Application and verification of ECMWF products 2009

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1. Summary of major highlights

ECMWF products, especially the medium range forecasts, are extensively used at SMHI. For the short range, ECMWF forecasts are used together with products from the Hirlam and Alaro models. Alaro is a new model based on the French Aladin model dynamics, but with new cloud and convection physics called 3MT. Presently, it is semi-operational. The Hirlam model is used with three different resolutions, 22, 11 and 5 km. 40 vertical levels is used for the coarse resolution and 60 for the others. Alaro has 5 km resolution and 60 levels. ECMWF data is used for boundaries for the 22 and 11 km runs while Hirlam 11 provides boundaries for Hirlam 05. ECMWF boundaries are also used for Alaro.

Surface parameter verification of ECMWF forecasts from July 2008 to beginning of June 2009 show good results for 2 meter temperature, 10 meter wind speed and precipitation. The verification results will be presented in more detail below. The quality of the 2-metre temperature and 10-metre wind speed is further increased by a statistical adoption with a Kalman filtering technique.

2. Use and application of products

2.1 Post-processing of model output

2.1.1 Statistical adaptation

A Kalman filter is used for adjusting 2 meter temperature and 10 meter wind speed forecasts. The correction increments are derived station-wise and then interpolated to a grid in the forecast database using optimal interpolation and utilizing the original forecast as a background field.

ECMWF data is used for creating wind gust forecasts and thunderstorm probabilities. The wind gust forecasts are used together with wind gust forecasts provided as DMO by ECMWF. The thunderstorm probabilities are valid for forecast length up to five days.

2.1.2 Physical adaptation

The ECMWF model data is used to provide lateral boundary conditions for limited area modelling. There are two different areas. The larger area has a horizontal resolution of 22 km and is covering Europe and the north Atlantic and the smaller area covers northern Europe with 11 km or 5.5 km resolution. The one with 5.5 km resolution is used for Alaro, the others are used for Hirlam. The purpose of the small area is to provide a somewhat more detailed forecast than from ECMWF for the short range and a smooth transition to ECMWF forecasts for the medium range.

HIROMB is an oceanographic circulation model including ice. This model is forced by model data from ECMWF and Hirlam and is run up to 10 days. Hydrological models, dispersion models etc. are also using ECMWF model data as input.

2.1.3 Derived fields

There are a lot of such products. The most important ones are probabilities for thunderstorms, near gale, storm and hurricane force winds. Those probabilities are derived from deterministic ECMWF forecasts.

The use of ECMWF deterministic forecasts at SMHI to make medium-range ice forecasts for the Baltic Sea

Information about sea ice is important for navigation in ice-covered sea areas. For the Baltic Sea this is of great importance due to the heavy maritime transports at all time of the year. The ship traffic is normally dependent on assistance from ice breakers. For the logistic planning of the ice breaking activity. e.g. whether to engage another ice breaker and move it to a certain area, it is of great help to have medium-range ice forecasts available.

At the Swedish Meteorological and Hydrological Institute (SMHI), the 10-day deterministic weather forecasts (resolution T799) from the ECMWF are combined with the forecasts from ECMWF's VarEPS system (day 11-15, resolution T255), from which the unperturbed member is used. The result is a 15-day deterministic and also a 12-day ensemble forecast of the Baltic Sea ice conditions. The horizontal resolution of the deterministic and ensemble forecasts are 3 and 12 nautical miles, respectively. (Approximately 5.5 and 22 km, respectively.) Lagged (0-3 days old) deterministic ECMWF forecasts are used to create an atmospheric forcing ensemble, and together with five different initial conditions (perturbed ice concentration and level ice thickness) this yields 20 ensemble members all together.

The result is disseminated on a web page (http://www.smhi.se/polarview/) as a contribution to the Polar View project. Every day, more than 1,000 images are produced for predefined areas and variables; see an example in Figure 1. The system is pre-operational.

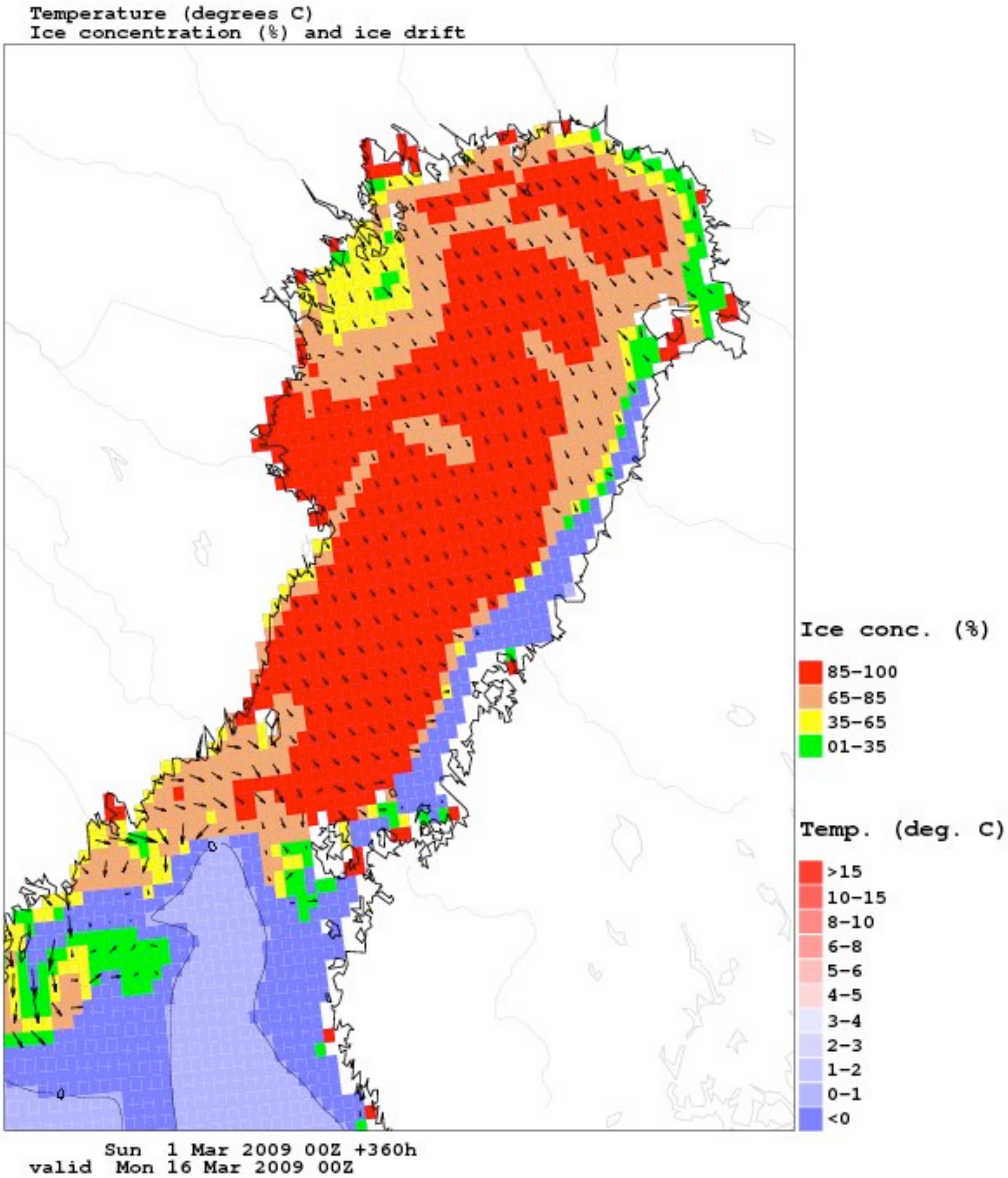

Fig. 1 Example of a figure from the Polar View web page at SMHI. Forecasts of several sea ice variables as well as SST are included on the web page.

2.2 Use of products

Many ECMWF products are used for public warnings. The deterministic runs from 00 UTC and 12UTC are used for our quality controlled forecast database, which covers forecast lengths from 0 to 240 hours. Normally the deterministic forecasts above 30 – 42 hours are used. (Limited area models are selected for shorter forecast lengths.) Sometimes ECMWF is selected already from 6 hours. During 2008 the DMO temperature from ECMWF forecasts had less bias than those from Hirlam 11 and Hirlam 5 km. However, the 10 metre wind seems to be better from the Hirlam models. To obtain better temperature forecasts a statistical method, Kalman filtering, is used on DMO from both Hirlam and ECMWF.

SMHI is using the medium range ECMWF forecasts for products to the media, energy market, etc. An important application is warnings for severe weather for both short and medium range forecasts. ECMWF forecasts have an ongoing good reputation as a guideline for those warnings.

The EPS products from the ECMWF web page are also used for public weather warnings. Most common are wind- and precipitation products, but also plume charts for different places. The monthly forecast is used to obtain signals of a possible change of the general weather situation. An experimental product is the so-called lagged EPS. It is based on the last four deterministic runs from ECMWF and weight them 40,30,20 and 10 percent. The highest weights are given the the most recent forecasts.

Application of ECMWF products for off-line Chemistry Transport Model calculations at SMHI

ECMWF products, especially the deterministic forecast runs for 00 UTC and 12 UTC, MARS archived data, EPS and ERA-40/ERA-Interim data are used as input to the off-line Chemistry Transport and Model (CTM) MATCH in several different types of applications covering Europe and beyond. Examples of applications are real-time nuclear emergency preparedness for forecast times and model areas not covered by the Hirlam operational runs at SMHI. It is also used as a back-up for the Hirlam based forecasts, real-time forecasting of ordinary regional scale air pollutants and retrospective air pollution analyses. The retrospective air pollution analyses sometimes go as far back as to the 1950. Such an example is given below.

An application of ERA-40 for chemistry transport modelling

Air pollution, such as aerosol particles, acidifying and eutrophying deposition and surface ozone has an impact on the environment and on human health. Anthropogenic emissions of air pollution precursors are important for determining the load of air pollutants on the natural environment. However, processes governing creation, transformation, transport and removal of air pollutants from the atmosphere are highly dependent on meteorological conditions.

The long term climate change has a potential of significantly affecting the air quality. For shorter time scale, meteorological conditions have the potential of causing episodes of for example severe concentration of surface ozone or on particle concentration. The summer of 2003 was such a case.

In order to investigate how long-term variations of meteorological conditions affect air pollution, the meteorological data sets, such as the ECMWF Reanalysis (ERA-40) are of great importance. This type of data provides high-quality meteorological input to CTMs. One strength with reanalysis is the dynamically integrated observations. Another is the constant resolution and model version. This gives opportunity to investigate the inter-annual variation and long-term trends in air pollution due to meteorological conditions. This will reduce the risk of biases or other errors caused by changes in numerical model resolution or version.

In this study, the model was coupled to meteorological data from the ERA40 data set. Emissions and boundary conditions of chemical compounds and particles of matter were kept constant at present levels.

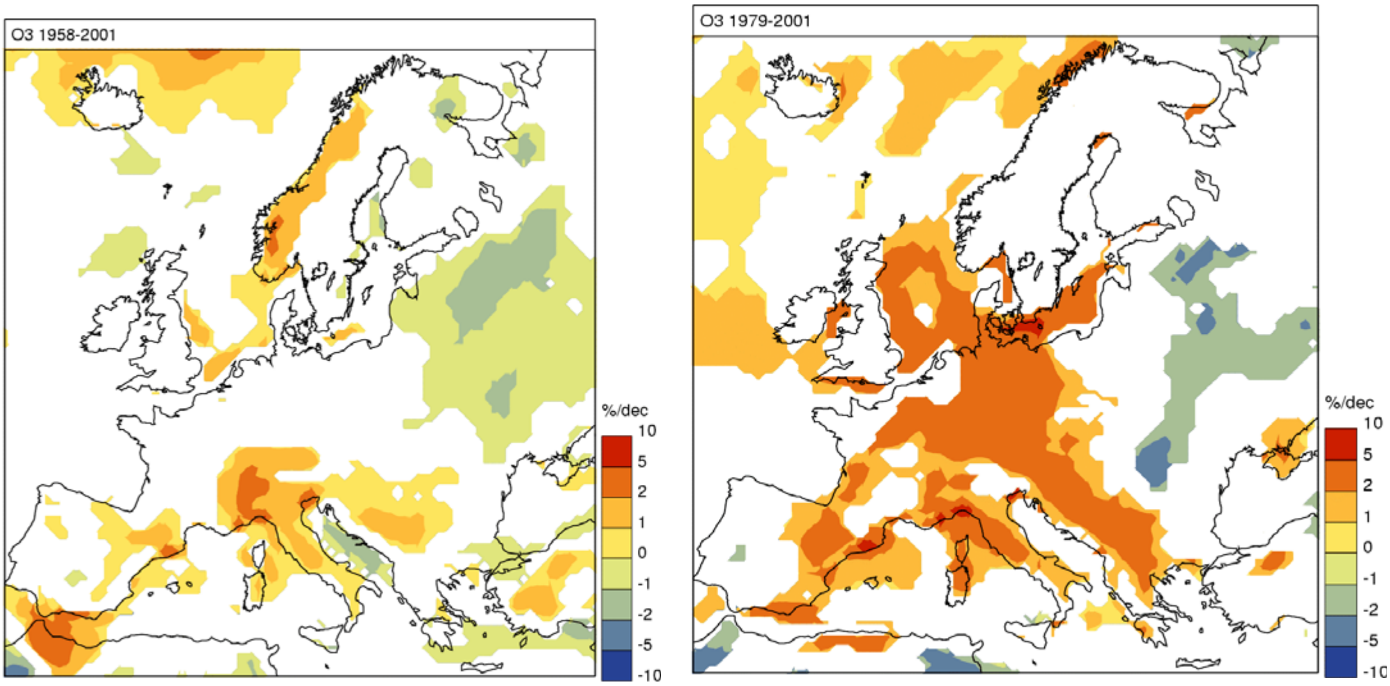

Fig. 2 Linear trend in April-September average surface ozone for two time periods: 1958-2001 and 1979-2001. White areas have no significant trend at 90% significance level. Unit: precent change per decade.

So all trends and all variations are due to changes in meteorological conditions. We see that climate variability in the ERA40 data set induces significant trends in surface ozone over parts of

Europe. The figure displays the linear trend over the periods 1958-2001 and 1979-2001. In central Europe there is a clear increasing trend and in north-eastern Europe the trend is decreasing.

3. Verification of products

3.1 Objective verification

3. Direct ECMWF model output (short range deterministic)

2 metre temperature

The overall quality of the ECMWF 2-metre temperature forecasts is very high. For the short range the forecasts are essentially of the same quality as those from Hirlam. Both models were too warm in February 2009, when there was a period of cold weather and weak winds in the northern part of Sweden. There was a cold bias for both Hirlam and ECMWF in spring this year. This cold bias was more pronounced in Hirlam. By Kalman filtering the forecast, the biases were reduced (Figure 3) and the absolute error was also reduced. Note that only a very short period has yet been verified for June this year.

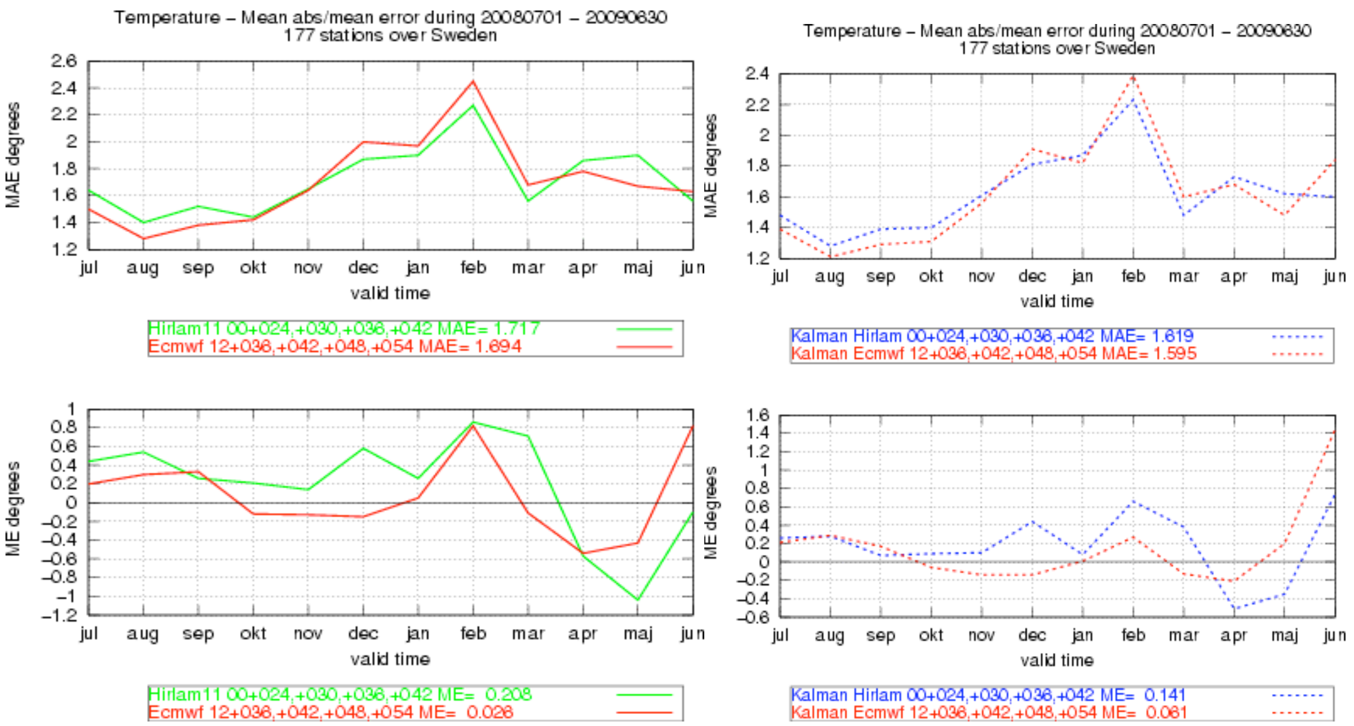

Fig. 3 To the left: Mean absolute error and bias (mean error) for Hirlam 11 km (green) and ECMWF (red) for different months. To the right: The same for Kalman filtered Hirlam and ECMWF 2 metre temperatures.

10 metre wind

For inland stations ECMWF forecasts overestimates the 10 metre wind speed with up to 1 m/s. This overestimation is somewhat smaller in Hirlam 11. (Figure 4, left) The error is larger during winter than in summer in both models. The same types of error were also present in 2007. For coastal stations, the systematic error is less while the mean absolute error is larger.

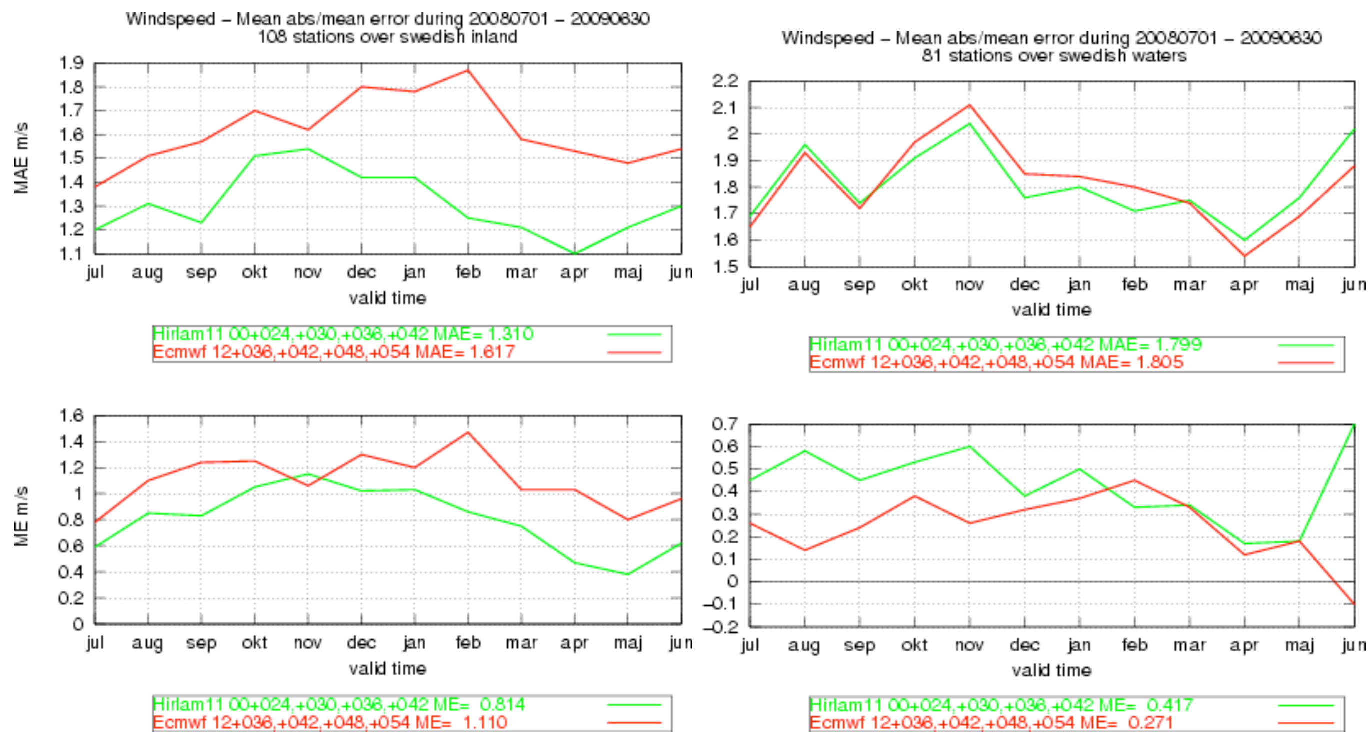

Fig 4 To the left: Mean absolute error and bias (mean error) for Hirlam 11 km (green) and ECMWF red, for different months and inland stations. To the right: The same for coastal stations.

The error is significantly reduced by the Kalman filter for inland stations. (Figure 5) The error reduction is also seen for coastal stations but smaller, and there is a negative bias, especially in the Kalman filtered forecasts from ECMWF.

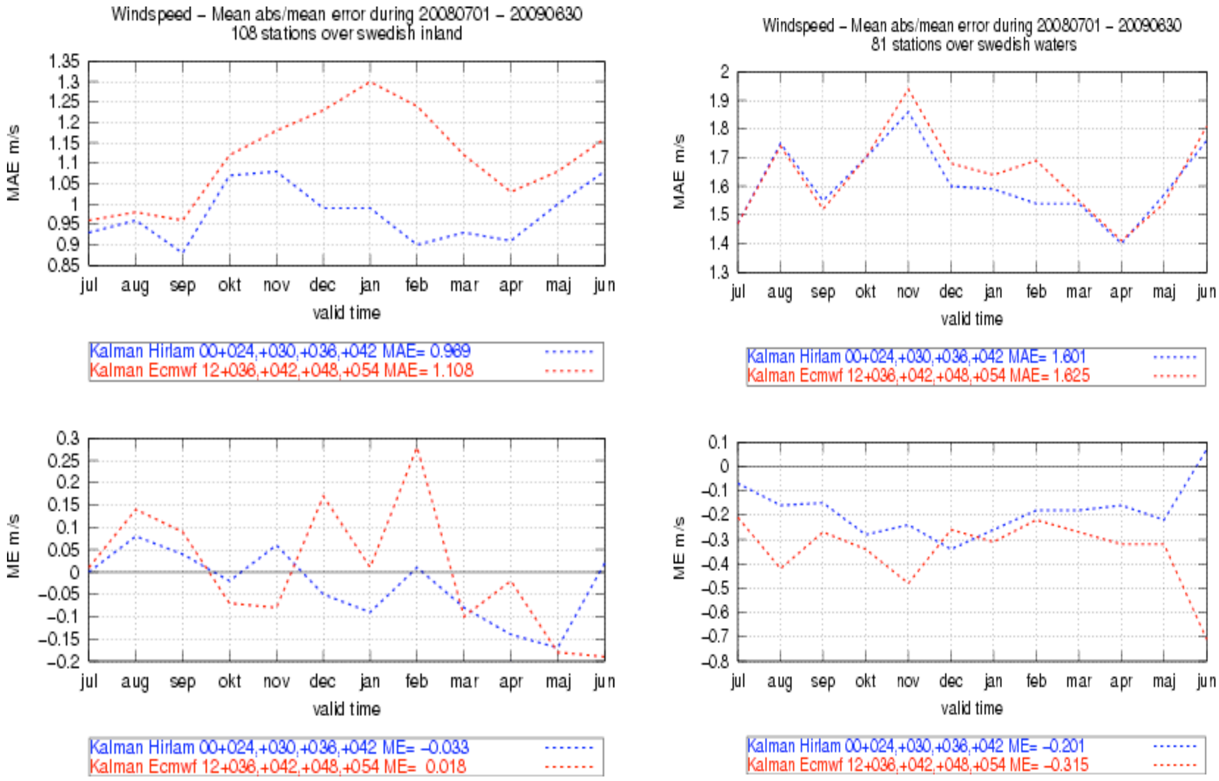

Fig 5 To the left: Mean absolute error and bias (mean error) for Kalman filtered Hirlam 11 km (blue) and Kalman filtered ECMWF red, for different months and inland stations. To the right: The same for coastal stations.

10-metre wind gusts

The forecasts of wind gusts are important for the weather warnings to the public. During 2008, the wind gust DMO from ECMWF and Hirlam have been verified against observations and also against a simple method of creating wind gust forecasts from 10- metre wind and the static stability near the surface. (Hultbergs method) This study was focused mainly on the methods of wind-gust post processing, so to minimize the effect of forecast lead time errors, only very short forecasts have been studied here. All wind gust forecasts have been compared to the maximum wind gust recorded in a time-window of +/- 3 hours of the forecast valid time. (A forecast valid at 12 UTC have been verified against observations from 9 UTC to 15 UTC etc.) The measurements of wind gusts should correspond to the maximum average wind speed recorded during 2 seconds.

Wind gust forecast	**RMSE**	**Mean error (Bias)**
ECMWF DMO	2.60	0.81
ECMWF (Hultbergs method)	2.52	-0.77
Hirlam 11 DMO	2.47	0.74
Hirlam 11 (Hultbergs method)	2.45	-1.01

Table 1 Root mean square error (RMSE) and mean error (bias) for different wind gust forecasts. (February – November 2009.) Only 06 and 12 hours forecast for Swedish stations below 61 N are verified.

The RMSE is approximately the same for all four products, except for the pure DMO from ECMWF which has a somewhat higher RMSE. There is a positive bias for the DMO from both ECMWF and Hirlam and a negative for the simple alternative method for both models. Only stations south of 61 N are used in table 1. By this selection, the influence from stations in the mountain region is avoided. The wind on those stations is highly dependent on local sub-grid scale effects which make the interpretation of the average verification result more difficult. Those local effects can also be seen in figure 6 as a large variability of mean error and mean absolute error in this region.

In windy situations, the DMO forecasts from both ECMWF and Hirlam often have the highest wind gusts values over land compared to the simple alternative method. This is especially the case for the DMO from ECMWF. In such cases, the ECMWF DMO has been useful for public warnings. But a drawback is a large number of false alarms, due to the over prediction of wind gust speed.

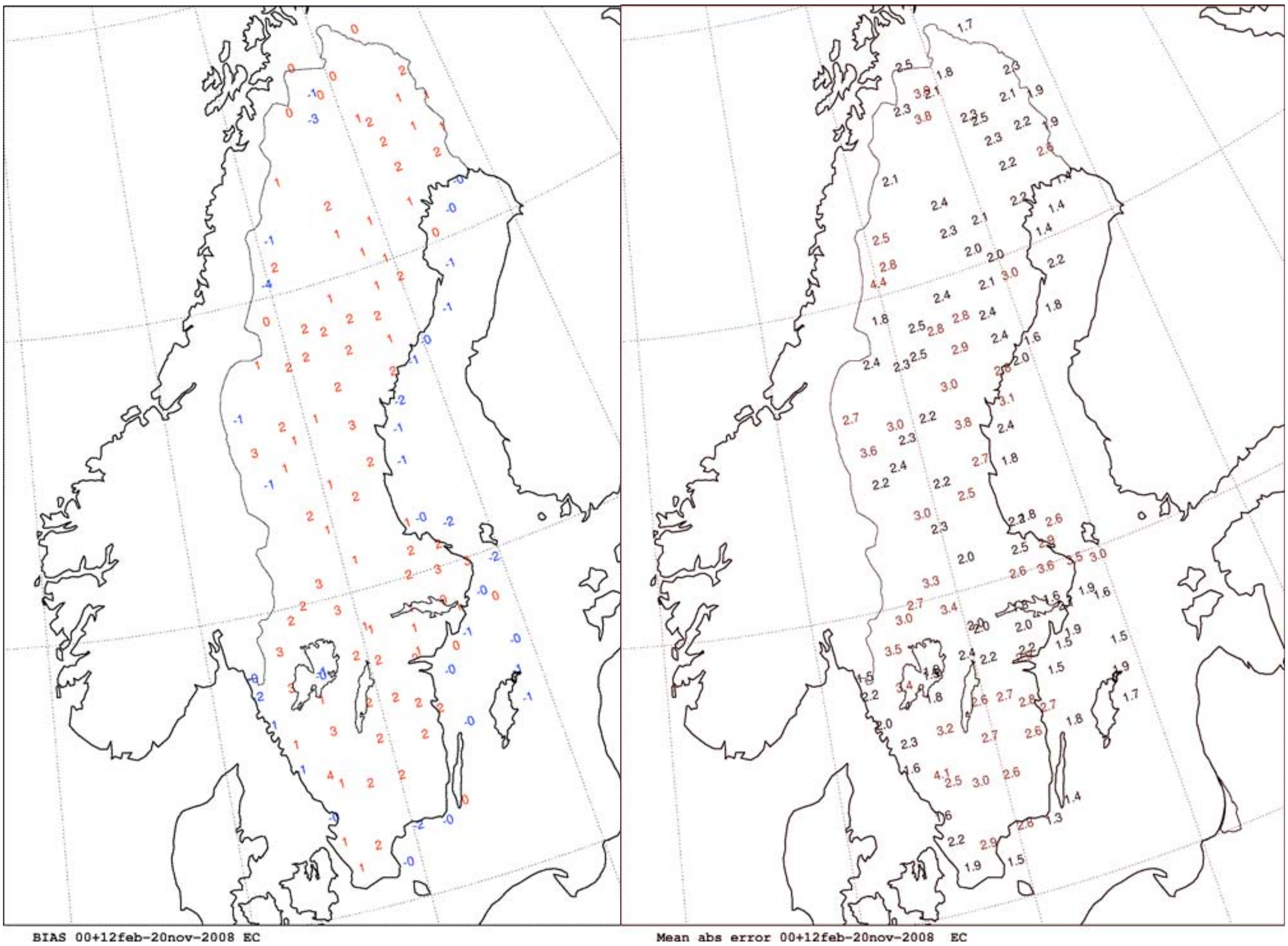

Fig. 6 The geographical distribution of the bias (mean error, to the left, positive in red, negative in blue) and mean absolute error (to the right) of the ECMWF DMO wind gust forecasts. Mean absolute errors larger than 2.5 m/s are in reddish colour. Verified forecasts are issued at 00 UTC and valid 12 UTC.

The positive bias of the ECMWF DMO wind gusts is mainly found in the land areas. (Figure 6 to left panel.) Over water there is none or a small negative bias. The mean absolute error is largest over land, which probably is due to a larger difference between the mean wind speed and the speed of the wind gusts. This makes the wind gusts less predictable. (Figure 6 to the right.)

Precipitation

The capability of different models to predict the probability of precipitation over certain threshold values and for different areal sizes can be monitored by using the Fractional Brier Skill-Score (FBSS). The observed and predicted 24 hour precipitations are from 2008. Observations from the Swedish climate station network (770 stations) have been used. The models in this study is ECMWF, Hirlam and the Unified Model. (UM, Met Office model, but the UM-model forecasts have been produced by Met.no.) The sample climatology has been used as reference forecast. It is the observed relative frequencies of precipitation during this test period.

Here, Sweden was divided into areas of a specified size. The fraction of observations over a threshold value and corresponding forecast values were calculated. Areas with less then 3 observation stations were not used. The observed sample climate fraction was used as the reference value in the FBSS calculations. The computation was made for different threshold values and area sizes. The result is seen in Figure 7.

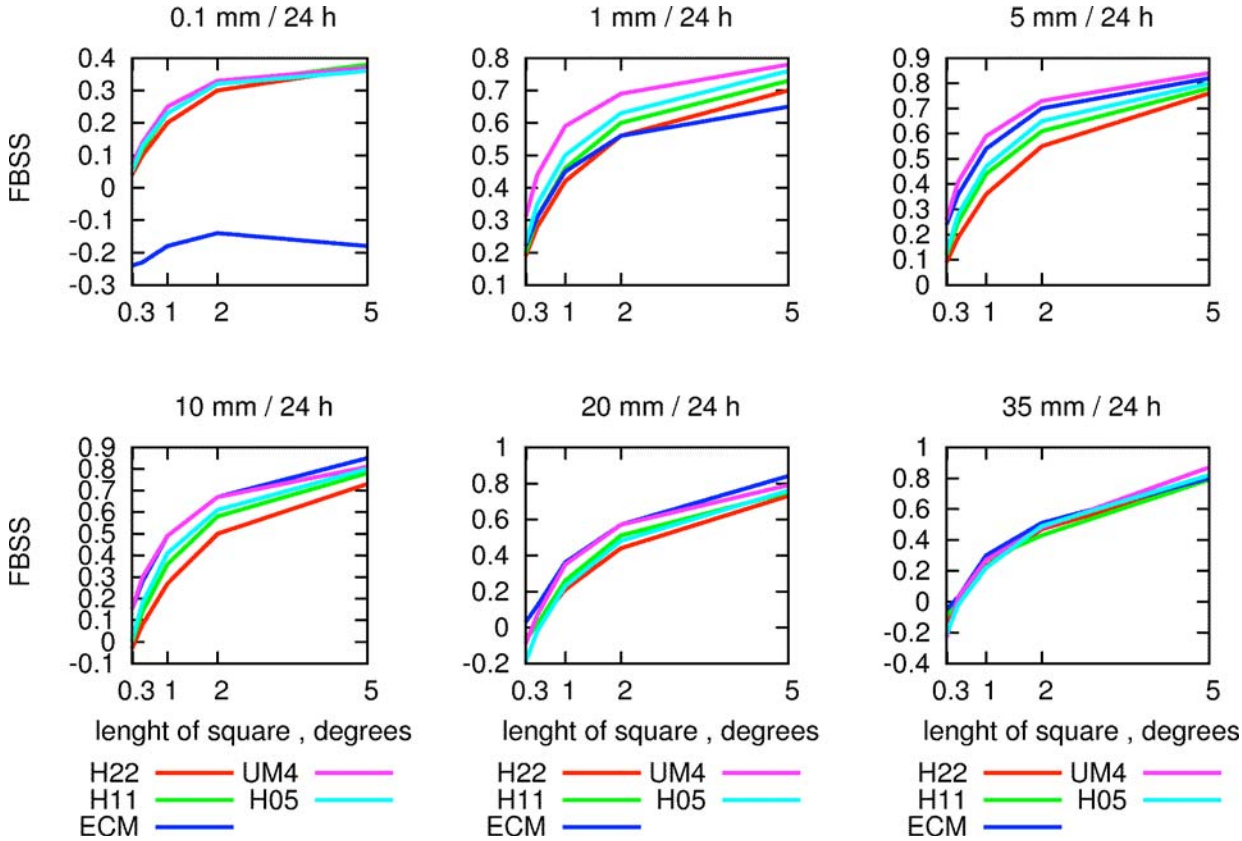

Fig. 7 FBSS for different precipitation thresholds and areas. H22 (red), H11(green), and H05(light blue) are Hirlam with different horizontal resolutions in km. UM4(rose-red) is unified model with 4km resolution and ECMWF. (dark blue) The forecast length is 30 hours and 24 hours precipitation is verified.

ECMWF has the highest skill for most of the area sizes for 10mm and 20mm, also if the comparison is done with the most high-resolution models and for the smallest areas in this test. For 35 mm there are no big difference between the models, and all have negative skill for the smallest area, 0.3 degrees (around 30x30 km).The problematic behaviour of the ECMWF forecast is mainly only related to small amounts of precipitation, which occur too often in the forecasts. This is the main reason for the negative skill for 0.1mm and the less good result for 1mm.

3.1.4 End products delivered to users

3.2 Subjective verification

One important forecast variable is the amount of low clouds. Generally, the quality of the low cloud forecast from ECMWF are good, especially in winter. But in very cold conditions, (2-metre temperatures -25 C or lower) low clouds are over predicted. In autumn and spring there is some under prediction.

4. References to relevant publications

Andersson, C. and Langner, J. ,2007 Interannual variations of ozone and nitrogen dioxide over Europe during 1958-2003 simulated with a regional CTM. *Water, Air and Soil Pollution:* Focus. Doi: 10.1007/s11267-006-9088-4

Andersson, C., Langner, J. and Bergström, R. ,2007 Interannual variation and trends in air pollution over Europe due to climate variability during 1958-2001 simulated with a regional CTM coupled to the ERA40 reanalysis. *Tellus 59B,* pages 77-98.

An application of operational ECMWF meteorology in CTM calculations at SMHI

Andersson, C., Bergström, R. and Johansson, C. 2009. *Population exposure and mortality due to regional background PM in Europe – long-term simulations of source region and shipping contributions.* Atmospheric Environment 43, *3614-3620. Doi: 10.1916/j.atmosenv.2009.03.040.*