An ECCO Perspective on the AMOC

Christopher G. Piecuch (cpiecuch@whoi.edu)
Woods Hole Oceanographic Institution, Woods Hole, MA

Estimating the Circulation and Climate of the Ocean (ECCO) Summer School
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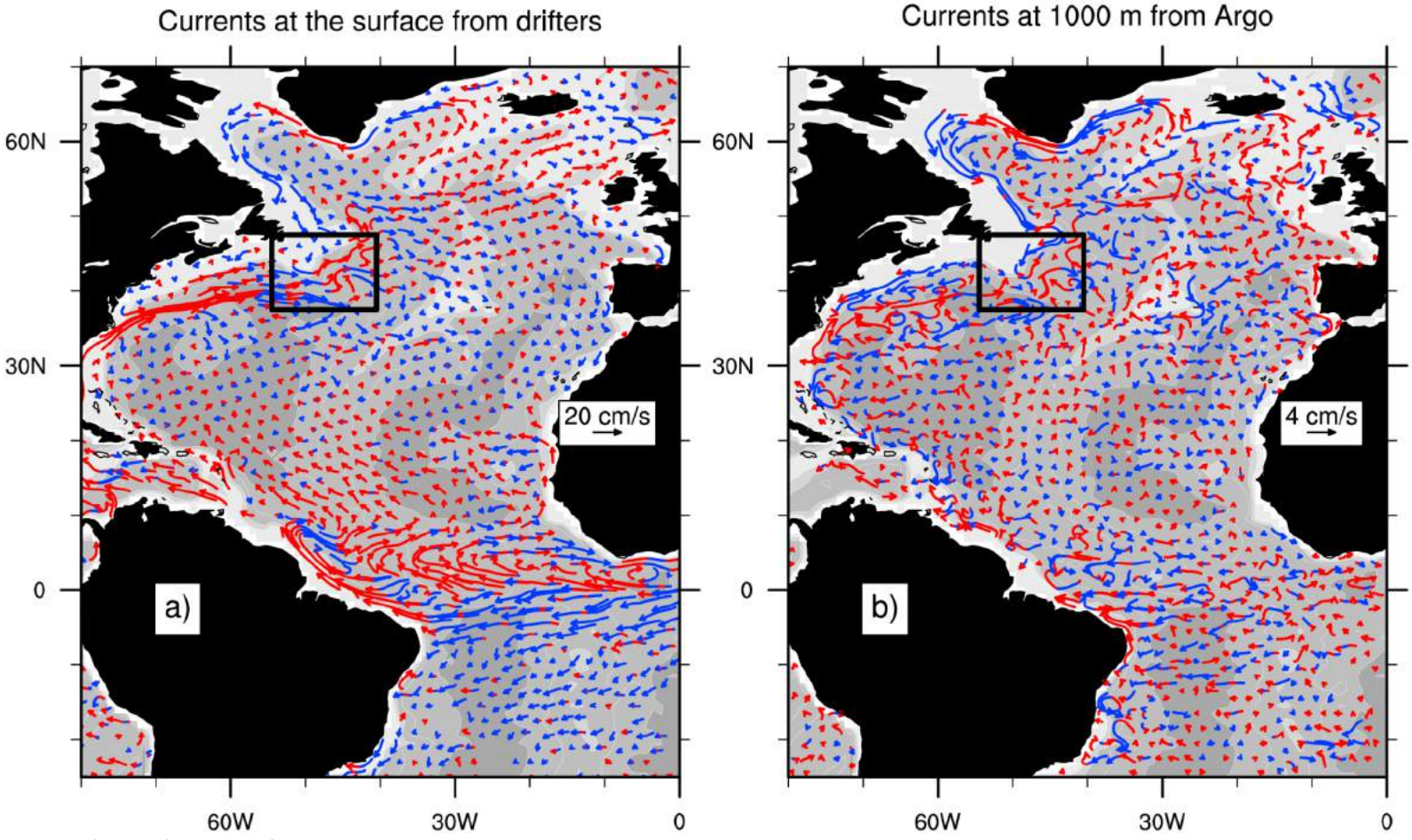
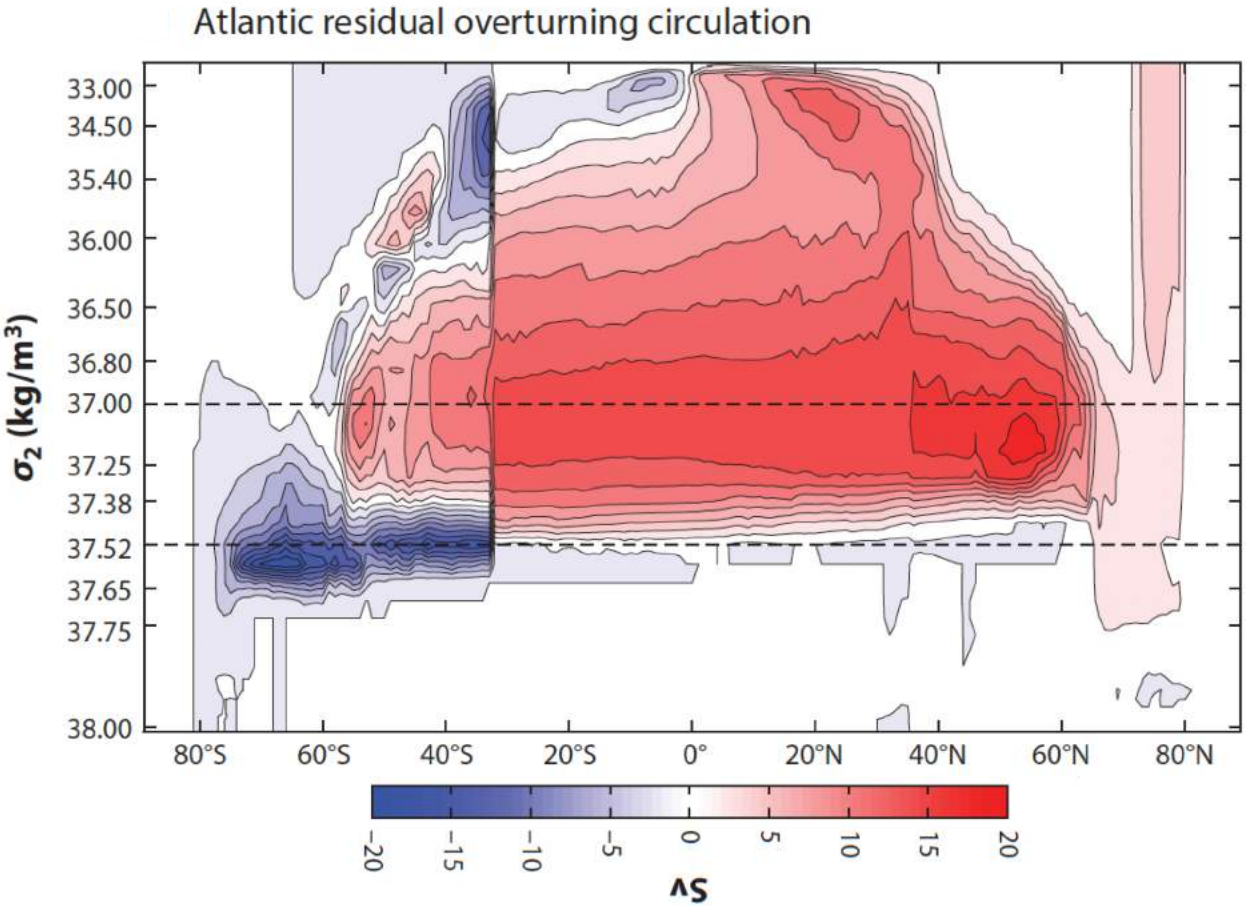
The Notion of the AMOC (Atlantic meridional overturning circulation)

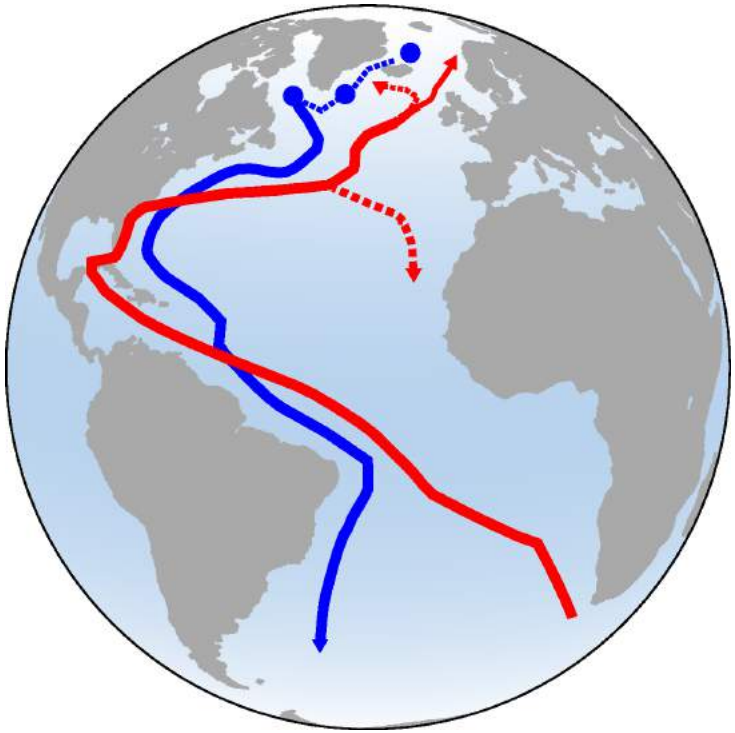
The Atlantic Ocean Circulation



Buckley & Marshall (2016), Rev. Geophys.

The AMOC

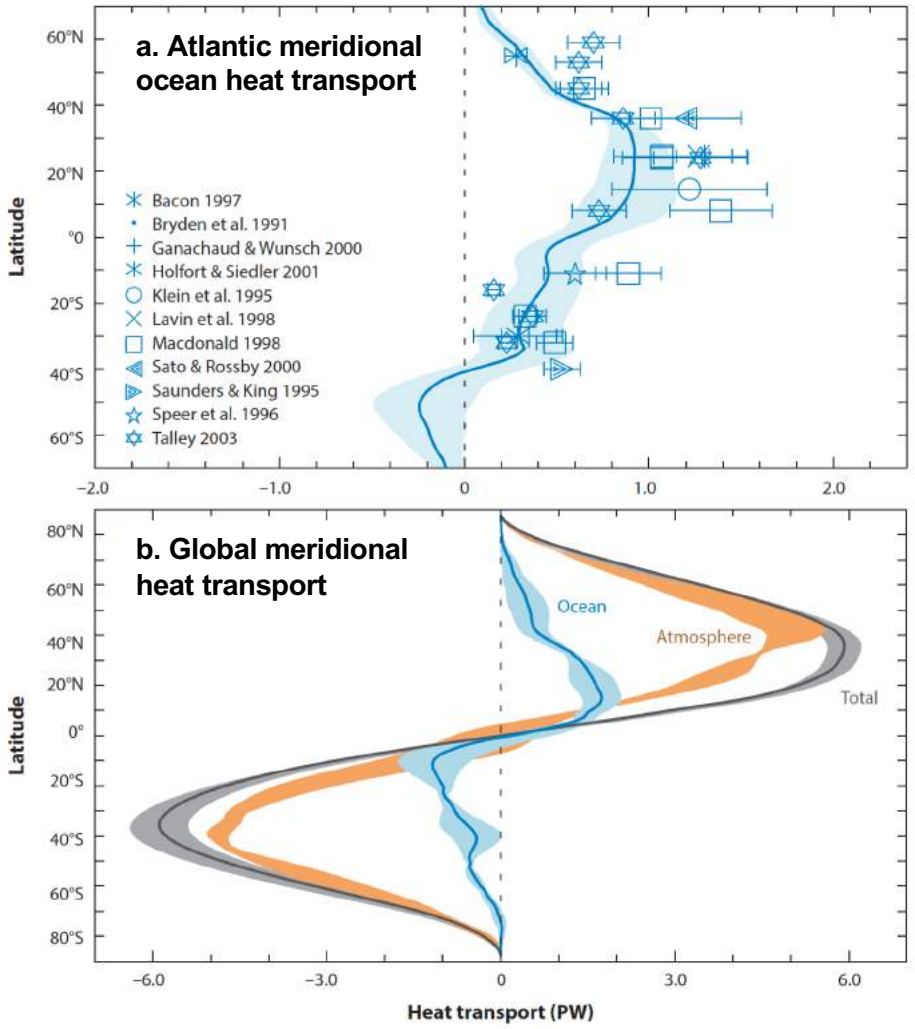




Cessi (2019), Annu. Rev. Mar. Sci.
Frajka-Williams et al. (2019), Front. Mar. Sci.

The Impact of AMOC on …

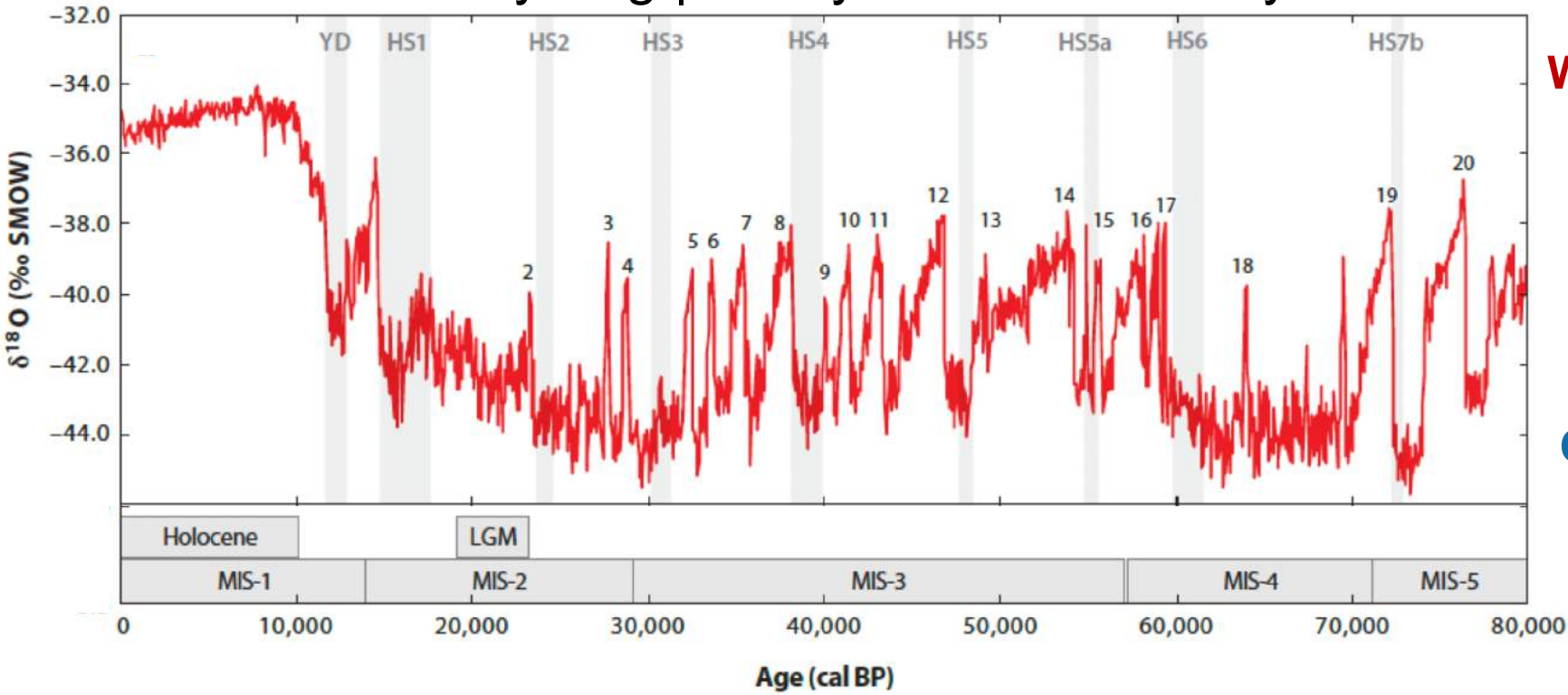
- **Climate & Variability**
- Abrupt Change
- Sea Level Rise
- Carbon Cycling
- Ecosystem/Productivity



Palter (2015), Annu. Rev. Mar. Sci.

cf. Sutton & Hodson (2005), Science; Knight et al. (2006), Geophys. Res. Lett.; Zhang and Delworth (2006), Geophys. Res. Lett.

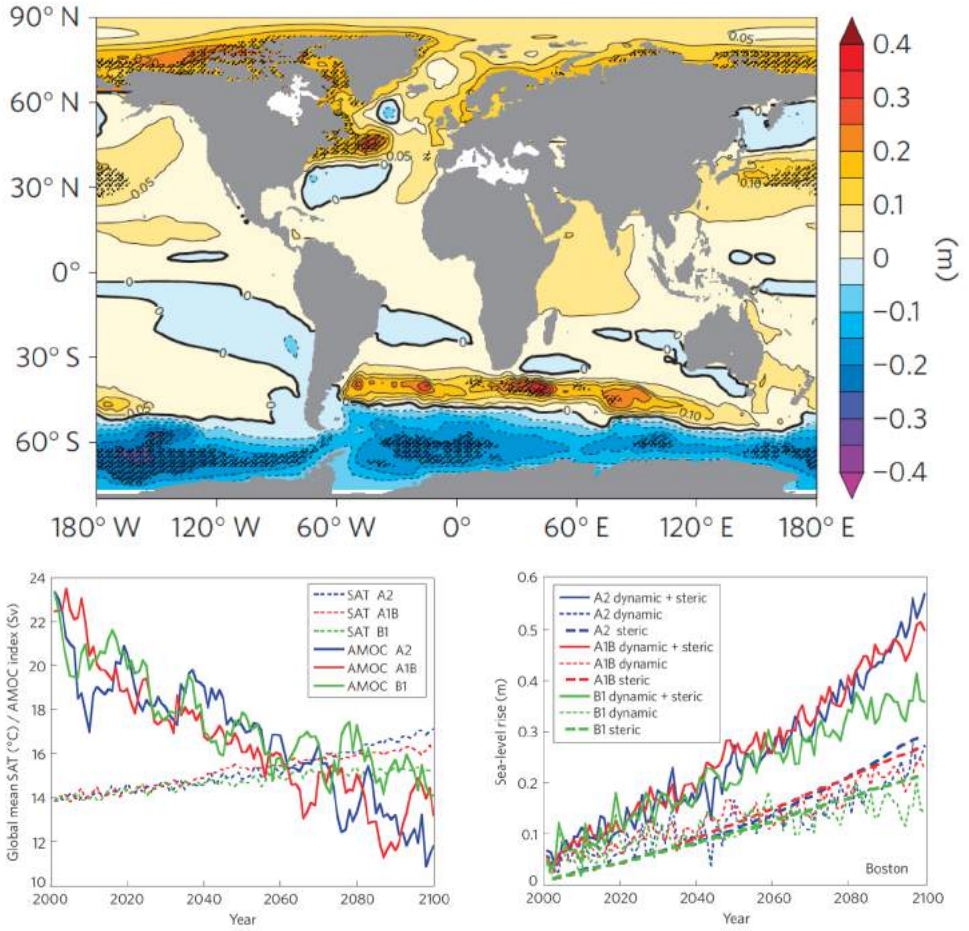
Climate & Variability | **Abrupt Change** | Coastal Sea Level
Carbon Cycling | Ecosystem/Productivity



YD = Younger-Dryas Cooling; HS = Heinrich “Stadials” (Cold Periods)
Numbers = “Dansgaard-Oeschger Events”; LGM = Last Glacial Maximum
MIS = Marine Isotope Stage

Lynch-Steiglitz (2017), Annu. Rev. Mar. Sci. cf. McManus et al. (2004), Nature; Palter (2015), Annu. Rev. Mar. Sci.

- Climate & Variability
- Abrupt Change
- **Sea Level Rise**
- Carbon Cycling
- Ecosystem/Productivity



Yin et al. (2009), Nat. Geosci.

cf. e.g., Landerer et al. (2007), J. Phys. Oceanogr.; McCarthy et al. (2015), Nature; Little et al. (2017), J. Geophys. Res. Oceans;

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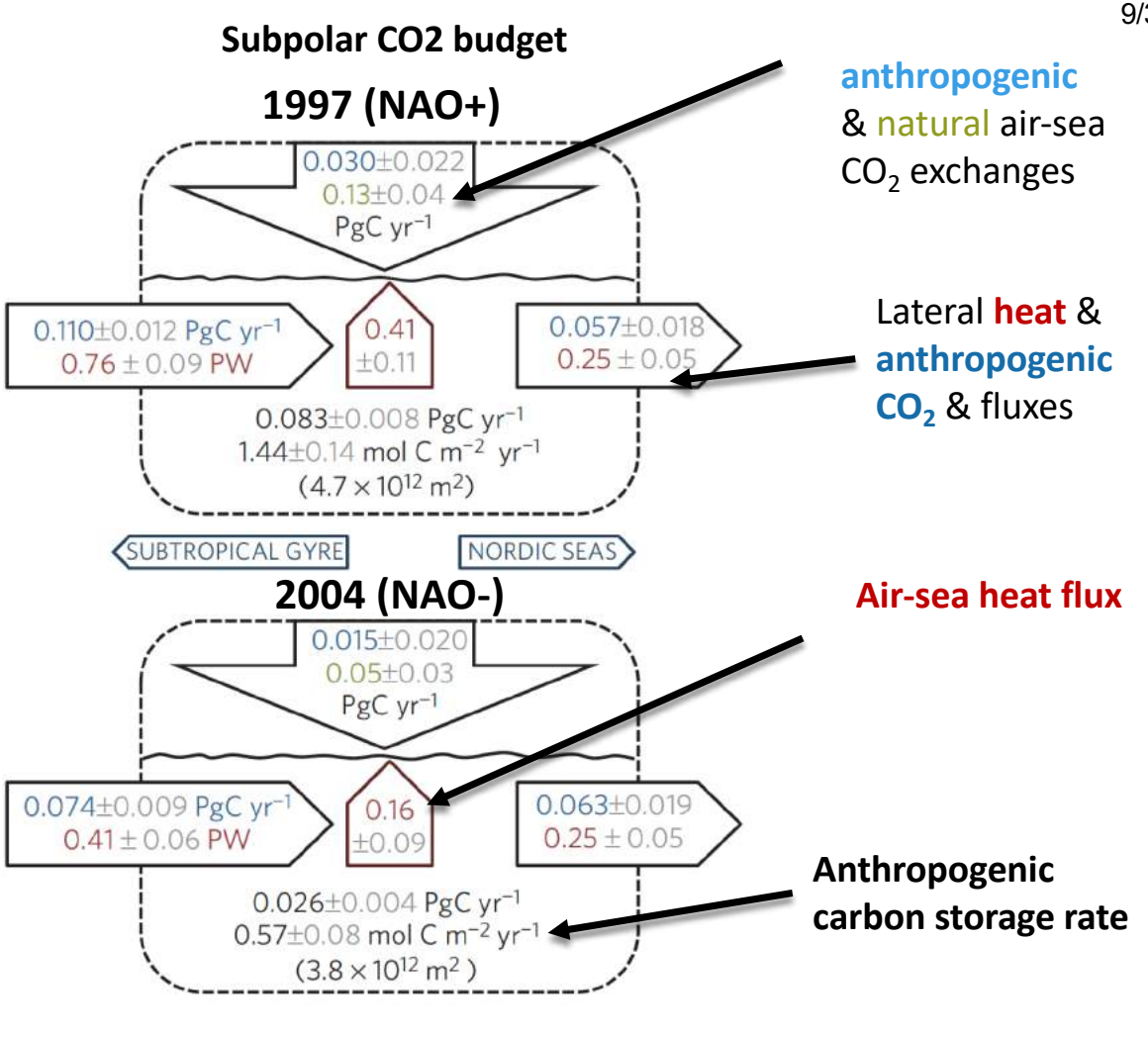
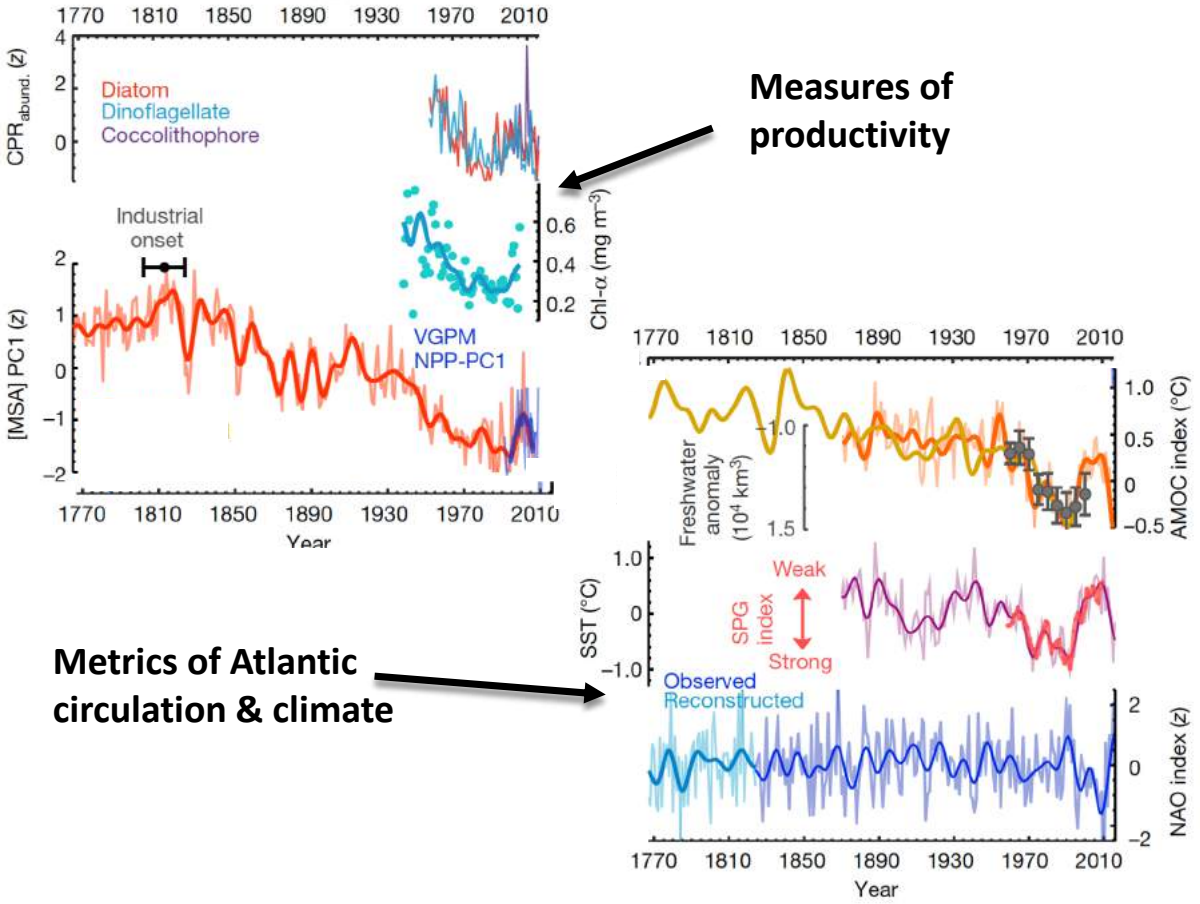


Pérez et al. (2013), Nat. Geosci.; cf. McKinley et al. (2017), Annu. Rev. Mar. Sci.

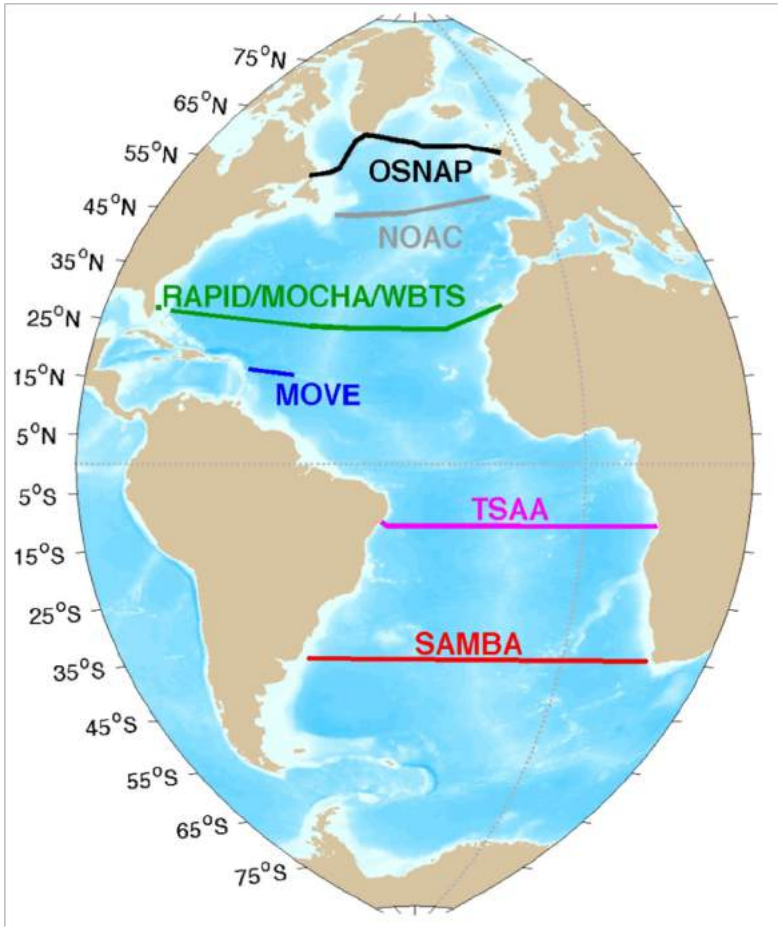
- Climate & Variability
- Abrupt Change
- Sea Level Rise
- Carbon Cycling
- **Ecosystem/Productivity**

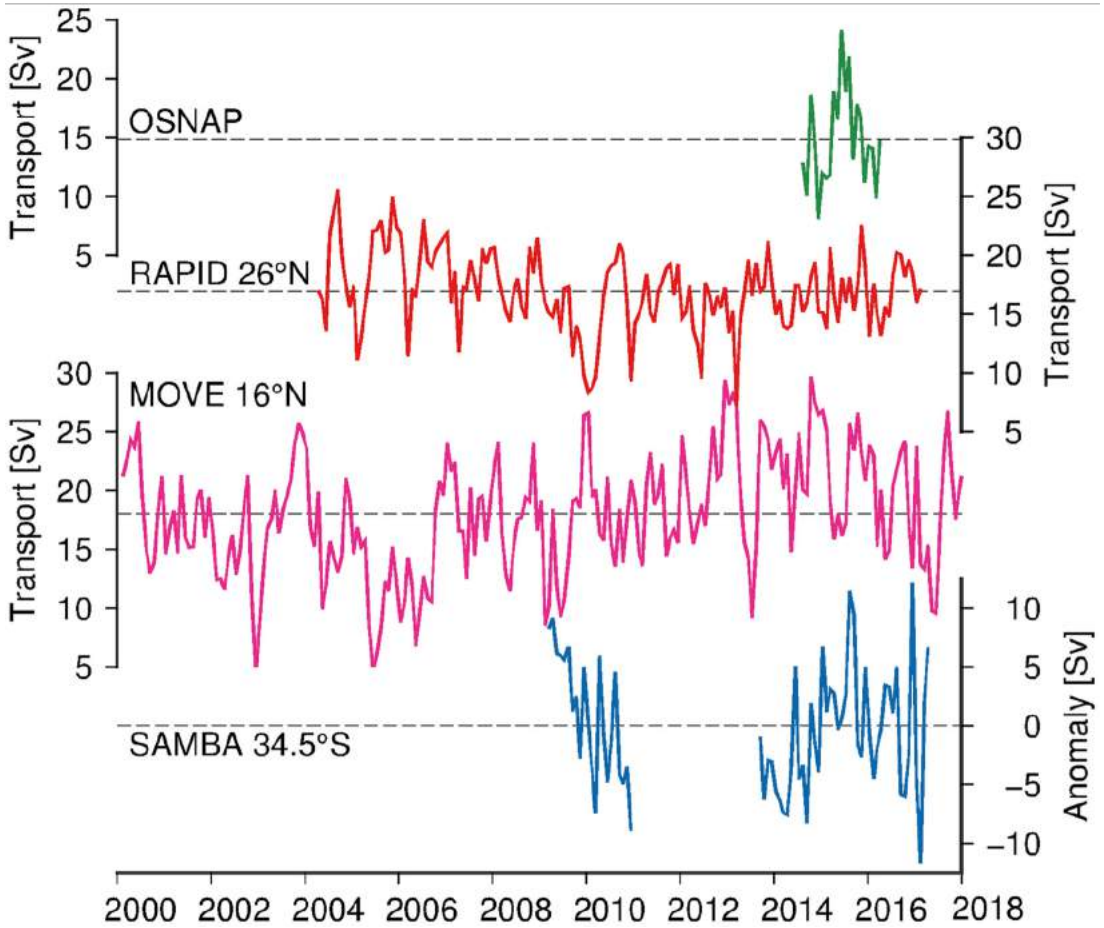


Osman et al. (2019), Nature; cf. Schmittner (2005), Nature

The AMOC Observing System

Observing the AMOC

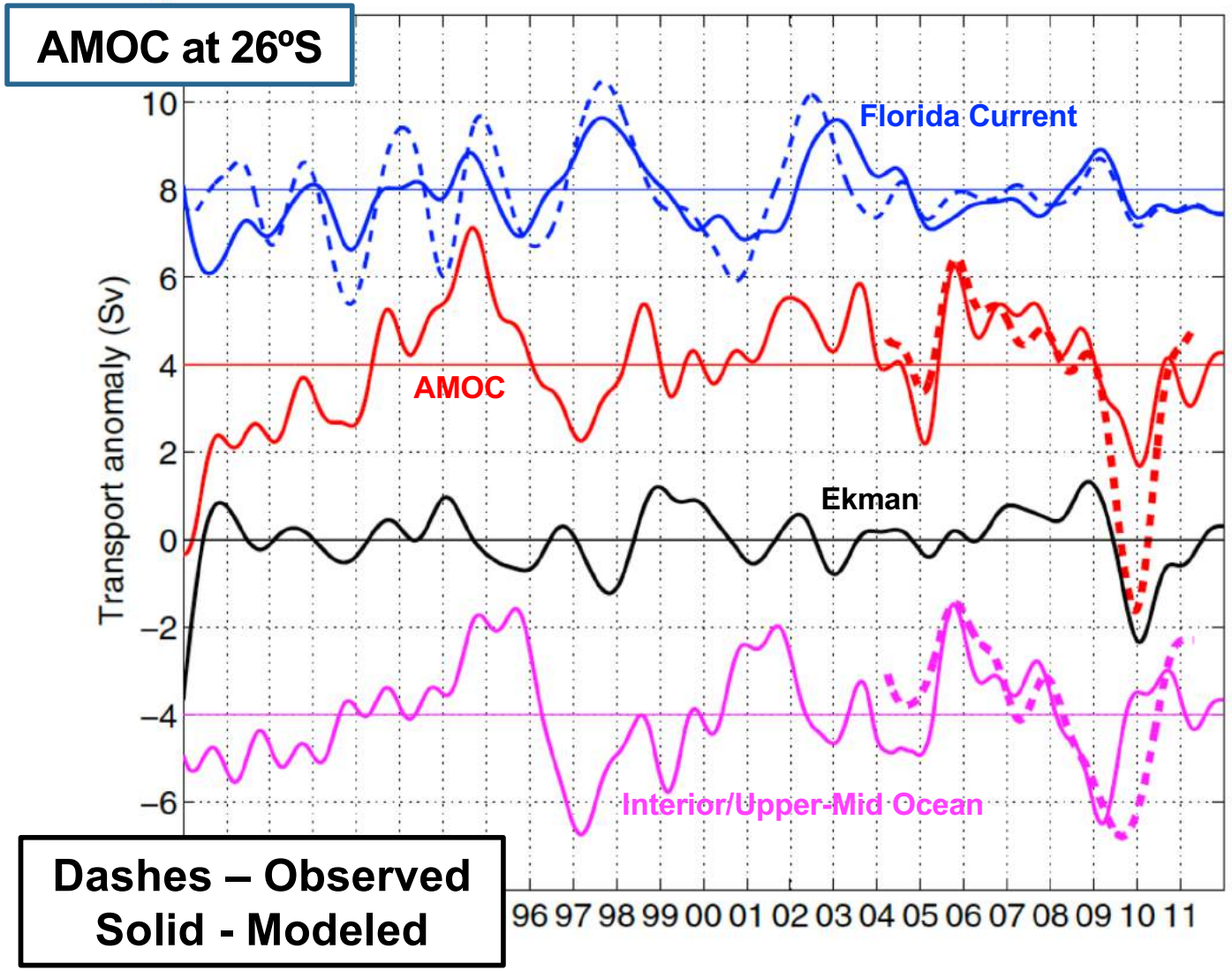




Frajka-Williams et al. (2019), Front. Mar. Sci.

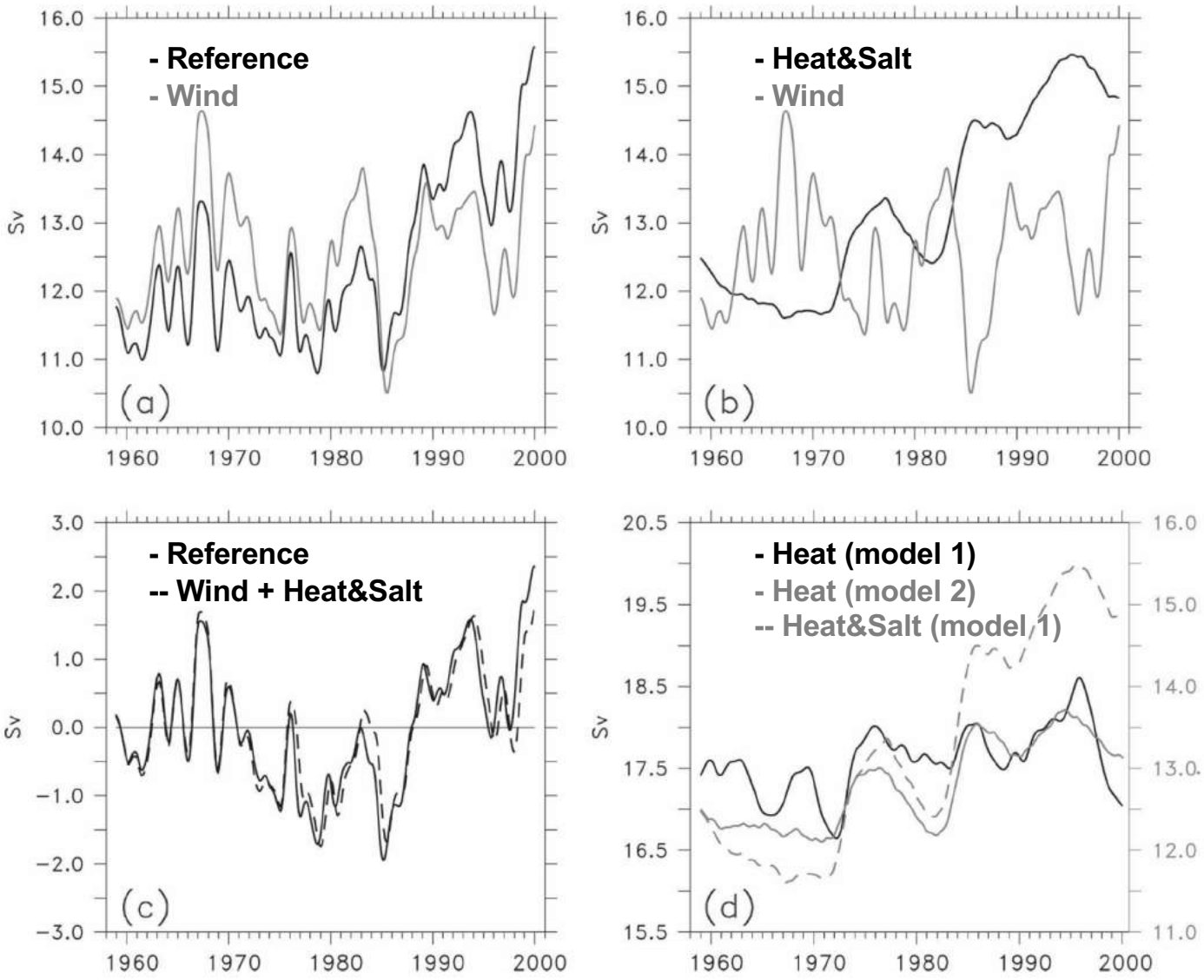
Attributing Changes in AMOC

Reduced modeling studies



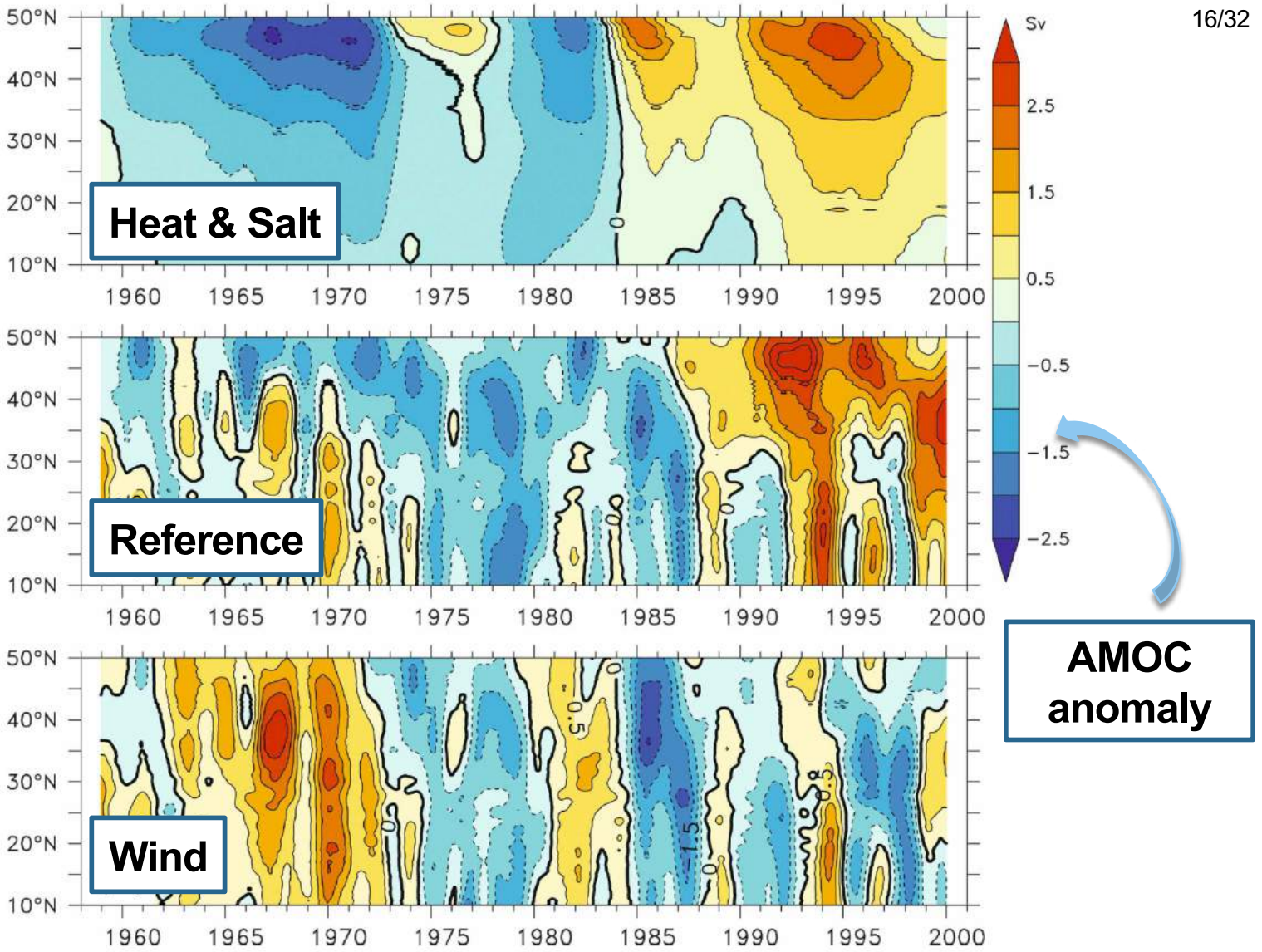
Zhao & Johns (2014)
J. Geophys. Res. Oceans

Model perturbation experiments



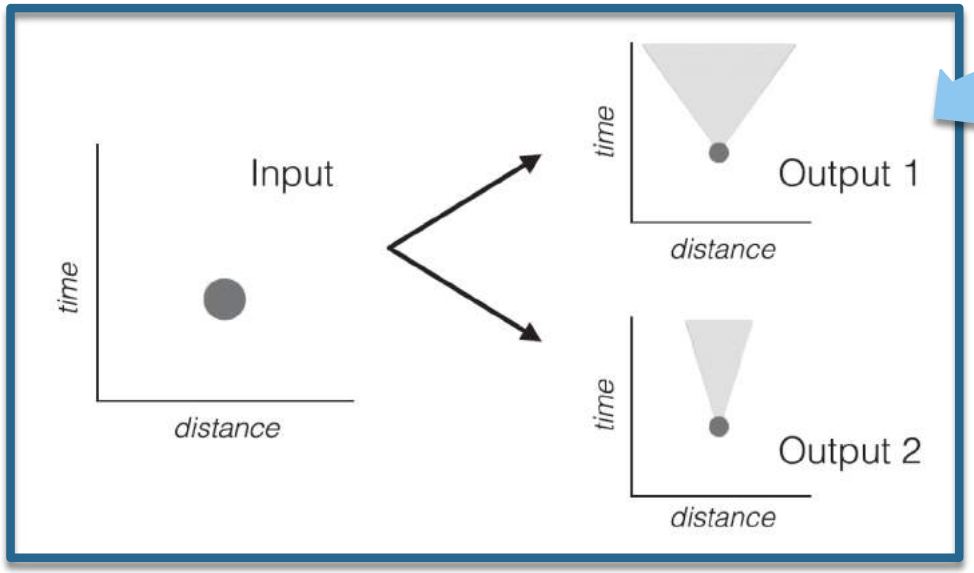
Biastoch et al. (2008)
J. Climate

Model perturbation experiments



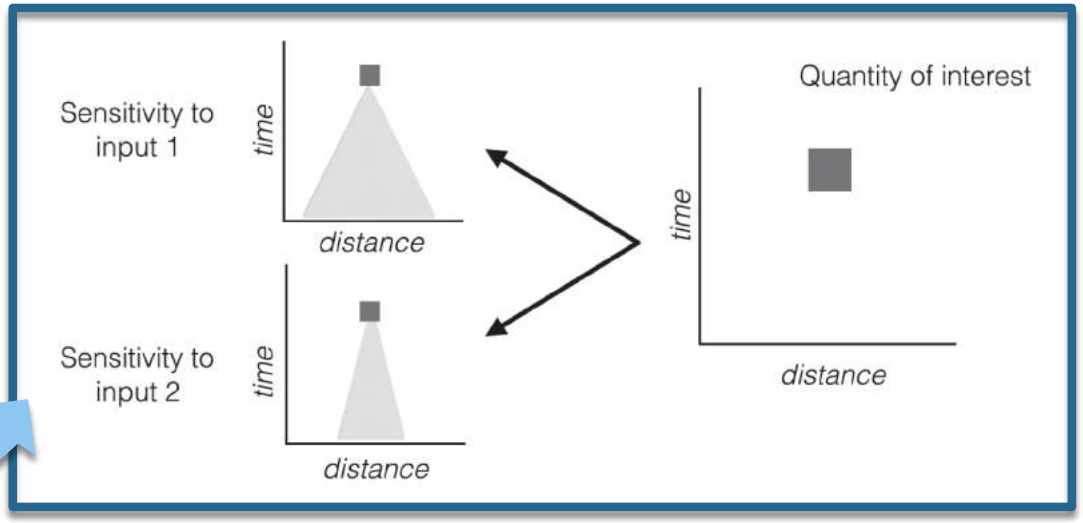
Biastoch et al. (2008)
J. Climate

An alternative: adjoint sensitivity experiment



a. Perturbation experiment

b. Adjoint sensitivity experiment



Jones et al. (2018)
J. Geophys. Res. Oceans

Adjoint Reconstruction

$$J(t) \approx \sum_i \sum_{\mathbf{x}} \sum_s \frac{\partial J(t)}{\partial \phi_i(\mathbf{x}, s)} \delta\phi_i(\mathbf{x}, s)$$

Expand QoI as linear function of forcing

Assume stationarity of the sensitivities in time

$$\frac{\partial J(t)}{\partial \phi_i(\mathbf{x}, s)} \approx \frac{\partial J}{\partial \phi_i(\mathbf{x}, \Delta t)}$$

Express QoI as function of forcing variable, space, and time lag

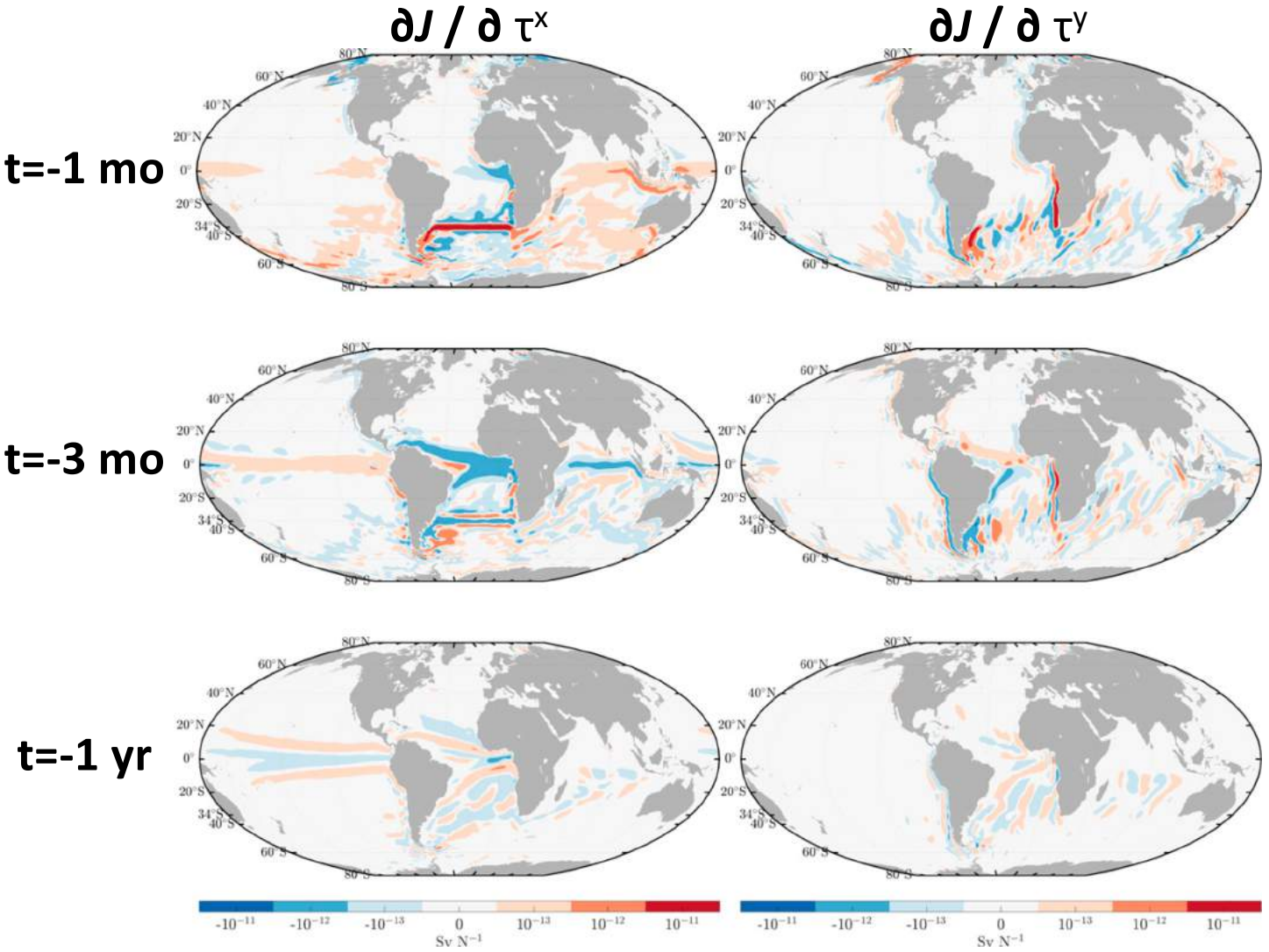
$$J(t) \approx \sum_i \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial J(t)}{\partial \phi_i(\mathbf{x}, \Delta t)} \delta\phi_i(\mathbf{x}, t - \Delta t)$$

Fukumori et al. (2015), Prog. Oceanogr.

Vignettes—
Adjoint AMOC Reconstruction

Vignette #1—AMOC at 34ºS

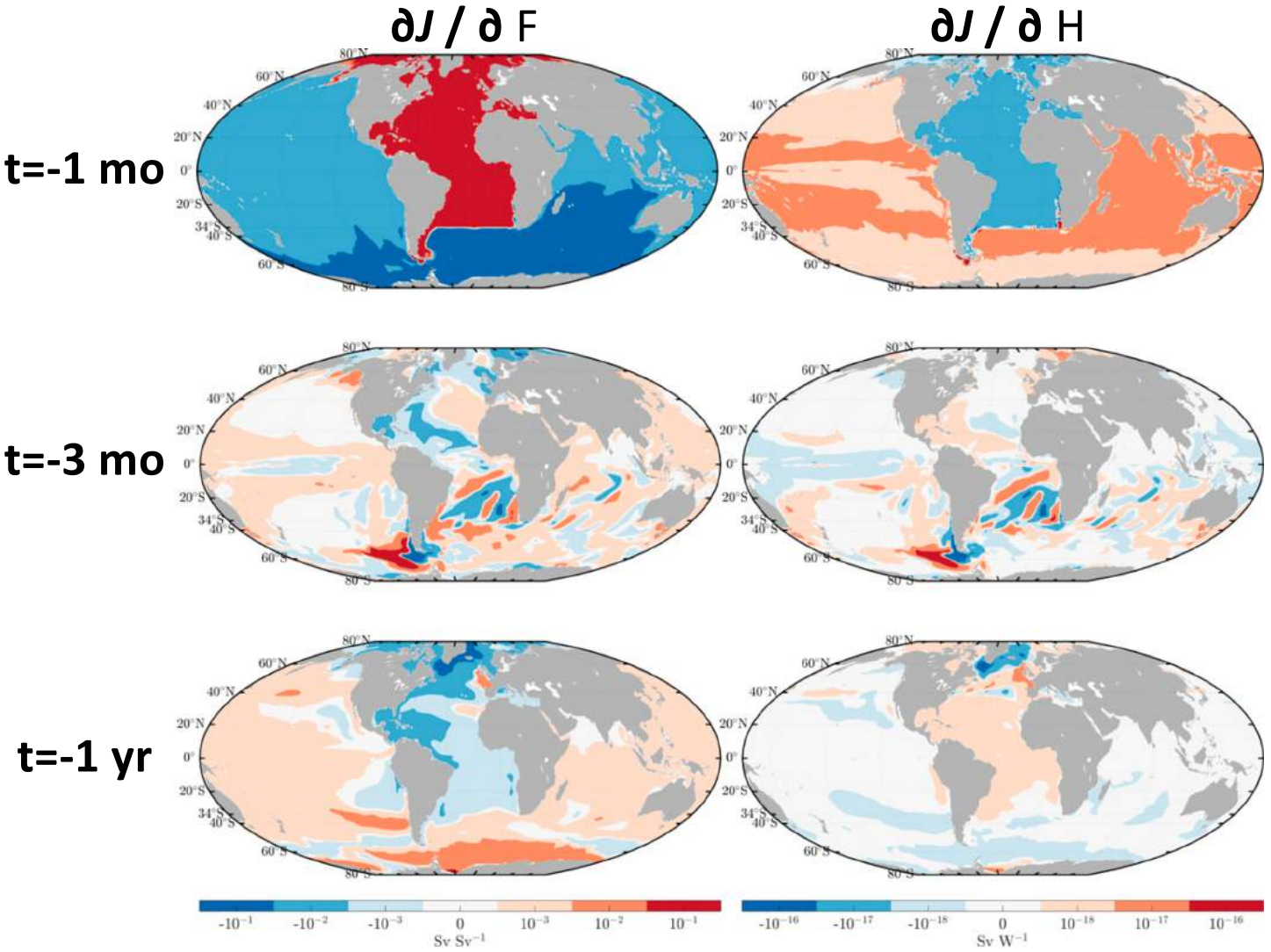
AMOC at 35ºS



J = max MOC@34ºS

Smith & Heimbach (2019), J. Climate

AMOC at 35ºS

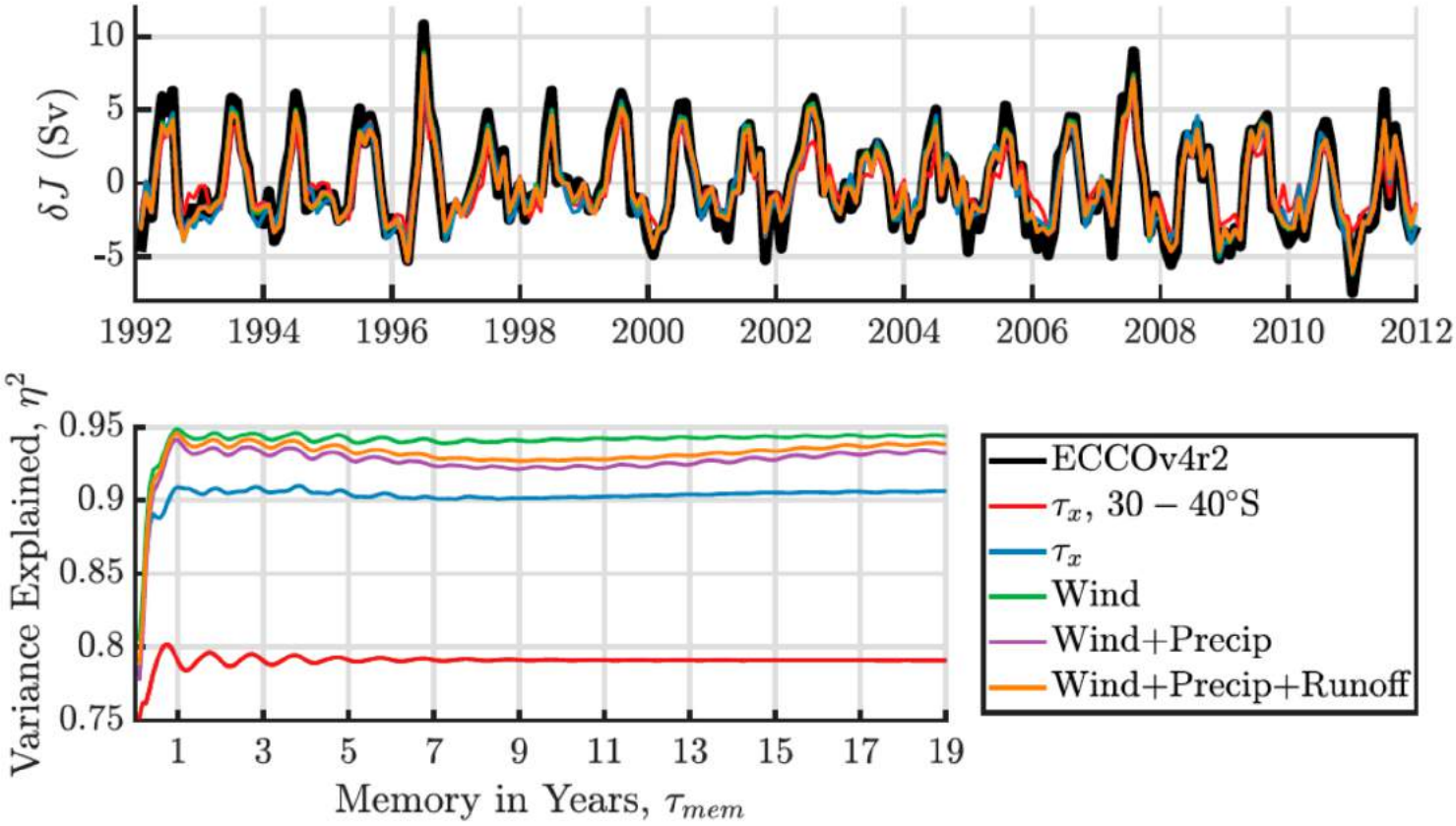


J = max MOC@34ºS

Smith & Heimbach (2019), J. Climate

AMOC at 35ºS

Monthly reconstruction

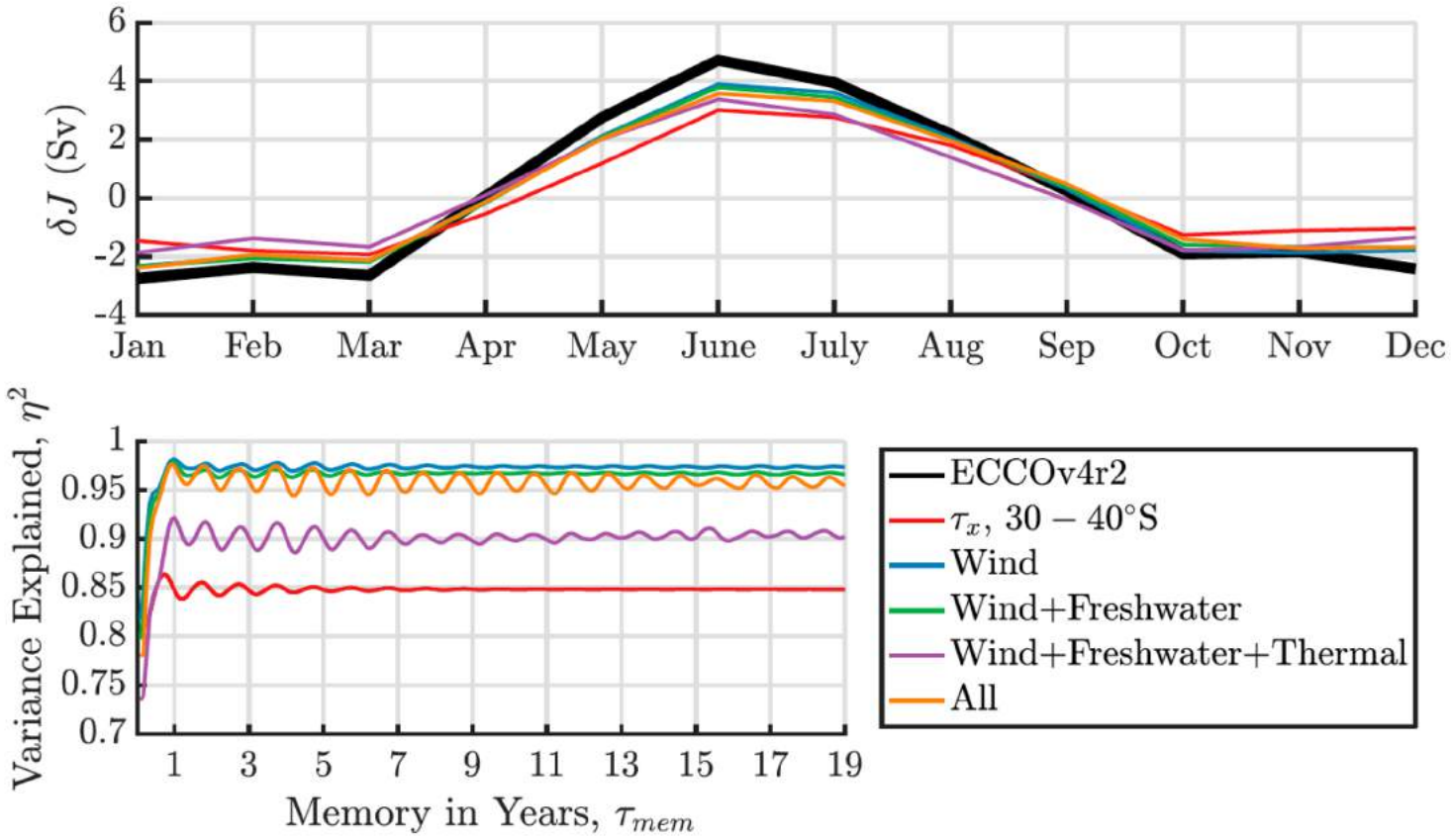


J = max MOC@34ºS

Smith & Heimbach (2019), J. Climate

AMOC at 35ºS

Seasonal reconstruction

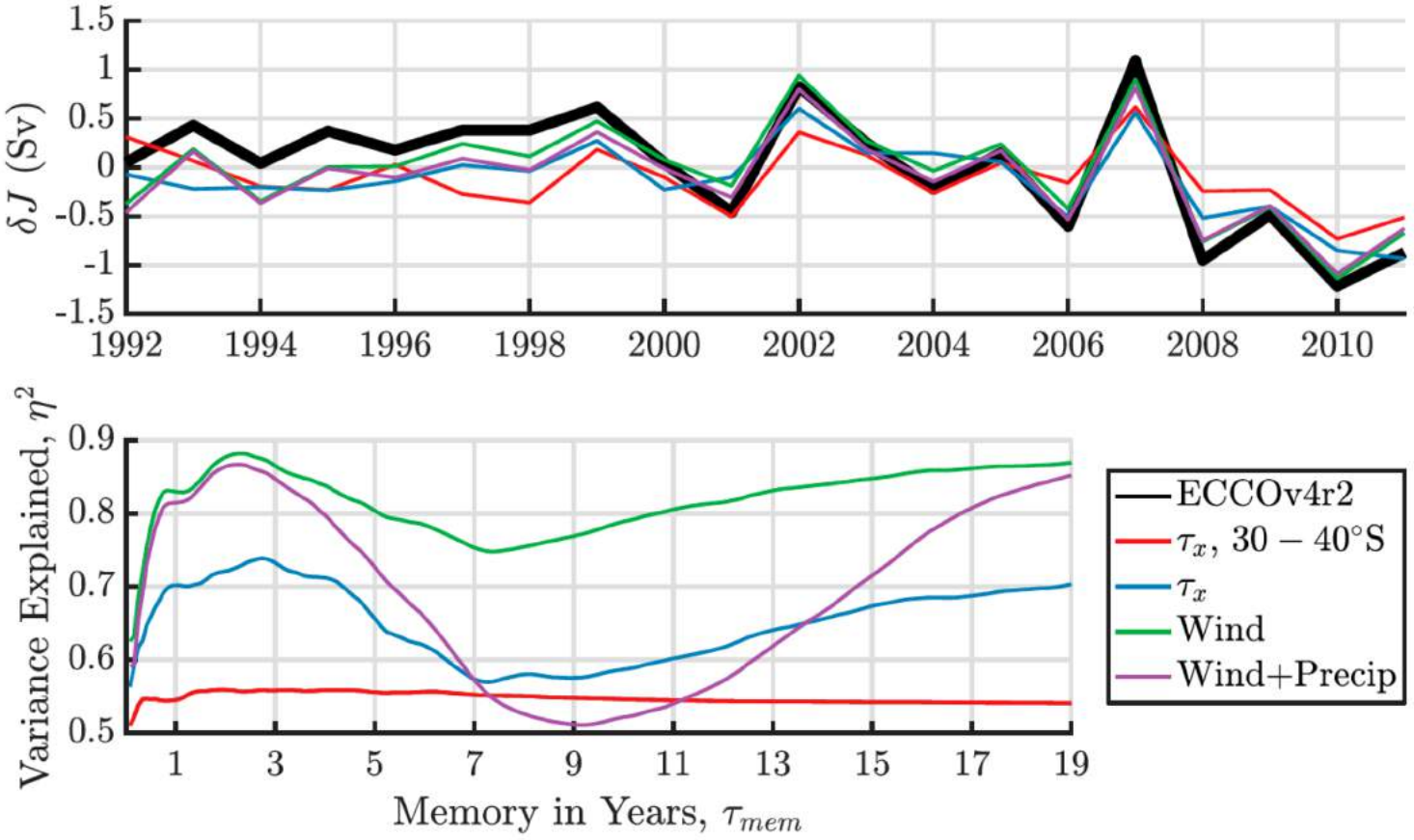


J = max MOC@34ºS

Smith & Heimbach (2019), J. Climate

AMOC at 35ºS

Interannual reconstruction

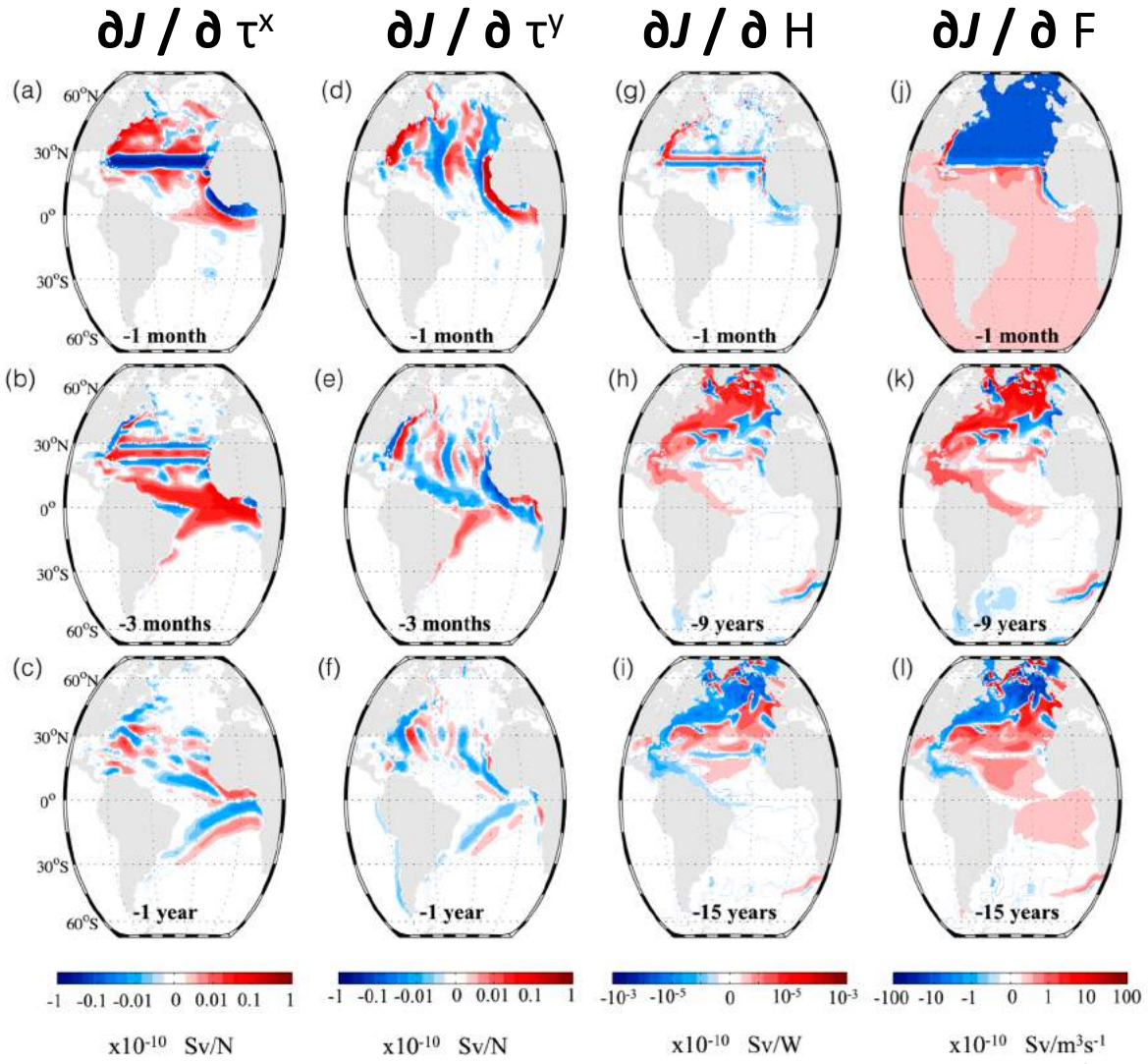


J = max MOC@34ºS

Smith & Heimbach (2019), J. Climate

Vignette #2—AMOC at 25ºS

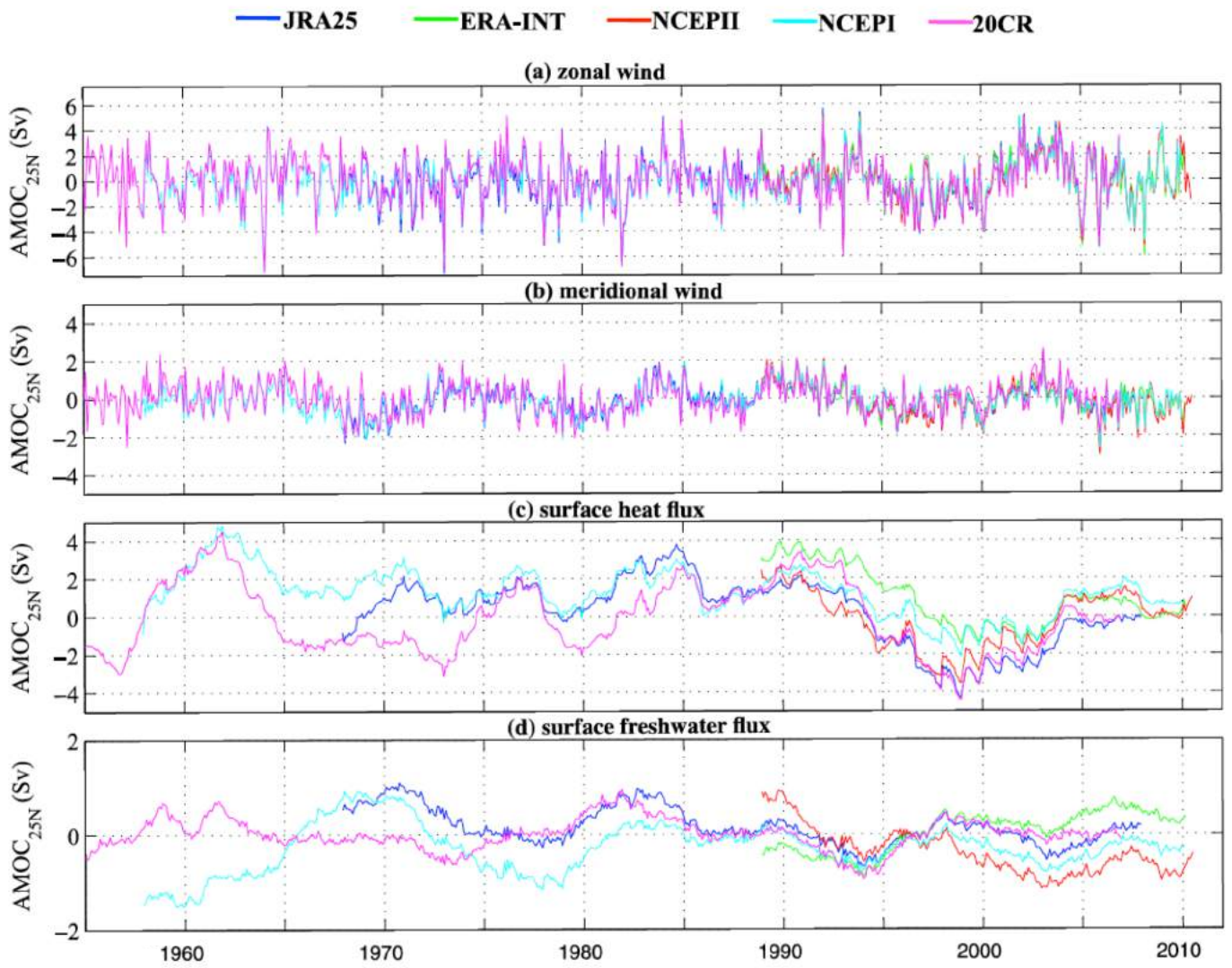
AMOC at 26ºN



J = MOC@25ºN

Pillar et al. (2016), J. Climate

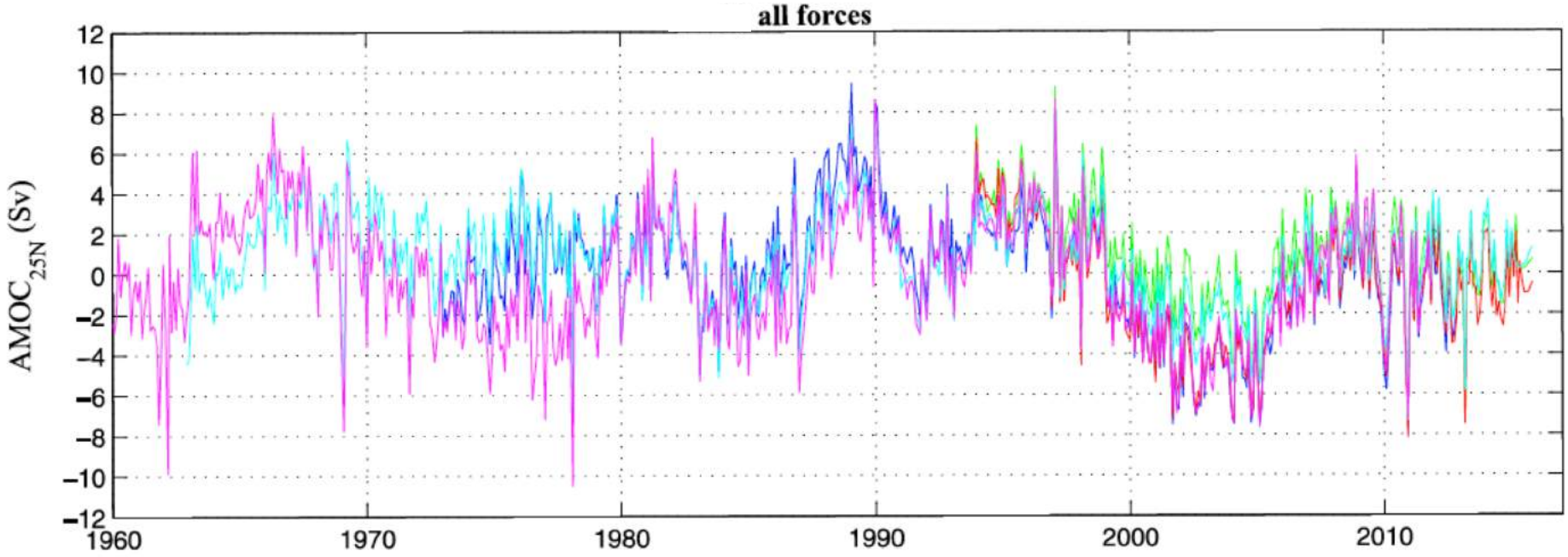
AMOC at 26ºN



J = MOC@25ºN

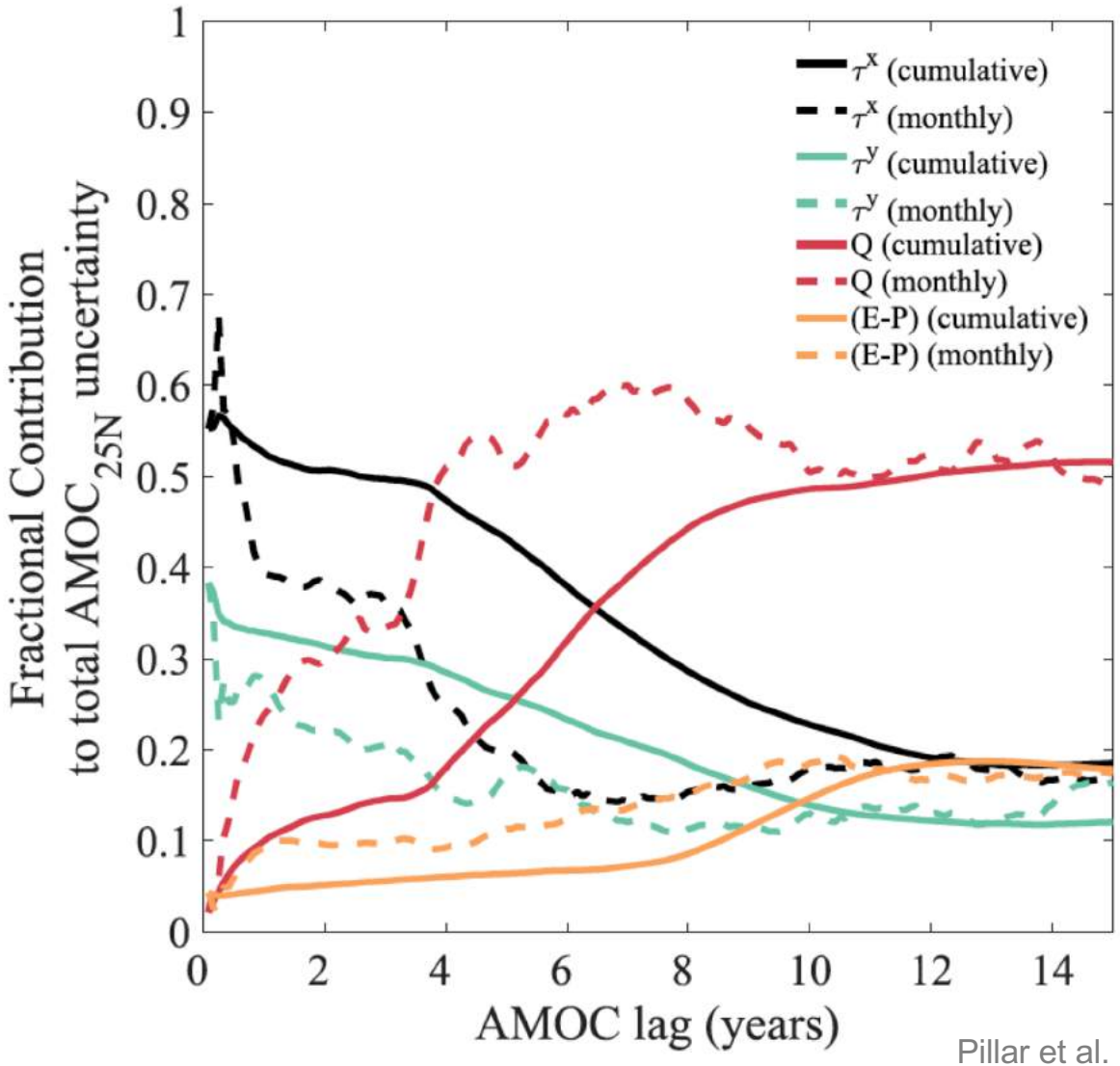
Pillar et al. (2018), J. Climate

AMOC at 26ºN



Pillar et al. (2018), J. Climate

AMOC at 26ºN



Pillar et al. (2018), J. Climate

Summary

- AMOC plays an important role in climate and the Earth system
- The adjoint is an informative tool for attributing observed AMOC changes in terms of atmospheric forcing and ocean dynamics
- The action of winds is most prominent on shorter timescales, whereas surface buoyancy fluxes become more important on longer timescales


Thank you.
https://www.metoffice.gov.uk/weather/learn-about/weather/oceans/amoc