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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Technical Note: Description and assessment of a nudged version of the new dynamics Unified Model" *by* P. J. Telford et al.

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The paper introduces the nudging method briefly, then presents statistics of the simulations. What is missing is a more careful explanation of the following issues, which are important for the potential user of this method in the UM model, or in other models:

A *Conservation / sinks and sources: The nudging method was invented to steer the GCM gently along the time trajectory of the analysed atmospheric state, acknowledging that even a perfect model cannot follow the observed time series due to the incomplete knowledge of the atmospheric state. In this ideal case very small "nudging" increments added to the modelled tendencies would be sufficient to keep the model on track. The nudging would not correct for biases. In the real*

world AGCMs have systematic errors and a plain nudging scheme affects the seasonal means or climatologies of the model. Generally, nudging schemes as presented here introduce net sources and sinks of momentum or energy in the model atmosphere, which modify momentum fluxes (e.g. surface stress) or the energy cycle, with possibly unwanted side effects. For example: AGCMs like the UM are tuned to represent realistically the observed average radiative fluxes at the top of the atmosphere, for given realistic lower boundary conditions. If the nudging scheme corrects biases in the temperature structure of the atmosphere, the radiative fluxes will adjust, and the original TOA radiative balance of the AGCM is changed. Analogous effects may be observed for surface fluxes etc. A priori, it is not clear that the correction of a modelled field with respect to analyses is not deteriorating another field. (Example: assimilating observed tropical moisture in ERA-40 is related to the excess in convective precipitation.) These problems should be addressed in the introduction.

We agree with these statements, although we would note that, as good as it is, the UM is not a perfect model where all quantities provide a perfect description of reality. The alteration of variables that are not directly adjusted is shown by the improved agreement with the analyses produced by using nudging, for surface pressure and tropospheric moisture. It is possible that other quantities are affected adversely which we can discuss in the text, maybe clarifying that when using the model it cannot be assumed to behave exactly like the free running model.

B *Scale separation: The ERA-40 analysis represent instantaneous states of the IFS model atmosphere including the assimilated observations. Hence, ERA-40 fields may include slowly propagating large scale fluctuations as well as fast and small scale fluctuations, which are often considered as "noise". The nudging method is usually applied with the aim to include the slow and larger scale waves, preferably without the "noise", requiring the filtering of the original analyses for the wanted*

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slow modes of variability. In spectral models, this filtering has been implemented through reduction of the considered wave number space. This issue should be discussed, and it should be explained why no attempt is made here for such a scale separation.

We apply no explicit filtering, but the original data is taken at T159 resolution and interpolated to a much coarser (N48) resolution. This should have the effect of removing much small scale variability. The choice of the relaxation parameter with a relaxation time of 6 hours and using a smooth interpolation between the data will also favour the slow and large scale horizontal motions. However it is possible that some residual noise remains and this can be noted in the text. There are however other sources of noise, such as the advection scheme, which we feel obviates introducing more complicated pre-processing of the data.

C *Diabatic vs. adiabatic heating errors: Temperature (or theta) differences occurring in a nudged simulation can result from inaccurate diabatic or adiabatic tendencies. While nudging the temperature field is useful in the former case, it should not be applied in the latter case, where a dynamic adjustment should indirectly correct the temperature error. The authors should explain this potential problem. In which atmospheric regions could this be relevant? Is this problem the case for the tropical stratosphere?*

We nudge potential temperature (θ), which remains invariant under adiabatic motion. Hence by definition biases in θ are due to errors in the diabatic rate or transport.

On a more general note, nudging is not intended to be a sophisticated data assimilation program, integrating measurements into the model, but is employed as a simple approach to constraining the model to global data sets. The philosophy is that we accept that the analyses represent 'reality' and induce the model to resemble them. We accept that this lacks the subtlety of attempting to understand the underlying physical processes, but it has the advantage of being applied in

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a uniform global manner. There is a possibility of errors being introduced above the upper cutoff for nudging, but as the model will not be used to study this region and nudging will correct most propagation of dynamics downwards this is not felt to be a major concern.

0.1 SPECIFIC COMMENTS

1. *Equation 2: As this is a technical report, it should be explained if (2) is implemented explicitly or implicitly. An implicit implementation would provide better numerical stability. Currently (2) does not indicate the time levels of the involved variables. If an explicit implementation is used, this should be justified.*

   The equation is implemented explicitly. Although we are aware that implementing the equation implicitly would be more stable, as the nudging seems stable and the form of the equation is such as to be free from singularities, we are happy that the explicit implementation that we use will suffice.

2. *Figure 1: Axis labels are much too small*

   There seems to be a technical issue with this figure, the axes have been corrupted. We'll consult the editors and correct this.

3. *Evaluation of RMSE, Bias, TC and SC: - This should make use of 6 hourly data, so that the quality of the simulated diurnal cycle has an influence on the results. - Why is April not included in the assessment?*

   We chose not to use the data at six hourly intervals to allow the removal of the daily cycle from the assessments. We agree that investigating whether the nudging improves the daily cycle would make an interesting subject of future study. The choice of months is fairly arbitrary; in the validation of the ECHAM model (Jeuken et al) only January and July are used.

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4. *Table 1 and 2: The entries in the Mean and Bias column are not clear. I assume that "Mean" minus "Bias" should result in the mean of the ERA-40 reference field. This seems not to be the case, for example: Table 1, Theta, level 29: Mean-Bias = 416.2-0.0=416.2K Table 2, Theta, level 29: Mean-Bias = 420.1-3.4=416.7K* $-1 > difference of 0.5K$.

   This is a result of translating from a model on pressure levels to a model on height levels. The Mean - Bias does result in the ERA-40 reference field, but the interpolation is slightly different with and without the nudging due to changes in the pressure distribution as a function of height. As the example above (referee 1, comment 6) illustrates this difference is only small (around 0.1%).

5. *3.1.1. line 4: ... giving evidence ...*

   This change will be made.

6. *Discussion of Figure 2 and 3: The presence of sea ice seems to have an influence on the RMSE. Has ERA-40 used the same sea ice data in 1999/2000 as used here in UM?*

   Comparing the sea ice fraction distribution between the model and the ERA-40 analyses the differences are small, around 0.1%. The increase in RMSE seems to relate to snow cover, as discussed in the reply to the 5^{th} comment of referee 1.

7. *p.4, right, line 3: The nudging, as applied here, also introduces small scale "noise" from ERA-40, since no filtering has been applied. The UM is nudged also towards small scales, using the same 6 hour timescale. The statement on the nudging of (only) large scale dynamics (line 3) must be revised.*

   See answer above to comment 'B'. The statement will be modified to reflect this.

8. *3.1.2: Would it be possible to infer from the bias correction resulting from the nudging the cause of the bias?*

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Maybe, but the exact method of doing so would require some consideration. It can certainly identify key regions to study.

9. *3.1.3: What is the expectation value for TC of the unadjusted simulation? Beyond the timescale of predictability of weather, TC is not meaningful to describe the performance of the unadjusted simulation, especially if the diurnal cycle is excluded by using only daily time series.*

   It is true that the unadjusted TC would not be expected to have high values, but for instance Figure 5 shows that it contains some information, with TC rising in the stratosphere, providing some information on characteristic time-scales.

10. *3.2, above Table 4: The low TC in the tropical omega does imply that the tropical variability in omega500 in UM is not compatible with that in ERA-40, but does not prove errors in the precipitation of the analysis.*

    This claim was not intended to be made and is probably as a result of a lack of clarity in the text. This will be tidied up to avoid confusion.

11. *Table 5: the ratios are surprisingly high, going beyond the original idea of gently steering the model along the analysed time series. Obviously the UM model requires relatively heave nudging, at least in some regions of the atmosphere (near tropopause, convectively active regions in troposphere ...). Does this have implications for the usefulness of the nudging in the comparison of modelled processes with observations? Should regions with heavy nudging be avoided?*

    The values are comparable to similar numbers available in the literature. Jeuken et al (1996) examine the ratio of the nudging and diabatic heating terms, not exactly the same as the ratio we use, but similar. They calculate that this ratio is around 0.1 and larger, which would seem to indicate that the size of this ratio is related to the technique as much as the model.

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12. *The authors should however explain better the limitations and risks of applying the nudging technique.*

    This can be done.

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