The Large-Scale Circulation Change at the End of the Baiu Season in Japan as Seen in ERA40 Data

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Abstract

The time evolution of the circulation change at the end of the Baiu season is investigated using ERA40 data. An end-day is defined for each of the 23 years based on the 850 hPa \(\theta_e\) value at 40\(^\circ\)N in the 130–140\(^\circ\)E sector exceeding 330 K. Daily time series of variables are composited with respect to this day. These composite time-series exhibit a clearer and more rapid change in the precipitation and the large-scale circulation over the whole East Asia region than those performed using calendar days. The precipitation change includes the abrupt end of the Baiu rain, the northward shift of tropical convection perhaps starting a few days before this, and the start of the heavier rain at higher latitudes.

The northward migration of lower tropospheric warm, moist tropical air, a general feature of the seasonal march in the region, is fast over the continent and slow over the ocean. By mid to late July the cooler air over the Sea of Japan is surrounded on 3 sides by the tropical air. It is suggestive that the large-scale stage has been set for a jump to the post-Baiu state, i.e., for the end of the Baiu season. Two likely triggers for the actual change emerge from the analysis. The first is the northward movement of tropical convection into the Philippine region. The second is an equivalent barotropic Rossby wave-train, that over a 10-day period develops downstream across Eurasia. It appears likely that in most years one or both mechanisms can be important in triggering the actual end of the Baiu season.

1. Introduction

The Baiu is a rainy season of early summer in the east Asia. It is called ‘Mei-yu’ in China and ‘Changma’ in Korea. The ‘Baiu’ and ‘Mei-yu’ mean ‘plum-rain’ because the plum trees bear their fruits in this season. In the Baiu season, a precipitation zone is frequently present from China to the far east of Japan, and is referred to as the Baiu front or frontal zone. Precipitation in this period is very important as a water resource but the associated heavy rainfall can cause disasters such as floods and landslides.

There are many studies of the activity of the Baiu front. Its multi-scale features are well summarized in Ninomiya and Akiyama (1992), Kodama (1992, 1993) discussed features of the subtropical frontal zones, such as the South Pacific convergence zone.
(SPCZ), the South Atlantic convergence zone (SACZ) and the Baiu frontal zone and noted conditions necessary for such quasi-stationary precipitation zones: 1) low-level poleward flow prevailing in the western periphery of the subtropical high, 2) upper sub-tropical jet and 3) quasi-stationary trough to the west of the poleward flow.

Several studies have focused on describing the seasonal march in the region. Yoshino (1965, 1966) divided the Baiu season into four stages and described the circulation in each stage. Kato (1989) described the seasonal march of the Baiu season of 1979. Saito (1985) also analysed the relationship between the seasonal march of the Baiu season and quasi-stationary waves in mid-latitude and showed the westward movement of decaying trough, which was clear in late June, at the end of the Baiu season in 1979. Murakami and Matsumoto (1994) described the seasonal march of the summer monsoon over the Asian continent and the western North Pacific and indicated that it is difficult to find a clear connection between the Baiu season and the ITCZ.

In synchrony with the Indian monsoon, the Baiu season starts in late May (Suda and Asakura 1955). However, unlike the Indian monsoon which continues into September, the Baiu typically ends in late July. Figure 1 shows the seasonal march of precipitation for the longitudinal sector 130–140°E according to ERA40 data averaged for calendar days for the 23-year period 1979–2001. The large precipitation near 30°N in June corresponds to the Baiu front. This rainy zone tends to drift slightly north to about 28–38°N by the beginning of July and then it disappears in mid-late July. In any year, the withdrawal of the Baiu is usually very abrupt, but it tends to get smoothed in this picture because the day of this rapid change changes from year to year.

Figure 2 shows the average seasonal march of the westerly winds at 250 hPa in a similar sector. During the Baiu season, just before mid-July, the jet is near 37°N, and then in late July it moves to near 45°N. This shift of the westerly jet, which in any year is abrupt, is one of features of the circulation change at the end of the Baiu season. This wind change is generally associated with the anticyclonic development. The popular explanation for cause and effect is that the stronger Pacific high pushes the front northward and the Baiu season comes to an end.

Many studies have pointed out the relationship between particular phenomena and the end of the Baiu season. Murakami (1951) showed for one case that there is no westerly jet after the Baiu season. Ueda et al. (1995) investigated the northward

![Fig. 1. Time-latitude distribution of precipitation in the 130–140°E sector from May to August averaged for 23 years from 1979 to 2001. The contour interval is 2 mm day⁻¹, with the key given in the bar on the right.](image-url)
shift of convective activity in the western Pacific and showed that it is synchronous with the end of
the Baiu season. Enomoto et al. (2003) proposed
that the formation mechanism of the Bonin high,
an equivalent barotropic high in mature summer,
is due to Rossby waves propagating along the
Asian jet in August and raised the possibility that
these Rossby wave trains also terminate the Baiu
season.

However, a complete physical understanding
of the circulation change at the end of the Baiu has
not yet been produced. For example, the following
questions should be answered:

Why does the Baiu front dissipate at the time it does?
Why does the Baiu front disappear so suddenly?
What related changes occur at the end of the Baiu
season?

The data for the current study were taken from the
ERA-40 data set (Uppala et al. 2005) for the period
1979–2001 when satellite data was plentiful. Daily
fields were constructed from the 6-hourly data, in
particular for equivalent potential temperature ($\theta_e$) at 850 hPa, stream function $\psi$ and horizontal winds
($u, v$) at 250 hPa and 850 hPa, and vertical velocity
$\omega$ at 500 hPa. The end-day of the Baiu season is
defined from time series of $\theta_e$ at 850 hPa. Composite
time series are made with respect to the end-day in
order to describe a ‘typical’ circulation change and
to consider the possible processes involved.

As will be emphasised in this paper, the Baiu sea-
son has many time-scales, from the annual cycle
down to the time-scale of its abrupt ending. The
JMA declares the day of the end of the Baiu season
every year and also states that there is a terminal
stage of about 5-days in length. Kawamura and
Murakami (1998) used time-filters to separate the
changes in the circulation associated with the slow
annual cycle (longer than 120 days) and shorter,
but greater than synoptic periods (9 to 90 days).
The approach here is to consider the general march
of the seasons, but then to define the end-date of
the Baiu season each year using 5-day averaged
data and form composites with respect to it. These
composites will be made using daily data and also
using the average of the 10 days before and after
the end day. Analysis of these fields will be used to
suggest possible triggers for the abrupt end of the
Baiu season.

2. Analysis of $\theta_e$ at 850 hPa

2.1 Definition of the end of the Baiu season

The feature of the end of the Baiu season that is
dominant for most people is the cessation of the
heavy rainfall associated with it. Precipitation amounts have often been used also for meteorological analysis of the Baiu and the definition of its end-date. However, here we prefer to base our analysis in general, and the definition of the end-date in particular, on \( \theta_e \) at 850 hPa, a rather smoother field that reflects the general moist thermodynamic state of the atmosphere on local and planetary scales, and the contrast in air mass across the Baiu front.

When averaged from 130°E to 140°E, it provides a summary of the moist thermodynamic state in the longitudinal sector of Japan. The average evolution based on calendar days is given in Fig. 3, where the shading indicates the regions of enhanced horizontal gradient. The Baiu frontal zone is clearly seen moving slowly northwards from about 35°N on 21 June towards 39°N by mid-July. There is then a quite sharp reduction in gradients at this latitude and a simultaneous increase near 53°N where they remain until mid-August.

An 850 hPa \( \theta_e \) evolution figure for an individual year, 1986, is given in Fig. 4, along with contours of precipitation rate. As can be expected, there are fluctuations in the Baiu as indicated by the small meridional excursions of the \( \theta_e \) contours in the region and also by the variations in precipitation. However, both variables pick out the Baiu front, and its dissipation in later July as a frontal region forms near 50°N.

Based on the 23-year average and many individual years, it was concluded that 850 hPa \( \theta_e \) provides an excellent delineation of the Baiu front. It was also concluded that the end-day of the Baiu season each year can be defined as the day that the 330 K \( \theta_e \) contour passes through 40°N in the 130–140°E average, 5-day running mean 850 hPa \( \theta_e \) evolution picture. After this day, the lower troposphere over Japan contains warm, moist tropical air.

In 1986 (Fig. 4), for example, the 330 K \( \theta_e \) contour corresponded to the precipitation zone and had little meridional fluctuation before 26th July. On 26th July, the contour suddenly moved northward to about 45°N. So the end-day of the Baiu season in 1986 is defined as 26th July. Strong horizontal Baiu gradients of \( \theta_e \) also disappeared on this day.

In years in which two or more end-days are given using this criterion then the latest one is chosen. The Baiu end-days from 1979 to 2001 according to our definition are shown in Fig. 5. The range for the 23 years is from 29 June to 2 August. However,
17 Baiu end-days (76% of the total) occur between 13 and 27 July, and 9 of these (39% of the total) in the 3 day period from 21 to 23 July. On the average there is consistency with the Japanese Meteorological Agency (Japan Meteorological Agency, 2001) who has given the mean 1971 to 2000 Baiu end-dates for the Japanese main island (Honshu) ranging from 20 July in the west to 23 July in the north.
Also shown in Fig. 5 are the end dates given by
the JMA for ten regions in Japan. In most years
the end-dates defined here are within 2 or 3 days of
those defined by the JMA. However there are some
discrepancies. For example, the dates defined here
are about 10 days earlier in 1998 and 1999, and
the JMA did not give end dates in 1993.

Taking day 0 to be the end-day for each of the 23
years, composites of fields have been constructed
from day \(-C30\) to day \(+20\) with respect to it. Such
composite time-series have been made for 850 hPa
\(\theta_e\), for \(\psi, (u; v)\) at upper and lower tropospheric
levels and for 500 hPa \(\omega\), and these provide the basis
for the subsequent analysis in this paper.

2.2 Composite evolution in the Japanese sector

Figure 6 shows the time-latitude distribution of
850 hPa \(\theta_e\) averaged from 130°E to 140°E using
composites with respect to the end-day. This figure
should be compared with Fig. 3 in which the averaging
was done using the calendar day. The same
features are apparent but the strong horizontal gradients
of \(\theta_e\) in the Baiu front are more marked. The
end of the Baiu season is clearly much more definite
and abrupt in Fig. 6, with the strong \(\theta_e\) gradient
switching to 50–55°N for the next 20 days.

The evolution of the precipitation in the 130–
140°E sector, when composited with respect to the
end-day is shown in Fig. 7. The sudden shift of the
rainfall from the 30–37°N belt to the 40–57°N belt
at day 0 is marked, again considerably more so
than when the calendar day is used (Fig. 1). In the
tropical and subtropical regions, before the end-
day, there is intense rain around 15°N and some
tropical rain up to 23°N. Some 3 to 5 days before
the end-day, the tropical rainfall region begins to
extend poleward, as can be seen in, for example,
the 4 mm/day contour, which moves from about
23°N to 30°N by the end-day. At the same time
the boundary of the intense rain (e.g., the 12 mm/
day contour) moves from 15°N to 20–22°N, so
that it covers the Philippines.

2.3 Seasonal march of \(\theta_e\)

The 325 K contour in 850 hPa \(\theta_e\) will be used to
give an indication of the extent of the region cov-
ered by warm, moist subtropical air. Here this
value is preferred over the 330 K used in the defini-
tion of the Baiu-end day. It is evident from Fig. 6 that the 330 K contour is in the centre of the Baiu region but not really involved in the later northern frontal region. However, the 325 K contour is both on the northern side of the Baiu frontal region and on the southern side of the northern frontal region. Figure 8 shows the seasonal evolution of the extent of subtropical air by means of the position of this contour averaged every half month.

After little change in May, the contour moves quite uniformly poleward over the Asian continent at a rate of about 10° per month. The \( \theta_e \) increase over the Pacific Ocean is less rapid and the northward motion of the contour is much slower. The Japanese sector can be viewed as the transition region between the continental and oceanic behaviours.

To get a more focused view of the behaviour during the period around the end of the Baiu season, the position of the contour is shown in Fig. 9 every 5 days in composites with respect to the Baiu end, from day \(-15\) to day \(+5\). Except some wave pattern east of 160°E from day \(0\) to \(+5\), there is no major change over the 20 day period outside the region 120°E to 160°E and inside it there is little change from day \(-15\) to \(-10\). However, from day \(-10\) to \(-5\) the contour makes a large poleward movement over north China but the cooler, drier air on the northern side of the Baiu front remains over the Sea of Japan. In the Japanese sector the large movement in the contour occurs from day \(-5\) to day 0 when the region is virtually covered with high \( \theta_e \) air.

In the evolving summer, warm, moist subtropical air progressively invades the East Asian continent. By 5 days before onset (day \(-5\)) the process has proceeded over NE China to the extent that, as seen from Figs. 6 and 9, there is a reversal in the meridional gradient of \( \theta_e \) in the 130–140°E sector as in a breaking wave with the cold air over the Sea of Japan becoming almost surrounded by high \( \theta_e \) air from the west. On day 0, the anomalous situation has been removed and the Baiu front vanishes.

Figure 10 shows horizontal wind vectors at 850 hPa for every 2 days from day \(-8\) to day \(+2\). At days \(-8\) and \(-6\) it is evident that south-westerly winds bring warm, moist subtropical air in the subtropical region to the southern part of Japan. However, the weak winds in the north of China suggest that the increasing \( \theta_e \) there between days \(-10\) and \(-5\) is due to local thermodynamic processes rather than advection. From day \(-4\) mean southerly/ south-westerly winds become strong in north and
northeast China. The advection of high $\theta_e$ air into the region can be expected to increase through days $-2$ and $0$ as these winds strengthen, so that the movement of the 325 K contour in Figs. 6 and 9 can then be associated with these circulation changes.

Fig. 8. The seasonal evolution of the extent of tropical/subtropical air as indicated by contours of $\theta_e = 325$ K at 850 hPa for every half month. The region whose surface pressure is generally less than 850 hPa in July is shown in black.

Fig. 9. The evolution of the extent of tropical/subtropical air near the Baiu end-day as indicated by contours of $\theta_e = 325$ K at 850 hPa for every 5 days for the period from 15 days before to 5 days after the end-day. The surface height of the regions that are blacked-out is generally less than 850 hPa in July.
3. Circulation changes

3.1 Differences in 10-day means

In this section the investigation of the circulation changes at the end of the Baiu season is based on the differences between 10-day-averaged circulation fields just before and just after the end-day. 10-day-averaging appears to be appropriate as the composite time-series of $\theta_e$ looks quite stable during both 10 day periods and such averaging reduces random fluctuations.

Figure 11 shows the 850 hPa stream function before and after the end of the Baiu season, the difference between them and the statistical significance of this difference. The subtropical anticyclones over the oceans and the Indian Ocean clockwise circulation with westerlies over southern Asia are domi-
nant in both periods. From one period to the next
the North Pacific anticyclone intensifies and its
western tip moves northward near Japan. This
change is expressed in Fig. 11(c) as an anticyclonic
difference east of the date-line and near Japan, and
a zonally extended cyclonic difference over and to
the north of the Philippines, consistent with the in-
creased convection there. This figure also shows a
midlatitude sequence of positive, negative and posi-
tive changes near 0, 30 and 60°E, respectively.
All these features are statistically significant (Fig.
11d).
Figure 12 gives a similar collection of figures for
the 250 hPa stream function. In both periods the
Tibetan high is dominant over Asia and the wester-
ly jet is on its northern flank. As is clear from
Fig. 12(c), the primary change from before to after
the end of the Baiu is the increase in anticyclonic
circulation centred over Japan and extending from
90 to 150°E and also to another centre east of the
date-line. Both of these are statistically significant
(Fig. 12d). The result of this change is that much
of Japan becomes included in the closed stream
function contours of the Tibetan anticyclone and
da ridge on its eastern flank extends towards the
Aleutians (Fig. 12b). Both these difference centres
are equivalent barotropic, being present also at
850 hPa (Fig. 11c). The 850 hPa cyclonic change
north of the Philippines has a weak 250 hPa signa-
ture of the same sign near Taiwan but the opposite
sign near the Philippines, the latter being consistent
with the tropical baroclinic response to the en-
hanced convective latent heat release. The midlati-
tude wave-like structure at 850 hPa from 0 to 60°E
is also present at this upper tropospheric level and
here extends into western Asia with additional
wave pattern. Only the positive centre satisfies the
test for statistical significance. As in Enomoto et al.
(2003), there are indications that equivalent baro-
tropic Rossby waves may propagate along the
westerly jet and affect circulation changes in the re-
gion of Japan.
Figure 13 shows similar pictures for 500 hPa ver-
tical velocity. Ascent is seen in both periods over
India, south-east Asia, the western Pacific and
along the ITCZ, as well as in West Africa. There is
descent over the eastern Atlantic, the Mediterr-
anean and the Kyzylkum desert. Near 120°E, the
difference between the periods (Fig. 13c) exhibits
a negative, positive, negative pattern in the meri-
dional direction in the region that corresponds to
more ascent over the Philippines, consistent with
the enhanced precipitation there, the ending of the Baiu over Japan, and the transition from weak descent to weak ascent over NE China. The pattern in the difference field over Europe and Asia of alternating ascent and descent is again a signature of the equivalent barotropic Rossby wave on the westerly jet, though no trigger for it is apparent at the western end of the jet.

3.2 Temporal evolution

To resolve the circulation changes better, the differences between stream function fields at the two levels and average fields will be shown every 2 days from day –7 to day +7. Figure 14 shows such a depiction of the evolution of the 850 hPa stream function difference from the average from day –10 to day +10. Consistently with the changes
Fig. 14. Time development of 850 hPa stream function (thick solid contours every $5 \times 10^6$ m$^2$ s$^{-1}$) every 2 days from day $-7$ to day $+7$, and its deviation from the average for the period day $-10$ to day $+10$ (thin contours every $6 \times 10^5$ m$^2$ s$^{-1}$). Dark shading indicates regions of anticyclonic deviation and light shading regions of cyclonic deviation.
in the 10-day averages seen in Fig. 11(c), the general flavour in the 120–150°E region is one of a meridional anticyclone-cyclone-anticyclone tripole at days −7 and −5, with the cyclone being over Japan and the southern anticyclone being over the north Philippines, changing to the opposite sign by day +3 and day +5. The transition is not a smooth one, but the Philippines and Japan centres both show signs of the change at day −1. The Philippines change may be associated with tropical depressions or typhoons, which generally affect this region after the end of the Baiu season.

For the evolution of the 250 hPa stream function (Fig. 15), the departures are taken from the average for the 30-day period before the end-date. This is done to emphasise the development of the post-Baiu signatures. The anticyclonic difference over Japan is present by day −1 and intensifies and extends after that. The weaker zonally extended cyclonic difference to its south becomes evident soon after the end-day. At day −7 the midlatitude wave pattern from 0 to 90°E is clear. The evolution from then until day −1 is very suggestive that the anticyclone over Japan is associated with the downstream development of this quasi-stationary wave-train.

To investigate the temporal and longitudinal aspects of this wave-train development further, a Hovmöller plot of the departure of the 30–60°N, zonally asymmetric composite 250 hPa stream function from its day −15 to day −10 average is shown in Fig. 16. The downstream development of the quasi-stationary wave pattern from 0°E at day −10 to 140°E at day −2 is striking. By construction the day −15 to −10 values are small, but there is even some evidence from day −12 of mobile, slightly smaller scale systems in the Atlantic, a possible signature of linkage to midlatitude depressions there. There are signs of two speeds for downstream development in Fig. 16. The fast speed joins the fringes of the development near 20°E at day −11 to the fringe near 140°W at day −7 and also the maximum there at day −7 to the maximum at day −4. This speed of about 50 m s−1 is approximately double the speed of the upper tropospheric jet north of the Tibetan Plateau and could correspond to the group velocity associated with barotropic disturbances on this jet. However, this rapid downstream propagation appears to have only a small signature in the Japanese sector. The development in this sector from about day −3 appears to be associated with a downstream development from the same 20°E anticyclone at day −11, but moving at about half the speed, 20 m s−1. This is comparable with the Rossby wave in Enomoto et al. (2003). The wavelength of this pattern, corresponding to about zonal wave number 6, is also consistent with the one found by them.

4. Discussion

In this paper 850 hPa θe has been used as a marker of the edge of the region of warm, moist tropical air, in particular to describe the association of this tropical air with the Baiu front. A Baiu end-day has been defined in terms of the last occasion in the summer in which, in 5-day running mean pictures, the 330 K contour in the 130–140°E sector moves through 40°N. The end-day determined in this manner is in general similar to more standard versions, but there can be significant differences in some years. Composites with respect to it have enabled the production of clear pictures of the Baiu front and of the changes in thermodynamic and dynamic fields that are associated with its end.

The poleward progress of the tropical air in the East Asia region during the summer, as delineated by the 325 K contour, shows the steady movement northward and eastward over East Asia, but not over the ocean, until, by mid- to late July the cooler air over the Sea of Japan is surrounded on 3 sides by it. This is highly suggestive that the large-scale stage has been set for a jump from the Baiu state to a new post-Baiu state, i.e., the end of the Baiu. The triggering of such a jump leads to the sudden end of the Baiu season.

Consistent with previous studies, two likely triggers for this change to occur have been suggested by the results presented here. The first is the northward movement of tropical convective activity in the Philippines region. Ueda et al. (1995) indicated that the convectively active region over the subtropical Pacific ocean around 150–160°E moves northward at the end of the Baiu season. A similar northward movement of intensified convection and an associated cyclonic anomaly occurs around the Philippines in our analysis, though it is somewhat to the west of that discussed by Ueda et al. (1995). This movement has been seen (Fig. 7) to start some 3–5 days before the end-day and to be completed by that day. The differences in circulation before and after the end-day (Figs. 11–13) show a physically coherent behaviour in the region from the Philippines to Japan and have features that are similar to those of the ‘PJ pattern’ (e.g., Nitta 1987;
Fig. 15. Time development of 250 hPa stream function (thick solid contours every $2 \times 10^7$ m$^2$ s$^{-1}$) every 2 days from day $-7$ to day $+7$, and its deviation from the average for the period day $-30$ to day $0$ (thin contours every $2 \times 10^6$ m$^2$ s$^{-1}$). Dark shading indicates regions of anticyclonic deviation and light shading regions of cyclonic deviation. Arrows show wave-activity flux as defined by Takaya and Nakamura (2001) for the deviation with scaling given at the bottom of each panel.
Kosaka and Nakamura (2006) which appear in monthly data. The actual process by which the shift in the convection triggers the end of the Baiu could involve an imposition of descent in the Japanese region compensating the enhanced ascent in the convective region further south. However the observed change here (Fig. 13c) could be mostly a signature of the removal of the front itself.

The other potential trigger identified here is the equivalent barotropic Rossby wave-train that develops downstream across Eurasia seen in Figs. 11–13, and highlighted in Fig. 16. The anticyclonic centre over Japan is set up some 2–3 days before the Baiu end-day. The possible role of such wave-trains in terminating the Baiu season has been suggested by Enomoto et al. (2003), who highlighted their role in post-Baiu anticyclone developments near Japan. This wave-train can occur with the opposite sign, resulting in a cyclonic anomaly over Japan even in July. However, only the sign shown here is associated with the Baiu season end. As suggested by Figs. 9 and 10, the end of the Baiu front could be associated with the increase in the southerly winds near 120°E between the trough to its west and the ridge near Japan, and the consequent advection of high theta air. As mentioned for the PJ pattern, the change in vertical motion near Japan seen in Fig 13(c) may partially reflect descent forced locally by the wave-train, or it may represent only the end of the ascent associated with the Baiu front.

In the analysis of the PJ pattern performed by Kosaka and Nakamura (2006), a mid-latitude wave-train was detectable upstream of the pattern. This raises the possibility that the wave-train could trigger the PJ pattern and that this leads to the end of the Baiu. However it should be noted that the time-scale of the wave-train is shorter than that of the PJ pattern that is detected in monthly data.

In order to give further information on the rela-
tive frequency of occurrence of the two possible triggers for the end of the Baiu, indices have been developed for them based on their signatures in 10-day averaged before and after differences in stream function for individual years (Δψ) compared with those in the composites (Δψ). For the PJ pattern the level is 850 hPa and the region is the Philippine-Japan region (14.6–45.0°N and 114.8–144.0°E). For the wave-train the level is 250 hPa along the Asian jet (29.3–59.6°N and 0.0–159.8°E). The index in each case is defined to be (Δψ/Δψ), where the dot product denotes an areal integral of the product of the fields. The average value of each index is one by definition. A positive value indicates that some, but not necessarily all, of the features are present with phases similar to those in the composite.

Figure 17 shows a scatter diagram of the indices for the PJ pattern and the wave-train defined in the text for the 23 years from 1979 to 2001. The indices for the PJ pattern and the wave-train pattern are given on the abscissa and ordinate, respectively.

Since both the indices are based on patterns found in after minus before Baiu end composites, it is possible that they are signatures of the change in the Japan region, rather than indicators of the trigger for the change. In particular, both patterns include the anticyclonic circulation over Japan that occurs after the Baiu end. Modified versions of the indices have also been used that do not include this aspect. The modified PJ index only measures the Philippine cyclone at 850 hPa, and the modified wave-train index is based on the longitudinal range (both greater than 1.0). In other 5 years the PJ index is greater than 1.8 and the wave-train index is between 0.1 and 0.7, with an additional year having the PJ index greater than 1 and the wave-train index slightly negative. In 5 years the wave-train index is greater than 1 and the PJ index is negative. In the remaining 4 years, neither index is much greater than 0. In summary, both signatures are often seen, with one or other tending to dominate in some years and in only a few years are they both absent. The wave-train pattern is nearly always found to occur with the sign of that in the composite, but there are more exceptions for the PJ pattern.

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0–110°E. The scatter-plot (not shown) is quite similar in character to Fig. 17, though there are now 7 years in which the wave-train index is weakly negative (all between 0 and −1). There are only 2 years in which neither index is greater than 0.8.

It appears likely that in most years one or both mechanisms can be important in triggering the actual end of the Baiu season, the inevitability of which has been determined by the larger, continental scale progression of the East Asia summer Monsoon.

The mechanisms and possible relationships that have emerged from the analysis of observed data described here require experimentation with models to evaluate them further. Some such research has been performed using idealised models and the results will be discussed elsewhere.

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References


