Application and verification of ECMWF products 2016

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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 customers. ECMWF provides boundary values to the AROME-MetCoOp and AROME-Arctic Limited Area Models (covering Scandinavia + Svalbard), and is also basis for LAM ensembles, downstream ocean and chemistry models, input to statistical methods, and is used more or less directly by end uses.

The forecasts are mainly verified directly against observations and less against computed areal observations. Results are presented in quarterly reports and on internal web pages.

The resolution increase and improvements made in the most recent IFS code (cycle 41r2) has led to outphasing of MET's local HIRLAM (8 and 12km). Outside the AROME-MetCoOp domain (Scandinavia) and AROME-Arctic (Svalbard), weather forecasts and downstream predictions in need of NWP input will from 2017 be based upon ECMWF only.

2 Use and application of products

2.1 Post-processing of ECMWF model output

2.1.1 Statistical adaptation

The ECMWF ENS forms the basis for the public medium range forecasts (3-10 days) for Norway presented on yr.no. The ECMWF HRES is used for the rest of the world. For Norway there is currently a statistical calibration of air temperature (2m) and precipitation, and from this winter (2016) also of wind speed (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.

2.1.2 Physical adaptation

Output from the ECMWF model provide lateral boundary values for limited area modelling, mainly for the AROME-MetCoOp and AROME-Arctic models (2.5 km horizontal resolution, based on Harmonie) at 00, 06, 12 and 18 UTC, and for the AROME-MetCoOp EPS system (MEPS) that went pre-operational this spring (2016). It is also used in forcing of Wave- and Ocean models and as input to dispersion models for volcanic ash and nuclear emissions.

As a result of the newest upgrades and resolution improvement of Cycle 41r2 (spring 2016), it has been decided to outphase our HIRLAM 8-and 12km Limited Area Models (covering Northern Europe/Atlantic), and as of next year (2017) all downstream production for areas outside the AROME-MetCoOp and AROME-Arctic domains will be based upon ECMWF (HRES/ENS).

2.1.2 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 AROME-MetCoOp/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 near 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 Use of ECMWF 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 rr6h is also represented as time series/meteograms. We are currently working on how to present ENS products in verical cross sections and profiles.

Monthly forecasts are presented in general terms to the general public (News article on yr.no with some simple graphic. Monthly temperature and precipitation forecasts (split into separate weeks) are distributed internally and to dedicated users within the energy supply industry and flooding authorities in the form of tables and plotted charts, overing the Nordic and Baltic countries and supplemented with an explanatory text.

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/MEPS are used as supplementary products in general forecasting.

Other applications of ECMWF medium range products - both deterministic and probabilistic - include data supply and consultancy services for the energy supply and offshore industry, shipping a.o. For example; MET has worked closely with some of the big users in the Energy sector to help them use Monthly and Seasonal forecasts instead of Climatology as input to their local impact models and production planning tools.

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:

Our main focus is 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 deterministic models, including AROME-MetCoOp and AROME-Arctic (up to 2 days) and ECMWF HRES (up to 3 days), and the ensemble systems (MEPS, GLAMEPS and ECMWF ENS). ECMWF ENS is used as an 'early warning' tool, with GLAMEPS and MEPS as supplementary products for shorter time ranges. 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 regularily. 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 heavy precipitation.

3 Verification of products

3.1 Objective verification

3.1.1 Direct ECMWF model output (both HRES and ENS)

MET has in the previous years reported a large winter cold-bias in Surface Temperature along the coast of Northern Norway. With the model and resolution upgrade of March 2016 (IFS cycle 41r2), these problems are clearly reduced, as described in ECMWF Newsletter No. 148 - Summer 2016. The improvement origins both from increase in horisontal resolution, and from the significant improvement in the radiation scheme, where radiative heating and cooling of the surface is now updated on full model resolution for every time step.

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 1 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 2015 for ECMWF HRES (Cycle 41r1), HIRLAM8 and AROME-MetCoOp. The HRES output compares well to the local LAMs on moderate precipitation amounts, but is too heavy on small precipitation amounts, and sightly too weak on the largest values.

3.1.3 Post-processed products

Examples of 10 metre wind speed forecast verification of the ECMWF HRES model compared to HIRLAM8 and various versions of AROME-MetCoOp are given in figures 2 and 3, showing time series of monthly mean and standard deviation of errors from October 2012 to December 2015. 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 shows that all models have similar quality of the 10 metre wind speed with respect to standard deviation of errors.

3.1.4 End products delivered to users

As we have had problems with too low winter temperatures in the previous IFS cycles, we were interested to see the impact of the improvements in IFS Cycle 41r2. We have compared ENS 2m temperature forecasts from the new and the previous cycle for at test period from 10 Dec 2015 to 1 February 2016.

Figure 4 shows the probability density functions of the forecast errors from the old and new cycle. It is evident that the old cycle is leaning towards negative values. The new cycle is significantly better, with fewer examples of large under-prediction of temperature. Out of 37 stations in the study, 20 have a cold bias of more than 2°C in the old cycle, whereas only 11 has a similar bias in the new cycle. The PDF from the post-processed forecast has almost no bias.

When applying statistical calibration on the new EC-ENS temperature forecasts, we are confident that MET can provide its users with significantly better medium range temperature forecasts for the coming winter season.

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 mountainous regions is seriously under-estimated 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 airmasses are warm and the temperature in 850hPa 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 Arome-MetCoOp/MEPS than by EC HRES/ENS

3.2.2 Case studies

Severe weather event 'Synne', 4-6 Dec 2015

4-6 December 2015 Southwestern Norway was hit by a severe precipitation episode, with close to 300 mm accumulated rain on top of snow melting. This lead to widespread flooding and disruption of transportation. This case was named 'Synne' by the MET forecasters (and 'Desmond' by UK Met Office').

The EC EFI/SOT and EC ENS probabilities of heavy precipitation were able to predict the severity of the event 2-3 days ahead, even though the the areas of highest precipitation was slightly misplaced, as shown in figure 5.

Figure 6 show the synoptic situation leading to the flooding, and the forecast issued by the MET forecasters.

Figure 7 illustrates the importance of local high-resolution forecasts in addition to the global forecasts from EC. In the case of 'Synne', EC HRES and ENS was not able to predict more than 130 mm accumulated rain, while AROME-MetCoOp forecast more than 230 mm, and the highest observation was 299 mm.

Mountain waves

A random case from November 7th 2014 shows mountain waves at the coast of northeastern Norway. The highest wind was observed at 01092 Makkaur between 18Z and 21Z with SW 51G61KT, which is rather typical in these situations. There are strong southwesterly winds aloft over rather low (typically 500 masl) and flat mountains, steep towards the coast. As shown in figure 8, AROME-MetCoOp (yellow/orange) forecasts strong gale at the coast, while ECMWF (green) forecasts strong breeze with 17 m/s gust (red). Surface wind is not used for forecasting in these cases, but wind aloft is used for medium range forecasting.

4 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. They are hard to find from the ordinary WEB pages, and their existence is not well-known among the users of ECMWF products.

5 References to relevant publications

http://www.ecmwf.int/sites/default/files/elibrary/2016/16523-newsletter-no148-summer-2016.pdf :

Better temperature forecasts along the Norwegian coast (Seierstad, Kristiansen, Nipen / MET Norway)

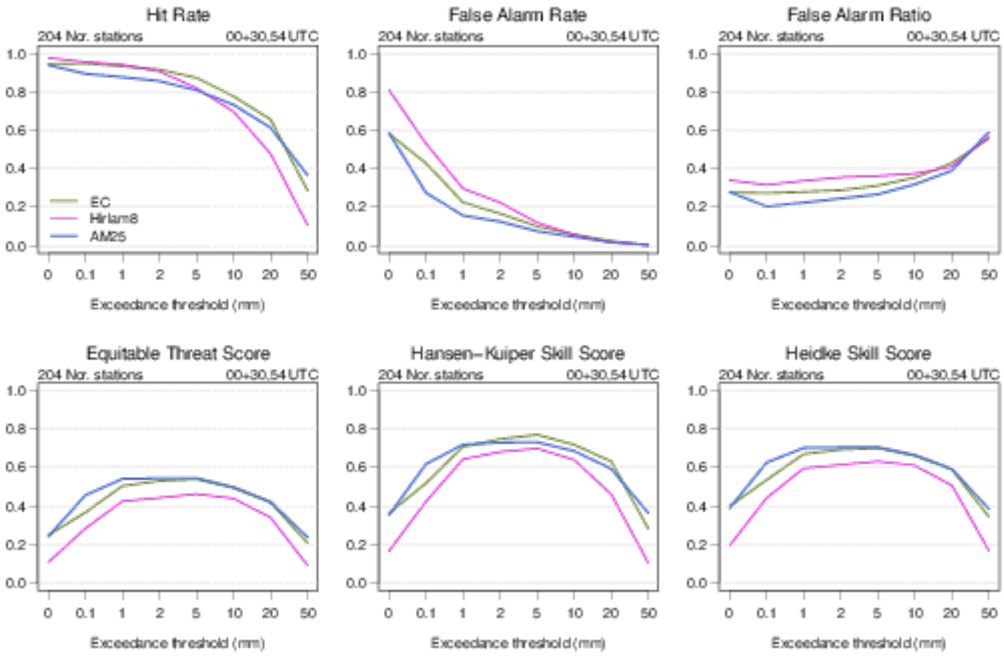

Fig 1 Hit rate, false alarm rate, false alarm ratio, equitable threat score and Hanssen-Kuipers skill score and Heidke Skill Score for 00+30/54 **24h accumulated precipitation** forecasts for the autumn 2015**.** ECMWF 41r1 (olive), HIRLAM8 (pink), AROME_MetCoOp2.5 (blue)

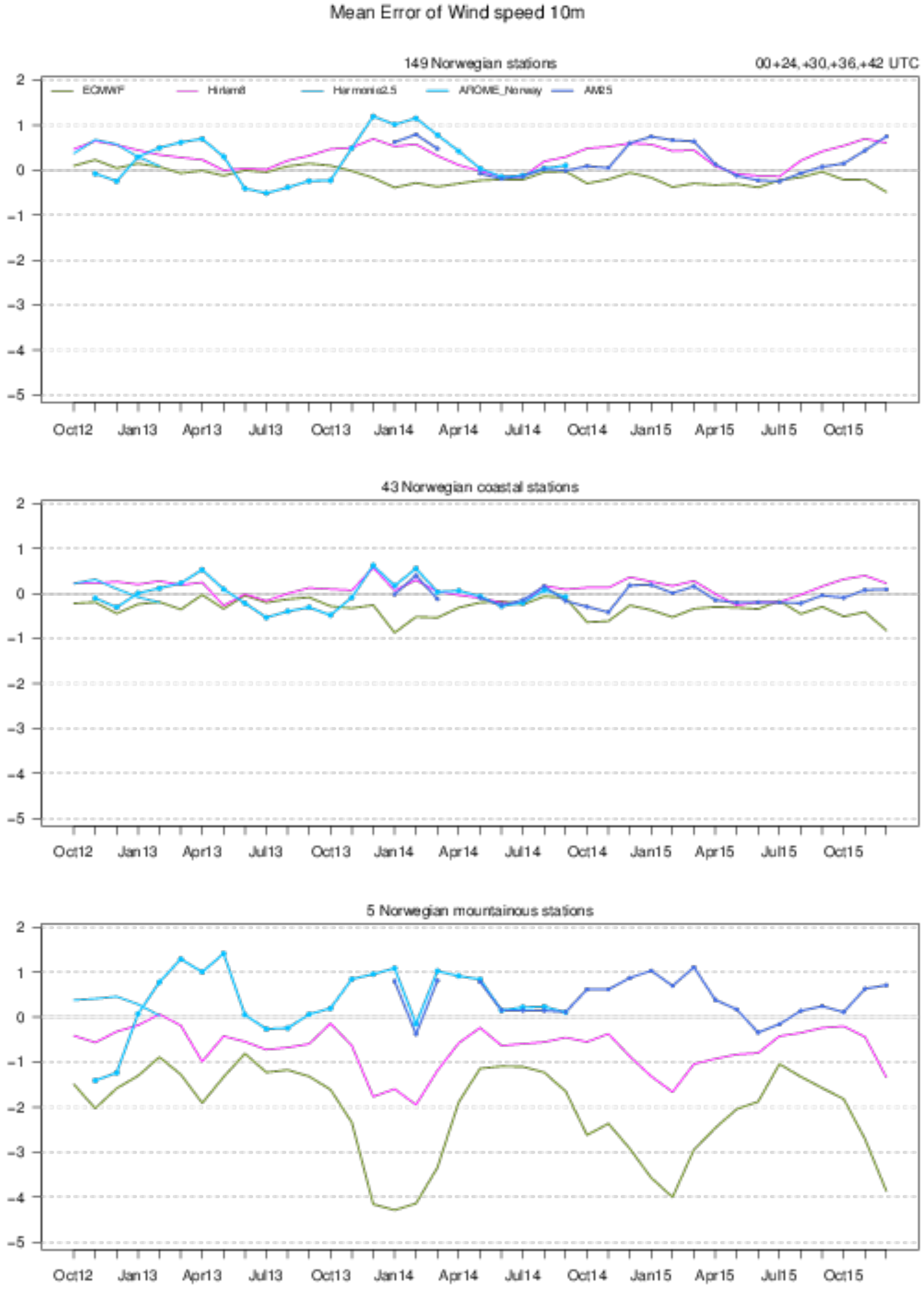

Fig 2 Monthly mean errors from October 2012 to December 2015, 00+24,+30,+36,+42 **10 m wind speed** forecasts. ECMWF (olive), HIRLAM8 (pink), Harmonie2.5 (cyan, solid), AROME_Norway (cyan, solid and dotted) and AROME_MetCoOp (dark_blue, solid and dotted)

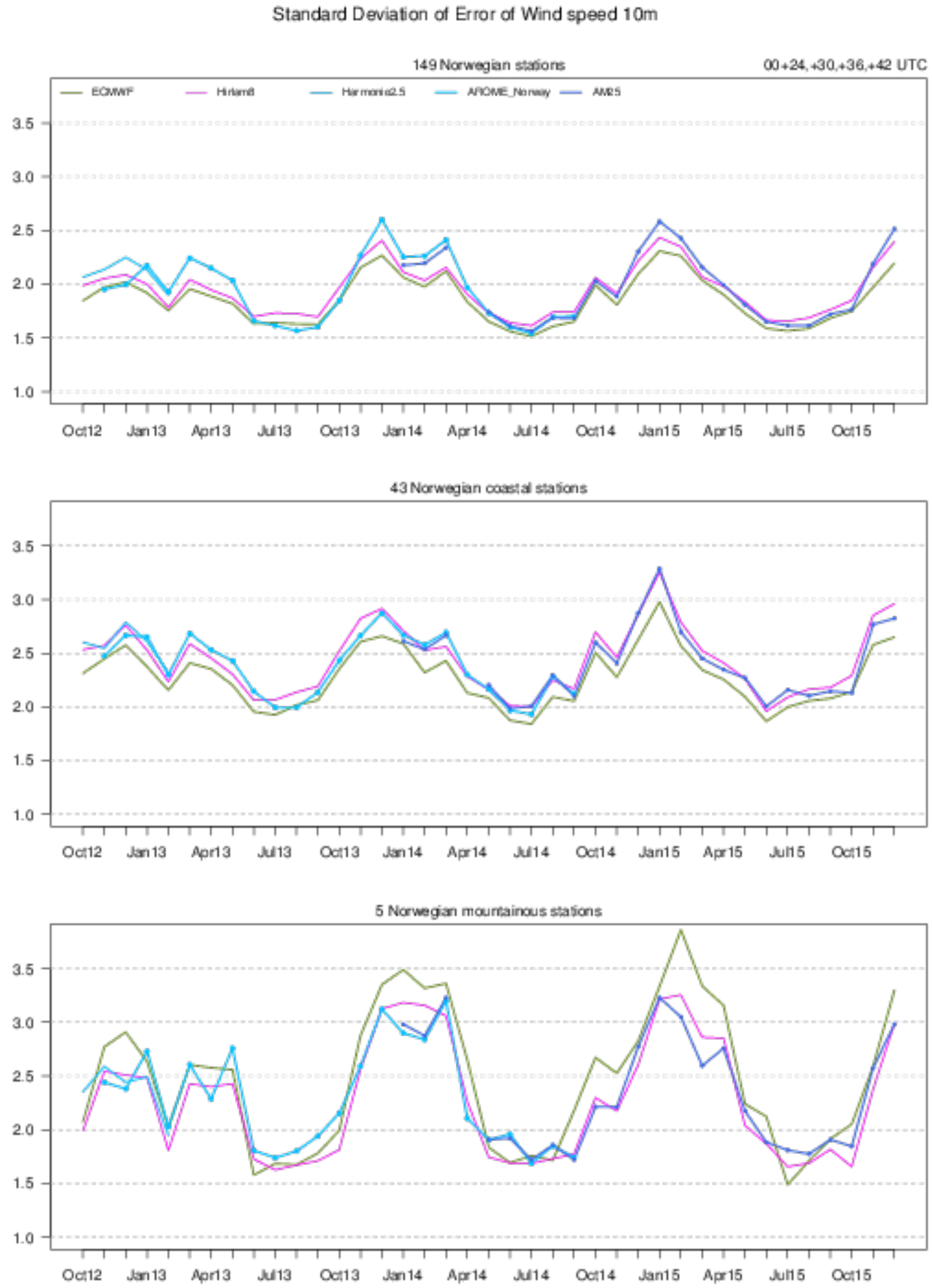

Fig 3 Monthly standard deviation of errors from October 2012 to December 2015 of 00+24,+30,+36,+42 **10m wind speed** forecasts. ECMWF (olive), HIRLAM8 (pink), Harmonie2.5 (cyan, solid), AROME_Norway (cyan, solid and dotted) and AROME_MetCoOp (dark_blue, solid and dotted).

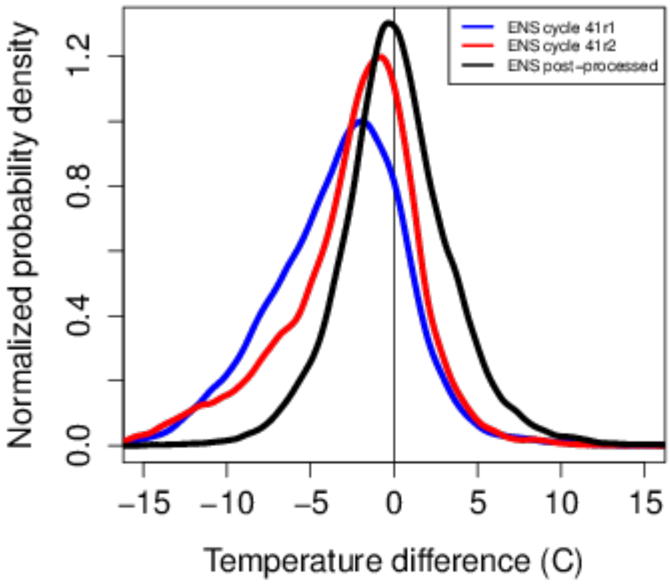

Fig 4 **Reduced temperature errors.** Probability density functions (normalised to maximum values) of the difference between 3-5 day forecasts and observations at 37 costal stations in northern Norway. Negative values mean the forecasts are too cold. The post processed forecast was produced using IFS Cycle 41r1. The evaluation period is 10 December 2015 to 1 February 2016 (see article in ECMWF Newsletter - Summer 2016)

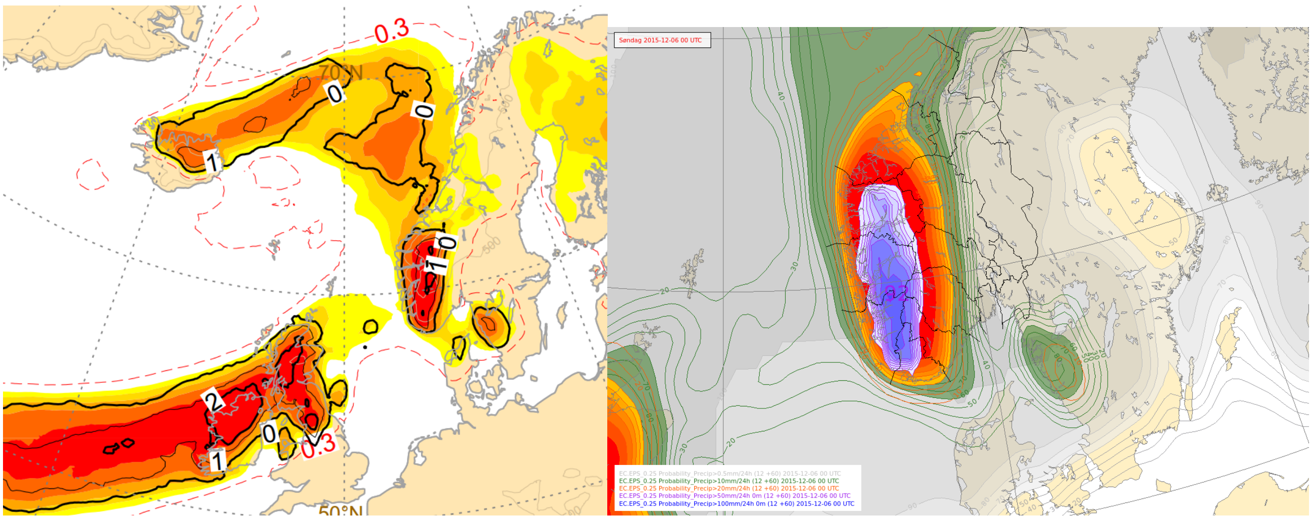

Fig 5 **Flooding event 'Synne', 4-6.dec 2015**. Left: **EC EFI/SOT for precipitation**, base time 12z 3.dec 2015, period T+36-T+60. The highest rainfall occured slightly to the south of the maxima of the SOT contours. Right: **EC ENS probability** of accumulated precipitation exceeding different thresholds. Blue=100mm/24h, probabilities were more than 70% in the forecast from 12z, 3.dec 2015. These types of plots helps the forecasters determine the area most affected by the weather.

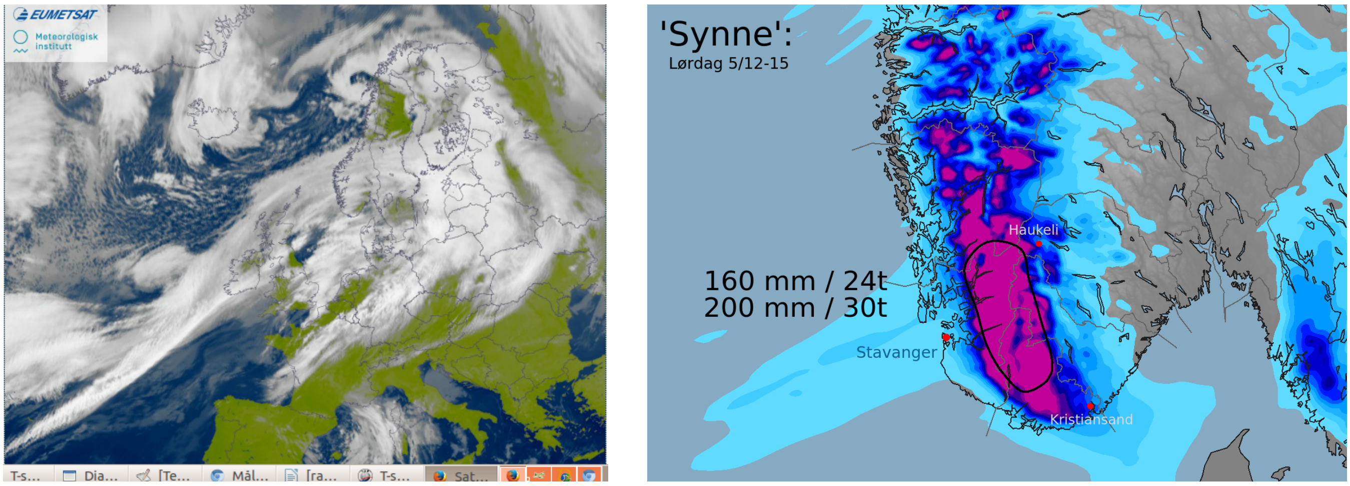

Fig 6 **Flooding event 'Synne', 4-6 Dec 2015.** Left: Meteosat image from 5.Dec 2015, showing the 'Atmospheric River' causing the persistent rain across UK and Southwest Norway. Right: MET forecaster's illustration following the warnings issued for the event. The highest accumulations of rain were 140 mm/24h, 235 mm/48h and 299 mm/72h.

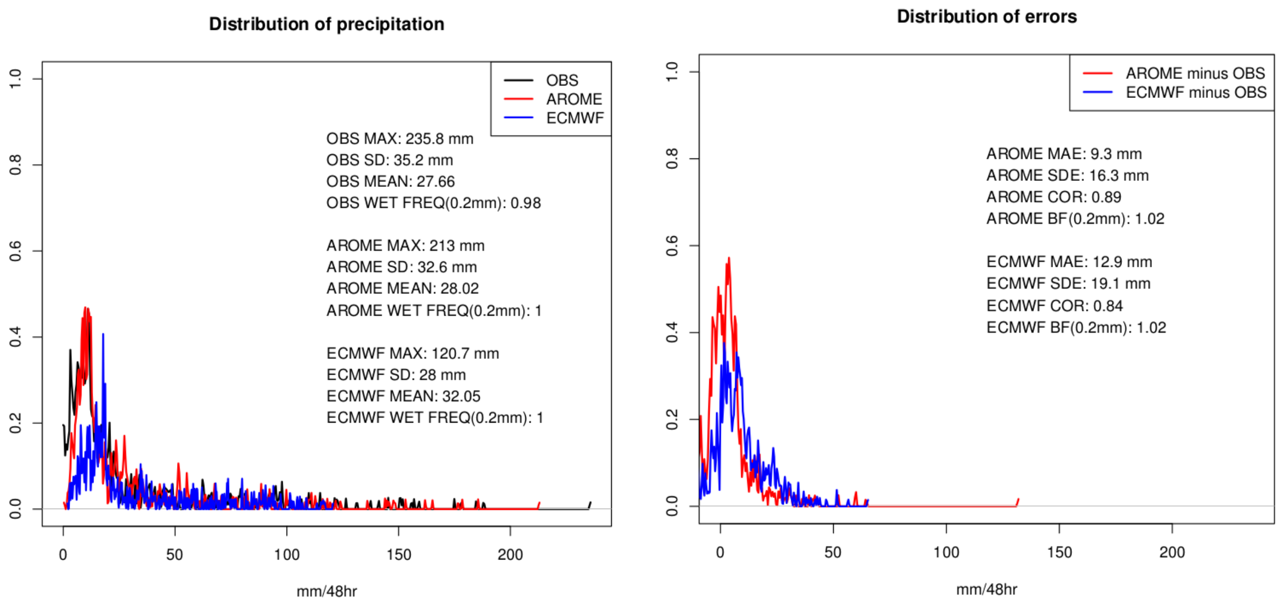

Fig 7 **Observed accumulated 48h rainfall 4-6 Dec 2015**, compared to forecasts from 4.Dec 2015 00Z. Observarions from the entire rain gauge network in Norway (~450-500 stations) Left: The high resolution model AROME-MetCoOp (red) is closer to prediciting the extreme 48h rainfall than is EC HRES (blue). HRES does not predict rainfall above 120mm/48h, whereas AROME-MetCoOp predicts above 200mm . Right: The predicion errors of EC HRES are skewed towards the 'wet' end of the distribution, ie HRES is struggling to predict the highest rainfall amounts.

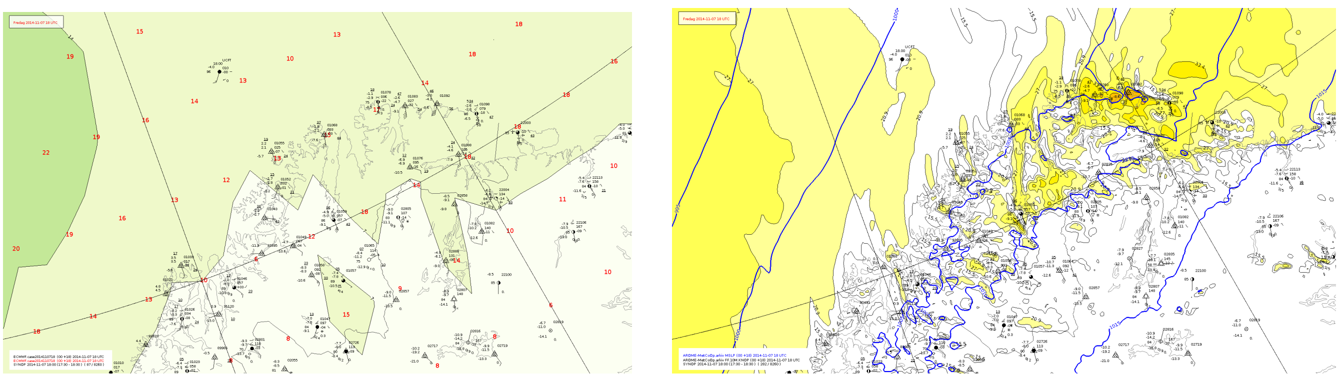

Fig 8 **Mountain waves over Northeastern Norway.** Left: 10m wind from EC HRES (green contours) is too weak, and cannot be used to forecasting Mountain Waves over the terrain in Norway Right: AROME-MetCoOp (yellow contours) is closer to forecasting the observed wind on the lee side of the mountain plateau.