Associations with the Interannual Variations of Onset and Withdrawal of the Changma①

Lu Riyu (陆日宇)[1], Jai–Ho Oh[2], Baek–Jo Kim[2], Hee–Jeong Baek[2] and Huang Ronghui (黄荣辉)[1]

[1] *Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing* 100029

[2] *Meteorological Research Institute, Korea Meteorological Administration, Seoul* 156–720, *South Korea*

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ABSTRACT

The associations of onset and withdrawal of the rainy season in South Korea (called Changma) have been examined. Composite studies showed that there are significant differences in circulations between extremely early and late onset (or withdrawals) not only over East Asia, but also over remote areas. The *in situ* significant differences include the upper–level jet over East Asia and the subtropical anticyclone over the western North Pacific at lower levels. The significant remote associations include the Indian monsoon and ENSO. The Indian summer monsoon is related to both onset and withdrawal of the Changma, while ENSO has a significant relation only to onset, but not to withdrawal.

Key words: Changma, Onset, Withdrawal, Interannual variation, Association

1. Introduction

Korea, East China and Japan are located in the East Asian monsoon region, characterized with rainy seasons in summer. Because of the significant interannual variability of the East Asian summer monsoon (hereafter signified as EASM) and the close relationship between the intensity of summer monsoon and rainfall amount during rainy season, droughts and floods often occur and may cause tremendous damages in this region.

The EASM system is characterized by the monsoon trough over the South China Sea and the western Pacific, the subtropical high over the western Pacific, the upper–level northeasterly return flow, the quasi–stationary frontal zones, and the disturbances at middle latitudes (Tao and Chen, 1987). It is one of the major components of the global general circulation. Its development, maintenance and decay should be viewed as a large–scale phenomenon having thermal and dynamic causes (Ding, 1994). The study of the EASM, therefore, should be based on the background of atmospheric general circulation and global climate.

The EASM is differently called Meiyu in China, Baiu in Japan and Changma in Korea. It has been shown that Meiyu is not only a local phenomenon, but also the results of seasonal adjustment of the atmospheric circulation over the Eurasian continent and the whole

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Northern Hemisphere (Tao and Chen, 1957; Tao and Chen, 1987; Chen, 1994; Yeh, 1958). Tao and Chen (1957) and Yeh (1958) studied the evolution of atmospheric circulation in Asia, and showed the abrupt changes of atmospheric circulation from winter to summer and from summer to winter. Correspondence to the onset of summer circulation pattern is the outburst of SW monsoon in India, the onset of Meiyu in China and a rapid northward shift of ITCZ.

Some studies on Baiu also have shown that Baiu is also associated with large-scale circulations (Ninomiya and Mizuno, 1987; Ninomiya and Murakami, 1987; Misumi, 1994). Ninomiya and Mizuno (1987) analyzed the variations in the Baiu precipitation amount from 1951 to 1980, paying special attention to the occurrence of dry-Baiu and wet-Baiu. They pointed out that the circulations in the middle latitudes and the subtropics independently contribute to the interannual variations of Baiu precipitation. In addition, Misumi (1994) found that there are variations of large-scale characteristics associated with the increase of Baiu precipitation amount around 1950.

In South Korea, generally, more than half of the annual precipitation occurs during summer, and more than 40% of the summer precipitation occurs during the Changma season, which generally lasts for one month from late June to late July. There have been numerous studies on the Changma (Oh et al., 1997). However, it is difficult to make short-term climate forecasts on the onset and withdrawal of Changma, because of large interannual variability of the Changma and lack of knowledge on the large-scale characteristics connected with the Changma.

To make reliable short-term climate forecast on the Changma seasons and rainfall, it is necessary to understand the large-scale circulation characteristics, since the short-term climate anomaly is connected with the large-scale atmospheric circulation anomaly. Some studies showed that before the Changma season, a high pressure appears around Korea (Moon, 1981; Luo and Yanai, 1983; Park et al., 1986). Lee (1989) and Lee and Kim (1992) investigated the interannual variability of the East Asian monsoon circulations in conjunction with the Changma precipitation in Korea. They showed that the Changma seasons depend strongly upon the zonal and the Hadley circulation driven by the velocity potentials in the Indian Ocean and the western Pacific of the equatorial belt.

However, the above-mentioned studies focus on the EASM rainfall and its associated atmospheric circulations. Compared with the precipitations, the onset and withdrawal of EASM may have a closer relationship with the atmospheric circulations. On the other hand, the onset and withdrawal of EASM influence greatly the temporal distribution of rainfall and total summer precipitation. The accurate forecast on the onset and withdrawal of EASM, as well as on precipitations, is very helpful in policy making.

Since Changma is a component of the EASM, its onset and withdrawal do not merely represent the rainy seasons in South Korea, and can also describe the evolution of the whole EASM to a large extent. Actually, there is a close relationship among the Meiyu, Baiu and Changma (Huang, 1999). The study on Changma will be helpful for better understanding EASM. In this paper, therefore, the atmospheric circulations related to the onset and withdrawal of Changma will be considered cautiously as the associations with the EASM.

The rainy season has been traditionally defined according to rainfall in the countries in East Asia. Recently, there were attempts to define the onset and withdrawal of EASM as an integrated system, emphasizing its common features. The OLR and TBB data were widely used for this purpose (Tanaka, 1992; Murakami and Matsumoto, 1994; Wang and Xu, 1997). Most recently, 850 hPa relative vorticity was also used (Kawamura and Murakami, 1998). Kang et al. (1999) identified the principal modes of climatological variation of high clouds over the entire Asian monsoon region during summer and associated circulation changes. They showed that the seasonal evolution of the Asian summer monsoon is adequately described by a few leading EOFs, and suggested that the Changma cloud band is associated with the northward propagating climatological intraseasonal oscillation. However, these approaches are applied only in a climatological sense, because of the great variability on the intraseasonal and interannual scales. Therefore, the dates of Changma onset and withdrawal announced by the Korea Meteorological Administration (KMA) were used in this study to select the cases of extremely early or late onset and withdrawal.

2. Data

In this study, we examined the associations of the Changma onset and withdrawal, by using the National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP / NCAR) reanalysis data and the dates of Changma onset and withdrawal announced officially by the KMA. Composite studies were performed for cases of extremely early or late onset and withdrawal. The data for geopotential heights and winds are monthly average of analyses and the data for surface temperature are monthly average of the first guess. The data for heat flux, such as latent heat flux, net solar radiation at surface and top, are monthly average of accumulations. All data are on a 2.5° longitude $\times$ 2.5° latitude grid.

The determination of dates of the Changma onset and withdrawal is difficult and not unique. In general, the dates are determined on the base of daily variation of rain and cloudiness, and large–scale movement of quasi–stationary front and associated large–scale circulation pattern. We used the dates of Changma onset and withdrawal in the southern part of South Korea (Tae–gu) announced officially by the KMA. The criteria of the onset of Changma by KMA are as follows: at a specified region, (a) the duration of rainfall is more than 3 days, and (b) the quasi–stationary front is located over. The withdrawal is defined by that the duration of non–precipitation exceeds 3 days and the quasi–stationary fronts leave northward.

Both datasets are for 38 years from 1961 to 1998.

3. Comparison between the late and early onset of Changma

Figure 1 shows the dates of Changma onset and withdrawal from 1961 to 1998. The Changma onset shows a tendency of interdecadal variability, with many years of early onset in the 1970's. The Changma seasons usually start in late June and end in late July. The onset and withdrawal of Changma, however, have a significant variability from year to year (see Table 1). The standard deviation of the Changma withdrawal dates is somewhat greater than that of the onset dates. In addition, the contribution of the Changma withdrawal to the Changma periods is also somewhat more than that of the Changma onset (see the correlation coefficients shown in Table 1). The Changma periods appear to depend more on the withdrawal dates than the onset dates.

In the following, composite studies are performed for cases of extremely early and late onset or withdrawal. Among the 38 years from 1961 to 1998, the years when the Changma onset occurs one deviation (6.15 days) earlier than normal are 1970, 1974, 1975, 1978, 1980 and 1984, and the years when the withdrawal occurs one deviation later are 1962, 1965, 1968, 1982, 1987, 1992 and 1995. The years when the Changma withdrawal occurs one deviation (8.14 days) earlier than normal are 1961, 1972, 1973, 1981, 1984 and 1994, and the years when

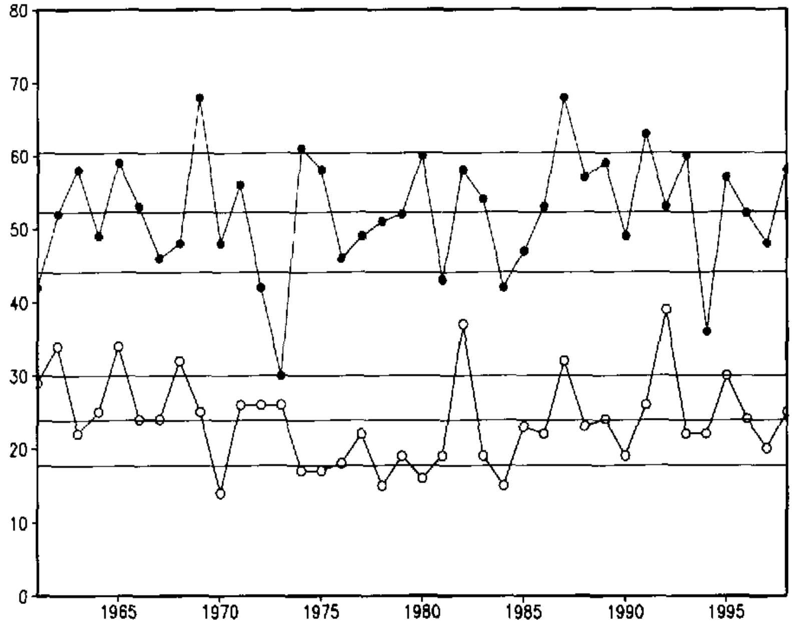

Fig. 1. The dates of Changma onset and withdrawal in the years of 1961–1998. The curve with blanket points is for onset, and curve with black points is for withdrawal. The middle one of the three lines going through each curve indicates the average, and the other two lines indicate one standard deviation less and more than the average, respectively. The numbers labelled on the ordinate indicate the dates numbered from June 1.

Table 1. Some statistical values on the Changma onset and withdrawal dates during the 38 years from 1961 to 1998. The values shown in parentheses are degrees of confidence

Standard deviation of the Changma onset dates	6.15 days
Standard deviation of the Changma withdrawal dates	8.14 days
Correlation coefficient between the Changma onset and withdrawal dates	0.16
Correlation coefficient between the Changma lengths and the onset dates	−0.51(99.9%)
Correlation coefficient between the Changma lengths and the withdrawal dates	0.76(99.9%)

the withdrawal occurs one deviation later are 1969, 1974, 1987 and 1991. These years were chosen as the extreme cases and used for the composite study. The Student's t–test was used to access the statistical significance of the results.

Since the Changma onset occurs generally in June, the major differences between the early and late onset should appear in June. For the same reason, the major differences between the early and late withdrawal should appear in July. Thus, in the following, the monthly averages in June are used to investigate the differences between the early and late onset, and July to the withdrawal.

Figure 2 shows the composite differences in zonal winds at 200 hPa and 850 hPa levels between the late and early onset. Figure 2a shows that west of the Tibetan Plateau and over East Asia, there are significant differences in zonal winds. These significant differences in zonal winds are associated with two cyclonic differences, which are clearer in the differences of the horizontal winds (not shown). Since these two cyclonic differences are located respectively to the west and the east of the Tibetan Plateau high, they may be related to the weakness and shrinking of the Tibetan Plateau high. Over East Asia, the upper–level jet is slightly weakened and moves poleward for the early onset (Fig. 2b).

The Changma onset is associated with changes in circulation at both upper and lower levels. The circulation changes are mainly associated with the upper–level jet at upper levels, and with the North Pacific subtropical anticyclone at lower levels. Figure 2c shows that there is a cyclonic difference over the subtropical western North Pacific. It indicates that the North Pacific subtropical anticyclone is weaker for the late Changma onset. Over the equatorial middle and eastern Pacific, there is a significant westerly difference at 850 hPa, corresponding to the easterly difference at 200 hPa (Fig. 2a). A significant difference in 850 hPa horizontal winds appears also over the Indian and Arabian Sea.

The significantly weakened westerlies for the late Changma onset decrease the Indian summer monsoon rainfall and suppress the atmospheric convection significantly (Fig. 3). The atmospheric convection is also suppressed significantly over the tropical western Pacific and enhanced significantly over the equatorial eastern Pacific. There is a slight difference in convection over South Korea and southern Japan.

Associated with the suppressed convection, the surface temperature is significantly higher in India for the late Changma onset (Fig. 4). There is a positive difference in the equatorial Pacific, which suggests that the El Nino events may be favorable for the late Changma onset.

The above–mentioned differences associated with the extreme Changma onset can be summarized and discussed as follows. The warmer SSTs over the equatorial eastern Pacific are favorable for ascent flows and enhanced convection, and thus influence the Walker circulation and suppress the convection over the tropical western Pacific. However, the suppressed convection over the tropical western Pacific does not correspond to the enhanced convection over East Asia, which is not in agreement with the results of Huang and Li (1987), Huang and Sun (1992) and Nitta (1987). Actually, Kurihara and Tsuyuki (1989) studied the relation between the tropical convection activity and the Northern Hemispheric circulation during summer on intraseasonal scales, and found that the tropical convection is not strongly related to the mid–latitude flow over East Asia during the first part of summer (May 26–July 14).

Although the Changma onset is not strongly related to the convection in the tropical Pacific, it is significantly associated with the convection over the Indian monsoon region. The stronger Indian monsoons in June correspond to the earlier Changma onset. The convection difference over India and the SST difference in the equatorial eastern Pacific are in agreement with the previous studies. In general, drought years over India are associated with the warm phase of ENSO, and flood years with the cold phase.

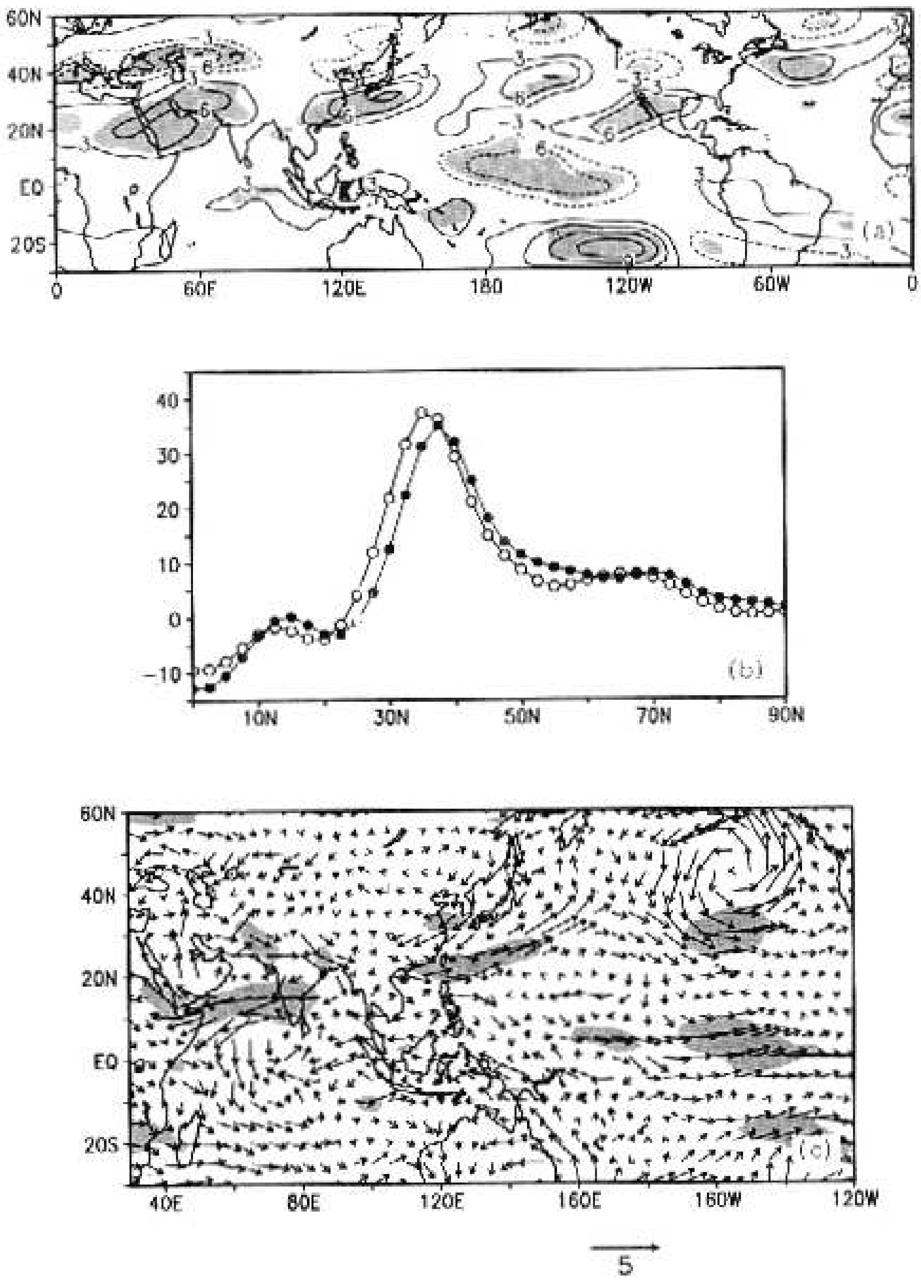

Fig. 2. (a) Composite difference in zonal winds at 200 hPa between late and early onset. Units: m / s. Contour interval is 3, and zero contour is not shown. (b) Composite zonal winds at 200 hPa along 140°E. Units: m / s. The curve with blanket points is for late onset and curve with black points is for early onset. (c) Composite difference in horizontal winds at 850 hPa between late and early onset. Units: m / s. Shaded areas in (a) and (c) illustrate the significance of the differences in zonal winds at 95% level determined from the Student's t-test. Note that the longitude scope in (c) is different from that in (a).

Usually, the higher surface temperatures in continents are favorable for a stronger summer monsoon, i.e., the surface boundary condition influences the intensity of monsoon. The

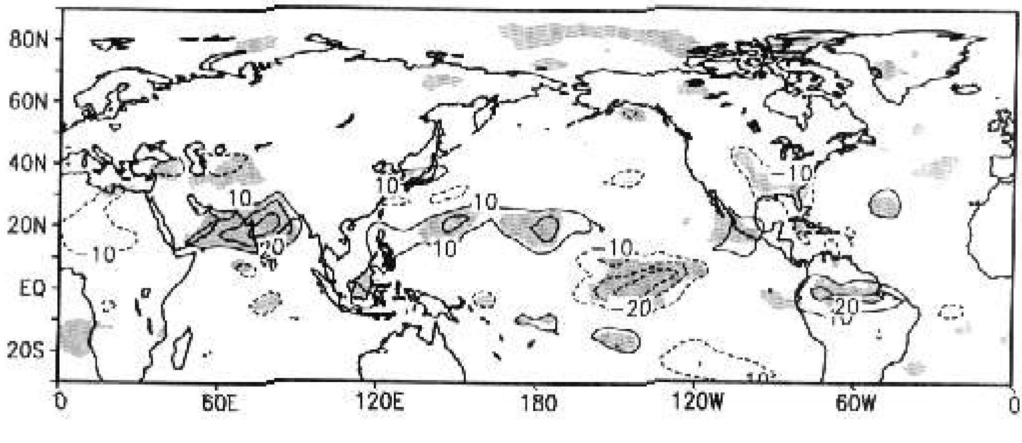

Fig. 3. Composite difference in OLR between late and early onset. Units: Wm^{-2}. Contour interval is 10, and zero contour is not shown. Shaded areas illustrate the significance of the differences at 95% level.

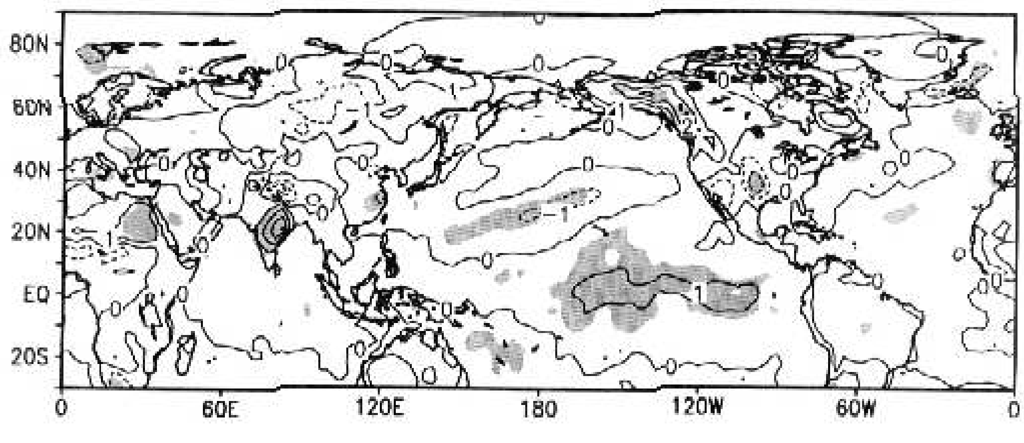

Fig. 4. Composite difference in surface temperature between late and early onset. Units: °C. Contour interval is 1 and negative contours are dashed. Shaded areas illustrate the significance of the differences at 95% level.

results in this study, however, showed that the higher surface temperatures in India correspond to weaker monsoon, i.e., weakened westerlies and suppressed convection. This fact suggests that the difference in convection is the cause, rather than the effect of the surface temperature difference in India. The suppressed convection over India allows more net solar radiation flux into the surface (Fig. 5a). In addition, weaker wind and fewer precipitation in conjunction with the suppressed convection lead to less latent heat flux at the surface (Fig. 5b). Hence, higher surface temperature appears in India as a result. In East Asia, the surface temperature does not show any significant difference (Fig. 4), since the more downward flux of net solar radiation is approximately balanced by the more latent heat flux at the surface.

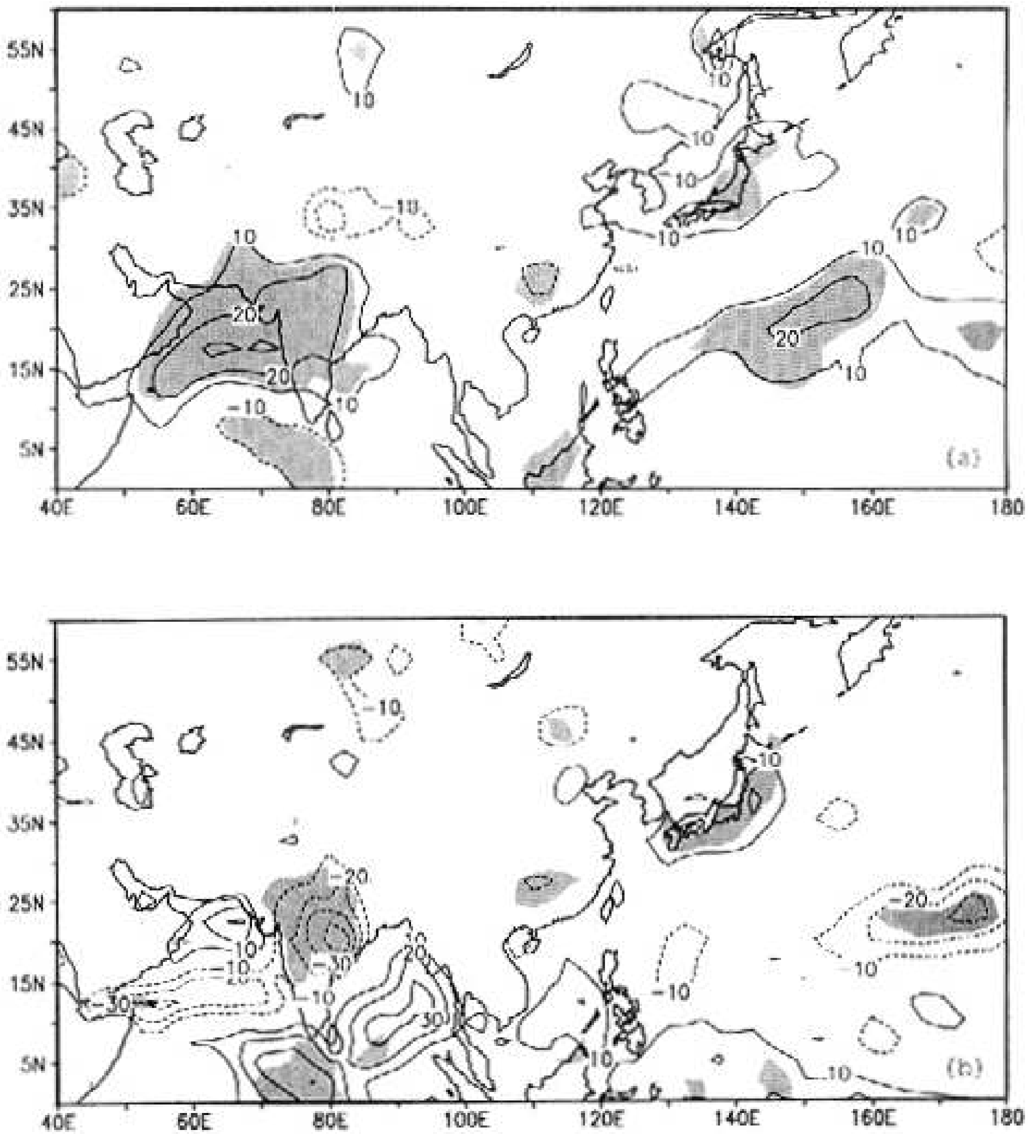

Fig. 5. Composite difference in net solar radiation flux (a) and latent heat flux (b) at the surface between late and early onset. Units: Wm^{-2}. Contour interval is 10, and zero contour is not shown. Shaded areas illustrate the significance of the differences at 95% level.

4. Comparison between late and early withdrawals of Changma

In the preceding, monthly mean data in June are used in the comparison between the early and late onset of Changma. In this section, monthly mean data in July are used. Figure 6 shows the differences in zonal winds at 200 hPa between the late and early withdrawals. Figure 6a shows a fairly good similarity to the differences between the late and early onset (Fig. 2a), with greater differences over East Asia and smaller differences in the tropics. The significant differences in zonal winds appear west of the Tibetan Plateau and over East Asia in a shape of zonal belt with a slight tilt. Over East Asia, the upper-level jet is strongly weakened and moves poleward for the early withdrawal (Fig. 6b). It has long been known that the poleward shifts of the upper–level jet are associated with the evolution of the EASM. Our results show that such an association exists also on the interannual scale. In addition, the present results show that the poleward shifts are in association with weakness of the jet, and that the change in circulation is much more significant for the withdrawal than for the onset over East Asia.

The circulations related to the Changma withdrawal can also be seen from the differences in geopotential heights at upper and lower levels (Fig. 7). Figure 7a shows that significant differences appear roughly along the jet north of the Tibetan high. The fact that positive differences appear at troughs and negative differences at ridges indicates that for the late withdrawal, the upper–level jet is not only stronger and located southward (Fig. 6), but also relatively in a zonal orientation. On the other hand, the positive and negative differences are located alternatively over the coastal areas of Europe, Russia, East Asia and the western North

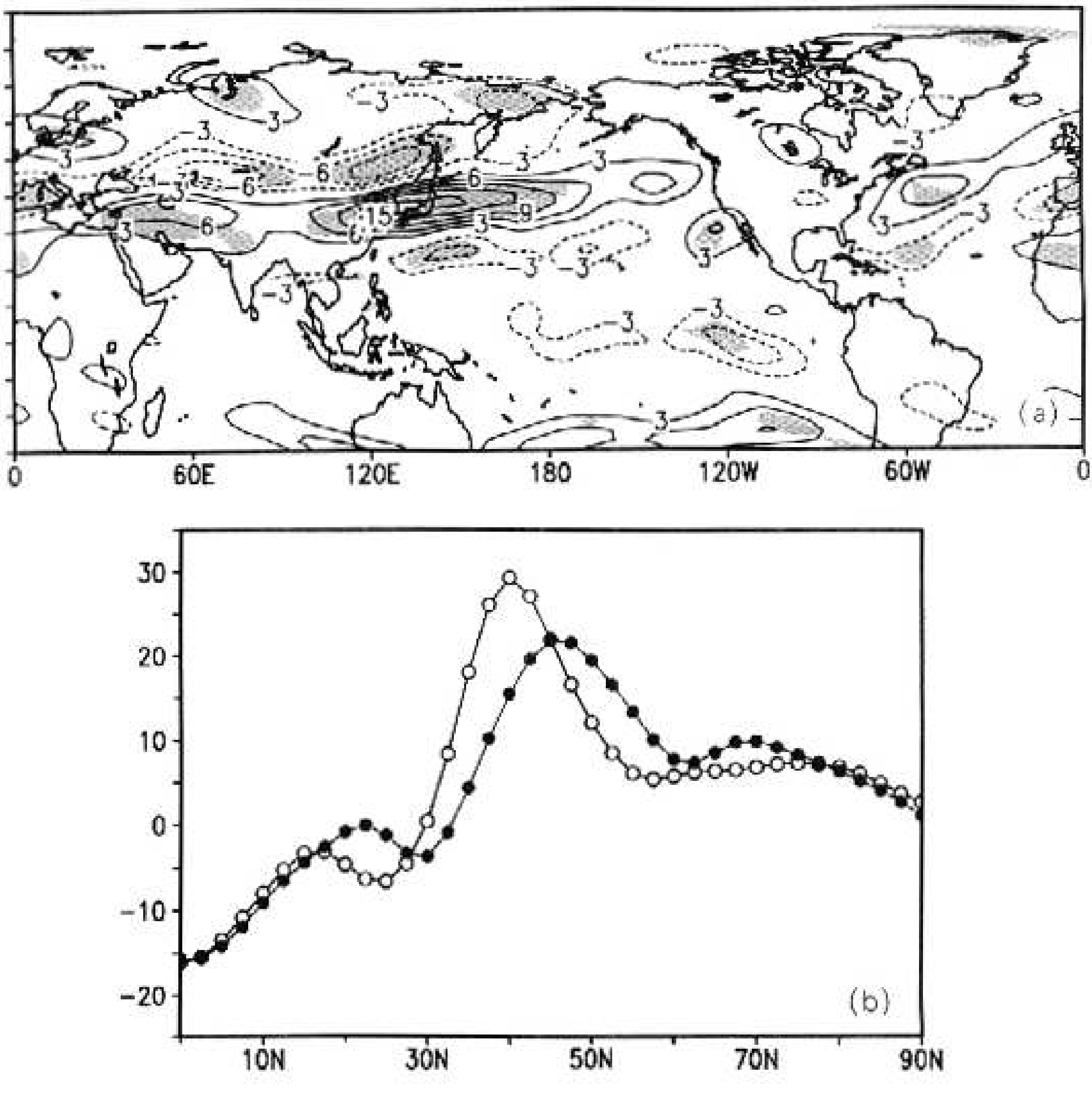

Fig. 6. Same as Fig. 2a and Fig. 2b, but for withdrawal and scope.

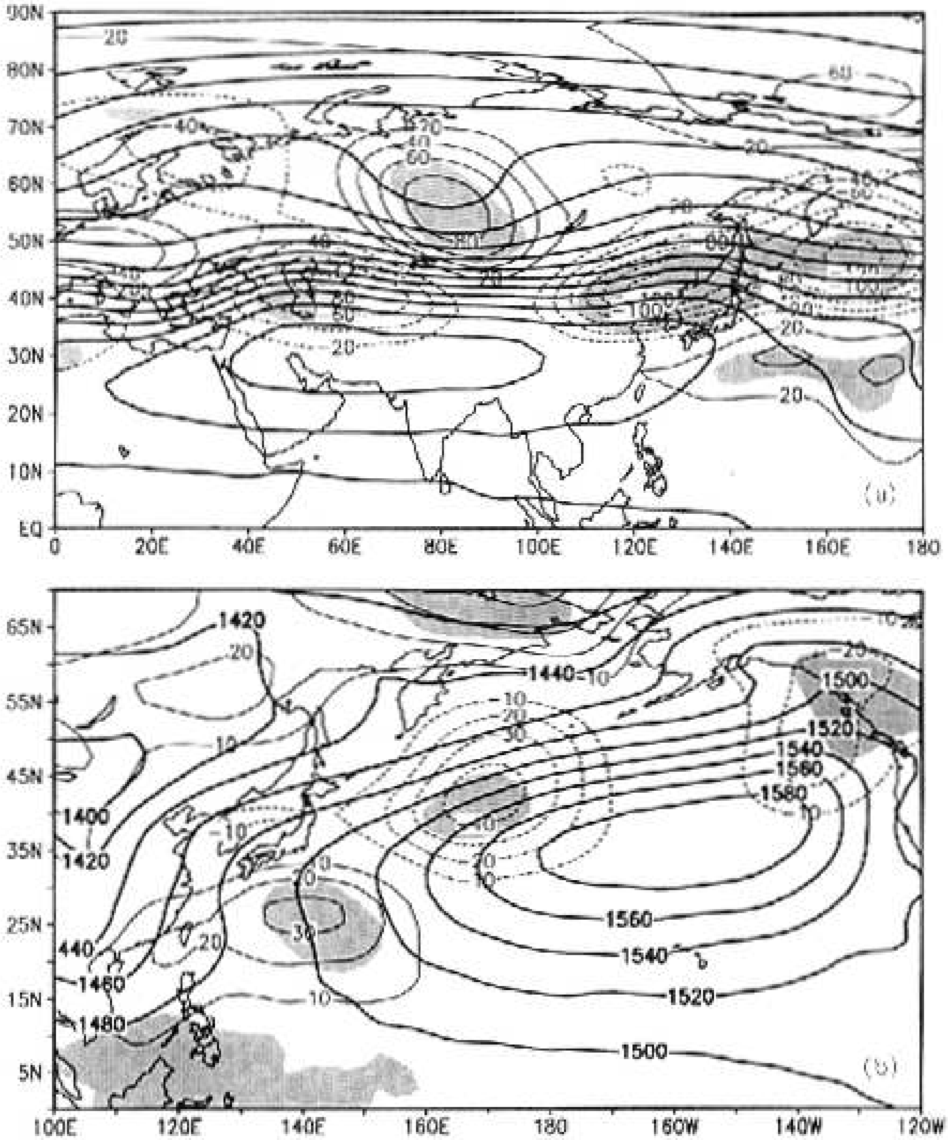

Fig. 7. Composite difference in geopotential heights between late and early withdrawal, as well as composite geopotential heights for early Changma withdrawal, at 200 hPa (a) and 850 hPa (b). Thin contours are for composite difference and thick for heights. The labels of thick contours are not shown in (a) for the sake of clarity. The greatest contour that indicates the center of the Tibetan high is 12540 m, and contour interval is 60 m. Thick contours are labelled in (b). Note that the scope in (b) is different from in (a), since the upper-level jet and subtropical high are focused in (a) and (b), respectively.

Pacific. This distribution is reminiscent of the Eurasian (EU) teleconnection pattern. It is believed that the EU pattern may influence the East Asian summer monsoon. However, the differences are not significant over the coastal areas of Europe.

At lower levels, the North Pacific subtropical high is located westward and southward for the late withdrawal (Fig. 7b). The southward shift, which is widely believed as a favorable condition for the late withdrawal, however, is not significant over East Asia.

In contrast to the difference related to the onset (Fig. 3), the difference in OLR between late and early withdrawals is significantly negative over East Asia, and shows a seesaw pattern between East Asia and the western North Pacific (Fig. 8). The seesaw pattern is consistent with the previous studies (Huang and Li, 1987; Huang and Sun, 1992; Nitta, 1987; Kurihara and Tsuyuki, 1989). There is no more significant difference over the equatorial Pacific, suggesting that the Changma withdrawal has no clear relation with ENSO. Consistent with difference related to the onset, there is also a positive difference over India, showing that suppressed convection over India is associated with the late Changma withdrawal. Surface temperature (Fig. 9) is significantly higher in India for late Changma withdrawals, and does not show any significant difference over the equatorial Pacific, suggesting again that the Changma withdrawal has no clear relation with ENSO.

For the late Changma withdrawal, over India the suppressed convection and fewer precipitations lead to more net solar radiation flux downward and less latent heat flux at the

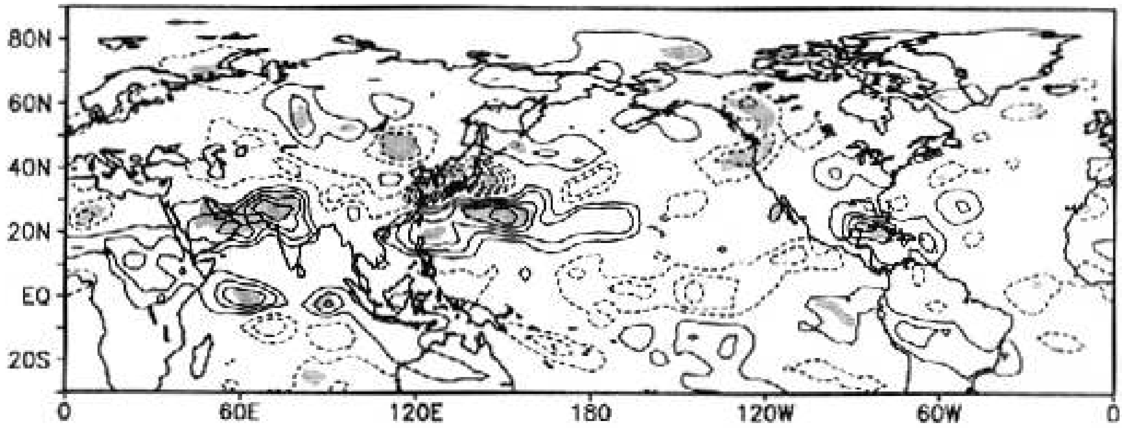

Fig. 8 Same as Fig. 3, but for withdrawal. Note that contour labels are not shown in this figure. Contour interval is 10, too.

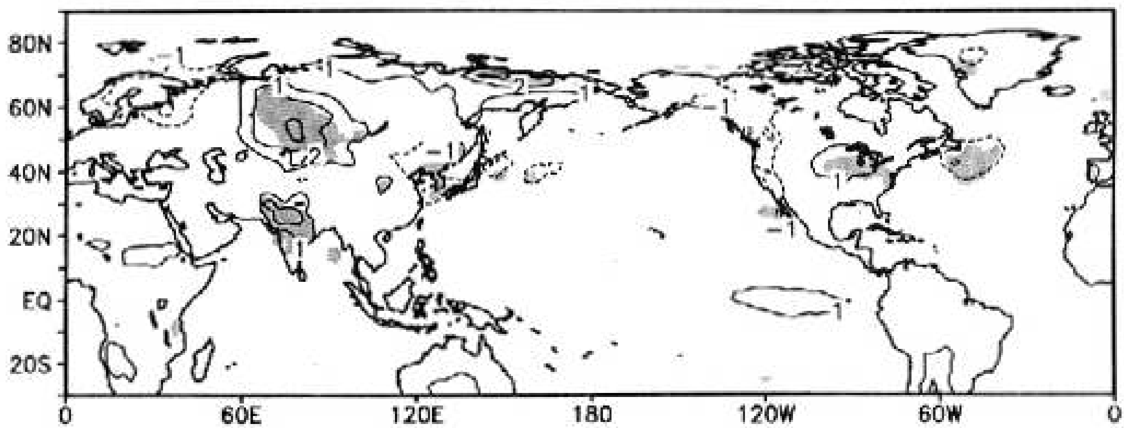

Fig. 9 Same as Fig. 4, but for withdrawal.

surface (Fig. 10). In East Asia, the clouds prevent significantly solar radiation flux into the surface, and thus the surface temperature is lower for the late Changma withdrawal.

5. Summary

In the present study, the NCEP / NCAR reanalysis data and the dates of the Changma onset and withdrawal announced officially by the KMA were used to examine the associations of Changma (rainy season in Korea). The onset and withdrawal of Changma have a significant variability from year to year with standard deviation of about one week.

The monthly mean data in June were used to analyze the differences between the early and late onset, and July averages to withdrawal, since the Changma onset and withdrawal usually occur in late June and late July, respectively. Composite analyses were performed and the statistical significance was determined from the Student's t–test. It was found that in association with the late Changma onset, the upper–level jet is stronger and located relatively

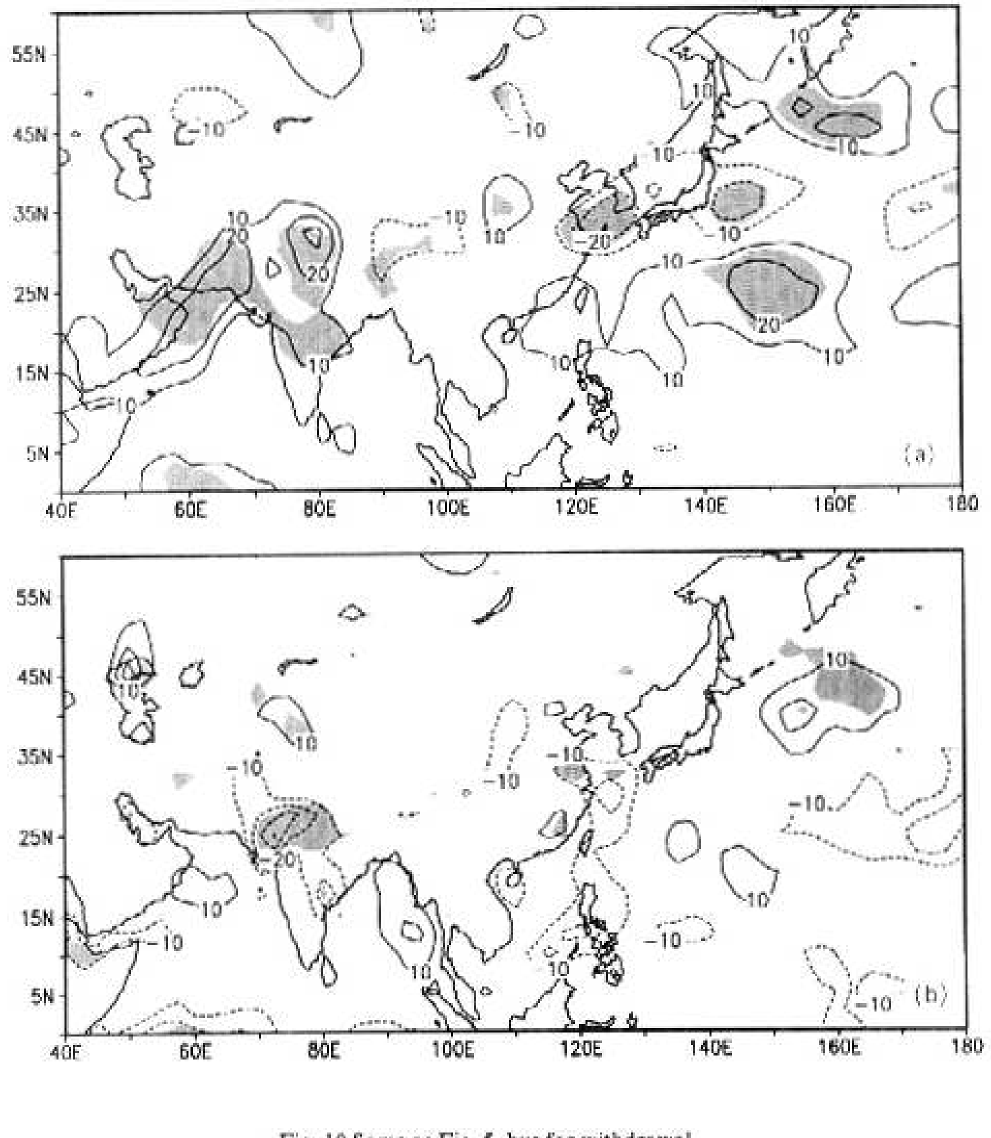

Fig. 10 Same as Fig. 5, but for withdrawal.

southward over East Asia, and the subtropical anticyclone is weaker over the western North Pacific at lower levels. Besides these *in situ* differences, significant differences also appear in remote places. Significant north–south displacement of zonal flows appears not only over East Asia, but also west of the Tibetan Plateau. Associated with the late Changma onset, the Indian monsoon is significantly weakened, i.e., the lower–level westerlies are weakened and the atmospheric convection is suppressed. Under the circumstances, the surface temperature is higher due to more net solar radiation flux and less latent heat flux at the surface. Relation between the Changma onset and ENSO is also significant — the late Changma onset is associated with the warm phase of ENSO—but is difficult to be explained by the previous results.

The differences between the late and early withdrawal are interestingly similar to the differences related to onset. For instance, associated with the late Changma withdrawal are also the southward located and stronger upper–level jet over East Asia, the suppressed convection over the western North Pacific and India, and higher surface temperature in India. This similarity implies that the evolution of the EASM is closely related to seasonal march. However, unlike the onset, the Changma withdrawal has not a significant relation to ENSO. In addition, the difference of the upper–level jet over East Asia is much more significant between the late and early withdrawal than that between the late and early onset, and the zonal shift of the North Pacific subtropical high is more important for the Changma withdrawal.

Being consistent with the results of the previous studies on the EASM, the Changma onset and withdrawal are significantly associated with south–north displacement of the upper– and lower–level jet streams over East Asia. This consistency is one more evidence for the close relation between Changma and the EASM.

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伴随韩国雨季开始和结束早晚的关联场分析

陆日宇 Jai-Ho Oh Baek-Jo Kim
Hee-Jeong Baek 黄荣辉

摘 要

分析了与韩国雨季开始和结束的年际变化相关联的一些要素场发生的变化。分别对雨季开始和结束早晚的个例进行了合成分析。6月月平均资料用来分析与雨季开始早晚相关联的要素场变化，而在分析与雨季结束早晚相关联的要素场变化时则利用7月月平均资料。结果表明，对应雨季开始(或结束)早晚、大气环流和表面温度等要素不仅在东亚地区、而且在远离东亚的地方具有显著的差异。在东亚地区的显著差异主要是高空急流和西太平洋副热带高压。远离东亚的显著差异主要是印度季风和ENSO现象。印度季风与韩国雨季开始和结束均有关联，但ENSO现象只与雨季开始显著相关、而与结束并没有显著的关联。

关键词: 韩国雨季, 雨季开始, 雨季结束, 年际变化, 关联场