Tropical Convection and TTL Structure in the UM Forecast and Climate Models

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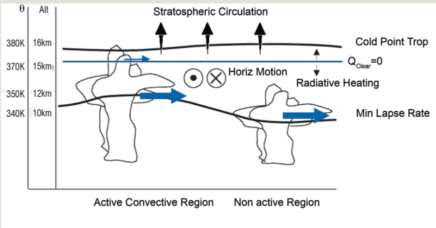
1. Introduction

Convection plays an important role in shaping the structure and composition of the tropical tropopause region. Transport of boundary layer pollutants to the Upper Troposphere and Lower Stratosphere (UTLS) can be separated into two main components, convective and large scale. The extent to which these contribute to the overall transport is unclear; furthermore both components have spatial and temporal variations, therefore it's difficult to quantify their relative effect on the budget of global stratospheric ozone and water.

The Tropical Tropopause Layer (TTL) is the transition region observed within the tropics between the troposphere and stratosphere. There are many definitions to the structure of the TTL, some of which are illustrated in the picture below. This research aims to study how this view changes within models as you increase spatial resolution and concentrate on individual meteorological events.

The focus of this poster will be on one particular month (November 2005) during the Australian-Indonesian pre-monsoon season. Within this season measurement campaigns were undertaken (SCOUT-O3 & ACTIVE) where attention was directed towards the structure and composition of the TTL.



Gettelman & Forster's (2002) climatological view (right) illustrates that, over active convective regions, the Cold Point Tropopause (CPT) reduces in height whilst the Lapse Rate Minimum (LRM) increases. The level of clear sky Q=0 is less affected. If air reaches above the clear sky Q=0 level then it can be heated radiatively, causing it to rise slowly to the stratosphere. A quantitative assessment of the temporal and spatial scales of this transport is complex.

2. The Model

Experiments are conducted with the UK Met Offices non-hydrostatic Unified Model (UM v6.1) with focus on the impact resolution has upon convection and the TTL structure. The experiments will run over the November 2005 period and will use standard 'tried and tested' model setups, the climate model setup HadGAM2 (N96) and a higher resolution global forecasting model (N216). N216 is initiated from assimilated atmospheric data representative of November 2005, whereas N96 starts from a climatological November. Both models are constrained daily with the same climatological soil moisture, soil temperature, ozone and SST and sea ice fields.

To validate the models, monthly mean Outgoing Longwave Radiation (OLR) and Total Precipitation Rate are compared to satellite data (see below) . These parameters are affected by many processes including convection; thus the relatively good match between observations and numerical simulation increases our confidence in the model parameterisations. Satellite and N216 compare to a high degree, especially over the maritime continent. N96 broadly captures the global pattern of convection although the model deviates to some extent over the east coast of Africa which seems to be triggered by low level convergence flow.

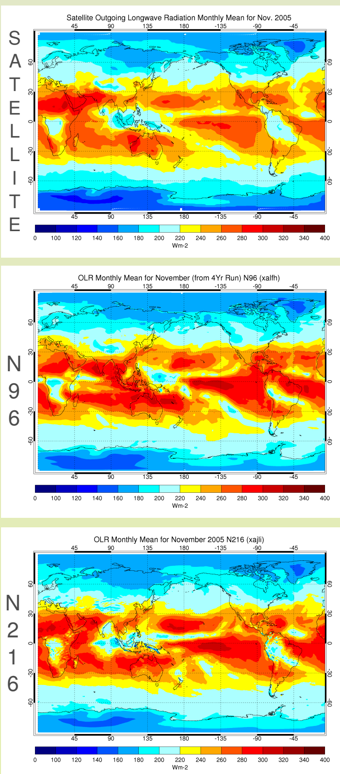


Fig. 2-4: November 2005 monthly mean OLR. NOAA Satellite (Top), HadGAM2 N96 (Middle) and Global Forecast N216 (Bottom)

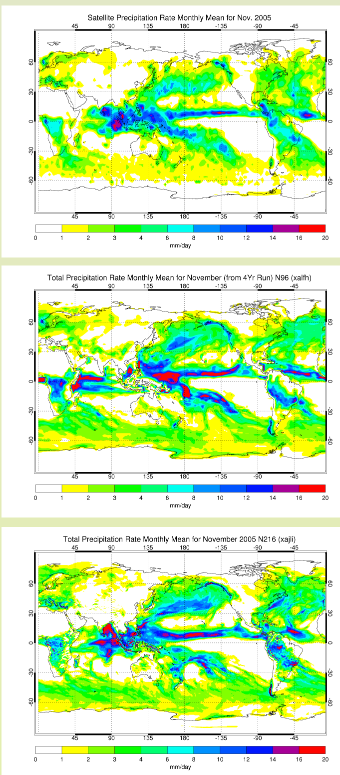


Fig. 5-7: November 2005 monthly mean Total Precipitation Rate. CMAP Satellite (Top), HadGAM2 N96 (Middle) and Global Forecast N216 (Bottom)

3. Convection and the Tropical Tropopause Layer

Figures 8 & 9 illustrate the modelled distribution of convective cloud top heights during the month (i.e. PDF's). To this, monthly mean lines are added representing the TTL upper (CPT) and lower (LRM) boundaries and the Q=0 levels averaged over a large spatial area (20N:20S). These plots also highlight the difference in convective activity between continental and oceanic regions. Over the Pacific ocean (between 140° to 260° E) shallow convection dominates with more than 10% of convection reaching 3km whilst over the continental regions, the key signatures of frequent deeper convection are clearly visible.

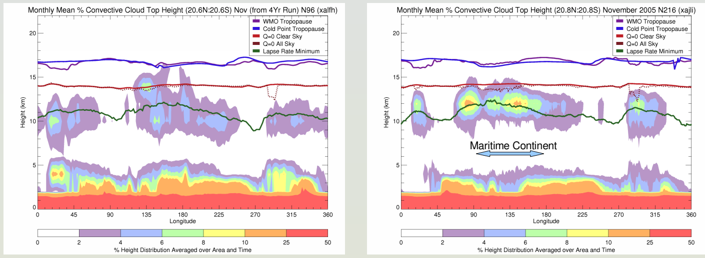


Fig 8 & 9: Distribution of convective cloud top heights and TTL structure from the models. Area averaged data between 20N:20S . N96 (left) and the corresponding area in N216 (right).

In figures 8, 9, 10 and 11 the relative position of TTL levels are similar to that shown in figure 1. Figure 10 and 11 illustrate model data analysed between 1N and 1S with both resolutions showing regions where convective cloud top height reaches well into the TTL. This demonstrates that deep convection events occur frequently within the modelled month for the region shown. Over the maritime continent the models show somewhat differing convective distributions. At N216 more convection reaches the lower TTL compared to N96 where the model captures more stratosphere-reaching convection. The N96 climate model also produces too much convection over east Africa, this feature is also seen in figures 3 and 6.

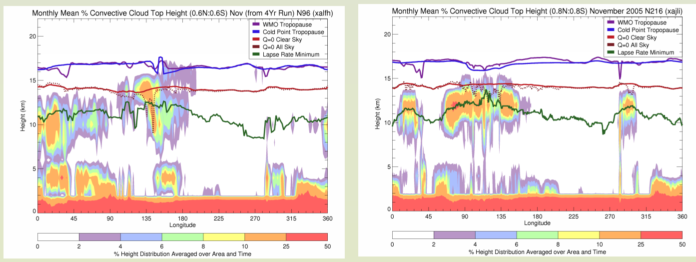
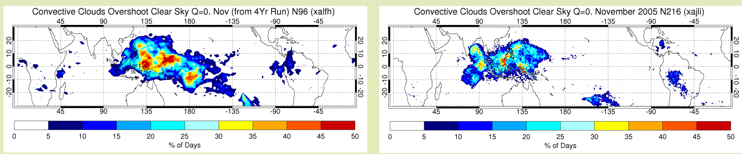


Fig 10 & 11: Distribution of convective cloud top height and TTL structure from the model between 1N:1S at N96 (left) and the corresponding area in N216 (right).

4. Convective Overshooting of Clear Sky Q=0

Spatial and temporal averaging are useful tools when describing the overall effect of atmospheric processes, such as convection and transport, but in doing so the significance of events occurring on smaller spatial and temporal scales is lost. Figures 12 and 13 show the occurrence frequency, within November 2005, of the convective cloud top height overshooting the monthly mean Q=0 clear sky level (estimated from 3 hourly model data). The plots demonstrate clearly that convective overshooting in the model occurs frequently in many areas over the Maritime Continent for both model resolutions. However, in this region, the lower resolution captures more convection reaching above the Q=0 level allowing more tropospheric air (which may contain ozone depleting chemical species) up into lower stratosphere. Thus, these results imply that tropical cross-tropopause exchange is somewhat different within the two model resolutions.



Figs. 12 & 13 – The occurrence frequency of overshooting events relative to the clear sky Q=0 level estimated from three hourly model data. N96 (left) and N216 (right)

5. Conclusion

At N96 and N216 the Unified Model produces a realistic TTL structure thus providing a good base for modelling chemical transport to the UTLS and subsequent impact on ozone chemistry. The global pattern of convection is somewhat different between higher and lower resolution models, with N216 comparing to the satellite monthly mean data to a high degree (Figures 2 with 4; and 5 with 6). To further this study we will include a set of idealised coastal tracers to try and quantify the influence of tropical convection on ozone destruction within the UTLS by short lived halogenated chemical species.

Acknowledgements: NERC, UK Meteorological Office, NCAS-CMS and the ACTIVE and SCOUT-O3 research consortia

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Sept 2008