An Anatomy of the 1960s Atlantic Cooling

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Introduction

During the 20th Century, Sea Surface Temperatures (SSTs) in the North Atlantic exhibited substantial decadal-scale variability. SSTs in the North Atlantic warmed rapidly 1920-1940 and cooled rapidly 1960-1980 (**Figure 1**). These observed changes in SST have been linked, in both observational and modelling studies, to substantial changes in climate e.g. changes in rainfall over the Sahel[1-3] and Nordeste Brazil region[4-7] , summertime North American Climate[8-10] , and Atlantic Hurricane Genesis [11-14].

There is as yet no consensus on the causes of the North Atlantic cooling event. Several potential explanations exist - the cooling may have followed as a consequence of a rapid influx of cold fresh water during this period (The Great Salinity Anomaly, GSA[15,16]), or as a result of a slow down in the Atlantic Meridional Overturning Circulation (AMOC). Alternatively, the cooling may have been driven by the changing external forcings during this time (**Figure 2**).

Here we examine the spatial evolution of the 1960s North Atlantic cooling and comment on possible causal mechanisms.

Forcings

There were significant variations in external climate forcings during this period (**Figure 2**). The eruption of Agung in 1963 ended a 30 year hiatus of volcanic activity. Stratospheric aerosols from large eruptions reduce downwelling surface shortwave radiation resulting in cooler global SSTs that persist for 1-2 years. Models suggest that such aerosols may also strengthen the northern polar vortex and modulate the AMOC.

Solar irradiance also declined after the late 1950s. Although these changes are small, some modelling studies suggest that these changes may result in larger regional impacts .

Finally, the post-1950s rise in anthropogenic Sulphur Dioxide (SO_2) emissions is likely to have had a significant cooling impact. Once in the atmosphere SO_2 oxidises to SO_4 and acts to reduce downwelling shortwave radiation, both via direct scattering and indirectly by increasing cloud reflectivity and

Datasets

SSTs were extracted from HadISST - the UK Met Office Hadley Centre's (UK MOHC) reduced-space optimal interpolation product. Mean Sea Level Pressures (MSLP) were extracted from the UK MOHC HadSLP2 dataset. - both downloaded from *http://www.metoffice.gov.uk/hadobs/*
CMIP5 Historical Forcings:
CO_2 equivalent and Anthropogenic SO_2 emissions: RCP Database (v.2.0.5).
Total Solar Irradiance: *http://sparcsolaris.geomar.de/cmip5.php*
Open Solar Flux:
http://www.eiscat.rl.ac.uk/Members/mike/Open\%20solar\%20flux\%20data/openflux1675to2010.txt.
Historical optical thickness changes due to stratospheric aerosols: *http://data.giss.nasa.gov/modelforce/strataer/*

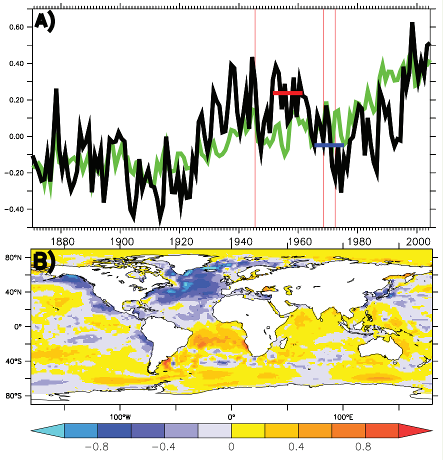

Figure 1: A) (Black) Atlantic Multidecadal Oscillation (AMO): Annual mean North Atlantic Sea Surface Temperatures (SSTs) (7.5:75W,0:60N). (green) as black but for area outside (7.5:75W,0:60N). Horizontal Red and Blue lines indicate periods used to form the composite in B). B) Mean SST difference (1951:1961) minus (1965:1975).

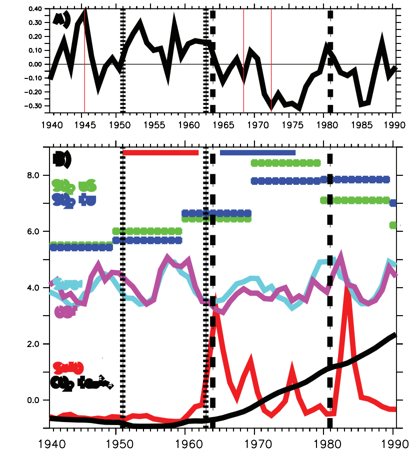

Figure 2: A) AMO (Oct-Jun mean. Units:K). B) External forcing timeseries for the 20th Century. Upper Blue/Green lines: Total Sulphur Dioxide emissions, mean over United States (Green - 65:160W,25:50N) and Europe (Blue - 20W:70E,25:70N). Middle Light Blue line: Total Solar Irradiance (TSI), (Magenta), Open Solar Flux.
Lower Red line: Global mean stratospheric aerosol optical thickness due to volcanic emissions. Black line: CO_2 equivalence concentrations - agregate of all anthropogenic forcings (greenhouse gases plus aerosols). All indices standardized and offset from zero. Vertical dotted lines: warm Atlantic - (1951:62) vertical dashed lines: cold Atlantic (1964:1980)

Evolution of the Cooling

The decadal pattern of Atlantic cooling is well-known, but the details of its development have been obscured by decadal averaging.
Here we examine successive five-year averages of October-June means to elucidate the stages involved in the cooling (**Figure 3**).

1964:68
The initial cooling is largely confined to the Nordic Seas and the Gulf Stream Extension. There are no notable atmospheric circulation anomalies during this period.

1968:72
Cool anomalies extend to cover much of the Sub Polar Gyre (SPG) and northern mid-latitudes. There is a hint of low MSLP anomalies over north Africa.

1972:76
The cool anomalies reach their maximum magnitude and spatial extent during this period. Cool anomalies extend from the SPG (17W:46W,54:63N), where they are maximum (-0.8 K), into the Tropical North Atlantic (TNA:14W:91W 9N:22N, -0.5K), and as far east as the Mediterranean (-0.5K). The western part of the Subtropical North Atlantic does not show a significant cooling, resulting in a Tripole, or Horseshoe pattern. Interestingly, this pattern is partly mirrored in the similar, but weaker, cooling pattern seen in the Pacific in Oct-Jun during this period.

There are significant anomalies in MSLP and these are reminiscent of the positive phase of the North Atlantic Oscillation (NAO): the anomalous pressure difference between the two lobes is nearly 4hPa. Significant low pressure anomalies are also seen over Western Africa and Eastern South America, extending over The Tropical Atlantic.

The emergence of widespread Atlantic cooling and significant atmospheric circulation anomalies at the same time suggests a link between the two. The MSLP anomalies are consistent with enhanced westerly winds over the SPG and enhanced north-easterly trade winds over the TNA. These anomalous winds will have acted to cool the ocean surface in these regions through enhanced sensible and latent heat fluxes. The wind anomalies could also have favoured an increase in the transport of dust from North Africa over the TNA region, which would also have acted to cool the ocean surface. Finally, longshore wind anomalies may have enhanced coastal upwelling on the eastern side of the Atlantic and Pacific basins.

1976:80
In the last stage of the event, cool anomalies retreated back to higher latitudes leaving significant cool anomalies only in the SPG region, and in the Mediterranean. The strong MSLP anomalies of the previous stage are no longer seen.

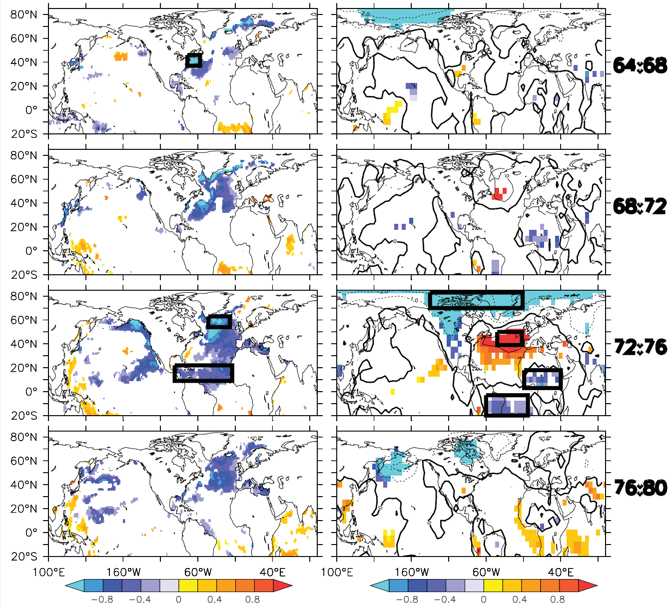

Figure 3: Left: Means of October-June Observed Sea Surface Temperatures (HadISST) for four successive period: 1964-1968, 1968:1972, 1972:1976, 1976:1980 minus the 1951:1962 mean. Units K. Shaded (non-white) areas show significant differences ($p<0.05$). Right: as Left, but for Mean Sea Level Pressure (HadSLP) and units hPa.

Conclusions

Following the 1960s sea surface temperatures in the North Atlantic Ocean cooled rapidly accompanied by significant changes in climate in many regions. The key findings from this study are as follows:

The cooling of the North Atlantic proceeded in several distinct stages. Cold anomalies appeared in Nordic Seas and Gulf Stream Extension, spread to the Subpolar Gyre and then extended to the tropical North Atlantic before retreating, in the late 1970s, back to the Subpolar Gyre. Theories for the cooling event must account for this distinctive space-time evolution.

There is strong evidence that changes in atmospheric circulation played an important role in the cooling event, particularly in the period 1972-76 when the cooling spread into the tropical North Atlantic associated with a pattern of winter SLP anomalies that projects on the positive phase of the North Atlantic Oscillation.

References:
1 Folland, C.K., et al: 1986, Nature, 320, 602--607.
2 Hoerling, M.,et al: 2006, J. Climate, 19, 3989--4008
3 Zhang, R. and T.L. Delworth: 2006, Geophysical Res. Let., 33, L17712
4 Uvo, C.B., et al: 1998, J. Climate, 11, 551--562.
5 Folland, C.K., et al: 2001, J. Climate, 14, 1937--1958.
6 Zhou, J. and K.M. Lau: 2001, Int. J. Climatology, 21, 1623--1644.
7 Knight, J.R., et al: 2006, Geophys. Res. Lett., 33, L17706+.
8 McManus, J.F., et al: 2004, Nature,428, 834--837.
9 Sutton, R.T. and D.L.R. Hodson: 2005, Science, 309, 115--118.
10 Sutton, R.T. and D.L.R. Hodson: 2007, J. Climate, 20, 891--907.
11 Shapiro, L.J. and S.B. Goldenberg: 1998, J. Climate, 11, 578--590.
12 Enfield, D.B., et al: 2001, Geophys. Res. Lett., 28, 2077--2080.
13 Goldenberg, S.B., et al: 2001, Science, 293, 474--479.
14 Baines, P.G. and C.K. Folland: 2007, J. Climate, 20, 2721--2744.
15 Dickson, R.R., et al: 1988, Prog. in Oceanography, 20, 103--151.
16 Belkin, I.M., et al: 1998,Prog. in Oceanography, 41, 1--68.