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Analysis of temporal-spatial precipitation variations during the crop growth period in the Lancang River basin, southwestern China

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ABSTRACT

In recent years, droughts and upstream/downstream water conflicts (such as those between water supply and demand) have been occurring frequently in the Lancang River basin, threatening local food security. In this research, the empirical orthogonal function (EOF) analysis and the rotated empirical orthogonal function (REOF) analysis were employed to investigate the temporal and spatial characteristics of precipitation variations during the crop growth period over 1960 to 2009. The results indicated the following: (1) annual precipitation increased slightly over the period of 1960–2009 but decreased significantly (at the 5% significance level) since 2001. An increasing trend was observed in the northern region, while a decreasing trend was observed in the southern region; (2) five regions with different precipitation variation patterns were identified in the crop growth period, including the northern, the northeastern, the southwestern, the western, and the southernmost end patterns; (3) overall, a slightly increasing trend was identified in summer over the study period. Over the period of 2000–2009, precipitation in the summer and autumn decreased, (the strongest decreasing trend was observed in the autumn). Unlike that of the whole area, precipitation in the northern region decreased insignificantly in summer and increased slightly in autumn. Results of this study may facilitate the prevention of potential disasters (e.g., abnormal precipitation) and the reduction of the associated losses through early warning and forecasting of variation trends of regional precipitation. The approach could provide a support for decision-making related to international rivers and agricultural water resources management under global climate change.

1. Introduction

With an average temperature increase of 0.85 °C in the past 130 years, the Earth experienced frequent extreme weather conditions, and the global land area suffered severe droughts or floods (IPCC, 2013). Under global climate change, excessive precipitation, widespread drought and continued high temperatures would result in large-scale economic losses (Xia et al., 2011; Cai et al., 2011a, b). The change in precipitation has greatly affected regional climate stability, hydrological processes and water availability. It was noted that the spatial and temporal inhomogeneity of precipitation distribution increased while its utilization rate decreased, resulting in an increase in the threat of droughts and floods. In the crop growth period, abnormal variations in precipitation may lead to crop failures and intensified conflicts between water supply and demand, as well as significantly increasing the inundated crop area (Wu and Peng, 2010). As a result, a critical food supply issue has arisen due to a water deficit or excess affecting staple crops, a reduction of the crop life period and a decline of crop yield and quality. Climate change would pose a threat to the worldwide water supply and agricultural production security by affecting the amount of water resources available for agriculture. (Yang et al., 2013; Yan et al., 2013; Tan et al., 2013). Therefore, it is essential to identify the spatiotemporal characteristics and variation trends of precipitation in the crop growth period in order to provide a scientific decision-making basis for the early warning and zoning management of drought or water logging. This issue has caused widespread concern and is considered to be of great importance in various circles of society.

Previous research on regional precipitation variations and characteristics mostly focused on two approaches. The first approach

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was to use a global or regional climate model for climate change simulation and prediction. For example, the Atmospheric General Circulation Models (GCMs) use essential data to simulate the current situation and predict future climate change, while hydrological models play very important roles in research examining changes in hydrological factors, the water cycle and water resources assessment (Wang and Fu, 2006). In recent years, scholars emphasized the theoretical study of the statistical downscaling method and made many improvements by coupling regression method, parting technology circumfluence and weather generator (Chu and Xia, 2008). Considering that this type of approach needs a large amount of input data, further efforts should be made to gather more detailed hydrological information to improve the forecasting accuracy (Wang et al., 2012). The second approach was to use statistical methods focusing on the cycle, mean, variance and trend analysis of the changes in climatic factors with historical data. Common precipitation variation analysis methods include Mann–Kendall, Pettitt, moving *T*-test, Yamamoto methods and so on (Li and Xu, 2011). For a long-term series of field data, the use of the empirical orthogonal function (EOF) or the rotated empirical orthogonal function (REOF) analysis to decompose the data into spatial and temporal variations is very effective for the identification of physical variables (Montroy, 1997; Hannachi et al., 2009; Wei, 1999). The relationship of winter precipitation in southeastern Europe with North Atlantic sea-surface temperature was revealed by the EOF analysis to elucidate the impacts of global warming on regional climate (Hatzaki and Wu, 2013). Unal et al. (2012) conducted a REOF analysis on the temporal and spatial patterns of precipitation variability for the annual, wet, and dry seasons in Turkey. The EOF and REOF analyses have their own advantages, i.e., the EOF analysis can conveniently decompose the variations of meteorological elements field involving different space points over time, so as to better reveal the variations of characteristics and trends of the field; the REOF analysis can further simplify the original eigenvector structure resulting from the EOF analysis and reflect the difference in precipitation among subzones more precisely. Thus, the combination of the EOF and REOF analyses for precipitation trends could better identify regional temporal and spatial characteristics of precipitation variations. This combination has been applied to the plains or coastal areas (Zhang et al., 2009; Kim et al., 2011). It was seldom used in mountainous areas with more complex topography or precipitation formation mechanism. Many rivers flow across mountainous areas; therefore, it is important for water basin resource management to conduct studies on precipitation distribution in the mountains. An in-depth analysis of the precipitation variation characteristics in mountainous areas is being sought by comprehensively using the EOF and REOF analyses at the basin-scale.

In recent years, extreme weather conditions, such as a sharp precipitation decline and severe drought, have frequently occurred on the Lancang River basin of Southeast Asia, which was a warm, humid and water-rich mountainous zone in the past. Especially in the crop growing season (May–October, summer through fall), drought can not only cause crop failures and intensify conflicts over water supply and demand, but also exacerbate water conflicts between upstream and downstream locations. Li et al. (2011) analyzed trends of precipitation, rainy days and average daily precipitation intensity on the basis of daily precipitation data observed at 35 stations located in the Lancang River basin from over 1961 to 2005. However, previous studies were limited to annual variations in precipitation, while seasonal variations at the watershed scale were less reported, especially in crop growth period which is critical to food security under the rapid development of social economy (Cheng and Xie, 2008). However, seasonal variability should be taken into consideration, which could provide an in-depth and comprehensive perspective for identifying precipitation anomalies for water resources management and agricultural production. Especially in the context of drought-prone areas, studies on the spatial and temporal variation trends of precipitation during the crop growth period could help to prevent potential hazards related to the abnormal precipitation ahead. Thus, it is necessary and of interest to identify the regional characteristics of precipitation variations of the Lancang River basin by combining the EOF and REOF analyses, especially focusing on the crop growth period.

Therefore, the objective of this research is to analyze the long-term regional characteristics of precipitation variations during the crop growth period under climate change in the Lancang River basin in southwestern China. This objective entails the following tasks: (1) examining temporal precipitation characteristics with the EOF analysis and (2) investigating spatial characteristics of precipitation variations with the REOF analysis. The combination of the EOF and REOF analyses can be used for supporting relevant decision-making regarding agricultural water resources management under climate change.

2. Materials and methods

2.1. Overview of the Lancang River basin

The Lancang River, known as the “Oriental Danube”, is located in the upper Mekong River basin, which is the largest international river in Southeast Asia. Therefore, the Lancang River’s hydrological processes and the condition of its water resources play an extremely important role from the perspective of water resource security for downstream countries and regions. As a trans-boundary river in Southeastern Asia, the Mekong River flows southwards across Tsinghai, Tibet, and Yunnan provinces of China, as well as Myanmar, Laos, Thailand, Cambodia, and finally imports South China Sea from Vietnam. It is the world’s 12th-longest river and the 7th-longest in Asia. From the point where it rises to its mouth, the most precipitous drop in the Mekong River occurs in its upper basin, a stretch of some 2200 km. Here, it drops 4500 m before it enters the lower basin where the borders of Thailand, Laos, China and Burma (Myanmar) come together in the Golden Triangle. Downstream from the Golden Triangle, the river flows for a further 2600 km through Laos, Thailand and Cambodia before entering the South China Sea via a complex delta system in Vietnam. The Lancang River basin makes up 24% of the total area and contributes 15–20% of the water that flows into the Mekong River. The Lancang River has extremely rich water resources and becomes the longest river of southwestern China. It lies approximately between 21–29° N and 98–102° E, with an area of approximately 1.65×10^5 km^2, accounting for 37.2% of the Yunnan provincial territory. The catchment here is steep and narrow. As a coarse-bed mountain stream, the Lancang River in Yunnan Province is the core area of the longitudinal range-gorge region (LRGR), which is composed of mountain-valley regions in the north-south direction with an elevation between 500 and 4000 m. To sum up, as an important hydrologic backbone of southwestern China, the Lancang River basin crosses 13 latitude degrees and six types of climatic zones; thus, it is of great importance even to the rest of Southeast Asia.

The climate of the upper reach of the Mekong River basin is dominated by two distinct monsoon seasons: the rainy southwest monsoon from the Indian Ocean and the Bay of Bengal, which occurs between mid-May and early October, and the dry northeast monsoon, which occurs between November and April. A clear dry-wet season is an important climate characteristic of the basin. The crop growth period includes summer and autumn (May to October) in this region. The amount of precipitation slopes down

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