Assimilation of 2-m temperatures and adaptive adjustment of uncertain model parameters building upon it

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1 Introduction

In NWP models, near-surface forecast variables like 2-m temperature (T2M) or 2-m relative humidity (RH2M) can be subject to substantial systematic forecast errors for a variety of reasons, e.g. limited quality of external parameter data and physical properties of soil and vegetation derived therefrom, poor knowledge of soil moisture in deeper layers, and simplifications or inadequacies in the parameterization of related physical processes. Attributing specific biases to one of these potential sources is difficult due to the lack of data, and tuning exercises frequently end up with improvements in some regions or seasons and degradations in others. In particular, transient model biases cannot be reduced this way. Moreover, the assimilation of 2-m variables suffers from the presence of substantial model errors. Assimilating T2M even tends to degrade the lower-tropospheric analysis quality if the data assimilation has to act against severe model biases, and therefore, only RH2M has been assimilated in DWD's operational global ICON forecasting system (Zängl et al., 2015) so far. Significant progress could be made, however, by a co-development between model and data assimilation, using information from data assimilation to adaptively adjust uncertain model parameters in order to minimize systematic errors.

2 Methodology

Our algorithm builds upon the assimilation of RH2M and T2M by computing time-filtered assimilation increments of temperature and humidity at the lowest model level, which are subsequently used as a proxy for the respective model biases. Time-filtering is accomplished by a Newtonian relaxation approach with a time scale of 2.5 days, which is needed to separate random from systematic errors and to remove possible diurnal cycles from the average biases. In addition, a filtered temperature increment weighted by the cosine of local time is calculated as a proxy for the diurnal temperature amplitude bias.

Based upon these quantities, a variety of model parameters whose basic values are either tuning parameters or estimated from external parameter data are adaptively adjusted in order to minimize systematic model errors. Specifically, average temperature and humidity increments are used over snow-free land surfaces to vary the minimum stomata resistance of plants and a tuning parameter for scaling bare-soil evaporation. They are used to define a combined temperature-humidity bias $TRH_b = \alpha RH_{if} - \beta T_{if}$, where RH_{if} and T_{if} are the time-filtered assimilation increments and α and β are positive tuning parameters (noting that assimilation increments have the opposite sign as the model bias). Based upon this, a model parameter ψ having a reference value ψ_r is modified according to

$$\psi = \psi_r/(1 + TRH_b) \text{ if } TRH_b > 0 \quad ; \quad \psi = \psi_r \, (1 - TRH_b) \text{ if } TRH_b < 0 \qquad (1)$$

if ψ needs to be reduced in order to mitigate a warm bias; otherwise multiplication and division are reversed. On snow-covered land surfaces, a similarly defined pure temperature bias is used to vary the snow albedo otherwise depending on vegetation cover and snow aging. Moreover, to reduce biases in the diurnal temperature amplitude, the above-mentioned weighted increment is used to vary the heat conductivities of the soil and the skin layer as well as the soil heat capacity using a similar algorithmic approach.

3 Results

The changes presented here have been operationalized in the global ICON forecasting system of DWD in May 2022. Extensive experiments conducted in the preparatory phase indicated that the direct impact of the T2M assimilation is rather short-lived, typically decaying to zero after two forecast days. However, exploiting the potential for adaptive model parameter adjustment substantially prolongates the beneficial impact not only for T2M, but also for RH2M. This is illustrated in Fig. 1, showing the relative RMSE improvements for the extratropical hemispheres and the tropics for a 2.5-month period in late 2020. In all regions, statistically significant improvements are obtained for both variables during the whole forecast range (180 h).

A closer analysis reveals that the improvements exhibit strong regional (and also seasonal) variability because they are proportional to the magnitude of the model biases in the reference configuration. Particularly large benefits have been obtained in several central Asian regions, where the diurnal temperature amplitude used to be significantly underestimated, and in snow-covered regions, where the uncertainties of the albedo and heat conductivity generally enhance the forecast errors. Reducing model errors of the diurnal temperature amplitude was in turn found to be important for the quality of the analyses. Specifically, a nocturnal warm model bias tends to induce cooling increments extending over a too deep layer, degrading the analysis quality between about 500 m and 1000 m above ground (as indicated by the radiosonde verification; not shown). Thus, the initially mentioned co-development between model and data assimilation was indeed crucial for the successful implementation of this ugrade.

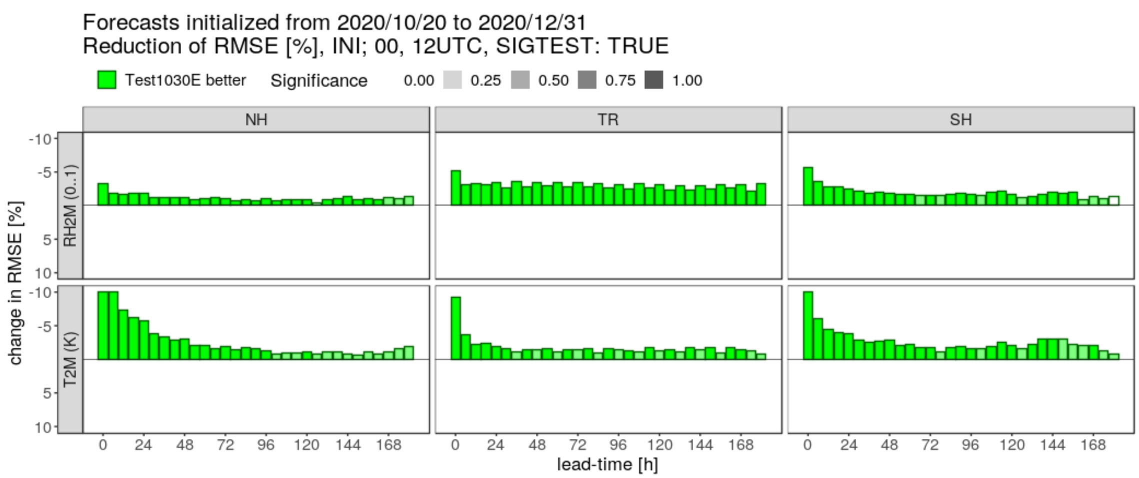

Figure 1: Relative RMSE improvements achieved due to the T2M assimilation and the related model parameter coupling for an experiment period in autumn/winter 2020. Color filling indicates significance at the 95% level.

Reference

Zängl, G., D. Reinert, P. Ripodas and M. Baldauf, 2015: The ICON (ICOsahedral Nonhydrostatic) modelling framework of DWD and MPI-M: Description of the nonhydrostatic dynamical core. *Quart. J. Roy. Met. Soc.,* **141**, 563–579.