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New progress of research on water cycle in atmosphere in China

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Abstract: New progresses are introduced briefly about the water cycle study on atmosphere of China made in recent years. The introduction includes eight aspects as follows: 1) precipitation characteristics, 2) stability of climatic system, 3) precipitation sensitive region, 4) regional evaporation and evapotranspiration, 5) water surface evaporation, 6) vegetation transpiration, 7) cloud physics, and 8) vapor source.

1 Precipitation characteristics Since the 1980s, Chinese climatologists have conducted a lot of researches on the law of precipitation variation in recent 100 years. Zhang Xiangong et al. (1982)[1], Tu Qipu (1984)[2], Wang Shaowu (1994)[3], Chen Longxun, et al. (1998)[4] have carried out researches on temperature and precipitation changes of the last 100 years in China, viewing that China has the characteristics of cold-wet and warm-dry alternations. Shi Neng et al. (1983) studied the relationship between summer monsoon in East Asia and summer precipitation in China, and indicated that the rainfall belt is located in the north when the strong summer monsoon comes while it is located in the south if the summer monsoon is weaker, and the interdecadal changes of the summer monsoon precipitation in the Yangtze River and Huaihe River drainage basins are related to the interdecadal changes of monsoon intensity in East Asia[5]. The research on the precipitation of individual rainstorm has been a main concern in the last five years. And the published dissertations on rainstorm occupied a quarter of the total dissertations on precipitation. The research on the statistic features of temporal and spatial distribution of rainstorm achieved many valuable new outcomes that were demonstrated in articles such as "The periodical change of precipitation and rainstorm in China" (Wang Jiaqi et al., 1997)[6], "Analysis of precipitation temporal-spatial change characteristics in small catchments in loessial region" (Li Changguang et al., 1995)[7], and "Studies on Design Storm and Rainstorm Characteristics in China" (Wang Jiaqi, 1999)[8]. As to the research on regional amount of precipitation, Li Jiantong et al. (2000) theoretically studied the impact of the correlation function of element field and the distribution of calibrated rainfall stations on the optimized weighting coefficient in the optimized interpolation[9]. Then, they implemented calculation and verification with 3 correlation function models on 113 times of radar and gauge station surveyed rainfall records collected from 1996 to 1997. The results showed that the most optimized calibration method of self-adapting correlation function model could effectively improve the measurement accuracy of the regional precipitation amount. Wang Shaowu et al. (2000) have established a complete seasonal and annual precipitation sequence from 1880 to 1998 from 35 stations east of 110°E[10]. According to the precipitation observation records and historical materials, they found that the typical cycle periods of annual precipitation are 3.3 years and 26.7 years, respectively. Ye Jinlin et al. (1998) have accomplished the REOF analysis of a combined data set of all quarterly precipitation volume levels from 1880 to 1996, six precipitation change areas were found out[11]. Ren Guoyu (2000) utilized the weather record material from 1951 to 1996 to calculate the long-term annual and seasonal precipitation changing trend characteristic index in China, and addressed that the annual and summer precipitation in the lower and middle reaches of the Yangtze River was increasing obviously, the precipitation in the Yellow River basin of northern China was decreasing slightly, and the summer precipitation in Shandong and Liaoning provinces obviously decreased, but in the high-latitude regions, such as Xinjiang, northern part of Northeast China, northern part of North China and Inner Mongolia, the changing trend of precipitation was not obvious[12]. In the middle and upper reaches of the Yellow River and the middle reaches of the Yangtze River, the ratio of precipitation in spring and autumn to annual total obviously reduced, while in the eastern part of Hebei Province, the western part of Liaoning Province, and the Horqin Sandy Land in northeastern China, precipitation in sp

ring increased comparatively. 2 Stability of the climatic system Qin Yunshan et al. (2000) have investigated the ancient climate records gathered from the polar region ice core, ocean deposit and land, and thought that the Earth had experienced a series of climatic events within the time scale of several hundred years to one thousand years since the Last Ice Age (LIA), and under the background of macroscale climate change from first phase of the last ice age gyration, the climate on the globe had experienced relatively great instability[13]. Although apparent uncertainty existed in the genesis and scope of the influence of catastrophic climatic events occurred in the time scale of several hundred to several thousand years since the last interglacial period, general understanding and comprehension have been acquired to the process of climate change from 130 ka BP through medium dry-cold events in the MIS 5E, Dansgaard - Oeschger gyration in MIS 5E, Heinrich event, Younger Dryas event and some temperature decreasing events happened in the last ice age. Ren Jianzhang et al. (1998) have compared the climate instability record discovered in the north Pacific region and the high-resolution loess climate record, and found out that the climate instability in East Asia had its own unique aspect, especially there is an obvious difference between extreme climate abrupt-change which happened in the period of last ice age in the loess record and that recorded by the bottom deposit in north Atlantic Ocean and Greenland ice core[14]. At that time, the Siberian high-pressure change had severely affected the atmospheric flow. The climate instability record of the high-latitude and mid-latitude regions in the Northern Hemisphere has provided the reference for future climate instability. The proof of climate instability possessed the important function to recognize the internal factors and their effect. The recently discovered climate instability proof should be involved in the future climate development trend modelling. The predicted result to the future will become indefinite because of the inadequate recognition to the changes of climate system. However, the high-resolution climate instability record will provide the important proof for reducing such an uncertainty without any doubt. Fang Xiaomin et al. (1999) analyzed the Asia historical climate abrupt-change since the previous phase of last Ice Age in the loess profile in Shajinping, Lanzhou, with a thickness of 28 m, and thought that the summer monsoon since 60 ka BP showed the changing trend of enhancing impulse of 1-2 kyr time-span at the time scale of one thousand years, as well as presented the 500-year perturbation with "strong to weak" on the low frequency[15]. The soil was characterized by color darkening, organic material accumulation, biological bore increase and certain carbonate solution. Its intensity corresponds well with the above-mentioned summer monsoon enhance, which commonly reflected the effects on this region of the fast climate abrupt-change in LIA in the North Pacific Ocean. Yao Tandong (1999) implemented the comparison of Guliya Ice Core and Greenland GRIP ice core, and discussed the Qinghai-Tibet Plateau climate abrupt-change affair, the ice stage changing and seven warming events (BrΦrump, Odderade, Oerel, Glinde, Hengelo, Denekamp, BΦlling) which reflected the climate abrupt-change in great scope[16]. There is a common reflection on these two ice cores for all those events, but Guliya Ice Core had its unique character compared with Greenland GRIP ice core. The Guliya Ice Core owns the greater climate warm changing rate and degree. The other obvious character of Guliya Ice Core is that there were a series of cycles with the time scale of 200 yr in 35-18 kyrBP. Within this period, there were 22 times of warming up events with temperature increasing over 7oC and 22 times of cooling down events with temperature decreasing over 7 oC, and warming and cooling events within the temperature changing of 3 oC exceeded more than 100 times. According to the study, different factors brought the effect on the climate abrupt-change in different time phases, and the climate abrupt-change in LIA from warm to cold was caused by the solar radiation change, which drove the accumulated snow on the Qinghai-Tibet Plateau to change. And the climate abrupt change in the shorter period was caused by the sun´s activity and the monsoon. Zheng Jingyun et al. (1999) investigated the climate abrupt-change history in LIA and discussed the climate abrupt-change in recent 2000 years, and thought that the climate abrupt-change existed in warm period or cold period[17]. Especially as the climate abrupt-change happened in recent 2000 years and the period of Eemian, which provided the important proof for the climate abrupt-change in the warm period. Meanwhile, it was discovered that, the climate abrupt-change happened before 1230 AD, although its degree was smaller than the climate abrupt-change in LIA and interglacial age, it was still universal. Such results have negated the old conclusion that "climate only changed in the cold period and had been stable since Holocene epoch", which also figured that the climate instability in the 21st century would possibly increase. 3 Precipitation sensitive region Wang Shaowu et al. (1979), utilizing the drought and waterlogging material in recent 500 years, indicated that there was a 36-year cycle period in the eastern part of China, especially in the downstream of the Yangtze River[18]. They held that it was related to the 36-year period in the central Pacific equator region. Cui Maochang et al. (2000), utilizing the method of rotating principal component analysis and complex variable Molaite wave conversion analysis, analyzed the measured precipitation data from 1982 to 1995 in China and the weekly averaged sea-surface temperature data issued by American Environment Forecast Center from 1982 to 1994, studied the time-space variation features and their relationship, and held that the water temp erature on the sea surface and the annual precipitation change were mainly affected by the moving of sub-solar point from the south tropic to the north tropic and sea surface cloud and fog coverage as well as annual monsoon changes related to it. According to annual variation, 12 precipitation areas could be naturally divided in China[19]. From the perspective of the sea-atmosphere interaction, its annual variation mainly depended on solar radiation intensity, effective sunshine ratio and summer annual monsoon change in Asia. The El Ni?o phenomenon only affected precipitation amount in the northern part of the Great Bend of the Yellow River, and Guangdong and Guangxi in South China. The inter-annual changes for the ocean surface temperature in the east of the warm pool of West Pacific only affected the annual precipitation amount in the northern part of the Great Bend of the Yellow River. Yang Meixue et al. (1998) considered that, the Qinghai-Tibet Plateau, as the special uplifted underlying surface, its abnormal snow covered area and the number of snow days were related with the intensity of the summer monsoon and its beginning and end regimes[20]. In the years with more snow-covered area and more snow days, Asian Monsoon is weak, its occurrence is late, and the speed of forward moving was slow. In the years with less covered area and less snow lasting time, Asian Monsoon is strong with early occurrence and quicker speed of forward moving. The Pacific Ocean temperature in the east tropic is related with the temperature and precipitation in China. Dong Jie et al. (2000) studied the relationship between Pacific Ocean temperatures located at the east side of the Pacific in spring, summer, autumn, and winter, El Ni?o and La Nina events and the temperature and precipitation in China[21]. It is shown that temperature correlation is better in winter. As to the precipitation correlation, it is better in autumn. Utilizing summer precipitation and temperature material from 29 observation stations from 1881 to 1998, Shi Neng (2000) studied the changing character of the summer precipitation and temperature average value over 30 years in the eastern part of China and the summer precipitation and temperature characteristic model and evolution law with the empirical orthogonal analytical method[22]. They thought that the summer precipitation and the basic climatic characteristic parameter such as summer temperature in the eastern part of China were closely related with basic climatic status of China´s summer climate and summer atmospheric activities. Tan Guirong et al. (1998), utilizing the material of monthly average altitude field with 500 hPa in the Northern Hemisphere and the ocean temperature in North Pacific, making use of composite analysis, Singular Value Decomposition (SVD) method, analyzed the relations between China´s summer precipitation types and atmospheric circulation and sea temperature field of the same and previous (winter) periods[23]. They thought that the summer precipitation type, atmospheric cycle and ocean temperature of North Pacific had the close relationship. Different pertains of circulation fields correspond to different summer rain belt distribution. Especially in the westerlies belt of Europe and Asia, it is obviously reflected in the previous period circulation fields, and the obvious deviations exist between different types. Corresponding to the three rain types, the previous winter ocean temperature also presents different features. Gong Daoyi et al. (1999) implemented the χ^2 test to the global land average amount precipitation sequence in recent one hundred years, and thought that the average precipitation on the globe decreased obviously in the year of El Ni?o, but in the year of La Nina, it increased obviously[24]. In recent one hundred years, the amount of winter and autumn precipitation in the eastern part of China had the close relation with ENSO. In the year of El Ni?o, precipitation in the south of the Yangtze River would be more, but less in the northern part of China. On the contrary, in the year of La Nina, the relation in summer was not as obvious as that in autumn and winter, but in the year of El Ni?o, the desiccation trend existed in the northern part of the Yellow River, but in spring no such relations existed.

4 Regional evaporation and evapotranspiration Li Lin et al. (2000) utilized the Penman formula to calculate the regional evapotranspiration capacity in the upper reaches of the Yellow River and analyzed the changing trends of the climatic factors in the region such as evapotranspiration capacity, sunshine duration, air temperature and air saturation deficit, mainly focusing on study of impact of these factors on evapotranspiration capacity[25]. They thought the evapotranspiration capacity in the upper reaches of the Yellow River appeared an increasing trend at a rate of 3.25 mm each year. As the main influencing factor, sunshine duration was increasing at a rate of 3.6 hours each year. Meanwhile, temperature also presented a yearly rising trend of 0.4 oC/10yr, and the air saturation deficit also increased at a rate of 0.02 hPa/yr. Therefore, the author held that the increase in sunshine duration, air temperature, and saturation deficit enhanced the grassland evapotranspiration capacity. And the increase in evapotranspiration and the decrease in precipitation would directly cause the decrease of the flow discharge and desertification expansion in the upper reaches of the Yellow River. Li Xin et al. (2000) accomplished the study on the observations and experiment at Aksu Water Balance Station of CAS (the north edge of the Taklimakan Desert) and the analysis on daily evaporation change process in some arid, semi-arid and humid areas[26]. Guo Wei et al. (1998) studied evaporation capacity in Jiamusi Accurate Research Area with multiple calculation methods[27]. As to the evaporation capacity of the water surface, water-permeable and non-water-permeable surface, the theoretical model calculation and the actual measured data verif

ication were accomplished. Experiment and analysis on non-water-permeable underlying surface evaporation were also carried out. Liu Heping (1999) studied the water and energy exchange between earth and atmosphere and the water and heat transmission simulation issues in the desert regions[28]. 5 Water surface evaporation Li Wanyi (2000) analyzed the main factors affecting the water surface evaporation, and put forward a calculation model of water surface evaporation based on the process of water surface evaporation[29]. According to data obtained from Bayan Gol Evaporation Station and other 19 evaporation stations in China, parameters of this model suitable for calculating national water surface evaporation was given, and the accuracy of the model was improved as well. Liu Xiaoning et al. (1998) analyzed the evaporation data characteristics based on comparisons of the E-601 type evaporator data and 20 cm small-scale evaporimeter data, presented their conversion coefficients, relevant coefficients and deviations, and established the reduction formula which can use small-scale evaporator data to calculate the large-scale evaporimeter data[30]. Zhang Dan (1998) addressed that the changes of water surface evaporation with the temperature could be divided into temperature-increasing period and the temperature-decreasing period, according to the yearly measured data from Yichang Evaporation Station[31]. 6 Vegetation transpiration Xie Senchuan (1998) marked out soil evaporation and crop transpiration based on crop coefficients and crop coverage, studied the empirical relation between soil evaporation and topsoil water content with the experimental data, and calculated actual soil evaporation[32]. Zhou Haiyan (1998) indicated that the precipitation on Loess Plateau mainly increased the water content in the soil layer of 30-80 cm, so as to improve the air relative humidity before 13:00[33]. At that time, the air vent conductivity and blade water potential increased obviously. Before raining, the daily process curve of the transpiration rate of green poplar appeared double peaks, with the daily average value of 38.8 μmol/mm2/l, and the transpiration rate was mainly controlled by the air vent conductivity and the air relative humidity near leaves. After raining, the daily process curve of transpiration was in single peak, with daily average value of 49.9 μmol/mm2/l, and the plant transpiration was mainly controlled by air relative humidity and the soil moisture content, without obvious influence of air vent. The daily average water use efficiency was higher before rain than that after rain. Wang Yajun (1999) conducted the transpiration measurement by using buoyancy weighting type transpiration instrument in Zhangye oasis of Gansu Province[34]. He analyzed the daily and seasonal changing characters of transpiration, and addressed that the daily transpiration of wheat got to the maximum at 12:00-16:00, and got to the minimum at 20:00-8:00, even to the negative value. And the peak value before irrigation and after irrigation was different. After irrigation, evaporation and transpiration were all getting increased, and the daily transpiration capacity would increase with the increase of net radiation. During different growth phases, the transpiration of wheat was different, being less before stem extension, and increased after stem extension, getting to the maximum during grain-filling stage. Liu Shiping (2000), based on the observation data obtained by the new type weighting type evapotranspirometer used in farmland transpiration and evaporation and groundwater-soil conversion, analyzed the winter wheat transpiration and infiltration process from October 1998 to June 1999[35]. He thought that the groundwater replenishment to soil water made up 16.6% of the total transpiration when groundwater fluctuated between 1.6-2.4 m. The excess irrigation will not only reduce the groundwater replenishment to soil water, but also infiltrate to the ground. The groundwater exerts great impact on soil water distribution and soil water flow distribution. Li Kun (1999) analyzed the data from field measurement in Jinshajiang dry-hot valley from 1992 to 1998, and thought that the natural saturation shortage of reforested tree species such as big leaf acacia, silk-like leave acacia, red eucalypt, and the native species of mountain willow was relatively high in dry season[36]. The native tree species and the eucalypt type tree have the stronger transpiration effect, and the acacia species has the weaker transpiration effect. The transpiration effect in the dry season will exert a direct effect on temperature of the leaves and withering or falling of the leaves, which means that they are affected by drought and high-temperature weather condition. Zhang Jiahua (2000), utilizing the remote sensing information in combination with crop photosynthesis physiological character, studied crop yield water enforcement model, and gave the solution formula aiming at and based on model parameters[37]. Wei Tianxing (1999) compared transpiration measurement methods, and thought that the hydrologic method had the strong applicability without restrictions of time, weather condition and forest condition, and could be used for measuring long-term total transpiration volume over one week, as well as measuring the water consumption volume for the transpiration in the forest and drainage regions[38]. The micro meteorological method was suitable for the forest with the uniform growth circumstance, and could be used to measure the transpiration of the forest. The plant physiological method could be used to measure the individual plant water consumption. The evaporator could be used to measure the individual plant transpiration and forestland soil evaporation, with conditions easy to be controlled and with high accuracy. The climatological method could be used to estimate the potential transpiration volume in some regions and the relative water consumption volume. The remote sensing method could be used to calculate the regio nal forest transpiration. Wei Tianxing (1998), utilizing the water balance method and the Boven ratio-energy balance method, analyzed the water consumption proportion of all components in total water consumption quantity of locust and Chinese pine in the loess area of southwestern Shanxi Province: forest transpiration, 57.7-60.2%; forestland soil evaporation, 13.2-22.8%; forest canopy holding, 17.0-28.2%; whereas the transpiration water consumption accounted for 80% of the year´s total in June, July and August[39]. The water consumption in different forest growth seasons was different, more on the shady slope and less on the sunny slope, the more density, the more water consumption. Mo Xingguo (1998) studied the comprehensive soil-vegetation-atmosphere system water and energy transportation model and winter wheat field experiment data in shallow groundwater area. He thought that the influence of leaf area index on the total transpiration would be decreased gradually with the increasing of leaf area index when the groundwater table was less than 1.5 m. The effect of groundwater to transpiration was not obvious, but, when in 1.5-1.75 m, the transpiration would decrease quickly[40]. He Kangning (1998), using the self-recording Comprehensive Meteorological Observation Tower, studied the transpiration of locust-tree and Chinese pine. He thought that the proportion of latent heat flux which was consumed in the transpiration to daily acquired net radiation quantity was as the following: 65% in spring, 82% in summer and 85% in autumn. In the growth season of 1994, the transpiration of locust was 519 mm and the Chinese pine was 597 mm[41]. Wan Zihu (1999), utilized the energy balance method in combination with the Penman formula, calculated annual transpirations of three plants at the north edge of the subtropics: the broad-leaved forest, 1125.7 mm; the fir forest, 1105 mm; and Pinus taiwanensis forest, 1074.2 mm[42]. Because of the concern for the farmland and crop protection, the research on crop transpiration and soil and groundwater evaporation has been developed rapidly in recent years, and some vegetation transpiration formula (Xie Xianqun et al., 1997)[43] and soil evaporation formula (Luo Yi et al., 1997)[44] have been established. Ma Zhuguo (1999) analyzed the relation between soil humidity and climate change, while summarizing and evaluating the effect of soil humidity on the climate change, discussed the types of land surface models associated with soil humidity change and three evaporation calculation formulas[45]. He thought that the following issues should be studied further: 1) Research on the seasonal and annual changes of soil humidity, temperature and their relation with regional climate diagnostic analysis, as well as relevant physical mechanism; 2) design of scenarios for initializing soil humidity in climate models; 3) simulation of impact of soil humidity and temperature anomaly on regional climate; and 4) impact of mid-altitude soil desiccation on the regional environment.

关键词： progress; water cycle; atmosphere