Some remarks on Ocean Currents and Climate

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Since the time of Ben Franklin, Americans have recognized the influence of ocean currents on climate. During the American Revolution, Franklin is reputed to have proposed the impractical but scientifically tenable idea of diverting the flow of the Gulf Stream to freeze the British. In the following 230 years, our knowledge of the interplay between ocean currents and climate has grown exponentially.

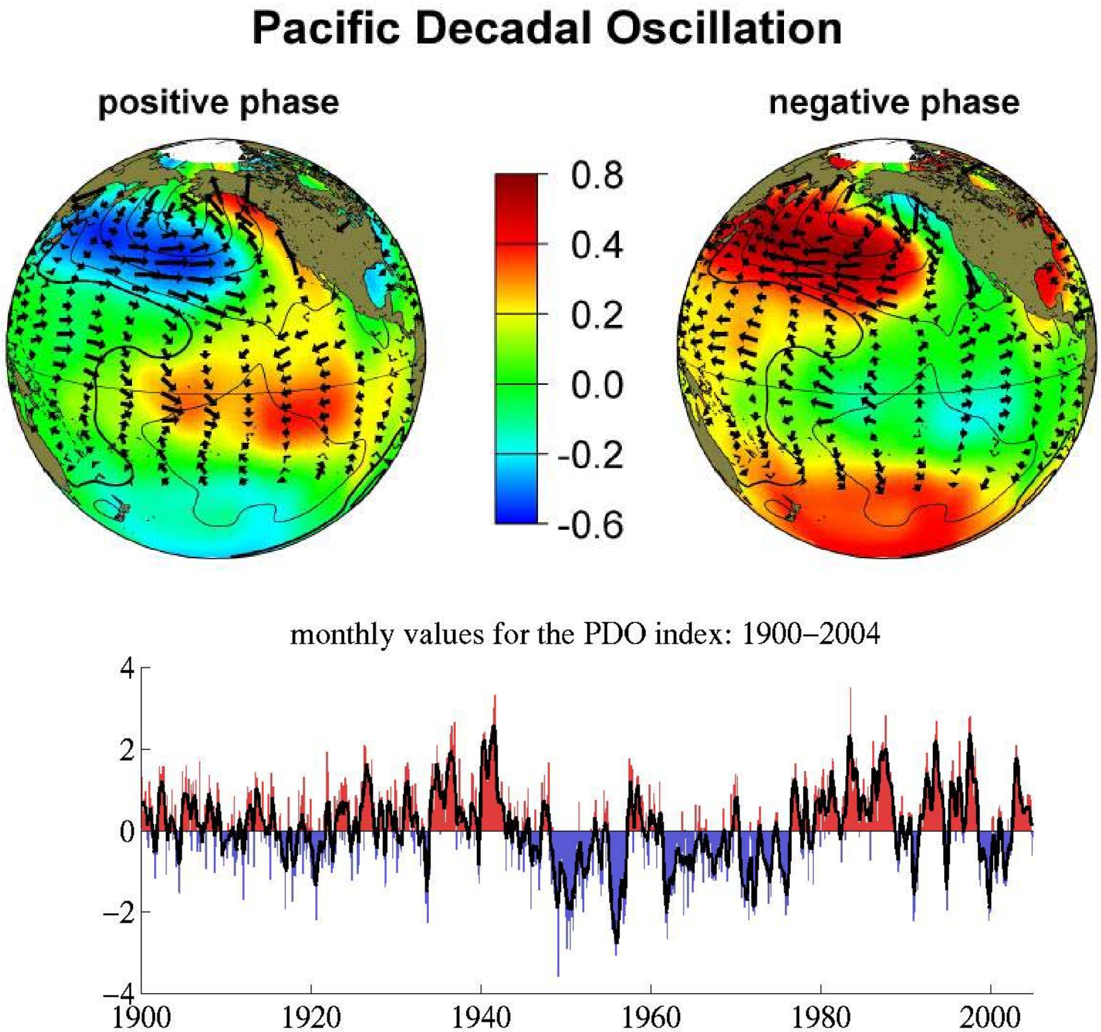
We know, for example, that ocean currents circulate water around the entire globe, moving both energy and moisture. We know these currents move at hugely varying rates, some at a few kilometers per hour, others at a few kilometers per year. We also know that current-related phenomena far from our shores can have profound affects within our borders, from droughts to floods, and extremes of heat and cold.

There are a few principal ocean currents affecting the U.S. climate. Perhaps best known is the abrupt end of the coastal upwelling currents off Peru which, when it occurs, usually happens near Christmas, hence the name El Niño. During El Niño, warm water leaves the western side of the Equatorial Pacific Ocean and heads east. The opposite phase, in which cool waters surface in the eastern Pacific, has been called La Niña. Both El Niño and La Niña are understood well enough to be forecast with reasonable accuracy. El Niño profoundly affects fisheries in the eastern Pacific and increases wintertime temperature and rainfall in the southwestern and southeastern U.S. It is also associated with reduced hurricane intensity in the tropical Atlantic. The typical cycle of this phenomenon is 2 to 5 years.

A phenomenon operating at a much longer time scale (20 to30 years), is the Pacific Decadal Oscillation (PDO). In this phenomenon, what "oscillates" is the strength and location of the surface low-pressure system south of the Aleutians. When this pressure is *lower* than usual,

- stronger westerlies cool ocean surface waters in the central Pacific,
- a gyre of subarctic water expands
- the strong, wind-driven current, the Kuroshio, takes a more southerly course east of Japan
- and sea temperatures are warmer off the U.S. west coast and in the Gulf of Alaska.

During this positive phase, there are significantly larger catches of salmon and pollock in the Northeast Pacific. It is also associated with increased precipitation and warmer winters in the U.S. Southwest and Southeast. Unlike El Niño, the dynamics of the PDO are not well understood, and therefore predictions are made only on the basis of past statistics, not present physics.



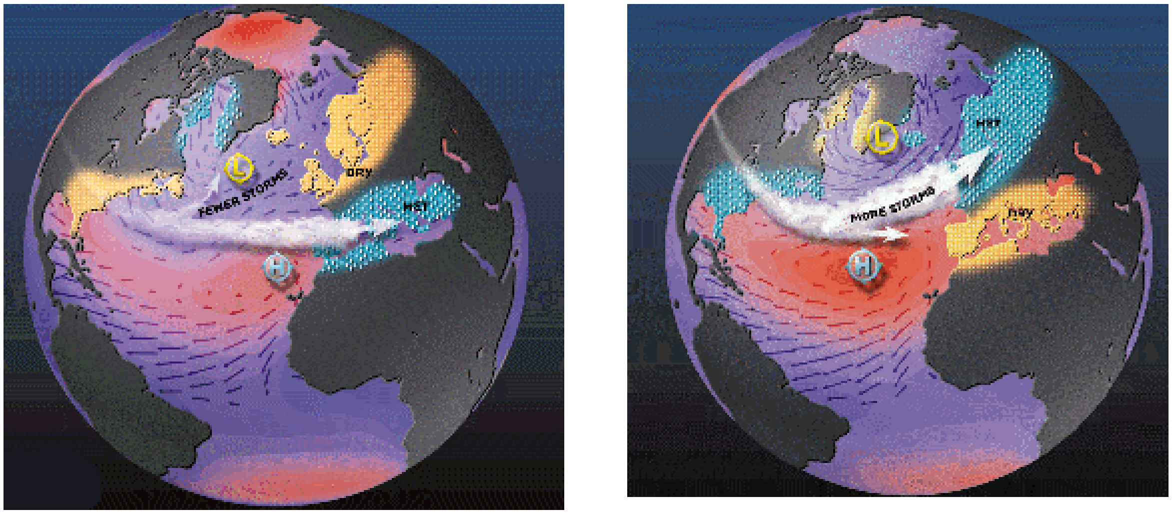
The two phases of the PDO (Upper panels) indicate the sea surface temperature anomalies (SST, colors), surface winds (arrows) and atmospheric pressure (solid lines). The 100+ year time series, based on the SST pattern, shows (lower panel) a shorter time scale in the early period, with major periods in one phase of 20-30 years beginning in about 1920.

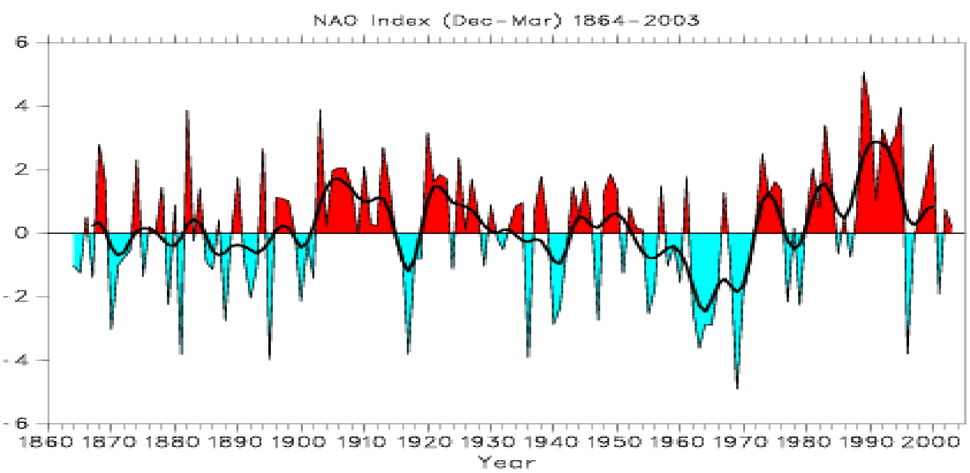
Climate variability in the North Atlantic is influenced largely by the North Atlantic Oscillation (NAO), which involves changes in the low pressure center near Iceland and the high pressure near the Azores. When the phase of the NAO is positive both pressure centers are more intense, we encounter both stronger westerlies at mid-latitudes and trade winds in the tropics. The shifting patterns of the NAO cause the mid-latitude storm track to shift north/south: high NAO to the north, low NAO to the south. A negative NAO and a more southerly storm track, such as what we have had the past two winters, leads to a

colder, snowier winter in the Midwest and Northeast US, colder offshore waters, and a more southerly track of the Gulf Stream & a colder Britain, recalling “Dr. Franklin”.

North Atlantic Oscillation [NAO]

negative phase   positive phase

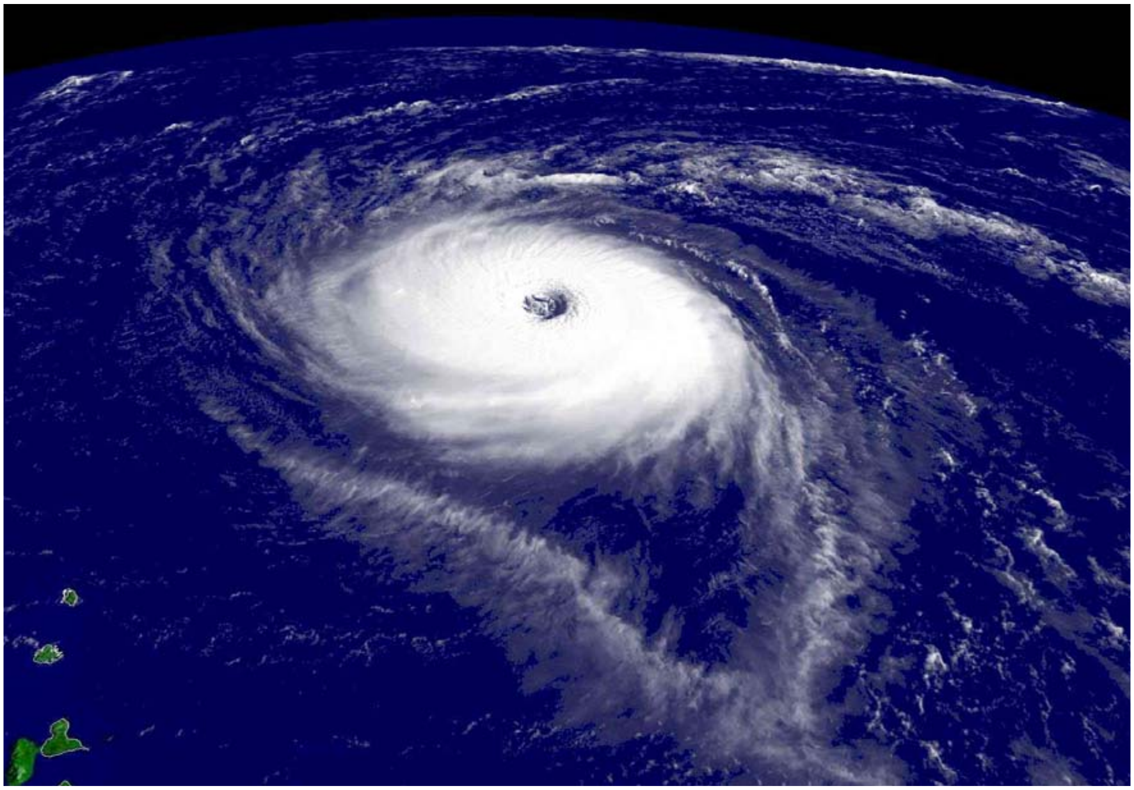




The negative NAO phase is one with a southerly storm track, weaker trades, more southerly Gulf Stream path, colder SSTs near the eastern US coast, warmer SSTs and increased COD production near the Grand Banks, with the opposite effects in the positive phase. On multi-decadal timescales, the NAO looks quite similar to the PDO, suggesting some common cause.

The time scale for the NAO is poorly defined. In the early part of the instrumental record, during the late 19th century, it was quasi-biennial, such that each cold winter in the Northeast US was followed by a warm one and visa versa. However, in recent decades, the time scale is long, about a decade. As with the PDO, the reasons for a persistent time scale over several years or decades is unknown, and the role played by the ocean in any possible coupling with the overlying atmosphere is also unknown. Today our ability to

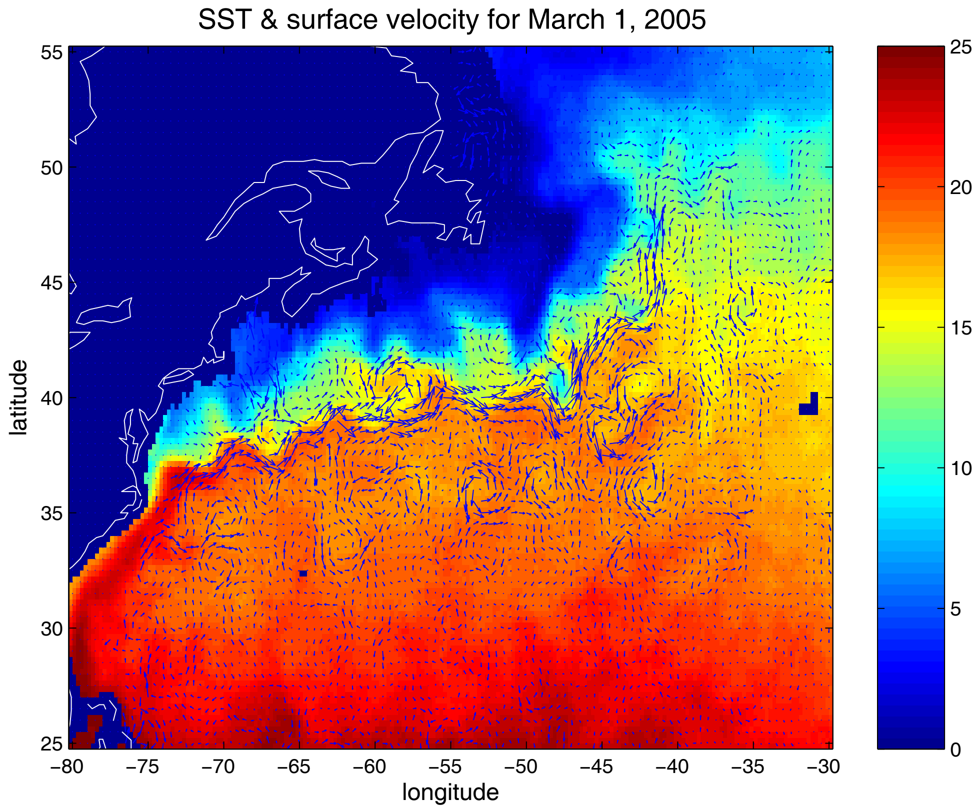
forecast future climate changes due to the NAO is low, and based only on *ad hoc* statistical methods, usually involving sea surface temperature.



Hurricane Isabel, September 2003, approaches the Bahamas. Isabel, a top-rated category 5 hurricane, weakened before its landfall in N. Carolina & Chesapeake Bay.

During the negative phase of the NAO, the southeast trades are reduced and waters north of the Equator get warmer. This causes the Inter-Tropical Convergence Zone –a region of intense rainfall–to shift northward in the Atlantic. This shift leads to increased rainfall in the northern tropics, and reduced precipitation to the south of the Equator. During this phase, hurricanes tend to become more intense, and track more to the west, instead of re-curving up into the North Atlantic Ocean. This results in more hurricanes making landfall in the U.S. Southeast and Gulf of Mexico. Colder NAO winters are therefore generally followed by increased chance of hurricanes in the eastern and southeastern U.S.

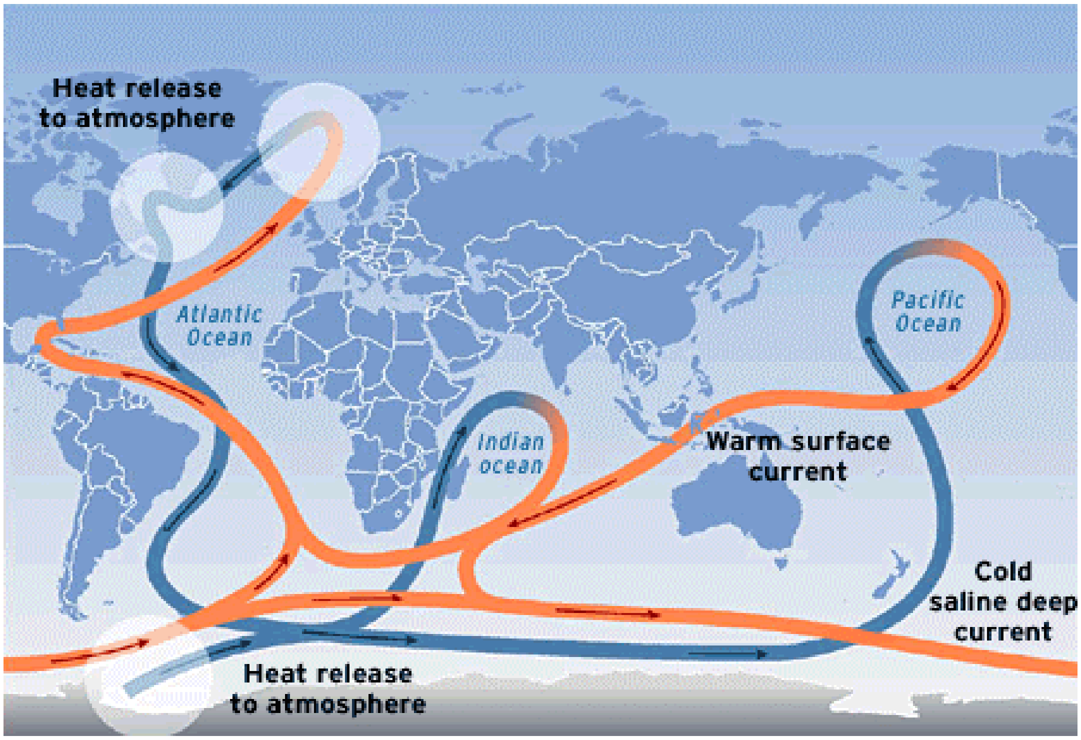
Satellite imagery can provide both broad and detailed views of major currents, like the Gulf Stream as it leaves the U.S. coast near Cape Hatteras. Yet our knowledge about changes before the satellite era must draw on progressively fewer, and eventually only proxy, data. Major ocean currents, like the Kuroshio in the Pacific and the Gulf Stream, transport huge amounts of heat poleward away from the tropics. They are thus important partners with the atmosphere in regulating earth's climate. And therefore, changes in theses currents may be expected to effect changes in our climate. While the Pacific Ocean is nearly twice the width of the Atlantic at latitudes where the Kuroshio and Gulf Stream



Satellite-based, microwave sensors are providing all weather views of both ocean currents (arrows) and sea surface temperature (SST, colors). Here is an image of the Gulf Stream and the surface (geostrophic) currents in the region where it leaves the coast near Cape Hatteras. The current map is based on 10 days of altimeter data, while the SST is from a single day.

are found, the Gulf Stream carries about 50% more heat northward than the Kuroshio. The reason for this is because cold, deep water sinks in the northern Atlantic, but not the northern Pacific. This deep water then flows towards the equator and to replace this, the surface flow of the Atlantic must be enhanced beyond what may be driven by the winds. This "overturning" circulation brings warm, near-surface water to the north and returns cold, deeper water to the south. This flow system transports heat poleward and accounts for the enhanced heat transport in the North Atlantic over the Pacific. This circulation, driven by pole to equator temperature and salinity differences and not the winds, is called the overturning circulation or popularly, the Great Ocean Conveyor.

The Gulf Stream wind-driven transport is augmented by this conveyor flow of approximately 15 million m^3/s, or about 50 times the net transport of the Amazon River. The heat carried by this circulation is about 0.7×10^{15}W, more than 1000 times the total capacity for electricity generation in the US in the year 2000.



Schematic of the Ocean Conveyor. Warm, surface currents are red, while cold, deep flows are blue. These currents are not part of the wind-driven system. Cold regions of sinking are shown in both the Antarctic and in the N. Atlantic.

Disruptions in this part of the ocean current system have been associated with major and—in the geologic scheme of things—rapid climate shifts of the past, such as the ice ages. Yet the role of ocean dynamics is only poorly known. In some instances, climate change may have preceded change of these flows; in other cases, it might have been instigated by changes in the ocean currents. Because of the large heat transport associated with this mode of the circulation, changes can have major climate consequences. We know that the conveyor is very sensitive to amounts of freshwater in the northern N. Atlantic: river runoff, melting of glaciers and multi-year sea ice, enhanced precipitation. We also know that one consequence of global warming is that all of these freshwater forcings are now occurring precisely where they can cause climate disruptions. Most projections of future climate change due to increasing greenhouse gases show the ocean conveyor decreasing in strength with less deep water forming in the N. Atlantic. Models also indicate that greenhouse gas forcing will alter not only the global mean temperatures and the hydrological cycle, but will affect the natural modes of climate variability such as El Niño, the Pacific Decadal Oscillation and the North Atlantic Oscillation.

With continued, critical federal support, we are working with international partners to build an ocean observing system capable of giving us a better knowledge of both the surface and subsurface changes in the ocean properties and currents, and to develop better models of the atmosphere, ocean, ice, and terrestrial systems necessary to uncover the processes needed for understanding, hence forecasting the regional structure, timing, rate, and severity of future climate change.