WATER VAPOR CONTENT AND MEAN TRANSFER IN THE ATMOSPHERE OVER NORTHWEST CHINA

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ABSTRACT

The interannual and intermonthly climatic features of the water vapor content (hereafter WVC) and its mean transfer in the atmosphere over Northwest China (hereafter NWC) are calculated and analyzed by using the NCEP/NCAR global reanalysis grid data ($2.5° \times 2.5°$ Lat/Lon) for 40 years (1958—1997). The results show that the WVC in the total air column over NWC in four seasons of the year is mainly concentrated on eastern and western NWC respectively. On the average. the WVC over eastern NWC decreases obviously during recent forty years except for winter. while it decreases over western NWC in the whole year. But the WVC over NWC has been increasing since late 1980s in summer. The water vapor comes from the southwestern warm and wet air current along the Yarlung Zangbo River Valley and the Bay of Bengal. and from mid-western Tibetan Plateau and also from the Qinling Mountains at southern Shaanxi Province. The yearly water vapor divergence appears over the middle of NWC to northern Xinjiang and southeastern Shaanxi Province. The yearly water vapor convergence appears over the Tarim Basin and the Tibetan Plateau as well as western Sichuan and southern Gansu.

Key words: Northwest China (NWC). water vapor content (WVC). mean water vapor transfer. climatic variation

I. INTRODUCTION

Water vapor content (WVC) is one of the major parameters and marks characterizing weather and climate in atmospheric sciences. as well as the important project in studying the formation and variation mechanism of weather and climate. The WVC and its mean transfer in the whole atmosphere not only have close relation with atmospheric circulation. but also play an important role in the regional water balance which serves as one of the global energy and hydrological cycle. To estimate correctly the WVC and its mean transfer can further understand the formation and evolution of the general circulation. thus to learn the process of the weather and climate and the hydrological cycle. so as to reach the objective of utilizing water resource reasonably and realizing sustainable development. Researches on this subject have been carried out extensively by domestic and abroad hydrologists and geologists for many years. For instance. Starr et al. (1955) indicated that the water vapor transfer played an important role in regional water balance. Chen (1985). Chen and Tzeng (1990) thought that the moisture convergence in tropics was responsible for the planetary scale divergence circulation and was related to the diabatic heating induced by release of latent heat.

Some studies on WVC and vapor transfer have been performed such as analyzing heavy rain formation and investigating the monsoon feature aspects. and have achieved some valuable knowledge. Xu (1958) calculated the water vapor transfer and water balance in eastern China in 1956 and pointed out that the inflow of water vapor from the south was much more important than that either from west or from north. Xie and Dai (1959) investigated the vapor transfer of the heavy precipitation process in the Huanghe-Huaihe Basin based upon a selected synoptic case. and pointed out that the heavy precipitation was closely related to the inflow vapor. Chen et al. (1991) discussed the water vapor transfer of rainfall over areas east of 105—110°E in China during summer monsoon as viewed in the Asian monsoon system. and indicated that the water vapor of summer rainfall in mainland of China firstly came from tropical South China Sea. next came from southwest monsoon flow of the Bay of Bengal. the last came from southeast monsoon of subtropical high. Huang et al. (1998). by using the daily data of water vapor and wind fields at various levels analyzed by ECMWF. found that there was an obvious difference of the water vapor transport between the East Asian monsoon region and the South Asian monsoon region in summer. and that the meridional water vapor transport was larger than the zonal water vapor transport in the East Asian monsoon region. But the zonal water vapor transport is dominant in the Indian monsoon region. Zhai and Zhou (1997) analyzed the climatic distribution of atmospheric water vapor and the climatic change trend by using the radio sounding data which are made through the quality control of CHQC (comprehensive hydrostatic quality control) and the check of sequence homogeneity. We can find that all of above studies are usually focused on the area of southeast part of China and the lower tropical latitude in May—June or midsummer. The main subjects include the moisture for heavy rain formation. the water vapor source. the water vapor transfer path and the convergence. and also the relationship with rainy season and rain belt. But little attention is paid to West China or NWC. Because the past researches were limited by the observational data and computable condition. the non-homogeneity existed in the sounding data of temperature and moisture sequence due to the non-homogeneity coverage of station. the migration of station and the change of the observation standard. the time levels and instruments. In this paper. the interannual and intermonthly climatic feature of the WVC and its mean transfer in the atmosphere over NWC are calculated and analyzed by using the NCEP/NCAR global reanalysis grid data (2.5°×2.5°Lat/Lon) for 40 years (1958—1997). Attempts are directed at assessing water resources. studying climate variation and providing some scientific basis for climatic prediction in NWC. The data and formulation are discussed in Section II. the seasonal variation of water content is described in Section III. and the water vapor transport in Section IV. Section V examines the horizontal divergence or convergence of the water vapor flux. with the concluding remarks in Section VI.

II. DATA AND ANALYSIS METHODOLOGY

1. *Data Description and Examination*

The data used in this study are the wind fields. specific humidity at mandatory levels of 1000. 925. 850. 700. 600. 500. 400 and 300 hPa generated by NCEP/NCAR reanalysis. which provided by Nanjing Atmospheric Data Service Center and the data of Monthly Aerological Bulletin of China published by NMC of China. Figure 1 shows the geography of NWC located in East Asia. which is the emphatic area discussed in this paper. Accordingly. the range selected is 72.5—112.5°E. 30—50°N.

Whether or not the NCEP/NCAR reanalysis data are suitable for the study of long range climatic variability in NWC? We select three representative sounding stations (Urumqi. Yinchuan and Xi'an) in NWC. by interpolating the NCEP/NCAR grid data to these stations. the specific humidity (see Fig. 2) and the wind (see Fig. 3) are tested.

Figure 2 is the specific humidity at 850 hPa for 0800 and 2000 GMT. Figure 3 shows the u. v component of wind at 500 hPa for 0800 and 2000 GMT. Both Fig. 2 and Fig. 3 show that the basic features and variation of the reanalysis data are almost consistent with the observation data. There is small bias only in quantity. Su et al. (1999) also suggested that the basic features and distribution patterns of the NCEP/NCAR reanalysis data are almost consistent with the climate data and the reanalysis data are more reasonable after examining the confidence of the reanalysis data for wind and moisture of Tibetan Plateau and its adjacent areas. Therefore. it can be sure that the reanalysis data are suitable for the study of long range climatic variability in NWC.

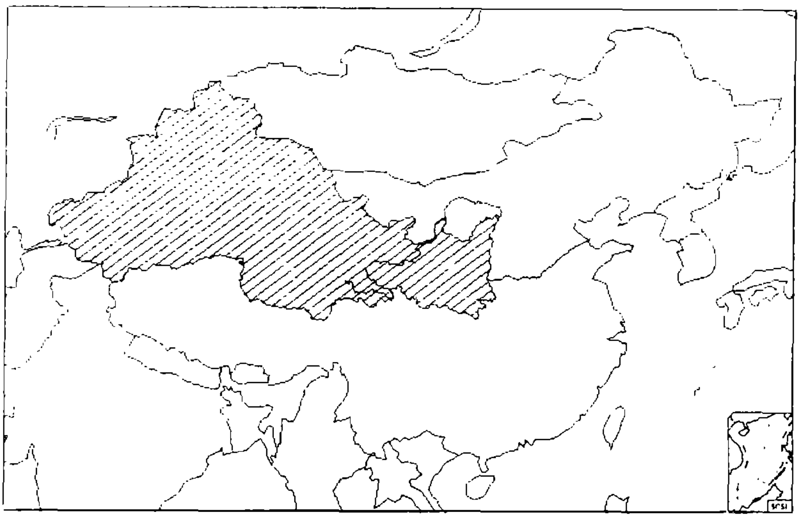

Fig. 1. Geographic location of NWC (shaded area).

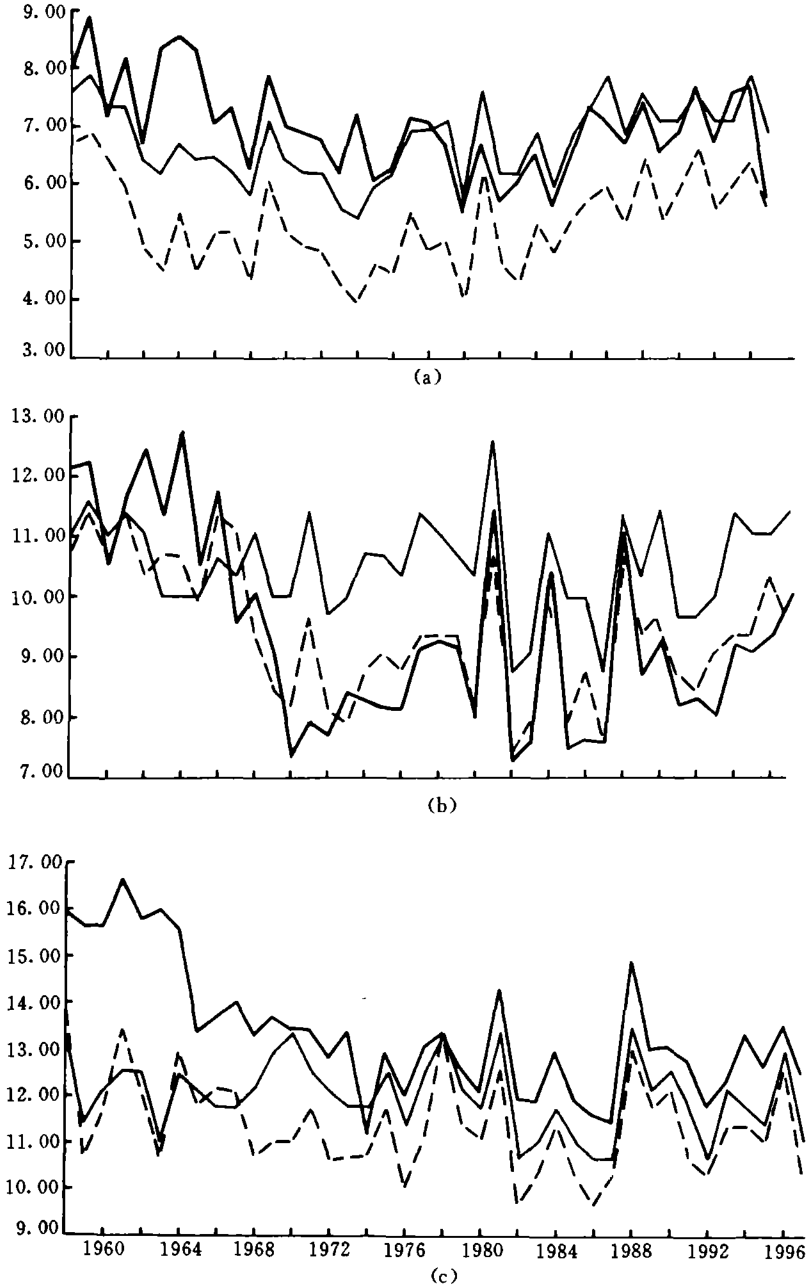

Fig. 2. The specific humidity (bold solid for NCEP) at 850 hPa for 0800 (solid) and 2000 (dotted) GMT in July (unit: mm) (a) Urumqi, (b) Yinchuan, (c) Xi'an.

2. *Methodology*

The WVC in an air column is given by

$$W_a = \frac{1}{g}\int_{P_z}^{P_s} \bar{q}\,\mathrm{d}p, \qquad (1)$$

where g is the gravity, q is the specific humidity, and the overbar represents a time

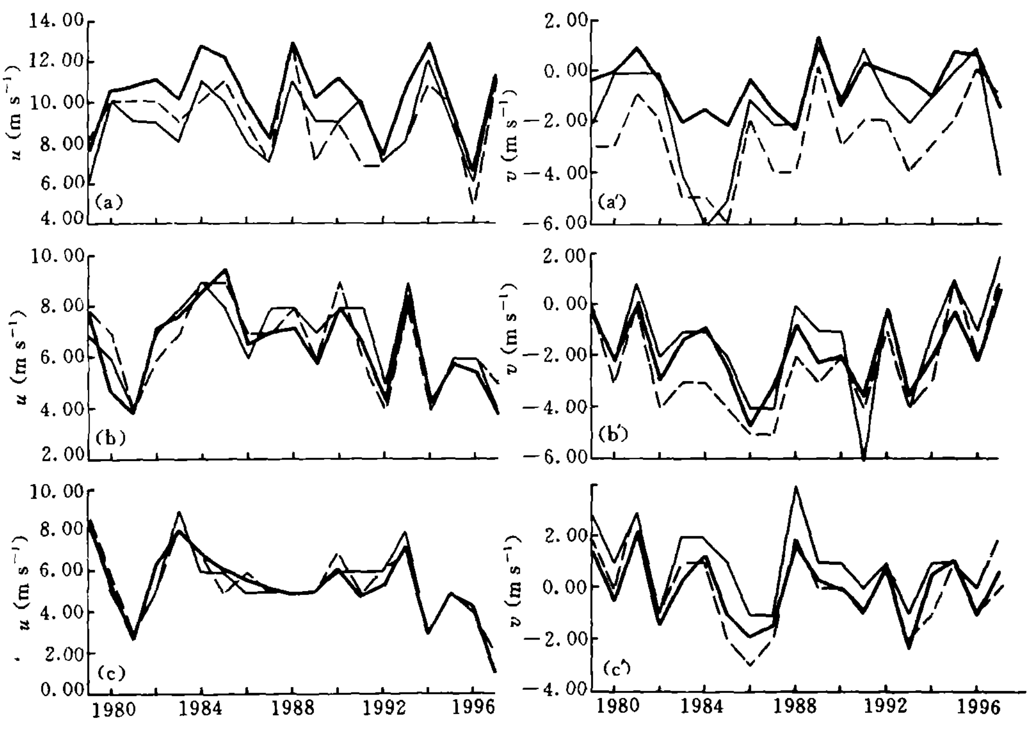

Fig. 3. As in Fig. 2, except for the u, v component of wind at 500 hPa (unit: m s^{-1}).

average. P_z is the pressure at the top of atmosphere. P_s is the surface pressure.

Since the moisture is essentially concentrated below 300 hPa, the moisture in the whole atmosphere is integrated from surface to 300 hPa. Following the mass transfer equation, the moisture transfer is given by

$$Q = \frac{1}{g}\int_{P_z}^{P_s} \overline{V}\overline{q}\,\mathrm{d}p + \frac{1}{g}\int_{P_z}^{P_s} \overline{V'q'}\,\mathrm{d}p, \tag{2}$$

where the horizontal wind vector is $\boldsymbol{V} = u\boldsymbol{i} + v\boldsymbol{j}$, overbars and primes denote the contributions by the stationary and transient mode, respectively.

The divergence or convergence of the moisture in an unit area can be written as

$$\nabla \cdot Q = \frac{1}{g}\int_{P_z}^{P_s} \nabla \cdot (\overline{V}\overline{q})\,\mathrm{d}p + \frac{1}{g}\int_{P_z}^{P_s} \nabla \cdot (\overline{V'q'})\,\mathrm{d}p. \tag{3}$$

Thus, the mean value, the transport direction and the divergence (convergence) of the moisture over NWC can be calculated according to the above formulas, so that their temporal and spatial distributions are analyzed.

III. THE CLIMATIC DISTRIBUTION OF THE MEAN WVC IN THE ATMOSPHERE OVER NWC

In NWC, the factors such as seasons, geographic locations and topography have the impact on the distribution of moisture. Thus its annual variation is very obvious.

In this paper, January, April, July and October represent the winter, spring, summer and autumn respectively in order to analyze the climatic distributions of WVC in the total air column over NWC.

Influenced by the predominance of the dry and cold air flow coming from Siberia and Mongolia. winter is the season with the least WVC and January has the minimum value in the year (see Fig. 4a). amounting to 10—30 mm. The maximum value is over the South Shaanxi where is more than 30 mm. The relative high value of 25 mm is over the Tarim Basin in Xinjiang. while a low value belt below 10 mm appears over the Northeast and Southwest side of the Qaidam Basin. where is the minimum value of WVC over NWC. another low value of less than 10 mm is also over the Ili Valley in North Xinjiang. The WVC becomes increasing in spring (see Fig. 4b). and is up to 20 mm over the total area. in which WVC may reach up to 50 mm and 40 mm over southeast part of NWC and over the Tarim Basin respectively. The low centers appearing in winter remain to exist. but their ranges are reduced. In summer. the WVC is the largest over the total area in the year (see Fig. 4c). The high value appears over north part of the Tianshan Mts.. as well as over the southeast part of NWC and the Tarim Basin. all of them may reach to 80 mm. The low center located over northeast of the Qaidam Basin moves northward to the border of Gansu and Xinjiang. while the one over southwest of the Qaidam Basin moves southward and weakens. In autumn. the WVC over the total area become reducing. and the distribution is similar to spring. but the ranges of the low centers mentioned above extend obviously.

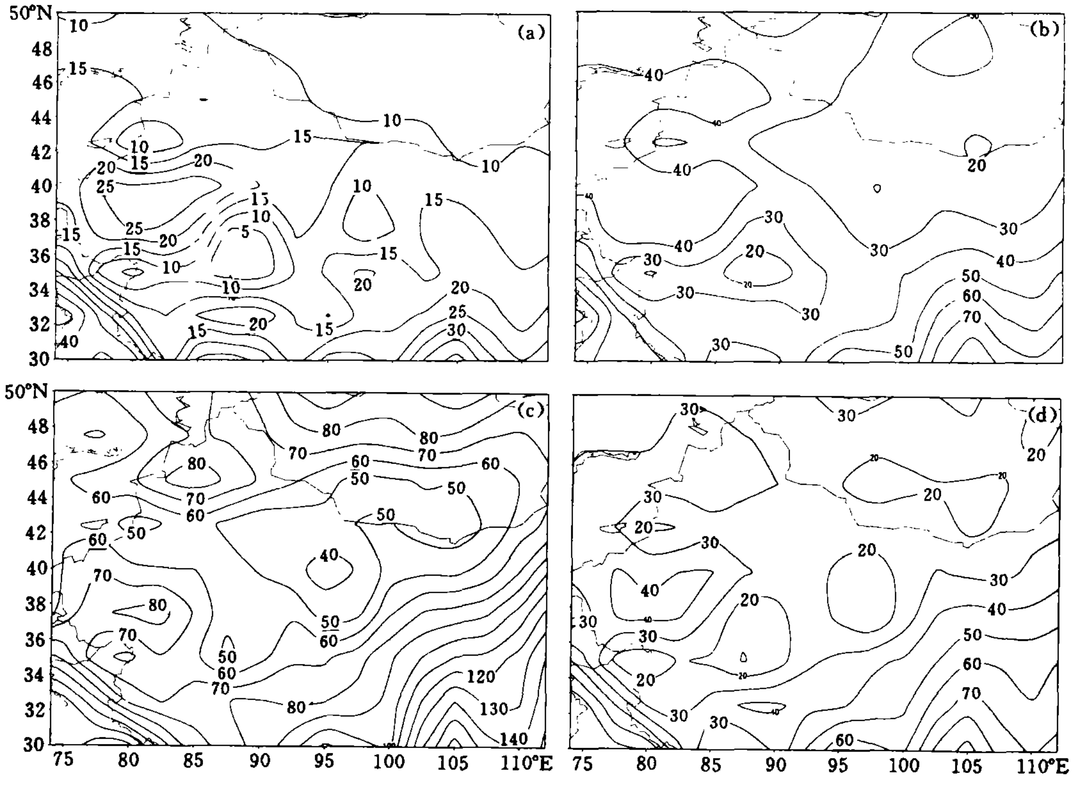

Fig. 4. Seasonal distributions of WVC in the total air column over NWC (unit: mm): (a) January. (b) April. (c) July. and (d) October.

Overall, the climatic averaged WVC in whole air column over NWC is concentrated in the east and west areas. The east one is the most abundant and the most stable, while the west one, located over the Tarim Basin and north part of the Tianshan Mts., varies prominently with the season course. The WVC over the middle of NWC is the least, especially over the west and north part of Qinghai. By comparing with Zhai and Zhuo (1997) and Lu and Gao (1984), the conclusions of annual variation of WVC are coincident well with each other, but the high value centers over the west part of NWC shown in Fig. 4are not reported by Zhai and Zhou and Lu and Gao. This may be the lack of stations selected in west part of NWC. By using the observation of meteorological satellite TIROS-N/NOAA and monitoring the cloud system over the Taklamakan Desert and the rainfall traces for about three consecutive years, Xu (1995) pointed out that the rainfall or even heavy rainfall can happen in the desert and the frequency of rainfall in summer is more than in spring and autumn. The highest frequency of rainfall appears in the hinterland desert. It is the combination of the north and south cloud systems with the superposition of the low and high cloud systems that leads to rainfall in the desert. The moisture can leap over the Tibetan Plateau and go straight into the Tarim Basin by means of the transportation of the moisture-laden southwesterlies. The satellite observations further verify our conclusions.

IV. THE INTERANNUAL VARIATION OF THE MEAN WVC IN THE ATMOSPHERE OVER NWC

Based on the analysis of Fig. 4, we understand that the WVC in total air column over NWC is mainly concentrated in the eastern and western regions in the year. Therefore, we select the range of 32. 5 — 40°N, 100 — 110°E and the range of 35 — 42. 5°N, 80 — 90°E respectively so as to discuss the interannual variation of WVC over NWC during 1958 to 1997. Figure 5 shows the evolution of the WVC over eastern part of NWC during 1958—1997. We can observe that the WVC has increased since recent forty years over eastern part of NWC in winter (see Fig. 5a), in which the two relative high phases of WVC are in early 1970s and in early 1990s, while the relative low phases of WVC are in early 1960s, late 1970s and middle 1980s. In spring (see Fig. 5b), the WVC has decreased since recent forty years. The fluctuation, of which the range is generally just between 55—65 mm, is not notable except for the middle 1960s. In summer (see Fig. 5c), the fluctuation of WVC behaves very notable for recent forty years. The high phase of WVC appears from the late 1950s through the middle 1960s, then it decreases rapidly afterwards. The lowest phase of WVC appears during the middle and later stages of 1970s to the middle and later stages of 1980s, but it has seemed to be increasing since 1990s. In autumn (see Fig. 5d), the WVC over eastern NWC has decreased continuously for recent 40 years. The most WVC is in early 1960s, which is up to 90 mm, the least is in late 1990s, only about 55 mm.

The counterparts of western NWC, which centered in the Tarim Basin in southern Xinjiang, are illustrated in Fig. 6. It is shown clearly in Fig. 6a that the WVC in winter has decreased slightly since recent forty years, especially since 1990s. The relative high phase of WVC appears during the 1970s to the earlier stage of 1980s, while the relative low phases of WVC appear in the 1960s as well as in the middle and late stage of 1990s. During spring, the WVC has decreased obviously since recent forty years (see Fig. 6b).

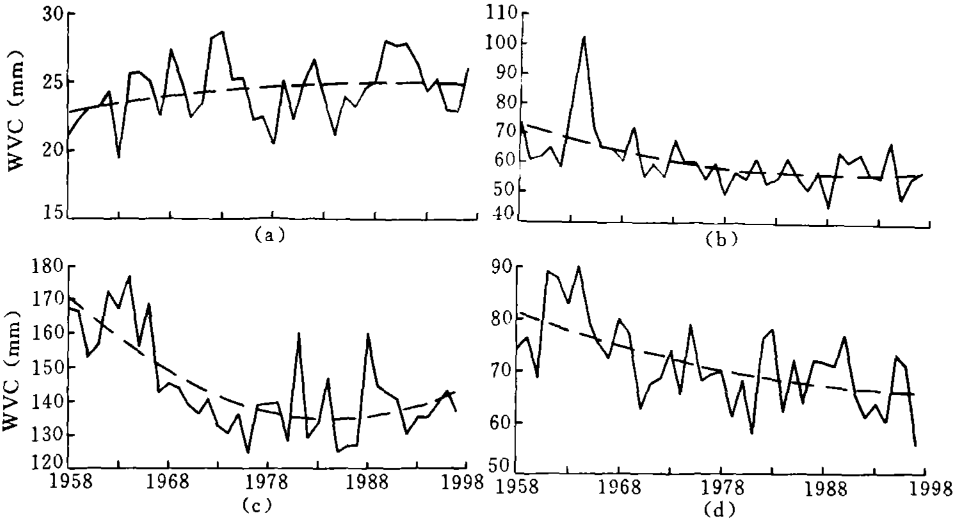

Fig. 5. The evolution of the WVC (unit mm) over eastern part of NWC during 1958—1997: (a) January. (b) April. (c) July. (d) October.

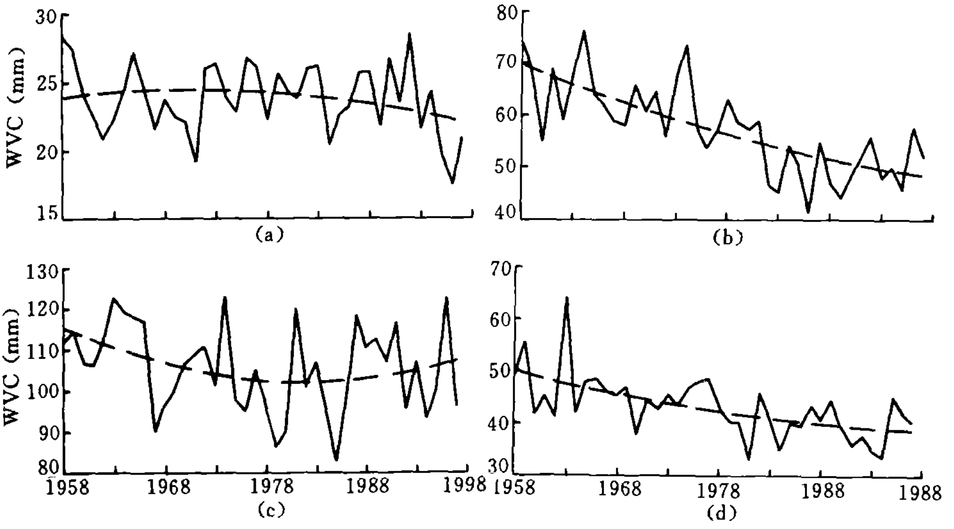

Fig. 6. As in Fig. 5. except for western part of NWC.

The relative high phase of WVC appears during the late stage of 1950s to the middle of 1970s. while the lowest phases of WVC appear during 1980s to the late 1990s. During summer (see Fig. 6c). similar to the case of eastern NWC. the variation of WVC has been very prominent during recent forty years. The high phase appears in the late 1950s till to the mid-1960s. whereas the lowest phase appears in the mid-1970s till to the mid-1980s. but it seems to have been raised again since 1990s. During autumn (see Fig. 6d). the WVC over western NWC has been decreasing since recent forty years. The relative high phase appears in the early 1960s. whereas the low phase appears during late 1980s to 1990s. Zhai and Zhou (1997) pointed out that the WVC over eastern NWC in summer decreased evidently by analyzing the linear tendency of annual variation of the WVC over different areas in China. Their results are identical with ours, but the data they used are only confined to 1970—1990, therefore the increasing tendency of the WVC over NWC in summer since 1990s as shown in Fig. 5 and Fig. 6 was not reported by them.

V. THE TEMPORAL AND SPATIAL DISTRIBUTION OF THE WATER VAPOR TRANSPORT (WVT) FLUX OVER NWC

Moist flux, i.e. WVT, is the physical factor indicating the direction and quantity of WVC. In order to investigate the annual variation and the source of the WVC over NWC, the climate averaged water vapor fluxes in total air column over NWC in the four seasons of the year are calculated respectively. The results are shown in Fig. 7. During winter (see Fig. 7a), the moisture over NWC comes mainly from the south adjacent Tibetan Plateau and the western part of the Tarim Basin. The southwest warm and wet air flow over the western and middle part of Tibetan Plateau (31—34°N, 80—92°E) is the strongest one with the center value up to 200 kg cm^{-1} s^{-1}. The second one, reaching above 140 kg cm^{-1}s^{-1}, comes from the Yarlung Zangbo River Valley in the eastern Tibet and stretches northward to the fountainhead of Huanghe River in the southeast side of Qaidam Basin. Another one is the south warm-wet air flow with the value up to 100 kg cm^{-1}s^{-1}, which comes from the western Tarim Basin. During spring (see Fig. 7b), besides the

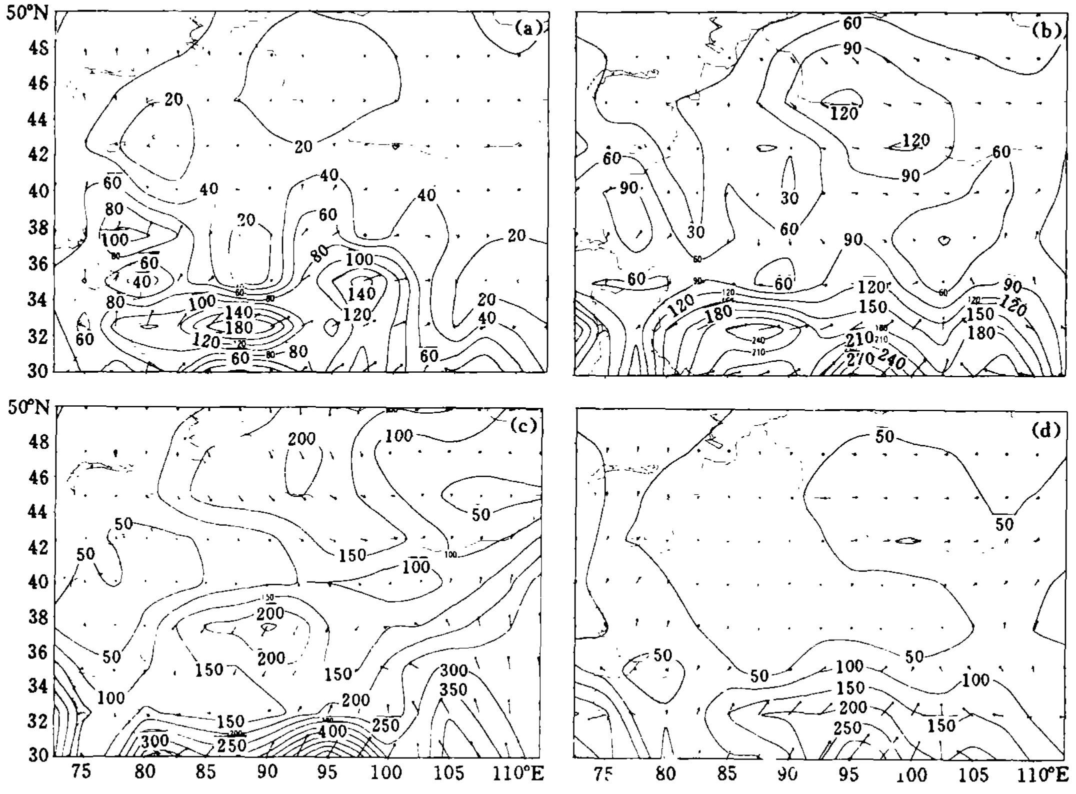

Fig. 7. As in Fig. 4, except for the water vapor fluxes (unit: kg cm^{-1}s^{-1}).

paths of WVT mentioned above. the northwest MVT with the value amounting above 90 kg $cm^{-1}s^{-1}$ appears over Mongolia. In the case of southern WVT. the WVT coming from southeast over the Qinling Mts. in southern Shaanxi. with the value up to 200 kg $cm^{-1}s^{-1}$ is observed as well as the WVT with the value up to 240 kg $cm^{-1}s^{-1}$ over the western and middle part of Tibetan Plateau. The most notable WVT is the southwest one from the Yarlung Zangbo River Valley in the eastern Tibetan Plateau which exceeds to 270 kg $cm^{-1}s^{-1}$. During summer (see Fig. 7c). the WVT from the Yarlung Zangbo River Valley in the eastern Tibetan Plateau is up to 600 kg $cm^{-1}s^{-1}$. Another one from the southeast warm-wet air flow over the Qinling Mts. in south Shaanxi is also up to 400 kg $cm^{-1}s^{-1}$. The northwest WVT coming from the Siberia and Mongolia alongside the northern side of NWC is up to 200 kg $cm^{-1}s^{-1}$. while the previous WVT existed in the western part of Tarim Basin weakens and disappears. It is worth noticing that the southwest WVT over the western and middle part of Tibetan Plateau. which maintained in winter and spring. does not exist any more. As replacement of it. there are two WVTs in opposite direction in its northern and southern sides respectively and therefore a shear of WVT is formed here. This implies that the WVT over western and middle parts of Tibetan Plateau does not weaken yet. moreover. the shear of WVT has been formed over western and middle parts of Tibetan Plateau due to the obstruction of the Kunlun Mts. in the northern Tibetan Plateau when the strong WVC transports northward. a part of moisture is forced to turn back to transport southward. During autumn (see Fig. 7d). the WVT started to weaken entirely. but the main WVT with the value up to 300 kg $cm^{-1}s^{-1}$ coming from the Yarlung Zangbo River Valley can also be observed clearly. Another one over southern Shaanxi amounts to 180 kg $cm^{-1}s^{-1}$. The southwest WVT over the western and middle parts of Tibetan Plateau appears again. and the south WVT over the western Tarim Basin also reappears. While the northwest one coming from Siberia and Mongolia existed in spring and summer presents now a weak west WVT with the center value reducing to 100 kg $cm^{-1}s^{-1}$. Lin and Zheng (1992) indicated that the moisture of rainfall over NWC is mainly supplied by westerly circulation and South Asia monsoon. The former comes from west boundary and input zonally. The latter comes from Indian Ocean. in which the east path comes from the Bay of Bengal. then along the Yarlung Zangbo River and the eastern part of Tibetan Plateau and northward into eastern NWC at last. while the west path comes from Arabian Sea and crosses over the Karakorum Mts. and straight into southern Xinjiang. but its value is far less than the one of east path. Our conclusions with different data analyzed are basically consistent with theirs.

In generally. the WVT over NWC in a year mainly comes from the southwest warm and wet air flow over the adjacent Tibetan Plateau. the second one comes from southeast warm and wet air flow over the Qinling Mts. in southern Shaanxi. and the third one is the northwest WVT from Siberia and Mongolia during spring and summer as well.

VI. THE SEASONAL VARIATION OF THE MEAN DIVERGENCE OF WATER VAPOR TRANSPORT FLUX IN THE ATMOSPHERE OVER NWC

In order to understand further the character of climatic variation of the mean convergent (or divergent) WVT in the total atmosphere over NWC. the divergence fields of WVT flux in the four seasons of the year are calculated as illustrating in Fig. 8. During winter (see Fig. 8a), the notable negative divergence regions are located in the Tarim Basin and stretch southeastward along the Kunlun Mts. down to southwest of Qinghai, where the maximum convergent center with the value up to -30×10^{-5} kg $cm^{-2}s^{-1}$ is located in the Tarim Basin. Another notable negative divergence is located in northeastern side of Tibetan Plateau where the maximum convergent center with the value up to -30×10^{-5} kg $cm^{-2}s^{-1}$ is located in western Sichuan and southern Gansu. The positive divergence regions are located in northern Xinjiang down to western Qinghai, with the maximum divergent center reaching to 10×10^{-5} kg $cm^{-2}s^{-1}$ as well as the most part of Shaanxi in eastern NWC. During spring (see Fig. 8b), the convergent regions of WVT extend northward and the values are gradually increasing. Besides the northern Xinjiang, the Qaidam Basin in middle NWC and eastern NWC belong to positive divergence regions, the rest regions of NWC are the negative divergence, where the positive center with the value above 20×10^{-5} kg $cm^{-2}s^{-1}$ is located in the Lop Lake of Xinjiang. The negative divergence centers are located in the Tarim Basin of southern Xinjiang, western Sichuan and southern Gansu with the value up to -25×10^{-5} kg $cm^{-2}s^{-1}$, and -60×10^{-5} kg $cm^{-2}s^{-1}$ respectively. During summer (see Fig. 8c), the divergent regions are mainly located in the juncture of Gansu, Qinghai and Xinjiang in the middle of NWC as well as the most part of Shaanxi Province with the value up to 60×10^{-5} kg $cm^{-2}s^{-1}$. The negative

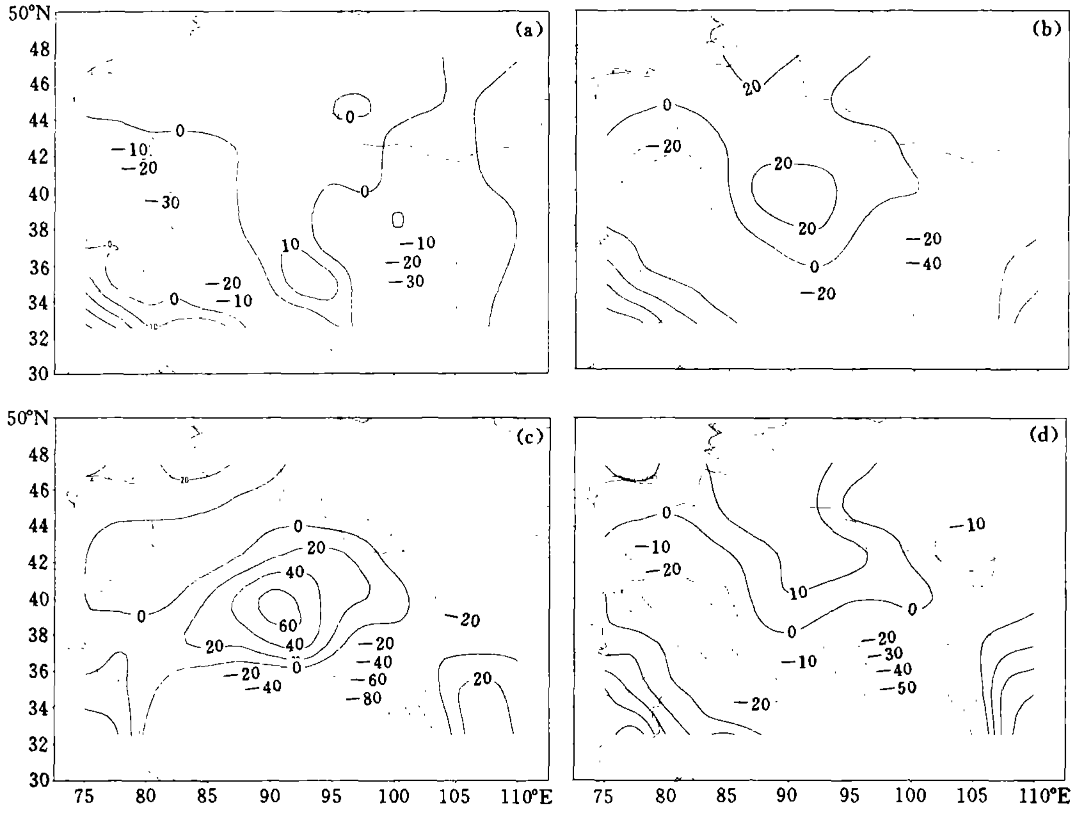

Fig. 8. As in Fig. 4, except for the divergence of water vapor fluxes (unit: $\times10^{-5}$ kg $cm^{-2}s^{-1}$).

divergence appears in the rest regions of NWC, where the maximum convergent region is located over the south adjacent Tibetan Plateau and southern Qinghai with the central value amounting to -100×10^{-5} kg $cm^{-2}s^{-1}$. The convergence over Mongolia Plateau amounts to -40×10^{-5} kg $cm^{-2}s^{-1}$ as well. During autumn (see Fig. 8d), the situation is similar to that of spring basically. The positive divergence appears over the northern Xinjiang, extending southeastward to northern Qinghai and western Gansu as well as the most part of Shaanxi respectively, the rest regions of NWC are belong to the convergent regions of negative divergence. After investigating the WVT over eastern China and the moisture of summer precipitation in mainland of China, Chen et al. (1991) pointed out that the WVT mainly comes from tropical South China Sea, from southwest monsoon of Bay of Bengal and from southeast monsoon of subtropical high. When the three monsoon flows come into China, the WVT gradually increased. This indicates that the considerable part of WVT is provided by the local moisture evaporation over South China and Southwest China, rather than entirely provided by the moisture coming from the boundary of China. Therefore, we think that the moisture of NWC may be provided by the evaporation of glacier, snow cover and rainfall on the Mts. located in the western or eastern Tibetan Plateau as well as by the above mentioned three monsoon WVTs. In fact, our conclusioos have verified this.

In a word, the convergent WVT flux appears in the Tarim Basin of western NWC, Tibetan Plateau and the western Sichuan and southern Gansu for an average year, while the divergent WVT flux appears in northern Xinjiang southeastward to the middle of NWC as well as the eastern NWC.

Shi (1995) indicated that the annual precipitation in NWC obviously decreases from the two sides of the southeast and the northwest to the middle of NWC, which is identical with the situation of the WVT from the southeast and the northwest directions. This may be because the southeast warm wet air flow subjected to eastern Asia monsoon system prevails in southeastern NWC. There is a westward opening east-west oriented air flow channel in northwestern NWC, and enable the westerly wet air flow from Atlantic Ocean and Arctic Ocean to drive straight into NWC. The extremely drought region is located in Qiemo and Ruoqiang southeast of the Tarim Basin as well as the Turfan Basin and the Qaidam Basin. The center of precipitation in NWC is mainly concentrated in the Mts. such as the Tianshan Mts., the Altay Mts., the Alkin Mts., the Kunlun Mts. and the Pamirs. Therefore, the WVT over NWC not only subjected to the influence of Asia monsoon system, but also that of the Mts. and Basins, the glaciers and snow covers, and by the westerly from Atlantic Ocean and Arctic Ocean as well, thus the conditions are much more complex than the other regions of China. This needs to be studied further, the results in this paper are preliminary only, the further researches are going on.

VII. CONCLUDING REMARKS

Based on the above analysis, the following conclusions may be drawn:

(1) The climatic averaged WVC in whole air column over NWC with the largest in summer and the smallest in winter is concentrated in the east and west areas respectively. The east one is the most abundant and stable, while the west one, located over the Tarim

Basin and north part of the Tianshan Mts., varies prominently with the season course. The climatic WVC over the middle of NWC is the least, especially over the west and north parts of Qinghai.

(2) The WVC in the year has decreased obviously for recent forty years except for winter over eastern NWC, while it has decreased over western NWC. But the WVC over NWC in summer has been increasing since late 1980s. This may result from the East Asian monsoon and the vegetation and the water resources being changed for recent forty years.

(3) The WVT over NWC in a year mainly comes from the southwest warm and wet air flow over the adjacent Tibetan Plateau, the second one comes from southeast warm and wet air flow over the Qinling Mts. in southern Shaanxi, and the third one is the northwest WVT from Siberia and Mongolia during spring and summer as well. Therefore, the WVT over NWC is subjected to the influence of Asia monsoon system, and also that of the Mts. and the Basins, the glaciers and the snow covers and that of the westerly from Atlantic Ocean and Arctic Ocean.

(4) The water vapor divergence appears over the middle of NWC to northern Xinjiang and southeastern Shaanxi Province in the year. The water vapor convergence appears over the Tarim Basin and the Tibetan Plateau as well as western Sichuan and southern Gansu in the year.

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