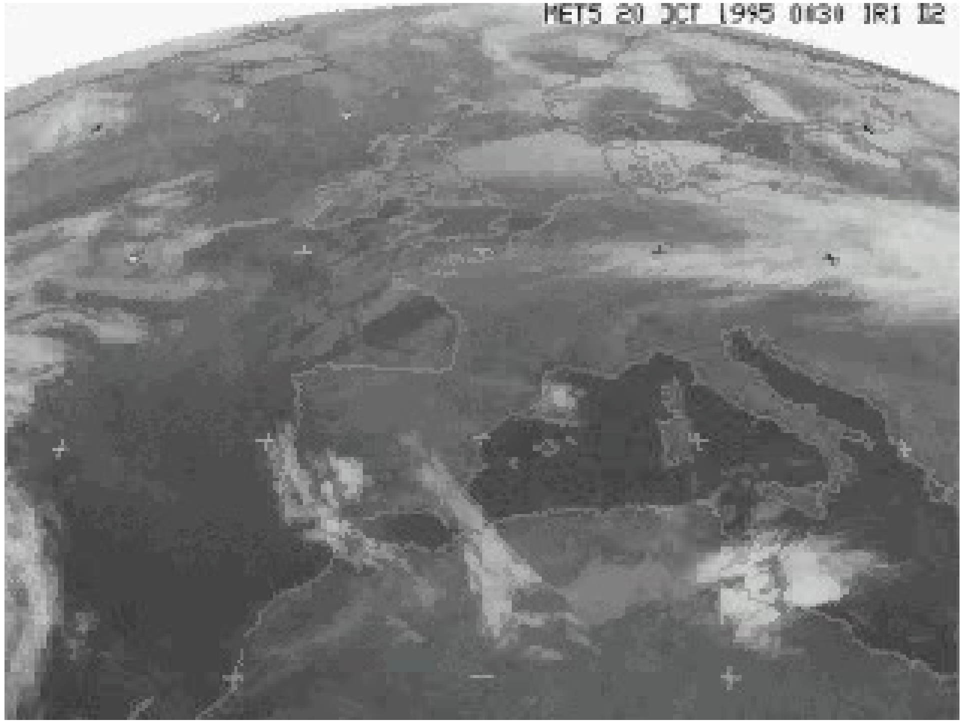
Climate change: what role is the ocean playing?



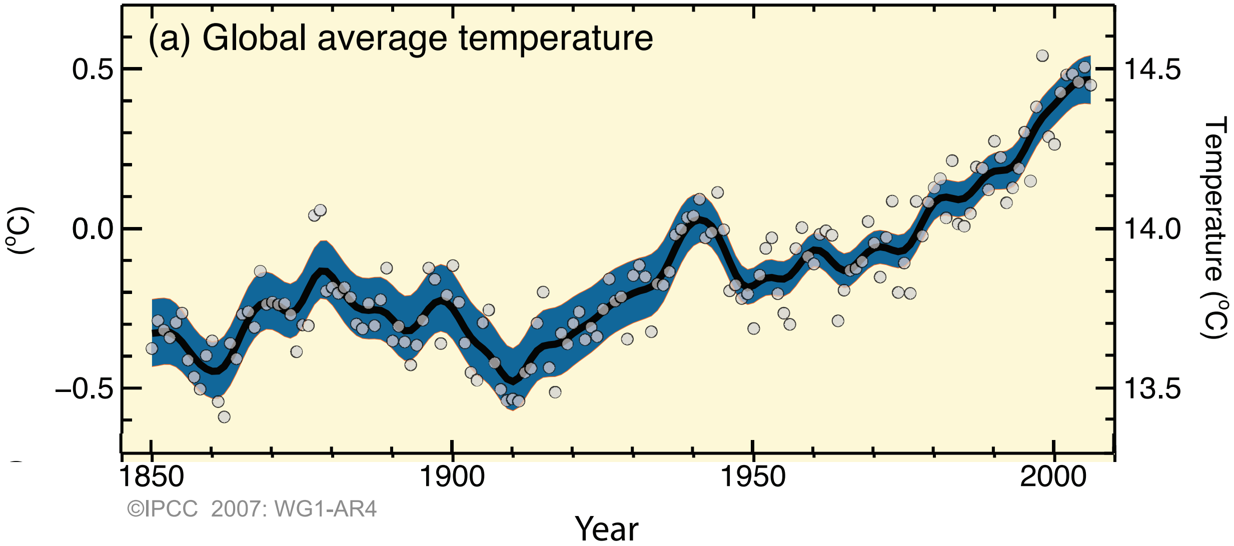
Infra-red satellite data (white is cloud)

1. Surface and atmospheric temperature
2. Ocean change in heat stored
   - data view
   - model experiments
3. Attribution? Link back to the atmosphere

Ric Williams, Vassil Roussenov (Liverpool),
Susan Lozier, Susan Leadbetter (Duke University)

Return to global mean surface temperature

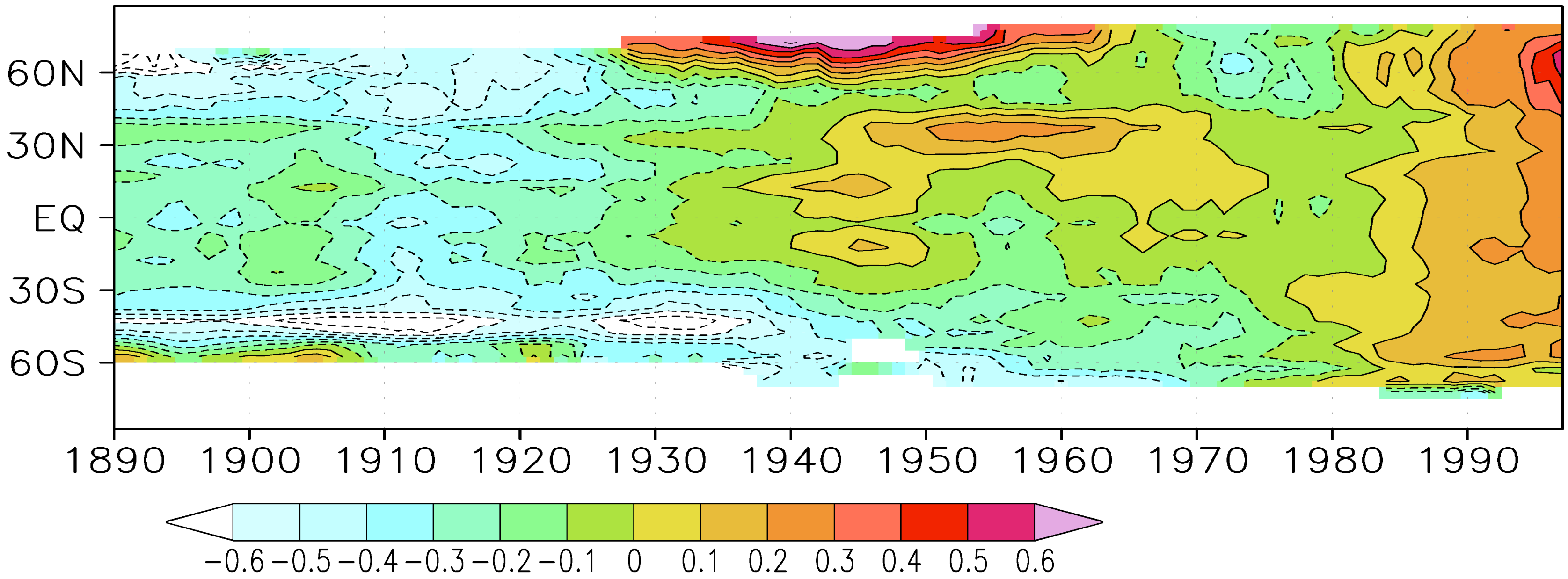
IPCC (2007)



dots: annual mean
shading: 5-95% decadal error bars

1. Surface and atmospheric temperature
2. Ocean change in heat stored
   data view
   model experiments
3. Attribution? Link back to the atmosphere

Observed change in *surface* air temperature (°C)



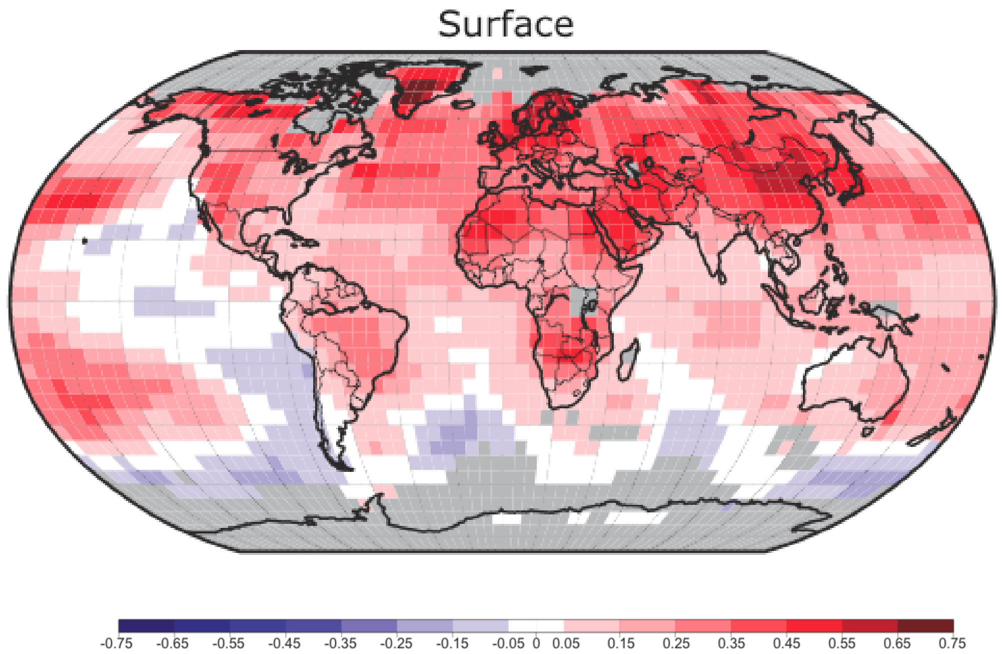
(Delworth & Knutson, 2000,Science)

recent warming at all latitudes

Surface warming trend from satellite data since 1979:

• warming over most of globe
• land warming faster than ocean

IPCC (2007)



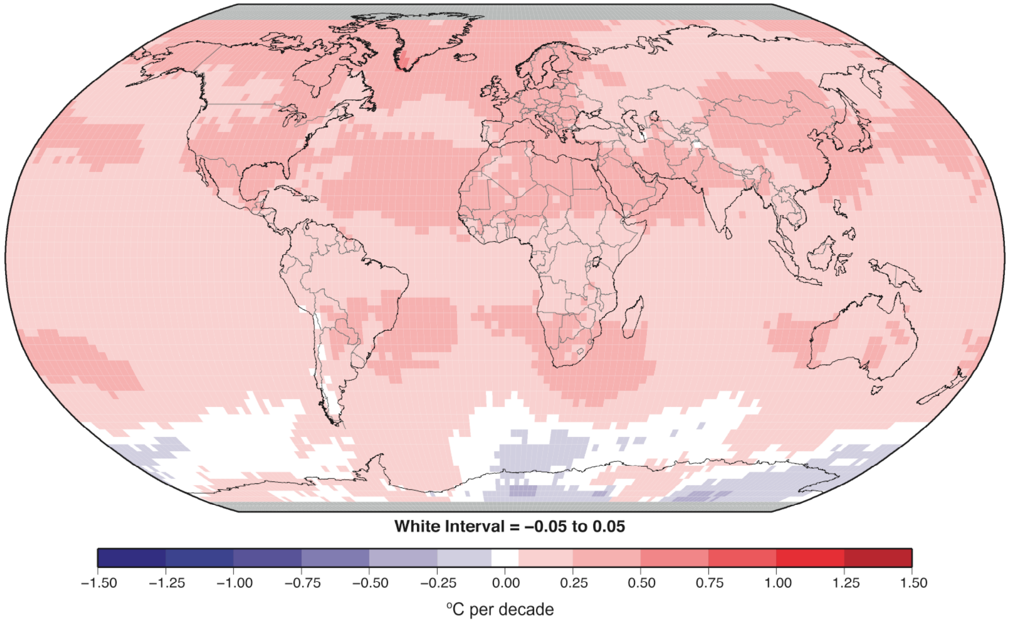
-0.75 -0.05 0.05 0.75

°C per decade

How about the atmosphere?

Atmospheric warming trend from surface to 10 km since 1979.

IPCC (2007)



-0.75

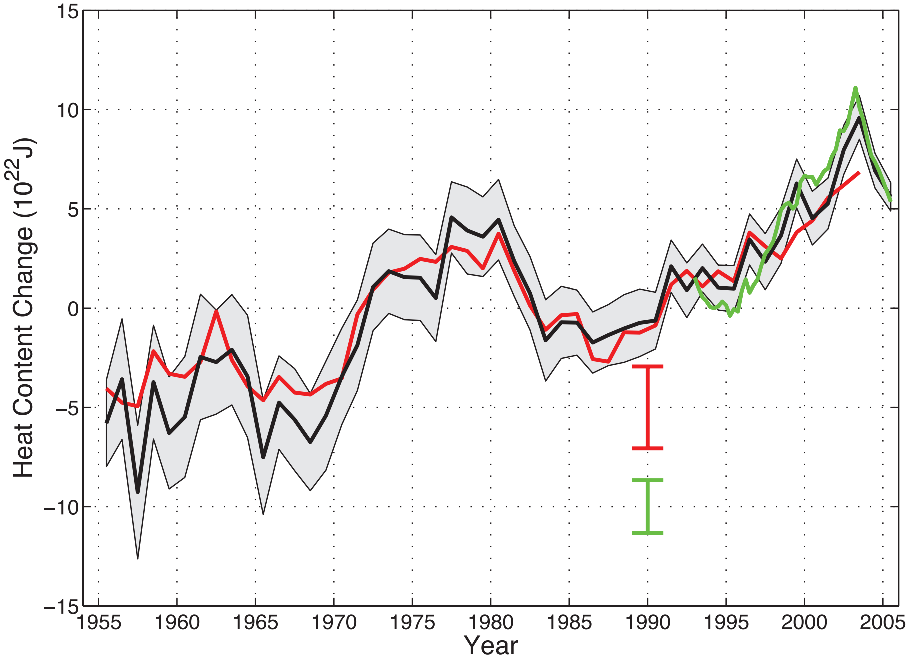
0.75

°C per decade

How about the ocean?

Why care about the ocean?

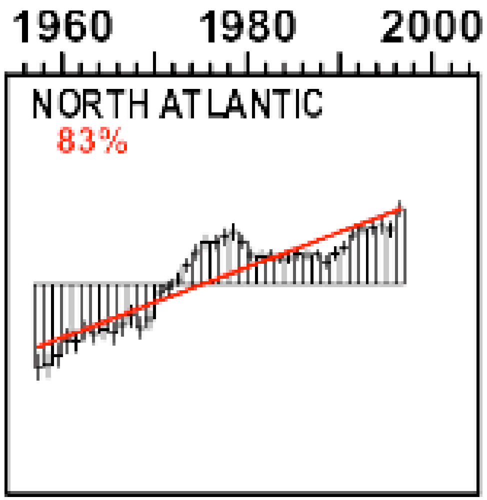
- upper 2.5 m of ocean holds as much heat as overlying atmosphere
- oceans have absorbed more than 80% of the heat added to the climate system (IPCC, 2007)



Time series of upper ocean heat content (10^{22}J) for the upper 700m. IPCC (2007); Levitus et al. (2006) for black line

Ocean Heat Content Change

focus on N. Atlantic where high data coverage and a reported warming signal

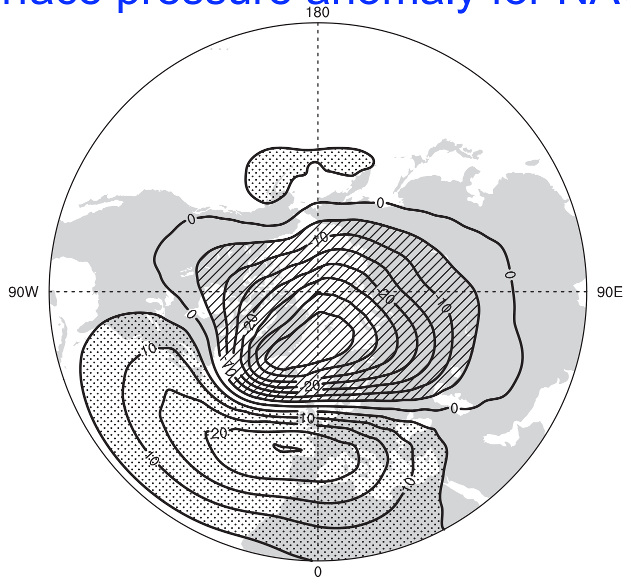


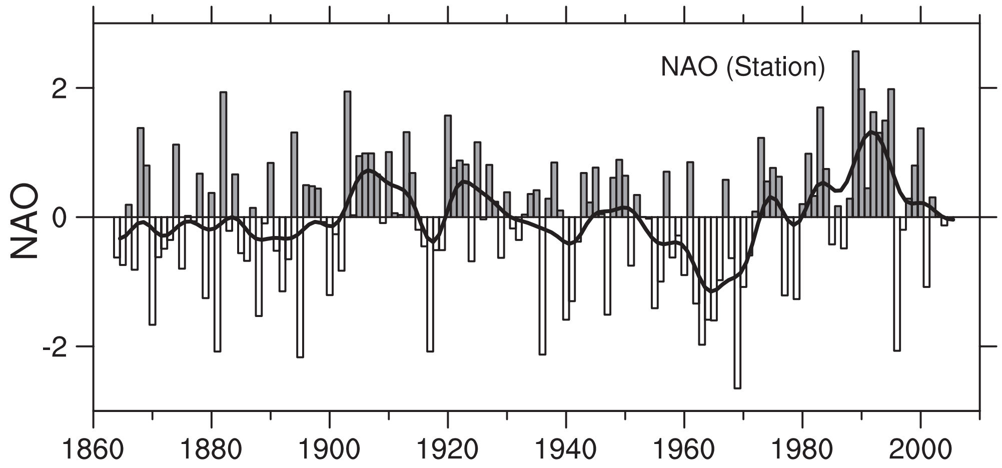
Levitus et al. (2006) – rise in heat content of upper 3000m from 5 year running averages (10^{22} J)

- **What is the spatial pattern of warming?**
- **How is the warming controlled**?

North Atlantic Oscillation

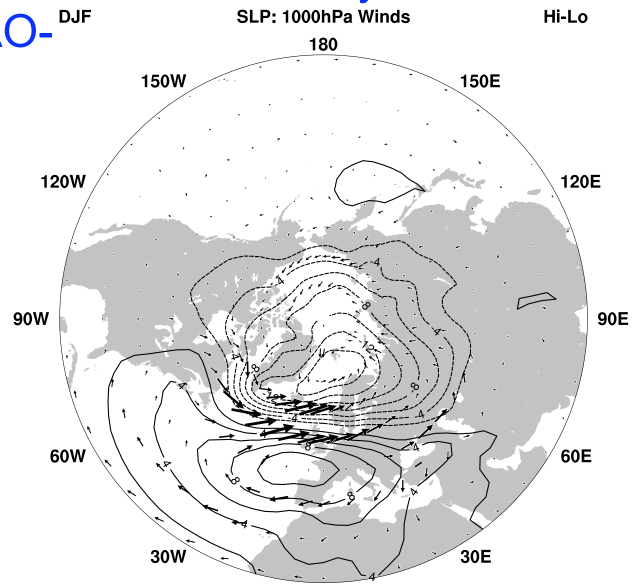
surface pressure anomaly for NAO+





Winter indices of the NAO for sea level pressure from Portugal-Iceland

surface wind anomaly for NAO+ minus NAO-

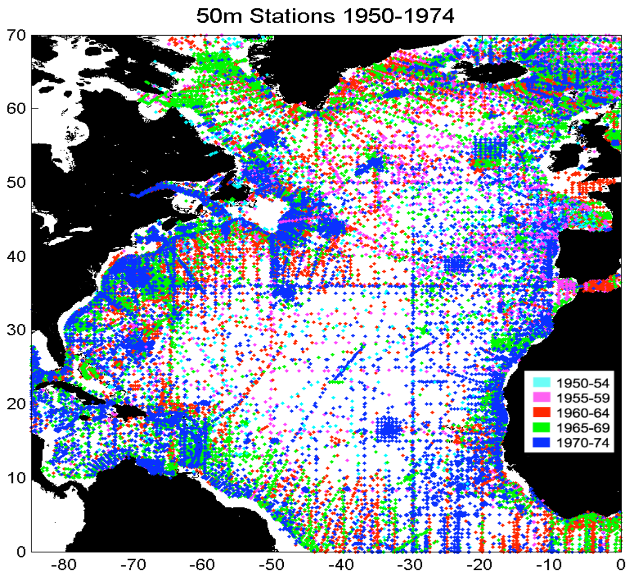


Hurrell et al. (2003)

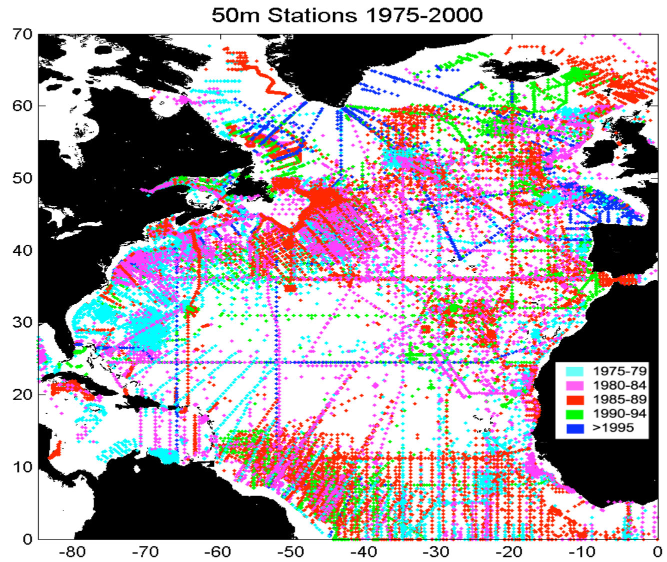
North Atlantic Data

Ocean Heat Content

1950-1974

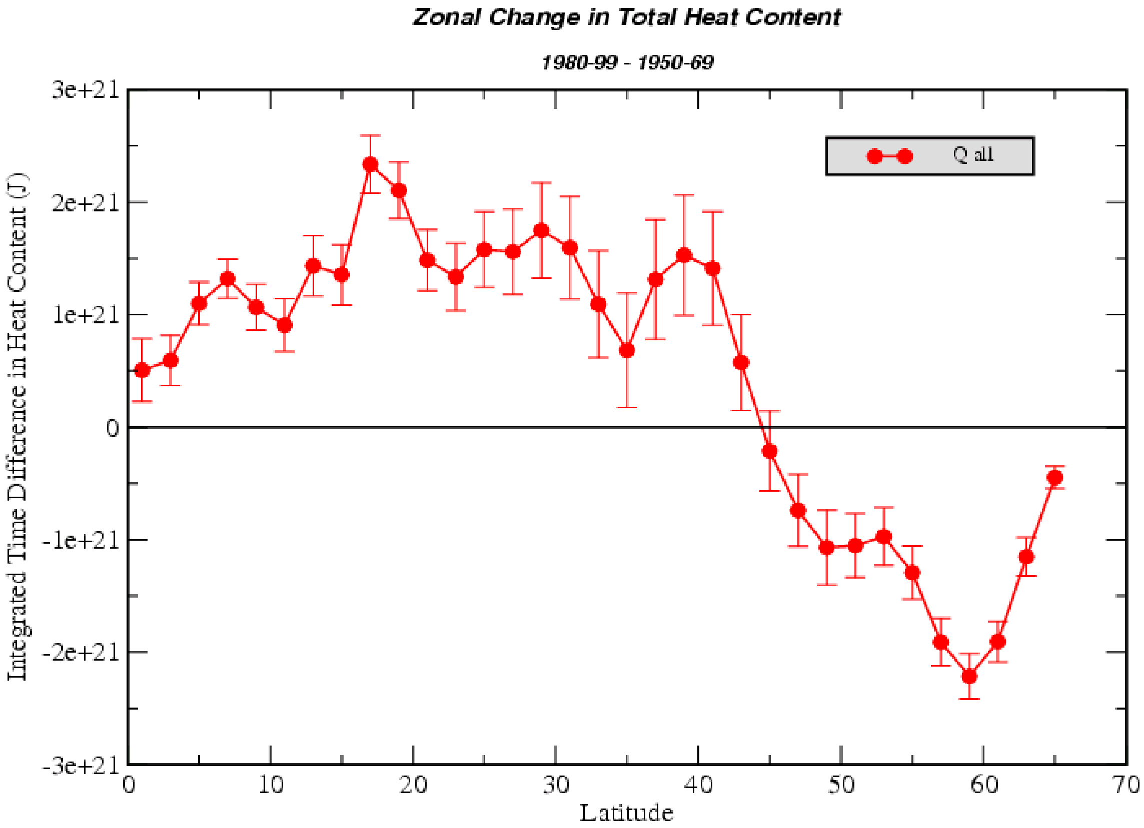


1975-2000



data from NODC World Ocean Atlas (2001)
and WOCE programme

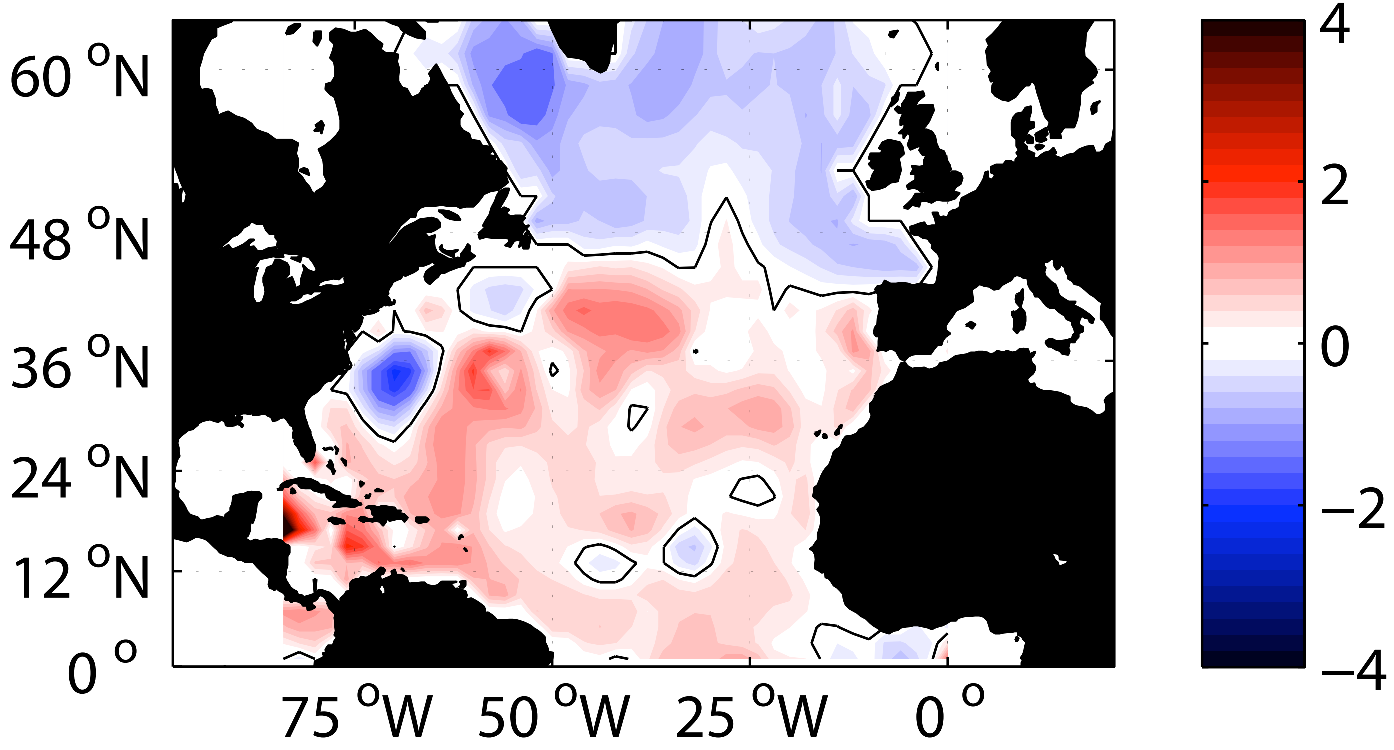
North Atlantic Data



- Overall heat gain equivalent to 0.4 +/- 0.05 W m^{-2}
- Smaller than anthropogenic heat gain 1.6 W m^{-2} (0.6 to 2.4 Wm^{-2})
- **Not** the same pattern as for surface & atmosphere T

Data

Ocean heat content change



Change in ocean heat content (10^{20}J) between 1980-2000 and 1950-1970

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Science DOI: 10.1126/science.1146436

Science Express Index

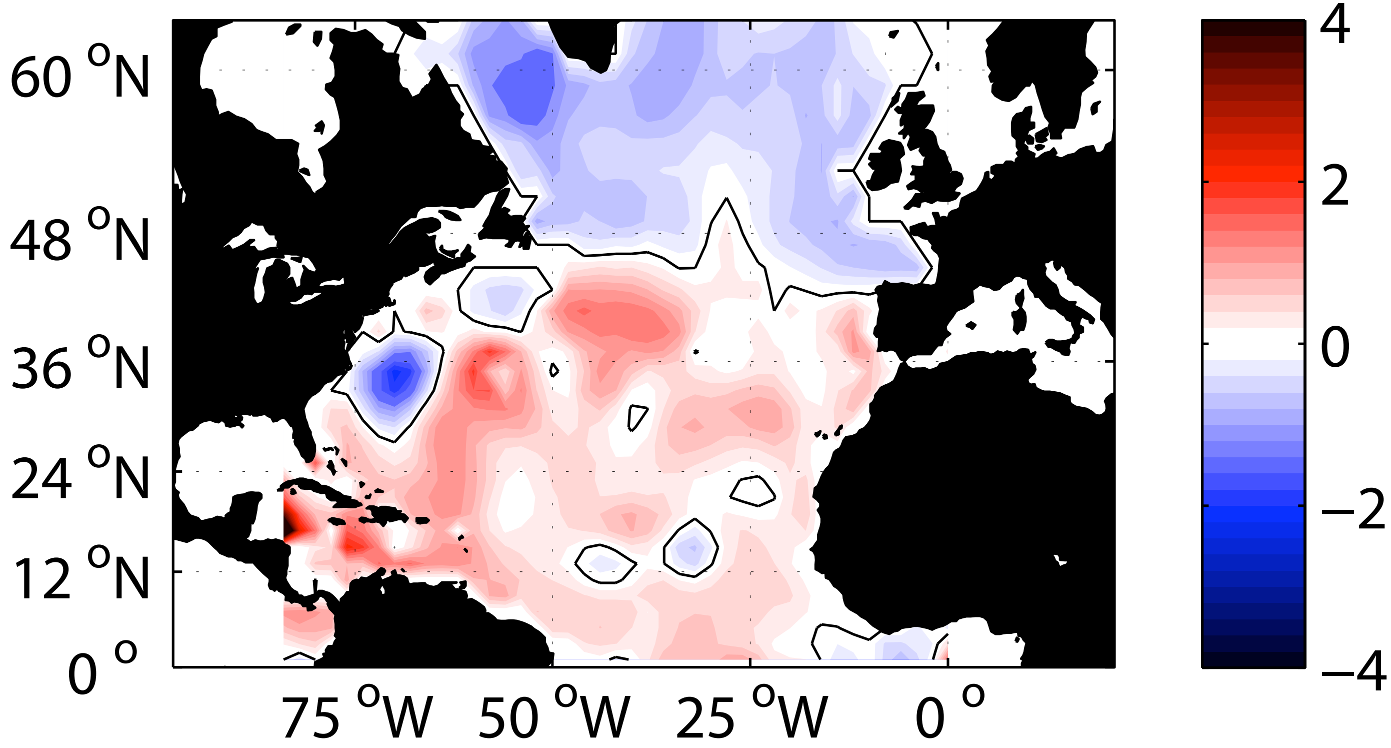
REPORTS

The Spatial Pattern and Mechanisms of Heat Content Change in the North Atlantic

M. Susan Lozier [1], Susan Leadbetter [2], Richard G. Williams [2], Vassil Roussenov [2], et al.

Data

Ocean heat content change



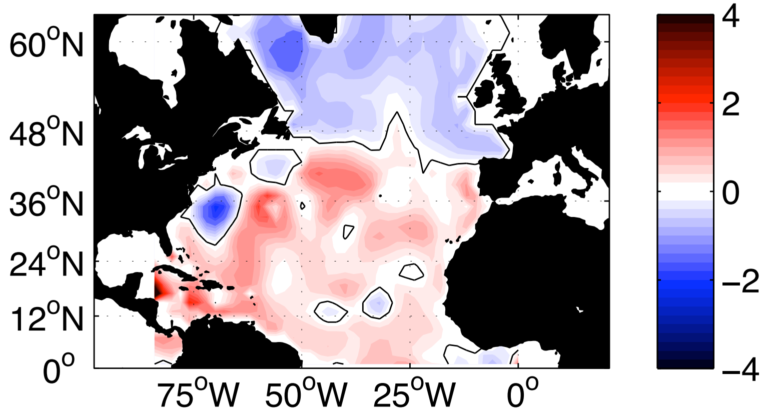
Change in ocean heat content (10^{20}J) between 1980-2000 and 1950-1970

- Overall heat gain is significant (0.4 +/- 0.05 W m^{-2})
- Larger regional changes (+/- 4 W m^{-2})

How should this pattern be interpreted?

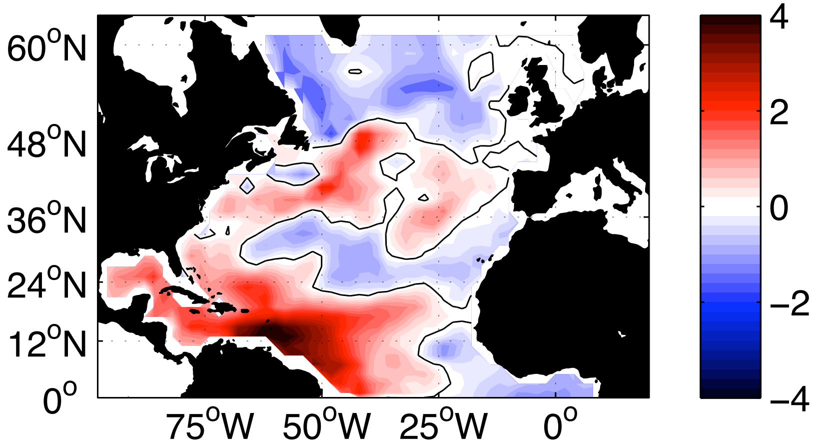
MICOM

Default Model Results

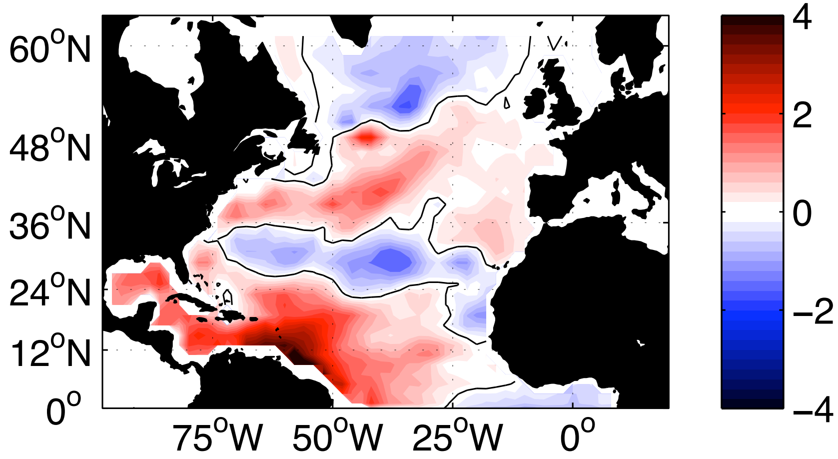


Observations

- Comparison of two 20-year runs (1980-2000 – 1950-1970)
- 1.4° resolution
- Heat content difference (10^{20}J)



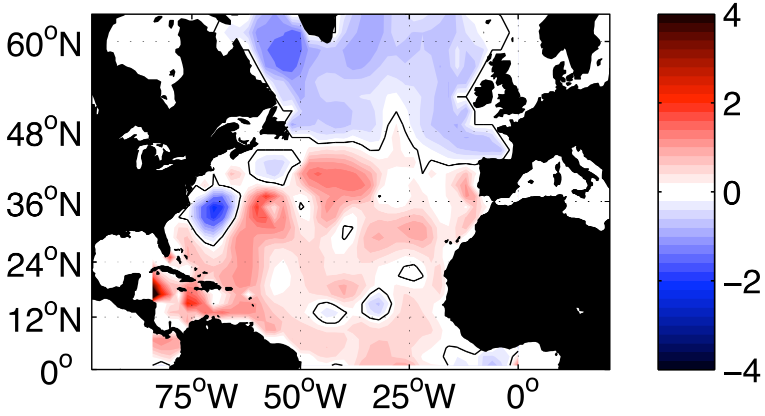
Model - ECMWF



Model - NCEP

MICOM

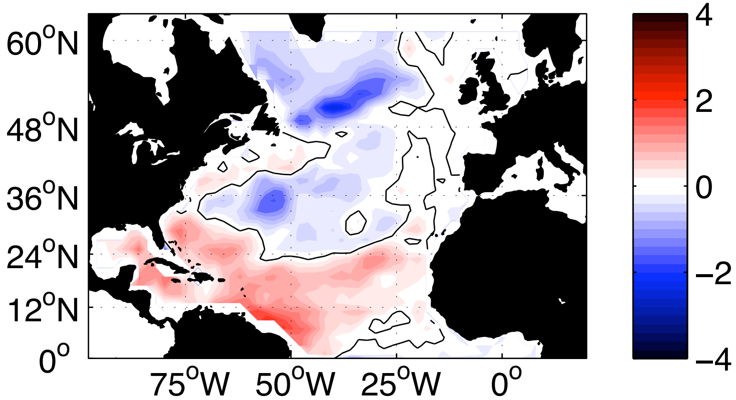
Model sensitivity experiments



Observations

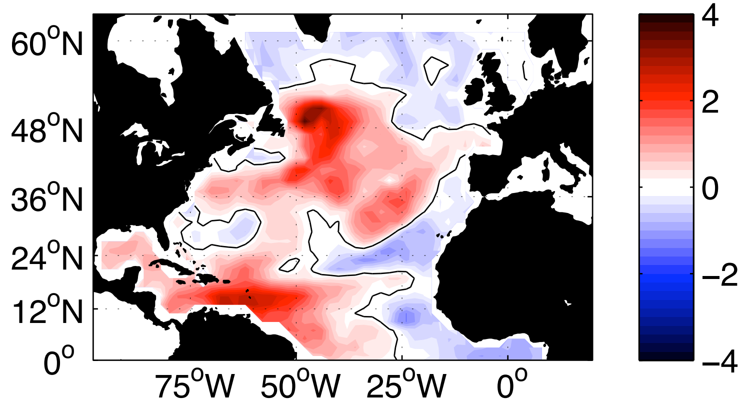
- Comparison of two 20-year runs (1980-2000 – 1950-1970)
- 1.4º resolution
- ECMWF

(a) Climatological Winds and Variable Buoyancy



Includes changes in air-sea heat fluxes

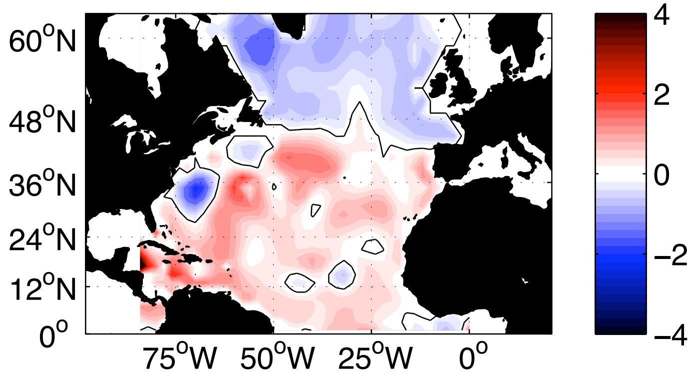
(b) Climatological Buoyancy and Variable Winds



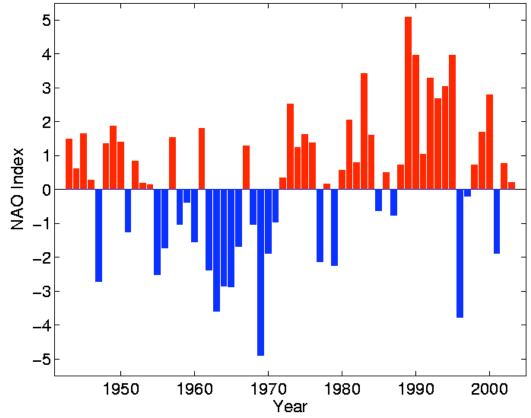
Include changes in winds

MICOM

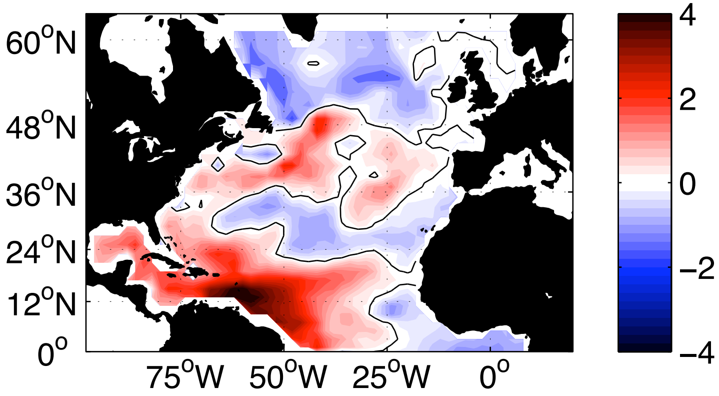
North Atlantic Oscillation (NAO)



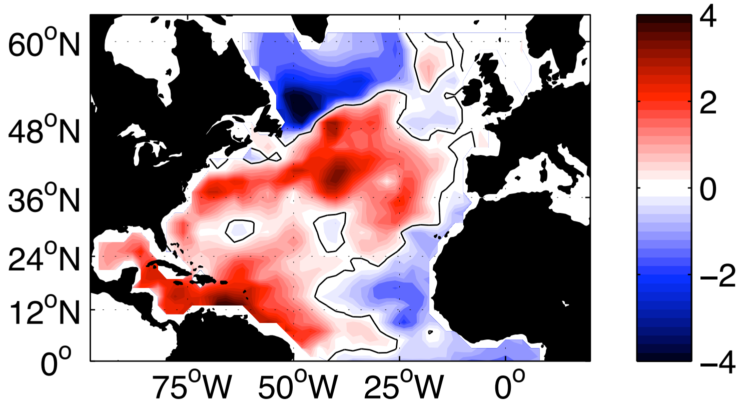
Observations



NAO Index



Model - Default



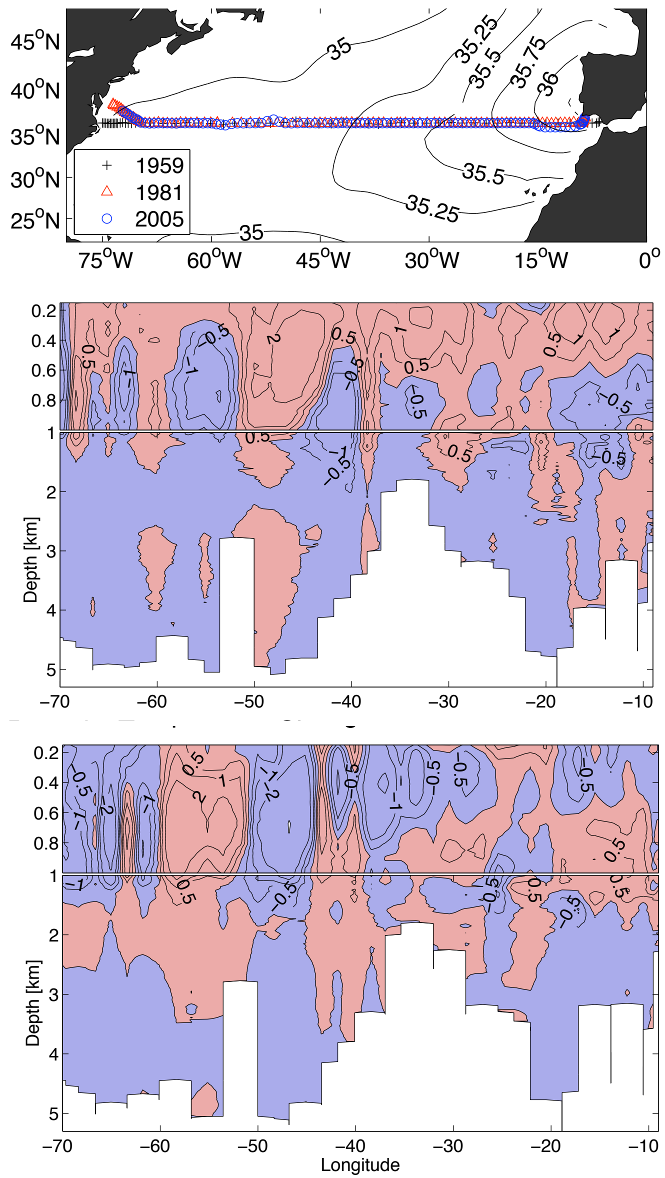
Model – NAO+ minus NAO-

What is seen in single sections?

Changes 2005 - 1981:
upper ocean warming
slight mid-depth cooling

Changes 1981 - 1959:
upper ocean cooling

Changes in upper 800 m explained by changes in winds linked to the NAO



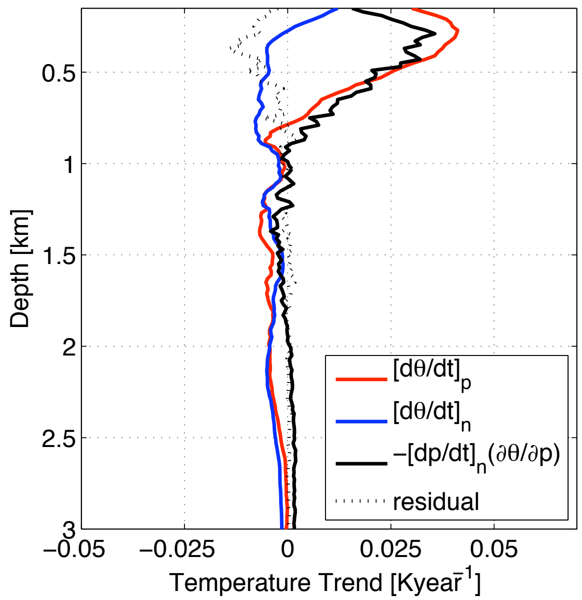
Leadbetter et al. (2006) GRL

NERC 36N Consortium led by Liverpool

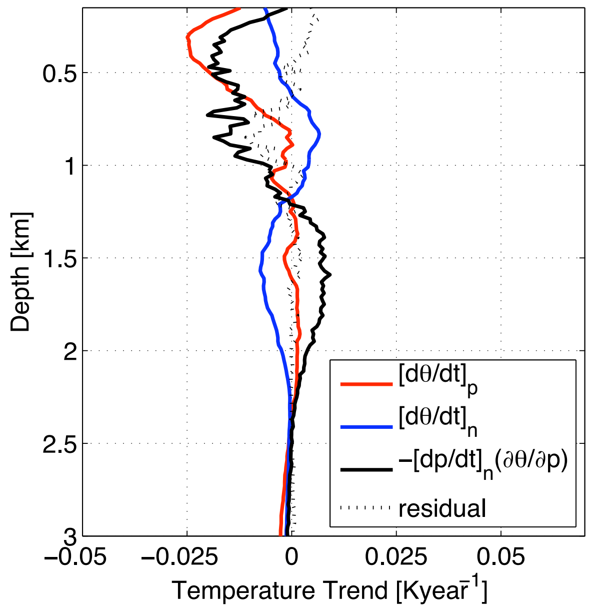
2005-1981

1981-1959

(a) Decompostion - 2005-1981

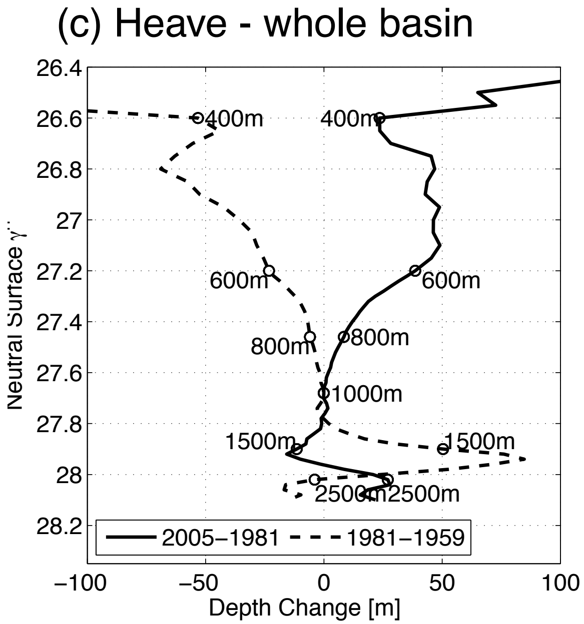


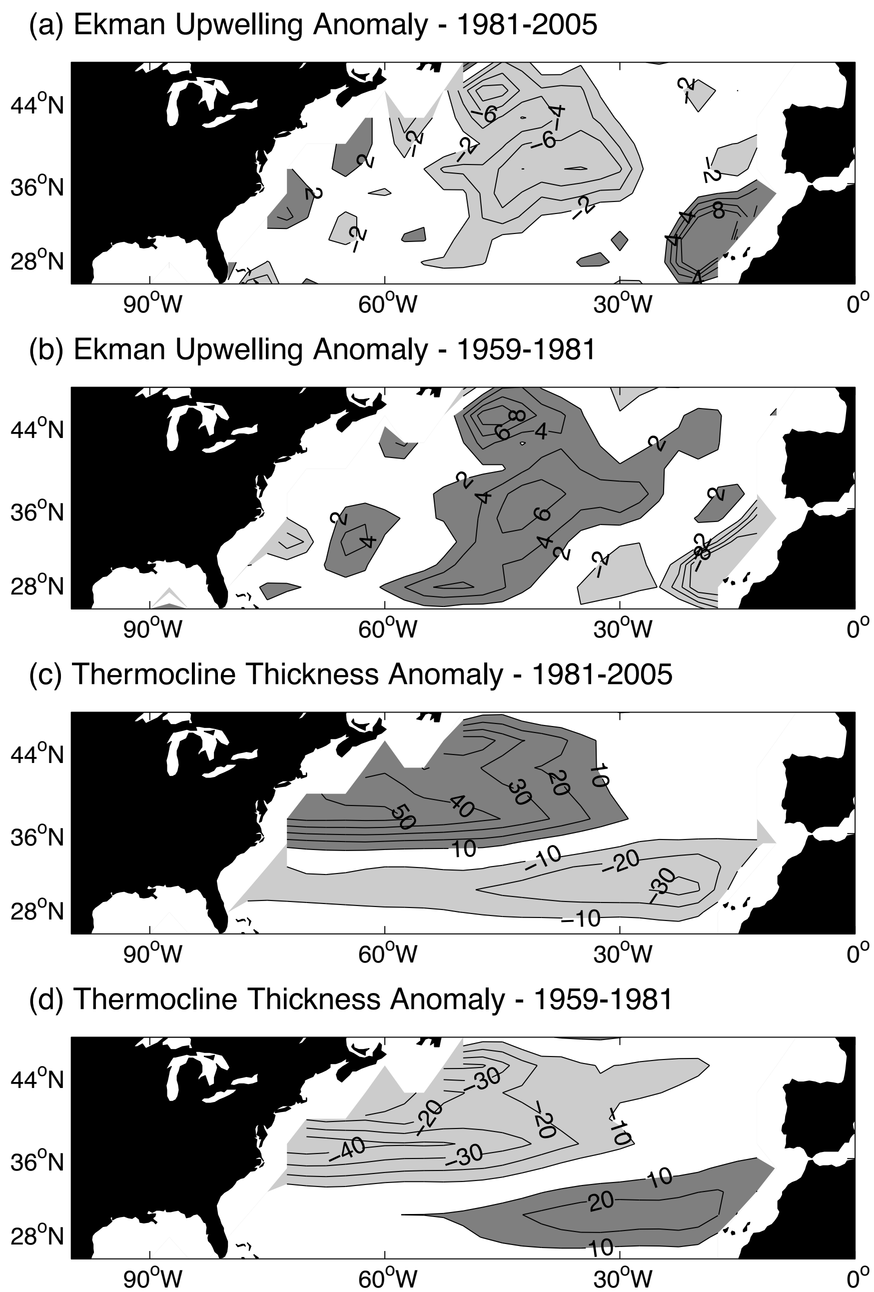
(b) Decomposition - 1981-1959



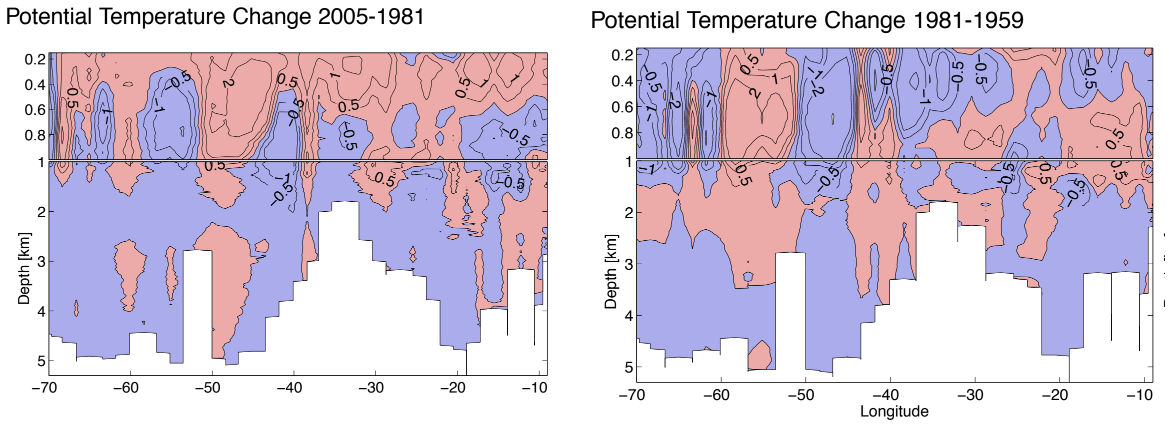
$$\left.\frac{\partial\theta}{\partial t}\right|_{depth} = \left.\frac{\partial\theta}{\partial t}\right|_{neutral} - \left.\frac{dz}{dt}\right|_{neutral} \frac{\partial\theta}{\partial z}$$

Opposing heave signal in each period

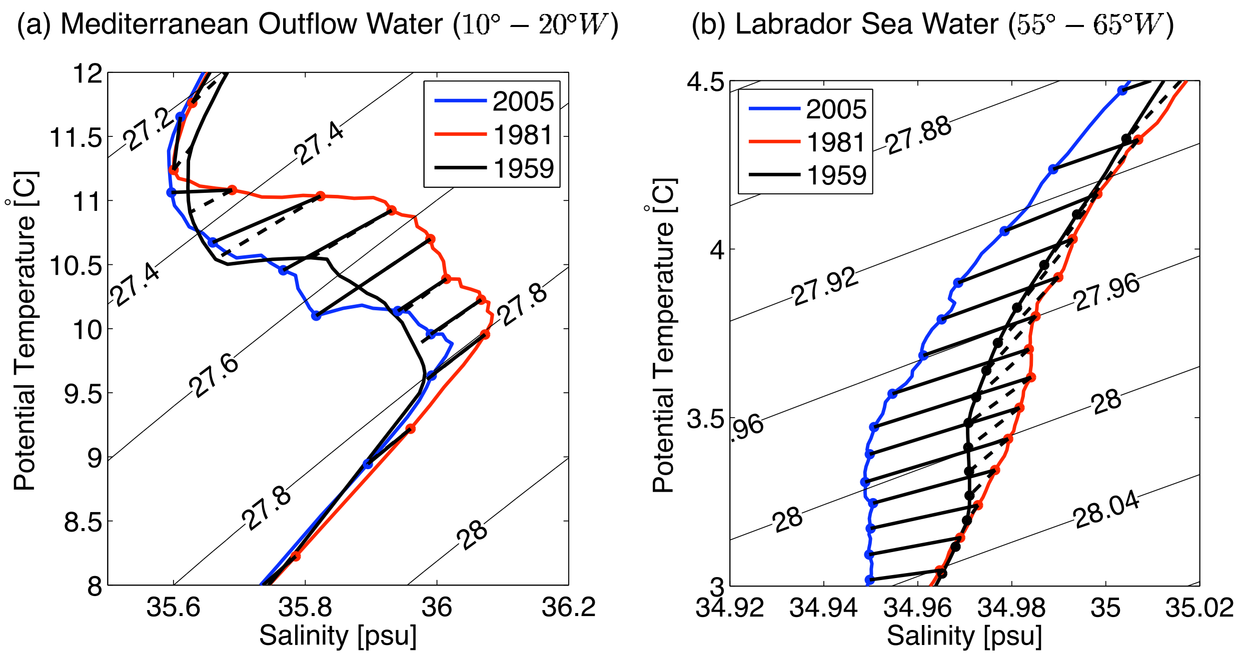




Reversing pumping/ heave signals in upper 800m

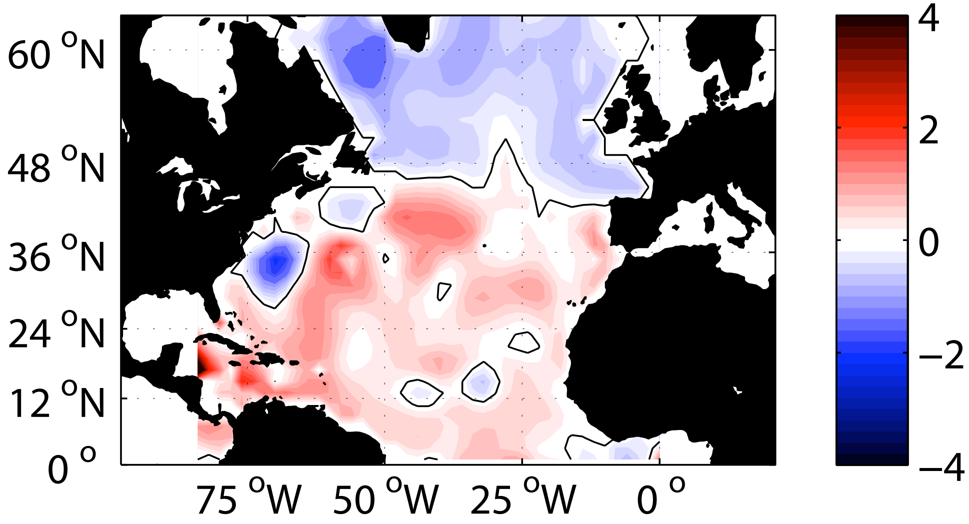


Reversing T/S changes seen below 1 km



1959 to 1981: warmer & saltier Med Water and slightly for Labrador Sea Water
1981 to 2005: cooler & fresher Med. Water and Labrador Sea Water

Speculations



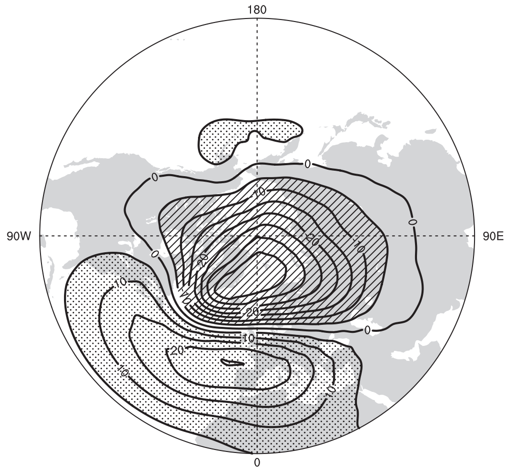
Change in ocean heat content (10^{20}J) between 1980-2000 and 1950-1970

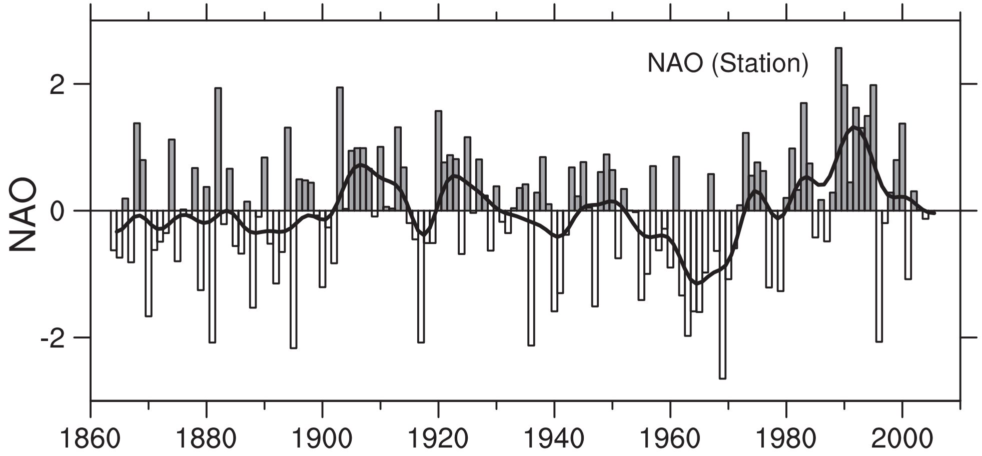
- Ocean heat content change can be explained by the change in wind forcing linked to the North Atlantic Oscillation

- Possibly seeing decadal, natural variability masking any greenhouse forcing

- Or any anthropogenic change is being imprinted on the ocean with the *same pattern* as that of the North Atlantic Oscillation

Unclear as to link of the North Atlantic Oscillation & greenhouse forcing





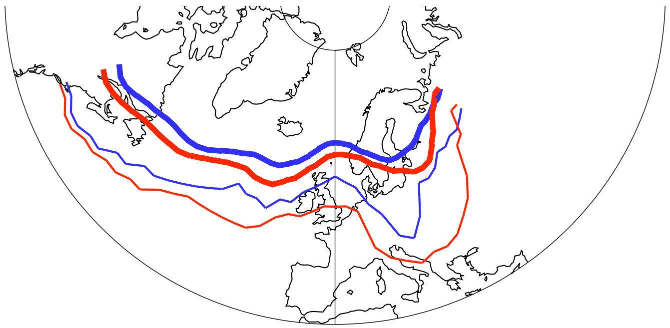
- Greenhouse warming has been speculated as being achieved by increasing NAO+ states

- 18 global climate models assessed (Stephenson et al., 2006)
  15 models simulate NAO pressure dipole
  13 models predict increase in NAO+ with greenhouse forcing
  no models able to reproduce decadal trend over last 40 years

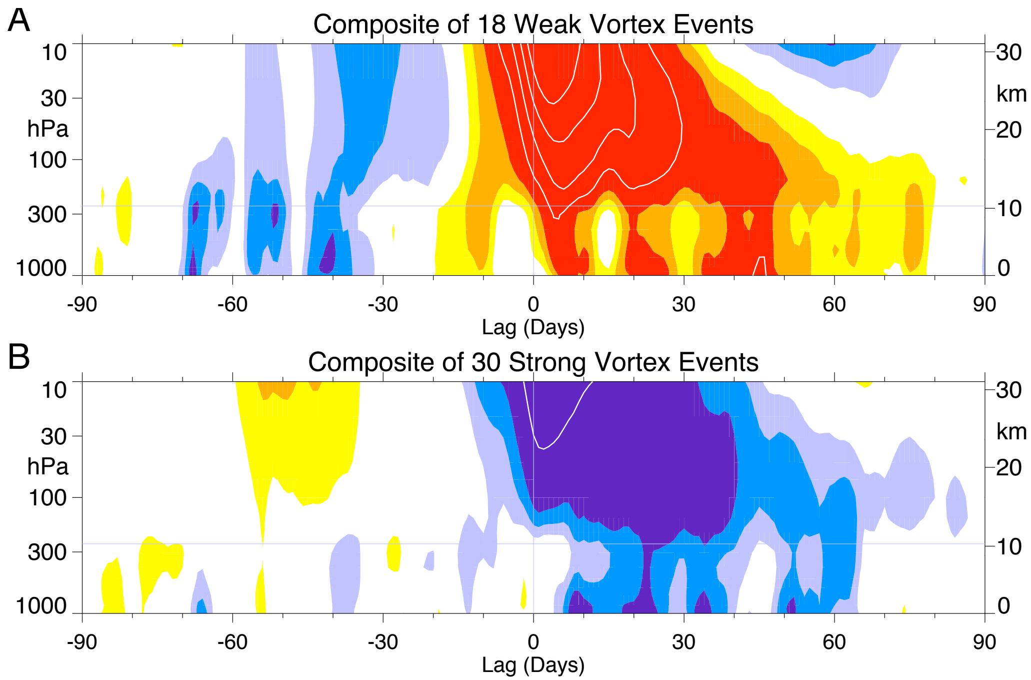
- Tropical variability might induce random NAO variations based on ensemble of climate models (Selton et al., 2004)

- Stronger stratosphere circulation linked to greenhouse forcing (Butchart et al., 2006), possibly more blocking & NAO- states

Possible link back to the upper atmosphere



Storm tracks (1961-1998):
strong vortex events (blue)
weak vortex events (red)



time lag for strong & weak vortex events for a pressure anomaly

Bladwin & Dunkerton (2001) Science

Conclusions

- Overall warming of the N. Atlantic
  - 0.4+/- 0.05 W m^{-2}
  - Larger regional changes
- Any anthropogenic warming signal over the basin is not spatially uniform
- Either
  - decadal variability masks anthropogenic warming
  - warming signal is being *imprinted* via the pattern of NAO induced forcing

Whilst many other proxy signals of global warming, still need to be cautious on making attribution of changes.