Predictability of Baiu Precipitation in the Western North Pacific

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Abstract

The baiu is specified by a rainy transition period between northern spring and summer in East Asia. The interannual variability of the baiu progress is examined using the extended empirical orthogonal function (EEOF) analysis and the regression or correlation techniques based on the score. Data used are the globally gridded GPCP precipitation and the atmospheric parameters estimated in the NCEP-DOE AMIP-II reanalysis for the period of 1979-2003.

The interannual variability of the baiu progress is represented by the following three types. Type A indicates the reversal of precipitation anomalies from May to June and the persistence of anomalies during June and July. The large amplitudes appear after 1989. Type B identifies the specific precipitation anomalies only in June, and the large scores are concentrated in the period of 1993-1999. In Type C, the precipitation anomalies appear from May to July near the baiu front, which is predominant before 1992.

Type A concurrents with the SSTAs off the Philippines between 135°E and 180. It is suggested that the anomalous meridional circulation induced by the SSTAs forces the anomalous north-south shift of the subtropical Pacific high and the resulting precipitation anomalies near the baiu front. The precursor of Type B is the SSTAs appearing from the South China Sea to the south of Japan in the pre-baiu season. The SSTAs seem to directly excite the anomalous upward flow near the baiu front and to control the following anomalous baiu precipitation. In Type C, the SSTAs persist from May to July near the Philippines to the west of 145°E. The SSTAs seem to contribute to smaller water vapor transport from the tropics. It is found that the baiu progress is quite sensitive to the spatial distribution of SSTAs in the western North Pacific.

1. Introduction

Baiu (in Japanese, *Meiyu* in Chinese, *Changma* in Korean) characterizes a rainy transition period from northern spring to summer in East Asia. Precipitation in the baiu season is one of prerequisite water resources in the East Asian countries. It is, therefore, of quite importance to diagnose the interannual variability of the baiu phenomenon.

The baiu front, which appears from early June through late July near Japan, climatologically extends along the northwestern periphery of the North Pacific subtropical high (the Pacific high) as part of the Asian summer monsoon (Fig. 1, Murakami and Matsumoto 1994; Wang and LinHo 2002). Therefore, the interannual variability could be primarily controlled by the development of the Pacific high, the Asian summer monsoon, the large-scale heat low over the Asian continent, and the circulations in mid-high latitudes including the Okhotsku high. In addition, the remote effects through the El Niño/Southern Oscillation (ENSO) may indirectly modulate the interannual variability (Nitta 1989; Tanaka 1997). Quite recently, Tomita et al. (2004) found that the meridional variation of the baiu front indicates the two interannual variations; one is the biennial (2-3 yr) and the other is the lower-frequency (5-6 yr) variations. The most notable differences between them appear in the spatial development of sea surface temperature anomalies (SSTAs) from northern winter to early summer in the western North Pacific, which further suggests a potential predictability of the baiu phenomenon.

The present study examines the predictability, particularly focusing on the anomaly fields in late spring. Furthermore, this work divides the baiu season into two,

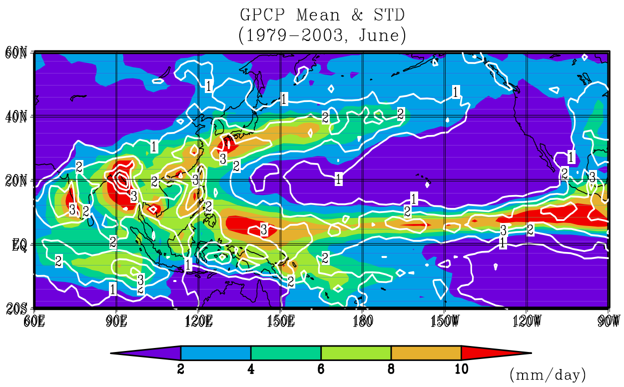

Fig. 1: Long-term mean of June precipitation (color, mm day^{-1}) and the standard deviation (line, mm day^{-1}).

that is, June and July, since the season is put in transition from northern spring to summer and the rainy period may easily shift back and forth. The findings derived from the present work would contribute to raise the seasonal prediction of the baiu phenomenon.

In the remaining sections, section 2 introduces the employed datasets and analysis procedures briefly. Section 3 exhibits the interannual tendencies of baiu transition, and the precursors and physical mechanisms are examined in section 4. Section 5 gives a summary and further discussion.

2. Data and analysis procedures

The present study uses the following two datasets: (1) global precipitation estimated in the Global Precipitation Climatology Project (GPCP; Adler et al. 2003), and (2) atmospheric parameters assimilated in the National Centers for Environmental Prediction (NCEP) - Department of Energy (DOE) Atmospheric Model

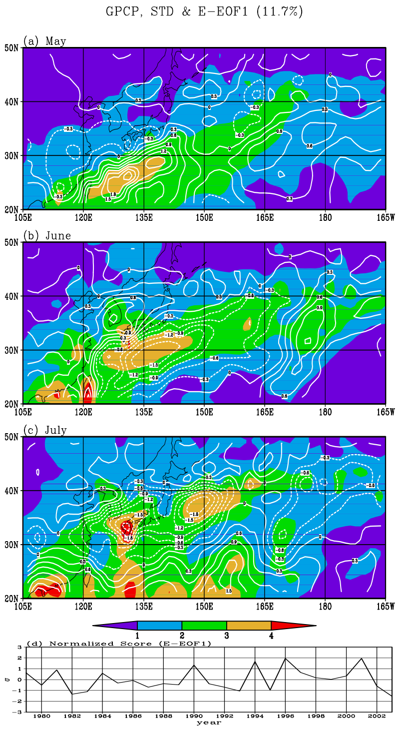

Fig. 2: Eigen vectors of EEOF1 (11.7%; (a) May, (b) June, and (c) July; contour), and (d) the score time series. The time series are normalized, while the standard deviation (SD) is imposed on the eigen vectors. Color indicates the SD of monthly precipitation with a unit of mm/day, and the color scale is put near the bottom of (c).

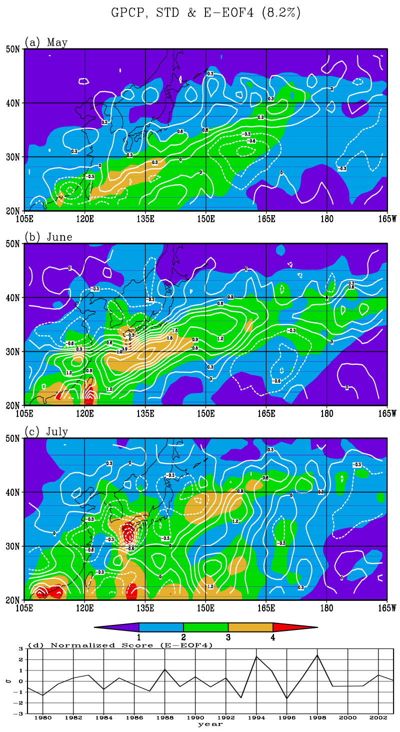

Fig. 3: As in Fig. 2 but for EEOF4 (8.7%).

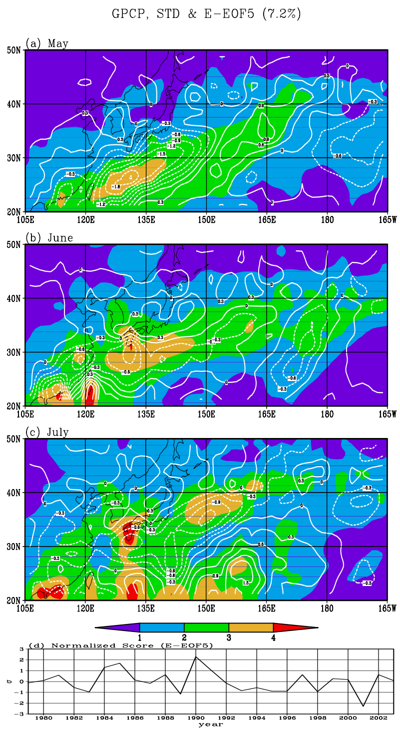

Fig. 4: As in Fig. 2 but for EEOF5 (7.2%)

Intercomparison Project II (AMIP-II) reanalysis (Kanamitsu et al. 2002). Both datasets are gridded globally, and the monthly mean data are employed for the updated period from 1979 to 2003.

In order to investigate the interannual variability of baiu progress, we first applied extended empirical orthogonal function analysis (EEOF; Weare and Nasstrom 1982) to the continuous three-month (May-June-July) precipitation field in the western North Pacific. Then the precursors and the associated physical processes are examined using regression and correlation techniques based on the score time series, where the significance of correlation coefficients is tested by the 95% level of Student *t*-test. In this work, we particularly focused on a surface temperature (SFT) field, which corresponds to sea surface temperature (SST) in oceans.

3. Interannual variability of baiu progress

Since the baiu indicates a rainy transition period from northern spring to summer, it is necessary to investigate the variability of progress but not of the temporal mean. For this purpose, we utilized the EEOF analysis for the continuous three-month precipitation fields from late spring to early summer (May-June-July). However, since the main rainy period is June, we chose the three EEOF modes based on how well the eigen vectors explained the large-scale precipitation anomalies near the baiu front in June. The selected EEOF modes are first (EEOF1; 11.7%), fourth (EEOF4; 8.2%), and fifth (EEOF5; 7.2%) ones (Figs. 2, 3, and 4). The second EEOF mode (10.7%; not shown) explains the precipitation anomalies in May and July well but not those in June, while the third mode (8.7%; not shown) demonstrates the anomalies only in July. The other lower modes seem to reflect smaller-scale disturbances in precipitation anomalies. The tendency of small contribution rates would be ascribed to that the small-scale disturbances can largely contribute to precipitation anomalies in midlatitudes and that the analyzed domain covers somewhat larger area than that of action centers. The local contribution rates of the chosen EEOF modes could be larger near the baiu front in June.

The baiu progress associated with the three EEOF modes are summarized as follows. Type A defined by the EEOF1 is characterized by the reversal of precipitation anomalies from May to June (Figs. 2a and 2b). Then the anomalous baiu precipitation continues in July with the same sign (Fig. 2c). The large amplitude tends to appear after 1989 (Fig. 2d). Type B shown in the EEOF4 is featured by the temporally local precipitation anomalies in June (Fig. 3b). In May and July (Figs. 3a and 3c), the precipitation is not well organized. The large amplitude is concentrated in the period of 1993-1999 (Fig. 3d). The precipitation anomalies persisting from May to July (Fig. 4a, 4b, and 4c) distinguish Type C of the EEOF5 from the former two. The score time series (Fig. 4d) clearly

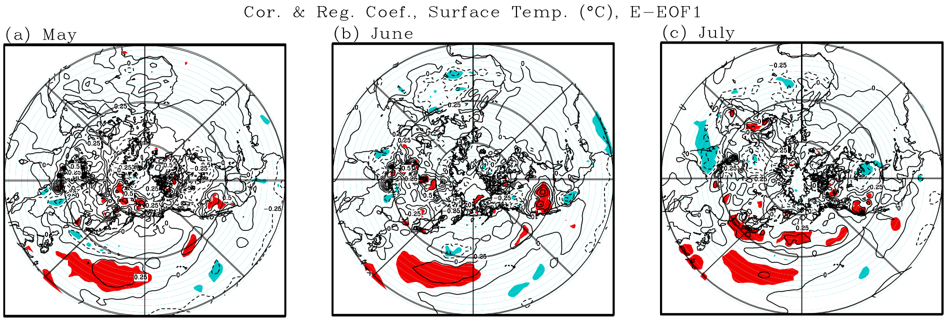

Fig. 5: Correlation (color) and regression (contour) coefficients of surface temperature with the score time series of EEOF1. Positively (negatively) significant correlations at 95% level are colored with red (blue).

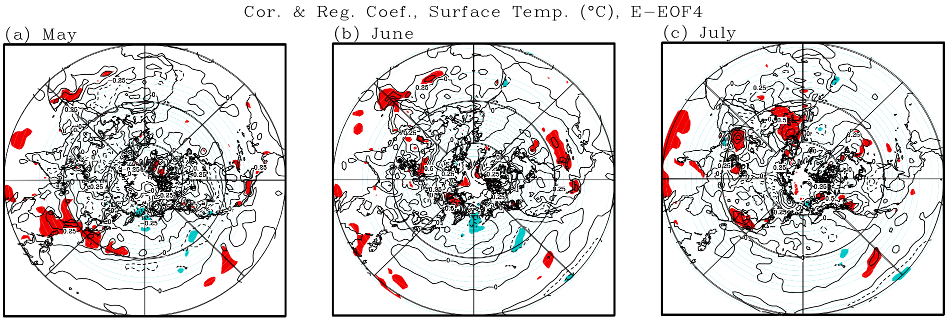

Fig. 6: As in Fig. 5 but for the EEOF4.

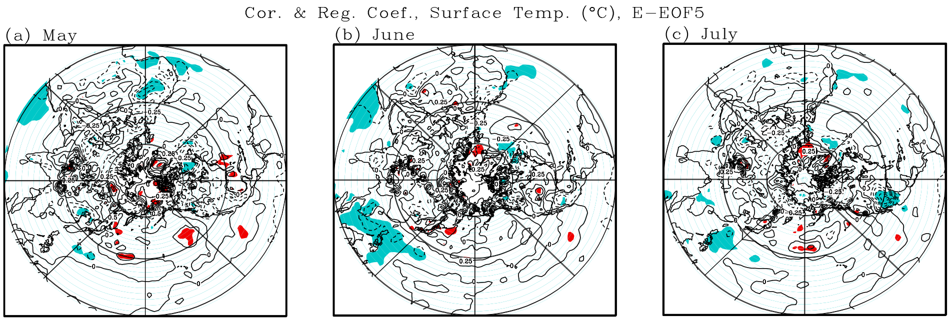

Fig. 7: As in Fig. 5 but for the EEOF5.

exhibit that the Type C was dominant before 1992. As such, the baiu progress is systematically changed on decadal or interdecadal timescales.

4. Development of surface temperature field

In order to find out the precursors of anomalous baiu progress and to examine the physical processes from May to July, we employed the correlation and regression techniques based on the score time series. Figures 5, 6, and 7 show the anomalous surface temperature fields associated with each type of baiu progress.

Type A concurrents with positive SSTAs off the Philippines between 135°E and the international date line (Fig. 5). Although the regression coefficients get small as month passes, the correlations remain significant with a positive sign in the region for the three months. On the other hand, the sign of SSTAs is changed from May to June near Japan corresponding to the change of precipitation anomalies (Figs. 2a and 2b). The continuous SSTAs off the Philippines should be regarded as a precursor of Type A. The anomalous meridional circulation inferred from the positive SSTAs, that is, an anomalous circulation cell with ascent off the Philippines and descent near Japan, may indicate the anomalous northward shift of the subtropical Pacific high in the western North Pacific and the negative precipitation anomalies in the baiu front.

When Type B is dominant, the significant positive SSTAs appear from the northern part of the South China Sea to the south of Japan in the pre-baiu season (Fig. 6a). It is conceivable that the positive SSTAs induce the upward motion resulting in the positive precipitation anomalies near the baiu front of June (Fig. 3b). The precipitation anomalies themselves modify the SSTAs in June, and the neutral temperature condition seems to appear in June and July (Figs. 6b and 6c). We could consider the positive SSTAs to the south of Japan in May as a precursor of Type B.

Type C is characterized by the significant negative SSTAs near the Philippines to the *west* of 135°E remaining for the three months (Fig. 7), although the signal is somewhat weak in May (Fig. 7a). Unlike the case of Type A, the negative SSTAs could contribute to smaller water vapor transport along the eastern coast of the Asian Continent resulting in the weaker-than-normal baiu activity. It is worth noting here that the SSTAs near the Philippines can have opposite effects on the baiu activity due to the zonal distributions (compare Figs. 5b and 7b).

Nitta (1989) found that the so-called Pacific-Japan pattern had a potential to alter the baiu precipitation anomalies through the anomalous meridional circulation. Tomita et al. (2004) recently pointed out that the spatial distribution of the SSTAs in the western North Pacific modified the meridional location of anomalous baiu precipitation. The present study proposes the SSTAs just to the south of Japan and the zonal distribution along the latitude of the Philippines as the precursors to the anomalous baiu progress.

5. Summary

A rainy transition period is specified between northern spring and summer in East Asia, which is called *Baiu* (in Japanese, *Meiyu* in Chinese, *Changma* in Korean). The precipitation in this period is a prerequisite for the summer water resources in the East Asian countries. The present study examines the interannual variability of the baiu progress from May to July using the EEOF analysis. Then the precursors and the associated physical processes are discussed.

Data used in this work are the GPCP precipitation and atmospheric parameters estimated from the NCEP-DOE AMIP-II reanalysis. Both datasets are globally gridded, and the monthly mean data are used for the period of 1979-2003.

Based on the eigen vectors near the baiu front in June, the three EEOF modes are distinguished, i.e., EEOF1 (11.7%; Type A), EEOF4 (8.2%; Type B), and EEOF5 (7.2%; Type C). Type A is characterized by the reversal of precipitation anomalies from May to June and by the persistence of anomalies during June and July. The large scores tend to appear after 1989. On the other hand, Type B is featured by the specific precipitation anomalies only in June, and the large scores are concentrated in the period of 1993-1999. The persisting precipitation anomalies for the three months distinguish Type C from the other two types, which is predominant before 1992. It is of interest that the baiu progress indicates the decadal or interdecadal variability.

Type A concurrents with significant positive SSTAs off the Philippines between 135°E and the international date line, while the sign of SSTAs is changed from May to June near Japan. The significant SSTAs to the east of 135°E in the subtropical western Pacific are regarded as a precursor of Type A. The anomalous meridional circulation induced by the positive SSTAs could force the anomalous northward shift of the subtropical Pacific high in the western part and the resulting negative precipitation anomalies near the baiu front. The precursor of Type B is the positive SSTAs appearing from the South China Sea to the south of Japan in the pre-baiu season. The positive SSTAs would directly excite the anomalous upward flow resulting in the positive precipitation anomalies in the baiu front of June. However, the neutral SST condition continues in the following June and July. Type C is featured by the negative SSTAs near the Philippines to the *west* of 135°E remaining for the three months from May to July. The negative SSTAs would contribute to smaller water vapor transport from the tropics rather than modifying the meridional circulation in the western Pacific. The baiu activity seems to be very sensitive to the spatial distribution of SSTAs near the Philippines. The precursors would contribute to raise the seasonal prediction of baiu progress.

The physical mechanisms how the spatial distribution of SSTAs is determined in the western North Pacific remain controversial. Wang et al. (2000) and Wang and Zhang (2002) proposed a specific air-sea interaction with horseshoe SSTAs extending in the entire tropical Pacific, which is forced by the teleconnection associated with the ENSO. Diagnosing the output from GCM experiments, Lau and Nath (2000) proposed another physical mechanism that was based on the Rossby-type atmospheric response on the SSTAs in the tropical western Pacific. Tomita and Yasunari (1996) and Tomita et al. (2004) pointed out that the spatial pattern of horseshoe SSTAs that is associated with the biennial oscillation of the Asian-Australian monsoon is different from that appearing with the ENSO. Further study is needed to identify the effects of the ENSO and of the Asian-Australian monsoon on the interannual variability of baiu progress.

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