Performance of HIRLAM with ECMWF physics

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Abstract

ECMWF physics has been successfully ported into the HIRLAM system, version 5.0.6. Model integrations have been carried out in the reference framework at 0.5 degree horizontal resolution for the month December 1999 and a 14-day period in May 2000. Relative to the reference HIRLAM version 5.0.6, verification scores of near-surface parameters range from neutral in the Spring period to significantly better in the Winter period. In particular, the forecast of the mean sea level pressure during a stormy episode improved considerably. HIRLAM with ECMWF physics is found competitive in terms of verification scores to the more recent HIRLAM version 5.1.4 operating land surface scheme ISBA.

1 Introduction

In contribution to the HIRLAM-5 project the ECMWF parameterization package of physical processes has been ported into the HIRLAM forecast component. Such a system is expected to provide a platform in which the HIRLAM community can more easily and more directly benefit from research and development at the ECMWF. Furthermore, it offers the possibility to objectively inter compare the physics components of HIRLAM and ECMWF in a LAM oriented framework. HIRLAM 5.0.6 was taken as the reference version. The ECMWF physics has been adopted from release CY23R4, which also served as the basis for the ERA40 project. In the past year, the forecast component of the new model has been adopted by the Atmospheric Research division at KNMI for the purpose of regional climate modeling. In that context the model is referred to as RACMO2 (Regional Atmospheric Climate Model, version 2).

For the purpose of this contribution, the model has been operated in NWP-mode involving an assimilation-forecast cycle. The model output is examined using the standard verification package of the HIRLAM system. The performance of the NWP model is given in terms of bias and standard deviation. Results are also compared with a more recent version of HIRLAM 5.1.4 which operates the land surface scheme ISBA.

For the purpose of verifying short-term integrations of the new model in NWP-mode none of the components or parameter settings in the ECMWF physics package has been altered. However, a recent assessment of the quality of RACMO2 operated for present-day climate conditions revealed some serious shortcomings (Lenderink et al., 2003). In particular, the model showed a tendency to (very) substantially overestimate near-surface summertime temperatures (up to +8 °C) across much of Central and Southern Europe associated to a strong reduction of the local hydrological cycle. A detailed analysis learned that this anomaly could, at least partly, be ascribed to the treatment of soil water in the land surface scheme. In particular, it was found that the total water holding capacity of the soil layer was insufficient to store the winter precipitation. The excess was carried away through runoff and thus lost as a source term for evaporation during spring and summer. Sheer enhancement of the soil water reservoir in the order of 60 % together with a change in the response of vegetation to soil drying have indeed been found to greatly improve the RACMO2-simulation of the present-day summertime conditions across most of continental Europe.

The impact of these modifications has not yet been examined in NWP-mode. The enhancement of the soil water reservoir is not expected to have much impact on the model performance when operated in NWP-mode as it primarily affects the long-term response of the soil. However, the modification in the response of model vegetation to soil drying will affect the partitioning of the net surface radiative flux into sensible and latent heat fluxes, and hence result in different diagnoses for 2m temperature and humidity. The latter is only relevant in spring and summer conditions, in winter conditions there will be no effect at all.

2 Model description

The physical package of the ECMWF model version CY23R4 was adopted and embedded in HIRLAM version 5.0.6. Details on the concept and the technical implementation can be found in Newsletter 38 (van Meijgaard, 2001). Additionally, an extensive description of the physical package itself can be found in (White et al.,2002). Here we provide a brief overview of the major components which form a part of this package. As a first step the tendencies due to radiative transfer are calculated with the long wave radiative fluxes resulting from a Rapid Radiative Transfer Module (RRTM) computation. Subsequently, the turbulent diffusion scheme solves for exchange processes in the atmospheric boundary layer using Monin-Obukhov similarity. Deep convection is parameterized by means of a mass flux scheme with a CAPE closure formulation. Cloud and precipitation processes are accounted for by the prognostic cloud scheme, which solves for sub-grid scale effects on cloud liquid water, cloud ice and cloud fraction. Finally the soil processes are treated with a tiled surface soil scheme, known as TESSEL (Tiled ECMWF Scheme for Surface Exchanges over land) (van den Hurk et al., 2000). To calculate the exchange of heat, moisture and momentum at the interface of surface and atmosphere in the tiled formulation, each grid-box is divided into fractions (tiles), with up to six fractions over land (bare ground, low and high vegetation, intercepted water, shaded and exposed snow) and up to two fractions over sea and freshwater bodies (open and frozen water). Each fraction has its own properties defining separate heat and water fluxes used in an energy balance equation in order to solve for the tile skin temperature. Tiled flux information is aggregated over the entire grid box in order integrate the atmospheric profiles of temperature, moisture and momentum.

3 Experimental setup

In this contribution, model integrations are carried out at 0.5-degree horizontal resolution and with 31 layers in the vertical. The model domain, counting 114x100 grid points, covers Europe and a large part of the North Atlantic Ocean. The model is integrated with a semi-Lagrangian advection scheme employing a time step of 12 minutes. An optimal interpolation analysis is carried out every 6 hours; the forecast length is 48 hours. Lateral boundary conditions are inferred from ECMWF analyses and are updated every 6 hours. Information to prescribe surface characteristics has been taken from various sources. The surface roughness lengths for momentum, heat and moisture are calculated following the description in the IFS documentation (see White et al., 2002, paragraph 9.5).

Two periods with different weather regimes, i.e. December 1999 and May 2000, were selected to verify the models. December 1999 was a striking month because of its heavy storms (Anatol, Lothar and Martin). May 2000 was a springtime period characterized by a blocked circulation in the beginning followed by a sudden transition to unsettled weather around 16 May. Of more general interest and typically occurring in spring is the pronounced diurnal cycle of 2m temperature and relative humidity.

4 Verification results

The Figures 1 and 2 present the verification scores for December 1999 and May 2000, respectively. In these diagrams the standard deviation and bias are given as a function of the forecast length. Each verification period consists of a sample of forecasts during the verification period. In the diagrams hereafter we use the following acronyms to identify the model versions. HIRLAM 5.0.6 and 5.1.4 are abbreviated as V506 and V514, respectively, and HIRLAM 5.0.6 + ECMWF physics is referred to as PHEC. To study the occurrence of compensating errors in the bias, averages are calculated as function of the hour of the day (Fig. 3). These averages are calculated based upon time series of analyses and +48 hours forecasts.

For each surface parameter, the main outcomes of the verification is briefly summarized hereafter.

- **Mean sea level pressure.** The first test period, December 1999, shows a significant improvement in the bias and standard deviation of mean sea level pressure forecasts from PHEC relative to V506 (Fig.1). V514 shows a less pronounced improvement. No improvement is found for this parameter in the May 2000 verification period (Fig.2). The bias is considerably smaller than in the first test period.

- **10m wind speed.** For both periods the bias reduces when PHEC and V514 are applied, but the standard deviation hardly improves. The averaged time series of 00 and 48 h forecasts (Fig. 3) show diurnal oscillations in the bias of the wind speed. In the May period values are alternating around zero, so averaging implies that positive contributions are evened out by negative values. In December the bias of PHEC remains positive and at +48h it becomes 1m/s, while the standard deviation is 2.5 m/s, which does not differ much from the other models.

- **10m wind vector difference.** This parameter takes in account errors in wind direction in relation to significant wind speeds. Note that in these diagrams only the rms value is presented. In May 2000 there is hardly any difference between the model versions. In December 1999 PHEC shows the best results.

- **2m temperature.** PHEC reveals an improvement in the bias for December. At first sight this looks like a positive outcome, but upon further examination

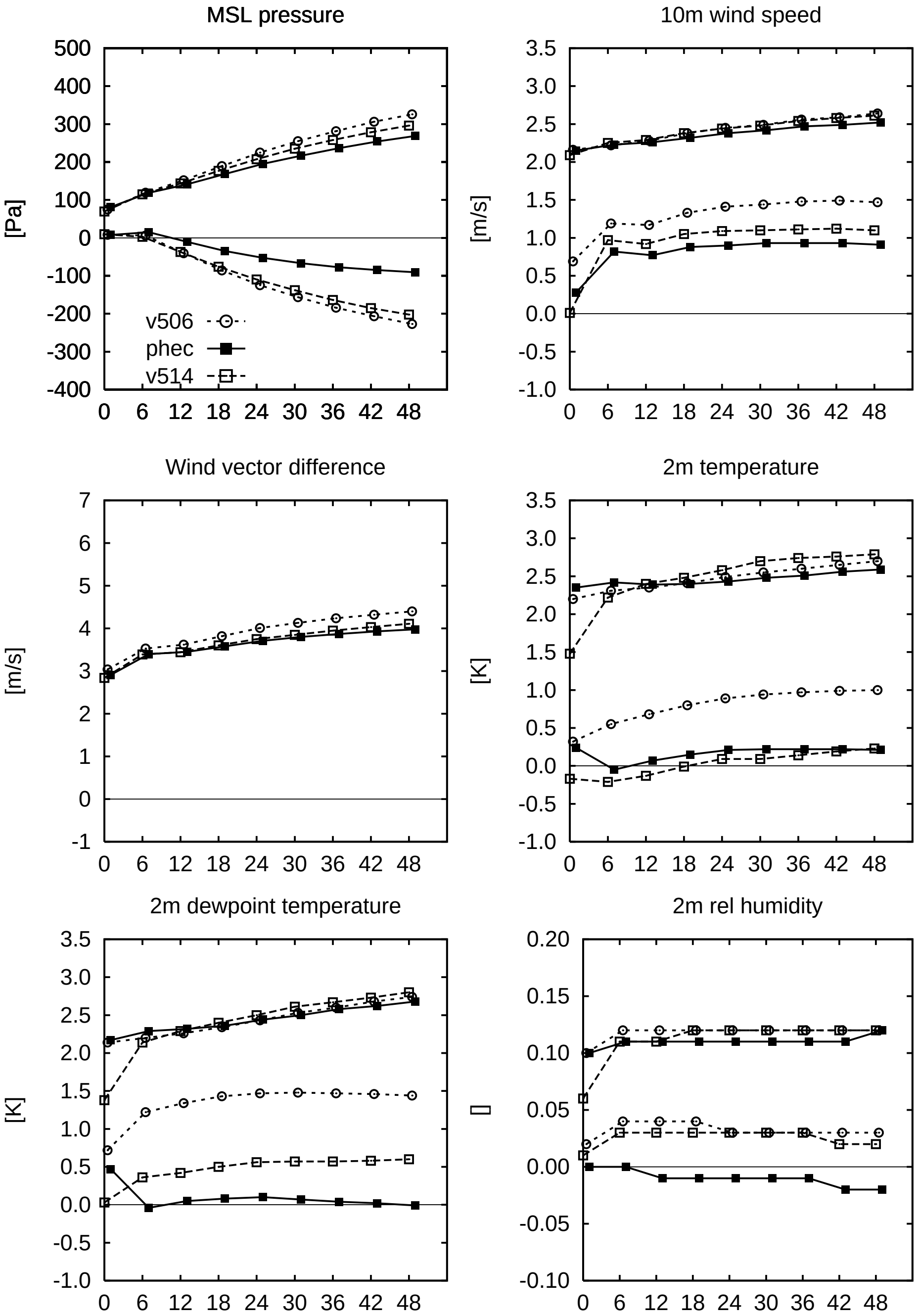

Figure 1: Surface verification 01-31 December 1999, EWGLAM stations

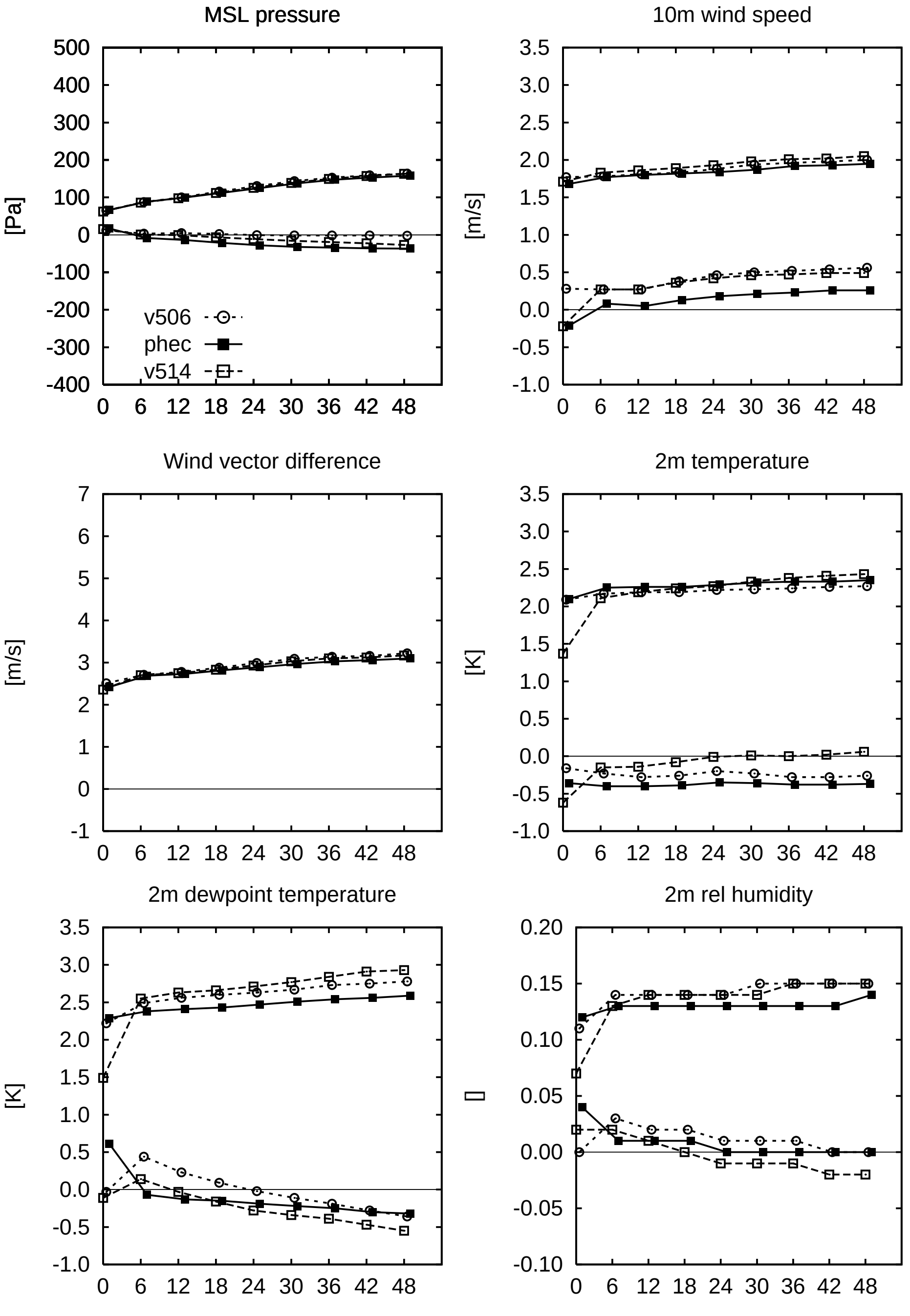

Figure 2: Surface verification 05-23 May 2000, EWGLAM stations.

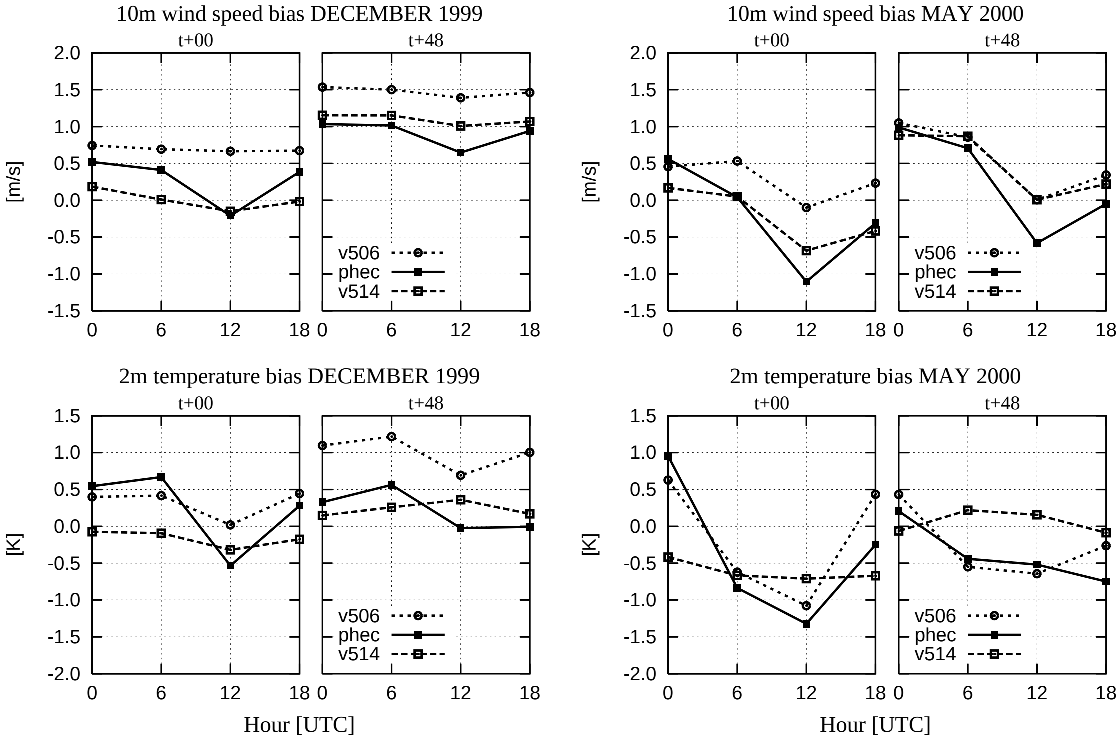

Figure 3: Averaged bias as function of the hour of the day for 10 m wind speed (upper row) and 2m temperature (lower row) for analyses (t+00) and +48 forecasts obtained from forecasts for December 1999 (left) and May 2000 (right).

the averaged bias is found to have a profound diurnal cycle around zero (Fig. 3). In May, the negative bias of the control run (V506) becomes even more negative when PHEC is applied. V514 becomes close to zero for larger forecast times and this reduction is mainly due to compensating errors. However, close to the analysis the bias is negative and steady during the integration period. V514 is found capable of substantially reducing the bias of the temperature close to the analysis.

- **Humidity at screen height.** Scores of dew point temperature and relative humidity at 2m are depicted on the bottom part of Figs. 1 and 2. For December 1999, PHEC yields a good result in reducing the bias. However, on inspection of the time series (not shown) it became clear again that compensating errors play a role. Another reason to suspect the bias reduction is that the standard deviation hardly improves. During the May period the dew point biases of all model versions deteriorate with increasing forecast times and become negative. Note that the standard deviation improves for the PHEC model version.

5 Conclusions

1. HIRLAM 5.0.6 + ECMWF physics works well in December 1999 and shows better scores for surface parameters relative to the control experiment (HIRLAM 5.0.6). HIRLAM 5.1.4, carrying the ISBA-scheme, yields similar scores as HIRLAM + ECMWF physics, but the surface pressure is slightly worse.

2. May 2000 does not show a substantial improvements for any new model version. However HIRLAM 5.0.6 + ECMWF physics has the best results in terms of the humidity at screen height.

3. HIRLAM 5.1.4 greatly benefits from an ISBA compatible surface analysis component in the data-assimilation. Scores close to analysis time are superior to those from the other model versions. In the current implementation (near) surface parameters are not assimilated in the HIRLAM 5.0.6 + ECMWF-physics version, with the exception of sea surface temperature. In order to lift the HIRLAM 5.0.6 + ECMWF-physics scores at and close after analysis time to the same level as the HIRLAM 5.1.4 scores, it is probably required to implement a surface analysis scheme that is compatible with the TESSEL

surface scheme. However, for longer forecast times the skill of HIRLAM 5.0.6 + ECMWF-physics is comparable or better, in particular in December 1999.

4. HIRLAM 5.0.6 + ECMWF-physics shows a strong diurnal cycle in the bias of the 2m temperature and 10m wind speed, which is largest at analysis time and reduces with growing forecast time. For HIRLAM 5.1.4 the amplitude in the diurnal cycle of biases is found much smaller.

6 Recommendations

Recommendations 1 to 3 are of general nature, recommendations 4 and 5 point to the technical implementation.

1. The promising results presented in this paper have been obtained without any change in the formulation of the ECMWF physics package. It remains to be investigated how the ECMWF physics performs at higher resolution. More experimentation, likely case-study oriented, is also required to examine the performance in other parameters, e.g. the hydrological cycle, surface energy exchange, cloud parameters, etc.

2. In the current implementation (near) surface parameters are not assimilated in the HIRLAM 5.0.6 + ECMWF-physics version with the exception of sea surface temperature. In order to lift the performance of this model at and close after analysis time to similar levels as the HIRLAM 5.1.4 scores requires the development of a surface analysis scheme that is compatible with the TESSEL surface scheme. It is recommended to study the feasibility of such an effort.

3. In order to fully exploit the potential of having ECMWF physics as an alternative available in the HIRLAM system it is given into consideration to upgrade the current experimental situation by bringing the ECMWF physics package and all necessary modifications into the HIRLAM reference system. In that way it can be beneficial to the entire HIRLAM community. Such status also accommodates the implementation of future releases of the ECMWF physics package (or parts of it).

4. To facilitate the implementation of ECMWF physics in future HIRLAM releases it is strongly recommended to convert the scalar prognostic cloud variable into an array variable suitable for a model-specific number of prognostic cloud parameters.

5. It is desirable to recode the HIRLAM modules into Fortran 90. It will release some of the current overhead in the modules interfacing the ECMWF physics with the HIRLAM dynamical core. It also allows the user to specify the desired accuracy independently from the platform by means of the KIND-function. It finally offers the possibility to introduce structures which can be a very useful tool in generating transparent code, in particular in swapping information between subroutines.

References

[1] Lenderink, G., B.J.J.M van den Hurk, E. van Meijgaard, A.P. van Ulden and H. Cuijpers, 2003: Simulation of present-day climate in RACMO2: first results and model developments. *KNMI Technical Report* **252**, 24 pp.

[2] Meijgaard, E. van, 2001: ECMWF physics in HIRLAM. *Newsletter* **38** , 137-143.

[3] Van den Hurk, B.J.J.M., P. Viterbo, A.C.M. Beljaars and A.K. Betts, 2000: Offline validation of the ERA40 surface scheme. *ECMWF Tech. Mem.* **295**, 42 pp.

[4] White, P.W. (editor), 2002: Physical processes (CY23R4). *IFS documentation http://www.ecmwf.int/research/ifsdocs.*