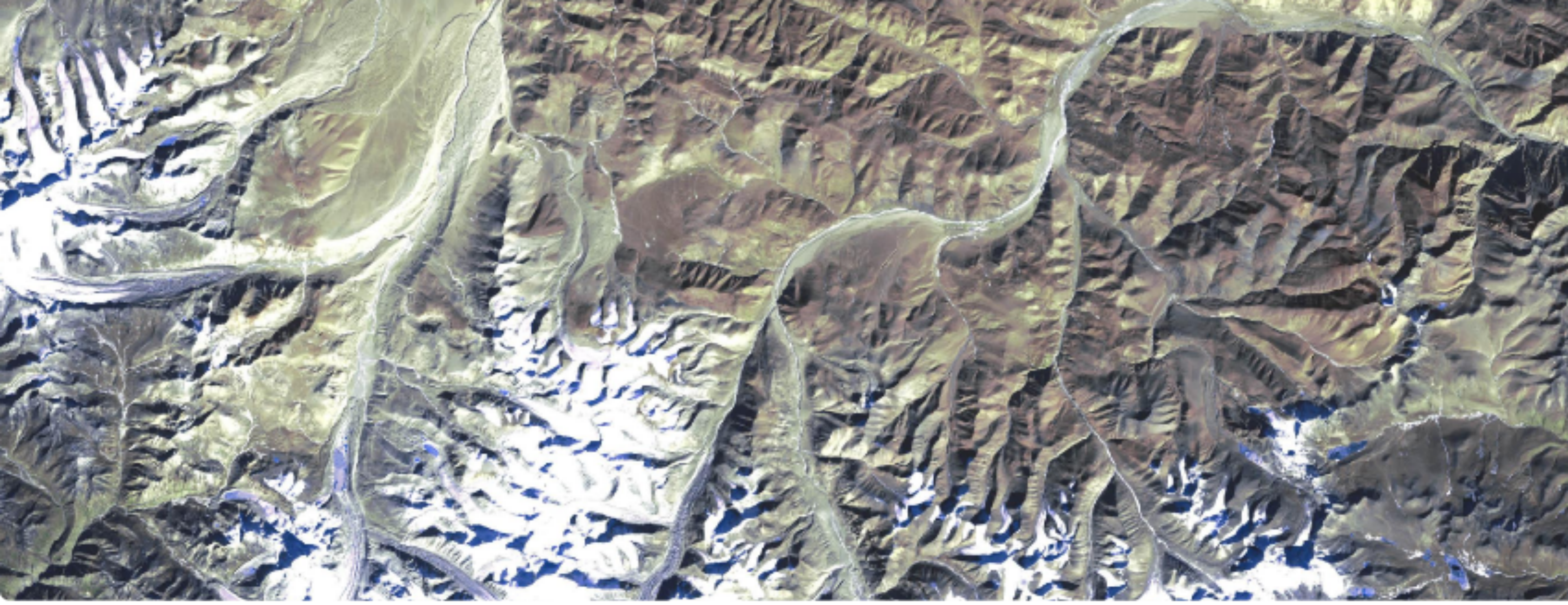
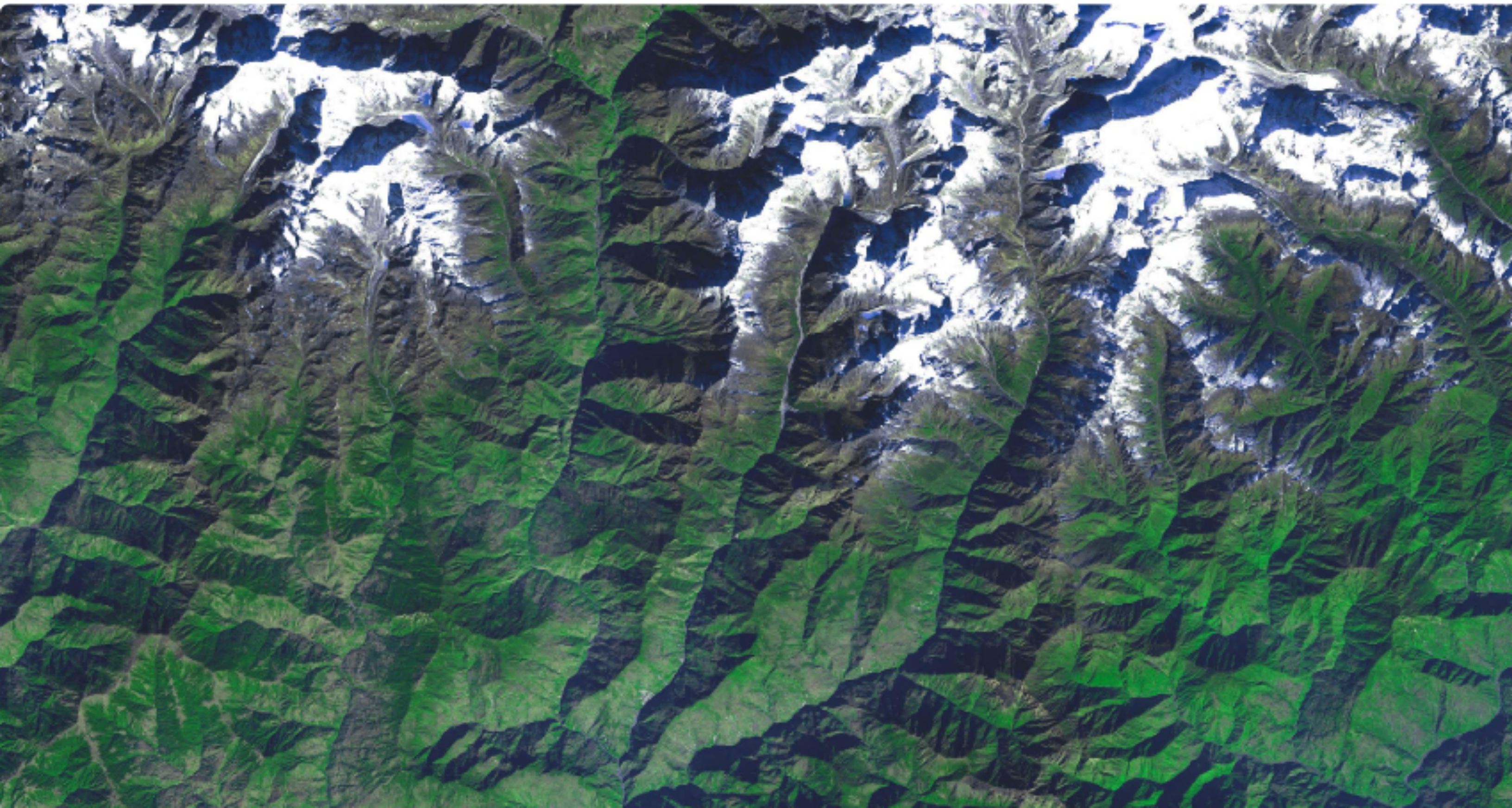


COnstraining ORographic Drag Effects (COORDE)

A GASS/WGNE Modeling Intercomparison Project

Annelize van Niekerk and Irina Sandu



Contents

1. Introduction

This document describes the GASS/WGNE project aimed at understanding the impact of resolved and parametrized orographic drag on the atmospheric circulation through the **COORDE**nation of model experiments and output from several modeling centres. The protocol follows the study of van Niekerk et al. (2018), which demonstrates a method for assessing the accuracy with which parametrizations of orographic blocking and orographic gravity wave drag are able to reproduce the explicitly resolved impacts of orography on flow over complex mountain ranges. van Niekerk et al. (2018) found that, at resolutions ranging from tens to hundreds of kilometres, short-range forecasts performed with both the Met Office Unified Model (MetUM) and the European Centre for Medium Range Weather Forecasts Integrated Forecasting System (ECMWF IFS) exhibited too strong zonal winds relative to analyses in the lower stratosphere over these regions. This bias was not present in high resolution simulations with high resolution orography, in which the large deceleration from the breaking of resolved orographic gravity waves acted to mitigate it. As a result, this bias could be directly linked to insufficient deceleration from orographic gravity waves (parametrized or resolved) in these low resolution experiments. Diagnosis of the parametrized physics and resolved dynamics tendencies further revealed that this model bias is partly due to the orographic gravity wave drag (OGWD) parametrization and partly due to the compensation and response of the resolved dynamics to the parametrized OGWD.

Motivated by these findings, the particular questions we aim to address with this project are: how does the formulation and combination of parametrizations of orographic drag vary across models?; to what extent does the circulation impacts of the parametrized orographic drag mimic those obtained when explicitly resolving the orography in high resolution simulations?; which model errors at lower horizontal resolutions are a result of errors in the parametrization of orographic drag?; are these errors systematic across models or dependent on the formulation of the orographic drag parametrization?; how does the interaction between the parametrized orographic drag and the model dynamics vary between different models?

To answer these questions, we propose experiments at high and low horizontal resolutions. Each experiment consists of a set of short-range (24-hours) forecasts initialized from analyses. A pair of low resolution (ranging from $\sim$80km to $\sim$200km) experiments with and without parametrized orographic drag turned on will be used to determine the impact of parametrized orographic drag on the circulation. A second pair of high resolution (km scale e.g. 4km) **global or regional** experiments with high and low resolution orography will be used to deduce the impact of explicitly resolved orography on the circulation. By comparing and contrasting the impact of the parametrized and resolved orographic drag in different models, along with the drift relative to analyses, we hope to both validate the orographic drag parametrization schemes and to gain a better understanding of the interactions between the circulation and resolved/parametrized orographic drag.

If you have any questions please contact: Annelize.vanNiekerk@metoffice.gov.uk

2. Experimental Setup

2.1 Model Initialisation

Each of the experiments described below consists of a set of 14 short range forecasts, initialized every day at 00UTC from **January 1st to January 14th 2015** and are run for 24 hours. The preferred method of model initialisation is to use the operational ECMWF analyses data for this period (16km global resolution). The simulations should be atmosphere only, i.e. with prescribed sea-ice and sea surface temperatures and the methods of initialisation generally follow that of the Transpose-AMIP experiments described in Williams et al. (2013). Land surface should be interactive and initialised using either of the methods described in section 2a of Williams et al. (2013), namely: initialised from fields produced by a land surface assimilation system; initialised using a suitable climatology; or initialised with a nudged method. We are able to help with the provision of data for the atmospheric initial conditions if necessary.

If it is not possible to initialise the model from ECMWF analyses, an alternative method of initialisation, whereby, the model is initialised using the modeling centres own (or another modeling centre's) analysis or reanalysis would also be acceptable but participants should clearly indicate their methods of initialisation. This can be done by providing details of the experiments using the table on sheet 2 of the file 'Parametrizations_and_experiments.xls' (the Met Office Unified Model experiments have been filled out as an example).

2.2 Global low resolution experiments

The impact of parametrized orographic drag on the atmospheric circulation will be deduced by taking the difference between two global low resolution experiments: one with the orographic drag parametrizations turned on and one in which these parametrizations are turned off. Our main interests lie in validating the low-level drag and gravity wave drag components of the orographic drag parametrizations that account for orography with horizontal scales of $>\sim$5km. This includes processes such as orographic blocking, gravity waves (Lott and Miller (1997)), downslope wind storms (Scinocca and McFarlane (2000)) and trapped lee-waves (Teixeira et al. (2013)).

These experiments should be performed using global atmospheric models that have an approximate horizontal resolution of $\sim$**80km to 200km** (in mid-latitudes). The vertical resolution should be that used operationally by the model. The model must employ at least an orographic gravity wave drag parametrization. We propose two experiments that we would like all participants to perform as the minimum requirement, denoted LR_CTL and LR_NOSSO.

In order to investigate the interaction between the parametrized orographic gravity wave drag and the model dynamics (as in section 5 of van Niekerk et al. (2018)), we also propose the experiments LR_NOGWD and LR_GWD4.

2.2.1 Experiment LR_CTL

This experiment should be performed with the standard configuration of the model and will act as the global low resolution control. All orographic drag parametrizations should be on and use their standard parameter settings. If participants have more than one model that fits this criteria (e.g. the same model at different horizontal resolutions or with different scientific configurations), we welcome more than one submission but we do require all LR_CTL submissions to have an accompanying LR_NOSSO submission. In the case of more than one submission that fits this criteria, experiments should be labelled (LR_CTL, LR_NOSSO), (LR_CTL_A, LR_NOSSO_A), (LR_CTL_B, LR_NOSSO_B) and so on.

As an example, the MetUM contribution will be two global simulations at a resolution of ∼150km and ∼80km, with 70 vertical levels extending to 80km.

2.2.2 Experiment LR_NOSSO

This experiment should be performed in the same manner as experiment LR_CTL but with the parametrization(s) that account for drag from subgrid orographic features with scales **above ∼5km** switched off (or the coefficients set to zero). In these experiments, drag that accounts for subgrid orographic features with scales smaller than 5km (e.g. turbulent orographic form drag) should **not be** switched off.

For example, the Met Office Unified Model employs an orographic gravity wave drag, low-level blocking drag (Vosper (2015), Lott and Miller (1997)) and an orographic form drag parametrization (Wood and Mason [1993]). For this experiment, their contribution will be two simulations at a resolution of ∼150km and ∼80km with 70 vertical levels with the orographic gravity wave drag and orographic blocking drag switched off. The turbulent orographic form drag parametrization will be left on.

2.2.3 Experiment LR_NOGWD

This experiment should be performed in the same manner as experiments LR_CTL but with the parametrization that accounts for orographic gravity wave drag switched off (or the coefficients set to zero). For this experiment, the Met Office contribution will be simulations at a resolution of ∼150km and ∼80km with 70 vertical levels with the turbulent orographic form drag switched on, the orographic blocking switched on and the gravity wave drag switched off.

2.2.4 Experiment LR_GWD4

This experiment should be performed in the same manner as experiments LR_CTL but with the coefficient multiplying the orographic gravity wave drag stress increased four-fold. For this experiment, the Met Office contribution will be simulations at a resolution of ∼150km and ∼80km with 70 vertical levels with the turbulent orographic form drag switched on, the orographic blocking switched on and the gravity wave drag coefficient (G) increased from G=0.5 to G=2.

2.3 Global or limited area high resolution experiments

Global or limited area high resolution experiments will be used to determine the impact of resolved orography on the atmospheric circulation. The impact of the resolved orography will be deduced by taking the difference between a high resolution experiment with high resolution orography and a high resolution experiment with a low resolution orography, described below.

These experiments should be performed using either global or limited area atmospheric models that have a horizontal resolution of <∼10km (in mid-latitudes). The vertical resolution should also be sufficiently high to match the increase in horizontal resolution. If participants wish to contribute

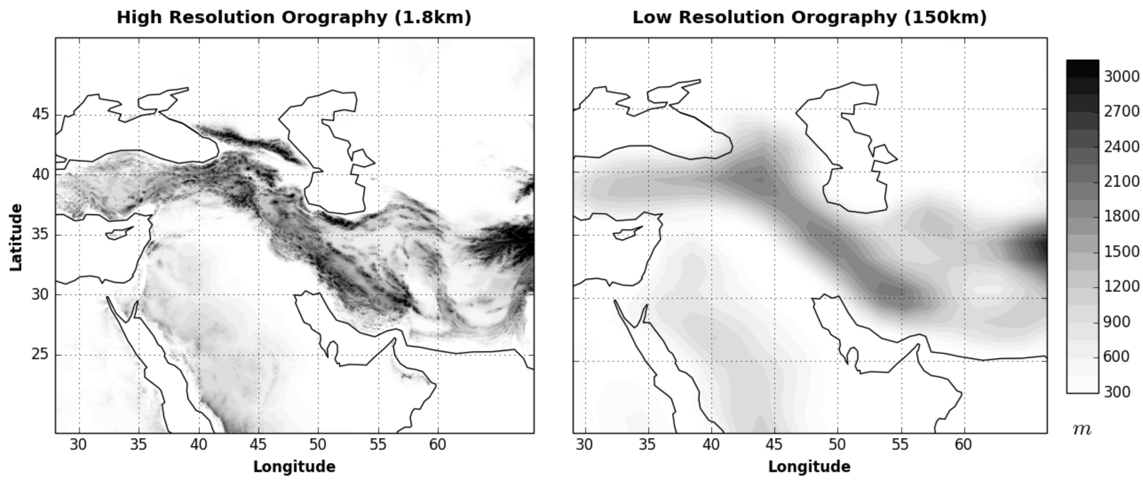


Figure 1: Mean orographic heights used in the MetUM Middle East LAM contribution to experiments (a) HR_CTL_ME and (b) HR_LROR_ME.

more than one high resolution simulation (e.g. one global and one limited area), they are encouraged to do so.

In the case of a limited area domain being employed, the region of interest is the Middle Eastern Mountainous region. This region was chosen as a result of the large orographic gravity wave magnitudes that are produced by the resolved orography and the parametrization scheme during our chosen period (see van Niekerk et al. (2018)). Figure 1 shows the region of interest which extends from 20.0° N to 50.0° N and from 28.0° E to 68.0° E in the MetUM LAM. The grid-point resolution of this LAM domain is 0.02° lat by 0.02° lon, corresponding to ∼1.8km resolution.

If participants would like to include an additional limited area simulation, we are also interested in the Himalayan region. This region also exhibited large resolved and parametrized orographic gravity wave magnitudes during our chosen period (see van Niekerk et al. (2018)). Figure 2 shows the additional region of interest which extends from 15.625° N to 50.625° N and from 55.3125° E to 126.5445° E in the MetUM LAM. The grid-point resolution of this LAM domain is 0.035° lat by 0.053° lon, corresponding to ∼4km resolution.

If participants are submitting a limited area simulation they may use either their model at a suitable resolution (initialised as instructed) to force the lateral boundaries or ECMWF analyses may be used as forcing for the lateral boundaries. The lateral boundaries should preferably be updated 6hourly.

We propose two high resolution experiments that we would like participants to perform, labelled HR_CTL and HR_LROR. The parametrized orographic drag that accounts for scales above ∼5km should be switched off in all high resolution simulations, since we wish to avoid interaction between the resolved and parametrized orographic drag at these resolutions. These should be labelled HR_CTL and HR_LROR for global simulations, HR_CTL_ME and HR_LROR_ME for limited area simulations over the Middle East and HR_CTL_HI and HR_LROR_HI for limited area simulations over the Himalayan region.

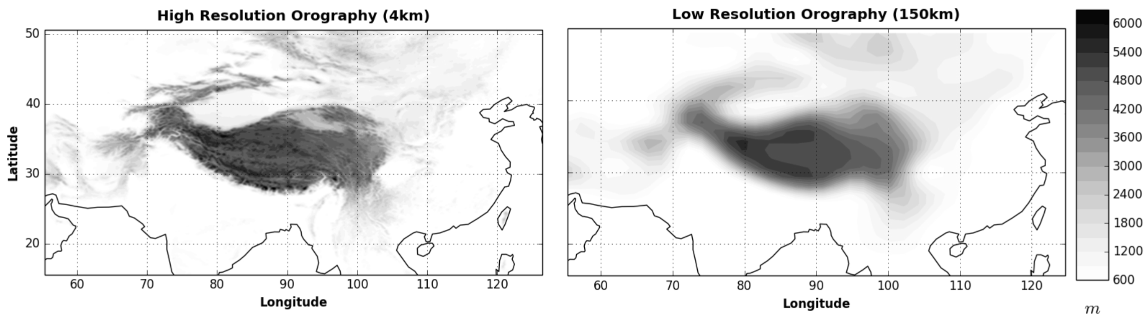


Figure 2: Mean orographic heights used in the MetUM Himalayas LAM contribution to experiments (a) HR_CTL_HI and (b) HR_LROR_HI.

2.3.1 Experiment HR_CTL

This experiment should be performed with high resolution orography and the standard model science configuration for that resolution.

For example, the Met Office Unified Model's contribution will be a global simulation at a resolution of ∼10km, a limited area simulation at a resolution of ∼1.8km centred on the Middle East and a limited area simulation at a resolution of ∼4km centred on the Himalayas. The lateral boundaries will be generated from the 40km version of the Met Office unified model, which is also initialised from ECMWF analyses.

2.3.2 Experiment HR_LROR

This experiment should be performed with the same configuration and atmospheric resolution as HR_CTL but with the surface mean orography replaced with that of experiment LR_CTL. This involves interpolating the orography from the low resolution grid onto the high resolution grid. A standard linear interpolation is used.

3. Objectives

First and foremost, we would like to explore the diversity of orographic drag parametrizations that are used in models. This information will be gathered from contributors completing the table on sheet one of 'Parametrizations_and_experiments.xls' and will be used to inform the conclusions drawn from the low resolution global experiments.

Secondly, we will look at the zonal wind impacts of parametrized versus resolved orographic drag, as described in sections 3 and 4 of van Niekerk et al. (2018).
The objectives of this stage is as follows:

- **Investigate the impacts of resolved orography:**
  The impact of the resolved orography on the circulation, deduced from the high resolution experiments (with high and low resolution orography), will be used to validate/constrain the parametrized orographic drag. The spread in the resolved orographic impact, from several models and across different resolutions, will provide some measure of uncertainty in our use of the high resolution simulations for parametrization validation. Additionally, it will give us with some indication of the convergence (or lack thereof) of the circulation impact of resolved orography with increasing resolution.
- **Investigate the impacts of parametrized orographic drag:**
  The impacts of the parametrized orographic drag (and its various components) on the circulation, deduced from the low resolution experiments with and without parametrized orographic drag, will be used to understand the consequences of different parametrization formulations and combinations for the model evolution. The aims is to not just look at the tendencies from the individual drag components but to understand their combined impacts on the circulation.
- **Compare the impacts of resolved versus parametrized orographic drag:**
  The ability of the parametrization scheme to reproduce the impact of the resolved orography on the circulation will be assessed. This will allow us to validate the parametrization schemes, and, by gathering knowledge of the parametrization scheme formulations, this will improve our understanding of why some schemes or combinations of schemes perform better than others.
- **Compare the model drift relative to analyses:**
  At short lead times, the model errors due to the orographic processes will remain localised. By comparing the model error relative to analyses with the impacts of resolved versus parametrized orographic drag, we may be able to attribute certain model errors to the orographic processes. These may be systematic between the models (as was found for the ECMWF IFS and MetUM in the lower stratosphere) or dependent on their individual orographic drag parametrization schemes.

Finally, we wish look at the zonal momentum tendencies and their response to varying the parametrized orographic drag, as was done in section 5 of van Niekerk et al. (2018). This part can only be performed if enough modeling centres have provided momentum tendency outputs.
The objectives of this stage is as follows:

- **Compare the magnitude of parametrized orographic drag and the individual drag components:**
  The WGNE Drag Project (Zadra et al. (2013)) demonstrated that the contributions from different parametrized drag processes varied across several models, indicating that they have different ways of closing their momentum budget. By diagnosing and comparing the magnitude of the individual orographic drag components across the models, we hope to delve deeper into the reasons for and implications of this spread across models. An important distinction from the WGNE Drag Project is that we hope to look at the vertical and horizontal distribution of the different drag components.
- **Investigate the interaction between resolved dynamics and parametrized orographic drag:**
  In section 5 of van Niekerk et al. (2018), the authors show that there is a significant interaction between the resolved dynamics and the parametrized orographic drag in both the MetUM and the ECMWF IFS. By looking at the response of the resolved dynamics to the addition of parametrized orographic drag in other models, we wish to determine the importance of this interaction for the circulation response in other models.

4. Output

Please see ‘Diagnostic_output.xls’ for more detail on output required.

4.1 Parametrization information

As a means of understanding the different ways in which models represent the drag from unresolved orographic processes, we would like all participants to provide information on their model parametrizations using the headers in sheet 1 of ‘Parametrizations_and_experiments.xls’. This table should be completed, along with a description of the modeling contributions on sheet 2 of ‘Parametrizations_and_experiments.xls’, **prior to performing experiments**. As an example, the table is completed for the Met Office Unified Model parametrization schemes and modeling experiments.

4.2 Data format

For all submissions, data should be provided in NetCDF Climate and Forecast (CF-compliant) Metadata Convention. We request one file per variable and the axes should be: forecast lead time (hours since the beginning of the forecasts i.e. 6 to 24), forecast initial date (1 to 14th January 2015), level, latitude and longitude. The file metadata should contain the relevant information about all of the dimensions, such as the model level information.

Once data is ready for delivery, please contact Annelize van Niekerk for FTP username and password.

4.3 Spatial sampling

For global output, the horizontal resolution of the output data should be 0.5x0.5 degrees, with the longitude points starting at 0° E and ending at 359.5°E (720 points) and the latitude points starting at 90°N and ending at -90° N (361 points). For regional output, the horizontal resolution of the output data should also be 0.5x0.5 degrees. For the Middle East region the longitude points should start at (and including) 28° E and end at 68° E (81 points) and the latitude points should start at 20° N and end at 50° N (61 points). For the Himalayan region, the longitude points should start at (and including) 55.5° E and end at 126.5° E (70 points) and the latitude points should start at 15.75° N and end at 50.25° N (143 points).

Since the high resolution experiments will have many more points than the low resolution experiments, the high resolution output should be conservatively interpolated to the 0.5x0.5 degree grid or, in the case of a spectral model, should be truncated in spectral space to the low resolution truncation prior to converting to grid-point space.

4.4 Variables

Details of filenaming and output are given in ‘Diagnostic_output.xls’. The winds, temperature, surface pressure, mean sea level pressure and surface altitude are required for all modeling experiments.

However, the zonal momentum tendency diagnostics are only requested for the low resolution global experiments (i.e. LR_CTL, LR_NOSSO, LR_NOGWD and LR_GWD4 etc.). The zonal momentum tendencies can be output on model levels or interpolated onto pressure levels, with the latter being preferred, and should be accumulated over a 24 hour period. The tendencies should include all those required to close the zonal momentum budget: the total u tendency is the total rate of change of the zonal winds; the dynamics u tendency is the rate of change of the zonal wind due to the resolved dynamics; the orographic drag u tendency is the sum of all orographic drag tendencies that account for orographic processes at scales >5km (see notes in .xls file); boundary layer drag u tendency is the rate of change of the zonal winds due to turbulent mixing within the boundary layer, which includes turbulent orographic form drag; and the additional u tendencies is the rate of change of the zonal winds due to all other parametrized processes and the breakdown of the orographic drag into its individual components.

4.5 Verifying analyses

If the experiments have been initialised from a source other than ECMWF analyses, contributors should clearly state this and should to provide winds and temperatures from their initialising analyses for the dates 2-15 of January 00 UTC (the verification date of the forecasts starting on 1-14 of January) on the pressure levels given in ‘Diagnostic_output.xls’.

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