Major Scientific Achievements of the First China–Japan Cooperative GAME/HUBEX Experiment: A Historical Review

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ABSTRACT

In the summers of 1998 and 1999, Chinese and Japanese scientists cooperatively conducted the first large-scale energy and water cycle experiment (WCRP/GEWEX/GAME/HUBEX: World Climate Research Program/Global Energy and Water Cycle Experiment/Asian Monsoon Experiment/Huaihe River Basin Energy and Water Cycle Experiment) in the Huaihe River basin, Anhui Province of China. The main objective of this field experiment (HUBEX) was to investigate the multiple-scale structure characteristics, life cycles, and genesis and development mechanisms of the Meiuy system in East Asia as well as the cause of related flooding disasters. It was a joint China–Japan cooperative meteorological and hydrological observation experiment. On the basis of intensive observations, scientists from the two countries conducted follow-up investigations through collating and compiling data and performing scientific analysis during the following five years. It can be concluded that the HUBEX project has yielded comprehensive and remarkable achievements. This paper introduces the major scientific results derived from this field experiment and the ensuing investigations, and reassesses their merits and shortages for the purpose of providing useful experience and proposing new research targets as well as prospects for the initiation of a new joint scientific Meiuy experiment in the middle and lower Yangtze River basin.

Key words: Meiuy, Huaihe River basin, energy and water cycle, meteorological and hydrological observations, Huaihe River Basin Energy and Water Cycle Experiment (HUBEX)/Global Energy and Water Cycle Experiment (GEWEX)/Asian Monsoon Experiment (GAME)

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1. Introduction

The Huaihe River basin in China is located in the transition zone between the humid and arid climate regimes in East Asia. The weather and climate in this region are complex and diverse. At the same time, the interlaced river network, the fertile land, and the rich light, heat, and water resources make it an important agricultural area in China. However, this region is also susceptible to frequent flooding, especially in the Meiuy season from June to July. The Meiuy front system not only affects the Yangtze River and Huaihe River basins, but also significantly influences the Korean Peninsula and Japan. Therefore, disaster prevention and mitigation are a major problem that China, Korea, and Japan commonly face.

Energy and water are the foundation of human survival and development. The energy cycle forms as the earth system absorbs solar radiation and releases longwave radiation from the atmosphere, clouds, land surface, and oceans. Meanwhile, global and regional water resources are balanced through the water cycle of precipitation, evaporation, and surface and groundwater runoff. Energy and water cycle studies are of great significance to

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the establishment of regional climate and hydrological models and to the improvement of extended weather and climate forecasts, as well as to the accuracy of precipitation forecast (Zhao and Takeda, 1998; Zhao and Ding, 1999; Lin et al., 2001; Hu and Ding, 2002; Ding and Hu, 2003; Yao et al., 2003; Zhou and Luo, 2004; Fujiyoshi and Ding, 2006; Hu et al., 2006; Shusse and Tsuboki, 2006; Chen et al., 2015).

Based on the Coordinated Energy and Water Cycle Observation Program (CEOP), the accuracy of the land surface energy balance model has been verified in different climate regions and land surface types, and improvements to the land surface model have been proposed. It is found that the numerical model simulation skill has been distinctly improved over snow-covered areas (Hirai et al., 2007; Su et al., 2007). The Qinghai–Tibetan Plateau (QTP) is a strong heat source during the daytime and a significant cold source in the nighttime. The radiative heating effect of the QTP is significant. Based on satellite remote sensing data combined with ground observations, the ground temperature, surface albedo, vegetation index, and other parameters over the QTP can be derived, which provide valuable references for the parameterization of land surface processes in the plateau area (Ma et al., 2000, 2002; Wen et al., 2003).

The Huaihe River Basin Energy and Water Cycle Experiment (HUBEX) was conducted under the above background. It is a part of the Asian Monsoon Experiment (GAME) under the Global Energy and Water Cycle Experiment (GEWEX). The GAME project also includes the South China Sea Monsoon Experiment (SCSMEX), GAME–Tibet (Qinghai–Tibet Plateau Experiment), and GAME-Tropics (Asian Tropical Experiment). Through these four sub-programs, the obtained data can be integrated and comprehensively analyzed. The research results and main publications of this program are archived in related albums (Yasunari, 2001).

The field campaign of HUBEX lasted for two years. The experiment accomplished the overall goals and main tasks, and obtained a large amount of intensive high-resolution meteorological and hydrological data. Through joint and cooperative research, new results have also been achieved. Chinese scientists focused on the synoptic-scale weather and hydrology while Japanese scientists focused on the mesoscale weather and precipitation physics. Due to time constraints, the above two focused areas of studies have not been really integrated, and new experiments are expected to work out this issue.

2. GAME/HUBEX experiment review

Based on the particularity and importance of the weather and climate background in the Huaihe River basin, the HUBEX was conducted in the summers of 1998 and 1999 under the joint support of the National Natural Science Foundation of China and the GEWEX/GAME under the World Climate Research Program (WCRP). HUBEX is a large-scale international cooperative meteorological and hydrological joint observation experiment. Eight Doppler radars and conventional weather radars from China and Japan and many advanced hydro-meteorological observation instruments were implemented in the HUBEX. Data were also collected at dozens of high-altitude sounding stations and several hundreds of hydro-meteorological observational stations. Hundreds of Chinese–Japanese meteorological and hydrological scientists and engineers participated in the experiment. The Tropical Rainfall Measuring Mission (TRMM) satellite jointly launched by the United States and Japan also provided continuous observations for this experiment.

From 2000 to 2005, scientists from both China and Japan conducted data collation and analysis as well as scientific research. Comprehensive and fruitful results were achieved. The scientists of the two countries published the final report of the first HUBEX in 2006, which summarized the main achievements of the HUBEX in nine aspects, including (1) analysis of large-scale circulation characteristics and weather system in East Asia during the HUBEX period, (2) mesoscale systems and flood disasters during the HUBEX period, (3) atmospheric water vapor source and transport for the Meiyu rainfall, (4) land surface processes, (5) rainstorm mechanisms, (6) regional/basin-scale water and energy budgets, (7) Huaihe River basin runoff observations and prediction, (8) the GAME/HUBEX four-dimensional data assimilation analysis (4DDA), and (9) storm and flood forecasting. This article provides a general introduction to some of the main results mentioned above. Details for individual aspects can be found in the final report jointly published by Chinese and Japanese scientists in 2006 (Fujiyoshi and Ding, 2006).

3. Major results of the GAME/HUBEX

3.1 Large-scale circulation characteristics and synoptic weather systems during the Meiyu period in East Asia

The year 1998 was the one right after the strongest El Niño outbreak in the previous 100 years. From the spring of 1997 to the beginning of the summer of 1998, continuous high sea surface temperature (SST) occurred in the equatorial eastern Pacific, and the Niño3 sea surface temperature anomaly (SSTA) in winter 1997 even exceeded
The year 1999 was a La Niña year. The equatorial convergence zone of the tropical western Pacific was exceptionally weak with a southerly than normal position. Meanwhile, the WPSH significantly shifted eastward and southward, located over the Pacific to the southeast of Japan. The polar vortex in the high latitudes frequently developed and moved southeastward, and the cold air from East Siberia moved along the eastward path, reaching Mongolia, Northeast China, and the Sea of Japan. As a result, the low trough persisted in the area from East China to the Sea of Japan. Precipitation mainly occurred in the middle and lower reaches of the Yangtze River in June and July, especially in the lower reaches of the Yangtze River. In late June and early July, extremely heavy rainfall occurred in this region, breaking the historical record since 1949. Precipitation in Shanghai and Wuhu even broke the 100-yr historical record. In Anhui Province, there was also noticeable heavy precipitation. The precipitation in southern Anhui was mostly two to four times the long-term average.

The above analysis of the climatic conditions and the average precipitation during the Meiyu period shows that the 2-yr intensive observation period of the HUBEX was an abnormally rainy period in the entire Yangtze River basin and the middle and lower reaches of the Yangtze River, respectively. Record-breaking precipitation occurred in various regions. In the Huaihe River basin, heavy rain also occurred during the Meiyu period. However, due to the different influences of El Niño and La Niña, the East Asian atmospheric circulation and heavy precipitation areas were obviously different between the two summers, and the distribution and intensity of the Meiyu precipitation were also obviously different. This result indicates that as a rain band on the climatic timescale, the Meiyu rainbelt distribution and total rainfall forecast must consider those main climate impact factors such as the impact of the ENSO; that is, in the subsequent summer of an El Niño event, it would be rainy in the Yangtze River basin, and the Meiyu rainfall would be strong. In contrast, in the subsequent year of a La Niña event, it would be a weak Meiyu year, and strong Meiyu rainfall would only occur regionally. At present, ENSO has become a major interannual signal for short-term climate prediction.

Under the above climate background conditions, characteristics of synoptic-scale systems can be further analyzed (Kato et al., 1999; Ding et al., 2001). Figure 1 shows distributions of the average daily rainfall from 22 June to 2 July 1999. This pattern corresponded to an east–west oriented shear line in the circulation field. It can be seen that the Meiyu rainbelt was distributed steadily in the east–west direction along the Yangtze River basin, with rainfall centers propagating from west to east. The total rainfall during the 10 days is displayed in the last panel, which shows that the maximum rain center was located in the middle and lower reaches of the Yangtze River. These heavy rainfall centers corresponded to intermediate scale or mesoscale low vortices (southwest vortices) originating from the upstream (Fig. 2). Therefore, the southwest vortex was the main system causing heavy rain and rainfall storms along the Meiyu front. The southwest vortices originated in Southwest China and moved eastward along the shear line. The rainstorm centers induced by these vortices also propagated downstream along the shear line or the Meiyu front.

Figure 3 shows the eastward propagation of two low vortices generated downstream of the Tibetan Plateau.
They further developed in the downstream and produced heavy rainfall. The low-level jet is another important weather system that can cause rainstorms during the rainy season. As shown in Fig. 4, strong wind speeds (12–13 m s⁻¹) developed at 850 hPa on the south side of the Meiyu front or shear line. They originated from the tropical monsoon region, especially the South China Sea and the western Pacific, which are also the main sources of water vapor transported to the Meiyu area. Positive shear vorticity developed on the north side of the low-level jet center, which coincided with the area of ascending motion on the right side of the upper-level westerly
Fig. 2. Daily distributions of 850-hPa wind vectors (left panels; m s\(^{-1}\)) and geopotential height (right panels; gpm) from 22 June to 1 July of the typical Meiyu year 1999 (Ding et al., 2001).
Fig. 2. (Continued).
Fig. 3. (a) Daily streamline distributions at 850 hPa from 26 June to 1 July 1999. C2 and C3 denote mesoscale vortices, which formed on the east side of the Tibetan Plateau, then propagated eastward, and strengthened along the coast. (b) Longitude–time cross-section of daily mean precipitation along 28°–30°N of the Meiyu area (made from GPCP data). The thick dotted line is the maximum precipitation axis, which is consistent with the moving paths of the three southwest vortices shown in Fig. 3a (comparing C2 and C3 vortices in Figs. 3a, b; Ding et al., 2001).
jet exit area. The vertical coupling effect of circulations on the right side of the upper-level jet entrance area can produce strong ascending motion, which may subsequently trigger and sustain the formation and development of Meiyu rainstorms (Fig. 5).

The above discussion clearly indicates that Meiyu in East Asia is the product of multi-scale weather and climate systems and their variability. Climate background such as ENSO (El Niño and La Niña events) determines the interannual differences and seasonal anomalies of Meiyu, i.e., rainy years or dry years; the strength of the intraseasonal scale low-level jet in the East Asian summer monsoon determines the water vapor transport and total precipitation in the Meiyu area; the strong ascending motion generated by the interaction between centers of the upper and lower level jets determines the intensity of Meiyu rainfall and the location of the rainstorm. The synoptic and sub-synoptic scale systems such as shear lines and southwest vortices propagating along the Meiyu shear line or Meiyu front are the main systems responsible for Meiyu rainfall processes. Those mesoscale and small scale convective systems embedded in the synoptic and sub-synoptic systems are the main producers of heavy rainfall. The intensive phase of the HUBEX and follow-up research have made positive contributions to the clarification of these large-scale circulation and weather systems, and greatly deepened our understanding of the large-scale and synoptic-scale conditions for the formation and development of Meiyu rainfall.

3.2 **Mesoscale and small scale systems in the Meiyu area**

During the intensive observation phase of the HUBEX, an observation array consisting of three X-band Doppler radar stations (Shouxian, Huainan, and Fengtai) was established, from which the three-dimensional dynamic structures and life-long evolutions of mesoscale and small scale disturbances were obtained. During the intensive observation period (IOP) in 1998, the Meiyu front from 28 to 30 June (IOP-1) and from 1 to 3 July (IOP-2) slowly moved northward, and moved across the Huaihe River from the end of June to the beginning of July. The Observations show that the precipitation efficiency of the cloud system during the IOP-2 was 70%, which was much greater than that (50%) during the IOP-1. During the IOP-1, a meso-α scale convective system formed and developed along the Meiyu front, causing heavy rainfall ($\geq$ 110 mm) over a large area. During the IOP-2, large amounts of cloud clusters were observed in the Meiyu front, whereas there was no obvious meso-α scale vortex formed.

During the entire 2-yr IOP observation period, vortices of two different scales were observed. The meso-β
scale vortex formed near the front, while the meso-γ scale vortex formed directly under the melting layer of the Meiyu rainbelt. Strong vorticity developed at the inflection point of wind speed. The mesoscale vorticity in the middle layer formed in the horizontal shear zone, that is, in the layer where the wind speed increased at the boundary between the stable dry layer and the unstable wet layer. In these two layers, there existed not only strong wind speed shears, but also vertical velocity that increased with height, and precipitable clouds that vigorously developed. The unstable horizontal shear and the density difference between the two sides of the front were the conditions for the formation of meso-β scale disturbances, which could cause the dry and stable air layer to suddenly increase in thickness. Meso-α-scale disturbances might be organized directly under the melting layer. Because such kind of disturbances developed in wet and unstable layer, strong updrafts and convective clouds were generated. When the lower-level vorticity merged with the upper-level vorticity, a stronger and larger vortex formed. At the same time, huge amounts of dry and cold air from the north could be attracted to the south, accelerating the southward movement of the front. Therefore, the mesoscale observations of the HUDEX Doppler radar array played a very important role in the in-depth understanding of the formation and mechanism of the vortices.
of the meso-α, meso-β, and meso-γ scale disturbances in the Meiyu front (Fujiyoshi and Ding, 2006).

3.3 Precipitation system along Meiyu front, rainstorm mechanism, and conceptual model

According to the observations and analysis during the HUBEX intensive study period, the precipitation system along Meiyu front consists of multi-scale systems (Mae-saka and Uyeda, 2006), including synoptic-scale (such as Meiyu front), sub-synoptic scale (southwest vortex), and meso–small scale systems (α, β, and γ scale systems). Based on the data collected in the intensive observation period in 1998 and 1999 and follow-up research, synoptic-scale Meiyu front can be classified into two types: the Meiyu front in the subtropical air mass (ISA type) and the merged cold Meiyu front (MCF type). From the perspective of frontal movement, the former moves northward in the subtropical air mass, while the latter moves southward with the polar front. The temperature gradient of the MCF type is −4.0°C/15° latitudes, which is larger than that of ISA type (−1.5°C/15° latitudes). This weak temperature gradient of the ISA type Meiyu front is actually a kind of polar front that reaches the subtropical zone, which is why the temperature gradient is less than the temperature gradient of general mid–high latitude cold fronts. In the Meiyu season, the temperature gradient weakens or even reverses after the polar front reaches the southern land area, so the temperature gradient of the ISA type Meiyu front is smaller than that of the MCF type. But temperature gradients of both types of Meiyu front are higher than that in other latitudes. For the wind field, the wind speed of the MCF type is three times larger than that of the ISA type, and the vertical shear is 1.6 times larger. Comparison of the above conditions shows clearly that the MCF type cold front is more active than the ISA type, because both its temperature gradient and horizontal convergence are larger than those of the ISA type. Yet, the regional average daily precipitation is larger for the ISA type than for the MCF type. Note that on the watershed scale, the precipitation distribution of the two types of Meiyu fronts is different. For the ISA type Meiyu front, there are two types of precipitation: convective precipitation along the low-level convergence line and stratiform precipitation to the north of the front. For the MCF type front, stratiform precipitation along the low-level convergence line is dominant. There are convective and stratiform precipitation near the lower-level convergence line for both types of Meiyu front, but there is no precipitation to the south of the convection line for the MCF type Meiyu front.

Regarding the intensity of the two types of Meiyu front, stratiform precipitation is stronger for the MCF type, but the rainfall area is much larger for the ISA type. Therefore, the latent heating in the troposphere caused by precipitation for the ISA type is larger than that for the MCF type, while the rising movement can reach higher altitude for the ISA type than for the MCF type. As a result, their heating profiles are different and the heating altitude is higher for the MCF type. In addition to the different types of Meiyu front mentioned above, which can cause different heating profiles on the basin scale, the characteristics of meso-γ convective precipitation can also cause differences in the non-adiabatic heating profile and precipitation structure. The meso-γ vortices only exist when heavy precipitation associated with the MCF Meiyu front occurs. Studies have shown that differences in precipitation systems can also affect the generation process of meso-α low pressure systems in the Meiyu front.

The conceptual models of the two types of Meiyu front discussed above were summarized based on analysis of cases observed during the intensive observation period of HUBEX. The conceptual model of Meiyu front (ISA type) in the subtropical air mass is displayed in Fig. 6a, which shows that the zonal convective system along the humidity discontinuity zone can maintain itself, because the surface pressure in the convergent zone is lower than that around the convection zone. As a result, the air in the lower troposphere converges into the zonal convective system, and the low-level southerly airflow on the south side of the convective zone enhances. Large amounts of water vapor are then transported to the zonal convective area. After the air mass being lifted, condensation will form, leading to convective precipitation. This is why large-scale precipitation can be formed along this type of Meiyu front. Precipitation is not only distributed along the main convergence line, but also extends to the south of the convergence line.

Figure 6b is a conceptual model diagram of the type of merged cold Meiyu front. As the Meiyu front merges with the cold front, warm and humid (cold and dry) air is located to the south (north) of the Meiyu front. The cold air from the north invades the Meiyu front, while the warm and humid air in the south rises along the front and then condenses. Convective precipitation system occurs 40 km north of the ground front. In addition, there often exist meso-γ vortices. Stratiform precipitation system usually develops to the north of the convective precipitation system. Similar to the ISA type Meiyu front, this can enhance local temperature gradient in the lower troposphere.
The conceptual diagram of the three-dimensional structure of the mesoscale convective system associated with the Meiyu front in the lower reaches of the Yangtze River is displayed in Fig. 6c (Uyeda, 2011), which shows a strong southwesterly flow to the south of the Meiyu front. Meanwhile, an easterly from low-latitude ocean...
also flows to the mesoscale system. Three convective systems are displayed in the figure, and the convection centers are all located at around 2-km altitude. As it moves closer to the coastal area and moves eastward to the Sea of Japan, the convective cloud belt accompanied by low pressure systems continues to develop. Note that dry and cold westerly–northwesterly flow can be found above the warm and humid low-level southwesterly.

3.4 Land surface processes and development of regional hydrological model in the Huaihe River basin

Land surface processes are an important component of climate models (Dai et al., 1999), and the land surface hydrological process in the hydrological model is an important component of the land surface processes. It represents a key issue of the interaction and feedback between the climate system and the hydrological process. At present, the land surface hydrological process has been considered in both global circulation models and climate models, i.e., the hydrological model is coupled with climate models. This not only makes the prediction of hydrological variables more reasonable, but also ensures a longer forecast lead time, and the feedback between hydrology and climate can also improve the prediction accuracy of the climate model. It should be noted that there exist certain differences between the climate processes and the terrestrial hydrological processes on the spatial and temporal scales. However, through the land–air coupling method, climate models currently can be well coupled with hydrological models to establish a land–atmosphere coupled hydrological model that is generally applied on the watershed scale.

One of the earliest land–atmosphere hydrological models developed and applied by the hydrological department in China is the Xin’anjiang model (Hao et al., 1999). After certain improvements, this model was applied to the Shiguan River basin during the HUBEX field campaign. It is fully digitized and the results can be displayed by using digital images. With the hydrological data obtained during the intensive observation period of HUBEX, this model could not only simulate the runoff and flood conditions of Shiguan River and its tributaries, but also provided flood forecasts. The digital method used in this model can provide real-time, comprehensive information of the evolution of watershed hydrological processes. This model had become an objective platform for calculating runoff and assessing water resources (Ren, 2006), and played a key role in the observations (Gao et al., 1999; Li et al., 1999), analyses, and predictions (Qian et al., 2006) of hydrological conditions during the HUBEX intensive study period in 1998 and 1999. An example of flow simulation using this hydrological model is presented in Fig. 7, which shows that during the enhanced observation period in 1998, the four flood processes were well simulated, especially for the major flood from the end of June to the beginning of July, during which the simulated peak flow and the time of occurrence agreed well with observation.

Based on hydrological and meteorological data collected during the HUBEX intensive study period and farmland data, Japanese scientists calculated the energy and water budget over the Huaihe River basin from May to August 1998 using a surface energy and water budget model. The model output also includes soil moisture and changes in water depth and irrigation water in rice fields. On the basis of this work, changes in the components of the water balance averaged over the basin were obtained (Tanaka, 2006a). In addition, it is worth noting that in order to make better use of the observations obtained in the HUBEX-IOP, Tanaka (2006b) improved the land surface process in the mesoscale numerical model (a spectral model) used by the Japan Meteorological Agency at that time. Specifically, a new land surface process model (SiBUC) was developed to describe the complex land

![Comparison of observed and simulated discharges at Huangnizhuang hydrological station from 31 May to 3 August 1998. The efficiency coefficient of the model is 92.4% (Ren, 2006).](image-url)
use/land cover condition. This model has been coupled into the global spectrum model of the Japan Meteorological Agency. The new SiBUC land surface model can also calculate the surface water budget. Furthermore, four-dimensional data assimilation (4DDA) was implemented in the JSM-SiBUC model to make better use of the observations obtained by the HUBEX-IOP for meteorological and hydrological forecasting (Tsuboki, 2006). At the same time, Chinese scientists had developed a regional four-dimensional data assimilation method (Zhu et al., 2006).

In order to make better use of the high-quality data obtained during the HUBEX-IOP, a distributed hydrological model (MaScOD) was developed to simulate the flow of the Huaihe River. The results indicate that the use of finer-resolution forcing data is necessary for successful simulation of detailed features and changes of the complex flow. Finally, it is found that it is also necessary to develop a nested regional model (Hao et al., 2002; Liu et al., 2006). The example shown in Fig. 8 clearly indicates that most of the runoff in 1998 was underestimated, while that in 1999 was overestimated. When using the observed precipitation as forcing data, the simulated runoff biases were reduced; if using rainfall simulated by the regional model as forcing data, runoff was overestimated. Apparently, the accuracy of simulated precipitation is critical for the runoff calculation.

4. GAME/HUBEX-2 outlook

The GAME/HUBEX cooperated by China and Japan was conducted 20 yr ago. The aforementioned reviews and comments on its main achievements show clearly that this large-scale scientific experiment that lasted about 7 yr in total is successful, and many new scientific understandings and breakthroughs have been accomplished. These achievements have played an important role in the subsequent development and promotion of related scientific research and operational forecasting.

However, it should also be recognized that as the impact of global climate change continues to increase, the results and findings of the past may have also changed, especially due to the impact of climate warming caused by human activities. The hydrological processes and events corresponding to the multi-scale variability of climate background and extreme events will also change (Ding et al., 2020). Studies have shown that Meiyu in East Asia, including Meiyu in China, is characterized by multi-scale variability. They are related to quasi-bi-weekly and 30–60-day oscillations, ENSO events, quasi-biennial oscillations (QBO), the Pacific decadal oscillation (PDO), and the Atlantic Decadal Oscillation (ADO). In addition, many studies have also pointed out that under the influences of global warming, urbanization, and increased aerosols, the Meiyu precipitation characteristics have also changed, including precipitation continuity, precipitation increase or decrease, more uneven spatial distribution, the increase (decrease) in heavy (light) precipitation days, etc. (Li et al., 2011, 2016).

Of particular concern is that global warming is changing the global and regional water cycles. It is still unclear whether the Meiyu or related energy and water cycles may also increase in the Huaihe River basin, which is located in a fragile climate zone, and whether the risks of meteorological and hydrological disasters may also change. This involves the issues of disaster prevention and mitigation as well as economic and social sustainable development in the Huaihe River basin under the new situation. Therefore, we need to conduct more in-depth and comprehensive research and exploration from a global perspective, understand the new regularities of climate, environment and hydrological

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**Fig. 8.** Monthly mean runoff (m$^3$ s$^{-1}$) observations at Bengbu station from 1998 to 1999. The controlled area is 121,330 km$^2$. 
changes, avoid risks, and seek new development opportunities. This is an important issue that will benefit the people living in the vast areas of the Huaihe River basin.

Relying on the multi-scale observation network centered on the Shou County National Observatory and a variety of advanced detection equipment (Table 1), the second phase of the Huaihe River Energy and Water Cycle Experiment (HUBEX-2) will be carried out. Further in-depth and more comprehensive research and exploration of changes in the water cycle and corresponding changes in meteorological and hydrological disasters and risks will be conducted to understand new regularities of climate, environmental, and hydrological changes; to avoid risks; and to ensure healthy development of agriculture, ecology, society, and economy in the Huaihe River basin.

Aiming at the bottleneck problems in the research and meeting the actual needs of drought and flood disaster prevention and mitigation and sustainable development, we will further address the following issues. (1) Solve the problem in multi-platform and multi-method collaborative observation; rely on the National Climate Observation data collection from the comprehensive meteorological observation network in the Huaihe River basin of China to achieve integrated airborne, ground-based, and satellite observations; develop multi-variable blending and retrieval technology; and realize simultaneous and stereoscopic observations of hydrological processes, land surface processes, atmospheric dynamic and thermal dynamic processes, cloud microphysical processes, atmospheric chemical processes, etc. (2) Based on analysis of historical observation data and comprehensive experiment data, further reveal the characteristics of the energy and water cycles in the Huaihe River basin; understand the land surface processes, dynamics/thermal and microphysical processes of various weather systems, and the evolution and interaction of multi-scale systems; and study the interaction between the energy and water cycles in the Huaihe River basin and weather systems such as the Meiyu front, the subtropical high, and Jianghuai cyclones. (3) Use satellite and global meteorological observation data to study the impacts of global climate change, anthropogenic forcing (greenhouse gas emissions, radiative forcing caused by land use change) and human activities (urbanization, atmospheric polli-

| Dataset | Content (including meta data, equipment information, data usage note, etc.) | Start time |
|---------|-----------------------------------------------------------------------------|------------|
| Manual weather reports | Barometric pressure, air temperature, air humidity, surface and soil temperature, frozen soil depth, precipitation, evaporation, current weather/weather events | January 1955 |
| National baseline meteorological station observations | Barometric pressure, air temperature (mean, maximum, minimum), grass land surface temperature, water vapor pressure, precipitation, evaporation, wind direction and speed, relative humidity, dew-point temperature, cloud fraction, visibility, frozen soil depth, soil temperature (at surface, 5-, 10-, 15-, 20-, 40-, 80-, 160-, 320-cm depths), soil moisture (at 10-, 20-, 40-, 80-, 160-cm depths), insolation duration, snow cover (snow depth, snow pressure), ice load on power lines | January 2005 |
| Field soil moisture observations | Seed performance evaluation for summer maize and winter wheat during budding and harvest periods | January 1982 |
| Boundary-layer tower observations at varied heights | Soil moisture content in 0–5-cm layer and each 10-cm layer between 10 and 100 cm | January 1982 |
| Field agricultural science observations | Air temperature, humidity, and wind speed and direction at 30-, 20-, 10-, 2-, and 1-m heights; soil temperature at 5 layers, soil moisture at 9 layers, net radiation, downward and upward shortwave radiation, downward and upward longwave radiation, photosynthetically active radiation, soil heat flux | July 2007 |
| Flux data | Three-dimensional wind speed, CO$_2$ density, water vapor density; the sensible heat flux, latent heat flux, momentum flux, H$_2$O flux, CO$_2$ flux, and CH$_4$ flux between the farmland ecosystem and the atmosphere | July 2007 |
| Phenological data | Lignous plant phenological period, hydrophenological period, and animal phenological period | January 1985 |
| Baseline radiation observations | Total radiation, direct radiation, scattered radiation, reflected radiation, atmospheric longwave radiation, earth longwave radiation, net radiation, ultraviolet radiation, photosynthetically active radiation | January 2014 |
| Underground water level data | Underground water level | January 1982 |
| Atmospheric composition data | Aerosol (mass concentration, optical characteristic, vertical profile); volume concentrations of black carbon, CO, SO$_2$, NO$_2$, and some other reactant gases | January 2014 |
| Satellite remote sensing data | Data from NOAA series satellites, FY-1 and FY-3 polar orbiting meteorological satellites, MODIS, GMS-5, FY-2 and FY-4 stationary meteorological satellites; and high-resolution satellite data from 2000 onwards | January 1996 |
| Ground-based remote sensing data | Aerosol lidar, boundary-layer wind profile radar, microwave radiometer, C-band continuous wave radar, Micro Rain Radar (MRR), operational SA radar network in the surrounding area, dual-polarization radar, and so on | January 2015 |
tion, ecological restoration, etc.) on the Huaihe River basin energy and water cycles as well as drought and flood disasters and their mechanisms. (4) Take advantage of variable-resolution prediction models to improve the parameterization schemes of cloud microphysics and land–atmosphere interaction; develop a prediction platform suitable for the Huaihe River basin with full consideration of anthropogenic forcing and human activities; and couple the platform with hydrological models to improve the ability of simulation and forecast of drought and flood disasters. (5) Assess the energy and water cycle anomalies and the impacts of drought and flood disasters induced by these anomalies on agricultural production; combine numerical forecasting, disaster process simulation, and crop models to assess future agricultural production risks; and develop corresponding disaster mitigation technologies to effectively guarantee the increase of grain production in the Huaihe River basin.

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