The Impact of the South Asia High Bimodality on the Chemical Composition of the Upper Troposphere and Lower Stratosphere

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Abstract The South Asia High (SAH) is the dominant feature of the circulation in the upper troposphere and lower stratosphere (UTLS) during the boreal summer, and the upper tropospheric anticyclonic circulation extends into the lower stratosphere. The preferred locations of the center of the SAH occur in two different regions, and the center can be located over the Iranian Plateau or over the Tibetan Plateau. This bimodality has an impact on the distribution of chemical constituents in the UTLS region. We analyzed water vapor (H2O), carbon monoxide (CO), and ozone (O3) data derived from the Aura Microwave Limb Sounder (MLS) and total column ozone data from the Ozone Monitoring Instrument (OMI). For the Iranian Plateau mode of the SAH, the tropospheric tracers exhibited a positive anomaly over the Iranian Plateau and a negative anomaly over the Tibetan Plateau, whereas the stratospheric tracer exhibited a negative and a positive anomaly over the Tibetan Plateau and the Tibetan Plateau, respectively. For the Tibetan Plateau mode, however, the distribution of the anomaly was the reverse of that found for the chemical species in the UTLS region. Furthermore, the locations of the extrema within the anomaly seemed to differ across chemical species. The anomaly extrema for H2O occurred in the vicinity of the SAH ridgeline, whereas CO and O3 exhibited a northward shift of 4–8 degrees. These impacts of the variation in the SAH on the chemical constituents in the UTLS region can be attributed in part to the dynamical structure delineated by the tropopause field and the temperature field at 100 hPa.

Keywords: SAH, UTLS, chemical composition, bimodality

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1 Introduction

The South Asia High (SAH) is a large-scale anticyclonic system in the upper troposphere and lower stratosphere (UTLS) over South Asia during the boreal summer. Other than the polar vortex, it is the strongest and the steadiest circulation system at the 100 hPa level (Mason and Anderson, 1963). This circulation was originally thought to represent the atmosphere responds to the heating of the Tibetan plateau (Flohn, 1960), and it is known to be coupled with persistent deep convection over the South Asia region during the summer. Hoskins and Rodwell (1995) have shown that the climatological monsoon structure is primarily a response to diabatic heating associated with the presence of this persistent convection. Satellite observations show that SAH has persistent maxima (or minima) in tropospheric (or stratospheric) trace constituents, such as water vapor (H2O) (Rosenlof et al., 1997), methane (CH4), nitrogen oxides (NOx) (Park et al., 2004), carbon monoxide (CO) (Li et al., 2005), hydrogen cyanide (HCN) (Randel et al., 2010), aerosol (Vernier et al., 2011), and ozone (O3) (Randel et al., 2001). The anticyclonic circulation and the constituent extrema extend from the upper troposphere into the lower stratosphere (Park et al., 2007). The coincidence between the SAH and the constituent extrema is attributed to the trapping effect of the strong winds and closed streamlines associated with the anticyclone, which act to isolate air within the SAH for a few weeks (Li et al., 2005; Randel and Park, 2006).

From the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) pentad mean reanalysis data, Zhang et al. (2002) have shown that the longitudinal location of the SAH center during the boreal summer has two preferred regions, termed the Tibetan Mode and the Iranian Mode. Previous analyses have shown that the SAH appears to be favored by warm conditions (Qian et al., 2002) and that its circulation patterns show obvious differences between the two modes (Zhang et al., 2002). Zhou and Chen (2005) have shown that variation in the SAH’s location and strength has impact on the total amount of ozone over Asia. The purpose of this work is to explore the impact of the SAH bimodality on the distribution of trace constituents in the UTLS.

2 Data and methods

Vertical profiles of ozone, water vapor, and carbon monoxide were obtained from Aura Microwave Limb Sounder (MLS) version 2.2 level 2 products. The MLS instrument aboard the Aura spacecraft, one of the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) platforms, has been
measuring atmospheric parameters since August 2004 (Schoeberl et al., 2006). We constructed gridded data on 4° latitude × 10° longitude grids by averaging profiles inside the bins for five summers (2005–09). The quality screening of individual profiles was conducted according to the instructions given by Livesey et al. (2007). For more details, see the MLS validation paper by Froidevaux et al. (2008) and Livesey et al. (2008).

Daily time series of total column ozone were obtained from the Ozone Monitoring Instrument (OMI) onboard the EOS Aura. These time series are processed using the NASA Total Ozone Mapping Spectrometer (TOMS) Version 8 algorithm. The Aura/OMI dataset uses a horizontal resolution of 0.25° (latitude) × 0.25° (longitude). The Dobson Unit (DU) was used to measure total ozone. More information is available at http://toms.gsfc.nasa.gov/omi/.

The daily geopotential height and the zonal wind component (u-component) at the 100 hPa level from NCEP/NCAR reanalysis (Kalnay et al., 1996) for the boreal summer (June-July-August) during 2005–09 were used to classify the SAH into the Tibetan Plateau (TP) mode and the Iranian Plateau (IP) mode. The method for locating the center of the SAH was adapted from Zhang et al. (2002). In the domain of (15–45°N, 30–140°E), the curve along which the u-component was approximately equal to zero was defined as the ridgeline of the SAH. The major center of the SAH was defined as the point having the maximum geopotential height along the ridgeline. Figure 1a gives the statistical distribution of the longitude location of all the major centers of the SAH during the boreal summer for 2005–09. In agreement with the results derived from pentad data (Zhang et al., 2002), this

![Figure 1](a) Occurrence of the SAH center as a function of longitude during the boreal summer (June-July-August) for 2005–09; Horizontal wind fields at 100 hPa for (b) the IP mode and (c) the TP mode during the boreal summer
analysis found that the daily SAH centers had two preferred locations, TP to the east and IP to the west. The former mode had a much higher and more compact peak. In this work, the SAH with a center located between 80°E and 92.5°E was classified as the TP mode and had its peak occurrence at 87.5°E. The IP mode was considered to occur between 50°E and 67.5°E (peak at 60°E). In the 460 days (five years) analyzed, the TP mode occurred 194 times, the IP mode 159 times. The corresponding horizontal wind fields at 100 hPa are shown in Figs. 1b and 1c. In the IP mode, the anticyclone has a center over IP, whereas the center in the TP mode is shifted eastward over TP.

A composite analysis for the chemical species and the meteorological parameters was conducted for the IP mode and for the TP mode. The anomaly, i.e., the deviation relative to the climatic mean during summer, was used to investigate the influence of the SAH mode on the distribution of chemical species in the UTLS region.

3 Results and discussion

Figures 2a, 3a, and 4a show the climatological distributions of H2O, CO, and O3 at 100 hPa during the boreal summer for 2005–09. These figures also show the geopotential height contour at 100 hPa. In the area controlled by the SAH, water vapor, and CO (tropospheric tracer) had enhanced concentrations, whereas the concentration of ozone (stratospheric tracer) decreased (Rosenlof et al., 1997; Li et al., 2005; Randel et al., 2001). The maximum H2O values defined a belt located at approximately four degrees to the south of the SAH ridgeline, whereas the maximum (or minimum) belt in CO (or O3) was shifted southward an additional four–six degrees.

The impact of the variation in SAH on the distribution of the chemical composition at 100 hPa is obvious from a comparison of the two modes of the SAH. In the IP mode composites, H2O and CO exhibited a positive anomaly over IP and a negative anomaly over TP (Figs. 2b and 3b), whereas O3, in contrast, had a negative anomaly over IP and a positive anomaly over TP (Fig. 4b). However, the TP mode composites exhibited the opposite structure. Tropospheric tracers (H2O or CO) had a negative anomaly over IP and a positive anomaly over TP (Figs. 2c and 3c), whereas the stratospheric tracer (O3) exhibited precisely the opposite pattern (Fig. 4c).

The anomaly of the IP mode for the chemical constituents appeared to be larger than that for the TP mode. The extreme anomaly for H2O over IP was 0.3 ppmv for the IP mode and –0.2 ppmv for the TP mode. Over TP, the values of the corresponding anomalies were –0.2 ppmv (IP) and 0.15 ppmv (TP) (Figs. 2b and 2c). For CO, the extrema over IP were 7 ppbv (IP) and –3 ppbv (TP) vs. –5 ppbv (IP) and 1 ppbv (TP) over TP (Figs. 3b and 3c). For O3, the extrema were –60 ppbv (IP) and 50 ppbv (TP) over IP vs. 30 ppbv (IP) and –40 ppbv (TP) over TP (Figs. 4b and 4c). It should be noted that the geopotential field for the IP mode was somewhat stronger than that for the TP mode. Moreover, it can be seen that the chemical composition over IP exhibited a larger difference between
The above analysis has shown that the variation in the SAH has impact on the distributions of various chemical constituents at 100 hPa. Moreover, the responses of different chemical species differed according to their locations relative to the SAH center. For H$_2$O, the extreme anomaly was located near the SAH ridgeline (Figs. 2b and 2c). For CO and O$_3$, however, the extreme anomalies were located four–eight degrees to the north of the SAH (Figs. 3b, 3c, 4b, and 4c). This was particularly the case for O$_3$.

These differences among different chemical species must be related to the different physical and/or chemical processes that control variation in the species during their transport. An exception to this principle is that convective hydration or dehydration and cooling dehydration will have impacts on the concentration of H$_2$O except during transport (Jensen et al., 2007; Fan et al., 2010). To shed some light on these different responses, Fig. 5 shows the tropopause pressure field and the temperature field at 100 hPa. In the area controlled by the SAH, the tropopause formed a dome at a level of approximately 100 hPa. The top of the dome (approximately 95 hPa) was located over TP (Fig. 5a). However, the coldest region at 100 hPa was located at the southeast edge of the SAH (Fig. 5d). This area corresponds to the strongest convective activity (Randel and Park, 2006). For the IP mode, IP showed a higher tropopause and colder temperature at 100 hPa, whereas TP showed a lower tropopause and warmer temperature (Figs. 5b and 5e). For the TP mode, however, the anomaly had the opposite distribution (Figs. 5c and 5f). The anomaly extrema for tropopause and temperature at 100 hPa both occurred at 40–42°N, to the north of the SAH ridgeline, a similar pattern to that observed for CO and O$_3$. Moreover, the anomalies in the tropopause and temperature at 100 hPa for the IP mode were stronger than that over TP.
than those for the TP mode, as the responses of the chemical species showed. Similarly, larger differences in the tropopause and the temperature at 100 hPa between the two modes were seen over IP than over TP, as indicated by the chemical data. Most likely, different processes influence H$_2$O, O$_3$, and CO. For H$_2$O, the temperature plays a major role, whereas O$_3$ and CO are primarily affected by changes in circulation and by convective transport. The mechanism by which the SAH bimodality affects the distribution of the chemical species studied remains to be investigated. This underlying mechanism must be related to convective and large-scale transport and to other physical and/or chemical processes.

The influence of the SAH bimodality on the total ozone level may be inferred from the summertime mean total ozone distribution (Fig. 6a). The total ozone over the SAH was clearly lower than that found elsewhere at the same latitude, particularly in the northern half of the region. This pattern is caused primarily by the lower ozone concentration in the UTLS region over the anticyclone (Bian et al., 2011). In particular, an ozone valley is present over TP, as shown by Zhou and Luo (1994) and Zou (1996). The presence of this valley results from the higher terrain of TP and from the lower ozone level in the UTLS region (Bian et al., 2011). In the IP mode, the total ozone has a negative anomaly over IP and a positive anomaly over TP (Fig. 6b). For the TP mode, however, the total ozone has a less positive anomaly and a less negative anomaly over IP and TP, respectively (Fig. 6c). Moreover, the locations of the total ozone anomaly extrema (Figs. 6b and 6c) coincide with those for O$_3$ (Figs. 4b and 4c) and for the temperature at 100 hPa (Figs. 5e and 5f) and for the tropopause (Figs. 5b and 5c). Similarly, IP exhibits a larger difference between the two modes than TP.

4 Conclusions

The Asian monsoon anticyclone is the dominant circulation feature in the UTLS region during the boreal summer. It is forced by persistent deep convection over South Asia, coupled with the circulation (Hoskins and Rodwell, 1995). The upper tropospheric anticyclonic circulation extends into the lower stratosphere; the monsoon tropopause is relatively high and cold (Highwood and Hoskins, 1998). The constituent fields throughout the UTLS region often exhibit a monsoon signature during the boreal summer (Randel and Park, 2006). The SAH center has two preferred locations, termed the IP mode and the TP mode (Zhang et al., 2002). This study has investigated the effect of the SAH bimodality on the distribution of chemical constituents in the UTLS region. For the IP mode, tropospheric tracers (H$_2$O and CO) had a positive anomaly over IP and a negative anomaly over TP, whereas a stratospheric tracer (O$_3$) had a negative and a positive anomaly over IP and TP, respectively. However, the anomalies showed an opposite distribution for the TP mode. The IP mode seemed to exhibit a larger response than the TP mode. This difference may be related to the larger strength of the SAH in the IP mode. Further, the differences between the two modes in the responses of the chemical species over IP were somewhat larger than those seen over TP. Moreover, the locations of the anomaly extrema for different chemical compositions seemed to show some differences. The anomaly extrema for H$_2$O were located in the vicinity of the SAH ridgeline, whereas CO and O$_3$ exhibited a northward shift of four–eight degrees. These impacts of the variation in SAH on the chemical constituents in the UTLS region can be attributed in part to the dynamical structure delineated by the tropopause field and the temperature field at 100 hPa.

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References


Froidevaux, L., Y. B. Jiang, A. Lambert, et al., 2008: Validation of Aura Microwave Limb Sounder stratospheric ozone measure-


