Relationship between solar activity and flood/drought disasters of the Second Songhua river basin
Li Hong-yan, Xue Li-jun and Wang Xiao-jun

ABSTRACT

Based on the direct correlation method, this paper analyzes the correlation of sunspot number (SSN) and western Pacific subtropical high (WPSH) ridge index with flood/drought disasters in the Second Songhua River (SSHR) basin, combined with long sequences of SSN, WPSH ridge index, precipitation and other data. Results show that SSN is clearly correlated with flood/drought disasters, what is more, flood years mainly appear in three phases: Solar Maximum Year, years after Solar Maximum Year and Solar Minimum Year. In addition, there is an alternate change of flood/drought with a 10-year cycle. This paper uses the commensurable method to identify the periods of floods and droughts in the study area. According to the commensurable diagram, catastrophic nodes of the future floods or droughts in SSHR basin can be primarily predicted as follows: 2021 will be a flood year, while 2013, 2016 and 2024 will be high flow years; 2012 and 2022 will be dry years, while 2014, 2018 and 2027 will be low flow years. Moreover, forecast accuracy of flood/dry years is higher than the one of high/low flow years. Prediction of flood/drought has an error of ±1 year, which can be tracked and corrected with a scatter diagram.

Key words | disaster prediction, flood/drought disasters, sunspot number, the Second Songhua river basin

INTRODUCTION

China is located in the East Asian monsoon area with complex climate systems (Chang 2004), and its unique monsoon circulation leads to the complexity and variability of the hydrologic cycle in this area, for example, the temporal/spatial distribution of precipitation is uneven, which leads to frequent flood disasters (Fan et al. 2008). Located in the northeast of China, the Second Songhua River (SSHR) originates from the Changbai mountain (1) its geographical position determines the complex inter-annual changes of precipitation processes (Sun & Bai 2005), what is more, as it is located in the northern edge of East Asia monsoon, inter-annual climate variability caused by strength changes of the monsoon is very large; the weather system is complicated, which is affected by both the mid and low latitude weather systems (such as the western Pacific subtropical high (WPSH), the tropical depression and typhoon), as well as the high latitude westerly zone systems. (2) Because of the mountain effect (Zhong 2000), rainstorm is temporal/spatial concentrated (Wang 2002), which performed as frequent and swift flood-making rainstorms (Wang et al. 1999; Wang & Chen 2007). Therefore, causes and performance rules of flood/drought disasters in SSHR basin are complex.

The basin’s climate is mainly affected by the comprehensive effect of solar activity, atmospheric circulation, natural geographical environment and other factors (Huang & Jin 2005). The mechanisms of the three factors are as follows (Li et al. 2011): the solar activity is an astronomy factor which is beyond the hydrological cycle system and it has a cyclical influence on climate. As atmospheric circulation is
the dominant factor of a climate situation, so there exists the law of seasonal change. What is more, various factors influence the basin’s climate through their effects on atmospheric circulation, namely, atmospheric circulation provides basic foundations for different scales of weather system activities, and this has the rule of randomness; the basin’s natural geographic characters have a consistent effect on atmospheric circulation. Therefore, the basin’s climate is the coupling and overlay of periodicity law and randomness law: on a long-term scale, it shows periodicity law; on a short-term scale, it shows randomness law.

Researches have shown that solar variability can directly affect climate. The researches include: (1) influence of solar activity on the ancient earth climate (Rind 2002; Yuan et al. 2004); (2) influence of solar activity on inter-annual climate changes (Shindell 2001; Weng 2005); and (3) the influence on global warming (Kelly & Wigley 1992; Krivova & Solanki 2004). Meanwhile, research on the relationship between solar activity and disasters is also a very important aspect (Jian et al. 2006; Long 2011). What is more, because of China’s special climate conditions, researches on the relationship between solar activity and flood disasters are paid more attention (Tang et al. 2001, 2005; Liu & Gao 2002; Wang et al. 2003).

Generally, study methods about the influence of solar activity on climate and flood/drought disasters include mathematical statistics analysis and model calculation. However, the problem is so complicated that it is difficult to obtain good results using mathematical statistics (Christensen & Lassen 1991), and this is especially obvious for catastrophic disasters (such as floods and droughts). This is because the statistics has its premise conditions: (1) the sample can reflect the general rule of the population; and (2) the sample can represent the population. Statistical methods simulate the rule of mode, that is to say, the normal years’ situations; however, the sample of flood and drought accounts for a very small proportion, so its rules cannot be revealed with statistical methods. With a strong hypothesis and simplification of physical mechanisms, the model calculation also has unavoidable issues. This article uses the direct correlation method to analyze the correlations of solar activity with flood/drought disasters, and it also uses the commensurable method to identify the periodicity rule of flood/drought catastrophe.

STUDY AREA, METHOD AND DATA

Study area

The study area is the SSHR basin in the northeast of China (124°39’E ~ 80°45’E; 41°45’N ~ 45°29’N) (see Figure 1), and moisture in this river basin comes from the warm-moist air flow of the Pacific Ocean and the Indian Ocean’s Bay of Bengal, which mainly enters from the southwest and the west of the southwest. The multi-year average precipitation of this basin is about 600 mm, and its spatial distribution also varies greatly from the source, the Changbai Mountain Tianchi, to the dry downstream area, it fluctuates from 900 down to 400 mm. Influenced by the monsoon climate, the distribution of precipitation is extremely uneven within a year, and precipitation mainly concentrates in June–September, especially July and August, which accounts for about 70% of the total or more. The annual precipitation variation seems large and according to the precipitation statistics from 1936–2010: the variability coefficient of annual precipitation variation is 0.16, in May–September it is 0.20, flood season (June–September) is 0.22, and the main flood season (July–August) is 0.27. Therefore, the more concentrated the precipitation is, the greater the inter-annual variation of precipitation will be.

Study methods

The relativity between solar activities and flood/drought disasters are directly analyzed with a correlation diagram. This
method is simple, intuitive and effective, and with less assumption, it looks for laws directly from objective problems, thus reducing the information distortion. Instead, with more complex mathematical operation and more assumption, results will have more differences from practical situations. Without theory assumption being met, mathematical theory will not work, no matter how precise it is. Unfortunately, the reality is it is generally hard to meet the theory hypothesis.

The commensurable method is used to identify the periodic law of flood/drought disasters. In 1984, the commensurable prediction method (Weng 1984; Wang & Geng 2004) was proposed, commensurability can be regarded as a kind of nature’s order and a periodic expansion, that is to say almost periodic. Xia (1991) and Li (2011) have given detailed statements on how to test the applicability of commensurable method and the steps of commensurable prediction.

For a time variable \( y(t) \), if there is \( p \) satisfying the following equation:

\[
y(t + p) - y(t) = 0
\]

where \( p \) is regarded as a cycle.

If there is a time interval \( \varepsilon_0 \), which makes the following equation true:

\[
|y(t + p') - y(t)| < \varepsilon_0
\]

where \( p' \) is an almost period.

If the time variable \( y(t) \) is reduced to one of its discrete sections, time series \( y(i) \), while the unary relation is extended to the multivariate polynomial, and there is

\[
|\sum a(i) \times y(i)| < \varepsilon_0
\]

where \( a(i) \) is an integer, then the discrete time series \( y(i) \) has an almost commensurability, and \( \varepsilon_0 \) is the same as the former. If \( \varepsilon_0 = 0 \), then \( y(i) \) also has a commensurability.

### Data

Solar radiation is the energy source of climate systems, and changes in solar activity bring changes in solar radiation, thus leading to fluctuations in the basin climate systems. Solar variability can be described by solar cycle length and sunspot number (SSN) (Hao et al. 2007), and the former is selected in this paper. The greater the SSN, the fiercer the solar activity will be; the smaller the SSN, the weaker the solar activity will be. When drawing an SSN curve, the year on the top of the curve is called Solar Maximum Year (i.e. M years), and the year of the lowest is called Solar Minimum Year (i.e. m years). Precipitation data (1936–2010) of the SSHR basin are provided by Baishan Power Plant of Northeast China Grid Company Limited; WPSH ridge index (1951–2010), and SSN (1936–2010) data are supported by the National Climate Center of China.

With annual precipitation in SSHR basin, flood/drought grades are divided into five grades according to Table 1 (Song et al. 2005), where \( R \) = multi-year average precipitation; \( R_i \) = means annual precipitation; \( \sigma \) = means standard deviation.

### Table 1 | The partition table of drought and flood lever

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### Correlation Analysis of Solar Activity and Flood/Drought Disasters

Correlation diagram of SSN and annual precipitation

Directly comparing the annual precipitation and SSN of SSHR basin, see Figure 2 which shows that flood years mainly concentrate in three phases M, M + 2, M + 3, m – 1 and m. This is the so-called ‘double vibration’ (Huang & Jin 2005), that is to say, flood years occur both in M years and m years.

Calculate the average value of precipitation of years ending with 0, and years ending with 1–9 are done in the same manner, respectively, then analyze the 10 new data.
Figure 3 indicates that years ending with 1, 4 or 6 are flood years, years ending with 0, 3, 5 or 7 are normal years, and years ending with 2, 8 or 9 are dry years. The typical hydrological regime of the SSHR basin is as follows:

1. Years ending with 1 are flood years. 1941, 1951, 1961, 1971, 1981, 1991 and 2001 are all high flow years, moreover, precipitation in the main flood season is very concentrated.


3. Years ending with 8 or 9 are continuous low flow years, which is higher than Grade 4. 1949, 1958, 1968, 1978, 1999 and 2009 are all low flow years, meanwhile, precipitation in 1948, 1969, 1979, 1989 and 2008 is all less than the multi-year average value.

4. Generally, years ending with 4 or 5 are partial high flow years (between high flow and normal), and some years are partial low flow years (between low flow and normal).
Scatter diagram of annual precipitation, SSN and subtropical high ridge index

WPSH is the most important weather system that affects the distribution of the summer rain belt on the Chinese mainland. Under WPSH, downdrafts prevail and the weather is dry and hot. The SSHR basin is located in the zone of WPSH and interacts with the westerlies, the southwest wind is popular and it is also the main moisture channel of the summer wind. In this area, there are many low-pressure system activities, such as plateau vortex, shear line, cyclone waves and so on, and as they frequently interact with the north cold air, it is often the main distribution of rain belts. Rain belts are located at 8–10 latitudes north of the 500 hpa WPSH ridge. WPSH controls the precipitation area and its moving speed determines how long the rain will last in the precipitation area. There are three rainy seasons in the SSHR basin each year: (1) cold vortex rainy season (from spring to early July), (2) WPSH rainy season (from mid-July to mid-August), and (3) typhoon rainy season (from late August to late September). It is obvious that precipitation in the WPSH rainy season is the main part of the flood season that determines the wetness/dryness of the study area.

The mechanism and process of solar activity influence on the climate system are not very clear, and they also cannot be expressed using mathematical or physical methods. However, in theory, it is generally viewed that the strength of solar activity changes leading to the increase or decrease of solar radiation on the earth’s surface (especially the sea surface), then, ocean current produce feedbacks, eventually, climate systems respond to these changes through atmospheric circulation, and the obvious performance is increase or decrease of precipitation. As for the influence time, atmospheric circulation has a memory of 1 month (Мусаелян 1982), the influence period of ocean current is longer than 6 months (LU 1951), while sunspot is more than 1 year (Wang et al. 1997). The physical process above is the basic theory to establish the scatter diagram of SSN (last year), WPSH ridge (sum of December of last year and January of current year) and annual precipitation in the SSHR basin.

Figure 4 is the index scatter diagram of annual precipitation, sunspot and subtropical high ridge in the SSHR basin. From it, dry years and flood years are concentrated in the black zone ([26, 32; 50,170]), but 2010 was a very special year, for its annual precipitation was 1078.8 mm, which ranked first in the history. Based on the law that ‘years ending with 1 are flood years’, 2011 will be a flood
year, but Figure 4 shows that 2011 is outside the black zone, so it seems that 2011 is a non-disaster year with flood/drought (it is indeed true from the present condition). In addition, it seems that flood years and the SSN have a greater relevance, which is basically located in the range of \([80,160]\); dry years are closely related with WPSH ridge index, and general values of WPSH ridge index are 26 and 30. From Figure 4, the law of non-disaster years (such as high/normal/low flow years) seems to be more evident.

THE RECOGNITION OF PERIODICITY LAW OF FLOODS AND DROUGHTS DISASTERS

Correlation analysis on solar activity and flood/drought disasters shows that solar activity leads to periodic floods and drought, while random factors (such as ocean currents and atmospheric circulation) make the law complicated. The time series rule of flood/drought disasters can be identified by ‘commensurability’, then to identify the almost period of disasters.

Analysis of commensurability

Analysis of commensurability is commonly used to test whether a hydrological disaster information can be predicted by the commensurable methods, and there are three test indexes: the commensurable number, error interval of almost period \([-\epsilon, +\epsilon]\), which is the periodic expansion, as well as commensurable reliability. Theoretically, the larger the commensurable number is, the more reliable the prediction will be, and it requires that the commensurable number is more than 1; the less the error \(\epsilon\) is, the more reliable the prediction will be, and it requires that \(\epsilon\) is less than 1 year in the hydrological catastrophe analysis; if the average commensurable number of the measured sequence is \(m\) and the commensurable number of the forecasting sequence is \(m^*\), then the set of \(m^*/m > 50\%\) is often selected to issue the hydrological catastrophe prediction. Here, take Figure 5 as an example to discuss its commensurability (Figure 5 is the commensurability network diagram of flood and wet year in the SSHR basin). From Figure 5, at least two commensurable relations can be built: a vertical one and a lateral one, that is to say \(m^* = 2\), which meet the demand \(m^* > 1\). From the horizontal point of view, almost period is 30 years with an error of \(-1\) year. From the vertical point of view, almost period of flood years is 10 years with an error of \(-1\) year; almost period of high flow years is 4 years with an error range is \([-2, +1]\), which does not meet the demand, so in theory, forecasting the result of flood years is more reliable than that of high flow years. Common forecasting results from the two horizontal and vertical commensurable relations are as follows: 2015, 2016 and 2024 are high flow years, 2021 is flood year, which meets the demand of \(m^*/m > 50\%\). Therefore, almost period of this hydrological catastrophe information can be identified with commensurable methods.

The commensurable network diagram

Let the time interval chains of flood year (dry year) and high flow year (low flow year) be horizontal and vertical timing axis, respectively. Sunspot phases are shown in brackets. Commensurable network diagrams are shown in Figures 5 and 6.
From Figure 5, almost period of flood years is 10 years (or 30 years) with an error of $\pm 1$ year; almost period of high flow years is 4 years on average, with an error of $\pm 2$ or 1 year. It is important to note that 1960 and 1961 are flood years; however, annual precipitation of the 2 years is 876 mm and 803 mm, respectively. So, 1960 is selected as the flood year node on column 1 row 4.

From Figure 6, almost period of dry years is 10 years (or 30 years) with an error of $\pm 1$ year; almost period of low flow years is 4 years on average, with an error of $\pm 2$ or 1 year. Comparing Figures 5 and 6, the periodic rule of flood year is stronger than the one in the high flow year.

**CONCLUSIONS**

(1) Owing to the impact of the monsoon climate, precipitation in the SSHR basin is characterized as follows: (a) annual distribution is uneven; (b) inter-annual variation is very large; (c) precipitation in flood season accounts for more than 70% of the total amount; and (d) precipitation in different time intervals varies greatly with the range of variation coefficient [0.16, 0.2], and the maximum value appears in the main flood season. These hydro-climatic characteristics reveal the necessity of frequent flood/drought in this study area.

(2) Solar activity is directly related to flood/drought in SSHR basin, flood years mainly appear in three phases: M, M + 2, M + 3, m – 1 and m. Meanwhile, there exists a 10-year cycle, which is close to the 11-year sunspot cycle: years ending with 1, 4, or 6 are flood years, such as 1951, 1964, or 1976; years ending with 0, 3, 5, or 7 are normal years; years ending with 2, 8, or 9 are dry years. The reasonable explanation is that periodic solar activity causes the alternately occurring floods and droughts.

(3) There are three rainy seasons in the SSHR basin: cold vortex, WPSH and typhoon, what is more, the WPSH rainy season is the main flood season in this area which directly determines the basin’s wetness/dryness. Atmospheric circulation is the basic condition of weather systems, and its randomness makes the flood/drought rule complicated.

(4) Using a commensurable network diagram to analyze the flood/drought law of the SSHR basin, the results show that almost periods of flood and dry years are both 10 years with an error of $\pm 1$ year; almost periods of high and low flow years are both 4 years on average, with an error of $\pm 2$ or 1 year. Therefore, 2021 will be a flood year, 2013, 2016 and 2024 will be high flow years; 2012 and 2022 will be dry years, 2014, 2018 and 2027 will be low flow years.

(5) Based on the flood/drought analysis using a commensurable network diagram, a scatter diagram is used to track and correct, thus improving the prediction accuracy. Predictions released use five flood/drought grades, and similar years are provided as references.

**REFERENCES**


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