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Implementation of spectral nudging in the HIRHAM5 Regional Climate Model

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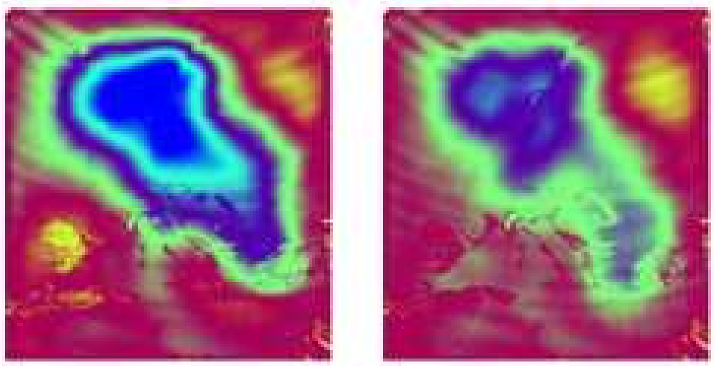

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Contents

1. Dansk resumé

I denne DKC-rapport præsenteres implementeringen af 'spectral nudging' i den regionale klimamodel HIRHAM5. 'Spectral nudging' ekstraherer bølger på stor skala fra den drivende globale model, og introducerer dem i modellens egne felter. Det gør at modellen ikke driver langt væk fra den drivende model. Den præsenterede implementering er i stand til at lave spectral nudging på alle modelniveauer for temperatur, horisontal vind og specifik luftfugtighed. Styrken af 'spectral nudging' kan også justeres for forskellige niveauer. I en standardsimulering er kun de øverste modelniveauer 'nudgede', og kun med lav styrke. Vi har gennemført en serie testsimuleringer for at indstille modellen til en tilstrækkeligt stærk 'nudging'.

2. Abstract

In this report, the implementation of a routine for spectral nudging in the HIRHAM5 Regional Climate Model is described. The main idea behind this implementation is to extract the large scale circulation from the driving data, and impose this on the fields produced by the HIRHAM5 model. The model-calculated fields will then be restrained, so that it will not drift far away from the driving field. The routines described here are capable of nudging all model levels for the temperature, horizontal winds and specific humidity. The strength of the spectral nudging can be adjusted for different levels, and in a standard model simulation with spectral nudging one will only have the top few model levels weakly nudged to the driving field. A series of test simulations was performed to tune the nudging for efficiency in nudging the fields, as well as for computational performance.

3. Introduction

An RCM nested in a GCM field will drift away from the driving field, as the small scales will feed back to the large scales. This causes a mismatch between the model fields and the driving fields foremost at the outflow boundary, but also in the inner parts of the domain. This effect increases with the domain size. For some model simulations, there is a desire to stay close to the driving boundary data, e.g. in a poor man's reanalysis. There are several methods to achieve this. At DKC, we have experienced with a method where the atmosphere is restarted every day, thus forcing the atmospheric variables to stay closer to the driving field [Berg and Christensen, 2008]. This method is computationally inefficient, as a spin-up of the model is required for each restart. Other methods include relaxing the model field towards the driving field. The method which has been found to perform most satisfactorily is the spectral nudging [Rockel et al., 2008]. In spectral nudging, the large scale waves of the driving field are extracted by Fourier analysis, and are then imposed on the model field.

In this report, we present how the spectral nudging has been implemented in the HIRHAM5 RCM, Section 2, the parameters that are used to tune the spectral nudging, Section 3, and some tuning test for the performance of the spectral nudging over the European domain, Section 4. We end with conclusions in Section 5.

4. The spectral nudging in HIRHAM5

We use the 2-D discrete cosine transform (DCT) algorithm to perform the Fourier filtering of the model fields, according to Denis et al. [2002]. The advantage of this special case of Fourier transform is that there is no need to mirror the domain to get a symmetrical field. The DCT has earlier been found to be suitable for spectral nudging in RCMs [Denis et al, 2002].

The routine is called every timestep from the SL2TIM.f semi-lagrangian time-step procedure. In short, the calling procedure is:

- SN_SETUP.f: Reconstructs a global field from the local field in each MPI-process. The spectral nudging calculations are then performed on process “0”.
- SN.f: Reads the input parameters and calculates the vertical profiles for the nudging coefficients. SN_PRE.f is then called from here.
- SN_PRE.f: This routine calculates the difference between the model field and the driving field, and calls SN_DCT2D.f.
- SN_DCT2D.f: Performs the 2-D DCT. First the forward transform is performed, and at the same time the data is filtered to only retain the specified scales. Second the inverse transform is applied, and the filtered field is returned.

5. Input parameters

In principle, the spectral nudging can be set-up to completely transform the horizontal winds, temperature and specific humidity, at all scales. The main parameters includes the scales, i.e. the wavelenghts, to retain, and the vertical profiles for each nudged variable. Table 5.1 lists all the parameters, and their default values.

Table 5.1: List of parameters for the spectral nudging.

Parameter	Default value [unit]	Function
SPEC_NUDGE	0	Whether to use (1) spectral nudging or not (0).
WAVE_MAX	1400 [km]	Scales larger than wave_max will be nudged.
WAVE_MIN	1400 [km]	Scales smaller than wave_min will be nudged.
RES	25 [km]	The horizontal resolution of the simulation.
SNTOPNLV{UV,T,Q}	1	The topmost level to nudge.
SNBOTNLV{UV,T,Q}	9	The lowermost level to nudge.
SNMAX{UV,T,Q}	0.2/0/0	The nudging coefficient at the topmost level.

6. Parameter tuning

We test the spectral nudging over the European domain, as defined in the ENSEMBLES project, in a 25 km horizontal resolution and 19 vertical levels. The horizontal grid is 194x210 grid points. The ERA40 reanalysis is used to drive the model. The test period is January 1958, and we compare the 500 hPa geopotential height from the simulation to that of the ERA40 reanalysis, and to that of the ERA40 reanalysis. The testing is performed for a few different sets of parameters. We perform three sets of experiments: first we study the impact of the number of waves included in the nudging, secondly we study the impact of the strenght of the nudging, and thirdly the impact of the number of levels nudged. As the three parameter tests are dependent on each other, the optimal test would be to test all combinations, but due to time constraints we perform the tests in the written order, and use the optimal setting for each test in the next test phase.

When setting the final parameters for the tuning, we strive for settings that nudge the model to perform closer to the driving data, but not too close, as this inhibits the small-scale behaviour from the RCM. So we try in these experiments to decrease the deviations from the driving data mostly for the periods of large deviations, and don't bother much with the mean level of the deviations. We comment on this in each of the experiments below.

We start with a set-up where only the horizontal winds are nudged at the top eleven levels, i.e. from 500 hPa and up, with a coefficient of 0.2. Figure 6.1 shows the root-mean-square error (RMSE) calculated from all the month and all the domain of the model in comparison to the ERA40 field, which has been interpolated to the RCM grid. The control simulation (with no spectral nudging) shows a high RMSE that varies over the period. The spectral nudging was tested for wave numbers less than or equal to 2, 4, 6, 8, 10, 12, and 14. We see that the RMSE decreases with the maximum wave number, but there is no further decrease after wave number eight. From the tests it is clear that the computational demand increases with the number of waves used. This is due to the routine SN_DCT2D.f which calculates the Fourier transform for each of the wave lengths on each model level. As we do not want to impose a too strong nudging on the fields, we choose to set the default maximum wave length at 1400 km, which corresponds to wave number six and seven in each direction for the current domain. With a spectral nudging at these wave lengths, the model retains the phenomena which cause the large peaks in the RMSE, but does not go closer to the driving field than that. The computational expense was calculated for these experiments to increase by roughly 15% per added wave. Note that this estimate is based on a nudging of 11 levels, so if fewer levels are used, the increase in computational time will be lower.

In the next test we use the default setting from the test above, i.e. 1400 km for the maximum wave

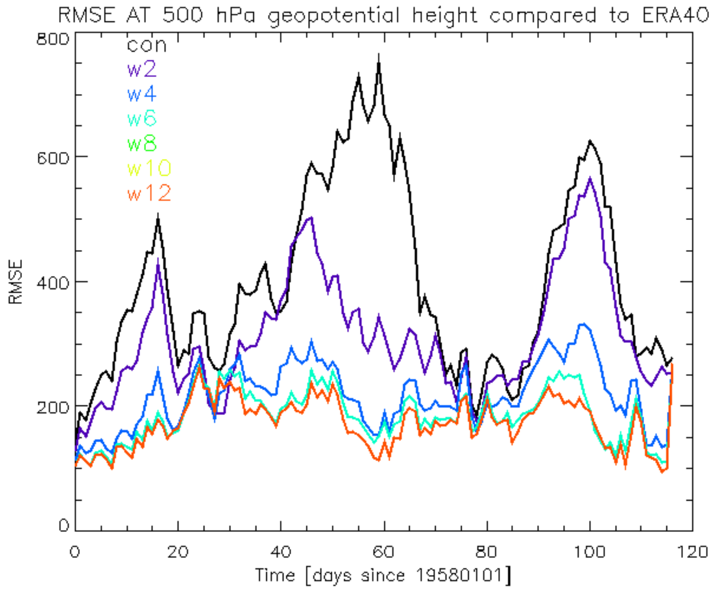

Figure 6.1: RMSE for experiments with different maximum wave numbers. Note that the plot starts six hours into the simulation.

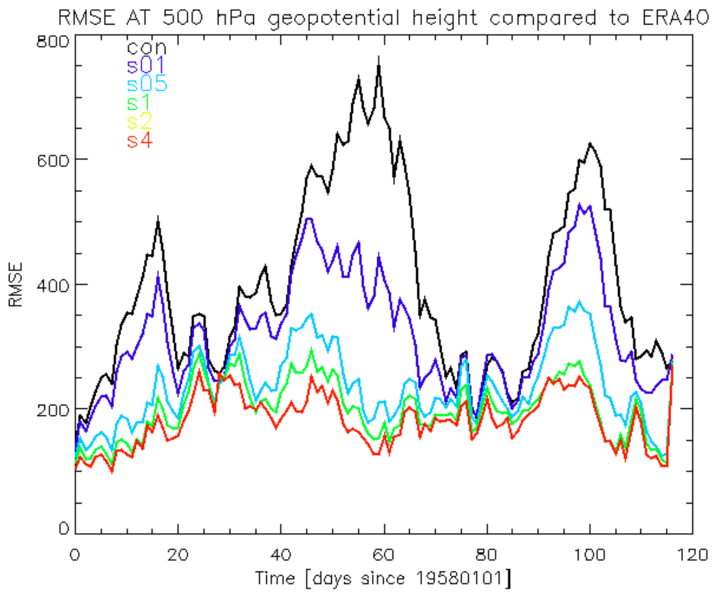

Figure 6.2: RMSE for the experiments with different nudging coefficients. Note that the plot starts six hours into the simulation.

length to be nudged. We then test the impact of changing the strength of the nudging, i.e. how large a part of the model large scales will be replaced by the driving field large scales. Figure 6.2 shows the RMSE for coefficients of 0.01, 0.05, 0.1, 0.2, and 0.4. We find that already for coefficients above 0.2, there is not gain in the RMSE.

Finally, we experiment with the number of nudged vertical levels. For reasons of computational expense, we want to use a low number of levels. By reducing the number of levels that are nudged, the effect on the 500 hPa geopotential height is reduced, and already at nine instead of eleven levels, the model again drifts into its un-nudged state. Therefore, we also need to tune the strength of the nudging. From a few experiments it is found that we can reduce the drift in the model to a reasonable level by nudging the top nine levels, with a linear increase of the strength from this level up to the top, with a maximum strength (*SN_MAX*) at the top level of 0.2.

In Figure 6.3 we see that the nudged simulation is closer to the ERA40 in the inner part of the domain. The variance in the nudged simulations is similar to that of the control simulation (not shown).

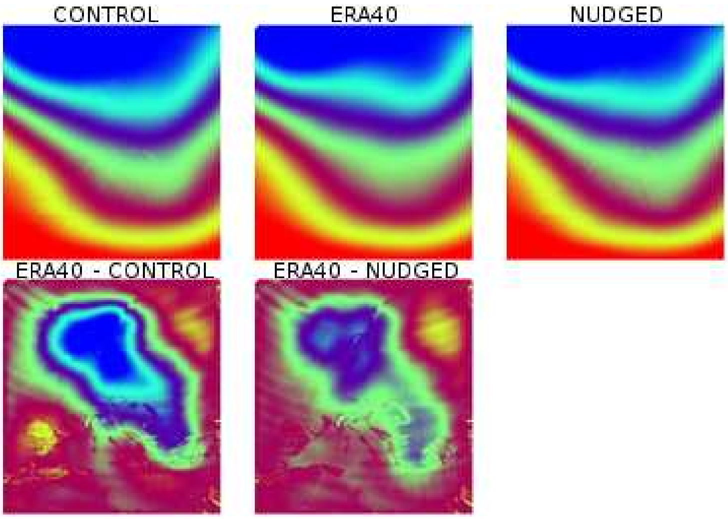

Figure 6.3: The top row displays the mean 500 hPa geopotential height of one month of the simulation for January 1958 for the control (left), ERA40 (middle) and a simulation with the top nine levels spectrally nudged with a nudging coefficient of 0.2 (right). In the lower row the difference between the ERA40 and the control simulation (left), as well as the difference between the ERA40 and the spectrally nudged simulation. The panels show the full European domain (the larger mountain ranges can be seen). The ERA40 data has been regridded to the 25 km resolution of the model data, which explains the longitudinal lines seen in the difference plots.

7. Conclusions

We have succesfully implemented spectral nudging in the HIRHAM5 RCM, and the model has been tuned for nudging performance and for computational efficiency for the European domain. The strength of the nudging to be used depends on the experiment carried out. To benefit from the RCM, the model needs to be free to develop its own small-scale climate, so the nudging must not be too strong. The default values were chosen so that the nudging performs satisfactorily in reproducing the ERA40 500 hPa geopotential height. Further tests at a climatological scale are needed to assess the choice of parameters.

Another issue when choosing the nudging parameters is the impact they have on the performance of the model. Each new level and wave number included increases the computational load, while the number of variables included has a negligible effect. In the present default settings, the model runs at about a quarter of the normal speed in a simulation on 64 cores on a CRAY XT5 machine. The extra computation time scales with the number of cores used, as the spectral nudging needs to collect all the sub-domains before calculating the new model levels. A considerable increase in the performance of the spectral nudging would be expected from the implementation of a fast Fourier transform.

Acknowledgements

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