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On the characteristics of the 1993/1994 east Asian summer monsoon convective activities using GMS high cloud amount

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GMS 상층운량을 이용한 1993년과 1994년의 동아시아 몬순대류의 특성

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Abstract

The characteristics of the Asian summer monsoon have been investigated for the periods of 1993/1994, the contrasting years in a view of the summer monsoon precipitation. In order to investigate the monsoon features over the eastern Asian monsoon region, the cloudiness(using the extensive data derived by the geostationary meteorological satellite), the condition of underlying surface including sea-surface temperature, and the summer rainfall are analyzed and some comparisons with 1993 and 1994 are also made and the characteristic differences are discussed.

An analysis of the 2-degree latitude-longitude gridded 5-day mean high cloud amount data shows the detailed movement and persistence of the convective activities.

In order to describe the spatial and temporal structures of the intraseasonal oscillation for the movement and evolution of the monsoon cloud, the extended empirical orthogonal function analysis with the twenty-day window size is used for the each year. Also, in order to find out the periodicity of the equatorial convective cluster, Fourier harmonic analysis is applied to the each year.

The most prevailing intraseasonal oscillations of high cloud amount are 61 day mode and 15 day mode in

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the equatorial and the subtropical oceans. However it was found that the most prevailing modes over the equatorial western Pacific and Indian Ocean were different for each year, hence raising the possibility that the contrasting monsoon precipitation may be more fundamentally related to the interaction of intraseasonal oscillations and seasonal variation of convective activities over the lower latitude ocean.

요 약

여름 몬순 강우가 대조적이었던 1993년과 1994년의 동아시아 여름 몬순의 특성이 조사되었다. 동아시아 지역에서의 몬순 특징을 조사하기 위해, GMS 구름양, 지표 조건인 해면 온도 그리고 여름 강우량이 분석되었으며, 위도/경도 2도 격자의 5일 평균 GMS 상층 운량의 분석을 통해 대류 활동의 자세한 이동과 지속성에 대한 1993년과 1994년의 특성이 비교되어 논의되었다.

몬순 구름의 이동과 발전에 대한 계절안 진동의 공간 및 시간 구조를 묘사하기 위해 20일의 창의 크기로 구성된 확장·경험적 직교 함수 분석이 각 해에 대해 수행되었다. 또한 적도 대류체의 주기성을 찾기 위해 퓨리에 조화 분석이 각 해에 적용되었다.

계절안 진동은 61일과 15일 모드가 적도 및 아열대에서 가장 탁월하였다. 그러나 이 탁월 모드들은 적도 서 태평양과 인도양에서 각 해마다 다르게 나타났다. 그러므로 대조적인 동아시아 몬순 강우는 저위도 해역에서의 대류 활동의 계절안 진동 및 계절 변화의 상호 작용과 더 근원적으로 관련되어 있을 것으로 본다.

1. Introduction

The intensity and duration of east Asia monsoon precipitation were thought to be connected with the onset and retreat dates of monsoon convective band, and its variabilities were characterized by sea surface temperature(SST) anomaly, the amount of snow mass over Eurasia, the equatorial flow of tropospheric low level, the process of flux convergence of moisture and the dynamic process of upper atmosphere. Specially, it has been well recognized by recent observational and theoretical studies that the summer precipitation over east Asia is largely affected by the SST and convective activity in the tropical Pacific(Nitta, 1987; Shen and Lau, 1995). This relationship between the tropical western Pacific and the summer climate over east Asia has been clarified by the interaction of annual and intraseasonal variation of convective activity in the tropical region(Li and Wang, 1994). In the key studies of this nature, the 30-60 day oscillation was analyzed by many studies(Madden and Julian, 1971; Lau and Chan, 1986), the quasi-biweekly oscillation has been significantly recognized (Krishnamurti and Bhalme, 1976).

In a more recent study, Tanaka(1994) have used the high cloud amount derived by the geostationary meteorological satellite(GMS) to analyze the summer monsoonal convection over

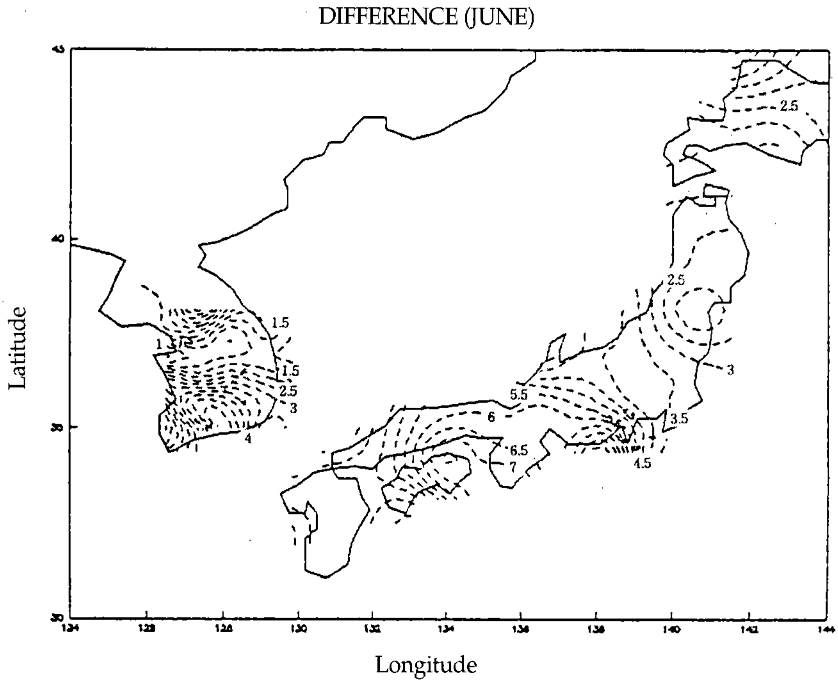


Figure 1. The monthly(June) rainfall(mm/day) differences(1994-1993).

east Asia. Maruyama *et al*(1986) showed also that the GMS high cloud amount can be used to estimate the rainfall in the tropical Pacific. Nitta(1987) and Tanaka(1991, 1994) analyzed this data set and investigated the onset and retreat dates, and seasonal cycle in the summer monsoon clouds and its interaction with the intraseasonal oscillation. These results let it confirm that GMS high cloud amount is useful to analyze the summer monsoon activity.

During the 1993/1994 summers over east Asia, we suffered from the contrasting climatic characteristics of precipitation such as a prolonged intense changma rainfall in 1993 and a weak changma with hot temperature in 1994 as shown in Fig.1, the difference of June rainfalls (mm/day) between 1994 and 1993. In this paper, this contrasting characteristics will be analyzed from connection to the monsoonal structure of convective activities over east Asia and the equatorial ocean.

In the present study, the extended empirical orthogonal function is used to obtain the evolutional structure of the principal spatial function of high cloud amount. And the intraseasonal oscillation is analyzed by the Fourier harmonic analysis, and its anomalous oscillation is established by means of the comparison of 1993 and 1994.

2. Data

The major data used in the present study is the five-day mean 2-degree latitude-longitude grid data of the GMS high cloud amount producted by the Japan meteorological satellite center. The data is constructed by time series from 1 April to 2 October in 1993 and 1994 respectively. The GMS high cloud amount is expressed as non negative integer below 10 and defined as the clouds having a cloud top temperature below the 400 hPa level climatological temperature based on observation. This data is useful to estimate the precipitation for the reason of no missing data over land and ocean.

For the detailed analysis, the 1-degree latitude/longitude SST derived from the optimum interpolation(Reynolds and Smith, 1994) by NOAA is analyzed.

3. The characteristics of east Asian convective activity for 1993/1994

Fig. 2 and 3 show time evolution and movement of 5-day mean high cloud amount for the period of 10 July - 8 August in 1993 and 1994 over the analyzed domain, respectively. In 1993, the strong convective activity is shown around Korea, Japan, and China, whereas, in 1994 the weak convective activity is characterized around Korea and Japan(for example, Tanaka(1992) defined the summer monsoon cloud by the regions with more than 3 of the mean high cloud amount). In July and August of 1993 and 1994 large cloud amount areas are lasted in south China near 15° N and extend further eastward.

Time-longitude sections of latitudinally averaged high cloud amounts for 32-38° N and 6-12° N are presented by Fig.4 and Fig.5, respectively. In case of 1993, the convective activity is situated strongly during summer monsoon period(June-July) over east Asia. Specially, one cloud branch moves to the northward toward Korea and Japan, while the inter-tropical convergence zone(ITCZ) in the Northern Hemisphere appears lastingly in 5-10° N and extends northwestward in summer monsoon. However, during June and July in 1994, the northward branch is not appeared and the large cloud amount is accumulated at 15-20° N and the convective activity around Korea becomes noticeable in August.

Specially, characteristics over eastward of 120°E is situated contrastly. The convective activity moves eastward in time for May-June in 1993. That is the horizontally extended convective cloud band is appeared from July to August. In 1994, this developmemt of convective activity is separated by two band with relatively small cloud area along northward movement and the strong convective cloud from 130° E to 150° E is lasted for July at lower latitude.

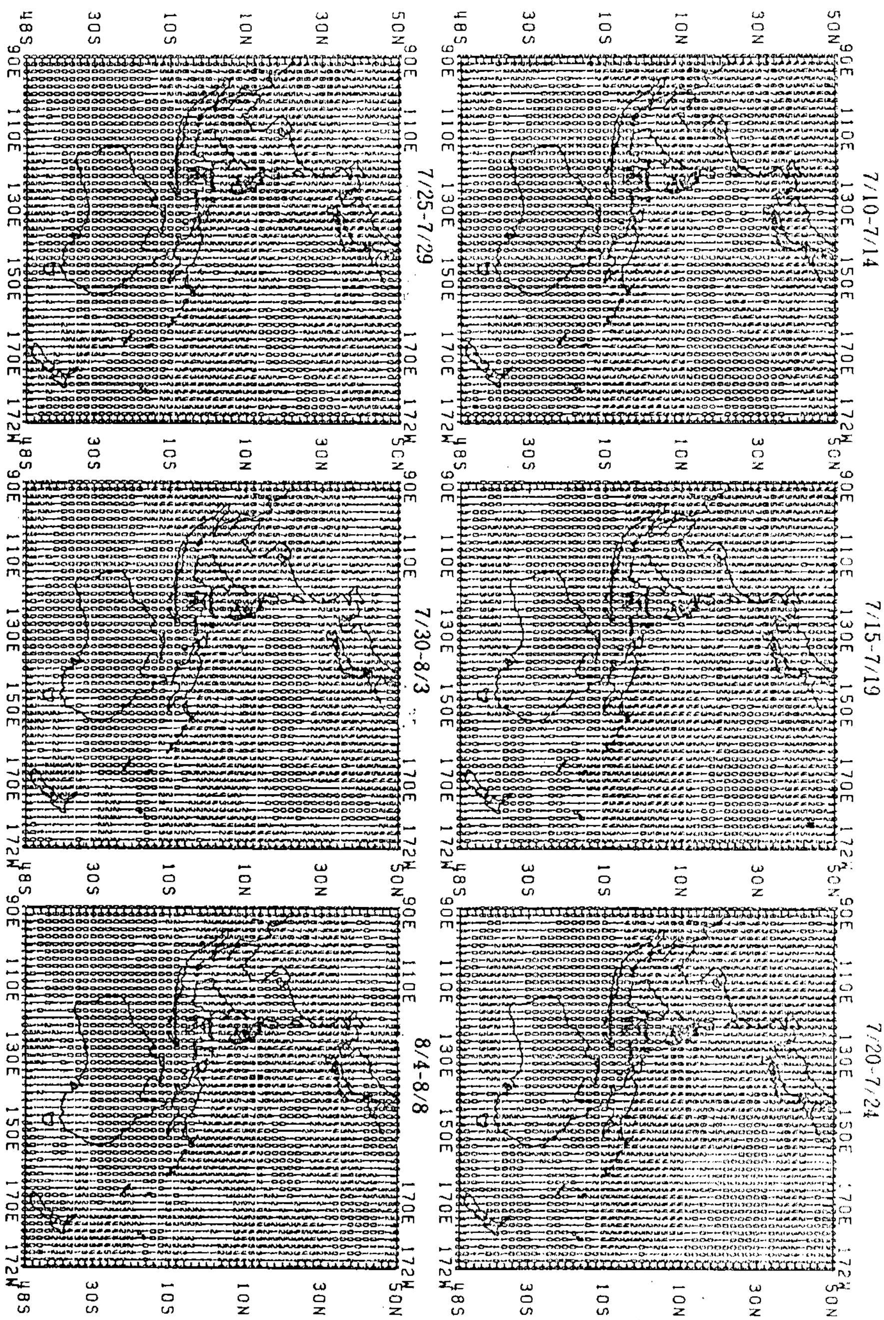


Figure 2. Plots of five-day mean high cloud amount(0-9) for the period of 10/July-8/August 1993 over the analyzed domain.

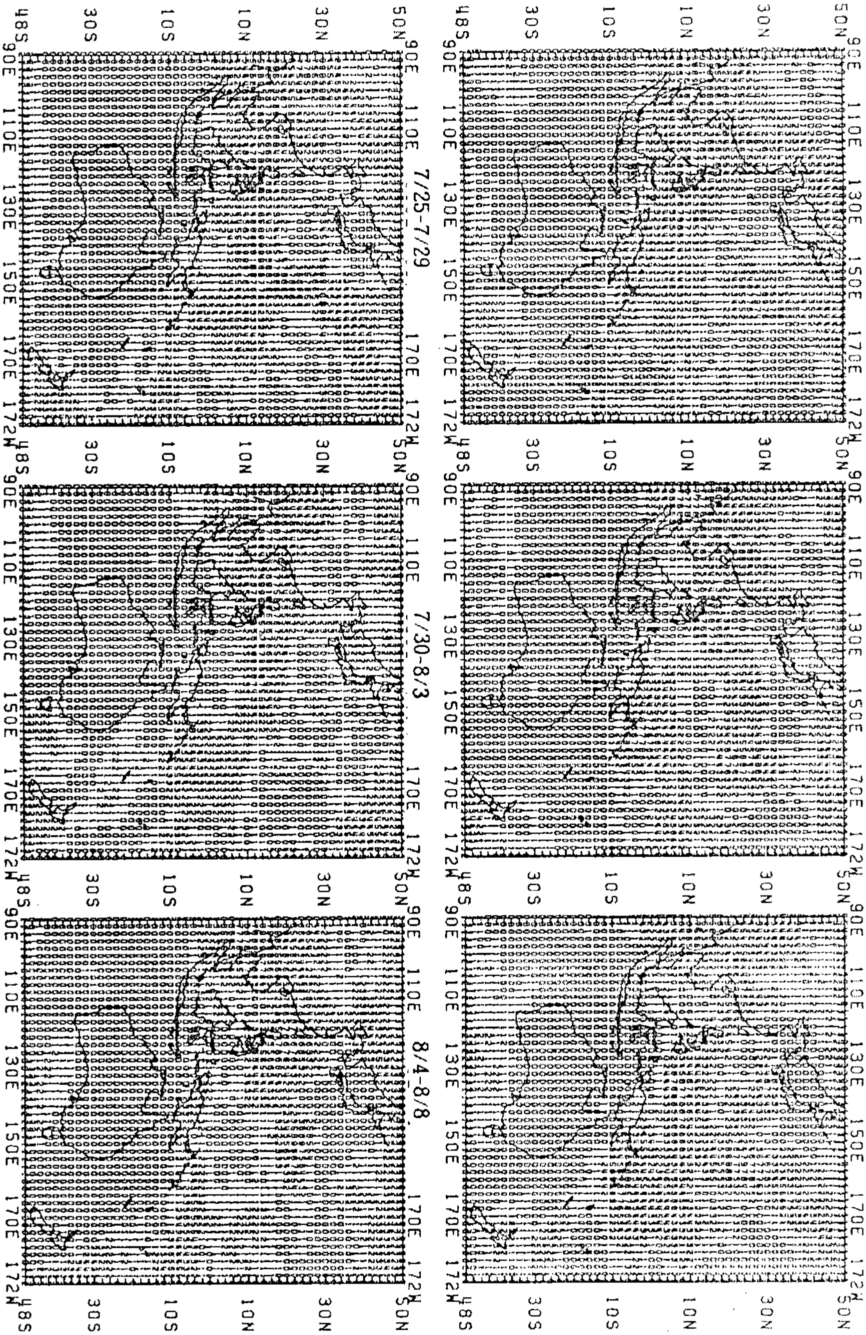
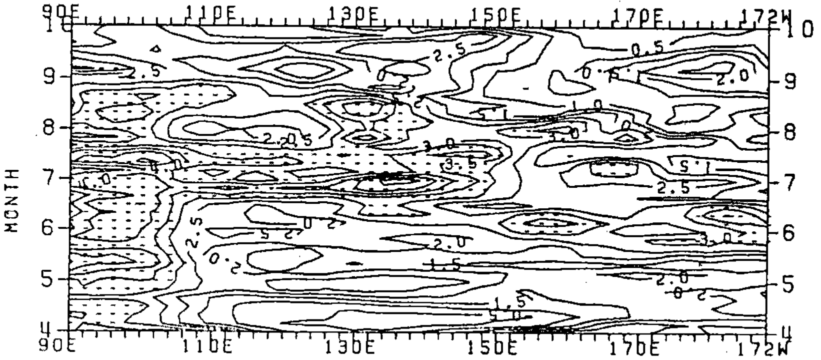


Figure 3. Same as in Fig. 2 except for 1994.

(a) High cloud amount (32° - 38 °N)
1. Apr. - 2. Oct. 1993



(b) High cloud amount (32° - 38 °N)
1. Apr. - 2. Oct. 1994

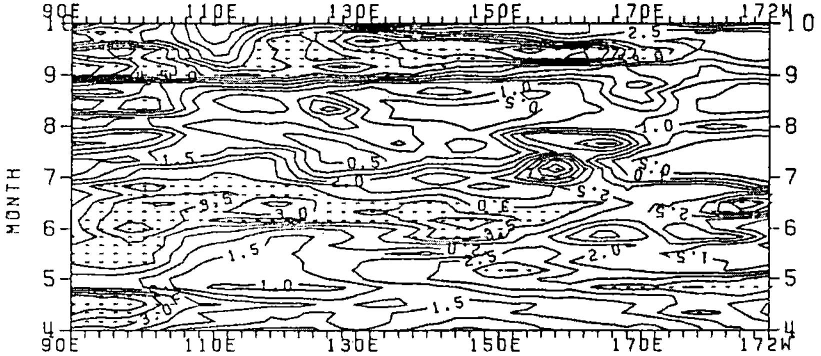
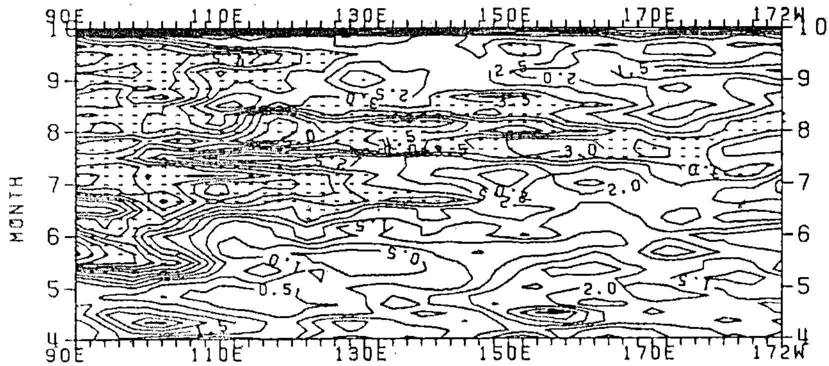


Figure 4. Time-longitude section of latitudinally(32-38°N) averaged high cloud amount (a) 1993 and (b) 1994.
The dotted regions indicate the area larger than 3.0 of high cloud amount fraction.

(a) High cloud amount (6 ° - 12 °N)
1. Apr. - 2. Oct. 1993



(b) High cloud amount (6 ° - 12 °N)
1. Apr. - 2. Oct. 1994

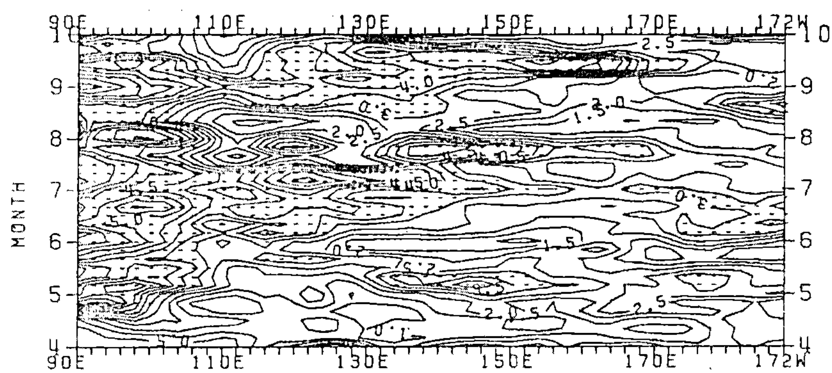


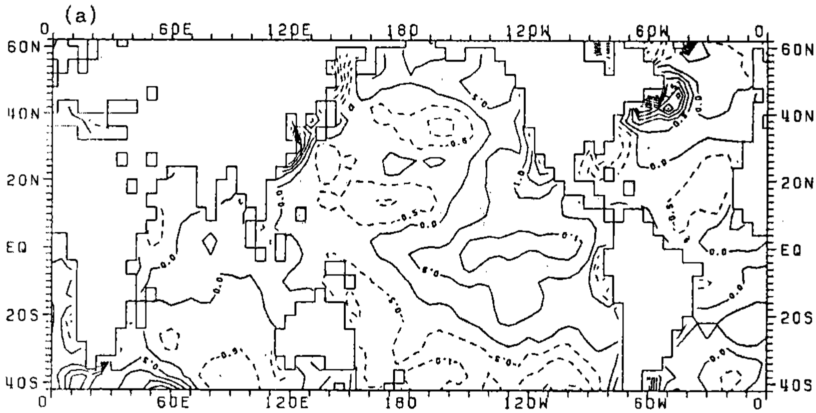
Figure 5. Same as in Fig. 4 except for 6° - 12° N.

Namely, in case of 1993, the strong activity at the lower latitude is appeared for whole changma period. Whereas, in 1994, for July the convective activity exists slightly around Korea and Japan, and it is distinctly lasted at the lower latitude.

3.1 Relationships with sea surface temperature

SST is an important factor to vary the atmospheric responses through the interaction of atmosphere and ocean. However, it is difficult to find out the consistent correlation between rainfall of east Asian monsoon and monthly SST anomaly, Fig. 6 (a) and (b) display the monthly

SST Anomaly (April 1993)



SST Anomaly (April 1994)

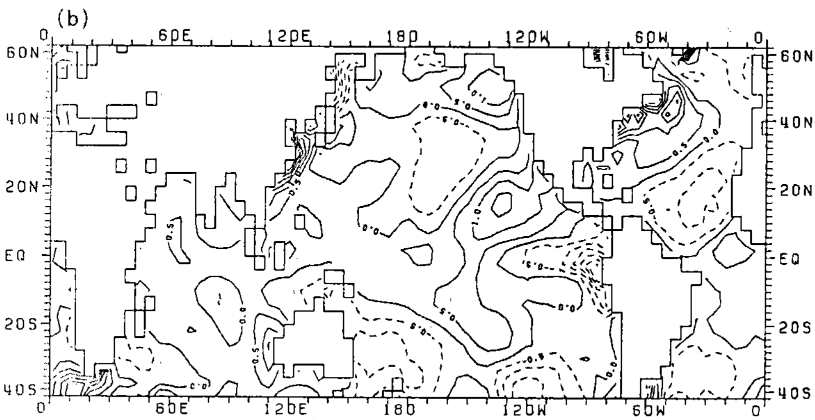


Figure 6. Plots of monthly sea surface temperature anomaly of (a) April 1993 and (b) April 1994.

SST anomaly in April 1993 and 1994, respectively. In 1994, a strong negative anomaly appears at NINO1+2, and the most of equatorial Pacific region except NINO1+2 is represented by positive anomaly. So SST at NINO1+2 region may be situated at La Ni a phase considerably, but El Ni o are still active over the whole NINO area.

Now, Fig.7 shows the plots of latitude-time sectional monthly SST at 120° E near the center of western Pacific warm pool. The top(bottom) panel in this figure explains monthly SST in

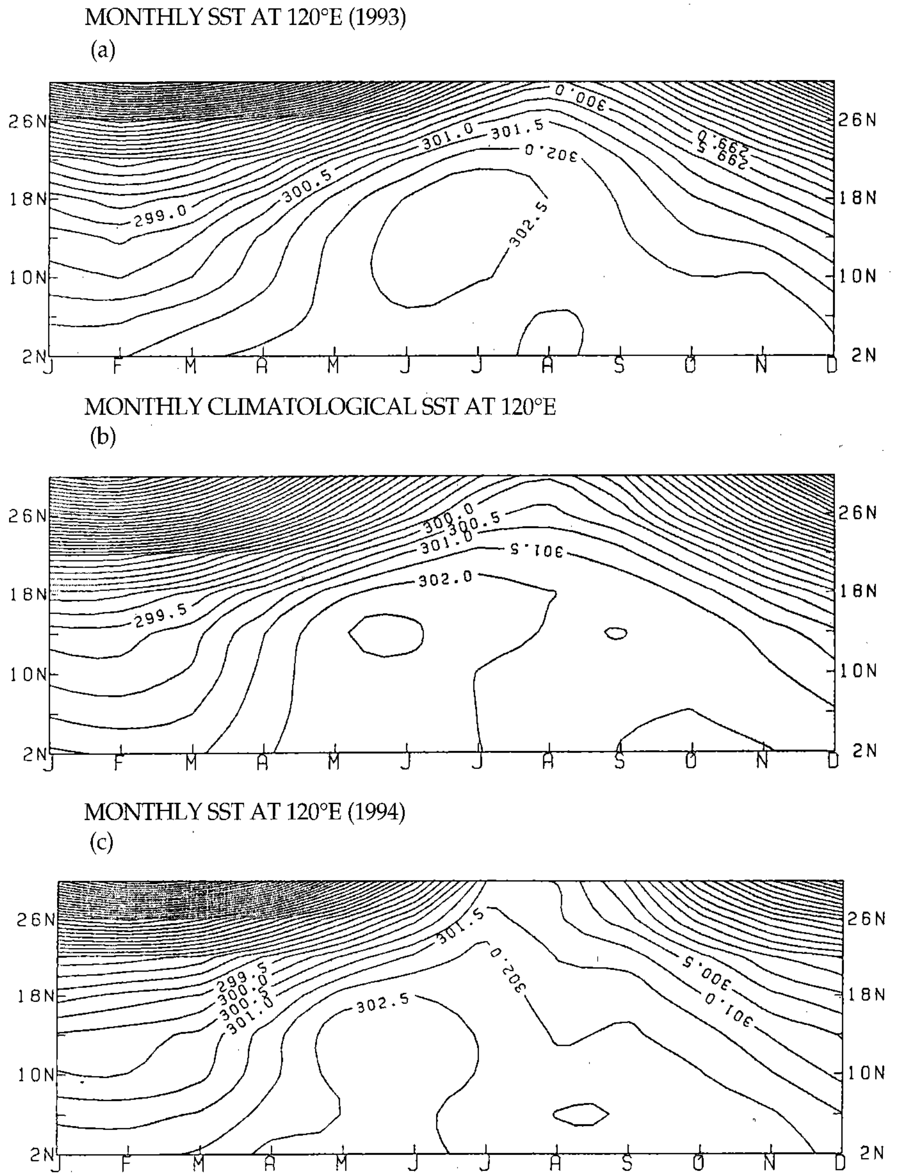


Figure 7. Latitude-time section of the monthly mean sea surface temperature at 120° E (a) 1993 (b) climatology (c) 1994.

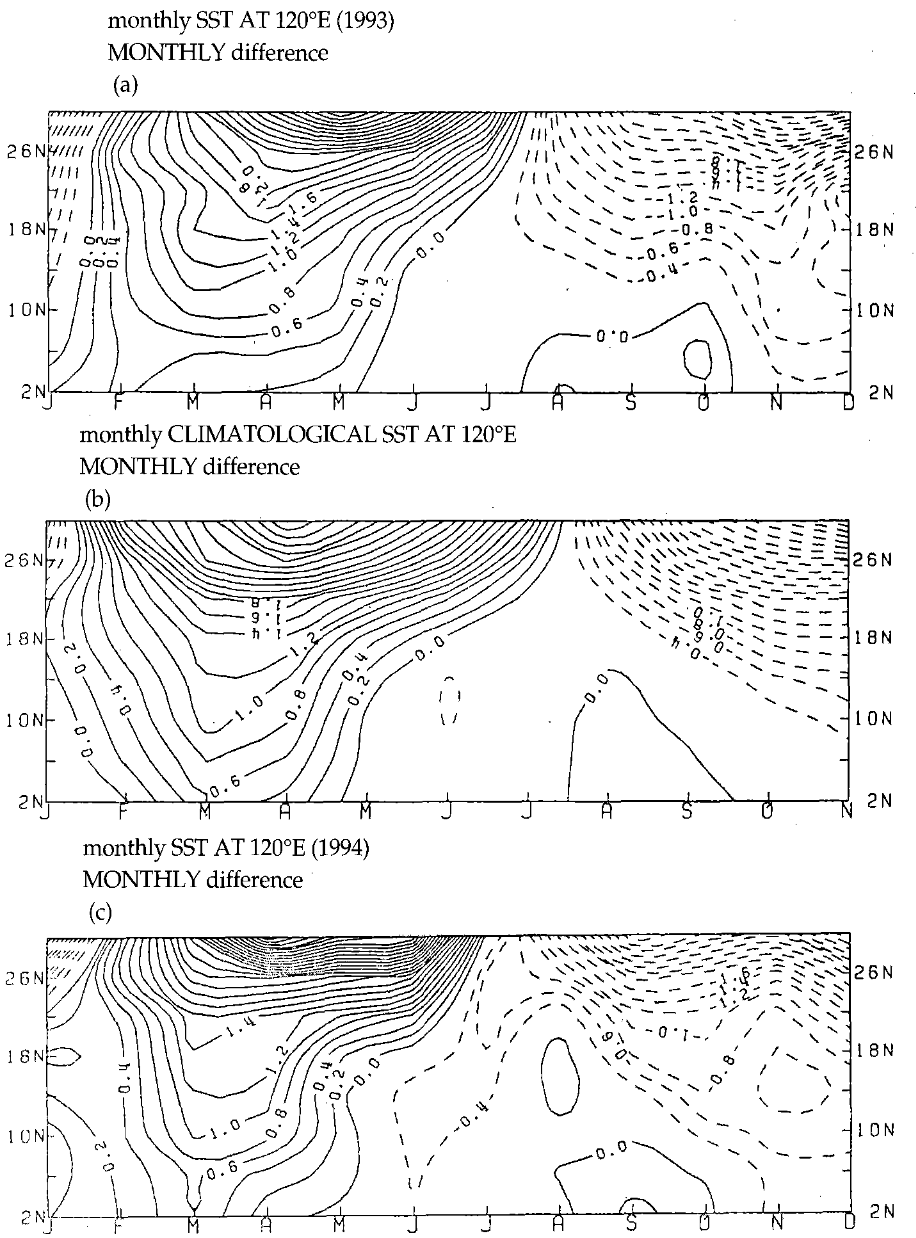


Figure 8. Latitude-time plots of the monthly difference of SST at 120° E
(a) 1993 (b) climatology (c) 1994.

1993(1994), and the middle panel shows the climatological SST. From comparing (a) and (c), it can be easily recognized that a warm core SST is quasi-persistently appeared near 15°N during the period of June-August in 1993, but, in 1994 this warm core is located for the relatively short period of May-mid June. Fig. 8 shows the latitudinal structure from 2°N to 28°N for the time evolution of the monthly SST at 120E. This value can be calculated as the monthly difference(next monthly SST- present monthly SST). Generally, the SST from the South China Sea to near 18°N appeares to activate the convective activity, it may be consistent with situation of the east Asian monsoon onset. Being limited to 18°N, we can discuss the different aspect in 1993 and 1994. The SST in 1993 tends to increase continuously and in 1994 it exhibit a tendency to decrease at the earlier time rather than 1993 and normal condition. At same time SSTs at the south of 18°N continue to increase. This mode is largely responsible for eastward moving cloud band at the lower latitude. The sharp SST increase at north of 18°N in July is well coincide with the fluctuation of the high cloud amount from late August. The latitudinal structure of the monthly SST differences at 125°E is similar to that at 120°E.

3.2 Extended empirical orthogonal function of high cloud amount

In order to investigate characteristics of time evolution for the principal spatial structure, Extended Empirical Orthogonal Function(EEOF) analysis with the 20-day window size and 10-day window size is applied to each year. The window size is decided by judgement that the 20-day can include the synoptic scale motion and then the mean structure in 20 day explains the quasi-stationary character. Now we can convert the original time-spatial function μ_{ij} of high cloud amount to new time-spatial function $\mu_{ij'}^{(n)}$ reconstructed by which n is the number of windows.

Then, $\mu_{ij'}^{(n)}$ can be expressed by the sum of the products of the time variation function, $\Psi_{j'l}$ and the space variation functions, $\alpha_{ij}^{(ln)}$ as following formula.

Then, $\mu_{ij'}^{(n)}$ is consisted of time function by spatial function.

$$\mu_{ij'}^{(n)} = \sum_{l=1}^{L} \alpha_{il}^{(ln)} \ \Psi_{j'l}$$

Where, α_{il} is the window averaged space structure with the weight being the l-th eigenfunction. $\Psi_{j'l}$ is the common time structure of windows, and can be determined as the eigenfunction of covarience matrix of μ_{ij}. Eigenvector represented by common time structure for the each window represents the time variation within the window size.

The first principle mode(Fig.9) explains the most of variability over 77% of mean total variances for 1993 and 1994. This EEOF mode exhibits relatively stationary phase, while second, third and fourth mode represent wave motion as shown by Fig.9. Fig.10 and Fig.11 represent the

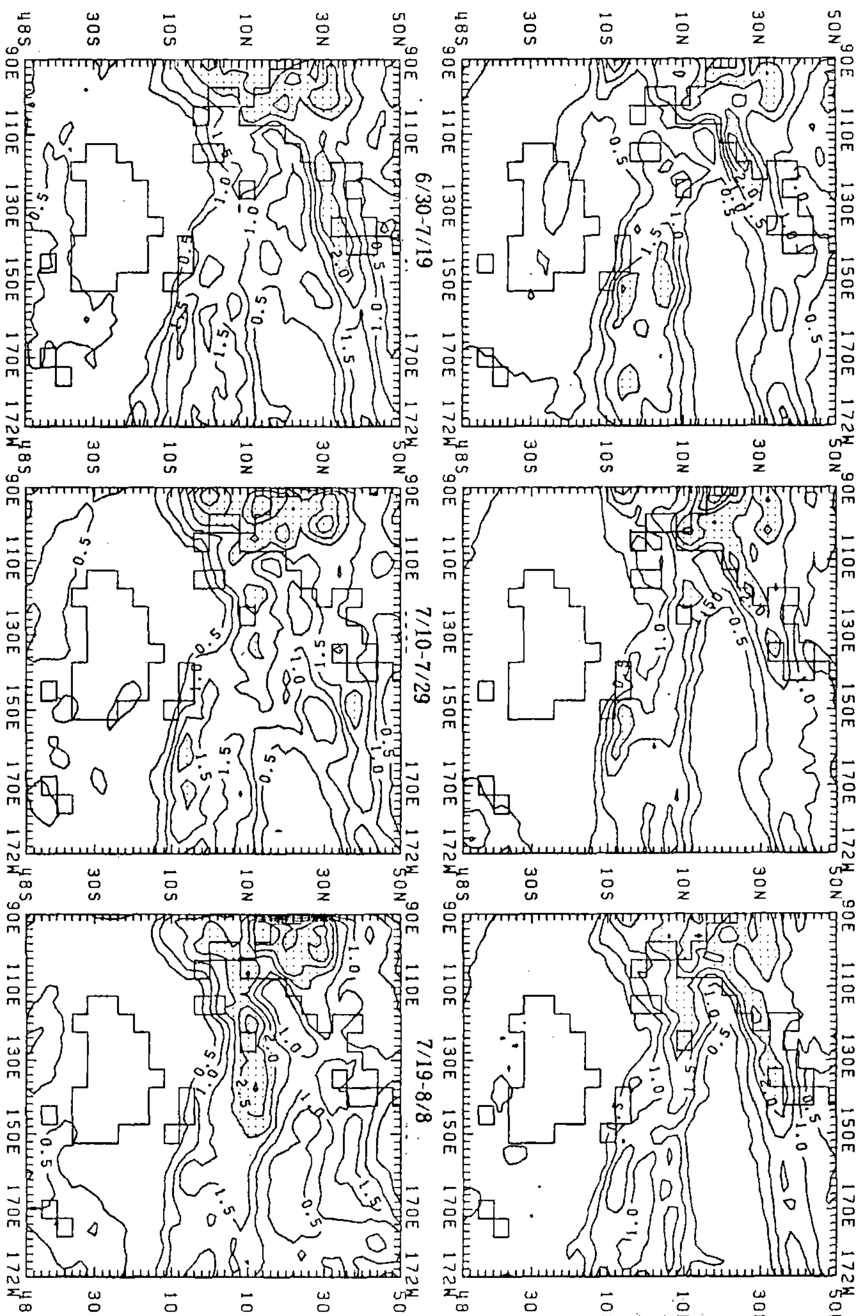


Figure 9. The spatial structure of the first extended empirical orthogonal function for the five-day mean high cloud amount in 1993.

Figure 10. Same as in Fig. 9 except for 1994.

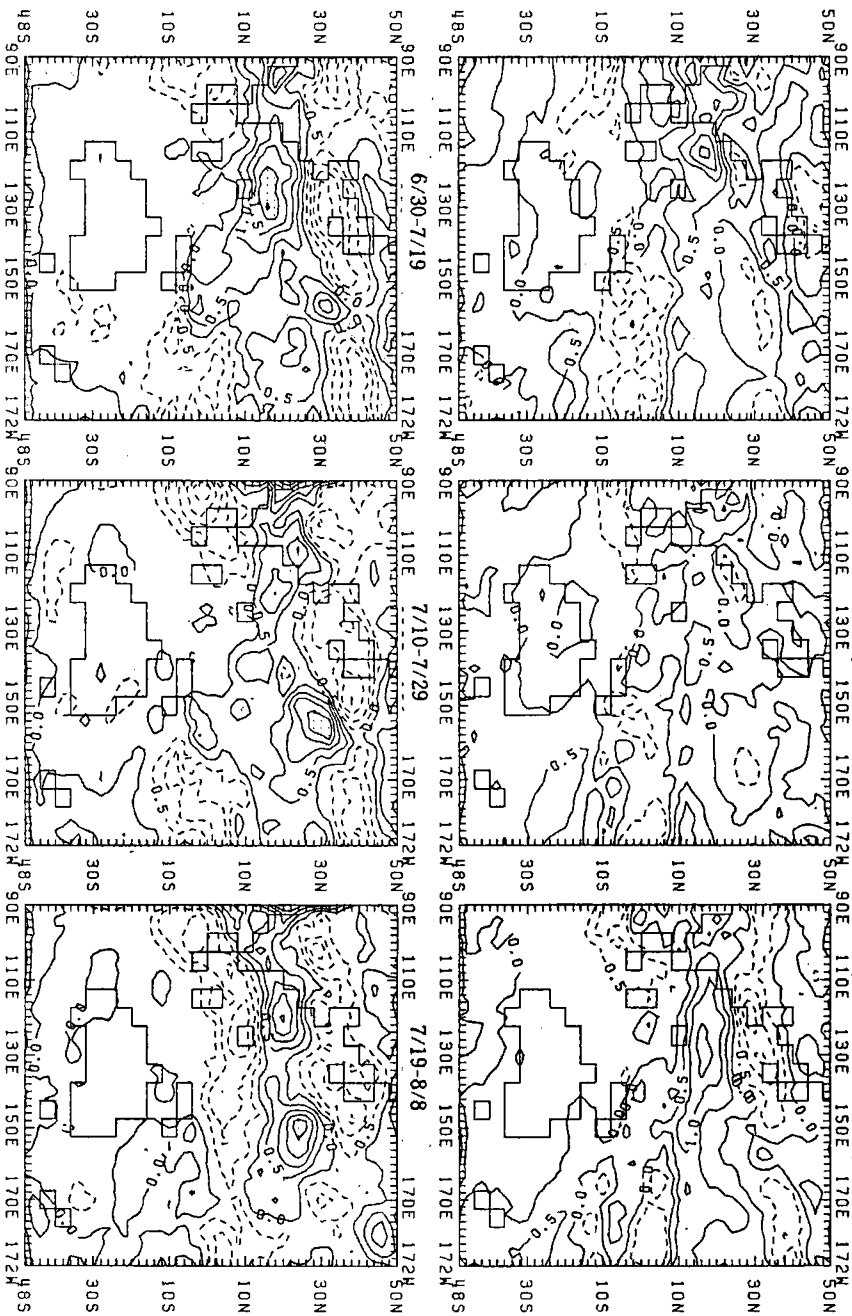


Figure 11. Plots of the spatial structure differences(1993-1994) of the first extended empirical orthogonal functions.

time evolution of the spatial structure corresponding to the first principal mode in 1993 and 1994, repectively. The period indicated in Fig.9 is from 31 May to 8 August including Changma season. We can percieve that the cloud band around 20N moves northward toward Korea and Japan during 20 June - 19 July. Whereas, in 1994 it is noticed that the cloud band near 20N exists continuously without moving northward.

In order to compare between characteristics in 1993 and 1994, we have obtained the differences(1994-1993) of the spatial structure of the first mode in time. It is characterized that the strong negative value around Korea and Japan is shown during 20 June - 29 July and the positive activity near 20N is sustained from 20 June. As a consequence, we can infer that the monsoon convective activity around Korea and Japan in 1994 is weaker than that of 1993, in contrast to the character in north region of east Asia, the convective activity in lower latitude near 20N in 1994 exists intensely and is stationary in character. One may thus conclude that the convective activity in 1994 doesn't move northward and continue to act at the lower latitude. The climatic variability which is producing this results is characterized as the contrasting features between 1993 and 1994. It may explain that this characteristics is forced by the constraint of equatorial and subtropical condition.

Unlike, the first mode, the second EOFs for 1993 and 1994 are relatively small on the contribution to total variance, however, the mode was produced by different character in 1993 and 1994. In 1993, the wave motion was concentrated on South China Sea, and in 1994 the wave motion was prominently represented at the western and northern borderline of Northern Pacific high. The second mode was not shown in the figures, but in order to find out the outstanding period of the wave motion for convective activity over east Asia, Fourier harmonic analysis was performed.

3.3 Fourier harmonic analysis

Fourier harmonic analysis is performed to determine what types of wave mode are pronounced over the analyzed area. The prevailing mode of intraseasonal oscillation in equatorial region and the different character between 1993 and 1994 are investigated.

One can write Fourier function Φ_n (t)

$$\Phi_n(t) = \begin{cases} \cos(n-1)\pi t/T & ; n = 1, 3, 5, 7 \\ \sin n\pi t/T & ; n = 2, 4, 6, 8 \end{cases}$$

where, n is 1,2,3,....,2N+1(N: rank number), T(=37) is the total period as a function of time scaled for 5-day mean. Then, harmonic function which is approximated observed 5-day mean high cloud amount as a function of time t is following.

$$\hat{C}(t) \equiv \sum_{n=1}^{2N+1} a_n \ \Phi_n(t)$$

Harmonic function which is derived from time series of high cloud amount at each grid point is represented as a function of wavenumber. Fig.12 shows the power amplitude as a

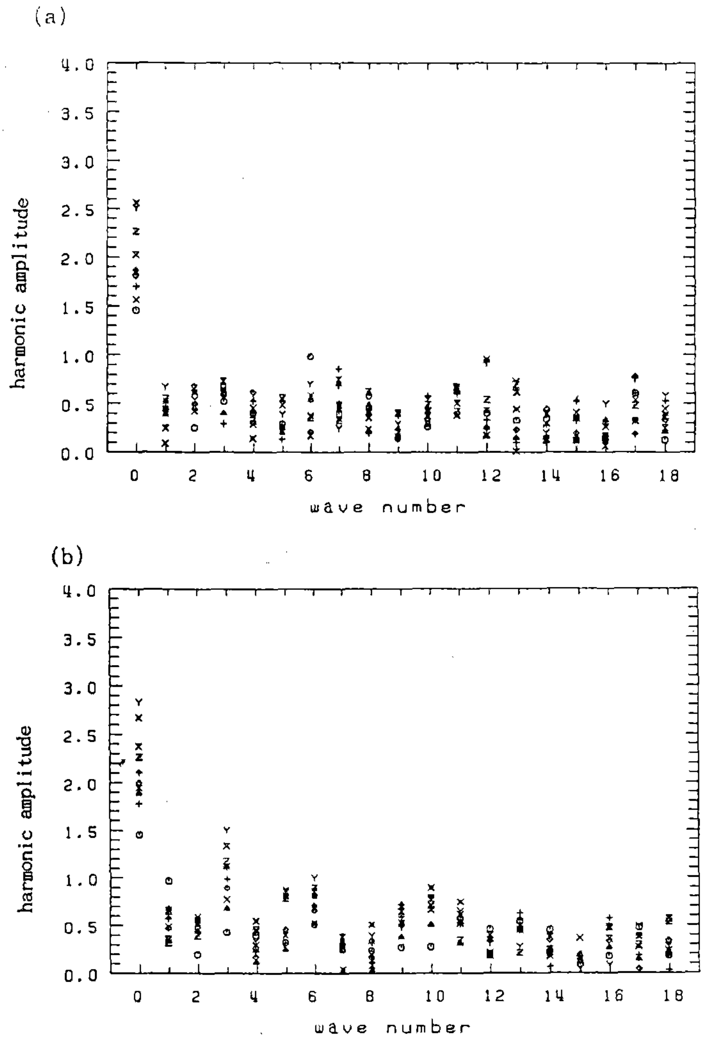


Figure 12. The Plots of the power amplitude as a function of wave number obtaimed from Fourier harmonic analysis. The ten symbols represent the amplitude of different area separating by two degree longitude from 130°E to 148°E.

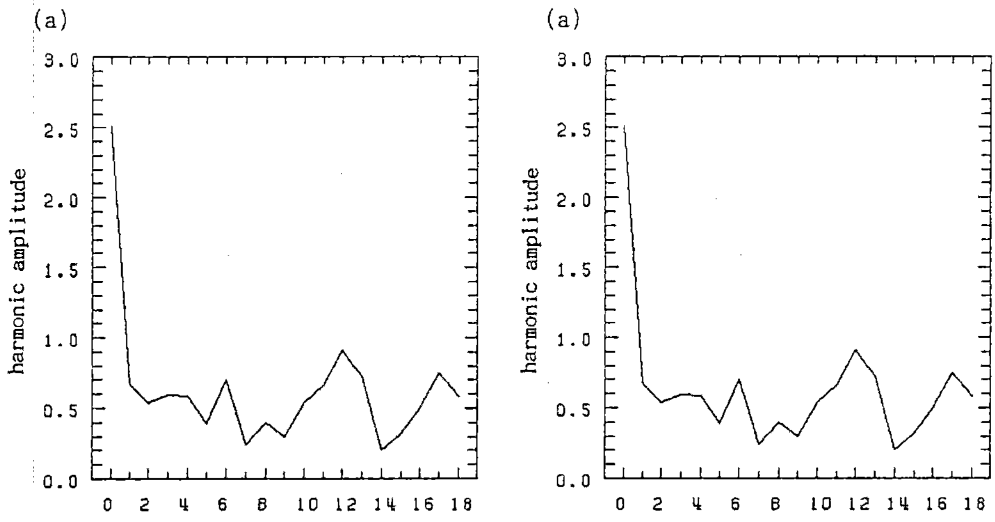


Figure 13. The harmonic amplitude as a function of wave number of high cloud amount at 134° E (a) 1993 and (b) 1994.

function of wavenumber obtained from Fourier harmonic analysis. The ten symbols represent the amplitude of different area separating by two degree longitude from 130E to 148E at equator. Symbol x at wavenumber 12 has higher harmonic amplitude than any other symbol in 1993. In 1994, the most dominent symbol is y at wavenumber 3.

Fig.13 shows harmonic amplitude as a function of wavenumber of high cloud amount at 134E. In 1993, the 15 day mode and 31 day mode are prevailing mode in western Pacific. In 1994, the 61 day mode is dominant in western Pacific. Then, it is possible to express over the equatorial and subtopical oceans. From the Fourier analysis applied to the tropical and subtropical region, it is noteworthy that the difference between 1993 and 1994 in wave modes is recognized.

Fig.14 informs that 15.4 day mode is predominant also in subtropical region. The 61 day mode is dominant in 1994 as shown by or in Fig.15. The 15.4 day mode of the most prevailing mode in 1993 is known as the quasi-biweekly mode. Like this, The most prevailing modes over the central equatorial Pacific and Indian ocean was obtained differently, in 1993 the 61 day mode is represent and in 1994 this mode is weak in Indian ocean. Then it is probably a judicious conjecture that the different climatic features between 1993 and 1994 may be claimed significantly in terms of the 15 day and 61 day modes at lower latitude, raising the possibility that the contrasting monsoon precipitation in 1993 and 1994 may be more fundamentally related to the interaction of intraseasonal oscillations and seasonal variation of convective activities.

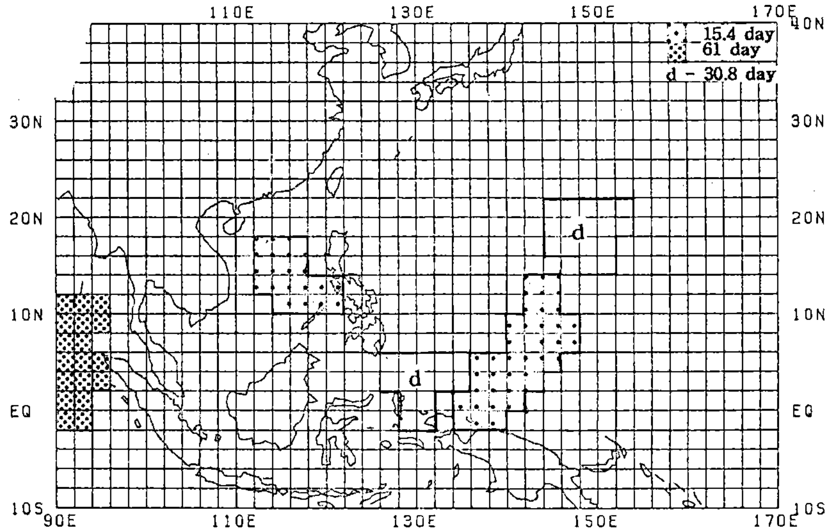


Figure 14. The prevailing modes of the intraseasonal oscillations over the equatorial and subtropical oceans for the period of 1 April- 2 October 1993.

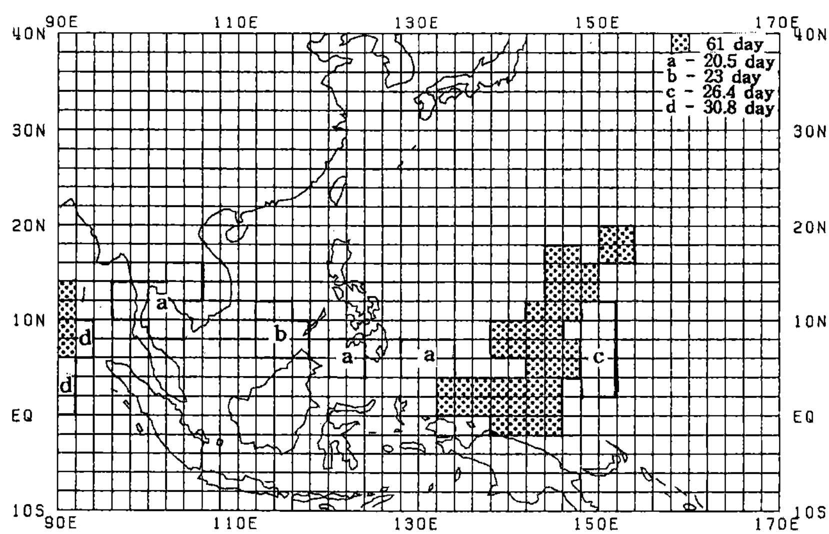


Figure 15. Same as in Fig. 13 except for 1994.

4. Conclusion

Rainfall is considered as an index for the strength of the east Asian monsoon. There are the contrast characteristics that we experienced a small amount of rainfalls in 1994 in comparison with 1993. The evolution of high cloud amount for the period of summer monsoon amount is compared as a function of latitude.

EEOF analysis is used to investigate the principal characteristics of time evolutional structure, and Fourier harmonic analysis is applied to examine the activity of wave mode in equatorial Pacific region. The results can be summarized as following.

First, high cloud amount is compared for the each year through longitude-time cross section averaged at 32-38° N and 6-12° N. There are strong convective activity during June and July, 1993. The other hand, the monsoonal convective activity for July, 1994 hasn't been appeared at the region from 110° E to 172° W of east Asia.

Secondly, from the analysis of SST monthly difference, at lower latitude than near 18N, the onset time of monsoon in 1994 is represented as the faster tendency than that in 1993. And it is shown that the continuous increasing tendency is represented to the sourthward of 18N in 1994. By this result, it seems to be explained that the convective activity at lower latitude is strengthened lastingly.

Thirdly, from the difference(first mode in 1994 - first mode in 1993)analysis of the first mode obtained from EEOF analysis, a positive difference of convective activity appeared at the lower latitude than 20N, and a negative difference at the higher latitude.

Lastly, it is noteworthy that the wave activity in the equatorial Pacific is represented differently for the contrasting years, 1993 and 1994. The 15 day mode and 31 day mode in 1993 and 61 day mode in 1994 than any the other modes were relatively dominant in equatorial central Pacific and western Pacific. And the 61-day mode in 1993 was predominantly shown in the Indian ocean to the westward of 100° E, and about 20 day oscillation was continuously existing over the east Asian monsoon region. From these results, we can infer that intraseasonal oscillation in equatorial Pacific, subtropical Pacific and Indian ocean plays an important role on the migration of the convective cluster to east Asia monsoon region during the monsoon period.

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