Article ID: 1006-8775(2008) 01-0077-04

LAND-SEA THERMAL CONTRAST OVER SOUTH ASIA AND ITS INFLUENCES ON TROPICAL MONSOON CIRCULATION

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Abstract: Based on the NCEP/NCAR reanalysis data, the thermodynamic features and the effect of spatially nonuniform heating on the circulation of the tropical monsoon area in South Asia due to the land-sea distribution have been analyzed. The influences of the subcontinent topography on the Asian tropical circulation are mostly characterized by its thermodynamic effects on low-level circulation, of which the strongest is observed in winter and spring but the relatively weak in summer, followed by the weakest in autumn. The thermodynamic difference between the Indochina Peninsula and Indian Peninsula and its influence on the circulation are regulated by the Tibetan Plateau. During the transitional period from spring to early summer, the Tibetan Plateau thermal forcing generates a large-scale cyclonic circulation in low latitudes in the lower troposphere. As a result, the southerlies/northerlies are increased to the east / west of the Bay of Bengal, Therefore latent heating of the atmosphere is strengthened and the surface sensible heating over the Indochina Peninsula is weakened. On the other hand the surface sensible heating over the Indian Peninsula is increased. It is shown that heating with various scales and different kinds can affect the tropical atmosphere in different ways, which lead to the unique characteristics of the tropical Asian circulation..

Key words: land-sea distribution; thermal contrast; tropical monsoon area

CLC number: P461.2 **Document code:** A

1 INTRODUCTION

Monsoon is a phenomenon at the near-surface layer of the atmosphere that is marked by prevailing winds in winter and summer being almost opposite in direction and remarkably different in climatological characteristics [1]. The thermal factor close to the underlying surface is mainly responsible for the phenomenon [2]. The meridional difference of insolation results in the formation of meridional heating gradient that is zonally symmetric and causes north-south shifts of the planetary wind zone in location. Due to the land-sea thermal contrast, on the other hand, the atmospheric circulation becomes inhomogenous in zonal distribution with the adjustment of the heating field and results in monsoonal airflow that is opposite in winter and summer [3, 4]. It cannot be neglected that the zonal temperature gradient caused by sub-continental land-sea contrast in South Asia plays a role in the tropical monsoon in Asia. By adding or subtracting the subcontinental orography or altering the land-sea thermal contrast, much of the research have used numerical simulation to study the role of the subcontinent singly and drawn some meaningful conclusions [5 - 7]. In this work, the data from a South China Sea monsoon experiment in 1998 will be used to study the surface heating field, emphasizing the role of heating over Indochina Peninsula on earlier-than-usual onset of South China Sea monsoon [8]. It is obvious that the subcontinental scale of South Asia (shortened as the subcontinental scale hereafter) acts as an important player in Asian monsoons due to its unique geographic location. In this work, the data of climatological mean heating and circulation will be studied in attempts to identify the mechanism through which the secondary

Received date: 2006-12-28; **revised date:** 2008-04-24
Foundation item: Key National Fundamental Research Foundation (2006CB403607); Natural Science Foundation of China (40475027; 40221503)
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land-sea contrast in South Asia affects the tropical monsoon circulation in Asia in general.

2 THERMODYNAMIC CONDITION AND ITS EVOLUTION IN SOUTHERN ASIA

It is known from the vertical cross section of the general rate of multi-year mean adiabatic heating over 10°N – 20°N (Fig.1) that wintertime heating is dominated by low-level sensible heating with significant difference between land and sea. In spring, the middle and upper troposphere over Indochina Peninsula witnesses an area of large heating values, which are even greater than that over western Pacific on the same levels, while low-level heating is resultantly reduced. This pattern of distribution is mainly caused by the release of latent heat, which becomes more and more obvious with time. At this point, sensible heating is still a dominant feature in the near-surface layer over India Peninsula while heating is negative (i.e. radiation cooling) in the middle and lower troposphere. In summer, due to monsoonal precipitation, there is intense latent heating in these layers of the troposphere over the Asian region of tropical monsoon. The most significant characteristics of autumn are the weak heating at the middle and upper levels of the troposphere over the Bay of Bengal and areas to the east, with the center being over South China Sea and western Pacific. The total heating is negative at the middle and higher levels over the Indian Peninsula and areas west of it. The secondary thermal contrast is relatively weak and mainly shown at lower levels. Except for a small area over the Indian Peninsula, heating is basically negative in the region of Asian tropical monsoon.

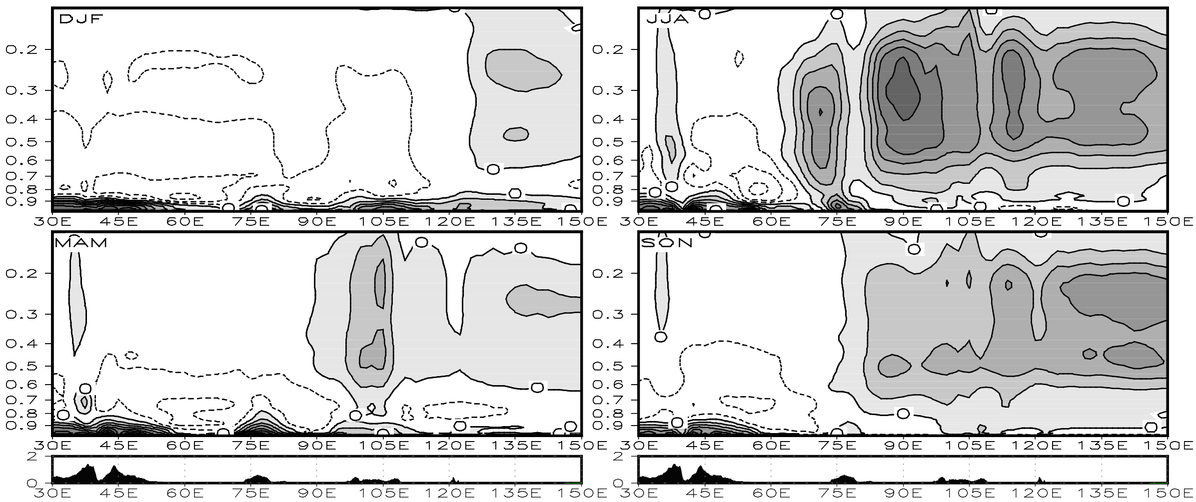

Fig.1 Vertical cross section of total diabatic heating rates over 10°N – 20°N averaged over 1979 – 1997. The ordinate is on σ and the interval is 1 K/day. Other captions are the same as Fig.1. Terrain is shown in the bottom panel.

As shown in an existing study [9], the thermal contrast between low-latitude subcontinental scale peninsulas is associated with the dynamic and thermodynamic effects of Tibetan Plateau. Daily sensible heating data climatologically averaged for the time March 6 – May 5 (just prior to the onset of summer monsoon) are used to study the correlation between the flux of plateau surface sensible heat and the field of sensible heat flux five days lagging behind (Fig.2). It is known that the zero contour of the correlation field is generally distributing along the coastline, being positive onshore but negative offshore in all of the area north of 15°N except East Asia. Within the zonal belt of 15°N – 25°N, the correlation is just the opposite between Indian and Indochina Peninsulas, which are much positively and negatively correlated. It shows that sensible heating over the

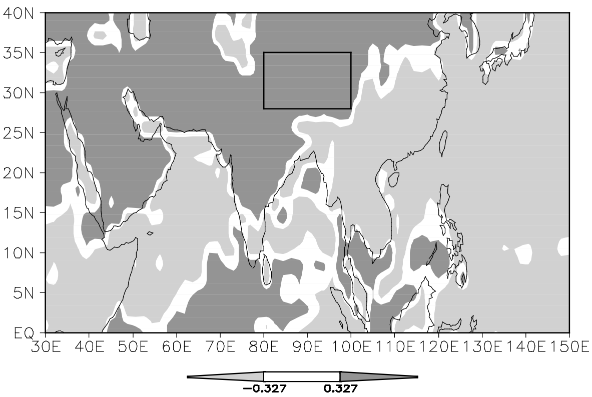

Fig.2 Correlation between the flux of plateau surface sensible heat and the field of sensible heat flux five days lagging behind for the plateau area (indicated by the box) climatologically averaged over Mar. 6 – May 5.

plateau is favorable for the increase of sensible heat over Indian Peninsula but the decrease of it (and the increase of latent heat) over Indochina Peninsula and heating over the plateau has some effect on low-latitude thermodynamic state via the action of circulation.

3 EFFECT OF INHOMOGENEOUS SPATIAL HEATING ON LOW-LATITUDE CIRCULATION

Fig.3 gives the zonal deviation of temperature and the vertical cross section of composite vectors of vertical motion, which are averaged over 15°N – 20°N for January and April. The heating effect of the subcontinent is remarkable in winter at lower tropospheric layers. There, it is warm and there is ascending motion, though it cools down a little on the levels of 600 – 800 hPa and the ascending motion maintains until somewhere around 700 hPa, i.e. an overshooting. In April, positive temperature deviation is strengthened at lower levels over the peninsulas, Indian Peninsula in particular, and reaches as high as 700 hPa, in association of a thickened layer of ascending motion (600 hPa). Though its lower-level positive deviation is not as intense as that of Indian Peninsula, Indochina Peninsula has vertical motion that prevails throughout the whole troposphere, with an obvious high-temperature center being at its middle and upper levels that corresponds to the convective heating shown in Fig.1. It is apparent that significant differences have now occurred in the thermodynamics of the atmosphere over the two peninsulas.

It is known from the cross section of meridional wind (figure omitted) that circulation below 600 hPa is mainly subject to the secondary land-sea thermal contrast at low latitudes. Sensible heating over the peninsulas has resulted in circulation that tops at 800 hPa and moves cyclonically at lower levels and anti-cyclonically at higher levels. Mid-tropospheric layers of 400 – 600 hPa are much affected by the plateau so that the most significant trough is over the Bay of Bengal. The circulation at 100 hPa – 400 hPa of the upper troposphere is closely linked with large-scale land-sea thermodynamic contrast. Additionally, condensation-based latent heat released in subcontinental precipitation is also having significant effect on the circulation at the middle and upper levels of the troposphere.

Seasonal evolution of meridional deviation wind at the low level of 850 hPa is studied together with the formation of subcontinent-scale troughs and ridges at low latitudes, which are climatologically averaged over 10°N – 20°N (figure omitted). In winter, the signs of meridional deviation wind are lined up in three positive and negative alterations from the west to the east over the range from 35°E to 120°E. The pattern is just the opposite in summer. Such distribution is each corresponding to that of the secondary land-sea contrast. Under the condition of surface sensible heat in winter, cyclonic circulation occurs over the peninsulas' heating area at 850 hPa, i.e. the vortex source is positive (S>0). Due to the effect of zonal easterly advection in winter, the area of positive vortex source is with strong negative advection, with the cyclonic center being over the western side of the heating source (of the peninsulas) and anti-cyclonic circulation over the eastern part of the peninsulas. One of the most significant features about the transition from winter to summer is the gradual eastward propagation of the systems of troughs and ridges on individual subcontinent scales, which is resulted from a gradually weakening easterly basic flow. Secondly, with the shift from negative to positive in the total heating of the plateau in early April [10], the thermodynamic, cyclonic circulation produced at low levels deepens a low-latitude trough to the south so that there is a pattern of widespread increase of the northerly on the western side and decrease of the southerly on the eastern side in the tropics that stretches to about 90°E. Of the deviation troughs and ridges in June – August, the trough maintaining near 83°E is also the most pronounced, for it is the combined resultant of heating over the Indian Peninsula and Tibetan Plateau. With

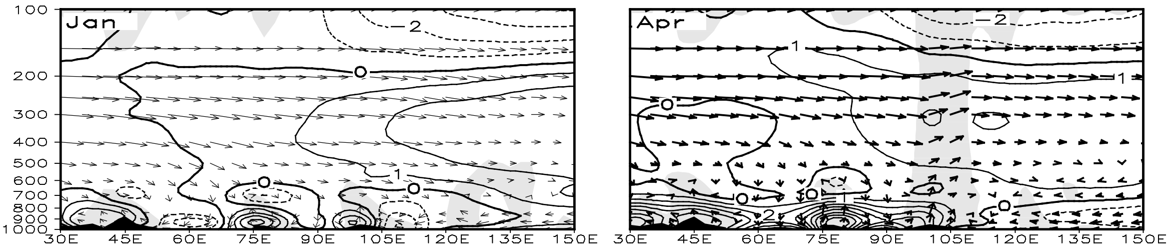

Fig.3 Zonal deviation of temperature and the vertical cross section of composite vectors of vertical motion, which are climatologically averaged over 15°N – 20°N for January (a, unit of contour: K) and April (b). The shallow shades indicate ascending motion (ω<0).

consistent southwesterly wind, the deviation trough over the east coast of Indochina Peninsula near 110°E is formed because of the high-level condensation latent heat released over the South China Sea.

For analyses of other aspects, refer to the Chinese edition of the journal.

4 CONCLUSIONS AND DISCUSSIONS

The following points are shown in the above analysis. (1) The thermodynamic nature of low-latitude land-sea contrast is particularly distinct in winter and spring but relatively small in autumn. Zonal heating, inhomogeneously distributed between subcontinents, is most outstanding in the period just before the onset of summer monsoon. Such thermodynamics and its evolution are related with the regulatory role of the Tibetan Plateau. (2) The roles of various inhomogeneous and diabatic heating are leading to different patterns of distribution of low-latitude meridional wind at different heights. The effect over the subcontinents by sensible heating is mainly shown in the near-surface layers and lower troposphere while the mid-tropospheric layers (400 hPa – 600 hPa) are mainly subject to the plateau. Latent heating at the subcontinent scale is also playing a part in the local circulation of middle and higher levels of the troposphere. (3) The secondary land-sea contrast has such effect on the circulation of low-level tropical monsoon area that the distributions of low-latitude subcontinental troughs and ridges in winter are just the opposite of those in summer. The effect of the subcontinents and plateau on low-level circulation in the tropical monsoon area can roughly be distinguished by the season of action and the differences in spatial scale.

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Citation: WANG T M and WU Guo-xiong. Land-sea thermal contrast over south Asia and its influences on tropical monsoon circulation. *J. Trop. Meteor.,* 2008, 14(1): 77-80.