Modeling the Southern Hemisphere winter circulation using stratospheric gravity wave information based on GNSS radio occultations

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Summary

A mechanistic global circulation model is used to simulate the stratospheric, mesospheric and lower thermospheric circulation during Austral winter. The model includes a gravity wave (GW) parameterization that is initiated by prescribed GW parameters in the troposphere. These are based on observations of potential GW energy using GPS radio occultations, but which is normalized to the same global mean amplitude. The model experiments show that this new gravity wave distribution, originating from enhanced GW activity east of the Andes and around the Antarctic, leads to additional forcing of stationary planetary waves (SPWs) in the stratosphere, a weaker zonal wind jet in the mesosphere, cooling of the mesosphere and warming near the mesopause above the jet. SPW1 amplitudes are generally increased by about 10%. However, at the upper part of the zonal wind jet, SPW1 in zonal wind and GW acceleration are out of phase, which reduces the amplitudes there.

Middle and Upper Atmosphere Model MUAM

- 3D primitive equations, time step 225 s, Matsuno integration scheme
- 56 layers × 0.4·ln p/p_s, model top ~160 km in log-pressure coordinates
- 5° × 5.625° horizontal grid
- 2000-2010 mean ERA-Interim zonal mean temperatures assimilated below 30 km
- SPW 1-3 from ERA-Interim forced at the lower boundary
- Solar and IR radiation schemes, prescribed ozone field, water vapour, CO_2

The GW scheme in MUAM is a Lindzen-type one based on Jakobs et al. (1986), with modifications described in Fröhlich et al. (2003). Every 2 hours, 48 GW in 8 directions are forced at ~10 km altitude. GW amplitudes at each latitude/longitude are taken from observations normalized to a global mean vertical amplitude of 1.7 cm/s.

GW fields and model experiments

The GW climatology is based on GPS RO potential energy (Ep) distributions. Ep is calculated using RO temperature profiles using FORMOSAT-3/COSMIC and MetOP satellites. The method bases on temperature anomalies in grids of 5°×10° in latitude and longitude calculated after horizontal detrending, i.e. removing mean and wavenumbers 1-6 (Schmidt et al., 2016). Data from 2007-2013 have been used, which have been averaged over 25-35 km altitude.

The 2D Ep distribution for July, weighted by their global mean, is shown in Fig. 1 (left panel). One can see an enhancement of Ep near the equator that is due to convective GWs, and large Ep around 60°S, connected with the polar vortex. Further enhancement is visible east of the Andes and above all around the Antarctic Peninsula. Zonal mean weights are presented in Fig. 1 (right panel).

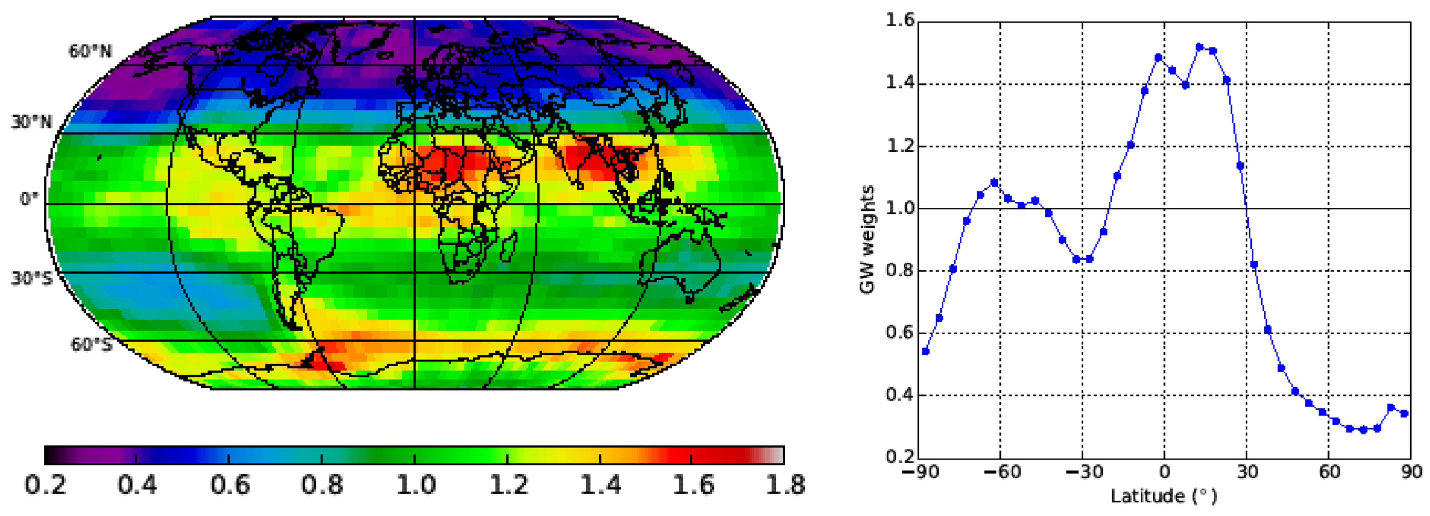

Fig. 1: Horizontal field of GW weights (left) and their zonal means (right).

We performed 3 runs (30 days, January) with different forcing of the model at its lower boundary:

Run name	GW weights	SPW 1-3 at lower boundary	Remarks
Run1	zonal mean	yes	direct SPW effects
Run2	2D	yes	direct SPW and non-zonal GW forcing effects
Run3	2D	no	only non-zonal GW forcing effects

Differences Run2–Run1 show the effect of non-zonal GW forcing. Comparison of Run1 and Run3 shows the relative effects of direct non-zonal GW forcing and non-zonal GW forcing through GW filtering by SPW.

References:

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Results: zonal mean parameters

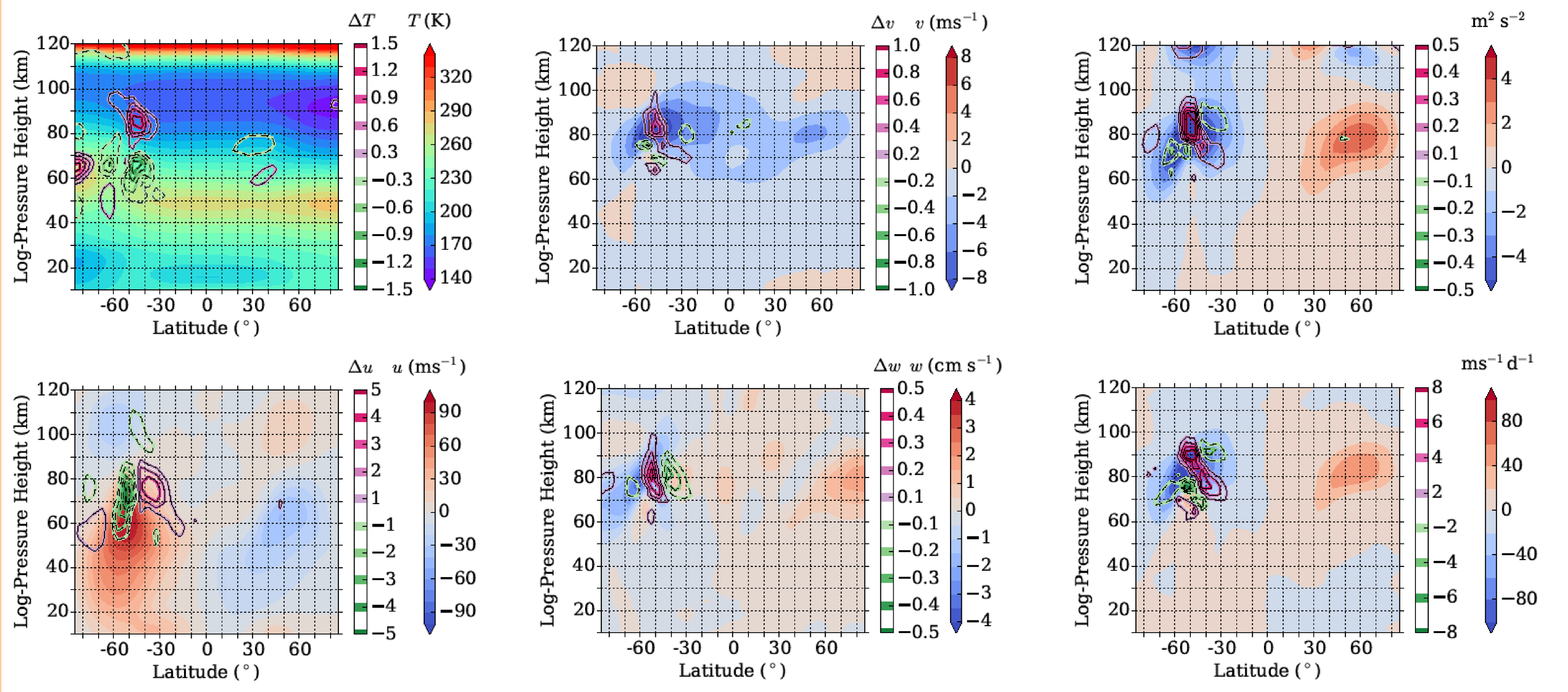

Fig. 2: Run2 zonal mean temperature (top left), zonal wind (bottom left), meridional wind (top center), vertical wind (bottom center), zonal GW momentum flux (top right), zonal acceleration of the mean wind by GW (bottom right). The differences Run2–Run1 are given as contour lines.

Results: planetary waves

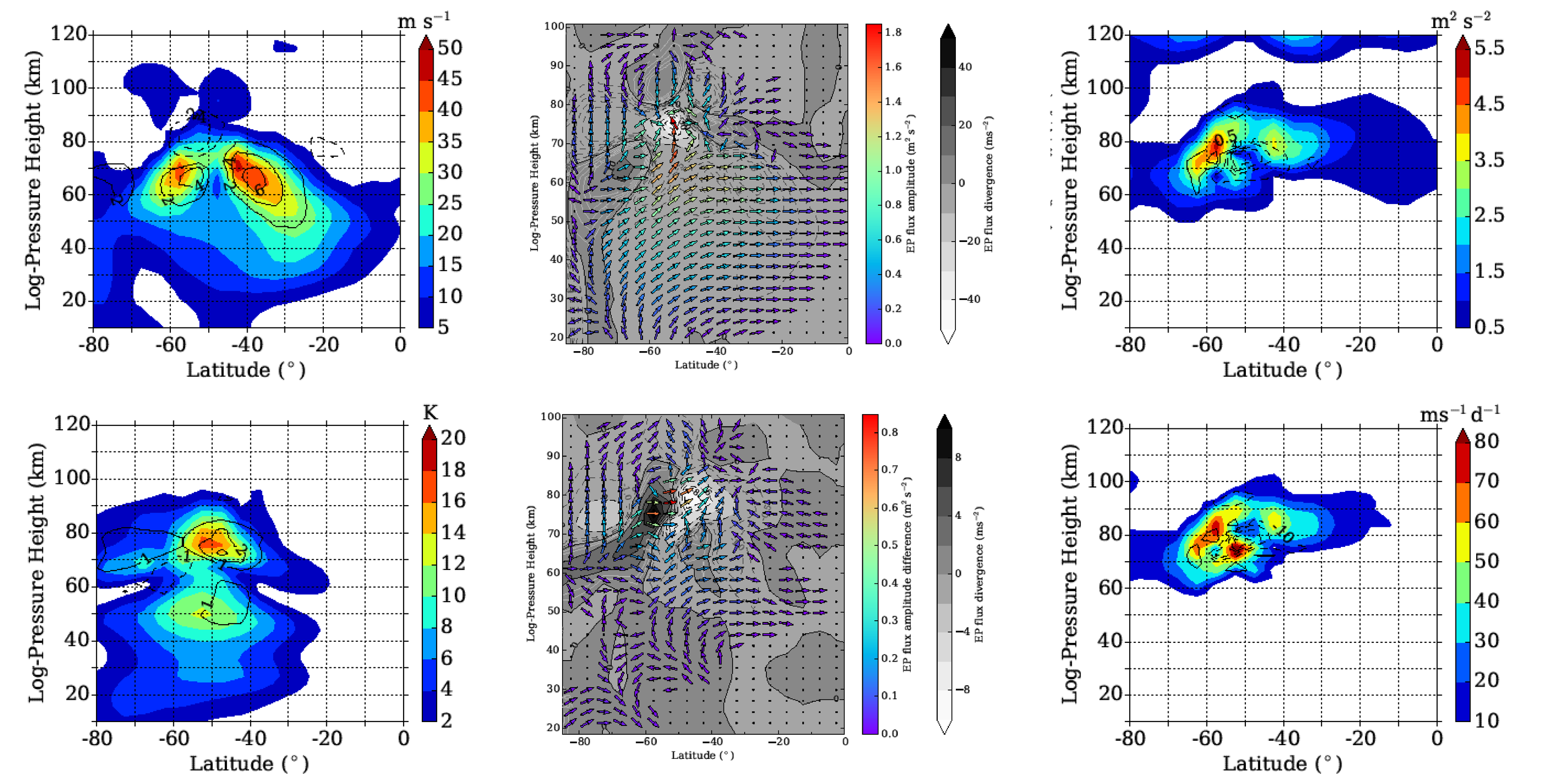

Figure 3: Left: Run2 SPW1 amplitudes of zonal wind (top) and temperature (bottom). The differences Run2–Run1 are given as contour lines. Top right: Run2 SPW1 EP flux (arrows) and divergence (contours). Bottom right: Run2–Run1 EP flux and divergence differences.

Figure 4: Run2 SPW1 amplitudes of GW zonal momentum flux (top) and divergence (bottom). Contour lines: Run2–Run1 differences.

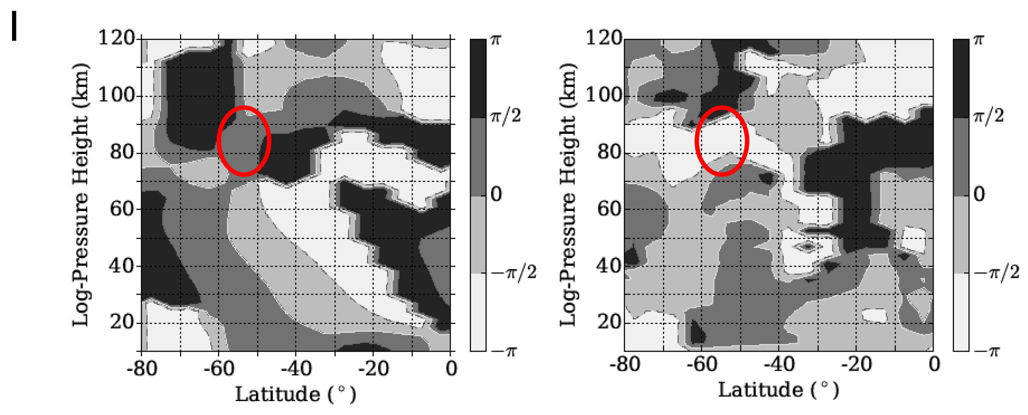

Figure 5: Left: Run1 zonal wind SPW1 phases, wave forcing only through lower boundary fields. Right: Run 3 zonal GW acceleration SPW1 phases. Wave forcing only through non-zonal 2D GW distribution.

Introducing 2D GW forcing increases the SPW amplitudes by ~10% (Fig. 3, left). Zonal wind and GW acceleration SPW1 are broadly in phase. EP fluxes are directed more towards middle latitudes (Fig. 3, middle) and lead to acceleration there (Fig. 2., bottom left). However, between 50°S and 60°S zonal wind SPW1 is reduced above 75 km (Fig. 3, top left). Here zonal wind and GW acceleration SPW1 are out of phase (red circles in Fig. 5).

The zonal wind jet itself is weaker in its upper part, with cooling in the mesosphere (Fig. 2, left). SPW amplitudes of GW flux and acceleration is generally increased, but not in the center of the zonal wind jet (Fig. 4).

SPW from 2D GW forcing alone

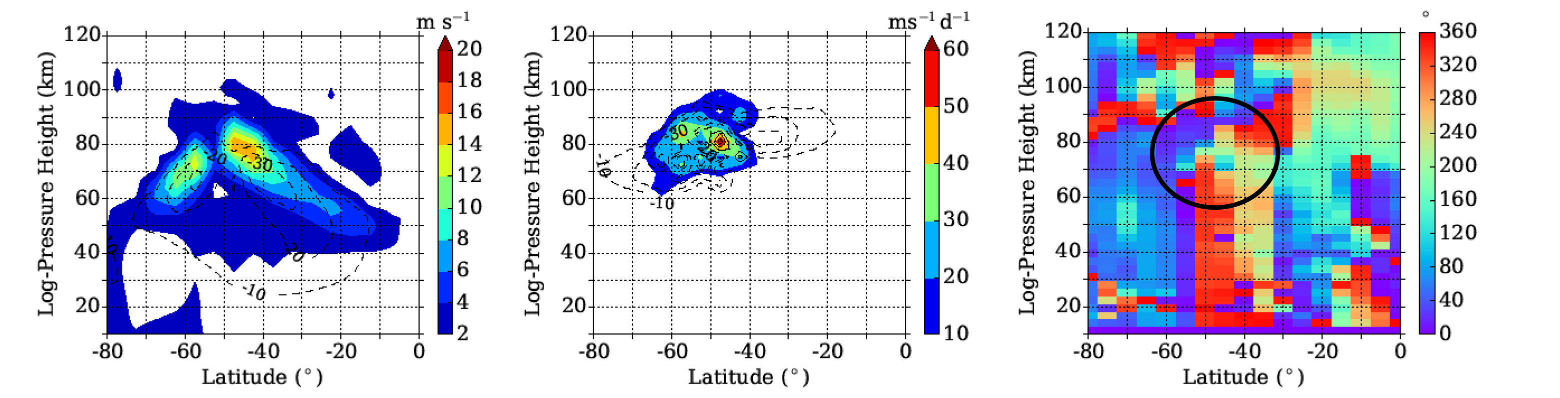

Figure 6: Run3: SPW1 amplitude of zonal wind (left) and GW zonal flux (center). Contours show Run3–Run2 differences. Right: Run3–Run1 phase differences of SPW1 GW flux (right).

SPW1 amplitudes solely forced by GW acceleration are larger than the differences between Run2 and Run1 (Fig. 6 left and center vs. Fig. 3 left and Fig. 4). This is due to the phase relationship (Fig. 6, right) which shows that GW fluxes from direct SPW1 interaction and from non-zonal sources are out of phase near the jet maximum. This result, however, depends on the respective phases of SPW1 in relation to the position of the Andes.