High Frequency Variability in the Stratosphere Resolving HadGAM2-A L60 and Comparison with HIRDLS AURA

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

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1. Abstract

An examination is made of parameterised gravity waves in the Hadley Centre's HadGAM2-A L60 and small-scale gravity waves retrieved from HIRDLS-AURA (v2.04.09). Seasonal similarities are seen at low and high latitudes during mid summer and winter. Differences are evident during Southern Hemisphere winter at high latitudes, most likely due to sources not represented in HadGAM2-A L60. The diminution of wave amplitude with height is significantly greater in the HIRDLS data and is most likely linked with HIRDLS vertical resolution or saturation processes rather than circulation differences. Maxima are seen in both model and HIRDLS data in the subtropics during summer possibly linked with the ITCZ or Asian Monsoon.

2. HadGAM2-A L60 Setup

The model used was the stratosphere resolving Met Office global climate model HadGAM2-A L60. It is presently configured with a horizontal resolution of 2.5°x3.75° and 60 vertical levels ranging from the surface to 0.01hPa, of which approximately 34 are above the tropopause. The horizontal grid is a staggered Arakawa B grid, with scalar variables such as temperature and density displaced from vector fields such as wind. The vertical coordinate is a height based Charney-Phillips grid. The dynamical core is semi-Lagrangian and runs using a semi-implicit timestep. For this study, methane oxidation is applied, but no sulphur-cycle, aerosol or chemistry schemes are used. Sub-grid gravity waves were parameterised using the Ultra-Simple Spectral Parameterization (USSP, Scaife *et al*., 2002) and an orographic scheme representing low-level flow blocking and upper level drag (Shutts, 1990; Webster *et al*, 2003). The source for this is constrained by the period of a model generated Quasi-Biennial Oscillation (QBO). The source was assumed isotropic and launched in the lower troposphere.

A 25-year integration was carried out from 1975. During this time, contemporaneous SST and sea-ice, CO2 and methane were applied while minor GHGs (N2O, CFC11 and CFC12) were fixed at mass-mixing ratios of 4.74 x 10^{-7}, 1.30 x 10^{-9} and 2.18 x 10^{-9}, respectively. A new seasonally varying stratospheric ozone climatology was also applied (K. Rosenlof and M. Dall'Amico, *pers. comm.*).

3. HIRDLS Data

The method used to calculate the vertical component of horizontal eddy momentum flux (IWM) due to gravity waves in the HIRDLS data is outlined by Alexander *et al*, 2008. Only data between 100hPa and 0.1hPa are analysed for small-scale variability. Daily vertical temperature profiles are binned to 2.5° latitude, 12° longitude, removing the mean and zonal wavenumbers 1-3. The S-Transform is applied to the residual (Stockwell *et al*, 1996), which returns the vertical wavenumbers, as a complex-valued function of height. For each adjacent profile pair the cospectrum and covariance spectrum are then computed, and the maximum in the covariance spectrum located for vertical wavelengths less than 16km, giving the dominant vertical wavelength as a function of height. From the phase differences between adjacent profiles characteristic horizontal wavenumbers k_h are obtained. This necessarily understimates the true k_h and consequently reduces the calculated IWM.

4. Global Annual Mean Gravity Wave IWM

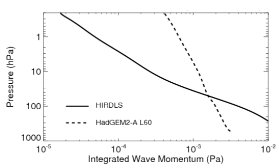

Figure 1: Global annual mean IWM for HIRDLS 2005-2007 and HadGEM2-A L60 1975-2000. Units are Pa

Figure 1 compares global annual mean IWM between HIRDLS and HadGEM2-A L60. In the lower troposphere, the model has weaker parameterised waves than is seen in the HIRDLS data. Above 10hPa, both model and observations are comparable and the observations fall off more steeply with increasing altitude. The decrease is consistent with the decrease in atmospheric density. Consequently, the model IWM is over an order of magnitude larger near the stratopause. These systematic differences are most likely attributable to saturation processes not captured by the GCM GW parameterisation or unresolved scales not captured by HIRDLS.

5. Annual Mean Gravity Wave IWM

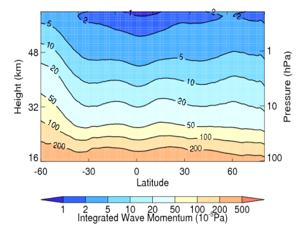

Figure 2: Annual mean IWM for HIRDLS 2005-2007. Units are 10^{-5} Pa

Figure 2 shows the meridional distribution of zonal mean IWM as a function of height. Little variation is seen in latitude near the tropopause, where IWM is consistently above 2x10^{-3}Pa. Similarly to figure1, IWM decreases exponentially with height at all latitudes. Larger values occur at high southern latitudes near the tropopause and above. This coincides with the southern tip of South America and the Southern Ocean. Around the tropics, a small dip is seen at the equator with peaks in the subtropics.

The latitude distribution of IWM in HadGAM2-A L60 can be seen in figure 3. Compared to HIRDLS, lower values occur at about the tropopause, with exponentially decreasing values above. Similarly to figure 1, a gradual diminution is seen with mean values for IWM of ~2x10^{-4}Pa near the stratopause. Significantly greater variation across latitudes is noticeable compared with HIRDLS suggesting effects other than saturation are also occurring.

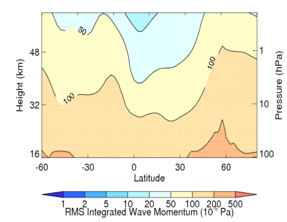

Figure 3: Annual mean IWM for HadGAM2-A L60 1975-2000. Units are 10^{-5} Pa

6. Seasonal Cycle

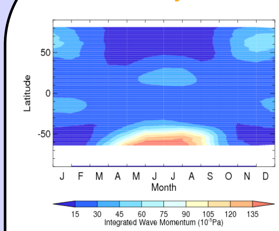

Figure 4: Seasonal timeseries at 10hPa of IWM for HIRDLS 2005-2007. Units are 10^{-5} Pa

The seasonal variation of IWM in the HIRDLS data is seen in figure 4. Minima occur during summer months at high latitudes, consistent with greater filtering by background winds. Maxima in IWM occur during winter. Large differences can be seen between the northern and southern extratropics during winter. These are associated with orographic IWM over Patagonia and the Southern Ocean. Summer maxima are seen in the tropics.

Similar seasonal variability is seen in HadGAM2-A L60 with notable differences (figure 5). The winter extratropical maxima seen in HIRDLS data also occur in the model, however, it is much weaker in the south. A significant difference occurs at high northern latitudes during summer, where a local maximum occurs. This is most likely associated with circulation biases in HadGAM2-A L60. Similarly to HIRDLS, subtropical maxima are also seen during summer.

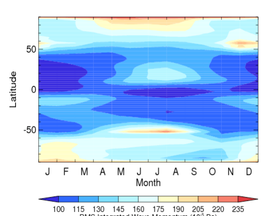

Figure 5: Seasonal timeseries at 10hPa of IWM for HadGAM2-A L60 1975-2000. Units are 10^{-5} Pa

7. Boreal Summer Gravity Wave IWM

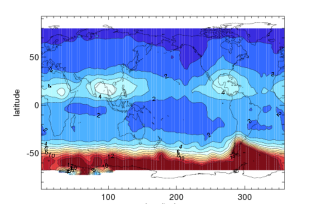

Figure 6: Climatological JJA IWM at 10hPa for HIRDLS 2005-2007. Units are 10^{-4} Pa

The summer subtropical maxima can be identified more clearly in figure 6 which shows IWM as a function of longitude and latitude at 10hPa during boreal summer. These features occur over North Africa, the Indian subcontinent and Central America and have been previously identified in UARS MLS data (Jiang et al., 2002). The timing may be linked to the Asian summer monsoon or to the position of the ITCZ. The southern maximum is clearly evident and appears not to be restricted to the southern part of South America. Large valued IWM also occurs about the southern ocean, perhaps linked with the wall of the polar vortex.

Significant differences can be seen in HadGAM2-A L60 at 10hPa (figure 7). Shown here is the contribution to model IWM from spectral sources only. High latitude maxima can be seen in the Northern Hemisphere with lower values seen at mid-latitudes in the Southern Hemisphere. This is contrasted with global mimima at high northern latitudes in the HIRDLS data. This would be expected from filtering by upper tropospheric westerlies and low-mid stratospheric easterlies. Also seen is a tropical maxima about the Asian subcontinent. This likely to be associated with differential filtering from circulation anomalies set up about the Tibetan High.

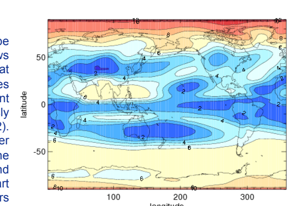

Figure 7: Climatological JJA IWM at 10hPa for HadGAM2-A L60 1975-2000. Units are 10^{-4} Pa

8. Conclusions

Significant differences in both latitude variation and the exponential diminution in height of IWM suggest that saturation processes may play a greater role than previously thought. Even so, a **significant seasonal cycle** is seen in both model and HIRDLS data, indicating background filtering from underlying windshear.

Large valued IWM in the southern extratropics is **not captured** by the model. This is especially apparent during the southern winter, most likely due to unrepresented sources in the model.

Future work: mask the model data to better compare waves represented in HIRDLS.

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