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Oceanic–atmospheric modes of variability and their influence on riverine input to coastal Louisiana and Mississippi

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SUMMARY

The present study examined the individual and combined influences of four oceanic–atmospheric modes of variability on northcentral Gulf of Mexico streamflows. Mississippi River and Pascagoula River mean flows, between phases of long-term modes of variability, were compared using a nonparametric rank-sum test (Mann–Whitney *U*-test). While the combination of Pacific Decadal Oscillation (PDO), Atlantic Multidecadal Oscillation (AMO), and North Atlantic Oscillation (NAO) determined long-term Mississippi River regimes, the coupling of AMO and NAO determined long-lasting Pascagoula River flow regimes. Mississippi River flow was higher during PDO warm, AMO cold (AMOc), and NAO positive (NAOp) phases than during PDO cold, AMO warm (AMOw), and NAO negative (NAOn) phases. Pascagoula River flow was higher during AMOc and NAOp phases than during AMOw and NAOn phases. During the long-term low Pascagoula River flow regime (AMOw/NAOn phase), fluctuations in river flow were associated with PDO or El Niño Southern Oscillation (ENSO). Pascagoula River flow decreased from PDOw to PDOc phases and from ENSO warm to ENSO neutral to ENSO cold phases.

1. Introduction

Climate in the northern hemisphere is influenced by oceanic–atmospheric modes of variability occurring on interdecadal (Mantua et al., 1997), multidecadal (Delworth and Mann, 2000; Sutton and Hodson, 2005), decadal (Mehta et al., 2000), and interannual (Wang and Fu, 2000) timescales. The Pacific Decadal Oscillation (PDO) is an oceanic–atmospheric phenomenon associated with the quasi-periodic (25–50 years) warming (PDOw) or cooling (PDOc) of the eastern North Pacific Ocean poleward of 20° north (Mantua et al., 1997; Mantua and Hare, 2002). The Atlantic Multidecadal Oscillation (AMO) represents below (AMOc) and above (AMOw) normal sea surface temperature (SST) across the North Atlantic from 0° to 70°N latitude (Enfield et al., 2001), with a characteristic periodicity of around 65–80 years (Gray et al., 2004; Kerr, 2000). The North Atlantic Oscillation (NAO) is associated with a meridional oscillation in sea level pressure (SLP) between Iceland and the Azores (Hurrell and Van Loon, 1997). The NAO has displayed quasi-biennial and quasi-decadal negative (NAOn) and positive (NAOp) phases since the late 1800s (Hurrell and Van Loon, 1997) and its behavior is generally referred to as decadal. The El Niño Southern Oscillation (ENSO) refers to the quasi-periodic (2–7 years) warming or cooling of the eastern equatorial Pacific Ocean (Bjerknes, 1969; Godfrey, 1975; Lighthill, 1969; McCreary, 1976; Walker, 1924) with the shift of southeast trades over the central and western Pacific (Krueger and Winston, 1975; McPhaden, 1999; Wyrtki, 1975). The warm phase of ENSO (ENSOw) is referred to as El Niño; the cool phase (ENSOc) is referred to as La Niña; and the phase between them is referred to as neutral (ENSOn). The ENSO phases are identified using the SST anomaly from the NIÑO3.4 region (5°S–5°N and 120°W–170°W) in the equatorial Pacific Ocean.

Studies in the continental US have shown the relationship between individual oceanic–atmospheric modes of variability and the hydrology and meteorology of the northcentral Gulf of Mexico (nGOM). During PDOw, AMOc, NAOp, or ENSOw years, a number of stations showed higher annual streamflow medians than during PDOc, AMOw, NAOn, or ENSOc years (Tootle et al., 2005). During PDOw years, below normal drought frequency (McCabe et al., 2004) and a relationship between prior year (spring–summer) warming of the northeast Pacific and the high annual (October–September) streamflows were found (Tootle and Piechota, 2006). While the warming of the tropical north Atlantic

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was associated with low annual rainfall (Enfield, 1996), the warming of the north and east Atlantic was linked to low spring–summer streamflows during AMOc years (Tootle and Piechota, 2006). The ENSOw phase was related to below average mean winter SLP (Gershunov and Barnett, 1998b), high annual rainfall (Enfield, 1996), and frequent heavy winter rainfall events accompanied by cooler and less frequent extreme warm temperatures (Gershunov and Barnett, 1998a). Drought frequency was below normal during PDOw/AMOc phase and above normal during the PDOc/AMOw phase (McCabe et al., 2004). The phases of PDO and AMO appear to modulate the ENSO-related hydrology and meteorology. Mean winter SLP was below average during the PDOw/ENSOw phase and above average during the PDOw/ENSOc phase (Gershunov and Barnett, 1998b). During AMOc phase, the NINO-3.4 SSTA index (December–February) was positively related to January–March rainfall (Enfield et al., 2001). Streamflow median was significantly higher during the AMOc/ENSOc than during the AMOw/ENSOc phases (Tootle et al., 2005).

The present study investigates flows of the major rivers in the nGOM (Fig. 1) in response to the influence of one or more of the four oceanic–atmospheric modes of variability: PDO, AMO, NAO, and ENSO.

2. Data and methods

Major data sets used to establish the relationships between oceanic–atmospheric modes of variability from the Pacific and Atlantic Oceans and nGOM river flows are described in Table 1.

2.1. River flows

The Mississippi River flow data extended from 1931 to 1999 at Vicksburg, Mississippi, USA, and from 1961 to 2004 at Talbert Landing, Mississippi, USA. For years in which river flow data were available at both stations, a Pearson Correlation test was conducted to determine the relationship between monthly flows. Flows were highly correlated ($r = 0.978$, $p < 0.0001$) between the two stations. To determine river flow at Vicksburg from the missing period

Table 1
Periods and sources of the oceanic–atmospheric modes of variability and river flows used in data analysis. PDO = Pacific Decadal Oscillation, AMO = Atlantic Multidecadal Oscillation, NAO = North Atlantic Oscillation, ENSO = El Niño Southern Oscillation, JISAO = Joint Institute for the Study of the Atmosphere and Ocean, NOAA = National Oceanic and Atmospheric Administration, ESRL = Earth System Research Laboratory, CDC = Climate Diagnostics Center, USGS = US Geological Survey, NWIS = National Water Information System, USACE = US Army Corps of Engineers.

Parameter	Period	Source
PDO, °C	1948–2004	JISAO (2007)
AMO, °C		NOAA-CDC (2007)
NAO, hPa	1950–2004	NOAA-ESRL (2007a)
ENSO (NINO3.4 index), °C		NOAA-ESRL (2007b)
Mississippi River flow, cm s		USGS-NWIS (2007a), USACE (2007a)
Pascagoula River flow, cm s		USGS-NWIS (2007b)
Pearl River flow, cm s		USGS-NWIS (2007c)
Atchafalaya River flow, cm s		USACE (2007b)

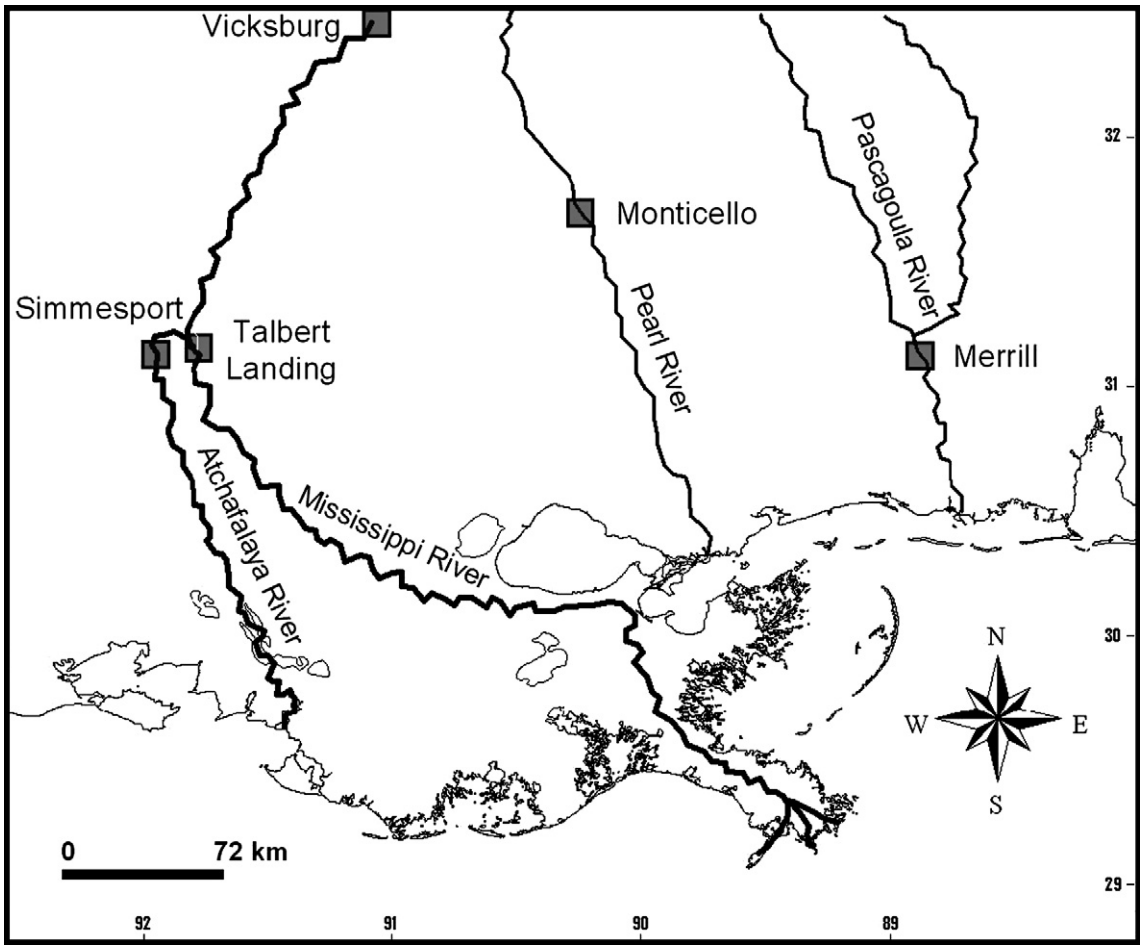

Fig. 1. River flow gaging stations in coastal Louisiana and Mississippi.