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Relationships between oceanic–atmospheric patterns and soil moisture in the Upper Colorado River Basin

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SUMMARY

Soil moisture is an important drought index in the Upper Colorado River Basin (UCRB) and understanding its relationships with oceanic–atmospheric patterns provides valuable information for sustainable water management. To begin with, this study generated 50 years (1950–2000) of soil moisture data in the UCRB using the Variable Infiltration Capacity (VIC) model. This was followed by a temporal evaluation of Pacific Ocean Sea Surface Temperatures (SSTs) and soil moisture in the UCRB during drought, normal, and wet years. Besides in-phase analysis, lead time analysis was also performed in which the previous year's SSTs were evaluated with the current year soil moisture. Furthermore, the Singular Value Decomposition (SVD) analysis revealed strong correlation between the first temporal expansion series of SSTs and soil moisture in the UCRB. Finally, this study examined the relationships between multiple oceanic–atmospheric patterns and soil moisture in the UCRB in drought, normal, and wet years. Both in-phase and lead time analyses indicated that the Pacific Decadal Oscillation (PDO) strongly influenced soil moisture by displaying positive coupled regions (significance >95%). In drought and wet years, the lead time analysis showed a positive correlation between the El Niño-Southern Oscillation (ENSO) and soil moisture but the in-phase analysis resulted in a negative correlation. The Atlantic Multi-decadal Oscillation (AMO) displayed similar coupled regions for both in-phase and lead time analyses in drought and wet years. Understanding the relationships between soil moisture and oceanic–atmospheric patterns has increasingly important implications for the water resources management in the UCRB since soil moisture plays a key role in predicting the runoff and streamflow.

1. Introduction

The lifeblood of the Southwestern United States is the Colorado River, which offers a primary water supply for 28 million people living in seven US states as well as Mexico. The Colorado River Basin (CRB), including the Colorado River, its tributaries, and the lands that these waters drain, spans an area of 637,000 km^2 (see Fig. 1). However, the CRB no longer provides sufficient water due to rapid growth of water demands and hydrological drought in the western region. Hydrologic and hydrogeological variability in the region is highly related to oceanic–atmospheric patterns which are of considerably importance in providing predictive information about water resources in the CRB.

Well-understood oceanic–atmospheric patterns including the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Atlantic Multi-decadal Oscillation (AMO), as well as oceanic factors such as the Sea Surface Temperatures (SSTs) have complex and overlapping effects on the hydrological processes in the CRB. Much of the previous research has focused on the relationships between the SSTs and hydrometeorology variables (e.g., precipitation and temperature) or hydrological variables (e.g., streamflow and snowpack), but to a lesser degree, the hydrogeological variables (e.g., soil moisture). For example, Aziz et al. (2010) examined the relationship between the Pacific Ocean SSTs and the snowpack in the UCRB. McCabe et al. (2007) found that the global SSTs had a significant impact on flow discharge of the Upper Colorado River. Tootle and Piechota (2006) evaluated the relationship between the SSTs and continental US streamflow and identified significant coupled regions in both Pacific and Atlantic Oceans. Harshburger et al. (2002) suggested that winter precipitation in the northern Idaho Mountains was negatively correlated with fall SSTs in the eastern tropical regions of the Pacific Ocean,

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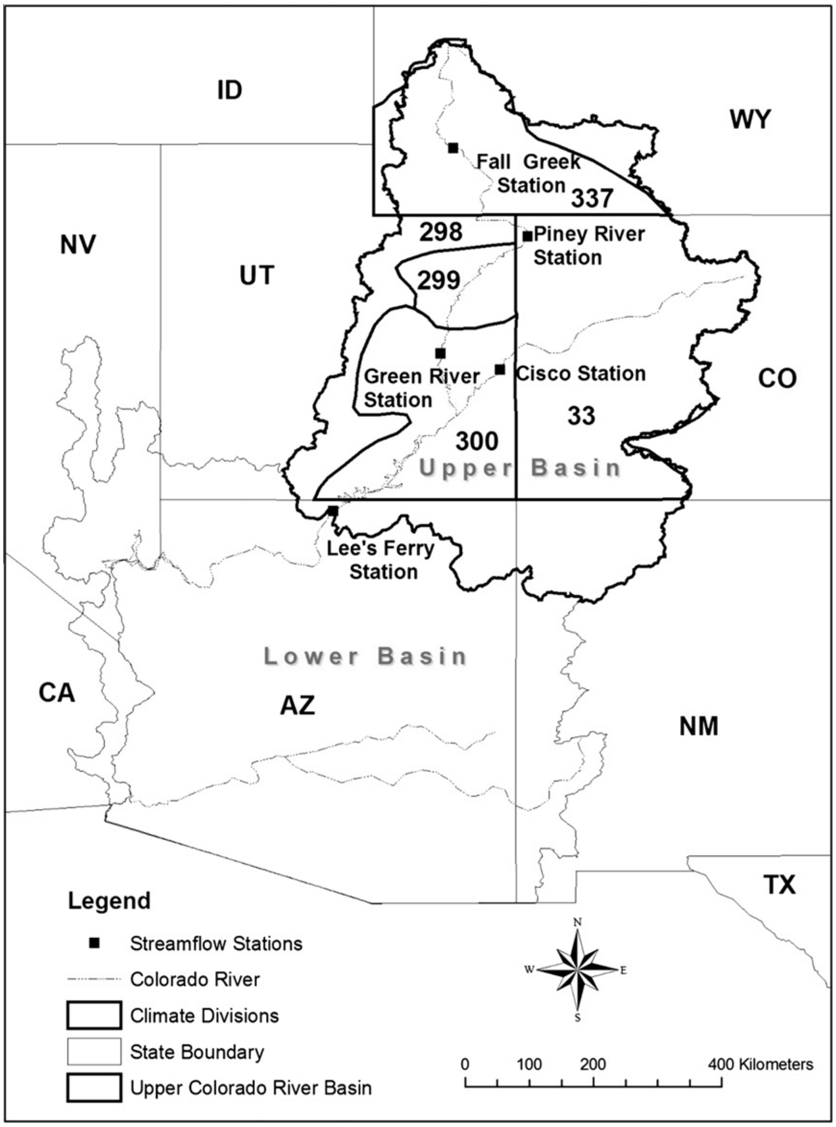

Fig. 1. The UCRB with five Climate Divisions from the NOAA.

while spring streamflow in Idaho was negatively correlated with SSTs in the eastern tropical and northern regions of the Pacific Ocean. Zhang and McPhaden (1995) suggested that warm SSTs in the Pacific Ocean led to low latent heat flux on a seasonal scale influencing hydrological processes in the equatorial Pacific.

Some previous studies have investigated the impacts of a specific oceanic–atmospheric pattern (e.g., ENSO) on streamflow (Marti et al., 2010; Piechota and Dracup, 1996; Trenberth and Branstator, 1992) or hydrometeorology variables (such as precipitation, air temperature, and wind) (Lee and Cheng, 2011). Shaman and Tziperman (2011) demonstrated how ENSO affected precipitation over southwestern Europe. Piechota et al. (1998) indicated that dry conditions in Australia were related to El Niño. Moron et al. (1995) found less rainfall amount in subequatorial America during an El Niño period; while more rainfall events occurred in Africa during a La Niña period.

Using the multiple oceanic–atmospheric patterns to predict the variations of the soil moisture is increasingly important because no single feature alone can adequately explain these variations. Hidalgo and Dracup (2003) studied the effects of ENSO and PDO on hydroclimatic variations (1909–1998) of the UCRB and found that the basin-wide ENSO played an important role in the warm season precipitation and warm season SSTs. Maurer et al. (2004) examined the relationships between runoff patterns and large-scale climate indices including ENSO, PDO, North Pacific (NP), and Arctic Oscillation (AO) by utilizing the Principle Component Method. Tootle et al. (2005) concluded that the ENSO during an AMO warm phase influenced the streamflow in the southeastern United States and PDO cool phase was associated with significantly less streamflow. Timilsena et al. (2009) indicated that the ENSO and PDO had significant influence on the streamflow, but not the AMO. Recently, Mehta et al. (2011) stated that the PDO and the Tropical Atlantic sea surface temperature gradient (TAG) had significant impacts on water availability in the Missouri River.

Despite the existing efforts directed at understanding the correlation between oceanic–atmospheric patterns and hydrometeorology/hydrological variables in watersheds (i.e., precipitation, air temperature, and streamflow), there is a great need for a better understanding of the relationships between multiple oceanic–atmospheric patterns and hydrogeological variables (e.g., soil moisture), which has not been adequately investigated and published to date. The first motivation for the current study is to fill the gap by investigating the correlation between multiple oceanic–atmospheric patterns and soil moisture in the UCRB. Soil