The North Atlantic Climate System Integrated Study

ACSIS aims to detect, explain and predict changes in the North Atlantic

Changes in the North Atlantic directly affect the UK's climate, weather and air quality, with major economic impacts on agriculture, fisheries, water, energy, transport and health. The North Atlantic also has global importance, since changes here drive changes in climate, hazardous weather and air quality in North America, Africa and Asia.

ACSIS focuses on understanding recent and often rapid changes in the North Atlantic's highly coupled ocean, atmosphere (including composition) and cryosphere. By understanding how these changes relate to external drivers of climate, such as human activity or natural variability, ACSIS will improve our capability to detect, explain and predict changes in the North Atlantic climate system. For further information see Sutton et al. (2017), *Atlantic Multidecadal Variability and the U.K. ACSIS Program*, BAMS.

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ATMOSPHERE & CLIMATE

This theme focuses on atmospheric and coupled processes and their role in the climate system over the Atlantic, using a combination of data and modelling studies.

Research Questions:

1. How have natural variability and radiative forcing combined to shape multi-year trends in the North Atlantic physical climate system?
2. To what extent are these changes predictable on multi-year timescales?

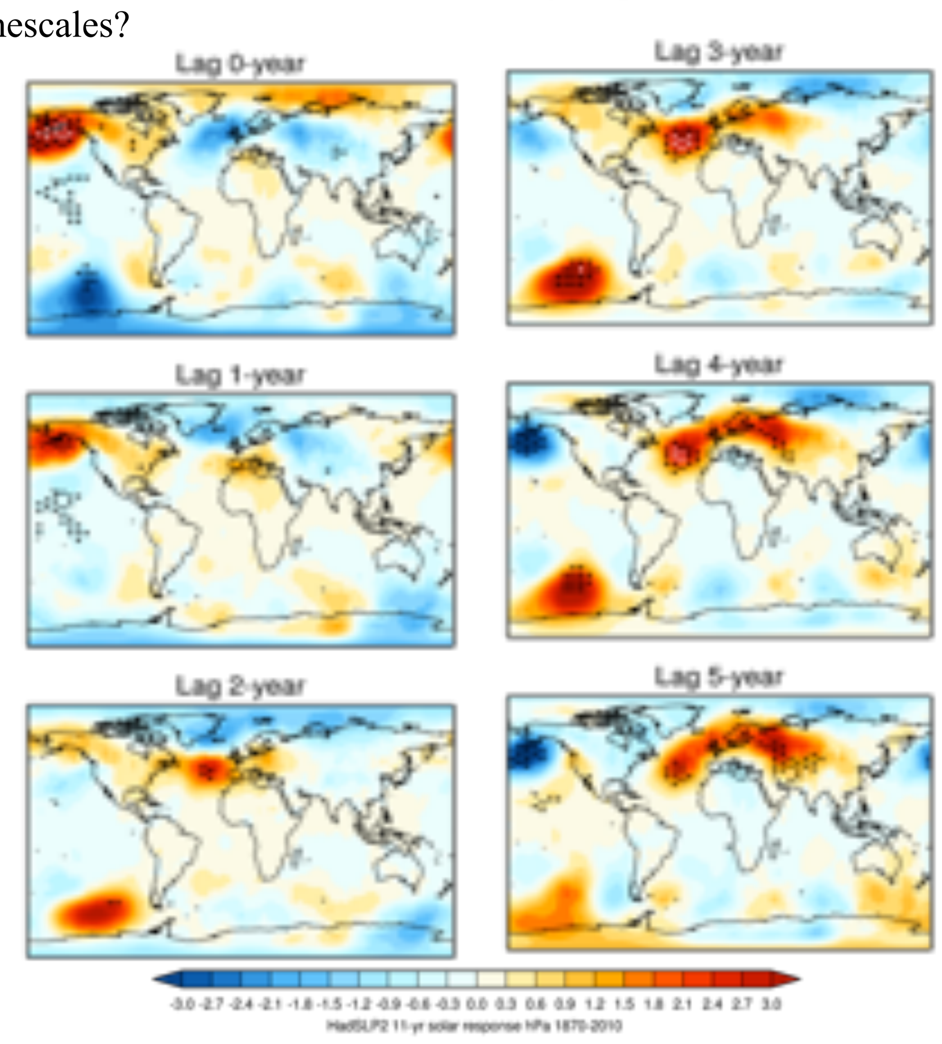

Figure 1: Solar cycle signal (max minus min) in HadSLP sea level pressure (hPa) for 1870-2010 from a multi-linear regression analysis that included indices for ENSO, volcanic and solar variability plus long-term trend term. Black dots: 95%. White dots: 99% statistical significance.

Science Highlight: 11-Year Solar Cycle's Impact on NAO

- There has been much scepticism of the 11-year Solar cycle's impact on the North Atlantic Oscillation (NAO) due to weak signals that depend on the time period examined.
- A number of different sea level pressure datasets extending back to 1660 have been analysed using a multi-linear regression analysis.
- There is no clear signal at lag-zero (Figure 1), but a clear positive NAO response emerges at 3-4 year lags. The response over the Azores reaches ~3 hPa, a significant proportion of the variance.
- A mechanism for this lagged response has been proposed in terms of ocean-atmosphere coupling, involving the re-emergence of a sea surface temperature anomaly from beneath the mixed layer, which amplifies the signal from one winter to the next.

For further information see Gray et al. 2013 JGR, Scaife et al. 2013 ERL, Andrews et al. 2015 JGR, Gray et al. 2016 QJ, Ma et al. 2018 ERL.

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ATMOSPHERIC COMPOSITION

This theme focuses on quantifying how atmospheric composition is changing across the North Atlantic by identifying key trends, predicting future changes, and investigating how composition relates to emissions and atmospheric dynamics.

Research Questions:

1. What is the impact of aerosol changes on the radiative budget of the North Atlantic?
2. What is the role of transport driven and emission driven changes in composition in the North Atlantic?

Science Highlight: NAO – Tropospheric Ozone Correlation

- Ozone is a powerful greenhouse gas and a major precursor to oxidants which form aerosols over the North Atlantic. Here we investigate the impact of the NAO on the regional distribution of tropospheric ozone.
- Two independent satellite products agree on an increasing trend in ozone (measured in Dobson Units) over the North Atlantic between 2005 and 2016 but the total amounts of ozone measured differ (Figure 2).

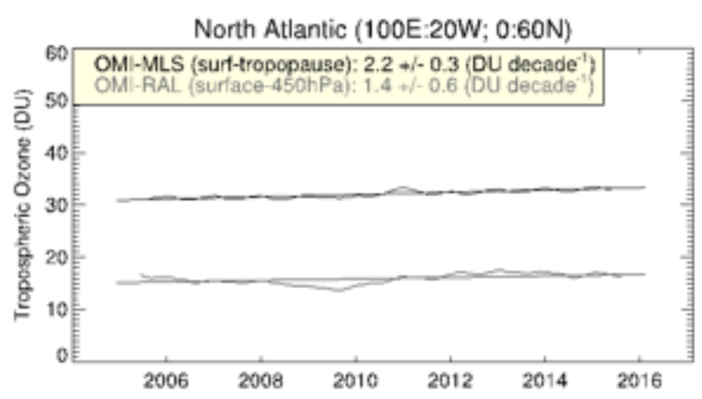

Figure 2: Trends in tropospheric ozone over the North Atlantic region from the OMI-MLS and OMI-RAL satellite retrievals.

- The correlation shown in Figure 3 between the amount of ozone measured from one satellite (OMI-MLS) with wintertime NAO shows an increase in tropospheric ozone (green) in some areas of the North Atlantic, and a decrease in other areas (brown).
- This pattern is related to the role of 1) ozone transport pathways from North America and the upper atmosphere, and 2) chemical changes. To support further analysis of this relationship we have begun experiments which use UKCA and UKESM-1 to disentangle the role of chemistry and transport.

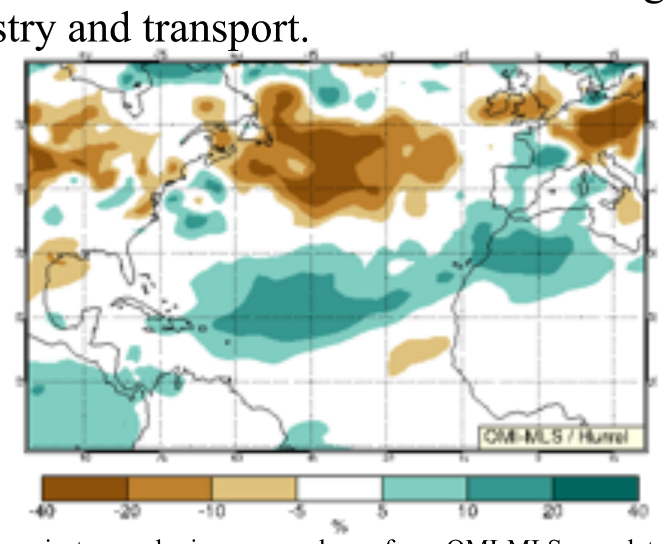

Figure 3: Changes in tropospheric ozone column from OMI-MLS correlated with the NAO and where ozone columns increase, brown regions show negative correlation and regions where ozone decreases.

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OCEAN & ICE

This theme focuses on why the North Atlantic ocean heat content (OHC), sea surface temperature (SST), sea ice and ice sheets undergo long term changes with associated impacts on climate.

Research Questions:

1. What are the causes of Arctic sea-ice decline, and how does it impact on the North Atlantic?
2. What is the cause of multi-year trends in ocean conditions, focusing on a) the ocean heat budget, and b) causes and consequences of Atlantic Meridional Overturning Circulation (AMOC) variability?

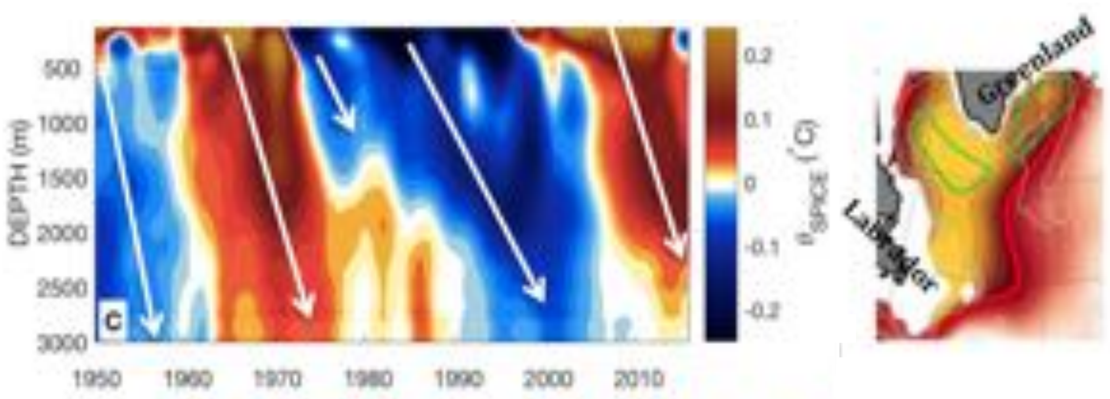

Figure 4: Downward propagation (white arrows) of *spice* (density compensated) component of potential temperature anomalies (colour shading) in the western SPG (left). Anomalies are averaged over the spatial region bounded by the red contour on the map shown on the right. Green contours indicate regions of oceanic deep convection.

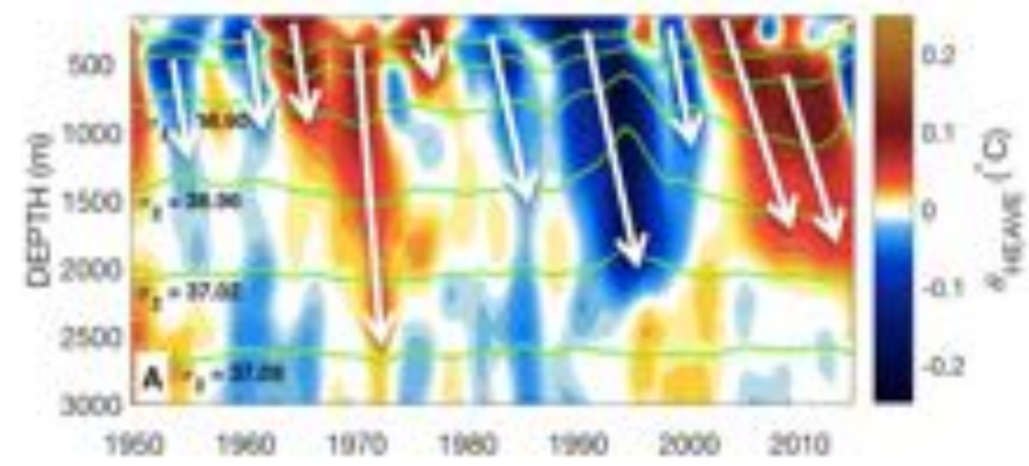

Figure 5: *Heave* (non-density compensated) component of temperature anomalies (colour shading) in the western SPG. Contours of constant potential density (isopycnals) are superimposed (green lines). Potential density (σ_2) is referenced to a depth of 2000m and selected isopycnals are labelled in black. White arrows indicate depth to which convection penetrates.

Science Highlight: Ocean Heat Content

- The North Atlantic Subpolar Gyre (SPG) contributed significantly to global ocean heat uptake during the recent global surface warming slowdown (aka hiatus).
- We have quantified the impact of the Labrador Sea (right panel, Figure 4) on SPG heat content via downward and southward propagation of temperature anomalies on decadal timescales.
- Oceanic deep convection does not dominate the transfer of temperature anomalies from the surface to depth. Instead, shallow convection, boundary mixing and recirculation are implicated (left panel, Figure 4), which shows that density-compensated (spice) anomalies dominate the downward propagation.
- In contrast, deep convection creates temperature anomalies which are not density compensated (heave). These are anomalies are weaker, more short-lived, and penetrate less deeply (Figure 5).

For further information see Drijfhout et al., 2014, and Desbruyères et al., 2018, submitted

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SYNTHESIS

ACSIS has compiled a review of "Recent observed changes in the North Atlantic with a focus on 2006-2015", which in particular highlights recent changes in variables that span the breadth North Atlantic Climate System (see Figure 6)

ACSIS has developed the Atlantic Climate System Indicators (ACSIs), which are observation-based measures that track the past and present conditions, and important trends, in the North Atlantic climate system for key variables.
Visit the ACSIS website to find out more about the ACSIs.

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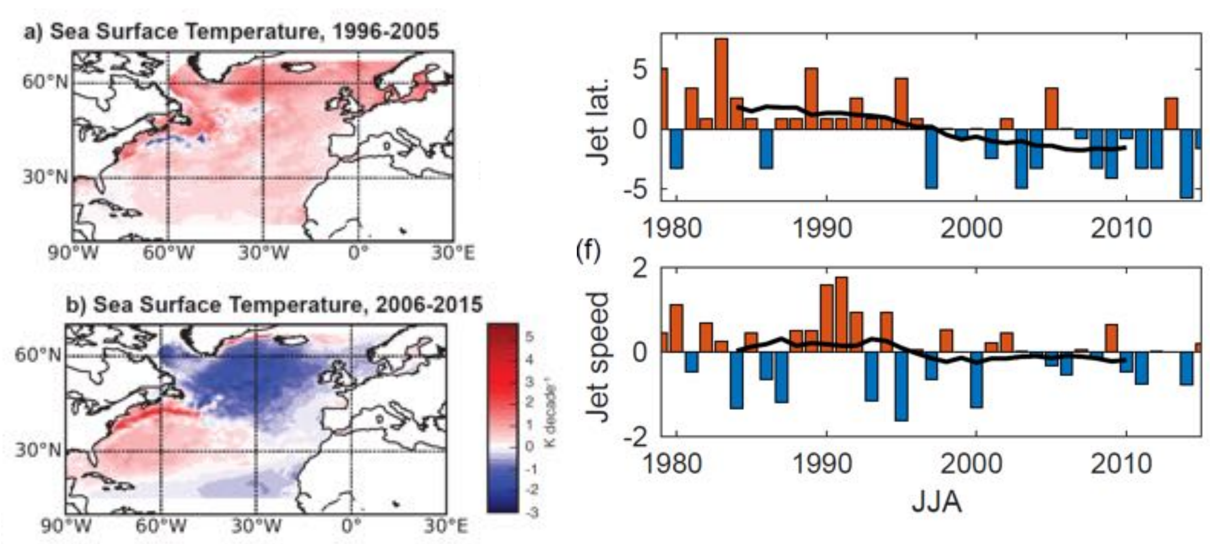
Figure 6: Recent changes in linear trends in annual-mean Sea Surface Temperature (SST) between the 1996-2005 (top left), and 2006-2015 (bottom left) periods, which highlights a recent cooling of the North Atlantic. Also shown is timeseries of changes in the mid-latitude atmospheric jet in the North Atlantic region for jet latitude (top right) and jet speed (bottom right) averaged over the months June to August (summer), which highlights a southerly shift in the Jet since ~1990 .



www.acsis.ac.uk

The ACSIS project is a collaboration between NERC research centres and the Met Office, and has been funded for five years (2016-2021) to tackle major scientific and societal challenges associated with changes occurring across the North Atlantic. ACSIS is led by a small team from the National Centre for Atmospheric Science and the National Oceanographic Centre. The wider project team is spread across the seven partner organisations, and is made up of about 80 scientists.

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