Excitation of stratospheric planetary waves by the Asian high heating center

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Abstract

We studied the topographic heating center over the Tibetan and Persian plateaus that forms the Asian high to try to understand its effects on circulation in the stratosphere. The results show that the heating center at 300 hPa excites planetary waves which can be propogated into the southern hemisphere. The u wind regression field demonstrates the planetary wave propogates from the northern to the southern hemisphere. Once the planetary wave is propagated to the southern hemisphere, then it forms another three-wave train, which strengthens as it propagates upward. The wave propogation channel is at the upper troposphere above the equator. The results also denote that the heating center of Asian high may contribute to the QBO in the stratosphere which mechanism needs to be argued deeply. These results partially explain why there are planetary waves in the stratosphere of the southern hemisphere.

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Key Points:

- Planetary waves excited by the heating center of the Asian high affects the circulation in the stratosphere in the southern hemisphere
- The heating center generates zonal wind planetary waves in the northern hemisphere that cross the equator via a channel at the upper troposphere into the southern hemisphere
- The heating center of the Asian high may contribute to the QBO (quasi-Biennial oscillation) in stratosphere above the equator (15°S-15°N)

Abstract

We studied the topographic heating center over the Tibetan and Persian plateaus that forms the Asian high to try to understand its effects on circulation in the stratosphere. The results show that the heating center at 300 hPa excites planetary waves which can be propogated into the southern hemisphere. The u wind regression field demonstrates the planetary wave propogates from the northern to the southern hemisphere. Once the planetary wave is propagated to the southern hemisphere, then it forms another three-wave train, which strengthens as it propagates upward. The wave propogation channel is at the upper troposphere above the equator. The results also denote that the heating center of Asian high may contribute to the QBO in the stratosphere which mechanism needs to be argued deeply. These results partially explain why there are planetary waves in the stratosphere of the southern hemisphere.

1 Introduction

The Asian high is a huge anticyclone in the upper troposphere and lower stratosphere. It is formed over the Tibetan and Persian plateaus in summer and covers almost half the northern hemisphere. The Asian high has an important role in controlling the climate in Asia and also influences the troposphere. The Asian high has a crucial effect on aerosols in the stratosphere and influences microphysical and radiative processes in the mid-levels of the atmosphere.

The Asian high was first reported in the south Asian summer in 1963 (Mason and Anderson 1963). The structure and time–frequency variation of the anticyclone have been described by Jijia Zhang, Yongqing Peng and Dingliang Wang (1980). Tao Shiyan and Zhu Fukang (1964) suggested that the circulation of the Asian high at 100 mbar varies with the position of the subtropical high over the west Pacific. The Asian high is an important part of the East Asian summer monsoon and a close relationship with the movement of the precipitation belt in east Asia has been observed (Guiying Chen and Quansun Liao, 1990; Yongren Chen, Yueqing Li and Dongmei Qi, 2011; Shuaihong Guo, Lijuan Wang and Miao Wang, 2014; Siwei Luo, Zhengan Qian and Qianqian Wang, 1982).

A number of studies have shown that the Asian high can transport material from the troposphere to the stratosphere outside the tropics. The first evidence of this was the observation of an ozone valley over the Tibetan Plateau in summer by Zhou and Luo (1994) using data from the Total Ozone Mapping Spectrometer onboard the Nimbus-7 satellite. Many different mechanisms have been suggested to explain the formation of this ozone valley (Qiu YY, Wei M and Jiang AL et al. ,2008; Ye ZJ and Xu YF, 2003; Zou H, 1996; Zhou SW, and Zhang RH, 2005; Cong C, Li W and Zhou X, 2001; Liu Y, Li W and Zhou X, 2003) and it is thought that the main mechanism is the transport of ozone from the lower troposphere to the upper troposphere and lower stratosphere via dynamic processes, combined with trapping by the Asian high (Randel, Park and Emmons et al., 2010).

The Asian high extends into the lower stratosphere, but rapidly disappears in the stratosphere and is absent at 70 mbar (Chongyin Li, Lin Li and Yanke Tan, 2011). Yie and Zhang (1974) reported that heating of the ground surface on the Tibetan Plateau is the major mechanism of formation of the Asian high, but details of the anomalous heating center and its influence on the global circulation, especially in the stratosphere and southern hemisphere, are still unclear. This paper presents a different view of the influence of the Asian high on the global circulation of the stratosphere and southern hemisphere via planetary waves. Section 2 introduces the data and methods, the results are given in Section 3 and our conclusions in Section 4.

2 Data and Methods

ERA-Interim temperature and height data for the time period 1979–2016 are used to analyze the three-dimesional thermal structures of the Asian high at a resolution of 1.5°×1.5° and 37 levels (www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim). We use regression analysis to detect the influence of the heating center of the Asian high on stratospheric circulation in the southern hemisphere. Regression analysis can help us to understand how the dependent variable changes when any one of the independent variables is varied and the other independent variables are fixed.

3 Results

Figure 1 shows cross-sections of temperature (color) and geopotential height (solid line) along 30° N over the Tibetan and Iranian plateaus. Figure 1a shows the climatology of the geopotential height (solid line) and temperature (color) over the time period 1979–2016 near the Asian high in the upper troposphere and lower stratosphere. The figures show the geopotential height from 500 to 10 hPa because the height of Tibetan Plateau can reach around 500 hPa and the Asian high is generally in the lower stratosphere. There is a cold core between 150 and 50 hPa and the warm center is near the background height over the plateaus. There is therefore a large temperature gradient between 500 and 100 hPa. The temperature gradient in the stratosphere is small relative to that in the troposphere. The heating caused by longwave radiation is very strong near the background height, whereas the heating in the stratosphere results from the absorption of shortwave radiation from sunlight by O_3 and longwave radiation from the Earth's surface (about 20%).

Figure 1b shows the anomalous temperature (color) and geopotential height (solid line) along 30° N latitude over the plateaus after removal of the zonal mean. There is a warm area from 500 to 150 hPa and a cold area from 100 to 50 hPa. The warm area is centered at about 300 hPa at 80° E, whereas the cold center is centered at about 70 hPa at 75 °E. The temperatures of the centers are both >6°C. The temperature decreases toward the northwest from 500 to 150 hPa;

150 hPa is the interface between the anomalous warm and cold centers over the plateaus. The warm anomaly covers almost all the eastern hemisphere in the longitudinal direction. The largest positive anomaly in the geopotential height is at about 150 hPa and covers almost all of the Tibetan and Persian plateaus from about 400 to 50 hPa in the vertical direction. The Asian high is usually a large anticyclone at 200 and 150 hPa. It can also be seen at 300 hPa and then disappears at 50 hPa (not shown).

There is a positive anomaly in the geopotential height at 150 hPa and a warm center at a different height of 300 hPa. This is because baroclinic processes in the mid-latitude atmosphere result in a phase difference between the geopotential height and the warm center at the same level. The warm area extends to 150 hPa and then rapidly becomes colder. This is because the atmosphere over the plateaus is heated by the background longwave radiation and latent heat from convection in the mid- and lower troposphere. The heating effects of the background and latent heat weaken rapidly in the upper troposphere. By contrast, the stratosphere is heated via the absorption of shortwave radiation from sunlight by O_3. Many studies (Dong Guo et al., 2015; Zhou Xiuji et al., 1995; and Dong Guo et al. 2015) have shown that there is a center of low O_3 over Tibet as a result of the dynamics of the Asian monsoon. That is why the warm center rapidly disappears in the upper troposphere.

We found that 300 hPa is the key level for warming the whole atmosphere over the area of the plateaus. Regression analyses were carried out on the geopotential height and *u* and *v* wind fields for the time series of the temperature of the warm center at 300 hPa to determine its influence on the global air circulation.

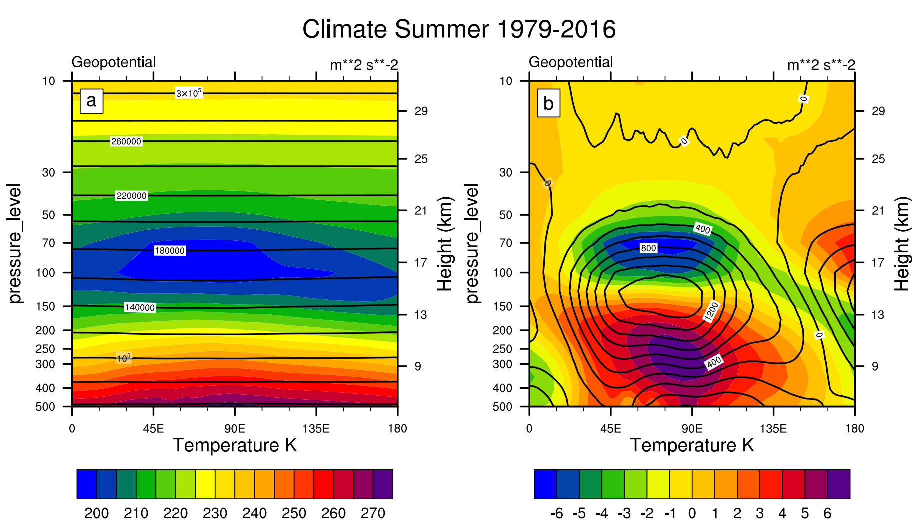

Figure 1. Mean longitude–height sections of the geopotential potential height (solid lines, units: $m^2\ s^{-2}$) and temperature (shaded, units: K) along 30 °N over the Tibetan Plateau in summer (June–August) from 1979 to 2016(a). Geopotential height after removal of the zonal mean and temperature after removal of the zonal mean(b).

Figure 2 shows the regression of temperature on the geopotential height fields at 10, 30, 50, 70 and 100 hPa using the temperature anomalies of the warm center at 300 hPa. There are three height planetary waves at 100 hPa (figure 2e) and dissipate rapidly at upper levels (figure 2a,2b,2c,2d) in northern hemisphere. The wave centers are located in 50°N,170°W, 70°N,100°E and 60°N,70°W respectively at 100 hPa.It is well known that the planetary wave cannot propagate in easterly wind.In summer,there is easterly wind in stratosphere in northern hemisphere. So the planetary wave generated by heating center in upper troposphere dissipate rapidly in the propagation upward in stratosphere. However,there are three planetary waves found in southern hemisphere that can propogate into the higher levels in stratosphere (figure 2) and the wave amplitude increases with altitude.The planetary waves are along the edge of the Antarctica and wave troughs are suited in around 140° E,100° W and the date line while the strongest wave trough is in 140° E. The geopotential height of polar vortex over the Antarctica throughout the stratosphere is positive value which means that the polar vorex becomes weaker in the stratosphere in the souther hemisphere due to the heating center of Asia High. It is not difficult to understand that the heating center of Asia High in the upper troposphere in the northern hemisphere generates the planetary waves propagating into the southern hemisphere and then increase the interaction between mid-latitude circulation and the polar vortex circulation, so the polar vortex was weakened in the stratosphere in the southern hemisphere. The following section will show the propogation avenue from the northern to the southern hemisphere acrossing the equator.

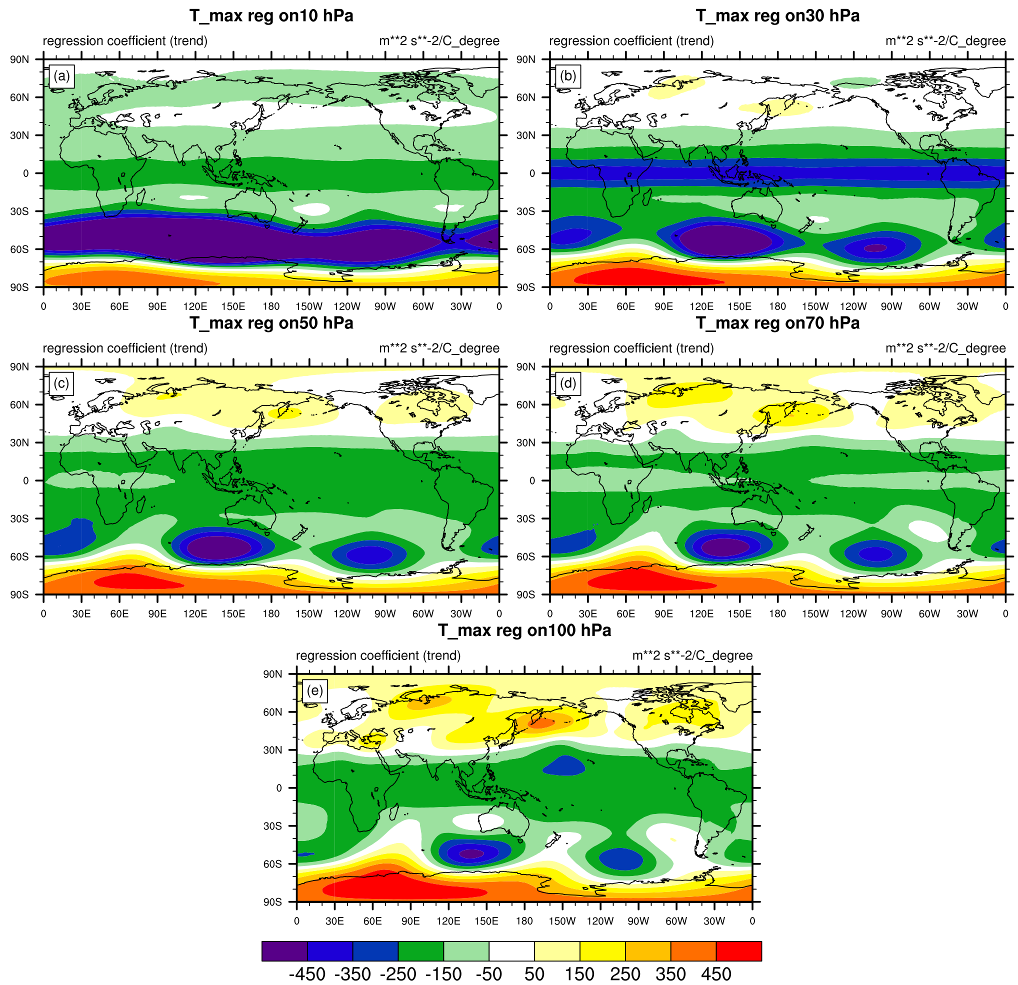

Figure 2. Time series of the maximum temperature at 300 hPa regressed on the geopotential height at (a) 10, (b) 30, (c) 50, (d) 70 and (e) 100 hPa.

Figure 3 shows the regression of the *u* wind field on the geopotential height at 10, 30, 50, 70 and 100 hPa. There are two wave trains from the plateaus through the equator to the southern hemisphere at 100 hPa (Figure 3e). The first wave train moves through the east Indian Ocean before crossing the equator and traveling toward the Antarctic circle. The second wave train moves over the western Pacific Ocean from east Asia to Antarctica. When these two separate wave trains arrive in Antarctica, they form another wave train along the polar circle. There is a remarkable difference between these two waves. The first wave train becomes stronger after crossing the equator because it is in the same direction as the zonal wind near the equator and is therefore reinforced. By contrast, the second (westerly) wave train over the Pacific weakens when it crosses the equator because the zonal easterly wind belt over the equator prevents it from moving between hemispheres. There is no clear wave train in the zonal direction in the northern hemisphere because this level is controlled by easterly winds, which makes the propagation of planetary waves difficult. The major winds in the stratosphere of the southern hemisphere in summer are westerly, whereas easterly winds dominate the stratosphere in the northern hemisphere.

Figure 3 shows that the planetary waves cannot propagate within the easterly wind in the stratosphere during the northern hemisphere summer. The waves are transported upward near 30° N and then weaken markedly before disappearing by 10 hPa. There are almost no planetary waves in the stratosphere at higher latitudes.

Westerly winds are seen at 70 hPa on the equator and form two centers over Indonesia and South America at 50 hPa. There are easterly winds at 30 and 10 hPa from 15° N to 15° S. These represent the change from an easterly to a westerly wind phase at the equator known as the quasi-biennial oscillation. The annual variability of the warm center of the Asian high in the upper troposphere and lower stratosphere contribute to the formation of the quasi-biennial oscillation, although this requires further research.

The waves transported from the Asian high in the southern hemisphere can be propagated to very high levels (Figure 3) by the westerly winds. This explains why there are planetary waves in the stratosphere in winter, but no prominent sea–land distribution of the winds in the southern hemisphere.

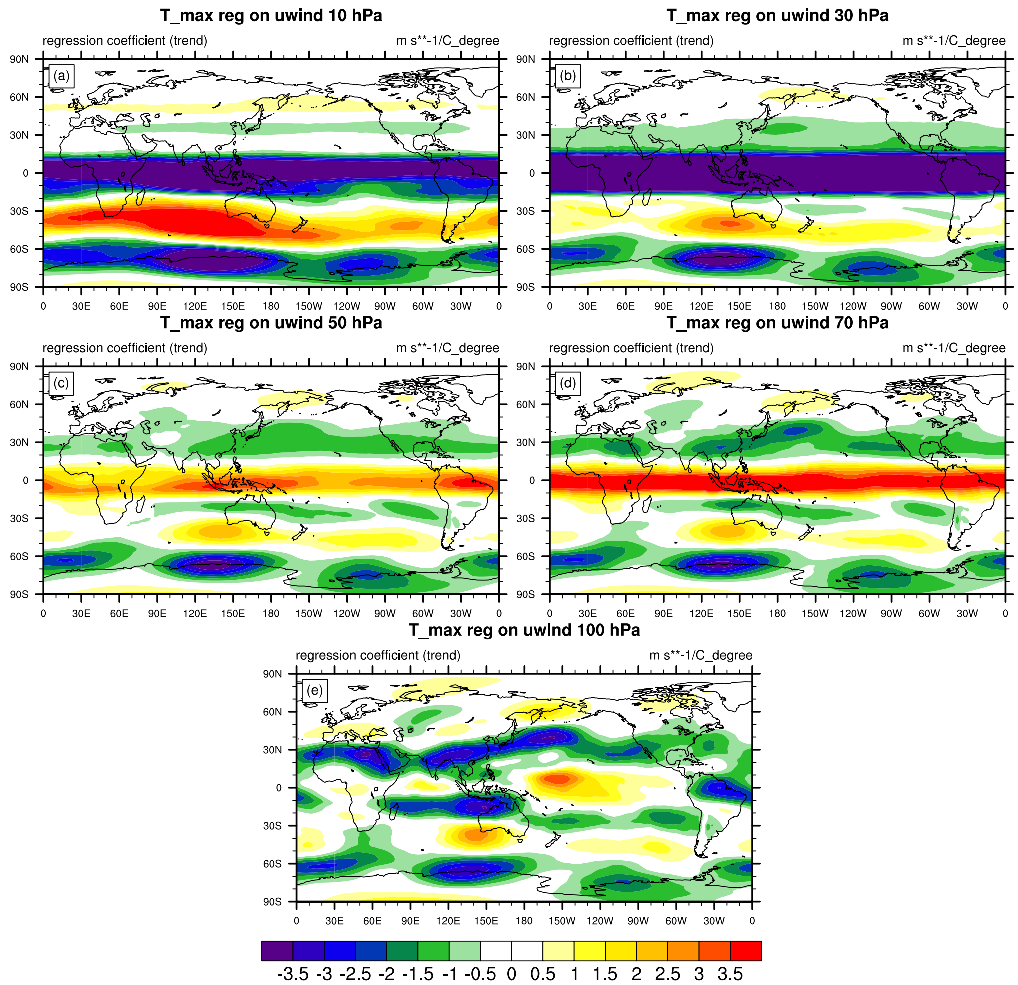

Figure 3. Time series of the zonal winds at 300 hPa regressed on the geopotential height at (a) 10, (b) 30, (c) 50, (d) 70 and (e) 100 hPa.

Figure 4 shows the regression of the *v* wind fields on the geopotential height at 10, 30, 50, 70 and 100 hPa. The heating center of the Asian high can excite planetary waves in the *v* wind field (Fig. 4e). The planetary waves in the northern hemisphere excited by the *v* winds of the Asian high have higher wavenumbers and a shorter wavelength than those in the southern hemisphere, although the waves in the upper troposphere and lower stratosphere are still affected by the sea–land distribution (Fig. 4e). The planetary wave train appears around 30° N in the eastern hemisphere and travels along the west coast of the Atlantic Ocean in the western hemisphere at high latitudes (reaching to 80° N). There is a large range of northerly winds over east Asia and the northwest Pacific Ocean as a result of the Asian high. The Asian high is an asymmetrical anticyclonic circulation—that is, the northerly wind component at the top of the eastern side of the Asian high has a wide range, but the southerly wind component at the top of the western side has a smaller range. The wave train caused by the meridional wind travels near to 60°S in the southern hemisphere. This wave train shows a three-wave feature along the zonal circle.

The wave train caused by the meridional winds in the northern hemisphere disappears rapidly as it propagates upward (Fig.4a–4d) and disappears by 10 hPa. The wave train gradually weakens at 70 (Fig. 4d), 50 (Fig. 4c) and 30 hPa. By contrast, the wave train in the southern hemisphere can propagate vertically to high altitudes. This wave train shows a three-wave feature and increases in amplitude as it propagates upward near 60° S (Fig. 4b and 4c), although it weakens at 10 hPa. This is a significant difference between the meridional and zonal wind components in the vertical propagation of the wave train.

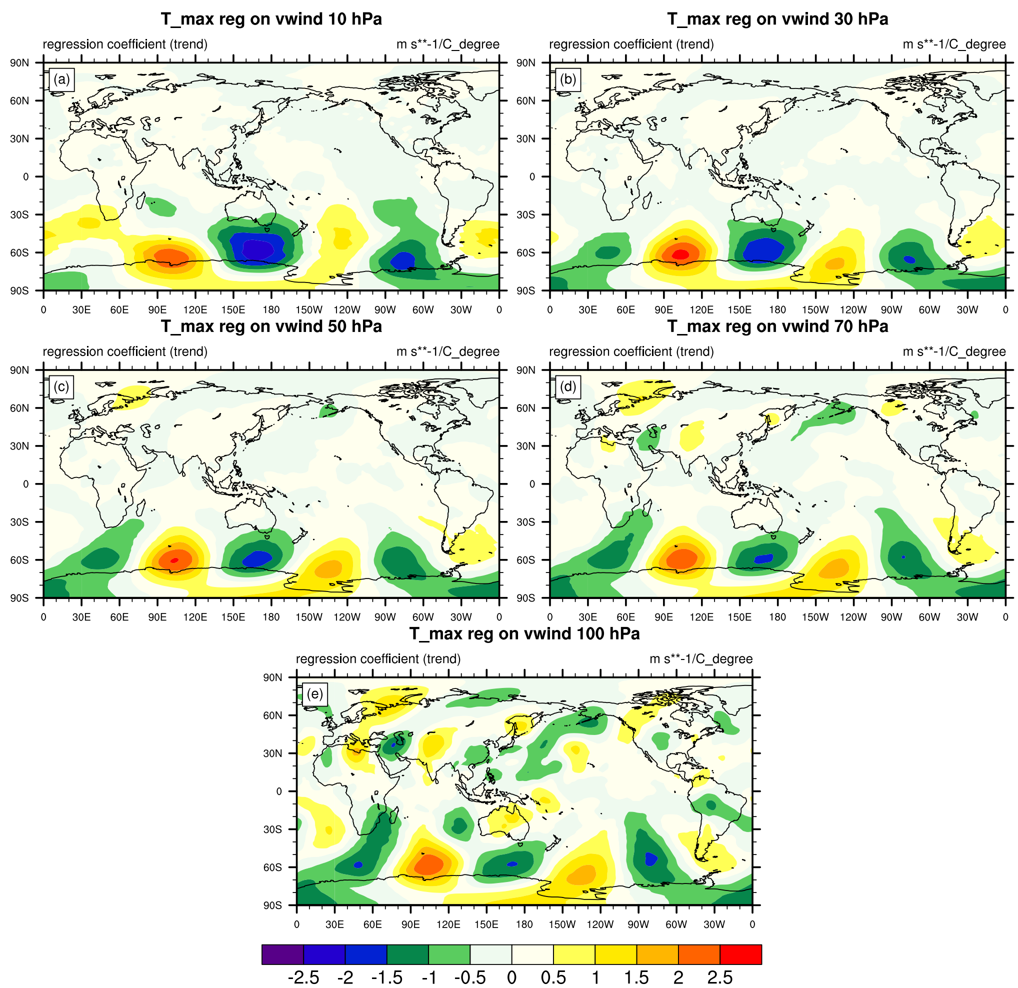

Figure 4. Time series of the meridonal winds at 300 hPa regressed on the geopotential height at (a) 10, (b) 30, (c) 50, (d) 70 and (e) 100 hPa.

4 Conclusions

The Asian high affects both the Asian and the global climate via its interaction with other synoptic systems in the troposphere and by changing the atmospheric circulation so that aerosol particles can be transported into the stratosphere from the Earth's surface. We investigated the characteristics of heating center that is the main cause of the Asian high and its impact on the propagation of planetary waves in the stratosphere.

The largest area of heating caused by longwave radiation is at about 500 hPa, which is close to the altitude of the Tibetan Plateau. A cold core is also observed covering a huge region from 0 to 180° E at 100–70 hPa. The center of the heating anomaly after the removal of the zonal mean is near 90° E at 300 hPa, whereas the center of the height anomaly is above the heating center at 150 hPa near 75 °E. The center of the heating anomaly of the Asian high covers a huge region. It persists in the upper troposphere and lower stratosphere from May to October and affects the atmospheric circulation in the stratosphere.

The heating anomaly at 300 hPa in the upper troposphere and lower stratosphere has an important effect on the strength and persistence of the Asian high. We investigated its effect on the global circulation in the stratosphere from June to August. Regression on the geopotential height field showed that there are the planetary waves with a three-wave characteristic at 100, 70, 50 and 30 hPa in the southern hemisphere. The amplitude of the trough increased with altitude. When the trough eventually strengthened, a lower belt appeared at 10 hPa. The wave and the lower belt were near 60° N, whereas the polar vortex over the Antarctica presents a positive value and the lower belt inclines to polarward, which means the polar votex weakens. Regression on the *u* wind showed that the planetary wave excited by the heating anomaly was unable to propagate in the vertical direction due to the presence of easterly winds in the northern hemisphere summer, but it could cross the equator to the southern hemisphere and then propagate upward in the westerly winds. This may explain why planetary waves can be found in southern hemisphere although there is no remarkable sea–land distribution. Another interesting thing in the *u* wind regression field of the heating center of the Asia high is that the easterly wind at 30 hPa and 10 hPa and the westerly wind at 70 hPa and 50 hPa above the equator between 15°N and 15°S. This denotes the heating center of the Asian high may contributes to the formation of QBO in the stratosphere. The future work will be done deeply on this issue. The meridional wind regression field in the southern hemisphere has a three-wave feature in the zonal wind regression field. The three-wave feature is consistent from 100 to 10 hPa, which means that the wave propagates upward in the southern hemisphere. The planetary waves cause by the meridional wind weaken rapidly when they propagate upward in the easterly winds of the northern hemisphere summer. The heating anomaly of the Asian high therefore affects the global circulation in different ways in different fields.

Acknowledgments, Samples and Data

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