to DMI HARMONIE-NEA. This is for instance represented in Figure 3, where the highest predicted wind speed by EC-HRES during this aforementioned period was 21 m/s, while the highest from HARMONIE was 25 m/s. To compare, the highest observed sustained wind speed was measured to 27 m/s. This value was observed during the transient, but quite strong storm, named “Rolf” on February 23th.

PRECIPITATION
Lastly, a similar pattern is observed in precipitation forecasts. Despite the overall excellent performance of ECMWF forecasts across a broad range of conditions, there is a notable exception when it comes to predicting the highest rainfall events:

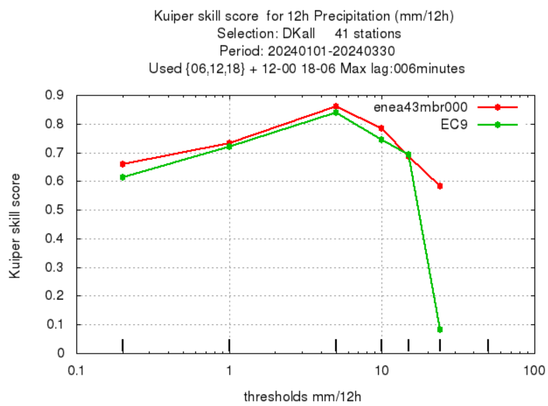

Figure 4: The EC-HRES model (green) consistently demonstrates a good capability to accurately forecast precipitation. However, during intense precipitation events it appears more challenging for EC-HRES model to capture the most intense rainfall, which often results from convective precipitation. These convective processes are, per se, limited in time and space and are generally better resolved by high-resolution Limited Area Models (LAMs) like HARMONIE (red).

4.1 Raw model output from ECMWF, and other operational models/ensembles

a) Short Range and Medium Range
Se under forrige punkter med verifikation af ECMWF mod DMI’s egen LAM.

b) Extended Range (Monthly) and Long Range (Seasonal)

4.2 Post-processed products and/or tailored products delivered to users

We do currently not have this type of products.

4.3 Subjective verification

Over all we are quite satisfied about the quality of the ECWMF data.

4.4 Case Studies

a) Case Study (“Pia”-storm, December 21st-22nd, 2023)

There is a general perception, albeit slightly subjective, that the EC-HRES model excels in predicting significant weather events on a larger scale, well in advance of their impact. This is particularly true for extratropical cyclones, where forecasts from EC-HRES can effectively anticipate the evolution of these systems days ahead of time, especially when these developments occur on a synoptic scale. A notable example of EC-HRES’s forecasting prowess was its accurate prediction of the storm named “Pia,” which impacted Denmark on December 21st-22nd, 2023. The forecast, visualized by MetDesk and available on wxcharts.com (see Figure 5), was based on the EC-HRES run initialized on Monday, December 18th, providing a 78-hour lead time for that specific time.

The depicted forecast map for December 21st showcased the forecasted sustained wind speeds over the Danish area, which corresponded overwhelmingly well with the wind speeds later observed. This precise alignment between forecasted and actual conditions underscores the EC-HRES model’s capability to handle significant meteorological phenomena.

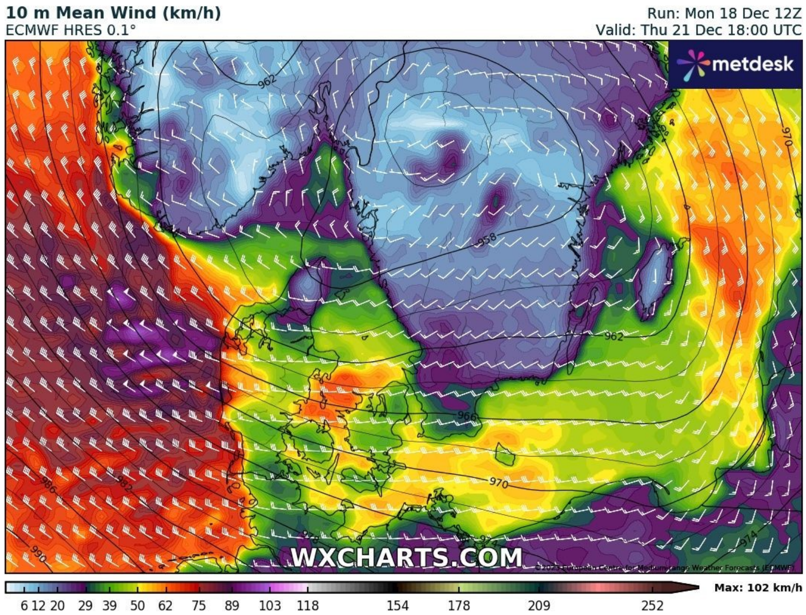

Figure 5: EC-HRES Forecast Initiated on Monday, December 18th at 18 UTC.
This forecast was for Thursday, December 21st, approximately +78 hours ahead. For many consecutive deterministic runs, the storm was very accurately predicted by ECMWF. The effectiveness of these predictions is highlighted when comparing this figure to observed sustained wind speeds, which were measured by automatic weather stations operated by DMI and displayed below (see Figure 6).

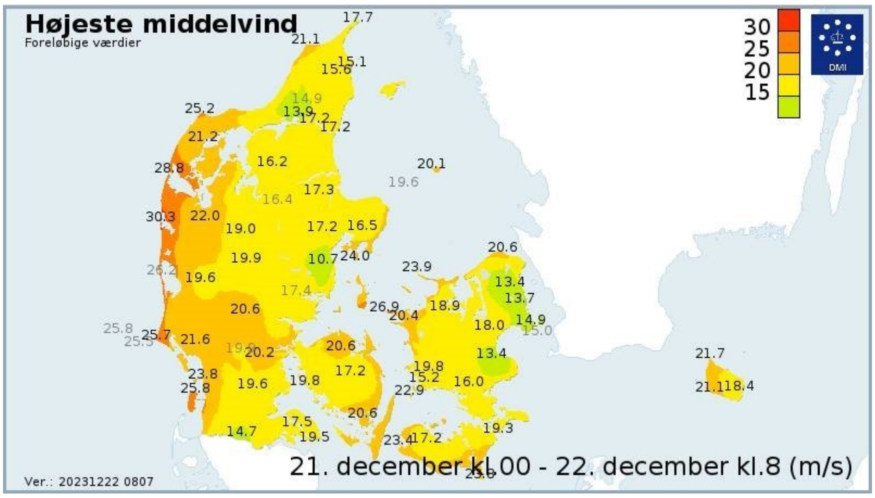

Figure 6: Highest Observed Sustained Winds During the "Pia" Storm in Denmark (December 21st-22nd, 2023)
This figure presents the highest observed sustained winds during the "Pia" storm, as recorded by automatic weather stations operated by DMI. Compare these in-situ measurements with the EC-HRES forecast depicted in Figure 5, which was made 78 hours in advance. The comparison highlights the forecast's accuracy in predicting storm conditions. (Map courtesy of DMI).

Section 5: Output Requests

Please describe, and illustrate if necessary, any particular requests you may have for new or modified ECMWF products. Add more sub-sections manually (c, d etc.) if you need them.

a) Product request 1: Mixed layer cape

Mixed layer cape available; e.g. in ecCharts

b) Product request 2: *add a title / short-form summary here in bold*

Describe the request here

Section 6: References

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Section 7: Additional comments and Feedback

I'm not sure if this is the right place to comment the below mentioned issue, but…

when using vertical profiles in ecChart you get overloaded by data and its hard to detect details which can be quite important when using this in aviation fprecasting and in severe precipitation predictions.