



## News &amp; Views

## Global climate effects of summer Tibetan Plateau

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Because the Tibetan Plateau (TP) has the highest elevation in the world and is a key area affecting the Asian extreme weather and climate events, studies on the Tibetan Plateau meteorology have been highly concerned by the international scientific community. In the late 1970s, Ye and Gao [1] revealed the climatic characteristics of the TP heating and its connection with global and regional atmospheric circulations. With the seasonal evolution from winter to summer, strong surface sensible heat regulates the timing of the establishment of the Asian summer monsoon [2]. However, Boos and Kuang [3] addressed that the large-scale South Asian summer monsoon is unaffected by removal of the plateau, provided that the narrow orography of the Himalayas and adjacent mountain ranges is preserved, and revealed the dominance of the uplift of the Himalayas in the formation of the present South Asian summer monsoon. Then, does this indicate a weak effect of the summer TP thermal forcing on the variability of the present South Asian monsoon and larger-scale climates? Some discussions have been also stimulated in *Science* [4].

Recently, we investigated effects of the summer TP thermal forcing on the present climate. On the climatological average, the main body of the TP acts as a tremendous heat source during summer (from June to August), which contributes to strong ascent locally and the large-scale South Asian high (SAH) in the upper troposphere. The SAH has a west–east span of more than 180° and covers the middle and lower latitudes of Africa, Eurasia and the western North Pacific, with large-scale vertical circulations from the TP to the adjacent oceans. In the west–east direction, one branch of the ascent over the TP flows toward the east in the troposphere, reaches the eastern North Pacific, and moves downward, which forms a Tibetan Plateau–Pacific west–east clockwise vertical circulation (TPC) (Fig. 1a). Another branch flows westward in the upper troposphere and the lower stratosphere, reaches the Atlantic, and then moves downward, which forms a Tibetan Plateau–Atlantic west–east anticlockwise vertical circulation (TAC). In the north–south direction, a large-scale anticlockwise vertical circulation appears in the troposphere between the TP and the tropical South Indian Ocean, called the Tibetan Plateau–Indian Ocean north–south circulation (TIC).

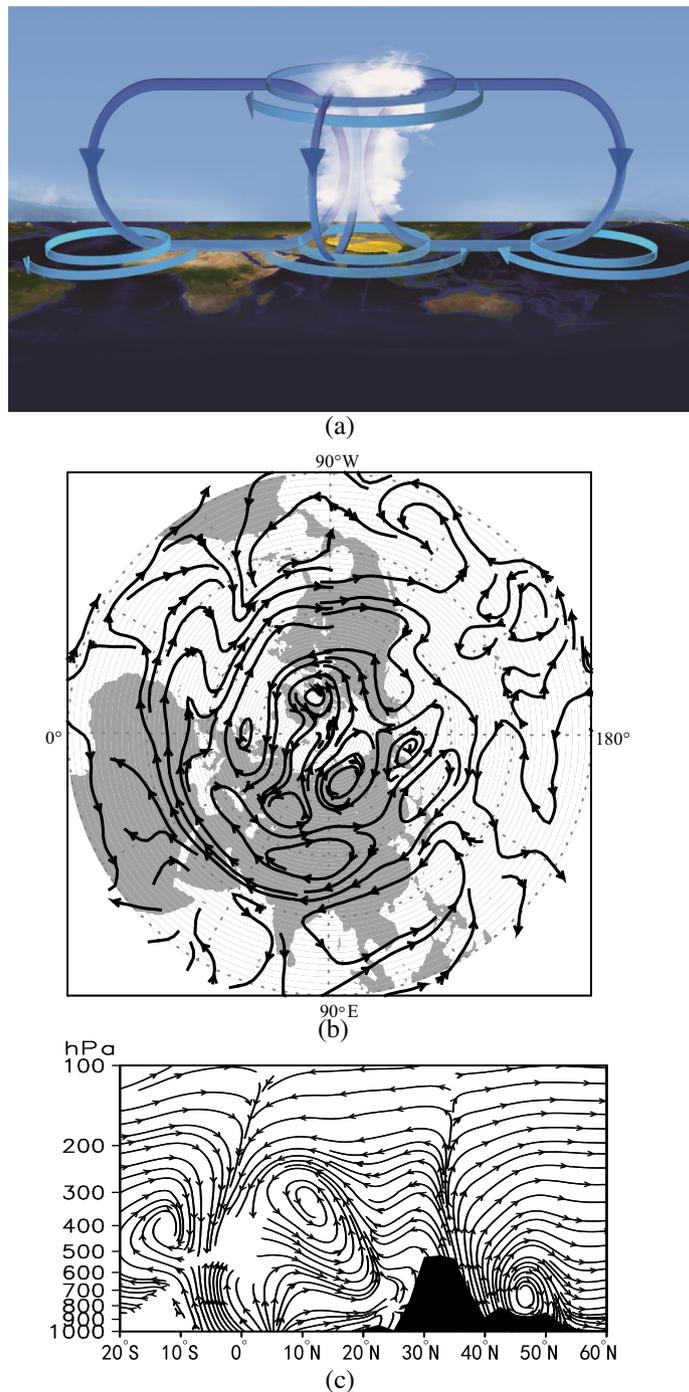
When the TP heat source is strong during summer, tropospheric temperature increases over a large region of Asia, anomalous

ascent appears over the TP and adjacent areas, and the SAH strengthens, with its horizontal anomalous circulation covering the middle and lower latitudes of Eurasia and the western North Pacific. An anomalous anticyclonic circulation also appears over the extratropical Atlantic and America, and anomalous cyclonic circulations appear over the Arctic area and the tropics of the Northern Hemisphere (Fig. 1b), which indicates an effect of the TP on the Arctic and tropical atmospheric circulations. The anomalous ascent over the TP flows toward both the east and west in the upper troposphere. The eastward branch reaches the central and eastern North Pacific, moving downward, which strengthens the TPC circulation [6]. The westward branch reaches the Mediterranean Sea, moving downward [7]. Meanwhile, the anomalous ascent over the TP also flows southward to the tropical Indian Ocean in the upper troposphere and the lower stratosphere, moves downward, and flows northward to the TP in the lower troposphere (Fig. 1c). Thus the anomalous signal forced by the TP thermal forcing can go across the equator along the TIC circulation, affecting climates over the Southern Indian Ocean [8]. Clearly, the TP heating variation modifies the TPC, TAC, and TIC vertical circulations during summer, which helps the TP anomalous signal to spread outwards to a larger area.

The TP thermal forcing also produces large-scale teleconnections such as the Asian–Pacific Oscillation during summer [6], with a large-scale anomalous cyclonic circulation from Africa to East Asia and southwesterly or southerly wind anomalies from Africa to East Asia in the lower troposphere [5]. Anomalous anticyclonic circulations appear over the middle latitudes of the North Pacific and Atlantic as well as Europe. These circulation anomalies strengthen the Asian and African monsoons and the subtropical anticyclones over the North Pacific and Atlantic. Accordingly, summer rainfall generally increases over the monsoon regions of Africa and South Asia and the main rainy belt is northward in eastern China (with more/less rainfall in northern/southern China). The evidence demonstrates the importance of the TP thermal forcing to variations of the present Asian and African monsoons. Meanwhile, rainfall decreases over Europe and the central-western part of North America, with increases of the local temperature. Moreover, heating over the main body of the TP could modify large-scale climates through triggering westward- and eastward-propagating Rossby waves along the extratropical westerly jets [9,10]. Strong ascent over the TP could also transport tropospheric aerosol and atmospheric composition into the stratosphere, change the

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**Fig. 1.** Effects of the summer TP thermal forcing on global atmospheric circulation. (a) Schematic diagram for the link between the TP and large-scale atmospheric vertical circulations during summer; (b) summer 200-hPa wind anomalies ( $\text{m s}^{-1}$ ) forced by the National Center for Atmospheric Research (NCAR) Community Atmosphere Model, version 3 (CAM3) through changing the surface vegetation types over the TP [5]; and (c) same as (b) but for the north–south vertical circulation along  $85^\circ\text{E}$ .

stratospheric atmospheric composition and radiative forcing, and affect climates over the Northern Hemisphere [8,11].

In view of the important role of the summer TP thermal forcing in affecting the present climate, global weather and climate research would be incomplete without considering the effects of the TP. The previous studies have documented close relationships between extreme climatic events and global warming [12,13]. Changes of the TP cryosphere under global warming may directly affect the local heat intensity and further cause large-scale climate

anomalies. Therefore, future research should emphasize effects of ice/snow processes on global climate, mechanisms for collaborative effects of both the TP and ocean signals, and methods of improving the climatic prediction through the TP signals.

#### Conflict of interest

The authors declare that they have no conflict of interest.

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