Journal of Atmospheric and Solar-Terrestrial Physics 71 (2009) 75–87

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Planetary waves observed by TIMED/SABER in coupling the stratosphere–mesosphere–lower thermosphere during the winter of 2003/2004: Part 2—Altitude and latitude planetary wave structure

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ARTICLE INFO

Article history:
Accepted 30 September 2008
Available online 17 October 2008

Keywords:
Sudden stratospheric warming
Stationary
Zonally symmetric and travelling planetary waves
Standing waves
Filtered gravity waves

ABSTRACT

Part 2 of the present paper is focused on the planetary wave coupling from the stratosphere to the lower thermosphere (30–120 km) during the Arctic winter of 2003/2004. The planetary waves seen in the TIMED/SABER temperature data in the latitudinal range 50°N–50°S are studied in detail. The altitude and latitude structures of the planetary wave (stationary and travelling) clearly indicate that the stratosphere and mesosphere (30–90 km) are coupled by direct vertical propagation of the planetary waves, while the lower thermosphere (above 90–95 km altitude) is only partly connected with the lower levels probably indirectly through in-situ generation of disturbances by the dissipation and breaking of gravity waves filtered by lower atmospheric planetary waves. A peculiar feature of the thermal regime in the lower thermosphere is that it is dominated by zonally symmetric planetary waves.

1. Introduction

The dynamics of the middle atmosphere in winter are known to be dominated by planetary waves of large amplitudes. The most important are quasi-stationary Rossby waves and travelling normal modes, also known as free modes with periods around 2, 5, 10 and 16 days. The interaction of the planetary waves and the zonal mean flow is known to be the major driver of winter stratospheric dynamics (Andrews et al., 1987). Classical studies showed that the zonal mean flow affects the planetary wave propagation by changing the refractive index (Charney and Drazin, 1961). Time-varying or dissipating planetary waves interact with the zonal mean flow and alter it dramatically, as happens in sudden stratospheric warmings (SSW). The time period preceding the onset of a SSW is usually characterized by high wave activity in the middle atmosphere during which more than one type of planetary waves may be present.

The problem of planetary wave coupling between the stratosphere and mesosphere has attracted significant attention only recently. It is supposed that much of the variability in the mesosphere and lower thermosphere (MLT) is a result of upward propagation of disturbances from the stratosphere, particularly during the winter. Analysis of stratosphere data by Krüger et al. (2005) prior to the first Southern Hemisphere (SH) major SSW revealed wave interactions between eastward propagating waves with periods near 10 days, quasi-stationary planetary waves and the zonal mean flow. This finding was supported by the temperature observations between 20 and 120 km from the TIMED/SABER instrument during the 60 days before the onset of the SH major SSW, 26 September 2002, and the results were presented by Palo et al. (2005). The authors showed that the wave

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doi:10.1016/j.jastp.2008.09.027

interactions between the eastward propagating 10-day waves with zonal wavenumbers 1 and 2, and a stationary planetary wave with zonal wavenumber 1 (SPW1) took place prior to the major SSW and it was found that these wave extend from the lower stratosphere up to the 100–120 km height. Dowdy et al. (2004) and Espy et al. (2005) found that after the onset of this major SSW the dynamical regime of the mesosphere was dominated by a travelling 14-day wave with zonal wavenumber 1. Later Chshyolkova et al. (2006) analyzed UK Met Office (UKMO) assimilated data together with mesospheric winds provided by five MF radars to investigate the vertical and latitudinal coupling processes due to planetary waves in December 2000–2002. They also found a strong 14-day planetary wave during the austral winter of 2002 and suggested that this oscillation was generated at lower heights and propagated upward.

Using the UKMO and mesospheric radar data Mukhtarov et al. (2007) examined the features of the large-scale thermo-dynamic anomalies present in the stratosphere and mesosphere of the Northern Hemisphere (NH) during the Arctic winter of 2003/2004. Utilizing the same data Pancheva et al. (2008a) later investigated the vertical coupling of the stratosphere–mesosphere system through quasi-stationary and travelling planetary waves present in the horizontal neutral winds, while the coupling of the dynamical regimes in the high- and low-latitude stratosphere and mesosphere through zonally symmetric waves during the major SSW in the Arctic winter of 2003/2004 was reported in Pancheva et al. (2008b).

As mentioned earlier, temperature measurements from the SABER instrument on the TIMED satellite are very suitable for studying the altitude and latitude structures of the planetary wave from the lower stratosphere up to the lower thermosphere. In Part 1 of this paper (Pancheva et al., 2008c), a new method for analysis of satellite data were presented where the migrating and nonmigrating tides and the planetary waves (stationary, zonally symmetric and travelling) were extracted simultaneously from the satellite data. The comparison between the altitude and latitude structures of the SABER and UKMO planetary waves in the temperature field of the NH (0–50°N) stratosphere (30–60 km) indicated a high degree of qualitative and quantitative resemblance and in this way the validity of the data analysis method was verified as well. It was found also that there is some difference between the features of the UKMO planetary waves observed in the temperature with those in the neutral winds reported by Pancheva et al. (2007) and Pancheva et al. (2008a).

The main purpose of Part 2 is to examine the spatial structure (latitude and altitude) and temporal evolution of the planetary waves seen in the TIMED/SABER temperature measurements for altitudes between 30 and 120 km and latitudes between 50°N and 50°S during the period of 1 October 2003–31 March 2004. This winter period is characterized be a major SSW in late December/January when the polar vortex was disrupted in the middle and lower stratosphere for a period of nearly 2 months (Manney et al., 2005) and a final SSW which took place in the second half of April. The emphasis is on the vertical coupling from the stratosphere to the lower thermosphere through different planetary waves (stationary, zonally symmetric and travelling waves) as for this purpose only one type of data is utilized.

2. Spectral analysis of the TIMED/SABER temperature data

It was mentioned in the Part 1 that our results are derived from the version 1.06 of SABER level 2A data, which are downloaded from the web site: http://saber.gats-inc.com. The details about the TIMED/SABER temperature data have been presented in Part 1 (Pancheva et al., 2008c).

The predominant periods of the planetary waves present in the SABER temperature data for the entire altitude range (30–120 km) are obtained by a two-dimensional analogue of the Lomb–Scargle periodogram method (Lomb, 1975; Scargle, 1982). The planetary waves with periods between 3 and 30 days and with zonal wavenumbers up to 3 are studied. As the emphasis is on the role of the wave forcing in preconditioning the atmosphere prior to the major (end of December/January) and final (middle of March) SSWs, which took place in the winter of 2003/2004, the amplitude spectra and the altitude structure of the planetary waves will be examined at the highest possible latitude in the NH, or at 50°N.

Fig. 1 shows the altitude amplitude spectra at 50°N latitude of: the zonally symmetric ($s = 0$) waves (upper plot), eastward (left column of plots) and westward travelling waves (right column of plots). To facilitate the comparison between the strength of the spectral peaks for the eastward and westward propagating waves, the same scales have been used in Fig. 1. The results from the spectral analysis can be summarized as follows: (i) quite surprisingly, the strongest spectral peaks turn out to be those for the zonally symmetric waves observed in the lower thermosphere; (ii) the spectral peaks of the westward travelling waves, particularly those for the zonal wavenumber 1, are significantly stronger than the eastward ones not only for the stratosphere, as it was shown in the Part 1, but for the mesosphere and lower thermosphere as well; (iii) there are three altitude ranges of the reinforcement of the spectral peaks: ~40, 70–80 and ~110 km; these ranges are better outlined for the westward travelling waves; and (iv) four prevailing periods observed in the stratosphere and mesosphere can be distinguished from the spectra: ~24, 15–17, 10–12 and 5–6 days. Similar spectral peaks are present in the lower thermosphere as well; however, there is a tendency of bifurcation of each peak into two peaks situated near the main one. This is particularly visible for the strong westward travelling waves with zonal wavenumber 1 (W1 planetary waves).

The spectral analysis indicated that the largest planetary waves present in the stratosphere–mesosphere–lower thermosphere system during the Arctic winter of 2000/2004 are the zonally symmetric and W1 planetary waves with the periods: ~24, 15–17, 10–12 and 5–6 days; therefore these waves will be further investigated in