Mechanisms of the recent decadal trend reversal in subpolar North Atlantic Ocean heat content

Chris Piecuch[1], Rui Ponte[1], Chris Little[1],
Martha Buckley[2], and Ichiro Fukumori[3]
[1]AER, [2]GMU, [3]JPL

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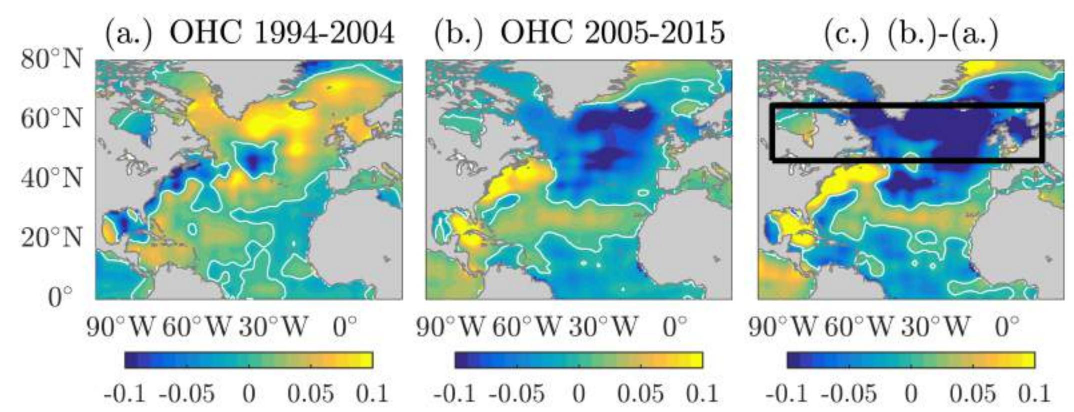
Recent Subpolar North Atlantic (SPNA) Decadal Climate "Shift"

- *Robson et al.* [2016, *Nat. Geosci.*, **9**] show that decadal trends in SPNA SST and OHC reversed sign in ~2005

Decadal trends in observed upper ocean (top 700 m) mean temperature [°C/yr]



- Not due to Ekman transports or surface heat fluxes, but related to changing AMOC and Labrador Sea densities

Focus of our Investigation

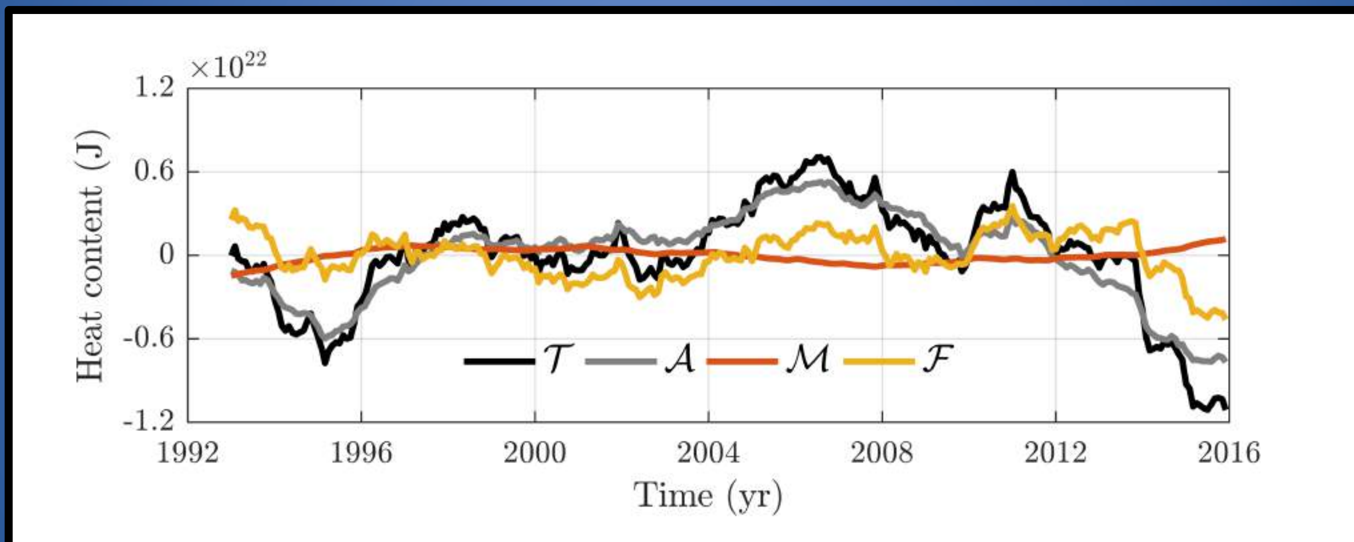
- What was responsible for the recent decadal trend reversal in the SPNA?

- Use ECCOv4 [*Forget et al.*, 2015, *Geosci. Model Dev.*, **8**]
  - Release 3 global ocean and ice state estimate over 1992-2015
  - Constrained to most available ocean observations (altimetry, GRACE, Argo and other *in situ* hydrography data, etc.)
  - Agreement with data achieved through adjustments to control vector (i.e., initial and boundary conditions, mixing coefficients)
  - Physically consistent general circulation model solution

ECCOv4 SPNA heat budget

- Diagnose OHC budget for SPNA (46-65°N) in ECCOv4:

$$\boldsymbol{T} = \boldsymbol{A} + \boldsymbol{M} + \boldsymbol{F}$$

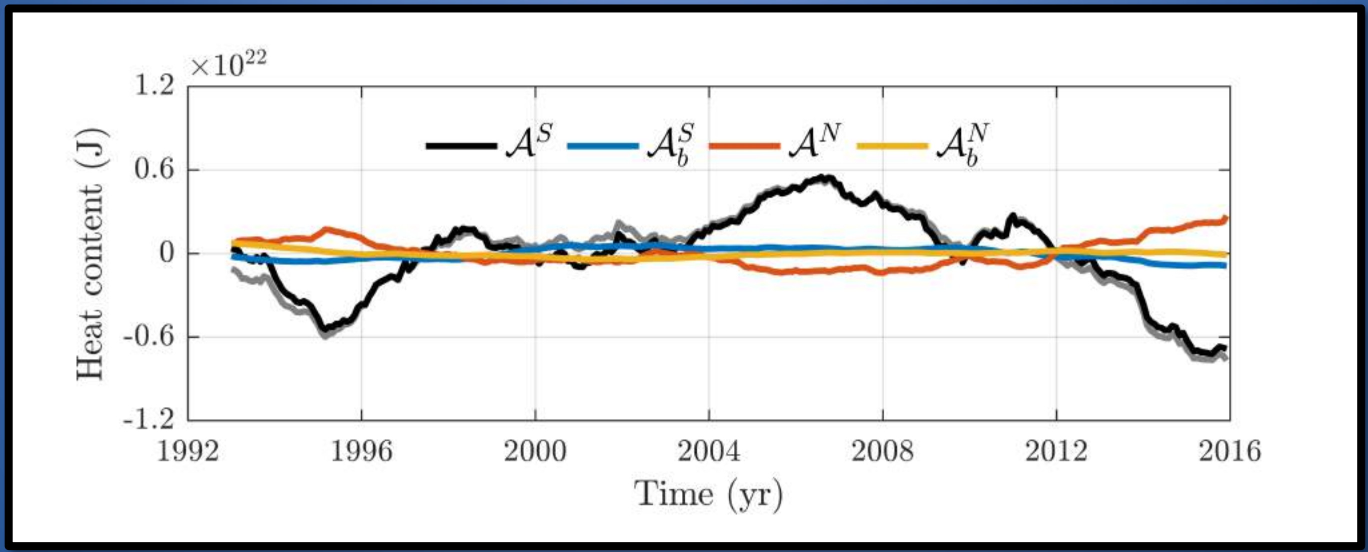


- Decadal SPNA OHC changes ***T*** are mostly related to changes in advection ***A***

Partitioning the advection

- Separate resolved and parameterized, southern- and northern-boundary components of advection [***A***]:

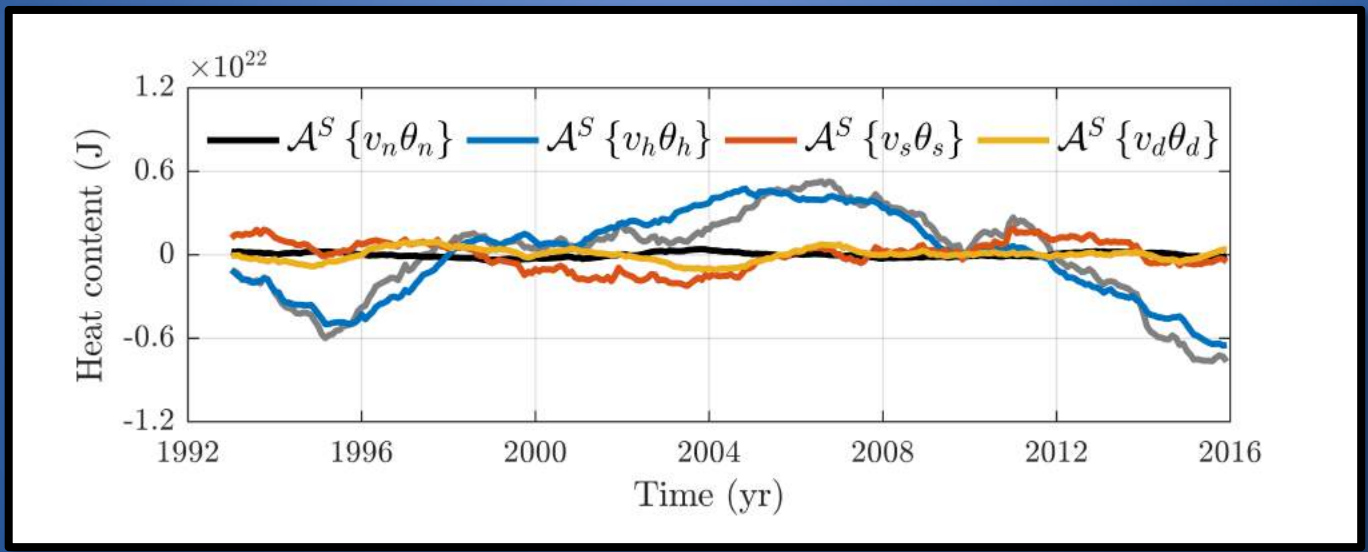
$$\boldsymbol{A} = \boldsymbol{A}^S + \boldsymbol{A}^S_b + \boldsymbol{A}^N + \boldsymbol{A}^N_b$$



- ***A*** mostly due to resolved advection across the SPNA southern boundary $\boldsymbol{A}^S$ (along 46°N)

Circulation decomposition

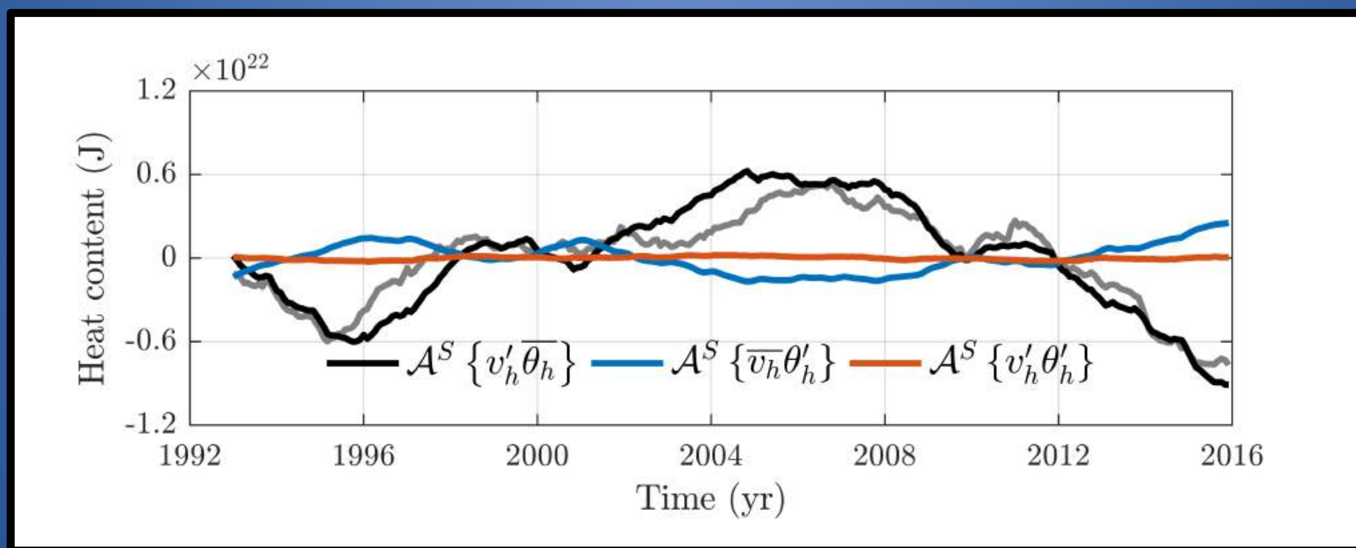
- Identify $\boldsymbol{A}^S$ changes due to net mass ($\boldsymbol{A}^S\{v_n\theta_n\}$), horizontal gyre ($\boldsymbol{A}^S\{v_h\theta_h\}$), shallow Ekman overturning ($\boldsymbol{A}^S\{v_s\theta_s\}$), and deep geostrophic overturning ($\boldsymbol{A}^S\{v_d\theta_d\}$)



- Horizontal gyre transports $\boldsymbol{A}^S\{v_h\theta_h\}$ contribute most importantly to decadal changes in advection $\boldsymbol{A}^S$

Variable decomposition

- Quantify roles of variable gyre velocity v_h ($\boldsymbol{A}^S\{v_h' [\theta_h]\}$), variable potential temperature θ_h ($\boldsymbol{A}^S\{[v_h] \theta_h'\}$), and covariance between v_h and θ_h ($\boldsymbol{A}^S\{v_h' \theta_h'\}$)



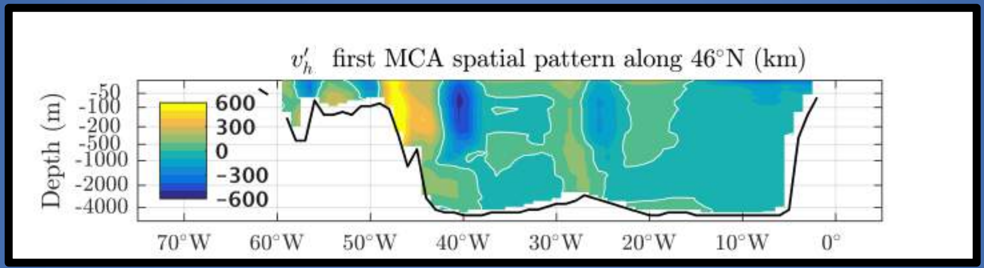
- Dominant decadal $\boldsymbol{A}^S\{v_h\theta_h\}$ contributions are rendered by horizontal gyre velocity anomalies $\boldsymbol{A}^S\{v_h' [\theta_h]\}$

Conclusions so far …

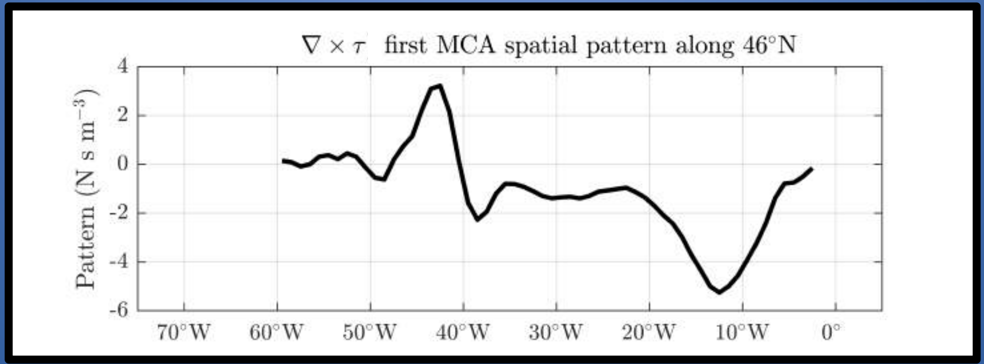
- Anomalous horizontal gyre circulations (v_h') along the SPNA southern boundary are the foremost contributor to a recent decadal SPNA OHC trend reversal in ECCOv4
- What drives these horizontal gyre circulation anomalies?
- Previous studies suggest that wind stress curl ($\nabla \times \tau$) is important forcing mechanism of gyre circulation changes
  - *Häkkinen and Rhines* [2009], *Häkkinen et al.* [2011, 2013], et al.
- Maximum Covariance Analysis of v_h' and $\nabla \times \tau$ along 46°N

MCA*—Spatial Structure

- v_h’ MCA pattern suggestive of anomalous gyre circulation



- ∇×τ MCA pattern is a modulation of mean ∇×τ pattern

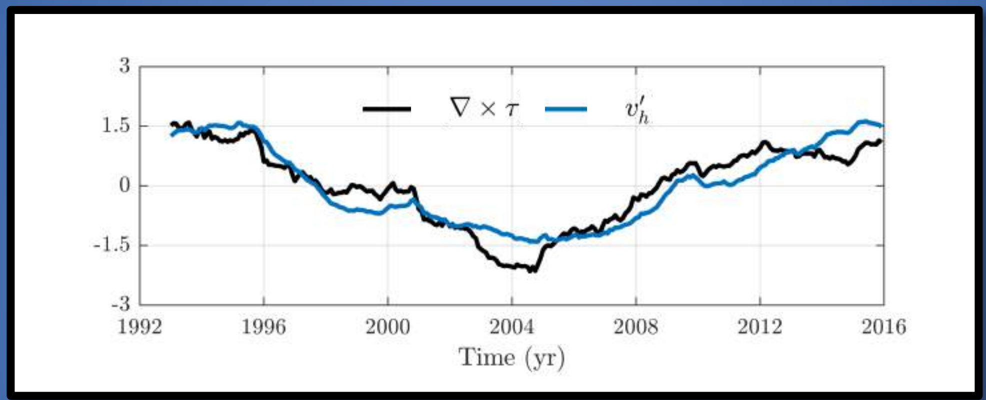


- The two MCA patterns roughly share the same sign

*Technical note—the MCA is performed on *time integrals* of v_h’ and ∇×τ

MCA*—Temporal Structure

- MCA time series are tightly correlated (*r*=0.92, *p*=0.05)



- Similar space and time structures suggest interpretation
  – Sverdrup balance: $V_{Sv} = (\rho\beta)^{-1}(\nabla\times\tau)$

*Technical note—the MCA is performed on ***time integrals*** of v_h' and $\nabla\times\tau$

Conclusions

- Decadal trends in SPNA OHC and SST reversed in 2005 and the ECCOv4 estimate captures the trend reversals
- Budget diagnostics reveal that the SPNA OHC trend reversal was mainly due to horizontal gyre circulation
- Statistical analysis suggests that gyre circulation anomalies were tied to changes in overlying wind curl

Conclusions (continued)

- Results do not support the hypothesis that the recent trend reversals were primarily linked to AMOC changes and declining Labrador Sea density [*Robson et al.* 2016]

- Future efforts will focus on quantifying uncertainties in the nature of SPNA heat budget over decadal periods [e.g., CMIP6, *Griffies et al.* 2016, *Geosci. Model Dev.*, **9**]

Thank you!

(questions?)

Recent SPNA Decadal Climate "Shift"

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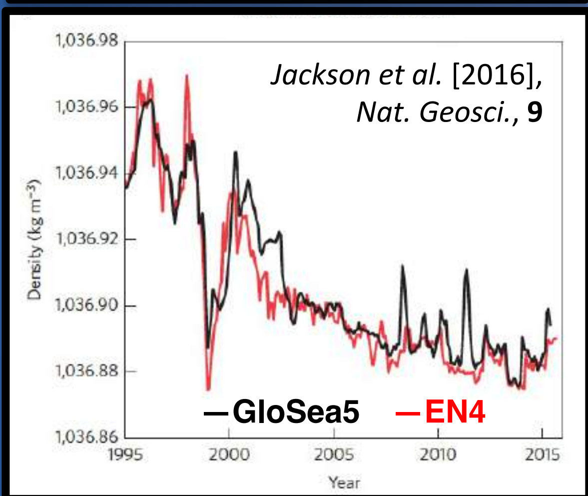
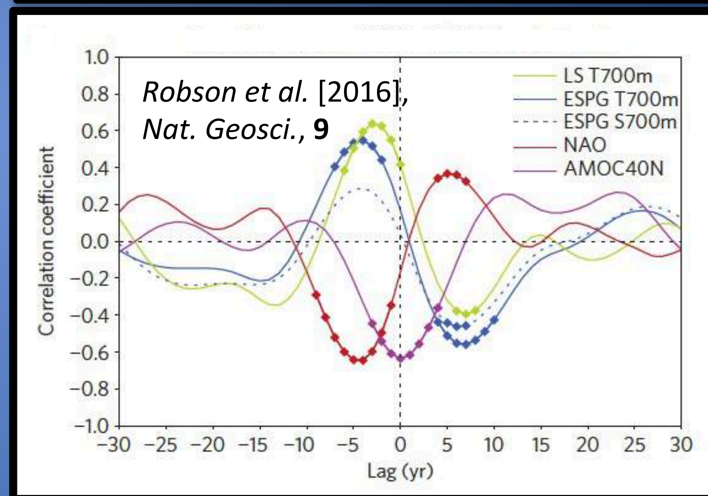
Observed Labrador Sea (LS) Density

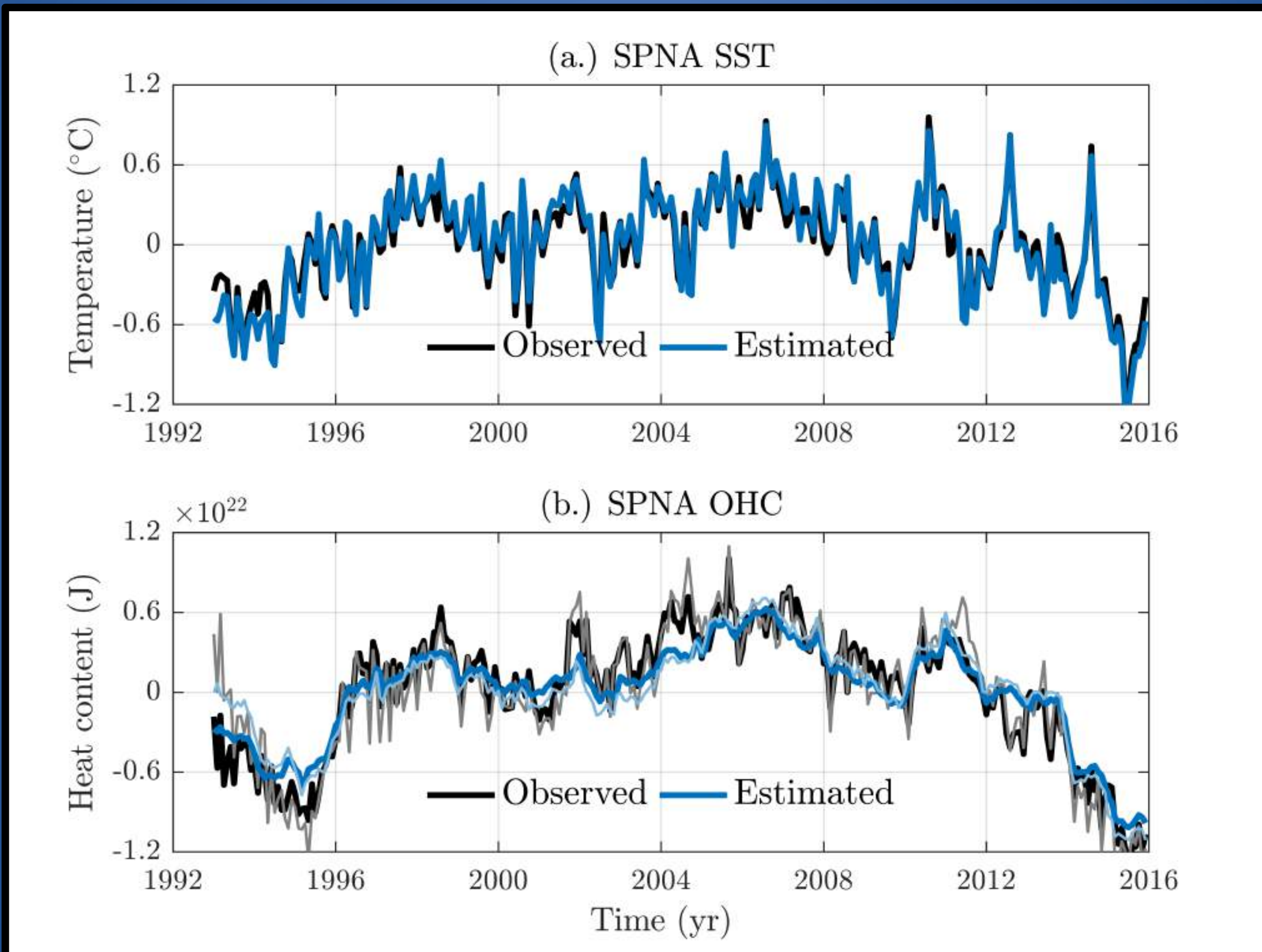


Correlation w/ LS Density Trends in HadGEM3-GC2



- Not due to Ekman transports or surface heat fluxes, but related to changing AMOC and Labrador Sea densities

Comparing ECCOv4 to Data in the SPNA



In (b), thick dark lines are 0-700 m values, while thin light lines are full-depth values