Journal of Hydrology: Regional Studies 5 (2016) 80–99

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

The influence of climate modes on streamflow in the Mid-Atlantic region of the United States

Justin A. Schulte[a,*], Raymond G. Najjar[a], Ming Li[b]

[a] Department of Meteorology, The Pennsylvania State University, University Park, 503 Walker Building, PA 16802, USA
[b] Horn Point Laboratory, University of Maryland Center for Environmental Science, P.O. Box 775, Cambridge, MD 21613, USA

ARTICLE INFO

Article history:
Received 2 May 2015
Received in revised form 6 November 2015
Accepted 10 November 2015
Available online 12 December 2015

Keywords:
Streamflow
Climate
Climate variability
Wavelet analysis
El-Niño-Southern Oscillation
Mid-Atlantic region

ABSTRACT

Study region: The Mid-Atlantic region of the United States.
Study focus: An understanding of past streamflow variability is necessary for developing future management practices that will help mitigate the impacts of extreme events such as drought or floods on agriculture and other human activities. To better understand mechanisms driving streamflow variability at all timescales, annual to multi-decadal streamflow variability of three major rivers in the Mid-Atlantic region of the United States (the Susquehanna, Delaware, and Hudson Rivers) was studied in the context of climate modes using correlation and wavelet analyses.
New hydrological insights for the region: Results from the correlation analysis detected statistically significant relationships between climate indices and streamflow that were similar for the three rivers. The results from the wavelet analysis showed that 18- and 26-year periodicities were embedded in the streamflow time series. Decadal variability of streamflow was coherent with the El-Niño Southern Oscillation (SO) and the Pacific Decadal Oscillation (PDO). The time series for the PDO and SO indices and precipitation were found to be synchronized to the decadal variability of a global circulation pattern consisting of a Rossby wave train emanating from the North Pacific. The SO explained 37–54% of the 1960s drought, 33–49% of the 1970s pluvial, and 19–50% of the 2000s pluvial in the three river basins.

1. Introduction

The Susquehanna, Delaware, and Hudson River Basins (SRB, DRB, and HRB) drain to three important estuaries of the Mid-Atlantic region of the United States (US, Fig. 1), which have experienced substantial climate change and are likely to continue do so with increases in greenhouse gas concentrations (Najjar et al., 2009). This projected climate change is likely to render more difficult efforts to restore these estuaries, which have been stressed by anthropogenic activities, including pollution (e.g., toxic metals, polychlorinated biphenyls, and excess nitrogen), dredging, conversion of wetland habitats, and overfishing (Najjar et al., 2010; Kreeger et al., 2010; Steinberg et al., 2004).

Climate change is likely to manifest itself through changes in existing climate modes, which are recurring and often oscillatory patterns of climate variables, such as sea level pressure (SLP) and sea surface temperature (SST), that operate on timescales ranging from weekly to multi-decadal. For example, Ning et al. (2012) found increases in projected wintertime

* Corresponding author.
E-mail addresses: jas6367@psu.edu (J.A. Schulte), rgn1@psu.edu (R.G. Najjar), Mingli@umces.edu (M. Li).

http://dx.doi.org/10.1016/j.ejrh.2015.11.003

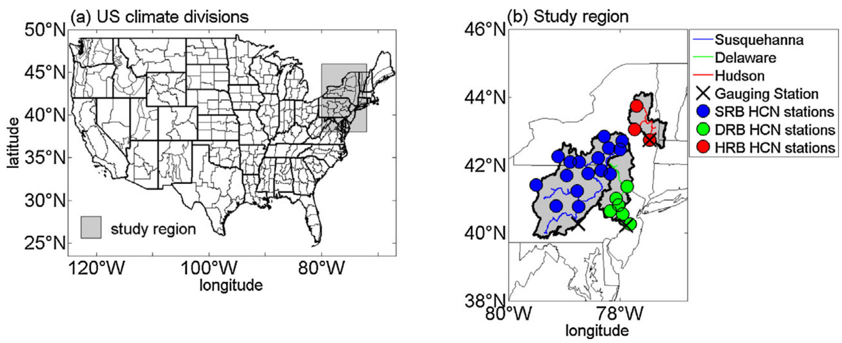

Fig. 1. (a) Location of the US climate divisions delimited with thin black lines. State boundaries are thick black lines and the study region is indicated by the gray box. (b) Locations of the Harrisburg gauging in the Susquehanna River Basin (SRB), the Trenton gauging station in the Delaware River Basin (DRB), and the Waterford gauging station in the Hudson River Basin (HRB) and Historical Climate Network stations. Thick black lines represent the boundaries of the Harrisburg, Trenton, and Waterford drainage basins and thin lines represent state boundaries.

precipitation in the Northeast US to be consistent with a projected decrease in the positive phase of one prominent climate mode, the North Atlantic Oscillation (NAO). The NAO and other important climate modes, such as the Atlantic Multi-decadal Oscillation (AMO), the Pacific Decadal Oscillation (PDO), El Niño-Southern Oscillation (ENSO), the Pacific Northern-American Teleconnection (PNA), and the North Pacific Oscillation (NPO), have regional- to global-scale impacts on climate and weather (Philander, 1983; Trenberth and Hurrell, 1994; Mantua et al., 1997; Thompson and Wallace, 1998; Hurrell et al., 2003).

An understanding of the historical impacts of climate modes on regional climate variability can enhance our understanding of future changes in that region. Furthermore, an understanding of climate-mode impacts on regional meteorological, hydrological, and ecological characteristics will improve monthly and seasonal forecasts, which are of economic importance. With that in mind, the goal of this study is to analyze the variability in streamflow of the Susquehanna, Delaware, and Hudson Rivers, three large rivers in the Mid-Atlantic region of the US, in the context of climate modes.

There are relatively few studies on the impacts of climate modes on streamflow variability in the Mid-Atlantic region as compared to precipitation-climate mode and temperature-climate mode studies. Dettinger and Diaz (2000) found associations between the December–February Southern Oscillation (SO) and October–September streamflow across the Northeast, where El Niño years are associated with wetter-than-normal conditions. Futhuremore, Xu et al. (2012) identified relationships between North Pacific SSTs and Northeast US streamflow and Barlow et al. (2001) found North Pacific SSTs to have been possible drivers of the 1960s drought, a major hydrometeorological event that strained water-management agreements between New York City and Philadelphia (USDA, 2000). The relationships may be the result of prevailing synoptic regimes that set up during certain NAO and ENSO phases (Miller et al., 2006). Barlow et al. (2001) and Miller et al. (2006), however, only considered climate mode-streamflow simultaneous relationships. It is not clear if relationships hold on decadal and multi-decadal timescales. Labat (2008) and Whitney (2010) investigated streamflow variability across the Mid-Atlantic Bight and found multi-decadal variability in the flows of many rivers in the region, which Whitney (2010) hypothesized was related to the NAO.

The streamflow-climate mode relationships discussed above are associated with changes in precipitation, temperature, snow cover, and evapotranspiration, all of which have been investigated in the context of climate modes. Leathers et al. (1991) found that positive PNA phases are accompanied by colder and drier conditions across the US on monthly timescales. Serreze et al. (1998) noted increased snowfall in the Mid-Atlantic region during positive phases of the PNA, which was found to be associated with below-normal maximum temperature on precipitation days. Barlow et al. (2001) noted ENSO, NPO, and PDO influences on Northeast US precipitation and drought conditions. Pattern et al. (2003) found associations between ENSO and winter snowfall across the Northeast US, with El Niño years being accompanied by more frequent major snow events. Archambault et al. (2008) found cool seasons under positive NAO and negative PNA regimes to be wettest. Eichler and Higgins (2006) found increased spring precipitation during El Niño years as a result of more frequent East Coast storms. Similarly, Seager et al. (2010) found strong winter snowfall-NAO and snowfall-ENSO linkages, both of which were related to the frequency of East Coast storms. Despite the impact of ENSO on Northeast precipitation, previous research did not relate ENSO to the 1960s drought in the Northeast US; in fact, it has been argued that the drought (and the subsequent wet period that continues to the present) resulted from internal atmospheric variability because global climate models with prescribed SSTs did not reproduce the drought (Seager et al., 2012).

This paper presents a comprehensive investigation into climate-mode impacts on Mid-Atlantic streamflow by considering all timescales ranging from months to decades. To understand the proximate forcing of Mid-Atlantic streamflow, data sets on mean watershed temperature and precipitation are analyzed as well. Relationships among streamflow, precipitation, temperature, and climate indices are investigated first through a standard linear correlation analysis at monthly, seasonal, and annual timescales. A more general understanding of the variability of Mid-Atlantic streamflow and its linkages to the proximate climate and climate modes is obtained via wavelet analysis and wavelet coherence analysis.