OVERALL TUNING OF THE TURBULENCE SCHEME OF HIRLAM WITH THE FOCUS ON THE STABLE BOUNDARY LAYER

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1. INTRODUCTION

Under stable conditions reference Hirlam versions have a large positive bias in the wind speed. During unstable conditions the wind speed bias is small, therefore the diurnal cycle of the atmospheric boundary layer parameters is not represented well enough in the model. To improve the model in stable conditions an overall tuning is needed. This tuning comprises a better choice of coefficients for the turbulence scheme in combination with the removal of the turning of the stress vector

2. TKE-l scheme

Since HIRLAM version 6.3.5 the turbulence scheme of the HIRLAM model was tuned by 1) turning the stress vector and 2) a reduced extra mixing due to gravity waves in stable conditions [1]. In previous HIRLAM versions there was either a large surface pressure bias caused by too deep lows or too much wind near the surface in stable conditions due to too strong mixing. The combination of the rotation of the stress vector and a reduction of the mixing under stable conditions finally resulted in good scores for both the wind speed bias and the surface pressure. The reduction of the mixing under stable conditions also significantly improved the ability of the model to represent the wind profiles under stable conditions. Note however, that the surface stress turning is a tuning for which we have not been able to find a physical basis only that it is necessary as long as the mixing in stable conditions is enhanced.

The impact of switching off the surface stress turning in combination with an alternative choice for exchange coefficients Cm=Ch=0.14 (Baas et al [3]) as well as the reduced extra mixing (zmix_help=0) is illustrated in Fig. 1.

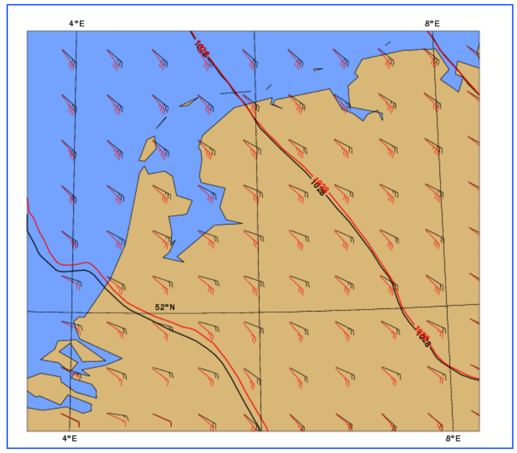

Figure 1: Impact of switching OFF the turning of stress vector in combination with a revised setting of the TKE-scheme. Ground pressure and the wind field at model level 38, +12h valid at 01 April 2005 00 UTC. black =control run, red=new settings TKE-scheme (less tuning)

3. Case studies with 1D/3D models

In two case-studies the performance of the new settings were tested.

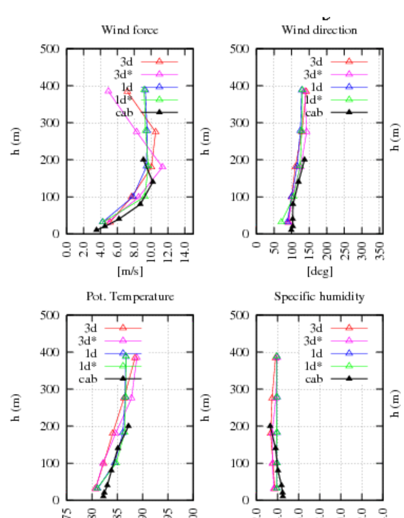

Figure 2a:Results of 1D and 3D simulations at Cabauw +12h valid 01 April 2005 00 UTC ;1D/3D means control run; 1D/3D* means run with new settings TKE-scheme; cab= mast observations.*

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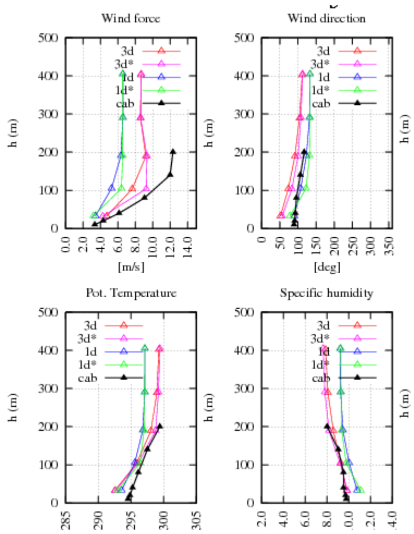

Figure 2b: as Fig 2a , but for 02 July 2006 00 UTC +24H. There is some overlap with the 3rd GABLS case. Labelling as Fig. 2a.

Both case studies are chosen around the Cabauw observational site in The Netherlands. The transition from unstable to stable regimes played an important role in these selected cases and Low Level Jets (LLJ's) were clearly observed. At first the new settings (zmix_help=0, Cm=Ch=0.14) were tested in the 1D-model and subsequently also applied in the 3D-model. In Fig. 2a the +12h forecast is valid for 1 April 2005 00 UTC. The new settings gave a larger wind speed and direction gradient close to the surface. However the simulated wind maximum in the 3D-model is still too high and the temperature profile showed no improvement, but also no deterioration.

Another case study was taken for further testing. This case coincides to some extent with the 3rd GABLS case. Here we focus at the +24h forecast at 02 July 2006 00 UTC. The positive impact of the new settings is clearly visible in both 1 and 3D simulations. The gradient in de wind speed in the lowest 100m becomes more realistic. The 3D results are better than the 1D-results, probably due to the change of large scale conditions during the experiment.

4. Diurnal cycle May 2000

With the new settings the model was tested for a larger area and for a longer period in which the diurnal cycle played an important role, namely May 2000. Also the domain was bigger now and consisted of The Netherlands and a part of the North Sea.

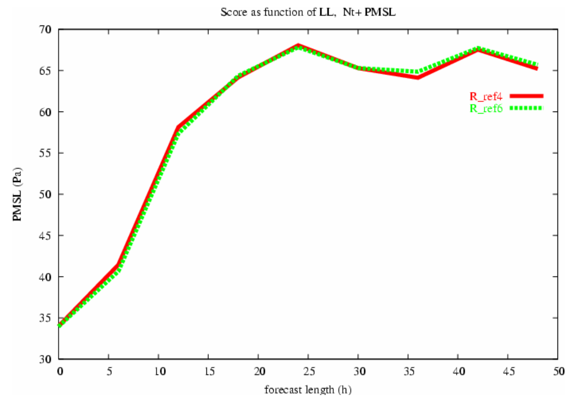

Figure 3:RMS Nt+ PMSL 01-15 May 2000; ref4=control run; ref5=new settings TKE-scheme

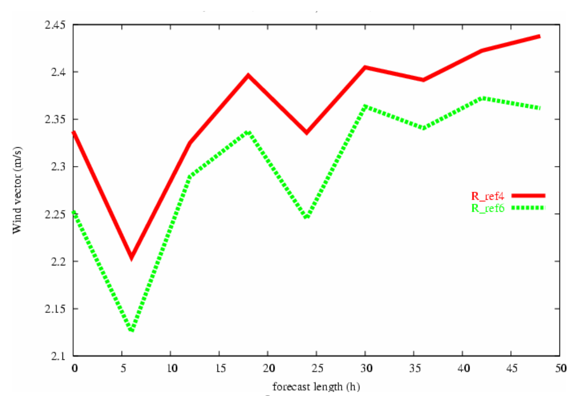

Figure 4: as Fig 3; RMS Wind vector, 01-15 May 2000

The PMSL verification showed hardly any deterioration, which is quite promising because in the past PMSL scores usually deteriorated when the mixing in stable conditions was reduced or when the surface stress turning was removed. Also the wind direction gave the impression that the new settings worked out well. Therefore we continued with further testing over the full domain and for a period with severe weather circumstances.

5. Stormy period January 2007

The above results are reasonably good, but do the new TKE-settings of the model behave so well in extreme weather circumstances? We ran an experiment over the full domain during 10-25 January 2007. During this period Europe was struck by heavy storms.

Based on experience of the last experiments we expect better results with slightly different coefficients. Now we take Cm=Ch=0.13. The RMS-scores for PMSL and Wind vector are shown in Figs. 5 and 6. The PMSL score does not deteriorate and the RMS-score of the wind vector show a slight improvement when the new settings are applied. The wind vector improves mainly due to a better wind speed score and a slightly worse wind direction score. RMS-scores for temperature and humidity were hardly affected.

It is interesting to know if the model is not too active at the end of the forecast and therefore we also study the momentum flux as function of forecast time. Results in Fig. 7 show a slightly smaller momentum flux which means that the model is less active, as the momentum flux is directly related to the near surface winds, and when no change has been made to the surface roughness, a decrease in momentum flux means a decrease in the wind speed. Also the momentum flux is not increasing with increasing forecast time, which means that the model is not becoming more active towards the end of the forecast. The question is where the improved dynamical behavior comes from, when the extra mixing for stable conditions and the surface stress turning are removed.

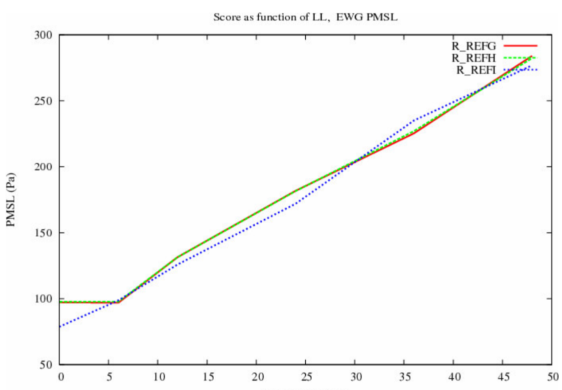

Figure 5: RMS PMSL during 10 -25 January 2007; REFG=control run, REFH=new settings TKE-scheme;REFI = QNSE + revised settings

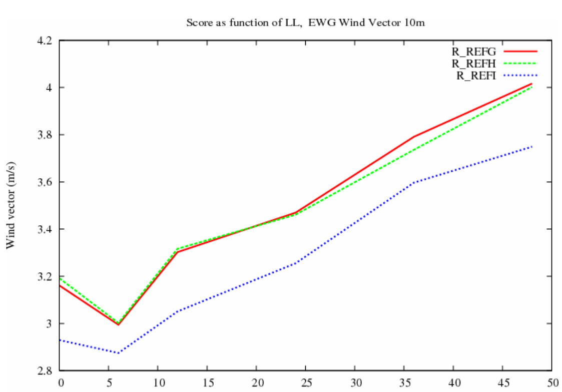

Figure 6: as Fig 5. RMS Wind vector

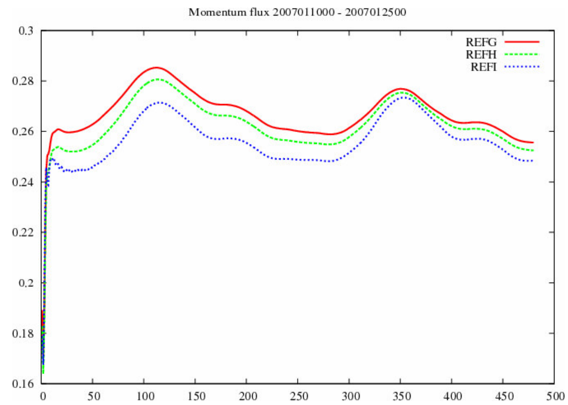

Figure 7: Momentum flux as function of timestep averaged over the period of 10-25 January 2007; REFG=control run; REFH=new settings TKE-scheme; REFI=QNSE+revised settings.

In older HIRLAM versions the mixing was increased a lot to keep the model in check, but that decreased the scores for the 10-m wind speed and direction considerably. In earlier studies it was found that any additional mixing under stable conditions caused a large bias in the wind direction. Apparently the slightly larger basis mixing, the increased mixing coefficients for Cm and Ch in stable conditions, has a larger impact than the increased mixing under stable conditions for momentum especially for Richardson numbers smaller than 1 combined with the surface stress turning. The increase in Cm and Ch are not so large that they again have a negative impact on the wind direction.

6. Test with QNSE-scheme

During the course of this research the turbulence scheme has been modified in the HIRLAM reference system. New stability functions based upon QNSE has been implemented (Sukoriansky 2006). Stability functions are determined with a spectral method. This QNSE-update results in a better performance of the model in stable conditions, especially the formation and decrease of LLJ's. In this version the extra mixing due gravity waves was already taken out, so the the revised settings consist of 1) no turning of the stress vector and 2) well chosen exchange coefficients for momentum and heat (Cm=Ch=0.13).

Results are also depicted in Figs. 5,6,7 (blue dashed line). The wind vector RMS shows a significant improvement, while there is not so much difference for PMSL. For the upper air scores the results are more mixed with QNSE.

The temperature scores in the upper air are a little better, as is the geopotential, but for the wind the scores are worse with QNSE included in the vertical diffusion scheme.

CONCLUSIONS

HIRLAM works well with a more rudimentary version of the TKE-l scheme, also when QNSE is applied. Removing the turning of the stress vector and additional mixing in stable conditions in combination and with an alternative choice for Cm and Ch gives significantly better results. The surface pressure scores are not deteriorating, the wind vector scores improve and the profiles reveal more realistic gradients in stable conditions. We therefore recommend implementation of these alternative settings in the HIRLAM reference version.

OUTLOOK

The new settings improve the HIRLAM model. In the near future a similar exercise should be carried out with the new HARMONIE system, to see if the stable part of the vertical mixing needs improvement and can be improved. Further experimentation is also necessary with the definition of the vertical model grid. Currently the lowest model level lies at 30 m; bringing the lowest level down to 10 m could also improve the results especially in stable conditions.

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