Evaluation of real-time MM5 forecast over Norwegian areas

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1 Introduction

The daily weather in Norway is primarily driven by large scale synoptical systems coming in from the west. In addition, complex topography with fjords and high mountains forces circulation patterns with large variations in weather conditions over a few kilometers.

Real-time weather prediction has until the last few years mainly been provided by large governmental institutions due to its demand of large computer power. Increased computer power combined with lower hardware costs has made real-time operational weather forecasts for smaller private weather companies feasible. Since the beginning of May 2003, Storm Weather Center has performed numerical weather forecasts with the well known non-hydrostatic mesoscale model, MM5V3.6.1 (hereafter MM5). The choice of model was based on thoroughly testing in for real-time applications under a variety of weather conditions throughout the world.

This study evaluates the forecast accuracy of MM5 runs over Scandinavian areas at 36, 12 and 4-km horizontal resolution. Main focus is on the winter season precipitation 2003-2004, ranging from November to March. One full year of temperature forecasts are also verified, ranging from May 2003 to May 2004.

2 The Storm Weather Center real-time modeling system

MM5 is developed by PSU (Pennsylvania State University) and NCAR (National Centre for Atmospheric Research) and is a mesoscale modelling system that includes advanced atmospheric physics. It is widely used for real-time weather forecasts, air quality investigations and hydrological studies (Warner et al. [1991], [Grell, Dudhia & Stauffer 1994], [Mass & Kuo 1998], Chatfield et al. [1999], Chang et al. [2000], Mass et al. [2002] etc.). MM5 offers of a variety of different physical parameterization schemes for cumulus clouds, planetary boundary layer turbulence closure, radiation, explicit moisture, soil models and shallow convection. In the present MM5 setup three main domains at 36, 12 and 4-km (see figure 1) are running operationally two times a day with initialization at 00 and 12 UTC. 29 vertically unevenly spaced full-sigma levels were placed in the vertical [1] with 12 layers below 1000 meters above

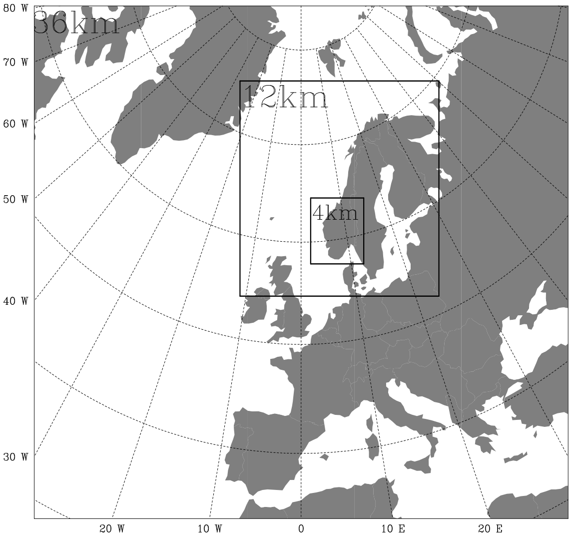

Figure 1: **Three domains are currently in the Storm MM5 setup.**

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[1] The 29 full sigma levels were $\sigma = 1.00, 0.995, 0.993, 0.989, 0.985, 0.98, 0.97, 0.96, 0.945, 0.93, 0.91, 0.89, 0.85, 0.80, 0.75, 0.70, 0.65, 0.60, 0.55, 0.50, 0.45, 0.40, 0.35, 0.30, 0.25, 0.20, 0.15, 0.10, 0.05, 0.00$

ground and model top at 50 hPa

In the current Storm-MM5 setup the turbulence scheme based on Hong & Pan [1996], coupled to the simple soil diffusion model is used. For moisture an explicit moisture scheme, including super cooled water and immediate melting of snow below freezing level the ice phase, is applied (Reisner et al. [1998]). Cumulus parameterization based on Kain & Fritsch [1993] has been used for the 36 and 12-km domains (KF1), and topography and land-use were derived from the 1 km USGS (United States Geological Survey) dataset [Eidenshink & Faundeen 1998]. Further information on the model system can be found in Grell et al. [1994]. MM5 is based upon a set of equations for a fully compressible and non-hydrostatic atmosphere. Consequently it is possible to run the model at fine horizontal and vertical scale corresponding to meso-γ scale ($O(1)km$). 4 km horizontal resolution has however been the limit for real-time applications at our 24 cpu large linux cluster.

The initial and lateral boundary conditions are obtained from the operational Global Forecasting System at NCEP. Forecast lengths are 72 hour for the 12 and 36-km domains. The fine scaled 4-km domain is initialized after 12 hours of the simulation and terminates after 48 hours. The 4 km model simulations are performed after the 36/12-km runs with 12-km data at the boundary. The real-time MM5 is initiated as a "cold start" with no preforecast spin up period or assimilation of additional observations.

3 Results and evaluation of MM5 performance

A real-time verification system has been created in order to evaluate the skill of the regional MM5 forecasts. The basic approach has been to verify at the observation sites by interpolating model fields to the observation location [Cressman 1959]. Verification statistics including rms error, mean error, standard deviations are calculated within all three domains. In addition, a system for evaluating long time time series and long time average statistics have been created. However, in this paper only statistics for the area encompassing the 4-km domain (see figure 1) are presented, using model data output from all three resolutions

There has been a growing number of studies verifying mesoscale models the last years in real-time setups, but few long time studies known to the author have earlier been published with focus on Scandinavian areas in order to evaluate mesoscale models with resolution down to 10 km or less. For validation of model results in this preliminary study, the synoptical network in the southern parts of Norway with 3 hour increment between the observations is applied. This study is the first step in order to evaluate MM5 performance over Norway as well as Scandinavian areas.

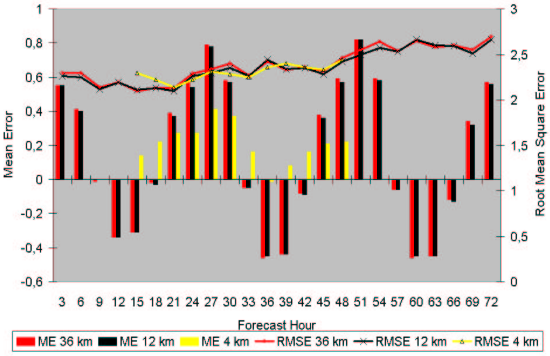

Figure 2: **Mean temperature error (ME) and Mean root mean square error (RMSE) as a function of forecast hour for synoptical stations in the 4-km domain. The mean is calculated using only the 00 UTC forecasts cycle and averaged its error from May 7 2003 to May 7 2004.**

3.1 Verification of temperatures

Figure 2 shows the mean temperature bias at 2 meters for the synoptical stations in the 4-km domain (see also figure 3 for positions) of the May 2003 - May 2004 season using approximately 60 stations in the synoptical network. The 2 meter temperatures are modified to take into account the difference between the actual height of the measurements and the topography at the observation points, using a fixed lapse rate of $0.6^oC/100$m.

The mean error has a clear diurnal variation at all resolutions, giving too low temperature in the middle of the day and too high temperatures during night time. This sinusoidal pattern is largest for the 36 and 12-km temperature forecasts, but is also seen in the 4-km domain. The cold bias in the middle of the day at forecast hour 36 is only slightly negative in the 4-km domain, which shows that the temperature maximum on average is good at this horizontal resolution.

The skill of the temperature forecasts seen on figure 2 reveals only small improvements of the mean temperature errors as a function of resolution for the 36 and 12 km domains. The diurnal amplitude of temperature errors at 4-km resolution is mostly positive and is also a lot smaller than the 36 and 12-km biases. This suggests that the 4-km forecasts are the best on *average*.

Mean errors does not increase much with increasing forecast time, but the root mean square errors (RMSE) have a near linear increase in time. It is at present time not clear to the author why the mean biases at 4-km are positive during day time.

Mean temperature biases seem strongly correlated to the mean wind bias (not shown here). Wind speeds are generally higher than observed on average, causing too much mixing in the boundary layer. At night time this causes less cooling of the surface by long wave radiation and a strong positive bias up to 0.8 degrees for the 36 and 12-km forecasts. At daytime high wind speeds causes too much mixing of colder air above the surface down to the ground giving cold biases at the surface . Another source of errors for the mean temperatures is the static height adjustments of the temperature forecasts. When surface temperature inversions are present, this will *increase* the bias. Since inversions most frequently occur during night time, some of the explanation of the large during the night can be related to this.

3.2 Verification of 2003-2004 cool season precipitation

Precipitation in complex terrain is often strongly forced by orographic effects in combination with synoptic scale systems. In order to give an estimate of the MM5 performance during the winter of 2003-2004 (ranging from November to March), the accumulated precipitation amounts at the observation sites are validated. In Norway, precipitation is only observed twice a day, at 06 UTC and 18 UTC. At winter-time the undercatchment of observed precipitation could be large in some areas, especially in mountain areas where strong winds and snow is frequent. A "perfect" forecast could therefore be expected to be associated with a modest positive bias. At the western coast of Norway, there are several observation sites exceeding 2000 millimetres a year. This is 3-4 times more precipitation than on the lee side of the mountains.

To evaluate the mean precipitation error, a bias score defined as (Colle et al. [1999]):

$$B = 100 \left(\frac{F}{O} \right), \qquad (1)$$

where B is the bias score, F is the forecasted amount of precipitation during the cool season at forecast hour 30, and O is the mean observed.

Only results for the 4-km domain is shown here (figure 3), but the general patterns are quite similar. With 36-km grid spacing, there is underprediction in the coastal areas. Overprediction is found to the lee (east) of the mountain ridge since subsidence is attenuated by the smooth 36-km terrain. Decreasing the grid spacing to 12-km significantly reduces the magnitude and extent of the underprediction, in addition to a decrease in the overprediction on the lee side. This underestimation is least in the 4-km domain, where the lee side of the mountain ridge has a slight underestimation.

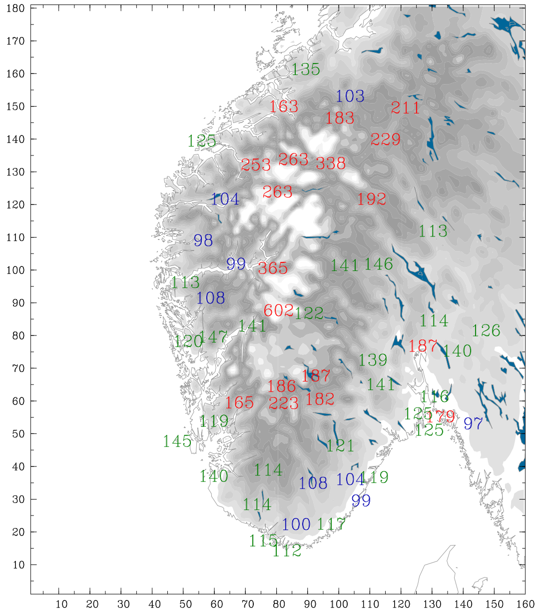

Figure 3: **The MM5 4-km mean precipitation error (percent of observed) on top of the 4-km topography for the 2003-2004 cool season (November 2003 to March 2004) at forecast hour 30. Bias larger than 150 % is highlighted in red, 110-150 are green and less than 110 are blue. Bias is calculated according to equation 1.**

Investigations of time series (not shown here) at different locations within the 4-km domain reveals that MM5 12-km in many cases show the greatest objective skill for precipitation. Timing and amount of precipitation is best, but underestimates the precipitation at strong precipitation events. 4-km domain often struggles with timing errors and too much precipitation on lower thresholds of precipitation. On the other hand, it has shown to give the most horizontally distributed *realistic* results, but a tendency for over-estimation. At higher thresholds (more than 40 mm/24 hr) it has in many occasions given best objective scores. The 36-km then tends to underestimate precipitation due to its smooth topography and advection of precipitation to the lee-side of the mountains.

This could be related to timing errors. With the complex topography shown on figure 3 only small errors of wind direction and speed can lead to large errors in the predicted precipitation.

One should however keep in mind that the observational network over the Norwegian areas are sparse, and very few observations are taken in mountain areas where the precipitation amounts are greatest.

4 Conclusive remarks

Results from the Storm real-time MM5 forecasts so far indicates an increase of performance from 36 to 12-km for temperature, wind speed and precipitation. At 4 km resolution improvements for temperature and winds (not shown in this study) on average are seen, The skill is somewhat more uncertain for the objectively scores for precipitation at this resolution. At grid distance of 4 km the realism of the forecasts are greatly improved, but timing errors are often apparent when verifying precipitation. Subjectively evaluated (by Storm's forecasters) the precipitation in mountain areas are overpredicted at 4 km resolution, especially at lower precipitation amounts. This could be related to deficiencies in the model formulations of precipitation processes at this scale. Since Norway have very steep topography in many areas the horizontal diffusion in the model will no longer become horizontal. Zängl [2002] has shown that this can be of great influence on MM5 precipitation in mountainous areas.

The increase of temperature accuracy at 12 and 4 km resolution are caused by better representation of the surface and thereby capturing of mesoscale phenomena's. Topographically driven mesoscale circulation can often result from the interaction of synoptic scale flow with fixed complex terrain. Since Norway has low solar angles wintertime and complex terrain this can cause large temperature errors since MM5 evaluate all surfaces as horizontal when dealing with short wave radiation. Hauge & Hole [2003] showed that slope irradiance could have a big impact on wind and temperature forecasts in steep topography.

Temperature forecasts in other regions of Scandinavia and Europe reveals some cold biases, especially during wintertime. These can be addressed to the GFS data used at the boundary which also have a tendency to be too cold over European areas.

Errors in real-time forecasts can result from initial condition uncertainties, insufficient horizontal resolution in areas of steep topography, and from deficiencies in model formulations of the surface, planetary boundary layer turbulence, microphysics, and convective clouds and radiation. Further work will be addressed to these issues to improve the realism and quality of forecasts over Scandinavia at all resolutions

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