Gravity wave activities in the polar region using FORMOSAT-3 GPS RO observations

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ABSTRACT: FORMOSAT-3 was launched in April of 2006. It consists of six low earth orbit (LEO) satellites that will be eventually deployed to an orbit at 800 km height. Its scientific goal is to utilize the radio occultation (RO) signals to measure the bending angles when the GPS signals transect the atmosphere. The bending angle is then used to infer atmospheric parameters, including refractivity, temperature, pressure, and relative humidity fields of global distributions through inversion schemes and auxiliary information. The expected number of RO events is around 2500 per day, of which 200 events or so fall into the polar region. Consequently, the FORMOSAT-3 observations are expected to play a key role to improve our knowledge in the weather forecasting and space physics research in the polar region. In this paper, we use temperature profiles retrieved from FORMOSAT-3 RO observations to study the climatology of gravity wave activity in the polar region. FORMOSAT-3 can provide about 200 RO observations a day in the polar region, much more than previous GPS RO missions, and, hence, more detailed climatology of gravity wave activity can be obtained.

KEY WORDS: gravity wave, GPS, radio occultation, polar region

1. INTRODUCTION

Gravity wave influences the large-scale circulation in the stratosphere by transporting the momentum and energy flux from disturbance sources in the troposphere to the stratosphere. In the polar region, gravity wave has been known to play an important role in the formation of polar stratospheric clouds (PSC), which increase ozone depletion. Gravity wave has been observed by different techniques such as radiosonde, rocket soundings, lidar, radar, satellite, and so on (Fritts and Alexander, 2003). Only satellite observations can achieve a global coverage, and GPS radio occultation (RO) technique is one of such observations.

GPS RO technique uses an LEO (low earth orbit) satellite to receive GPS signals which are bent and delayed by the atmosphere surrounding Earth. The excess phase of the received GPS signal can be used to reconstruct the refractivity profile of the atmosphere through the Abel integral, then the atmospheric temperature profile can be derived using the ideal gas law. Several experimental LEO satellites, such as GPS/MET, CHAMP and SAC-C, were launched in the past decade and showed the good accuracy of the atmospheric temperature profiles can be obtained. Ware et al. (1996) compared the temperature profiles of GPS/MET with 11 radiosondes and found the accuracy was within 1 K in the height between 5km and 40km. Wickert et al. (2001) compared the temperature profiles from CHAMP with corresponding ECMWF profiles and found the accuracy was 1 K in the height between 5km and 25km while some negative biases were found in the tropical region.

Tusda et al. (2000) used the atmospheric temperature profiles retrieved from GPS/MET observations to calculate the potential energy of gravity wave and study the global activity of gravity wave. They compared the climatology near Japan with their results with that obtained from the MU radar, and the consistent behaviour was found although two different observations extract different characteristics of gravity wave activity. They showed the most active gravity wave activity occurred around the equator with a strong longitudinal variation and the gravity wave activity at the mid-latitudes was larger in the winter in both hemispheres. Ratnam et al. (2004) used CHAMP observation data to study global and seasonal variations of stratospheric gravity wave activity. They compared the potential energy obtained from CHAMP and those from ground-based radiosonde and lidar observation and found the values of potential energy obtained from radiosonde were slightly higher than those from CHAMP observation. They also found the larger values of potential energy occurred over Antarctica in the winter of 2002 and suggested the cause is the stratospheric sudden warming during this period. Baumgaertnet and McDonald (2006) used CHAMP data to study the climatology of gravity wave activity over Antarctica. They found critical level filtering and Doppler shifting of gravity wave were the major causes of the seasonal variation of gravity wave over Antarctica.

FORMOSAT-3 (Liou et al., 2007) is the latest GPS RO satellite mission and was successfully launched on April 15, 2006. The FORMOSAT-3 is a constellation of 6 satellites and each satellite is equipped with GPS Occultation Receiver (GOX), Tri-band beacon (TBB), and Tiny Ionospheric Photometer (TIP). The constellation is on the way to its final orbit configuration with a altitude of 800 km and an inclination angle of 72° and all satellites are healthy except spacecraft flight model no. 2 (FM2) with a minor problem of power shortage. The current sounding profiles, retrieved from GPS occultation measurements, are over 1800 in average, and the number is expected to increase in the future. The sounding profiles have been used to study atmospheric and ionospheric structures such as gravity wave and total electron content and assimilated into numerical weather predictions models to improve the accuracy of prediction. FORMOSAT-3 can provide a much larger number of RO observations than previous GPS RO missions like GPS/MET and CHAMP, and, hence, more detailed climatology of gravity wave activity can be obtained.

In this paper, we use temperature profiles retrieved from FORMOSAT-3 RO observations to perform a preliminary statistical analysis of gravity wave activity in the stratosphere on a global scale.

2. POTENTIAL ENERGY OF GRAVITY WAVE

The perturbation energy per unit mass as a measure of the gravity wave activity is expressed as follows

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

where E_k and E_p represent the kinetic energy and the potential energy, respectively, and they are expressed as follows

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

where u', v' and w' are the velocity perturbation in the zonal, meridional, and vertical directions, respectively. $\overline{T}$ is the background temperature, T' is the fluctuating part of the instantaneous temperature and g is the gravitational acceleration. N is the buoyancy (Brunt-Väisälä) frequency and defined as

$$N^2 = g\frac{\partial \ln\theta}{\partial z} \qquad (3)$$

where θ is the potential temperature. $N^2 > 0$ indicates that the atmosphere is in the stably stratified condition. Because only temperature profiles can be obtained from FORMOSAT-3 RO data, we only study the distribution of E_p while E_k can be estimated from E_p using the linear theory of gravity wave, predicting E_k / E_p is constant. Applying a high-pass filter with a cutoff wavelength of 10 km, temperature profiles are been split into the background part (wavelength > 10km) and the fluctuating part (wavelength < 10 km). Because RO data have been applied a low-pass filter to reduce high-frequency noise, the vertical wavelength in our study lies between 2 km and 10 km.

3. RESULTS

Level 2 products of FORMOSAT-3 RO data from TACC (http://tacc.cwb.gov.tw) are used in this study. Temperature profiles in the Northern Hemisphere Winter of 2006, from December of 2006 to February of 2007, are been split into the background part and the fluctuating part, and then the mean potential energy per unit mass of gravity wave from 20 km to 30 km is calculated using the method stated above. The average amount of temperature profiles per day is near 1650 and the total number is near 150,000 nearly 32 times larger than that used in Tsuda et al. (2000). This indicates FORMOSAT-3 RO data can greatly increase the global atmospheric observation capability and produce a more detailed climatology of gravity wave activity in the stratosphere. We divided the Earth into 360×180 mesh with one degree width in longitude and latitude and averages E_p values in each cell as the mean E_p. Comparing the method of Tsuda et al. (2000) which the mean E_p was averaged over $20^\circ \times 10^\circ$, a more detailed global variation of gravity wave activity can be expected.

Figure 1 shows the histogram of available RO events along the latitude with an increment of one degree. It shows two local maximums in each hemisphere, one is at about 22° and the other at about 50°, and one minimum at equator. When the latitude exceeds 55° in each hemisphere, available RO events decrease with an increase of the latitude and the amount of RO events reduce to 25 at each pole. The total amount of RO events occurring at latitude exceeding 66° is 21557, about 240 RO events per day. Figure 2 shows the global distribution of the mean E_p from 20 km to 30 km in the Northern Hemisphere winter of 2006.

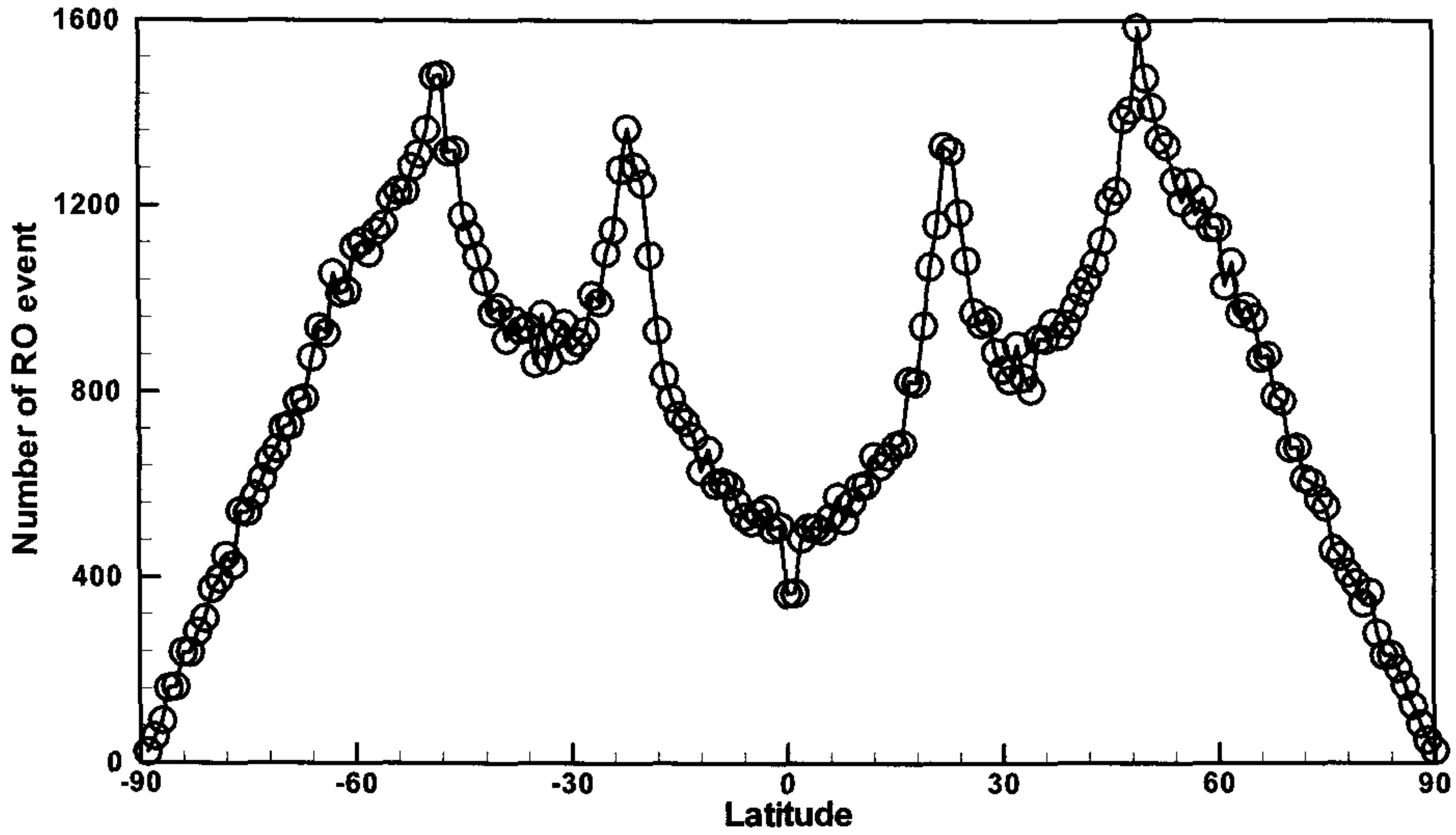

Figure 1. Histogram of available RO events along the latitude with an increment of one degree.

Figure 2 shows that the most active region of gravity wave activity occurs within $\pm 30^{\circ}$ latitude. The result is similar to that of Tsuda et al. (2000), but the mean E_p is near twice larger because of using a much smaller averaging window in the paper. The longitudinal variations of the mean E_p is less obvious when comparing with that of Tsuda et al. (2000), which showed the high mean E_p values highly concentrated on some regions. The distribution of the mean E_p shows asymmetric between two hemispheres, and the values in Northern Hemisphere are larger than those in Southern Hemisphere because gravity waves are more active in winter. The high mean E_p values in the extratropical latitude from $150^{\circ}E$ to $80^{\circ}W$ longitude occur mostly above $55^{\circ}N$ and those in the other longitude scatter between $30^{\circ}N$ to $70^{\circ}N$. Figure 3 highlights the E_p distribution in the Arctic region and Antarctic region. Although the gravity wave activity in polar region is less intense, the same pattern appears: the gravity wave activity in Arctic region is more intense than that in Antarctic region.

4. CONCLUSIONS

The preliminary analysis indicates the FORMOSAT-3

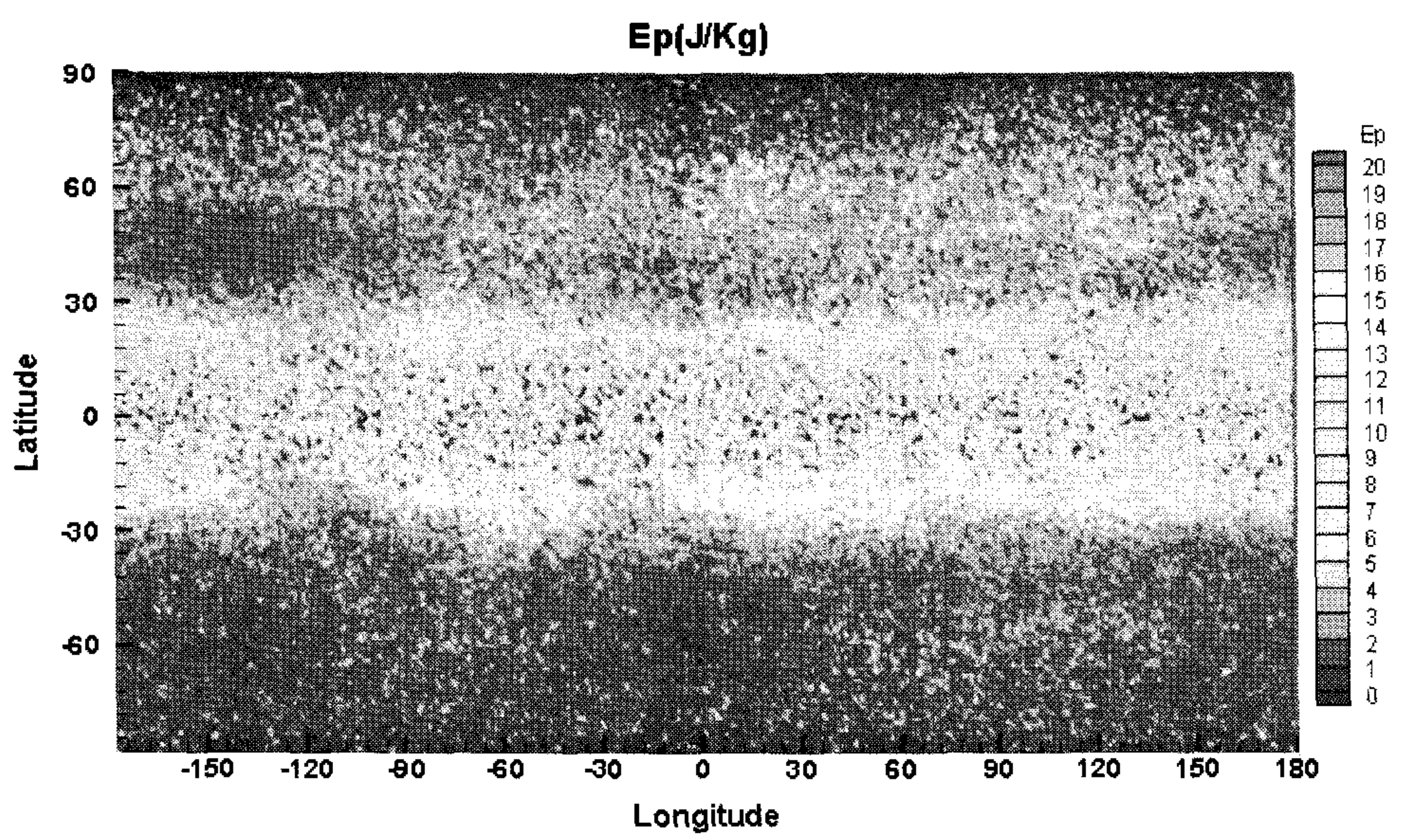

Figure 2. Global distribution of the mean E_p from 20 km to 30 km in the Northern Hemisphere winter of 2006.

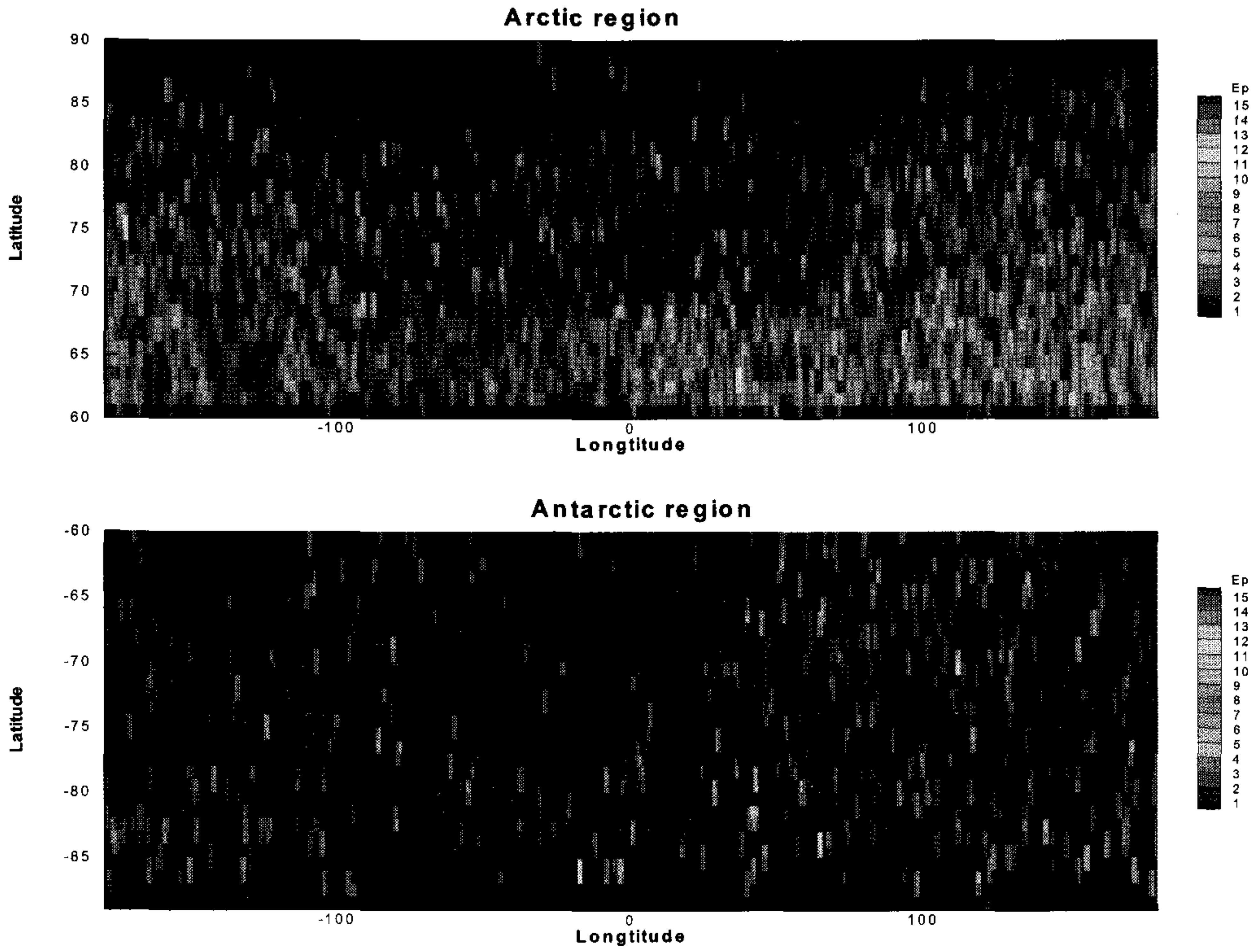

Figure 3. E_p distribution in the Arctic region and Antarctic region.

observations are valuable asset for gravity wave research and the more detailed global variations of gravity wave activity can be obtained. In the future, a more detailed study is underway to provide the detailed temporal and geographical variations of gravity wave activity and variations of gravity wave characteristics.

Acknowledgment

The authors acknowledge the National Science Council (NSC) of Taiwan for the support of grant NSC 95-2111-M-008-011-MY3.

References

Fritts, D. C., and M. J. Alexander, 2003, Gravity wave dynamics and effects in the middle atmosphere, Rev. Geophys., 41(1), 1003, doi:10.1029/2001RG000106.

Baumgaertner, A. J. G., and A. J. McDonald, 2007. A gravity wave climatology for Antarctica compiled from Challenging Minisatellite Payload/Global Positioning System (CHAMP/GPS) radio occultation, *J. Geophys. Res.*, 112, D05103.

Liou, Y. A., A.G. Pavelyev, S. F. Liu, A.A. Pavelyev, N. Yen, C.Y. Huang, C. J. Fong, 2007: FORMOSAT-3 GPS radio occultation mission: preliminary results, *IEEE Trans. Geosci. Remote Sensing*. (Submitted on October 5, 2006; accepted on April 24, 2007.)

Ratnam, M. V., G. Tetzlaff, and C. Jacobi, 2004. Global and Seasonal Variations of Stratospheric Gravity Wave Activity Deduced from the *CHAMP*/GPS Satellite, *Journal of atmospheric sciences*, 61, 1610-1620.

Tsuda, T., M. Nishida, G. Rocken, and R. H. Ware, 2000. A global morphology of gravity wave activity in the stratosphere revealed by the GPS occultation data, *J. Geophys. Res.*, 105, 7257-7273.

Ware, R., et al., 1996, GPS sounding of the atmosphere from low Earth orbit: Preliminary results, *Bull. Amer. Meteorol. Soc.*, 77, 19-40.

Wickert, J., T. Schmidt, G. Beyerle, R. Konig, and C. Reigber, 2004, The radio occultation experiment aboard CHAMP: Operational data analysis and validation of vertical atmospheric profiles, J. Meteorol. Soc. Jpn., 82(1B), 381– 395.