METCOOP MEMO No. 03, 2013

Verification study of HARMONIE AROME

Comparison of the effects of using horizontal resolutions of 2.5 km and 3 km.

Karl-Ivar Ivarsson

Front:

Cumulunimbus cell east of Norrköping August 13 at 9 PM local time. Photographer Karl-Ivar Ivarsson

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Comparison of the effects of using horizontal resolutions of 2.5 km and 3 km.

Karl-Ivar Ivarsson

Summary

The AROME model is normally used with a horizontal resolution of 2.5 km or finer. Since the computing time can be significantly reduced with a modest increase of the horizontal grid spacing, it is of interest to examine if this leads to a deterioration of the forecast quality. A comparison with 3 km resolution is presented here.

Summertime precipitation, 2-meter temperature, 10-meter wind speed , 2-meter dew point temperature and all upper air parameters show basically the same result with 3 km resolution, and total cloud cover is marginally better.

It can be noted that there is a small, but clear deterioration of the precipitation forecasts in winter using 3 km resolution. This may be related to the fact that deep convection generally has a smaller scale in winter than in summer.

Theoretically and scientifically, the choice of such a crude resolution as 3 km can be questioned, since deep convection may have a smaller scale than that which is possible to resolve with a 3 km resolution. One reason for the relatively good result with a 3 km resolution may be that the shallow convection scheme used for the experiments, in reality works as a simple deep convection scheme, since it has convective precipitation as output. There are also a lot of deep convection cells that are considerable larger than 3 km, especially in summer.

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1 Background

At present a 2.5 km or even a finer resolution is used for AROME. One of many benefits with this high resolution is that deep convection does not need to be parameterized; instead it is resolved by the model dynamics. There are some doubts as to whether a 2.5 km resolution is fine enough to resolve deep convection. The grid cell size must be smaller by a factor of two or more in order to properly describe a phenomenon. The smallest deep convection cells are approximately 2 km in horizontal size, so it can be argued that the resolution should be 1 km or finer.

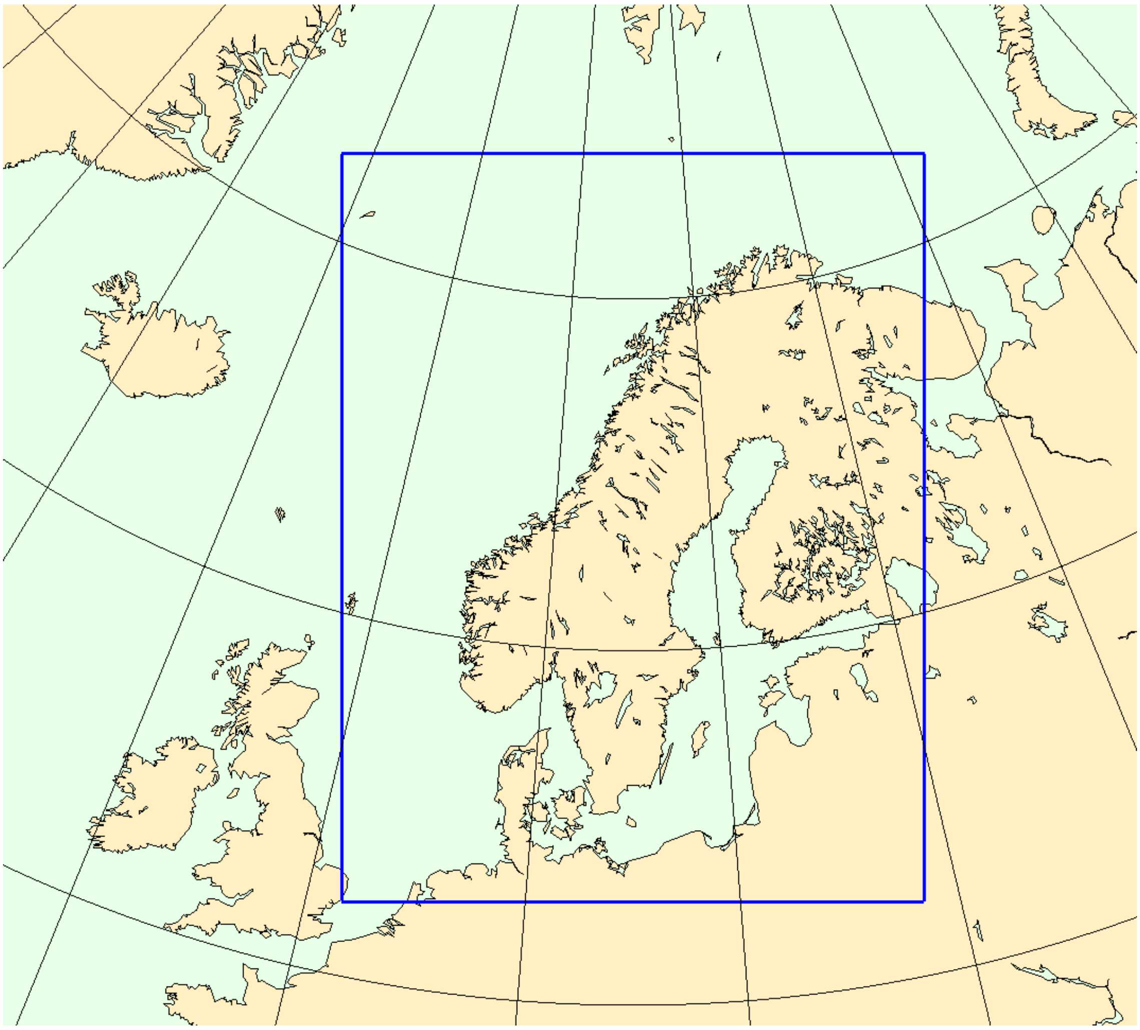
Unfortunately, the use of high horizontal resolution also creates problems. The time step used for the computation has to be short, which makes the model more expensive to run. The size of output files increases with increased (i.e.finer) resolution, which increases the cost of storage. For any prescribed model domain, the number of grid-points increases by a factor of four if the model grid resolution is increased by a factor of two, also the time-step has to be shorter by a factor 0.5. This results in an eight-fold increased computational cost when the horizontal resolution is increased by a factor of two!

A test with 3 km resolution is presented here. Despite the scientific doubts about the use of a cruder resolution there is a lot to gain if it is possible to use AROME with this resolution. The model computation may be reduced with a factor of approximately $(3/2.5)^3 = 1.7$. The need for storage of the model output will be reduced by approx. 30% for any prescribed model domain.

2 Comparison; using 2.5 km and 3 km grid cells.

2.1 Description of the experiments

The model domain used is shown in figure 1. In reality the domain using 3 km resolution was marginally smaller due to technical reasons.



a

Figure 1: The domain used for the experiments in blue.

Two test periods were selected. One summer period, August 12-23 2011, and one winter period, December 20 2011 to January 7 2012. For more information about the periods, see Køltzow et.al [2]. In both periods the model runs start a few days earlier due to the spin-up of the model. All experiments are based on cycle 37h1.1. CANARI OI-Main is used for the surface analysis. In the case where 3DVAR is used for the analysis of the atmosphere, only conventional observations are utilized. 3-hourly lateral boundaries from ECMWF are used. The forecast length used is 48 hours.

As mentioned earlier, it can be questionable to use such a crude grid resolution as 3 km for a deep convection resolving model such as HARMONIE AROME. One possible solution to overcome or at least reduce the problem of not being able the describe the smallest deep convection cells, is to let a shallow convection scheme describe the physical processes caused by the smallest deep convection cells.

Normally, the shallow convection scheme should only account for the convection cells that do not cause precipitation, i.e. which are not very deep. This is the reason why it is called 'shallow convection'. The shallow convection scheme utilized here is the EDMF scheme. In one sense, it is not a 'pure' shallow convection scheme, since it is also possible to parameterize some precipitation. For the 'default' horizontal resolution of 2.5 km, the maximum allowed depth of the convective cell is set to 4 km. By allowing the depth to be 10 km, one may indirectly describe some convection that is deep enough to be regarded as deep convection. The EDMF-scheme also has precipitation release when the maximum cloud depth is set to 4 km, but the release is increased when the depth is 10 km since the moisture may be released from a deeper layer.

For the August 2011 case, runs with 3 km resolution with the maximum allowed depth 4 km and 10 km will be compared, in order to see if there is any notable difference between these settings. Also the use of data assimilation for the free atmosphere (3DVAR) will be compared with an experiment without 3DVAR. The reason for this is that the structure-functions used for data assimilation describing the covariance in space of the forecast error are only been interpolated from 2.5 km resolution to 3 km. A more 'proper' way would have been to use structure-functions based on statistics from model results with 3km. It is of interest to examine if this causes any notable degradation of the analysis.

2.2 Results for the summer period

2.2.1 Mean sea level pressure

The verification result for Root Mean Square Error (RMSE) and BIAS for mean sea level pressure (MSLP) for the summer period is seen in Figure 2. For more information about the verification methods, see Køltzow et.al [2].

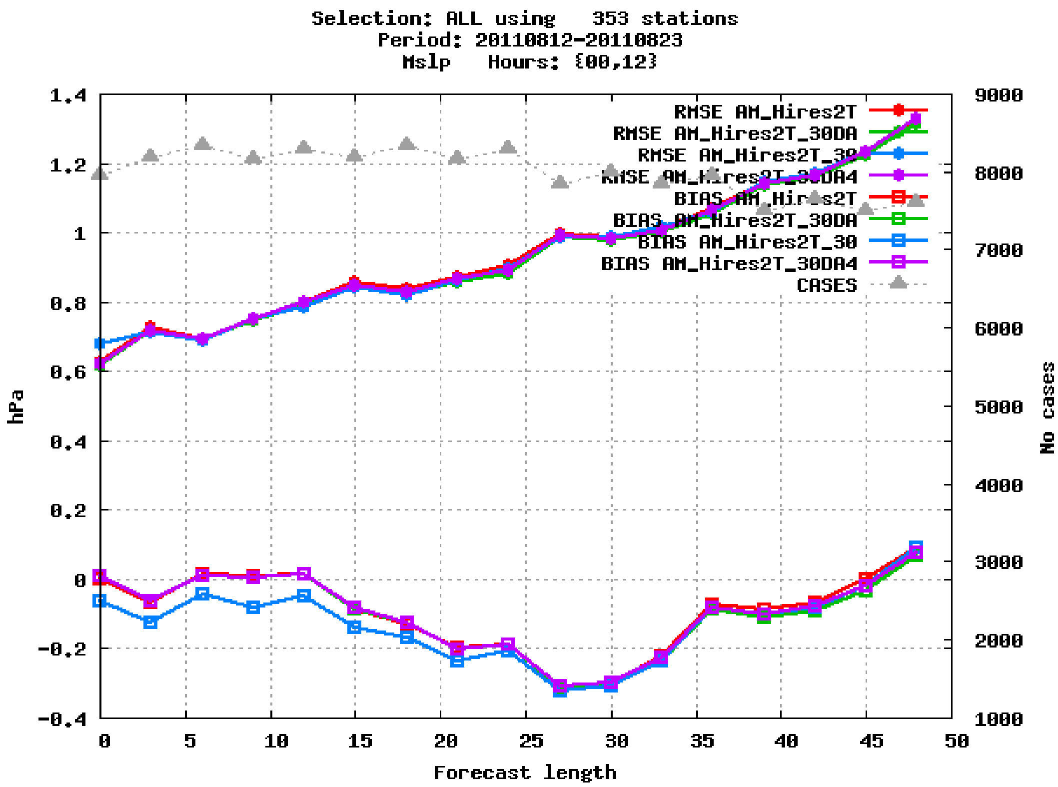


Figure 2: MSLP BIAS and RMSE for different forecast lengths. 2.5 km resolution (red), 3 km resolution with EDMF maximum cloud depth 10 km (green), 3 km resolution with EDMF maximum cloud depth 10 km, but no 3DVAR (blue) and 3 km resolution with EDMF maximum cloud depth 4 km (purple)

Omitting the 3VAR data assimilation results in a slightly lower MSLP for the short forecasts (and a slightly larger negative bias). In other respects the results for all four experiments are almost similar.

The result for 10-meter wind speed gives similar results (not shown)

Some small differences can be seen for 2m-temperature, 2m-dew point and total cloud cover. (Figures 3, 4 and 5)

2.2.2 Two meter air temperature

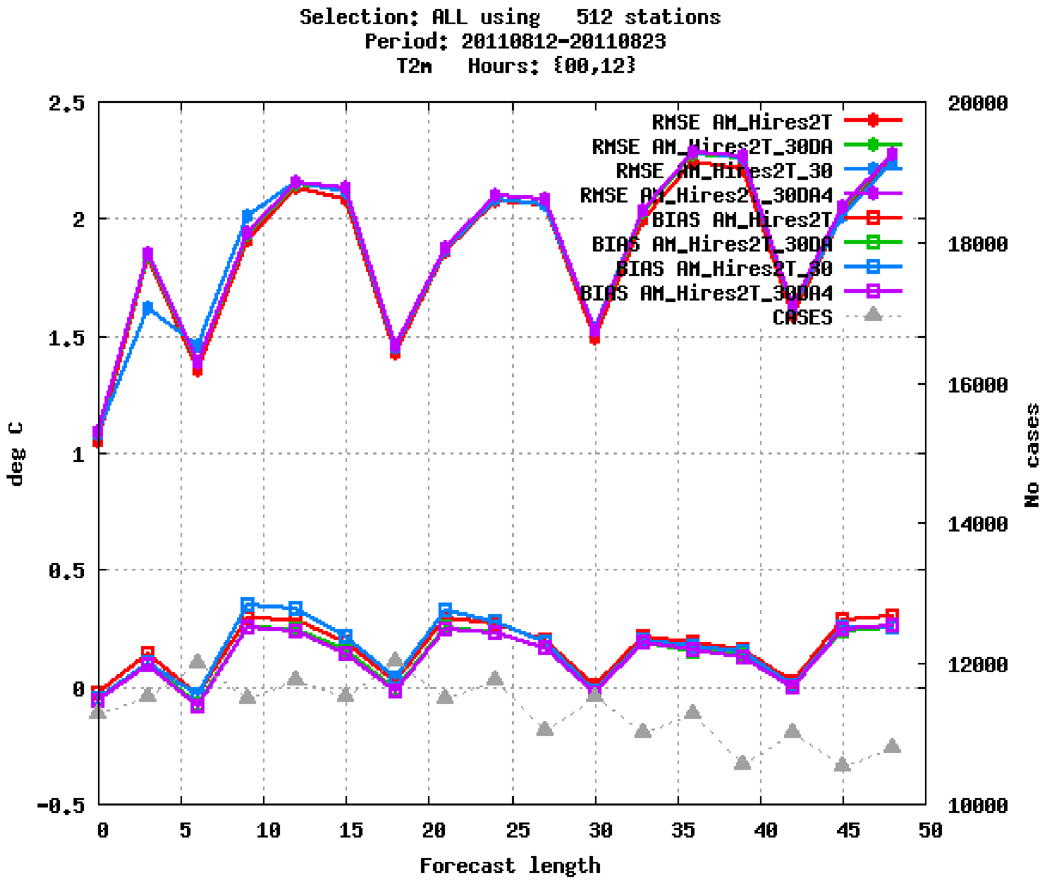


Figure 3: BIAS and RMSE for 2m-temperature. 2.5 km resolution (red), 3 km resolution with EDMF maximum cloud depth 10 km (green), 3 km resolution with EDMF maximum cloud depth 10 km, but no 3DVAR (blue) and 3 km resolution with EDMF maximum cloud depth 4 km (purple)

The RMSE of 2m-temperature is marginally less with 2.5 km resolution than with the 3 km resolution. The 3 km resolution experiments have slightly colder 2m-temperatures in general, especially the one without 3DVAR.

2.2.3 Two meter dew-point temperature

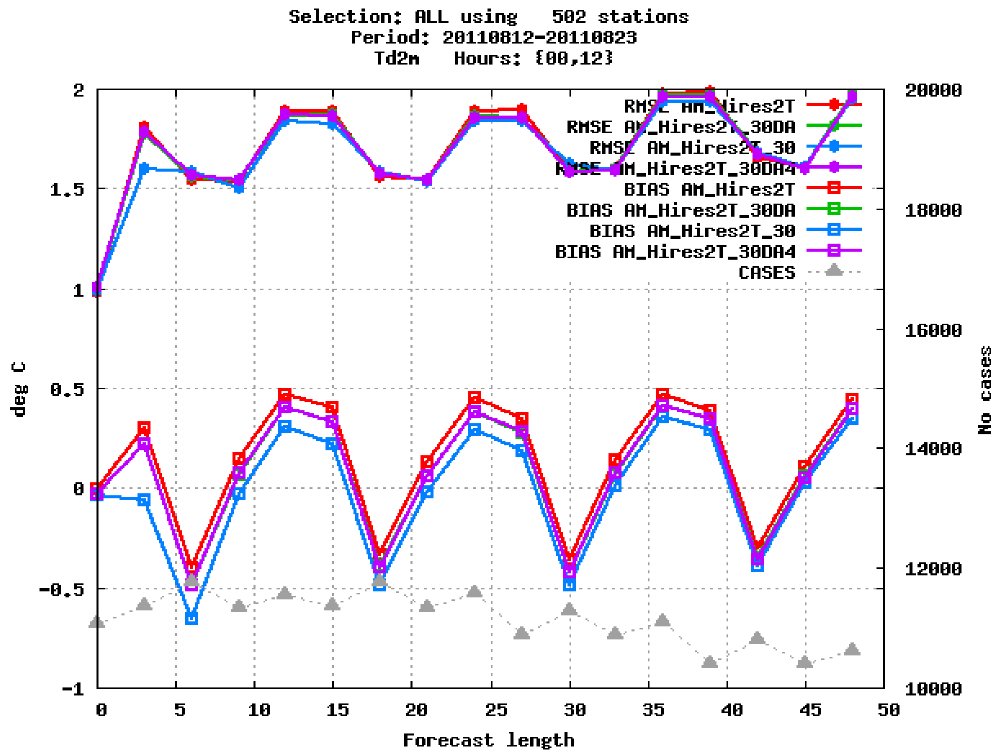


Figure 4: BIAS and RMSE for 2m dew-point temperature. 2.5 km resolution (red), 3 km resolution with EDMF maximum cloud depth 10 km (green), 3 km resolution with EDMF maximum cloud depth 10 km, but no 3DVAR (blue) and 3 km resolution with EDMF maximum cloud depth 4 km (purple)

For 2m dew-point temperature, the run with 2.5 km resolution is marginally worse than the one with 3 km resolution with respect to the RMSE. The 3 km resolution experiments are slightly drier than the 2.5 km resolution run.

2.2.4 Total cloud cover

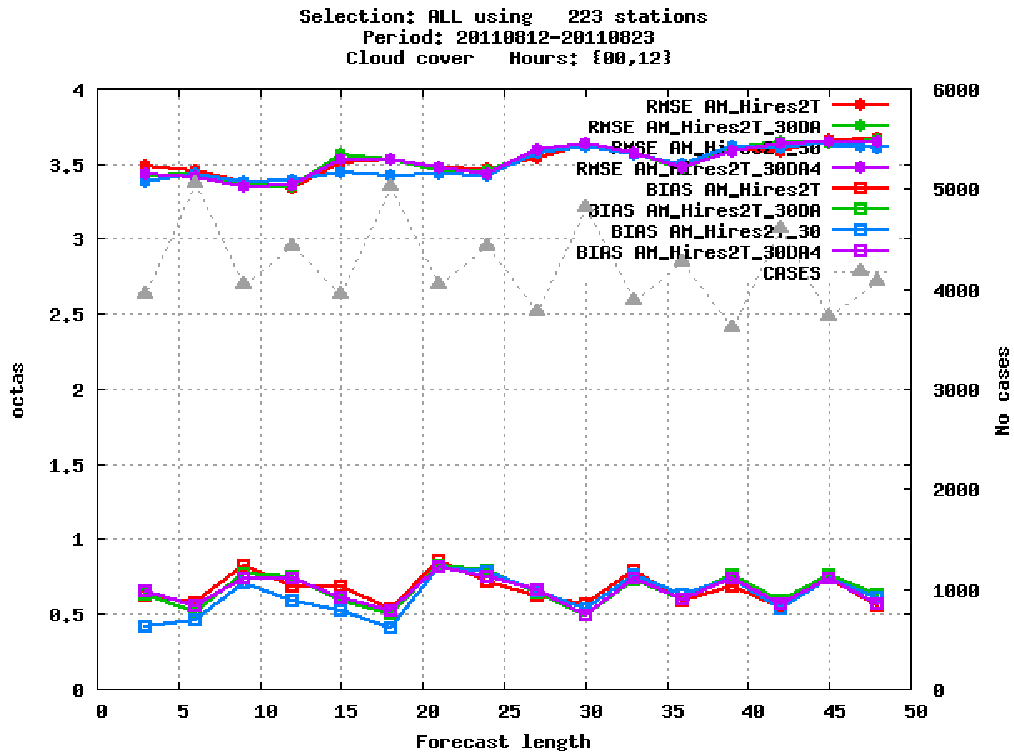


Figure 5: BIAS and RMSE for total cloud cover 2.5 km resolution (red), 3 km resolution with EDMF maximum cloud depth 10 km (green), 3 km resolution with EDMF maximum cloud depth 10 km, but no 3DVAR (blue) and 3 km resolution with EDMF maximum cloud depth 4 km (purple)

The results for total cloud cover are similar for all experiments, except the one with 3 km resolution and without 3DVAR, which has a slightly smaller RMSE. This experiment also has slightly higher ETS values than the other three (not shown). (ETS = Equitable threat score, the value one is perfect, zero is as good or bad as a random forecast)

The ETS is selected to show the performance of the precipitation forecasts, figure 6.

2.2.5 Precipitation

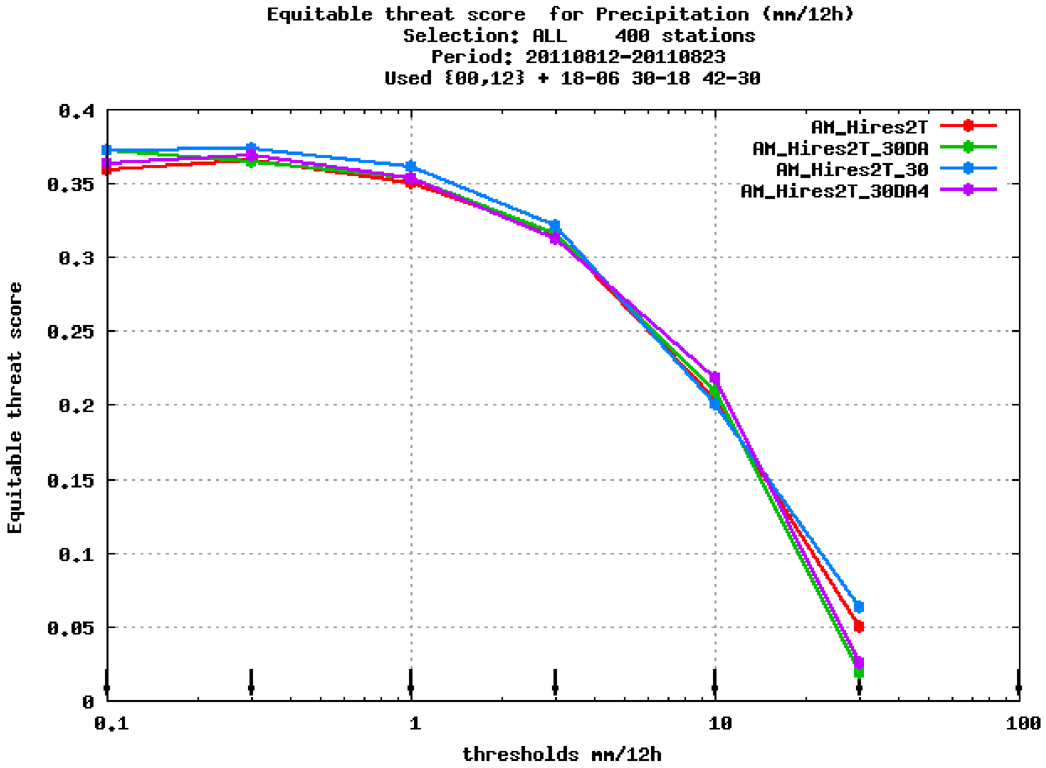


Figure 6: ETS values for different threshold values of precipitation. 2.5 km resolution (red), 3 km resolution with EDMF maximum cloud depth 10 km (green), 3 km resolution with EDMF maximum cloud depth 10 km, but no 3DVAR (blue) and 3 km resolution with EDMF maximum cloud depth 4 km (purple)

The ETS values are not very different between the experiments. For 3 mm or less, the run with 3 km resolution and without 3DVAR has somewhat higher ETS than the others. There is not much difference between using a maximum cloud depth of 4 km compared to 10 km in EDMF. But there is some evidence in favor of using 10 km instead of 4 km when using 3 km resolution. This is seen in figures 7 and 8.

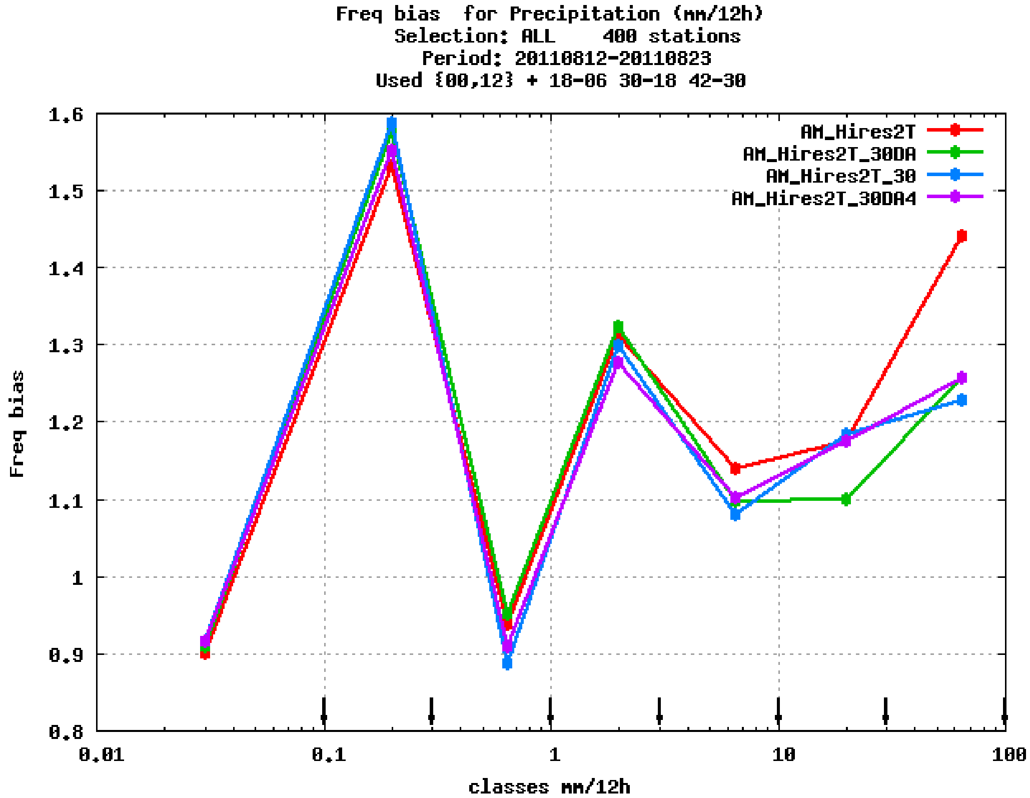


Figure 7: The frequency bias for different amounts of precipitation. 2.5 km resolution (red), 3 km resolution with EDMF maximum cloud depth 10 km (green), 3 km resolution with EDMF maximum cloud depth 10 km, but no 3DVAR (blue) and 3 km resolution with EDMF maximum cloud depth 4 km (purple)

The frequency bias should ideally be near one, which means that the precipitation within a specified interval is the same for the observations and the forecasts. Since the forecast values represent a grid-square average with a lower variability than the observations, the frequency bias may be a little lower than unity for the highest precipitation amounts. All four experiments have a frequency bias above one, which indicates a too 'spotty' precipitation distribution in space and/or time. It can also be explained as a general over-prediction of precipitation, or that the observations underestimate the precipitation amounts, but this is probably not the main reason this time. The run with 10 km maximum cloud depth shows a frequency bias that comes closer to one than the run with with 4 km, i.e. a slightly more realistic distribution of large precipitation with 10 km maximum cloud depth. This can also be seen in the variability of the different precipitation forecasts, figure 8.

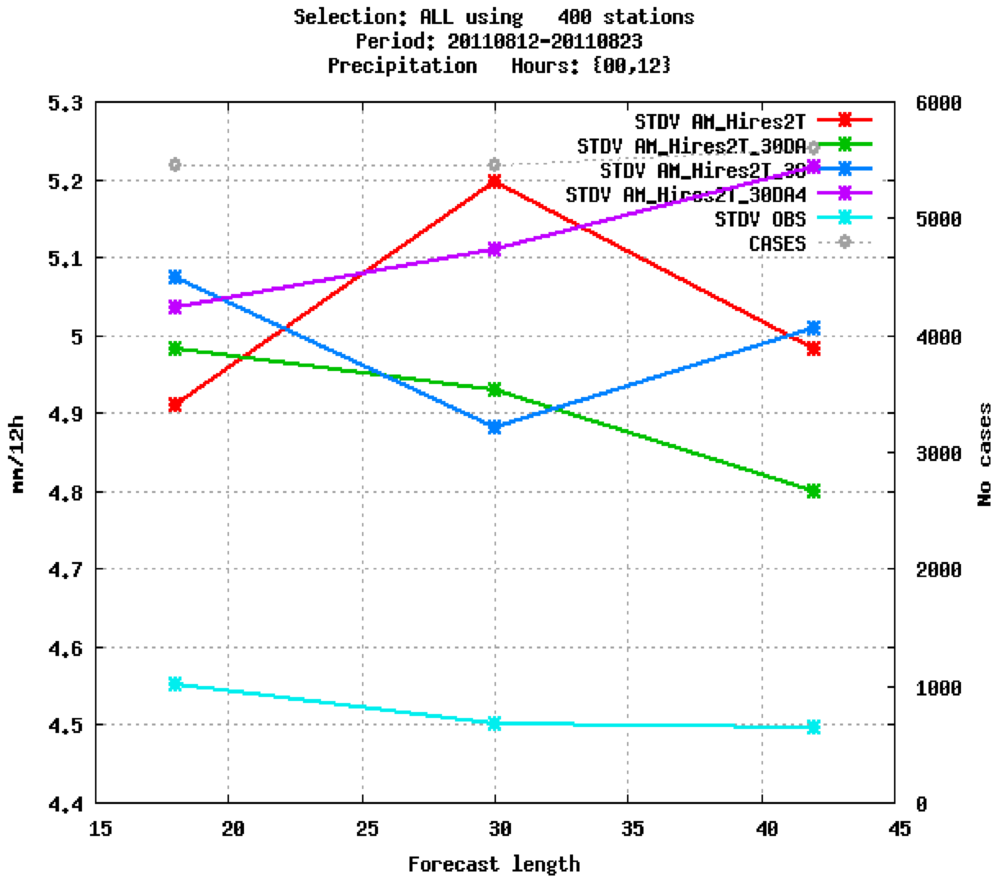


Figure 8: The standard deviation for different precipitation forecasts. 2.5 km resolution (red), 3 km resolution with EDMF maximum cloud depth 10 km (green), 3 km resolution with EDMF maximum cloud depth 10 km, but no 3DVAR (blue) and 3 km resolution with EDMF maximum cloud depth 4 km (purple) . The observed standard deviation is shown in light blue.

The standard deviation is too large for all the four experiments, but it is less for 3 km resolution with EDMF maximum cloud depth of 10 km, compared to the run with a maximum cloud depth of 4 km.

The precipitation forecasts from the different runs have also been verified against rain gauge measurement from climate stations. Only the forecasts starting at 00UTC with the forecast precipitation between 06 and 30 hours forecast length have been utilized. The verification result using Fractions Brier Skill Score (FBSS) is seen in figure 9. The FBSS is described in more detail in Køltzow et.al [2], or Roberts and Lean [1].

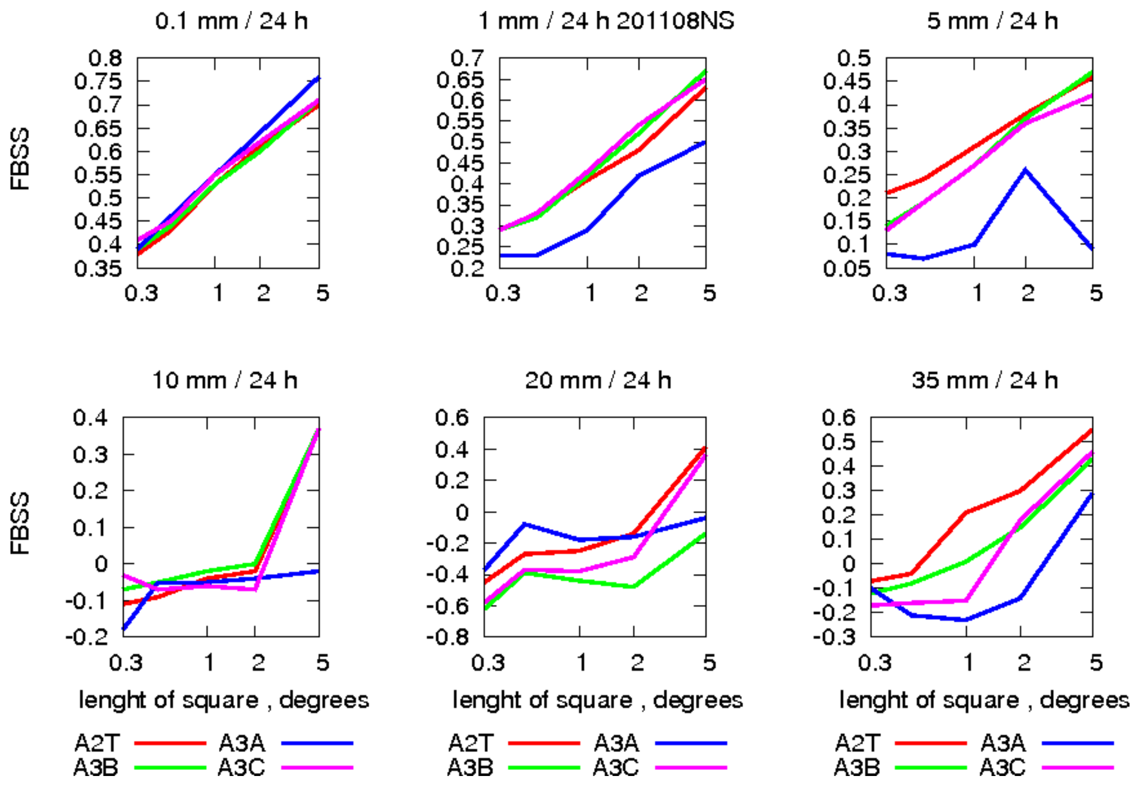


Figure 9: FBSS for different 24-hour precipitation forecasts. The FBSS value on the horizontal axis and the size of the different squares in degrees. (One degree is approx. 111km) 2.5 km resolution (red), 3 km resolution with EDMF maximum cloud depth 10 km (green), 3 km resolution with EDMF maximum cloud depth 10 km, but no 3DVAR (blue) and 3 km resolution with EDMF maximum cloud depth 4 km (purple). The reference forecast is ECMWF.

The results differ somewhat from the verification results using only point measurements with 12 hours precipitation. The best result is seen with 2.5 km resolution for the threshold 5- and 35 mm in 24 hours. For 1 mm, 5 mm and 35 mm there is a degradation of the skill when 3DVAR is omitted. None of the experiments are better than ECMWF for small areas with large precipitation thresholds.

The upper air parameters (temperature, dew-point temperature, relative humidity, specific humidity, wind speed and -direction and geopotential height) are also verified in a similar way (using RMSE and BIAS) against soundings. The results are almost the same for all four experiments (not shown). There is a small tendency to marginally lower RMSE values for the experiment with 3 km resolution and without 3DVAR, compared to the other three.

If one wants to show that higher horizontal resolution and also 3DVAR improves the forecasts, the results presented here are not encouraging. 2.5 km gives a marginally better forecast for 2m-temperature, and some better results for the 24 hours precipitation. Only the 24 hours precipitation forecasts seem to be improved by 3DVAR. In other respects the results are more or less the same. The lack of improvement with 3DVAR, may be due to that the structure-functions interpolated from 2.5 km resolution to 3 km. (Instead of being based on statistics from model results with 3km.) It is not obvious that this is a large problem because the results with 3DVAR and 2.5 km resolution and 3DVAR and 3 km resolution are generally very similar. A problem due to interpolation would have been seen as a general degradation of the result with 3 km resolution.

One reason for the small difference between 2.5 km resolution and 3 km resolution may be related to that many convection cells are considerably larger than 3 km. An example can be seen in the following figures.

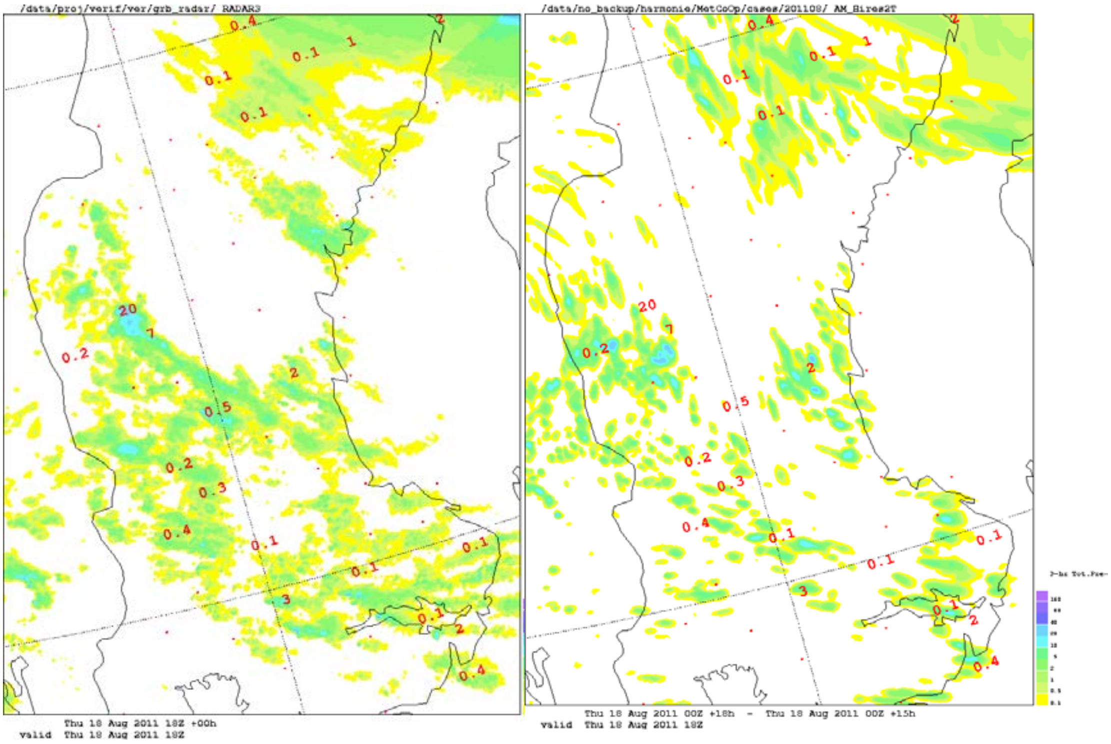


Figure 10: August 18 2011, 15-18 UTC which is a case with rain showers over central Sweden and large scale precipitation in the north. To the left: Radar measurement and rain-gauges (red numbers). To the right: AROME with 2.5 km resolution. The amount of precipitation is shown as different colors.

The structure of the precipitation in the south, (lower part of the map) in Figure 10, are most likely clusters of showers. In the north, large scale precipitation is predominant. AROME has a structure of the precipitation, which more resembles isolated showers everywhere, except in the very northeastern part of the map.

In figure 11 the same comparison is shown for AROME with 3 km grid.

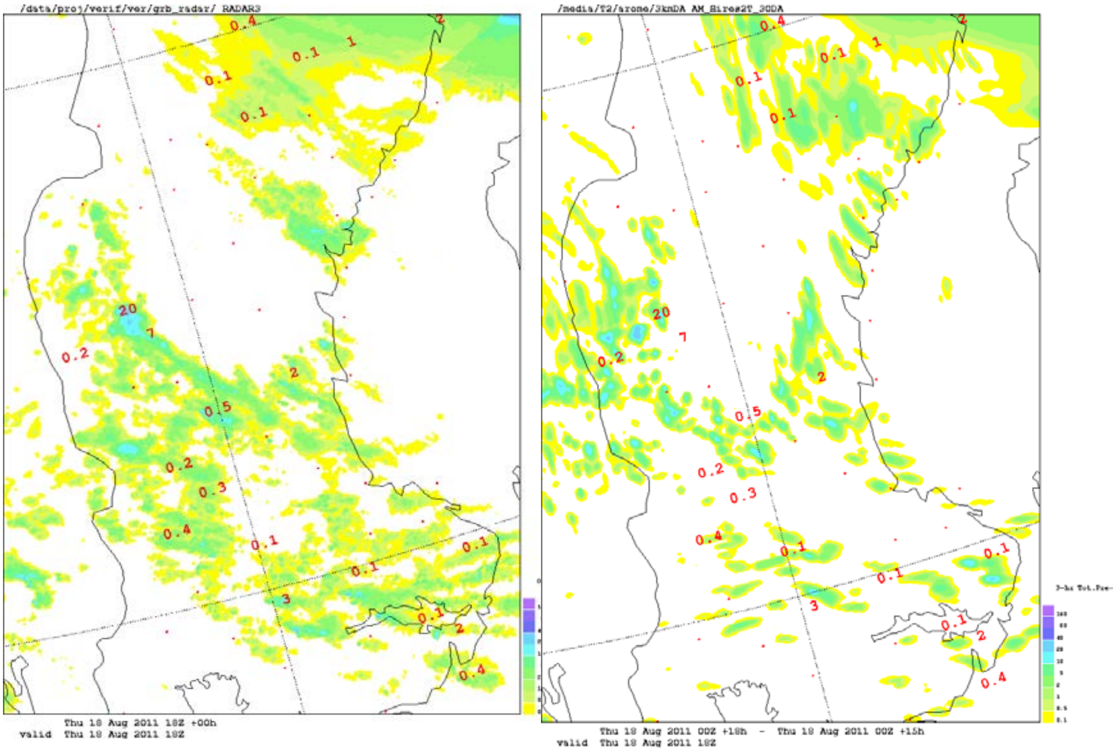


Figure 11: AROME with 3 km resolution to the right. For more explanation, see figure 10.

When 3 km resolution is used, the forecast showers in south are still more isolated than those seen in the corresponding radar composite picture. The forecast rain in the north is organized as stratiform precipitation which makes the forecast more realistic in this particular case.

The convective precipitation may be in a smaller scale during winter, since the convection is generally not that deep. It is therefore of interest to see the effect of a coarser resolution in a winter period. The winter period used in this study is December 20. 2011 to January 7. 2012.

2.3 Results for the winter period

Only two experiments are compared for the winter period. The reference set up (2.5 km resolution, 3DVAR and 4 km cloud height in EDMF) is compared with 3 km resolution, 3DVAR and 10 km cloud height in EDMF. The result for MSLP is seen in figure 12.

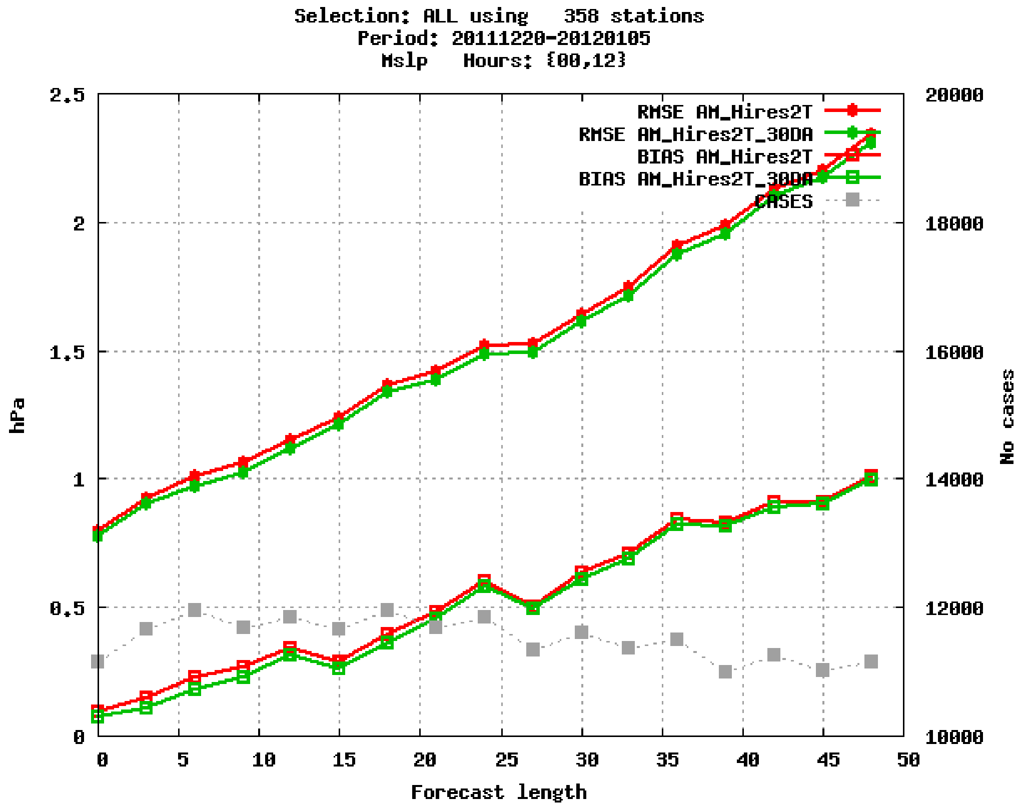


Figure 12: MSLP BIAS and RMSE for different forecast lengths. 2.5 km resolution (red) and 3 km resolution with EDMF maximum cloud depth 10 km (green)

The differences between the two experiments are small, with a marginally smaller bias and RMSE for the coarser resolution. A marginally smaller error with coarser resolution is also seen for total cloud cover. The results for 10-meter wind speed and -direction and 2m temperature are almost identical. Marginally better results are seen using 2.5 km resolution for 2-meter dew point temperature and 2-meter relative humidity. Since those differences are small, they are not shown. The ETS for 12 hour precipitation is shown in figure 13.

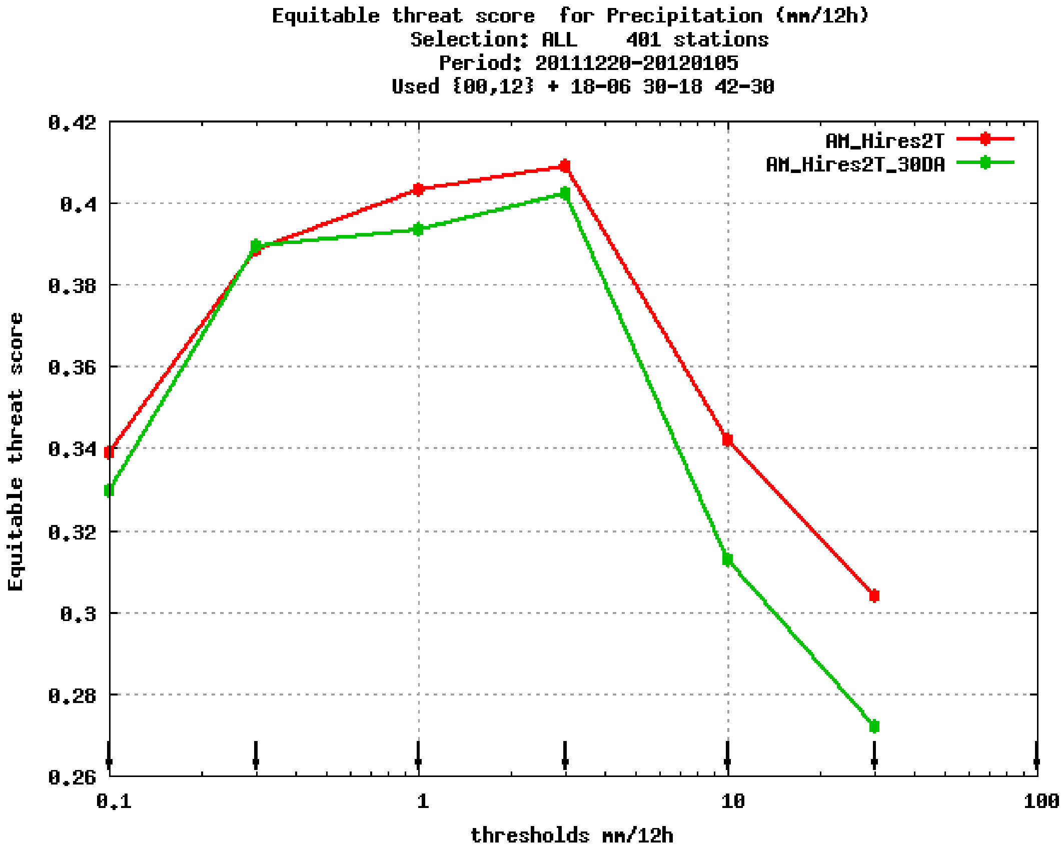


Figure 13: ETS values for different threshold values of precipitation. 2.5 km resolution (red) and 3 km resolution with EDMF maximum cloud depth 10 km (green).

The ETS values are somewhat better with 2.5 km resolution than with 3 km resolution, especially for larger precipitation thresholds.

The result with FBSS for 24 hours precipitation verified against climate station rain-gauges over Norway and Sweden is seen in figure 14.

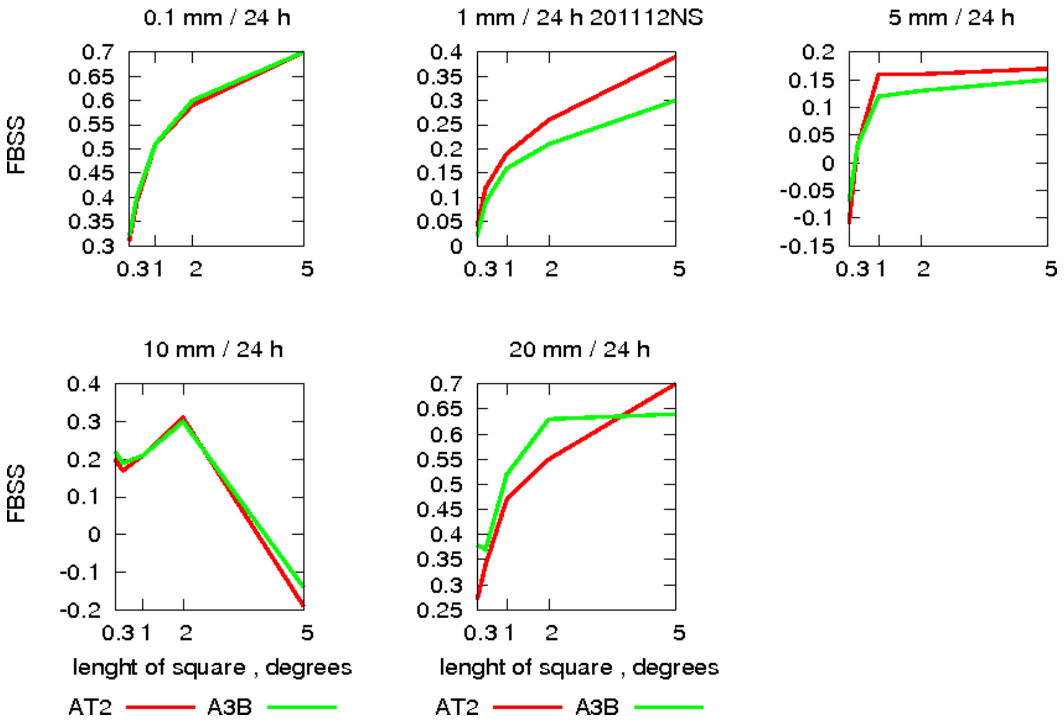


Figure 14: FBSS for different 24-hour precipitation forecasts. The FBSS value on the horizontal axis and the size of the different squares in degrees. (One degree is about 111 km) 2.5 km resolution in red and 3 km resolution with EDMF maximum cloud depth 10 km in green. The reference forecast is ECMWF.

The results seen in Figure 14 are mixed, with some tendency towards slightly better results using 2.5 km resolution.

No comparisons with radar measurements are shown, since the radar data seems to be less reliable than for the summer period.

The upper air parameters show basically the same result regardless of the resolution. One exception, however, is the dew point temperature, which has a lower RMSE with 2.5 km resolution. This is probably caused by a few erroneous very dry occasions, which give a very low dew point when 3 km resolution is used. The results for specific humidity and relative humidity are basically the same (not shown).

3 Summary

In this study HARMONIE AROME using 2.5 km resolution is compared with 3 km resolution for one summer period and one winter period. The conclusion is that there are surprisingly small side effects with the use of 3 km resolution. Theoretically and scientifically, the choice of such crude resolution can be questioned, since deep convection may have a smaller scale than that which is possible to resolve with a 3 km resolution. One reason for the good result with 3 km resolution may be that the convection scheme EDMF in reality works as a simple deep convection scheme, since it has convective precipitation as output. A lot of deep convection cells in summer also have a size considerably larger than 3 km. One example of such large convection cell is seen in the picture on the front page of this document.

Summertime precipitation, 2-meter temperature, 10-meter wind speed, 2-meter dew point temperature and all upper air parameters all show basically the same result with 3 km resolution, and total cloud cover is marginally better with 3 km resolution.

It can be noted that there is a small, but clear deterioration of the precipitation forecasts in winter using 3 km resolution, which may be related to that deep convection generally, has a smaller scale in winter than in summer.

There is probably some advantage in using a higher maximum cloud depth in the EDMF shallow convection scheme when a coarser resolution is used. 10 km has been utilized here for the 3 km resolution runs instead of 4 km, which is the default value used when running 2.5 km resolution.

The lack of improvement with 3DVAR analysis for the summer period is unexpected and has to be examined further.

Acknowledgments:

The author wishes to thank Solfrid Agersten and Rebecca Rudsar at the Norwegian Meteorological Institute for the help with the preparation of this manuscript.

4 References

[1] Roberts N.M. and Lean H.W. (2008). *Scale selective verification of rainfall accumulation from high-resolution forecasts of convective events.* Monthly Weather Review Vol 136 p 7

[2] Køltzow Morten A, Ivarsson Karl-Ivar, Agersten Solfrid, Meuller Lars, Bjørge Dag, Vignes Ole, Dahlgren Per, Eriksen Bjart, Ridal Martin, Rudsar Rebecca. (2012)
Verification study HARMONIE AROME compared with HIRLAM, UM and ECMWF. 01/2012 METCOOP MEMO (Technical Memorandum) http://metcoop.org/memo

5 Figures and tables

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