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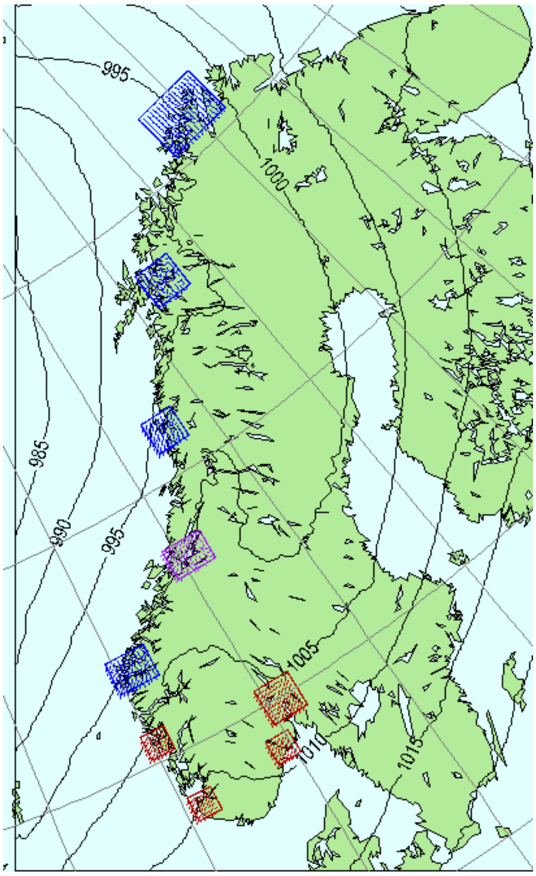
The benefit of going to higher resolution

- experiences with the UK Met Office Portable Unified Model on resolution 1km and beyond

Viel Ødegaard and Thor Erik Nordeng



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report

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Abstract

The UK Met Office Portable Unified model v6.1 has been run on several small domains in Norway with 1km resolution on a daily basis since February 2007. The high resolution forecasts have two purposes; to serve as initial and boundary conditions for the turbulence model (SIMRA) and an air quality modelling system (AirQUIS). The wind forecasts in complex terrain benefits from higher resolution, in particular when wind direction is taken into the verification score, but also wind speed can be improved. aviation reports (AMDAR) from Værnes airport have high resolution and confirm the benefit of higher resolution runs. Land use from the International Geosphere and Biosphere Programme (IGBP) dataset in UM is limited to ~1 km resolution. From the Norwegian Mapping Authority (NMA) a dataset of vector data in resolution 1:50 000 with 11 surface classes is extracted and converted to UM surface tiles. The new land use data are tested in stable winter period in a version of UM set up with 0.333 km resolution covering Oslo. The NMA dataset corresponds better than IGBP to what is seen on the satellite image. The forecasts showed to be sensitive to leaf area index (LAI) and canopy height (CH). In a case study of the snow storm over Southern Norway February 26 in 2006, UM with 1 km resolution on a much larger grid is compared to 4 km resolution. At 1 km we run with convection turned off. One run is made with 38 vertical levels and one run with 76 vertical levels. The main finding is that the 1 km model provides some more details but these are not confirmed by the radar observations. There are small differences between the simulations with 38 and 76 layers

Keywords

NWP, precipitation, snow storm, land use data, aviation turbulence, wind verification, local air quality

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1. Introduction

The UK Met Office Portable Unified model v6.1 has been run on several small domains in Norway with 1km resolution on a daily basis since February 2007. The high resolution forecasts have two purposes; to serve as initial and boundary conditions for the turbulence model (SIMRA) and an air quality modelling system (AirQUIS).

The Norwegian orography with high mountains, narrow valleys and fjords and a complex coastline plays an important role in the development of weather phenomena. To represent the orography properly met.no wants to run NWP models with resolution as high as 1 km or higher.

Mountain induced turbulence is serious aviation problem at many Norwegian airports. UM was first used at Norwegian Meteorological Institute to provide input data for the turbulence model SIMRA that was set up over two airports located in complex terrain. Daily forecasts of turbulence and wind at seven exposed airports are now provided for flight planning in a system where SIMRA is coupled offline to UM with 1 km resolution. The daily runs are monitored and routinely verified against available observations. Severe turbulence has not been reported during the period of this project therefore case studies re not presented. The daily runs however have shown problems with large vertical velocities developing in UM. A study of such a case and the chosen solution for our UM 1 km setup is shown.

Norwegian Institute for Air Research (NILU) and met.no have produced forecasts of air quality based on NWP in 1 km resolution coupled offline to an air pollution dispersion model. Since 2000 this system has produced daily forecasts for Norwegian cities that are exposed for winter time pollution episodes. In the forecasting system the NCAR (The National Center for Atmospheric Research, USA) community model MM5 was used until UM was taking over in 2007. Land use from the International Geosphere and Biosphere Programme (IGBP) dataset in UM and MM5 were both limited to ~1 km resolution. From the Norwegian Mapping Authority (NMA) a dataset of vector data in resolution 1:50 000 with 11 surface classes is extracted and converted to UM surface tiles. The new land use data are tested in stable winter period in a version of UM set up with 0.333 km resolution covering Oslo.

It has been argued that our 1 km domains are too small. Indeed they are if we expect that atmospheric structures should be allowed to develop inside these high resolution domains. On the other hand the air pollution episodes occur in situations with low wind speed and with a strong surface forcing. The slowly evolving surface processes will have time to develop within a forecasting horizon of 48 hours. The computing cost puts limitations on the size of the domain that we are allowed to run. Since the airports and the cities for which we want to produce forecasts in 1 km resolution are distributed all over Norway, many smaller domain were required. In a case study of the snow storm over Southern Norway February 26 in 2006, UM with 1 km resolution on a much larger grid is compared to 4 km resolution. At 1 km we run with convection turned off. One run is made with 38 vertical levels and one run with 76 vertical levels.

The model configuration for met.no runs is described in part 2. The precipitation case study is presented in part 3. Daily runs for turbulence and air quality forecasting are described in part 4. Study of improved resolution in land use data on a stable winter case is given in part 5. Summary and conclusions are given in part 6.

A list of acronyms is given in the end of the report.

2. Model configuration

2.1 Initial and boundary conditions

UM 1km is nested in UM 4km on a domain covering Scandinavia. A model dump from +3h forecast is reconfigured. In the reconfiguration, the fields in table 1 are taken from ancillaries that were created with ANCIL6.1. Boundary values for three times hourly are computed with MAKEBC, i.e. prognostic rain on the boundaries is not available. The orographic rim width is eight points. LSM is edited manually to remove isolated small islands and narrow fjords and straits. The orography in the domains for air quality forecasting is merged with orography created in the MM5 system.

ozone 24 levels
10 soil parameters
fraction of surface types
vegetation: LAI and Canopy height
orography (smoothing with epsilon=1)
LSM

Table 1 Fields reconfigured from ancillaries.

2.2 Domains

UM 1 km is set up on 9 small domains. The domains are shown inside the UM 4 km domain in Figure 2.1. Runs on domains with blue wind arrows are used as boundary and initial conditions for turbulence modelling, with red wind arrows for air quality modelling and with magenta for both. Details about the domains are shown in Table 2.

Domain name	domain size	application	init time and fc length
UM1HH	160*120	SIMRA	00/12 UTC +3 - +21
UM1NA	90*90	SIMRA	00/12 UTC +3 - +21
UM1SA	80*80	SIMRA	00/12 UTC +3 - +21
UM1VA	100*75	SIMRA/AirQUIS	00/12 UTC +3 - +48
UM1SO	100*80	SIMRA	00/12 UTC +3 - +21
UM1BE	60*60	AirQUIS	00 UTC +3 - +48
UM1ST	60*60	AirQUIS	00 UTC +3 - +48
UM1GR	60*60	AirQUIS	00 UTC +3 - +48
UM1OS	90*90	AirQUIS	00 UTC +3 - +48

Table 2 Domain name, size, application, initial time and forecast length.

The horizontal resolution is 0.009*0.009 deg. and the vertical resolution is 38 levels.

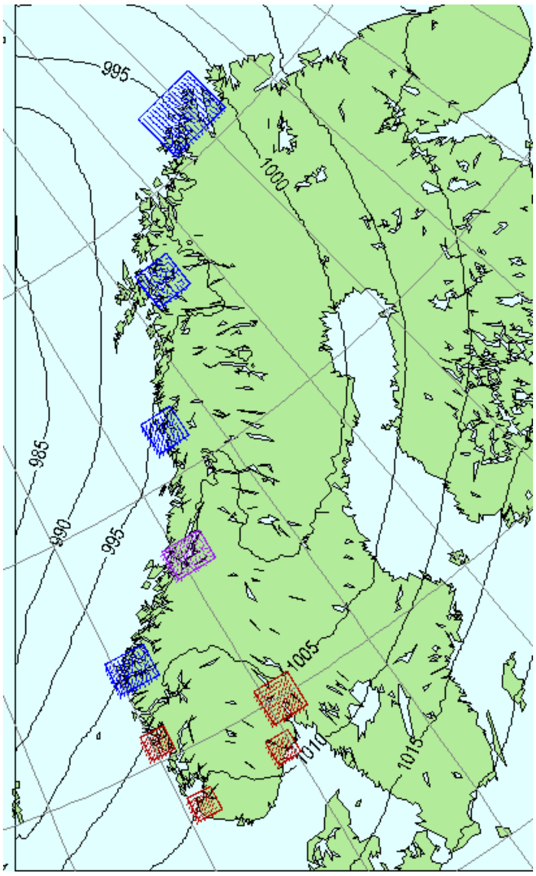


Figure 2.1 UM 1 km domains in Norway shown inside the UM 4 km domain.

2.2 Model code

At met.no UM runs on an IBM power 5 computer. UM version 5.5 was bench mark code in the tender and IBM provided modifications for making the code run efficiently on their computer. In addition a few modifications were necessary for running in our operational scheduling system. Several modifications to version 6.1 have been provided from Met Office and mostly taken into the code. A full overview over all modifications in the code is difficult to provide but some are worth mentioning. The "theta limiter" which was needed to solve the "valley cooling problem" that ruined the forecasts was introduced in the first versions of the code for both 1 km and 4 km resolution.

In March 2008 a number of changes were introduced into UM 4 km in order to reduce the cold bias over snow. These changes are developed at the Met Office and include introduction of a snow tile, using long tailed stability functions and decoupled temperature diagnostics. UM 4km is run with canopy model 4 with the modification that all snow is initially (after reconfiguration) under the canopy.

In UM 1km the actions to reduce negative temperature bias as described for UM 4km are not implemented. The reason for this is that the upgrade resulted in frequent model crashes. The reason is now found to be renormalized floating point values (1e-308 > x > 0) occurring in some of the surface exchange parameterization routines. However some test runs have been made and show positive impact.

2.3 Settings in umui

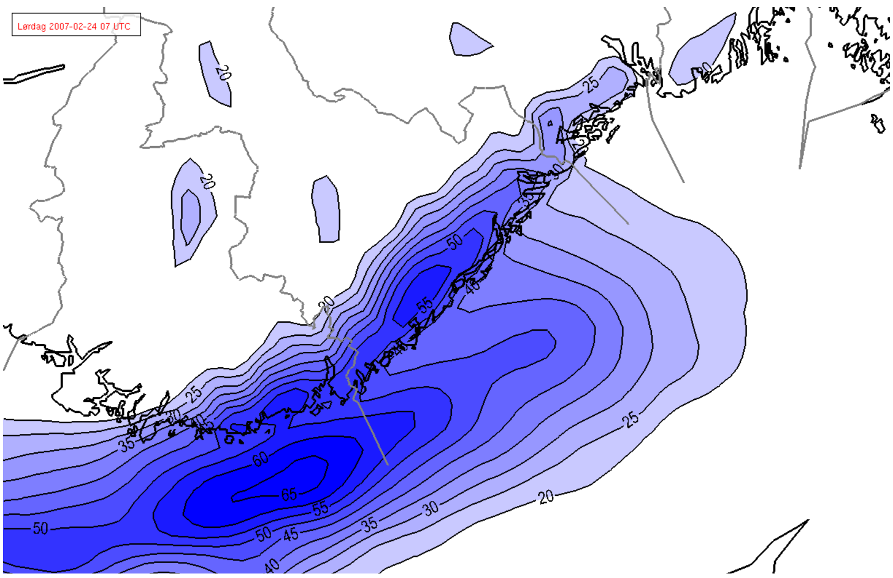
The time step is set to 30 seconds and a radiation time step ten times the time step. Canopy model 3 is used for UM 1km, together with boundary layer version 8A (MOSES-II with non-local K with entrainment scheme). Large scale precipitation is version 3D with prognostic rain. Convection is turned off and gravity wave drag is not included. For surface hydrology 7A for use with MOSES-II is used. Diffusion scheme is "standard" for the horizontal with diffusion coefficient 1.43e3 for all parameters and all layers, and "off" for the vertical. Targeted diffusion is not on.

total cloud cover	2d	AirQUIS
latent heat flux	2d	AirQUIS
momentum flux	2d	AirQUIS
precipitation	2d	AirQUIS
relative humidity	2d	AirQUIS
Richardson number	2d	AirQUIS
surface wind stress	2d	AirQUIS
sensible heat flux	2d	AirQUIS
surface roughness	2d	AirQUIS/SIMRA
dew point temperature	2d	AirQUIS
temperature	3d	AirQUIS/SIMRA
orography	2d	AirQUIS/SIMRA
geopotential	3d	AirQUIS
pressure	3d	AirQUIS/SIMRA
specific humidity	3d	AirQUIS/SIMRA
wind	3d	AirQUIS/SIMRA
vertical velocity	3d	SIMRA

Table 3 Output transferred to the applications

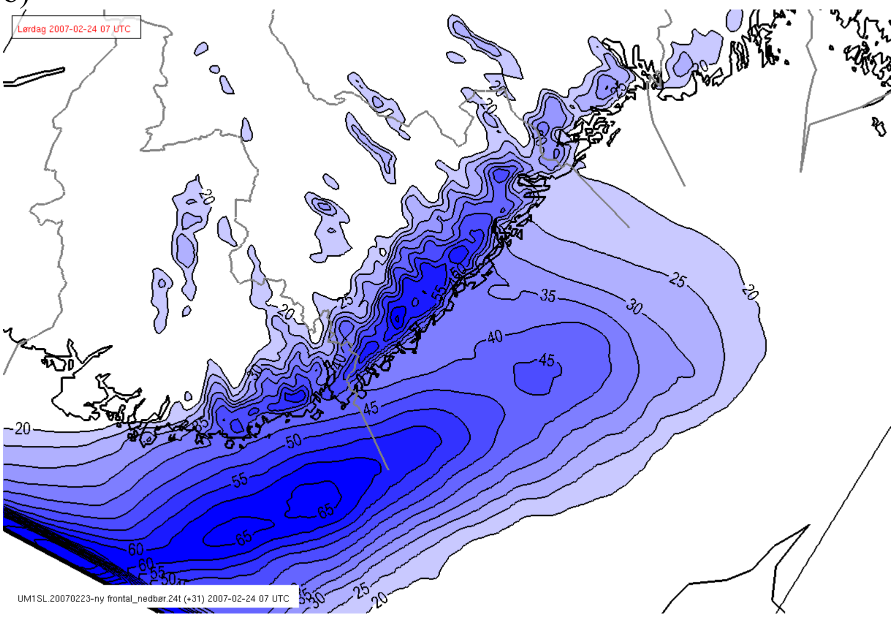
3. On the use of 1 km versus 4 km resolution for precipitation forecasts

Nordeng (2007) reported on a heavy snowstorm along the southern coast of Norway where the UM-model with 4km horizontal resolution and 38 vertical layers gave significantly better precipitation forecasts than the HIRLAM model with the same resolution. We have rerun the case with 1 km resolution to see if the precipitation forecast could be improved further. Large improvements are not expected since the 4 km runs gave not only very accurate estimates of accumulated precipitation amounts, but rather good temporal distribution as well. Figure 3.1 shows the effect of higher horizontal resolution for 24 hour accumulated precipitation by increasing the horizontal resolution from 4 km to 1 km but keeping the number of vertical levels unchanged at 38.



a)

b)



Lørdag 2007-02-24 07 UTC
UM1SL.20070223-ny frontal_nedbør.24t (+31) 2007-02-24 07 UTC

c)

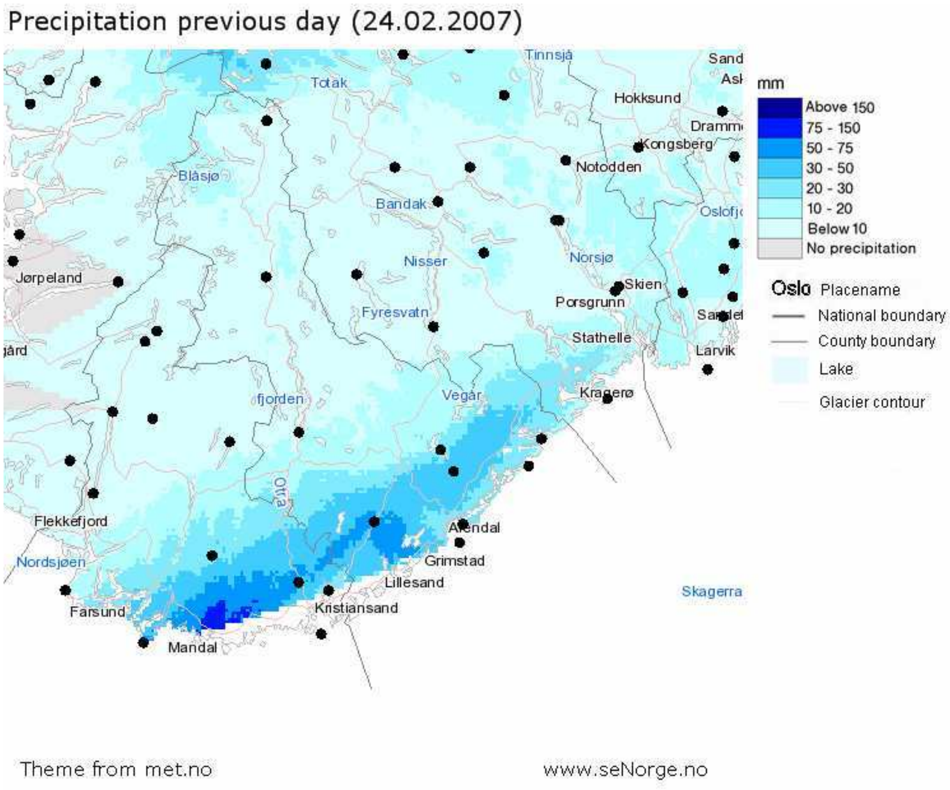


Figure 3.1 24 h accumulated precipitation (units mm) from UM4 (a) and UM1 (b) valid at 24. Feb 2007 at 06 UTC. Only precipitation amounts excess of 20 mm have been plotted. c) Verifying analysis taken from http://www.senorge.no/.

As expected, there are in general small differences, but the 1 km resolution experiment has more details particularly over land. When comparing with the objective analysis there seems to be best agreement between the observed and modeled local maxima close to the southern tip of Norway in the 1 km version of the model. The verifying analysis (http://www.senorge.no/) covers land only while model both simulations show large precipitation amounts over sea. Temporal and spatial distribution of precipitation may be evaluated by comparing with radar observations. Except for 6 hour accumulated precipitation valid at 18 UTC 23 Feb (Figure 3.2a) where the area of most intense precipitation is somewhat misplaced in the Skagerak, the simulation seems to capture intensity and distribution well.

a) b)

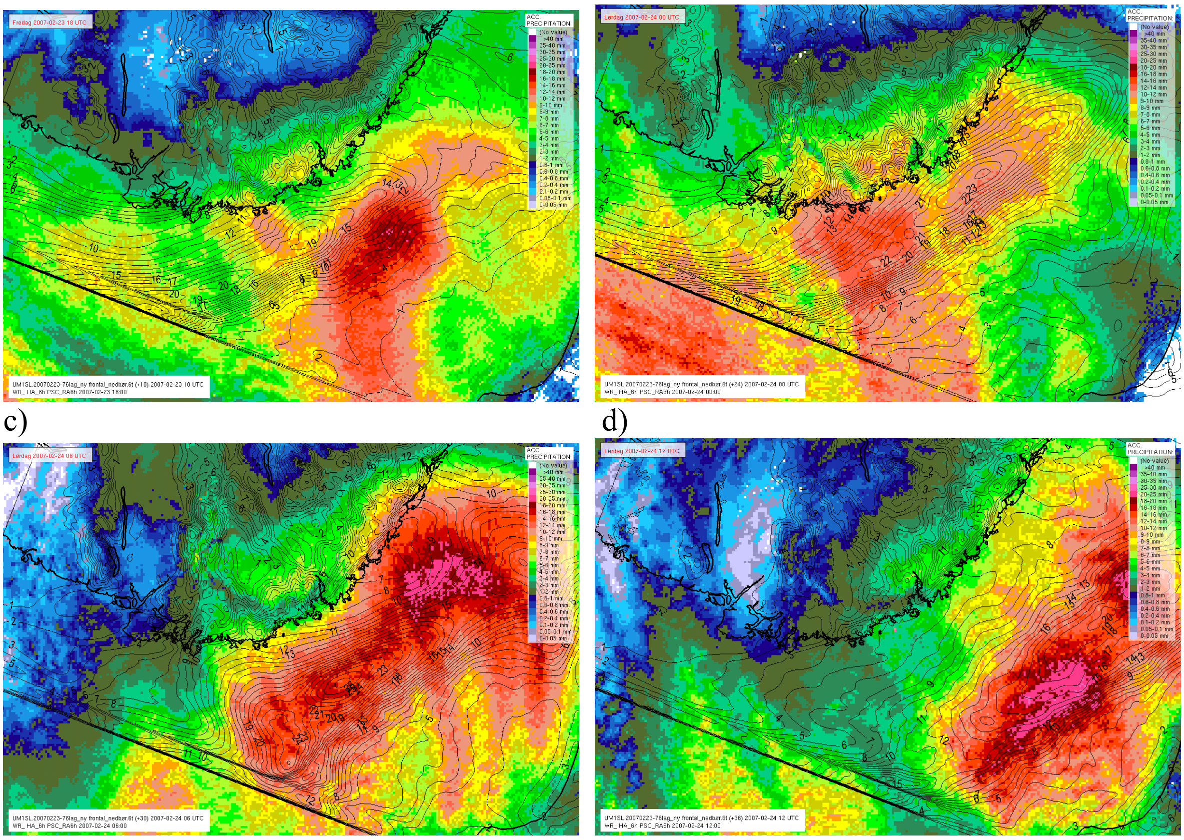


Figure 3.2 6 hour accumulated precipitation from the 1 km model (mm) and estimated precipitation from the Hægebostad radar. a) Valid at 23 Feb 2007 18 UTC, b) valid at 24 Feb 2007 00 UTC, c) valid at 24 Feb 2007 06 UTC and d) valid at 24 Feb 2007 12 UTC

Based on the radar observations it seems as the 1 km model has too much details over land and over predicts the precipitation amount. Over sea however the precipitation amount and position are well predicted.

It may be argued that the vertical resolution has to be increased together with the horizontal resolution for consistency (Lindzen and Rabinovitz, 1989). We have therefore rerun the 1km model but increased the vertical resolution to 76 vertical layers.

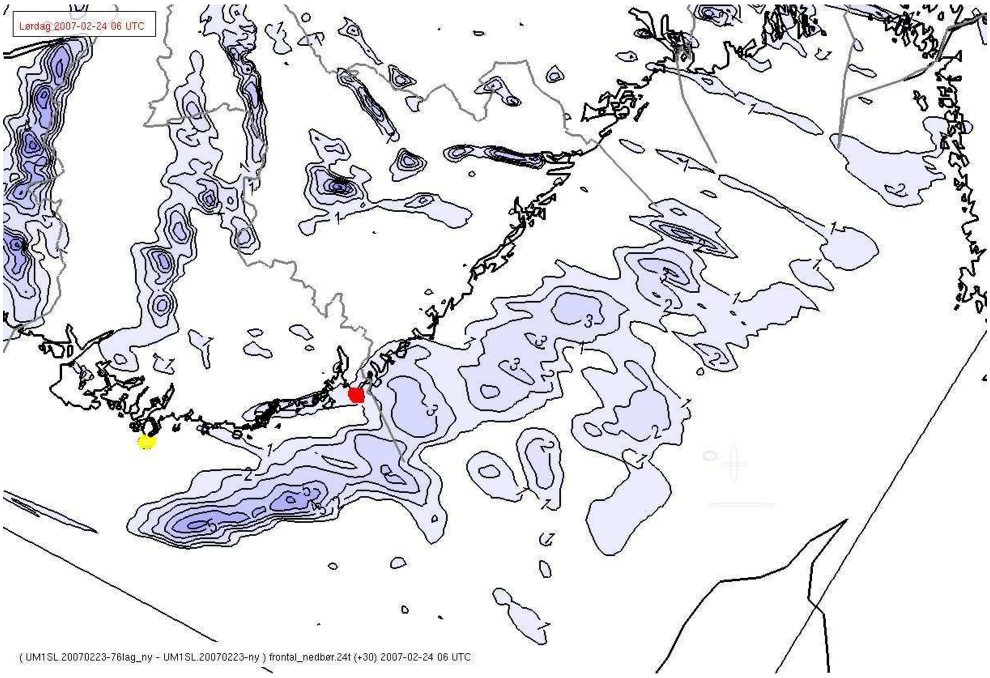
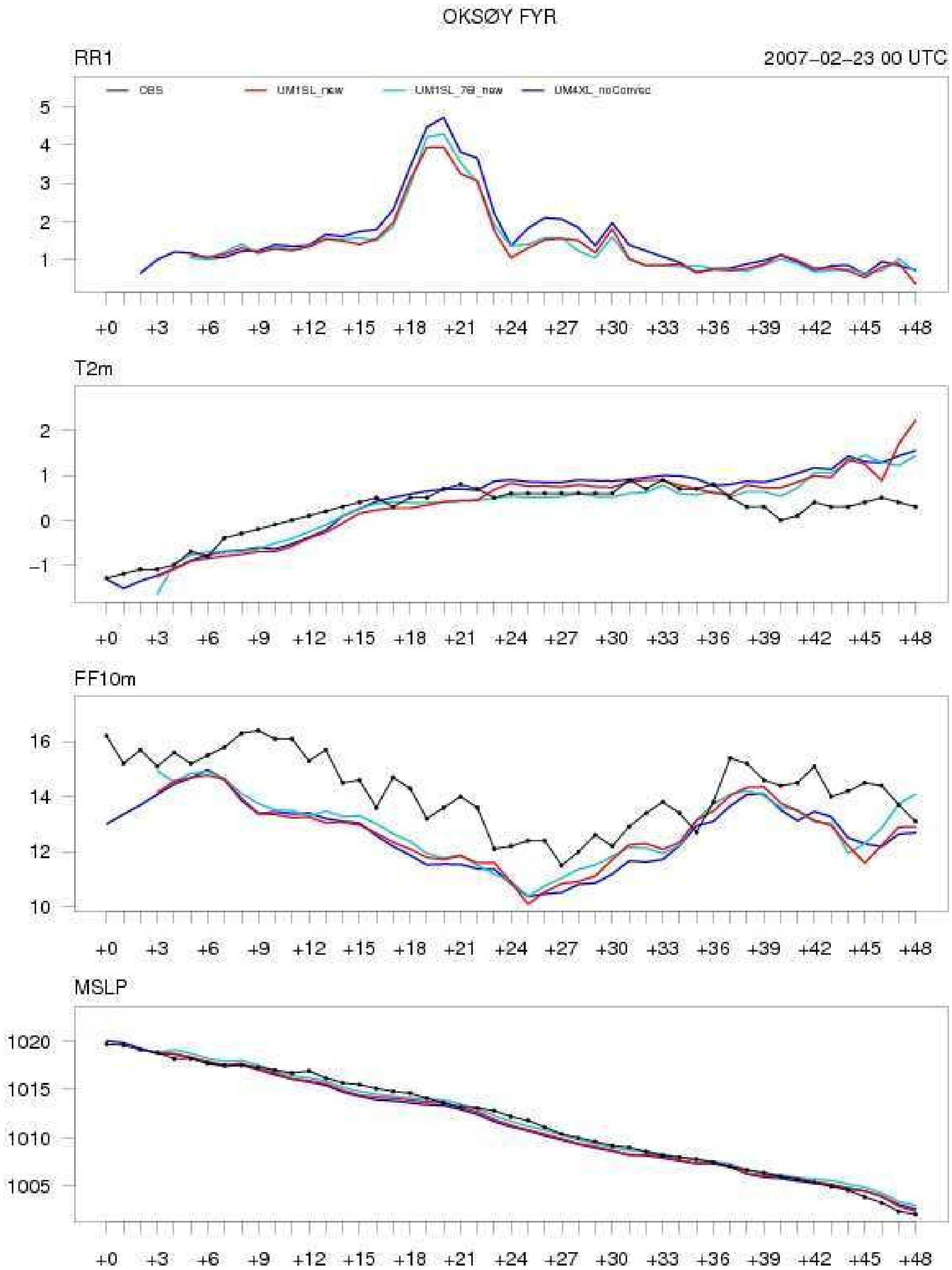


Figure 3.3 24 h accumulated precipitation difference between the 1 km run with 76 layers and 38 layers. i.e. (76 layers □38 layers) in units of mm precipitation valid at February 24 2007 at 06 UTC. Dots are positions for Oksøy light house (red) and Lindesnes light house (yellow).

We find some differences but the general pattern is quite similar. Differences are mainly found over sea and in the fjord areas along the South West of Norway (Fig. 3.3). 76 layers give slightly more precipitation at the very southern tip of Norway where a maximum was observed.

In Figure 3.4 we compare model simulations with observations from Oksøy and Lindesnes light houses (see figure 3.3 for positions).


OKSØY FYR
RR1
2007-02-23 00 UTC
OBS
UM1SL_new
UM1SL_78_new
UM4XL_noConvec
T2m
FF10m
MSLP

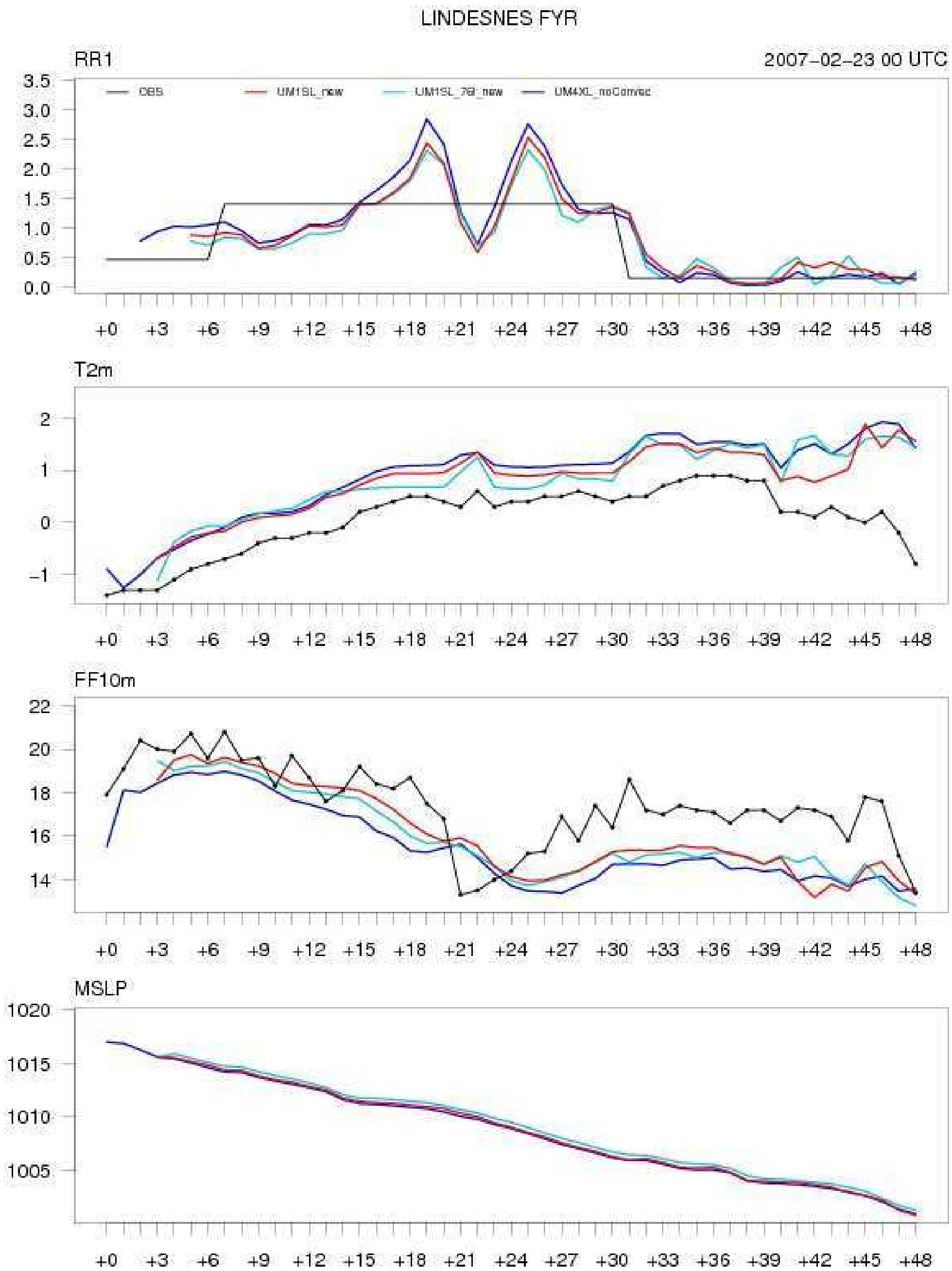


Figure 3.4 Model simulations version observations from Oksøy and Lindesnes light houses ("fyr") for precipitation (RR1), screen level temperature (T2m), wind strength (FF10m) and Mean Sea Level Pressure (MSLP). The positions are plotted in Figure 3.3 as red (Oksøy) and yellow (Lindesnes) dots respectively.

All models perform well with regard to standard parameters and are quite similar. An exception is wind speed which is systematically underestimated. We should however have in mind that the chosen synop stations are lighthouses at some elevation above the sea and that local effects may play a role. Precipitation is observed as accumulated precipitation over 24 hours (at Lindesnes) and it is therefore difficult to compare to the 1 hr. accumulated values from the models. We note however that for these stations UM4 has larger peak values than

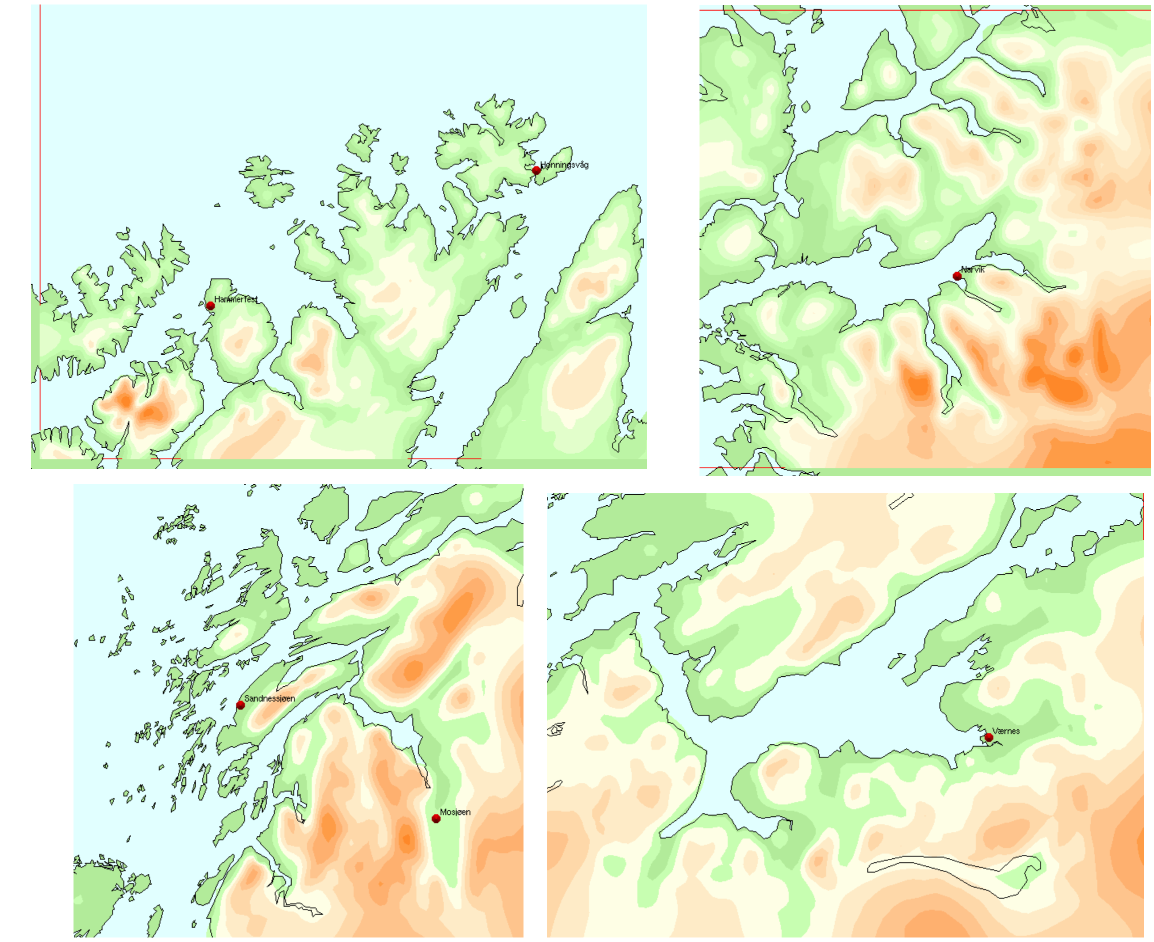
UM1 with the 76 layer versions of UM1 having less precipitation maximum than the 38 layer version.

For this case we find small differences between the UM4 and the UM1 model with regard to precipitation. UM1 provides more details, particularly over land, but it is difficult to judge from available observations whether this is more correct or not.

4. UM for turbulence modelling

4.1 Airport verification

The UM 1 km domains (see details in section 2.2) cover SIMRA domains around seven airports in western and northern Norway. This section focuses the verification of wind forecasts which are the main forcing data for SIMRA. The orography of the domains and location of the airports are shown in Figure 4.1.



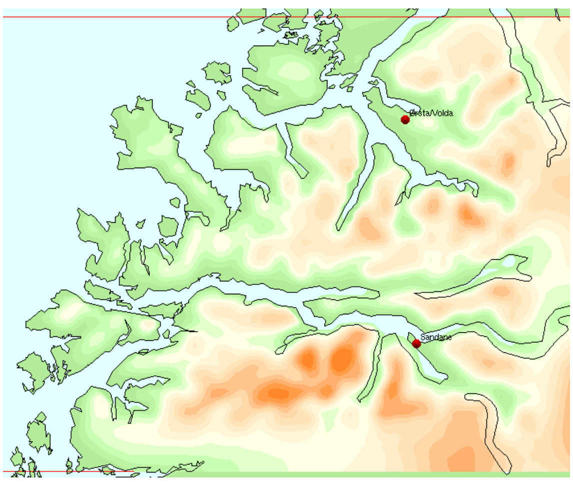


Figure 4.1 UM 1 km, orography and airport location in the domains HH (upper left), NA (upper right), SA (middle left), VA (middle right) and SO (lower).

Routine verification of wind is produced for four-monthly periods (Midtbø et al. 2008). SYNOP observations at the airports is the main data source when the ability of UM 1km to improve the description of other mountain induced flow characteristics is compared to UM 4km. Aircraft Meteorological Data Relay (AMDAR) observations from Værnes airport are used in addition to standard observations. Wind direction is taken into account in the verification by calculating the standard deviation for each of the wind vector components (s_u and s_v). These contribute to the measure standard deviation of error for U and V (S_{uv}) given by the formula

$$S_{uv} = \sqrt{\frac{1}{2}(s_u^2 + s_v^2)}$$

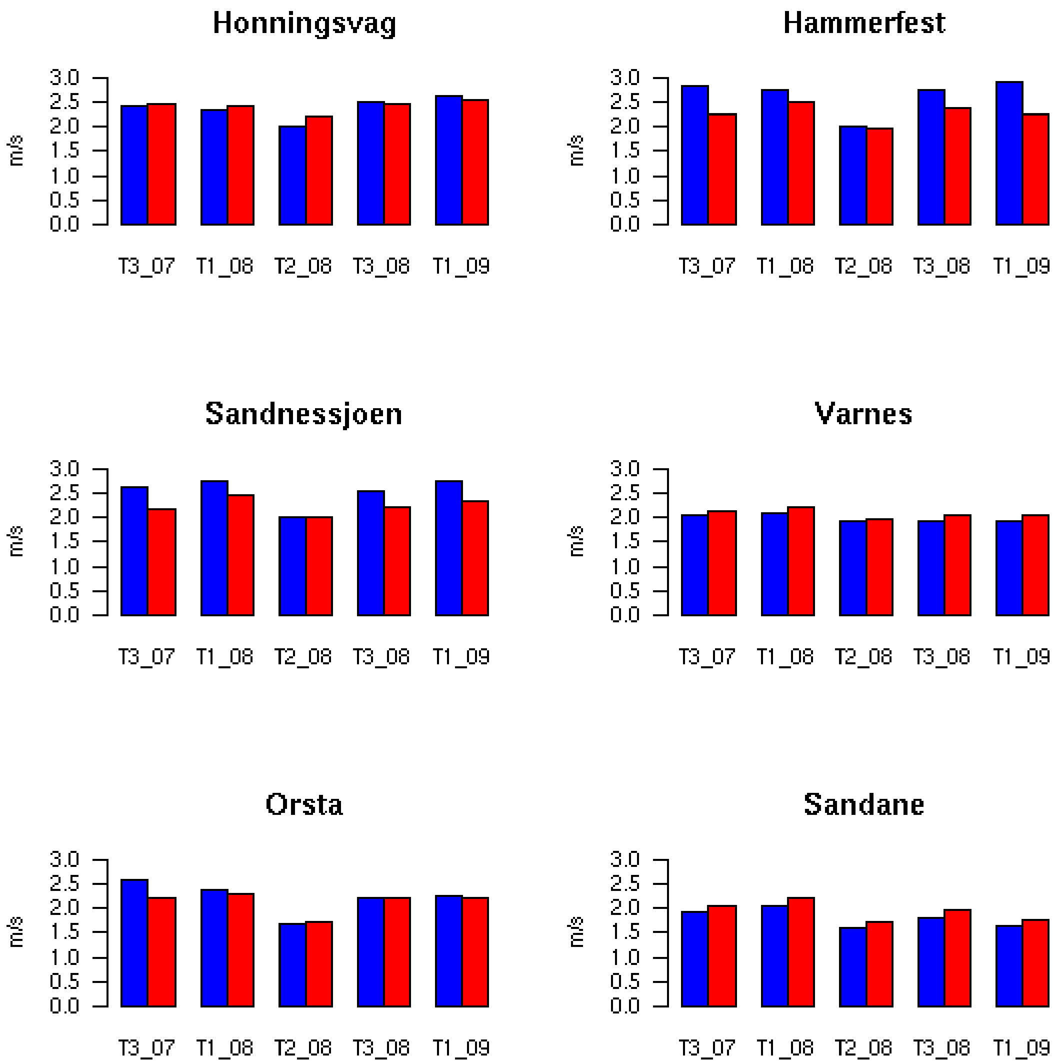


Figure 4.2 S_{uv} for UM 1km (red) and 4 km (blue) summarized over 4 months periods. Narvik is omitted due to unavailable data. Hammerfest and Honningsvåg are in domain HH, Sandnessjøen in domain SA, Værnes in domain VA and Ørsta and Sandane in domain SO.

The difference in performance among the models with 1 km and 4 km resolution is small as verified against SYNOP at the majority of the airports (Figure 4.2). For Hammerfest and Sandnessjøen airports the 1km model is superior to 4km. For the other stations there is not a benefit of going to higher resolution in terms of summary verification scores.

At Narvik only a shorter verification period is available (Figure 4.3). Here we show the wind roses and the results for mean absolute error (MAE), standard deviation of error (STDE) and mean error (ME) in wind speed. The wind roses (Figure 4.4) show that UM 1km is much closer to the observations than UM 4 km which has a majority of cases with easterly wind at the airport. The airport is located at the west side of high mountains and there is a fjord to the north. The easterly winds in the fjord turns north easterly as the fjord opens up near Narvik. This detailed orographic forcing is better captured with the 1 km resolution even if this result is not so explicit when only four directions go into the verification, as is the case for U and V. Due to the better correspondence in the north easterly winds, STDE and MAE are smaller in UM 1 km. However the underestimation of wind from south east is significant and compensates for an overestimation of north easterly winds in the 4 km model resulting in smaller ME in the 4 km model. The figures show results for HIRLAM and SIMRA as well because they are produced as a standard verification procedure.

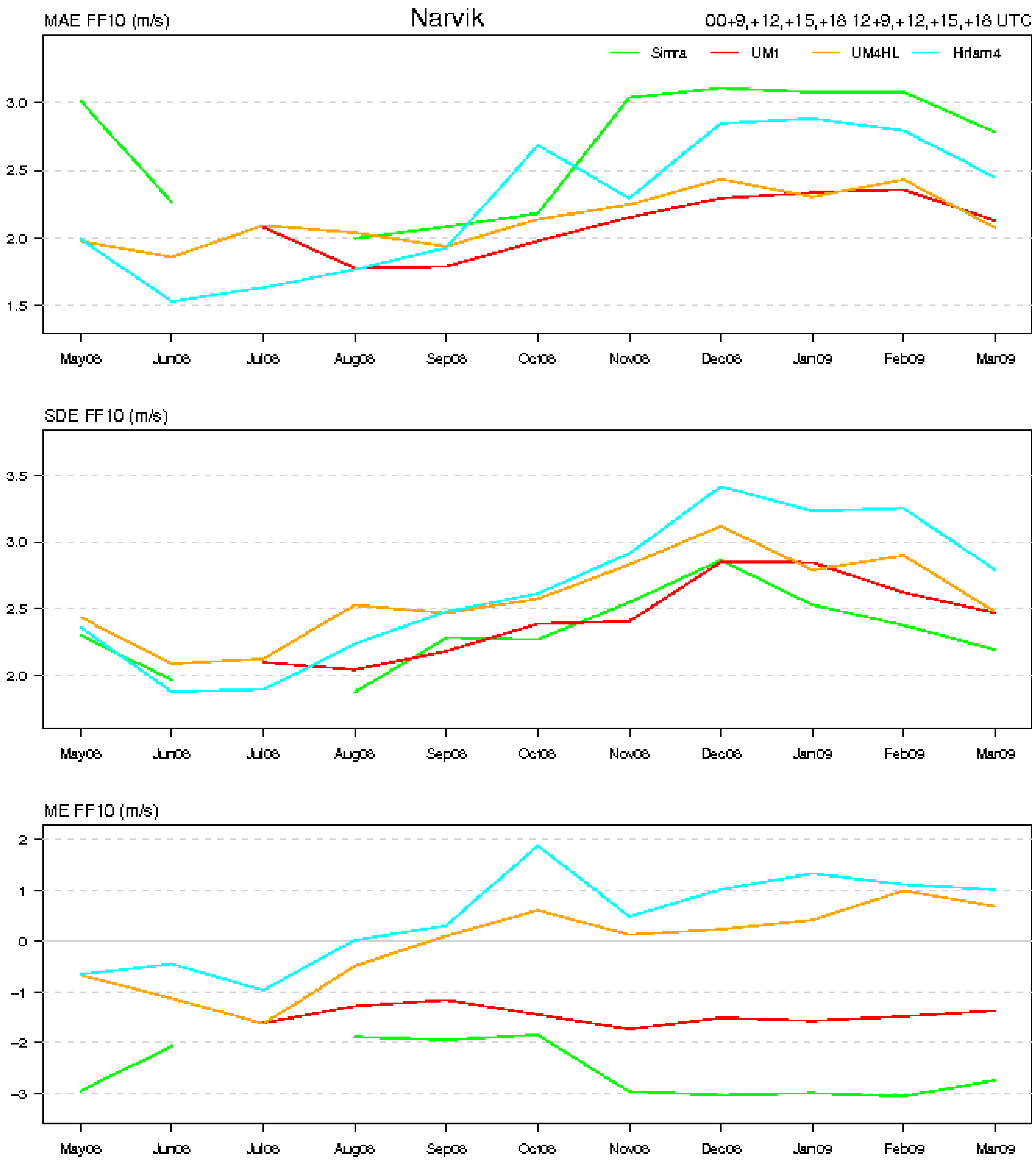


Figure 4.3 Monthly mean of wind speed statistics: Mean absolute error (top), standard deviation of error (middle) and mean error (bottom), UM 1 km (red), 4 km (orange). HIRLAM 4 km (cyan) and SIMRA (green) are shown as reference.

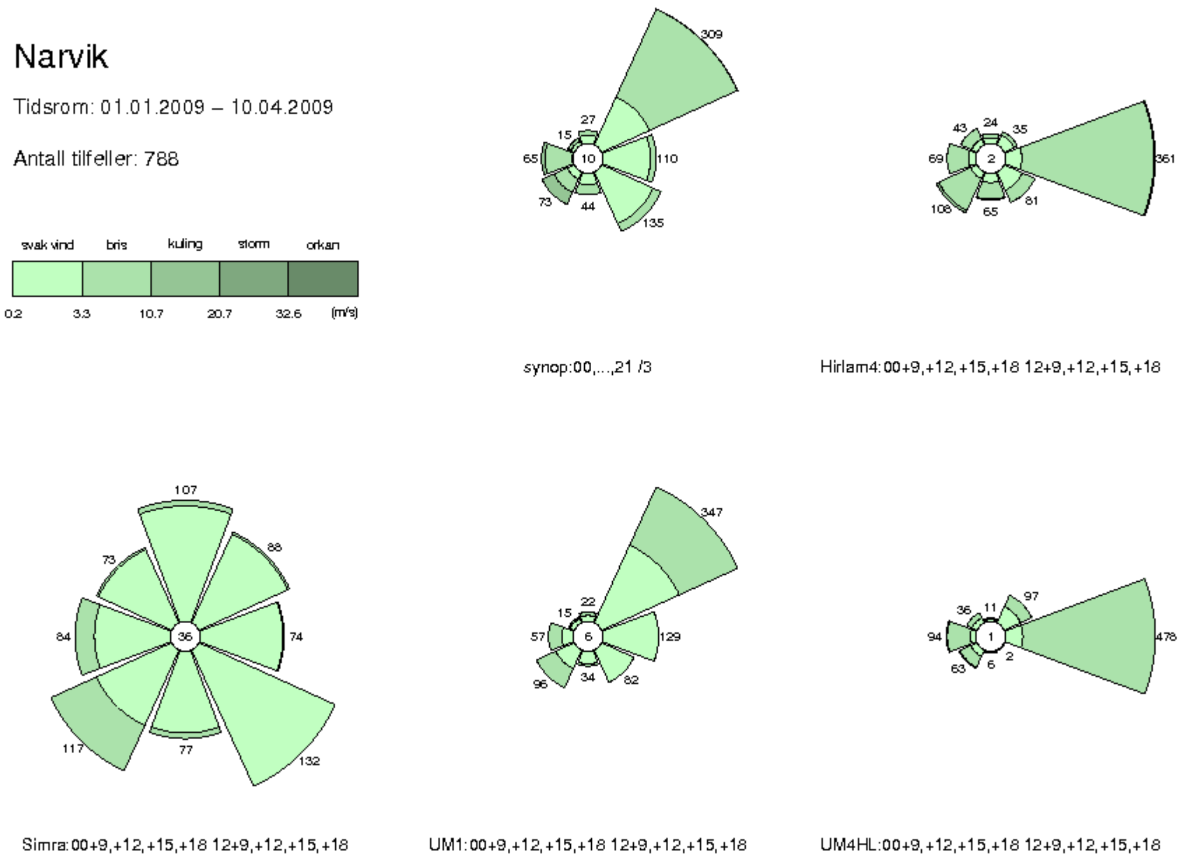
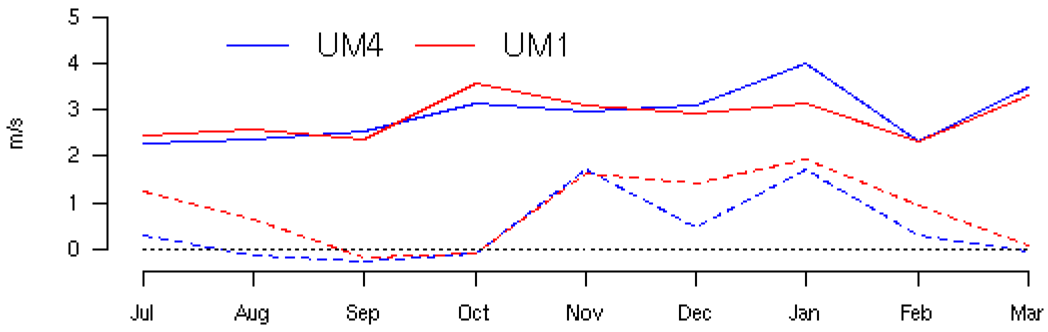


Figure 4.4 Wind roses for Narvik airport based on data from January 1st to April 10th 2009. Total number of cases (768) is distributed on eight directions. The number of cases with a given wind speed occupy the part of the sector (measured along the radius) that is proportional to it's percentage of the total cases in that sector. The data shown are SYNOP (upper middle), HIRLAM 4 km (upper right), SIMRA (lower left), UM 1 km (lower middle) and UM 4 km (lower right).

At Værnes airport AMDAR reports are available. AMDAR reports are produced continuously during take off and flight approaching the airport so that the observation results from a sampling procedure. Verification of short time forecasts from UM 1 km and UM 4 km against these observations over the period July 2008 to March 2009 is shown (Figure 4.5) for wind speed and S_{uv}. The standard deviation of wind speed error shows a slight benefit of running the higher resolution model. The mean error is positive and larger in UM 1 km than in UM 4 km. In terms of S_{uv} the benefit of higher resolution is larger suggesting a better representation of the wind direction when going to higher resolution.



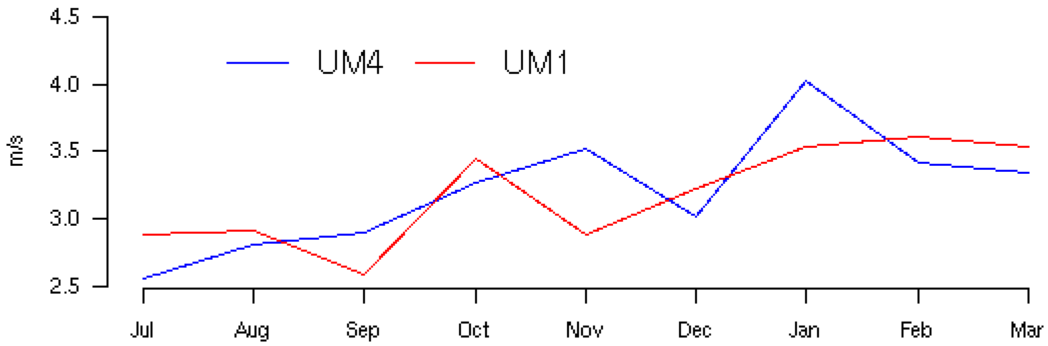


Figure 4.5 UM 4km and 1km verified against AMDAR reports. Upper panel: wind speed stde (solid) and mean error (dashed). Lower panel: S_{uv}.

Several attempts have been made to develop verification methods that can give a good description of the gain or loss in quality when increasing the model resolution. Verification methods have not been a part of this study, and we base our verification on standard methods and mostly on standard surface observations. This is a limitation for drawing conclusions about the benefit of going to higher resolution.

4.2 Vertical velocity

UM 1km tended to produce extreme vertical velocities which occasionally caused model crashes, but more frequently caused crashes in the SIMRA model. A forecast from January 25 2008 on the Finnmark domain was studied with a number of sensitivity runs including smoothing of orography, changing horizontal and targeted diffusion, changing the time step and compiling a new code with a fully-interpolating theta advection scheme. This is often desirable in high resolution local area model runs in domains with orography. One experiment was also run to eliminate the possibility of noise coming from errors in the lateral boundary conditions as calculated with MAKEBC.

The first sign of noise in the vertical velocity is after one hour run. The strongest signal is in model level 12 and it is spatially correlated with fog (Figure 4.6 top). After three more hours of integration this correlation can still be seen. The noise has also spread over a larger area possibly by reflection from the boundaries (Figure 4.6 bottom). From now the noise spreads over the entire domain.

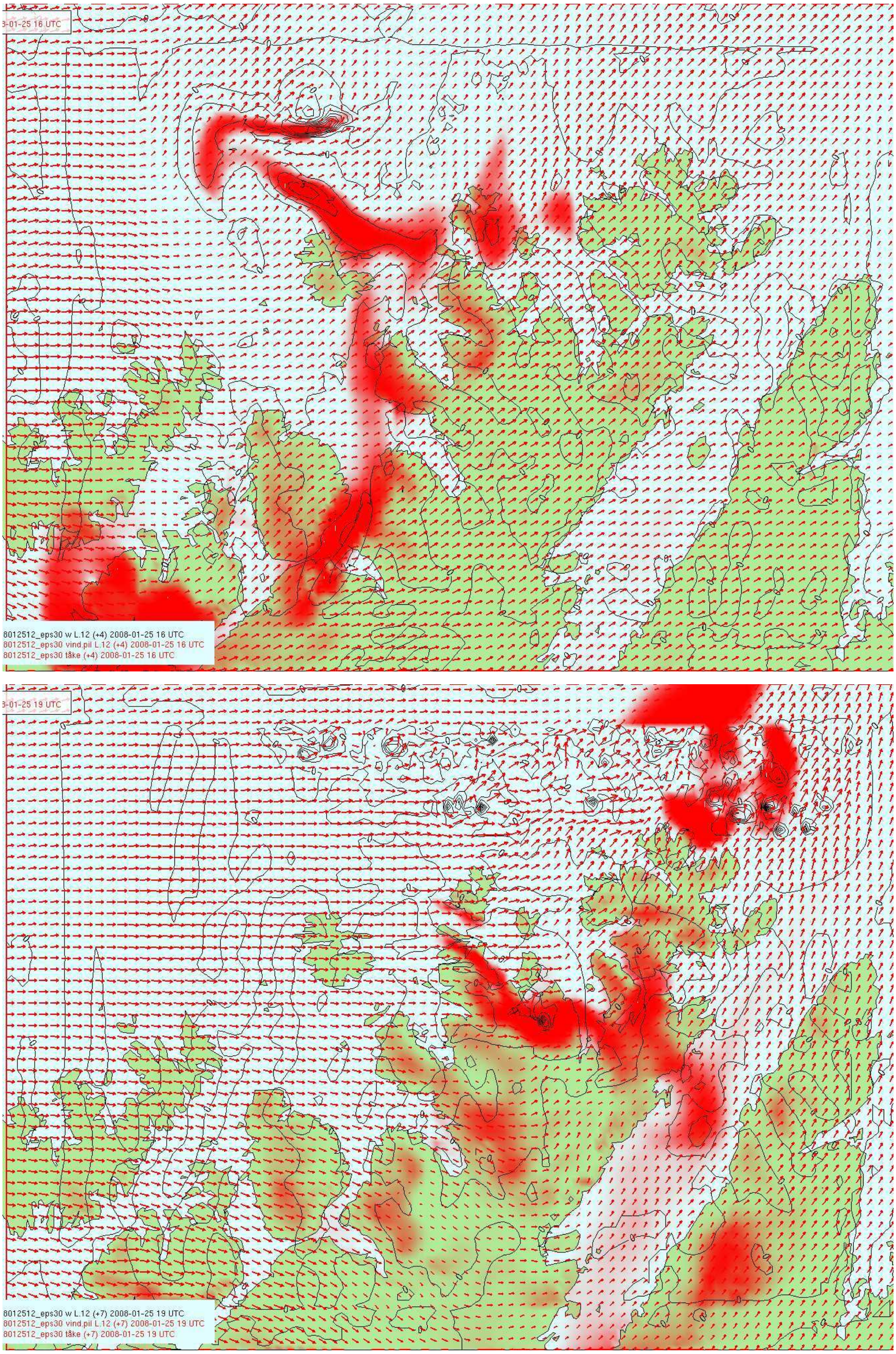


Figure 4.6 UM 1km 1 hour forecast (top) and 4 hour forecast (bottom) January 25 2008, wind and vertical velocity (black, 5 m/s isolines) in level 12 and fog.

The effect on maximum absolute value of vertical velocity from the different simulations is shown in table 5. In the control run we have time step=24 s, orography is smoothed with epsilon=1, all other settings as described in Table 4.

Name	**Description**	**$\vert$max w$\vert$**	**forecast hour for $\vert$max w$\vert$**
CTL	control	36.09	12
TDIF	turn on targeted diffusion	34.78	15
ZDIF	turn off horizontal diffusion	32.69	19
DT2	time step = time step / 2	72.39	11
2DT	time step = time step * 2	17.88	10
MLBC	boundary condition calculated in 4km run	42.06	16
Oe30	smoothing of orography with epsilon=30	39.37	13
O101	orography created from high resolution (100m) data base, epsilon=1	40.37	12
O130	orography created from high resolution (100m) data base, epsilon=30	41.57	13
NW	nw_extra9	15.91	17
NW2DT	nw_extra9, time step = time step * 2	14.59	20

Table 4. Sensitivity to vertical velocity. Experiment overview.

DT2 crashes after 11 hours, all other experiments completed 21 hours run. This was quite surprising together with the result that the doubling the time step had nearly as positive impact as the introduction of the code modification and that these two in combination gave the lowest absolute value of vertical velocity over all.

A case that also was studied in some detail was our first attempt to run on 333 m over Oslo. The orography in the Oslo domain is less steep than in Finnmark but the first sign of noise is seen over one of the steepest orographic gradients inside the domain. The correlation with fog is less obvious but a small fraction of fog is present nearby the initial wave. Vertical velocity after 27 hours run was -2 - 3 m/s in level 19. After 29 hours run it was -93 □71 m/s. Run with the code that included the modification nw_extra9.f90 meaning fully advection of theta removed the noise completely. On the background of these two case studies the code was used for daily runs on all of 1 km domains.

5. Sensitivity for high resolution land use data on urban winter time pollution cases

The land use data in the global UM database built on the IGBP dataset is given in 1km resolution. Ideally the resolution of the database should be higher than the resolution of the target grid. When interpolating to grids with higher resolution or 1km grids with displacement related to the data native grid, the database provides too limited information.

Orography data in 100 m resolution and land use data in approximately 250 m resolution covering the Norwegian areas are available from the Norwegian Mapping Authority (NMA). NMA defines 11 land use classes, and only two of the classes coincide with the 9 classes used in the UM model. Assumptions have to be made when the 11 classes from NMA are distributed on the 9 UM classes.

A model domain with 90x60 grid points covering the Oslo area and with 0.003 degree (333 m) resolution has been set up. The model domain is a sub domain of the 1km larger Oslo area which is run operationally at NMI for air quality forecasting purposes. Land use from NMA is used for the fraction of surface types in the 333 m model. The model is compared with the 1 km model in test runs.

The land use classes in the dataset from NMA distributed on UM land use classes that we have used in this experiment are given in Table 5.

	Broadleaf forest	Needle leaf forest	Grass	Shrubs	Urban	Water	Sum
Forest	0.3	0.7					1.
Agriculture	0.2		0.8				1.
Suburban	0.5		0.1		0.4		1.
Urban	0.2				0.8		1.
Lake						1.	1.
River						1.	1.
Wetlands/bog						1.	1.
Quarry					1.		1.
Industry					1.		1.
Airport					1.		1.

Table 5. Conversion matrix for NMA land use classes to UM land use classes

The 11th class in the NMA data is ocean. This is used for the Land Sea Mask. The motivation for the tabulated distribution of land use data is valid for the Oslo area, but not necessarily for other areas in Norway:

- Forests in Eastern Norway are a mixture of needle leaf and broadleaf. In mountainous areas, in Western and Northern areas broadleaf trees constitute a larger part of the forests, and are in some regions completely dominant.
- Agricultural areas in the selected domain are often composed of smaller fields with trees between them.
- Suburban is a complex class including both areas characterized by relative few and small houses with trees among them and areas with large, tall houses and less vegetation.
- Urban areas in Oslo are less urban than in most European cities. The tall houses are rather few, and parks and trees are abundant.
- Industry and airports are classified as urban mainly because of the surface cover which has very low water storage capacity. Roughness on airports is typically much lower than urban roughness. Quarries are classified as urban as well. The alternative would be bare soil. Airports and quarries contribute very little to the total area, and are therefore seen as less important.

There are no surface classes in the NMA dataset that are converted to inland ice, tropical grass or bare soil. These classes are set to zero. In the UM IGBP dataset tropical grass exists on isolated gridpoints, also on this northern domain.

The NMA data are given in UTM coordinates. Data are aggregated from their target resolution to 333 m resolution. In the next step the data are interpolated from UTM coordinates to rotated spherical grid using an averaging over the nearest 3x3 UTM points. Each surface class is then smoothed with the Raymond (1988) filter before a final check that they sum to 100% in each grid point.

The resulting surface type fields are shown together with the 1 km UM IGBP data in the following figures. A satellite photo over Oslo is shown for comparison. The green colour is not fully developed over fields as the picture is taken in spring. The NMA dataset gives more realistic fields when compared to the satellite image (Figure 5.4 left). The very small amount of broad leaf trees in UM is increased significantly (Figure 5.1 left). The distribution of needle leaf trees in NMA reflects the extension of the forests around Oslo (Figure 5.1 right) in the satellite image. Similar improvement can be seen in the extension of the urban area. In IGBP the 100% urban area is too large. High urban fraction is even found in the forest. In NMA the high urban fraction is located around the central city (Figure 5.3 left) as on the satellite image. The many small lakes are also present in the NMA dataset (Figure 5.3 right).

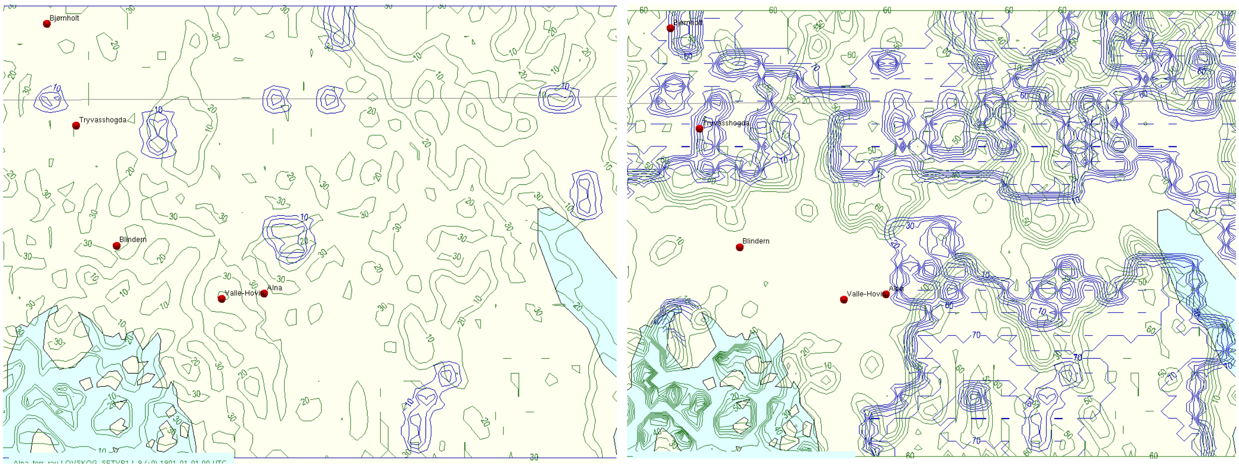


Figure 5.1 Fraction of broadleaf forest (left) and needle leaf forest (right) in the Oslo area, IGBP blue, NMA green. Observation sites are shown in red.

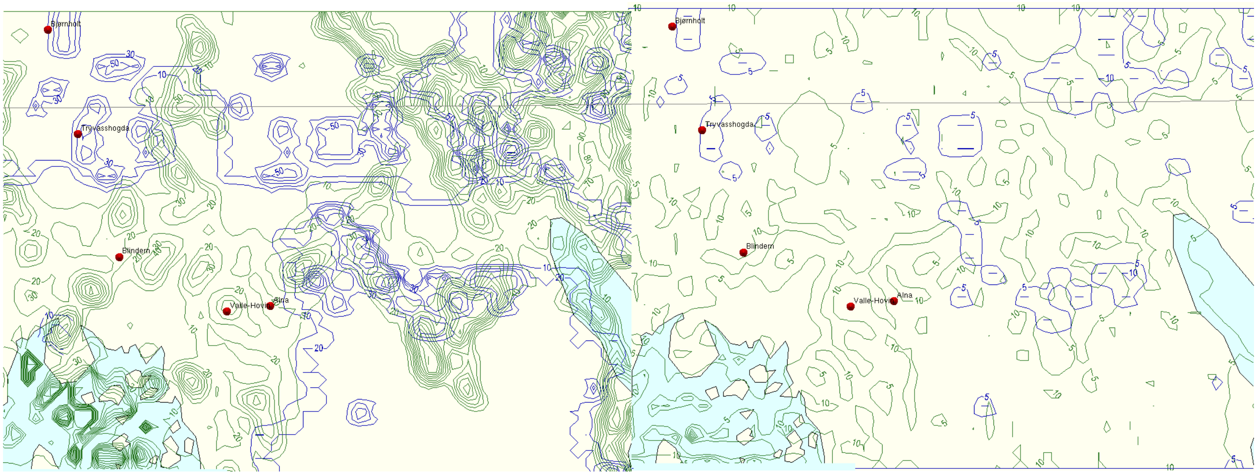


Figure 5.2 Fraction of temperate grass (left) and shrubs (right) in the Oslo area. IGBP blue, NMA green. Observation sites are shown in red.

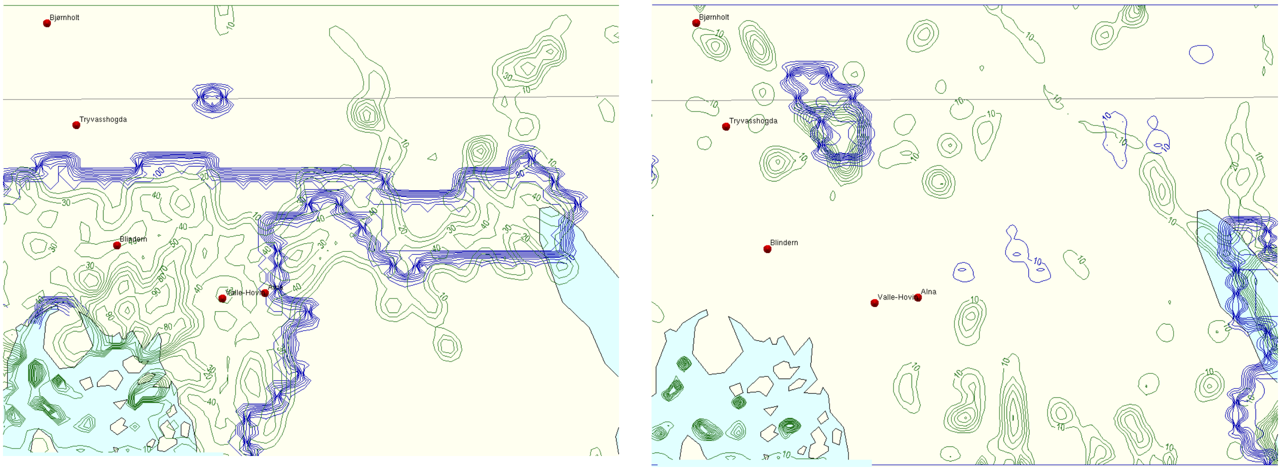


Figure 5.3 Urban fraction (left) and fraction of water (right) in the Oslo area, IGBP blue, NMA green. Observation sites are shown in red.

Figure 5.4 The model domain (left) and the area surrounding observation site Valle Hovin (right) as seen from satellite.

An inversion episode in the Oslo area from December 2007 was run with the high resolution land use data in UM 333 m resolution. The largest number of exceedance of critical pollution level in Oslo in 2008 was observed near Valle Hovin during December. The air pollution results will not be followed up in this report however.

The runs with high resolution model and land use data showed remarkably small differences compared to the 1 km runs. Further inspection of the ancillary fields showed that Leaf Area Index (LAI) and Canopy Height (CH) were still retained from the lower resolution data set. From our daily runs we have seen strong correlation between near surface temperature and CH and LAI. NMI has not available high resolution data set for CH and LAI so we attempted to use one value for each of the parameters for all representations of each vegetation type. The chosen values are approximately the maximum values that appear in the ancillaries for each of the vegetation types (Table 6) and the relation LAI to CH is consistent with the formula

$C_H = H_F LAI^{2/3}$,

where H_F for vegetation types 1 to 5 are given in Table 6.

The values for tropical grass are not used, as this fraction was set to zero (see above).

vegetation type	LAI	CH	H_F
Broad leaf trees	5	19	6.5
Needle leaf trees	6	21.5	6.5
temperate grass	4.9	1.46	0.5
tropical grass	4.9	1.25	0.5
shrubs	3	2.08	1.0

Table 6. LAI and CH for UM vegetation types.

After introduction of LAI and CH fields consistent with the new surface classes a larger impact from the high resolution data was seen. In Figure 5.5 a time series of 2m temperature from December 9 to 15 is shown. The legend 1 km refers to runs with 1 km resolution and data from the IGBP database, 333m refers to runs with 333 m resolution and land use classes from NMA and 333m_exp1 refers to runs with 333 m resolution, NMA land use and consistent LAI and CH.

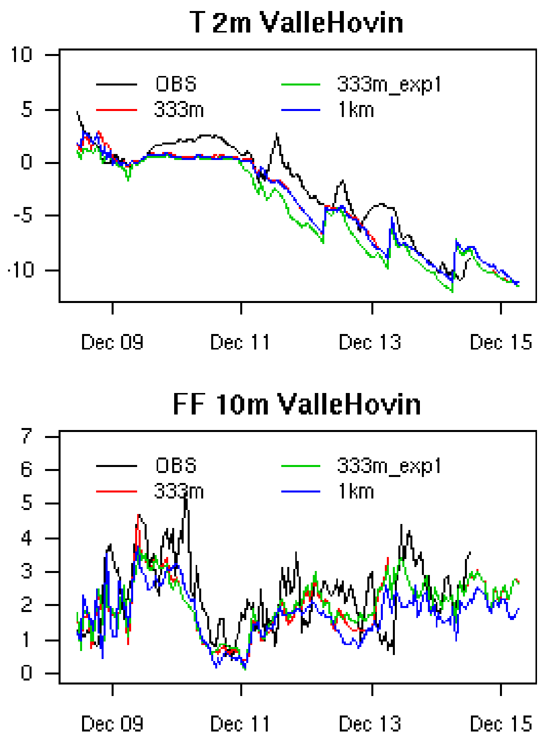


Figure 5.5 Temperature 2 m and wind speed 10 m at observation site Valle Hovin, observations and model runs (see text for explanation).

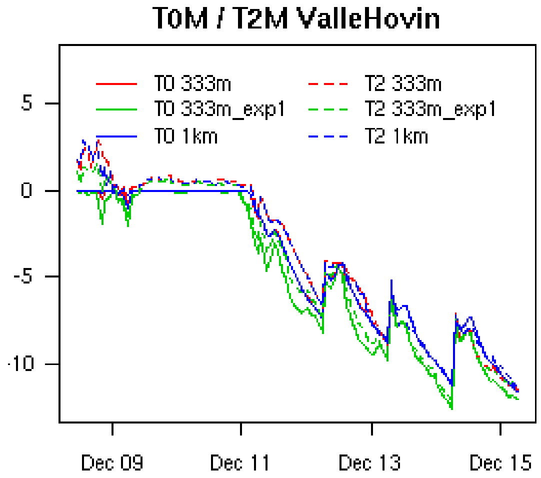


Figure 5.6 Temperature 2 m and 0 m at observation site Valle Hovin, model runs only (see text for explanation).

The land use classes in this particular grid box is changed from 100% urban to >20% broad leaf trees, >20% grass, >10% shrubs and 40% urban with introduction of the NMA dataset. The latter corresponds better to what can be seen from the photo in Figure 5.4 (right). Valle Hovin is at the red spot/arrow. The photo covers an area of approximately 1 square km.

In Figure 5.7 temperature observations from Valle Hovin in 2, 17 and 25 m are shown together with temperature profiles from UM 333m resolution and UM 333m resolution and consistent LAI and CH (_exp). The profiles are constructed form T0m, T2m, TL1-4. From the observations it is seen that there is a near surface inversion between 2 and 17 m all over the day except for 12 UTC (14 local time). Significant differences among the two different runs are limited to 0 and 2 m. In L1 just a small impact is seen. Moreover, as also seen from the timeseries in Figure 5.5 and 5.6, the temperature in 0 and 2 m is lower in 333m_exp. Temperature at 0 m is the prognostic variable, but not available from observations.

Without modified LAI and CH the inversion layer in UM is in the lowest 2 m of the atmosphere. The modification of LAI and CH makes the inversion layer extend over the lowest model layer in consistency with the available observations.

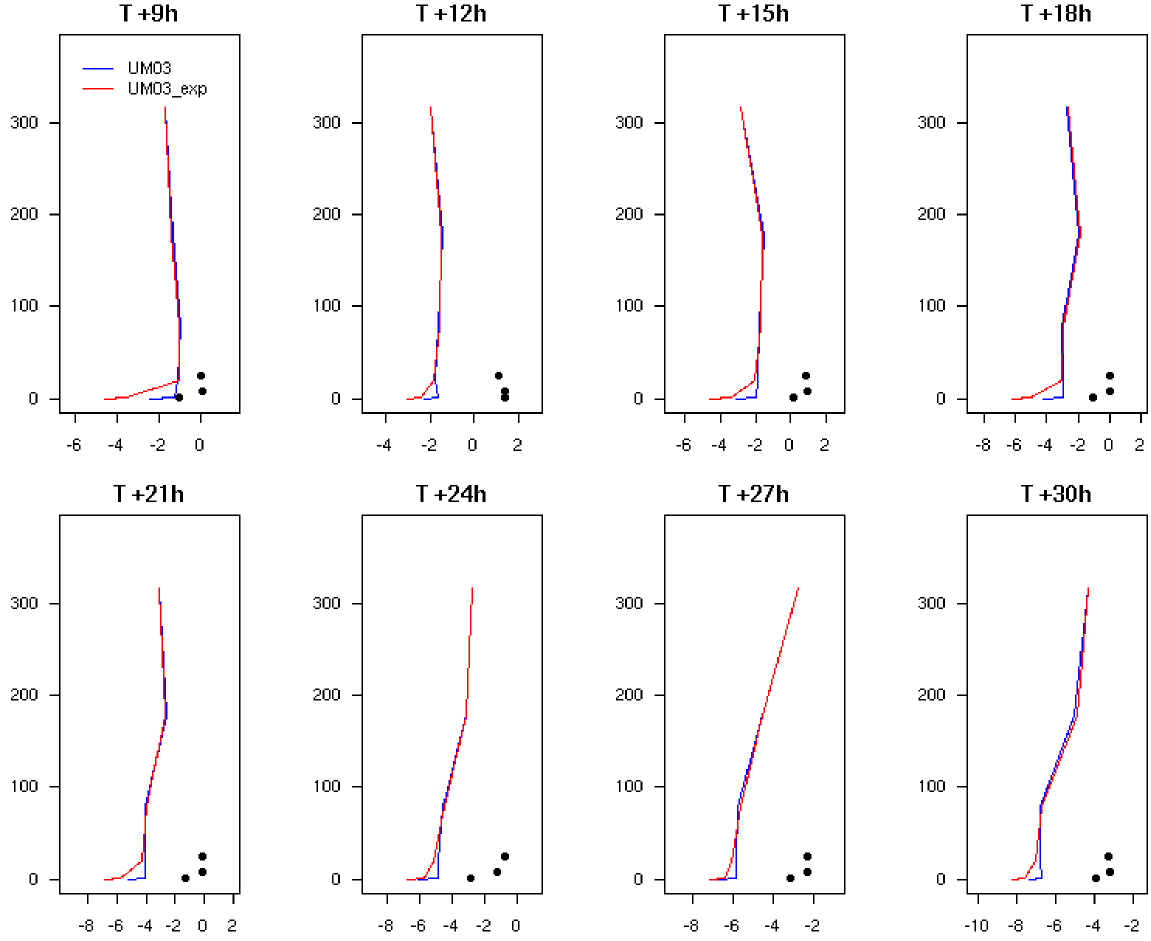


Figure 5.7 UM temperature profiles and observations in heights 2 m, 17 m and 25 m at Valle Hovin.

The result from another site in the winter case shows that the situation might be quite different dependent on which site we study and perhaps what the dominant surface types are. The observed temperatures at the station Tryvasshøgda (Figure 5.8) at 500 m were higher than temperatures at Valle Hovin 89 m above sea level. At this site we observe an improvement due to high resolution land use data, and a further improvement due to introduction of consistent LAI and CH. The land use classes for this grid point changes from 10% broad leaf trees, 30% needle leaf trees, 10% shrubs and 50% grass in IGBP to 20% broad leaf trees, 50-60% needle leaf trees, 10% shrubs and 10 % grass in the NMA dataset.

It should also be mentioned that the site Valle Hovin is studied by running two summer days when there was a large positive temperature bias at night time in the 1 km model. The stability in this case is low in contradiction to the winter case. The improvement in temperature is large when we used the NMA dataset with consistent LAI and CH. This shows that the sensitivity depends on the weather situation as well.

In these experiments we have simply replaced the land use and LAI/CH fields after they were created in the Ancillary generation system. There are technical issues about how to use alternative datasets in UM ancillaries. Introduction of alternative data to the database in the Ancillary generation system would ensure consistent treatment of the fields.

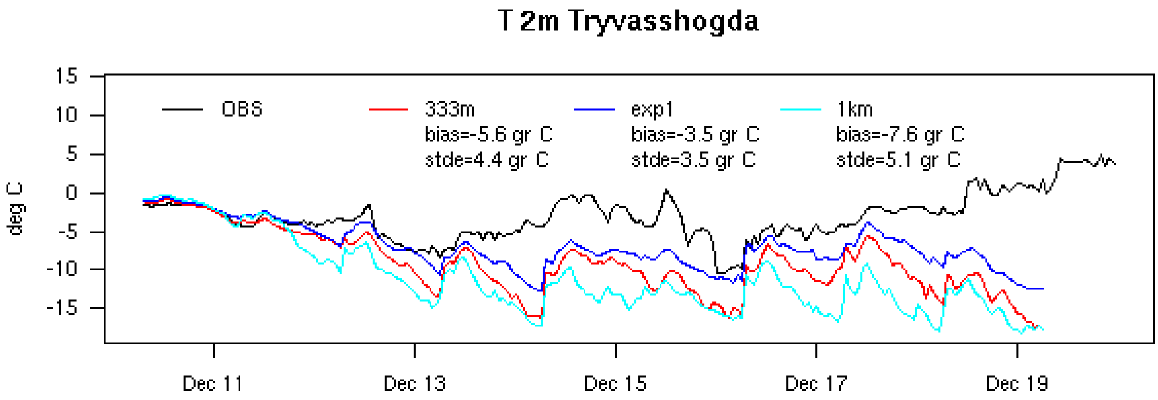


Figure 5.8 Temperature 2 m at Tryvasshøgda, observations and model runs (see text for description). Note the change in colours from previous figures.

The preliminary conclusion from this experiment is that the introduction of new land use data needs to be followed by consistent vegetation characteristics. The modified characteristics used here are not derived from observations of LAI. However for this winter period with frozen soil LAI is probably not the most important parameter. The change in land use composition from 100% urban to a mixture of vegetated and none vegetated tiles seems to improve the temperature vertical gradient in winter time. At the same time the surface temperature which is too cold in the forecast, decreases with about 2 degrees. Sensitivity tests with the physical properties of the surface tiles are needed to decide which parameters in the soil/vegetation parameterization that contributes to the changes we see here.

6. Summary

The UK Met Office Portable Unified Model (PUM) version 6.1 is set up with 1 km horizontal resolution on several small domains in Norway. The benefit of running with high resolution is studied with focus on wind forecasts in complex terrain, on precipitation from parameterized versus resolved convection and on sensitivity to land use data in winter time inversion cases.

In a case study of the snow storm on February 23 2007 UM 4 km resolution is compared to UM 1 km resolution with 38 layers and with 76 layers. The simulations are compared to gridded observations and timeseries of precipitation from two stations. The main finding is that the 1 km model provides some more details but these are not confirmed by the radar observations. There are small differences between the simulations with 38 and 76 layers.

The wind forecasts in complex terrain benefits from higher resolution, in particular when wind direction is taken into the verification score, but also wind speed can be improved. There is a shortage of observations compared to the large amount of model information, but aviation reports (AMDAR) from Værnes airport have high resolution and confirm the benefit of higher resolution runs.

The land use data in the UM IGBP dataset are replaced with data from NMA in experiments made for the city of Oslo with run in 333 m resolution. The NMA dataset corresponds better than IGBP to what is seen on the satellite image. It can be concluded from the experiments that the results vary among the different surface classes and weather situations. Sensitivity tests with altering the physical properties related to the surface classes will increase the understanding of the physical processes in the model and is recommended.

To achieve consistency in LAI and CH with land use data the alternative dataset should replace the original data in the database of the ancillary generation system rather than make a replacement of the fields after they were generated, as we did here.

Acknowledgement

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References:

Lindzen , R.S. and M. Fox-Rabinovitz (1989): Consistent Vertical and Horizontal Resolution. Mon. Wea. Rev. **117**, pp. 2575–2583.

Midtbø, K.H., J.B.Bremnes, M.Homleid and V.Ødegaard (2008) Verification of wind forecasts for the airports Hammerfest, Honningsvåg, Sandnessjøen, Ørsta, Værnes, Sandane and Narvik. met.no report **2/2008**, Norwegian Meteorological Institute (http://met.no/forskning/Publikasjoner/Publikasjoner_2008)

Nordeng, T.E., 2007: A study of the model performance for the February 2007 snowstorm on Sørlandet. Part I: Evaluation against observations. Met.no note no. **1/2007**. Norwegian Meteorological institute. (http://met.no/Forskning/Publikasjoner/Publikasjoner_2007/filestore/01_2007.pdf)

Raymond, W. H. (1988) High-order low-pass implicit tangent filters for use in finite area calculations. Mon. Wea. Rev. **116**, pp. 2132–2141.

List of acronyms

Acronym	Full name	Description
AirQUIS	Air Quality Information System	Owned by NILU and containing the modules i) Geographical Information System ii)Automatic Data Acquisition System iii)Measurement iv)Statistical and Graphical Presentation Tools v)Emission Inventory vi)Emission Model vii)Wind Model viii)Dispersion Model ix)Exposure Model
AMDAR	Aircraft Meteorological Data Relay	A programme initiated by the World Meteorological Organization used to collect meteorological data worldwide by using commercial aircraft by the aircraft navigation systems and the onboard standard temperature and static pressure probes.
ANCIL	Ancillary generation system	Creating fields needed for model runs, constant parameters, physiography and climatological fields
CH	Canopy height	Average height of vegetation or building canopy
HIRLAM	High Resolution Limited Area Model	Numerical Weather Prediction (NWP) forecast system developed by the international HIRLAM programme
IGBP	International Geosphere and Biosphere Programme	A research programme that studies the phenomenon of Global Change
LAI	Leaf Area Index	The ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows
LSM	Land Sea Mask	Mask defining the horizontal gridpoints as land or sea
MAKEBC	Make Boundary Conditions	programme for generation of lateral boundary conditions to the Unified Model
MM5	Mesoscale Model version 5	A limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation
MOSES	Met Office Surface Exchange Scheme	The land-surface model used in the Met Office General Circulation Model (GCM) for both climate modelling and numerical weather prediction. in which heterogeneous surfaces may be treated using a tiled representation.
NMA	Norwegian Mapping Authorities	National institution that serves the Norwegian society's need for a national covering geographical information.
SIMRA		SIMRA turbulence model based upon Reynolds equations with a standard (K, epsilon) turbulence closure and boundary conditions.
UM	Unified Model	UK Met Office numerical weather prediction model
umui	Unified Model User Interface	graphical user interface for setting up model runs
UTM	Universal Transverse Mercator (UTM) coordinate system	A grid-based method of specifying locations on the surface of the Earth where the amount of distortion is held below 1 part in 1,000 inside each zone.