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Forecasts of seasonal streamflow in West-Central Florida using multiple climate predictors

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SUMMARY

Large-scale climate can provide predictive information for streamflow forecasts in many parts of the world. However, the optimal selection of predictors can be problematic when focusing on a localized region. This work evaluated multiple gridded climate datasets in order to determine optimal predictors of seasonal streamflow in West-Central Florida. Using persistence in streamflow, existing indices of climate, and sea surface temperature (SST) expansion coefficient time-series from singular value decomposition (SVD) analysis, this work developed probability of exceedance streamflow forecasts for multiple stations, seasons, and lead-times. Forecasts were found to be generally skillful between the September–November and April–June seasons with this range narrowing as lead time increased and skill was mainly related to the impact of the El Niño-Southern Oscillation (ENSO) on the region. Using multiple indices of ENSO that were determined by correlation and composite analyses to track its evolution from the west Pacific at long lead-times to the east Pacific at short lead-times was not found to appreciably improve forecasts over using the Niño 3.4 index alone. Using SST expansion coefficient time-series from SVD analysis was found to capture the evolution of ENSO from west to east and to provide skillful forecasts of streamflow at earlier leads (up to 7 months in advance) compared to that found by pre-defined indices, indicating the importance of predictor selection in achieving optimal forecast skill.

1. Introduction

Streamflow variability has been shown to be linked to features of large-scale climate in many regions around the world. Several studies have found links between sea surface temperatures (SSTs), mean sea level pressures (MSLPs), geopotential heights (GpHs), and other atmospheric variables with regional streamflow (e.g. Chavasse and Seoane, 2009; Chiew et al., 1998; Johnson et al., 2013; Jury, 2010; Karabörk and Kahya, 2009; Kennedy et al., 2009; Kim et al., 2012; Massei and Fournier, 2012; Sveinsson et al., 2008b). In the continental USA considerable work has been conducted on the impact of the El Niño-Southern Oscillation (ENSO) on streamflow (e.g. Cayan et al., 1999; Dracup and Kahya, 1994; Kahya and Dracup, 1993, 1994; Redmond and Koch, 1991; Schmidt et al., 2001) and other phenomena such as the North Atlantic Oscillation (Sanchez-Rubio et al., 2011; Steinschneider and Brown, 2011; Tootle et al., 2005), Atlantic Multidecadal Oscillation (AMO) (Enfield et al., 2001; Johnson et al., 2013; Kelly and Gore, 2008; Rogers and Coleman, 2003; Tootle and Piechota, 2006), and the Pacific Decadal Oscillation (PDO) (Beebee and Manga, 2004; Harshburger et al., 2002; Hidalgo and Dracup, 2003).

Several studies have used large-scale climate phenomena to develop long-lead streamflow forecasts in multiple locations (e.g. Coley and Waylen, 2006; Grantz et al., 2005; Hamlet and Lettenmaier, 1999; Opitz-Stapleton et al., 2007; Piechota et al., 1998; Tootle and Piechota, 2004). Hamlet and Lettenmaier (1999) incorporated ENSO and the PDO into a macroscale hydrological model for the Columbia River above The Dalles and found that they could extend effective forecasts up to 6 months in advance. Grantz et al. (2005) incorporated custom indices of SSTs and 500 mb GpHs into a local regression model of spring streamflow in the Truckee-Carson River system and found significant forecast skill at leads of up to 5 months. Several studies have applied continuous probability of exceedance streamflow forecasts conditioned on the persistence of streamflow and various indices of climate as predictors in multiple regions around the world (e.g. Chiew et al., 2003; Oubeidillah et al., 2011; Piechota and Dracup, 1999; Piechota et al., 1998, 2001; Soukup et al., 2009; Tootle and Piechota, 2004). An advantage of exceedance forecasts is that such curves are familiar to the water resource management community since (climatological) exceedance curves are commonly used in the design and operation of water resource systems. Such curves can

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be readily used by the water management community to determine the particular level of risk deemed acceptable.

Due to its strong signal in the southeastern USA, and the state of Florida in particular, indices of ENSO have been used in several studies to understand the inter-annual variability of streamflow (e.g. Johnson et al., 2013; Sanchez-Rubio et al., 2011; Schmidt et al., 2001; Sun and Furbish, 1997; Zorn and Waylen, 1997). El Niño (La Niña) events have been found to correspond to higher (lower) streamflow along the coast of the Gulf of Mexico and in the state of Florida (Dracup and Kahya, 1994; Kahya and Dracup, 1993; Schmidt et al., 2001; Sharda et al., 2012). Tootle et al. (2005) found that La Niña events during the warm phase of the AMO resulted in significantly lower annual streamflow compared to the cold phase of the AMO across the southeastern USA. In studying streamflow in the Apalachicola-Chattahoochee-Flint river basin, Johnson et al. (2013) found influences of ENSO mainly in the southern portion of the basin along the Gulf coast, but that the AMO modulated the impacts of La Niña events across the entire basin throughout the year, with streamflow approximately 50% lower during the warm phase of the AMO compared to the cold phase. Sanchez-Rubio et al. (2011) found that long-term low streamflow in the Pascagoula River in Mississippi was associated with multidecadal and decadal variability associated with the warm phase of the AMO and negative phase of the NAO, respectively, and that influences of ENSO or the PDO were found during this low-flow regime. Sun and Furbish (1997) found that ENSO explained 30% of annual streamflow variability in Florida and Schmidt et al. (2001) found increases (decreases) in winter streamflow in Florida during El Niño (La Niña) events that tended to persist into the spring. However, the findings of Zorn and Waylen (1997) suggested that the response of streamflow to ENSO may not be homogeneous across the state of Florida. Kelly and Gore (2008) also identified a transition in streamflow response to the AMO between northern and southern Florida and that the influence of the AMO on streamflow in Florida was opposite compared to that of much of the conterminous USA.

Forecasts of streamflow using large-scale climate have also been developed in the state of Florida. Miralles-Wilhelm et al. (2005) used precipitation outlooks issued by the Climate Prediction Center to forecast inflows to Lake Okeechobee in Florida and found the outlooks did not provide large enough shifts in forecast probabilities. Coley and Waylen (2006) found that the Niño 3.4 index from the previous summer could be used to forecast dry season (winter) streamflow in the Peace River in Florida. Tootle and Piechota (2004) used several SST indices and the Multivariate ENSO Index (MEI) (Wolter and Timlin, 1998) to develop continuous probability of exceedance forecasts for winter and spring streamflow for the Suwannee River in Florida and found the highest model skill during ENSO events.

One issue that arises in developing localized forecast models based on large-scale climate is that commonly used pre-defined indices, while dominant on a large scale, can fail to provide optimal forecast skill in individual basins (e.g. Grantz et al., 2005; Harshburger et al., 2002; Switanek et al., 2009). For example, Grantz et al. (2005) found custom indices of 500 mb GpHs near the western USA and SSTs over the northern Pacific Ocean to be more significant predictors of streamflow in the Truckee-Carson River system compared to standard indices of ENSO and the PDO. Switanek et al. (2009) found spatial windows of SSTs in the equatorial and north Pacific, that were not fixed in space (as is the case for commonly used pre-defined indices), were stronger predictors of streamflow in the Little Colorado and Gunnison Rivers for multiple seasons and lags compared to the Niño 3, Niño 3.4, MEI, and PDO indices. Sveinsson et al., 2008a,b found multiple SST, MSLP, 700 mb zonal wind, 700 mb meridional wind, and 200 mb GpH regions that were better predictors of streamflow in the Churchill Falls basin in Québec, Canada compared to multiple commonly used climate indices. Evaluating 500 mb GpHs, Opitz-Stapleton et al. (2007) found two of the centers of action of the Pacific North American (PNA) pattern to exhibit a stronger relationship with spring runoff in the Yakima River basin compared with the standard index of the PNA.

The selection of predictors from gridded datasets in such studies is often done by correlation and composite analyses (e.g. Grantz et al., 2005; Opitz-Stapleton et al., 2007; Sveinsson et al., 2008b) or by using multivariate techniques such as principal component analysis (Jolliffe, 2004; Wilks, 2006), canonical correlation analysis (Barnett and Preisendorfer, 1987; Wilks, 2008), or singular value decomposition (SVD) analysis (Bretherton et al., 1992; von Storch and Zwiers, 1999; Wilks, 2006). Multivariate techniques such as SVD analysis have been used to identify predictors for streamflow from gridded climate datasets that outperformed pre-defined indices of climate in Colombia (Tootle et al., 2008), the North Platte River (Soukup et al., 2009), and in the Colorado River and Great Basin (Lamb et al., 2011; Oubeidillah et al., 2011).

The objective of this study was to develop continuous probability of exceedance streamflow forecasts for West-Central Florida using both pre-defined indices (confirmed by correlation and composite analyses) and indices defined by SVD analysis. There are 3 unique aspects of this study: first, it did not focus on a single specific target season of interest but rather evaluated the forecast skill for all seasons and multiple lead times; second, it provides a direct comparison between spatially-static, pre-defined indices of climate with climate predictors determined by a multivariate approach whereby their spatial footprint was allowed to evolve by season and lead time; and third, this work demonstrates the utility of seasonal streamflow to estimate seasonal withdrawals based on daily operating rules and quantifies the uncertainty in the seasonal relationship.

2. Data

Monthly streamflow data for 13 stations were obtained from the United States Geological Survey (USGS) (USGS, 2011) (Table 1). Streamflow was averaged into twelve 3-month seasons for analysis. Stations were chosen based on their location within the Southwest Florida Water Management District (SWFWMD) (Fig. 1), record length, and presence on larger rivers and streams. The presence on large rivers and streams was chosen as a selection criterion on the premise that they effectively integrate the impact of climate variability over a larger contributing drainage area. However, it is important to note that due to Florida's karst limestone geology many streams and rivers in the region are baseflow-driven and it is possible that surface watersheds and groundwater-sheds are not completely coincident. The homogeneity of the streamflow records used in this analysis was verified using double-mass curves (Searcy and Hardison, 1960) with stations included in the USGS Hydro-Climatic Data Network (Slack and Landwehr, 1992).

The three seasonal gridded climate variables evaluated by correlation and composite analyses included the 2.0° × 2.0° SSTs from the Extended Reconstructed SST version 3b (ERSSTv3b) dataset (Smith et al., 2008) and 2.5° × 2.5° MSLPs and 500 mb GpHs from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis project (Kalnay et al., 1996). All gridded variables were obtained from the data library of the International Research Institute for Climate and Society (IRI, 2011). Gridded climate variables in the region bounded by 35°S–65°N and 120°E–0° were used in this analysis. Since the NCEP/NCAR reanalysis data via IRI is limited to 1949-present, the resulting analyses using MSLPs and GpHs were restricted to the period 1949–2010. A linear warming trend was removed from the gridded SSTs.