Global Analysis of Stratospheric Gravity Wave Activity Using CHAMP Radio Occultation Temperatures

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Summary. Global analyses of E_p as a proxy for gravity wave activity in the stratosphere obtained using GPS radio occultation (RO) data from the CHAMP satellite are presented. Large E_p values are noticed at tropical latitudes, but also at midlatitudes during winter. A correspondence between tropical gravity wave activity and tropical deep convection is found. E_p values are also large during the sudden stratospheric warming that occurred in the southern hemisphere during September-October 2002.

Key words: Gravity waves, radio occultation, stratosphere

1 Introduction

In the Earth's atmosphere, gravity waves exert a major influence on the large-scale circulation and structure of the middle and upper atmosphere. Taking this into account, it is essential that gravity waves and their dissipation have to be modelled or parameterised, respectively, with great accuracy and these models should be tested by experimental observations. This requires the need for measuring systems that can observe gravity waves on a global scale.

During the past two decades, considerable effort has been devoted in characterizing gravity waves using ground-based systems as radar, lidar and radiosondes. Unfortunately, although these techniques can provide observations with good temporal and vertical resolutions, the ground-based instruments are sparse and unevenly distributed. Satellite observations are able to provide global coverage ([1], [2]), but are of poor spatial resolution and are not suitable to retain the spectral properties of gravity waves. However, they can give a quantitative picture of wave activity. Recently, using GPS/MET satellite radio occultation (RO) observations, [3] provided a global analysis of stratospheric gravity wave activity with special emphasis on winter months. However, radio occultation data from the GPS/MET experiment are limited to some campaigns and therefore to short time intervals compared with the climatological time scale. Therefore, in the present study, gravity wave activity on a global scale, observed by the CHAMP/GPS satellite, is presented with higher statistical significance.

Most of the sources for the generation of these gravity waves lie in the troposphere ([4]). In the tropics, it is generally thought that gravity waves are mostly generated by cumulus convection ([5], [6]). Therefore the possible connection of CHAMP satellite derived gravity wave activity with convection will be analysed.

2 Potential energy as a proxy for gravity waves

Under linear gravity wave theory, the energy spectrum of gravity waves can be separated in an energy density E_0 and a horizontal wavenumber and frequency part. While the later two cannot be derived from temperature profiles, E_0 is chosen as a measure of gravity wave activity. E_0 is defined as (see, e.g., [3], [7]):

$$E_0 = \frac{1}{2}\left[\overline{u'^2} + \overline{v'^2} + \overline{w'^2} + \left(\frac{g}{N}\right)^2 \overline{\left(\frac{T'}{\overline{T}}\right)^2}\right] = E_k + E_p \tag{1}$$

where E_k and E_p are the kinetic and potential energy per unit mass, u', v' and w' are the perturbation components of the zonal, meridional and vertical wind, respectively, g is the acceleration due to gravity, N is the Brunt-Väisälä frequency, and $\overline{T}$ and T' are the mean and perturbation temperatures. According to the linear theory of gravity waves, the ratio of kinetic to potential energy becomes constant, therefore it is possible to estimate E_0 from temperature observations only ([3]). However, since presenting E_0 after having applied linear theory would not give additional information, and because we have no wind measurements here to prove a relationship between E_0 and E_p, in the following we discuss results of E_p calculation alone. This calculation mainly depends on the estimation of the temperature fluctuation. For this, the procedure adopted from [3], i.e., calculating temperature fluctuation by high-pass filter with a cut-off at 10 km is closely followed here. Shifting a 10-km window through the respective vertical temperature profiles allows the calculation of E_p for different altitudes while, however, one has to take into account that E_p values referring to a specific height includes information from a 10 km height interval.

When interpreting potential energy from radio occultation data, one has to keep in mind that horizontal soundings generally see reduced temperature variances, which is especially true for short horizontal wavelengths [8,9]. From theoretical estimations, [3] found an up to 21% decrease in the amplitudes of radio occultation temperatures. Since the reduction of measured variance also depends on the viewing angle relative to the propagation direction of the gravity waves, which is not known, a simple straightforward correction procedure is not available. Therefore, one has to keep in mind that the following results may contain the effect of E_p reduction, which may be different for different heights or regions.

3 Global distribution of potential energy

Zonally averaged seasonal means (Nov-Feb, Mar-Apr, May-Aug, Sep-Oct) of E_p are shown as height-latitude cross-sections in Fig. 1. Data measured during May 2001 through Jan 2003 is used. Large E_p values at low latitudes up to a height of 25 km is visible from the figure. For the lowermost heights one has to consider a possible influence of the tropopause, however, this should not be the case with the data near 25 km height, so that we may conclude that the high values of E_p are at least qualitatively realistic.

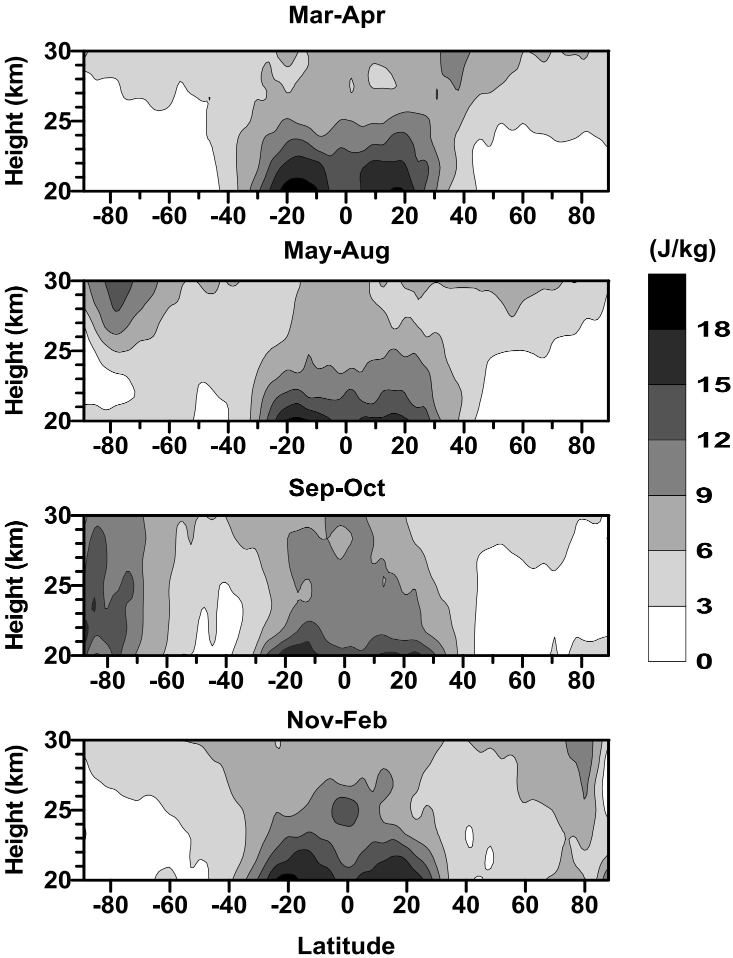

Fig. 1. Height-latitude cross-sections of E_p in different seasons during May 2001 through Jan 2003.

Another source of uncertainty especially in the tropics is a possible contribution of Kelvin or Rossby waves to the analysed E_p. With the approach chosen, i.e., analysing each temperature profile separately, we are not able to distinguish between gravity waves and large-scale waves if they have similar vertical wavelength. The region of large E_p in the lower stratosphere extends to 30^0 in both hemispheres in all seasons. Midlatitude E_p values are nearly independent of season in both hemispheres, and increase with height. At higher latitudes, in winter, E_p values are larger in both hemispheres. During March-April, the latitudinal distribution of E_p values is nearly symmetric with respect to the equator, which is the case with the entire height range considered. Another interesting feature visible in Fig. 1 is that large values of E_p are found at southern hemisphere polar latitudes during southern hemisphere spring (Sep-Oct), probably in connection with the major stratospheric warming in 2002.

Many of the features above mentioned are already noted by [3]. Fundamental differences are the wider latitudinal range of large equatorial values and the large values of E_p at southern polar latitudes during Sep-Oct. Further investigations will be necessary to reveal the possible reason for this significant enhancement and wider latitudinal range.

4 Outgoing longwave radiation and potential energy

In the tropics, convection is believed to be the major source for gravity waves. In order to study the coherence of E_p with tropical convection, outgoing long wave radiation (OLR) is used as a proxy for the latter. As an example, departures of E_p and OLR from their zonal means in September 2002 is shown in Fig. 2a (top panel). The data refer to equatorial values with latitudes up to 10°N or S, while the CHAMP data are again calculated as means over 20-25 km height.

An inverse relationship between E_p and OLR is visible. This is also shown in the scatter plot in Fig. 2b (bottom panel), presenting E_p. vs. OLR in all seasons together. High OLR values are connected with cooling of the lowermost stratosphere due to deep convection. Thus, the correlation seen in Fig. 2b indicates a connection between equatorial gravity waves and convection. Hence it may be confirmed from the data that convection is a primary source for the observed gravity wave activity in the tropics. Still, however, it has to be taken into account that of course a particularly a cold tropopause is connected with low OLR values, and the tropopause structure may affect the E_p results in the lower stratosphere. Therefore the clear connection between the calculated E_p and OLR possibly includes both the gravity wave effect and some residual influence of the sharp tropopause in the vertical profile.

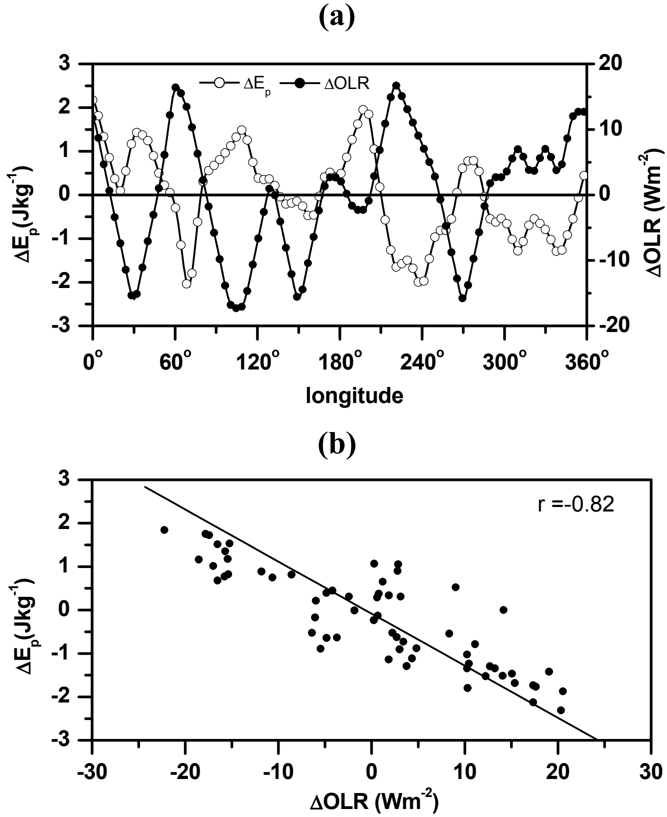

Fig. 2. (a) Longitudinal variation of low-latitude E_p and OLR deviations from the zonal mean in September 2002, **(b)** E_p vs. OLR at 20-25 km near the equator.

5 Conclusions

We have presented a first global picture of potential energy derived from CHAMP RO data for heights of 20-30 km. We restricted ourselves to that height range to avoid effects due to a sharp tropopause in the tropics and to ionospheric residuals at higher altitudes. Since the tropopause is situated at lower heights at middle and high latitudes, for these latitudes E_p can be calculated at lower heights also, but here we did not do that in order to ensure the comparableness between latitudes, and leave the more detailed analysis of high latitude E_p to a later study.

As expected, large E_p values are found near the equator, as has already been shown by [3], but the latitudinal range of this tropical maximum is wider than in [3]. Larger values are also found in winter higher latitudes. During southern hemisphere spring, in 2002 very large values have been measured, probably due to the stratospheric warming event then. At tropical latitudes, gravity waves are clearly owing to deep convection, which can be shown by a comparison of OLR and E_p.

CHAMP RO provide a tool for effectively producing maps of potential energy and thus gravity wave activity. Of course, not all relevant parameters are available from the vertical profiles, so information about horizontal wavenumber and frequency is not available, so that the momentum flux cannot be calculated. This means that the use of CHAMP-derived gravity wave maps as input for numerical models is limited. However, information on seasonal variability, vertical distribution and, in future, interannual variability will be available, so that CHAMP GPS measurements will significantly increase our understanding of middle atmosphere dynamics.

Acknowledgements: We wish to thank GFZ Potsdam for providing CHAMP/GPS data and NOAA for providing OLR data through the CDC. Our sincere thanks to W.N. Chen for providing Taiwan radiosonde observations. This research was funded by the DFG under grant JA 836/4-2.

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