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Seasonal Transition in the 850 mb Height Field and Moisture Distribution over East Asia during the *Bai-u* Season

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1 Introduction

The *bai-u* in the East Asia is a rainy season between early and mid summer. During the *Bai-u*, some temporal changes in synoptic conditions are experienced.

Yoshino (1965) recognized four stages of the *Bai-u* season by means of locating the frontal zone at sea level and the axis of the jet stream at the 500 mb level. Regarding water vapor transfer in the lower troposphere, Murakami (1959) described that the source of moisture flow in the early stage of the *Bai-u* season differs from that of the last stage. Concerning moisture distribution, temporal northward displacement of the humid area is known (Akashi and Shitara 1964) and is divided into stages showing steep movement or stagnancy (Asakura *et al.* 1973). Matsumoto (1984) recognized three types of 850 mb level circulation patterns and their periods of favorable appearance. From these facts, it is noted that the *Bai-u* season proceeds by steps. Nevertheless, the relationships among these seasonal changes were not clarified.

Saito (1966) mentioned that the area of high equivalent potential temperature regarded as a highly humid area is around the northern boundary of a southwesterly wind in the southern part of China, and that it shifts northward in accordance with the intensification of a southerly wind from the South China Sea. However, the relationships among the seasonal changes in moisture distribution including the steep movenent or stagnancy of the humid area, the variation of the water vapor transfer field (or wind system), and synoptic condition were not clarified.

Takahashi (1987) classified the daily water vapor transfer fields at the 850 mb level based on the location of the main axis of water vapor transfer and recognized the seasonal migration of the water vapor transfer axis. That is, the favorable locations of the northward transfer axis in the beginning, in the first half and in the latter half of the *Bai-u* season are to the south of Japan, in the vicinity of the Ryukyu Islands and the western part of the South China or Yangtze Plain, respectively. Consequently, the eastward axis which is the prolongation of the northward axis emerges farther west in the latter half of the *Bai-u* season compared with the beginning or first half of the

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Bai-u season.

Based on the aforementioned results (Takahashi 1987) the following two problems will be dealt with in this paper: (1) Relationships between the seasonal migration of water vapor transfer axis and the seasonal changes of the pressure system. (2) How the seasonal changes of water vapor transfer field contribute to the transition of moisture distribution at the 850 mb level.

Data set used in this study is the same 3°×3° mesh point data as used in the former

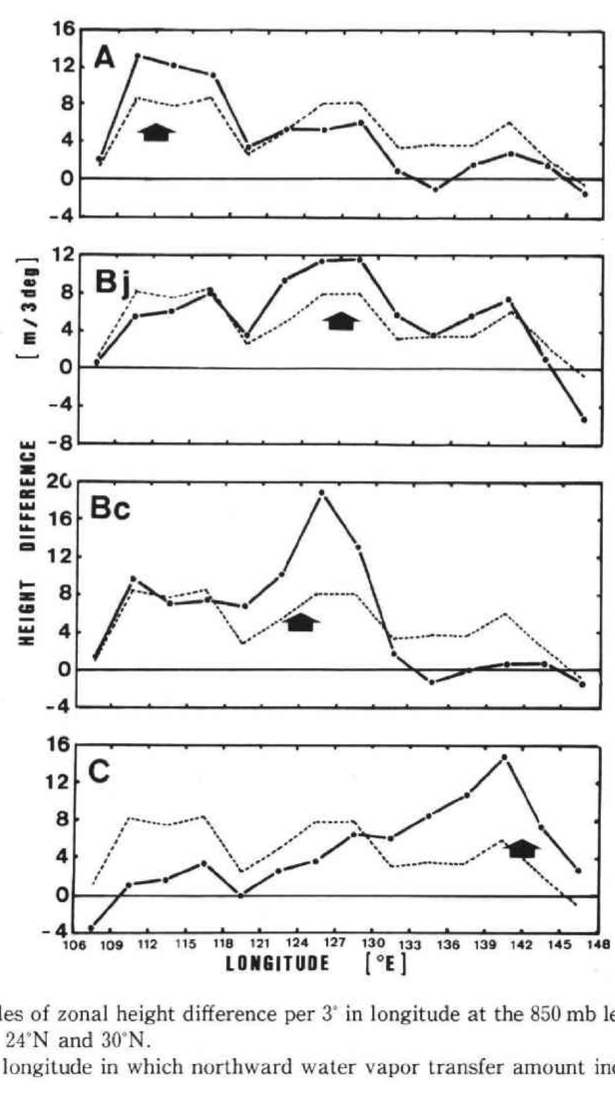

Fig. 1 Profiles of zonal height difference per 3° in longitude at the 850 mb level averaged between 24°N and 30°N.
Arrow: longitude in which northward water vapor transfer amount indicates maximum.
Broken line: mean profile of zonal height difference for June and July (1977-1981).

report by Takahashi (1987).

2 Water vapor transfer field and synoptic condition

Water vapor transfer, which has been obtained basically as a product of water vapor amount and wind vector should be controlled macroscopically by the prevailing wind according to the gradient of the height field. Fig. 1 shows the mean zonal height difference per 3° in longitude at the 850 mb level for each type averaged between 24°N and 30°N where the northward portion of the water vapor transfer axes are found. Positive value in the Y-axis of each panel is proportional to the southerly wind component of the geostrophic wind. The peak of the height difference in each profile (type-A ~ C) corresponds to the location of the maximum northward water vapor transfer amount indicated by arrows. Therefore, the location of the main axis of

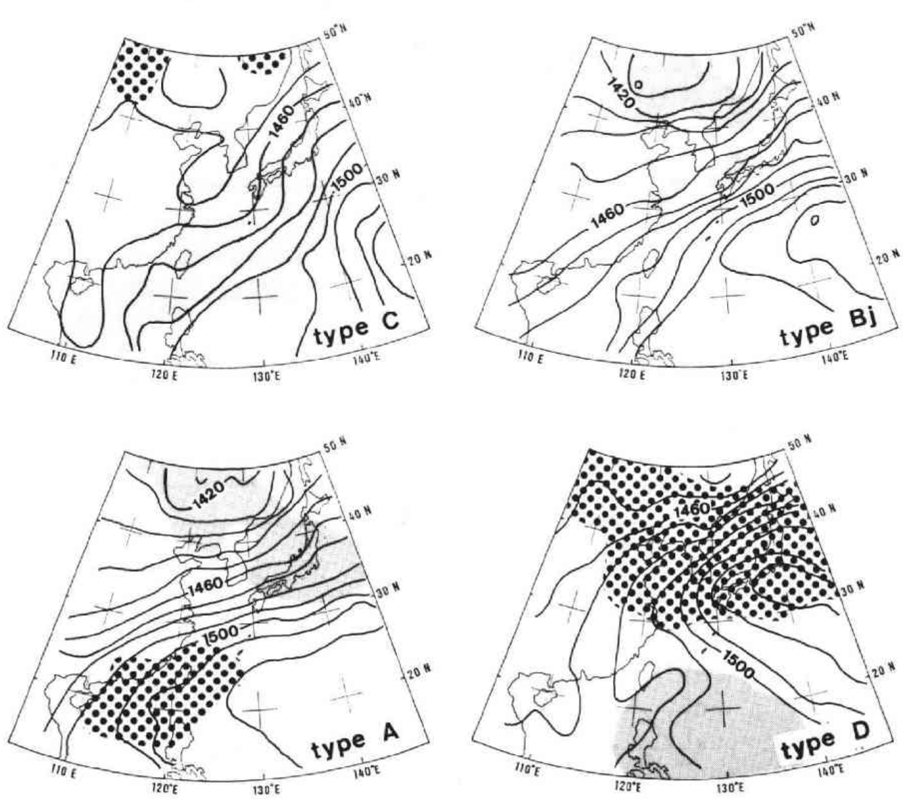

Fig. 2 Composite maps of the 850 mb height level and anomaly from the mean 850 mb height level (1977–1981 : June and July) corresponding to water vapor transfer patterns.
Dotted and shaded areas indicate marked positive and negative anomalies (≧15 m) respectively.

water vapor transfer is governed by the maximum height gradient zone.

Fig. 2 represents composite maps for the four types (type-C, Bj, A, D) of the 850 mb height level and anomaly from the average 850 mb height level for the entire target period. According to the seasonal migration of the main axis of water vapor transfer (type-C→type-Bj→type-A), a negative anomaly area around the Ryukyu Islands disappears and a positive anomaly area emerges around the South China Sea. Namely the Subtropical High expands westward around 20°N-25°N latitude. Owing to this, the maximum height gradient zone in the western periphery of the Subtropical High migrates westward and the water vapor transfer axis emerges farther west. Moreover, transition from type-A to type-D is due to the northward displacement of the positive anomaly area.

Saito (1966) and Matsumoto (1984) pointed out that the location of the South China High seen above the 500 mb level is related to seasonal changes in the wind field in East Asia. This high pressure cell can be seen most distinctively at the 300 mb level (Nemoto and Kuboki 1968), but it seldom appears around the South China Plain in the 850 mb level synoptic charts. To clarify the relationship between the location of the South China High and the distribution of the 850 mb level height, location of the anticyclone center at the 500 mb level for each type are shown in Fig. 3. In the case

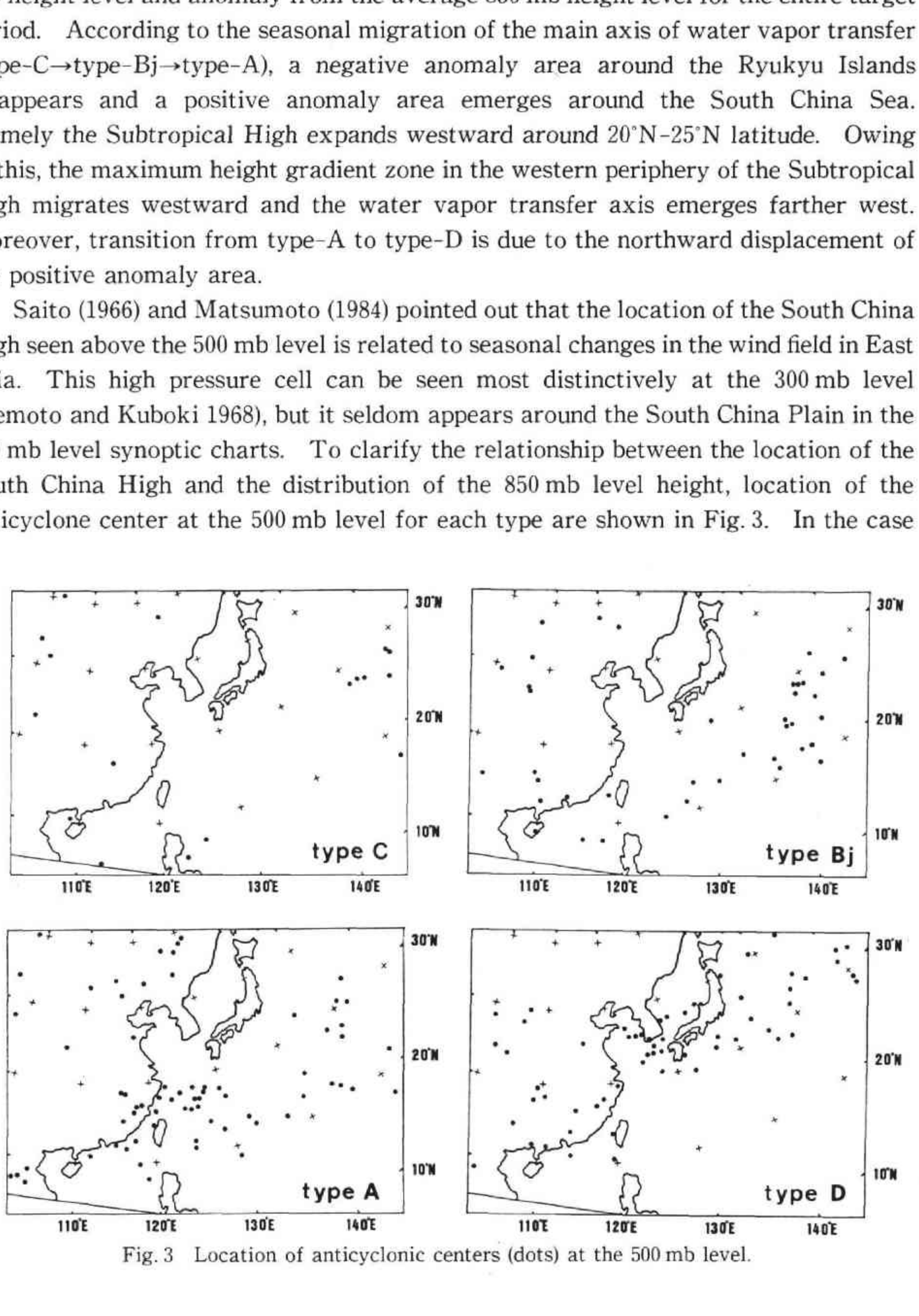

Fig. 3 Location of anticyclonic centers (dots) at the 500 mb level.

of type-A, anticyclones which are regarded to be the South China High appear in the southeastern part of China and the East China Sea more frequently than in the case of types-C or Bj. In type-D, anticyclones frequently appear north of 30°N.

In comparing Figs. 2 and 3, the positive height anomaly areas in type-A and type-D are considered to be corresponding to the appearance and northward displacement of the South China High.

Considering the facts above, it is concluded that the seasonal migration of water vapor transfer axis in the lower troposphere is related to the appearance and northward shift of the South China High in the middle or upper troposphere which causes seasonal changes of the 850 mb height field.

3 Seasonal changes in water vapor distribution

In this chapter, relationships between the seasonal migration of water vapor

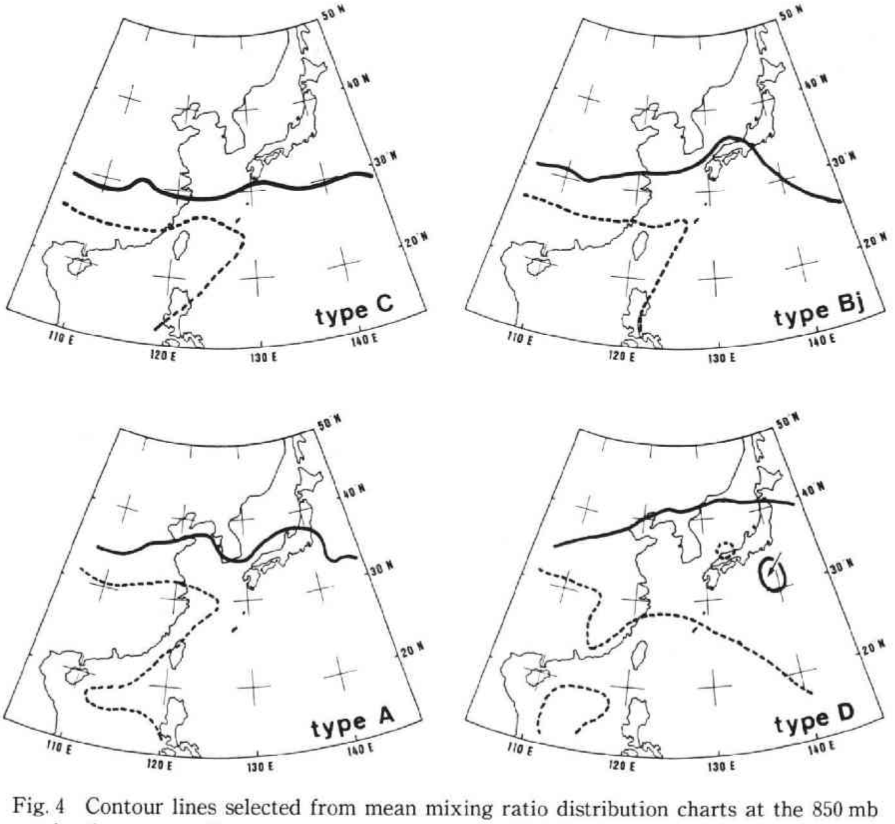

Fig. 4 Contour lines selected from mean mixing ratio distribution charts at the 850 mb level corresponding to water vapor transfer patterns.
Solid line: 11 [$g \cdot kg^{-1}$]. Broken line: 13 [$g \cdot kg^{-1}$].

transfer axis and the seasonal changes in water vapor distribution were examined.

Fig. 4 indicates the location of contour lines of the mixing ratio which are selected from composite maps of mixing ratio for four water vapor transfer types. Northward shift of the contour lines takes place in the vicinity of Japan accompanied by type-Bj which is frequently observed in the first half of the *Bai-u* season. In China however, contour lines remain around 30°N (11 [g • kg^{-1}]) and 25°N (13 [g • kg^{-1}]). In the presence of type-A which occurs very often in the latter half of the *Bai-u* season, contour lines in continental China migrate largely northward. In the South China Plain, the contour line identified as 13 [g • kg^{-1}] moves westward and a tongue-shaped humid area is formed. On the other hand, a northward shift of the contour line is not obvious in the vicinity of Japan. As for type-D, which is the post *Bai-u* pattern, the 13 [g • kg^{-1}] contour line retreats southwestward in the eastern part of China. Moreover, a relative low mixing ratio area appears to the south of Japan.

The transition of water vapor distribution in the appearance order of water vapor

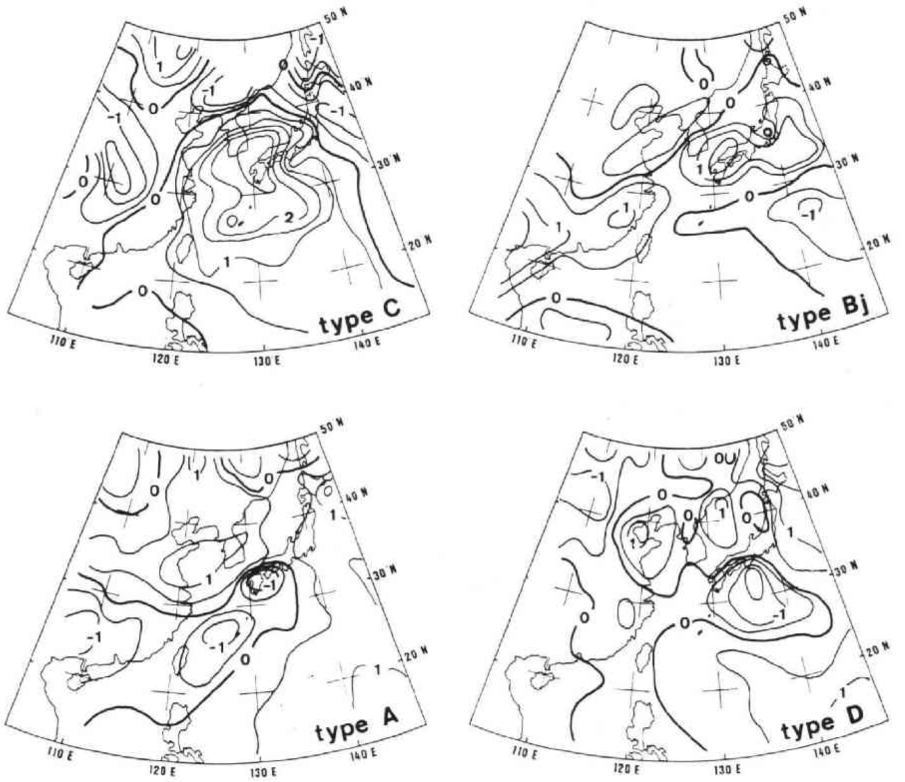

Fig. 5 Spatial variation of mixing ratio at the 850 mb level attended by appearance of water vapor transfer patterns [g • kg^{-1} • (2 days)$^{-1}$]

transfer types is consistent with previous studies on seasonal changes (for example, Asakura *et al.* 1973) in following points:

(1) Northward shift of iso-mixing ratio line takes place first in the vicinity of Japan. (2) Next, a steep northward displacement of the humid area occurs over continental China. (3) Relative dry area appears to the south of Japan.

Thus, it is said that seasonal changes of water vapor distribution are closely related to seasonal changes of water vapor transfer field.

Provided that changes of water vapor distribution are caused by seasonal changes of water vapor transfer field, variations of water vapor amount which contribute to the changes of water vapor distribution should be observed before and after the appearance of water vapor transfer patterns. Fig. 5 represents composite maps of the mixing ratio difference between one day before and one day after the appearance of the four water vapor transfer patterns. Only cases when any pattern including type-Bc has not occurred in the one day before were adopted.

In the presence of type-C, water vapor amount increases in the vicinity of Japan and decreases on the Chinese continent. According to Asakura *et al.* (1973), before the onset of the *Bai-u* in Japan, it becomes wet on the Chinese continent. With the onset of *Bai-u*, the humid area retreats southward on the continent and the vicinity of Japan becomes wet. Therefore, the onset of the *Bai-u* is closely related to the appearance of the type-C water vapor transfer pattern. Regarding type-Bj, water vapor amount increases in the vicinity of Japan to 45°N and in the South China Plain. The North China Plain, on the other hand, is an area of decreasing water vapor. Under these conditions, the northward shift of the humid area should appear not on the Chinese continent but in the vicinity of Japan. It is similar to the change of water vapor distribution from type-C to type-Bj. In this case, the meridional gradient of water vapor amount increases in the Yangtze Plain. Namely, a feature of the *Bai-u* front as a Subtropical front (Ninomiya 1984) is intensified on the Chinese continent. Opposite to type-Bj, type-A water vapor transfer pattern brings about increases in water vapor amount in the North China Plain and dereases both in the South China Plain and the South China Sea. This means the northward propagation of the humid area in the North China Plain and the westward retreat in the South China Sea. It also corresponds to the change of water vapor distribution from type-Bj to type-A. In the western part of Japan, though the 11 $[g \cdot kg^{-1}]$ contour line stays or shifts slightly northward, water vapor amount decreases. This may be due to the condensation of water vapor caused by heavy precipitation. Concerning type-D, water vapor amount decreases in the eastern part of the Chinese continent and south of Japan. This decrease in water vapor amount corresponds to the retreat of the 13 $[g \cdot kg^{-1}]$ contour line on the Chinese continent and the appearance of a comparatively dry area in south of Japan.

As mentioned above, with the appearance of water vapor transfer patterns, regional increases and decreases in water vapor amount which are considered to contribute to the seasonal transition in water vapor distribution are initiated.

4 Conclusion

In this paper, relationships between water vapor transfer pattern stated by Takahashi (1987), and water vapor distribution and synoptic condition during the *Bai-u* season (June and July) in East Asia have been investigated from the viewpoint of seasonal changes.

The main axis of water vapor transfer at the 850 mb level corresponds to the location of the maximum height gradient in the western periphery of the Subtropical High. Seasonal westward migration of the main axis (type-C, Bj, A) is due to the westward displacement of the maximum height gradient zone at the 850 mb level. This phenomenon is accompanied by the rise in the 850 mb height level around the Ryukyu Islands or the South China Sea. Appearance of type-D corresponds to the rise in the 850 mb height level around Japan.

These changes are related to the appearance and northward displacement of the South China High seen in the middle or upper troposphere.

The transition of water vapor distribution in the appearance order of water transfer patterns is as follows:

Northward propagation of the humid area takes place in the vicinity of Japan first (Type-C→type-Bj; from beginning to first half of the *Bai-u*), then in the Chinese continent (type-Bj→type-A; from first half to latter half of the *Bai-u*). With the ending of the *Bai-u*, a relatively dry area appears to the south of Japan (type-A → type-D). These changes are consistent with previous studies regarding seasonal changes.

Distribution of water vapor amount varies before and after the appearance of each water vapor transfer pattern. Variation of water vapor amount for each type contributes to the seasonal change of water vapor distribution. It is concluded that seasonal changes in water vapor distribution during the *Bai-u* season in East Asia are brought by the appearance of different patterns of water vapor transfer whose changes are attributed to seasonal changes of the pressure system.

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