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Physical processes in present and future large-scale models

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Summary

Gravity waves: introduction and global view - Peter Preusse (Forschungszentrum Jülich GmbH)

Dr. Peter Preusse started his career with the calibration and temperature and trace species retrieval of the CRyogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA) experiment. He earned his PhD in 2001 from Wuppertal university for inferring global GW distributions from CRISTA temperature data. Since 2002 he is head of the remote sensing group at the Institute of Energy and Climate Resarch: Stratosphere (IEK-7) at Forschungszentrum Jülich. Together with the Karlsruhe Institute of Technology (KIT) and partner institutes at Juelich, IEK-7 advanced the limb sounding technique by developing the novel Gimbaled Limb Observer for Radiance Imaging of the Atmosphere (GLORIA) for the use on research airplanes and stratosphere balloons. He is shared principal investigator (PI) of GLORIA and is majorly involved in proposals to apply this technique in space in order to provide altitude-resolved data of the stratosphere also in future. Furthermore, limb imaging from space could gain unprecedented information on gravity waves on a global scale.

Gravity waves are waves in a stably stratified medium where gravity or respectively buoyancy acts as the restoring force. In the atmosphere they can have horizontal wavelengths from a few kilometer to several thousand kilometer and vertical wavelengths from a few hundred meter to tens of kilometer. They are observed in terms of temperature and wind structures as well as vertical displacement of the flow and thus are sometimes visible also in cloud structures. Atmospheric gravity waves propagate in all three dimensions. In good approximation the momentum flux associated with a gravity wave is a conserved quantity as long as the wave is propagating conservatively: since density is decreasing exponentially, in compensation GW amplitudes are growing exponentially with height. Accordingly, most GWs are propagating upward thus conveying momentum from low to high altitudes. Where the amplitude exceeds a saturation threshold, the wave breaks and deposits energy and momentum. In this, GWs are an important coupling mechanism between the different layers of the atmosphere, i.e. between troposphere, stratosphere and mesosphere.

Upward propagating gravity waves carry momentum and interact with the background flow. Though every single gravity wave is a local phenomenon, as a whole they accelerate of decelerate the global wind fields, thus playing a major role in the quasi-biennial oscillation in the tropical winds and the momentum balances in the middle atmosphere jets. This momentum balance induces via the Coriolis force the general mean circulation. The effects of gravity waves, therefore, are global. This calls for global observations of gravity waves in order to understand the relative importance of the various sources of gravity waves on a global scale.

From early attempts of Fetzer and Gille (1994) and Eckermann and Preusse (1999) we have now developed techniques to infer global distributions of absolute values of gravity wave momentum flux from infrared limb sounder data. This picture is complemented by gravity wave temperature variances from microwave limb sounding and nadir viewing instruments. All these instruments view different parts of the spectrum of gravity waves due to their different observation geometry and it remains unclear to date which part of the spectrum may be most important for global momentum flux balances.

The global momentum flux distributions in the stratosphere show a typical pattern: Largest values are found in the winter polar vortices, lower values in the winter subtropics and tropics, a second maximum in the summer subtropics and the lowest values, in general, for the summer midlatitudes and high latitudes. General circulation models which need to parametrize gravity waves assume frequently a homogeneous and isotropic "source" in the mid troposphere in addition to the effects of mountain waves. Indeed, the general zonal mean structure of the gravity wave distribution described above can be reproduced by such an approach. However, in detail we can see in the observed global distributions clear indications for, in particular, orography and convection as prominent sources of gravity waves. The largest momentum flux is observed in the winter polar vortex of the southern hemisphere. Albeit orographic excitation at the Antarctic Peninsula and at Tierra del Fuego, for a major part of this momentum flux the source is not yet certain and subject of current research.

At higher altitudes the importance of gravity waves from subtropical convection increases. The waves propagate in the direction to the summer pole and are found at midlatitude in the upper mesosphere. They may thus evade wind reversals at lower altitudes at these latitudes and contribute to the formation of the wind reversal in the mesosphere - lower thermosphere (MLT). For the rebuild of a stratopause after a major stratospheric warming laterally propagating gravity waves may play a role as well. Effects of obliquely propagating gravity waves on the mean circulation are not well known, since gravity wave parametrizations in general circulation models neglect this effect in order to remain computationally efficient.

In recent years the spatial resolution of general circulation models used in numerical weather prediction increased to a degree that now larger parts of the gravity wave spectrum is resolved. These models may hence help to unravel such open questions as the sources of waves in the southern polar vortex. However, even if the resolution of the GCM is sufficient to resolve the propagation of the waves, the sources are not necessarily well represented. In addition, gravity waves are artificially strongly damped from the mid stratosphere upward, which may be the reason that these models still require GW parametrizations. Thus, models are not reality and also in future measurements remain indispensable for understanding and quantifying gravity waves, their sources and effects. A large step forward to this aim could be a further development of the limb sounding technique in terms of a space borne limb imager.

References

A review on gravity wave physics can be found in Fritts and Alexander, Rev. of Geophysics, 2003.

The role of gravity waves for coupling is described in Kim, Eckermann and Chun, Atmosphere-Ocean, 2003 and Alexander et al., Quarterly Journal of the Royal Meteorological Society, 2010

For an overview of different techniques see Preusse, Eckermann and Ern, Journal of Geophysical Research - Atmosphere, 2008

A climatology of GWs from infrared limb sounding data can be found in Ern et al., Journal of Geophysical Research, 2011

A survey of different models and climatological data sets is published by Geller et al., Journal of Climate, 2013

For gravity waves resolved in large-area simulations and NWP models see
for instance: Plougonven, Hertzog and Guez, Quarterly Journal of the Royal Meteorological Society, 2013 Preusse et al., Atmospheric Chemistry and Physics, 2014

The latter is also giving introduction to the benefits of limb imaging from space