# Climatic features of the water vapor transport around East Asia during June and September

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**Abstract**

Climatic features of water vapor transport, which is closely related to precipitation in the middle latitudes around East Asia, are investigated using a reanalysis data in June and September. The maximum pole-ward water vapor transport is formed along the continental coast in June, although it is formed over the western Pacific Ocean. The water vapor in June is quasi-stationary transported from low latitudes to high latitudes. On the contrary, the intermittently transportation of water vapor is clearly confirmed in September. It is indicated that the water vapor is primary transported by the southwesterly low-level wind due to the heat contrast between land and ocean in June. In September, it reveals that almost 92% of the total amount of pole-ward water vapor is transported by typhoons in 1998. It is suggested that Typhoon has an important role to form the climatic atmospheric field around East Asia in September.

*Keyword: Typhoont, Baiu, Akisame,Water vapor transport*.

## 1. Introduction

Baiu and the Akisame front formed in the early summer and early autumn. Many studies suggested that the pole-ward water vapor is very important to form the rainfall zones. Asakura (1971) indicated that the amount of water vapor transport from the southwest to rainfall zone is quite large in early summer (Baiu season). Murakami et al. (1962) indicated that the water vapor from the southeast to rainfall zone is remarkable in early autumn (Akisame season). However, there are few studies considered the difference of the water vapor transport and amount between Baiu and Akisame season from the climatic view point. In this study, difference in feature of the water vapor transport is investigated between Baiu and Akisame using a reanalysis data.

## 2. Features of water vapor transport

The water vapor transport is evaluated the vertical accumulated value from 1000hPa to 300hPa of reanalysis data every six hours of National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR). Figure 1 shows that the 20 year accumulated monthly water vapor distribution of June (Fig.1a) and September (Fig.1b), and the 20 year averaged monthly precipitation of June (Fig.1c) and September (Fig.1d) from 1980 to 1999. In the area between 25-30N degrees, water vapor is strongly transported pole-ward along the continental coast in June, although the water vapor is transported over the Ocean in September. Amount of the 20 year accumulated water vapor transport in June through the Region A (30N, 120E-150E) is about 2.3 times as in September. Accumulated water vapor transport of 20 year through the Region A in June and September are estimated about 3.38×1016 ton and 1.49×1016 ton, respectively. It is indicated that the difference of the amount of water vapor between June and September is corresponded to that of rainfall in the mid latitudes (Fig.1c and 1d). Many meteorologists have been indicated that the difference of the location of maximum water vapor between June and September is also corresponded to the difference of rainfall distribution between those months (Akiyama, 1975; Matsumoto, 1988). In June, it is found that the rain band, which is called the Mei-yu front in Chinese, is formed over the China continent, although the Mei-yu front is unclear in September. The same feature is pointed out by the study of T. C. Chen et al. (2004). It can be also found that the precipitation of Akisame front in September is smaller than that of Baiu front in June (Fig. 1c and 1d).

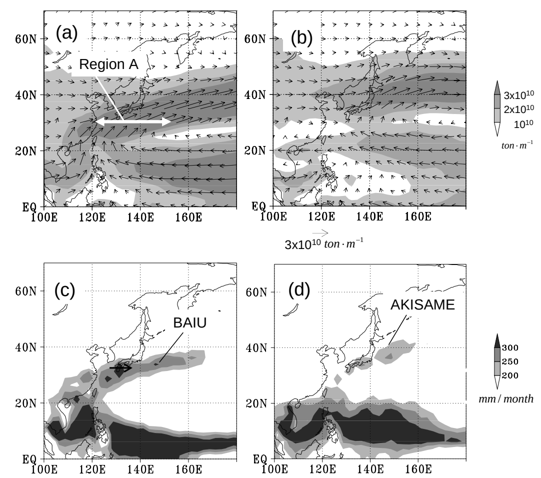


**Fig. 1**: 20 year accumulated monthly water vapor distribution of June (Fig.1a) and September (Fig.1b), and the 20 year averaged monthly precipitation of June (Fig.1c) and September (Fig.1d) from 1980 to 1999.

Figure 2 shows the water vapor transport every six hour in June (Fig.2a) and September (Fig.2b) 1998 in the Region A, as well as Typhoon tracks indicating the path of the minimum pressure center of Typhoon, in September 1998 (Fig.2c). The dark and semi-dark color in Fig.2a and 2b indicates the equator-ward and pole-ward components of water vapor, respectively. In Fig.2c, Typhoon number (e.g. T9804) was defined by Japan Meteorological Agency

(JMA). The solid and dot line indicates that Typhoon is existed in the Domain B (20N-40N, 120E-150E) and in outer area of the Domain B, respectively. The terms of the center of typhoon existence in Domain B (Typhoon term) are shown in the right side of Fig.2b. The typhoon has never existed in June 1998 in the same region. The water vapor fields of June and September in 1998 are likely to the climatic fields. The water vapor in June is quasi-stationary transported from the low latitudes to high latitudes. On the other hands, the intermittently transportation of water vapor is clearly confirmed in September. The strong water vapor transport corresponds to the Typhoon in Domain B as shown in Fig.2b. The water vapor transport is very small in the term without Typhoon (non Typhoon term). Almost 92% of total amount of pole-ward water vapor through the Region A is estimated to bring due to Typhoon in shown Fig.3, although the appearance term of Typhoon (Typhoon term) is only 15 day in September (30 day). The amount of accumulated pole-ward water vapor transport during Typhoon term and non-Typhoon term are estimated about 4.84×1014 ton / 15days and 3.58×1013 ton / 15days, respectively. It is found that the pole-ward water vapor transport due to the Typhoon is extremely large from this analysis result. We defined the water vapor transport due to the Typhoon when the center of Typhoon is in the Domain B (Typhoon term) after that.

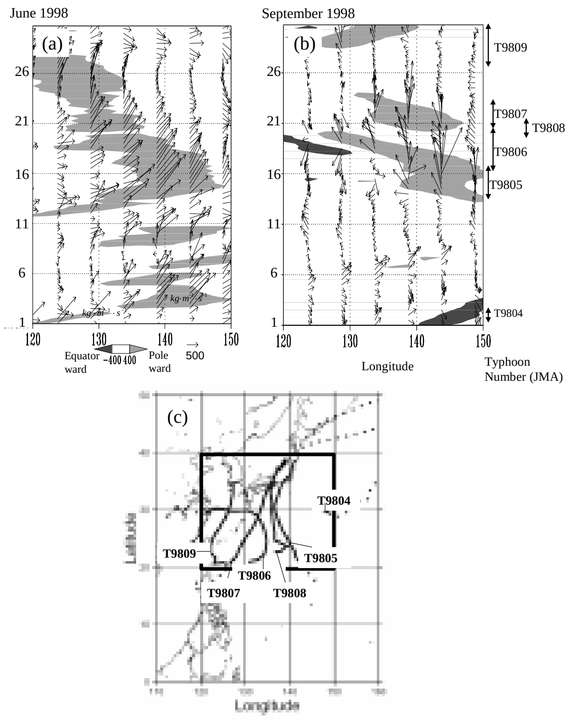


**Fig. 2**: Time latitude section of water vapor transport every 6 hour in June (a) and September (b) 1998 in Region A, and Typhoon track in September 1998 (c). The solid and dot line in Fig.2c indicates that Typhoon is existed in the Domain B (20N-40N, 120E-150E) and in outer area of Domain B, respectively.

## 3. Discussion

In general, the monthly mean of the meridional water vapor transport can be divided into the products of the average of the mean and its deviations. The same method of Mirakami (1962) is used to calculate the water vapor except for the calculation region. The zonal domain in this study is applied form 120E to 150E. This narrow zonal region is reasonable to estimate the water vapor transport in the limited area around East Asia. In this limited area, it is speculated that the constant flow such as the monsoon should be made a contribution to the water vapor transport of the average of the means, because the a mean variable is constant over the period of averaging (Holton, 1992). And the disturbances such as Typhoon should be made a contribution to the water vapor transport of the average of the deviations. The time averaged zonal mean water vapor transport is calculated by the equation as follows.

$$\overline{vh} = \bar{v}\,\bar{h} + \overline{v'h'} \qquad (1)$$

where is meridional component of wind and is mixing ratio. The time average and zonal means are indicated by over bars, and the fluctuating components by primes. The first and second terms on the right indicate the water vapor due to the product of the average of the means (120E-150E) and the eddy flux, respectively. Those components are evaluated by the vertically accumulation from 1000hPa to 300hPa.

Figure 4 shows the monthly meridional water vapor transport divided into the product of the average of the means and the deviations in June and September 1998. The maximum of the total pole-ward water vapor is remarkable around 30N in June. Almost all of water vapor transport is due to the constant flow. In September, the water vapor around 30N is much smaller than in June. Almost 75% and 25% of the total water vapor transport are due to the average of the means and the deviations, respectively. There are some studies to indicate that the average of the means dominates the total water vapor transport. Simmonds et al. (1999) investigated the interannual variations of water vapor flux over China in summer season (June - August) considering the mean and transient eddy transport. They concluded that the transient eddy transport along the path of the Indian monsoon is very small. The average of means component of water vapor should be very important in June. However, there are some objections in September. The water vapor transport by Typhoon is intermittently caused with the large amount of water vapor as shown in Fig.2b. It means that this transport is not caused by the constant flow but by the disturbance. However, it is quite difference between the estimated water vapor in Fig.3 and calculated in Fig.4. The Typhoon contribution is almost 92% of total in Fig.3, although the water vapor transport of the average of the deviations is almost 25% of that in Fig.4. Some reasons are considered as the cause of such difference. The meridional water vapor transport due to disturbance caused by the baroclinic instability is largely different from that due to the Typhoon disturbance. Therefore it is suggested that the water vapor transport due to the Typhoon could not be exactly estimated by the deviation component of the water vapor.

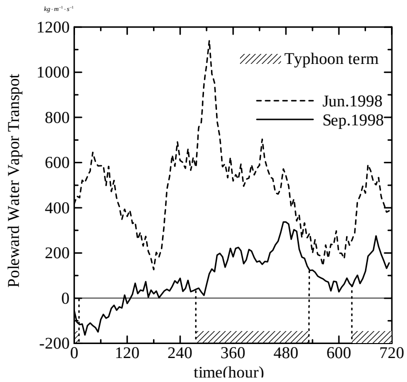


**Fig. 3**: Time variation of water vapor through the Region A (30N, 120E-150E) in September 1998. The slashes part of bottom of graph shows the water vapor transport when the Typhoon exists in Domain B (20N-40N, 120E-150E).

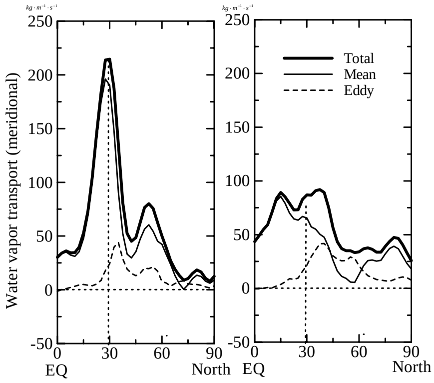


**Fig. 4**: Latitudinal distribution of meridional water vapor transport in limited area (120E-150E) in June and September 1998. The bold, solid, dash, and dash dot dash lines are the monthly water vapor transport, the product of average of the means, the eddy flux.

Figure 5 shows the 20 year accumulated water vapor transport of Typhoon existence case and the no existence case in June and September. The shadow shows the pole-ward water vapor transport. In June, the term of Typhoon existence is almost 13% of the total term. There are little amount of water vapor transport due to the Typhoon and most of water vapor transport is formed by the constant flow such as the summer Asian monsoon. In September, the term of Typhoon existence is almost 36% of the total term. It is clearly found that the strong pole-ward water vapor transport is formed by typhoon around Region A. Table 1 indicates that the difference of the water vapor transport between Typhoon term and non Typhoon term in June and September. In September, the water vapor transport due to the Typhoon is almost 54% of the total, although the term of Typhoon existence is almost only 36% of the total. The water vapor transport due to the Typhoon can never be ignored from the view of climate.

Accordingly, it is indicated that the large amount of water vapor is transported along the southwesterly Low Level Jet (LLJ) generated by the strong heat contrast between the continent and ocean in June. The quasi-stationary water vapor transport is produced by the fixed heat contrast. This mechanism has been showed by the study of Yoshikane et al. (2001) and Yoshikane and Kimura (2000) using a regional climate model. In September, the heat contrast is getting small due to the seasonal radiation change and the Typhoon disturbance is remarkable in the Northwestern Pacific Ocean. As the results, the large water vapor is intermittently transported by the Typhoon.

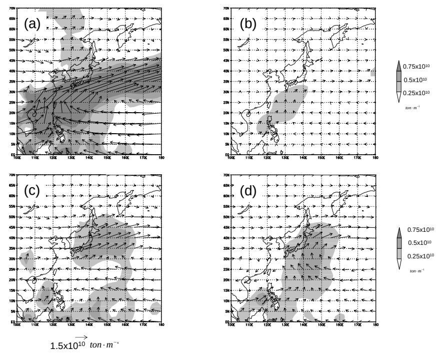


**Fig. 5**: 20 year accumulated water vapor transport of non Typhoon term and Typhoon term in June (a) (b) and September (c) (d). The shadow shows the pole-ward water vapor transport.

| | 20-year averaged Typhoon term | | 20-year accumulated poleward water vapor transport $(ton \cdot m^{-1})$ | | |
|---|---|---|---|---|---|
| | Term par month (day) | Ratio | Total | Typhoon Term | Ratio |
| June | 2.8 | 9.50% | 4.50E+06 | 5.90E+05 | 13% |
| September | 10.8 | 36.30% | 1.97E+06 | 1.08E+06 | 54.80% |

**Table 1**: Amount of the 20-year accumulated pole-ward water vapor transport and 20-year averaged Typhoon term in June and September.

## 4. Conclusion

Climatic features of water vapor transport, which is closely related to precipitation in the middle latitudes around East Asia, are investigated using a reanalysis data in June and September. The maximum pole-ward water vapor transport is formed along the continental coast in June, although it is formed over the western Pacific Ocean. The water vapor in June is quasi-stationary transported from southwestward to north. On the contrary, the intermittently transportation of water vapor is clearly confirmed in September. It is indicated that the water vapor is primary transported by the southwesterly low-level wind due to the heat contrast between land and ocean in June. In September 1998, it reveals that almost 92% of the total amount of pole-ward water vapor is transported by Typhoons, although the appearance term of Typhoon is about only 15 day in September 1998. However, the water vapor transport of the average of the deviations is almost 25%, although the typhoon contribution is almost 92% of total. It is suggested that the water vapor transport due to the Typhoon could not be exactly estimated by the deviation component of the water vapor, because the meridional water vapor transport due to disturbance caused by the baroclinic instability is largely different from that due to the Typhoon disturbance.

From the result of climatic water vapor transport from 1980 to 1999, the term of Typhoon existence in June is almost 13% of the total term. There are few amount of water vapor transport due to the Typhoon and most of water vapor transport is formed by the constant flow such as the summer Asian monsoon. The term of Typhoon existence in September is almost 36% of the total term. It is clearly found that the strong pole-ward water vapor transport is formed by typhoon around Region A. It is indicated that the large amount of water vapor is constantly transported along the southwesterly Low Level Jet (LLJ) generated by the strong heat contrast between the continent and ocean in June. In September, the large water vapor is intermittently transported by the Typhoon due to the weak heat contrast and the intensified Typhoon disturbance over the Northwestern Pacific Ocean.

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