# Anomalous Atmospheric Circulation, Heat Sources and Moisture Sinks in Relation to Great Precipitation Anomalies in the Yangtze River Valley①

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ABSTRACT

Using the summer (June to August) monthly mean data of the National Centers for Environmental Predictions (NCEP) – National Center for Atmospheric Research (NCAR) reanalysis from 1980 to 1997, atmospheric heat sources and moisture sinks are calculated. Anomalous circulation and the vertically integrated heat source with the vertical integrated moisture sink and outgoing longwave radiation (OLR) flux are examined based upon monthly composites for 16 great wet–spells and 8 great dry–spells over the middle–lower reaches of the Yangtze River.

The wind anomaly exhibits prominent differences between the great wet–spell and the great dry–spell over the Yangtze River Valley. For the great wet–spell, the anomalous southerly from the Bay of Bengal and the South China Sea and the anomalous northerly over North China enhanced low–level convergence toward a narrow latitudinal belt area (the middle–lower reaches of the Yangtze River). The southerly anomaly is connected with an anticyclonic anomalous circulation system centered at 22°N, 140°E and the northerly anomaly is associated with a cyclonic anomalous circulation system centered at the Japan Sea. In the upper level, the anomalous northwesterly between an anticyclonic anomalous system with the center at 23°N, 105°E and a cyclonic anomalous system with the center at Korea diverged over the middle–lower reaches of the Yangtze River. On the contrary, for the great dry–spell, the anomalous northerly over South China and the anomalous southerly over North China diverged from the Yangtze River Valley in the low level. The former formed in the western part of a cyclonic anomalous system centered at 23°N, 135°E. The latter was located in the western ridge of an anticyclonic anomalous system in the northwestern Pacific. The upper troposphere showed easterly anomaly that converged over the middle–lower reaches of the Yangtze River. A cyclonic anomalous system in South China and an anticyclonic system centered in the Japan Sea enhanced the easterly.

Large atmospheric heat source anomalies of opposite signs existed over the western Pacific—the South China Sea, with negative in the great wet–spell and positive in the great dry–spell. The analysis of heat source also revealed positive anomalous heat sources during the great wet–spell and negative anomalous heat sources during the great dry–spell over the Yangtze River valley. The changes of the moisture sink and OLR were correspondingly altered, implying the change of heat source anomaly is due to the latent heat releasing of convective activity. Over the southeastern Tibetan Plateau— the Bay of Bengal, the analysis of heat source shows positive anomalous heat sources during the great wet–spell and negative anomalous heat sources during the great dry–spell because of latent heating change.

The change of divergent wind coexisted with the change of heat source. In the great wet–spell, southerly divergent wind anomaly in the low level and northerly divergent wind anomaly in high–level are seen over South China. These divergent wind anomalies are helpful to the low–level convergence anomaly and

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high-level divergence anomaly over the Yangtze River valley. The low-level northerly divergent wind anomaly and high-level southerly divergent wind anomaly over South China reduced the low-level convergence and high-level divergence over the Yangtze River valley during the great dry-spell.

**Key words:** Anomalous atmospheric circulation, Heat sources and moisture sinks anomalies, Great precipitation anomalies in the Yangtze River valley

## 1. Introduction

Precipitation was considerable spatial and temporal variable in China. Too much rainfall cause devastating floods and too little rainfall produce drought. Serious floods and droughts happen frequently. For example, the serious drought occurred in North China during the summer of 1997, and the serious floods occurred in the Yangtze River and Songhuajiang River valleys in the summer of 1998. Main factor contributed to unusual rainfall is persistent circulation anomaly. Circulation anomaly is associated with atmospheric heat sources and sinks.

Droughts or floods in the Yangtze River valley are closely related to the rainfall of Meiyu. The interannual variability of Meiyu is caused by the changes in the components of the East Asian summer monsoon system in both position and intensity (Tao et al., 1988). The components consist of the monsoon trough (or ITCZ) in the South China Sea and the western Pacific, the cross-equatorial flow to the east of 100°E, the cold anticyclone in Australia, the subtropical high in the western Pacific, the upper-level northeasterly flow, the convection along the monsoon trough, the Meiyu frontal zones, and the midlatitude disturbances. Therefore, the interactions among the subtropical circulation and midlatitude circulation and tropical circulation arouse the rainfall of the Yangtze River valley. A case study shows that the frequent convergence of the warm wet southerly and cold northerly induced the great rainfall of the Yangtze River valley because the western Pacific subtropical high ridge line is steadily located on 20°–22°N, western point at 90°–105°E, northern boundary 25°–26°N (Li et al., 1977). On the contrary, during drought, the subtropical high was to the southeast or to the northwest. Luo et al. (1982) concluded that the central position and the direction of eastern ridge of the Qinghai-Xizang high on the 100 hPa surface influenced precipitation in East China in summer.

Huang (1990) and Huang and Sun (1992) showed the effect of the heat sources over the western Pacific warm pool on the western Pacific high, which affect the rainfall over the Yangtze River and Yellow River basins. Song et al. (1993) and Ye et al. (1996) analyzed atmospheric heat sources and moisture sinks in China.

What are atmospheric heat sources and moisture sinks and their anomalies during great wet-spell and dry-spell in the Yangtze River valley? What features are atmospheric heat sources? How are atmospheric heat sources connected with the circulation patterns and how do they sustain great dry-spell and wet-spell of the Yangtze River valley? The main purpose of this study is to explore these problems. In this paper, we shall examine monthly mean fields of OLR anomalies, atmospheric heat source anomalies, wind anomalies of the lower and the upper troposphere. Comparison of these parameters for 16 great wet-spells and 8 dry-spells is given.

## 2. Data and methods

The major data used in this work are the NECP-NCAR reanalysis (Kalney et al., 1996) on a 2.5° × 2.5° grid from 1980–1997. Monthly mean zonal and meridional wind components and temperature are given at 10 standard pressure levels (1000, 850, 700, 600, 500, 400, 300, 200, 150, 100 hPa). Monthly mean relative humidity is given at 7 levels from 1000 to 300 hPa. The global monthly mean outgoing longwave radiation (OLR) flux data were obtained from the NCAR. Monthly mean rainfall data at 160 stations in China for JJA (June, July and August) from 1951 to 1997 compiled by the China Meteorological Administration are used in this study.

There are 17 stations with rainfall data (Nanjing, Hefei, Shanghai, Hangzhou, Anqing, Tunxi, Jiujiang, Hankou, Zhongxiang, Yueyang, Yichang, Changde, Ningbo, Quxian, Guixi, Nanchang, Changsha) in the Yangtze River valley. The monthly rainfall deviation was computed as departures from 1961–1990 mean. Because we are mainly interested in the disastrous climate events, only larger monthly rainfall deviation percentage has been taken into consideration (is larger than 30%). During the summer (June–August) of 1980–1997, great wet–spells with the monthly rainfall deviation percentage greater than 30% were observed in the months of July 1980, August 1980, August 1982, June 1983, July 1983, July 1987, August 1987, August 1988, July 1989, July 1991, June 1993, July 1993, June 1994, June 1995, July 1996, and July 1997 over the Yangtze River valley. It has been found that great dry–spells with the monthly rainfall deviation percentage less than –30% occurred in June 1981, August 1983, June 1985, August 1985, August 1986, July 1988, July 1990, and July 1994. In order to reveal the main features in association with the precipitation anomalies in the Yangtze River vally, the composite charts of variables have been constructed using all the samples above.

The apparent heat sources $Q_1$ and the apparent moisture sink $Q_2$ were computed utilizing the methods and procedures used by Yanai et al. (1992, 1998).

In the following, Anomalies of the monthly mean vertically integrated atmospheric heat source $<Q_1>$ and atmospheric moisture sink $<Q_2>$, outgoing longwave radiation (OLR) and other variables are obtained by subtracting the average of monthly mean values for the 18 years (1980–1997) from the original monthly mean values of these variables.

### 3. Circulation anomalies

In summer season, the weather and climate of China are produced by the tropical southwest monsoon from the India Ocean, the subtropical southeast monsoon from the western Pacific, and the disturbances from middle latitudes. During the great wet–spell, there was an anticyclonic anomalous system over the western Pacific in the low level (Fig. 1a). It was centered at 22°N, 140°E with long ridge extending to the Bay of Bengal. It means that the western Pacific high located southwestwards of its normal position (not shown). A cyclonic anomaly was centered over the northwestern Pacific and stretched westward to North China with another center at the Japan Sea. Anomalous southwesterly is seen over the Bay of Bengal —the southeastern periphery of the Tibetan Plateau, which means southwesterly enhanced over that region. Strong southerly anomaly in the western part of the anomalous anticyclonic circulation systems and weak northerly anomaly from the western ridge of the cyclonic anomaly circulation system penetrated to the Yangtze River valley in the lower troposphere. The former strengthened moisture support of southerly and convergence in the Yangtze River valley. Over India and the Arab Sea, easterly anomaly is seen. Therefore, the southwest monsoon was weaker over those regions. At 200 hPa (Fig. 1b), an anticyclonic anomalous system prevailed from Indian peninsula to the western Pacific with the center at 23°N, 105°E. The South Asia high extended southeastward to southeast of the Tibetan Plateau (not shown). In the vicinity of 40°N, a cyclonic system is centered over Korea. The northwesterly between the two anomalous circulation systems was stronger than normal and diverged in the high layer of the Yangtze River valley. These anomalies were similar to those of type As of Song et al. (1993). These anomalies look alike in the whole troposphere which implies their barotropic features. The upper troposphere over the Philippines showed a cyclonic anomaly in opposite to the low–level anticyclonic anomaly.

During the great dry–spell, the anomalies were almost opposite to those of wet–spells (Fig. 2). At 850 hPa, a cyclonic anomaly was located to the south of 30°N with the long axis from the Bay of Bengal northeastward to the western Pacific and the center at 23°N, 135°E. An anticyclonic anomaly was located to the north of 30°N whose center was around 40°N, 180° with the ridge ranging from North China to Japan. The anomalous systems were smaller than those in the great wet–spell. It is interesting that the area greater than or equal to 5880 geopotential meters of the western Pacific high during the great dry–spell was smaller and was centered more north than that of the great wet–spell (not shown). The Indian southwest

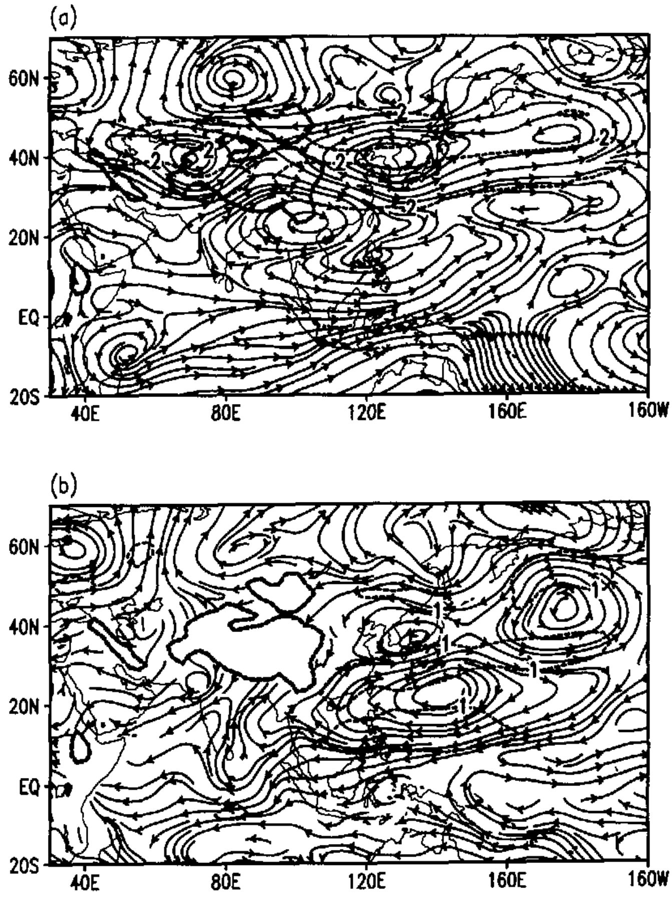



Fig. 1. The composite monthly mean anomalous streamlines and isotachs (dashed lines, units: m / s) (a) at 200 hPa and (b) 850 hPa for the great wet–spell.

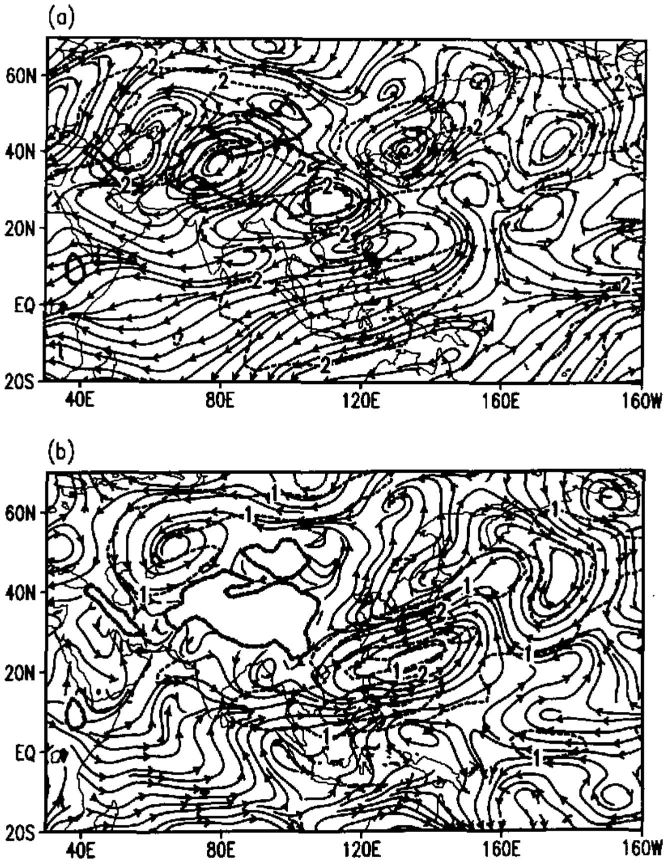



Fig. 2. As in Fig. 1 but for the great dry–spell.

monsoon is stronger. The anomalous northerly of the west part of the cyclonic anomaly and the anomalous southerly of the west part of the anticyclonic anomaly diverged from the Yangtze River valley and induced the great dry–spell of the Yangtze River valley.

At 200 hPa, a cyclonic anomaly prevailed over the southeast flank of the Tibetan Plateau extending to South China, and an anticyclonic anomaly dominated over North China and the northwestern Pacific. It is noted that the two anomalous systems are barotropic. The anomalies are like those generated by the heat source of the western Pacific (Nitta, 1987, Huang, 1990). An anticyclonic anomaly was centered over the Philippines.

## 4. Anomalies of heat sources and moisture sinks

In this section we examine the mean horizontal distributions of the vertically integrated heat source $<Q_1>$ and moisture sink $<Q_2>$, and outgoing longwave radiation. These analyses reveal the heating processes in relation to the circulation of the great wet–spell and great dry–spell.

The horizontal distributions of the composite monthly mean anomalies of the vertically integrated heat source $<Q_1>$ and moisture sink $<Q_2>$, and OLR for the great wet–spell are shown in Fig. 3. The most significant features were the strong positive $<Q_1>$ anomalies over the Bay of Bengal coast, the Yangtze River valley–Japan, indicating above normal heat sources over these regions (Fig. 3a). Positive $<Q_2>$ anomaly values extended from the Yangtze River valley to Japan (Fig. 3b). The OLR anomaly (Fig. 3c) shows that negative anomaly dominated over the region from the Yangtze River valley to Japan centered at the middle–lower reaches of the Yangtze River, indicating above normal convective activity over these regions. Over the Bay of Bengal—the Tibetan Plateau, positive $<Q_2>$ anomaly values are accompanied by positive $<Q_1>$ anomaly, so the major component of the heat source is latent release of convection. Negative $<Q_1>$ anomaly was located over the area from the South China Sea to the western Pacific with the center of 17°N, 148°E, indicating below normal heat source over the region. The negative anomalous $<Q_2>$ and the positive OLR anomalies are similar to the distribution of anomalous $<Q_1>$ over the region, indicating that the decreasing heat source was that latent release of cumulus convection became less during the great wet–spell.

During the great dry–spell (Fig. 4), negative anomalous heat source $<Q_1>$ is found along the Yangtze River valley to Japan. Its center was located over the middle–lower reaches of the Yangtze River and its center value was smaller than 30 W $m^{-2}$ (Fig. 4a). Negative anomalous moisture sink $<Q_2>$ and positive OLR anomaly are also seen over the Yangtze River valley–Japan centered at the middle–lower reaches of the Yangtze River. Large positive anomalies of $<Q_1>$ and $<Q_2>$ were located from the western coast of Indochina to the western Pacific with a center value larger than 60 W $m^{-2}$. Negative OLR anomaly was seen over these regions which was centered over the Philippines. Negative anomalous $<Q_1>$ and $<Q_2>$ dominated over the foothills of the Himalayas and most of the Tibetan Plateau.

## 5. Divergence and divergent wind anomalies

The anomalous convection gives rise to anomalous latent heat release that is accompanied by substantial changes in divergence and divergent wind.

During the great wet–spell, strong anomalous divergent winds converged over the Yangtze River valley in the low level (Fig. 5b). The anomalous convergence was centered over the middle–lower reaches of the Yangtze River with a value smaller than $-2\times10^{-7}/\mathrm{s}$. The anomalous divergent winds going to the Yangtze River valley were the southwesterly from the South China Sea and the southeasterly from the western Pacific. The high–level anomalous northerly diverged from the middle–lower reaches of the Yangtze River whose center value was larger than $3\times10^{-7}/\mathrm{s}$ (Fig. 5a). The low–level southerly divergent wind anomaly was under the high–level northerly divergent wind anomaly. A vertical circulation anomaly (ascending anomaly in the middle–lower reaches of the Yangtze River and descending anomaly along the South China Sea and the western Pacific) was seen (not shown).

An anomalous north–south vertical circulation expressed that anomalous upward motion over the western Pacific to the South China Sea is accompanied by anomalous downward motion over the Yangtze River valley during the great dry–spell (not shown). The horizontal distribution of the composite monthly mean anomalies of the divergent wind and horizontal divergence for the great dry–spell at 850 hPa is shown in Fig.6b. Rather strong positive anomalous divergence was over the Yangtze River valley. Anomalous divergent winds

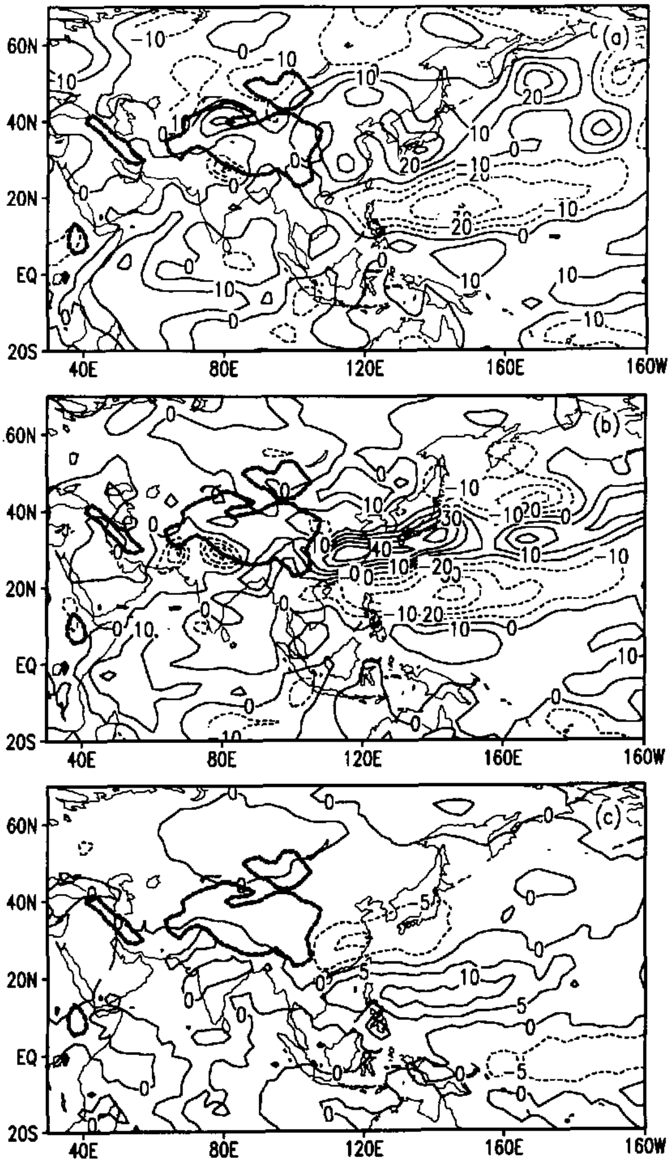



Fig. 3. The composed monthly mean anomalies of the vertically integrated (a) apparent heat source $<Q_1>$, (b) apparent moisture sink $<Q_2>$ and (c) OLR (units: W $m^{-2}$) for the great wet–spell.

entered the strong negative anomalous divergence area of the South China Sea and the western Pacific. A rather strong positive anomalous divergence is noted over the high level of the South China Sea extending northeastward to the western Pacific (Fig. 6a). Anomalous divergent southerly entered the area of the Yangtze River valley to Japan.

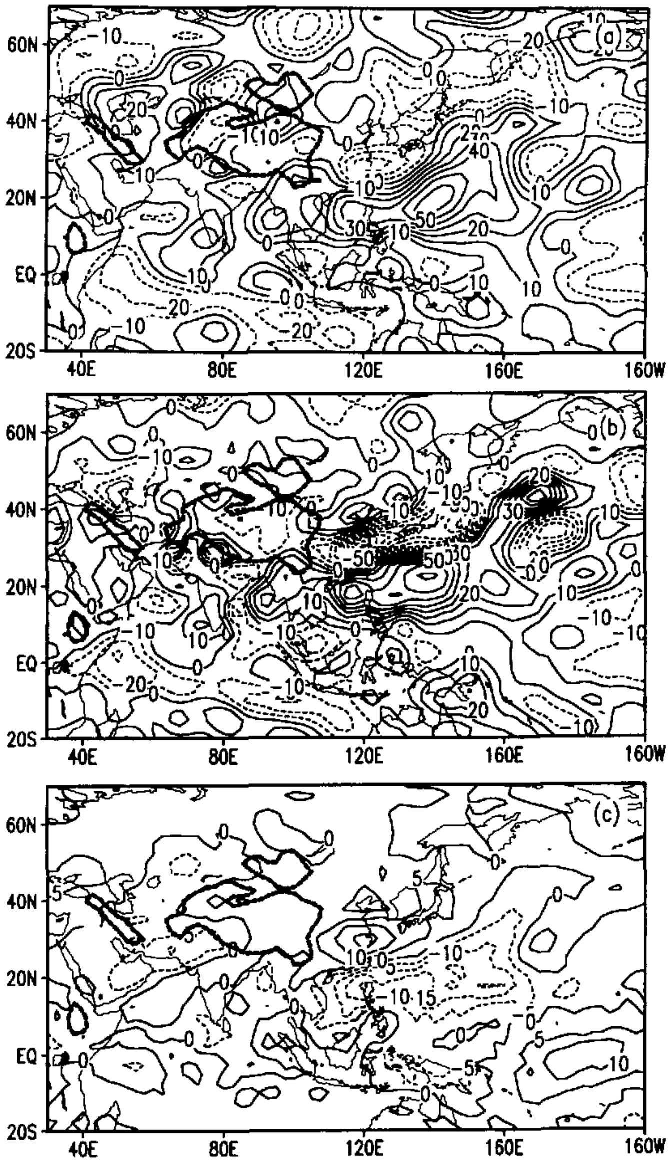



Fig. 4. As in Fig. 3 but for the great dry-spell.

Therefore, the weaker heat source of the western Pacific–the South China Sea is associated with below normal upward motion over those regions and is helpful to low–level convergence and high–level divergence anomalies and strengthened water moisture transport over the middle–lower reaches of the Yangtze River. The stronger heat source of the western Pacific—the South China Sea is associated with above normal upward motion over those regions and weakened low–level convergence and high–level divergence and moisture support

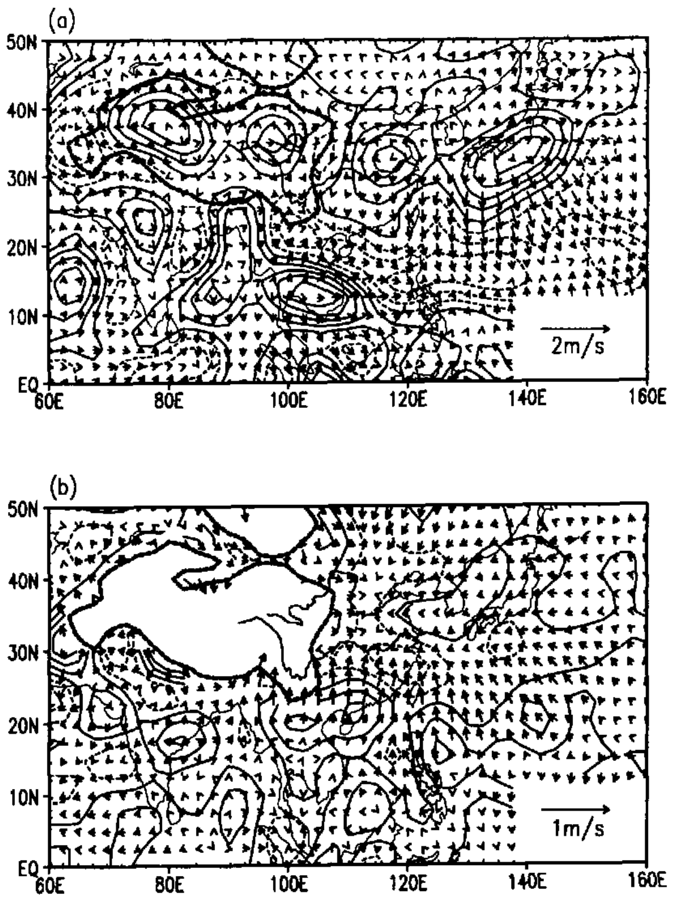
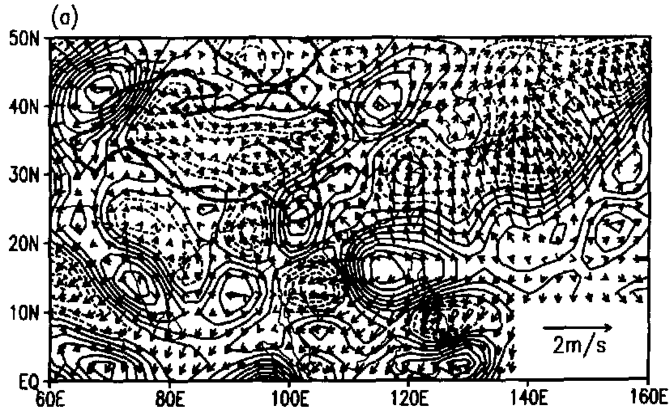



Fig. 5. Composite monthly mean anomalous divergent wind and divergence (contour interval $10^{-7}s^{-1}$) (a) at 200 hPa and (b) at 850 hPa for the great wet–spell.

over the Yangtze River valley. The atmospheric heat source over the western Pacific to the South China Sea contributed to the great wet–spell and great dry–spell over the middle–lower reaches of the Yangtze River by changing the divergent winds.

## 5. Conclusion

In this paper, great wet–spells and great dry–spells of the Yangtze River valley are selected when the absolute monthly rainfall deviation percentage of the 17 stations over that region is larger than 30%. There are 16 great wet–spells and 8 great dry–spells in June to August of 1980–1997. Based on composites, some important differences of circulation, divergent wind, OLR fields, and heat and moisture budgets between these two periods are described using the summer (June to August) monthly mean data of the National Centers for Environmental Predictions (NCEP) – National Center for Atmospheric Research (NCAR) reanalysis from 1980 to 1997.



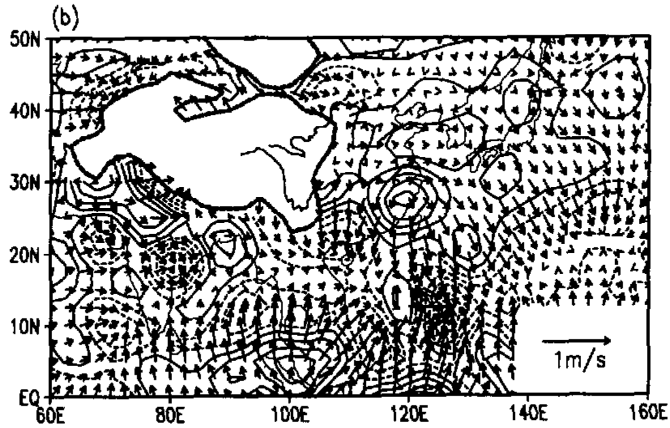




Fig. 6. Composite monthly mean anomalous divergent wind and divergence ($10^{-7}s^{-1}$) (a) at 200 hPa and (b) at 850 hPa for the great dry–spell.

1) During the great wet–spell, an anticyclonic anomaly occupied the south of 30°N and contributed to the ridge of the subtropical western Pacific high extending southwest. A cyclonic anomaly was located over the north of 30°N. The two circulation anomalies enhanced southwesterly and northerly anomalies in their west flanks. They penetrated to the Yangtze River valley contributing to enhancement of the low–level convergence over that region. The southwesterly anomaly increased the moisture to the Yangtze River valley. These features were opposite to that during the great dry–spell. A cyclonic anomaly dominated over the areas south of 30°N and an anticyclonic anomaly prevailed over the regions north of 30°N. Therefore, the subtropical western Pacific high was weak and its ridge extended northwest. The northerly and southerly in the western parts of the two circulation anomalous systems diverged from the Yangtze River valley. The former weakened the southerly and reduced the supply of moisture to that region.

2) The high level showed that an anticyclonic anomaly was centered over the southeast flank of the Tibetan Plateau during the great wet–spell. A cyclonic circulation anomaly was

located over Korea. The westerly anomaly between the two circulation anomalous systems diverged over the Yangtze River valley. On the contrary, during the great dry–spell, a cyclonic anomaly was centered at South China, and an anticyclonic circulation anomaly was centered at the Japan Sea in the upper troposphere. The easterly anomaly between the two circulation anomalous systems enhanced the high–level convergence over the Yangtze River valley. The ridge of the South Asia high of great wet–spell stretched more southeastward than that of the great dry–spell. The upper troposphere over the Philippines and nearby showed a reversal of the circulation anomalous system, a cyclonic anomalous system in the great wet–spell to an anticyclonic anomalous system in the great dry–spell.

3) During the great wet–spell, above normal heat sources are observed over the Yangtze River valley. Above normal heat sinks and below normal OLR display the importance of the convective cumulus latent heating. During the great dry–spell, below normal heat sources are observed over the Yangtze River valley. Below normal heat sinks and above normal OLR show that the below normal sources are convective cumulus latent heating decreasing. Below normal heat sources and heat sinks and above normal OLR are found over the South China Sea– the subtropical western Pacific during the great wet–spell. On the contrary, above normal heat sources and heat sinks and below normal OLR are found over the South China Sea– the subtropical western Pacific during the great dry–spell. Over the Bay of Bengal—the Tibetan Plateau, heat source anomalies was positive during the great wet–spell and negative during the great dry–spell. The vertically integrated heat source $<Q_1>$ and moisture sink $<Q_2>$ show the contribution from the release of latent heat of condensation.

4) During the great wet–spell, above normal low–level convergence and high–level divergence are found over the Yangtze River valley with centers in the middle–lower reaches of the Yangtze River. The low–level southerly divergent wind anomaly originating from the South China Sea– the subtropical western Pacific formed anomalous convergence in the low level of the Yangtze River valley. The high–level northerly divergent wind anomaly emanated outward from the Yangtze River valley into the South China Sea– the subtropical western Pacific because of the below normal heat source over the South China Sea–the subtropic western Pacific. During the great dry–spell, the below normal low–level convergence and high–level divergence over the Yangtze River valley are accompanied by the northerly divergent wind anomaly at the low level and southerly divergent winds at the high level which are associated with low–level convergence anomaly and high–level divergence anomaly over the Philippines and its vicinity. Therefore, the change of heat source over the South China Sea–the subtropic western Pacific contributed to the great wet–spell and dry–spell over the middle–lower reaches of the Yangtze River.

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# 长江中下游严重旱涝时期大气环流以及热源和水汽汇的异常

杨 辉

**摘 要**

利用 1980–1997 年 6–8 月 NECP / NCAR 月平均资料，计算了大气热源和水汽汇，研究了我国长江中下游夏季严重旱涝时期大气环流以及大气热源和水汽汇的异常特征，主要结果如下:

在对流层中下层，来自于孟加拉湾和南海的南风异常和长江流域以北的北风异常在长江中下游辐合。这两股异常气流分别与西太平洋上反气旋异常系统(中心位于 22°N, 140°E)和气旋异常系统(中心位于日本海)有关。在对流层高层，反气旋异常系统中心位于 23°N, 105°E，气旋异常系统中心位于朝鲜，两异常系统之间的西北异常气流在长江中下游辐散。而在印度西南季风区为偏东风异常，表示西南季风的减弱;

长江中下游严重干旱时，在对流层中下层，长江以北南风异常和长江以南北风异常从长江流域辐散，在以东的洋面上形成东风异常气流。这两股异常气流分别与西太平洋上气旋异常系统(中心位于 23°N, 135°E)和西北太平洋上反气旋异常系统有关。在对流层高层，气旋异常系统中心位于南海，反气旋异常系统中心位于日本海，两异常系统之间的偏东异常气流在长江中下游辐合。

热源异常的最主要特征是长江中下游严重洪涝时从西太平洋到南海热源异常为负，表示热源偏弱; 正热源异常位于长江流域。而长江中下游严重干旱时热源异常正好相反。垂直积分水汽汇和 OLR 表明西太平洋—南海热源以及长江流域热源异常均是由对流异常引起的。

长江中下游严重洪涝时长江流域和青藏高原东南部—孟加拉湾热源为正，严重干旱时为负。热源的性质是凝结潜热释放。

辐散和辐散风的分析表明长江中下游严重洪涝时形成长江中下游低空异常辐合的气流是来源于西太平洋到南海的异常辐散偏南风，对应高空是从长江中下游进入西太平洋到南海辐合的偏北辐散风。而在长江中下游严重干旱时这些特征相反。

**关键词** 大气环流异常，热源和水汽汇异常，长江中下游严重旱涝