論文内容の要旨

論文題目　　A study of climate system over Myanmar during the transition season to the summer monsoon

（ ミャンマーにおけるモンスーンオンセット期の気候システムに関する研究 ）

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Asian monsoon is a complex climate system involving many timescales of variations such as interannual and intraseasonal variations. The formation of monsoons is basically considered as the difference of diabatic heating between the land and sea during the winter and summer. In addition, large-scale sea surface temperature contrasts and release of latent heat from the convective systems are also crucial to maintain the monsoon circulation. Moreover, the other characteristics such as the shape of the continents, topography and upper tropospheric conditions influence the monsoon circulation. Between the summer and winter monsoon systems of Asia, the Asian Summer Monsoon (hereafter ASM) gets more attention because the monsoonal winds carry warm, humid air across the region, often bringing widespread rain and thunderstorms during the summer monsoon season which are essential for various aspects of human life and activities in Asia. The ASM has two distinct subsystems, South Asian monsoon (hereafter SAM) and East Asian monsoon (hereafter EAM). SAM is a typical tropical climate system and EAM is a combined tropical-midlatitude system (Chen and Chang, 1980). Indochina peninsula is a unique region which lies within the South Asia and East Asia and the monsoon system over it is a transitional feature of SAM and EAM (Zhang et al., 2002). Myanmar is located in the north-western part of the Indochina Peninsula, between latitudes 09° 32′ N and 28° 31′ N and longitudes 92° 10′ E and 101° 11′ E. Another difference between Myanmar and the other Southeast Asian countries is that Myanmar does not lie completely within the Tropics. According to the theoretical climatic zones based on

latitude and insolation, the northern part of Myanmar (hereafter N Myanmar) is located in the Temperate Zone, above 23.5°N (above the Tropic of Cancer) to 28° 31′ N and the southern and central part of Myanmar (hereafter SnC Myanmar) exists in the Torrid Zone (Tropics), between the latitudes of 09° 32′ N and 23.5°N. ASM is the predominant climate system in Myanmar and nearly 90% of total rainfalls are from summer monsoon. Meteorologists in Myanmar consider the climate of Myanmar based on the five seasons: the pre-monsoon season from mid-April to mid-May, the monsoon season from mid-May to early-October, the post-monsoon season from early-October to end-November, the dry and cool season from December to mid-March, and the hot season from mid-March to mid-April (Lwin, 2000). Mid-April to mid-May is a transition season to the summer monsoon over Myanmar and a period of continuous and rapid rise of maximum temperature in the whole country. Generally, the summer monsoon advances into the country during the middle of May with copious rain along the coastal areas. The study of local monsoon system is necessary as Myanmar is one of the world's great rice-growing countries and agricultural sector relies heavily on the summer monsoon rain. Of particular importance is to study the timing of monsoon onset.

The variations of monsoon onset dates over Asia have also long been of great interest (Yin, 1949; Rao, 1976, etc.) but no one emphasizes to depict the image of long-term monsoon onset climatology and interannual variations of Myanmar except Matsumoto (1997) who investigated the mean onset and withdrawal of summer rainy season over the Indochina Peninsula using 5-day averaged station rainfall data from 1975 to 1987. Present monsoon onset definition which is used in the Department of Meteorology and Hydrology (hereafter DMH), Myanmar, is also not the objective definition because of subjectively omission of rainfall prior to 25th April and onset regions based on the 1967 rain gauge stations in Myanmar. Thus one of the purposes of this study is to redefine the climatological onset dates of summer monsoon objectively using long-term precipitation data of Myanmar as monsoon rains are vital for agriculture and replenishment of water resources. The year-to-year monsoon onset variations from hot season to monsoon season, in other words, early and late of summer monsoon onset variations can cause serious environmental impacts on Myanmar including water deficit, drought, untimely rainfall and flood. Thus it is important to examine the interannual variations and climate conditions of monsoon onset over Myanmar during the transition season to the summer monsoon as the second objective of this study. Concerning the intraseasonal variations of monsoon onset, there are few intraseasonal oscillation (hereafter ISO) studies of Myanmar (Lwin, 2005, Yokoi et al., 2007) and these two studies also emphasized the climatological characteristics of ISO during the monsoon season. But monsoon onset period is vital for the agricultural sector of Myanmar and year-to-year variability in ISO activity should also be examined to understand the characteristics and influence of ISO during the onset period. Consequently this study also draws attention to the

activities of ISO for the period of summer monsoon onset over Myanmar as the third objective.

This study emphasizes the climatological, interannual and intraseasonal variations of summer monsoon onset over Myanmar using 33 years observed station data, frequency and tracks of storms and depressions in the Bay of Bengal and the Andaman Sea data of DMH (Myanmar), ERA-40 re-analysis data and NOAA-ERSST data from 1968 to 2000. To redefine the climatological monsoon onset dates of Myanmar objectively, seven meteorological parameters between the periods of 21st April and 9th June of 33 years data from 1968 to 2000 are examined. Regarding the study of the interannual variations, composite analysis of precipitation, sea level pressure, 850 hPa and 200 hPa horizontal wind, the geopotential height difference between 200 hPa and 500 hPa pressure levels (upper level temperature) and sea surface temperature anomaly (hereafter SSTA) are performed to know the favorable background (climatological) fields during the summer monsoon onset and the establishment of precondition to early and late onsets of Myanmar. Concerning the study of the intraseasonal variations, a Fourier analysis is applied to the anomaly of re-analysis precipitation data for the 120 day period from 1st March to 28th June of 33 years to investigate what time period is dominant over Myanmar. After subtracting linear trends from the 120- day anomaly data, the Fourier power spectrum is calculated for each year and the average of 33 years.

The climatological onset dates of summer monsoon over Myanmar are redefined as May 18 for SnC Myanmar and May 28 for N Myanmar, respectively by using mean pentad precipitation data. The time and place of monsoon onset stage are also confirmed by analyzing the observed station data and re-analysis wind data.

In the interannual variations of the monsoon onset, the trend lines of 5 year moving average shows the continuous delay trend from 1982 to 1994 and early trend from 1995 to 2000 in both areas. According to the 33-yr onset dates composite analyses, the favorable background fields for the summer monsoon onset of Myanmar can also be observed as tropical rain band over Myanmar, the low pressure center in the northwestern part of India with two trough lines which extend across Myanmar and along the east coast of India, low level southwesterly in the Bay of Bengal and the center of the upper level anticyclone over Myanmar during the monsoon onset period. In the 33-yr onset dates station rainfall composites of both areas, the sudden increase of precipitation over SnC Myanmar at the onset pentad and the decrease of precipitation in the inland area after the SnC onset can be found, while N Myanmar station rainfall composite maps show the general rainfall increase after the onset. These rainfall distribution patterns which are crucial for the local level cannot be seen in the global datasets while they can depict the rainfall propagation and associated weather system. Another difference between SnC and N Myanmar is that there is no relationship between May-June total rainfall and SnC onset but for N Myanmar, the

relationship is early onset with positive rainfall anomaly and late onset with negative rainfall anomaly. Thus the use of station data is of significant importance not only for the information of the public in the local level but also for scientific research.

The results of preconditioned signals in April to the early minus late monsoon onset of both areas also show different statistical relationship with upper-level thermal conditions which imply different variation mechanisms. The analysis of composite thickness anomaly indicates the importance of upper level warming over the western part of the Tibetan Plateau (27.5°N – 40°N; 65°E – 85°E) for the SnC Myanmar and the April thickness anomaly over the South China Sea and eastern part of the Indochina Peninsula regions (10°N – 17.5°N; 100°E – 120°E) for N Myanmar. Although April SSTA over the Nino-3 (central-eastern Pacific; 5°S – 5°N; 90°W – 150°W) area shows the precursory signal for both composite maps, N Myanmar has a weaker signal compared to SnC Myanmar for the Nino-3 area and no apparent signals exist in the Indian Ocean SSTA in case of N Myanmar. Hence it can be supposed that large scale system effect over the onset timing of N Myanmar is less than that of SnC Myanmar.

The noticeable difference of ISO patterns between SnC Myanmar and N Myanmar can also be seen from the time-latitude section of 30-60 day band pass filtered rainfall anomaly figures as the mid-latitude system from the north and tropical system from the south seem to converge over the northern part of Myanmar. It seems SnC Myanmar relies only on the tropical system to get rain in that area but N Myanmar can get rain not only from the tropical system but also from other systems such as the mid-latitude system. The results of intraseasonal variations are summarized as 30-60 day is a dominant periodicity of ISO during monsoon onset over Myanmar. The northward movements or standing oscillations of 30-60 day significant positive rainfall anomalies correspond to the early and late monsoon onset of Myanmar, especially for SnC Myanmar onset. The storm formation period can also be seen in the positive phase of 30-60 day ISO. The temporal and spatial structures of rainfall anomaly also show that the changes of maximum positive rainfall anomaly correspond with the movement of tropical disturbances from the Bay of Bengal to the north. In the 14 cases of early and late onset years of Myanmar, there are seven cases of monsoon onset which follow the storm formation in the Bay of Bengal.

This study is concluded that the timing of monsoon onset over Myanmar is regulated by both the background basic flow and the activity of 30-60 day ISO. The establishments of low-level southwesterlies over the Bay of Bengal and rain band from the equatorial Indian Ocean provide the favorable backgrounds for the monsoon onset over Myanmar .Regarding the activity of 30-60 day ISO, the torrential rain is triggered when an in-phase ISO moves into Myanmar.