Predictability of phase shifts of the Atlantic Multidecadal Oscillation

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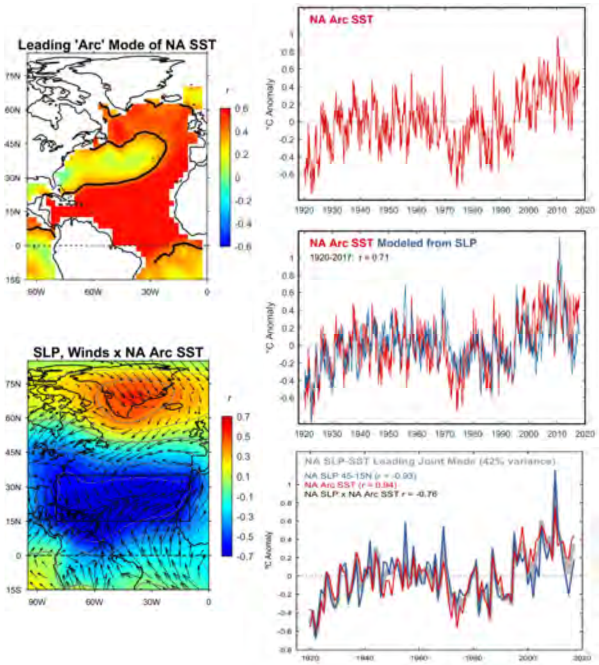
Abstract:

A shift from the current warm phase of the Atlantic Multidecadal Oscillation (AMO) would have substantial impacts for U.S. and European weather, and particularly for Atlantic hurricanes. Previous abrupt shifts in 1926, 1971 and 1995 share common precursors, suggesting predictability of major North Atlantic climate shifts. A new conceptual model of North Atlantic climate change is based on shifts between persistent stable states that are initiated as short-term sea surface temperature perturbations and maintained by ocean-atmosphere feedbacks for periods of multiple decades. Low-frequency climate changes occur through occasional pulses of upper-ocean heat uptake and release, rather than gradually, implying that interannual processes are intrinsic to low-frequency North Atlantic changes.



1) Coupled ocean-atmosphere variability and change over the North Atlantic from 1920 to 2017

The leading mode of North Atlantic SST variability is characterized by coherent anomalies within an 'Arc'-shaped pattern encompassing the tropics, the eastern margins, and the subpolar North Atlantic (upper left). The North Atlantic (NA) Arc SST index (upper right) represents 70% of the NA basin and correlates strongly with basin-mean SST anomalies (r = 0.98). The 1920-2017 monthly Arc index includes low-frequency variations represented by the Atlantic Multidecadal Oscillation (AMO) and net century-scale warming.

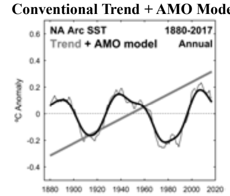
The monthly Arc index can be reproduced to a substantial degree (r = 0.71, middle right) by antecedent and concurrent anomalies of atmospheric sea-level pressure (SLP) from 45N to 15N. Coherent warming of the Arc is favored by *negative* SLP and *cyclonic* wind anomalies centered over the subtropical North Atlantic, which favor positive surface heat flux anomalies (largely involving the latent heat flux component) over the Arc domain.

Ocean-atmospheric variability and change is described by a primary coupled mode of basin-scale SLP and SST. Coupled changes include significant SLP declines that are consistent with dynamical atmospheric forcing of net century-scale warming, as well as the multidecadal SST changes described by the AMO.

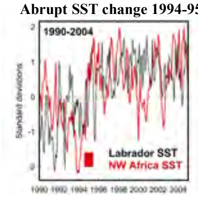
2) A new 'Coupled Shift Model' of low-frequency change:

Low-frequency changes in North Atlantic SST are conventionally described as separate (forced) trend and (internal) multidecadal components, i.e. the AMO (upper left). However, low-frequency SST changes display evidence of rapid shifts (upper right) that are highly obscured by the low-pass filtering that is intrinsic to the AMO's timescale-specific definition. Simultaneous SST shifts off Labrador and NW Africa in 1994-95 are consistent with direct atmospheric forcing, but inconsistent with a driving role for the Atlantic Meridional Overturning Circulation (AMOC), proposed by many studies as the primary source of the AMO. We propose an alternative 'Coupled Shift Model' of North Atlantic SST change, based on abrupt, step-like ocean-atmosphere changes that account for multidecadal variability and net warming (lower panels).

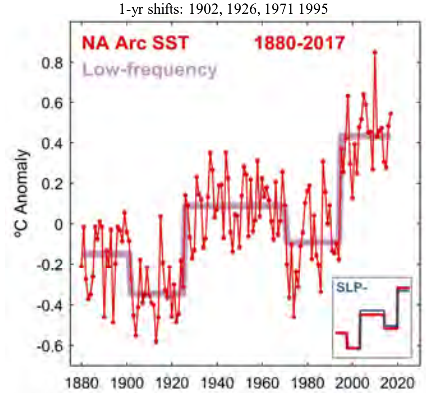
Conventional Trend + AMO Model



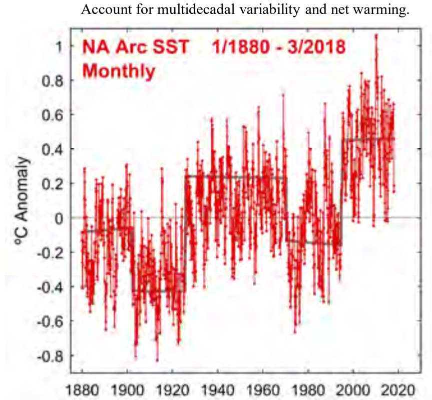
Abrupt SST change 1994-95



Coupled Shift Model 1880-2017 (annual)
1-yr shifts: 1902, 1926, 1971 1995



SST Shift Model 1880-2017 (monthly)
Shifts over windows of just 3 to 9 months
Account for multidecadal variability and net warming.

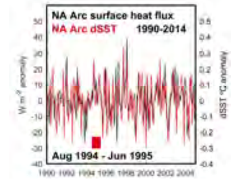


3) Physical causes and implications of the Shift Model

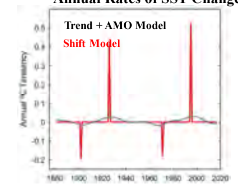
The abrupt, step-like North Atlantic warming of 1994-95 was generated largely by a transient, undamped heat pulse into the upper-ocean and followed by a new quasi-stable ocean-atmosphere state that persists to the near-present. In the Shift Model framework, low-frequency SST changes result from occasional perturbations followed by re-equilibration of the upper-ocean heat balance and little net warming or cooling over subsequent decades.

Such behavior suggests that short-term climate processes are intrinsic to mechanisms of low-frequency change. Coupled ocean-atmosphere changes have structures resembling known patterns of the extratropical North Atlantic Oscillation (NAO) and the tropical Atlantic Meridional Mode, as well as dynamical signatures of positive Wind-Evaporation-SST (WES) feedback and shortwave radiation (SW) feedbacks. These established feedback mechanisms tend to inhibit SST anomaly damping and promote climate persistence.

1994-95 Surface Heat Flux Pulse



Annual Rates of SST Change



4) Predictability of coupled North Atlantic climate shifts

Step-like changes imply the potential for short-term predictability of major North Atlantic climate shifts. We find consistent shift precursors in extreme SLP anomalies over Iceland and the Norwegian Sea. SST shifts are distinguished from other transient SST changes by extreme short-term changes off NW Africa, where positive tropical feedback processes are especially strongly manifest.

We propose that rapid, episodic North Atlantic climate changes might be monitored and anticipated through transient ocean-atmosphere anomalies and changes in the midlatitude, subtropical and tropical North Atlantic. New observations of coupled SLP-SST variability and change suggest that atmospheric dynamics are the direct cause of low-frequency SST change, and that multidecadal change and net warming result from a single phenomenon, rather than two separate processes, as implied by the current Trend + AMO paradigm.