1. Introduction

This paper reports on two main themes (i) progress towards developing a seamless global numerical prediction system from weather to climate timescales, and (ii) using the seamless prediction framework to evaluate global models and make progress on long standing model systematic errors. A core strategy is to keep the global model science as unified as possible across all prediction timescales to benefit from both weather and climate science activities and advance global model performance while also providing new environmental prediction capability and products for customers. This paper follows on from presentations on seamless prediction at MOSAC-12 (S.Milton), 13 (C.Senior) and 14 (A.Arribas).

2. Science re-structuring - Global Model Evaluation & Development

As part of the Science restructuring we have a new Global Model Evaluation & Development (GMED) research team in Foundation Science to take this seamless concept forward with specific responsibility for (i) evaluating the global performance across weather and climate timescales, (ii) pulling through parametrization, dynamics and resolution improvements into the global atmospheric modelling systems to provide an atmospheric global model fit for purpose for weather and climate science, (iii) exploiting earth system science at NWP timescales (aerosols, coupled Ocean-Ice-Atmosphere-Land modelling, atmospheric chemistry etc.) and collaborating on high resolution climate modelling with other groups in the Met Office.

GMED is made up of 19 staff in four groups;
(i) Global Atmospheric Model Development (Manager : David Walters , 5 staff)
(ii) Model Evaluation and Diagnostics (Manager: Keith Williams, 7 staff)
(iii) Global Coupled Model Development & Processes (Manager: Tim Johns, 4 staff)
(iv) Stratosphere and Large-Scale Dynamics (Manager: David Jackson, 3 staff)

3. Atmospheric Global Model Development & Governance

In order to successfully develop and maintain a seamless global prediction system the governance of the Unified Model science (and code base) is a critical issue. Until recently the global NWP and climate model science development operated somewhat independently. NWP was advanced through twice a year improvements to model formulation and climate on longer timescales driven by IPCC for AR4 (HadGEM1) and AR5 (HadGEM2). With the advent of an operational coupled seasonal prediction system (GLOSEA4) and the evolving climate services agenda there is a growing requirement for a continually evolving climate configuration that can capitalise quickly on the latest developments in the science. However, this also has to be balanced against the need for more stable climate configurations for IPCC activities such as CMIP5. These different requirements need to be accommodated in a seamless model development strategy.

With the science restructuring the responsibility for coordinating the global model development across all timescales now comes under the Global Atmospheric Model Development team (see (i) above). The aim is to advance the global atmospheric science in step across all configurations (NWP, MOGREPS (15-day), Seasonal (GLOSEA4), Decadal). To do this we are proposing a main global science development trunk (GlobAtmos – see Figure 1) with strict configuration management and an annual cycle for global model development involving a major upgrade each spring and coordinated testing across all timescales throughout the year leading up to the spring upgrade. This “implementation” development cycle will advance “mature” well tested science developments we are confident can be developed on an annual timescale. This approach rationalises our resources into a single development (and evaluation) strategy and provides a clearer interface for the model developers. Data assimilation changes will be offset from model
developments by 6 months. This allows a stable trialling environment for both DA and model avoiding problems we have had in the past with interactions between DA and physics being implemented in the same parallel suite.

We also envisage a “research development cycle” where model developers and evaluation teams work together on emerging model improvements tested against stable global configurations from the main trunk (e.g. GA4.0) to get them to a stage where they can be considered ready for testing in the “implementation cycle”. For a given model development this research cycle may be 2-5 years and will involve contributions towards model development from UM collaborators (KMA, CAWCR, NCMRWF…) and NERC (through the JWCRP). Of course, we recognise that a certain level of pragmatism will need to be exercised in order to maintain the pace of improvements. We may in the short term see NWP and climate configurations branch slightly, and there will inevitably be different dynamics settings (timesteps etc) for different resolutions. However, the aim long term is to drive the global science via the main development trunk which represents consolidated well tested and robust physics and dynamics. A similar strategy is being considered for the Global Ocean (NEMO) and Global Ice (CICE) components.

4. Global Model Evaluation across Timescales

Model error remains a key determinant of uncertainty in climate change and weather predictions and progress has been slow on a number of long-standing model systematic errors (e.g. Madden Julian Oscillation (MJO)) However, the advent of detailed Earth Observation (EO) platforms (e.g. CloudSAT & the A-Train) and in-situ measurements (ARM), coupled with high resolution modelling (cloud resolving – e.g. CASCADE) and novel diagnostic techniques (e.g. tendencies, relaxation experiments) all provides an exciting framework for better evaluating models at a process level (e.g. Bodas-Salcedo et. al (2008)).

We provide a focal point for the evaluation of the global model through the Model Evaluation & Diagnostics (MED) team (see section 2(ii)). Their remit is to monitor and evaluate the global model

Figure 1: Global Atmospheric Unified Model development path (see text for discussion)
across all timescales against observational data and reanalyses, develop novel diagnostics to highlight the source of systematic error growth, and study the role of model resolution. This team liaises closely with the model development teams, other diagnostic activities in climate science (CAPTIVATE\(^1\) project, UCC\(^2\) group), weather science (e.g. regional high resolution modelling), and with forecasters (NWP problem group) and UM collaborators/NERC scientists on all aspects of model performance.

It has been frequently demonstrated (at the Met Office and elsewhere) that many climate model biases develop on short timescales (Rodwell and Palmer (2007), Williams & Brooks (2008), Martin et. al (2010)). The NWP framework is very useful for understanding the origin of climate model biases as they develop from initialised states, and the dynamically constrained environment of short range forecasts permits the fast physical processes in models to be evaluated against a wealth of observations. In addition to “fast physics” errors we also need to study the slowly evolving components (ocean, ice, land surface, stratosphere-troposphere interactions) and potential errors arising from modelling of these components as well as interactions between them. Our strategy here will be to focus on the evolution of errors in the seasonal coupled model hindcast and forecast systems (see section 5).

The work of the MED group is wide-ranging and covers some of the following topics:

- **TRANSPOSE AMIP II (WGNE/WGCM)** – international collaboration to run climate models in ‘NWP mode’. The Met Office is the lead institution and chairs the project steering committee.
- **SURFA – WGNE study to evaluate surface fluxes in NWP models.**
- **ASIAN Monsoon – diagnostic collaboration with ECMWF.** The UM suffers from a dry bias and ECMWF has a wet/overactive monsoon. This has also been adopted as a demonstration project by the THORPEX PDP\(^3\) group. There is also a NERC JWCRP post dedicated to the Asian Monsoon.
- **Africa – improving seasonal-decadal climate variability and weather prediction (DFID-Met Office/CSRP\(^4\) and AMMA-2 (University of Leeds) projects).**
- **MJO – YOTC Task Force on the Madden Julian Oscillation.**
- **Evaluating against field experiments e.g. (i) ASCOS (Arctic Summer Cloud and Ocean Study (IPY)) – in collaboration with University of Leeds. (ii) VOCALS (iii) GERBILS –West African study of dust.**
- **CAPTIVATE focussed science development teams on monsoons, MJO, sst drifts etc.**
- **Novel diagnostics development – relaxation/nudging (Jung et. al. (2010), Telford et al. (2008)), tendencies, PV budgets etc.**
- **Studies of stochastic physics and model resolution.**
- **Impact of stratospheric representation on tropospheric weather.** (PhD with University of Reading)

I will present more science examples in my MOSAC talk, but here provide one from evaluation of the Global UM on weather and climate timescales in the Arctic against field experiment data from ASCOS and AOE\(^5\) (collaboration with University of Leeds (Birch et.al (2009)). This study highlighted deficiencies in near surface temperatures, modelled sea-ice albedo, boundary layer cloud and surface roughness which are being partly addressed in Parallel Suite 26 in spring 2010.

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\(^1\) Climate Processes, Variability And Teleconnections

\(^2\) Understanding Climate Change – see paper 15.13.

\(^3\) Predictability and Dynamical Processes.

\(^4\) Climate Science Research Partnership.

\(^5\) Arctic Ocean Experiment 2001.
Key areas where we may be weaker diagnostically include (i) linking the physical forcing errors (e.g. diabatic heating, frictional forcing) to errors in circulation at various timescales, (ii) diagnosing the interplay of errors between different components of the coupled ocean-atmosphere-land-cryosphere system, (iii) making use of the valuable diagnostics available daily from the data assimilation process.

5. Seamless Global Earth-System Model Development

A key part of the seamless strategy is to bring together the weather and climate prediction systems by incorporating earth system physics complexity into the NWP timescale while also pushing the resolution of the climate models as high as possible to increase the fidelity of the physical and dynamical processes. In addition we need to develop a seamless strategy for the ensemble prediction systems (EPS) which are currently quite distinct at NWP (MOGREPS), Seasonal (GLOSEA4) and Decadal (DePreSys) timescales.

Ocean-Atmosphere Interactions – The Met Office hosted a workshop on this topic in December 2009 and recommendations were made including (i) evaluate benefits of O-A coupling on NWP timescales, (ii) more research on upper ocean mixing processes, (iii) more "top down" evaluation against available observations (ARGO), (iv) research on coupled data assimilation. Four cross cutting working groups have been set up to take these recommendations forward. The Global Coupled Model Development & Processes team (see section 2(iii)) are evaluating the N216L85 ORCA025L75 coupled ocean(NEMO)-sea-ice(CICE)-atmosphere(UM) model (1metre ocean top and 3hr flux coupling) running over timescales from days to a month ahead. The atmosphere is initialised from UM analyses, the ocean from FOAM analyses and CICE from climatology. To
investigate the benefits of coupling for both ocean and atmosphere forecasts we also run an atmosphere only version (with persisted SST anomalies as in MOGREPS-15 and real SST’s) and ocean only using the FOAM global ocean component forced by fluxes from the atmosphere run (collaborative effort with the Ocean Forecasting teams). Key challenges to demonstrating benefit on NWP timescales will be the SST drift and dealing effectively with initialisation shock. The N216L85 ORCA025L75 coupled model is also being evaluated at seasonal and climate timescales and represents the cutting edge for high resolution climate coupled modelling given current computing resources (GLOSEA4 seasonal system is N96L85 ORCA1L75). However, this model remains far too expensive for multi-decadal & centennial predictions, despite its obvious benefits (see below).

**High Resolution Modelling** – research with the N216L85 ORCA025L75 model at seasonal and climate timescales is demonstrating the benefit of higher resolution. The improved stratospheric representation leads to improved teleconnections in modes such as the AO. The higher horizontal resolution of atmosphere and ocean improves the structure of El Nino with less westward extension into the west Pacific and better teleconnections with precipitation. The double ITCZ systematic bias common to many climate models is also improved at higher resolution (see paper 15.13). Finally the 0.25 degree ocean significantly improves the representation of the gulfstream and reduces a cold bias in the North Atlantic SST which leads to improvements in stormtracks and blocking. For global NWP we are working towards a target resolution of 20km (+ENDGAME dynamical core) to be implemented following the next supercomputer upgrade in 2012. A 16km version is also being trialled.

**Aerosols and Atmospheric chemistry** – while an integral component of HadGEM2-ES climate model we are only beginning to investigate the benefits of aerosols (and atmospheric chemistry) at NWP, sub-seasonal and seasonal timescales. As part of the EU FP7 MACC project we are investigating the impacts of prognostic aerosols (initially Met Office CLASSIC scheme but later UKCA) on NWP, initialising from the ECMWF MACC data assimilation products. In the regional models mineral dust is already implemented in the Southern Asia Model and a regional air quality NWP forecast system (AQUM) is under development.

**Land-Surface** – The JULES model will be made operational at parallel suite 26 in the global NWP model allowing us to take advantage of a new multi-layer snow scheme, urban scheme, and better representation of lakes with the FLAKE model.

**Seamless EPS** – A key issue is whether the current contrasts in the methodologies for different forecast lead times are for good reasons, or is there potential to improve capabilities by defining a more general strategy based on merging the best aspects of the different systems. In principle, this question can only be answered via systematic studies comparing alternative approaches and work is planned to do this. Last years MOSAC14 paper on seamless prediction (Milton, Arribas, Bell, & Swinbank) outlined a possible seamless EPS system from days to decades and estimated some costs. More work is required to develop this strategy which will move us closer to an operational seamless global EPS system.

The cost vs. benefit of all of the above needs to be carefully assessed at all prediction timescales. We are already investigating simplifying earth system components (e.g 2 bin dust scheme to replace 6 bin) to make them more tractable for the NWP prediction problem while maintaining traceability to the more complex E-S components being run at climate timescales.
References


