Estimation and Attribution of the Temperature Variances in the Stratosphere

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Introduction

Planetary scales are the dominant form of the stratospheric disturbances. Theoretical studies explain the features of the vertical propagation of planetary Rossby waves from the troposphere into the stratosphere (Charney and Drazin, 1961; Dickinson, 1968). The refraction in the meridional and the damping by critical layer absorption of the waves result in wave forcing on the zonal circulation (Dickinson, 1969; Matsuno, 1970). The Brewer-Dobson circulation (BDC) that dominates the meridional transport of trace gases in the stratosphere is also controlled by the wave forcing (Haynes et al., 1991; Holton et al., 1995). Recent simulation studies using general circulation models (GCMs) all predict intensification in the BDC under the global warming in climate due to the increase in greenhouse gases (Buchart and Scaife, 2001; Rind et al., 2001; Sigmond et al., 2004; Buchart et al., 2006; Eichelberger and Hartmann, 2005; Formichev et al., 2006; Olsen et al., 2007; Garcia and Randel, 2008). Some of the simulations suggest that the BDC intensification is correlated to the increase in the wave forcing (Eichelberger and Hartmann, 2005; Formichev et al., 2006;Olsen et al., 2006; Garcia and Randel, 2008).

Travelling planetary Rossby waves in the stratosphere, their spatial structure and phase speeds of these waves are determined by the resonance properties of the atmosphere,. are also reported in the researches using ground based measurements and satellite observations, e.g., those using Lidar observations, Hauchecorne and Chanin (1983), Hauchecorne et al. (1987), Hauchecorne et al. (2006); and using rocket data, Offerman et al. (1987) Bittner et al. (1994); and satellite data (Prata, 1989).

Moreover, among the waves of planetary scale in the middle atmosphere are the thermal tides that are most prominent in the mesosphere and lower thermosphere. The general features of the stratospheric diurnal tides are estimated by Wallace and Tadd (1974) using long records of 2- and 4- daily rawinsonde data of winds at various stations. They note that the diurnal tide at 30-hpa (24 km) exhibits large wind speed but only oscillate with period of 24 h without propagation, which is in agreement with the calculation of Lindzen (1967) suggesting that the (1, -2) Hough mode dominates the global diurnal tide at these altitudes. Subsequent estimation results by Wallace and Hartranft (1969) further show that in the stratosphere at high latitudes, the phase in the vertical are similar to Lindzen's (1967) theoretical calculations, but the tidal amplitudes are substantial larger than the theoretical calculations. Recently, Alexander and Tsuda (2008) report their estimation results with respect to the stratospheric diurnal tide at the Equator and at tropical Australia.

Data

The SABER/TIMED temperatures collected during 2002 to 2008 are used to estimate the variances of temperature (Temp-VARs) that in turn represent the contributions of the non-stationary perturbations. The data products of the most updated version 1.07 and of Level 2A data-set can provide the measurements of temperature, pressure, density and the concentration of several kind of trace gasses of the atmosphere from the upper troposphere to 140 km.

T-SDEVs (K) vs latitude and height in eight meridians

All the meridians show considerable resemblance in the latitude-height features of the Temp-SDEVs, which suggests the predominance of travelling disturbances of planetary scale. It is observed that the late-winter season is characterized by the strong wave activity, in particular at extra-tropical and high latitudes, as is shown in the top panels describing the Temp-SDEVs in boreal and austral lat-winter.

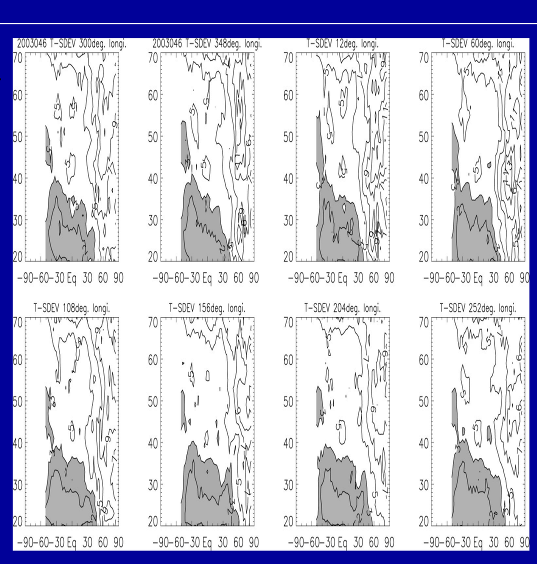


Fig. 4 Late-winter YP on 2003046, shading for Temp-SDEVs ≤ 3 K

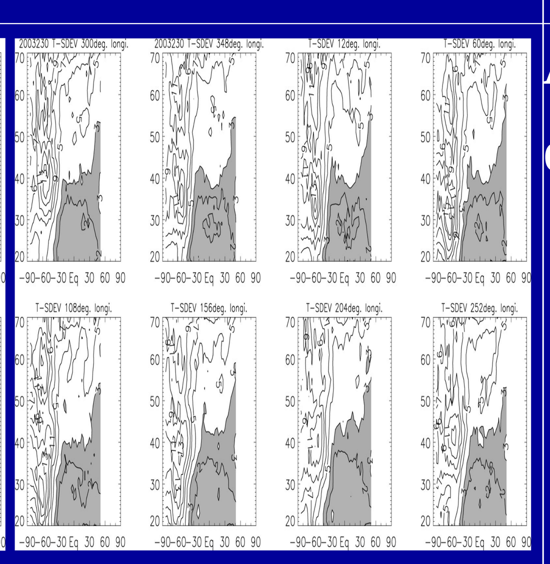


Fig. 5 Austral Late-winter YP on 2003230

Pre-processing

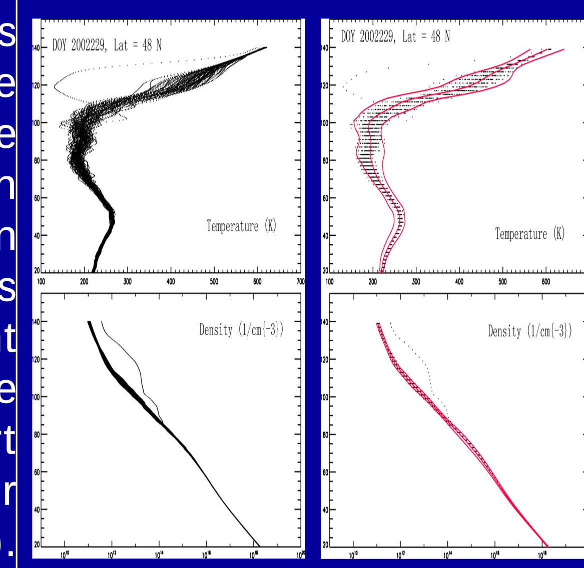


Fig. 1 A general data reduction in the vertical was carried out with each profile. Left Panel shows the profiles of temperature collected in 3° latitude width at the Equator during one day. Considering the 2-km width of the Field Of View (FOV) at tangent heights, the variable in a profile is averaged every 2 km interval to yield a standard vertical profile of the variable in 20-140 km range and saved for subsequent analysis (right Panel).

A quality control procedure (QC) was further applied with the standard vertical profiles. A global reference data-set of error statistics is created at a regular 3-dimensional (3-D) mesh covering the globe. The mesh consists of 15 meridians of 24° longitude width, 55 zonal cycles of 3° latitude width that centered at latitudes from 82° S to 82° N. In the vertical, it covers 20—140 km with 2 km interval.

Two-year long data in 2003and 2004 were used to estimate the error statistics for each grid box, e.g., the standard deviation σ_{ref} and the mean of each variable.

These statistics are used to control the quality of the variable in each standard profile. Figure 2 shows an example of all the profiles in the zonal cycle centered on the Equator on one day. Red curves (also shown in the right of the two left Panels) show the zonal mean T in the reference data-set and the range, ~4 σ ref. The data outside the range are removed (shown in the right of the two left Panels).

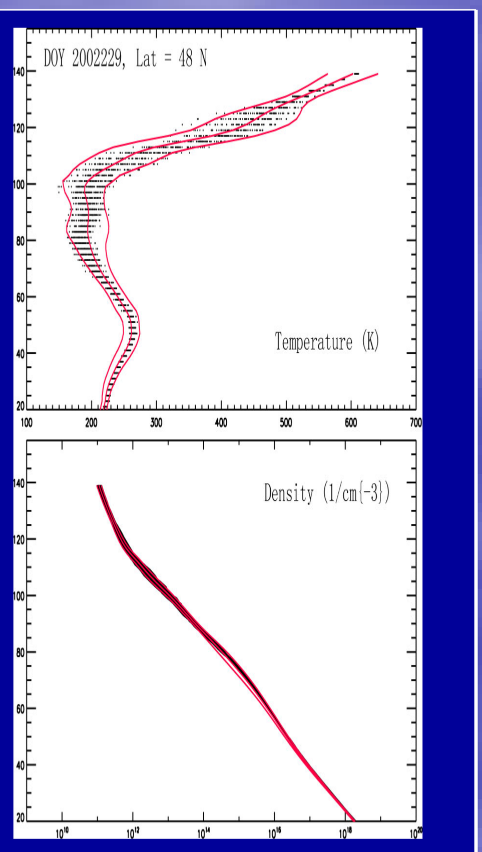


Fig. 2 demonstration of the results after the QC procedure.

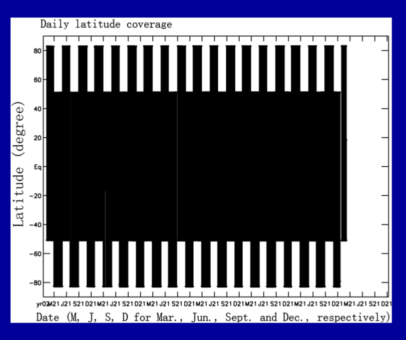


Fig. 3 The Yaw Periods in 2002—2008. Yaw maneuver scheme of the SABER/TIMED

Estimation of Temp-VARs in 20—70 km height

Six yaw periods every year.

- DOY 46 -- late-winter
- DOY 109– spring
- DOY 169 -- mid-summer
  - – Austral mid-winter
- DOY 231 -- late-summer
  - – Austral late-winter
- DOY 293 – autumn
- DOY 352 -- mid-winter
  - – Austral mid-summer

One yaw period consists of 60 days with the same major hemisphere

Estimates covering 52° to high latitudes (83°) in the other hemisphere

Major-hemisphere

From 52° latitude in one hemisphere to 83° latitude in the other hemisphere

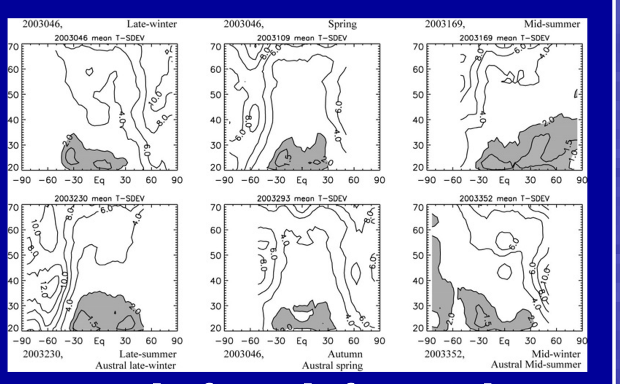


Fig. 6 Top Panels from left to right are late-winter, spring, mid-summer, respectively; the corresponding bottom Panels are the same austral seasons, respectively. Temp-SDEVs ≤ 2 K are shaded.

Annual course of the mean Temp-SDEVs over the 15 meridians

Figure 6 shows, for example, the annual cycle of 2003 the latitude-height cross section of Temp-SDEVs. During late-winter, the high latitudes in both hemispheres exhibit most prominent Temp-SDEVs with maximal value exceeding 8 K. Meanwhile, two maxima of Temp-SDEVs in austral late-winter (bottom left Panel), one locates at 35 km, another at 60 km; Against the austral feature, only one maximum Temp-SDEVs tilting pole-ward from extra-tropical upper stratosphere is seen in the boreal late-winter (top left Panel).

Across the tropics and the Equator, a quiescent slab is located at 20 km height where T-SDEVs reach a minimum, less than 1.5 K. Above the slab, the T-SDEVs increases monotonically and slowly with height, but less than 4 K until 40 km year around.

In both boreal and austral mid-summer, the slab extends pole-ward to high-latitudes in the summer hemisphere, then, large T-SDEVs greater than 4 K can only be seen in the extra-tropics of the opposite hemisphere.

Tidal contribution to Temp-SDEV

Scheme of tidal delineation

- Fourier Least-Squares fit
  - *– diurnal harmonics*
- FFT
  - *– zonal wavenumber components*

Chen and Lu, 2007, Chin. J. Geophys.(English endition), 50(3), 606.

Chen and Lu, 2008a, Chin. Phys. Lett. (in English), 25(4), 1510.

Chen and Lu,,2008b, Chin. Phys. Lett. (in English), 25(6), 2323.

Figure 7 shows the comparison between the Temp-SDEVs (left column) and the temperature standard deviations of the migrating diurnal (intermediate column) and semidiurnal (right column) tides, referred to as tidal Temp-SDEVs.

Significant migrating diurnal tidal Temp-SDEVs are observed at the tropics, in particular at the stratopause in spring hemisphere. Significant activity of the diurnal tide is frequently seen in the polar region, for instance, maximum of the tidal Temp-SDEVs is seen at the stratopause during boreal late-winter but at mid-stratosphere during austral late-winter, it is also seen in the lower stratosphere during the autumn for both hemispheres.

Tidal Temp-SDEVs of migrating semidiurnal tide exhibits more simple latitude-height distribution. In general, significant wave activity is only seen at high latitudes in the seasons except mid-summer.

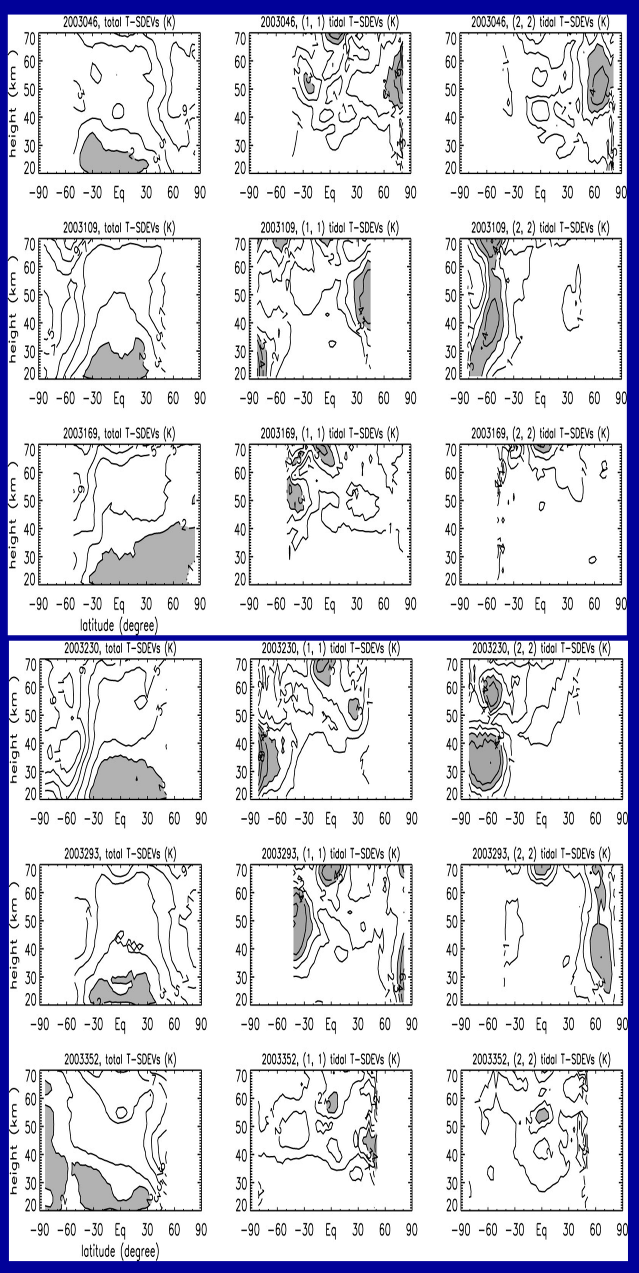
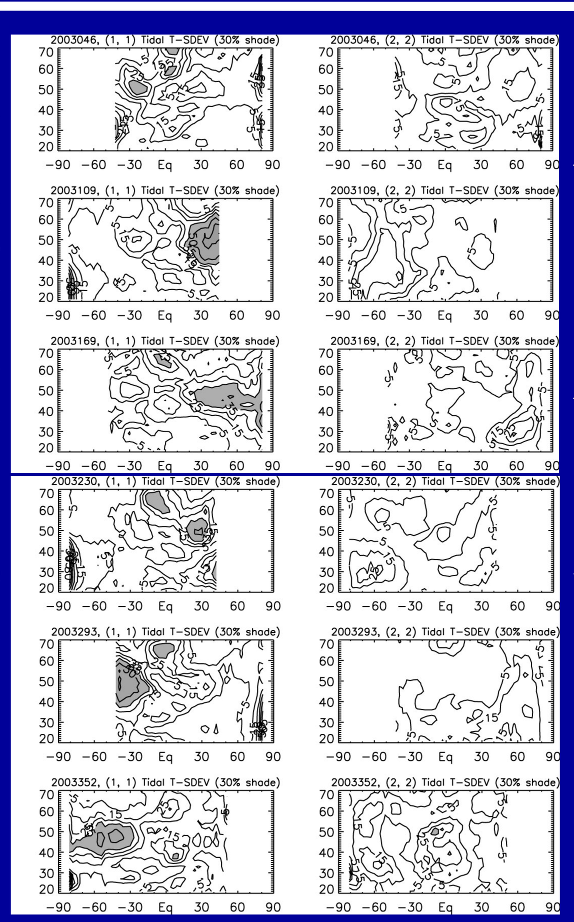


Fig. 7 Left column show the annual cycle of Temp-SDEVs, mid-column the migrating diurnal tidal Temp-SDEVs, and right column the migrating semidiurnal tidal Temp-SDEVs. While shading in the left column is for Temp-SDEVs ≤ 2 K, the shading in the mid- and the right columns indicate Temp-SDEVs ≥ 2 K.

Figure 8 shows tidal contributions to the Temp-VARs, which is measured by the ratio of the tidal Temp-VARs to the Temp-VARs. The Left column show the ratio (%) of migrating diurnal Temp-VARs to the total Temp-VARs (shading for the ratio ≥50%), and the right Panels the ratio (%) for migrating semidiurnal tide.

In the spring hemisphere, the migrating diurnal tidal Temp-VARs can account for greater than 50% of the Temp-VARs at sub-tropical latitudes in height range 40~60 km. The same amount contributions are also seen in mid-summer hemisphere at latitudes ranging from subtropics to polar region in 40—50 km range.



In all the seasons, the tidal contributions are always seen in the polar lower stratosphere. Migrating semidiurnal contributes significant temperature variances during autumn season in the middle stratosphere at high latitudes.

In the late-winter season in both hemispheres, tidal contributions are found to be substantially weak, which suggests that the most predominant wave activities are the travelling planetary Rossby waves. For example, the extra-tropical stratosphere that are characterized by most prominent Temp-SDEVs is found to be free of the diurnal contributions. Meanwhile, the contributions of the semidiurnal tide is significant with the ratio attaining 15%, that is small.

Conclusion

The general features of the travelling planetary waves in the stratospheric portion (20~70 km) are estimated in term of temperature standard deviations. The Equatorial lower stratosphere at 20 km height is characterized by a substantial weak activity of the waves, where Temp-SDEVs are less than 2 K. T-SDEVs increases monotonically and slowly with height, but less than 4 K until 40 km all year around.

Tidal temperature variance contribution are estimated. The results suggest that the migrating diurnal tide is of substantial importance in accounting for the Temp-VARs, in particular during the spring sub-tropics of both hemispheres in 40—60 km heights, and during mid-summer from sub-tropics to polar region in 40—50 km range, where and when the contribution of the migrating diurnal tide can account for 50%. Significant contributions of the migrating diurnal tide are also seen in the whole of the polar stratosphere in autumn and late-winter.

It is also observed that the most prominent Temp-SDEVs appear during late-winter in the extra-tropical latitudes for both hemispheres. Moreover, the Temp-SDEVs do not contain tidal contributions, which suggests the predominance of travelling planetary Rossby waves.

Abstract No 00006; SPARC 2008, Aug 31--Sept 6, Bologna, Italy