Application and verification of ECMWF products 2017

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1. Summary of major highlights

ECMWF products are widely used throughout the Norwegian Meteorological Institute (MET). Forecasters use HRES and ENS products to make weather forecasts for the public and for customers. ECMWF provides boundary values to the AROME-MetCoOp Ensemble System (MEPS) and AROME-Arctic Limited Area Model, and is also basis for several downstream ocean and chemistry models, is input to statistical methods, and is used more or less directly by end uses.
The ECMWF forecasts are mainly verified directly against observations and to some extent against computed area observations. Results are presented in quarterly reports and on internal web pages.

2. Use and application of products

2.1 Post-processing of ECMWF model output

2.1.1 Statistical adaptation

ECMWF ENS is the basis for the public medium range forecasts (3-10 days) for Norway presented on yr.no. Both a consensus forecast and probabilities are generated. ECMWF HRES is used for the rest of the world. For Norway there is currently a statistical calibration of air temperature (at 2m), precipitation, and wind speed (at 10m). For air temperature a quantile-quantile method is used with climatology from a limited area model as reference. The precipitation calibration is done using a combination of a logistic regression and fitting a gamma distribution. This procedure accounts for the lack of spread in the ensemble, ensuring that the presented probabilities for precipitation are reliable. The wind speed calibration is performed using quantile-quantile mapping against a high resolution (2.5 km) model.

2.1.2 Physical adaptation

ECMWF HRES provides lateral boundary values for both MEPS and the limited area atmospheric models AROME-Arctic model (2.5 km horizontal resolution, based on Harmonie, covering Scandinavia and Svalbard) at 00, 06, 12 and 18 UTC. Scaled Lagged Average Forecast (SLAF) is used for initial and lateral boundary perturbations to the MEPS.

ECMWF is also used in forcing of Wave- and Ocean models and as input to dispersion models for volcanic ash and nuclear emissions.

The resolution increase and improvements made in IFS cycle 41r2 last year led to outphasing of MET's local HIRLAM (8 and 12km). As a result, from January 2017, all weather forecasts and downstream production in need of NWP input is based upon ECMWF for areas outside the MEPS domain (Scandinavia) and AROME-Arctic domain (N-scandinavia + Svalbard) .

2.1.3 Derived fields

On the website yr.no, MET provide location-specific forecasts up to 10 days. In the medium range, the forecast is a combination of a consensus forecast and a probabilistic forecast, both based on EC-ENS. To achieve a smooth transition from the short range forecasts (based on MEPS/AROME-Arctic) we rely on the ECMWF re-forecasts to provide a reliable model climatology. These re-runs of the current operational ENS are very important, especially close up to major model upgrades, as they quickly provide a large training data set for statistical post processing.

To the end-users on yr.no, uncertainty is indicated for weather, temperature and wind in terms of green, yellow and red markers. Probability forecasts comprise the 10, 25, 75 and 90 percentiles for temperature and 6-hourly precipitation, see for example http://www.yr.no/place/Norway/Oslo/Oslo/Oslo/long.html. Probability maps for selected weather parameters based on ENS are also presented in the meteorological visualisation system Diana, and used daily by forecasters.

2.2 ECMWF products

2.2.1 Use of Products

ECMWF products - both disseminated and on the ECMWF website - are highly valuable in operational short range forecasting and indispensable in medium range forecasting. HRES variables are presented as horizontal maps, vertical profiles and cross sections in our Diana tool, and as time series (meteograms). ENS products are presented as probability fields in horizontal maps, as well as clusters and single members. The ensemble spread in t2m, z500 and 6h-precip is also represented as time series/meteograms. We are currently working on how to present ENS products in vertical cross sections and profiles.

Public short-range forecasting is mainly based on the limited area models AROME-MetCoOp and AROME-Arctic. From 8 November 2016 MET introduced MEPS (MetCoOp Ensemble Prediction System) consisting of 10 ensemble members with 2.5km resolution covering Scandinavia (identical domain as the AROME-MetCoOp). Ensemble members run up to +54h, while the control run is extended to +66h and replaces the deterministic AROME-MetCoOp to be presented to the public at yr.no. Boundary conditions come from EC HRES, and Scaled Lagged Average Forecast (SLAF) is used for initial and lateral boundary perturbations to the MEPS.

Public medium range (i.e.3-10 days) forecasts are presented on yr.no, and are based on ECMWF ENS (Norway) and ECMWF HRES (rest of the world), as described in 2.1.3. ENS/GLAMEPS are used as supplementary products in general forecasting.

Monthly forecasts are presented in general terms to the general public (News articles on yr.no with some simple graphics.) Monthly temperature and precipitation forecasts (split into separate weeks) are distributed internally and to dedicated users within the energy supply industry and flood forecasting authorities as tables and plotted charts, covering the Nordic and Baltic countries and supplemented with an explanatory text.

ECMWF medium range products - both deterministic and probabilistic - also include data supply and consultancy services for various end users in the energy supply and offshore industry, shipping a.o. MET is currently involved with the Norwegian Flood Forecasting Authorities (NVE) to facilitate the use of the ECMWF monthly forecasts for the purpose of running flood risk scenarios. MET’s contribution to the project is to prepare the data and provide consultation on optimal use.

On behalf of the Norwegian Ministry of Foreign Affairs, MET is involved in projects in Vietnam, Bangladesh and Myanmar, cooperating with the national weather services to build capacity and early warning systems. This includes facilitating the dissemination of NWP-fields (HRES / ENS) covering this region.

***Severe weather*:**

We aim to give authorities and the public special warnings if severe weather conditions are expected to occur within the next 72 hours. Elements include strong winds, heavy precipitation, avalanche risk and storm surge. Warnings are based upon both the regional models MEPS and AROME-Arctic, and the global models ECMWF and GFS. ECMWF ENS is used as an ‘early warning’ tool, with GFS, GLAMEPS and MEPS as supplementary products. The ensemble systems form a key part of a dedicated methodology in the forecasting of extreme wind and precipitation events.

The forecasters at MET have daily briefs with the Norwegian Flood Forecasting Authorities (NVE), who are responsible for forecasting and preventing flooding and landslides. Precipitation and temperature are of particular interest. For this purpose the Extreme Forecast Index (EFI) and the Shift Of Tails index (SOT) is used regularly. The EFI/SOT output is used and accessed both from the ECMWF website / EC Charts, and in the forecasters visualisation tool, Diana. In many cases the combination of EFI and SOT gives an indication of severe events as early as in the late medium-range. In the early medium-range much weight is put on the high resolution forecast. EFI/SOT has proven to be useful in forecasting severe weather involving both heavy precipitation and strong winds.

2.2.2 Product requests

MET currently produce a lightning index from the local MEPS, based on CAPE, vertical velocity and the Showalter Index. The product is much used by the electricity suppliers and helicopter services. Any plans to provide a lightning index from ECMWF (for example based on the Lopez lightning parameterization) are very welcome, both as a second source of information and for comparison.

Verification of products

3.1 Objective verification

3.1.1 Direct ECMWF model output (both HRES and ENS)

Figure 1 shows the scores for 10 m wind speed from last winter (Dec 16-Feb 17) verified against stations in Northern Scandinavia. It is clear that EC HRES does not produce sufficiently strong surface winds. The same is the case for EC ENS. More results can be found in Homleid & Tveter, 2017: Verification of Operational Weather Prediction Models December 2016 to February 2017.

3.1.2 ECMWF model output compared to other NWP models

Precipitation forecasts are verified using several measures in addition to ME, SDE and MAE. Figure 2 shows the hit rate, false alarm rate, false alarm ratio, equitable threat score, Hanssen-Kuipers skill score and Heidke Skill Score as a function of exceedance threshold for the autumn 2016 for ECMWF HRES (Cycle 41r2) and AROME-MetCoOp. The HRES output compares well to the local LAM on moderate precipitation amounts, but is still too heavy on small precipitation amounts. For the largest precipitation values there seems to be a change from the previous IFS cycle; the systematic underestimation of the highest accumulation is less pronounced during last autumn. It is too early to say if this is a result of one predictable autumn season, or if this is a significant result.

Examples of 10 m wind speed forecast verification of EC HRES compared to various versions of AROME-MetCoOp are given in figures 3 and 4, showing time series of monthly mean and standard deviation of errors from October 2013 to December 2016. The results are averaged over various selections of stations. Large negative mean errors for the 5 mountainous stations demonstrate that the wind speed is too weak in mountainous regions. Along the coastline the wind speed forecasts were unbiased or slightly underestimated (Figure 3).

Figure 4 shows that all models have similar quality of the 10 metre wind speed with respect to standard deviation of errors.

More results can be found in Homleid & Tveter, 2016: Verification of Operational Weather Prediction Models September to November 2016.

3.1.3 Post-processed products

As reported last year, the forecasts of 2m temperature in winter was significantly improved with IFS Cycle 41r2. However, there is still a bias in both EC HRES and EC ENS, growing with lead time. For end-users on yr.no, we therefore still need to apply some statistical calibration on the EC-ENS temperature forecasts (figure 5)

3.2 Subjective verification

3.2.1 Subjective scores (including evaluation of confidence indices when available)

Some comments on EC HRES / EC ENS from the duty forecasters at MET:

- 10m wind in complex terrain is seriously underestimated in both HRES and ENS. 850 hPa wind is generally more useful.
- There is too little precipitation in convective situations in summer, especially in squall lines ahead of a cold front.
- 2m temperature maximas are too low in summer (even though the air masses are warm and the temperature in 850 hPa indicates temperatures well above climate values)
- The synoptic situation is usually very well predicted up to 3-4 days.
- SOT/EFI are powerful tools in forecasting severe weather 24-84h ahead
- The highest rainfall amounts are better predicted by the local MEPS/MEPS-cntrl than by EC HRES/ENS

3.2.2 Case studies

Extreme rain event Spitsbergen 7-8 November 2016

An unusually persistent southwesterly flow bringing mild and humid air to Spitsbergen during 7-8 November 2016, caused large amounts of rain to the region. 24h rain accumulations for Svalbard Airport was 41.7 mm, Isfjord Radio 47.2 mm Barentsburg 64.0 mm and Ny Ålesund 86.8 mm. The real rainfall was probably higher due to observation loss caused by the strong wind. Even so, this event is the second largest rain event on record for the region.

The event was well predicted by the EC ENS & HRES, with consistent, strong signals of unusually high temperatures and heavy precipitation. In this case, the predicted precipitation from EC HRES was slightly too low, while AROME-Arctic was very close to the observed values. (Figure 7)

Severe wind and storm surge event 'Urd' 26.December 2016

The winter storm 'Urd' hit the western coast of Norway 26.December 2017, with hurricane force winds and storm surge along the southern coastline (Figure 8). There was a solid signal for high winds in the ENS forecasts 7 days ahead, and fairly consistent HRES forecasts the last 3-4 days prior to the storm. However, as shown in Figure 9 , EC HRES struggles in predicting the highest wind speeds, while the local Arome-MetCoOp with the operational post-processing does a decent job in forecasting the maximum 10 winds observed.

Feedback on ECMWF "forecast user" initiatives

The "known IFS forecast issues" page and the "severe event catalogue" are not used regularly by people at MET. Even though they are easier to find from the ordinary WEB pages, their existence is not well-known among the users of ECMWF products.

References to relevant publications

Homleid, M and **F. T. Tveter**, 2016: Verification of Operational Weather Prediction Models September to November 2016. http://www.met.no/publikasjoner/met-info

Homleid, M and **F. T. Tveter**, 2017: Verification of Operational Weather Prediction Models December 2016 to February 2017. http://www.met.no/publikasjoner/met-info

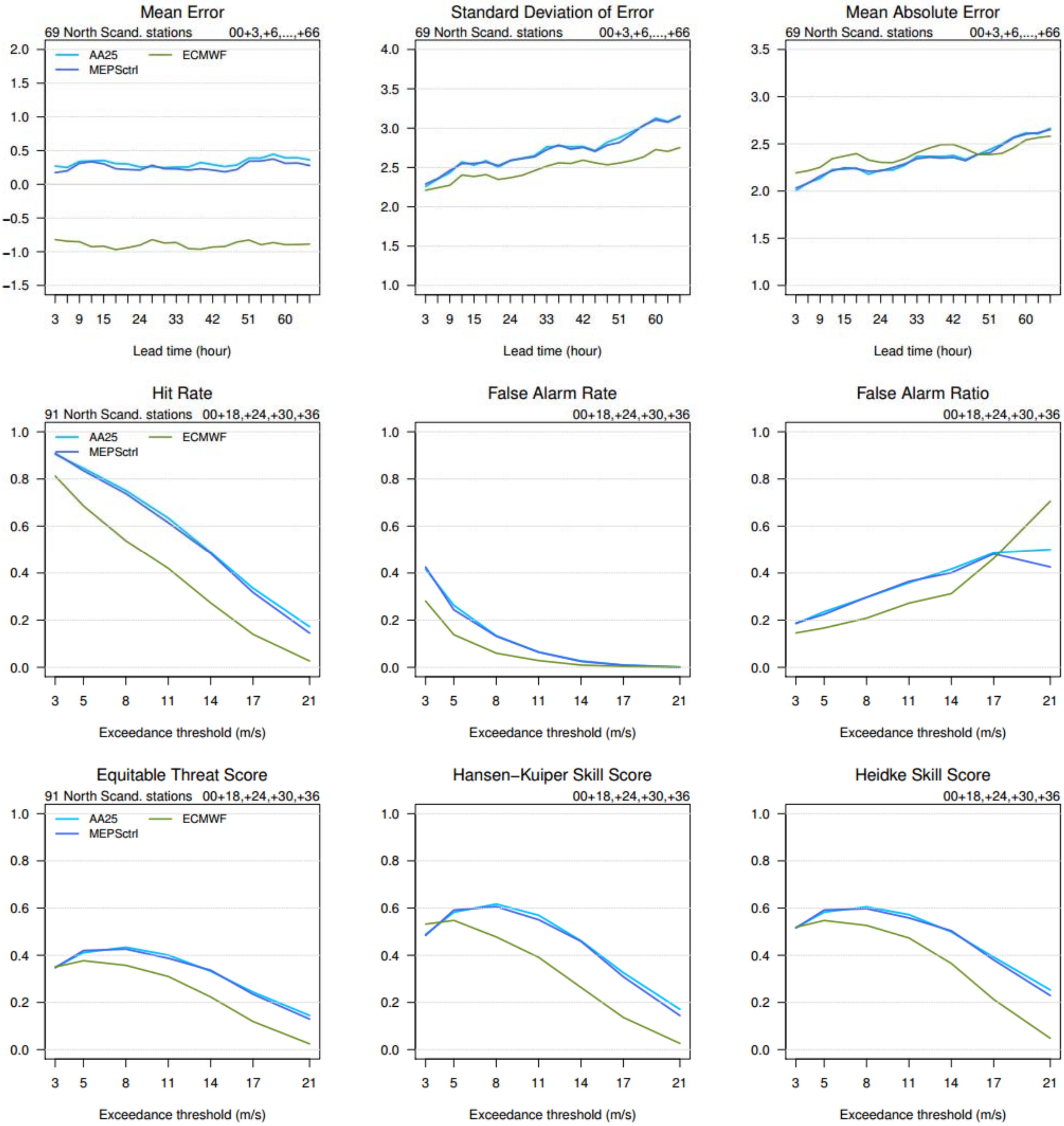

Fig.1 Standard skill scores for 00+3-66h **10 metre wind** forecasts for the winter 2016/2017**.** EC HRES (olive), MEPS-cntrl/AROME-MetCoOp (blue), AROME-Arctic (cyan)

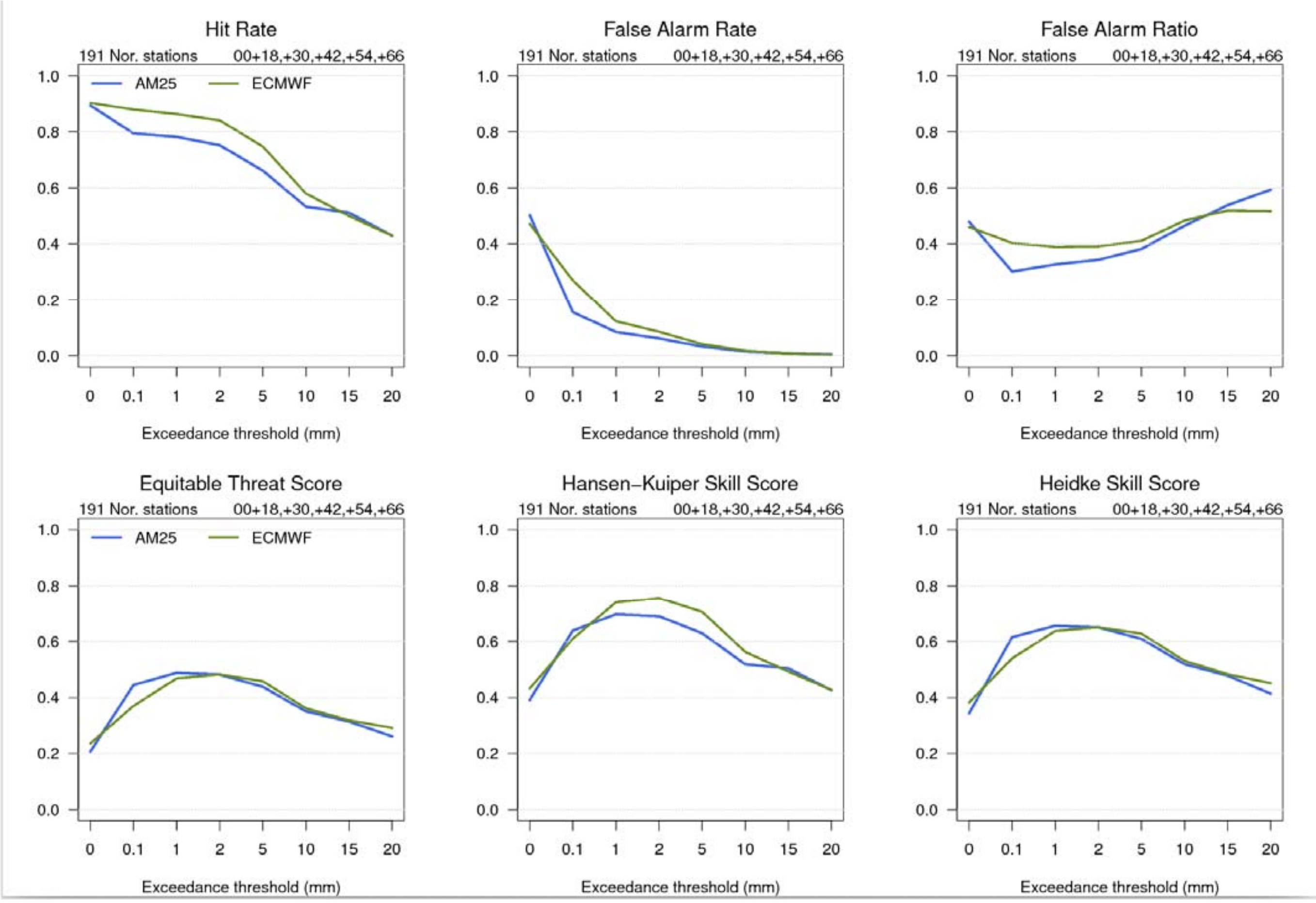

Fig.2 Hit rate, false alarm rate, false alarm ratio, equitable threat score and Hanssen-Kuipers skill score and Heidke Skill Score for 00+30/54 **24h accumulated precipitation** forecasts for the autumn 2016**.** EC HRES (olive), AROME_MetCoOp (blue)

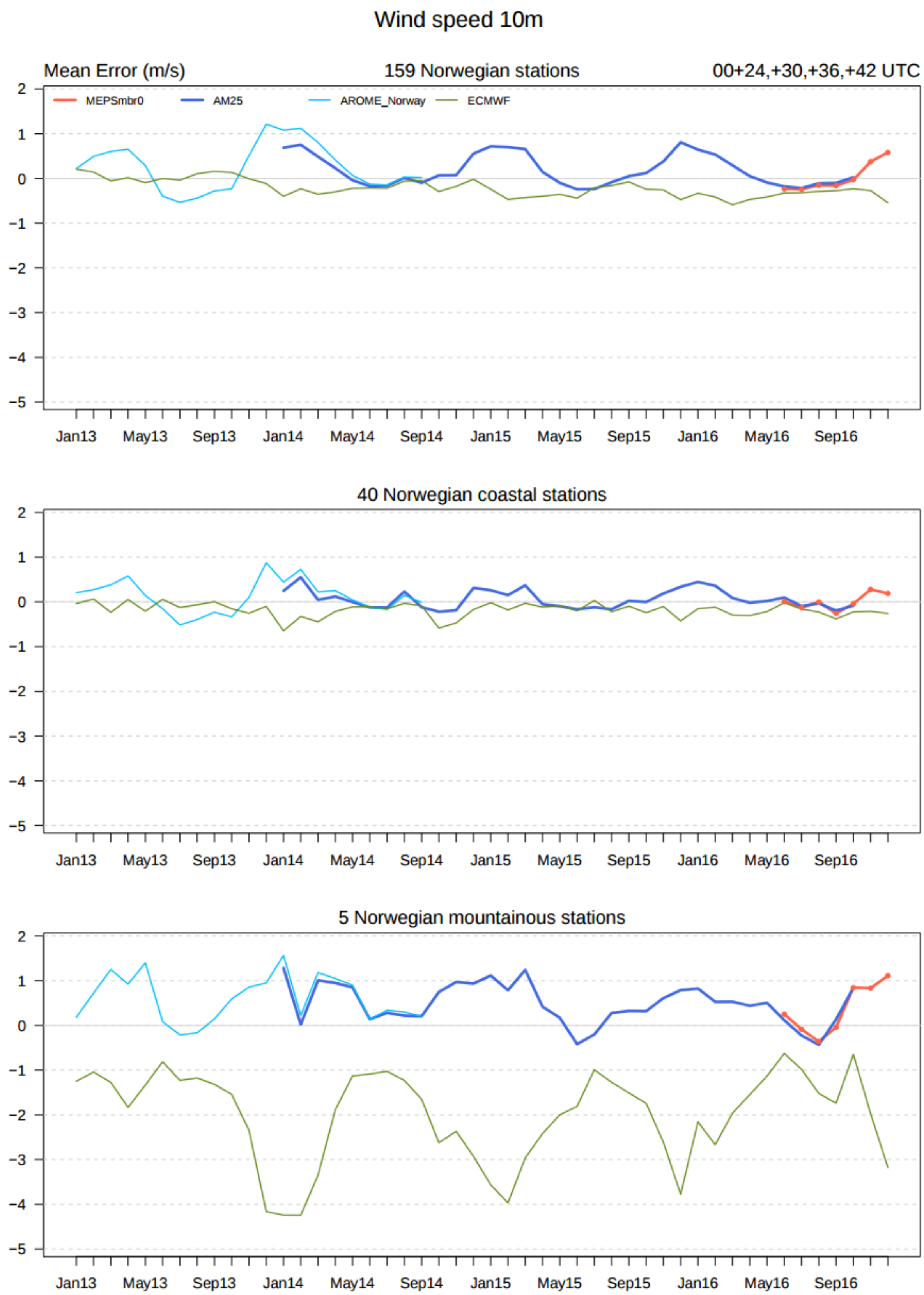

Fig.3 Monthly mean errors from October 2013 to December 2016, 00+24,+30,+36,+42 **10 m wind speed** forecasts. EC HRES (olive), AROME_Norway (cyan) , AROME_MetCoOp (dark_blue) and MEPS-cntrl (red).

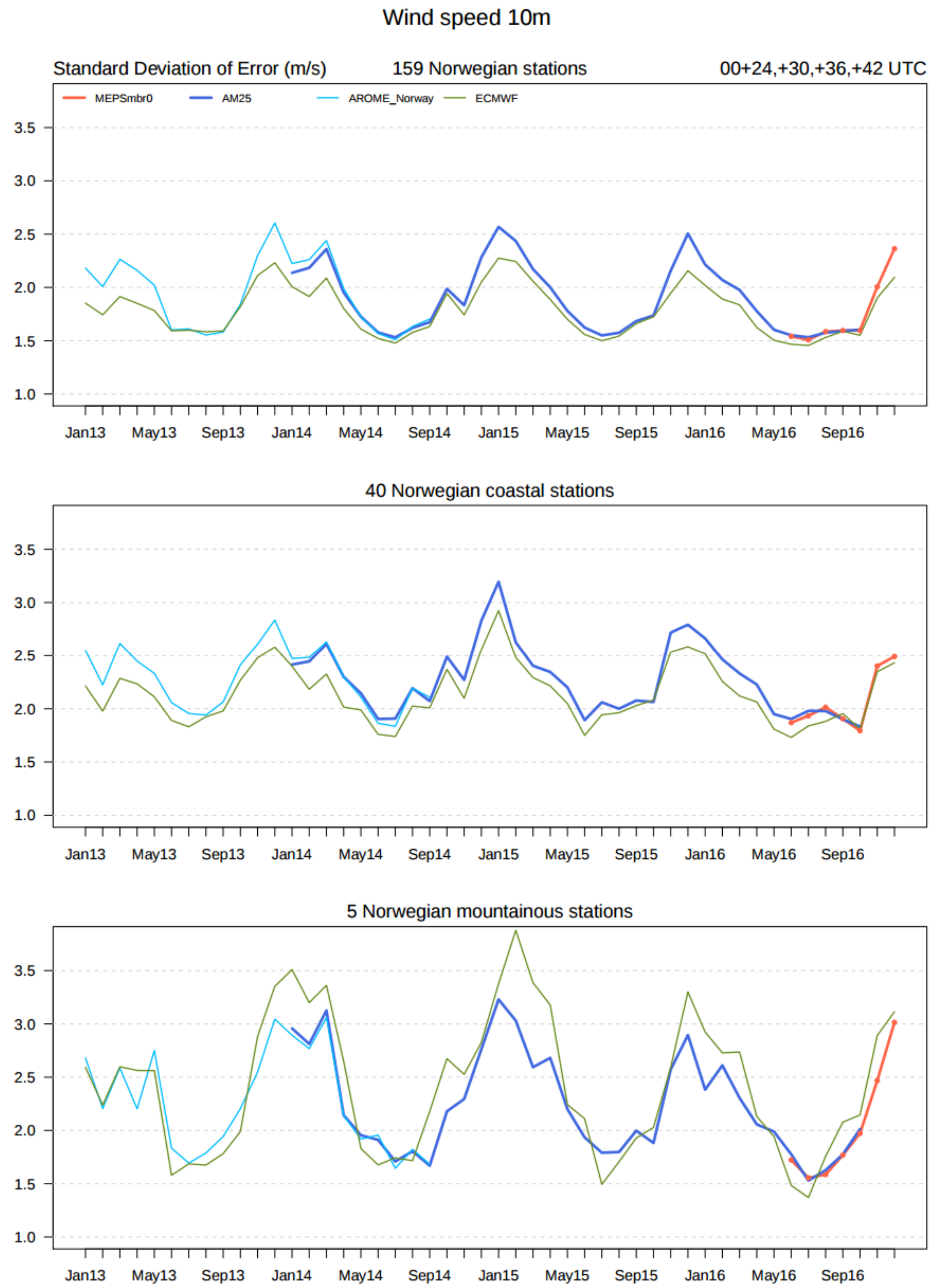

Fig.4 Monthly standard deviation of errors from October 2013 to December 2016, 00+24,+30,+36,+42 **10 m wind speed** forecasts. ECMWF (olive), AROME_Norway (cyan) , AROME_MetCoOp (dark_blue) and MEPS-cntrl (red).

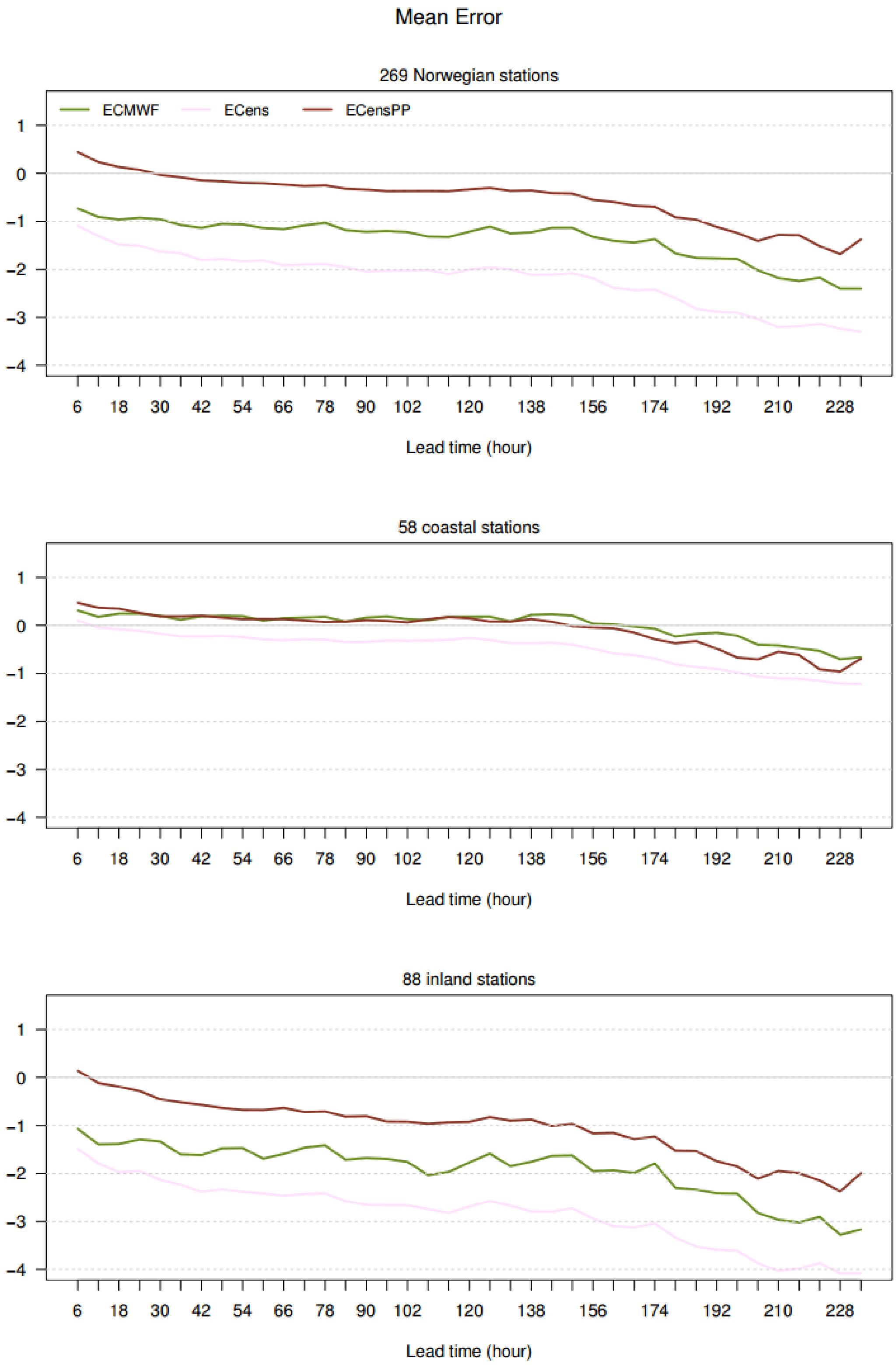

Fig.5 Mean error of **Temperature at 2 meters**, by lead time for the winter 2016/2017 (dec-feb)**.** ECMWF HRES (olive), EC ENS(pink), EC ENS with post processing (brown)

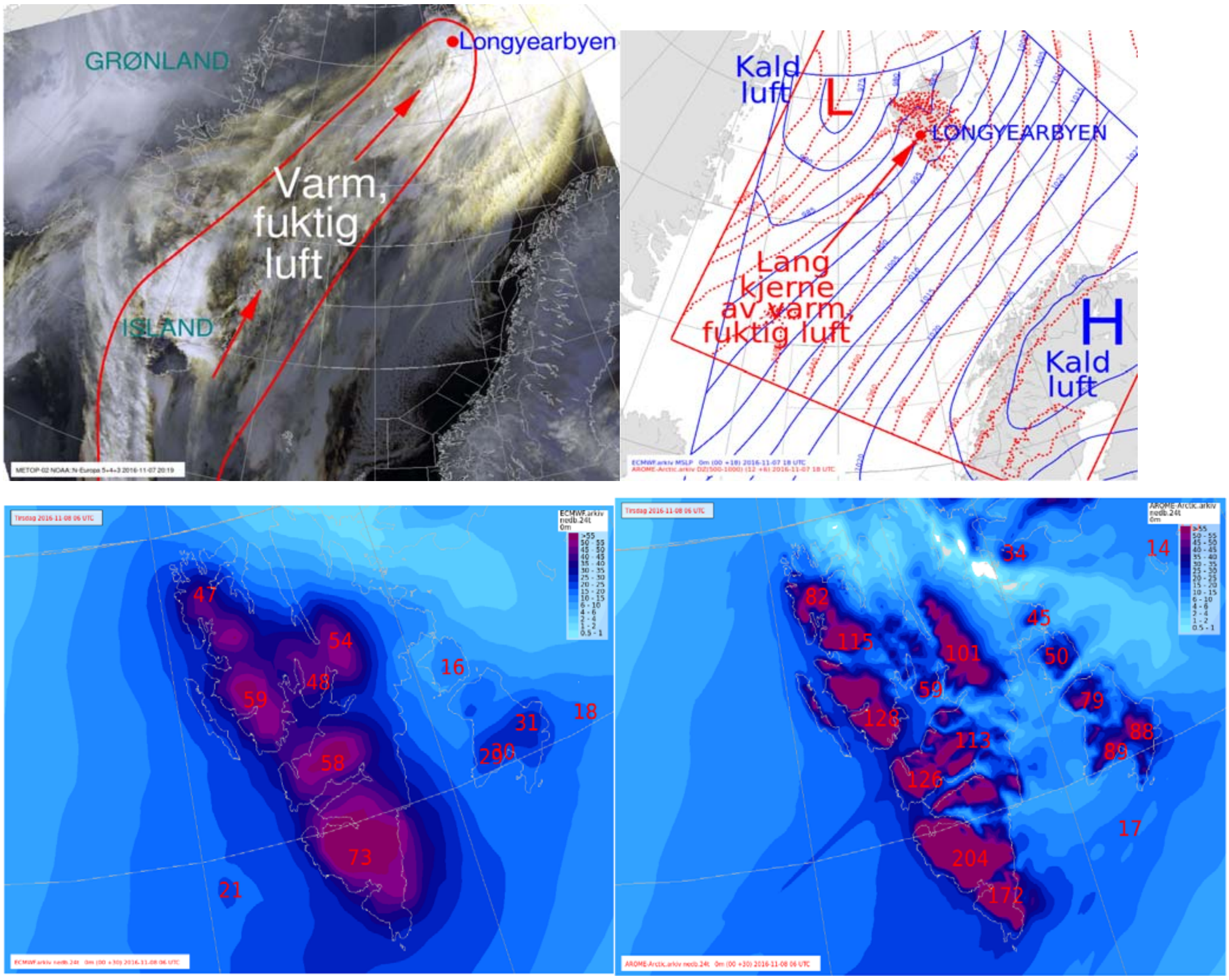

Fig.7 Severe rain event at Spitsbergen 7. November 2016. Top left: Satellite image with the narrow band of moisture transport marked in red. Top right: surface pressure and thickness on the evening of 7.November. Bottom left: Precipitation forecast (24h accum) from EC HRES 00+36h. Bottom right: Precipitation forecast (24h accum) from AROME-Arctic,00+36h.

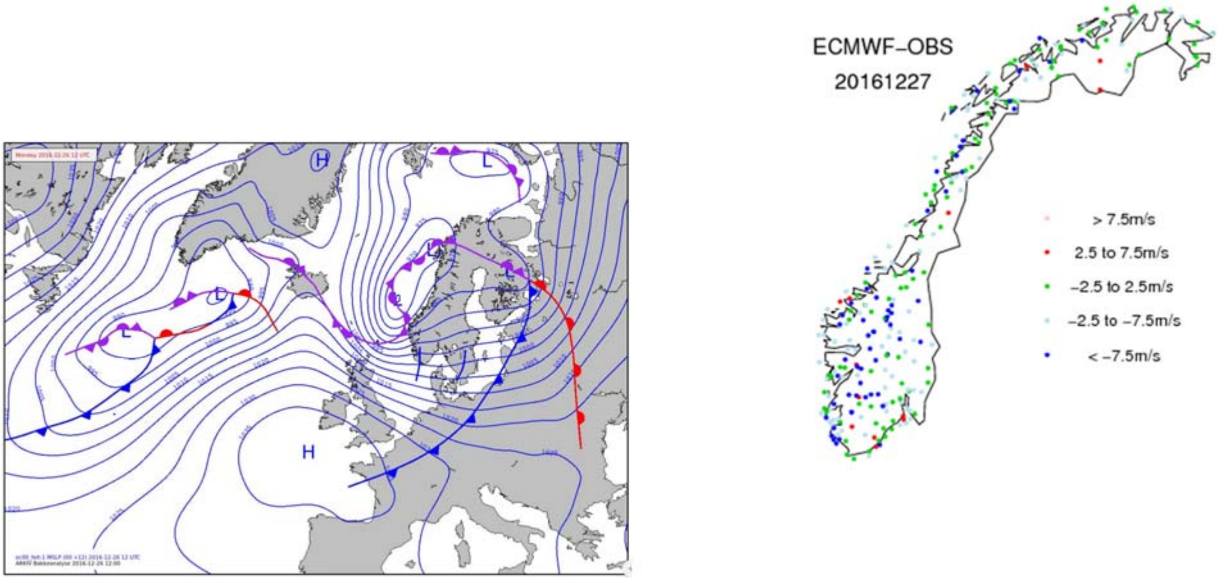

Fig.8 The winter storm ‘Urd’, 26. December 2016. **Synoptic situation (left)** with back-bent occlusion near the Western coast. **Observations compared to EC HRES (right)** show systematic under-forecasting of the highest wind speeds both along the coast and inland.

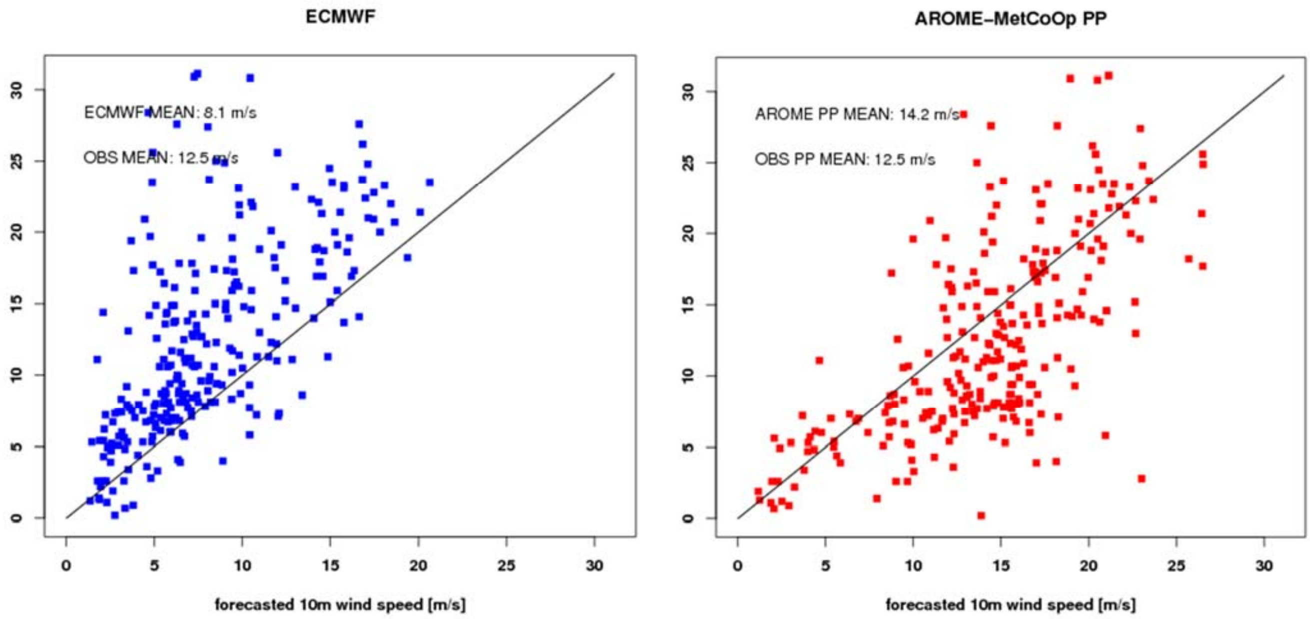

Fig.9 Scatterplot of **wind observations during the severe wind event ‘Urd’.** It is clear that EC HRES does not produce strong enough winds, while the local AROME-MetCoOp shows a closer fit to the recorded wind speeds.