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CLIMATOLOGICAL CHARACTERISTICS FOR THE ONSET OF ASIAN SUMMER MONSOON AS REVEALED BY HIRS-Tb12 AND DROUGHT AND FLOODS IN EASTERN CHINA

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ABSTRACT: As shown in comparison and study of the HIRS-Tb12 data and conventional data, temperature, humidity and vertical motion are structured differently in the Southern and Northern Hemispheres, which are well depicted with the HIRS-Tb12 data. When high pressures rapidly decrease over the regions of South China Sea and Arabian Sea with the HIRS-Tb12 less than 200 W/m^2, monsoons will set off in the South China Sea, Arabian Sea and Bay of Bengal, respectively. From a year of significant drought to one of significant floods, the trend of evolution is significantly different in the downdraft areas of the subtropical highs between the two hemispheres.

Key words: HIRS-Tb12; downdraft area of subtropical high; Asian monsoons; drought and floods in eastern China

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1 INTRODUCTION

In recent years, research is numerous on determining the onset of Asian monsoons with the aid of satellite observations. According to Jiang[1], who addresses it with OLR data, features can be sharply different between the equatorial, tropical and subtropical regions at the time summer monsoon establishes. He points out that the onset is the most explosive in tropics and the dates of onset can be determined using dual thresholds of OLR and its inter-pentad difference for waters of Asia and the adjacent ocean. By studying the preceding signs and interannual differences in OLR data for the monsoon onset in the South China Sea, Xie et al[2]. report that the equatorial vortex active around 105°E can be precursory to some degree. Zhang[3] has concluded that ITCZ shows reversed variation of intensity against the Mei-yu front within the East Asian monsoon region while tropical eastern Asia and India vary consistently in monsoon intensity but oppositely with the Mei-yu front intensity, when he applies the T_{BB} data in studying the relationship between monsoons in tropical and subtropical eastern Asia and in searching for foretelling signs for variation of monsoon intensity. The studies above mainly focus on how convective, converging motion evolves in tropical, subtropical regions and the Southern Hemisphere. During the onset process of summer monsoons in Asia, the downdraft areas in the subtropical regions of both hemispheres are actually closely linked with the evolution of Asian monsoons. The current work will focuses on the discussion of climatological characteristics of subtropical downdraft evolution in the hemispheres and their relationship with drought / floods in eastern China, in the course of summer monsoon onset in Asia.

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2 DATA

Brightness temperature data (1979 ~ 1995) measured by 12 channels at the high-resolution infrared radiation probing meter of NOAA (HIRS-Tb12) are used in the work. For the convenience of application and ready comparison with OLR data, its unit has been converted following $F = \sigma T^4$, where T is the HIRS-Tb12 in unit of °K, F in unit of W/m^2 and σ =5.67 $\times 10^{-2}$W/m^2 K^4. Besides, NCEP/NCAR global reanalysis data (1979 ~ 1995) and monthly precipitation amount from 160 stations in China (1951 ~ 1997) are also used in the study.

3 STRUCTURES OF DOWNDRAFTS IN TROPICS OF TWO HEMISPHERES

With comparison and analysis of OLR and HIRS-Tb12 fields, Jiang et al [4]. summarizes that OLR, integrating various information on the ocean and atmosphere, is especially sensitive to activity of convection in ITCZ and monsoon troughs. Over the area of large-scale downdraft (fine sky), OLR varies with the temperature of the underlying surface. As the intensity of downdrafts is independent of it, OLR is limited as a tool in analyzing tropical areas of descending airflows. In contrast, HIRS-Tb12 is not only capable of indicating the moisture content in the atmosphere but reflecting physical parameters for the intensity of downdrafts. The larger the value, the drier the air and the stronger the descending airflows will be.

Fig.1 gives the 500-hPa geopotential and HIRS-Tb12 fields for June ~ August in 1979 ~ 1995. From Fig.1a, we have a picture of downdraft in the subtropical region of the hemisphere. There are a pair of east-west high-value centers from Africa to Iran / Arabian Sea in association with the West Asia high, with maximum intensity of 250 W/m^2, the highest across the globe.

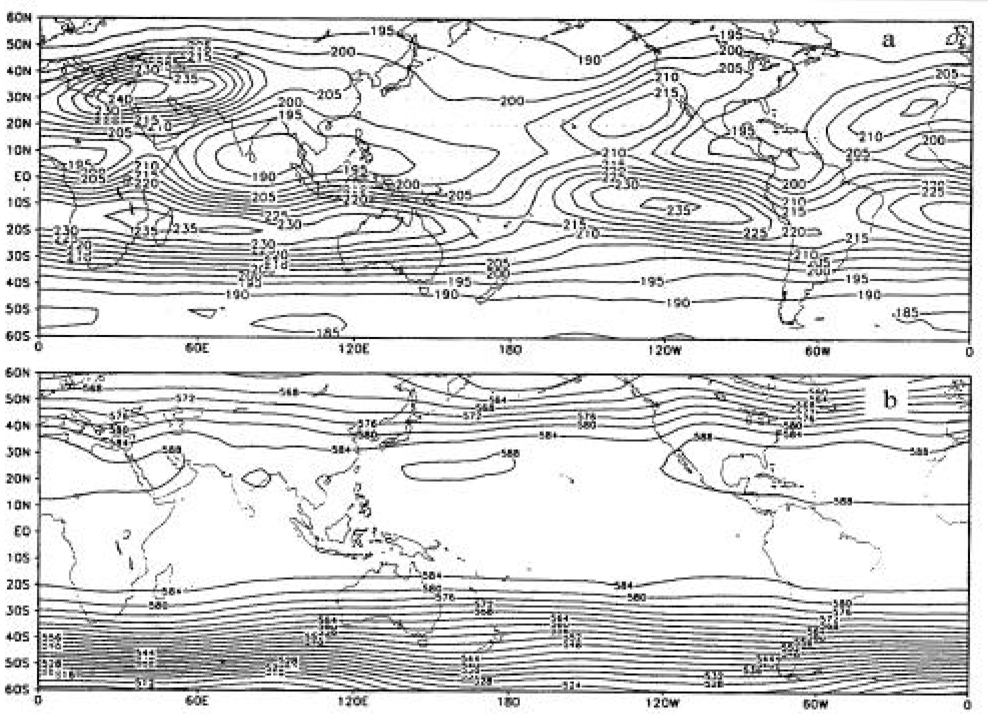

Fig.1 500-hPa geopotential height field (a) and HIRS-Tb12 field (b) for June-August averaged over 1979 ~ 1995.

There is a ring of less strong high-value area over the subtropical northeastern Pacific with maximum intensity above 220 W/m^2. There is an area of strong gradient between 0° and 15°S in the Southern Hemisphere, south of which lie three more subtropical rings of high-value. They are respectively over Southern Africa, southern Indian Ocean and Australia with the former two being more than 240 W/m^2. Another ring of high-value is found over southeastern Pacific that centers more northward with intensity again over 220 W/m^2. For the 500-hPa geopotential field shown in Fig.1b, a ring of powerful subtropical high is over North America, the Atlantic, Africa and Arabian Peninsula that centers at western Africa while another ring is active over central / western part of the Pacific. No such clear subtropical high zones appear in the Southern Hemisphere, where the geopotential height field declines from north to south.

To have more study of the structure of downdraft regions in the subtropics of both hemispheres, the NCEP / NCAR reanalysis global data are used in presenting zonal profiles of temperature, humidity and vertical velocity of the regions for June ~ August in 1979 ~ 1995. As shown in Fig.2a, there is a warm ridge of high pressure prevailing between 1000 hPa and 700

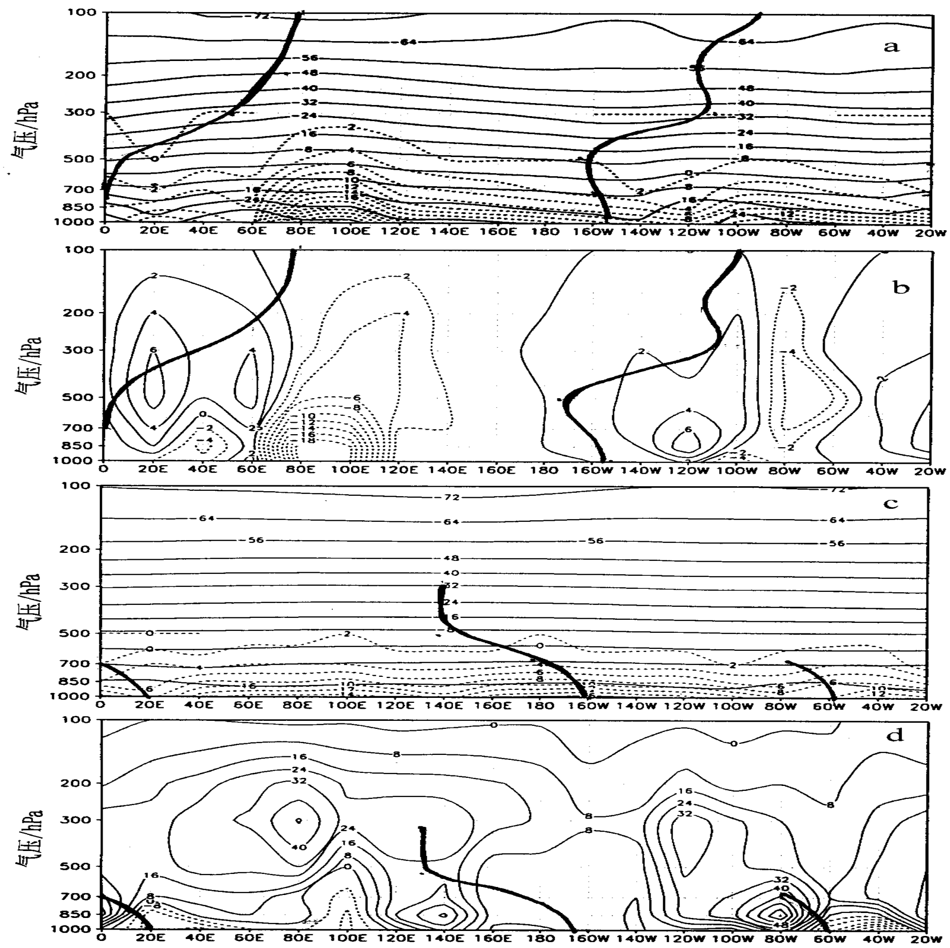

Fig.2 Cross-sections of boreal and austral downdraft. a. temperature (unit:°C) and specific humidity along 30°N (unit: g/kg), and the thin solid line is isothermohyps and the thin dashed line is isohume; b. vertical motion along 30°N (unit: 10^{-3} hPa/s); c. same as (a) but along 15°S; d. same as (b) but along 15°S. The heavy solid line connects centers of high-value profiles and the shaded areas are where high HIRS-Tb12 value locate.

hPa over regions of Arabian Peninsula, Tibetan Plateau and southern North America, from June to August. Extending to the east, the warm ridge weakens upward above 700 hPa until the level of 200 hPa. For the humidity field at the middle and lower troposphere below 500 hPa, regions from the Arabian Peninsula to the Tibetan Plateau are subjected to southerly airflows from the south (the Arabian Sea ~ Bay of Bengal), becoming the wettest region in the globe. Another highly humid region is situated over the Gulf of Mexico ~ western Atlantic. These two regions of high humidity are having the strongest ascending motion of air (Fig.2b) while dry, descending motion is present over Africa / West Asia and eastern Pacific / western North America. High-value areas of HIRS-Tb12 for the Northern Hemisphere are located west of the warm ridge, inside the low-humidity sector west of a ridge of high humidity and the central zone of the descending motion, being close to the longitude at which the center of a 300-hPa high pressure sits.

It is also clear from Fig.2 (a, b) that the subtropical areas from western Pacific, central North America and western Atlantic are within the warm eastern warm ridge and the moist eastern part of the high-humidity region, in addition to weak updraft. In the HIRS-Tb12 field, the subtropical western Pacific is shown as an ill-defined strip of high values while the region from the Gulf of Mexico to western Atlantic is the weakest on the circling belt of high values. It indicates that the two regions are of relative high temperature, humid and weak ascending motion, as compared with other regions in the subtropics.

From the comparison between Fig.2c and Fig.2a, we know that the temperature and humidity are homogeneously distributed in the Southern Hemisphere because it has vast surface of ocean, less complex terrain than the Northern Hemisphere and is in the time of winter. For the extensive region of the Pacific Ocean, a warm ridge from 1000 hPa to 500 hPa is gradually weakening upwards with the ridge line extending from 160°W westward to around 140°E. There is a narrowly distributed warm sector each over Africa and South America, weakening rapidly upwards from 1000 hPa to 700 hPa. There are three areas of high humidity, locating over southern Indian Ocean, southern Pacific and southern Atlantic and mainly below the level of 700 hPa, which are much weaker than those in West Asia. It is known from Fig.2d that strong descending motion is a significant feature for the circling belt in the Southern Hemisphere, which dominates the entire hemisphere but the eastern part of southern Indian Ocean where there is updraft. Corresponding to high values of HIRS-Tb12 for Southern Africa and southern Indian Ocean, a center of strong downdraft appears there at 300 hPa ~ 500 hPa and the whole area extends to central Pacific. There is another center of strong descending motion at 1000 hPa ~ 700 hPa between 120°E and 150°E, matching the high-value area of HIRS-Tb12 over the Indonesian ~ Australian region. There are three centers for the descending motion in the Western Hemisphere, one between 300 hPa and 500 hPa over southeastern Pacific and the other two between 850 hPa and 700 hPa, corresponding to the circling belt of high HIRS-Tb12 values inside the hemisphere. The centers of their high values associate with the downdraft area over southeastern Pacific.

From comparisons and analysis of downdraft areas in the Northern and Southern Hemispheres, we know that the two boreal high-value centers of HIRS-Tb12 are associating with areas of descending air motion while the two austral ones are ill-defined in terms of humidity field but with downdraft much stronger than their boreal counterparts. The conclusion is consistent with the one stating that the Hadley cell is the weakest in the Northern Hemisphere but strongest in the Southern Hemisphere for the period June ~ August, which is obtained with the wind field data from NCEP / NCAR[5]. The display of the western Pacific subtropical high as a mild ring of high values in the field of HIRS-Tb12 is the consequence of its relatively high temperature and humidity and weak ascending motion.

4 CLIMATOLOGY FOR THE ONSET OF ASIAN SUMMER MONSOONS

In East Asia and South Asia, the summer monsoon establishes and advances / retreats along with the strengthening of convective convergence and advancement / retreat of the rain bands. The variations are well depicted in the OLR field in relevant regions. Besides, the onset of East Asian monsoon and Indian monsoon are accompanied by eastward retreat of the South China Sea high, northwestward retreat of the Arabian Sea high and relevant variation of the subtropical high zone in the Southern Hemisphere. They are clearly shown in pentad-based distribution figures of HIRS-Tb12 for various key regions of the subtropics.

The South China Sea high is very stable between Pentads 1 ~ 21 (Fig.3a) with pentad-to-pentad value of HIRS-Tb12 stay above 210 W/m^2. Fluctuations begin in Pentads 22 ~ 23 and the curve drops substantially in Pentads 24 ~ 28 (May 16 ~ 20) and the high weakens drastically, with the HIRS-Tb12 value maintaining between 190 ~ 200 W/m^2 in Pentads 28 ~ 57, which corresponds to the control by a low-pressure convergence zone. The curve then climbs steadily as the South China Sea high reestablishes and strengthens. The fourth pentad of May is just the climatological mean date of the regional monsoon onset. In the meantime, similar changes are taking place in the western part of the subtropical Pacific high — there are indications that ascending motion and precipitation appear on the western edge of the high. The local value of HIRS-Tb12 is always higher than that in the South China Sea, signaling stronger subtropical high in western Pacific than the South China Sea high. The former high rapidly decreases in intensity between Pentads 21 ~ 27, showing that the former high weakens before the latter high does and withdraws to the east.

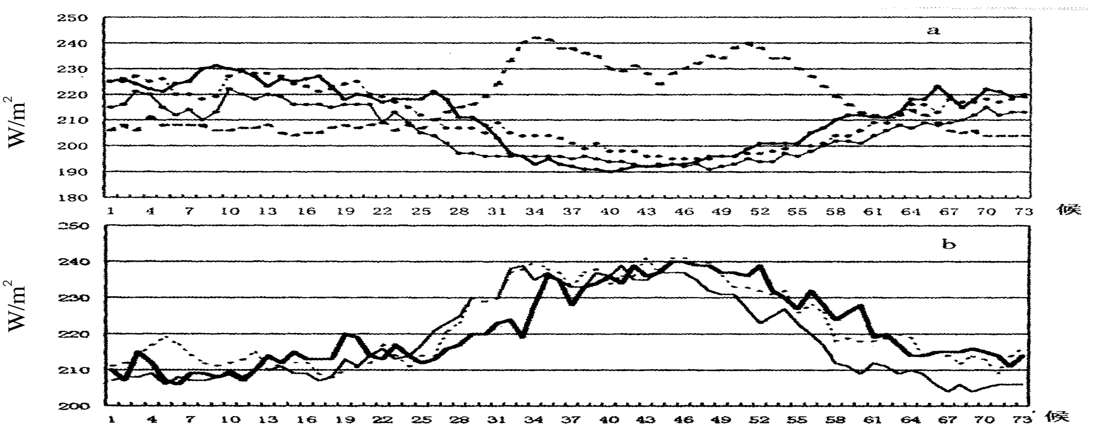

Fig.3 Curves of pentad-based (the abscissa) HIRS-Tb12 in key areas averaged over 1979 ~ 1995. a. The thin solid line represents South China Sea (10°N～20°N, 110°E～120°E), the thin dashed line represents northwestern Pacific (15°N～20°N, 120°E～150°E), the thick solid line represents the Arabian Sea (10°N～15°N, 50°～75°E), the thick dashed line represents the Iranian region (25°N～35°N, 40°E～75°E); b. The thin solid line represents South Africa (15°S～25°S, 30°E～55°E), the thin dashed line represents southern India Ocean (20°S～25°S, 70°E～90°E), the thick solid line represents the Australian region (15°S～20°S, 120°E～140°E).

Like what is described above, the Arabian Sea has been under the control of high pressure in winter and spring with intensity above 220 W/m^2 from Pentad 1 to Pentad 18 and around 220 W/m^2 from Pentad 19 to Pentad 26, which is stronger than the South China Sea high. The former high rapidly weakens and retreats to the northwest in Pentad 27 ~ 34 and the value of HIRS-Tb12 goes between 190 W/m^2 and 200 W/m^2 over the Arabian Sea in Pentads 32 ~ 51. Pentad 32 (June 5 ~ 9) is just the time of onset for the monsoon over the Arabian Sea and Bay of Bengal. Associating with it, the Arabian Sea high weakens and withdraws to the northwest while the West Asia high establishes and strengthens over the region of Iran. The latter rapidly increases in

Pentads 26 ~ 32 and the HIRS=Tb12 value remains above 230 W/m^2 for the Iranian region from Pentads 32 ~ 55.

The subtropical austral region is another place where there is dramatic change during the onset of Asian summer monsoons. From Fig.3b, we know that the regions of southern Africa, southern Indian Ocean and Australia are of low pressure in Pentads 1 ~ 23 and the HIRS-Tb12 value stays around 210 W/m^2 before coming into a period of rapid intensification —it increases sharply in southern Africa from Pentad 25 to Pentad 32 with the HIRS-Tb12 maintaining above 230 W/m^2 in local high pressure area from Pentad 29 to Pentad 50; the rapid rise for southern Indian Ocean covers a period from Pentad 27 to Pentad 32 with the value above 230 W/m^2 from Pentad 31 to Pentad 54; it increases rapidly from Pentad 27 to Pentad 35, staying above 230 W/m^2 in Pentads 35 to 54, though a little lower in Pentad 37. It is then known from the analysis that it is in the sequence from west to east that the austral subtropical high is strengthening from autumn to winter and weakening from spring to summer. The HIRS-Tb12 value is especially lower than that for southern Africa and southern Indian Ocean over Pentads 27 ~ 35, showing that both the establishment and strengthening of the Australian high are significantly later than the two rings of high pressure to its west.

In summary, the onset of Asian summer monsoon accompanies the eastward withdrawal of the South China Sea high and the northwestward withdrawal of the Arabian Sea; when the HIRS-Tb12 value begins to drop rapidly in Pentad 24 and below 200 W/m^2 in Pentad 28 in the South China Sea, the monsoon sets off in the region; when it begins to drop rapidly in Pentad 27 and below 200 W/m^2 in Pentad 32 in the Arabian Sea, the monsoon starts in the region and the Bay of Bengal. In the austral subtropical region, high pressures over southern Africa, southern Indian Ocean and Australia in turn experience a process of establishment and enhancement from Pentad 24 to Pentad 35.

5 HIRS-Tb12 CHARACTERISTICS FOR ANOMALOUSLY DRY AND WET YEARS IN EASTERN CHINA

The anomalous drought and floods in eastern China are caused by interactions between Asian summer monsoons and westerly systems in middle and high latitudes. The focus of the work is on the change of descending motion in both boreal and austral subtropics and the linkage with the appearance of drought / floods in eastern China, during the onset and progress / withdrawal of Asian summer monsoons. From the years 1979 ~ 1995, we have selected anomalously dry 1985 and 1994 and anomalously wet 1991 and 1993 for study. In 1985, areas hit by drought were distributed in the Changjiang River (the Yangtze) basin, basins between Changjiang and Huaihe and between Huaihe and Yellow River, subjecting to most severity in some parts between the Changjiang and Huaihe River basins. In 1994, the drought area was a little northward compared to 1985, locating in the Changjiang / Huaihe River basins and southern part of North China, with some places between the Changjiang and Huaihe River basins being the driest. In 1991, unusually severe floods occurred between the Changjiang and Huaihe River basins. In 1993, areas south of the Changjiang River suffered from severe floods, some unusually severe.

Fig.4 shows how the HIRS-Tb12 evolves in individual key areas for anomalously dry or wet years. From Fig.4 (a & b), we know that the value is lower in 1985 than average years over all pentads of spring in the South China Sea region, suggesting persistently stronger convection and convergence in the locality, resulting in the onset of monsoon in the fourth pentad of April, a month earlier than the average and also the highest for the years 1979 ~ 1995. After the onset, the monsoon remains strong. With the onset of monsoon over the Arabian Sea ~ Bay of Bengal, convection and convergence are also stronger than usual over the region of the Arabian Sea. In 1994, the South China Sea monsoon starts at a time quite close to the normal date and convection and convergence are also stronger than the average after the onset. The most significant point for

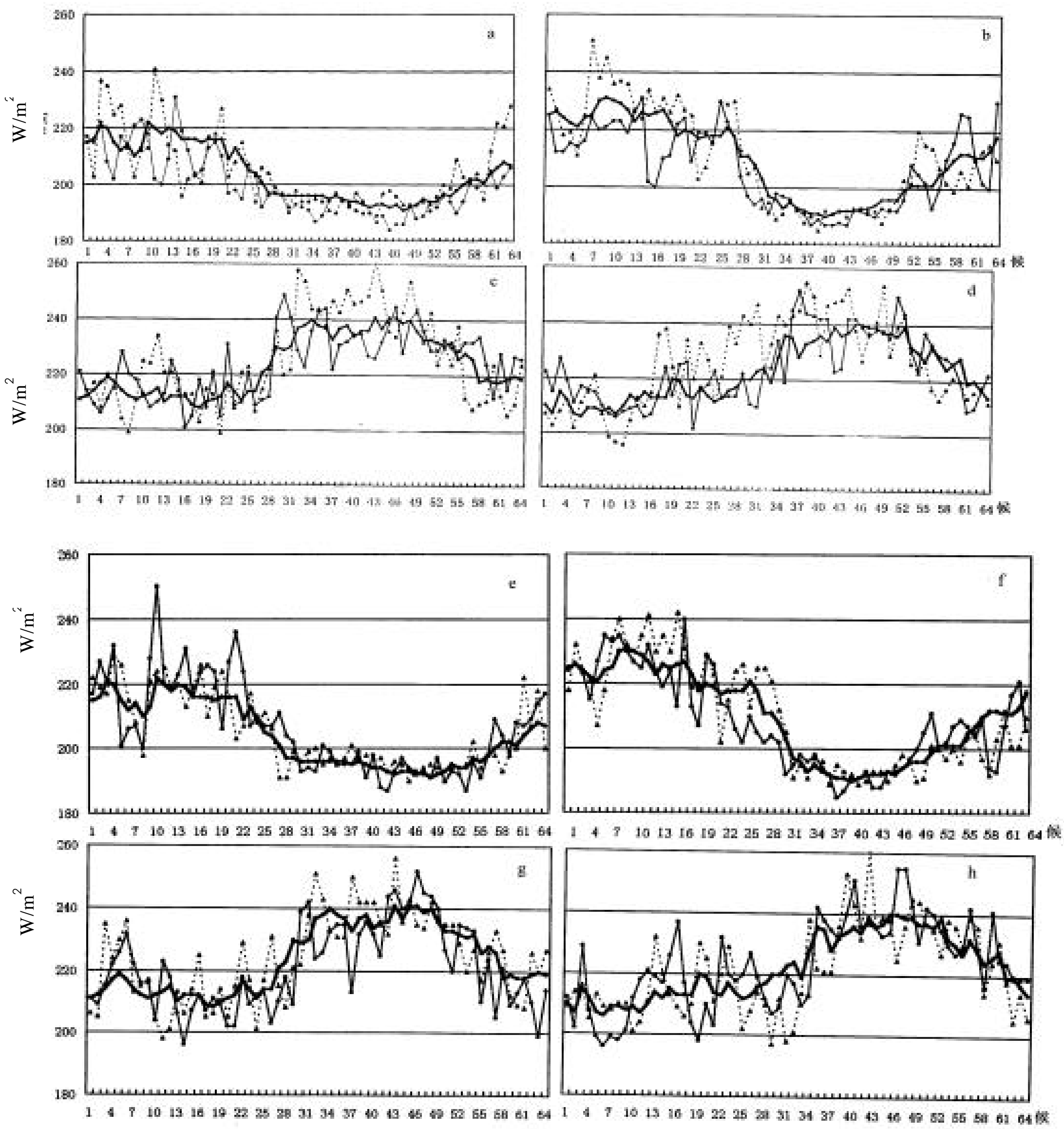

Fig.4 The evolution of pentad-based (the abscissa) HIRS-Tb12 in anomalous drought/flood years in unit of W/m^2. (a) South China Sea in drought years, the thin solid line represents 1985, the thin dashed line represents 1994; b. Same as (a) but for the Arabian Sea; (c) same as (a) but for southern India Ocean; (d) same as (a) but for Australia; (e) South China Sea in flood years, the thin solid line represents 1991, the thin dashed line represents 1993; (f). same as (e) but for the Arabian Sea; (g) same as (e) but for southern India Ocean; (h) same as (e) but for Australia.

the year is that the high pressures over southern Indian Ocean and Australia are extremely strong. Setting up earlier, the Australian high increases the HIRS-Tb12 value above 230 W/m^2 from Pentad 18 and remains on a high level after the establishment of the high (Figs.4c & 4d). As shown in some studies[6], the highs over these regions are playing an important role in establishing and maintaining the cross-equatorial air current —the earlier they set up and the stronger they become, the earlier the powerful cross-equatorial current would push the Indian and East Asian monsoons northward. The consequence is causing drought in eastern China. Sufficient attention must be paid to any early set-up and anomalous strengthening of the Australian high.

From Fig.4 (e & f), we know that convection and convergence are weaker than usual over Pentads 10 ~ 30 in 1991 for the region of South China Sea. The monsoon starts in the third pentad of June, which is 5 pentads late compared to the average year. Around the monsoon onset in the Arabian Sea area (Pentads 22 ~ 31), however, convection and convergence are stronger than usual. From Fig.4 (g & h), we find that the high pressures over southern Indian Ocean and Australia are significantly oscillating between high and low intensity. There were three active Mei-yu periods in 1991 between the Changjiang and Huaihe River basins, appearing in Pentad 29, 33 and 38. Two to three pentads prior to each of them are marked by a decrease of the Australian high intensity and the cross-equatorial air current at 120°E ~ 130°E setting off towards the north. Jointly acting with the southerly flow west of the subtropical high and southwesterly flow that changes direction from a cross-equatorial current in southern Indian Ocean, the airflow give rise to centers of strong southerly (more than 10 m/s at 850 hPa) in areas south of the Changjiang River in Pentads 29, 32 ~ 33 and 38 ~ 39. It also interacts with the cold air mass progressing southward in groups from the region of Lake Bajkal to cause strong precipitation[6]. In the spring of 1993, the HIRS-Tb12 oscillated in intensity over the South China Sea and the monsoon started in the fourth pentad of June, a month late compared to normal circumstances. The convection and convergence are weaker than usual in Pentads 29 ~ 48 for this region and in Pentads 25 ~ 30 for the Arabian Sea. The second northward jump of the western Pacific subtropical high was about 7 pentads late than normal. The high pressures over southern Indian Ocean and Australia are weak in June but vary alternatively in intensity in July and August, leading to stagnation of rain bands over areas south of the Changjiang River.

6 CONCLUDING REMARKS

a. Our analysis and study employing the HIRS-Tb12 and conventional data have shown that the structure of temperature, humidity and vertical motion differ in the Southern from the Northern Hemisphere —two boreal centers of high HIRS-Tb12 are associating with areas of low humidity and descending air motion while high austral HIRS-Tb12 areas are marked with intense downdraft.

b. The onset of Asian summer monsoon accompanies the eastward withdrawal of the South China Sea high and the northwestward withdrawal of the Arabian Sea; when the HIRS-Tb12 value begins to drop rapidly in Pentad 24 and below 200 W/m^2 in Pentad 28 in the South China Sea, the monsoon sets off in the region; when it begins to drop rapidly in Pentad 27 and below 200 W/m^2 in Pentad 32 in the Arabian Sea, the monsoon starts in the region and the Bay of Bengal. In the austral subtropical region, high pressures over southern Africa, southern Indian Ocean and Australia in turn experience a process of establishment and enhancement from Pentad 24 to Pentad 35.

c. In the years of significant drought over eastern China, the monsoon has early onset and high intensity over the South China Sea and Arabian Sea and the high pressures have early establishment and high intensity over southern Indian Ocean and Australia. Strong cross-equatorial air currents are responsible for drought spans in eastern China by making possible early northward advancement of the Indian and East Asian monsoons. In the years of significant floods, rain bands stagnate between the Changjiang and Huaihe River basins because of weak monsoon, late northward jumps of the subtropical high and weak cross-equatorial air current, or the onset is late for the East Asian monsoon while the northward progress is early for the Indian monsoon, which is stronger than usual. One of the common point about the flood years is that the high pressures over southern Indian Ocean and Australia are varying in alternative intensity and the Australian high is especially important for the meridional transportation of low-frequency oscillations that cross the equator at 110°E ~ 120°E.

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