Seasonal Variations of the Synoptic-Scale Transient Eddy Activity and Polar Front Jet over East Asia

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ABSTRACT
Seasonal variations of the synoptic-scale transient eddy activity (STEA) and the jet streams over East Asia are examined through analysis of the 40-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40) data. Extracted from the 6-hourly upper-level wind fields, the distribution of the jet core numbers exhibits a distinct geographical border for the East Asian subtropical jet (EASJ) and the East Asian polar front jet (EAPJ) at the latitudes of the northern Tibetan Plateau (TP). In the cool seasons, two branches of the STEA and low-level baroclinicity exist over the East Asian landmass, accompanied by the two-jet state of the EASJ and EAPJ. In the warm seasons, a single jet pattern of the EASJ along the north flank of the TP is accompanied by the weakened STEA over the mid- to high latitudes of East Asia. Further analysis shows two distinct features of the seasonal variations of the STEA over East Asia, compared with that over the North Pacific. First, during the transitional period of April–June, the main STEA band over East Asia migrates northward dramatically, in conjunction with the EAPJ shifting in the same direction. Second, both the upper-level STEA and the lower-level baroclinicity poleward of the TP are prosperous in spring. The relationship between the STEA, baroclinicity, vertical wind shear, and static stability in the EAPJ region in different seasons is further investigated. It is found that in addition to the time-mean wind fields, the rapid increase in the sensible heat flux poleward side of the TP region in spring and the associated boundary layer processes are partially responsible for the spring prosperity of the local baroclinicity and the STEA.

1. Introduction
In the midlatitude troposphere the jet stream and the associated synoptic-scale transient eddy activities (STEA) are special features of earth’s atmospheric motions. The jet stream is considered the large-scale circulation, while the STEA can be measured by the synoptic-scale filtered daily data. Both are strongest in the upper troposphere. In terms of the climatological seasonal variation, the jet stream and STEA demonstrate increasing (decreasing) variations in their intensity. At the same time, they also show northward–southward (westward–eastward) movement in its spatial distribution harmoniously, however, with a large discrepancy in regional characteristics (Whittaker and Horn 1984; Chang 2001; Hoskins and Hodges 2002, 2005; Nakamura and Shimpo 2004; Newton 2004; Wernli and Schwierz 2006; Mesquita et al. 2008). Many studies focus on the seasonal-to-interannual variations of the STEA and the associated zonal wind fields over the oceanic regions in the Northern Hemisphere, resulting from their level of activity and their obvious connection with weather processes and the time-mean flow. Over the North Pacific the wintertime jet stream intensity and STEA have an anticorrelated relationship, which has been extensively studied using observations and models (Nakamura 1992; Chang 2001; Chang and Guo 2007; Chang 2009; Son et al. 2009).
Over the East Asian continent the STEA is dramatically reduced compared with the oceanic regions, resulting from the topographic effect and strong surface friction (Hoskins and Hodges 2002; Chang et al. 2002; Chang 2009; Son et al. 2009). Therefore, the seasonal variation of the STEA over the East Asian region has received relatively less attention. Statistical analyses on the surface cyclone activity in the midlatitude East Asian continent have shown a clear seasonal cycle, with the most frequent cyclones occurring in the spring season (Whittaker and Horn 1984; Asai et al. 1988; Chen et al. 1991; Wernli and Schwierz 2006; Wang et al. 2009). The interesting questions to ask are whether the STEA...
over East Asia is also more vigorous in spring than in other seasons; and, if so, what are the processes responsible for this seasonal variation? The traditional approach to address this issue is to investigate the variation of the time-mean (over a month or a season) flow. This is because the level of activity of the transient eddies in the midlatitude bands is primarily related to the strong baroclinicity of the time-mean flow. Following Eady (1949) and Hoskins and Valdes (1990), the baroclinicity is mainly determined by the vertical shear of the time-mean wind fields and the static stability between two pressure levels. The main body of the STEA over East Asia is located to the north of the Tibetan Plateau (TP), where the land surface is dominated by the Gobi Desert, with little vegetation cover. During spring season, the rapid increase in surface sensible heat flux and low-level turbulent diffusion in this region may lead to large fluctuations of low-level static stability (Xu et al. 2006; Song et al. 2009; Zhang et al. 2009). Consequently, the seasonal cycle of the baroclinicity over East Asia may be associated with both the vertical shear of the time-mean wind field and the static stability. In this study, we will try to demonstrate that the distinct land–air interaction is partially responsible for the seasonal cycle of baroclinicity and STEA over East Asia, thus leading to a sharp contrast to the oceanic region.

Our interest in exploring the relationship between the STEA and jet stream over East Asia is also motivated by a schematic diagram showing the jet stream distributions in the Northern Hemisphere [Fig. 2 of Lee and Kim (2003), originally illustrated by Riehl (1962) and Palmén and Newton (1969)]. According to this diagram and other studies (e.g., Mahlman 1973; Bals-Elsholz et al. 2001; Nakamura and Shimpo 2004; Gallego et al. 2005; Koch et al. 2006), a state of two jets—the subtropical jet and the polar front jet (also referred to as the subpolar jet or the eddy-driven jet) in the mid- to high latitudes—is a general characteristic in both hemispheres. Over the East Asian region in the cool seasons, the two-jet state consists of the East Asian subtropical jet (EASJ) and the East Asian polar front jet (EAPJ) lying zonally along the southern and poleward sides of the TP, respectively. After the confluence over the East Asian coastal waters, the jet extends eastward into the oceanic region (Sheng 1986; Lee and Kim 2003; Newton 2004; Koch et al. 2006). By examining the upper-level time-mean (e.g., monthly or seasonal mean) wind fields in the respective winter seasons of both hemispheres, one can identify a notable feature over the North Atlantic region and at the latitudes of Australia and New Zealand in the Southern Hemisphere. That is, a state of two jets with a noticeable minimum in the westerlies between the two jet branches is presented (Black and Dole 2000; Bals-Elsholz et al. 2001; Nakamura and Shimpo 2004). However, over East Asia the EASJ is stronger than the EAPJ. The intensity of the time-mean wind gradually decreases from the EASJ to the EAPJ region. Thus, it is difficult to define an area between the EASJ and EAPJ where the minimum in time-mean westerlies is located. The EASJ is persistent and dominant in both the time-mean and high-frequency fields. Hence, its physical characteristics and seasonal-to-interannual variations have been addressed by using the pentad-mean and monthly-mean wind fields (Kuang and Zhang 2005; Zhang et al. 2006). Comparatively, less attention has been paid to the climatological features of the EAPJ, because of its transient characteristics (Lee and Kim 2003) and an indistinct geographical border between the EASJ and EAPJ. In some recent studies, the daily data are used for identifying the jet cores and for counting the frequency of the jet cores in a certain season (or month; see Koch et al. 2006; Strong and Davis 2007, 2008; Schiemann et al. 2009). These studies suggested that the time-mean wind field can well depict the subtropical jet, but that it is not suitable for the more transient polar front jet stream. Therefore, the daily or higher-frequency data should also be used for a detailed description of the EAPJ seasonal variation. In this study, the 6-hourly wind fields are analyzed for identifying the jet cores and the geographical border between the EASJ and EAPJ. Furthermore, the 6-hourly data are used to investigate the seasonal cycle of the EAPJ and its congruent relationship with the STEA over East Asia.

One robust feature of EASJ’s seasonal cycle is the rapid transition and location change of the jet core associated with the East Asian summer monsoon activity (Wang and LinHo 2002; Lim et al. 2002; Chen et al. 2004; Li et al. 2004; Zhang et al. 2006; Wu et al. 2007). According to previous studies, the EASJ demonstrates a northward jump from the south flank to the north flank of the TP in passing from the late spring to early summer (Li et al. 2004; Zhang et al. 2006; Schiemann et al. 2009). As the counterpart of the EASJ, the behaviors of the EAPJ and the associated STEA during late spring and early summer are still unclear. We shall try to address this issue when examining the seasonal cycle of the EAPJ and STEA. Specifically, we shall illustrate a harmonious activity of the EAPJ and STEA from April to June, when they both display a northward propagation.

In summary, the main questions to be addressed in this paper are the following:

1) What is the geographical border between the EASJ and EAPJ? What are the seasonal cycle, and the associated behavior of EAPJ, baroclinicity, and STEA over East Asia? In particular, what is the harmonious
activity of the EAPJ and STEA during the transition period from spring to summer?

2) What is the relationship among the dramatically increased surface sensible heat in the midlatitude band to the north of the TP, the strong atmospheric baroclinicity and the active STEA in spring?

The next section contains the descriptions of the data and analysis methodology. The general features of the seasonal marching of the EASJ, EAPJ, and STEA are presented in section 3. In section 4 we discuss why the baroclinicity and the STEA are more robust in spring. Section 5 provides a summary of conclusions and topics for further discussion.

2. Data and analysis methodology

The atmospheric data are from the 40-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40, Uppala et al. 2005). The data have a horizontal resolution of 2.5° × 2.5° in longitude and latitude and cover the period from 1 September 1957 to 31 August 2002. We use the 6-hourly and monthly-mean fields, as well as the data averaged for each pentad. The pentad data are created according to the following procedure: In each calendar month, the first 5 pentads are obtained by nonoverlapping, consecutive 5-day averaging applied to the first 25 days; and the last pentad is obtained by averaging the remaining days. Thus, every month (year) consists of a total of 6 (72) pentads.

The number of the jet cores per month at each grid point is calculated using the 6-hourly upper-level wind fields. A jet core is regarded to exist, and the corresponding latitude and longitude are recorded, if (1) the wind speed $|\mathbf{V}|$ is equal or greater than 30 m s$^{-1}$ and (2) the wind speed is the local maximum of the surrounding 24 grid points. The above counting procedure repeats for every day, month, and year. To extract the transient fluctuations associated with migratory synoptic-scale disturbances at periods of 2.5–6 days, a bandpass-filtered technique (Murakami 1979) is applied to the 6-hourly dataset at the 300-hPa level. STEA is measured by the variance of $\nabla^2 z$. The overbar represents averaging over a specified period, and the prime denotes perturbations with periods of $\sim$ (2.5–6) days. The regions of the mid-latitude ocean, over which abundant STEA span zonally, are referred to as storm tracks (Blackmon 1976).

The midlatitude STEA is primarily attributed to the atmospheric baroclinicity. An accurate measure of the baroclinicity is the Eady growth rate maximum (Eady 1949; Hoskins and Valdes 1990). It is defined as $\sigma_{BI} = 0.31 f (\partial \mathbf{V} / \partial z) N^{-1}$, where $f$ is the Coriolis parameter, $N$ the Brunt–Väisälä frequency, $\mathbf{V}$ the time-mean horizontal wind, and $z$ the vertical height. In general, the growth rate is calculated in the lower level of the atmosphere because the baroclinic development primarily occurs in the lower troposphere (Lunkeit et al. 1998). Therefore, the pressure levels of 850 and 700 hPa are used for computing $\sigma_{BI}$ in this study.

3. An overview of seasonal variations in EASJ, EAPJ, STEA, and $\sigma_{BI}$

a. Wind fields and number of the jet cores

Figure 1 shows the climatological distributions of the wind fields at 300 hPa over the East Asian–North Pacific regions for each of the four seasons. During the cool seasons (spring, autumn, and winter), the zonally prolonged EASJ south of 40°N is characterized by the strong westerly wind, while the EAPJ poleward side of the TP is anchored by the westerly and northwesterly wind. In winter and autumn, the wind speeds gradually decrease from the EASJ to the EAPJ regions, with no indication of there being a split between the two that can be taken as a geographical border between the two jets. In spring, the wind field displays a similar pattern as that in the winter; however, it shows an area of weak wind over the TP region. In summer, the EASJ is located along the north flank of the TP with significantly reduced intensity, accompanied by the disappearance of the EAPJ in the 50°–70°N band.

Figure 2 displays the distribution of the number of the jet cores at 300 hPa for each season. During seasons other than summer, the jet cores are concentrated mainly in two lobes, corresponding to the EASJ and the EAPJ regions. The dominant one is trapped zonally on the south flank of the TP, parallel with the other one on the poleward side of the TP. A distinct area with the minimum jet cores appears between the two lobes. This area extends zonally from the west side to the east side of the TP, indicating a clear geographical border between the two jet core lobes. This area can also be considered as the border between the EASJ and EAPJ in the cool seasons, especially in wintertime. In summer, accompanied with the northward jump of the EASJ, the south lobe is unanimously located along the north side of the TP. The number of the jet cores in the north lobe is dramatically reduced in the region of 50°–65°N.

b. STEA and $\sigma_{BI}$

The climatological distributions of the STEA at 300 hPa, and the Eady growth rate maximum $\sigma_{BI}$ between 700 and 850 hPa for the four seasons are shown in Fig. 3. Two branches of the STEA are located over the East Asian landmass. The strong northern branch is located in the
broad midlatitude bands and extends southeastward, while the weak southern branch is zonally elongated over the south flank of the TP and joins the northern branch over the East Asian coastal region. The STEA is much suppressed over the TP region. For the seasonal cycle aspect, the STEA in the northern branch is stronger in spring, autumn, and winter and weaker in summer, while the south branch of the STEA appears only in winter and spring. Accompanied by the two-jet state over East Asia, the baroclinicity over the landmass shows two noticeable bands. The dominant one is located on the poleward side of the TP; it has a spring maximum and a summer minimum, resembling the local STEA. The other $\sigma_{BI}$ band on the equatorward side of the TP appears only in spring and winter, with dramatically smaller values than that on the poleward side of the TP.

c. Latitude–pentad section of STEA, $\sigma_{BI}$

We further examine the details of seasonal marching of the synoptic-scale eddy activities and their associated large-scale flow in East Asian, especially in the EAPJ region. We attempt to show that both the STEA and EAPJ (also $\sigma_{BI}$) demonstrate northward propagation from April to June. It is one of the distinct features of the STEA over East Asia, compared with that over the North Pacific. The latitude–pentad sections of the climatological STEA, upper-level zonal wind fields, and low-level $\sigma_{BI}$ are shown in Figs. 4a, 5a, and 6a, respectively. The longitude bands of the section span over the East Asian region. To provide a convenient comparison with the features over the oceanic region, the sections over the North Pacific are depicted in Figs. 4b, 5b, and 6b, respectively. Figure 4a shows that the main body of the STEA (located poleward of $40^\circ$N and especially in the $45^\circ$–$70^\circ$N band) increases in strength from early spring and is continuously prosperous until the middle of June. Accompanied with this intensification, the center of the main STEA band conspicuously shifts poleward in May and June. It begins to get weaker after the middle of June, and reaches minimum strength in July and August. After reviving in early September, the STEA over East Asia goes into the second active period of the year. The STEA over the North Pacific (Fig. 4b) also demonstrates gradual northward movement from winter to summer. However, the extent of north–south shifting of STEA over the North Pacific is dramatically smaller than that over the East Asian region.

In cool seasons, the EASJ dominates the subtropical region over East Asia (Fig. 5a). It occupies the north side of the TP in July–August and retreats to the south...
side of the TP after September. The features of the northward–southward movement of the EASJ shown in Fig. 5a are generally consistent with the results of Schiemann et al. (2009). This previous study has examined in detail the transitions of EASJ in spring and autumn. Hence, here we focus on the EAPJ evolution. In contrast to the strong and quasi-steady EASJ, the EAPJ poleward of $40^\circ$N is highly transient, and displays detectable subseasonal variations (Fig. 5a). However, it is still notable that the EAPJ is more intensified in April and May. In early June, accompanied by a gradual decrease in wind intensity, the belt of strong EAPJ quickly migrates northward and dominates the higher latitudes. After the migration, the EAPJ is dramatically weakened in July and August. Its intensity recovers at midlatitudes in October and November. Over the oceanic region, the westerly jet stream is located in the subtropical region steadily during cool seasons and only moves northward slightly during summer (Fig. 5b).

Consistent with many previous studies, the evolution of $\sigma_{BI}$ over the oceanic area (Fig. 6b) does not match that of the local STEA (Fig. 4b). The STEA in Fig. 4b is robust in spring but not in winter, though $\sigma_{BI}$ (also the zonal wind shown in Fig. 5b) reaches its peak in winter, demonstrating the suppression of the Pacific storm track in midwinter (Nakamura 1992). In the EAPJ region in Fig. 6a, conversely, $\sigma_{BI}$ exhibits a marked maximum in spring accompanied with a prosperous STEA during the same period. The band with large $\sigma_{BI}$ values shown in Fig. 6a also expands northward in May and June, similar to the STEA behavior shown in Fig. 4a. In July and August, the values of $\sigma_{BI}$ decrease rapidly in both the EASJ region and the mid- to high latitudes. In autumn, large values of $\sigma_{BI}$ reappear in the midlatitude bands (Fig. 6a).

4. Why are the STEA and $\sigma_{BI}$ over East Asia prosperous in spring?

The analysis in section 3 demonstrates that both the upper-level STEA and lower-level baroclinicity poleward of the TP are prosperous in spring. This is another distinct feature of the STEA over East Asia, compared with that over the North Pacific. In this section, we attempt to show that the seasonal variation of the land–air interaction on the poleward side of the TP region, especially the sensible heat flux on the land surface, is partly responsible for the spring prosperity of the local STEA and $\sigma_{BI}$.

As mentioned early, the value of $\sigma_{BI}$ is mainly determined by the vertical wind shear $\partial |\mathbf{V}|/\partial z$ and the Brunt–Väisälä frequency $N$ in the lower-level troposphere. The detailed seasonal marching of $\partial |\mathbf{V}|/\partial z$ and $N$ are summarized by the latitude–pentad sections in Fig. 7.
Figure 7a suggests that, in the EAPJ region, the seasonal cycle of the wind shear does not completely match that of $\sigma_{HI}$ shown in Fig. 6a. For example, $\sigma_{HI}$ in the EAPJ region has a spring maximum, though the local wind shear reaches its maximum in late autumn and winter. The reason for the spring maximum of $\sigma_{HI}$ is that $\sigma_{HI}$ is also related to the seasonal cycle of the local $N$. The values of $N$ over the East Asian midlatitude landmass show a robust seasonal variation (Fig. 7c). It decreases rapidly from about 1.1 at the beginning of March to less than 0.8 at the end of May. Thus, the dramatically decreased $N$ contributes to the large local $\sigma_{HI}$ in spring jointly with the slightly weaker (compared with that in late autumn and winter) but still significant wind shear in the EAPJ region. In contrast, the values of $N$ over the oceanic region are relatively large (Fig. 7d). The values are bigger than unity even during the warm seasons, indicating that there is a comparatively stable atmosphere over the ocean. On the other hand, the amplitude of $N$ over the oceanic region during the entire year is small and nearly negligible. Therefore, the vertical wind shear shown in Fig. 7b is responsible for the seasonal cycle of $\sigma_{HI}$ in the oceanic region shown in Fig. 6b.

Figure 3. Climatological distributions of the STEA (contours, $m^2 s^{-2}$) at 300 hPa and the Eady growth rate maximum $\sigma_{HI}$ between 700 and 850 hPa (color shading, day$^{-1}$) for (a) spring, (b) summer, (c) autumn, and (d) winter.

Fig. 4. Latitude–pentad section of climatological STEA at 300 hPa for the longitude bands of (a) 80°E–120°E and (b) 160°E–130°W. The contour intervals are 15 m$^2 s^{-2}$ for (a) and 30 m$^2 s^{-2}$ for (b).
The rapid decrease of $N$ in the EAPJ region in spring indicates a decrease in local static stability. This could be caused by either of the following two factors: a decrease in the difference in potential temperature ($\Delta \theta$), or an increase in the thickness ($\Delta z$) between two pressure levels. Figure 8 shows the latitude–pentad sections of $\Delta \theta$ and the $\Delta z$ between the 700- and 850-hPa levels. Clearly, over both the landmass and the oceanic regions, the thickness between the two levels increases steadily from January to July and then decreases gradually afterward. In contrast, the evolution of the $\Delta \theta$ over the landmass bears close resemblance to that of $N$, suggesting that the rapid decrease in $N$ to the north of the TP in spring is mostly attributed to the local decrease in $\Delta \theta$.

Most of the EAPJ region is arid or semiarid with relatively small rainfall climatologically. This region is desert or semidesert, with scattered vegetation cover. In spring, the land surface in this region is bare soil with little soil moisture (Xu et al. 2006). With the rapid increase in solar radiation in spring, the land surface is warmed up and then heats the low-level atmosphere mainly through the surface sensible heat flux. At the same time, the intensified turbulent diffusion can transport the heat from the lower to higher levels (Qian et al. 2006; Song et al. 2009). The upper panels in Fig. 9 show the latitude–pentad sections of the surface sensible heat over the East Asian landmass and the western North Pacific. The rapid decrease in $N$ in the EAPJ region in spring (Fig. 7c) is accompanied by a dramatic increase in the local sensible heat flux (Fig. 9a). The lower panels in Fig. 9 depict time evolutions of the air temperature at 850 and 700 hPa for the two regions. Figure 9e shows that over the landmass as the air is heated via the sensible heat flux in spring; the air temperature at 850 hPa increases more rapidly than that at 700 hPa. This leads to a rapid decrease in $\Delta \theta$ between 850 and 700 hPa (Fig. 8a), and a simultaneous significant decrease in static stability in the lower troposphere (Fig. 7c). In contrast, over the oceanic region the temperature difference between the two levels shows weaker changes in the whole year (Fig. 9d).
though the seasonal variation of the sensible heat flux is significant (Fig. 9b). This leads to smaller variations in \( \Delta \theta \) and \( N \) (Figs. 7d and 8b).

To further investigate the relationship between the STEA, \( \sigma_{HI} \), wind vertical shear, \( N \), \( \Delta \theta \), and surface sensible heat flux in the EAPJ region in different seasons, Fig. 10 shows the scatter diagrams between each pair of the elements from the above list. The first two rows in Fig. 10 are for the EAPJ region, and the third row is for the North Pacific region. Climatologically, a simple quasi-linear relationship is found between STEA and \( \sigma_{HI} \) in the EAPJ region. That is, the strong \( \sigma_{HI} \) in the EAPJ region corresponds to active local STEA (Fig. 10a). Figures 10b,c tell that in the EAPJ region, \( \sigma_{HI} \) is mainly determined by local wind shear in winter, autumn, and summer. However, in spring the relationship between \( \sigma_{HI} \) and wind shear is not obvious, and \( \sigma_{HI} \) is jointly affected by wind shear and \( N \). This result is in distinct contrast to that in the oceanic region where the seasonal cycle of the wind shear is always responsible for the local \( \sigma_{HI} \) (see Figs. 10h,i). In the EAPJ region, the overall seasonal marching of \( N \) shows a quasi-linear relationship with that of \( \Delta \theta \) (Fig. 10d). The relationship between the sensible heat flux and \( \Delta \theta \) shows a seasonal dependence to a certain extent (Fig. 10e). The long oblique blue-dotted lines in Figs. 10e,f demonstrate that,
from March to May, $\Delta \theta$ and $N$ decrease robustly accompanied with the rapid increase in surface sensible heat flux. Thus, the large local $\sigma_{BI}$ is maintained in spring. The long, oblique yellow lines for autumn in Figs. 10e,f demonstrate an opposing process, that is, an unfavorable condition for the local $\sigma_{BI}$. In Figs. 10b,c, the two blue dots near the purple ones (representing summer) correspond to the last two pentads of May, when the atmospheric circulation begins to transform from spring to summer patterns. Thus, the relationship between the two variables bears some resemblance to that in summer.

How the atmospheric boundary processes influence the eddy activity is an interesting issue. Recently, Zhang et al. (2009) discussed the equilibrium response of eddy activity to different boundary layer processes by using a plain multilevel quasigeostrophic channel model with interactive static stability and a simplified parameterization of atmospheric boundary layer physics. Their model results show that boundary processes, for example, the turbulent vertical heat transport and the surface heat flux, play important roles in baroclinic eddy equilibration. This is carried out through modifying the mean flow and maintaining the mean flow available energy. These processes result in more active eddy activities. The model results of Zhang et al. (2009) are confirmed in this study using the reanalysis data. Namely, in the EAPJ region, the rapid increase in the sensible heat flux in spring and the associated boundary processes (the decrease in $\Delta \theta$ between 700 and 850 hPa, and the increase in the turbulence transport) lead to the decrease in the static stability and the increase in $\sigma_{BI}$ at the lower level. This is favorable to the active STEA in spring.

5. Conclusions and discussion

In this paper we attempt to investigate the seasonal variations of the jet streams and the associated synoptic-scale eddy activities over the East Asian landmass, with an emphasis on the seasonal marching of the East Asian polar front jet and the STEA. We try to explore an explanation for the spring prosperity of the STEA and low-level baroclinicity in the EAPJ region.

Through counting the number of jet cores in the 6-hourly wind fields combined with the monthly fields, the geographical border between the EASJ and EAPJ is identified. This border lies at the latitudes of the northern part of the Tibetan Plateau. In the summer season as a consequence of the northward jump of the EASJ and the disappearance of the EAPJ, the two-jet state is replaced by a single jet pattern of the EASJ over East Asia. Corresponding to the two-jet state in the cool seasons, two branches of the STEA and baroclinicity dominate over the East Asian landmass. The active northern branch is located to the north of the TP and the weak southern branch is zonally elongated over the south flank of the TP. Associated with the single jet pattern in the warm season, the relatively weakened STEA belt is located in the mid- to high-latitude bands, while the STEA and the
baroclinicity along the south flank of the TP disappear with the absence of the strong local westerlies. The STEA over the TP region is suppressed throughout the entire year.

By examining the latitude–pentad sections of the climatological STEA, and upper-level zonal wind fields and low-level baroclinicity in the EAPJ region, it is revealed that the STEA in the EAPJ region demonstrates spring


