Propagating and influence on tropical precipitation of intraseasonal variation over mid-latitude East Asia in boreal winter

1. Introduction

Intraseasonal variations have been identified over the mid-high latitudes of East Asia in boreal winter (Jeong et al. 2005, 2008; Park et al. 2010; He, Lin, and Wu 2011; Yang and Li 2016; Yao et al. 2016; Song et al. 2016; Song, Wu, and Jiao 2018), and they have a large influence on the weather and climate over East Asia. For example, Song, Wu, and Jiao (2018) showed that intraseasonal oscillations play a large role in sustaining persistent strong cold events, such as the one in late-January 2016 – the so-called ‘century cold wave’, which set a new lowest-temperature record in many low-latitude East Asian regions (Song and Wu 2017). Thus, it is important to understand the characteristics, influences, and processes of intraseasonal variations over East Asia in boreal winter.

Most previous studies about intraseasonal variations over East Asia in boreal winter focus on their influence on temperature in mid-high latitude and subtropical regions (Jeong et al. 2005; He, Lin, and Wu 2011; Yang and Li 2016; Yao et al. 2016; Song et al. 2016; Song, Wu, and Jiao 2018). Here, we investigate plausible impacts of intraseasonal variations over midlatitude East Asia in other regions — in particular, precipitation in the tropics. Some studies have indicated that intraseasonal sea surface temperature and rainfall variations in the South China Sea may be induced by a southward propagating intraseasonal wind signal (Wu and Chen 2015; Wu 2016). Cao and Wu (2017, 2018) revealed that northerly wind anomalies related to the East Asian winter monsoon play a dominant role in 10–20-day intraseasonal rainfall variations over the southern South China Sea and near the east coast of the Philippines in boreal winter. However, these studies only considered the southward propagating signal from the subtropical region. The question remains as to whether the mid-latitude intraseasonal wind signal over midlatitude East Asia can propagate to the equatorial region and contribute to tropical rainfall intraseasonal variations.

In the present study we examine the propagation characteristics of intraseasonal wind variations over midlatitude East Asia and their influence on intraseasonal fluctuations...
of tropical rainfall. The rest of the paper is organized as follows: The data and methods used in the study are described in Section 2. Section 3 shows two different propagation directions of the wind field at the 9–29-day time scale. Section 4 presents the effect of southward propagating intraseasonal wind variations from midlatitude East Asia on tropical rainfall. A summary and discussion are provided in the final section.

2. Data and methods

The present study utilizes daily data from the NCEP-DOE Reanalysis-2 (Kanamitsu et al. 2002), which is available since 1979. Variables used include meridional and zonal wind, vertical velocity on 2.5°×2.5° grids at pressure levels, and surface wind at 10 m on T62 Gaussian grids. Precipitation is derived from the GPCP 1° daily precipitation dataset (Huffman et al. 2001), which is available since October 1996.

Our analysis focuses on intraseasonal variations on the 9–29-day time scale. Previous studies have indicated that boreal winter intraseasonal variability over East Asia displays obvious peaks above and below a 30-day time period (Yang and Li 2016; Yao et al. 2016; Cao and Wu 2017), and the characteristics of intraseasonal variations with 10–20-day and 30–60-day periods are different (Ye and Wu 2015). Meanwhile, our comparison shows that the variance of intraseasonal wind variations in winter in East Asia is dominated by that with a period shorter than 30 days (figure not shown). This study focuses on the intraseasonal signal in boreal winter covering November through March (NDJFM). Our analysis covers the time period from 1979/80 to 2015/16, except for the precipitation that is available from 1996 to 2015.

Following the method of Wu and Chen (2015) and Wu (2016), the intraseasonal variations on the 9–29-day time scale are obtained by a 9-day running mean minus a 29-day running mean. Composite analysis is utilized to obtain common features for different types of cases. The Student’s t-test is used to estimate the level of statistical significance for the composite anomalies.

3. Propagation characteristics of intraseasonal variation over East Asia

Lower-level wind is a fundamental element of the East Asian winter monsoon system and it has a direct impact on weather. So, we analyze the meridional wind variations at 850 hPa to detect the characteristics of intraseasonal variation over midlatitude East Asia. Figure 1(a–c) show the first three EOF modes of the

Figure 1. The (a–c) first three EOF modes of meridional wind variations at 850 hPa, (d) lead–lag correlation between PC1, PC2, and PC3 during NDJFM from 1979/80 to 2015/16, and (e) lead–lag correlation between the area-mean meridional wind at 850 hPa in the north region (frame in (a)), east region (frame in (b)), and south region (frame in (c)) during NDJFM of 1992 and 1999 on the 9–29-day time scale.
meridional wind variations at 850 hPa on the 9–29-day time scale in the domain (15°–60°N, 90°–150°E) during NDJFM from 1979/80 to 2015/16. The three modes account for about 20.5%, 17.2%, and 11.6% of the 9–29-day variance, respectively. The leading mode has large negative loading along the east coast of the Asian continent (Figure 1(a)). The second mode has large negative loading extending from the Sea of Okhotsk to the subtropical western North Pacific. The third mode displays a north–south contrast of loading between the midlatitudes and the subtropics. The principal component of the first mode (PC1) leads that of the second mode (PC2) and the third mode (PC3) by about 3–9 days (Figure 1(d)). This lead–lag correlation and the spatial distribution indicate that the intraseasonal wind signal may propagate both eastward and southward. This feature is confirmed by the lead–lag correlation of area-mean 850-hPa meridional wind variations on the 9–29-day time scale in three regions as shown in Figure 1(a–c), which are denoted as the north, east, and south region, respectively. Figure 1(e) displays two examples for the lead–lag correlation between the north region and the east/south region. In 1992, the correlation of meridional wind between the south and north region is above 0.4 when the meridional wind in the north region leads by 1–7 days, whereas the correlation between the east and north region is weak. This indicates that the intraseasonal wind signal is dominated by a southward propagation in 1992. In 1999, the correlation of meridional wind between the east and north is above 0.4 when the meridional wind in the north region leads by 4–11 days, whereas the correlation between the south and north region is relatively weak (below 0.3). This suggests that the intraseasonal wind signal has a larger eastward propagation component in 1999.

To investigate the propagation characteristics further, we examine the day-to-day variations of the 9–29-day filtered area-mean meridional wind in the three regions in every year. Then, we select eastward and southward propagation cases based on the following criteria. First, we identify the peak days when the meridional wind values in the north region are greater than one standard deviation of the whole time series. Then, if the meridional wind value in the north region is declining and at the same time the meridional wind value in the east (south) region is rising to more than one standard deviation within a time interval of 12 (10) days, it is considered as an eastward (a southward) propagation case. The peak day of the meridional wind in the north and east (south) region is considered as the beginning and end phase of each case, respectively. In order to differentiate eastward from southward propagation, we only consider those monodirectional propagation cases. In other words, those cases when the meridional wind in both the east and south regions rises to one standard deviation after the peak of the meridional wind in the north region are excluded in the following analysis. The selection of the 12- or 10-day time interval is based on the temporal evolution of the area-mean meridional wind in the three regions. According to the above criteria, we identify 44 eastward propagation cases and 36 southward propagation cases. The time interval varies from case to case. The average time interval between the beginning and end phases for the eastward and southward propagation cases is 7 and 6 days, respectively. The maximum time interval is 12 and 10 days, respectively. Figure 2 presents the composite 850-hPa wind anomalies for the two types of propagation cases. Middle phases 1 and 2 are determined by dividing the time interval between the beginning and end phases by 3 for each individual case.

The composite 850-hPa wind-anomaly evolution shows clear differences between the eastward and southward propagation cases. In the beginning phase, a large anomalous cyclone is located over the Sea of Japan in both cases (Figure 2(a and e)). In comparison, an anomalous cyclone and anomalous northerly winds have a larger meridional extension in the southward propagation cases. In the eastward propagation cases, the anomalous cyclone remains intact and just moves eastward to the midlatitude North Pacific (Figure 2(a–d)). In the end phase, an anomalous anticyclone controls northeastern China (Figure 2(d)). Given an average time interval of 7 days from the beginning to end phase, the average moving speed is about 4° of longitude per day. In the southward propagation cases, the anomalous cyclone weakens and anomalous northerly winds migrate southward to the equatorial region (Figure 2(e and f)). In the end phase, the whole South China Sea is covered by strong anomalous northeasterly winds, with anomalous convergence and divergence over the southern South China Sea and eastern China, respectively (Figure 2(h)). These results indicate that the eastward propagation mainly features the eastward migration of anomalous cyclones and anticyclones and southward propagation is characterized by southward migration of anomalous northerly winds from midlatitude East Asia to the equatorial region.

4. Impact of intraseasonal variation on tropical precipitation

Previous studies found that intraseasonal variations in tropical precipitation around the Maritime Continent have a linkage to East Asian winter monsoon activity. Large rainfall anomalies over the southern South China Sea are preceded by strong northerly wind anomalies in the northern South China Sea and subtropical western
Section 3 shows that a distinct northerly wind signal on the intraseasonal time scale can propagate from midlatitude East Asia to the equatorial region. This section examines the intraseasonal rainfall variations in the southward propagation cases.

Figure 3 displays the composite rainfall and 10-m wind anomalies from the beginning phase to 4 days after the end phase for 14 southward propagation cases during 1996/97 to 2014/15.

In the beginning phase, the precipitation anomaly distribution displays a tripole pattern from the tropics to the midlatitudes (Figure 3(a)). Positive rainfall anomalies are observed over the eastern China–subtropical western North Pacific region in association with anomalous northerly wind convergence. Negative rainfall anomalies along the East Asia Seas and northern Pacific Ocean are associated with anomalous southerly wind convergence in the midlatitudes.
10°–20°N are attributable to an anomalous anticyclone over the tropical western North Pacific. The southern South China Sea has positive rainfall anomalies due to anomalous northerly wind convergence. Following the southward migration of anomalous northerly winds, positive rainfall anomalies in the north move southward and are replaced by negative rainfall anomalies (Figure 3(b and c)). At the same time, negative rainfall anomalies along 10°–20°N weaken. In the end phase, positive rainfall anomalies increase over the eastern China–Japan region following a switch in the anomalous wind direction that leads to anomalous divergence (Figure 3(d)). In the meantime, positive rainfall anomalies over the southern South China Sea increase because of enhanced anomalous wind convergence. In the following days, both positive rainfall anomalies in the southern China Sea and negative rainfall anomalies over eastern China decrease with the weakening of wind anomalies (Figure 3(e and f)).

Notably, when positive rainfall anomalies increase over the southern South China Sea, negative rainfall anomalies develop over midlatitude Asia with large anomalous northerly winds in between (Figure 3(c–e)), consistent with Wu (2016). Thus, there is anomalous convergence and upward movement and anomalous divergence and downward movement over the tropics and midlatitudes, respectively. This indicates there may be an anomalous vertical circulation in the meridional direction. To confirm this, we analyze the divergent component of anomalous meridional wind and anomalous vertical velocity at pressure levels. Figure 4 presents the evolution of the composite anomalous meridional circulation along 100°–117.5°E for the southward propagation cases.

In the beginning phase, an anomalous vertical cell is present between 20°N and 45°N (Figure 4(a)). Both anomalous descent in the north and anomalous northerly wind at the lower level intensify and move southward in the following phases (Figure 4(b and c)). In the end phase, anomalous downward motion reaches a peak, with the center along 30°–35°N (Figure 4(d)). Following the southward movement of anomalous lower-level northerly winds, anomalous upward motion near the equator intensifies, forming an anomalous overturning cell between the

![Figure 3. Composite precipitation (color shading; units mm d$^{-1}$) and 10-m wind anomalies (vectors; units: m s$^{-1}$) for southward propagation cases on the 9–29-day time scale during NDJFM from 1996/97 to 2014/15. Dark red dots denote precipitation anomalies that are significant at the 90% confidence level. Only wind anomalies that are significant at the 90% confidence level are plotted. The wind scale is shown in the bottom-right corner.](image-url)
tropics and midlatitudes. In the following days, anomalous vertical motion in the tropics becomes weak and anomalous downward motion in the subtropics weakens, accompanied by the appearance of an anomalous vertical cell of opposite direction to the north (Figure 4(e and f)).

We also examine the intraseasonal rainfall variations in the 20 eastward propagation cases during 1996/97 to 2014/15. The composite rainfall anomalies appear weaker and have smaller spatial coverage compared to the southward propagation cases. Positive rainfall anomalies are confined to east of the Philippines in middle phase 2 through 2 days after the end phase, and the northwestern South China Sea in the end phase to 4 days after (figure not shown). Both are associated with easterly wind anomalies.

5. Summary and discussion

The present study reveals that the 9–29-day intraseasonal wind signal over midlatitude East Asia in boreal winter can propagate both eastward and southward. In eastward propagation cases, the low-level wind signal is characterized by an eastward migration of anomalous cyclones and anticyclones along the midlatitudes. The average eastward moving speed is about 3–4° of longitude per day, based on composite analysis. In southward propagation cases, the midlatitude anomalous cyclones and anticyclones weaken and anomalous meridional winds move southward from the midlatitudes and reach the equatorial region. In addition to the eastward and southward propagation dominant cases, there are over 20 cases when southward propagation of northerly winds is accompanied by an eastward propagation component (not shown).

The southward propagating meridional wind anomalies induce prominent rainfall anomalies in the equatorial region. When anomalous meridional winds cover the South China Sea, opposite anomalous lower-level convergence/divergence and rainfall anomalies form over the southern South China Sea and eastern China–Japan region. An anomalous vertical cell is established between the tropics and midlatitudes, which plays an important role in linking the intraseasonal rainfall variations between the southern South China Sea and midlatitude East Asia.
There are two issues relevant to the present study worthy of investigation in the future. The first is what determines the propagation direction of intraseasonal wind anomalies over East Asia. Such change in the propagation direction is related to when intraseasonal wind signals over midlatitude East Asia may induce intraseasonal tropical rainfall anomalies. The other issue is whether intraseasonal variations over the tropics may affect those over midlatitude East Asia. The present study focuses on the impacts of midlatitude intraseasonal wind variations on tropical rainfall anomalies. It is possible that the intraseasonal rainfall changes around the Maritime Continent may affect midlatitude Asia through anomalous heating-induced circulation changes, such as meridional overturning circulation between the tropics and midlatitudes.

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Disclosure statement

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