Section 6

Developments in global forecast models, case studies, predictability investigations, global ensemble, monthly and seasonal forecasting

Seasonal to interannual predictability of high northern latitude climate

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Introduction:

The aim of this ongoing work is to analyze the predictability of seasonal to interannual climate conditions in high northern latitudes. One climate mode showing a high potential for interannual predictability is characterized by the formation of sea ice anomalies at the Siberian coast, their propagation across the Arctic towards Fram Strait, anomalous sea ice export through Fran Strait and advection of the sea ice/freshwater signal into the Labrador Sea, where it significantly influences ocean convection, salinity, sea ice distribution, ocean- and air temperature (Koenigk et al., 2006). The potential predictability of climate is analyzed by performing ensemble experiments with a global coupled atmosphere-ocean-sea ice model.

Model, Experiments and Method:

The model used in this study is the Max-Planck-Institute for Meteorology global atmosphere-ocean-sea ice model ECHAM5/MPI-OM (Roeckner et al., 2003; Marsland et al, 2003). The atmosphere model is run at T31 resolution and has 31 vertical levels. The grid spacing of the ocean model varies between about 30 km and 390 km. The model has 40 vertical layers.

A set of 40 ensemble simulations was performed to analyze the predictability. Each ensemble consists of 6 members and all runs were started in January from different initial conditions of a 300-year control integration. In half of the ensembles, the members of one ensemble were differently perturbed by a slight change of the atmospheric diffusion parameter in the first model month. In the other half, a small randomly distributed perturbation was added to ocean temperature, salinity and sea ice thickness. However, it turned out that on the time scales of interest it does not make any difference where a perturbation, if small, is introduced to the system. The prognostic potential predictability (PPP) in the model of a climate variable X at time t is calculated:

$$PPP(t) = 1 - \frac{\frac{1}{N(M-1)} \sum_{j=1,N} \sum_{i=1,M} \left[X_{i,j}(t) - \underline{X}j(t) \right]^2}{\sigma^2}$$

$X_{i,j}$: run i of ensemble j, $\underline{X}_j$: mean of ensemble j, N (M): number of ensemble runs, σ^2 : variance of control run.

A PPP of 1 shows perfect predictability while a value of 0 shows no predictability at all. The 95%-significance level (using a F-test) varies between values of 0.2 and 0.3 depending on the decorrelation time of the different variables. Furthermore, the gain of predictability of the ensemble experiments in comparison to the predictability gained by the autocorrelation of the control run is analyzed ($PPPa=PPP-r^2_{auto}$).

Results:

Arctic sea ice thickness shows a high predictability in the first two years in most areas of the central Arctic, the Canadian Archipelago and in the Labrador Sea (fig. 1). A large part of this predictability is due to the persistence of sea ice thickness. However, in an area from the Laptev Sea across the North Pole to Fram Strait and along the east coast of Greenland and in the Labrador Sea, the persistence explains only a small part of the predictability. This gain of predictability is attributed to the advective character of the climate mode mentioned above. Also air temperature and surface salinity show a quite strong gain of predictability in the Labrador Sea in comparison to the predictability by the autocorrelation. The largest PPP of 2m air temperature after one year occurs in the northern North Atlantic and in the northern North Pacific (fig. 2). Here, significant predictability lasts for several years. Beside a relatively high autocorrelation, advection of sea surface temperature anomalies into these areas lead to high and long-lasting predictability. Over the continents and in the ice-covered Arctic, the one-year predictability of air temperature is much smaller than over the oceans. Only in parts of southern Europe, southern Asia and in Alaska, PPP is significant. PPP of spring (MAM) temperature is significant in most of Europe with a lead time of 2 to 4 months. In contrast to air temperature, the predictability of sea level pressure is generally quite small and do not show any land – sea contrast. Also the predictability of the NAO is not significant.

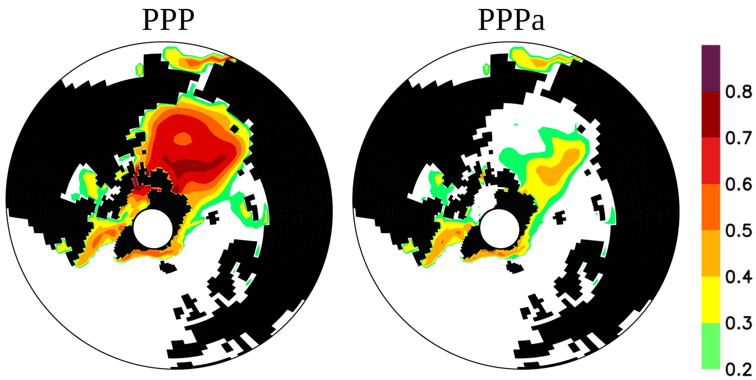

Fig.1: Predictability and gain of predictability compared to predictability of the autocorrelation for winter centered annual mean sea ice thickness after one year.

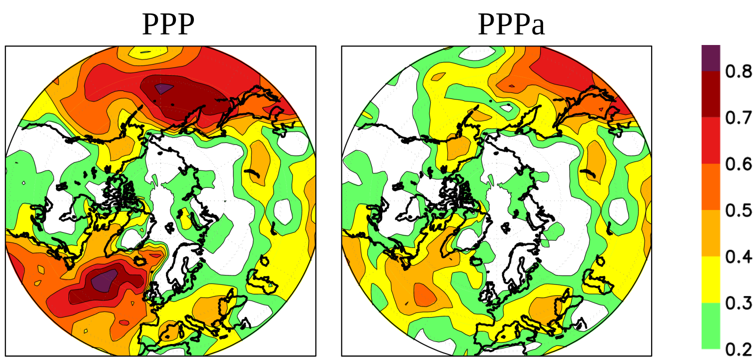

Fig.2: Predictability and gain of predictability compared to predictability of the autocorrelation for winter centered annual mean 2m air temperature after one year.

Outlook:

Further predictability experiments are planned: Sets of ensemble simulations with initial conditions from summer, from high/low NAO-cases, high/low sea ice exports shall be performed. Larger perturbations in the different ensemble members shall be used to get more realistic initial conditions.

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High Resolution Ensemble West Atlantic Basin Seasonal Hurricane Simulations

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Introduction

This paper will examine the use of an ensemble of seasonal integrations using a global spectral model at a high horizontal resolution (T126L27) in hindcasting the June-November Atlantic tropical storm activity for the seasons 1986-2005. This horizontal resolution is generally higher than existing seasonal tropical system studies, although there are a few studies of note which are of even higher horizontal resolution (e.g., Bengtsson et al. 2006). We will examine whether the use of a high horizontal resolution improves the seasonal hindcasts in terms of interannual variability and intensity.

Model and Experiments

The Florida State University/Center for Ocean Atmospheric Prediction Studies model (Cocke and LaRow 2000) with a relaxed Arakawa-Schubert deep convection scheme was used. Four ensemble members for each of the 20 years (1986-2005) were calculated. Time lagged initial conditions for the atmospheric model were obtained from the ECMWF re-analysis and were centered on 1 June of the respective year. Observed weekly SSTs were obtained from the Reynolds and Smith ((1994). The detection algorithm is the same as that used in Vitart et al. (2003) and modified slightly for our model resolution. In this paper, the observed tropical storms are identified by the National Hurricane Center Best Track data set, HURDAT (available at http://www.nhc.noaa.gov/pastall.shtml).

Interannual Variability

The number of storms for each year from each ensemble is calculated from the detection algorithm and the ensemble mean is plotted along with the observed as a function of time in Figure (1). The observed number of storms is shown with the solid black line while the ensemble mean is the dotted line. The spread of the ensembles is shown by the two squares. Overall the ensemble mean does well in simulating the interannual variations in the storm numbers except during the cold ENSO event years of 1998 and 1999 when the ensemble mean was much higher than the observed. The pattern of reduced number of storms during a warm event and increased numbers during a cold event is clearly seen in the ensemble mean. The model did well in simulating the record number of storms during 1995 and 2005. The temporal correlation of the ensemble mean with the observed was 0.78. The observed variance was 25.25 while the ensemble mean variance was slightly lower at 12.55. The high correlation and variances noted are most likely related to the use of weekly observed SSTs and the choice of the convection scheme.

Intensity

For each of the four ensembles the storm's lowest surface pressure was identified and shown in Figure (2). Out of the four ensembles, the lowest surface pressure found was 936hPa, indicating that even at this high horizontal resolution the model was able to generate only one category 4 storm on the Saffir-Simpson scale. Similar difficulties in producing intense storms using a even

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higher resolution model than used in this study were noted by Bengtsson et al. (2006). Indicating that model resolution (and perhaps model physics) are still insufficient.

Acknowledgments

We gratefully acknowledge Dr. Frédéric Vitart of ECMWF for providing us with the detection/tracking algorithm. All computations were performed on NCAR's Bluesky supercomputer. COAPS receives its base support from the Applied Research Center, funded by the NOAA Climate Program Office awarded to Dr. Eric Chassignet.

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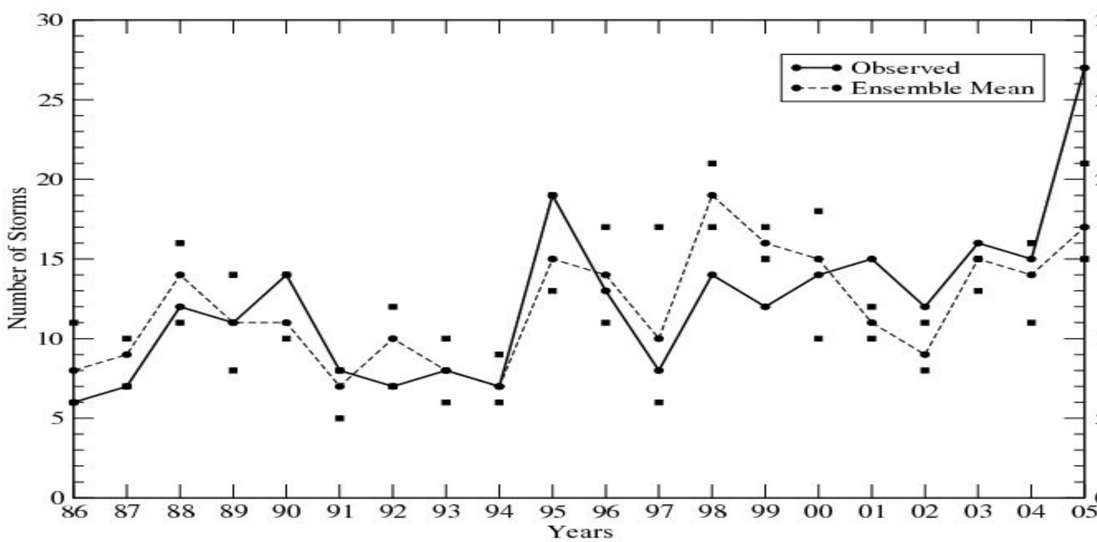

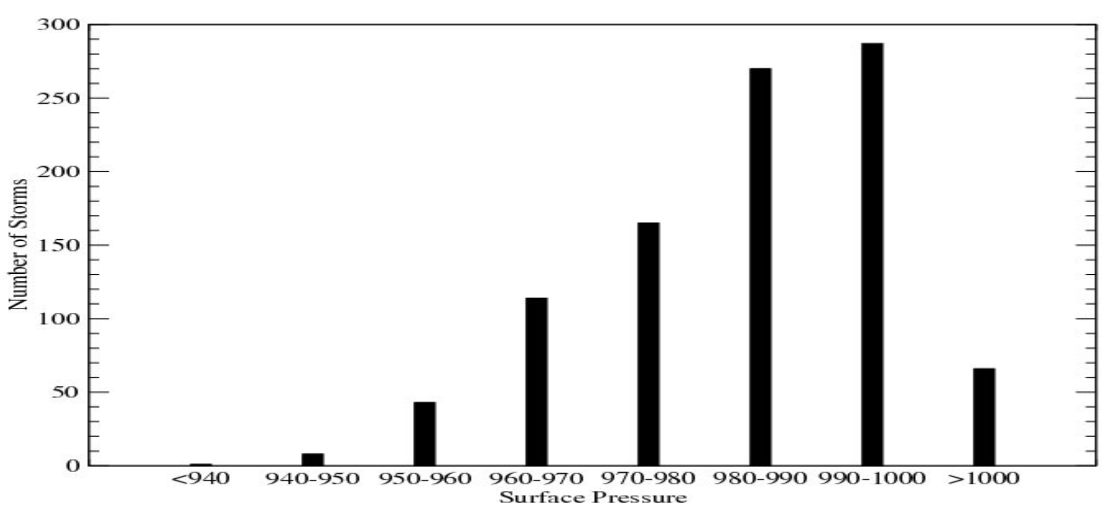

IMPROVEMENTS TO MET OFFICE FIFTEEN DAY FORECASTS WITH REVISED PHYSICAL PARAMETERIZATIONS

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1. INTRODUCTION

The WMO project THORPEX is a ten-year international global atmospheric research and development project. Its aim is "to reduce and mitigate natural disasters by transforming timely and accurate weather forecasts into specific and definite information in support of decisions that produce the desired societal and economic outcomes". Swinbank et al (2007) describes the Met Office contribution to the THORPEX research program through the implementation of medium range global ensemble forecasts run on a regular basis. This paper describes work to evaluate systematic (model) error growth in the current model configuration and the impact on these errors of a package of improved physical parameterizations which were introduced into the operational 5-day global forecast model in March 2006.

2. UNIFIED MODEL CONFIGURATIONS AND EXPERIMENTS

This study uses the UK Met Office Unified Model (Davies et al, 2005) at a horizontal resolution of N144 (1.25° longitude by 0.83° latitude) with 38 levels in the vertical from the surface to 38 km. The first model formulation tested is very similar to the atmospheric part of the climate model configuration HadGEM1 (Martin et al, 2005) and is almost identical to the version of the model currently used for the medium range ensemble forecasts. The second model version includes a package of improvements to the physics recently introduced in the global forecast model. The package of improvements included changes to the boundary layer and convection parameterizations and the main aim was to improve the tropical performance of the model.

Boundary layer changes improved the rate of evaporation from the sea surface; over the sea, the model has been revised to have a more realistic decline in amount of turbulence as the stability of the atmosphere increases ('sharp tails') and a non-gradient parameterization of transport by turbulent eddies has been extended from temperature to wind fields which results in higher near surface wind speeds in convective boundary layers.

The major change to the convection scheme was the introduction of adaptive detrainment. Forced detrainment of air from a cloudy plume of ascending air occurs when the parcel's buoyancy falls below a critical threshold. The critical level has been changed from a fixed value of 0.2 K to a function of the parcel's local buoyancy gradient giving a more realistic detrainment profile. For more details of these changes to model physics and their impact on the short range forecasts see Willett (2006). In addition the new model formulation also had a restructured convection scheme, changes to the CAPE closure formulation and different values of sea surface temperature (SST), snow depth, soil moisture content, deep soil temperature and sea ice.

A set of twenty cases has been used to evaluate these two different model formulations: ten cases from two Northern Hemisphere summers (2003 and 2006) and ten cases from two Northern Hemisphere winters (2003/4 and 2005/6). Each fifteen day model run was initialised from analyses produced with the Met Office operational variational data assimilation system (3D Var before 10/2004 and 4D Var thereafter). The results from both model versions have been evaluated against UM operational analysis, surface and sonde data plus Global Precipitation Climatology Project (GPCP) data which is a global precipitation dataset based on a combination of rain gauge and satellite data.

3. RESULTS

With the revised physics, improvements in model performance for temperature, wind speeds, humidity and precipitation were observed for most regions. We found a much reduced Northern Hemisphere winter cold bias at 1000hPa (the initial runs had a bias of -8K whereas in the new configuration this is close to zero in many parts of this region, see Figure 1) possibly as a result of increased cloudiness reducing radiative cooling. A small reduction in temperature bias over tropical oceans can also be seen in Figure 1. In the tropics at 250hPa the cold bias is also reduced from -1K to near zero and there are beneficial changes in mid-latitude zonal wind speeds in response to these improvements in the temperatures via thermal wind balance. We also see a reduced dry bias (from over -12% to -8%) in the tropical upper troposphere, and large reduction of errors in tropical circulation due to an improved treatment of convective detrainment. In particular, errors in the Indian Ocean (with a low level convergent bias and an upper level divergent anomaly indicating too much ascent in this region) is much reduced.

Connected with this improved circulation in the Indian Ocean is a reduction in precipitation over the Indian Ocean giving better agreement with GPCP data. Although the revised model still does not do a very good job of representing the precipitation patterns associated with the Madden-Julian Oscillation (MJO) it does weaken significantly spurious westward propagating disturbances seen in the control and for some of the cases an improvement in the forecasts of the MJO index of Wheeler and Hendon (2004) is found. The new physics however does cause some detriments: in particular the summer warm bias over Asia and North American is made worse and a positive precipitation bias over Africa and the north of South America is worsened. Both these issues are also found with the operational model and work is ongoing to resolve them via modifications to cloud cover over land, changes to aerosol fields and other model changes.

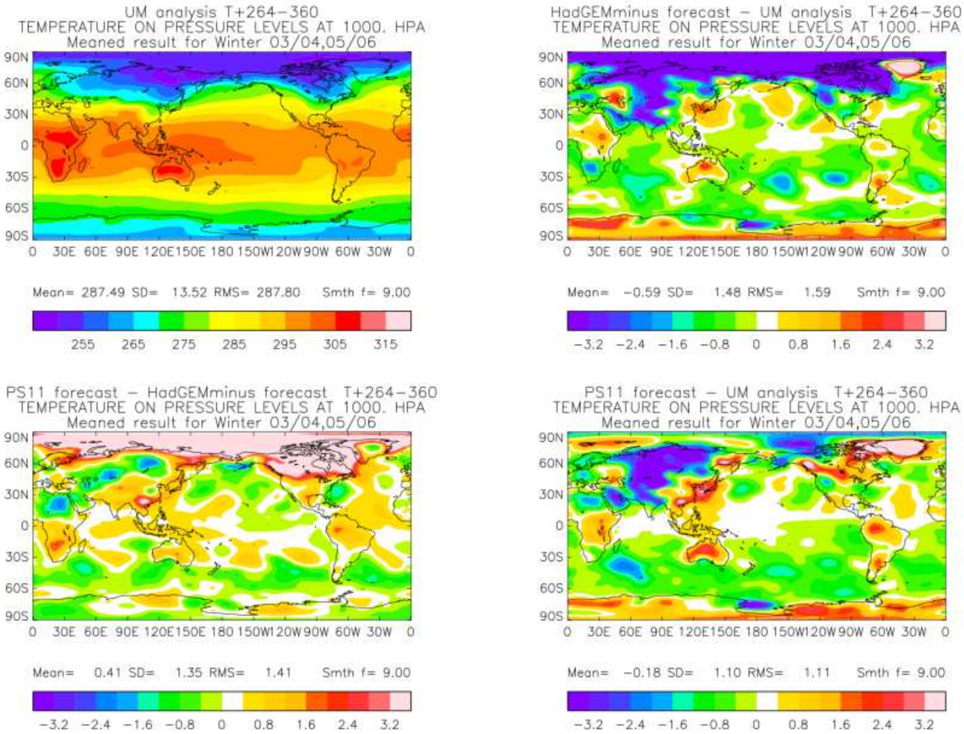

Figure 1. Differences in Temperature (K) at 1000 hPa between model runs averaged over days 10-15 of the 10 DJF cases. Top left: mean temperature in UM analyses from days 10-15 of forecasts. Top right: control (HadGEMminus) forecast minus analysis. Bottom left: new physics forecast (PS11) minus control. Bottom right: new physics minus analysis. The new model configuration shows a large reduction in the divergent anomaly over the Indian Ocean.

4. CONCLUSIONS

A set of improvements to model physics recently introduced to the Met Office global operational forecast model have been tested at the resolution now used for medium range ensemble forecasting. Substantial reductions in systematic errors have been found in most regions. Revised stochastic physics schemes have also been tested in the fifteen day forecasts and these improvements will shortly be implemented in the regular medium range forecasts.

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Simulations of Multiple Tropical Cyclones with a Global Mesoscale Model: A Preliminary Study on the NASA Columbia Supercomputer

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1. Introduction:

Over the past several decades, hurricane track forecasts have steadily been improving, but progress on intensity forecasts and understanding of hurricane formation/genesis has been slow. Major limiting factors include insufficient model resolution and uncertainties in cumulus parameterizations (CP). A CP is required to “emulate” the statistical effects of unresolved cloud motions in coarse resolution simulations, but its validity becomes questionable at high resolutions. Facilitated by the NASA Columbia Supercomputer, the ultra-high resolution finite-volume General Circulation Model (fvGCM) has been deployed and run in real-time experimentally to study the impact of increasing resolution and disabling CPs on hurricane forecasts. While doubling the resolution of a numerical weather prediction (NWP) model requires an 8-16X increase in computational power, the unprecedented computing power afforded by Columbia enables us to rapidly increase the resolution of the fvGCM to $1/4^o$, $1/8^o$, and $1/12^o$. During the active 2004 and 2005 hurricane seasons, the mesoscale-resolving fvGCM produced promising forecasts of intense hurricanes such as Frances, Ivan, Jeanne, and Karl in 2004 and Emily, Dennis, Katrina, and Rita in 2005 (Atlas et al. 2005; Shen et al. 2006a-c). To further illustrate the capabilities of the fvGCM coupled with Columbia, we present simulations of multiple tropical cyclones.

2. The fvGCM and Model Validation:

The fvGCM is a unified NWP and climate model that runs on daily, monthly, decadal, and century timescales. The model has three major components: a finite-volume dynamical core (Lin 2004) and the community built physical parameterization schemes and land surface model at NCAR. Initial conditions are obtained from the state-of-the-art data assimilation system (Global Forecast System, GFS) at NOAA/NCEP.

The impact of increasing resolution (in this case, to $1/8^o$) and disabling CPs on the forecasts of hurricane Katrina has been documented in Shen et al. (2006b). They obtained comparable track predictions at different resolutions but better intensity forecasts at finer resolutions. The predicted minimum sea level pressures (MSLP) in the $1/4^o$, $1/8^o$, and $1/8^o$-no-CPs runs are 951.8, 895.7, and 906.5 hPa with respect to the observed 902 hPa (Figure 1). Consistent improvement as a result of using a higher resolution was illustrated from the six 5-day forecasts with the $1/8^o$ fvGCM, showing small errors in center pressure of only ±12 hPa. The notable improvement in Katrina’s intensity forecasts was attributed to the sufficient fine resolution used for resolving hurricane near-eye structures. As the hurricane’s internal structure has convective-scale variations, it was shown that the $1/8^o$ run with disabled CPs could lead to further improvement on Katrina’s intensity and structure (asymmetry).

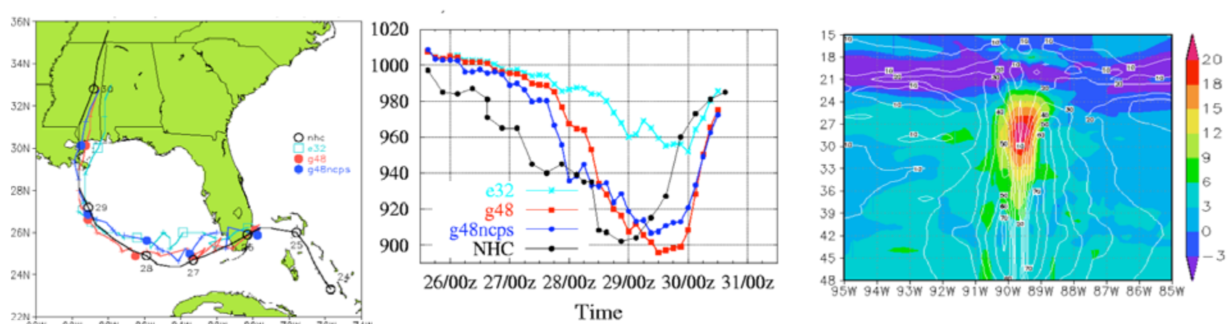

Figure 1: Track (left) and intensity (middle) forecasts of hurricane Katrina (2005) from 5-day simulations initialized at 1200 UTC August 25, 2005 with the fvGCM at different resolutions. e32 ($1/4^o$), g48 ($1/8^o$), g48ncps ($1/8^o$ without CPs). Simulated vertical structure (right) of Katrina along lat=28.5^o from the 96h run with no CPs. The vertical axis represents model levels. This panel shows realistic features such as maximum horizontal winds (white) near the top of the boundary layer, a narrow eyewall, and an elevated warm core with positive temperature anomalies (shaded).

3: Simulations of Multiple Tropical Cyclones in 2004:

The 2004 Atlantic hurricane season was very active. There were 16 tropical storms and 9 hurricanes, 6 of which were rated Category 3 and higher. Accurate forecasts of these storms posed a great challenge to global and mesoscale modelers. While our earlier studies with the high-resolution fvGCM showed promising track and intensity forecasts of intense hurricanes, we extend our study to understand the impact of increased resolution on the simulations of multiple cyclones. We conduct a series of 36h simulations initialized 0000 UTC 19 September 2004 at a variety of resolutions (1^o, $1/2^o$, $1/4^o$, and $1/8^o$). According to the reports by the National Hurricane Center (NHC) (http://www.nhc.noaa.gov/2004atlan.shtml), one extratropical cyclones (ETC) and three tropical cyclones (TCs) were reported at the end of time integration, 1200 UTC 20 September. They were Ivan (extratropical, 1009 hPa, 27.5°N, 78.7°W), Jeanne (tropical, 989 hPa, 26.6°N, 71.7°W), Karl (hurricane, 951 hPa, 17.5°N, 46.0°W), and Lisa (tropical, 1002 hPa, 13.5°N, 35.4°W). In the parentheses, storm stage, intensity, latitude (LAT), and longitude (LON) are listed sequentially. By comparison, GFS T254 (~55km) analysis data resolve these storms with weaker intensities (Table 1 and Figure 2). While the 1^o run could simulate three TCs, it gives the largest errors in the location and intensity predictions among our experiments. For ETC Ivan, higher resolution runs ($1/4^o$ and $1/8^o$) give remarkable location forecasts, but slightly stronger model storms. In the higher resolution simulations of Jeanne, Karl, Lisa, increased resolution could improve track forecasts slightly and intensity forecasts noticeably.

4: Concluding Remarks:

In this report, the capabilities and advantages of a global mesoscale model for hurricane simulations are illustrated with realistic forecasts of Katrina's track, intensity, and structure (see also Shen et al. 2006b). We further show the model's capabilities in simulating multiple storms at a variety of resolutions, producing noticeable (slight) improvement in intensity (location) predictions of tropical cyclones with increased resolutions. These confirm the model's stability and robustness from scientific and computational perspectives. In the future, we will conduct studies with this global mesoscale model on multiscale interactions among multiple cyclones and large-scale flows.

Table 1: The (MSLP, LAT, LON) (hPa, °N, °W) of Ivan, Jeanne, Karl and Lisa (2004) from the GFS analysis valid at 12Z UTC 20 SEP and model simulations at a variety of resolutions.

	Ivan	Jeanne	Karl	Lisa
NHC	(1009,27.5,78.7)	(989,26.6, 71.7)	(951,17.5,46.0)	(1002,13.5,35.4)
GFS	(1010,27.25,78.75)	(1001,26.4,71.7)	(1003,17.6,45.8)	(1013,12.6,35.4)
1^o	(---,---,---)	(1005,26,73.8)	(1007,17.7,47.2)	(1013,12.0,33.7)
$1/2^o$	(1008.5,27.25,80.1)	(1002,26.9,73.2)	(1004,18,47.6)	(1007.5,13.1,35.6)
$1/4^o$	(1006.5,27.25,79.9)	(1000,26.8,73.4)	(1000,17.4,47.9)	(1007.5,13.7,36)
$1/8^o$	(1005.5,27.25,79.9)	(997,27.2,72.6)	(997,17.8,47.5)	(1000,13.8,36.4)

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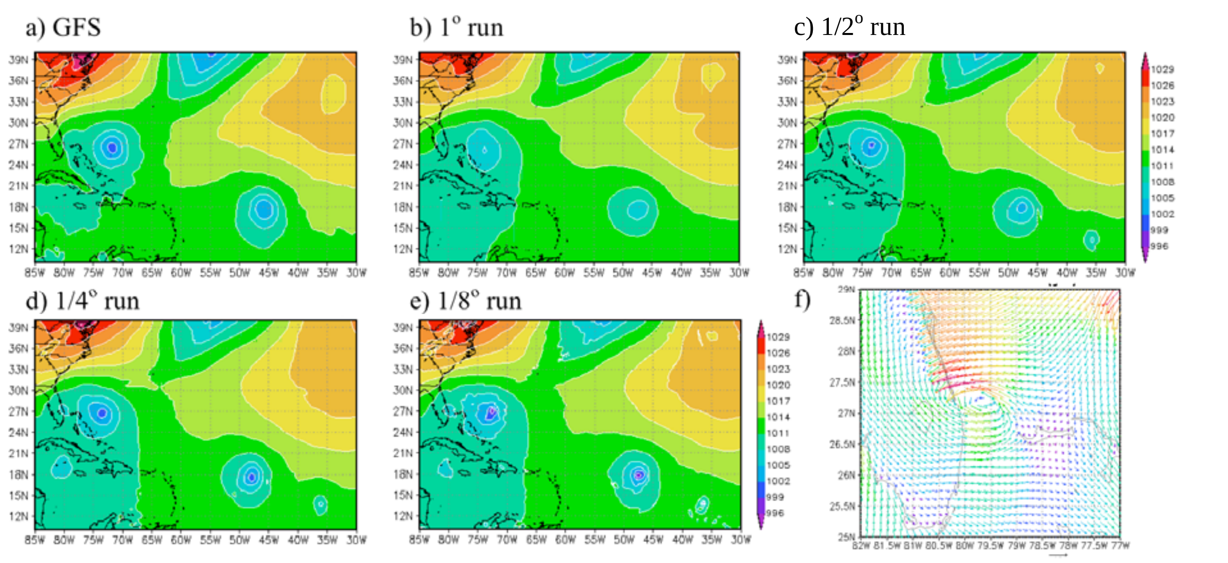

Figure 2: Comparisons between NCEP GFS data and 36h simulations of multiple tropical cyclones initialized at 0000 UTC 19 SEP. 2004 with the global mesoscale model at a variety of resolutions. (a) GFS analysis data valid at 1200 UTC 20 SEP., (b-e) 1^o, $1/2^o$, $1/4^o$, and $1/8^o$ run, respectively (f) Close up of the 10m winds simulated for Ivan in a 4x5 degree box from the $1/8^o$ run. The observed location of ETC Ivan is (27.5°N, 78.7°W).

MEDIUM-RANGE ENSEMBLE FORECASTS AT THE MET OFFICE

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1. MEDIUM-RANGE ENSEMBLE FORECASTS

The central aim of the Met Office contribution to the THORPEX research programme is to improve the prediction of high-impact weather using multi-models ensemble forecasts. To that end, the Met Office has recently implemented regular medium-range global ensemble forecasts based on the Met Office Global and Regional Ensemble Prediction System (MOGREPS). MOGREPS was originally developed for short-range ensemble forecasting, and comprises a regional model (covering the North Atlantic and Europe) with boundary conditions taken from global ensemble forecasts. The 24-member ensemble forecasts are run twice daily. Perturbations to the initial conditions are generated using an Ensemble Transform Kalman Filter (ETKF) method (Bishop et al, 2001).

For the medium-range ensemble forecasts, the global Unified Model has been ported to the ECMWF supercomputer. Initial conditions for the ensemble forecasts are generated by the MOGREPS system at the Met Office, and transferred to ECMWF (see Figure 1). The global ensemble forecasts are each run to 15 days, using a model with resolution N144L38, i.e. a horizontal resolution of 0.83° latitude by 1.25° longitude, with 38 levels. The model's physical parameterizations are described by Savage and Milton (2007). The forecast model produces output fields which are stored in the THORPEX Interactive Grand Global Ensemble (TIGGE) archive database. Other output streams are used for verification and to generate products - particularly those aimed at forecasting high-impact weather, as described in section 3.

2. MULTI-MODEL ENSEMBLES

As shown in Figure 1, it is planned to combine the Met Office medium-range forecasts with forecasts from other models that will be available via the TIGGE database. We are using an ensemble test-bed based on simple models to help guide the approach we will use to calibrate and combine the ensemble forecasts (Johnson, 2006). Based on that work, we are currently producing an experimental bias-corrected ensemble mean combining Met Office and ECMWF forecasts. We will continue to develop techniques for multi-model ensemble forecasting, and to evaluate the benefits of a possible future operational multi-model ensemble.

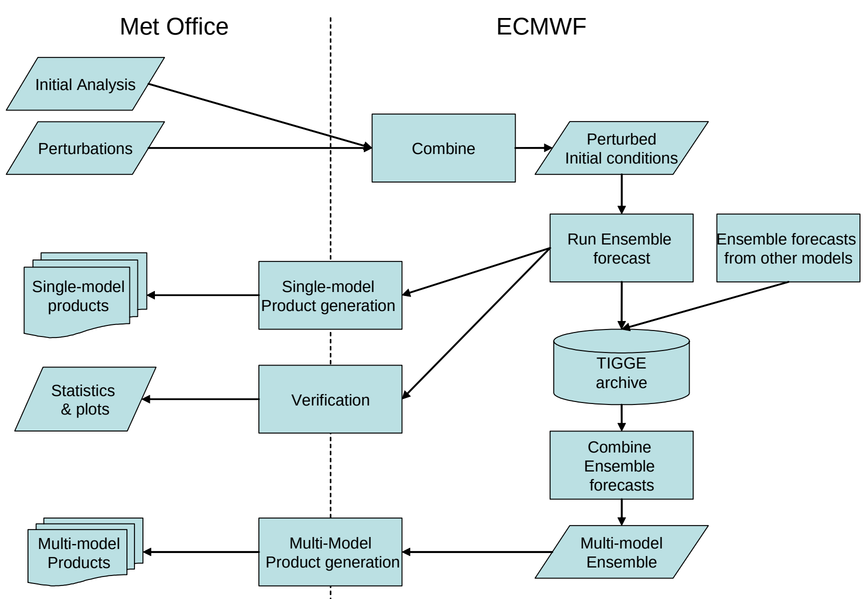

Figure 1. Schematic of the Met Office medium-range ensemble forecast system. At present experimental products and verification statistics are being produced from the single-model forecasts. Work is currently in hand on the combination of forecasts from multiple models.

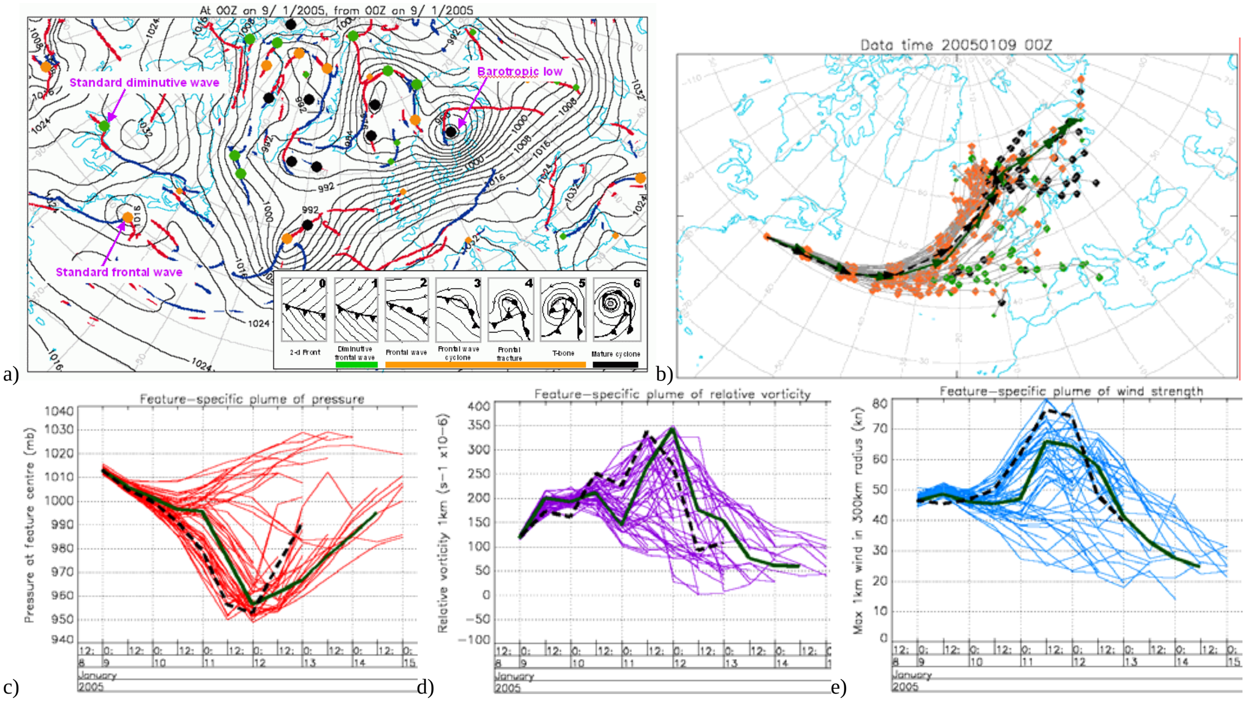

Figure 2. Example case study using the Cyclone Database on ECMWF EPS data from 00Z 09/01/2005: a) Control T+0 image of objectively identified fronts and cyclonic features. The key frontal wave is off the New England coast; b) Forecast tracks from each ensemble member; c/d/e) Associated feature-specific plumes of intensity (control=thick, analysis=dashed).

3. FORECASTING HIGH-IMPACT WEATHER

Ensemble forecasts, and in particular multi-model ensembles, produce vast amounts of data. To aid interpretation a suite of intelligent diagnostics is needed, to highlight when high-impact weather is forecast. For example, a new ‘heatwave’ product has been developed, showing when temperatures on successive days and the intervening night exceed significant thresholds for health. Similar approaches are used to highlight persistent wet or cold periods.

Much of the high-impact weather in Europe is associated with synoptic features. At the Met Office, the ensemble forecast output is objectively analysed to identify extra-tropical cyclones and fronts, with feature-point attributes stored in a cyclone database (Hewson, 1997). The features are then processed through tailored tracking software, to show how each feature is likely to develop and whether it has potential to cause high-impact weather. This feature-based approach is also able to address some of the deficiencies of the lower resolution ensemble models.

Figure 2 illustrates use of the cyclone database products on the ECMWF EPS in a high-impact weather case study: the development of a frontal wave situated off New England at 00Z on 9th Jan 2005. By 00Z on 12th this low had rapidly deepened to 945mb, resulting in major disruption from heavy persistent rain and hurricane force winds over Northern Scotland. Figure 2a shows the identified fronts and features in the control T+0 forecast. Clicking, within a web browser, on the key frontal wave would bring up plots 2b-e showing how the ensemble is predicting it to develop. There is an interesting bifurcation of the tracks and the feature-specific plumes, but there is a cluster of tracks lending good support to the actual outcome (overlain in black), for both track and intensity.

The products are now available to Met Office forecasters in real time using input from the new Met Office 15-day ensemble. Further products to highlight high-impact weather are being developed, in response to the needs of forecasters and other users. These will also be adapted to benefit from the multi-model ensemble forecasts.

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