Initial comparison of the Arctic and Antarctic gravity wave field and their influence on the Stratosphere

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Abstract

Gravity waves have a significant influence on the atmospheric mean state, dynamics and chemistry [Fritts and Alexander, 2003]. By transporting energy and momentum from their source regions in the troposphere into the middle atmosphere, gravity waves play an important role in driving the general circulation of the atmosphere. In the Arctic and Antarctic gravity waves have also been found to have an influence on the formation of polar stratospheric clouds (PSCs) [Cariolle et al., 1989; Palm et al., 2005] which play an important role in ozone depletion.

This study describes observations of temperature and the gravity wave field made with GPS radio occultation observations made with the Challenging Mini-satellite Payload (CHAMP) experiment. Radio occultation is an active remote sensing technique which examines transmissions passing through the atmosphere from GPS satellites using a sensitive receiver onboard a Low-Earth-Orbiting (LEO) satellite. The dual-frequency radio signals transmitted by GPS satellites, normally used for position measurements, are bent as they pass through the earth's atmosphere due to variations in the radio refractive index. The bending angles derived from the measurements onboard the LEO can then be inverted to produce high resolution measurements of atmospheric temperature. These temperature measurements can in turn be examined to identify gravity wave activity in the lower to upper stratosphere (approximately 15 to 35 km). This study examines the differences between the Antarctic and the Arctic temperature and gravity wave fields and discusses the relative importance of these waves on PSC formation in the two regions.

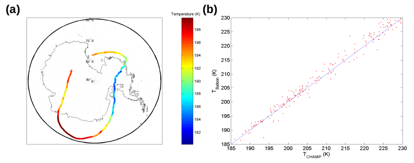

Figure 1 Temperature measured along the trajectory of a long-duration balloon flight associated with the VORCORE campaign (a). Comparison between co-located near-simultaneous temperature observations measured by all the VORCORE balloons and those measured by the CHAMP satellite (b). Blue line displays the one to one line.

Results 1

Figure 1 (b) illustrates the accuracy of the CHAMP temperature measurements by comparing these observations to in-situ temperature measurements made by instruments on long-duration balloon flights made during the VORCORE campaign [Hertzog et al., 2007]. The comparison shows excellent agreement between these two sets of measurements and a very small bias of 0.4K between the two instruments mean values. This close agreement between these instruments agrees with numerous previous studies which have indicated the accuracy of the CHAMP data. Figure 1 (a) shows the temperatures measured along the trajectory of a single long duration balloon flight associated with the VORCORE campaign.

Introduction

Observations from the CHAMP (Challenging Mini-satellite Payload) GPS radio occultation (RO) instrument provide a well quality controlled atmospheric data set with global coverage and high vertical resolution in the troposphere and stratosphere. The RO technique [Kursinski et al., 1997] uses the fact that radio waves propagating through the atmosphere are bent by variations in the radio refractive index to retrieve temperature information. Vertical profiles of atmospheric refractivity are first derived from bending angle profiles determined by the very precise timing provided by GPS signals.

Several recent studies have used RO satellite observations to examine small-scale structures in the temperature field that can not be observed by the majority of other satellite instruments. The most significant of these small-scale structures are internal gravity waves. These waves have a significant influence on the atmospheric mean state, dynamics and chemistry [Fritts and Alexander, 2003] by transporting energy and momentum from their source regions in the troposphere into the middle atmosphere. In the Arctic and Antarctic the temperature perturbations associated with these waves has also been found to have an influence on the formation of polar stratospheric clouds [Cariolle et al., 1989; Palm et al., 2005]. This poster aims to highlight the utility of CHAMP data for examining gravity waves and to examine whether the temperature perturbations associated with these waves are likely to have an impact on early PSC formation in both hemispheres.

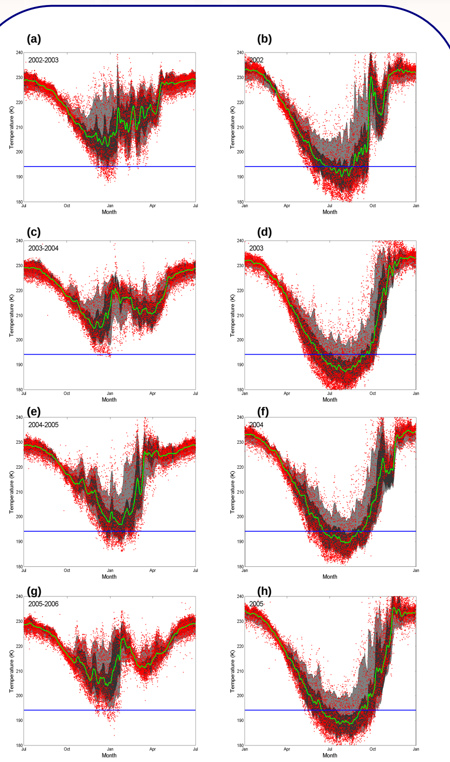

Figure 2 Seasonal variation of temperature for the northern hemisphere (a, c, e and g) and Southern hemisphere (b, d, f and h). The green line indicates the mean temperature from NCEP/NCAR reanalyses, the dark grey envelope shows the 25th to 75th percentile, the light grey envelope shows the 10th to 90th percentiles. These envelopes are derived from all the temperatures between 60° to 90°N (a, c, e and g) and 60° to 90°S (b, d, f and h) associated with the NCEP/NCAR reanalyses, respectively. The red dots display individual measurements from the CHAMP satellite. Both sets of observations relate to an altitude of 16 km.

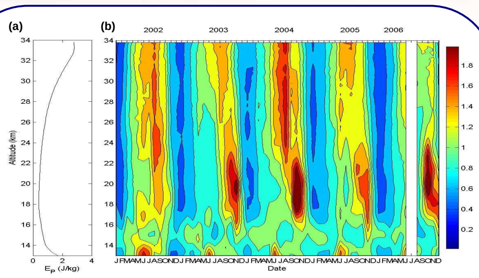

Figure 3 Mean potential energy per unit mass associated with gravity waves as a function of altitude for 2002 to 2006 for 60°S to 90°S (a). Time and height dependence of normalized potential energy per unit mass (b). Monthly means of all the individual potential energy per unit mass profiles over Antarctica were formed. The results at each altitude were then normalized by dividing the value for each month by the mean value over the entire period from this altitude.

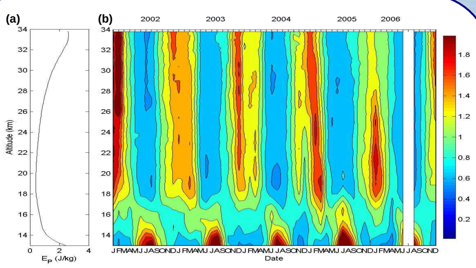

Figure 4 Mean potential energy per unit mass associated with gravity waves as a function of altitude for 2002 to 2006 for 60°N to 90°N (a). Time and height dependence of normalized potential energy per unit mass (b). Monthly means of all the individual potential energy per unit mass profiles over Arctic were formed. The results at each altitude were then normalized by dividing the value for each month by the mean value over the entire period from this altitude.

Results 2

Figure 2 shows the seasonal variation in temperature for the Arctic (60° to 90°N) and Antarctic (60° to 90°S) for a number of years from the NCEP/NCAR realyses dataset (green line shows the mean and the greyed regions show the distribution of the data) and the CHAMP data (red dots). Note the time axis has been transformed so that the winter season is in the centre of each diagram. The temperature necessary for PSC formation to occur is also displayed in Figure 2 as a blue line. Examination of the data from the southern hemisphere suggests that individual CHAMP observations fall below the PSC formation temperature each year between late May and early June. The mean temperature associated with the NCEP/NCAR reanalyses also passes this threshold each year in the southern hemisphere. In the northern hemisphere individual CHAMP observations pass the PSC formation threshold in December. The mean of the NCEP/NCAR observations does not pass this threshold. This suggests that small temperature perturbations, such as those associated with gravity waves, may have an influence on PSC formation in the early winter.

Figure 3(a) and 4(a) display the mean potential energy per unit mass, a measure of gravity wave activity which is directly related to the magnitude of temperature perturbations, as a function of altitude for 2002 to 2006 for the Antarctic (60° to 90°S) and Arctic (60° to 90°N) regions, respectively. Comparison of these figures highlights the very similar forms of the potential energy per unit mass mean profiles over these regions. Figure 3(b) and 4(b) display the time-altitude dependence of the normalized potential energy per unit mass. The values have been normalized by dividing the value for each month by the mean value over the entire period at that altitude. Comparison of these figures also shows a number of similarities these include:

- i, A strong annual variation in the normalized potential energy per unit mass is evident above 16 km.
- ii, The maximum of the seasonal variation occurs in the winter to spring period in both hemispheres.
- iii, A different seasonal structure is observed below 16 km.

Comparison of these figures also displays a number of differences, these include:

- i, The annual variation of the normalized potential energy per unit mass is stronger in the southern hemisphere than the northern hemisphere in general.
- ii, The inter-annual variation in the northern hemisphere winter seems to be larger than in the southern hemisphere when the 2002 southern hemisphere winter is excluded.

These findings support work by Baumgaertner and McDonald (2007) and Ratnam et al.(2004) who indicated that the gravity wave field in Antarctica is significantly affected by the strength of the background winds. It should be noted that the Antarctic background winds are significantly stronger than those in the Arctic. Ratnam et al. (2004) suggested that the gravity wave field over Antarctica in 2002 was significantly disrupted.

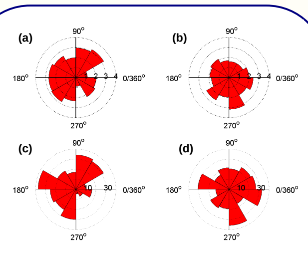

Figure 5 Polar diagrams of the potential energy per unit mass in the Antarctic (a) and the Arctic (b) at different longitudes. Polar diagrams of the percentage of CHAMP temperature observations below the PSC formation threshold in the Antarctic (c) and Arctic (d) at different longitudes. Both sets of observations relate to an altitude of 16 km.

Results 3

Figure 5 displays polar diagrams which indicate the average potential energy per unit mass in a longitude sector (a and b) and the percentage occurrence of temperatures below the PSC formation temperature (c and d) in May in the southern hemisphere (a and c) and December in the northern hemisphere (b and d). Comparison suggests that high PSC occurrences do not necessarily match sectors with high potential energy per unit mass values in the southern or northern hemisphere. In addition, the potential for PSC formation seems to be greatest in the European sector in the northern hemisphere. This suggests that while gravity wave temperature perturbations may be important other factors such as planetary scale wave temperature perturbations are also likely to be a factor in early winter PSC formation.

Conclusions

This study examines temperature data from the CHAMP radio occultation satellite to derive gravity wave data in the Arctic and Antarctic and to determine whether gravity waves are likely to have a significant impact on the occurrence of PSCs. Comparisons of the temperatures derived from the CHAMP satellite observations and in-situ temperature measurements onboard long-duration super-pressure balloon flights associated with the VORCORE campaign suggest that the satellite observations are accurate. Further comparison of the radio occultation temperatures with those taken from the NCEP/NCAR reanalyses indicates that small temperature perturbations may be important in producing the temperatures necessary for PSC formation in some periods, particularly early winter. Metrics of the gravity wave activity, potential energy per unit mass, show similar seasonal patterns in the Arctic and Antarctic and very similar variations with altitude. Comparison of PSC formation temperature occurrence and potential energy per unit mass suggests that while gravity wave temperature perturbations may be important other factors such as planetary scale wave temperature perturbations are also likely to be a factor in early winter PSC formation.

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