Large-Scale Features Associated with the Frontal Zone over East Asia from Late Summer to Autumn

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Abstract

Large-scale situations over East Asia associated with the frontal zone extending from China to Japan are examined from late August to the beginning of November on the basis of 5-day averaged fields during 1981 to 1985, mainly in 1983.

As a result, the investigated period from late summer to autumn is divided into four stages according to the frontal positions, stagnating feature of fronts and characteristics of large-scale thermal, moisture and height fields. The relationship with the retreat of the Indian summer monsoon is also examined.

In Stage 1, the frontal zone was situated in the northern part of Japan. The center of a subtropical anticyclone was located to the south of Japan and an associated ridge extended over South Japan. This Stage is regarded as a part of mid-summer season. The beginning of this stage roughly coincided with the beginning of the retreat of the Indian summer monsoon from Northwest India.

In Stage 2, the frontal zone shifted to the southern coast of Japan and stagnated there, although the stagnating nature was less pronounced than the Baiu frontal zone. Over the Eurasian Continent, the mid-latitude westerlies were meandering and a quasi-stationary trough was formed between 160°E and 160°W . The horizontal temperature gradient around the frontal zone over China in Stages 1 and 2 was small ($\sim 4^{\circ}\text{C}/1000\text{km}$), while the moisture gradient was large ($\sim 5\text{g/kg}/1000\text{km}$). The temperature gradient was relatively large ($6\sim 8^{\circ}\text{C}/1000\text{km}$) over Japan during these stages. These characteristics are similar to those of the Baiu frontal zone. The frontal zone and this stage are regarded as the Shurin (Akisame) frontal zone and the Shurin season, respectively. The period of this stage was from September 6 to 26 on a five-year average.

In Stage 3, the position of the frontal zone was not changed from Stage 2. However, the stagnating nature of fronts was not pronounced compared with Stage 2. The height field of the westerlies over the Eurasia Continent abruptly changed to the zonal pattern at the beginning of this Stage and a quasi-stationary trough was formed between 100°E and 150°E . The temperature gradient along the frontal zone over China strengthened ($\sim 10^{\circ}\text{C}/1000\text{km}$). This stage is the early period of the autumn season. The period was on a five-year average from September 27 to October 21.

At the beginning of Stage 4, the frontal zone abruptly shifted southward to the southern part of Continental China and was located away from the Japanese Islands. At the same time, the subtropical jet stream suddenly shifted to the south of the Tibetan Plateau in its eastern part, and the northeast monsoon began in South India. This stage occurs in the late period of the autumn season.

1. Introduction

We have two rainy seasons in Japan. One is the "Baiu" season preceding the summer, and the other is the "Shurin" or the "Akisame" (autumn rain) season after the summer. In these two rainy seasons, a stationary front called the Baiu front

in the Baiu season and the Shurin front (Akisame front) in the Shurin season runs along the southern coast of Japan forming the Baiu frontal zone and the Shurin frontal zone, respectively. In general, the rainfall amount is large in Southwest Japan during the Baiu season, whereas it is large in East Japan during the Shurin season (Sekiguti and Tamiya, 1968).

The seasonal change of the general circulation from the summer to the Shurin season was analyzed by Asakura (1957). He showed that the hemispheric change of the flow patterns in westerlies took place with the beginning of the Shurin season in 1951. He also pointed out that the blocking or splitting of westerlies, which is one of the main features in the Baiu season, is also characteristic of the Shurin season. However, the large-scale change associated with the end of the Shurin season has not been studied yet.

The large-scale characteristics of flow patterns during the Shurin season were investigated by Murakami *et al.* (1962). They analyzed the vapor transport over East Asia and revealed that the most important vapor transport during this season is via the southeasterlies which flow anticyclonically around the Pacific High.

The differences of large-scale situations associated with these two frontal zones were discussed by Kurashima (1959, 1968) and Kurashima and Hiranuma (1970, 1971). They pointed out that the Baiu frontal zone is the polar frontal zone characterized by a steep temperature gradient in Japan, while in China it is the tropical frontal zone characterized not by a temperature gradient but by a large moisture gradient. On the other hand, the Shurin frontal zone is regarded as the polar frontal zone with strong thermal gradient in both Japan and China. According to them, the frontal zone is different over China between the Baiu and the Shurin season. Kato (1981) also pointed out the differences of mean monthly fields of some meteorological elements during these two seasons. However, several authors regarded both Baiu and Shurin frontal zones are parts of the Pacific Polar frontal zone (*e.g.*, Yoshimura, 1967). Therefore, whether these two frontal zones are different or not is controvertible.

The beginning and end of the climatological Shurin season in Japan has been determined by many authors (*e.g.*, Saito, 1957; Kimura, 1966; Maejima, 1967; Kawamura, 1973; Yoshino and Kai, 1977; Yamakawa, 1988). Maejima (1967) pointed out that the Shurin season can be subdivided into early and late periods with a break on September 26 in Central and Southwestern Japan. However, the large-scale

circulation associated with the break of the Shurin season has not been analyzed.

The early autumn rainy season is also found over the central part of China. Kao and Kuo (1958) demonstrated that the autumn rain is pronounced over Western China and the Yangtze delta. Zhang (1979) investigated the duration of early autumn rain periods at Shanghai. The seasonal transition of the large-scale circulation from summer to autumn in China was referred to by some Chinese meteorologists (*e.g.*, Staff Member Academia Sinica, 1957; Yeh, *et al.*, 1958). They showed that the autumn season in China begins in early September and that it ends in mid-October, accompanied by the southward shift of the subtropical jet stream over the Tibetan Plateau. Therefore, the end of the autumn season in China is nearly simultaneous with the end of the Indian summer monsoon. However, whether there are associations between the Japanese Shurin season and the Indian summer monsoon season has not been investigated.

As to the Baiu season, Yoshino (1963, 1965) divided it into four stages by considering the positions of frontal zones and the features of the westerly zonal wind at 500mb. Saito (1985) pointed out that the intermittent shift of quasi-stationary waves in mid-latitude westerlies related to the beginning and end of the Baiu season. Kato (1985, 1987) and Ninomiya and Muraki (1986) have revealed that large-scale characteristics associated with the Baiu frontal zone are different among the following three stages; May, early June, and late June to early July. However, whether there are stepwise changes of the large-scale circulation during the transition from the summer season to the Shurin season and from the Shurin season to the autumn season has remained unsolved.

In the present study the author will analyze the large-scale situations associated with the frontal zones over East Asia from the summer to the autumn season, and demonstrate the relationship between the seasonal transition over East Asia and the withdrawal of the Indian summer monsoon.

The following data are utilized in this study:
(1) Daily weather maps and daily weather

reports from late August to the beginning of November, published by the Japan Meteorological Agency (JMA).

- (2) Mean maps from late August to the beginning of November, published by JMA.
- (3) Monthly bulletin for long range forecast from August to November, published by JMA.
- (4) Unpublished daily weather maps at 300mb analyzed by the forecasting division of JMA.
- (5) Withdrawal date of the Indian summer monsoon presented in "Mousam", published by the Indian Meteorological Department (IMD).

The period analyzed was from 1981 to 1985, and the case mainly analyzed was that for 1983.

2. Seasonal evolution of the frontal zone during the autumn of 1983 and division of the stages

The time-series of twice-daily positions of fronts based on the surface daily weather maps of JMA (data 1) are presented along 120°E and 140°E meridians in Fig. 1. The frontal systems were liable to be located in two latitudinal zones, around 40-55°N and around 20-40°N along both meridians. The former zone and the latter one are regarded as the northern frontal zone and the southern frontal zone, respectively. The number of fronts was higher in the southern frontal zone than in the northern one. Macroscopically, these frontal zones shifted southward, as the season advanced.

In order to see the seasonal evolution of the thermal and moisture field around these frontal zones, the time-latitude sections of 5-day

Fig. 1. The twice-daily positions of fronts, (a) along 120°E and (b) along 140°E. Thin solid lines denote a series of frontal systems. Arrows and numerals in the upper part of the figures indicate the division of stages (see text).

Fig. 2. Time-latitude sections of the 5-day averaged 850mb temperature (T_{850} ; °C, solid line) and specific humidity (q_{850} ; g/kg, broken line), (a) along 115°E and (b) along 140°E. The hatched area is the approximate location of the southern frontal zone. The minus signs show the value is lower than surroundings.

averaged temperature (T_{850}) and specific humidity (q_{850}) at 850mb along 115°E and 140°E are analyzed (Fig. 2). 5-day data are based on the plotted data on the daily 850mb weather maps at 12GMT (data 1).

Compared with the frontal positions shown in Fig. 1, the following characteristics are pointed out:

1) Around September 7, the southern frontal zone was abruptly displaced from 40°N to 35°N along 140°E .

2) The northern frontal zone was generally located in a zone of strong temperature gradient ($\sim 15^{\circ}\text{C}/1000\text{km}$) both over China and Japan.

3) In early September, the horizontal temperature gradient along the southern frontal zone was small over China ($\sim 4^{\circ}\text{C}/1000\text{km}$) but it was not small over Japan ($6\sim 8^{\circ}\text{C}/1000\text{km}$). The moisture gradient was relatively large ($\sim 5\text{g/kg}/1000\text{km}$) around the southern frontal zone both over China and Japan.

4) Around September 27, cold air ($< 0^{\circ}\text{C}$) rapidly extended southward and the thermal gradient along the southern frontal zone strengthened ($\sim 10^{\circ}\text{C}/1000\text{km}$) both over China and Japan. After this event, a wide zone ($> 1000\text{km}$) of large temperature gradient ($\sim 10^{\circ}\text{C}/1000\text{km}$) was found to the north of the southern frontal zone around Japan. The zone of large thermal gradient almost coincided with that of large moisture gradient ($\sim 5\text{g/kg}/1000\text{km}$) both over China and Japan.

5) Around October 23, the southern frontal zone which coincided with the zone of large thermal ($\sim 10^{\circ}\text{C}/1000\text{km}$) and moisture gradient ($\sim 5\text{g/kg}/1000\text{km}$) suddenly shifted southward from $30\sim 35^{\circ}\text{N}$ zone to $25\sim 30^{\circ}\text{N}$ zone.

Based on these abrupt changes related to the position and thermal and moisture fields of the southern frontal zone, the analyzed period was divided into four stages shown by arrows and numerals in the upper part of Figs. 1 and 2. In the following sections, the horizontal distribution of several meteorological elements in each stage are presented and large-scale features associated with the southern frontal zone are analyzed.

3. Positions of fronts at the surface in 1983

Figure 3 presents the positions of the fronts as they appeared on the daily surface weather maps (12GMT) during 20 days of each stage. The characteristics of each stage are as follows:

Stage 1 (Fig. 3-a)

A concentrated zone of fronts was located from Central China to North Japan forming the southern frontal zone. These fronts were located at the northern periphery of the North Pacific anticyclone. The central and southern part of Japan was commonly situated in the warm sector of these fronts and was covered by the tropical air-mass of the North Pacific anticyclone. Most of fronts were accompanied by depressions and had a migratory nature.

Stage 2 (Fig. 3-b)

At the beginning of this stage, the southern frontal zone abruptly shifted southward to the southern coast of Japan. Although the frontal positions fluctuated between 26°N and 34°N , fronts were liable to be stagnated from Central China to the southern coast of Japan during this stage. The concentration of fronts were the most outstanding among the investigated periods.

Stage 3 (Fig. 3-c)

Though the positions of fronts did not change clearly in transition from stage 2 to 3, some important changes took place between these stages. In this stage, the fronts along the southern coast of Japan had a migratory nature. The passages of cold fronts were frequent along 140°E . The occlusions of fronts, which rarely occurred to the west of 150°E around Central Japan in Stage 2, sometimes occurred around 140°E . The above characteristics of the southern frontal zone seem to be caused by the strong baroclinity of this frontal zone in this stage (see Fig. 2).

Stage 4 (Fig. 3-d)

The southern frontal zone suddenly migrated southward to $20\sim 30^{\circ}\text{N}$ zone at the beginning of this stage. No fronts appeared in the central and southern part of the continental China during this stage.

Fig. 3. Frontal positions at 12GMT over 20 days of each stage.

4. Characteristics of thermal and moisture fields at 850mb in 1983

In this section, 5-day averaged fields of temperature (T_{850}) and specific humidity (q_{850}) in each stage are analyzed. Hereafter, figures are presented for four five-day periods, September 3-7, September 13-17, October 3-7 and October 23-27. These periods are regarded as examples of each stage.

Figures 4 and 5 show that horizontal thermal and moisture fields were different among these stages. Along the southern frontal zone in Stages 1 and 2, the temperature gradient was weak ($\sim 5^{\circ}\text{C}/1000\text{km}$) but the moisture gradient was large ($\sim 6\text{g}/\text{kg}/1000\text{km}$) to the west of 130°E . East of 140°E , the temperature gradient was relatively large ($6\sim 8^{\circ}\text{C}/1000\text{km}$) in Stages 1 and 2 compared with the situations west of 130°E . While, in Stages 3 and 4, the thermal gradient along the frontal zone was large ($\sim 10^{\circ}\text{C}/$

1000km) over the whole investigated area. On the other hand, the moisture gradient along this frontal zone was large ($\sim 5\text{g}/\text{kg}/1000\text{km}$) in all stages. In Stage 4, the southern zone of strong thermal gradient shifted southward to $25\sim 30^{\circ}\text{N}$. The situations in mid-high latitudes region were similar to that in Stage 3.

The large-scale features characterized by a large moisture gradient ($\sim 5\text{g}/\text{kg}/1000\text{km}$) and a small thermal gradient ($\sim 4^{\circ}\text{C}/1000\text{km}$) along the southern frontal zone in Stage 2 are similar to the characteristics of the Baiu frontal zone in the mature stage of the Baiu season shown by many previous studies (e.g., Akiyama, 1973; Ninomiya, 1984; Kato, 1985, 1987; Ninomiya and Muraki, 1986). The difference in thermal conditions between China and Japan also resembles the Baiu situations. On the other hand, the characteristics of the frontal zone with strong thermal gradient in stage 3 and 4 are similar to those of the frontal zone in the pre-Baiu period (Ninomiya and

Fig. 4. Five-day averaged temperature at 850mb, 12GMT ($T_{850}; ^\circ\text{C}$).

Muraki, 1986; Kato, 1987). Therefore, Stage 2 in this paper is regarded as the Shurin season, which can be compared with the Baiu season.

The change of thermal structure along the southern frontal zone from Stage 2 to 3 in late September was abrupt and seems to be a change comparable with the abrupt "structure change" of the Baiu frontal zone in late May pointed out by Kato (1983, 1985, 1987). In the case of late September, the abrupt change was not significant over China, whereas it was clear over Japan in contrast to the case of late May. Although the physical processes causing this change in the Shurin season are unknown, it seems that both changes occurring in late May and late September are important processes related to the seasonal change of general circulation from winter to summer and summer to winter, respectively.

It should be noted that although the features of the southern frontal zone in Stage 2 resemble

those of the Baiu frontal zone, there exist some distinct differences between these two frontal zones. Moisture transport analyzed by Murakami *et al.* (1962) is one of the examples. The heavy rainfalls occurring around the Shurin frontal zone are less frequent in comparison to those around the Baiu frontal zone. The Shurin season is not prominent over Central China, while the Baiu season is apparent both over China and Japan. In addition, the Shurin frontal zone is more mobile than the Baiu frontal zone, as Sekiguti and Tamiya (1968) and Kawamura (1973) have mentioned. Why such differences exist is not investigated here.

5. Characteristics of 500mb height field in 1983

In this section, the state of upper air mainly at 500mb is analyzed in order to correlate the differences among each stage to the large scale

Fig. 5. Five-day averaged specific humidity at 850mb, 12GMT (q_{850} ; g/kg).

circulation. Figure 6 presents the 5-day averaged 500mb height field over the northern hemisphere based on data 2.

In Stage 1 (Fig. 6-a), the contour intervals over East Asia were wide ($\sim 100\text{m}/1000\text{km}$). The center of a subtropical anticyclone was located to the south of Japan ($\sim 30^\circ\text{N}/140^\circ\text{E}$) and an associated ridge covered the southern part of Japan. The zone of strong height gradient ($\sim 250\text{m}/1000\text{km}$) was seen to the north of 60°N over eastern part of Eurasia. The westerlies over mid- and high latitudes were meandering and a pronounced ridge was formed over the eastern part of Eurasia Continent ($\sim 140^\circ\text{E}$). Troughs were formed around 80°E and 160°W .

In Stage 2 (Fig. 6-b), the center of the anticyclone to the south of Japan and the anticyclonic flow over South Japan identified in Stage 1 vanished. Contour intervals over Japan became narrower ($\sim 150\text{m}/1000\text{km}$) than Stage

1. The meandering feature of the westerlies with a distinct ridge and trough over mid- and high latitudes over Eurasia was as pronounced as in Stage 1. The trough extending from the Bering Straits to the Aleutian Islands deepened and extended southwestward to $\sim 160^\circ\text{E}$. However, it did not extend to North China, unlike the “Baiu trough” which is one of the predominant systems in the Baiu season according to Ninomiya and Muraki (1986). The zone of strong height gradient ($\sim 250\text{m}/1000\text{km}$) was located north of 60°N over East Eurasia similarly to Stage 1.

In Stage 3, the state of westerlies in mid- and high latitudes over Eurasia apparently changed from Stage 2. The zone of strong height gradient ($\sim 250\text{m}/1000\text{km}$) shifted southward to $45\text{--}60^\circ\text{N}$ zone. The meandering features of the westerlies weakened, and a deep trough was formed around 140°E .

In Stage 4, the basic contour patterns over the

Fig. 6. Five-day mean height field at 500mb (Z_{500} ; gpm).

Eurasia Continent were similar to those in Stage 3. The main differences were the deepening of the trough at 140°E and the southward shift of the westerlies over the Tibetan Plateau, accompanied by the disappearance of the low pressure area over Indian Peninsula. Figure 7 shows the daily positions of the subtropical jet streams at 300mb around South and East Asia from October 21 to 25 using data 4. The subtropical jet stream suddenly shifted from the north to the south of the Tibetan Plateau in the Eastern part of the plateau on October 24. Thus, the change from Stage 3 to 4 took place almost simultaneously with the sudden southward shift of the subtropical jet stream around the Tibetan Plateau and is supposed to be closely related with the retreat of the Indian summer monsoon. According to data 5, the retreat of the southwest

Fig. 7. Daily location of the subtropical jet stream at 300mb around the Tibetan Plateau and East Asia for October 21-25, 12GMT.

monsoon from the whole Indian Peninsula was on October 21 and the beginning of the northeast monsoon was on October 24. The transition from Stage 3 to 4 roughly coincided with the beginning of the northeast monsoon over South India.

In order to investigate the temporal variations of the mid-latitude westerlies more clearly, time-latitude section of 5-day mean 500mb height (Z_{500}) along 140°E using data 3 is presented in Fig. 8. Figure 8 shows that both transitions from Stage 1 to 2 and from Stage 2 to 3 were abrupt along 140°E , which coincides with the temporal evolution of the thermal field. The transition from Stage 3 to 4 was not clear in Fig. 8.

Finally, longitude-time sections of the 5-day mean 500mb height deviation from zonal average (Z^*_{500}) at 60°N and 30°N are shown in order to show the quasi-stationary wave pattern is the westerlies (Fig. 9). Figure 9-a shows that the transition from Stage 2 to 3 is recognized by the sudden change in the location of ridge and trough at 60°N . A pronounced ridge area around 150°E in Stage 2 was replaced by a trough in Stage 3. At the same time, a trough around 160°W in Stage 2 was also replaced by a ridge in Stage 3. It is noted that the transition between Stage 2 and Stage 3 is not a phenomenon local to Japan, but was of large-scale extent over Eurasia along 60°N .

The transitions from Stage 1 to 2 and from Stage 3 to 4 were not clear along 60°N but were seen along 30°N (Fig. 9-b). The eastward shift of a ridge area from $\sim 140^{\circ}\text{E}$ to $\sim 160^{\circ}\text{E}$ occurred in early September along 30°N . A further eastward

shift of the ridge area was seen during transition period from Stage 3 to 4. At the same time, a stagnating trough along 80°E extended eastward and a branch of this trough was formed at the beginning of Stage 4 around 130°E , corresponding to the establishment of the southern branch of the jet stream around the Tibetan Plateau.

Fig. 8. Time-latitude section of the 5-day mean 500mb height (Z_{500} ; gpm) along 140°E .

Fig. 9. Longitude-time sections of the 5-day mean 500mb height deviation from the zonal mean (Z^*_{500} ; gpm), (a) along 60°N and (b) along 30°N .

6. Seasonal division over East Asia from summer to autumn and its relation to the retreat of the Indian summer monsoon

In this section, the situations during 1981 to 1985 except 1983 were analyzed in order to investigate whether similar characteristics are recognized in other years.

The time-latitude sections of positions of the fronts along 140°E (Fig. 10) and the time-latitude sections of Z_{500} along 140°E (Fig. 11) are constructed during late August to the beginning of November. Stage divisions are performed mainly by examining these two time-latitude sections. Spatial distribution of daily fronts at the surface, 5-day mean and daily height distribution at 500mb over East Asia are also referenced. Figures 10 and 11 demonstrate that the year to year variation of seasonal change was quite large. However, the four stages were recognized in these years, as for the case of 1983. The periods of these stages are presented in Table 1 and in the upper part of Figs. 10 and 11.

The end of Stage 1 corresponded to the sudden southward shift of the southern frontal zone around Japan accompanied with the southward retreat of the subtropical anticyclone. The case in 1982 was rather abnormal, since Typhoon 8215 was located around 140°E from the end of August to the beginning of September.

The transition from Stage 2 to 3 is determined by the establishment of a high north-south height gradient ($> \sim 250\text{m}/1000\text{km}$) zone around 40°N . The end of Stage 2 determined by this manner roughly agreed with the change of stagnating nature of fronts along the southern coast of Japan. However, the case in 1982 was an exception. In this year, fronts were stagnated along the southern coast of Japan ~ 10 days after the end of Stage 2. Therefore, the large-scale height field in Stage 2 presented in this paper is not the only factor which determines the stagnating nature of the southern frontal zone.

The year to year variation of the wave pattern in the westerlies was also quite large. However the location of the quasi-stationary trough at 60°N showed good agreement with the stage division between Stage 2 and 3. A trough located

Fig. 10. The twice-daily positions of fronts, along 140°E . Thin solid lines denote a series of frontal systems. Arrows and numerals in the upper part of the figures indicate the division of stages.

between 160°E and 160°W in Stage 2 suddenly shifted to $100^{\circ}\text{E}\sim 150^{\circ}\text{E}$ at the beginning of Stage 3.

The beginning of Stage 4 is based on the

Fig. 11. Time-latitude sections of the 5-day mean 500mb height (Z_{500} ; gpm) along 140°E .

Table 1. Periods of the four stages from 1981 to 1985.				
Year	Stage 1	Stage 2	Stage 3	Stage 4
1981	−9.4	9. 5− 9.20	9.21−10.23	10.24−
1982	−9.4	9. 5− 9.25	9.26−10.20	10.21−
1983	−9.7	9. 8− 9.28	9.29−10.23	10.24−
1984	−9.2	9. 3− 9.22	9.23−10.21	10.22−
1985	−9.9	9.10−10.7	10. 8−10.19	10.20−
MEAN	−9.5	9. 6− 9.26	9.27−10.21	10.22−

location of the frontal zone. The sudden southward shift of the southern frontal zone was recognized at the beginning of this Stage. The establishment of the trough around 130°E shown by the longitude-time section of Z^*_{500} along 30°N is also noted. The date of the southward shift of 300mb subtropical jet stream from the north to the south of the Tibetan Plateau based

Table 2. The date of southward shift of the 300mb subtropical jet stream in the eastern part of the Tibetan Plateau from 1981 to 1985 based on data 4.

Year	1981	1982	1983	1984	1985
Jet Shift	10.27	10. 8	10.24	10.23	10.24

on data 4 is shown in Table 2. Here again the case in 1982 was abnormal. In case of other years, the date of the beginning of Stage 4 roughly coincided with the sudden southward shift of the jet stream.

In summary, the stage division was also effected for these other years, although the case in 1982 was rather abnormal. In comparison with the seasonal division of previous climatological studies (e.g., Maejima, 1967; Yoshino and Kai, 1977), the beginning of the Shurin season is similar, while the end is about ten days earlier and almost corresponds to the break period of the Shurin season described by Maejima (1967). However, several studies imply that the change in late September is significant. For instance, Yamakawa (1984) stated that the courses of cold fronts in October of 1979 were scattered unlike in September. Tsuruta *et al.* (1987) showed that the concentration of the background ozone in 1986 suddenly rose in late September around South Japan with the southward retreat of the maritime tropical air mass. These results seem to support the thesis that the Shurin season does not last to mid-October but ends in late September.

After the end of the Shurin season, the autumn season sets in. This season is subdivided

into an early and late period in late October in terms of the frontal position and location of the jet stream around the Tibetan Plateau. Since the basic height field of westerlies and horizontal thermal field around the southern frontal zone were not changed in late October, Stages 3 and 4 are regarded as one season over East Asia.

Table 3 gives the withdrawal date of the Indian summer monsoon where such information is available from data 5. In Table 3, the beginning date of the northeast monsoon is also determined by examining the daily 850mb wind field based on published ECMWF daily global analyses, which was somewhat different from the date determined by IMD. Compared with the stage division over East Asia (Table 1), the end of Stage 1 occurs, on average, several days prior to the beginning of the withdrawal of the Indian monsoon. The beginning of Stage 4 is roughly simultaneous with the beginning of the northeast monsoon over South India. However, further study is needed to verify the simultaneity between the seasonal transition over East Asia and the withdrawal of the Indian summer monsoon in each year.

Finally, a brief comparison with the stage division of early summer presented by Yoshino (1963, 1965) is made. His Stage I and Stage IV seem to correspond to Stage 4 and Stage 1 in this study, respectively. The situations of Stage 2 in this study resemble Yoshino's Stage II and III, although there are some differences between the situations in the Baiu season and in the Shurin season, as stated in section 4. Stage 3 in this study seems to have no comparable situations in

Table 3. Withdrawal date of the summer monsoon and the onset date of northeast monsoon over India from 1982 to 1985 based on data 5. In parentheses the date of beginning of the northeast monsoon examined by the wind field at 850mb using ECMWF daily global analyses is shown.

Year	Withdrawal of SW Monsoon		Beginning of NE Monsoon	
	Beginning	End		
1982	9. 3	10.11	NO DATA	(10. 8)
1983	9.13	10.19	10.24	(10.20)
1984	9.12	10. 3	10. 5	(10.19)
1985	9.11	10.24	10.25	NO DATA
MEAN	9. 8	10.14	10.18	(10.16)

early summer. In this stage, the circulation over mid- and high latitudes is a winter type. On the other hand, circulation over low latitudes is of the summer type, and the summer monsoon circulation over India is still maintained. Therefore, the seasonal transition from summer to autumn is not a completely reversible transition from spring to summer.

The mechanism of seasonal change has not been fully analyzed in the mid-latitude region. The above results have shown that the climatological division of natural seasons should be re-examined from the view point of the large-scale circulation. Therefore, studies of longer periods are necessary. In addition, the physical processes related to the seasonal changes and the interaction between the retreat of the Indian summer monsoon and large scale circulation must also be studied.

7. Conclusions

The large-scale situations over East Asia was analyzed from late August to the beginning of November for the period of 1981-85, mainly in 1983. As a result, the analyzed period was divided into four stages related to the positions of the frontal zone, horizontal thermal and moisture fields at 850mb, and the height field at 500mb. The seasonal transition over East Asia around Japan and its relation to the withdrawal of the Indian summer monsoon are as follows:

1. The mid-summer season (Stage 1) ended, on a 5-year average, around September 5 with the southward displacement of the southern frontal zone from North Japan to the southern coast of Japan. This change was accompanied by the disappearance of the subtropical anticyclonic center to the south of Japan. This change took place on average a few days prior to the beginning of the withdrawal of the Indian summer monsoon. Afterwards the Shurin season set in around Japan.

2. During the Shurin season (Stage 2), the mid-latitude westerlies showed a blocking pattern over East Eurasia. The southern frontal zone characterized by a weak thermal gradient ($\sim 4^{\circ}\text{C}/1000\text{km}$) and a strong moisture gradient ($\sim 5\text{g/kg}/1000\text{km}$) to the west of 130°E stagnated along the southern coast of Japan like

the Baiu frontal zone. This frontal zone and this period are regarded as the Shurin frontal zone and the Shurin season, respectively. The stagnating nature of the Shurin frontal zone was less pronounced than the Baiu frontal zone.

3. The horizontal thermal field in the lower troposphere along the southern frontal zone and the height field of the upper mid-latitude westerlies abruptly changed around September 27 on a 5-year average. The temperature gradient along the southern frontal zone was strengthened ($\sim 10^{\circ}\text{C}/1000\text{km}$). The westerlies over Eurasia showed a zonal pattern. The migratory depressions along the frontal zone sometimes passed near the southern coast of Japan. These events signify the end of the Shurin season and the commencement of the early period of the autumn season (Stage 3).

4. The southern frontal zone shifted southward to the South China Sea around October 22 on a 5-year average. This was roughly simultaneous with the southward retreat of the subtropical jet stream in the eastern part of the Tibetan Plateau and with the beginning of northeast monsoon over India. After this change, the late period of the autumn season began (Stage 4).

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東アジアにおける晩夏季から秋季にかけての前線帯に伴う 大規模場の特徴について

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東アジアにおける8月下旬から11月はじめにかけての前線帯に伴う大規模場の特徴と推移, およびインドの夏季モンスーンの撤退との関連性を, 1983年を中心に1981年から1985年について, 主に半月平均資料を用いて解析した。

中国大陆から日本列島にかけて準定常的に存在する前線帯の位置および停滞性と大規模場の特徴により, 対象とした期間は以下の四つのステージに分けられた。

ステージ1では, 前線帯は北日本以北にあり, 前線の出現頻度も低い。日本列島の南方海上には亜熱帯高気圧の中心があって, 日本列島南部にはりだしており, 盛夏のつづきとみなした。

ステージ2では, 前線帯は日本の南岸に移り, 梅雨前線帯ほど顕著ではないが停滞する。ユーラシア大陸上の偏西風は大きく蛇行し, ブロッキングを形成し, 北緯60度では準定常的なトラフが, 年により位置はちがうが東経160度から西経160度の間に形成される。この時期までの前線帯は, 中国大陆上で気温の水平傾度が小さく, 水蒸気傾度が大きい。一方, 日本付近では気温傾度が若干大きい。この特徴は, 梅雨前線帯ときわめてよく類似しており, 秋りん前線帯(秋雨前線帯)とみなすことができる。このステージは秋りん季とみなされ, その期間は5年間の平均で9月6日から26日であった。秋りん季の開始は, インドの北西部からの南西モンスーンの撤退の開始とほぼ同時であった。

ステージ3では, 前線帯の位置はステージ2とあまり変わらないが, 前線はあまり停滞しない。ユーラシア大陸上の偏西風の流れのパターンは, ステージ3の開始とともに急にゾーナルパターンに変わり, 東経100度から150度付近に準定常的なトラフが形成される。また中国大陆上の前線帯では, 気温傾度が大きくなる。このステージは, 5年間の平均で9月27日から10月21日ごろにあたり, 秋季の前期とみなした。

ステージ4になると, 前線帯は中国大陆以南に南下し, 日本列島からも遠ざかる。同時にチベット高原東部の亜熱帯ジェット気流は, チベット高原の南縁に南下し, 南インドでは北東モンスーン季にはいる。ユーラシア大陸上の偏西風の状態は, ステージ3と比較的類似しており, 秋季の後期とみなした。