

The impacts of explicitly simulated gravity waves on large-scale circulation in the Southern Hemisphere.

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Introduction

In the past three decades much work has been done on gravity waves in global models at low resolution, using gravity-wave drag parameterizations. Improvement in the computational speed has allowed the resolution in the global climate models (GCMs) to increase tremendously over the years. GCMs now even can resolve features at mesoscale level or smaller though this is not typical. Consequently, the explicit simulation of gravity waves in global simulation appears not to have been examined. Our study will use a global model in which high resolution is applied at a localized place on the globe through grid stretching. The focus of our study will be over the southern hemisphere. We will run a model with idealized topography for a long enough period of time for gravity waves to break and possibly influence the large-scale flow.

We will use a dynamic grid adaptive (DGA) model (Iselin 1999) in our studies. In this model grid points can move with a changing target or they can focus higher resolution on a fixed region. This type of model allows one to increase the resolution locally at the expense of the resolution in the areas surrounding that region. Prusa *et al.* (1996), among

others, has studied the propagation and breaking of gravity waves forced at the tropopause. Our study will be focused in the troposphere. We are interested in gravity waves generated by stratified air moving over an obstacle, in this case irregular terrain.

Problem.

Much gravity-wave research in the past using global models has focused on using gravity wave parameterization or implicit effects via envelope orography. In experiments carried out by McFarlane (1987), he showed that introducing gravity wave drag in a GCM improved the large scale flow in the northern hemisphere but caused little change over the southern hemisphere. Rabinovitz *et al.* (2000) introduced an orographic forcing in a uniform resolution GCM and a variable resolution, stretched-grid GCM that may have had gravity waves in the high-resolution region though they were not diagnosed. In our study we want to simulate gravity waves explicitly using grid stretching to give fine resolution to a mountain region. We wish to examine the effects of explicitly simulated gravity waves, as opposed to parameterized drag, on the evolution of the large-scale circulation.

Experimental Design.

A number of experiments will be carried out to observe the impact of introducing orography in a dry GCM when gravity waves are simulated directly. The first experiments will use low resolution with a grid size of 5.625° for both the longitude and latitude and 750m in the vertical. Further experiments will gradually increase the resolution to determine the minimum resolution necessary to resolve gravity waves adequately.

The experiments to be carried out are as follows:

Simulations at low resolution.

1. The control experiment will have a uniform grid and no orographic forcing and integrated at a low resolution with a horizontal grid size of $5.625^{\circ} \times 5.625^{\circ}$ and 750m-grid spacing in the vertical.
2. Orographic forcing is introduced into a uniform grid, which uses the same grid spacing as in the control.
3. Grid is stretched at a preferred location for an idealized southern hemisphere mountain chain and the simulation uses the same grid points as in the control.

Simulations at high resolution

Simulations at high resolution will also be carried out at NCAR with a parallel processor code version to reduce the overall time needed to complete simulations. All the other specifications for these experiments will be the same as in the low-resolution experiments.

- 1b. Same as in the control experiment but at a higher uniform resolution.
- 2b. Simulations done with a uniform grid and orography included at a higher resolution.
- 3b. Stretching of the grid will be done over the southern hemisphere with orographic forcing and at a high resolution.

The simulations will be forced by the Held and Suarez (1984), idealized forcing used to test dynamical cores of models

Research Questions

Do the gravity waves simulated directly by orography have an effect on the global large scale flow?

Methodology.

A series of experiments with varying horizontal resolution will be carried out with a model in which topography is included to address the research question. A dynamic adaptive grid (DAG) model will be used in our study. The grid points in the model can be moved in response to the flow field development (Iselin 1999). The DAG will be used to resolve internal gravity waves over southern hemisphere because of the ability of the DAG to increase the resolution locally. A global model GCM will be used in our study to perform a suite of experiments focusing on the southern hemisphere.

Literature Review

Internal gravity (buoyancy) waves in the atmosphere exist in a stably stratified atmosphere (Holton 1982). For a shallow bounded fluid, the gravity waves would only propagate in the horizontal but for an unbounded fluid like the atmosphere the gravity waves can propagate both vertically and horizontally. Vertically propagating waves where the phase varies with height are known as internal gravity waves. These waves generally have weak influence on synoptic weather forecasting but are important at the mesoscale level. They are also known to transport energy and momentum to high levels such as the stratosphere and the mesosphere (Holton 1983 and McFarlane 1986), they are associated with clear air turbulence. Numerical experiments done by Holton (1983) revealed that mechanical dissipation resulting from breaking of vertically propagating gravity waves played an important role in the general circulation of the mesosphere. Gravity waves are oscillations of air parcels produced by the lifting force of positive buoyancy and the restoring force of gravity. These waves propagate vertically as well as

horizontal and actively transport momentum through the troposphere to the middle and upper atmosphere. There are many causes of gravity waves such as flow of stably stratified air over irregular terrain (McFarlane 1987). The other sources of gravity waves cited by the same author were the onset of shear instability, rapid development of convective complexes and squall lines.

Vertically propagating waves transport momentum from the source region to regions where they are dissipated (McFarlane 1987). The dissipation or absorption of gravity waves of sufficient magnitude and horizontal extent could modify the large-scale mean flow in the atmosphere through wave momentum flux convergence or divergence (e.g., McFarlane 1987 among others. Wave absorption occurs at critical levels when the Richardson number exceeds 25 (McFarlane 1987). The question one can pose is 'Does the gravity wave momentum convergence or divergence modify the troposphere large-scale mean flow?

Momentum sources and sinks are very important in the dynamics of the mesosphere. Holton (1983) in his studies showed that incorporation of momentum source/sinks due to gravity wave saturation into zonally averaged models of the mesospheric circulation can lead to realistic simulations of the mean zonal flow structure. Observational data from Lilly's (1982)'s studies revealed that gravity wave momentum flux convergence that is associated with orographically excited waves may occur in the upper troposphere and lower stratosphere. The convergence could be of sufficient magnitude and horizontal extent to substantially alter the larger scale flow in those regions.

Kim *et al.* (1996) used the gravity wave drag (GWD) parameterization developed

by Kim and Arawaka (1995) and envelope orography to increase the surface drag in the UCLA GCM, thus adding drag to the free atmosphere, and reducing a westerly bias (Palmer *et al.* 1986, and McFarlane 1987). They used the scheme with idealized and enhanced or envelope orography. The use of a GWD parameterization scheme together with envelope orography resulted in the improvement of the ensemble mean flow for January. McFarlane (1987) also studied the westerly bias problem in the mid-latitudes. Inclusion of the GWD with the standard (idealized or smoothed) orography resulted in a slight decrease in the meridional eddy heat, momentum and other fluxes. Addition of the GWD to the envelope orography did not make the fluxes to decrease.

Slingo and Pearson (1986) did two simulations to solve the westerly bias problem: one with envelope orography in the model and another where they included the parameterization of the effects of orographic gravity wave drag. They compared these to the control run. In both cases there were significant changes in the climatology of the model. The gravity wave scheme gave results, which were very close to the observations for both hemispheres and seasons. On the other hand the envelope orography did not solve the westerly bias over Europe, and it also resulted in the distortion in the summer flow. It was shown that in the envelope orography experiment the excessive increase in the mountain pressure torque reduced the westerlies. The gravity wave drag is the one that was responsible for the decrease in the westerly bias in the gravity wave scheme. They postulated that with a high horizontal resolution the major effects of mountains (gravity waves) would be resolved.

They are found to affect atmospheric tides in the middle atmosphere and terrestrial weather in the lower atmosphere.

Diagnostic output expected.

For the six experiments we are going to diagnose the following:

- ® Latitude-height cross-section of the mean zonal winds. This will enable us to see if the orography modifies the global circulation.
- ® Latitude-height distribution of potential temperature time/zonal averaged.
- ® Latitude-height distribution of the time/zonal averaged eddy heat flux.
- ® Sea level pressure distribution over the globe and the difference between the sea level pressure distribution for the control and the other 5 experiments mentioned in the methods.
- ® 500 mb geo-potential heights and the difference from the control.
- ® Latitude-height distribution of momentum flux.

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