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# Predictors of precipitation for improved water resources management in the Tarim River basin: Creating a seasonal forecast model

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ABSTRACT

In recent years, an expansion of irrigated agriculture and rapid population growth have threatened the Tarim River basin's natural ecosystems and caused water shortages. Improving the water resources management in the basin requires accurate seasonal precipitation forecasts. Based on previous research, possible predictors of precipitation were selected and either downloaded directly or calculated using NCEP/NCAR Reanalysis 1 or NOAA Extended Reconstructed Sea Surface Temperature (SST) V3b data. Predictors were correlated with precipitation data, provided by the National Climate Centre of the China Meteorological Administration for the period 1961 to 2010 and averaged over the subbasins of the Tarim River. The Spearman rank correlation analyses with lead times of up to six months (or two seasons) revealed significant (at the 1% level) and strong ($\rho \leq -0.6$ or $\rho \geq 0.6$) correlations of precipitation in all subbasins with the SST and monsoon indices as well as with the Siberian High Intensity (SHI) and the Westerly Circulation Index (WCI). Lastly, we demonstrate the setup of a forecast model based on a multiple linear regression on the example of the Hotan River subbasin. This model predicts precipitation 5 months in advance with reasonable accuracy in two out of three configurations.


## 1. Introduction

Seasonal forecasts of precipitation, also known as seasonal outlooks, are an important tool for water resources management and planning with different priorities depending on the regional climatic setting. In humid regions such as Bangladesh (Webster et al., 2010) and Indonesia (Garcia, 2002), seasonal precipitation forecasts have been integrated into flood forecasting schemes. In these regions they offer potential for flood mitigation as they enable an increase of the warning lead time for a flood event and improve emergency management procedures: levees can be strengthened, people can be evacuated, and elements at risk can be protected with more time. Even more useful are seasonal forecasts in arid regions and allow strategic decisions to be made, reflecting the outlook on water availability, such as the selection of crops and seed varieties, the design of adapted cropping patterns (Webster et al., 2010), and adjustment of the irrigation management plans.

In this study, we focus on the endorheic Tarim River basin covering an area of about $1.02 \times 10^6$ km$^2$ in Central Asia (Tao et al., 2008). The Tarim River is the longest inland river of China, disappearing in the Taklamakan Desert. The river basin is arid to hyperarid, and water scarcity is a severe threat for the population. Even though surface water is a scarce resource, diverting river water for irrigation farming, which is the principal human activity in the oases, such as the Hotan Oasis, is very common. In a study by Chen et al. (2014) it was shown that precipitation and discharge in the Hotan subbasin are well correlated. Therefore, credible and satisfactorily accurate seasonal forecasts of precipitation offering early warnings for precipitation deficits could facilitate water scarcity mitigation efforts. This can help improve operations of water storage facilities and may allow adjustments in water resources management (Kim et al., 2000). It should be noted that the water scarcity phenomenon is slowly evolving. Therefore, accurate

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predictions of precipitation one or even two seasons in advance would not only allow for an improved planning of water resources but also of crops, as the best planting time and the most appropriate crops for the subsequent season(s) could be chosen earlier. This is of high importance for developing a sustainable agriculture in the oases.

The aim of this paper is twofold: (a) to evaluate the appropriateness of potential predictors of precipitation for the Tarim River basin for seasonal precipitation forecast, and (b) to suggest and test a precipitation forecast model for the Hotan subbasin based on a multiple linear regression. After an introduction of the study region and the challenges faced there due to global environmental change, we explain atmospheric indices and describe ocean-atmosphere conditions that are, according to the literature, linked to precipitation in the Tarim River basin. Following this description and an introduction of this study's data, we define several new Sea Surface Temperature (SST) indices. Subsequently, we present results of a Spearman rank correlation analysis between all indices (potential predictors) and precipitation averaged over the subbasins of the Tarim River in monthly resolution with lead times between 0 and 6 months. By this we assess their relevance for seasonal forecasting, and determine the optimum lead time with which the indices should be integrated into a forecast model for best performance. As some of the indices are anticipated to be linked to precipitation only during part of the year, we include a seasonal approach as well. Prior to the integration of the predictors into a forecast model, they were correlated with each other to test whether multicollinearity is present. Finally, precipitation is forecasted using the constructed forecast model on the example of the Hotan River subbasin.

## 2. Materials and methods

### 2.1. Study area

The Tarim River basin (Fig. 1) is one of the world's largest closed hydrological drainage systems. Most of the basin is located in the Xinjiang Autonomous Region, Northwestern China. From the 18th century to the early 20th century, there were nine rivers with 144 tributaries flowing into the mainstream of the Tarim River (Xu et al., 2009). However, due to reclamation of land for irrigated agriculture and rapid population growth, the water withdrawal from all rivers in the Tarim River basin has increased since 1950 (Peng et al., 2014). Today, only the three headstreams, the Aksu, Yarkand, and Hotan Rivers, are naturally connected to the Tarim, the Aksu being the only perennial tributary (Guo et al., 2013). The Hotan River, even though presently only discharging into the Tarim River during periods of high flow in the summer like the Yarkand River, still is a vital water resource for irrigation farming especially in the Hotan Oasis (Shen and Huang, 2010). Since 2000, water is also diverted from the Bosten Lake to the lower Tarim River (Ye et al., 2009).

The basin is surrounded by the high mountain ranges Tian Shan, Karakorum, Pamir, and Kunlun Shan. Orographic precipitation is typical for the windward sides of these mountain ranges and rain shadow effects for their leeward side result in a large desert, the Taklamakan desert. There, the total annual precipitation is equal to zero in some years; however, in the high mountains surrounding the desert, annual precipitation can be of the order of 400 mm and higher (Kundzewicz et al., 2015). Highest precipitation totals, mostly in the form of snowfall, are typically recorded in June, July, and August (Tao et al., 2011) with the maximum on average in July. From these mountains snow and glacier melt feed the Tarim River through its tributaries (Kundzewicz et al., 2015).

The Tarim River is the major water source for human activities and for the natural ecosystems in the Xinjiang region, with irrigation agriculture, mainly cotton, being the most important water consumer (Thevs, 2011). The two basic drivers of changes in water discharge in the basin are climate change and intensive agricultural land use (Kundzewicz et al., 2015).

The outcomes of several studies indicate that over the period of 50 years until about 2005 air temperature shows a significantly increasing trend over vast areas of the Tarim River basin (Tao et al., 2011; Xu et al., 2010) including its headwater region (Krysanova et al., 2015; Kundzewicz et al., 2015; Li et al., 2012; Xu et al., 2005; Ye et al., 2006; Zhang et al., 2010). This increasing temperature created a surplus in meltwater, and together with a very slight increasing trend in precipitation (Tao et al., 2011; Xu et al., 2010), which was also found for the headwaters (Krysanova et al., 2015; Kundzewicz et al., 2015; Li et al., 2012; Xu et al., 2005; Ye et al., 2006; Zhang et al., 2010), caused an increase in water supply from the Aksu and Yarkand Rivers (Xu et al., 2005; Zhang et al., 2010). Yet over the same time period, a decreasing trend in runoff was reported for the Hotan River (Xu et al., 2005, 2010bib_Xu_et_al_2010; Ye et al., 2006; Zhang et al., 2010). This was attributed to the smaller decrease of glaciated area compared to the other headwater subbasins (Zhang et al., 2010) and rapid population growth in the Hotan oasis concurrent with the expansion of agricultural land area and increasing water consumption (Amuti and Luo, 2014). The downstream hydrologic stations along the Tarim River mainstream show significantly decreasing runoff trends (Xu et al., 2005; Ye et al., 2006). This is caused by a strong increase of consumptive water use (Xu et al., 2005; Ye et al., 2006) already described above for the Hotan River.

### 2.2. Teleconnections for precipitation: an overview of indices and moisture transportation

This subchapter includes a review of studies analyzing the influence of atmospheric indices on precipitation in the study area and moisture transportation paths to the Tarim River basin.

Bothe et al. (2012) described the precipitation climate in the larger Tian Shan region of Central Asia in terms of climatological seasonal moisture fluxes and background circulation. They computed the standardized precipitation index (SPI) (McKee et al., 1993) for three regions, one of which covers the Tarim River basin. Several northern hemispheric teleconnection patterns (Barnston and Livzey, 1987) were significantly (p values smaller than 0.05) and mostly positively correlated with the monthly regional standardized precipitation series (Bothe et al., 2012). For the Tarim River basin, the Polar Eurasia (POL/EUR) pattern showed dominant correlation links to precipitation in winter and spring. Overall, Bothe et al. (2012) evaluated the Scandinavia (SCA) pattern (referred to as Eurasia-1 pattern by Barnston and Livzey, 1987), the East Atlantic/Western Russia (EA/WR) pattern (referred to as Eurasia-2 pattern by Barnston and Livzey, 1987), and the East Atlantic (EA) pattern as most influential for precipitation in Central Asia.

Gong et al. (2001) explained that the Arctic Oscillation (AO) (Thompson and Wallace, 1998) and the Siberian High intensity (SHI) are highly significantly correlated. A positive phase of the AO is associated with lower Sea Level Pressure (SLP) over the polar region and most of the Eurasian continent including Siberia; there is a substantial out-of-phase relationship (Gong et al., 2001). Accordingly, a negative phase of AO is associated with a stronger Siberian High, which is associated with a precipitation decrease over most of the Asian continent (Gong and Ho, 2002). The strongest association was found in the central region of the Siberian High (40°N-60°N, 70°E-120°E), and it weakened steadily with an increasing distance to the central region. For the winter (January, February, March), mean precipitation averaged over 30°N-70°,