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A PRIMARY STUDY OF SUMMER MONSOON INDEX OVER THE SOUTH CHINA SEA AND EAST ASIA BASED ON SATELLITE OBSERVATION

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Abstract: The results by statistical analysis of black body Temperature (*TBB*) pentad mean from the Japanese GMS in the period of May to August, 1980-2002, show that the summer monsoon index (SMI) is defined to be the pentad mean *TBB*≤273 K. Its intensity includes three levels: *TBB*＞268 K for weak monsoon, 268 K≥*TBB*＞263 K for normal monsoon and TBB≤263K for strong monsoon over the South China sea and East Asia. In the meantime, a diagnostic method using TBB pentad anomaly is also introduced to help identify monsoon intensity. The SMI is used to run statistical analyses of the initial onset of the monsoon and its pentad variations with the year and month. A fairly close relationship is found between pentad monsoon activity and heavy rainfall periods in the two typical flood years of 1994 and 1998, which resulted from heavy rainfall over the Yangtze River basin and south China.

Key words: pentad summer monsoon index; black-body temperature (TBB); monsoon intensity

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1 INTRODUCTION

The intensity and duration of the East Asian monsoon onset as well as its timing of onset, in particular, have close links with summer precipitation in central, eastern and southern parts of China.

A lot of important research results have been achieved since the 1980's on the classification of monsoon regions and mechanisms responsible for the forming of monsoons. As shown in Chen[1]. and Tao et al.[2], Asian monsoons can be classified into the Indian Monsoon and East Asian Monsoon. Their main difference, as pointed out by Tao[3], is that the former is tropical while the latter subtropical. The two monsoons are divided generally on 100°E (Yu[4]). It was proposed that the East Asian monsoon can be subdivided into a tropical monsoon in the South China Sea and West Pacific and a subtropical monsoon in the Asian continent and Japan (Zhu et al.[5]). While the East Asian monsoon covers the South China Sea and low-latitude regions of northwestern Pacific, the sea connects the Indian Ocean and Pacific Ocean and plays a key role in the interactions between the South Asian and East Asian monsoon systems[6]. It may be more relevant to study the systems separately for probing into their respective influence on the summer precipitation in China.

To have an objective and accurate knowledge of the onset, evolution and intensity of East Asian summer monsoons, an index is needed. Due to limited observations of conventional meteorological elements over low-latitude tropical oceans, monsoon indexes are not determined with ease. It has been studied in some depth that weather satellites provide high spatial and temporal measurements of the movement and evolution of cloud regimes and aid in monitoring the onset, movement and intensity of the summer monsoon. With the theory of multiple equilibrium to interpret possible physical mechanisms for the active and break phases of South Asian Monsoon, Wu et al.[7] pointed out that it was in the active (break) phase when cumulus convection intensifies (weakens). Hamilton[8] had the following discovery. The Northern Hemisphere summer monsoon usually begins when cold air from the

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Southern Hemisphere flows into the tropics with large amount of cloud surge; the tropical monsoon transports from the south to the north in Asia, with the cloud areas obviously shifting from the equatorial region to low and middle latitude regions and cloudage varying periodically with the active and break phases of the Indian Monsoon. Years of GMS's TBB were used to conduct a complete analysis of the seasonal shifts in the Asian-Australian monsoon region and the establishment of the summer monsoon in Asia (He et al. [9]). With daily mean TBB data of ECMWF and GMS winds, the summer monsoon in the South China Sea was defined by Jin and Tao[6] to begin if the westerly / southwesterly establish in the region for more than 3 days with severe convection (TBB<275 K).

Being a complicated issue, monsoon indexes differ varying with scientists and types of data. There is also some useful work on the exploitation of satellite information. The work by Wang and Fan[10] is one such example. With two convection indexes, i.e. the negative anomalies of mean OLR for the Bay of Bengal (8.75-23.75°N, 7-100°E) and waters near the Philippine islands (8.75-21.25°N, 115-140°E), were used to depict the interannual variation of the Indian Monsoon and Southeast Asian Summer Monsoon, respectively. The region of Southeast Asia (0-30°N, 70-140°E) was divided to four parts and standardized OLR values in these parts and their different combinations were used to describe the intensity and north-south and east-west shifts of the Asian summer monsoon. The current paper uses the pentad mean of TBB to discuss the summer monsoon in the South China Sea and East Asia[11].

Most of the monsoon indexes presented above and those determined with other methods are based on the interannual variation of monsoons on monthly or even seasonal timescale, which is the best for the research into the causation of droughts and floods and the monitoring and predicting of short-term climate. Focusing on the effect of summer monsoons on the formation of heavy rains in central, eastern and southern China, the current paper determines an index for East Asian monsoon on the timescale of pentad, for the purpose of monitoring the onset, evolution and intensity of the monsoon and providing precursory signals for the monitoring and prediction of heavy rains and severe convection weather.

2 DATA AND DETERMINATION OF MONSOON INDEX

Annual data of May through August from 1980 to 2002 (with those for 1995 – 1996 missing) from the infrared radiation observation by GMS (in the wavelength of 10.5– 12.5 μ m), available 8 times daily at the interval of 3 h, were selected for projection, transformation of the coordinates and interpolation to calculate gridpoint values of daily mean TBB at the interval of 1°lat.×1°long. The area bounded by 10 – 20°N, 110 – 120°E is defined as the monsoon region for the South China Sea and that confined by 10 – 20°N, 100 – 150°E as the monsoon region for East Asia. Then, pentad mean and pentad anomalies of TBB for individual pentads in the aforementioned 21 years are separately determined.

There are a total of 377 pentads in June, July and August among the 21 years with exception of the first pentad of June in 2001. On the basis of total mean TBB for each of the pentads in the above two regions, a standard was set, by which the monsoon was defined to be active if the pentad mean TBB ⩽ 273 K was met, after statistical analyses and references to previous frequencies of monsoon activity[6, 12]. As shown by verifications of hourly animated satellite cloud imageries and TBB values, a majority of the pentads meeting the standard all have convective clouds, which represent the monsoon while those falling short of the condition occur mostly over some parts of the waters for one day or two generally, though they are also with convective clouds, sometimes at considerable intensity.

According to this monsoon standard, a total of 264 pentads are with monsoon over the 21 years in the South China Sea, taking up 70% of all pentads of interest. It is less than the frequency of 88% given by Jin[6], who obtained it from daily statistics. 292 pentads are with East Asian monsoon and about 77.5% of the total, slightly higher than the ratio of 73%, which compose of years with strong monsoon (22%) and years with normal monsoon (53%), respectively, as concluded by Zhang et al.[12] using annual frequencies. The results of the three methods are quite consistent and comparable to each other and have advantages of their own, though with different methods and dataset and describe the monsoon on different timescales. It is obvious that this new index and the frequencies for monsoon activity it determines can be used to monitor the monsoon in a way that is both illustrative and ready for routine application.

With the standard set for the activity of summer monsoon, next comes another important issue of determining its intensity. On the basis of known pentads with monsoon, the assessed annual monsoon activity and periods of time in which precipitation occurs in the middle and lower reaches of the Yangtze River and southern China are statistically studied to draw a preliminary definition as follows. The monsoon is weak, moderate or strong, when 268 K<*TBB*⩽273

K, 263 K<*TBB*≤268 K or *TBB*≤263 K, respectively. The standard has clear physical implication. For weak monsoons, it indicates the presence of weak convective clouds, sharply different from the absence of large-scale convective clouds in formation and development due to the break of monsoon. For moderate monsoons, the pentad mean TBB of 268 – 263 K shows active convective clouds at some intensity. For strong monsoons, the pentad-mean TBB below 263 K displays strong and active convective clouds that last long and wide.

By this standard of intensity, there are all together 64 pentads of weak monsoon (24% of the total of 264 pentads with monsoon), 56 pentads of moderate monsoon (21%) and 144 pentads of strong monsoon (55%, being the most of all), in the South China Sea in June – August over the 21 years. In other words, weak and moderate summer monsoons combined are nearly as many as strong monsoons in the sea. The intensity of East Asian monsoon is quite different. Of a total of 292 monsoon pentads, weak monsoon is seen in 95 of them (33%), moderate monsoon in 86 (30%) and strong monsoon in 111 (37%). It is then clear that weak and moderate monsoons take up more than 60%, much more than those in the South China Sea while strong monsoons are less than 40%, less than those in the South China Sea. The summer monsoons in East Asia are generally weaker.

3 ANALYSIS OF THE MONSOONS

As shown in Tab.1, the South China Sea summer monsoon has the initial onset in May in 17 out of the 21 years and in June in 4 out of them, concentrating in the middle and late time of May (16 years) with mid-May having the most onset (10 years) and relatively more in the fourth pentad (6 years). The earliest onset is in the first pentad of May (1984) and the latest one in the fourth pentad of June (1993).

Tab.1 Statistics of South China Sea summer monsoon from 1980 to 2002

Year	Onset (month, pentad)		May Order of pentads	June Order of pentads	July Order of pentads	August Order of pentads	Σ (number of pentads)
1980	5	4	4, 5	3, 4, 5, 6	1, 2, 3, 4, 5, 6	4, 5, 6	15
1981	5	3	3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 6	19
1982	5	4	4	2, 3, 5, 6	1, 2, 3, 4, 6	2, 3, 4, 5, 6	15
1983	5	5	5	2, 5, 6	3, 4, 5, 6	1, 2, 3, 4, 5, 6	14
1984	5	1	1, 2, 5, 6	2, 4, 5, 6	1, 2, 6	1, 2, 3, 4, 5, 6	17
1985	6	1		1, 2, 3, 4, 5, 6	1, 2, 4	1, 2, 3, 4, 5, 6	15
1986	5	3	3, 4, 5	3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 6	16
1987	6	2		2, 3, 4, 6	1, 2, 3, 4, 5, 6	4, 5	12
1988	5	5	5, 6	1, 2, 3, 4, 6	3, 4, 5, 6	1, 2, 3, 4	15
1989	5	4	4, 5	1, 2, 5, 6	2, 3, 4, 5	1, 2, 4, 5, 6	15
1990	5	4	4, 5, 6	1, 3, 4, 5, 6	2, 4, 5, 6	1, 4, 5, 6	16
1991	6	1		1, 2, 3, 4, 5, 6	1, 3, 4, 5, 6	3, 4, 5, 6	15
1992	5	6	6	1, 3, 5, 6	3, 4, 5, 6	3, 4, 5, 6	13
1993	6	4		4, 5, 6	2, 3, 6	2, 3, 4, 6	10
1994	5	6	6	1, 2, 4, 5	1, 2, 3, 4, 5, 6	1, 5, 6	14
1997	5	5	5, 6	5, 6	1, 2, 3, 4, 6	1, 4, 5, 6	13
1998	5	4	4, 5, 6	5, 6	1, 2, 3	1, 2, 4	11
1999	5	6	6	1, 2, 4	1, 3, 5, 6	1, 2, 3, 5	12
2000	5	3	3, 4, 5	3, 4	1, 2, 3, 4, 5	1, 4, 5, 6	14
2001	5	3	3, 5, 6	4, 5, 6	2, 4, 5, 6	1, 2, 3, 4, 5, 6	16
2002	5	5	5, 6	1, 2, 4	1, 2, 3, 6	1, 2, 3, 4	13
Σ (number of pentads)			37	79	93	91	

As shown in Tab.2, the East Asian summer monsoon has the initial onset in May in 13 years and in June in 8 years, with relatively more onsets in the fourth pentad (6 years), fifth pentad (4 years), of May, taking up nearly half the years of interest. The earliest onset was in the second pentad of May (2000) and the latest onset in the fifth pentad of June (1992 and 1993). Compared with the South China Sea monsoon, the East Asian monsoon is late by a pentad in terms of the earliest and latest onsets and concentrated period of onset, which is consistent with the result by previous studies that the monsoon transports to the west and east after onset in the sea.

Based on the TBB mean and anomalies from pentad to pentad in May – August over the 21 years (figure omitted), one can know whether there is monsoon and how intense it is according to the standard set above using the pentad mean of TBB. Furthermore, the larger the negative TBB anomalies are, the stronger the convective clouds are than the mean state and more intense the monsoon is. Therefore, the pentad mean TBB can then be used as a powerful supplementary tool to determine the monsoon intensity, especially illustrative when the monsoon is either very strong or very weak. For analyses of other aspects, refer to the Chinese edition of the journal.

Tab.2 Statistics of East Asian summer monsoon from 1980 to 2002

Year	Onset (Month, pentad)		May Order of pentads	June Order of pentads	July Order of pentads	August Order of pentads	Σ (number of pentads)
1980	5	3	3, 4, 5	2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	4, 5, 6	17
1981	5	5	5	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	19
1982	5	4	4	2, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	16
1983	6	2		2, 5	3, 4, 5	1, 2, 3, 4, 5, 6	11
1984	5	5	5	4, 5, 6	1, 2, 6	1, 2, 3, 4, 5, 6	13
1985	5	4	4	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	19
1986	5	4	4, 5, 6	3, 4, 5, 6	1, 2, 3, 4	1, 2, 3, 4, 5, 6	17
1987	6	2		2, 3, 4, 6	1, 2, 3, 4, 5, 6	3, 4, 5, 6	14
1988	5	5	5, 6	1, 2, 3, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 6	18
1989	5	4	4, 5	1, 2, 5	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	17
1990	5	4	4, 5, 6	1, 3, 4, 5, 6	2, 4, 5, 6	1, 3, 4, 5, 6	17
1991	6	2		2, 3, 4, 5	3, 4, 5, 6	1, 3, 4, 5, 6	13
1992	6	5		5, 6	1, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	13
1993	6	5		5, 6	3, 5, 6	1, 2, 3, 4, 5, 6	11
1994	6	1		1, 2, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	17
1997	6	4		4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	15
1998	5	5	5, 6	5, 6	1, 2, 6	1, 2, 4	10
1999	5	6	6	1, 2, 4, 6	1, 3, 4, 5, 6	1, 2, 4, 5, 6	15
2000	5	2	2, 3, 4	3, 4, 6	1, 2, 3, 4, 5, 6	1, 2, 4, 5, 6	17
2001	6	4		4, 5, 6	2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	14
2002	5	4	4	1, 6	1, 2, 3, 5, 6	1, 2, 3, 4, 6	13
Σ (number of pentads)			24	76	104	112	

4 CONCLUSIONS

As the summer monsoons in the South China Sea and East Asia have direct and important impacts on the summer precipitation in China, it has been a key research project. Due to insufficient conventional observations in the tropics and the fact that frequent local convective weather there have immediate effects on the limits the conventional observations can represent, it is much difficult to determine the activity, break and intensity of the monsoons. In this work, TBB data generated from the infrared observations of Japanese GMS are used to study pentad mean and pentad anomalies over 21 years, having advantageous representativeness and objectivity.

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