Impact of the representation of the stratosphere on tropospheric weather forecasts

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Introduction

There has been increasing interest in understanding the dynamical coupling between the troposphere and the stratosphere, particularly in the context of a stratospheric influence on surface weather patterns and climate (Baldwin and Dunkerton, 2001). The cause and mechanisms for this dynamical interaction is not well understood. Furthermore, the impact this interaction should have on the design of future Numerical Weather Prediction (NWP) systems has not been addressed. This project aims to investigate the importance of the representation of the stratosphere for tropospheric weather forecasts and in addition the optimum representation of the stratosphere in GCMs. The knowledge obtained from this project will help towards the selection of future NWP forecast setups at the Met Office. Results will also provide a significant contribution to the understanding of the mechanisms by which the stratosphere may influence the troposphere, a subject which has generated much discussion in recent scientific literature (Hartley *et al*., 1998, Perlwitz and Harnik, 2004, Thompson *et al*., 2006).

Details of model experiments

A case study suite of ten winter cases spanning 2005–2008 were each run for 15 days with forecasts initialised from both the Met Office operational analyses (N320L50) and ECMWF (T799L91~25km) at a range of vertical resolutions (fig 1).

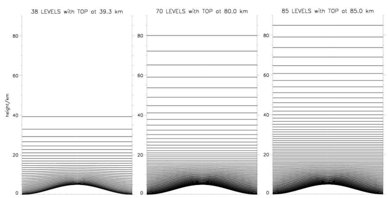
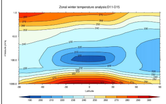


Figure 1: Comparison of the number of levels and their placement between model configurations. L38 (left), L70 (middle) and L85 (right).

Impact of resolution on stratospheric circulation

Figure 2 shows the zonal winter temperature forecast error against analysis averaged over days 11–15 for the different experiments.

- The most striking feature is the large positive bias seen just above 10hPa in all experiments, this may be associated with problems in the radiation scheme as these errors increase throughout the 15 day forecast.
- The high-top simulations show a reduction in systematic error in the tropical lower-stratosphere (100hPa) where the extent of the +3K bias seen in L38 is largely reduced with the additional stratospheric levels.
- The surface bias seen at the southern pole in the MO initialised experiments, appears reduced in the L85 configurations compared to L70.
- Comparisons between the MO and EC initialised experiments (left hand column v right hand column) show an improvement in the northern hemisphere stratosphere where the large positive bias discussed earlier around 10hPa is significantly less. This is seen from day 6 and appears to descend with lead time and is probably due to the extra stratospheric information obtained by initialising from ECMWF.
- The southern polar tropopause however shows a degradation in in the EC experiments with respect the to the MO analyses. This may be as a result of differences in the representation of the tropopause region between ECMWF and MO, as the biases are detectable in days 1–5 and progressively worsen through the forecast.



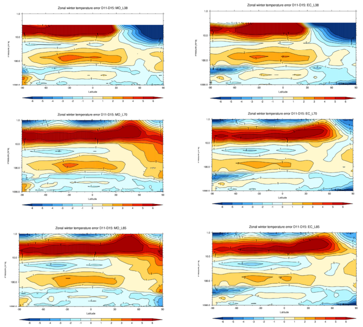


Figure 2: Zonal mean temperature fields for days 11-15 of MO forecast (middle column) and EC forecast (right column). The MetUM analysis at N320L50 (far left), temperature errors for N216L38 (top row), N216L70 (second row) and N216L85 (bottom row).

As mentioned above the largest improvements appear to be seen in the stratosphere which is reiterated in figure 3 which shows the daily averaged northern polar cap temperature error for all experiments. Evidently, the L38 models show poorer skill compared to the high-tops from day 1 and follow their own error trajectory throughout the forecast. The high-tops have similar forecast error until day 4 after which they diverge. The EC initialised L70 and L85 model runs outperform the equivalent MO initialised runs with the EC L70 demonstrating the least forecast error throughout the entire 15 day forecast. This may be attributable to both the physics being tuned to the L70 setup and the additional stratospheric information provided by the ECMWF initial conditions.

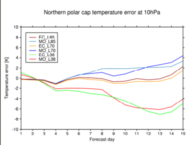


Figure 3: Northern polar cap mean forecast error for al MO and EC initialised experiments at 10hPa. A positive mean error indicates that the forecast temperature exceeds the analysis temperature.

Assessing forecast skill

- Skill scores between the different experiments were calculated from the mean square error for daily NH polar cap geopotential height fields (for details see Roff *et al*., 2009) in the following manner:

$$SS = (1 - \frac{MSE}{MSE_{ref}}) * 100$$

  where SS>0 indicates a forecast improvement (i.e. a reduction in MSE) relative to the reference forecast and SS=100 indicates a perfect forecast.
- The largest improvements in skill scores are seen to occur in the stratosphere in the L70 model with respect to L38 (Figure 4 left) and likewise in L85 with respect to L38 (not shown), a similar picture is seen in the MO initialised experiments (not shown).
- The L85 configuration yields an improvement of 10-25% in the stratosphere at lead times of day 12 onwards over the L38.
- Improvement in skill of 2.5-10% is also seen in the troposphere in the 10–15 day timescale in L85 with respect to L70.

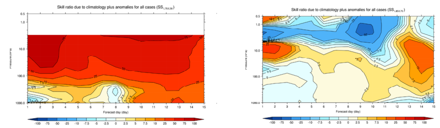
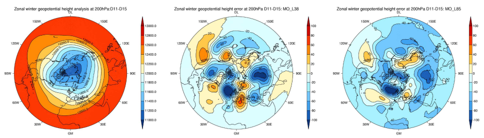


Figure 4: Skill score of total geopotential height) anomaly plus climatology) for L70 relative to L38 (left) and L85 relative to L70 (right) for the ECMWF initialised experiments.

Geographical distribution of tropospheric errors

- Improvements in the troposphere as a result of a better representation of the stratosphere can also be seen in geopotential height errors at 200hPa (fig 5).
- The >+40m errors seen in the Pacific in the L38 model are much reduced in the L85 (and L70, not shown).
- The negative bias seen over the UK is also much less in magnitude in the high-top simulation as is the large positive error extending over Europe.



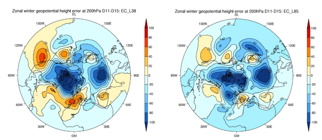


Figure 5: Northern winter geopotential height at 200hPa for MetUM analysis (far left) and forecast errors for L38 (middle column), L85 (right column) for MO initialised experiments (top row) and EC initialised experiments (bottom row)

Conclusions and future work

- Increased stratospheric resolution improves the representation of the stratosphere and even the troposphere on the 10–15 day timescale.
- The initial conditions are important as demonstrated by the increased skill in the forecasts when the experiments were initialised with a higher resolution analyses.
- Perform 30 day ensemble experiments of the 2010 warming at L85 to assess whether any tropospheric skill is obtained with the extra vertical resolution and to provide a better insight into the results seen here.
- Investigating the impact of growth of forecast error. One option may be to constrain the stratospheric forecast to the operational analyses for each day in the 15 day forecast period. What impact will this have on tropospheric skill when compared to the control run?

References:

- Baldwin, M.P. and Dunkerton, T.J., Stratospheric harbingers of anomalous weather regimes, Science, 244, 581-584,2001.
- Perlwitz, J., and Harnik, N., Downwardcoupling between the stratosphere and troposphere: The relative roles of wave and zonal mean processes. J. Climate, 17, 4902-4909, 2004.
- Roff G., Thompson D.W.J., Hendon H., Does increasing model stratospheric resolution improve extended-range forecast skill? Submitted to Geophys. Res. Letters, 2009.

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