

A seesaw pattern of summertime precipitation over North Eurasia and associated Rossby waves

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1. Introduction

In North-East Asia (Mongolia and Inner Mongolia), a large part (~60%) of precipitation occurs during summer [Yatagai and Yasunari, 1995], so the summertime precipitation has a large impact on the ground environment. This region experienced high precipitation summers in the mid- to late 1990s and low precipitation summers from 1999 to 2002 [Iwao and Takahashi, 2006]. This drought led to recent natural disasters, e.g., the megadeath of livestock in winter [Morinaga and Shinoda, 2003] and the increase of dust events [Kurosaki and Mikami, 2003]. In this region, a break in the rainy season was found by Iwasaki and Nii [2006] who suggested that it sometimes occurs in July in association with large-scale atmospheric (Rossby) waves over the Asian jet.

Iwao and Takahashi [2006] found a seesaw pattern between North-East Asia and Siberia in interannual variation of summertime precipitation. They suggested that this pattern is also associated with Rossby waves propagating eastward both over the subtropical jet and over Northern Eurasia. Wave trains over these two regions in summer are well known as dominant Rossby wave patterns propagating on wave guides over Eurasia continent [Enomoto *et al.*, 2003; Nakamura and Fukamachi, 2004; Sato and Takahashi, 2006]. Iwao and Takahashi [2006] showed possible process that the Rossby waves over the subtropical jet affects the precipitation in North-East Asia, and that the waves over Northern Eurasia affect the precipitation in Siberia. However, the reason is not clarified why the wave propagation over these two regions appears simultaneously to form the seesaw pattern.

On the other hand, Terao [1998] investigated interseasonal variations of the atmosphere over the Eurasian continent during summer. He mainly focused on two types of low-frequency waves over the subtropical jet, i.e., a 25- to 60-day standing wave with a 6 or 7 zonal wave number and a 15- to 25-day eastward traveling wave with a 3 to 8 zonal wave number. Moreover, standing and traveling waves with a 3 or 4 zonal wave number over Northern Eurasia at 70N latitude were briefly subscribed through a case study for one year (1983).

In this study, we investigate the precipitation seesaw pattern by analyzing the low-frequency interseasonal variations over the subtropical jet and over Northern Eurasia during summer. We try to explain the appearance of the seesaw pattern from the behavior of Rossby waves

over these two regions.

2. Data and analysis method

To investigate the interannual change in summertime precipitation, monthly mean precipitation data were prepared for 39 stations over North-East Asia and Siberia (Figure 1) from two daily datasets of Global Daily Climatology Network (GDCN) and Global Summary of Day (GSD) compiled by National Climatic Data Center (NCDC). This data were averaged from June to August (JJA) for years 1961-2002.

For meteorological fields, we use 6-hourly datasets of the European Centre for Medium-Range Weather Forecast, 40 year Re-Analysis (ECMWF ERA40), which have horizontal resolution of 2.5x2.5 (latitude/longitude) grids and 23 pressure levels from 1000 to 1 hPa, and cover the period from 1958 to 2002. Low-frequency daily anomaly data were constructed using ERA40 data as follows. First, climate daily data were made by averaging from 1958 to 2002 for each calendar day, and then, applying the running mean of 31-day. The low-frequency anomaly data were calculated by applying the Butterworth 10-day low-pass filter to daily anomalies from the climate daily data. We examine this low-frequency data for summers (JJA) from 1961 to 2002.

3. Results

3.1 A precipitation seesaw pattern

Iwao and Takahashi [2006] showed the seesaw pattern in interannual July precipitation change (1979-2004) using grid data. In order to confirm the seesaw pattern, we apply the Empirical Orthogonal Function (EOF) analysis to the interannual change in summertime (JJA) precipitation from 1961 to 2004 for 39 stations evenly selected over North-East Asia and Siberia. The EOF is calculated to the precipitation change after the normalization. Figure 1 shows the spatial pattern and the interannual change of the first EOF mode which explains 15% of the total variance. Stations with positive values are extended over Mongolia and the southeast of Mongolia, while negative values are distributed over Siberia particularly to the northwest of Lake Baikal. Though the boundary of these two regions is not sharp as shown in Iwao and Takahashi [2006], the seesaw pattern is obviously seen between North-East Asia and Siberia. The interannual change of this seesaw mode (Fig.1b) indicates high scores in the mid-1990s and low scores

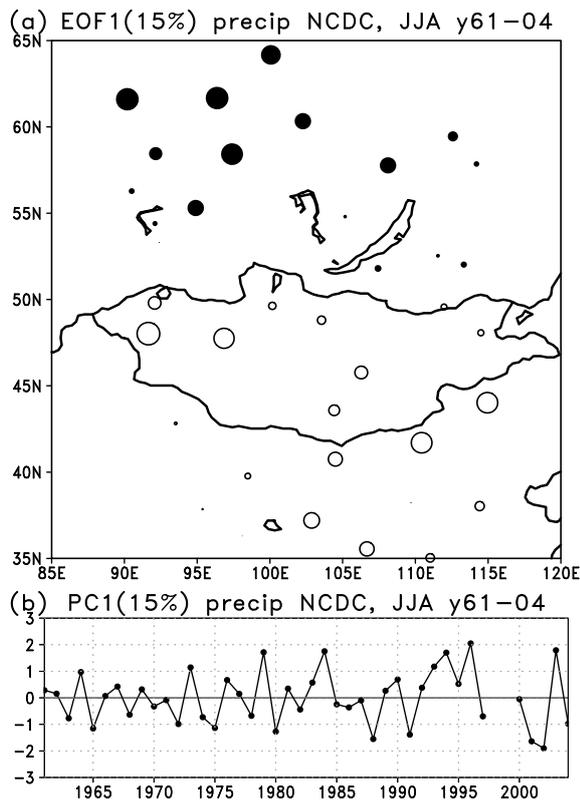


Figure 1: (a) The horizontal pattern and (b) the time coefficient of the first EOF of interannual change in summertime precipitation from 1961 to 2004 for 39 stations over Northern Eurasia (90-115E, 35-65N). Open and close circles in (a) show positive and negative values, respectively.

especially in 2001 and 2002. These results are generally consistent with *Iwao and Takahashi* [2006], while data are missing in 1998 and 1999 for station data.

3.2 Low-frequency variation over two jets

As mentioned in Introduction, it is known that there are wave guides over the subtropical jet and over Northern Eurasia. In order to investigate the relationship between Rossby waves on these two regions, we apply the EOF analysis to the low-frequency daily variation of meridional winds along latitudes of 40N and 60N over the Eurasia continent (30E-150E) for summers (JJA) from 1961 to 2002. Figure 2 shows spatial patterns of the first and second modes of the EOF (VEOFs 1 and 2). If the waves along two latitudes are completely independent, these waves would be extracted as different modes. However, VEOFs 1 and 2 have signals along two latitudes together, suggesting relationship between waves along two latitudes. In both patterns of VEOFs 1 and 2, the waves along 40N and 60N have zonal wave lengths of about 60 and 80 longitudes, respectively, which are consistent with the atmospheric wave theory [e.g., *Hoskins and Ambrizzi*, 1993]. Moreover, anomalies along two latitudes show opposite phases over eastern Eurasia

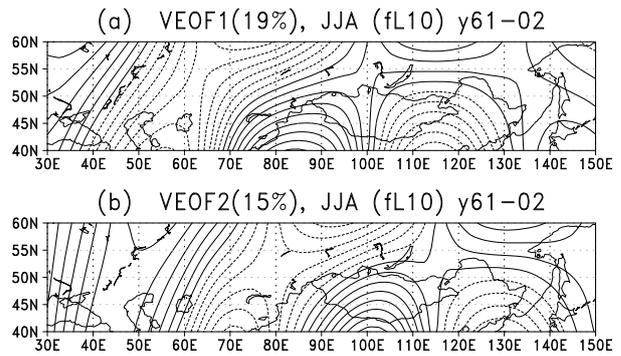


Figure 2: (a) First and (b) second EOF patterns of low-frequency daily variations of meridional wind (VEOFs 1 and 2) during summer from 1961 to 2002 along two latitudes 40N and 60N over the Eurasia continent (30-150E).

and closer phases toward the west. The pattern of VEOF 2 is seen to be shifted eastward from VEOF 1 roughly by a quarter wavelength, so that both EOF modes can explain not only standing waves but also traveling waves in the zonal direction.

When the spectrum analysis is conducted to the reconstructed fields from VEOFs 1 and 2 (not shown), we can find a strong peak in 46-day standing waves and a relatively weak peak in 18-day eastward traveling waves. All of these features are consistent with *Terao* [1998] except for that the wave length over Northern Eurasia is slightly shorter in this study. The difference could be caused by the difference of investigated latitude.

Based on the Principal Components of the VEOFs (VPCs 1 and 2), we try to identify associated phases of VPCs with the precipitation seesaw mode. Figure 3 shows probability density anomalies from the Gaussian distribution on the plane of VPCs 1 and 2 plotted for high (low) precipitation years over North-East Asia (Siberia), Fig.3a, and low (high) precipitation years over North-East Asia (Siberia), Fig.3b. Significant years of the precipitation seesaw mode are defined on the basis of the time coefficient of the precipitation EOF (Fig.1b) as top or bottom seven years. High probability is seen at the fourth quadrant in Fig.3a, while the probability is high roughly at the second quadrant in Fig.3b. It means that meridional wind anomalies with the fourth quadrant phase appear frequently in high (low) precipitation years over North-East Asia (Siberia), and the anomalies with the second quadrant phase appear frequently in high (low) precipitation years over Siberia (North-East Asia). By comparing with spatial distribution of VEOFs 1 and 2 (Fig.2), the fourth and second quadrant phases indicate strong meridional wind anomalies around the 100-115E longitudinal region at 40N and around the 92-115E region at 60N, where the precipitation seesaw is clear in Fig.1a.

3.3 Anomalies associated with the seesaw pattern

In order to investigate anomaly fields associated with

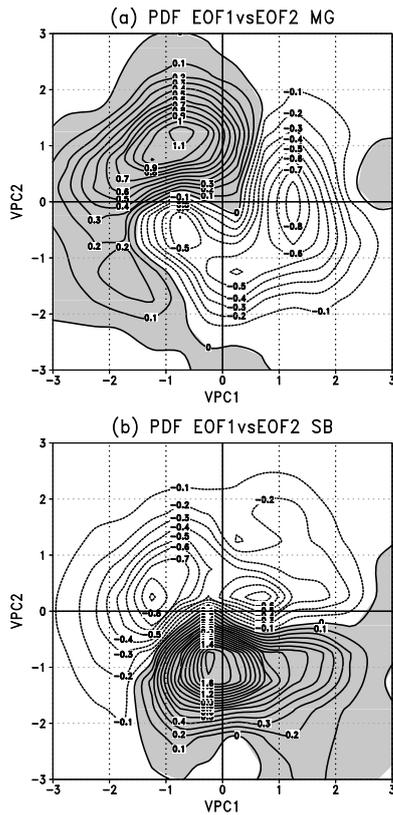


Figure 3: Deviation of probability density (%) from the Gaussian distribution on the plane of VPCs 1 and 2 for (a) top seven years and (b) bottom seven years of Fig. 1b. The coordinate is normalized by the standard deviation of VPC 1. Positive values are shaded.

the precipitation seesaw pattern, we composite low-frequency variations of events with the fourth and second quadrant phases in Fig.3. The composited events are selected to fulfill a threshold condition that the VPCs 1 and 2 are plotted in the fourth or second quadrant in Fig.3 and the magnitude exceeds 1, more than five days. As a result, 36 and 35 events are selected to construct composite fields for the fourth and second phases, respectively, which we call VMG and VSB cases. The VSB events are highly concentrated in July (not shown) corresponding to the break in rainy season [Iwasaki and Nii, 2006], and the VMG events are also concentrated in July. This feature is consistent with that the seesaw pattern is significant in July [Iwao and Takahashi, 2006].

Figure 4 shows the composited geopotential height anomalies and the associated wave activity fluxes [Takaya and Nakamura, 2001] at 300 hPa for the VMG case from -8 to 0 day (Fig.4a to c). The time development of the anomalies seems like eastward propagation of quasi-stationary waves. The geopotential height anomalies located around England and East Europe on -8 day propagate eastward and branch off in the south-north direction around the 30E longitude. The waves propagating over the subtropical jet and Northern Eurasia

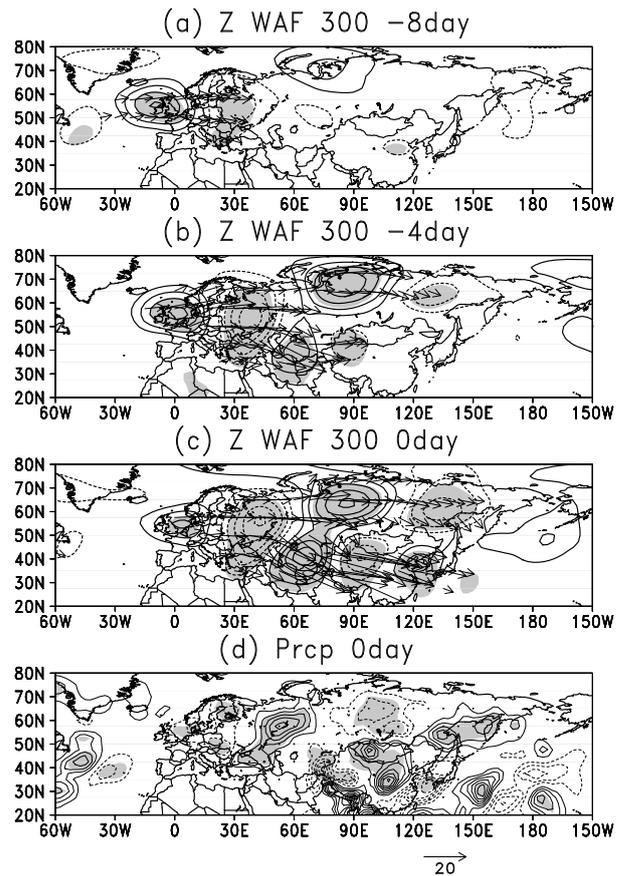


Figure 4: Composited anomalies of geopotential height (contoured with 20 m intervals) and wave-activity fluxes (vectors) at 300 hPa from (a) -8, (b) -4, (c) 0 days, and (d) the precipitation anomalies (0.25 mm/day intervals) on 0 day for the VMG case. Shadings show the significant area above the 95% confidence level. See the text for detail.

get out of phase toward the east due to the difference of longitudinal wave lengths on -4 day. On 0 day, the phases get opposite around the 100E longitude, and high and low precipitation anomalies are found over North-East Asia and over Siberia (Fig.4d). A similar development of anomalies can be seen in the VSB case (not shown), while all the signs are opposite.

Further examination using budget analyses of vorticity, heat, and water vapor shows that the horizontal advection of vorticity is mainly balanced with the stretching effect in the upper troposphere, and the associated vertical flow anomalies in the middle troposphere are balanced with the condensation heating. The anomalous condensation is the direct cause of precipitation anomalies over these two regions.

4. Concluding remarks

A seesaw mode of summertime precipitation between North-East Asia and Siberia is investigated from a view point of interseasonal variations over the subtropical jet and over Northern Eurasia. It is found that there is a wave

propagating mode over these two regions originated from a same atmospheric anomaly around England. The eastward propagating Rossby waves from England tend to branch off onto the two wave guides and propagate further. Over eastern Eurasia, these waves get out of phase due to the difference of longitudinal wavelengths, which would be one of causes of the precipitation seesaw pattern.

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