T_{BB} DATA-REVEALED FEATURES OF ASIAN-AUSTRALIAN MONSOON SEASONAL TRANSITION AND ASIAN SUMMER MONSOOM ESTABLISHMENT①

He Jinhai (何金海), Zhu Qiangen (朱乾根)

Nanjing Institute of Meteorology, Nanjing 210044

and M. Murakami

Meteorological Research Institute of Japan

Received 9 January 1995, accepted 18 July 1995

ABSTRACT

Based on T_{BB} data from Meteorological Institute Research of Japan, study is carried out of the features of seasonal transition of Asian-Australian monsoons and Asian summer monsoon establishment, indicating that the transition begins as early as in April, followed by abrupt change in May-June; the Asian summer monsoon situation is fully established in June. The winter convective center in Sumatra moved steadily northwestward across the "land bridge" of the maritime continent and the Indo-China Peninsula as time goes from winter to summer, thus giving rise to the change in large scale circulations that is responsible for the summer monsoon establishment over SE Asia and India; the South China Sea to the western Pacific summer monsoon onset bears a close relation to the active convection in the Indo-China Peninsula and steady eastward retreat of the subtropical T_{BB} high-value band, corresponding to the western Pacific subtropical high.

Key words: T_{BB} data, Asian-Australian monsoon region, seasonal transition, features of summer monsoon establishment

I. INTRODUCTION

For over a decade in the past, with the deepening investigation of monsoon, substantial progress has been made in the understanding of monsoon circulation systems. The review includes Tao and Chen (1987), who showed that summer monsoons of East Asia and South Asia (India) are separate subsystems, and Zhu, He and Wang (1986), who indicated that the east Asian summer monsoon system can be made up of the South China Sea to western Pacific and China mainland to Japan, the former being of tropical and the latter of subtropical nature, and concurrently with the east Asian summer monsoon, winter monsoon prevails over Indonesia to North Australia; these systems are both independent and interrelated, constituting a complete picture of monsoon. For northern winter, east Asian NE monsoon crosses the equator into the Southern Hemisphere, changing to the summer monsoon blowing in Indonesia to North Australia. The seasonal transition between winter/summer winds makes a seasonal cycle of the system.

The establishment of summer monsoon with its transition features has long been a major concern of meteorologists. The sudden change of atmospheric circulations in June and October was discovered by Yeh, Tao and Li. as far back as in 1958. However, ever-

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① This work is supported jointly by China State Meteorological Administration Monsoon Cooperation Funds and the National Natural Science Foundation of China.

increasing evidence suggests that the seasonal transition characteristics related to summer monsoon establishment appear at tropics prior to June; the northern spring is of vital importance to the recognition of the subsequent evolution of the monsoon and interannual variability of a sea-air-land coupled system. Webster and Yang (1992) reported that spring represents the season for the coupled system to lose "memory" at fastest speed and during this time equatorial circulation is extremely "fragile" and hence more sensitive to the change in boundary conditions and random forcing from extratropics. Yasunari (1991) pointed out that the precipitation and circulation anomaly associated with monsoon-ENSO are in a locked phase with the annual cycle with changed anomaly sign in late spring to early summer, and he suggested a concept of "monsoon year" commencing in April-May and terminating in the same period the next year. This definition implies the importance of northern spring to the determination of the seasonal winter/summer monsoon transition features. This article concerns the signatures of seasonal Asian-Australian monsoon transition during the aforementioned Key period alongside the characteristics and difference in summer monsoon establishment in a range of Asian areas with possible mechanisms for the difference examined.

Ⅱ. DATA AND SCHEME USED

The data used in the present work are a series of GMS-observed black body radiation temperature (T_{BB}) provided by Meteorological Research Institute of Japan covering 60°N~60°S, 80°E~160°W with 1°×1° resolution.

It is worth noting that in cloud-free and partly cloudy portions T_{BB} denotes the surface black body temperature, giving a higher value so that the high-value T_{BB} band is related to a high-pressure system, but in a cloudy segment the T_{BB} reflects the cloud top condition, showing a lower magnitude and the higher the top is and thus the lower the T_{BB}, the stronger the convection will be, leading to the fact that low T_{BB} areas are cloudy sectors with the low center representing a vigorous core. Caution must be exercised when analysis is done in winter, when extratropics and highlands show lowered ground temperature, resulting in the fact that T_{BB} is rather low even if the area is cloud-free. Moreover, for extratropical latitudes, the higher the latitude reaches, the lower the surface temperature gets, and so is T_{BB}, thereby causing (most of) the isopleths to be of zonality, which is notably pronounced in a winter hemisphere. And when these isolines extend into tropics, generating a trough with such low T_{BB} inside (as compared to the bands at the same latitudes), a cloud band can be identified. As such, extratropical T_{BB} trough lines can be used to recognize a cloud area. Our practice has shown that the pattern of T_{BB} high and low centers related to temperature ridge and trough bears close resemblance to that of 500-hPa geopotential height.

Ⅲ. RESULTS AND ANALYSIS

1. *Seasonal transition features viewed from a climatological chart*

Fig. 1a~d presents the monthly horizontal T_{BB} distribution on a long-term mean basis for March~June, respectively.

Evidently, the March situation remains identical to the January's one (figure not shown), i.e. a T_{BB} high-value belt is seen at southern subtropics with its ridge around 25°S and the main center in central Australia, corresponding to the southern subtropical high-pressure strip and the Australian high pressure center, separately; a zonal high-value belt is at northern subtropics, with its ridge about 15~29°N and the predominant core

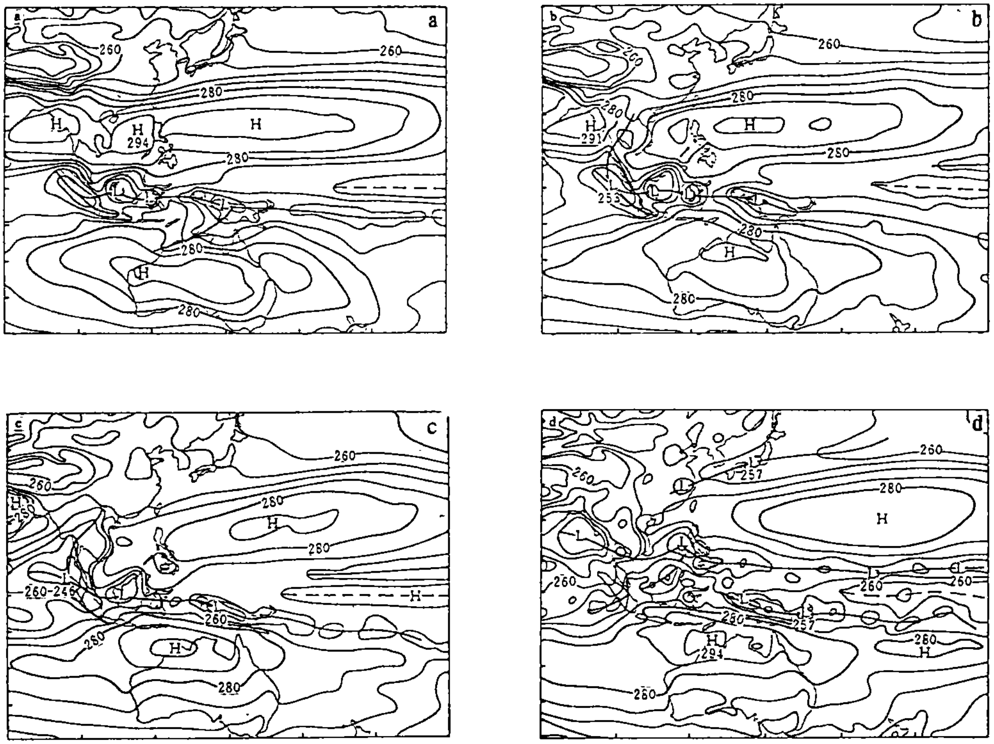

Fig. 1. 1980-1988 monthly mean T_{BB} horizontal pattern for March to June shown in a) to d), respectively, with the high belt ridge denoted by dotted line and the low band axis or the 280°K isopleth by heavy solid line.

in the western Pacific and minor centers, one in the South China Sea and the other in the northeast of the Bay of Bengal, corresponding, respectively, to the subtropical high-pressure band and related center; a zonal narrow high T_{BB} strip is observed at equatorial latitudes east of 170°E (with the 272°K isoline as the characteristic line), associated with the relatively high-pressure belt between ITCZ's of both hemispheres.

The low T_{BB} strips intervening between the high bands just described are i) those of low value at bihemispheric midlatitude belts over which several weak (low-value) troughs are located, and ii) those on the south side of the equator, covering the whole project area (80°E~160°W) with pronounced low cores situated over Sumatra, Bornea, Sulawesi and New Guinea, suggesting vigorous convection therein. Further, two low belts stretching from New Guinea low core dominate North Australia in relation to the summer monsoon there.

Yet, one sees from the April plot that the above features have experienced remarkable change (See Fig. 1b), characterized largely by i) the breaking of the northern subtropical high T_{BB} band with the 280°K isotherm as the characteristic line in the Indo-China Peninsula (10~20°N, 100~110°E), into which a strong trough extends from the Sumatra center, connecting the low strip at northern midlatitudes; ii) the Australian high-value area is significantly moved equatorward (with its axis situated around 20°S), thereby making the trough between New Guinea and North Australia disappear. All these indicate that due to seasonal variation in solar radiation and the difference in the response to it of land and sea, the monsoon system as a whole is shifted equatorward, resulting in the disintegration of the summer monsoon over Australia, ushering in the beginning of seasonal transition of bihemispheric large-scale circulation at low to mid latitudes.

The May chart shows that the high T_{BB} core in the east of the northern subtropical zone makes a swift retreat towards the east, which is accompanied by the start of active convection from the Philippines to the South China Sea, the Sumatra low center travelling northwest with increased vigor and coverage, leading to the Indo-China Peninsula dominated by a pronounced low trough and northwestward shift of the high core in the NE Bay of Bengal close to 25°N, 80°E. These imply that the summer monsoon convection has been fully initiated over the Peninsula to the Bay. Additionally, the equatorial eastern Pacific high strip has extended a great distance in the neighborhood of 150°E.

The situation of June shows that the western Pacific high center of T_{BB} continues its eastward retrogression at a quick pace, accompanied by considerable northward jump of the high value axis to 22°N, with two low cores on the low belt on the north side of the T_{BB} high-value band, one in the mid/lower basins of the Changjiang (relative to the Meiyu period in China) and the other in south of Japan (to the Baiu season in Japan); a very intense low core of T_{BB} dominates the South China Sea to Philippines, connecting the low strip on the north side of the equator in the central eastern Pacific that substantially expands westward, as does the equatorial high band, thus generating a rather complete low belt, which suggests the full establishment of summer monsoon over the South China Sea to the western Pacific. In the meantime, the winter Sumatra low core becomes a feeble trough zone and an extensive low center of high vigor comes into being in the NE of the Bay, just in contrast to the high center in winter, suggesting the full establishment of summer monsoon from the Bay to India. It should be noted that the winter low core in Sumatra advances northward as time goes from winter to summer, with considerable jump in May-June, reaching the northernmost position (north of 20°N) for July to August and retreating in September. This issue will be dealt with in a later section.

In summary, the seasonal transition occurring in the Asian to Australian monsoon area begins in April with the abrupt change in May～June and full establishment in June. It can be seen that our results agree well with the statement of Yasunari (1991) who defined the period April to May as the starting interval of the "monsoon year".

2. *Features of summer monsoon establishment on a time-latitude section*

To investigate the establishment features in the aforementioned areas with their difference, calculation is performed of the 1980～1988 pentad T_{BB} data with the time latitude cross sections (Fig. 2a～d) prepared along 80, 100, 120 and 140°E, respectively.

Fig. 2a portrays largely the characteristics of summer monsoon establishment in East India. Evidently, for January to May East India around 20°N is controlled by a high T_{BB} belt, which is strongest in Februay～March, relative to a spell of fine weather in the dry season of the country, and becomes weak quickly in early June, changing to a low strip, suggesting the onset of Indian summer monsoon; the low belt is most intense, reaching its northernmost limit in late July, meaning that the monsoon attains its climax throughout India; afterwards, the low strip travels equatorward, leaving the country again under the control of high belt in late September, implying that winter monsoon takes the place of the summer analog India. It is worth noting that a low belt propagates

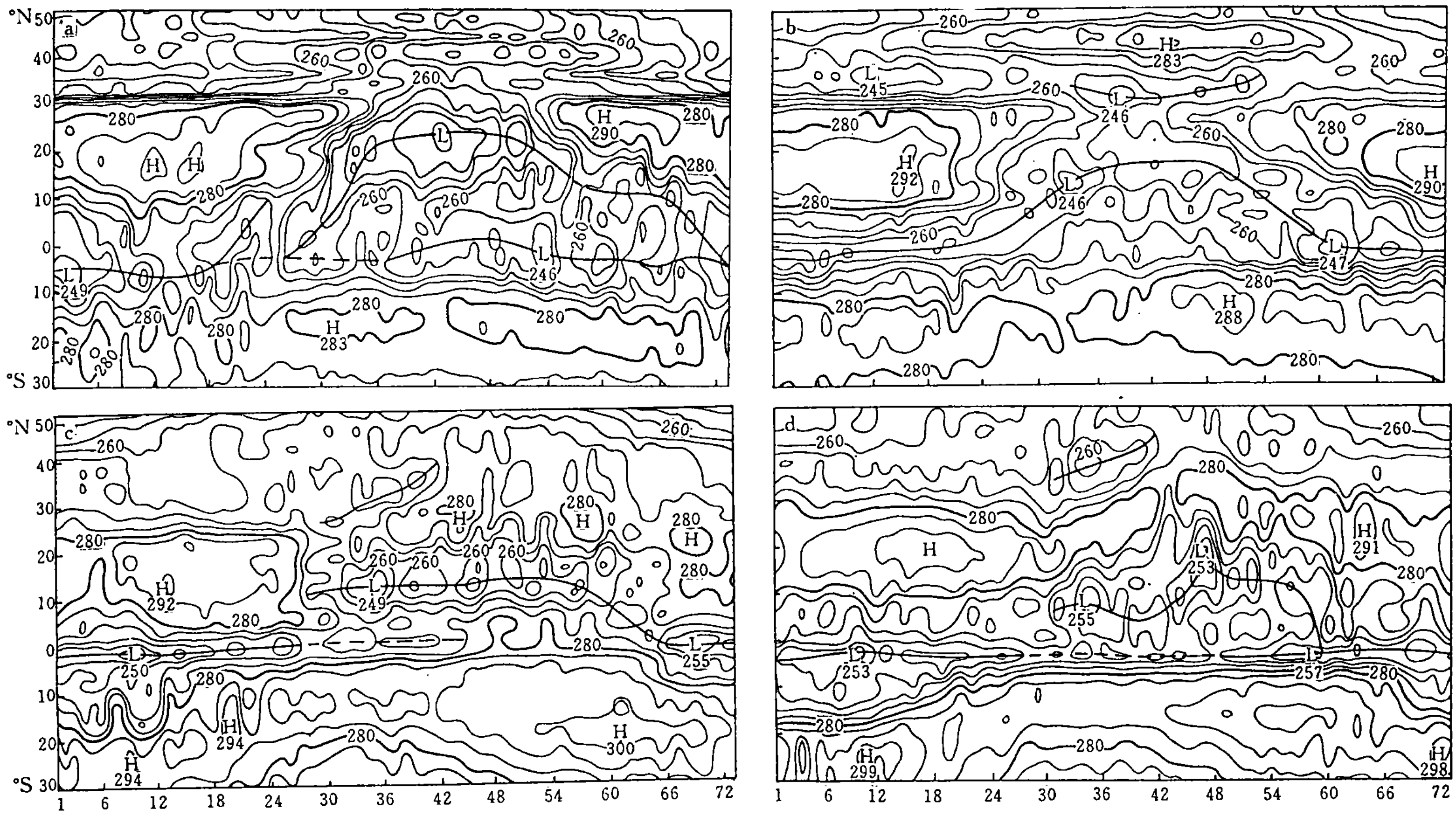

Fig. 2. Time-latitude cross sections of 1980—1988 pentad mean T_{BB} along 80, 100, 120 and 140°E, shown in a) to d), respectively, with the abscissa marked by pentad and heavy solid line representing the 280°K isothern or low belt axis.

northward from the equator persistently in early May, forming a low T_{BB} core in early June over India, indicating enhanced convection and summer monsoon established in this country. The establishment process shows that, though of abrupt nature, the transition from the high T_{BB} band to its low belt, which implies the establishment of Indian summer monsoon, is intimately related to the poleward propagation of the equatorial low-value strip.

Fig. 2b depicts the features of summer monsoon established in the east of the Tibetan highland and SE Asia. Inspection shows that the SE Asian monsoon has its seasonal cycle more similar to that of the Indian analog except for the following: i) the high belt begins changing to a low one in early May over SE Asia, meaning that the establishment in this region occurs about one month earlier than that in India; ii) a low strip does not always appear at SE Asian longitudes on the south side of area near the equator as in India but, as winter monsoon transits to the summer counterpart, an equatorial low T_{BB} band moves steadily poleward as a system, which returns to the south side of the equator in accordance with summer monsoon retreats; iii) a low strip is also found in the east of the highland (about 32°N) for June to September and disassociated with the SE Asian analog (15°N), with a relatively high belt in between. This suggests that the summer monsoon in the east of the Plateau is independent of that over SE Asia, differing from the system in the west of the Plateau that is the northward extension of Indian summer monsoon.

Fig. 2c delineates the evolution features of monsoon over Indonesia to North Australia, the South China Sea and east of China. It is apparent that the South China Sea high strip (12°N) changes swiftly into a low one in mid May, suggesting the monsoon established there. But it should be noted that, unlike the establishment over India and SE Asia, the South China Sea monsoon is not featured for its establishment by the poleward march of a near-equatorial low band. It seems abrupt for a high to change to a low belt, a problem that will be handled in detail in a later part. Besides, a low strip is observed east of China mainland, in relation to the subtropical summer monsoon cloud/rain belt in that area, whose inclination indicates the poleward shift of the mainland summer monsoon as time progresses. Corresponding to the western Pacific subtropical high-pressure band, a high T_{BB} belt is between this low and the South China Sea low strip. For December to February, a vigorous low core appears near the equator, extending southward to the west of North Australia, in association with the span of summer monsoon prevailing over the continent.

Fig. 2d shows the seasonal cycle over Japan, the western Pacific and NE Australia at the same longitude, where the northern subtropical high T_{BB} strip displays significant meridional movement in accordance with season; in January ~ May the T_{BB} ridge is around 18°N, moves quickly northward in June and reaches its northernmost limit in the vicinity of 30°N by the end of August, then it travels southward arriving at its winter position in December. Interestingly, the low belt is of the same abrupt character around 10°N as on the meridional section, moving poleward with the subtropical high T_{BB} band, attaining its northernmost position around 18°N in August, followed by retreat. Therefore, the northern western Pacific tropical summer monsoon associated with the low belt acts in June to October only; a strong low-value belt shows up in June-July at 35~40°N in South Japan, corresponding to the Baiu period there and connecting the analog from east China, thereby constituting a subtropical monsoon system over the mainland to Japan; North Australia is under the effect of a low T_{BB} strip from December to March, which acts as an indication of summer monsoon prevailing in that region.

From the foregoing analysis, two important features are of note: i) the summer monsoon onset over India and SE Asia occurs concurrently with the fast poleward advance of the equatorial low T_{BB} band, in contrast to the formation of the low strip for the summer monsoon over the South China Sea, which is characterized by abrupt genesis and similar to and faster than the counterpart in the western Pacific; ii) the monsoon establishment is earlier in SE Asia and the South China Sea than in India and the western Pacific. What processes and mechanisms are responsible for these features will be dealt with in the following.

3. *Discussion of the establishment processes and mechanisms of the summer monsoon*

Based on the 1980~1988 monthly mean T_{BB} (figure not shown) and the contributions (Lau and Chan, 1986; Meehl, 1987), we see that as time goes from winter to summer, the winter Sumatra convective center (5°S, 100°E) is shifted northward not along the longitude but following the "land bridge" of the maritime continent to the Indo-China Peninsula with its persistent stay over the North Bay of Bengal to India in mid summer. Afterwards, concurrently with the seasonal retrogression, this convective core moves southward to Sumatra. To trace and confirm the sequence of Sumatra core evolution, a time section is prepared based on the multi-yearly pentad mean T_{BB} for the "land bridge" to the Peninsula from 4°S, 100°E to 24°N, 90 °E (see Fig. 3).

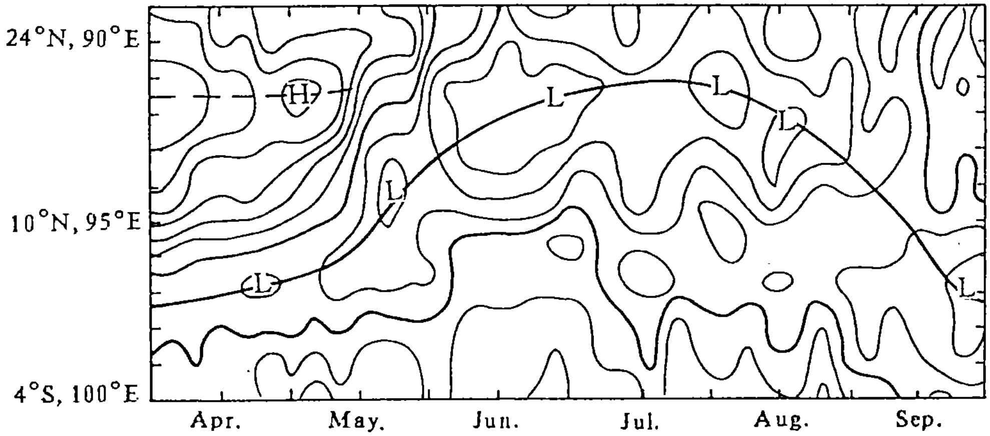

Fig. 3. Time section (4°S, 100°E to 24°N, 90°E) spanning the land bridge to the west coast of the Peninsula with the low T_{BB} axis or the 260°K line denoted by bold solid line and high-value belt axis by dotted line and H(L) symbolizing the high (low) value center, contoured at 5.

The low belt axis and the center shown in Fig. 3 indicate the continuous evolution and annual cycle of position and strength of the convective core. Obviously, it is in the neighbourhood of 3~5°N in April and a swift northward shift occurs in May~June, reaching its northernmost limit in July~August and returning to near-equatorial latitudes in September, suggesting that the winter convective center in Sumatra has a regular annual cycle in following its path to and from the Peninsula via the land bridge. It is the convective core movement towards the Peninsula that leads to the features of summer monsoon established first in SE Asia and then in India.

To make clear the features (shown on the meridional section) of the South China

Sea low T_{BB} belt marked by abrupt generation locally, a plot (Fig. 4) is constructed for March～June evolution of the 280°K characteristic line of the northern subtropical high T_{BB} strip. It is seen therefrom that this belt in March (denoted by solid line) traverses the whole research area; its breaking takes place in April in the Peninsula (10°～20°N, 100°～110°E) with the western piece disappearing in May～June and the eastern continuing eastward shift accompanied by pronounced advance towards the north in June, in relation to the intensified subtropical high of the western Pacific. It is the steady eastward movement of the high T_{BB} strip that gives rise to the active convection first in the South China Sea, then the western Pacific, followed by summer monsoon established in these regions in a chronological order. This interprets why the South China Sea monsoon low T_{BB} band is suddenly generated without the concurrent poleward movement of the equatorial low T_{BB} belt, as illustrated on the 120°E section.

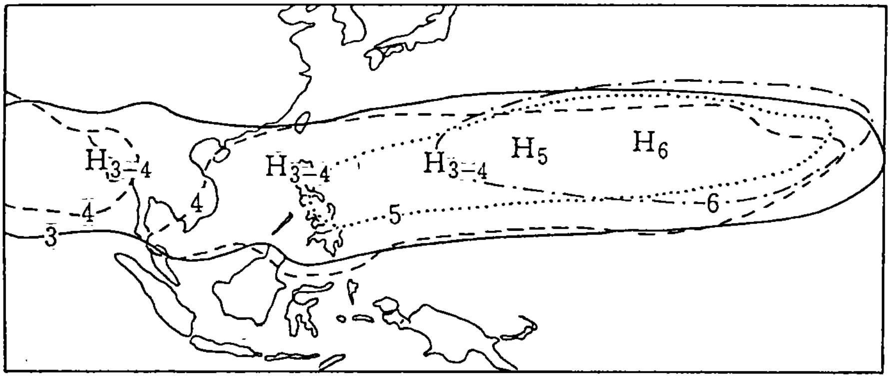

Fig. 4. Month-to-month pattern of the outermost characteristic (280°K) line of northern subtropical high T_{BB} band and the related centers. H (L) stands for the high (low) center, with subscript giving the month. Digit in the line indicates the month.

From the analysis above we obtain the results as follows. The Sumatra convective core makes its way steadily towards the NW from winter to summer, leading to the variation in large-scale circulations that represent the direct processes responsible for the summer monsoon establishment in SE Asia and India; active convection over the Peninsula and the subsequent steady eastward retreat of the high T_{BB} strip in the South China Sea to the western Pacific serves as the principal process of the monsoon onset in that area, which is bound up with the movement of the Sumatra convection center from winter to summer. Of great scientific interest is the mechanism for this center shift following this course. According to Li and Yanai (1995), as time proceeds from winter to summer the quick warming of the narrow land bridge between Sumatra and the Peninsula and sensible heating of the atmosphere serve as a precursor and triggering to the seasonal transition of large-scale circulations over Asia to Australia.

Ⅳ. CONCLUSIONS

Following the above analysis, we reach the conclusions shown below:

a. The seasonal transition in the Asian-Australian monsoon region begins in April and is featured mainly by the Australian high T_{BB} strip moving northward by 5 degrees of latitude and the disintegration of the northern Australian monsoon; active convection and the breaking of the subtropical high T_{BB} belt over the Peninsula; May and June see the sudden change, largely characterized by the Sumatra convective center swiftly travelling northwest to Bay of Bengal and the steady retrogression towards the east of the South China Sea to western Pacific high T_{BB} band; in June the Asian monsoon prevails in the related regions.

b. The summer monsoon establishment in SE Asia and India bears a direct relation to the steady shift of the Sumatra convective core to the Peninsula via the land bridge when time goes from winter to summer. In contrast, the onset of the South China Sea to western Pacific summer monsoon is associated closely with the steady eastward retreat of the high T_{BB} belt relative to the western Pacific subtropical high pressure system.

c. The swift warming of the narrow maritime land bridge between Sumatra and the Indo-China Peninsula and the related sensible heating of the air may act as a forerunner and triggering to the seasonal transition of large-scale circulations over the Asian-Australian monsoon area. Of great scientific interest is the annual cycle of the movement of th Sumatra convective center.

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