Connections between AMOC, meridional heat transport and heat content in the North Atlantic from satellite altimetry

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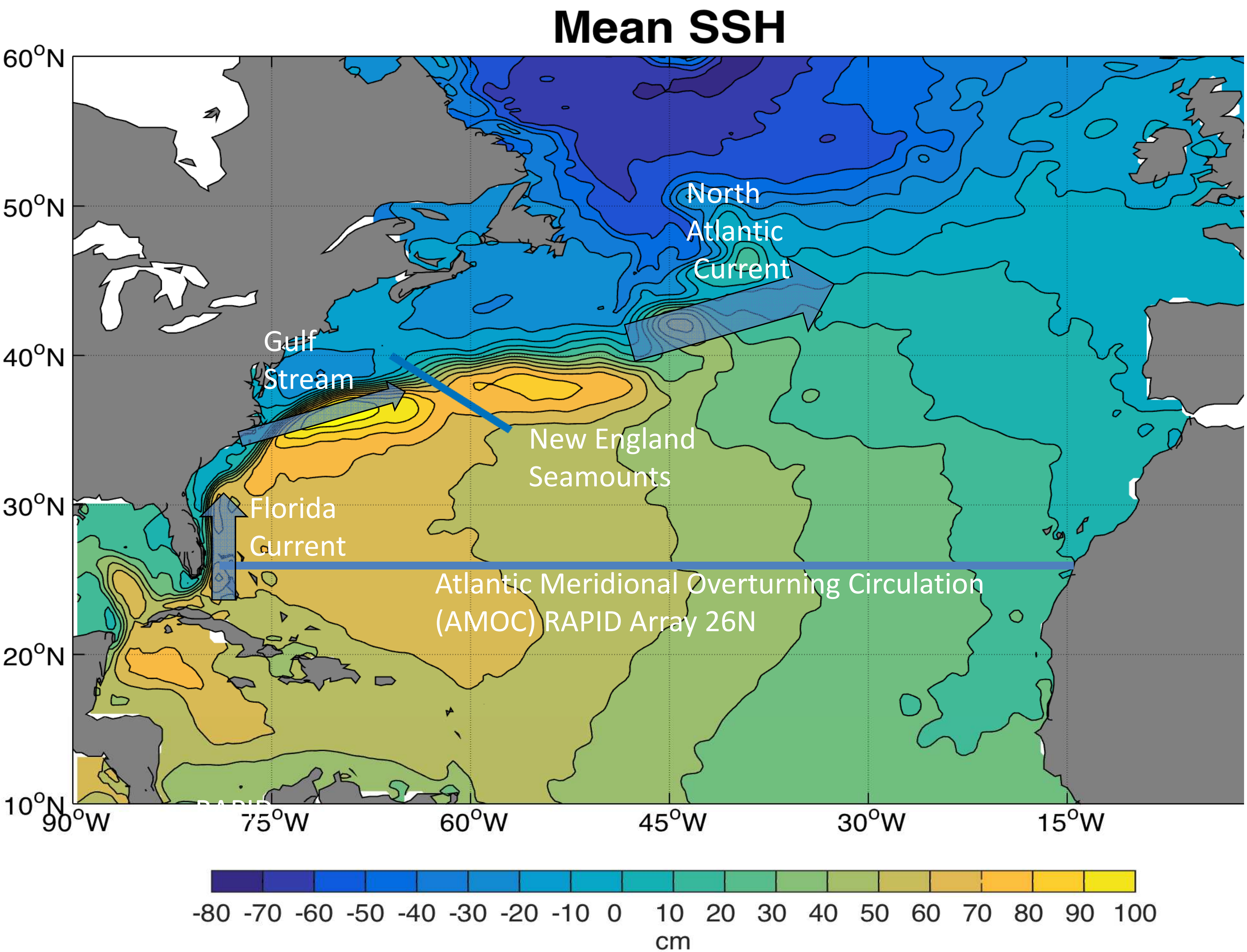
Question: How are the different components of North Atlantic Upper Ocean Circulation connected to the winds, to each other and to heat content changes?

Approach: use altimetry to enhance direct observations of those components

1. Interannual variability using lagged regressions
2. 10 year trend


Mean SSH
60°N
50°N
40°N
30°N
20°N
10°N
90°W
75°W
60°W
45°W
30°W
15°W
North Atlantic Current
Gulf Stream
New England Seamounts
Florida Current
Atlantic Meridional Overturning Circulation (AMOC) RAPID Array 26N
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100
cm

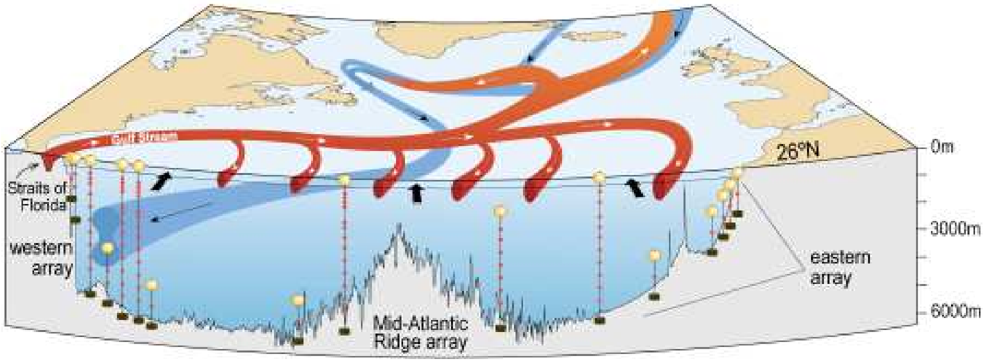
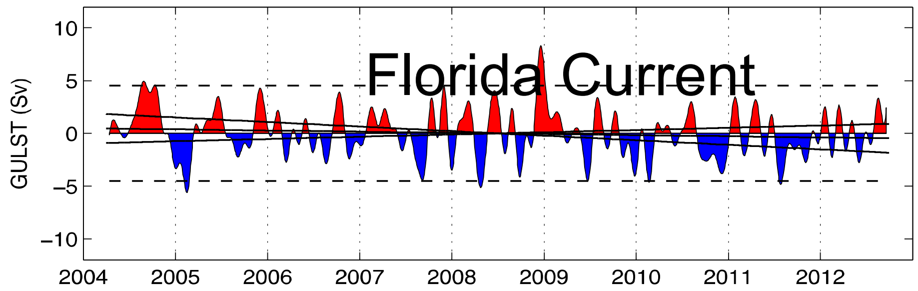
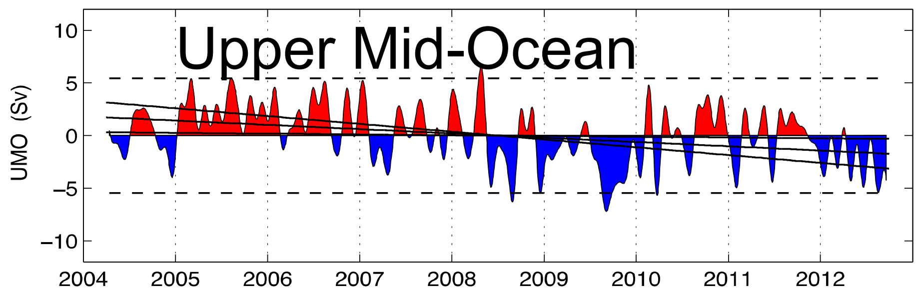
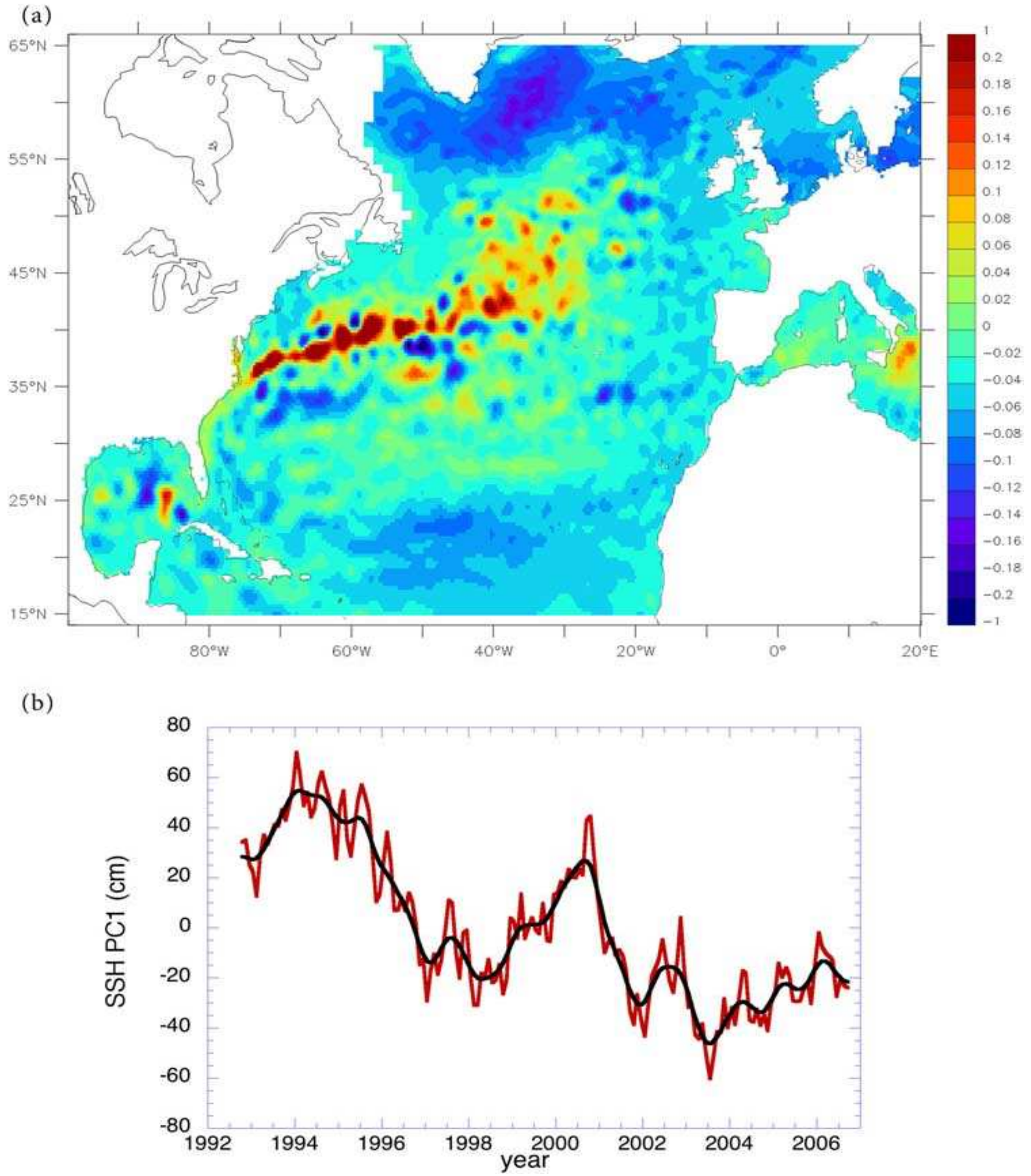


Fig. 1. Schematic diagram illustrating the component parts of the AMOC and the 26° N observing system. Black arrows represent the Ekman transport (predominantly northward). Red arrows illustrate the circulation of warm waters in the upper 1100 m, and blue arrows indicate the main southward flow of colder deep waters. The array of moorings used to measure the interior geostrophic transport is illustrated too.



RAPID trend in observed AMOC: mostly owing to Upper Mid-Ocean transport Smeed et al 2014





Dominant SSH pattern in the North Atlantic: shifting currents and changing heat content Hakkinen and Rhines, 2009

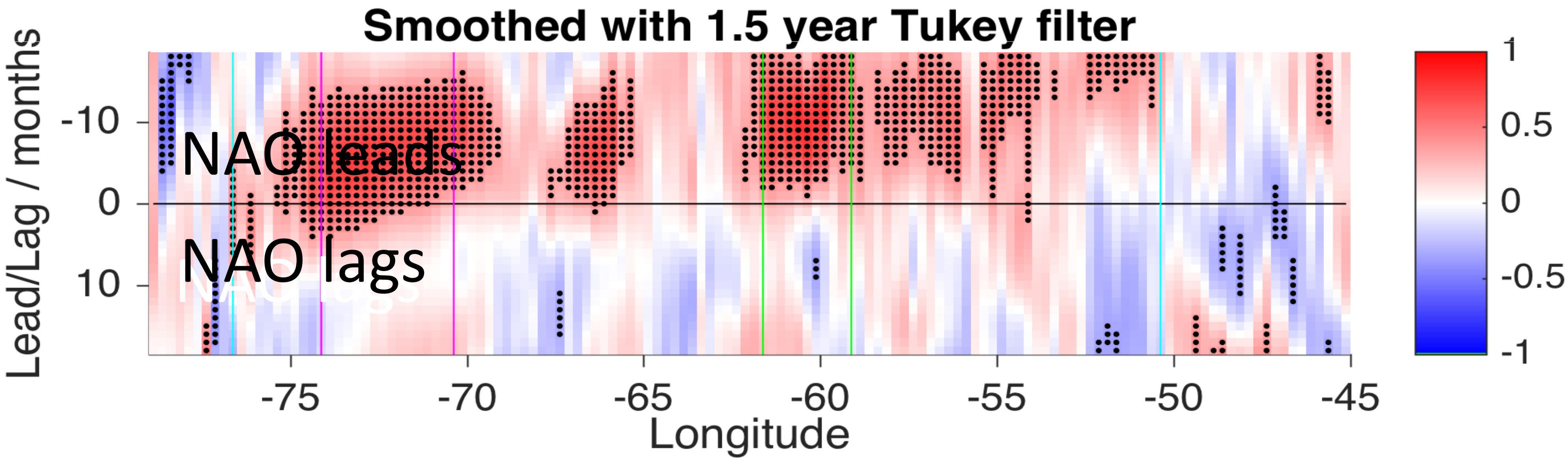
Figure 11. (top) The spatial pattern of the first empirical orthogonal function and (bottom) associated time series for the sea surface height from AVISO altimeter data. The spatial pattern is dimensionless, the time series have units of centimeters. This is an update to *Hakkinen and Rhines* [2004] time series using AVISO sea surface heights.

Circulation and heat content variability enhanced by SSH:

Quantity	Method
SSH	Monthly AVISO fields spatially smoothed with 400 km Gaussian smoother to removed eddies, Use SSH as a proxy for upper ocean heat content (Lyman and Johnson, 2014)
AMOC at 26N	Atlantic Meridional Overturning Circulation: Extend RAPID AMOC time series back to 1993 using altimetry Frajka-Williams (2015) for Upper Mid Ocean transport
Florida Current	Fill 1.5 year gap of cable measurements using SSH difference across Florida Strait
Gulf Stream path and strength	Fit the across path structure of the SSH to an error function (Kelly and Gille, 1990)

Example:
Influence of North Atlantic Oscillation on Gulf Stream Path on interannual times scales

NAO leads location of Gulf Stream by 1-18 months at almost all longitudes (Frankignoul et al, 2001)

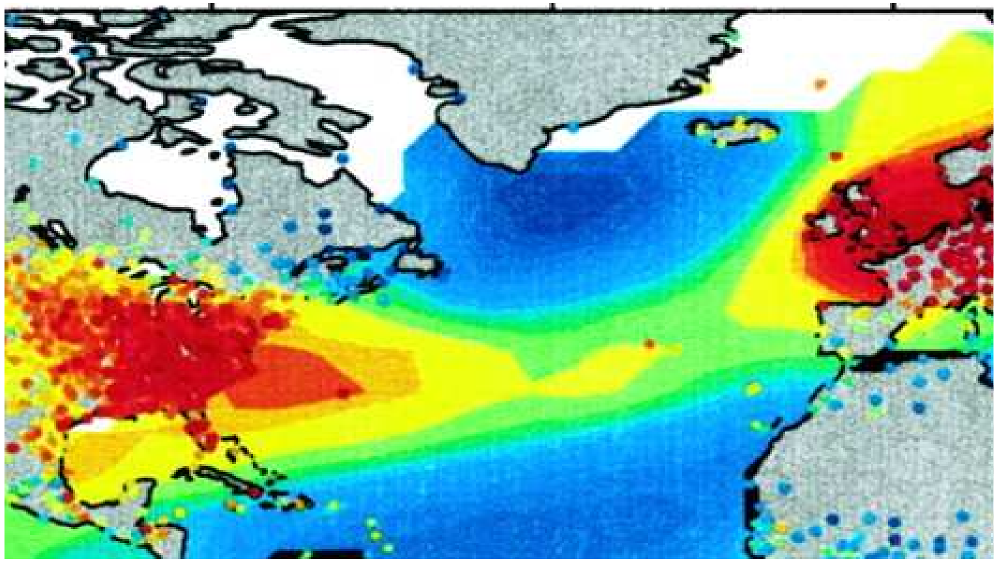


Results: Gulf Stream moves north and gets stronger about a year after changes in transport or winds

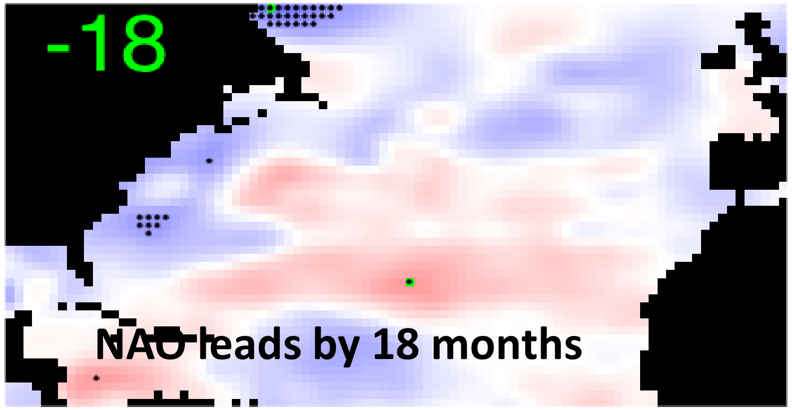
Index	Gulf Stream Path	Gulf Stream Strength
NAO	35 km/unit NAO Over Entire Path (See Frankignoul et al, 2001)	9 cm/unit NAO Near New England Seamounts
AMOC at 26N	7.7 km per Sverdrup Upstream of New England Seamounts *Opposite to what is found in climate models (Joyce and Zhang, 2010)*	4 cm per Sverdrup Downstream of New England Seamounts
Florida Current	-	1.6 cm per Sverdrup Over entire path
UMO/Thermocline Transport at 26N	5 km per Sverdrup Over entire path	-

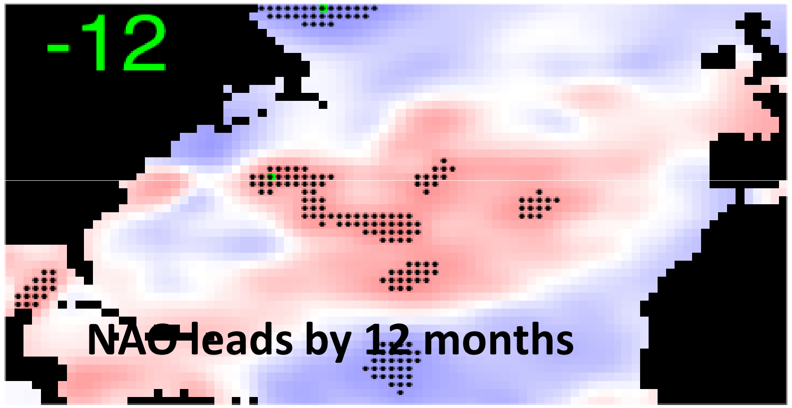
SSH pattern Forced by the NAO (interannual, spatially smoothed)

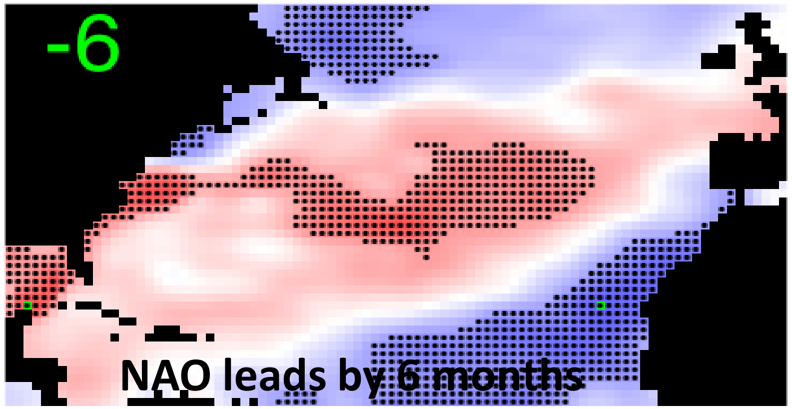
- SSH increases in the central tropical gyre and decreases in the subpolar and SE Subtropical gyre.
- GS path shifts North and increases in strength downstream



SST pattern associated with NAO (Vizbeck et al, 2001)



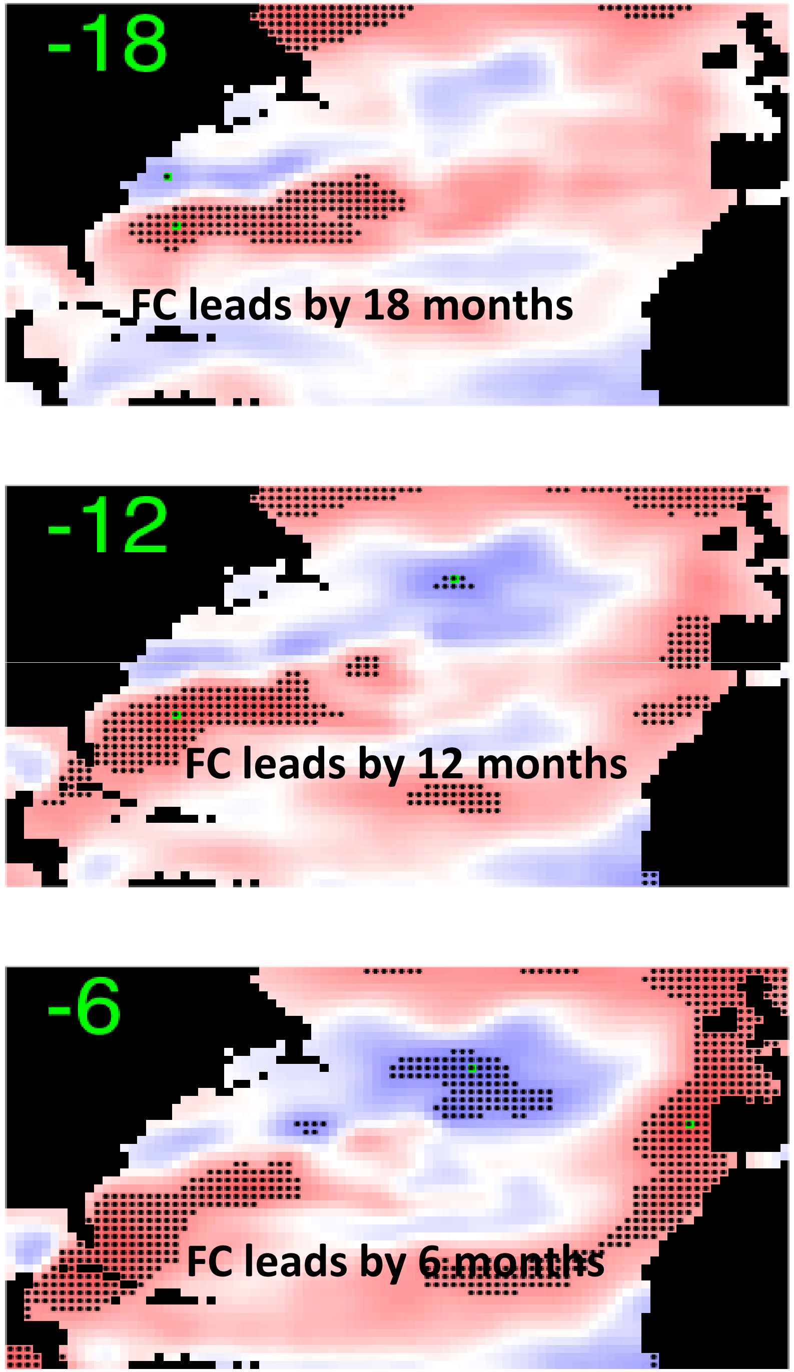




SSH pattern forced by changes in the Florida Current (interannual, spatially smoothed)

SSH increases in the western subtropical gyre (heat content increase)
Decreases in NAC (heat content decrease)

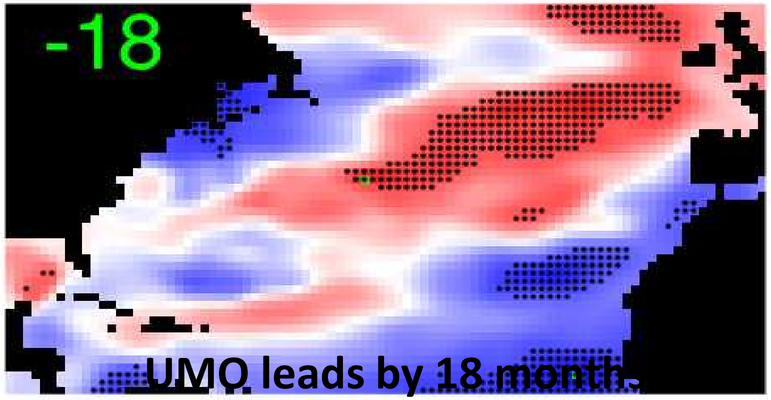
GS increases in strength downstream of seamounts

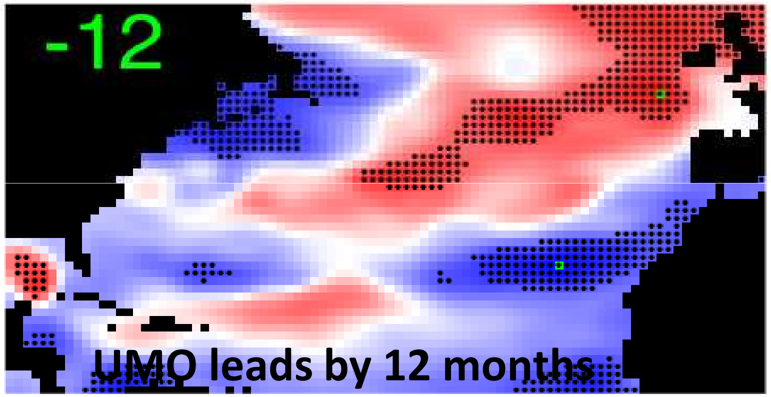


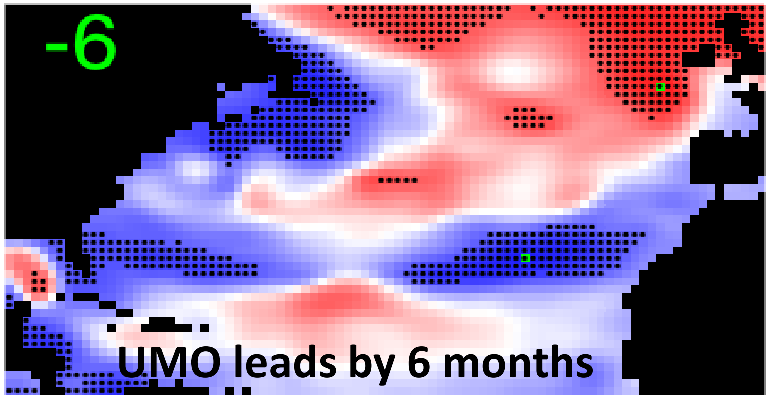
SSH pattern forced by changes in UMO

SSH/heat content increases in "intergyre"/NAC
Decreases northeast of North America
Decreases across the basin at 26N

Northward shift of GS path upstream of seamounts



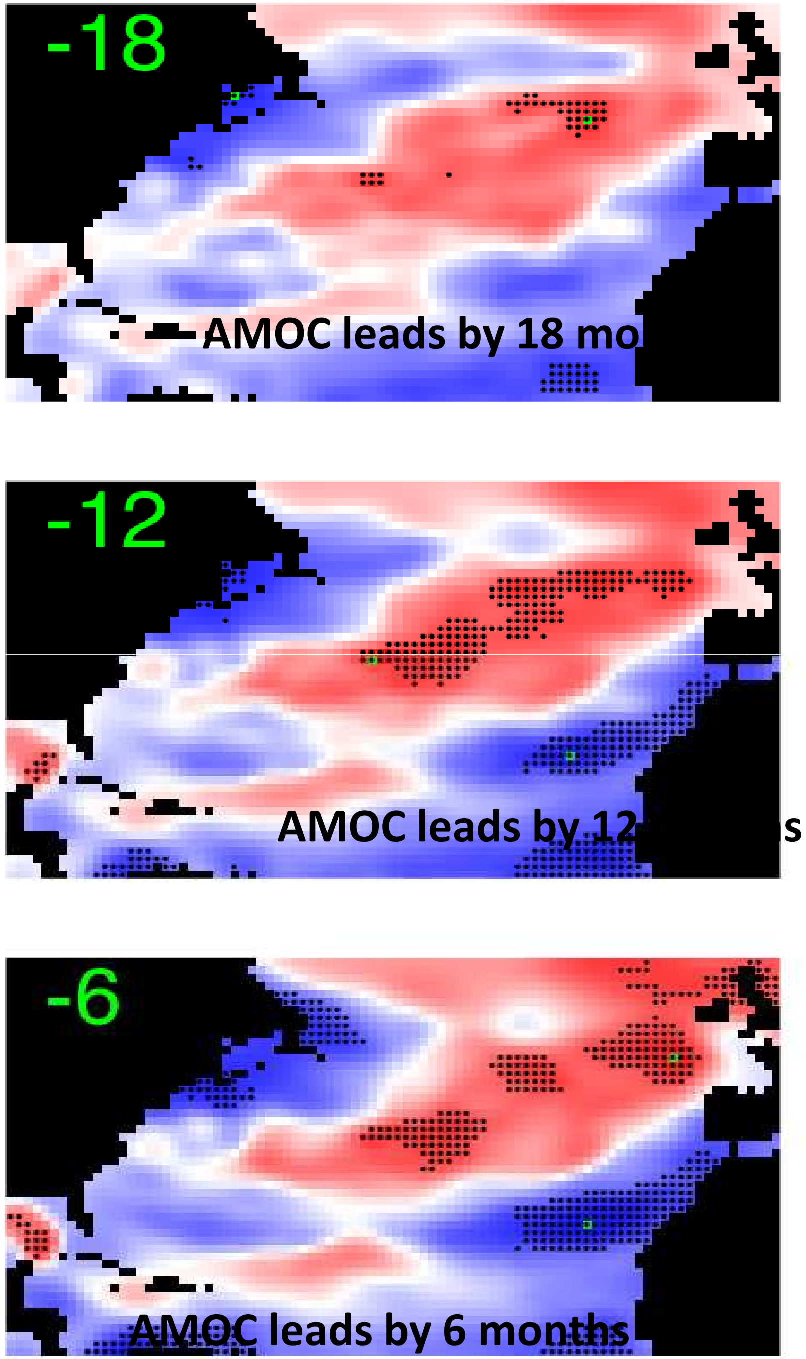


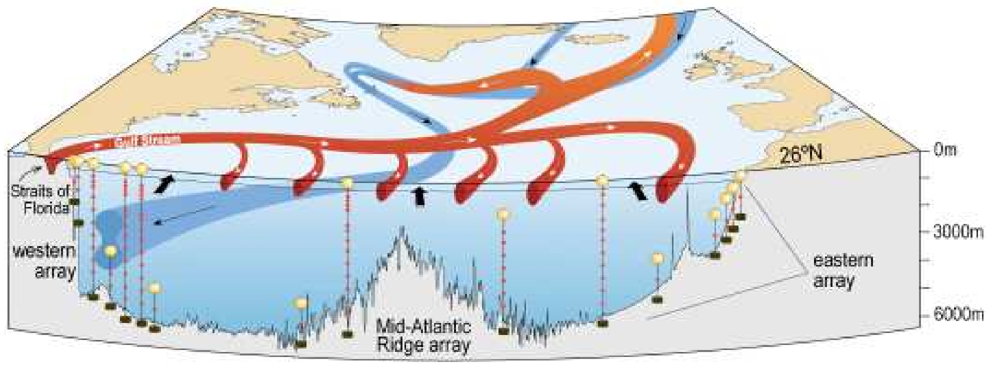


SSH pattern forced by changes in AMOC: combination of Florida Current and Upper Mid Ocean response

SSH/heat content increases in “intergyre” and decrease off northeast North America

Northward shift of GS path upstream (UMO) and strengthening downstream (FC)





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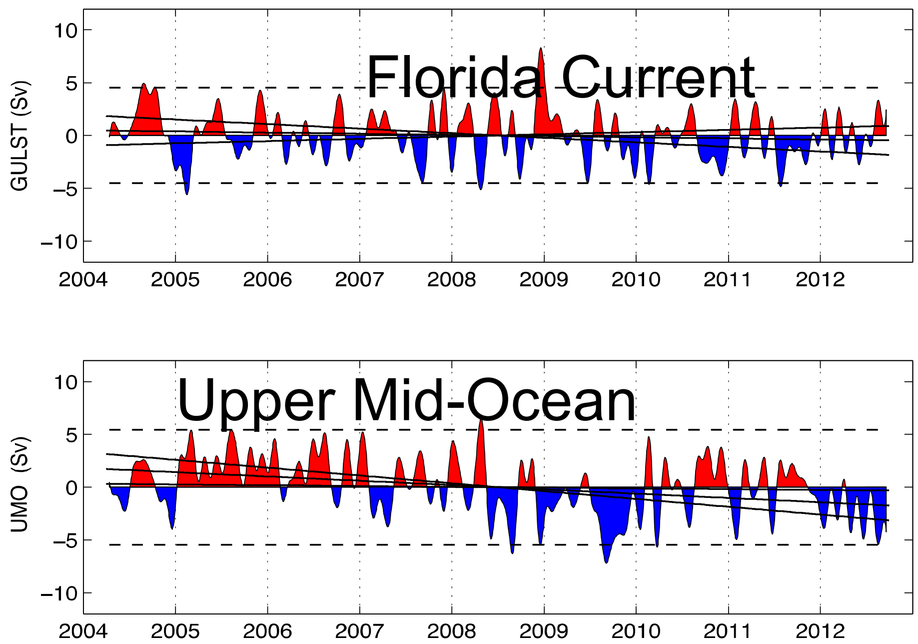
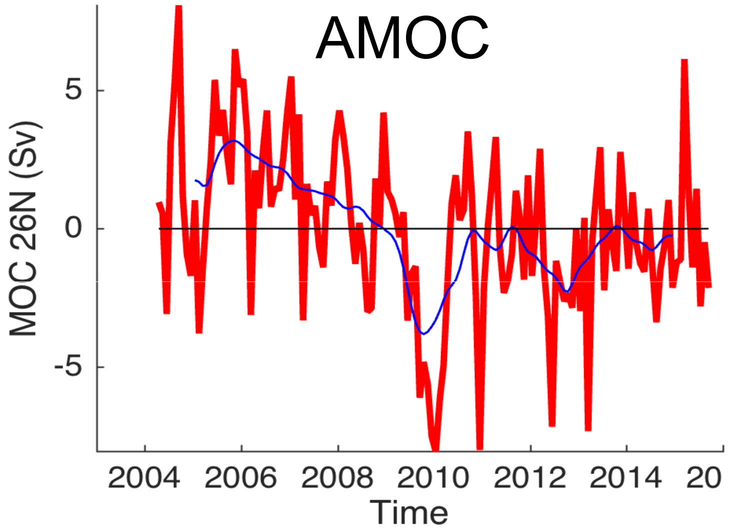
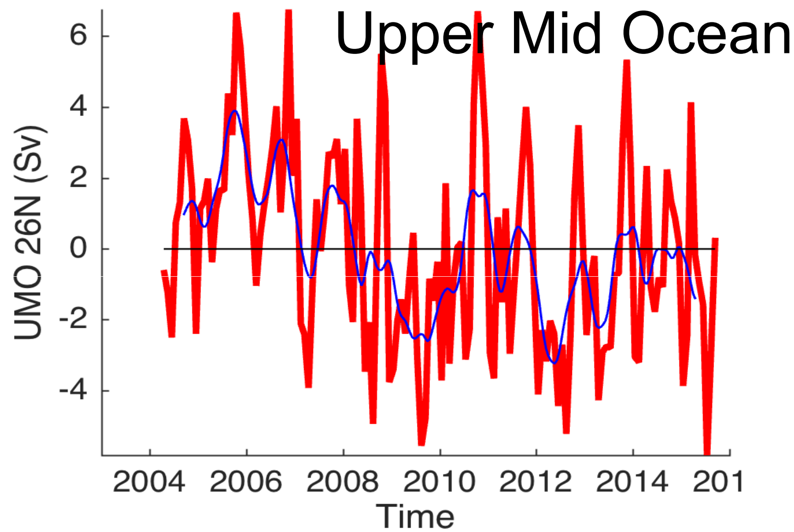
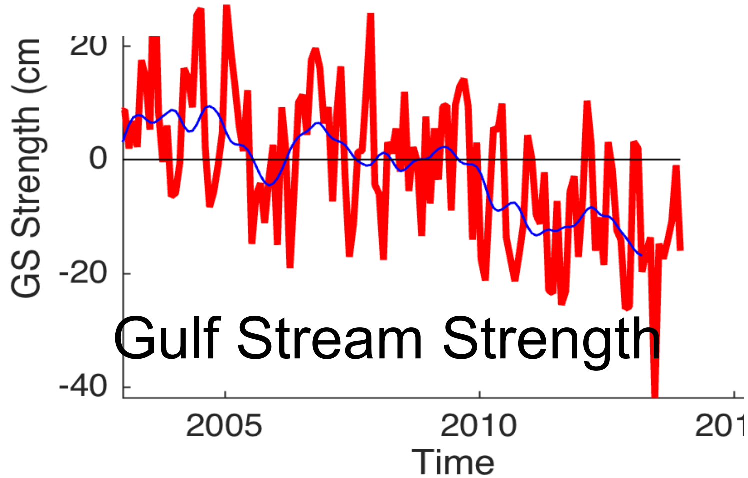


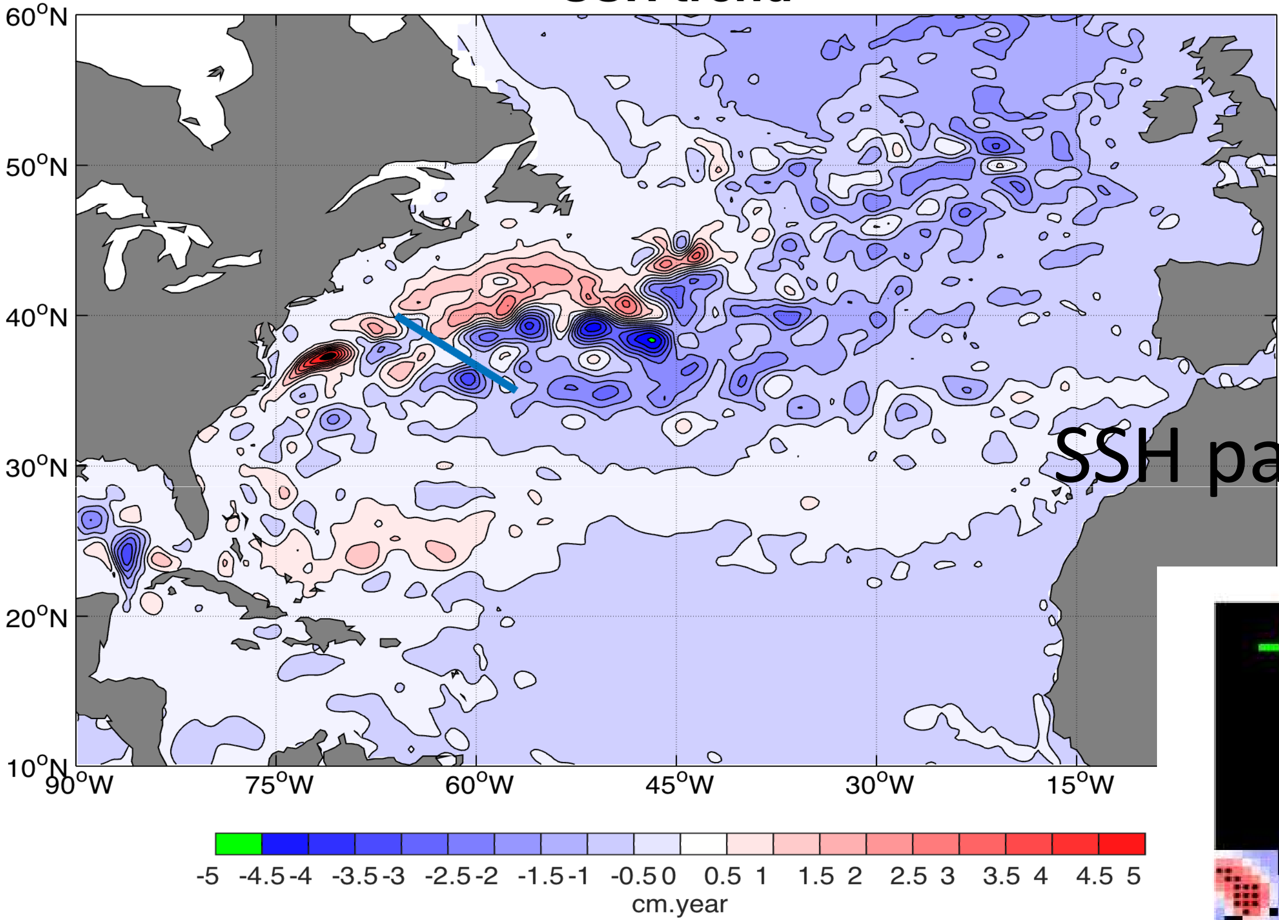
Trend in AMOC 2004-2014: linked to SSH/heat content and GS changes 2004-2014



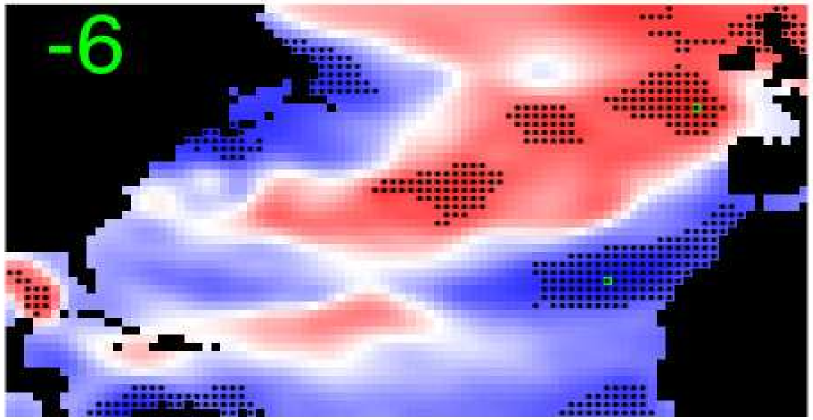




Trend in SSH 2004-2014



SSH pattern associated with AMOC



- ***Interannual Variability***
  - Response of Gulf Stream different upstream and downstream of New England Seamounts; the location where the mean speed of Gulf Stream decreases.
  - Confirmation of the important role of the NAO in controlling Gulf Stream position, and we also find a relationship with strength
  - Increase UMO linked to northward shift
  - Increase in Florida Current linked to increase in Gulf Stream Strength
  - Increase in AMOC linked to northward shift and increase in strength
- ***Trends***
  - Downward trend in AMOC occurs at the same time as the decrease in Gulf Stream Strength downstream of the New England Seamounts
  - Structure of SSH trend mirrors the response of SSH to AMOC on interannual time scales.

Conclusions

SSH allows us to build continuous times series

- Florida Current
- Upper Mid Ocean transport and AMOC at 26N
- Gulf Stream path and strength
- Also 41N AMOC Hobbs and Willis (2012)

This analysis shows that basin scale upper ocean heat content and Gulf Stream properties are tightly linked to changes in all components of AMOC at 26N.

See poster by Kelly et al SC2-008 where we use SSH along with in situ compilations to infer meridional heat and fresh water transport
Impact of slowdown of Atlantic Overturning Circulation on heat and fresh water transports