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Comparison of trends and abrupt changes of the South Asia high from 1979 to 2014 in reanalysis and radiosonde datasets

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ABSTRACT

The South Asian High (SAH) has an important influence on atmospheric circulation and the Asian climate in summer. However, current comparative analyses of the SAH are mostly between reanalysis datasets and there is a lack of sounding data. We therefore compared the climatology, trends and abrupt changes in the SAH in the Japanese 55-year Reanalysis (JRA-55) dataset, the National Centers for Environmental Prediction Climate Forecast System Reanalysis (NCEP-CFSR) dataset, the European Center for Medium-Range Weather Forecasts Reanalysis Interim (ERA-interim) dataset and radiosonde data from China using linear analysis and a sliding *t*-test. The trends in geopotential height in the control area of the SAH were positive in the JRA-55, NCEP-CFSR and ERA-interim datasets, but negative in the radiosonde data in the time period 1979–2014. The negative trends for the SAH were significant at the 90% confidence level in the radiosonde data from May to September. The positive trends in the NCEP-CFSR dataset were significant at the 90% confidence level in May, July, August and September, but the positive trends in the JRA-55 and ERA-Interim were only significant at the 90% confidence level in September. The reasons for the differences in the trends of the SAH between the radiosonde data and the three reanalysis datasets in the time period 1979–2014 were updates to the sounding systems, changes in instrumentation and improvements in the radiation correction method for calculations around the year 2000. We therefore analyzed the trends in the two time periods of 1979–2000 and 2001–2014 separately. From 1979 to 2000, the negative SAH trends in the radiosonde data mainly agreed with the negative trends in the NCEP-CFSR dataset, but were in contrast with the positive trends in the JRA-55 and ERA-Interim datasets. In 2001–2014, however, the trends in the SAH were positive in all four datasets and most of the trends in the radiosonde and NCEP-CFSR datasets were significant. It is therefore better to use the NCEP-CFSR dataset than the JRA-55 and ERA-Interim datasets when discussing trends in the SAH.

1. Introduction

The South Asian High (SAH) is an anticyclonic system in the upper troposphere and lower stratosphere over the Tibetan Plateau and is an important part of the circulation system of the Asian summer monsoon. Mason and Anderson (1958) reported that, after the polar vortex, the SAH is the most powerful and stable circulation system at 100 hPa in the northern hemisphere. Its influence extends from the Atlantic Ocean on the west coast of Africa to the western Pacific Ocean in East Asia. With the enrichment of datasets since the 1980s, much research has been carried out on the SAH, broadened our understanding of this important system (Chen and Liao, 1990; Qian et al., 2002; Ding and Wang, 2005; Jiang et al., 2011; Xue et al., 2016).

As a planetary scale system, the SAH affects atmospheric circulation in the northern hemisphere and the summer climate in Asia (Tao and Zhu, 1964; Chen et al., 1980; Luo et al., 1982; Zhang et al., 2002; Huang and Qian, 2007; Sun et al., 2016). Sun et al. (2016) discussed the relationship between the characteristics of different types of SAH and atmospheric circulation in the northern hemisphere using the NCEP/NCAR monthly mean height and wind field reanalysis dataset and showed

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significant positive anomalies in the geopotential height and temperature fields in the upper to middle troposphere.

Luo et al. (1982), based on the analysis of 13 years of data, showed that there are close relations between positions of the ridge and center of the SAH and the large-scale distribution of floods and droughts in East China during the summer months. Using multiple reanalysis datasets, Chen et al. (1980), Zhang et al. (2000), Tan et al. (2005) and Chen et al. (2009) showed clear interannual variations in the ridge line, area, center and intensity of the SAH throughout the year, which were strongly related to the El Niño Southern Oscillation and the eastern equatorial Pacific sea surface temperature anomaly. Peng et al. (2009) studied the interannual change in the summer SAH and its relationship with El Niño Southern Oscillation events based on the NCEP/NCAR monthly reanalysis dataset and found that the SAH becomes stronger (weaker) during the decaying stage of the El Niño Southern Oscillation warm (cool) phase.

Many researchers have studied the relationship between the SAH and the composition of the upper troposphere and lower stratosphere. Li et al. (2017) compared the seasonal evolution of the SAH associated with two types of El Niño. The dynamic effects of the SAH on the ozone valley over the Tibetan Plateau have been emphasized (Liu et al., 2003; Tian et al., 2008; Bian et al., 2011; Guo et al., 2012; Su et al., 2016; Shi et al., 2017a, 2017b) and the close circumfluence of the SAH enabling air particles to inside the anticyclone also has been concerned (Fu et al., 2006; Park et al., 2007; Chen et al., 2011).

Reanalysis datasets are widely used in research on the SAH and therefore an evaluation of their validity is important (Zhao and Fu, 2006; Zhao et al., 2010; Fu and Li, 2012; Zeng et al., 2013). Zhao et al. (2010) showed that the quality and evaluation of reanalysis datasets could affect the reliability of climate change research and that they were also important in improving data assimilation technology. Wang and Li (2013) compared the characteristics of the SAH in the MERRA and NCEP-2 reanalysis datasets and found that the SAH intensity index was significantly different between the two reanalysis datasets. Guo et al. (2017) found that satellite data agreed with the SAH trend in the NCEP-CFSR dataset by evaluating the uncertainty of the trend in the ozone valley over the Tibetan Plateau and the SAH in the ERA-Interim, Japanese 55-year Reanalysis (JRA-55) and National Centers for Environmental Prediction Climate Forecast System Reanalysis (NCEP-CFSR) datasets. Zhou and Zhang (2009) investigated the NCEP/NCAR dataset by comparing it with the geopotential height from radiosonde reports of 12 stations over the Tibetan Plateau and confirmed that the geopotential height estimated from the NCEP/NCAR dataset can be applied to climate research in Tibet.

The assessment of reanalysis datasets is worthy of attention in studies of the SAH. The current comparative analyses of the SAH mainly use reanalysis datasets, which lack further evaluation using sounding data, especially in upper troposphere and lower stratosphere. This study assessed the SAH using JRA-55, NCEP-CFSR, ERA-Interim and radiosonde datasets from May to September in the time period 1979–2014 at 200–70 hPa. It provides a scientific basis for the rational use of reanalysis datasets.

2. Data and methods

The three datasets used in this study were the JRA-55 dataset from the Japan Meteorological Agency, the National Centers for Environmental Prediction Climate Forecast System Reanalysis (NCEP-CFSR) dataset and the Reanalysis Interim dataset from the European Center for Medium-Range Weather Forecasts (ERA-Interim). Radiosonde observational data were available from the National Meteorological Information Center of China. The JRA-55 dataset has a horizontal resolution of $1.25^\circ \times 1.25^\circ$ and provides data from 1958 (Kobayashi et al., 2015; http://jra.kishou.go.jp/JRA-55/index_en.html). The NCEP-CFSR dataset has a horizontal resolution of $2.5^\circ \times 2.5^\circ$ and a temporal coverage from 1979 to 2014 (Saha et al., 2010, 2014; http://cfs.ncep.noaa.gov/). ERA-Interim dataset has a horizontal resolution of $1^\circ \times 1^\circ$ and a temporal coverage from 1979 to 2014 (Dee et al., 2011; https://www.ecmwf.int/). Therefore all three datasets were available for the period 1979–2014. The radiosonde observational data included daily observations from 87 stations within mainland China from 1951 to 2014. The SAH is visible from May to September. Four confidence levels (200, 150, 100 and 70 hPa) were selected in the vertical direction because the SAH is a center of atmospheric activity in the upper troposphere and lower stratosphere.

Our study covered the period from 1979 to 2014 for all three datasets and the radiosonde observation daily data were gaged monthly from 1979 to 2014. We computed the average geopotential height at 200, 150, 100 and 70 hPa to study the distribution and trend of the SAH in the upper troposphere and lower stratosphere. The trends from May to September and the abrupt change in the SAH from the year 2000 were analyzed by linear analysis and a sliding student's *t*-test, respectively (Wei, 2007).

3. Climatology of the South Asian high

All four datasets showed similar spatial patterns for the SAH, except for an area outside China where there is no radiosonde station (Fig. 1). The geopotential height amplitude was similar in the reanalysis datasets, but the radiosonde data were slightly higher (Fig. 1). The peak values of the geopotential height (15480 gpm) were all south of 20° N in May in the four datasets and the center of the SAH at (20° N, 105° E) could only be identified in May in the NCEP-CFSR dataset (Fig. 1f). In June, the SAH strengthened and moved northwards in all four datasets and its center (15560 gpm) was located at 20° N in the three reanalysis datasets (Fig. 1b, g, l and q). The SAH moved north (30° N) and became stronger (15640 gpm) again in July (Fig. 1c, h, m and r) and maintained its position and intensity in August (Fig. 1d, i, n and s) in all four datasets. In September, the SAH moved south (25° N) and weakened (15520 gpm) in all four datasets. The center of the SAH in the radiosonde dataset was surrounded by the 15560 gpm contour in June and the 15600 gpm contour in July and August. The 15520 gpm contour in September was further to the east and north. The range of movement of the center of the SAH in the JRA-55 and ERA-interim datasets was larger than that in the NCEP-CFSR dataset (Fig. 1b-e, g-j and l-o).

4. Trends of South Asian high from 1979 to 2014

There were significant differences in the trends of the SAH between the three reanalysis datasets and the radiosonde data from May to September (Fig. 2), although the climate patterns for the SAH were similar in the three reanalysis datasets (Fig. 1). The linear trend of the geopotential height in the control area of the SAH (circled by black lines) was positive in the JRA-55, NCEP-CFSR and ERA-Interim datasets, but negative in the radiosonde data (Fig. 2). To simplify the analyses, the control areas (see Fig. 2 for definition) of the SAH in the three reanalysis datasets are represented by the NCEP-CFSR 15480, 15530, 15600, 15600 and 15528 gpm data from May to September, shown as black lines in Fig. 2. The positive trends of the geopotential height in the NCEP-CFSR dataset (Fig. 2f–j) were stronger than those in the JRA-55 (Fig. 2a–e) and ERA-Interim (Fig. 2k-o) datasets from May to September and most of the trends were significant at the 90% confidence level. Only small areas of the SAH showed negative trends of geopotential height in the three reanalysis datasets. By contrast, there were decreasing trends for almost all the sounding stations inside the SAH control area from May to September, most of which were significant at the 90% confidence level (Fig. 2p–t).

Radio stations were selected for comparison with the reanalysis datasets in the definite ranges of the SAH, which are defined as the smallest rectangles that contain all the radio stations inside the SAH control area (outlined in purple in Fig. 2). The mean geopotential height in the definite ranges of the SAH was used as an index to reflect the variability and trends in the SAH (Figs. 3 and 5; Tables 1 and 2).

The trends for the SAH in the radiosonde and reanalysis datasets were