Medieval Warm Period, Little Ice Age and 20th Century Temperature Variability from Chesapeake Bay

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We present paleoclimate evidence for rapid (<100 yr) shifts of ~2-4ºC in Chesapeake Bay (CB) temperature ~2100, 1600, 950, 650, 400 and 150 years before present (yr BP) reconstructed from magnesium/calcium (Mg/Ca) paleothermometry. These include large temperature excursions during the Little Ice Age (~1400-1900 AD) and the Medieval Warm Period (~800-1300 AD) possibly related to changes in the strength of North Atlantic thermohaline circulation (THC). Evidence is presented for a long period of sustained regional and North Atlantic-wide warmth with low-amplitude temperature variability between ~450 and 1000 AD. In addition to centennial-scale temperature shifts, the existence of numerous temperature maxima between 2200 and 250 yr BP (average ~70 years) suggests that multi-decadal processes typical of the North Atlantic Oscillation (NAO) are an inherent feature of late Holocene climate. However, late 19th and 20th century temperature extremes in Chesapeake Bay associated with NAO climate variability exceeded those of the prior 2000 years , including the interval 450-1000 AD, by 2-3°C, suggesting anomalous recent behavior of the climate system.

Statement of Problem

Eastern U.S. estuaries have common environmental problems: degraded water quality, loss of wetlands and riparian zones, sea-level rise, sedimentation, coastal erosion, declining fish and wildlife populations, loss of sub-aquatic vegetation (SAV) and increased algal blooms. Population growth, urban sprawl, intensified agriculture, and climate change exacerbate these. Mitigation of estuarine issues requires understanding of ecological, physical, and chemical changes due to climate variability and anthropogenic factors, the influence of regional geological framework, and impacts of land-use changes in watersheds and coastal zones. This project provides a scientific basis for resource managers and other policy-makers to address these issues. The initial work was in Chesapeake Bay, and eventually it will shift to other mid-Atlantic estuaries (possibly including, but not limited to, Albemarle and Pamlico Sounds, Chicoteague, and Delaware Bay) and apply techniques developed in Chesapeake Bay to issues in those estuaries.

Objectives

- Integrate studies on a wide range of time scales (subannual to millennial) to:
    - Establish the geologic framework for the estuarine system and its watershed.
    - Evaluate impacts of land-use changes on estuarine ecosystems through comparison of baseline (pre-Colonial) and post-Colonial rates, volumes, and extent of sediment/nutrient erosion, transport, and deposition.
    - Evaluate ecosystem response to past climate changes. The impacts of past and future climate change must be incorporated into any long-term management strategies to achieve sustainable goals. For example, increased precipitation associated with broad-scale climatic change will increase sediment and nutrient influx to estuaries, requiring changes to best management practices designed for present precipitation levels.
    - Identify modern centers of deposition and sediment sources (biogenic, shoreline erosion, oceanic).
    - Convey information to resource managers and policy-makers to develop restoration and preservation strategies and make land-use decisions concerning environmental change.

Strategy

- Examine past records of physical, biological, and landscape changes in response to climatic and human-mediated forces;
- Monitor some of these changes today, including emerging human health risks, and compare observations of modern processes with the records of past changes;
- Integrate the knowledge gained from specific project tasks to forecast future ecologic response to land-use changes under likely climatic and demographic conditions for time scales relevant to resource management decisions.

Geologic Framework of Sediment Sourcing, Transport, and Deposition in Chesapeake Bay

An understanding of the geologic framework of estuaries and their watersheds is needed to interpret sediment and nutrient cycling, groundwater recharge and discharge zones, and availability of certain resources.

This task documents the geologic framework of the estuary and watershed by:

- Mapping surficial deposits and erosional features in an allostratigraphic framework, and interpreting Holocene history and geology of estuaries in terms of sea level rise, coastal morphology, and antecedant geologic framework.

- Producing geologic maps of tidal tributaries showing deposits and erosional features as a continuum from drowned, sub-bottom deposits to upland deposits and weathered surfaces. This allows spatial analysis of sediment and nutrient cycling, ground-water recharge and discharge zones, and availability of certain resources.

- Determining the contribution of ongoing bluff erosion in selected parts of Chesapeake Bay. This is intended to furnish finite estimates of the volumes of sediment presently held on beaches, carried to the nearshore zone, and carried offshore as suspended sediment. In addition, it seeks to better understand the processes of bluff retreat, landsliding, and slope stabilization in the mid-Chesapeake Bay region.

For more information:

- Geologic history of Popes Creek, Virginia
- Geologic controls on turbidity and iron oxide precipitation, Nassawango Creek, Maryland
- Bluff erosion- Calvert Cliffs, Maryland

Impacts of Land-Use Changes on Chesapeake Bay Sediment Sources, Sinks and Oxygen

Chesapeake Bay Ecosystem History And Response to Land-Use Change in the Chesapeake Bay Watershed

The Chesapeake Bay Program has identified excess sediment in the bay as a major factor affecting water clarity in the bay. Therefore, sediment reduction strategies are being developed to improve water clarity, habitats for submerged aquatic vegetation, and other living resources. Development of sustainable strategies requires an understanding of patterns of sedimentation in the bay and tributaries over time scales ranging from annual to centennial, as well as the impact of altered sediment patterns on biotic components (benthos, phytoplankton, submerged aquatic vegetation). Sedimentation patterns are affected by changes in land cover and by natural climatic processes (i.e., precipitation, sea-level rise); a comprehensive assessment of sediment flux in the bay and its tributaries should include sites with very high and very low sediment influx. Because the Chesapeake Bay Program is committed to reducing sediment input to the bay, an understanding of the relative influences of land cover change and climate variability on estuarine sedimentation is critical to develop realistic reduction goals.

Task objectives include:

- Evaluate temporal and spatial patterns of sediment accumulation in critical regions of Chesapeake Bay over decadal to centennial time scales.

- Assess the relative roles of land-cover changes and natural climate variability in altering sediment supply, nutrient influx, and other environmental parameters.

Impacts of Past and Future Climate Variability on Chesapeake Bay Salinity, Temperature, Sediment and Biota

Chesapeake Bay Ecosystem History And Response to Past Climate Variability

The geosciences play a key role in environmental reconstruction by providing an understanding of the long-term history and development of ecosystems as well as the impacts of past (and future) climate change. Incorporation of such information into restoration planning is necessary to achieve sustainable results. For example, increased precipitation, associated with broad-scale climatic change, would increase sediment and nutrient influx to estuaries and require changes to management practices designed for present precipitation levels. This task focuses on ecosystem response (terrestrial and estuarine components) and decadal- to millennial-scale patterns of climatic changes (precipitation, temperature, salinity) to document the natural variability of the system. Such data are critical for prediction of ecosystem response to projected climatic changes.

The overall goal of this task is to develop a long-term (decadal- to millennial-scale) Holocene and late glacial paleoclimate record using estuarine sediments that contain proxies of precipitation (which influences salinity via stream discharge), water temperature, and atmospheric temperature.

Objectives of the task include:

- Evaluate natural variability in precipitation, salinity, temperature, and sedimentation over decadal to millennial time scales.
- Establish the baseline variability of climatic variability for comparison with post-industrial variability to search for anthropogenic influence.
- Document impact of abrupt climate changes such as the Medieval Warm Period, the Little Ice Age, the 8.2 ka cooling and the Younger Dryas on the estuarine ecosystem including temperature and salinity.

Sediment sources and rate of delivery to the estuary catchments within Chesapeake Bay

Patterns of Modern Sediment Transport in Chesapeake Bay

To develop sediment-reduction strategies and sustainable water-clarity standards for Chesapeake Bay, it is necessary to understand sediment sources and sinks in component parts of the system. An important aspect of the sediment regime is the rate at which sediment is transported and where it is deposited. This information will be used to interpret results from down-core analyses and may be useful in validation of sediment-transport models.

Objectives of the task include:

- Identify modern depocenters in the bay and tributaries through mapping of the short-lived radioisotopes ^{7}Be and ^{137}Cs in surface sediments.

- Document temporal changes in sediment source using analysis of the distribution of ^{137}Cs and ^{210}Pb in long (up to 5 meters) sediment cores.

- Establish a record of erosion and deposition of short-lived radioisotopes within the watershed over the last century.

Remote sensing of water clarity and sediment dynamics in Chesapeake Bay

Time Series Maps of Total Suspended Sediment and Chlorophyll in Chesapeake Bay 1997 to Present

An issue of particular concern in Chesapeake Bay is optical water quality. Over the past three decades, submerged aquatic vegetation (SAV) in the Bay has declined dramatically, and poor water clarity (hence low light availability) has been targeted as a primary cause. Since the 1980's, a great deal of attention has been devoted to nutrient loading and its impact on water clarity. Only in more recent years have sediments been recognized as a significant additional consideration. At present, many fundamental questions about sedimentary processes in Chesapeake Bay and its tributaries remain unanswered.

In addition, the need for frequent, high-resolution monitoring data is becoming increasingly apparent in ongoing Chesapeake Bay Program (CBP) restoration efforts. Of particular interest would be information about the new chlorophyll-a, dissolved oxygen (DO) and water clarity criteria that have been established for the Bay. CBP currently maintains a network of more than 100 water-quality monitoring stations, but this field sampling program cannot adequately resolve the details of spatial and temporal variability within the Bay.

Satellite imagery can provide frequent, bay-wide views of optical parameters related to water clarity and suspended sediments, but coastal remote sensing presently offers methodological challenges as well as potential promise.

The overall goal of this task is to use multi-platform remote sensing coupled with optical modelling and ancillary meteorological, water quality, and hydrologic data to better understand the sources of Chesapeake Bay suspended sediments, and to examine the consequences of suspended sediments for water quality and benthic habitats in the Chesapeake Bay.

The objectives of this task are to:

- Describe the spatial and temporal variability of water quality parameters related to optical water quality in Chesapeake Bay.
- Investigate the causes of suspended sediment plumes that are observed within the Chesapeake Bay.
- Undertake research to improve capabilities to retrieve information about suspended sediments and other light-attenuating substances from optical satellite observations.
- Characterize variable water clarity in Chesapeake Bay and its effect on the benthic light environment.