Pre-operational testing of Aladin physics

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Abstract: A modified subgrid scale orography representation was introduced and tested. The envelope was removed and to compensate for the loss of volume, changes in gravity wave drag parametrisation were introduced. Unsatisfactory model forecasts of 2m temperature and cloudiness in inversion cases with fog and low stratus clouds have encouraged research of alternative parametrization for radiation processes and cloud parameterizations that could be used in the operational version of the Aladin model. Few computationally cheap modifications are introduced and tested. During intensive cyclogenesis, especially over steep surfaces, the physical horizontal diffusion should not be neglected. A stable and efficient non-linear horizontal diffusion, based on the control of the degree of interpolation needed for the Semi-Lagrangian advection scheme, has been implemented in ALADIN and tested.

Keywords *Radiation, Cloudiness, Xu-Randall Scheme, Fog, Envelope, Gravity Wave Drag, Bura, Semi-Lagrangian, horizontal diffusion, Adriatic cyclone*

1. INTRODUCTION

Unresolved orographic effects have been represented by the enhancement of terrain by adding an envelope (see Wallace et al., 1983), or with a modified parametrization of gravity wave drag and lift. In ALADIN, both methods are implemented. Although the envelope method is proved to give a better representation of the airflow over and around mountain ranges, it artificially increases the mountain height, and therefore gives excessive precipitation on the windward side, stronger katabatic winds in the lee and overestimated amplitude of the mountain waves (see Bougeault, 2001). Because of the exaggerated terrain height, numerous measurements from the stations situated below the envelope are systematically rejected in data assimilation. Furthermore, studies of local behaviour of the ECMWF model near Pyrenees (Lott, 1995) and Alps (Clark and Miller, 1991) have shown that mountain drag is underestimated, and cannot be adequately substituted with the envelope. For those reasons, in a number of NWP models the envelope has been suppressed, and the gravity wave drag parametrization tuned to compensate for the lack of volume. The new sub-grid scale orography representation is tested on a few bura cases.

For the cases of stable atmosphere with low-level inversion, low cloudiness and fog, the operational ALADIN/HR model did not predict the diurnal pattern of the surface temperature nor the low cloudiness well. Although the model initially recognized the existence of the temperature inversion and an almost saturated state of the atmosphere adjacent to the ground, the diagnosed cloudiness was too low and radiation scheme heated the ground and broke the inversion. There are several radiation schemes available in Aladin, the operational one (Geleyn and Hollingsworth, 1979), and FMR (Morcrette 1989). The first one is very simple and computationally cheap and may be used at every time step. The other is computationally expensive, so it is called only every few hours. Alternative versions of cloudiness and radiation schemes have been introduced and tested on a synoptic case marked by a strong temperature inversion, low cloudiness and fog in inland part of Croatia, that lasted for several days.

Main form of horizontal diffusion commonly used in NWP models is the numerical diffusion acting as a numerical filter and selectively damping short waves applied on model levels that often follow orography, thus it is not purely horizontal. Simon and Vaña (2004) have shown that physical horizontal diffusion should not be neglected when the horizontal component of the turbulent mixing is stronger than the vertical one. This could be in situations with strong horizontal wind shear, but also in statically stable situations.

2. METHODS

The operational model version is described in Ivatek-Šahdan and Tudor (2004). The operational model results are compared to the results from the experimental version of ALADIN/HR, without the envelope and with the new gravity wave drag parametrization.

In the operational model, envelope is obtained by adding the standard deviation of the sub-grid scale orography on the mean height. Removing the envelope actually means lowering the mountain peaks as well as the valleys (see Fig 1). The difference is largest in the areas where the orographic variability is highest, e.g. on the mountain slopes.

With the reduction of the mountain volume, the pressure drag decreases, and has to be compensated by parametrization. The pressure drag is addressed by its two components: the lift (perpendicular to the flow), and the drag (parallel to it). In the experiment, the orographic lift is activated and gravity wave drag is tuned.

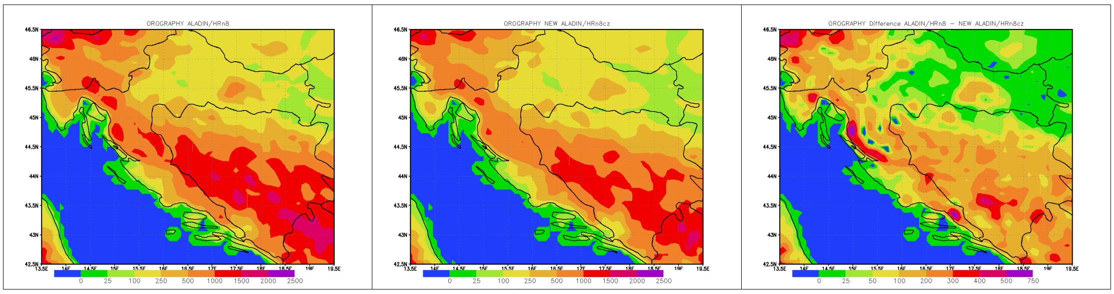

Figure 1. Orography in the operational (left) and experimental (centre) model version, and their difference (right).

Three cases with bura wind are examined. Firstly, a case with generally weak bura (03rd November 2004), when the drainage of air through the mountain-passes was induced by the pronounced difference in the air-mass characteristics in the inland and coastal part of the region. In addition, two extreme events of synoptically induced gale-force bura along the Adriatic coast (24th December 2003 and 13th November 2004) are studied.

The operational cloudiness parametrization results have been compared to the results from the scheme adapted from Xu and Randall (1996). Secondly, the operational radiation scheme has been enhanced (Bouyssel et al. 2003, Geleyn 2004) and the results have been compared to the one without the enhancements. In addition, the effect of different cloud overlap assumptions and modified vertical profile of critical minimum mesh averaged relative humidity producing a cloud has been tested.

The operational cloudiness scheme diagnoses cloudiness in such a way that if a parcel is oversaturated the amount of diagnosed cloudiness depends on oversaturation (cloudiness ranges from 0.7 to 1.0). Therefore e.g. a 0.7 cloudiness allows part of the radiation through. Therefore, the surface cools more during the night and warms more during the day giving pronounced diurnal pattern in surface temperature. In the morning this leads to the temperature rise due to heating, inversion breaking and eventual loss of cloudiness.

In the scheme adapted from Xu and Randall (1996) the oversaturated parcel has cloudiness equal to one. Therefore shortwave radiation is more efficiently reflected and longwave radiation is more efficiently absorbed. This helps in preserving the temperature inversion, fog and low stratus clouds.

If there are several layers of clouds with cloudiness less than one, the maximum overlap will vertically align these clouds in a way that they will be on top of each other, leaving a part of the column without clouds permiting radiation transfer. On the other hand, randomly overlapped clouds produce more total cloudiness and reduce the cloud free area in the grid cell.

The operational ALADIN model is conducted with a 4th order numerical diffusion scheme. A new horizontal diffusion scheme has been developed (Vaña 2003, Vaña et al. 2005) controlling the horizontal diffusion intensity using local physical properties of the flow and acting horizontally. In the Semi-Lagrangian advection scheme, the origin point is found by interpolation. The interpolator characteristics (the degree of interpolation) depend on the local flow yielding a horizontal diffusion based on physical properties of the flow. We will call this new scheme Semi-Lagrangian horizontal diffusion (SLHD).

3. RESULTS AND DISCUSSION

3.1. Orography and gravity wave drag parameterizations

In cases with severe bura, the most obvious feature of the experiment results is the increase of the 10m wind speed on the windward and even more pronounced decrease on the leeward side (Fig 3). The reason for this is found in the reduction of the mountain range height and the slope angle on one, and the increase of the pressure drag related to the orographic lift on the other hand. Due to the removal of the envelope, the pressure gradient across the coastal mountains is reduced. Moreover, the relative difference between the high peaks and low valleys is smaller, hence the canalised structure of the wind is less pronounced. However, there is no significant change in the wind direction.

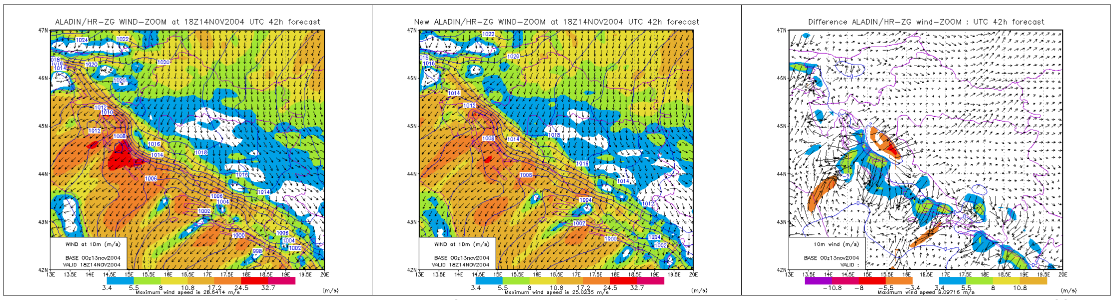

Figure 3. 10m wind in the operational (left) and experimental (centre) model version, and their difference (right), 42 hours forecast starting from 00 UTC 13th November 2004.

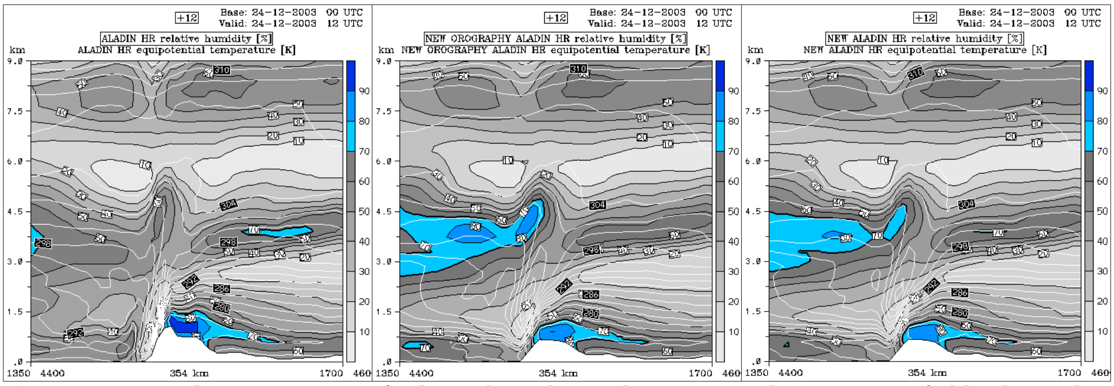

Figure 3. Vertical cross-sections of relative humidity and equipotential temperature fields obtained with old GWD+envelope orography (left), old GWD+mean orography(center), new GWD+mean orography (right), 12 hours forecast starting from 00 UTC 24th December 2003.

Results show a pronounced orographically induced humidity maximum (cloudiness) near the mountaintop. As expected, in the experimental version the wave structure is smoothed. There is a more pronounced downstream momentum transfer leading to the different distribution of vertical motion induced by the obstacle. Therefore, the humidity maximum near the mountain peak is somewhat decreased, while the one in the middle troposphere is more pronounced and closer to the mountain.

3.2. Radiation and Cloudiness

December 2004 has been characterized by long lasting fog in valleys inland. Results are shown for one run covering 2 days during that period. The 2m temperature varied very little during that period and showed no diurnal pattern. The reference forecast (most like the operational one) is the experiment 1 (exp1). The use of random maximum overlap assumption when computing cloudiness significantly reduces the amount of clouds and even amplifies the diurnal variation of temperature. However, the introduction of the Xu-Randall cloudiness scheme gives more clouds and improves the 2m temperature forecast. Finally, the random overlap assumption produces even more clouds. Thus, the scheme with most clouds forecasts surface temperature that is closest to the measured data.

The operational radiation scheme with Xu-Randall cloudiness parametrization and random overlap assumption produces the thickest low cloud layer that reduces the night cooling and heating during the day. It still shows signs of diurnal variation but is closest to the measured data. Radiation scheme using NER increases the amplitude of the diurnal variation of temperature, which gives worse forecast in this case. It seems that the modification in the critical relative humidity profile does not play a significant role.

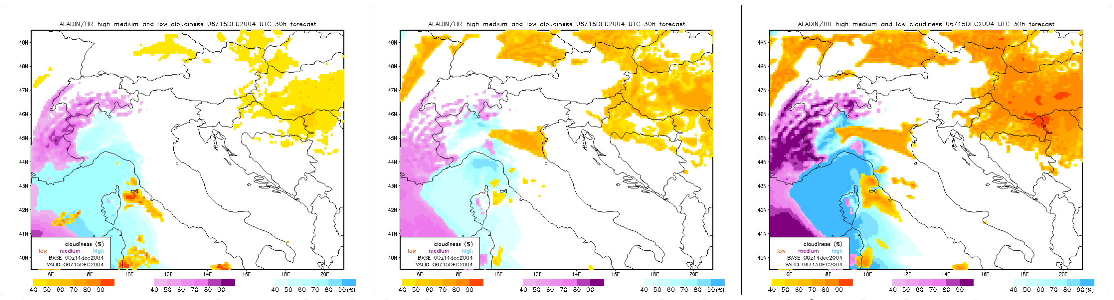

Figure 3. Low, medium and high cloudiness with operational radiation (left and right) and NER (center), random overlap (left and right) and random maximum overlap (center) using operational (left) and Xu-Randall cloudiness scheme with new critical relative humidity profile (center and right), 30 hour forecast starting 00 UTC 14th December 2004.

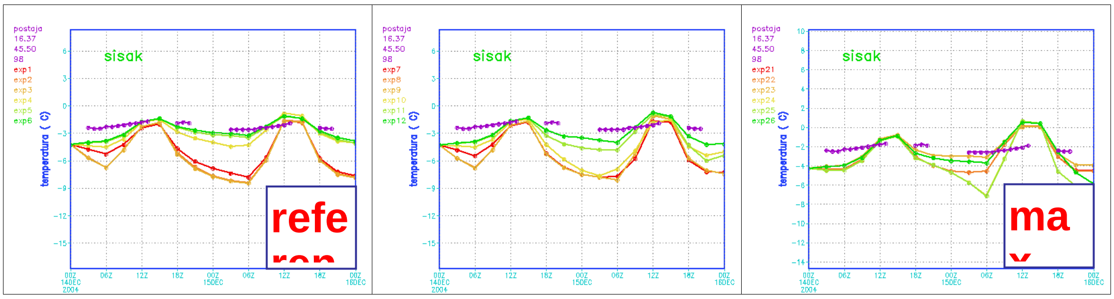

Figure 3. Comparison of the modelled 2m temperature evolution for 00 UTC run on 14th December 2004 with measured data from synoptic station with operational radiation scheme (left) including NER (center) and FMR (right).

3.3. Semi-Lagrangian Horizontal Diffusion

3.3.1. Twin cyclones

There are two cyclones, one above the Adriatic and another above the Tyrhenian Sea,. The strength of the second one was overestimated by the operational model.

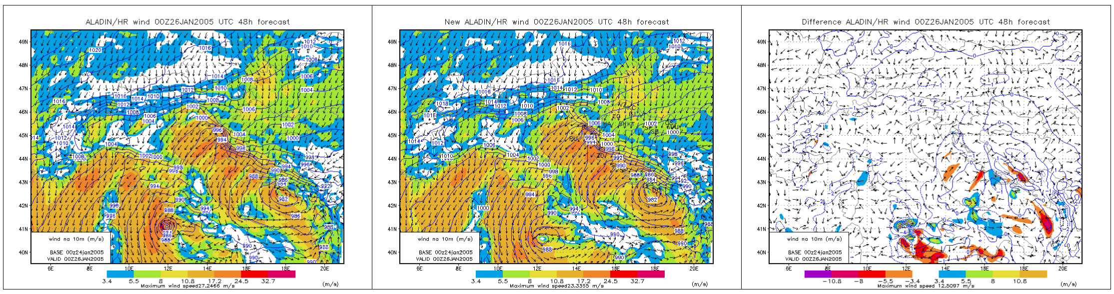

Figure 3. 10m wind and mean sea level pressure obtained with numerical diffusion (left), SLHD (center) and their difference (right), 48 hour forecast starting from 00 UTC 24th January 2005.

3.3.2. Fog case

In the case of fog in an anticyclone, use of SLHD increases the amount of fog in alpine valleys (Fig 4), especially on the border between Switzerland and Germany and in Danube valley in Austria.

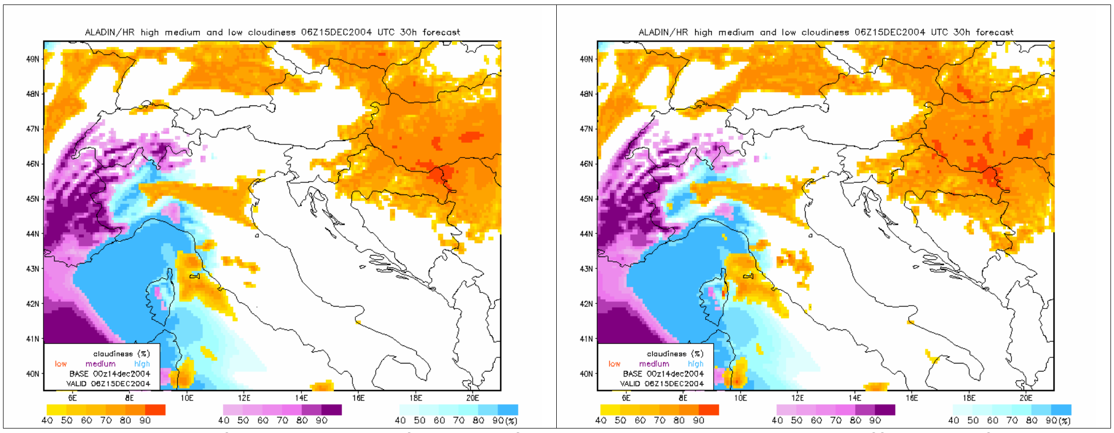

Figure 4. Impact of SLHD on the forecast of low clouds, pure numerical diffusion (left) and SLHD (right).

4. CONCLUSIONS

New orography representation resulted in slight enhancement of upstream and general decrease of downstream wind speed, as well as reduction of mountain wave amplitude. The computationally cheap cloud schemes and cloud overlap assumptions are more important for the low stratus and fog forecast than an expensive radiation scheme. The results show significant improvement in the low cloudiness and the surface temperature (2m AGL) diurnal pattern for certain configurations. SLHD has shown beneficial impact in different cyclonic situations as well as in an anticyclone. The results of several numerical experiments show better simulation of a mesoscale Adriatic cyclones, upper troposphere cyclones and beneficial impact on forecast of low cloudiness in anticyclones.

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