Seasonal effects of the Southern Oscillation and Bermuda High on freshwater delivery to the central Georgia coast

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Abstract

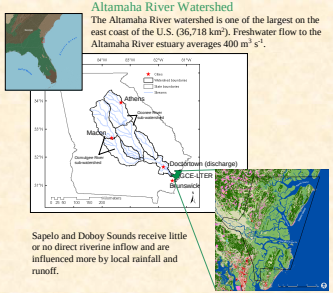
Freshwater delivery to the central Georgia coast is alternately correlated with the Bermuda High Index (BHI) and the El Niño/Southern Oscillation Index (SOI), but only in a limited way with the North Atlantic Oscillation Index (NAOI). The BHI describes the east-west position of the southern pole of the NAO, which influences southeastern U.S.A. weather more than the north-south NAO. Three-month standardized anomalies of Altamaha River discharge and precipitation at two stations in its watershed and one on the coast were compared with each other and the three climate indices. In winter, precipitation is correlated more with winter SOI than with other climate indices, but precipitation is only weakly correlated with the previous winter's SOI during other seasons. In spring, the BHI develops a strong correlation with coastal precipitation. This influence weakens somewhat during summer and fall but spreads to the Altamaha watershed. Fall precipitation is correlated with the spring NAOI as well as the fall BHI. At times, climate signals explain as much as 29% of the variability in local data. Evaluating the relative strengths of these climate signals will aid in estimating the potential effects of climate changes in eastern Georgia.

Georgia Coastal Ecosystems Long-Term Ecological Research (GCE-LTER) Project

The project study site, located on the Georgia coast in the vicinity of Sapelo Island, encompasses the lower Altamaha River estuary, Doboy Sound, and Sapelo Sound. The first six years of the project have focused on the differences and interactions among these three estuaries, especially with regard to the effects of differences in freshwater inputs.

Altamaha River Watershed

The Altamaha River watershed is one of the largest on the east coast of the U.S. (36,718 km²). Freshwater flow to the Altamaha River estuary averages 400 $m^3 s^{-1}$.



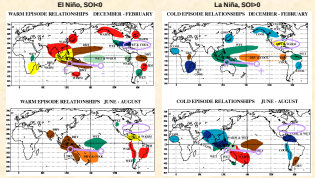
Sapelo and Doboy Sounds receive little or no direct riverine inflow and are influenced more by local rainfall and runoff.

Purpose of Study

The El Niño/Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), and Bermuda High (BH) may be expected to affect the GCE study site by different pathways. ENSO effects would likely act primarily via weather fronts from the west, reaching the Altamaha River watershed before reaching the GCE site itself. The NAO would likely have a more direct effect from the east and may be expected to influence coastal precipitation more than inland precipitation. However, the GCE study site is not considered to be in the higher correlation regions for indices of these climate signals. We also considered the potential effects of the southern pole of the NAO, the Bermuda High, as it moves toward and away from the Georgia coast. **The purpose of this study is to determine if these three large-scale climate signals can be detected in observational data about freshwater delivery to the GCE site and surrounding area.** For this purpose, we considered two stations in the upper (Athens) and middle (Macon) Altamaha watershed and one on the coast (Brunswick) that had long-term precipitation records, and the most downstream USGS discharge gaging station (Doctortown) on the main Altamaha River channel.

El Niño / Southern Oscillation (ENSO)

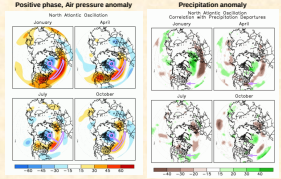
The atmospheric component of this well-known pattern, the Southern Oscillation, is reflected in air pressure differences between the western and eastern tropical Pacific. The Southern Oscillation Index (**SOI**), one measure of this pattern, is usually calculated based on the air pressure anomaly between Tahiti and Darwin, Australia and corresponds well with changes in eastern tropical Pacific Ocean temperatures. We used raw pressure data from the Australian Bureau of Meteorology to construct an SOI in a manner consistent with the normalization of the other data that were analyzed.



Maps from NOAA, National Weather Service, National Centers for Environmental Prediction, Climate Prediction Center web site.

North Atlantic Oscillation Index (NAO/NAOI)

This prominent large-scale pattern primarily describes north-south fluctuations in air pressure between the higher and central latitudes of the North Atlantic Ocean, with one pole over Greenland and the other spanning the central North Atlantic between latitudes 35°N and 40°N. (See the Bermuda High, below.) The NAO is associated with changes in the intensity and location of the North Atlantic jet stream, storm tracks, and patterns of temperature and precipitation from eastern North America to western and central Europe. Index data from the National Center for Atmospheric Research were used.



Maps from NOAA, National Weather Service, National Centers for Environmental Prediction, Climate Prediction Center web site.

Above-normal temperature is associated with periods of below-normal precipitation, and vice versa.

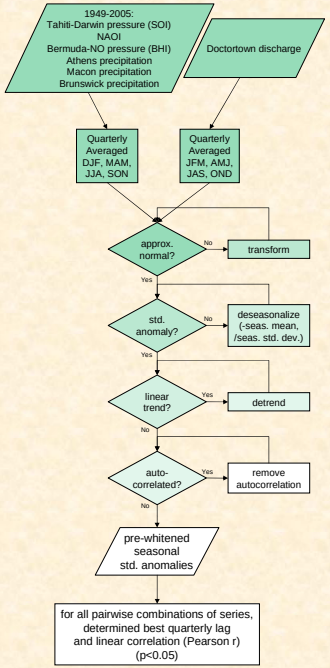
Bermuda High Index (BHI)

The BHI describes the east-west position of the southern pole of the NAO, which has more of an influence on the southeastern U.S.A. weather than does the north-south NAO. When the Bermuda High extends westward over the continent, hurricanes and frontal weather systems from the west tend to track around the high pressure, resulting in decreased rainfall in eastern Georgia. The BHI was constructed as the normalized pressure difference between Bermuda and New Orleans, using the same NCAR station data as Katz et al. (2003).

Images from NASA/Goddard Space Flight Center Conceptual Images Lab; map from National Geographic.

Data Treatment

Previous analysis of monthly data (Sheldon and Burd, unpubl.) showed broad correlation peaks at multiple adjacent lags between some variables, suggesting that examining the data at a quarterly scale might combine lags spread over several months and reduce the noise in the data (Trenberth 1984). Multiple optimum lag times also suggested that there could be inter-seasonal differences in the connection patterns, so we examined quarterly subsets of the data independently. Doctortown discharge was aggregated into quarters lagged one month behind the quarters used for other data to allow for the approximately one month lag for precipitation to be reflected at the discharge gauge.

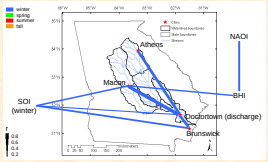


Results

Linear correlations among the pre-whitened series are presented on the quarterly maps, below. Presence of a line indicates a significant correlation ($p<0.05$). Color of the line indicates the season of the explanatory variable, which may be lagged relative to the dependent variable. Width of the line indicates the strength of the linear correlation (Pearson r).

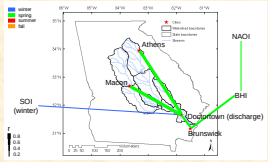
Precipitation at all three stations (Athens, Macon, Brunswick) is correlated in all seasons except summer, when there are no relationships among any of those stations. These correlations are not shown on the maps, to improve clarity. As expected, Altamaha River discharge at Doctortown is significantly correlated with precipitation at one or more of the watershed stations (Athens, Macon).

Winter (Dec, Jan, Feb)



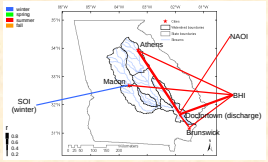
In winter, precipitation is correlated more with winter SOI than with other climate indices. Other variables are only weakly correlated with the previous winter's SOI during other seasons.

Spring (Mar, Apr, May)



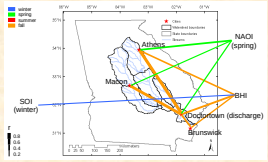
In spring, the BHI develops a strong correlation with coastal precipitation.

Summer (Jun, Jul, Aug)



The influence of the BHI on the coast weakens during summer and fall but spreads to the Altamaha watershed.
Spring and summer are the only seasons for which the NAOI explains any of the precipitation and discharge data.

Fall (Sep, Oct, Nov)



Fall precipitation is correlated with the spring NAOI as well as the fall BHI.

Conclusions

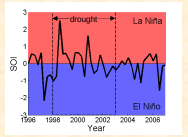
- Analyzing data independently by seasons was crucial to finding these links because the optimum lags were different for different seasons. Lagging all the data uniformly would have led to erroneous conclusions.
- River discharge is more strongly correlated with central GA (Macon) than with NE GA (Athens) precipitation during winter and spring, but the pattern reverses during summer and fall, in spite of the fact that the Oconee and Ocmulgee sub-watersheds are nearly identical in size.
- Freshwater delivery to the central Georgia coast is alternately correlated with the BHI and the SOI in different seasons, but only in a limited way with the NAOI.
- At times, climate signals explain as much as 29% of the variability in local data (BHI and summer discharge).

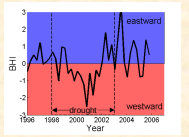
Acknowledgments

We thank Sylvia Schaefer and John Carpenter for providing maps of the Altamaha River watershed and the GCE study area, Merryl Alber for marsh dieback information and pictures and discussions related to these analyses, and Mark Ohman for discussions related to these analyses. This work was funded by the National Science Foundation through the Georgia Coastal Ecosystems LTER project (NSF Awards OCE 9982133 and OCE 0620959).

Consequences for GCE-LTER

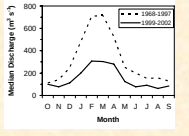
- Long-term trends:
  - Athens precipitation decreased over this time period.
  - Slight increasing trend in NAOI suggests increased fall precipitation.
  - Slight downward trend in SOI not significant for quarterly data over this time period, but suggests increased winter precipitation.
  - No overall trend in BHI.
- But short-term trends in 1998-2002 were consistent with drought:





The 1998-2002 drought showed some potential effects of climate change that might act through freshwater delivery patterns:

- Freshwater inflow decreased
  - Salinity increased (Amft, Blanton)
  - Marsh vegetation changed spatial distribution (White, Alber)
  - Spartina production changed (Pennings)
  - Macrofauna populations changed size and/or spatial distribution (Bishop, Alber, Wiegert)
  - DON:DIN ratios changed (Joye, Hollibaugh)
  - Marsh surface elevation changed (Craft)
- Links between drought and marsh dieback
  - 2001-2002
  - 40 sites reported (1,000 acres)
  - 2004 workshop consensus: Climate-induced, with drought as driving factor



Researchers unravel a marsh dieback mystery.
Drought probably killed 1,000 acres of Georgia salt marsh, but it wasn't working alone.
Mary Landers
Savannah Morning News

Future Work

- The BHI is not routinely calculated and made widely available, but it affects weather in this region. More investigation and reporting of the BHI and its effects is needed.
- Evaluating the relative strengths of these climate signals will aid in estimating the potential effects of climate changes in eastern Georgia.
- We are actively seeking links to other east coast sites.

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