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The relationship between ENSO cycle and high and low-flow in the upper Yellow River

作者: LAN Yongchao DING Yongjiang

Firstly, the hydrological and meteorological features of the upper reaches of the Yellow River above Tangnag are analyzed based on observation data, and effects of El Nino and La Nina events on the high and low flow in the upper Yellow River are discussed. The results show El Nino and La Nina events possess consanguineous relationship with runoff in the upper Yellow River. As a whole, the probability of low flow occurrence in the upper Yellow River is relatively great along with the occurrence of El Nino event. Moreover, the flood in the upper Yellow River occurs frequently with the occurrence of La Nina event. Besides, the results also show dissimilarity of El Nino event occurring time exerts greater impact on high flow and low flow in the upper Yellow River, that is, the probability of drought will be greater in the same year if El Nino event occurs in spring, the high-flow may happen in this year if El Nino occurs in summer or autumn; the longer the continuous period of El Nino is, the lower the runoff in the upper Yellow River is.

The relationship between ENSO cycle and high and low-flow in the upper Yellow River LAN Yongchao1, DING Yongjiang1, KANG Ersi1, MA Quanjie2, ZHANG Jishi1 (1. Cold and Arid Regions Environmental and Engineering Research Institute, CAS, Lanzhou 730000, China; 2. Lanzhou Administrative Office of Hydrology and Water Resources of the Upper Reaches of the Yellow River, Lanzhou 730030, China) Abstract: Key words: CLC number: 1 Introduction Scholars of the international meteorological and oceanographical circles generally think El Nino event has occurred when the positive departures of mean sea-surface temperature (SST) at Equatorial East Pacific Ocean Area (lying between 0o-10oS, 180o-90oW) occur continually with 0.5oC exteeding the long-range mean and continual period lasting half a year. They also think La Nina event has occurred when the stronger negative departures occur. Southern Oscillation occurring synchronously with El Nino indicates it is an event with alternative occurrence of high and low air pressure on the sea surface of the southern and the eastern Pacific Ocean (Zhang, 1999). El Nino and Southern Oscillation (ENSO) cycle is a strong signal of global weather change, which induces the marked changes on climate throughout many parts of the world (e.g. Ropelewski and Halpert, 1987, 1989, 1996; Kiladis and Diaz, 1989; Glantz et al., 1991). Despite of ENSO occurring in the Equatorial Pacific Ocean Area, its impact has far exceed this scope (Luo, 2000; Kiladis and Diaz, 1989; Jones, 1988). The occurrence of ENSO is a result of large-scale interaction between ocean and atmospheric circulation processes in the Equatorial Pacific Ocean. These interactions result in fluctuations in both sea surface temperature (SSTs) and sea-level pressures across the Tropical Pacific Ocean (Kiem and Franks, 2001). El Nino events commonly start in winter or spring, a few also in summer or autumn, so they can be divided into Spring type (one year type) and Autumn type (continuance type) according to their appearance time. Spring type of El Nino usually starts in April or May, and ends in spring next year; Autumn El Nino usually starts in July or August, and ends in December next year. El Nino event has appeared 19 times since the 1950s, in which the strongest one of them occurred in 1997-1998. The analytical results show the El Nino event appearing in 1951, 1953, 1957, 1963, 1972 and 1976 belong to Spring type, and that in 1968-1969, 1982-1983, 1986-1987 and 1997-1998 belong to Autumn type (Wang and Gong, 1999). Biggish positive departures of ocean temperature can persist for one year or more. The greatest positive departures commonly appear during November to December, which can meanly reach more than 0.5oC. The status of ocean and atmosphere in Tropic Pacific Ocean Area presents an anomalistic change sometimes, which represents an alternate appearance between El Nino and La Nina. At present, people think that ENSO is not only a sort of event, but also even more a sort of quasi-cycle. Commonly, ENSO is thought to possess a quasi-cycle for 2-7 years, with its cycle period dealing with a multiplex-time scale reciproci ty process. The phase where ENSO cycle is in is determined by special form of SST at Tropical Pacific Ocean Area. Many studies have shown that although ENSO cycle just appears at Tropical Pacific Ocean Area, its effects have gone far beyond the scope. The viewpoint that almost three-fourths of the global area are affected by climate variations has been commonly accepted by meteorologists at home and abroad. Chinese scientists have made sure that variable SST at Equatorial East Pacific Ocean Area also affected badly the climates and the weather of vast area in China (Dong and Liu, 2000; Li Yaohui and Li, 2000; Zhu and Teng, 2000). The analytical results of historical data of the past 500 years display that there is a relationship between over one half of the droughts in North China and temperature rise of Equatorial East Pacific Ocean Area (Li and Yao, 1991). Lately many results also show that the variational SST at Equator East Pacific Ocean Area possesses marked influence on summer precipitation in China at different developing phases of El Nino event (Zhu and Li, 1989). So the study on specific effects of variations of SST in Equatorial East Pacific Ocean Area on precipitation and temperature in the upper Yellow River at the northeastern part of the Tibetan Plateau is quite an important issue since the entire drainage basin of the Yellow River is experiencing serious shortage of water resources and the middle and lower reaches of the river channel witnessing constant dried-up. 2 Features and general situation survey about the studied basin Precipitation in the upper Yellow River basin is affected by three factors, geographical positions, underlying surface and atmospheric circulation. The basin above Maduo is the headstream areas, with an average altitude of more than 3,000 m, where the annual average precipitation is about 300 mm, and the precipitation increases gradually approaching to the lower reaches. The annual average precipitation is about 600 mm in the area between Jimai and Maqu, in which the largest may reach 800 mm. The annual average precipitation decreases in the area from Maqu to Tangnag. Heat difference is quite great between ocean and land because the area is located in the interior of the central region, far from the ocean. The dissimilarity on surface quantity of heat resulted from the dissimilarity of the physical features between ocean and land brings various temperature pressure fields on continent and ocean forming in winter and summer, which produces obvious monsoon circulation. So the upper Yellow River basin is controlled mainly by the northern cold high pressure in winter and spring, and it is mainly in the extension of the continental hot low pressure in summer. Whenever tropic ocean air masses containing abundant vapor from Bengal Bay are affected by the temperature pressure fields between ocean and land to penetrate into the northwest interior and also by the effect of landforms to drive northward along the south-north trending Hengduan Mts., where it meets cold air masses to form consequentially precipitation when it arrives at the upper Yellow River basin. Besides, precipitation is prone to form when low eddy engender under the affection of the thermal and dynamic conditions of the Qinghai-Tibet Plateau, and precipitation also can be formed when little trough moves to east. The atmospheric circulation system which engenders rainstorm in the upper Yellow River basin is mainly due to a powerful and steady high pressure ridge in midsummer in the north of the Ural Mts. Accordingly, there is a steady low pressure on central Asia, which brings the radial circumfluence in the sky through mid-latitudes and the cold current of westerlies by north in the sky through the western Siberia constantly transmits to southeast, which provides the sources of the cold air for the upper Yellow River basin and creates the uplifting condition for the northward warm and damp current, and impels rainfall weather forming. The upper Yellow River basin above Tangnag is located in the northeastern part of the Qinghai-Tibet Plateau (95.5o-103.5oE, 32.5o-36.0oN) with a drainage area of 121,972 km2, accounting for 1/6 of the total area of the Yellow River Basin (Lan, 1998, 2002), which is the main runoff forming area. It remains with the Qinghai-Tibet Plateau monsoon regions in climate type, possesses many rainy days and abundant rainfall, and air temperature is lower, evaporation is little, so runoff is prone to form at the Tangnag Hydrological Station, which is set up at the outlet of the basin, more than 110 km away from the Longyangxia Hydropower Plant, the first large-scale hydropower project of the Yellow River, and it is the typical station of the inflow into the Longyangxia Reservoir. The water flows from the Tangnag Station account for 95% of the inflow into the reservoir. The reservoir plays a very important role in the economic development of northern China because of its capability of 24.7×109 m3. The hydro-meteorological data have been collected at Tangnag Station since 1956. 3 Relations between ENSO cycle and atmospheric circulation of the Qinghai-Tibet Plateau Cold waves through eastern Asia are weaker and temperatures are higher in the winter in the years of El Nino occurrence, but low temperature disaster often occurs in other seasons in northeastern China and some areas in Japan and D.P.R. Korea. On the contrary, temperature rise singularly in winter in most areas of northern China and Alaska of America and the northwestern part of Canada. Moreover, the south branch of the westerlies through the southern part of the Qinghai-Tibet Plateau and its perturbance are stronger than in normal years, and northward water vapor transportation from the Indian Ocean increases, which results in winter snow-fall increasing and subsequent impact of summer climate in the Qinghai-Tibet Plateau in the years associated with El Nino events. The results also show that there is a consanguineous corresponding relationship between summer runoff in the upper Yellow

River and ground sensible heat flux of the Qinghai-Tibet Plateau in the previous winter (especially in the later part of the winter). That is to say, ground sensible heat flux in winter (February) is great in the same year; the runoff in the upper Yellow River in July tends to be higher and that in the Yangtse and the Huaihe rivers tends to be lower. For example, the snowfall in 1997 on the Qinghai-Tibet Plateau is exceptionally high which brings excessive precipitation in the summer of 1998 in the middle and the lower Yangtse River and areas south of the Yangtse, but exceptionally less precipitation on the Qinghai-Tibet Plateau and areas north of it in the corresponding period. If El Nino occurs before May, perturbance of the south branch of the westerlies passing along the Qinghai-Tibet Plateau will be less, and the weather of the plateau will often be controlled by Western Current through the summer 500 hpa high altitude chart of Northern Hemisphere in the same year. Under such condition, the Ural Mountains high-pressure ridge is weaker, the position of the sub-tropic high-pressure ridge is located in the south of its primary position, and the East Asia trough is deeper. These changes led to a precipitation increase in eastern China and a decrease in western China. Snowfall will decrease and Deep Trough will appear often through the Qinghai-Tibet Plateau on the summer 500 hpa chart of Northern Hemisphere, and that longitudinal circulation is very strong and sometimes the south and north branches of deep trough will link each other to form a new deep trough of the running-through south-north direction along the western part of the Qinghai-Tibet Plateau, and to form a position combined with strong high ridge in the east of the plateau, that is, there is a strong high ridge in the east and a weaker high ridge in the west, but the positions of the trough and the ridge on the north branch of the air current are almost adverse with the mean. Medium scale low-pressure system often occurs in the northeastern part of the plateau, which brings through the northward southern bias current stronger through the low altitude at the northeast side of the plateau if El Nino occurs in June or La Nina occurs after June. This weather collocation is useful either to transforming vapor for the plateau and to providing dynamic condition for precipitation in the plateau. Runoff in the upper reaches of the Yellow River is exceptionally high on this condition. Of course, El Nino event is only one of the factors affecting climate of the upper Yellow River. There are also other influencing factors such as South Asia monsoon, East Asia sub-tropic high pressure monsoon, and the mutual effects of heat condition of the Qinghai-Tibet Plateau itself (Ma and Zhu, 2000). 4 Responses of runoff in the upper Yellow River to ENSO cycle Dynamic variations in runoff in the upper Yellow River depend on the natural process of climate fluctuations on the Qinghai-Tibet Plateau to a great extent, and this process constantly changes along with the energy exchange between land and atmosphere, sea and atmosphere. Some research results show that various scales of atmospheric movements at low latitudes are affected by interactive process between sea and atmosphere, and the circulation and the weather at mid-latitudes are further affected by the exceptional distribution of equatorial sea temperature (EST) through interaction between Woke Circulation and Hadley Circulation (Zhang et al., 1983). It is difficult to forecast exactly the appearing time, intensity and persistent time of El Nino event up to the present because of the complexity of its mechanisms. It is one of the effective methods to analyze the responses of runoff in the upper Yellow River to ENSO cycle by use of statistic rule. Firstly, the yearly runoff sequence at the Tangnag Station is extended by use of that at the Shangquan and Lanzhou stations located at its backward position (Lan, 1998), and the grades of the high and the low flows of the extended yearly runoff sequence at the Tangnag Station in the upper Yellow River can be classified into five types according to the departures of yearly runoff, that is, -2 (the special low-flow years, the departures < -20%); -1 (the common low-flow years, -20% (the departures < -10%); 0 (the normal flow years, -10% (the departures < 10%); 1 (the common high-flow years, 10% (the departures < 20%); and 2 (the special high-flow years, the departures >20%). These data together with corresponding El Nino and La Nina occurring years are listed in Tables 1 and 2 (Lan, 1998, 2002). It can be observed that 28 El Nino events have occurred since the 1920s, and 16 low-flow and the special low-flow years, seven normal-flow years and five high-flow and special high-flow years in the upper Yellow River occurred corresponding with the El Nino years (Table 1). Besides the 16 low-flow and special low-flow years, five normal-flow years and seven high-flows and special high-flow years in the upper Yellow River occurred in the following years of El Nino events. The occurrence probability of low flow, normal flow and high flow in the El Nino appearing years are respectively 56%, 14% and 10%, and the occurrence probability of low flow, normal flow and high flow in the following years of El Nino appearing are respectively 56%, 10% and 14% in the upper Yellow River. It also can be observed that 14 La Nina events have occurred since the 1920s, and six low-flow and special low-flow years, two normal-flow years and 6 high-flow and special high-flow years in the upper Yellow River occurred corresponding with the La Nina years, and that three low-flow and special low-flow years, four normal-flow years and six high-flow and special high-flow years in the upper Yellow River occurred in the following years of El Nino occurrence (Table 2). The occurrence probability of low flow, normal flow and high flow in the La Nina appearing years are respectively 42.9%, 14.2% and 42.9%, and the occurrence probability of low flow, norma l flow and high flow in the following years of La Nina appearing are respectively 21.4%, 28.6% and 42.9% in the upper Yellow River. As a whole, the occurrence probability of high-flow is more than that of low-flow or normal-flow in the La Nina appearing years and the following years in the upper Yellow River. It is especially worth mentioning that the major floods often occur along with La Nina event. Except for 1981, the greater floods occurred since 1949 associated with La Nina appearing, which are respectively the major floods in 1949, 1955, 1964, 1967, 1975, 1989, 1998 and 1999. It is not difficult to find that effects of ENSO cycle on the runoff on the upper Yellow River are obvious, which occur not only in the same years, but also in the following years according to the analysis. Besides, the results also show that the effects of different appearing time of El Nino are various. It can also be observed that the probability of the corresponding negative departures of the yearly runoff in the upper Yellow River in current years of the seven spring type El Nino events since 1951 is 6/7, and it is 5/7 in the following years (Table 3). The probability of the corresponding positive departures in current years of the five autumn type El Nino events since 1951 is 4/5, and it is 1/5 in the following years. That is to say, the occurrence probability of high-flow in the upper Yellow River in current years will be larger if El Nino occurs in summer and autumn, and the occurrence probability of low-flow in the upper Yellow River in the same year will be larger if El Nino occurs in spring. In addition, the sustaining time of El Nino also has some effects on the runoff, that is, the longer El Nino persisting period is, the lower the runoff in the upper reaches of the Yellow River is. For example, the persisting time of El Nino events that occurred in 1987, 1991, 1994 and 1997 is longer, which brought serious low-flow in the upper reaches of the Yellow River (Ma, 2000). 5 Conclusions Restricted by current technology and research conditions, mechanism of the remote-correlation between ENSO cycles with runoff in the upper Yellow River has not been clarified completely. According to analysis of scholars and experts, the above relationship of both was linked reciprocally by subtropical high on the Western Pacific Ocean. In the typical El Nino years, the intensity of equatorial eastern-bias trade decrease greatly and equatorial westerlies intensify because the difference in temperature between Equatorial East Pacific Ocean and Equatorial West Pacific Ocean is little. Therewithal, normal Walker circulation weakens (low exponent), and summer subtropical high located at West Pacific Ocean is weaker or ridge line position is southern-bias. Subtropical high located at West Pacific Ocean is weaker or ridge line position is southern-bias, and that the upper Yellow River basin and the northwestern China are controlled by northwestern-bias current, inducing formation of less tropic cyclone on the West Pacific Ocean and transportation of less southeastern warm-wet current to the inland regions of China. The dry air is unfavorable for the formation of precipitation, causing less rainfall and runoff in the upper Yellow River basin; whereas, subtropical high located at West Pacific Ocean is stronger or ridge line position is northern-bias because the difference in temperature between Equatorial East Pacific Ocean and Equatorial West Pacific Ocean is greater and Walker circulation strengthens (high exponent) in the years of La Nina events, which brings more vapor to north and more precipitation and runoff to the upper Yellow River basin. Based upon the above analysis, some preliminary conclusions are presented for discussion as follows: (1) the occurrence probability of the lower runoff in the upper Yellow River is larger in El Nino occurring years; (2) the longer duration of El Nino is, the lower the runoff in the upper Yellow River is; (3) the occurrence probability of the lower runoff will be large, if El Nino occurs in spring, and the occurrence probability of the higher runoff will be large, if El Nino occurs in summer and autumn; and (4) the occurrence probability of the higher runoff in the upper Yellow River is larger in La Nina occurring years, even the occurrence possibility of major floods is quite large in the same years. References

关键词： El Nino event; La Nina event; the upper Yellow River; high-flow and low-flow