New insights into decadal North Atlantic SST and OHC variability from a high resolution coupled

Ben Moat[1], Bablu Sinha[1], Simon Josey[1], Jon Robson[2], Pablo Ortega[3], Florian Sévellec[4], N. Penny Holliday[1], Gerard McCarthy[5], Adrian New[1], and Joel Hirschi[1]

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IUGG19, 13th July 2019

NERC SCIENCE OF THE ENVIRONMENT

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Relationship between AMOC -> OHC -> SST
Decadal time scales
Subpolar North Atlantic

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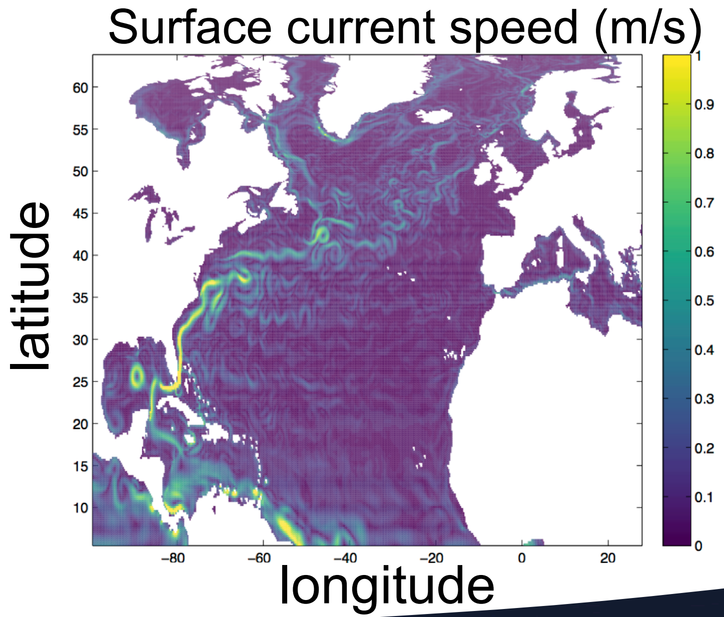
HADGEM3-GC2 CONTROL

Williams et al., (2015)

- NEMO ocean circulation/sea ice model (CICE)
- 1/4 degree NEMO GO5 ocean with 75 levels in the vertical.
- Atmosphere GA6: N216 (65km)
  85 levels in the vertical
- Eddy permitting ocean
- Run for 300 years
- Pre-Industrial forcing

Run by the Met Office, UK.

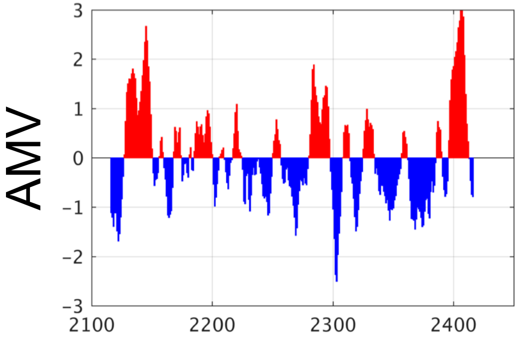


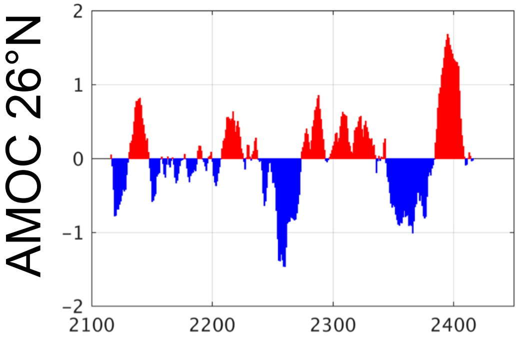
HADGEM3-GC2 Model Evaluation

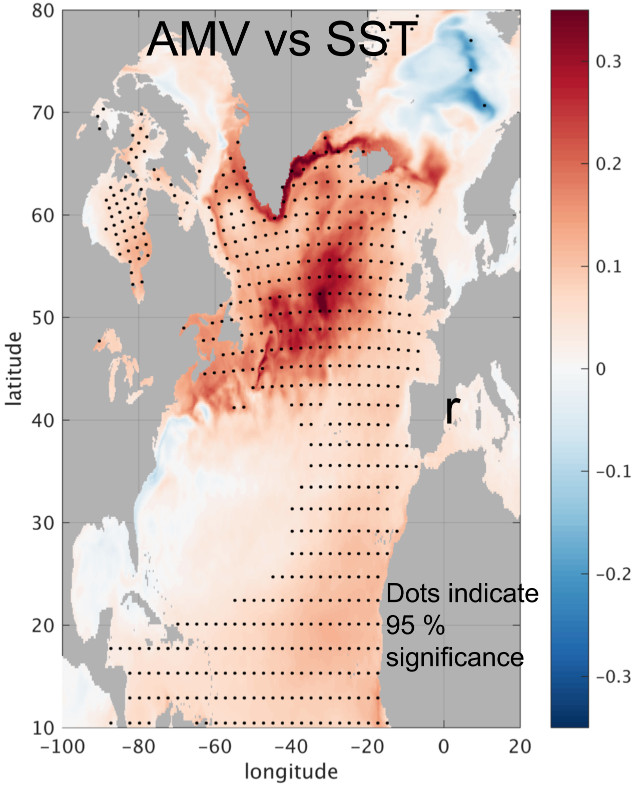
AMV period
Model: ~50 years
Obs: (30-70 years)

AMOC period 26N:
~60 Years

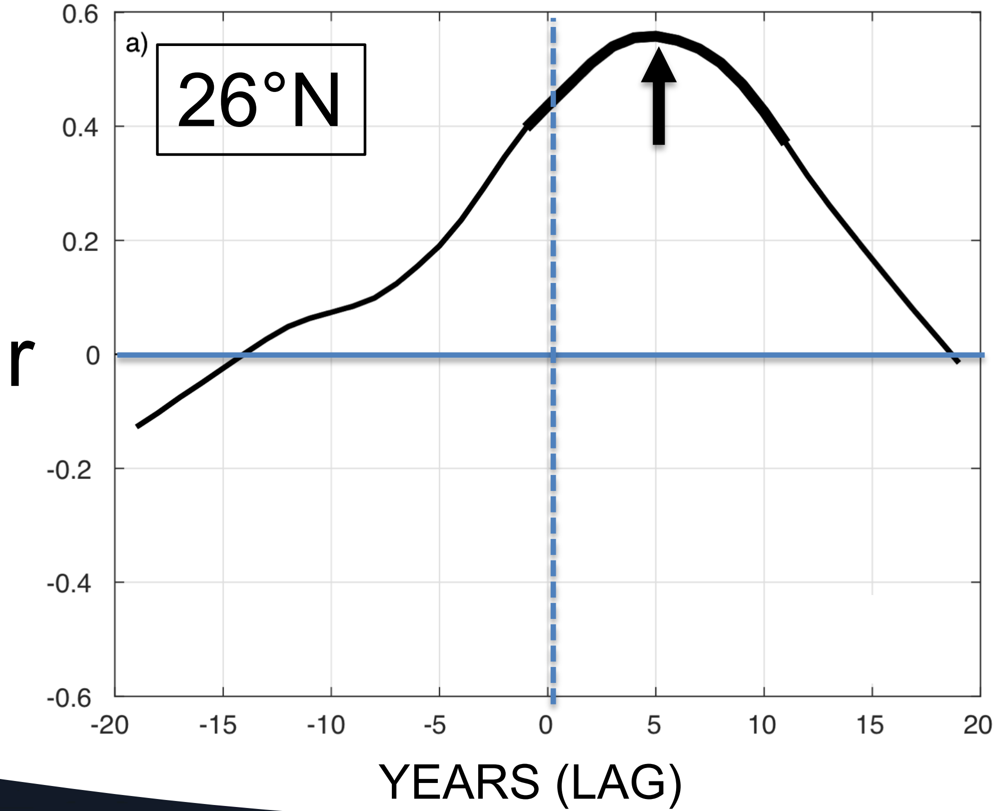
model 26N AMOC:
14.7 Sv, range 6.1 Sv
Observation:
17.1 Sv, range 7.6 Sv







Relationship between AMOC26N and AMV



AMOC leads the AMV by 5 years 26N.

What are the processes?
AMOC-> OHC ->SST

Thick lines indicate 95% significance

Mixed layer equation for SST

$$h\frac{\partial T_a}{\partial t} + h v_a . \nabla T_a + \nabla . \left(\int_{-h}^{0} \hat{v}\, \hat{t}\, dz\right) + (T_a - T_{-h})\left(\frac{\partial h}{\partial t} + v_{-h} . \nabla h + w_{-h}\right) = \left(\frac{Q_{NET} - Q_{-h}}{\rho_o C_p}\right)$$

Mixed layer temperature tendency

Horizontal advection

Vertical shear

Entrainment

Heat flux between the surface and base Of the mixed layer

Stevenson and Niiller, (1983)

Reformulated mixed layer equation for SST

$$\frac{\partial SST *}{\partial t} = \frac{(1-\lambda)Q^*_{NET}}{\rho \mathrm{Cp}\, \bar{h}} + \frac{R^*_{ML}}{\rho \mathrm{Cp}\, \bar{h}}$$

Adjusted advection-entrainment term for SST

$$Q^*_{-h} = \lambda Q^*_{NET}$$

λ=0.99

SST tendency
Diagnosed from model temperature

Adjusted surface fluxes term for SST

$$h = \bar{h} + h^*$$
$$Q_{NET} = \overline{Q_{NET}} + Q^*_{NET}$$
etc etc ..

$\bar{h}$ - mixed layer depth
ρ – density
Cp –specific heat capacity

Equations for SST and OHC

$$\frac{\partial SST^*}{\partial t} = \frac{(1-\lambda)Q^*_{NET}}{\rho \mathrm{Cp}\,\bar{h}} + \frac{R^*_{ML}}{\rho \mathrm{Cp}\,\bar{h}}$$

Mixed layer model for SST

$$\frac{\partial OHC^*}{\partial t} = Q^*_{NET} + R^*_{FD}$$

Full depth Ocean heat content

R^*_{FD} → **Advection**

$\bar{h}$ - mixed layer depth
ρ – density
Cp –specific heat capacity

Equations for SST and OHC

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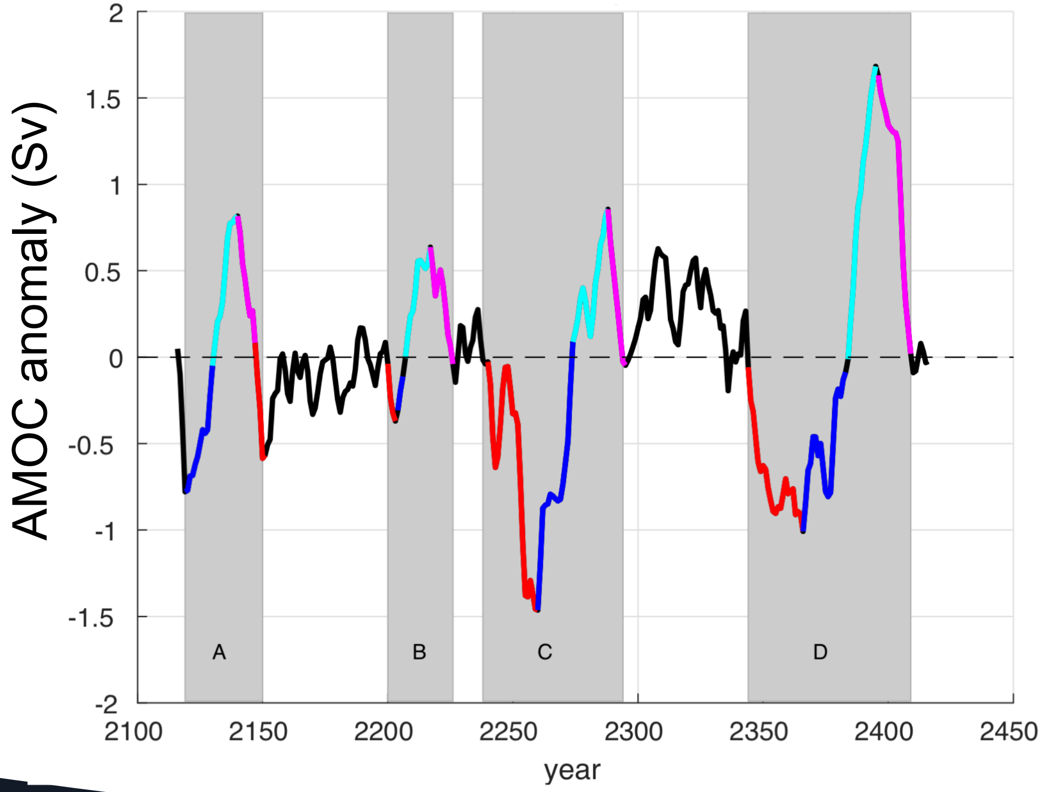
Composite AMOC 26° N



Analyze the cycles of the AMOC in terms of:

$$\frac{\partial SST*}{\partial t}$$

And

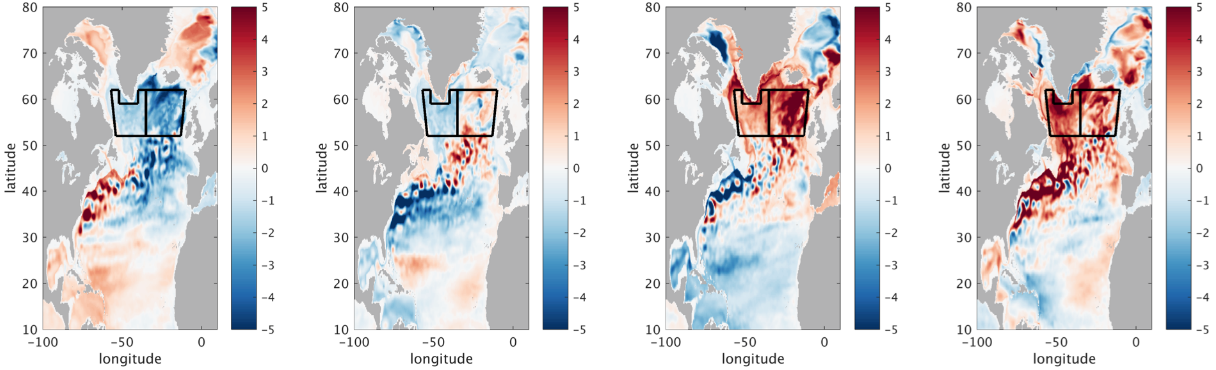
$$\frac{\partial OHC*}{\partial t}$$

25 to 65 year cycle

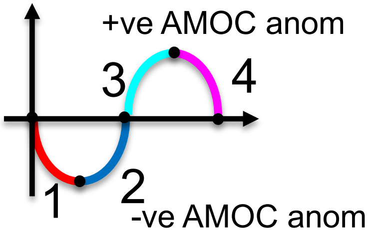
Mean OHC and SST tendency (26N)

OHC tendency (W m^{-2})

$$\frac{\partial OHC*}{\partial t}$$



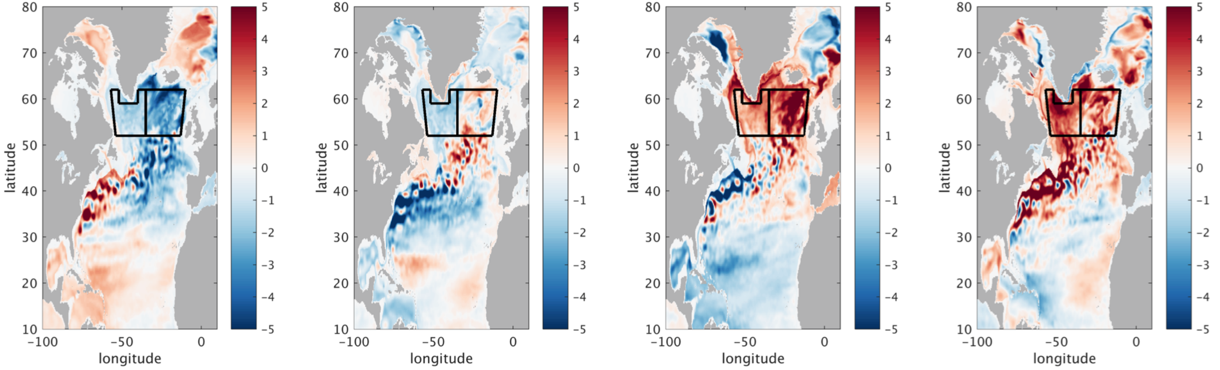
phase1 phase2 phase3 phase4



Mean OHC and SST tendency (26N)

OHC tendency ($W\ m^{-2}$)

$$\frac{\partial OHC *}{\partial t}$$

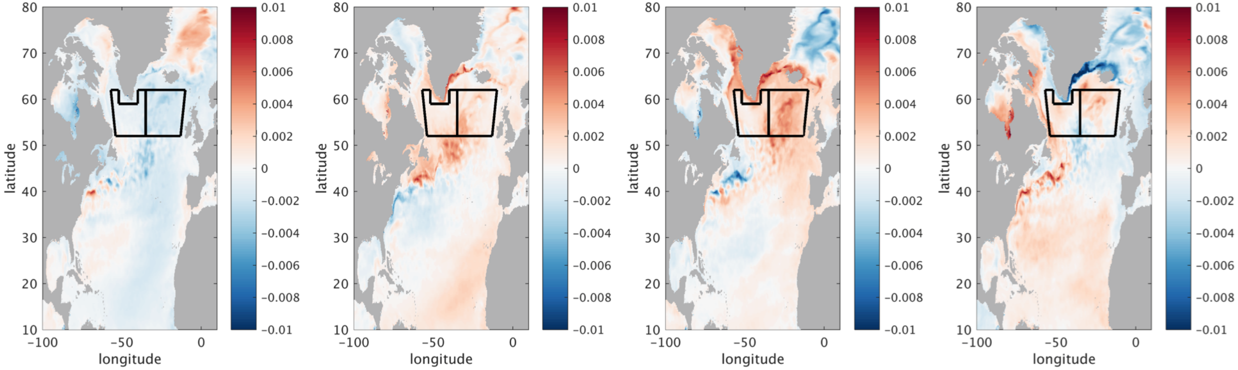


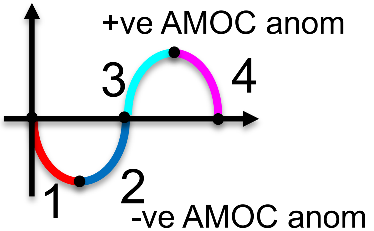
phase1 phase2 phase3 phase4

SPNA SST and OHC different in the SPNA

SST tendency ($K\ month^{-1}$)

$$\frac{\partial SST *}{\partial t}$$





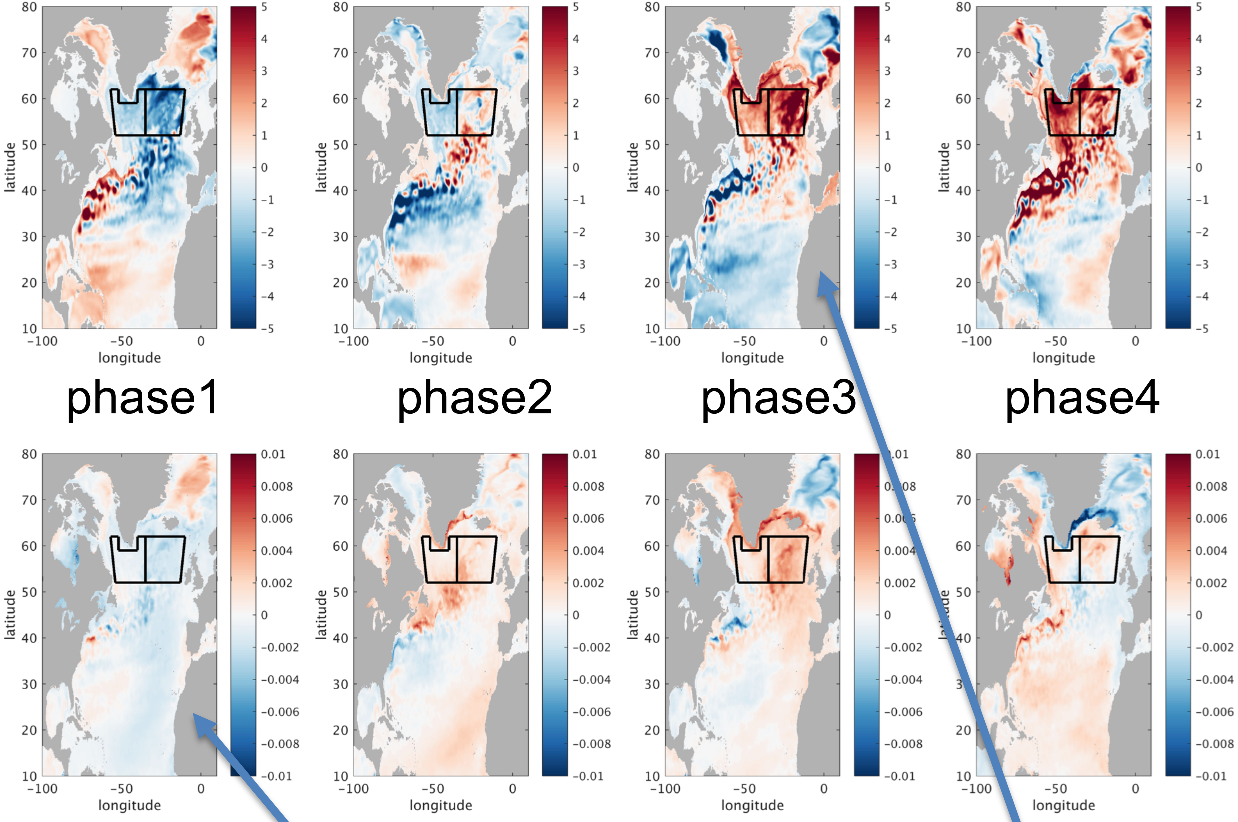
Mean OHC and SST tendency (26N)

OHC tendency (W m^{-2})

$$\frac{\partial OHC*}{\partial t}$$

SST tendency (K month^{-1})

$$\frac{\partial SST*}{\partial t}$$



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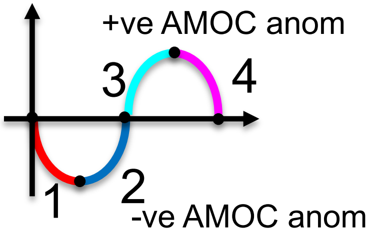
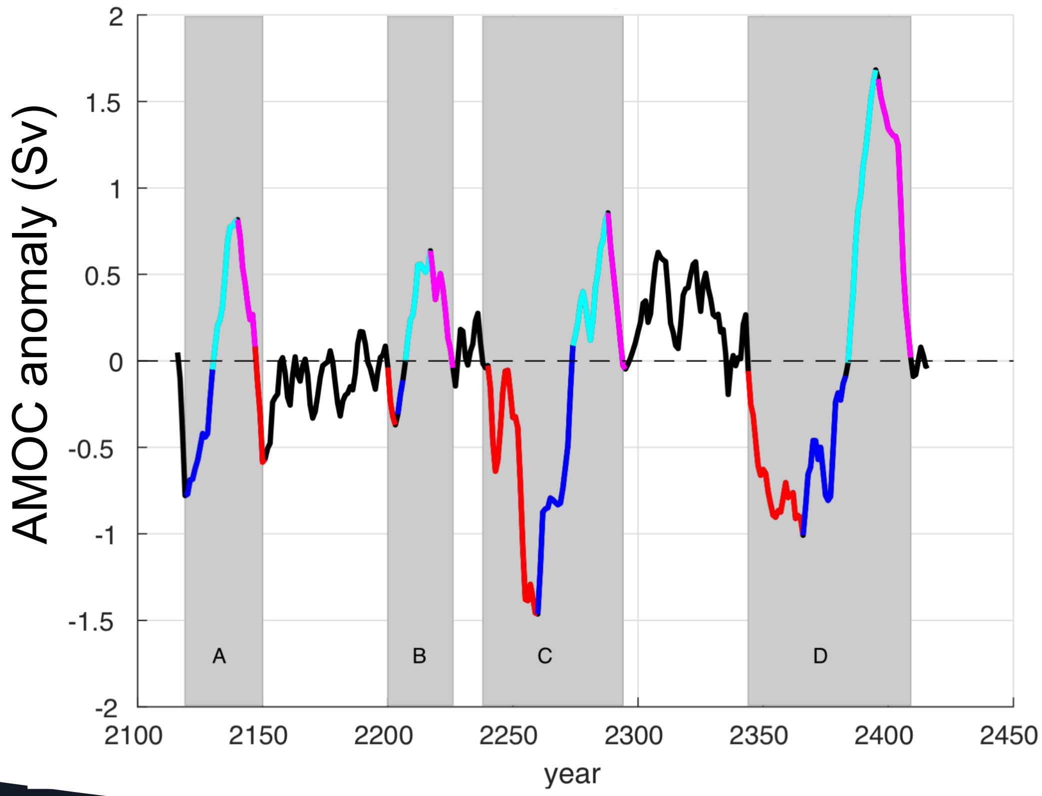


Agrees with: Smeed et al. (2018) and Zhang et al. (2008)

Composite AMOC 26° N



Analyze the cycles of the AMOC in terms of:

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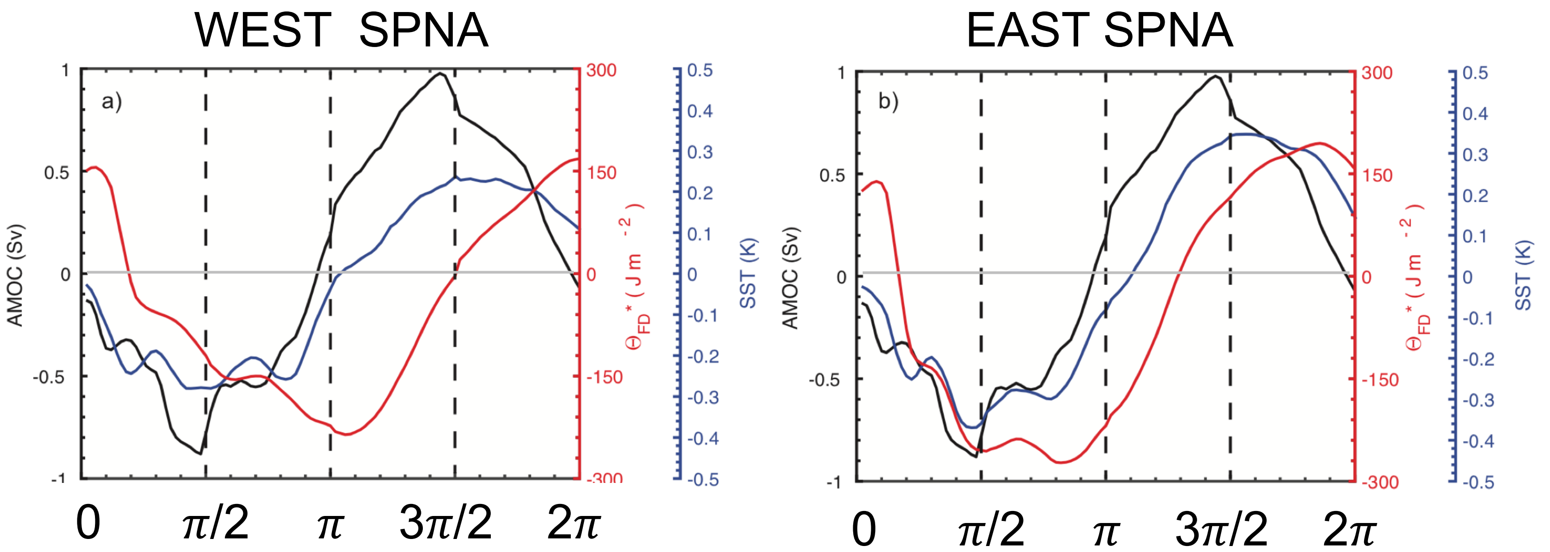
25 to 65 year cycle

SPNA composite

AMOC
OHC
SST



AMOC leads the SST and OHC

AMOC leads the SST and OHC
EAST OHC peaks before the west

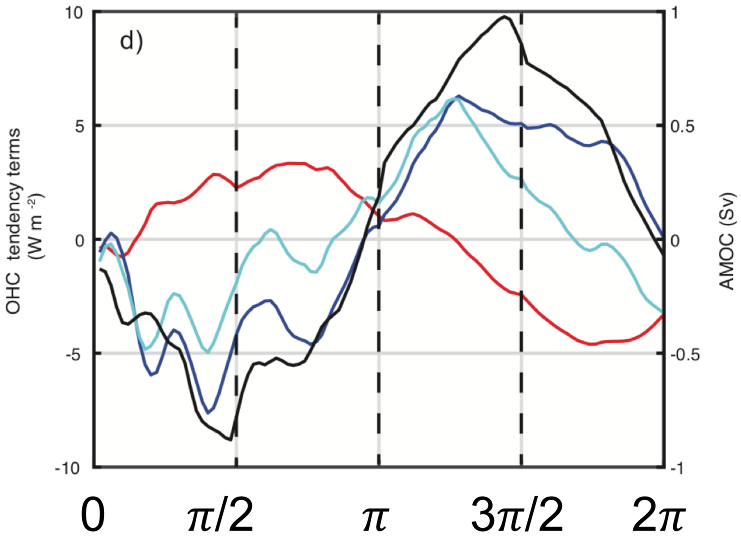
OHC and SST do not respond simultaneously

OHC tendency terms

WEST SPNA

EAST SPNA

$$\frac{\partial OHC^*}{\partial t} = Q^*_{NET} + R^*_{FD}$$



R_{FD}^* clearly related to the AMOC

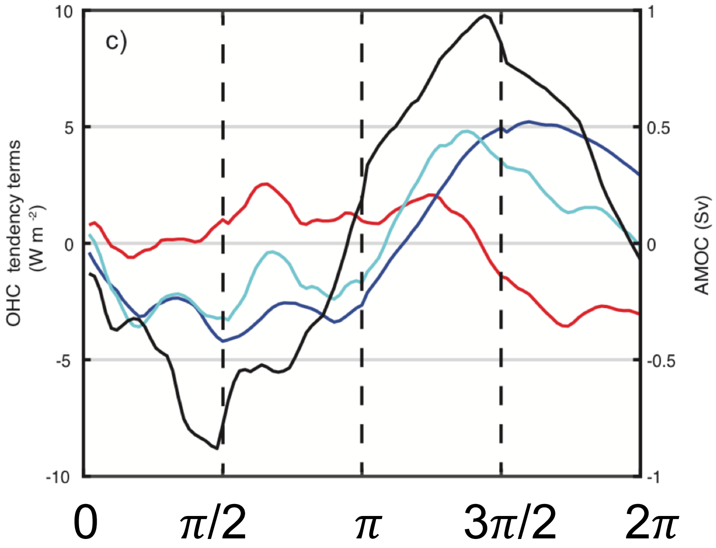
R_{FD}^* explains most of the tendency

Q_{NET}^* opposite sign and damping.

OHC tendency terms

$$\frac{\partial OHC^*}{\partial t} = Q^*_{NET} + R^*_{FD}$$

WEST SPNA

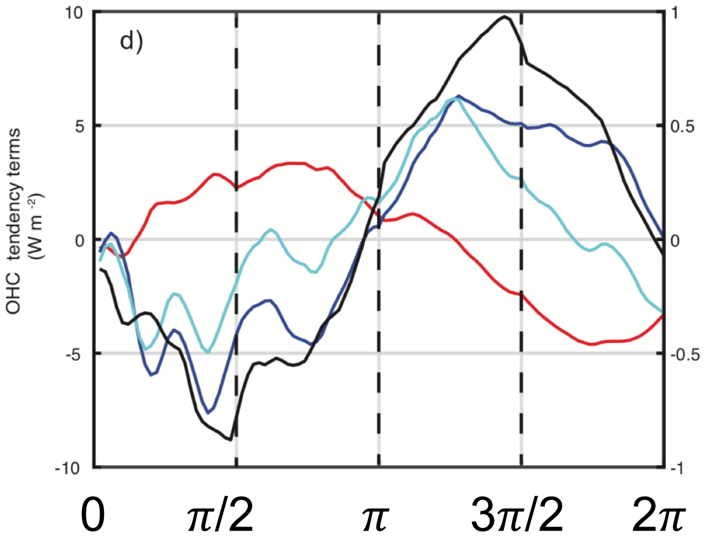


R_{FD}^* clearly related to the AMOC

R_{FD}^* explain most of the tendency

What's happened to Q_{NET}^*?

EAST SPNA



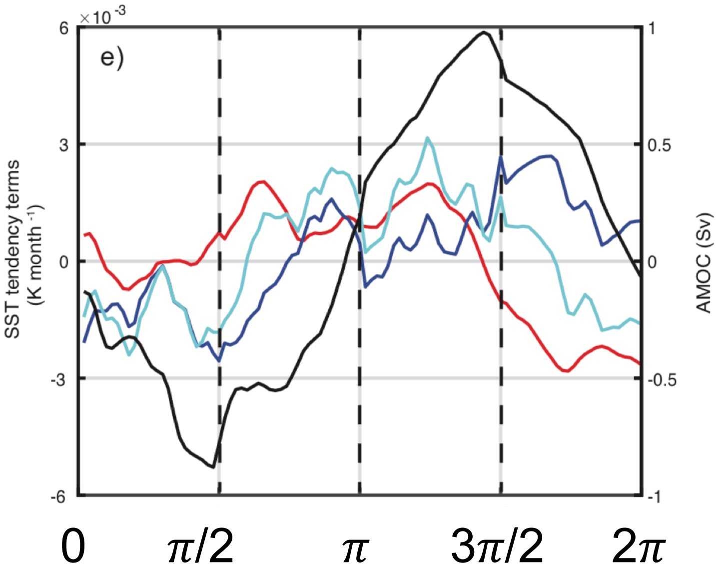
R_{FD}^* clearly related to the AMOC

R_{FD}^* explains most of the tendency

Q_{NET}^* opposite sign and damping.

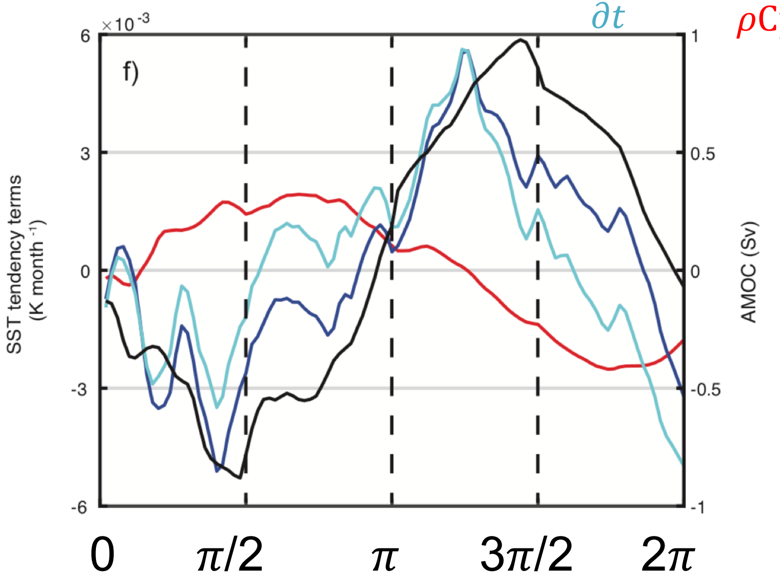
SST tendency terms

WEST SPNA



EAST SPNA

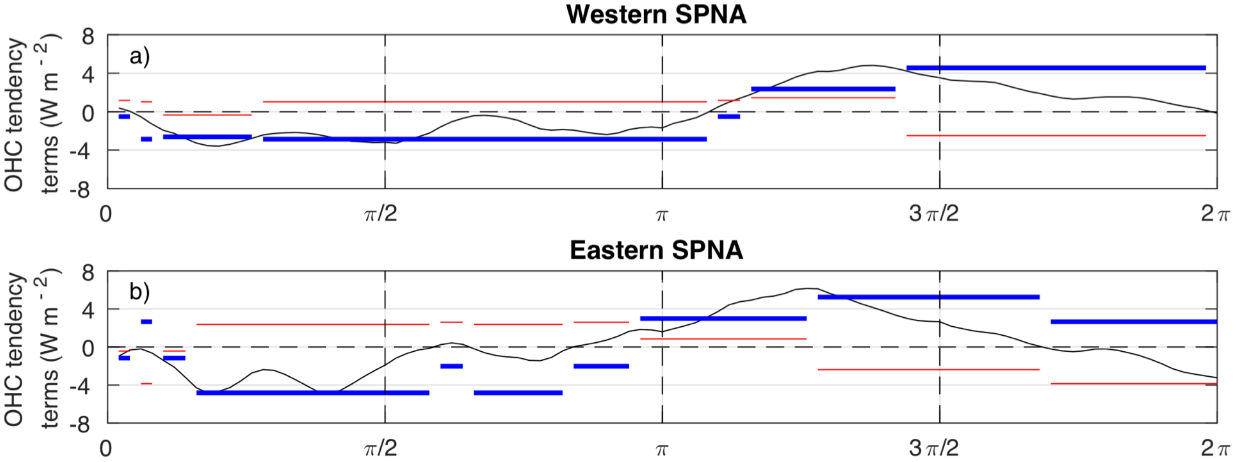
$$\frac{\partial SST^*}{\partial t} = \frac{(Q_{NET}{}^*)}{\rho \mathrm{Cp}\,\bar{h}} + \frac{R_{ML}{}^*}{\rho \mathrm{Cp}\,\bar{h}}$$



SST tendency proceeds AMOC
Q_{NET} changing SST.

Behaves similar manner to OHC in the east. SST tendency related to AMOC.

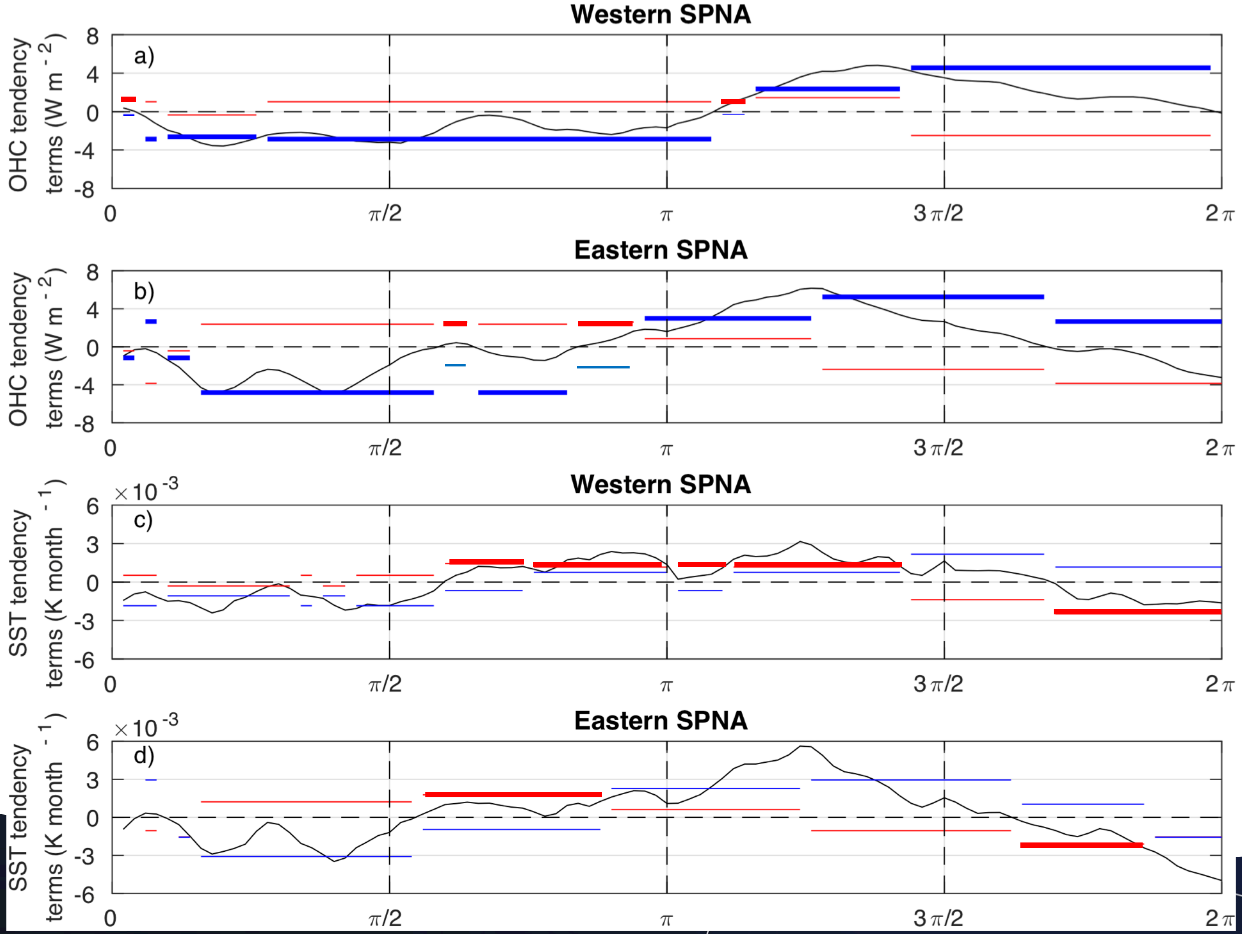
Drivers of OHC and SST variations



R_{FD}* the main driver
88% of the time
Q_{NET}*

R_{FD}* the main driver
66% of the time
Q_{NET}*

Drivers of OHC and SST variations



R_{FD}* the main driver 88% of the time
Q_{NET}*

R_{FD}* the main driver 66% of the time
Q_{NET}*

R_{FD}* (53% of the time)
Q_{NET}* largest at times

R_{FD}* (61% of the time)
Q_{NET}* largest at times

Conclusions

On decadal time scales in the subpolar North Atlantic (SPNA):

- OHC anomalies propagate (anticlockwise) around the SPNA with a clear relationship to the AMOC

- SST leads the OHC anomalies in the SPNA.

- OHC variability largely dominated by advection

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