Unified Model Documentation Paper 083

Nudging the Unified Model

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Contents

1   Introduction

The ability of a climate model to realistically reproduce the state of the atmosphere, *the weather*, is useful to study processes with short timescales. *Nudging, or Newtonian relaxation*, is a simple form of data assimilation that adjusts dynamical variables of free running Global Climate Models (GCMs) using meteorological re-analysis data to give a realistic representation of the atmosphere at a given time.

Nudging can be used to align a climate model simulation closer to the real meteorology for comparison with measurements. Another application of nudging is to reduce variation between two climate model runs on order to compare the effect of a small change e.g. during sensitivity tests.

The variables in the Unified Model (UM) that can be currently nudged are: horizontal wind components (U and V) and potential temperature (Θ) by using the ECMWF ERA-40[1] or ERA-Interim[2] Reanalyses data, ECMWF Operational Analyses, UM Analyses or the Japanese 25-year Re-Analysis (JRA-25)[3].

The nudging code in the UM carries out two main operations: bringing the analysis data onto the model grid as well as time; and relaxing the dynamical variables to this data. The interpolation to model grid and time step is currently done through simple bilinear interpolation, using L_n(Surface pressure) for vertical interpolation of data on hybrid levels.

The analyses are introduced into the model by the addition of a non-physical term to the model equations. The change in a variable (ΔX) is given by

$$\Delta X = F(X) + G(X_{ana} - X_{mod})$$

where,

X_{ana} is the value of the nudged variable in the analyses;

X_{mod} is the value of the variable in the model and

G is a constant, known as the 'relaxation parameter'.

The value of G can be fairly arbitrary, though keeping it too small will render the technique ineffective, while making it too strong can introduce instabilities. The recommended value of G is 1/(time frequency of analysis data), which is usually 6 hours.

A detailed description of the methodology, UM nudging experiments and sensitivity studies can be found in Telford et al, 2008[4].

The Nudged model was developed originally at the University of Cambridge under the Met Office - NCAS (National Centre for Atmospheric Sciences) collaboration for UM6.1 but finally lodged in the main UM trunk at version 7.7. It is also available at UM versions 7.1 and 7.3 on the MONSooN[5] system. It is represented in the UM by a dedicated code section viz *Section 39*.

2   Description of the Analysis Files

The original analysis data have to be processed before they can be used with the UM. For example, in case of ERA-40 the variables are obtained at T159 resolution on ECMWF hybrid-p levels at six hourly interval and regridded to N48 resolution. The pre-processed files are in NetCDF[6] with standardised dimension and variable names.

As described in Section 1, the ECMWF ERA-40 data is expected to be in hybrid-p levels and contain Ln(Psurf). No vertical interpolation is done for UM analyses and hence these have to be on the exact levels as the proposed simulation. The ECMWF pressure level and JRA-25 data are expected to be on standard pressure levels. Each NetCDF file must contain only a single time record. The file naming convention for the data files based on the existing available file types is as follows:

- ECMWF (ERA-40/ ERA-Interim/ Operational):
  ecm-e40_1deg-model-levs_YYYYMMDDHH_all.nc

- UM Analysis : **HPYYYYMMDDHH00.GLOUM6.nc**

- JRA-25 data : **JRAYYYYMMDDHH_all.nc**

Where YYYYMMDDHH refers to the date and time.

At the present, pre-processed ECMWF ERA-40 data are available from September 1957 to March 2002, extended with ECMWF Operational Analysis upto August 2009. The ECMWF ERA-Interim data are available from January 1979 and are regularly extended as and when recent data is made available by ECMWF.

The available data for other sources covers a limited period only. *Note that the UM has not yet been tested extensively with ECMWF pressure level data or UM analyses*.

Please contact the owner of the Nudging Section for information on the location of these data on the HPC systems running the UM.

3   Setting up a UM nudging job

Pre-requisite: To apply Nudging to any UM model configuration, this must already be set up to use the **Gregorian calendar**, as most of the operational and analysis datasets are produced according to this calendar. The 360-day calendar may be used only for short runs (less than a month) as the discontinuities in the data, such as the exclusion of the 31st of different months, are likely to cause instabilities in the simulation.

The following changes are required in Rose GUI to apply Nudging to a given job:

Main Panel:*namelist ⇒ UM Science Settings ⇒ Section 39: Nudging*

1. Set **l_nudging = true**: This will activate all the required options.

2. *ndg_analysis_source* : The source and type of analyses data to be used. The available options are: 0 = ECMWF on hybrid levels (*recommended option*) 1 = ECMWF on pressure levels, 2 = UM analyses 3 = JRA Analyses

3. *ndg_data_path*: Directory for the location of analyses data files on the computing server. All the files corresponding to the simulation period are expected to be present in this folder.

4. *ndg_hours_per_data*: Time Interval (in hours) between analysis data files. This is expected to be uniform throughout the simulation period. The recommended value is *6* since the already preprocessed data are at *6-hourly* interval.

5. *ndg_lev_bottom*: Bottom level from which to apply Nudging. Note: The lowermost model levels should be excluded to avoid likely errors while interpolating the analysis data to the UM levels, since the orography differs between the two models. In general, it is advisable not to apply nudging in the boundary layer.

6. *ndg_lev_top*: Topmost level up to which Nudging is applied. This value should be chosen so as to avoid using the topmost 'sponge' layers of the analyses and keeping in mind the vertical extent of the source analysis data.

7. *ndg_on_lev_bottom, ndg_on_lev_top*: These specify the span of layers, starting from the lowermost (and topmost) *Nudged* levels selected above, over which nudging will be gradually applied to the variable starting from zero to full strength.

8. *ndg_relax_tvalue, ndg_relax_uvalue, ndg_relax_vvalue*: These are the Relaxation parameters (for $Theta$, U and V respectively), that control the amount by which the model variable is nudged towards analysis data. A too small value may be ineffective, while a too large value may lead to model instability. The recommended value for this parameter is 1/(time interval between analyses in sec) e.g. for analysis data at 6 hourly interval: (1/21600) = *4.62963e-05*

9. *ndg_strat_fac*:Stratospheric Reduction factor Experience with nudging of stratospheric model configurations has shown the need to reduce the strength of relaxation applied to the parameters, higher up in the atmosphere. This factor gradually scales down the relaxation coefficients (derived from above 'Relaxation parameters') in grid-boxes above the tropopause. The value of this factor should be 0.0 <F ≤ 1.0, with 1.0 signifying there is no reduction in the nudging strength.

   IMPORTANT NOTE: The Nudging module requires certain diagnostics to be requested in STASH with a time profile (*e.g. TALLTS*) that makes them active at each timestep. The items can be requested on the Rose STASH panel: *namelist ⇒ Model Input and Outputs ⇒ STASH requests and Profiles*

   The required items are :
   i) Pressure at Tropopause Level *(Section 30; item 451)*
   ii) Diagnostics related to Θ *(Section 39; items 001- 005)*

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iii) Diagnostics related to U *(Section 39; items 006- 010)*
iv) Diagnostics related to V *(Section 39; items 011- 015)*

If these diagnostics are not found in STASH when Nudging is ON, the model will stop with an error message:
'*Required Nudging diags or Tropopause pressure not requested in STASH*'.

4   References

1. The ECMWF ERA-40 Re-Analysis Project.
   http://www.ecmwf.int/research/era/do/get/era-40

2. The ECMWF ERA-Interim Re-Analysis Project.
   http://www.ecmwf.int/research/era/do/get/era-interim

3. The Japanese 25-year Re-Analysis (JRA-25) Project
   http://jra.kishou.go.jp/JRA-25/index_en.html

4. Telford, P. J., Braesicke, P., Morgenstern, O., and Pyle, J. A.: Technical Note: Description and assessment of a nudged version of the new dynamics Unified Model, Atmos. Chem. Phys., 8, 1701-1712, doi:10.5194/acp-8-1701-2008, 2008
   http://www.atmos-chem-phys.net/8/1701/2008/acp-8-1701-2008.html

5. MONSooN: The Met Office - NERC Supercomputing Node for Unified Model collaborations.
   http://collab.metoffice.gov.uk/twiki/bin/view/Main/WebHome

6. NetCDF: Network Common Data Format (Unidata/ UCAR):
   http://www.unidata.ucar.edu/software/netcdf/

For further details and latest updates please refer to the following links:

http://collab.metoffice.gov.uk/twiki/bin/view/Project/UKCA/UkcaNudging

http://www.atm.ch.cam.ac.uk/community/pg/pages/view/449/