ARTICLES

Chinese Science Bulletin

ATMOSPHERIC SCIENCES

Seasonal cycle of the zonal land-sea thermal contrast and East Asian subtropical monsoon circulation

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Based on analysis of the climatic temperature latitudinal deviation on middle troposphere, its seasonal cycle suggests that due to the rapid warming from eastern China continent to the east of Tibetan Plateau and the heating of Tibetan Plateau in spring, seasonal transition of the thermal difference between East Asia continent and West Pacific first takes place in the subtropical region with greatest intensity. On the accompanying low troposphere, the prevailing wind turns from northerly in winter to southerly in summer with the convection precipitation occurring at the same time. This maybe indicates the onset of the East Asian subtropical summer monsoon. Consequently, we advice that the seasonal cycle formed by the zonal thermal contrast between Asian continent and West Pacific may be an independent driving force of East Asian subtropical monsoon.

zonal land-sea thermal contrast, East Asian subtropical monsoon, tropical monsoon, Tibetan Plateau

1 Introduction

Zhu et al.[1] definitely brought forward that the East Asian monsoon system can be divided into South China Sea (SCS) tropical monsoon and subtropical monsoon in 1986. Some scholars[2−4] have discussed subtropical monsoon impact on precipitation by using the monsoon indexes. But the essence of East Asian subtropical monsoon and its interaction with the tropical monsoon have not been paid much attention to. They interact and influence directly large-scale flood and drought in China. But what is subtropical monsoon on the earth? Or what is the essence of subtropical monsoon? There are generally two ambiguities: one is based on regions, i.e. monsoon prevalent in the subtropical areas in East Asia is called "East Asian subtropical monsoon", and the other considers the northward extension of tropical monsoon in East Asia as subtropical monsoon. But both of them neglect the reason why the subtropical monsoon exists.

Eurasia plays an important role in Asian summer monsoon onset and intensity. Wu et al.[5−7] advanced that the heat pulley function made by Tibetan Plateau anchors the onset site of Asian summer monsoon. On the other hand, because the land-sea thermal contrast is generally considered as the fundamental mechanism of the formation of monsoon, at present, most research on monsoon[8−17] emphasized that the meridional land-sea thermal contrast in East Asia is the key driving force of tropical monsoon. However, over the subtropical region, the Tibetan Plateau, as an uplifted heat source (or cold source), strengthens the zonal land-sea thermal contrast (Asian continent and the West Pacific), making the seasonal transition of thermal contrast more sensitive and specific. Zhang et al.[18] and Qian et al.[19] firstly documented the effect of zonal land-sea thermal contrast on summer monsoon, but the subtropical monsoon was not involved. So the present paper focuses on the seasonal

Received March 20, 2007; accepted August 20, 2007
doi: 10.1007/s11434-007-0518-0
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Supported jointly by National Basic Research Program of China ("973" Program) (Grant No. 2006CB403607) and the National Natural Science Foundation of China (Grant No. 40633018)

cycle of zonal land-sea thermal difference over East Asian subtropical region, and its relationship with East Asian subtropical monsoon.

2 Data

We utilize two datasets: the daily meteorological variables form NCEP/NCAR reanalysis from 1950 to 2000[20] and pentad precipitation from CMAP (Climate Prediction Center Merged Analysis of Precipitation) [21] from 1979 to 2000. The pentad-averaged values were calculated from the former daily data.

3 Discussion on subtropical monsoon essence

Figure 1 depicts evolution of 500 hPa climatic air temperature latitudinal deviation (TLD, defined as the temperature difference between a certain longitude and the average of 80º－150ºE) on Northern Hemisphere. We can find that the magnitude of TLD increases with the latitude from south to north. The seasonal transition of its zonal contrast is significant at all latitudes except 35ºN (Figure 1(e)): the West Pacific is warm during winter and spring, and turns cool in later spring and early summer with anomalous centers located east of 130ºE. The Asian continent is cold during winter and spring, and becomes warm in later spring and early summer with centers situated from Bay of Bengal to Tibetan Plateau. That is, it is cold/warm in the west/east during winter and spring and vice versa during summer and autumn. However, the time and the features of transition at different latitudes are different.

At 15°N (Figure 1(a)), the TLD in the west of SCS (115°E) is almost opposite completely to that in east (the

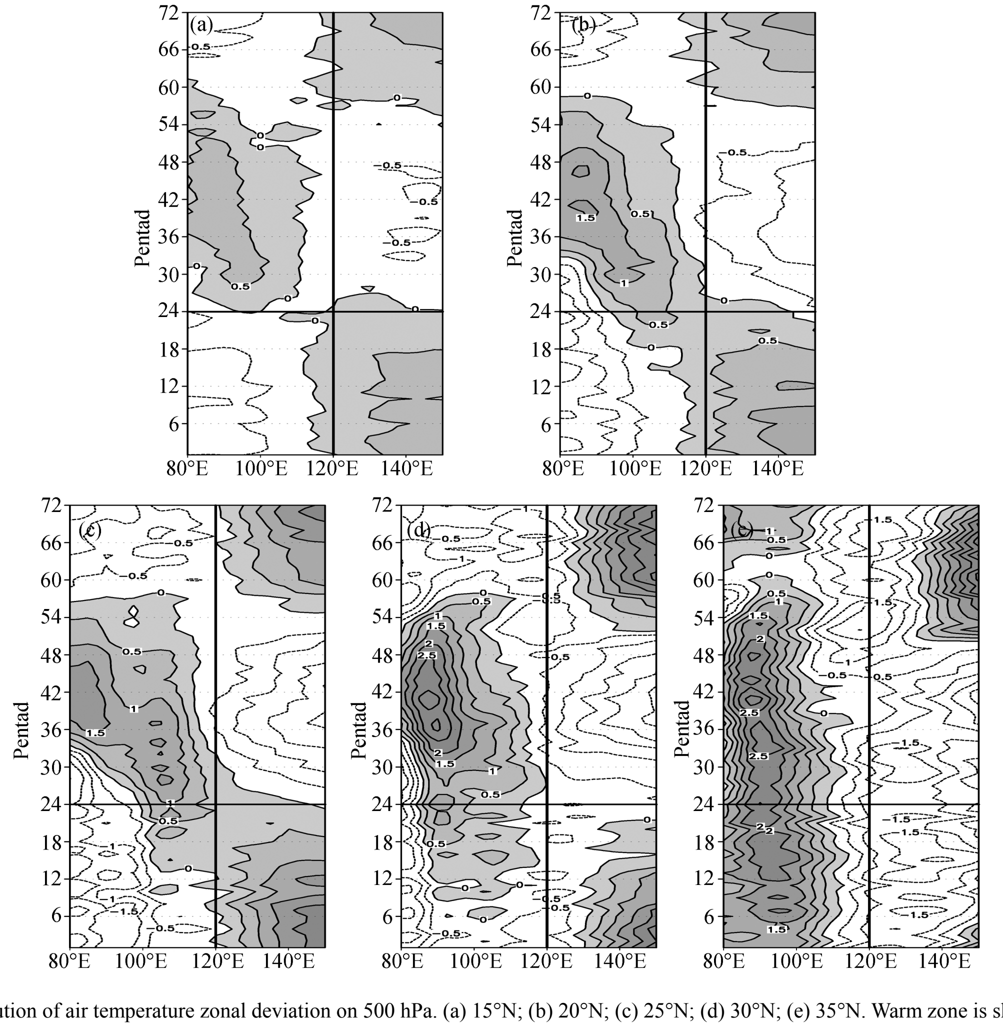

Figure 1 Evolution of air temperature zonal deviation on 500 hPa. (a) 15°N; (b) 20°N; (c) 25°N; (d) 30°N; (e) 35°N. Warm zone is shaded, units: K.

boundary is showed with the vertical line in Figure 1(a)); by pentad 24, the east/west to SCS turns from warm/cold to cold/warm; at all longitudes, transit occurs synchronously almost at the same time with explosiveness. 20ºN (Figure 1(b)) also is bounded by SCS; the ocean to the east of SCS turns cold in pentad 26, while on the other side, the Indochina Peninsula transits first in about pentad 18; then the seasonal transition advances westward .causing the east India to change warm later than pentad 30. The seasonal cycle at 25°N (Figure 1(c)) is similar to that at 20°N (Figure 1(b)) with the boundary little eastward to 120°E (the coastline of South China); on its east flank, the eastern continent (South China) warms first much earlier than pentad 14. Comparatively, the TLD at 30°N (Figure 1(d)) is much greater due to the Tibetan Plateau heating; moreover, its seasonal cycle transits earliest, that is, the ocean east of East China Sea has cooled before pentad 24, while East Asian continent east of the plateau (east of 90°E) turns warm all around pentad 12. At 35°N (Figure 1(e)), West Pacific is cool before pentad 50, and the continent west of 110°E is warm all the time with no seasonal cycle.

In order to calculate the zonal land-sea thermal contrast at every latitude, the TLD anomalous centers on both sides are chosen as the key regions, namely 130°—150°E for West Pacific, 80°—100°E for East Asian continent. As shown in Figure 2(a), the contrast in 35°N has no seasonal cycle leading to no seasonal transition of

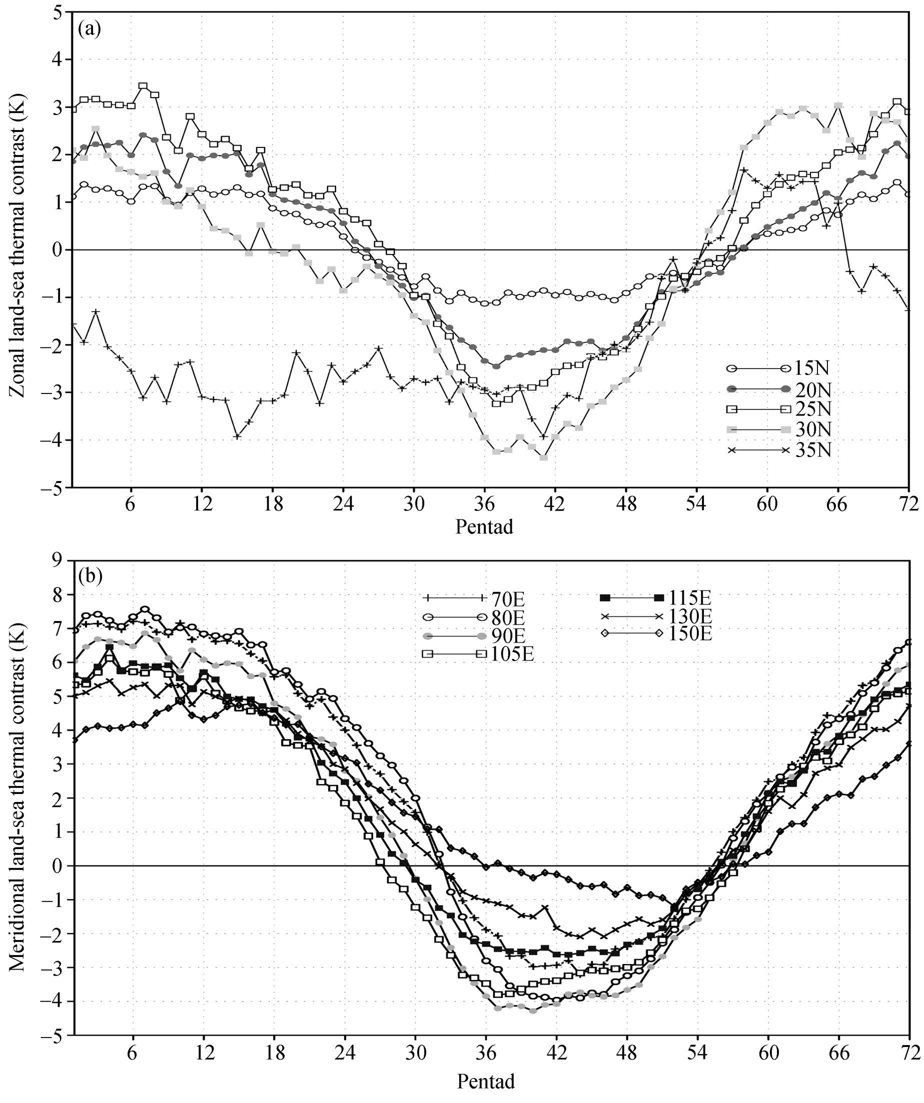

Figure 2 Evolution of land-sea thermal contrast (units: K) on 500 hPa. (a) Zonal (West Pacific: 130°—150°E, East Asia: 80°—100°E); (b) meridional (Tropics: 5°S—5°N, East Asia: 20°—30°N).

wind direction over this region[22]. However, it has significant seasonal variation at other latitudes. It turns from positive to negative in later spring and early summer, indicating that cold East Asian continent/warm West Pacific turns to warm continent/cool ocean forming westward temperature gradient. While it turns from negative to positive in autumn with eastward temperature gradient. Comparison between all latitudes suggests that the seasonal transition takes place earliest in subtropical region in later March. Later the tropical region transits at 15°N, 20°N, 25°N in turn in the first and middle ten days of May. Their interval is not longer than 1—2 pentad. It is probably connected with the onset of the East Asian tropical summer monsoon and advances northward.

On an average, the zonal land-sea thermal contrast transits in pentad 27 over tropical region (15°—25°N (figure omitted)) and in pentad 18 over subtropics (27.5°—32.5°N (Figure 3)). The time interval is greater than a month, proving that they are independent of each other. As shown in Figure 1, the West Pacific turns cool in about pentad 24 at all latitudes, just a little ahead at 30°N. However, the time is evidently different for Bay of Bengal and East Asia to turn warm. On this account, when zonal land-sea thermal difference transits occur depends on when the East Asia and its south turn warm. From spring to summer, east China continent and the east of Plateau (east of 90°E) warm in short order, with the quickest temperature rising and air pressure lowering at latitude of 30°N, leading to seasonal cycle of the zonal land-sea thermal contrast fist transiting here, that is, the latitude of Tibetan Plateau. On the other hand, heating source over the plateau begins to enhance in later March, as an uplifted one heating the middle and upper troposphere directly, and intensify the zonal land-sea thermal contrast there, leading to maximum. Nevertheless, the contrast over tropics transits along with the solar radiation seasonal cycle extending from south to north. On this account, the zonal land-sea thermal difference over subtropical regions is not only sensitive and specific, but also more ahead.

Furthermore, the zonal land-sea thermal contrast over subtropics is also ahead relative to the East Asia meridional land-sea thermal contrast. The meridional land-sea thermal contrast seasonal transition first takes place in Indochina Peninsula (105°E) in about pentad 27, presenting warm in south and cold in north changing to warm in north and cool in south. Then the seasonal transition extends to both sides at the same time. SCS and Bay of Bengal transit simultaneously during pentad 30 (more ahead in low troposphere), so do Indian Peninsula and the neighborhood of 130°E in pentad 32. The contrast transits last in West Pacific (150ºE). It is obvious that the seasonal cycle of the meridional land-sea thermal difference is basically consistent with the process of the onset of East Asian tropical summer monsoon and advances northward.

Generally speaking, the land-sea thermal contrast is considered as the fundamental mechanism of monsoon formation. The meridional land-sea thermal contrast in East Asia (including the Tibetan Plateau) is the key driving force of tropical monsoon. Could the seasonal transition of zonal land-sea thermal difference over subtropics be closely related with subtropical summer monsoon onset? From winter to summer, the zonal land-sea thermal contrast over subtropics turns from warm east and cool west to cold east and warm west in pentad 18 and persists (Figure 3). Before the transition (pentad 12—17(Figure 4(a)) at the 850 hPa level, the India-Burma trough is much evident; a vortex is centered around equator 85°E; the subtropical high cells have formed, but the high belt dose not split; the north edge of the southerly to the east of 110°E is located at about 25ºN, therefore the subtropics (27.5°—32.5°N) are controlled by northerly. After transition (pentad 19—24 (Figure 4(b))), the vortex moves to Sri Lanka; subtropical high belt is weakened but still orbicular; there is no cross-equatorial flow formed, suggesting that the interactions between the Northern and Southern Hemispheric atmospheres are not remarkable. On this account, the SCS summer monsoon does not set up here; the West Pacific subtropical high is strengthened with wide meridional span; the southerly advances northward to 35°N, that is, the wind over subtropics turns from northerly to southerly. Notable southerly sets up over subtropical region of East Asia, which mainly comes from the southwesterly from easterly of south West Pacific subtropical high over ocean and northwesterly from south Tibetan Plateau at mid and high latitudes, causing mixed feature of subtropics.

Moreover, precipitation anomaly over subtropical regions (averaged over 27.5°—32.5°N, 110°—140°E, annual mean is taken out (Figure 3)) turns from negative to positive as the zonal land-sea thermal contrast season-

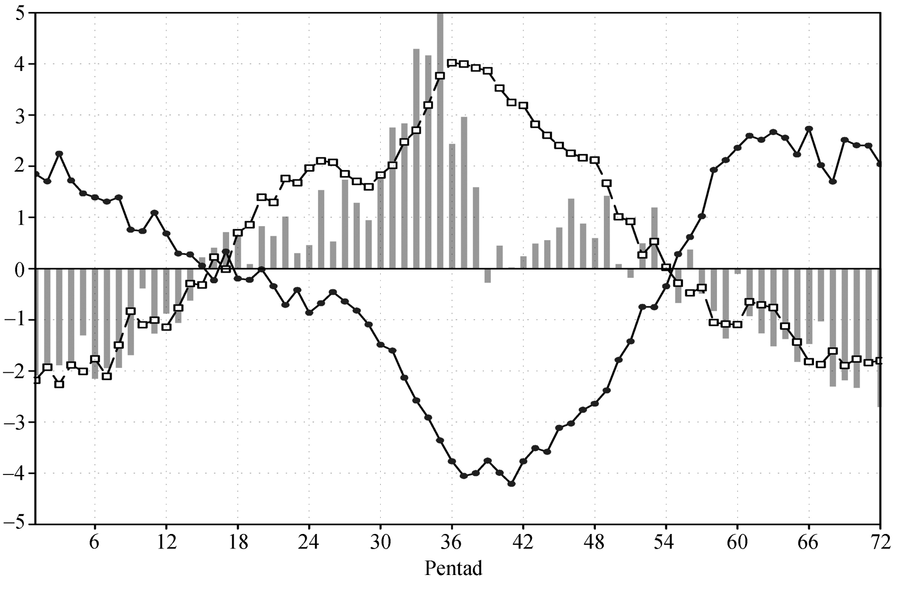

Figure 3 Climatological evolution of subtropics (27.5°—32.5°N) zonal land-sea thermal contrast on 500 hPa (solid dotted line, units: K), subtropics (27.5°—32.5°N, 110°—140°E on average) meridional wind on 850 hPa (line with open square, units: m/s) and anomaly precipitation (annual mean is taken off, histogram, units: mm).

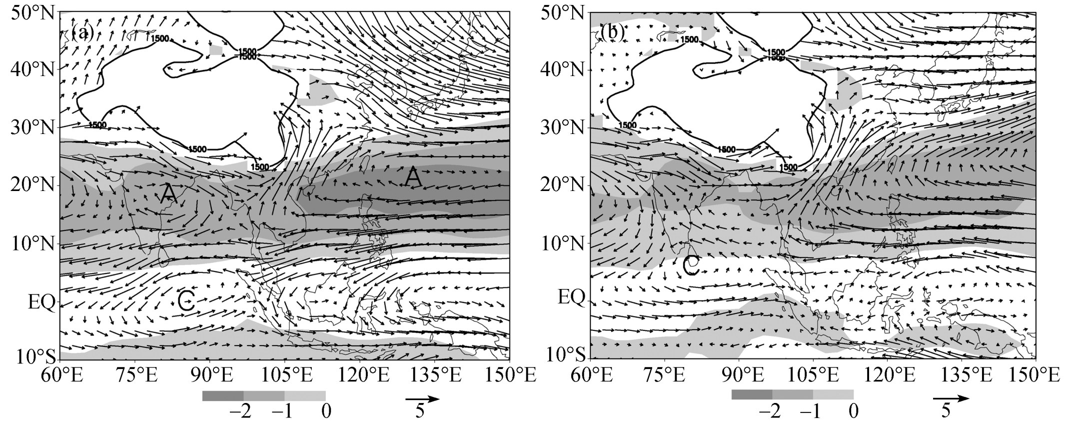

Figure 4 The stream filed on 850 hPa (m/s) and anticyclonic vorticity on 500 hPa (shaded, in 10^{-5} s^{-2}). (a) Before zonal land-sea thermal contrast transits over subtropics from winter to summer (12—17P); (b) after zonal land-sea thermal contrast transits over subtropics from winter to summer (19—24P).

ally transits.

Both wind and rain, two characteristics of the monsoon occur together, may indicate the onset of subtropical summer monsoon. It illuminates that the subtropical summer monsoon sets up earlier relative to the SCS summer monsoon.

4 Summary and discussion

Conclusively, based on the analysis of the climatic temperature latitudinal deviation in middle troposphere, its seasonal cycle suggests that due to the rapid warming of east China continent and the east of Tibetan Plateau and heating of Tibetan Plateau in spring, seasonal transition of the thermal difference between East Asia continent and West Pacific first takes place over the subtropical region with greatest intensity. Accordingly, the prevailing wind turns from northerly in winter to southerly in summer in low tropospheres, which partly come from the ocean and have the mix feature of subtropics. Wan and Wu[23] pointed out that the precipitation to the east of plateau during spring belongs to spring persistent rain over southeastern China, essentially caused by mechanical forcing and thermal forcing of Tibetan Plateau on a climatic basis. Herein, the convention precipitation is thought to take place at the same time. That is, both the wind and rain appear in the meantime. Based on the general viewpoint that the land-sea thermal contrast is the fundamental mechanism of the formation of monsoon, we might as well consider that the process of wind over subtropics turning from northerly to southerly indicates East Asia subtropical summer monsoon onset.

In consequence, (1) Subtropical monsoon is independent of tropical monsoon; the former is not the northward extension of the latter. (2) Subtropical monsoon sets up earlier relative to tropical monsoon. (3) The seasonal cycle formed by the zonal thermal contrast between Asian continent and western Pacific on the background of solar radiation seasonal variation may be an independent driving force of East Asian subtropical monsoon. Subtropical monsoon sets up earlier than tropical monsoon in that the temperature gradient between East Asia continent and the ocean transits earlier than the meridional one over tropics.

The authors would like to thank the two anonymous reviewers for their valuable suggestions and comments.

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