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Spatiotemporal analysis of precipitation trends under climate change in the upper reach of Mekong River basin

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ABSTRACT

Precipitation anomalies have greatly affected eco-hydrological processes in the upper reach of the Mekong River. In this research, an integrated spatiotemporal decomposition analysis method was proposed for the identification of precipitation trends under climate change at the basin scale. This method was a comprehensive use of multiple environmental statistical analysis approaches, including the S-mode empirical orthogonal function analysis, the inverse distance weighted interpolation, the Mann-Kendall trend test, the linear regression and the weighted moving average. Results indicated that precipitation trends were mainly obtained by two spatial-temporal variation patterns resulting from the decomposition of the original precipitation field. The primary spatial pattern (more than 40% variances) indicated that the annual and seasonal precipitation in the entire basin had a common variation trend. Moreover, variability of precipitation increased to the largest in the central basin and gradually decreased from north to south. Accordingly, precipitation-sensitive areas were mainly located in the east-central basin. The associated temporal trends showed that annual precipitation increased slightly over 1960–2009, and decreased significantly at the 5% significance level since 2000. Spring precipitation increased significantly over the entire study period. The secondary spatial pattern extracted at least 15% of the variance and represented a north–south inverse-variation trend. The northern mountainous region was more sensitive to climate change. Temporal trend analysis showed that annual precipitation had an increasing trend in the northern region and a decreasing trend in the southern region. Precipitation in the northern region increased significantly at the 1% significance level in winter. The research results could form a basis for supporting basin-scale water resources management, especially in the mountainous basin.

1. Introduction

The well-evidenced climate warming has a cascade of impacts on many eco-hydrological processes (Cai et al., 2009; Johnson and Weaver, 2009; Dunn et al., 2012; Saurer, 2012; Wang et al., 2013). It is altering hydrological cycles and the associated precipitation patterns under multiple spatial and temporal scales, which in turn is affecting runoff formation and flow regimes (Beyene et al., 2010; Willems and Vrac, 2011; Nie et al., 2012). Among the factors that are influenced by climate change, the precipitation pattern is probably one of the most useful indicators to reflect and describe effects of changing climatic conditions. Even a minor perturbation in the precipitation pattern would result in a series of major impacts on the water system within a basin (Muzik, 2001; Minville et al., 2008; Ficklin et al., 2010). Owing to its sensitivity to climate change, any changes of the precipitation pattern have attracted much attention especially in river basins where water is mainly sustained by natural precipitation (Hayhoe et al., 2007; Bhutiyani et al., 2010; Seguí et al., 2010; Ward et al., 2011). This feature is particularly distinctive in most mountainous basins, where seasonal variations in precipitation are extremely sensitive to any changing climatic conditions (Sato, 2009; Frumau et al., 2011). Therefore, it is useful to investigate spatiotemporal variations of precipitation in a mountainous basin to help understand impacts of climate change on water systems at the river-basin scale.

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Previously, many research efforts have been devoted to analyzing spatial and/or temporal variations of precipitation patterns in many watersheds across the world. Villar et al. (2009) examined precipitation variability over the period of 1964–2003 in the Amazon basin. Zhang et al. (2009) investigated the changing properties of precipitation concentration in the Pearl River basin, China. Blender et al. (2011) evaluated long-term variability of runoff and precipitation patterns in the Yangtze River basin, and established statistical connections between such factors and East Asian monsoon. After a thorough investigation, Timbal and Hendon (2011) confirmed that Murray-Darling basin of Australia has been experiencing precipitation deficits. Most of these studies were based on various statistical analysis methods, which could facilitate understand spatiotemporal variations in precipitation patterns. Particularly, the method of empirical orthogonal function (EOF) analysis is considered as an effective way to decompose a complex spatiotemporal field into spatial and temporal dimensions. In recent decades, this method was widely adopted in atmospheric, hydrological, environmental, resources, and geographical studies (Jolliffe, 2002; Houser et al., 2008; Liu et al., 2009a,b; Xu et al., 2010; Tan et al., 2010a,b,c).

Many parametric and non-parametric test methods were employed. For example, as a non-parametric method, the Mann-Kendall trend test is effective in dealing with long time-series hydrological and meteorological data that are not normal distributions. Comparatively, as one of the parametric test methods, the linear regression method is long on analyzing variation trends and precipitation intensities, especially when the sampling number of precipitation is small. Additionally, the moving average method was widely used in reflecting long-period features of many climatic factors. It has strength in acquiring potential long-term changes through smoothing short-term fluctuations of random climatic variables, and extracting periodic behaviors and changes of major climatic factors (William, 2007). Generally speaking, each method has both advantages and disadvantages. They can supplement each other for dealing with trend analysis and extracting impacts of climate change on water systems. Until now, few studies were conducted based on the integration of the three methods (i.e., EOF, Mann-Kendall trend test, and the moving average method). At the same time, most previous studies focused on major and/or inland basins. Few studies were conducted on mountainous regions at the basin scale. In such regions, effects of climate change may be amplified due to the discontinuance of air and vapor movement by mountains. This leads to a variety of complexities in analyzing spatiotemporal trends and distributions of precipitation, calling for an integration of the above-mentioned methods.

As one of the major international rivers in Asia, it is particularly necessary to analyze spatiotemporal variations of precipitation in the Mekong River basin. This river is of great importance not only to southwestern China but also to Southeast Asia. It has diverse topographical conditions and a variety of climatic zones due to the existence of many high mountains and deep valleys in southwestern China. Moreover, precipitation anomalies have been frequently occurring in this region, posing a significant challenge to downstream water resources management (Eastham et al., 2008; Erwin, 2009). In order to further understand responses of this international river to climate change, a spatiotemporal analysis of precipitation trends in the Lancang River was conducted, which provided a basis for river basin management in southwestern China. For example, insignificant precipitation variations have been identified in the Lancang River basin and the Mekong River basin during the last 50 years (Li et al., 2011; Xue et al., 2011). Previous studies in this river basin mostly focused on annual variations in precipitation. The corresponding seasonal variations were scarcely reported, which could provide an in-depth and comprehensive view to identify precipitation anomalies (Cheng and Xie, 2008; He and Zhang, 2009; Zhai et al., 2010; Li et al., 2011). Thus, a complete evaluation of precipitation variations is desired in the basin under multiple temporal and spatial scales, which could help formulate comprehensive basin management plans in southwestern China and Southwestern Asia.

The objective of this research is to propose an integrated spatiotemporal decomposition analysis method (ISTDAM) to help investigate long-term spatiotemporal precipitation trends in the upper reach of Mekong River basin (Lanchang River). Relationships between such trends and the changing climate conditions will be established and analyzed. Spatiotemporal variations in annual and seasonal precipitation from 1960 to 2009 will be analyzed through the adoption of ISTDAM. This method is based on an integration of multiple statistical analysis methods, including approaches of spatial-mode empirical orthogonal function (i.e., S-mode EOF) analysis, inverse distance weighted (IDW) interpolation, Mann-Kendall trend test, linear regression, and weighted moving average. Such an objective entails: (a) examination of spatial variations in precipitation at annual and seasonal scales from 1960 to 2009, and (b) investigation of temporal trends of precipitation associated with spatial variations. Results of this study will provide useful guidance for facilitating formulation of strategic decision alternatives regarding international river affairs and basin-scale water resources management.

2. Material and method

2.1. Overview of the Lancang River basin

The Lancang River basin in China is the upper reach of the Mekong River basin. It approximately lies between 21 and 29°N and 98–102°E in Yunnan province (Fig. 1). The basin is situated at the southeastern margin of the Tibetan Plateau within the Hengduan Mountains. It is affected by complex seasonal monsoons such as the southwest monsoon from the Indian Ocean and Bay of Bengal, the south-branch of the westerlies, and the local climate of the Tibetan Plateau (Xiao et al., 2010). With a coarse-bed mountain stream, the Lancang River basin includes mountain-valley regions with elevations ranging from less than 500 m a.s.l to greater than 4000 m a.s.l. The northern region of the basin is typically a range-gorge landscape characterized by north–south mountains and valleys aligned from west to east whose elevation is above 3000 m (Li et al., 2011). Due to the complex topographical conditions, seasonal monsoons and climatic zones, precipitation is sensitive to climate change. Spatiotemporal variations of precipitation trends have distinctly local features.

The monthly precipitation data from 11 meteorological stations (Deqin, Weixi, Dali, Baoshan, Jingdong, Lincang, Simao, Lancang, Jinghong, Jiangcheng, and Mengla) of the National Climate Center, China Meteorological Administration were selected (Fig. 1). Geographic characteristics of the stations are summarized and presented in Table 1. According to the method developed by Jones et al. (1986), the missing data from Deqin station from Jun to Oct in 1968 were interpolated as the mean values of actual monthly precipitation in 1966, 1967, 1969 and 1970. Differing from most plain and inland basins, the existence of both rainy and dry seasons is the main feature in this mountainous basin. The dry season refers to the period from November to April. Comparatively, the rainy season lasts from May to October. To analyze intra and inter-annual precipitation trends, annual and seasonal mean values of precipitation data were calculated.