Experimenting with the orography of HIRLAM

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1 Background

During the last few years two important problems have shown up in HIRLAM: 1) near the surface there is always windy, and 2) the model has problems in filling cyclones in time. Solutions have been sought in order to increase the drag in the model: a new mesoscale orography (gravity wave) parametrization scheme has been implemented Rontu et al. (2002); Rontu and Bazile (2003), turbulent surface drag has been modified by modifying the effective roughness de Rooy (2003) and new formulations for turbulent mixing have been applied, e.g. Tijm (2003). An attempt to derive high-resolution climate variables, suitable for HIRLAM meso-scale and small-scale orography parametrizations was made in Rontu (2003a,b). Recently, an entirely new approach of turning the surface stress vector has been suggested and tested (Sass and Nielsen, 2004; Järvenoja, 2004).

The aim of this study is to test and compare modifications of the surface stress using the reference orography and newly derived fine-scale orography. In addition to the reference HIRLAM system experiments with modified roughness, new small-scale orography (SSO) stress and mesoscale orography (MSO) parametrizations were performed.

2 Experiments

An eleven-day period in January, 2000 was chosen for comparisons. Fig. 1 shows the averaged over the period ten-metre wind and mean sea level pressure averaged over the time period and integration area. A north-westerly flow over the Scandinavian mountains was prevailing.

The integration area was that of Baltex-BRIDGE, Δx=22 km/40 levels. Long forecasts (+48h) were started from 00 UTC only, using a HIRLAM version of $\approx$ 6.2.1 but with the radiation scheme of 6.2.4[1]. Boundaries were obtained from a 33 km/40 level HIRLAM reanalysis 6.2.2 run at ECMWF for the year 2000. Observations were taken from ECMWF archive. The experiments are defined in Table 1. Experiments ORO1-ORO4 use the orography and effective roughness based on the reference HIRLAM system while experiments ORO5-ORO7 use the alternative fine-scale orography variables and methods. Thus, in the latter experiments the orographic roughness is not applied but replaced by the (tuned) vegetation roughness plus new treatment of the small-scale orographic turbulence. The new orographic turbulence parametrization utilizes the ideas by Brown and Wood (2001) and the needed orography-variables are derived as explained in Rontu (2003a,b).

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[1] Note that the reference HIRLAM orography was not yet correctly filtered in these experiments

Table 1: Definition of the numerical experiments

experiment	description
ORO1	reference HIRLAM unmodified
ORO2	ORO1 but z_0 modified according to de Rooy (2003)
ORO3	ORO2 but enhanced $z_{0,oro}^{(a)}$
ORO4	ORO2 but $z_{0,oro}=0$
ORO5	ORO4 but with new mean orography
ORO6	ORO5 + new orographic turbulence + tuned $z_{0,veg}^{(b)}$
ORO7	ORO6 + mesoscale orography parametrizations

$^{(a)}z_{0,oro} = z_{0,oro,orig}^2$ if $z_{0,oro,orig} > 1$ m
$^{(b)}z_{0,veg} = 2z_{0,veg,orig}$

3 Results and discussion

There are several possibilities and several problems in comparing vector fields like the wind and surface stress. Using the standard verification methods we compare forecast wind velocity and p_{msl} with observed values at synoptic stations (station verification) or analyse maps of the differences between analysis and forecasts. Analysis of the resolved scale kinetic energy and vorticity budgets would offer additional possibilities for comparison. In any case, the choice of the area and period for averages may have a significant effect on the results when the sample is small, as often is in the comparison experiments.

In Figs. 2 and 3 a series of station verification results over the EWGLAM stations are compared. Only ten-metre wind velocity and p_{msl} are shown. One can see that the positive wind bias of the reference experiment (ORO1) is halved by the roughness modifications of the experiment ORO2. The enhancement of orographic roughness (experiment ORO3) did not, somewhat unexpectedly, lead to a further improvement of the verification scores. Removal of the orographic roughness and leaving only the vegetation component (ORO4 and ORO5) had a negative effect, i.e. the positive bias of ten-metre wind increased again towards the original values. The difference between ORO4 and ORO5 is due to the different mean orography only, and is seen to be insignificant. In fact, the new and reference mean orography without filtering are practically identical in this coarse resolution study. Introduction of the new SSO parametrization (ORO6) made the bias somewhat smaller compared with the experiment with only vegetation roughness included (ORO5). Note that at every gridpoint in ORO5 $z_{0,veg}$ was doubled compared to ORO2. The combined experiment including SSO, MSO and using the new orography and related variables (ORO7) produces scores of equal quality to those of the reference-style experiment (ORO3). The surface pressure bias was practically not influenced by the modifications.

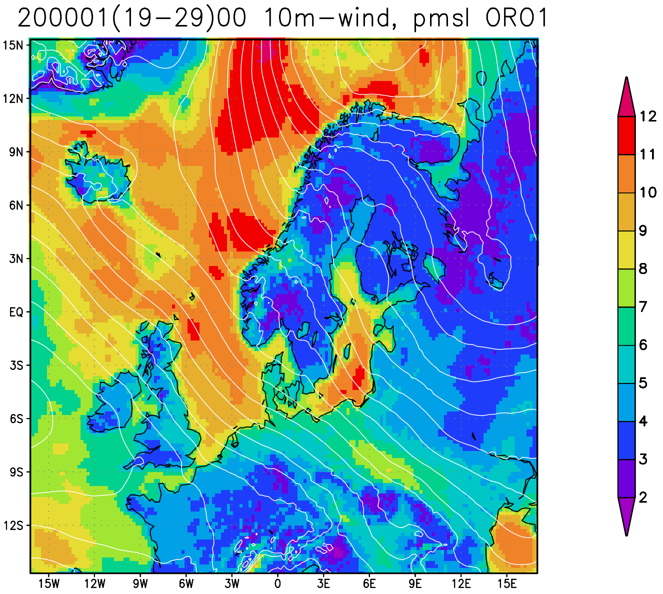

Figure 1: *Mean wind (shades of grey) and mean sea level pressure (contours) given by the reference experiment ORO1 (see Table 1) over the period January, the 11-19, 2000.*

A series of maps showing systematic difference between the +48h forecast and analysis of the lowest model level wind was drawn (not shown). No clear conclusions based on this material could be drawn, partly due to the possible problems of the wind analysis close to the surface. (During the discussion at ASM it was adviced to use the initialized analyses instead, where the unphysical oscillations should be removed and the data are technically more correctly handled than in the case of raw analyses.) The systematic difference between the predicted p_{msl} in the experiments ORO1-ORO7 (not shown) revealed the largest (negative) differences over the mountains. Over the Central Europe, the pressure in ORO7 is less than one hPa higher than that in ORO1.

An example of vertical profiles of the area-averaged kinetic energy budgets is shown in Fig. 4. The values are accumulated over the +48h forecasts and averaged over the north-eastern quarter of the area. Most notably, these pictures tell about interactions and compensation between the different parametrization schemes, noted alredy by Rontu et al. (2002); Rontu and Bazile (2003).

Components of the turbulent, small-scale orography and meso-scale orography surface stress vectors were compared over the complex orography of Iceland (not shown). The summary stress of ORO7 was somewhat larger than that of ORO3 (where turbulence only is responsible for the surface stress). In this case, the largest component of the surface stress over Iceland was due to the MSO parametrizations. The direction of the surface stress vectors was different in these experiments because directional effects are included in the MSO parametrization. Naturally, no difference over the sea areas was seen.

4 Conclusions

Based on this study, the following conclusions can be drawn.

Suggested by de Rooy (2003) et al. modifications to the vegetation roughness influencing

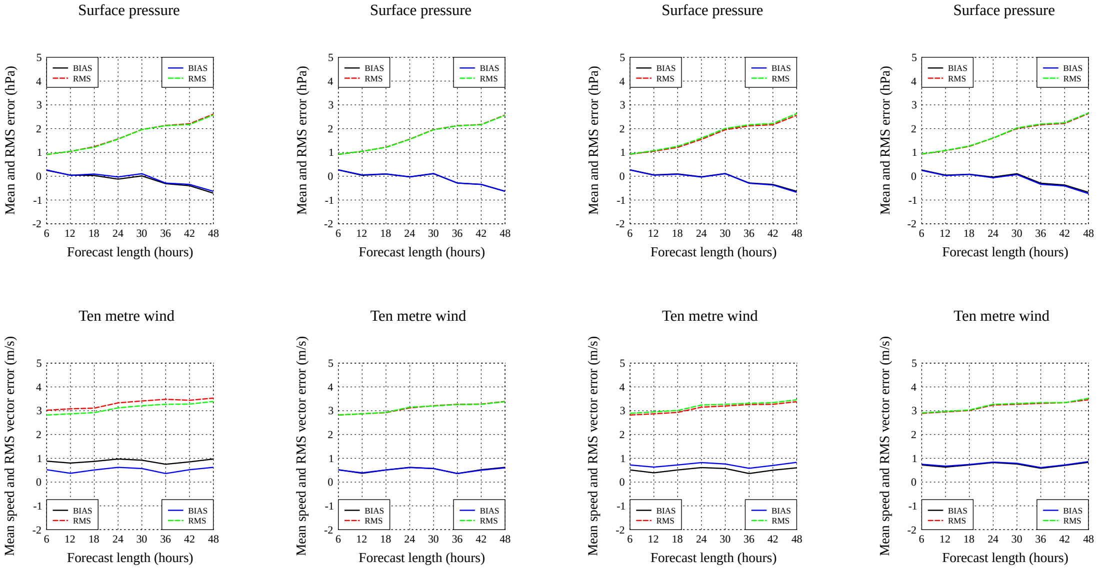

Figure 2: *Bias (solid black and blue) and RMS error (dashed red and green) from left to right: ORO1 and ORO2; ORO2 and ORO3; ORO3 and ORO4; ORO4 and ORO5. The first experiment in each pair is shown with black and red, the second in blue and green. Please look at the coloured version of the Newsletter at http://hirlam.knmi.nl*

momentum fluxes have a positive impact and should be implemented in the reference system. Also using the enhanced orographic roughness improves the wind verification scores. Still, the concept behind this modification is not clear or physically well based. [2]

The concept of orographic roughness can be fully replaced by correctly derived and formulated small- and meso-scale orography parametrizations. However, further studies are needed in order to validate the method and tune the parametres.

The parametrizations related to the different horizontal scales of the surface stress - rough surface described by the vegetation roughness, small- and mesoscale orography effects - interact and compensate each other. This requires careful testing of the whole complex when one component is modified.

None of the proposed modifications had significant influence on the negative pressure bias.

The present study raises several items related to the methods of validation and diagnostics, e.g.: How can the lowest model level and ten-metre wind be used in validation? What would the standard station verification of the initialized ten-metre wind show? What are the uncertainties related to space and time averages used in validation? What more could we learn from kinetic energy and vorticity budgets?

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[2] Both of these updates together with additional modifications to the turbulence scheme have implemented into the reference HIRLAM version 6.2.4.

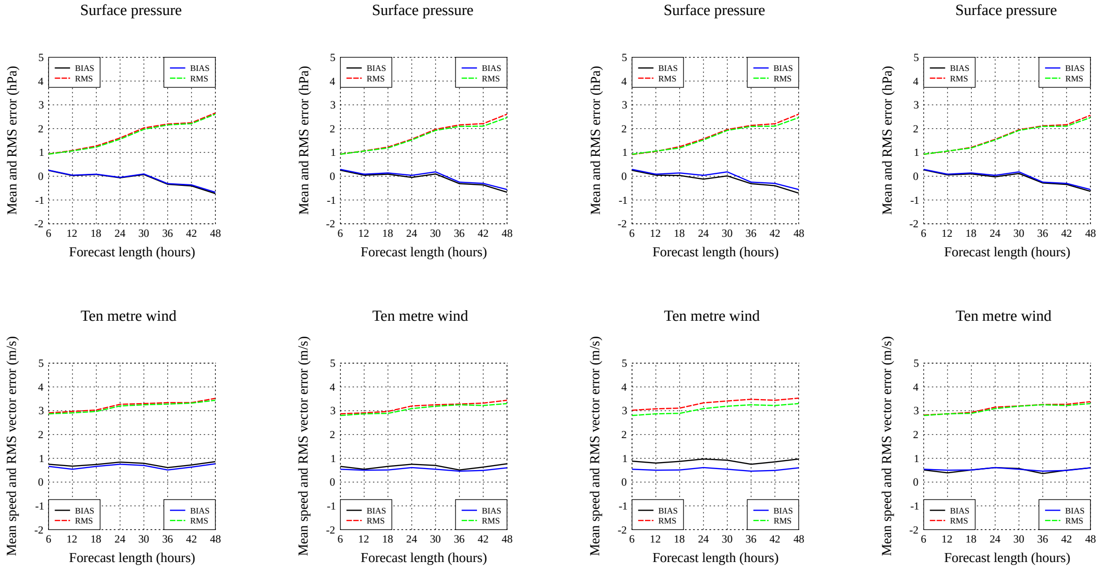

Figure 3: *As in 2 but for ORO5 and ORO6; ORO6 and ORO7; ORO1 and ORO7; ORO3 and ORO7.*

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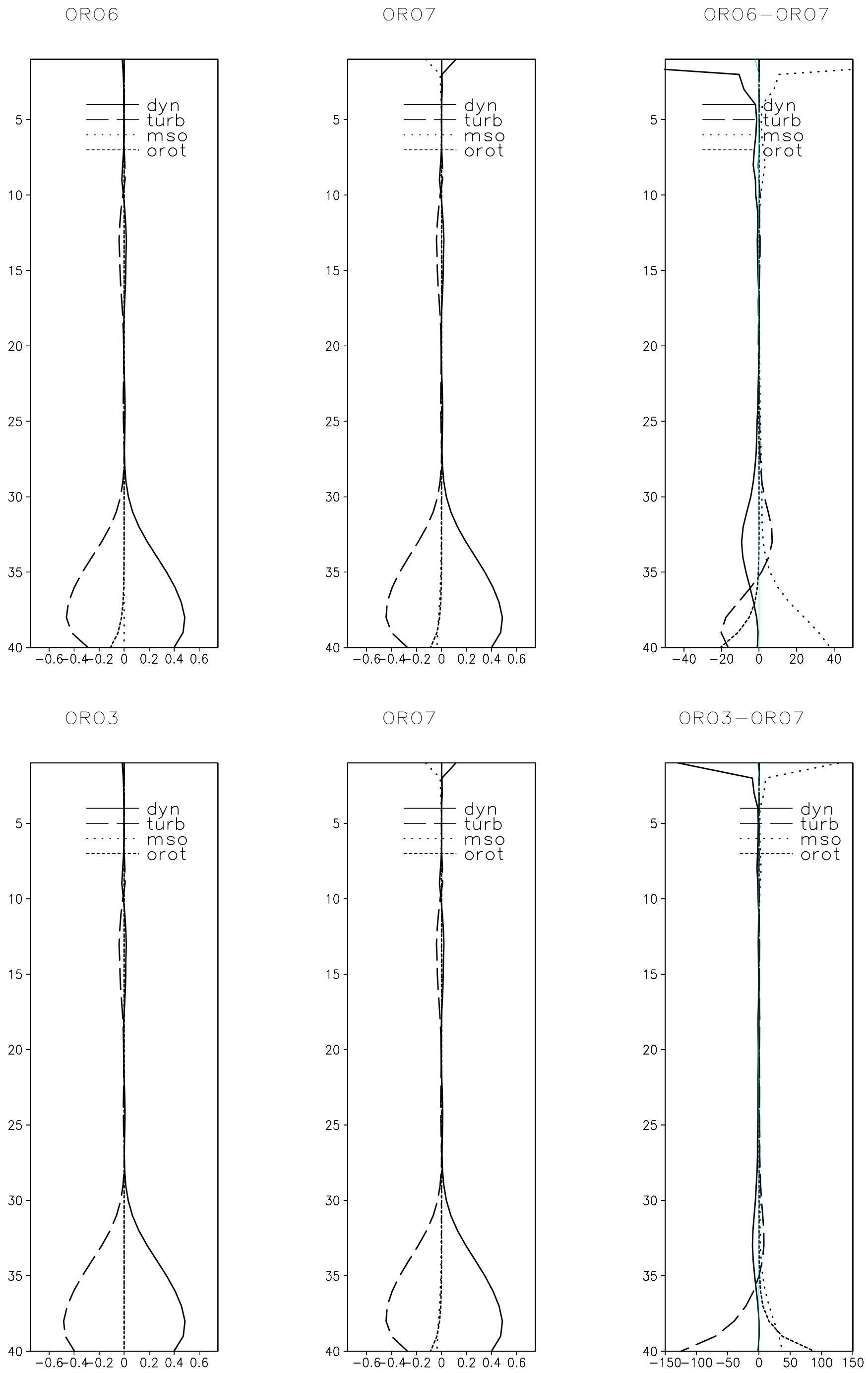

Figure 4: *Area- and time-averaged esolved scale kinetic energy tendencies due to model dynamics (dyn), parametrized turbulence (turb), meso-scale orography (mso) and small-scale orography (orot) from experiments ORO7 compared to ORO6 (upper panel) and to ORO3 (lower panel). Unit 1000*$m^2 s^{-2}$*/day (left and middle) and* $m^2 s^{-2}$*/day (right, note the different horizontal scales in the figures.). Vertical axis: model level from bottom to top. In this figure, every model layer gets equal weight in spite of the different thicknesses of the layers.*