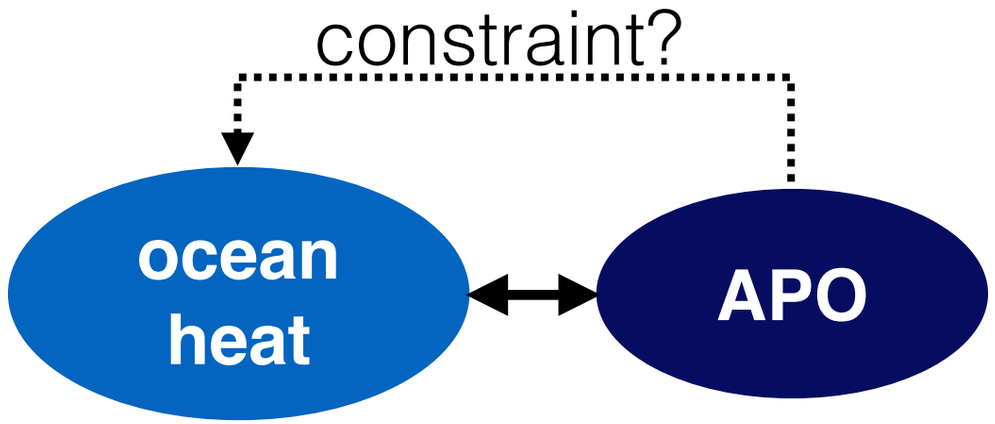
Scripps O_2 Program
Atmospheric Oxygen Research

Constraints on heat transport from atmospheric potential oxygen & implications for carbon

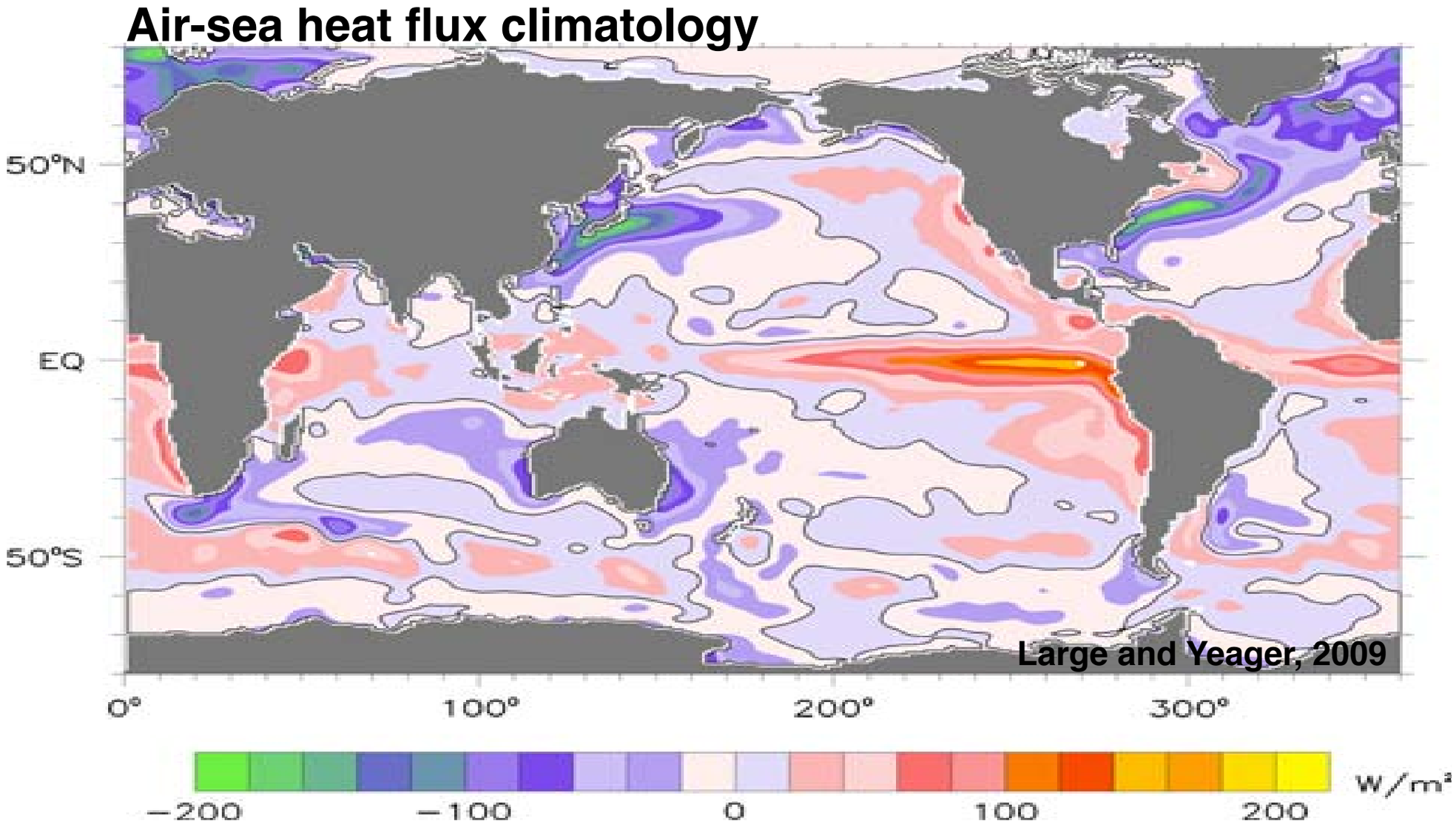


Laure Resplandy
Scripps Institution of Oceanography

R. Keeling (Scripps); A. Jacobson (NOAA); B. Stephens, J. Bent (NCAR)
S. Khatiwala (Oxford, UK); C. Rödenbeck (MPI, Germany)

Natural heat fluxes matter for climate

Larger heat loss in the North



ocean loses heat

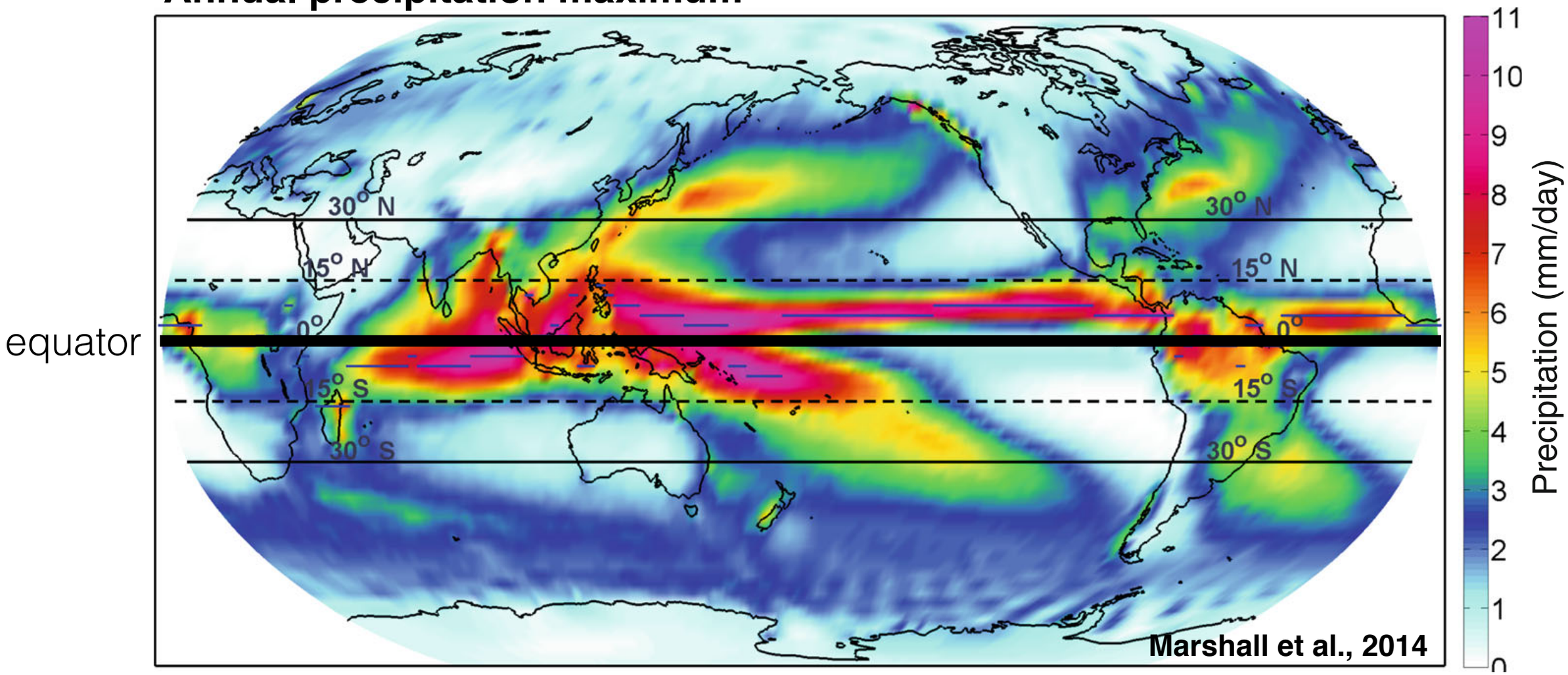
ocean gains heat

Natural heat fluxes matter for climate

Position of Intertropical Convergence Zone

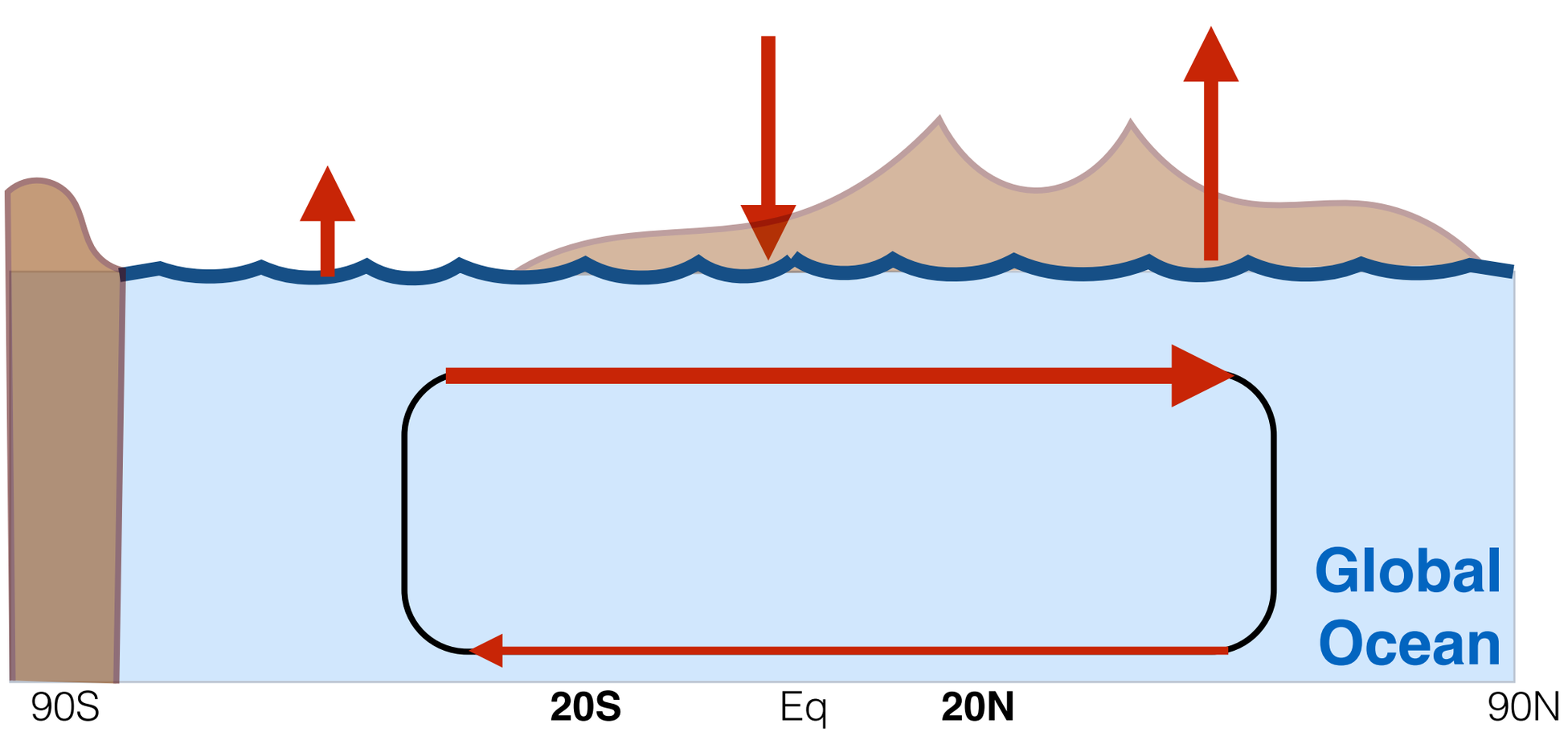
(Marshall et al., Clim. Dyn. 2014; McGee et al., EPSL 2014; Schneider et al., Nature 2014…)

Annual precipitation maximum

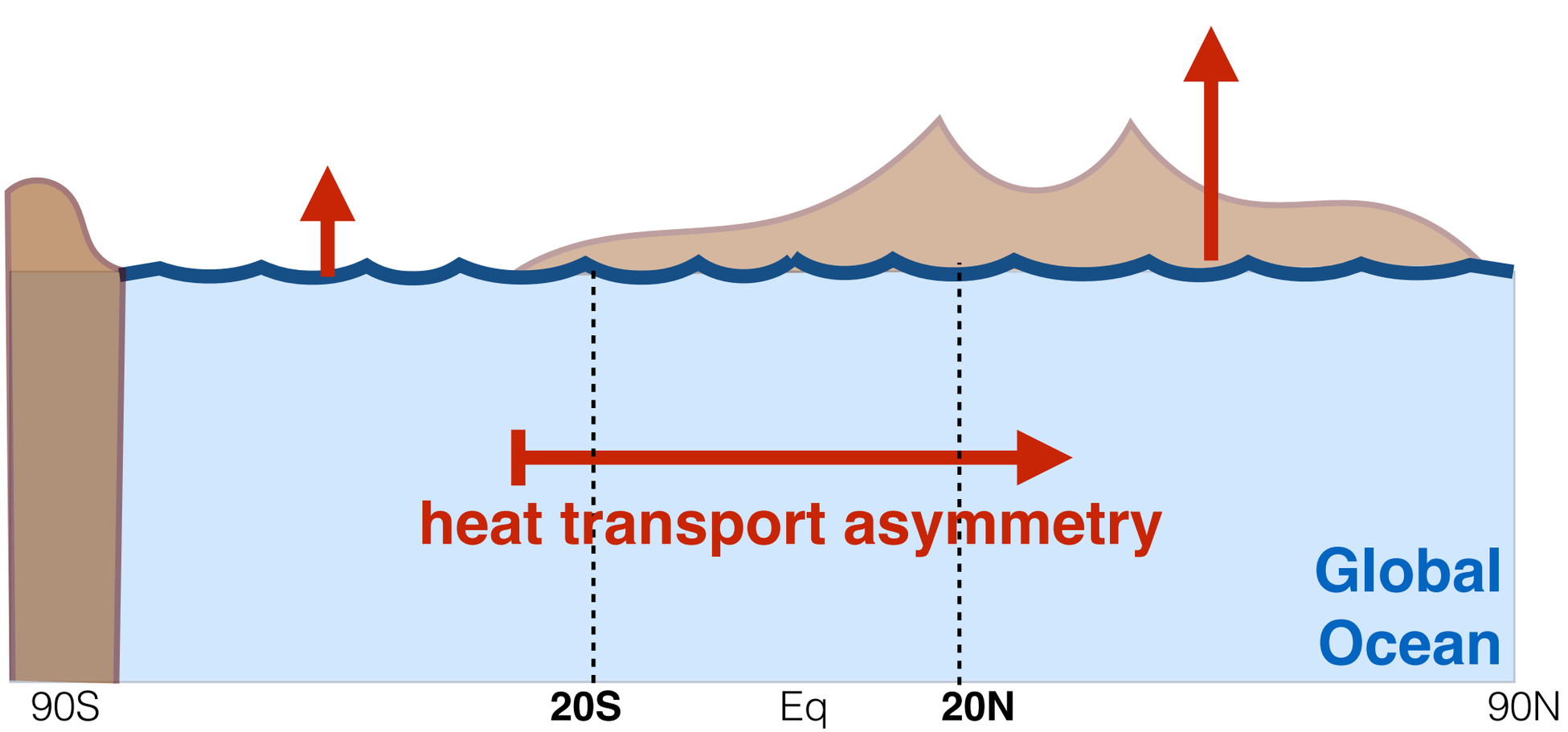


equator

Heat transport asymmetry introduced by Atlantic Ocean



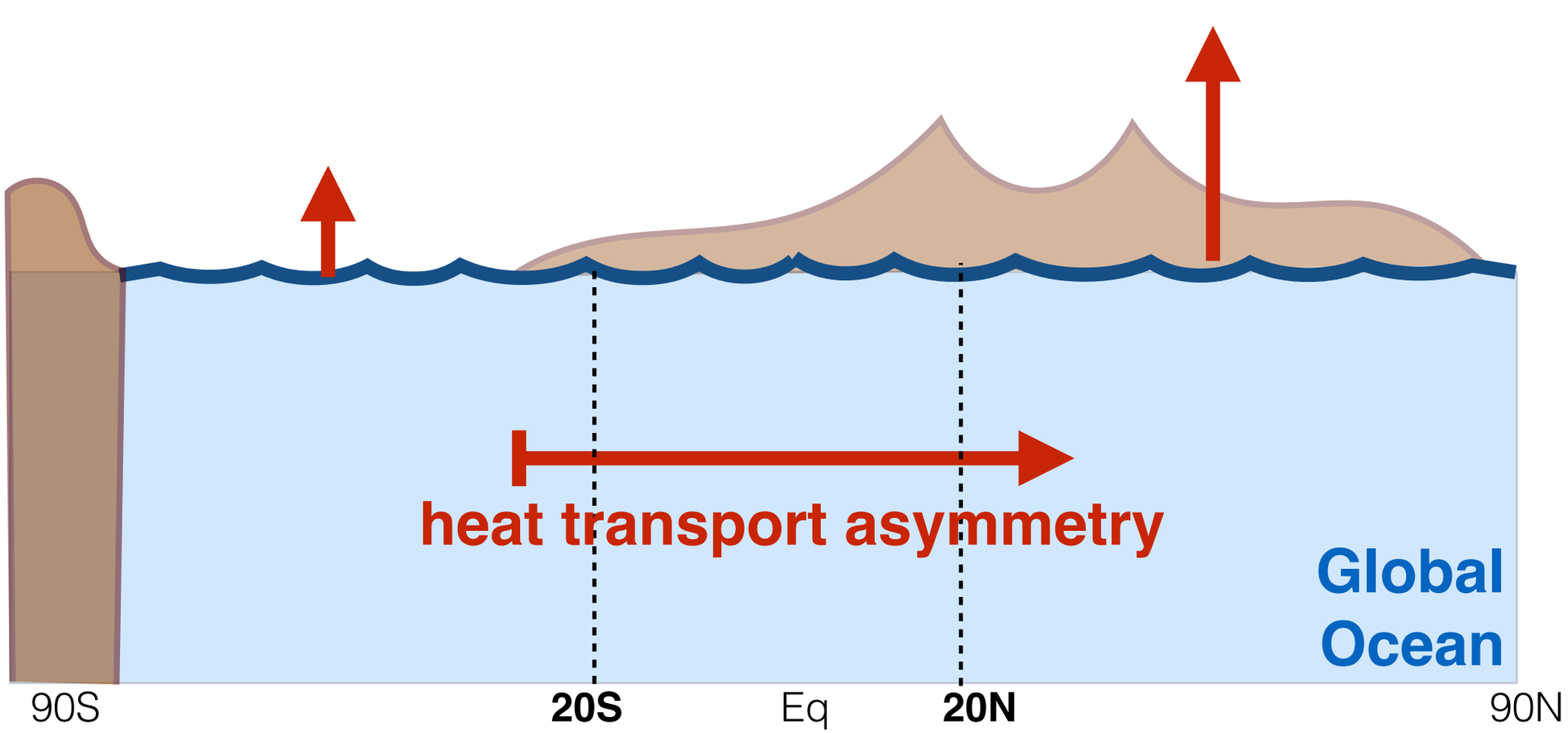
Heat transport asymmetry introduced by Atlantic Ocean



Heat transport asymmetry (20°S-20°N)

Surface flux climatology	0.8±0.3 PW	CORE2 (Large and Yeager, 2009)
Ocean sections	0.5±0.6 PW	(Ganachaud and Wunsch, 2003)
Top of the atmosphere	0.1-0.6 PW	(Trenberth and Caron, 2001; Fasullo and Trenberth, 2008)

-0.1/1.1 PW



Inert gas flux scales with heat flux

heat flux

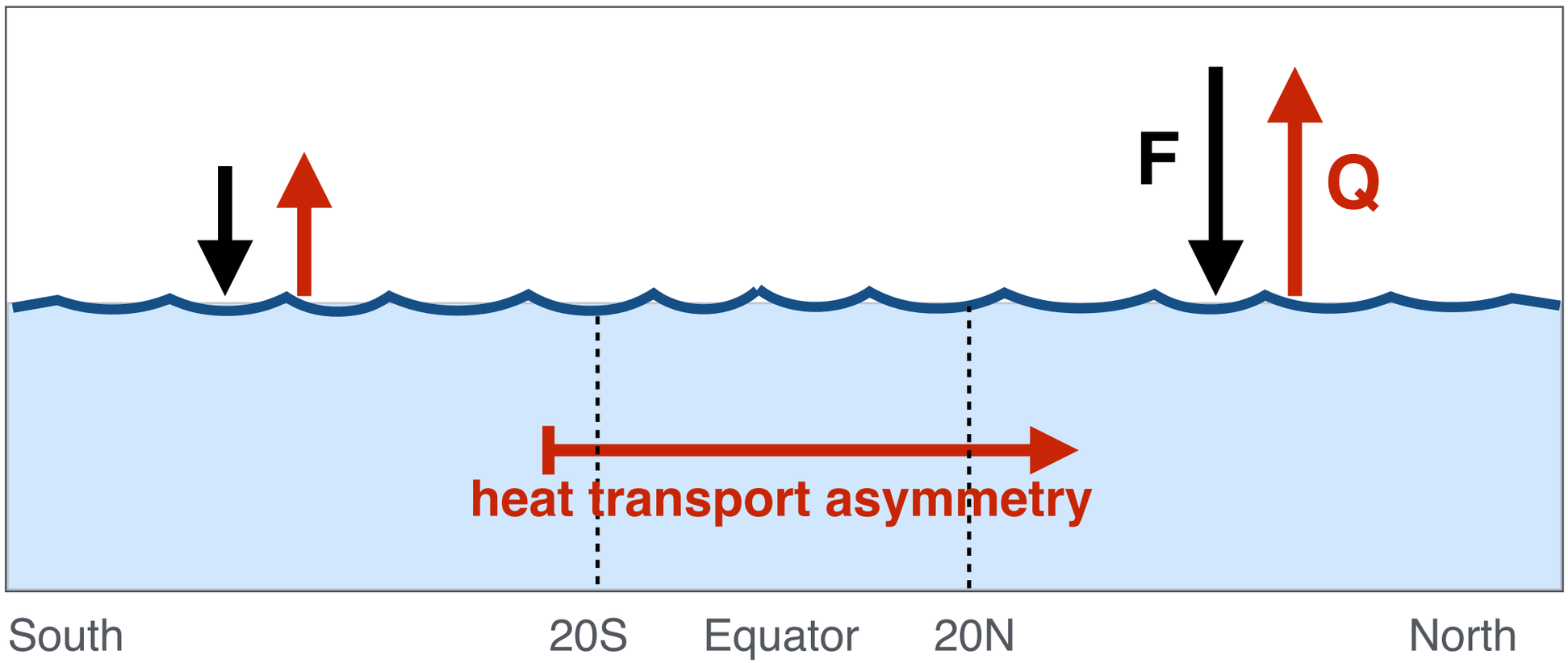
gas solubility

$$F = \frac{Q}{C_p} \times \frac{\partial S}{\partial T}$$

<0

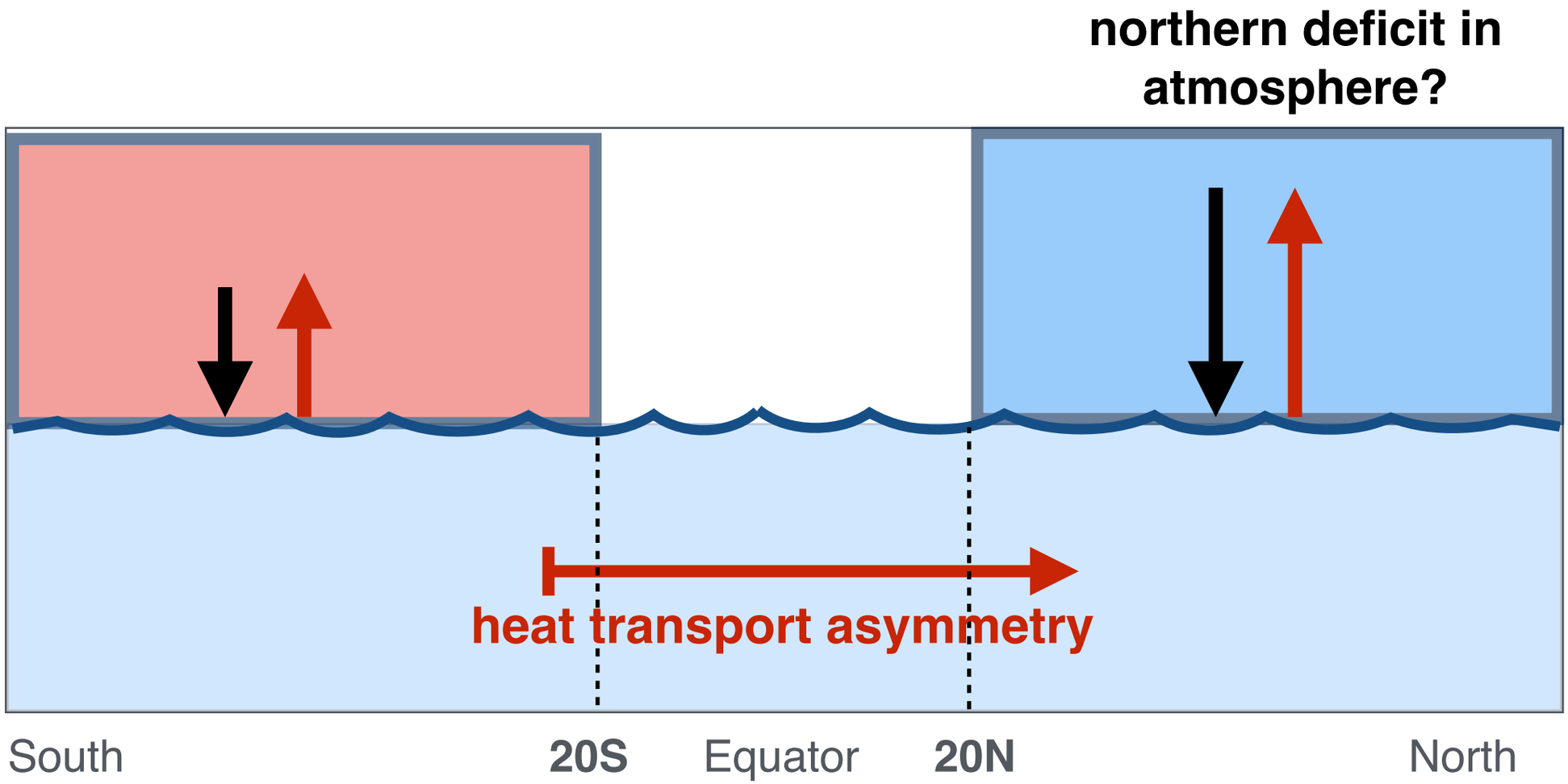
thermal capacity

Keeling and Shertz (1992)



Atmospheric fingerprint of the ocean heat transport

The atmospheric column integrates ocean processes

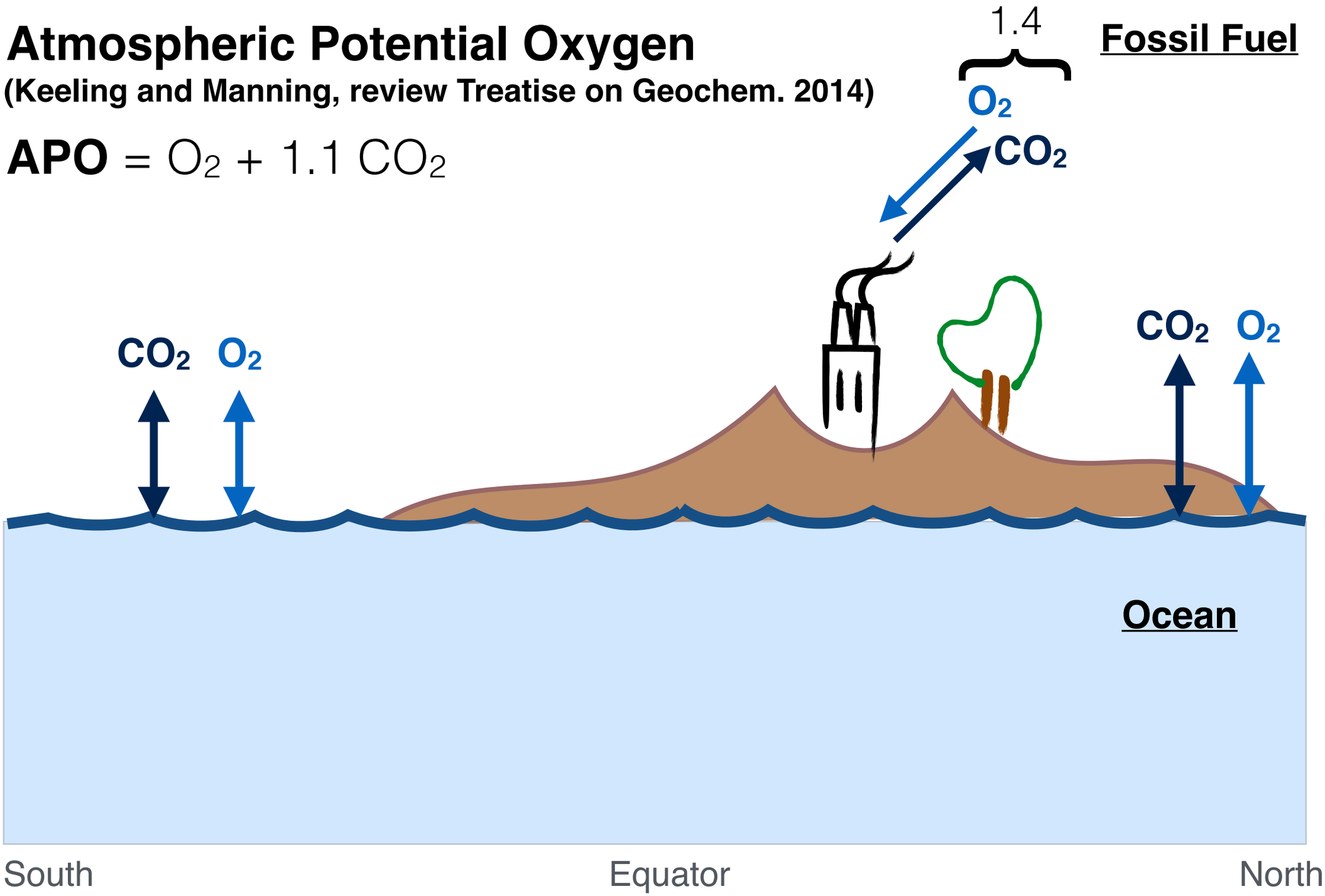


Potential Oxygen tracks air-sea flux

Atmospheric Potential Oxygen

(Keeling and Manning, review Treatise on Geochem. 2014)

APO = O_2 + 1.1 CO_2

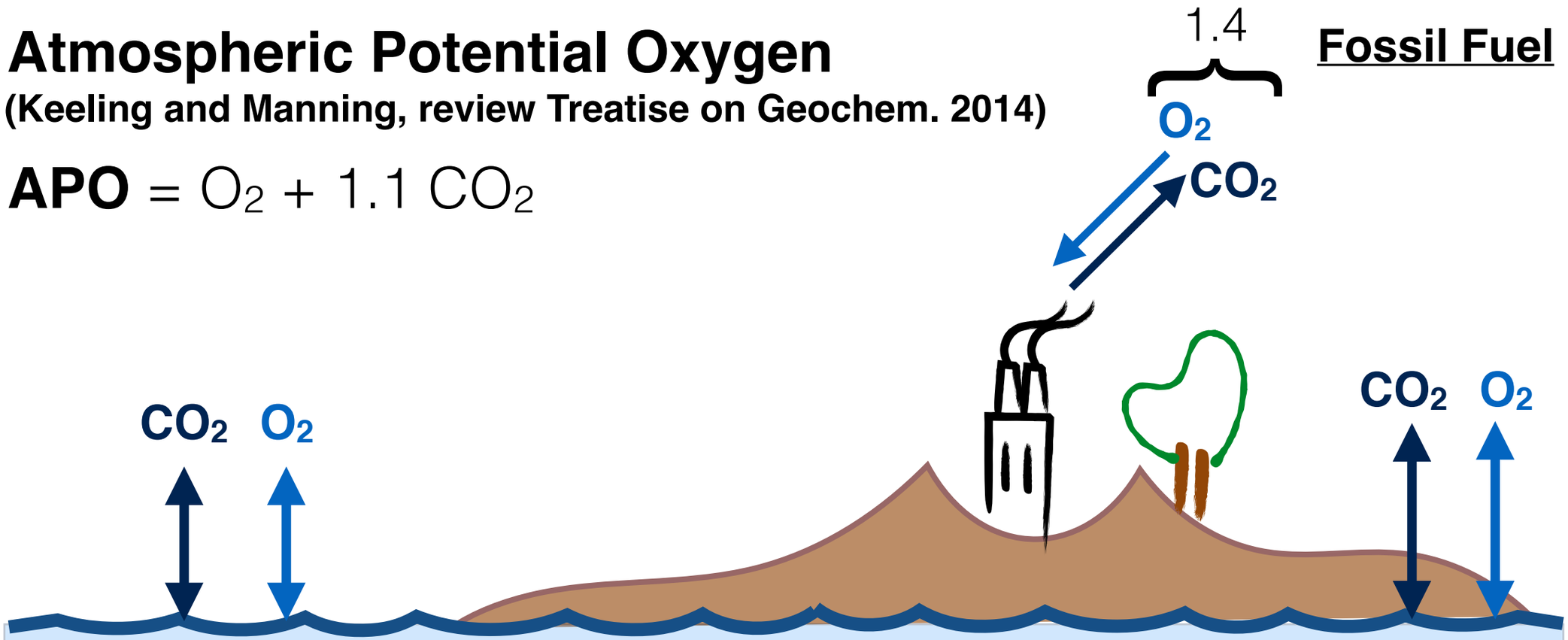


Potential Oxygen tracks air-sea flux

Atmospheric Potential Oxygen

(Keeling and Manning, review Treatise on Geochem. 2014)

APO = O_2 + 1.1 CO_2



Oceanic Potential Oxygen

(Keeling et al., Ann Rev Mar Sci 2010)

OPO = O_2^* + 1.1 C^*

$O_2^* = O_2 + 170\ PO_4^{3-}$

$C^* = DIC - 0.5\ (ALK + 16\ NO_3^-) - 117\ PO_4^{3-}$

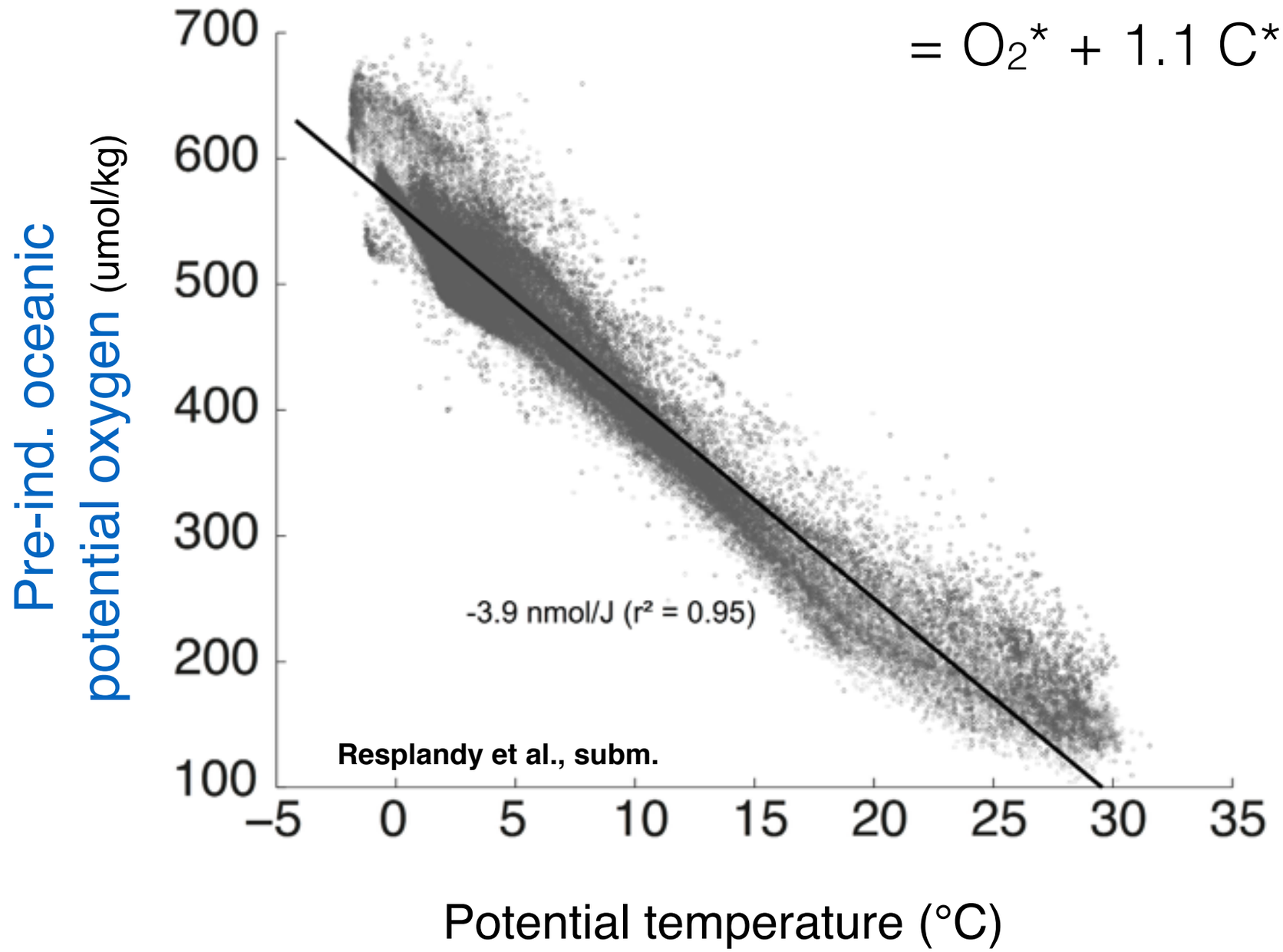
Ocean

South Equator North

Potential oxygen scales with ocean heat, like an inert gas (maybe even better…)

Pre-industrial Oceanic Potential Oxygen

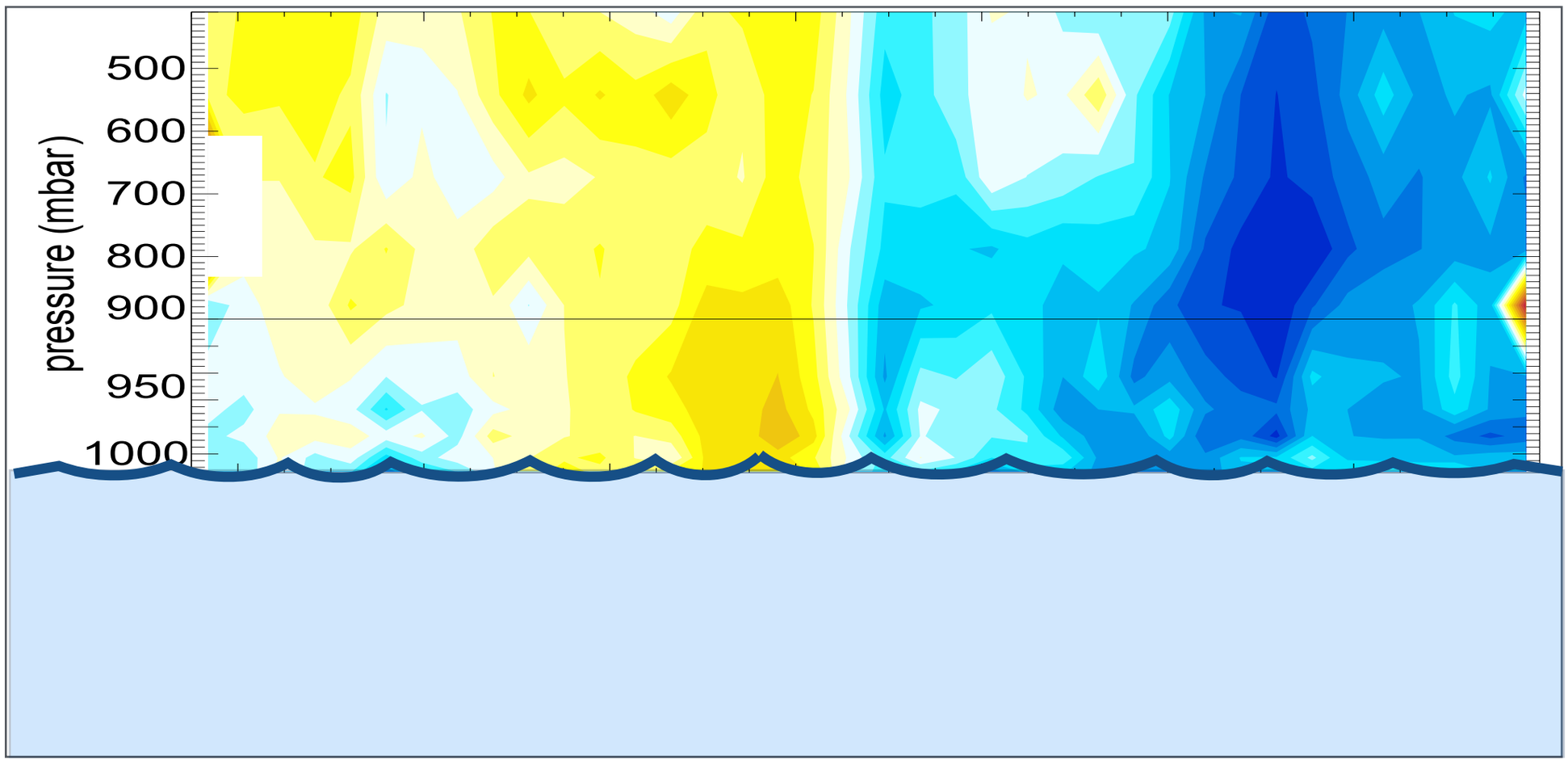
$= O_2^* + 1.1\ C^* - C_{anthropogenic}$



Airborne atmospheric potential oxygen data

B. Stephens, J. Bent (NCAR)
1600 observations
~500 hours of flight

Wofsy et al., 2011



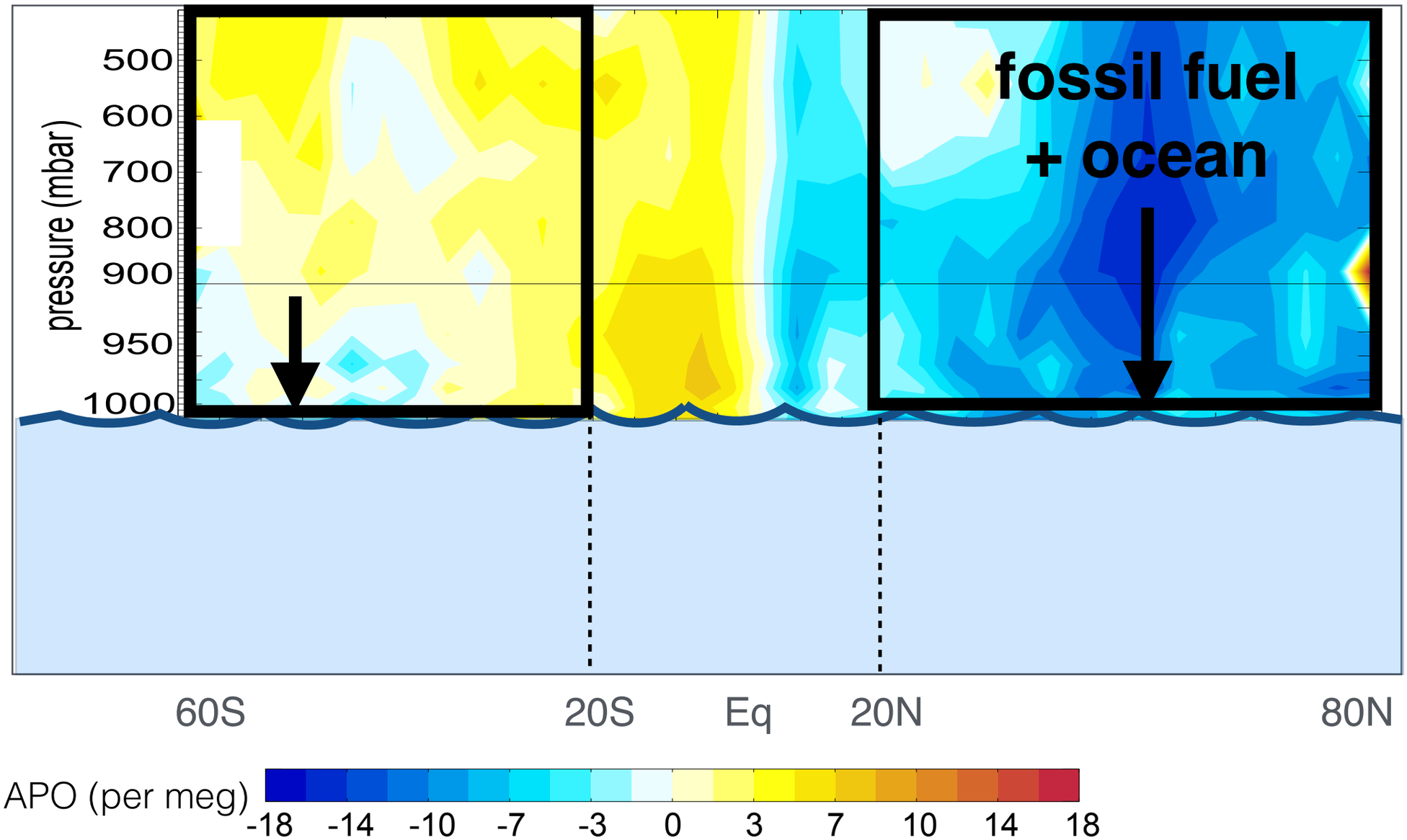
Resplandy et al., subm

Airborne atmospheric potential oxygen data

B. Stephens, J. Bent (NCAR)
1600 observations
~500 hours of flight

Wofsy et al., 2011

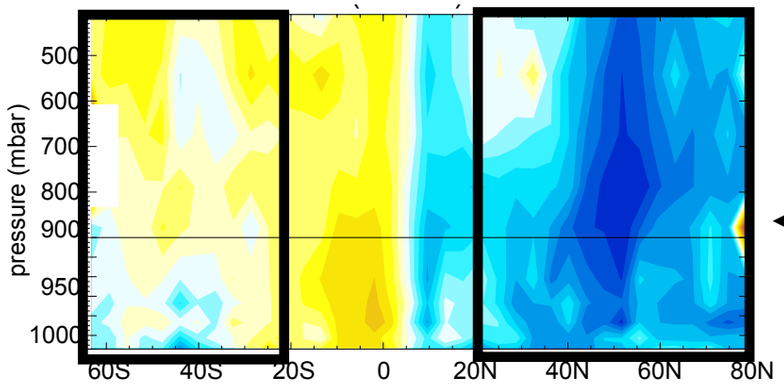
northern deficit ~ 10.5 per meg



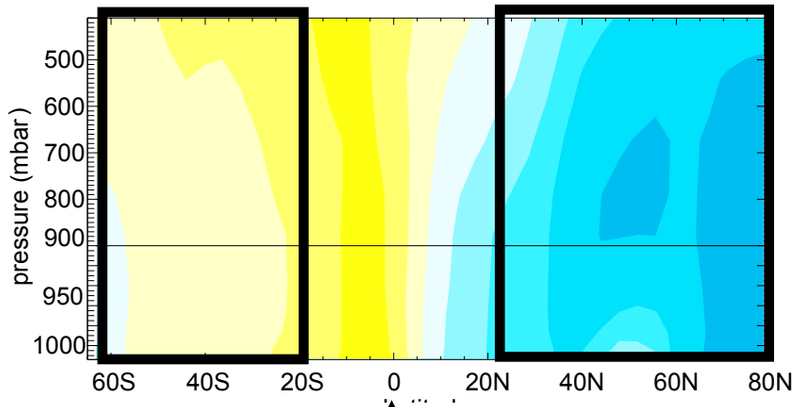
Resplandy et al., subm

Combine atmospheric and oceanic data to constrain ocean transport

DATA
atmospheric
potential oxygen



PREDICTION
atmospheric
potential oxygen



atmospheric transport

ocean transport

ocean DATA
O_2*, C*, T
(~60 000 obs.)

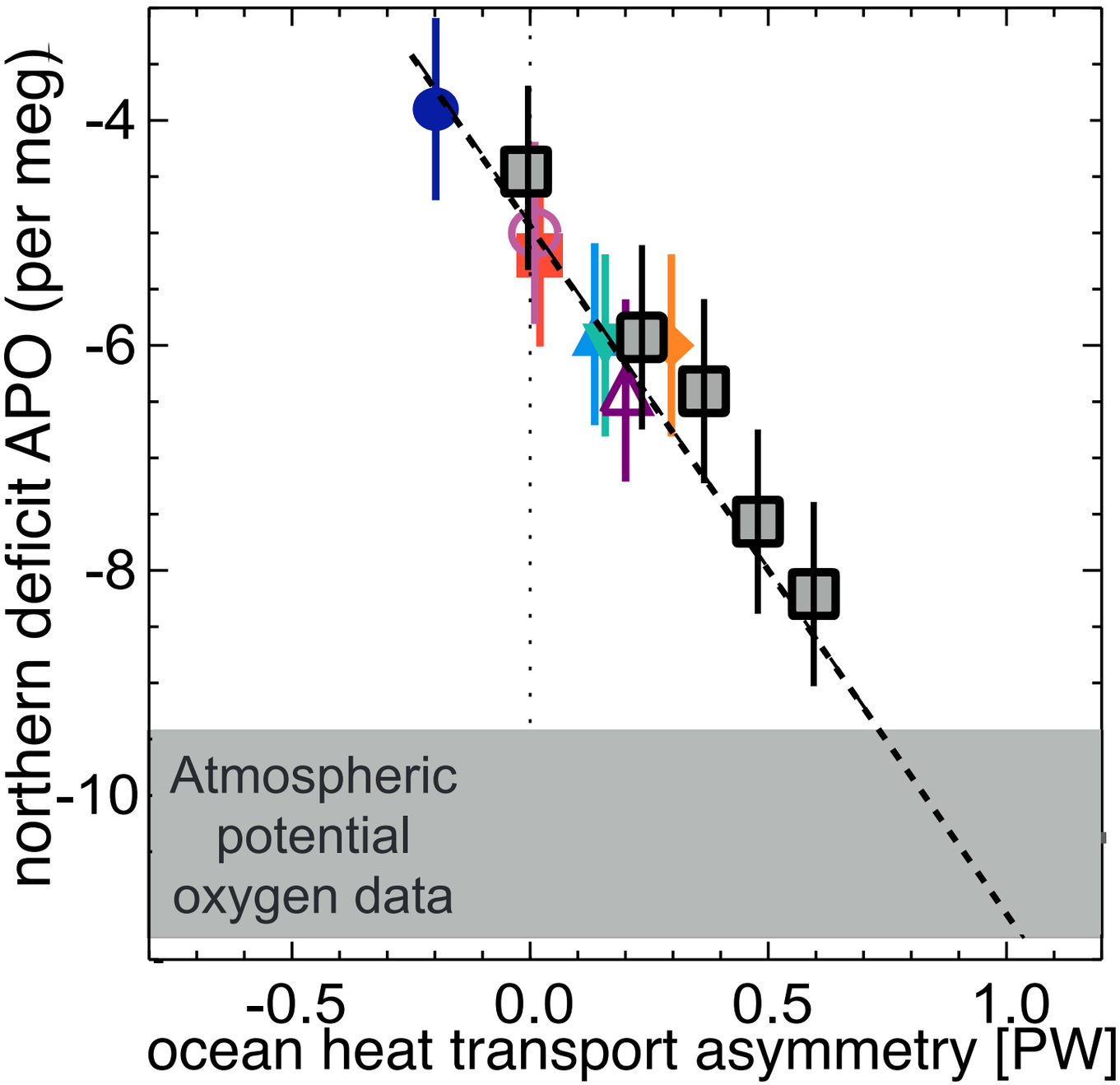
air-sea fluxes

+ Cant (Khatiwala, 2009)
+fossil fuel (EDGAR)

ocean inversion (Gloor et al., 2001; Gruber et al., 2001; MikaloffFletcher 2007; Jacobson et al., 2007)

Resplandy et al., subm

Ocean transport asymmetry is underestimated



7 Ocean inversions

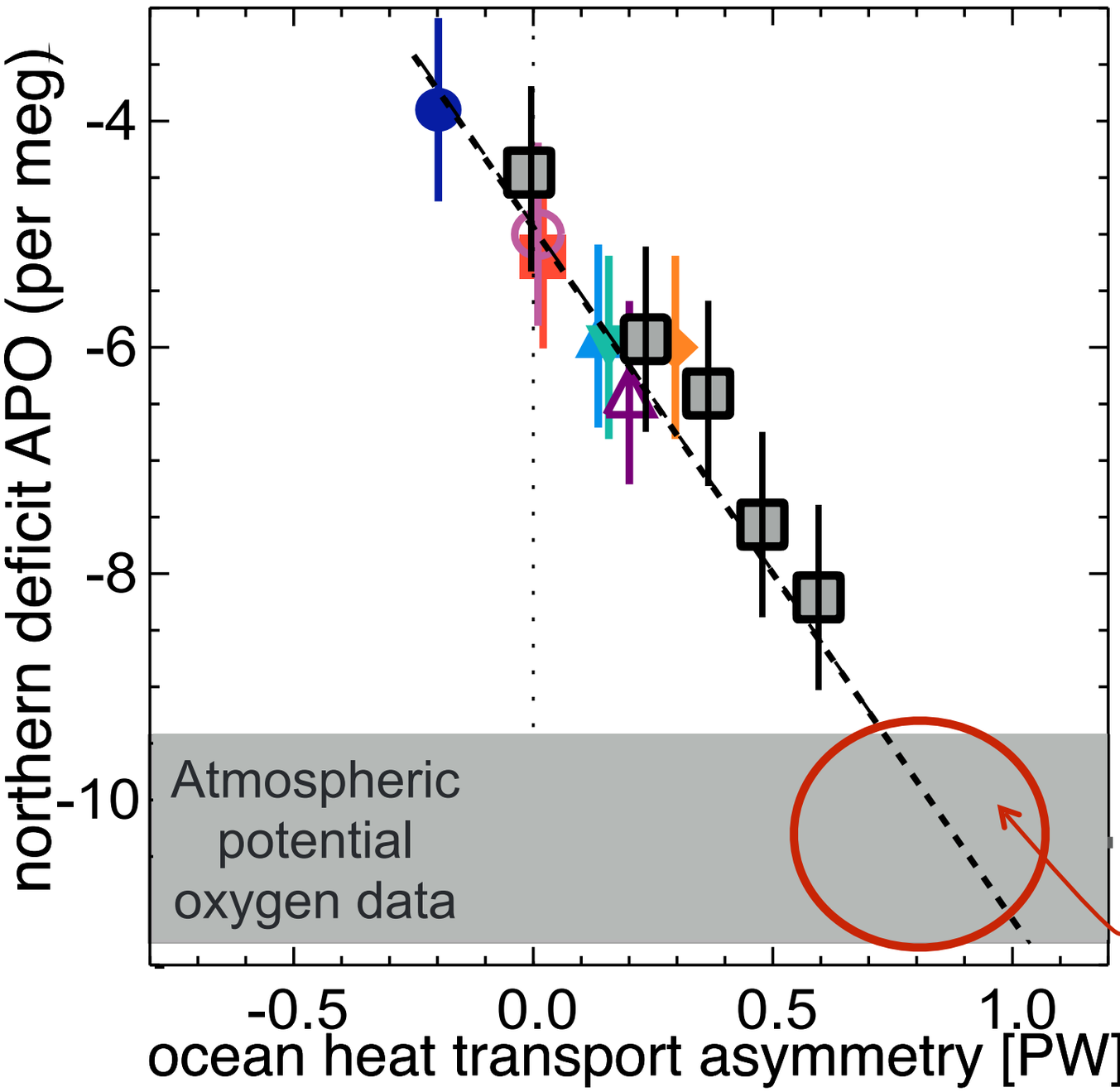
- MOM-HH
- MOM-LHS
- MOM-LL
- MOM-PSS
- MOM-RDS
- MITgcm-2.8
- MIT-ECCO **v1**

5 Climate models

- CESM, GFDL, IPSL, MPI (x2)

Resplandy et al., subm

Ocean transport asymmetry is underestimated



7 Ocean inversions

- MOM-HH
- MOM-LHS
- MOM-LL
- MOM-PSS
- MOM-RDS
- MITgcm-2.8
- MIT-ECCO **v1**

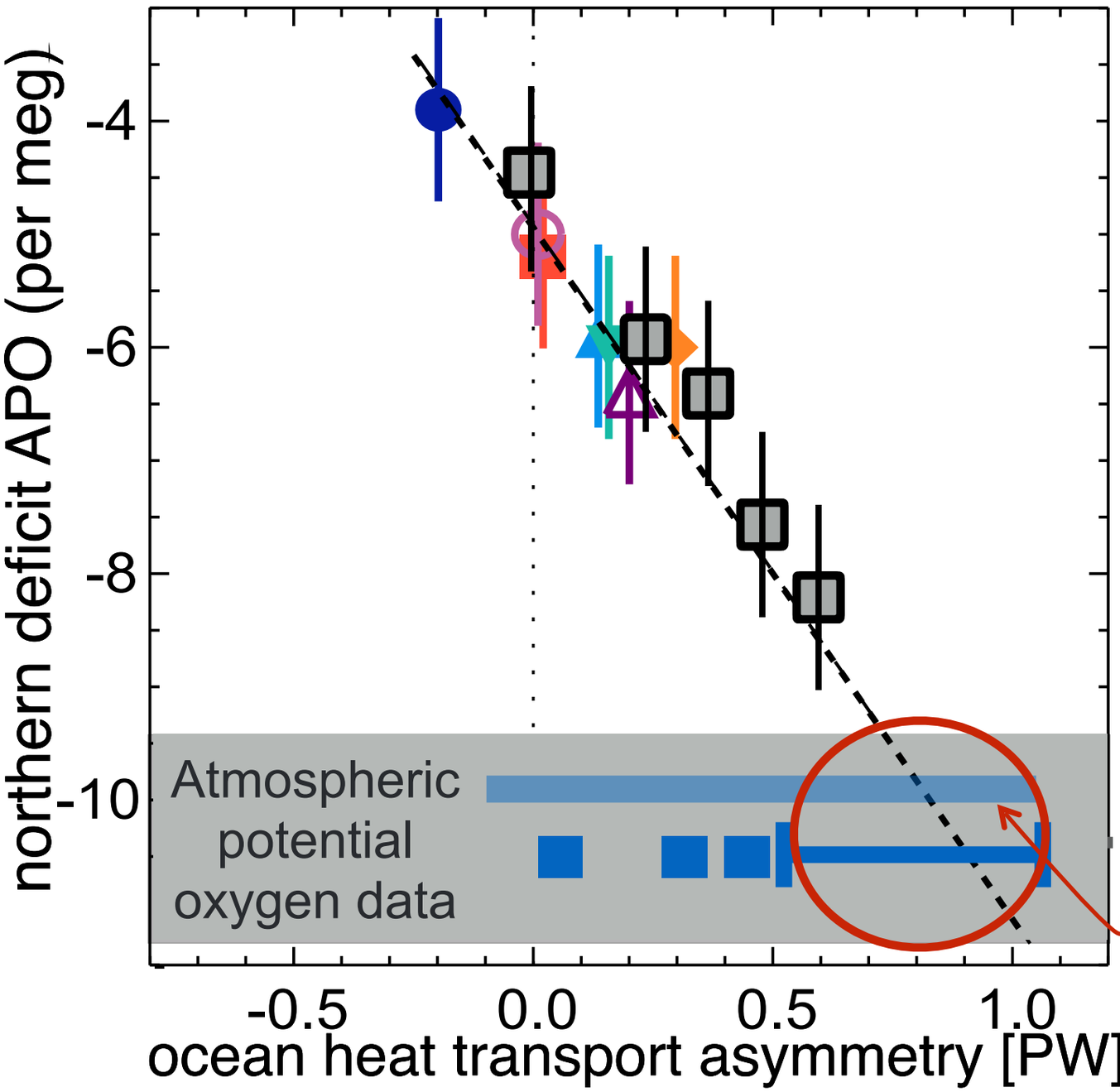
5 Climate models

- CESM, GFDL, IPSL, MPI (x2)

observational target 0.6-1 PW

Resplandy et al., subm

Ocean transport asymmetry is underestimated



7 Ocean inversions

- MOM-HH
- MOM-LHS
- MOM-LL
- MOM-PSS
- MOM-RDS
- MITgcm-2.8
- MIT-ECCO **v1**

5 Climate models

- CESM, GFDL, IPSL, MPI (x2)

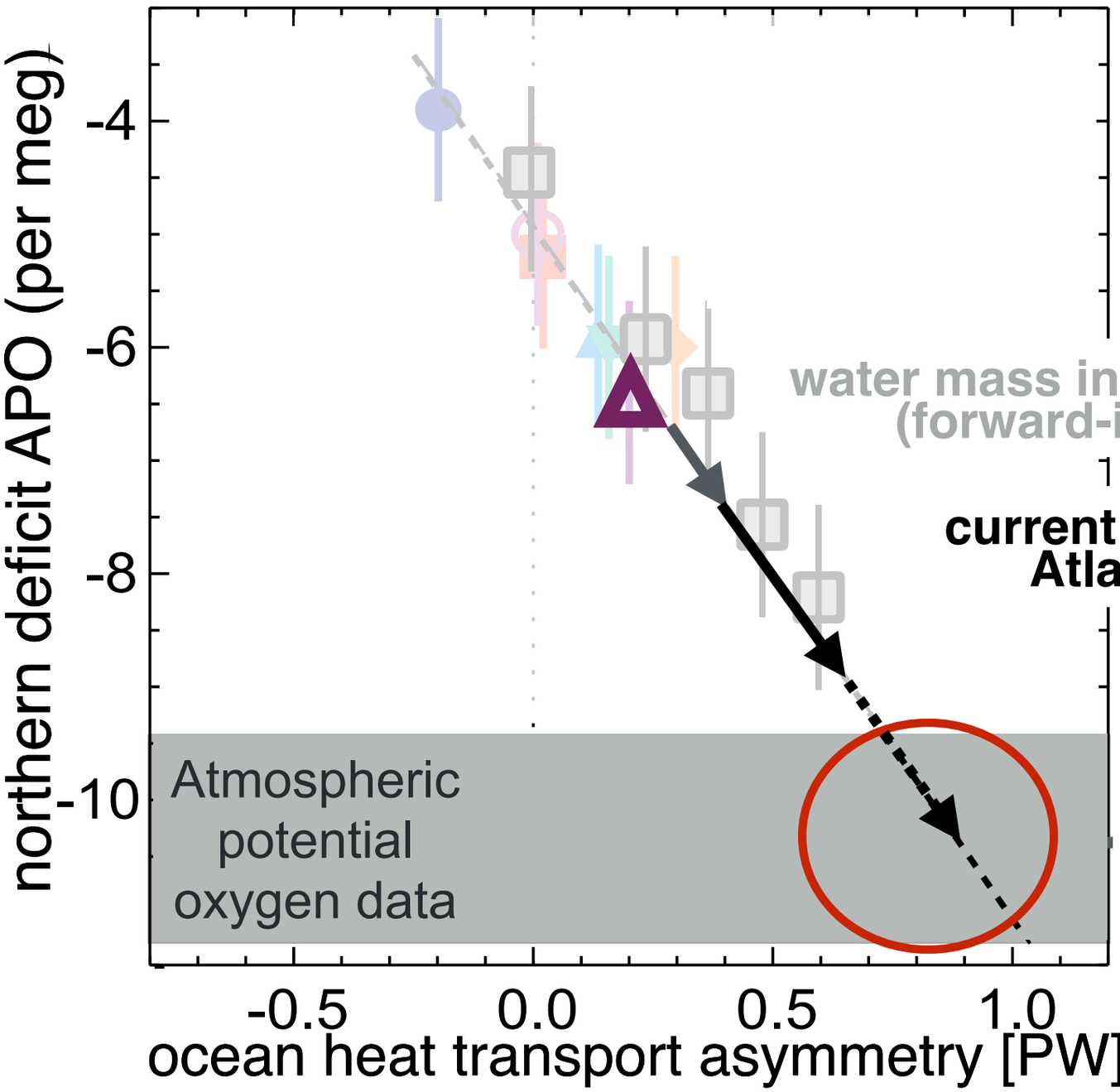
Previous estimates

- Ocean sections
- Air-sea flux bulk climatology
- Top of atmosphere budgets

observational target 0.6-1 PW

Resplandy et al., subm

Ocean transport asymmetry is underestimated
What is wrong?



Ocean inversion | Δ MIT-ECCO

water mass inconsistency (forward-inverse)

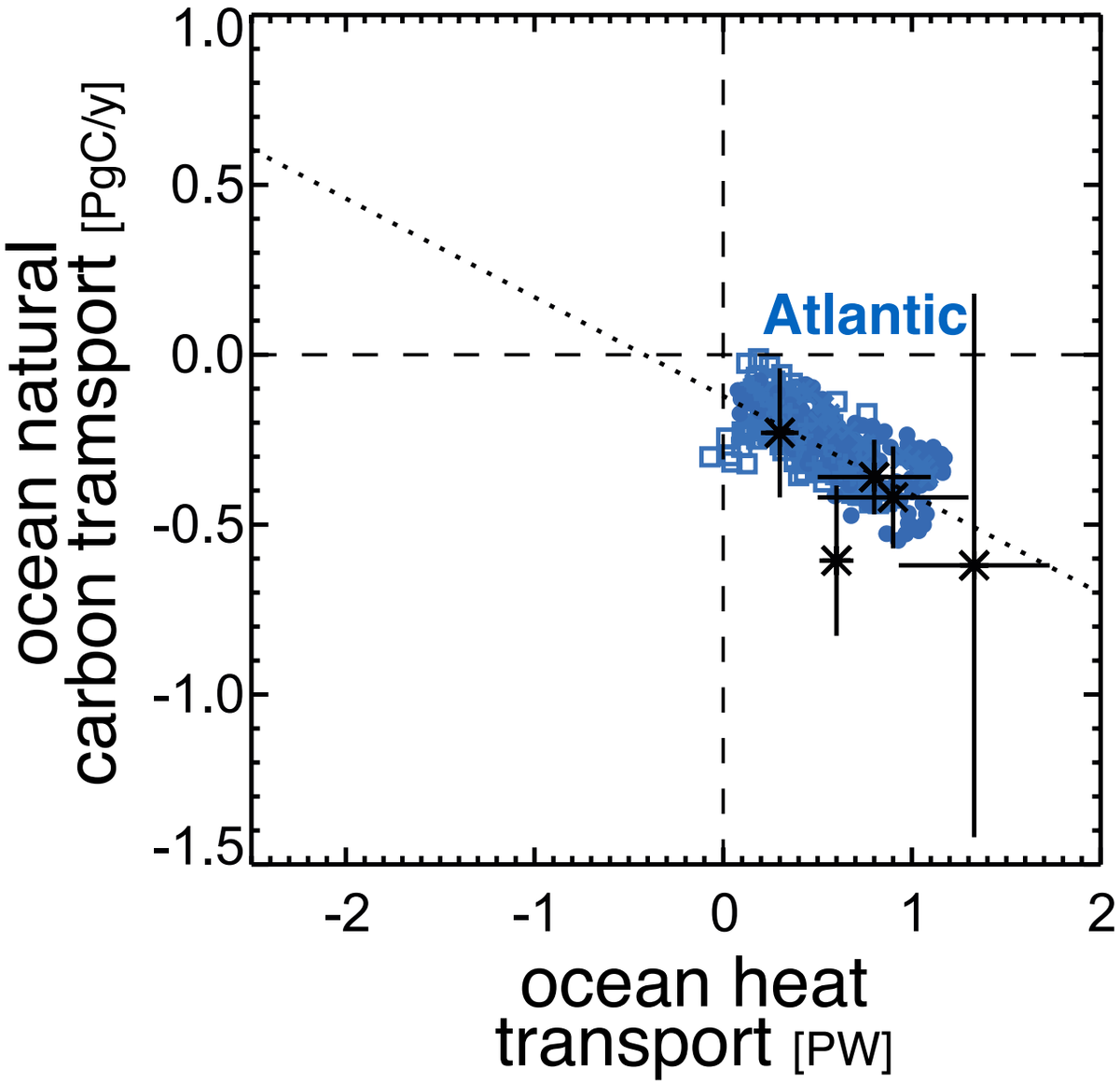
current models are "missing" Atlantic heat transport

"missing" Pacific APO sink?
(Tohjima et al., 2012)

Implications…?

Resplandy et al., subm

Close link between ocean natural carbon & heat



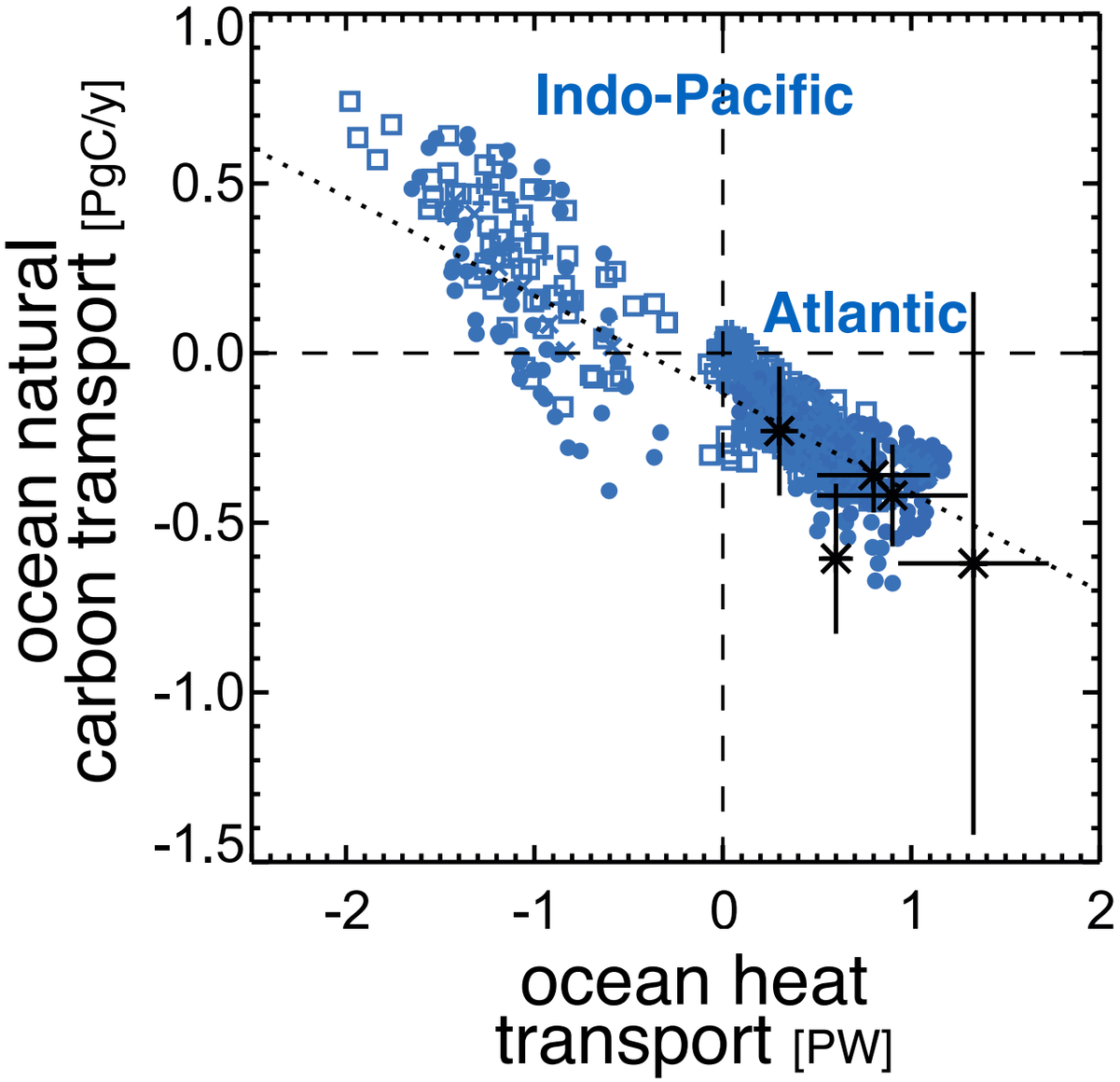
Data: Atlantic hydrographic sections

✳ Ganachaud & Wunsch, 2003;
Macdonald et al., 2003; Alvarez et al., 2003;
Holfort et al., 1998; Lundberg & Haugan, 1996

Models sections:

- □ 7 inversions
- ● 6 climate models (CMIP5)
- x 2 ocean models (CESM, IPSL)

Close link between ocean natural carbon & heat



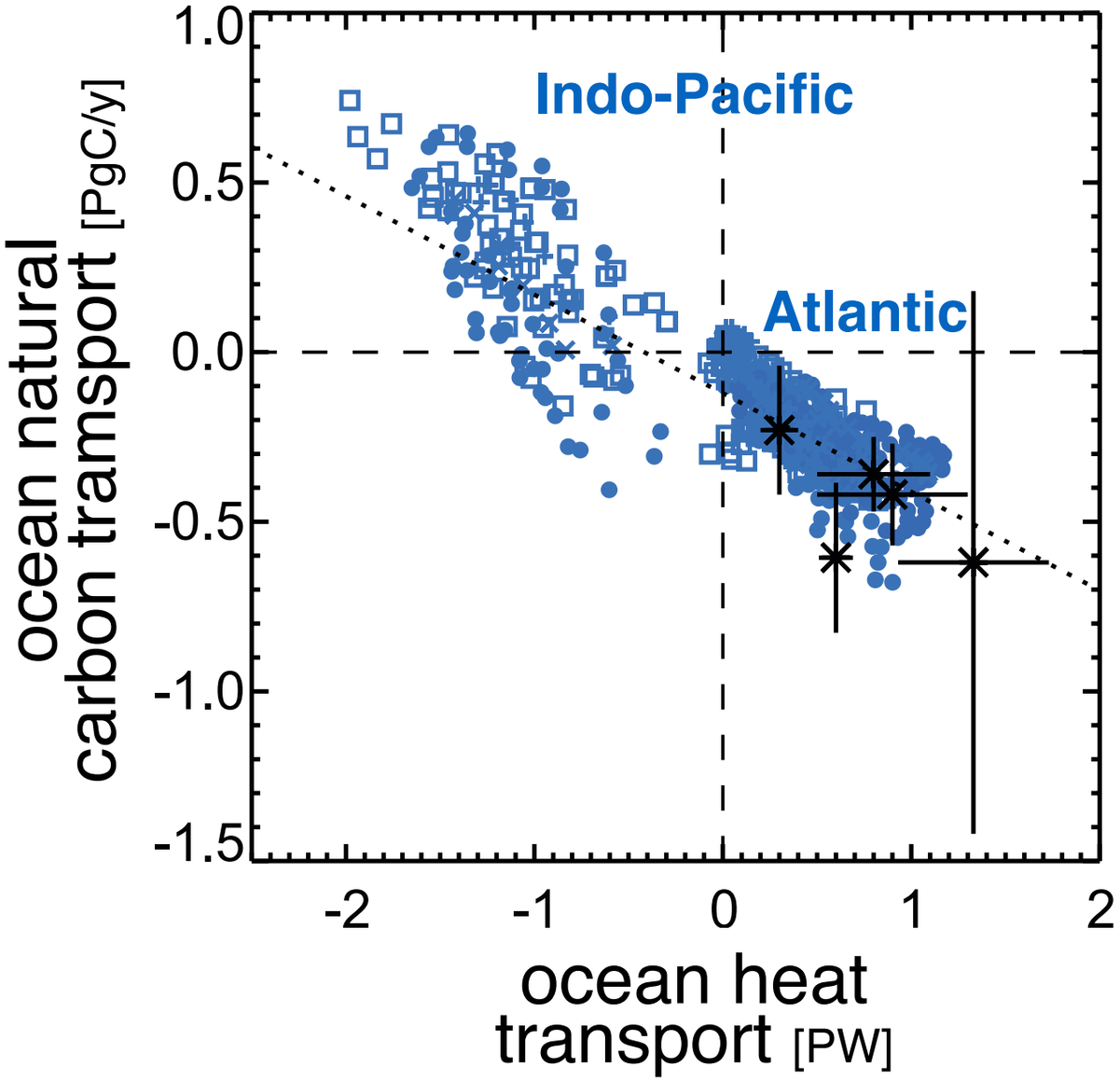
Data: Atlantic hydrographic sections

✳ Ganachaud & Wunsch, 2003;
Macdonald et al., 2003; Alvarez et al., 2003;
Holfort et al., 1998; Lundberg & Haugan, 1996

Models sections:

- □ 7 inversions
- ● 6 climate models (CMIP5)
- x 2 ocean models (CESM, IPSL)

Close link between ocean natural carbon & heat

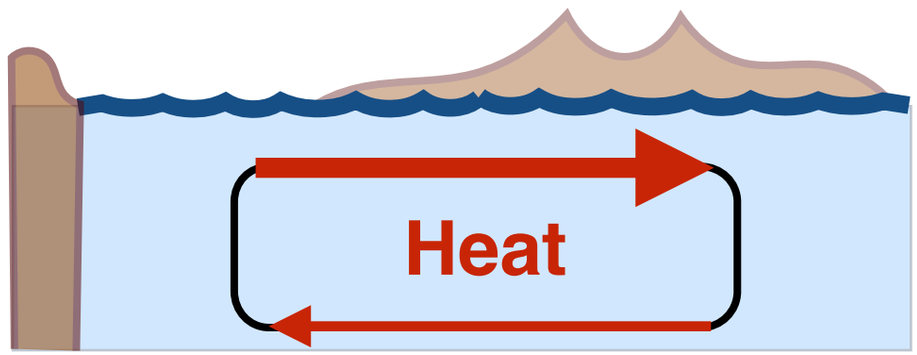


Data: Atlantic hydrographic sections

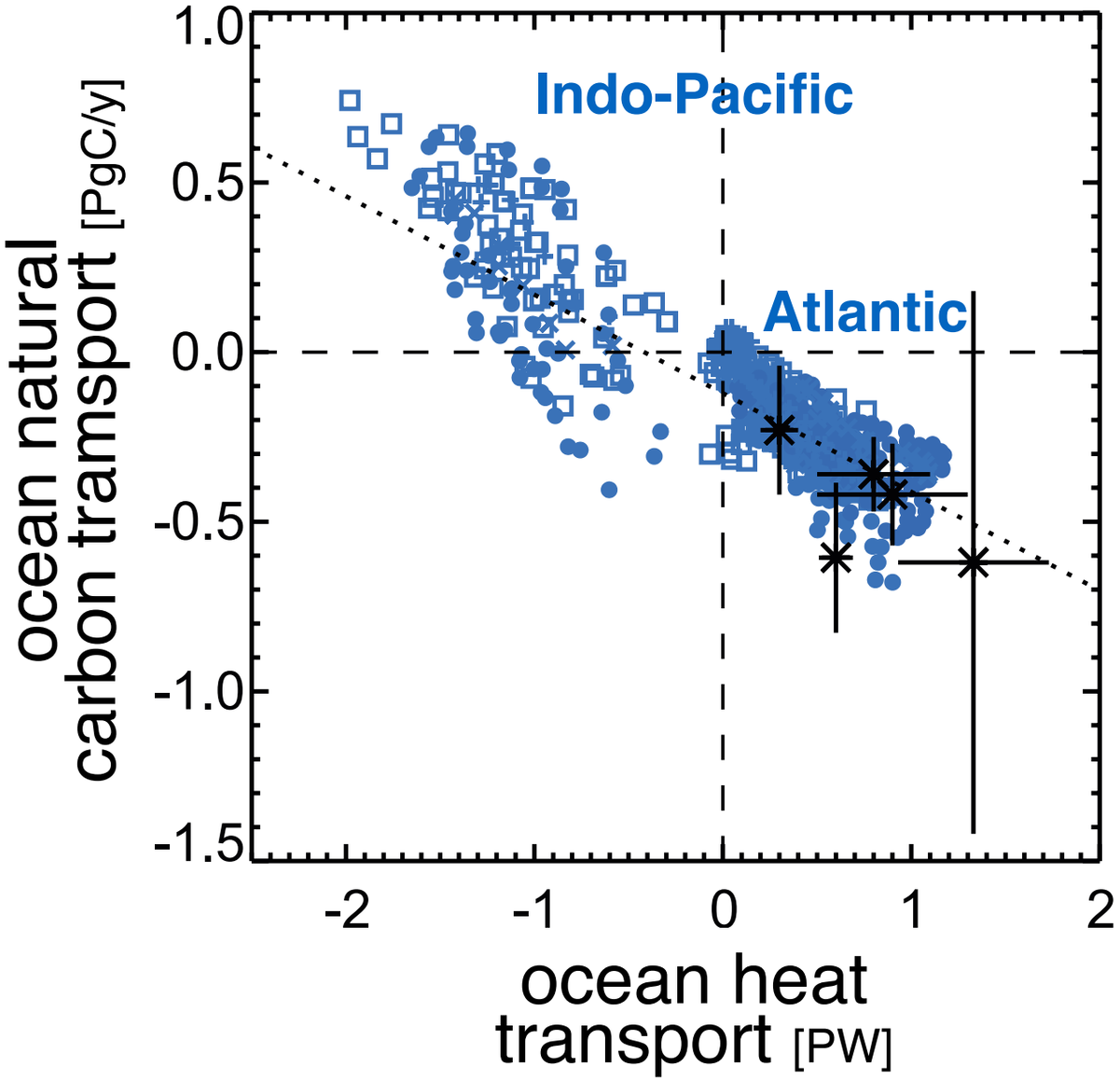
✳ Ganachaud & Wunsch, 2003; Macdonald et al., 2003; Alvarez et al., 2003; Holfort et al., 1998; Lundberg & Haugan, 1996

Models sections:

- □ 7 inversions
- ● 6 climate models (CMIP5)
- x 2 ocean models (CESM, IPSL)



Close link between ocean natural carbon & heat

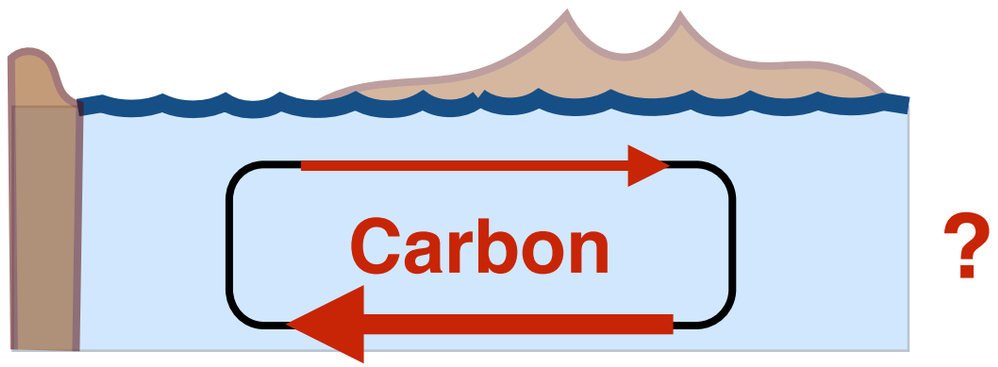


Data: Atlantic hydrographic sections

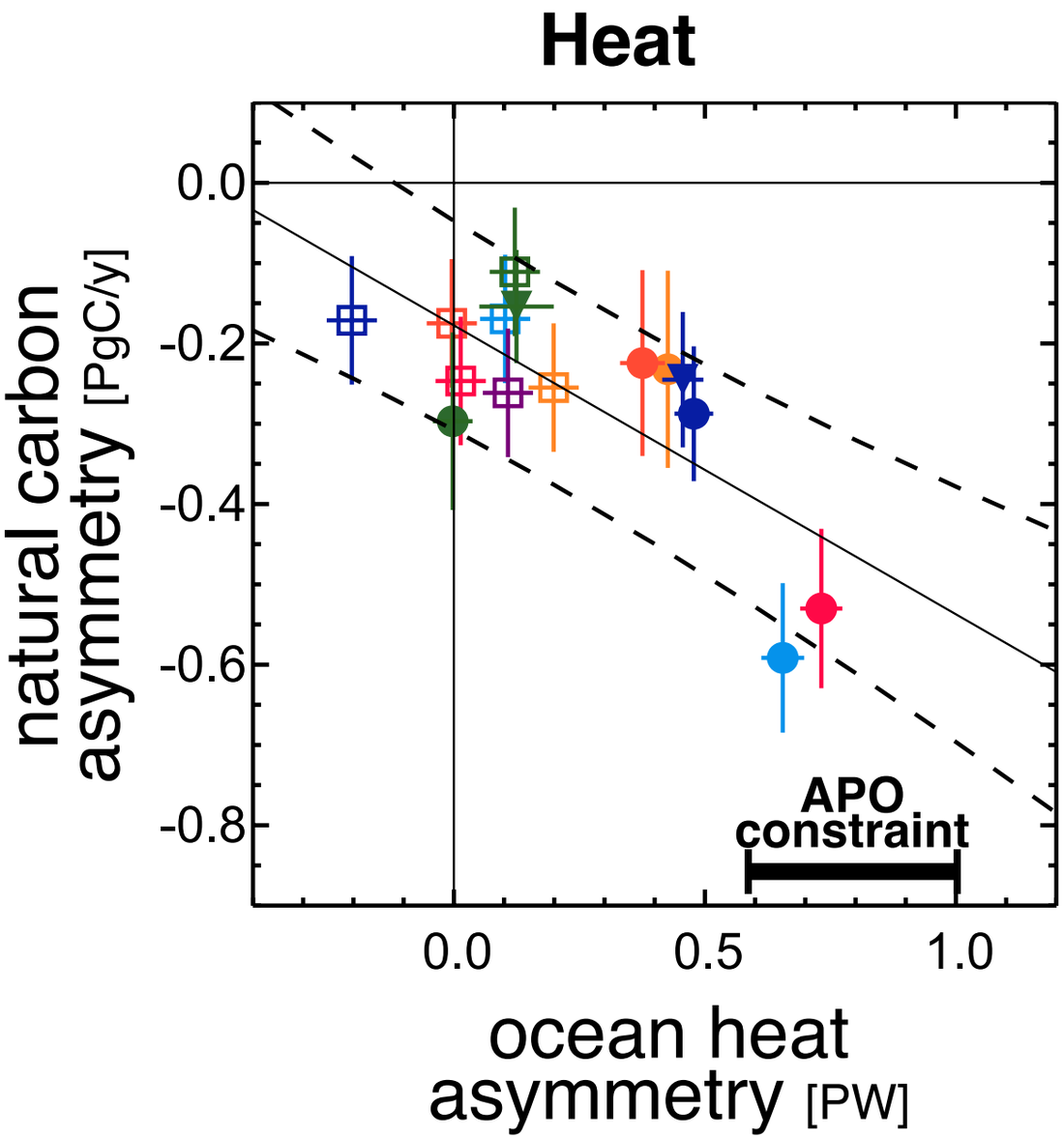
✳ Ganachaud & Wunsch, 2003; Macdonald et al., 2003; Alvarez et al., 2003; Holfort et al., 1998; Lundberg & Haugan, 1996

Models sections:

- □ 7 inversions
- ● 6 climate models (CMIP5)
- x 2 ocean models (CESM, IPSL)



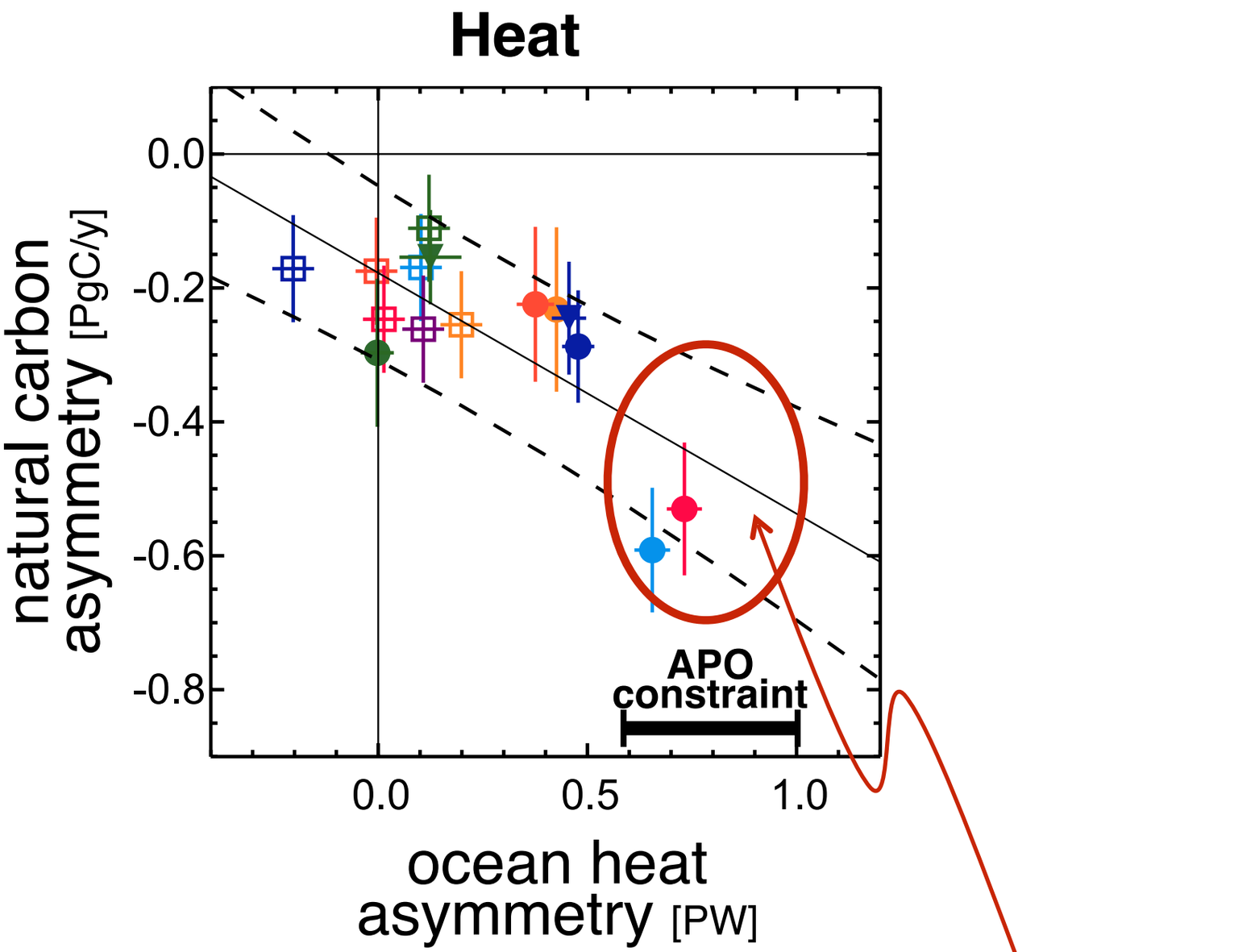
Independent constraints on natural carbon transport



Models

- □ 7 ocean inversions
- ● 6 climate models (CMIP5)
- x 2 ocean models (CESM, IPSL)

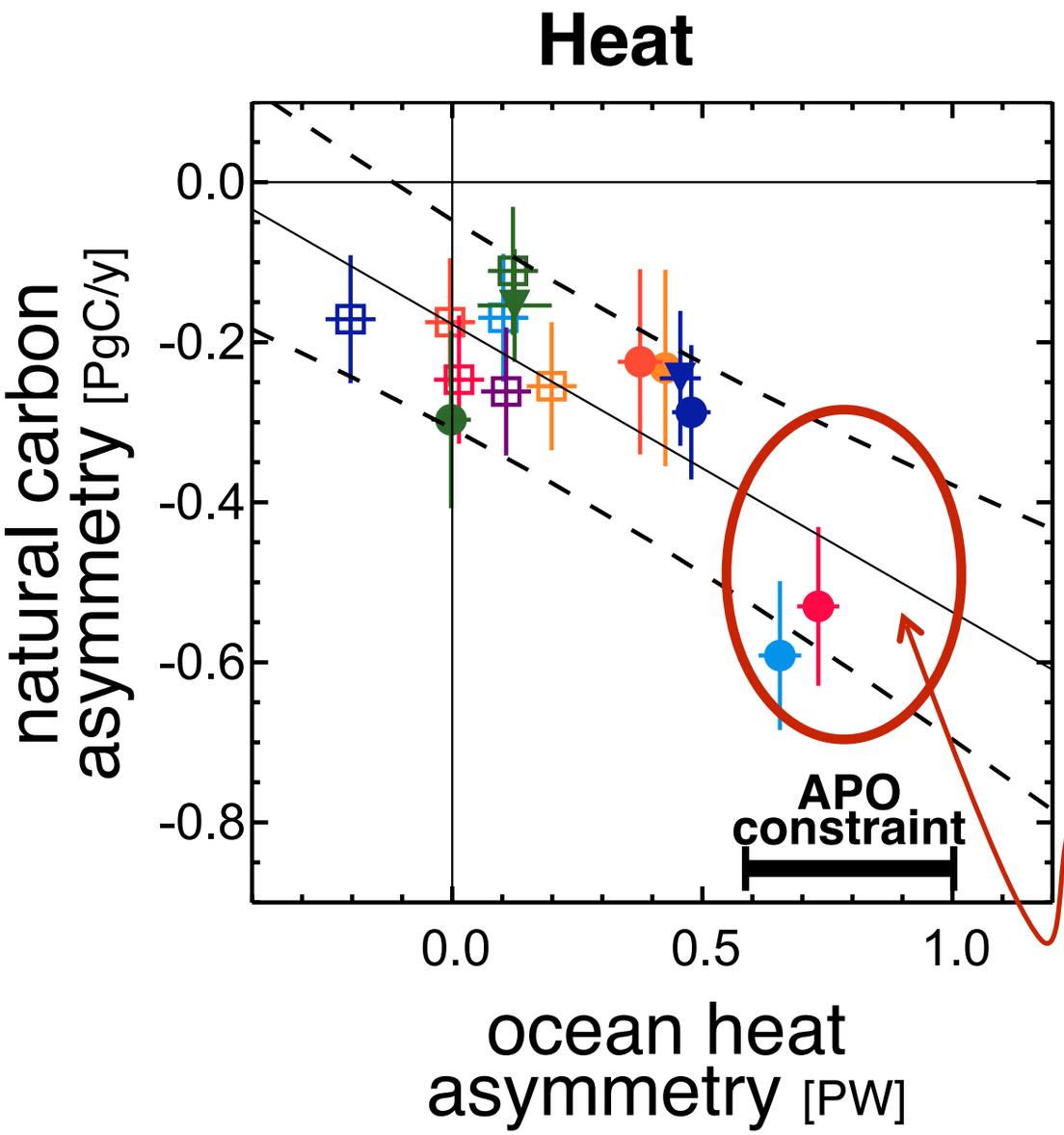
Independent constraints on natural carbon transport



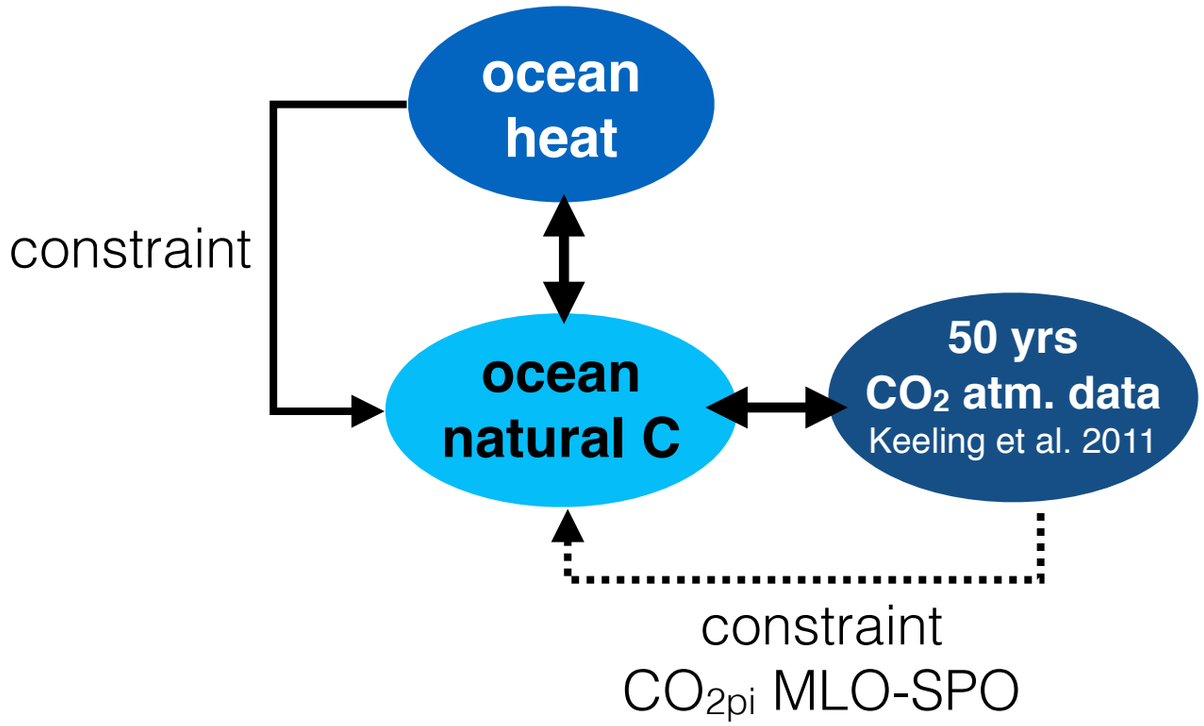
Models

- □ 7 ocean inversions
- ● 6 climate models (CMIP5)
- x 2 ocean models (CESM, IPSL)

Independent constraints on natural carbon transport



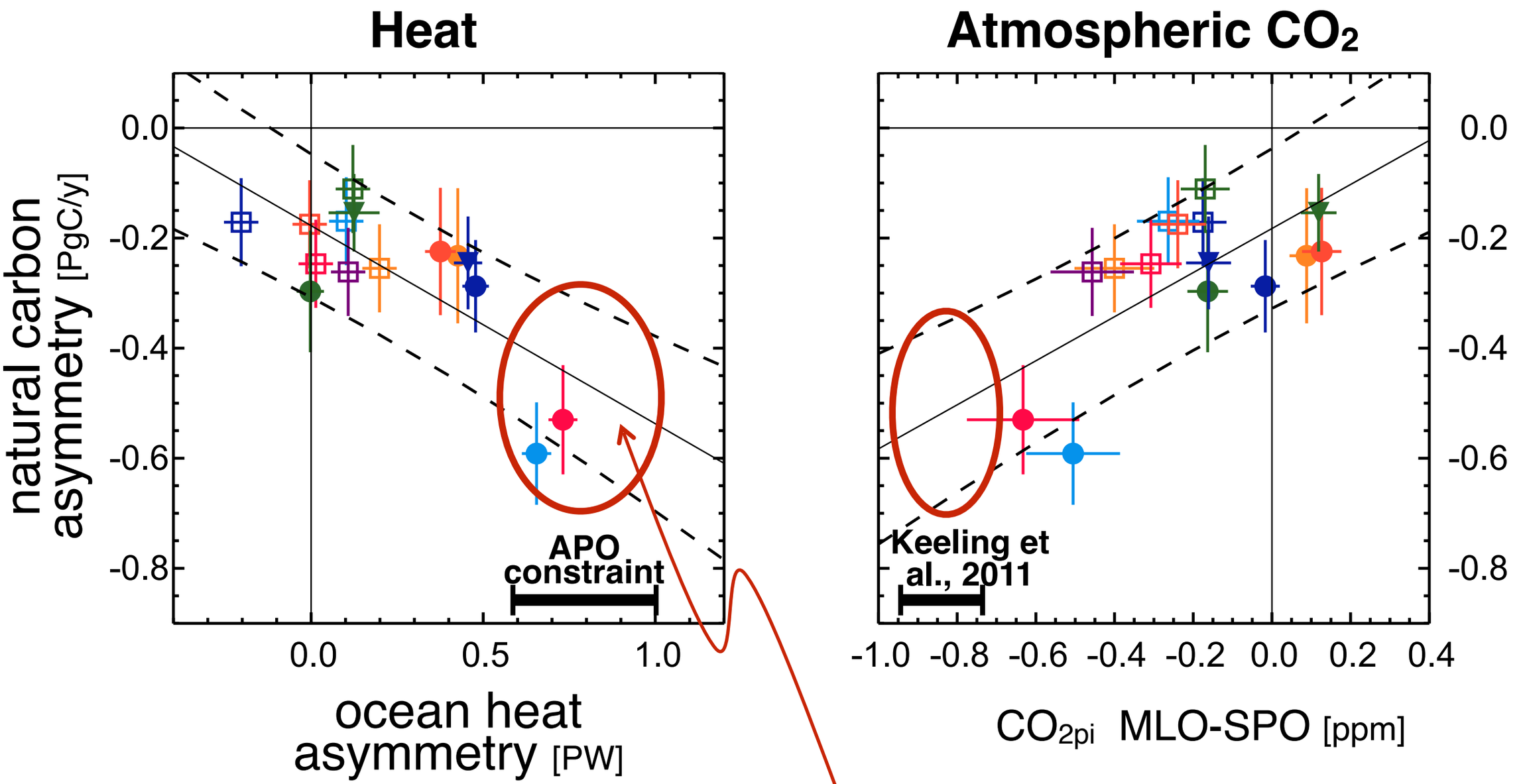
observational target 0.3-0.7 PgC/y



Models

- □ 7 ocean inversions
- ● 6 climate models (CMIP5)
- x 2 ocean models (CESM, IPSL)

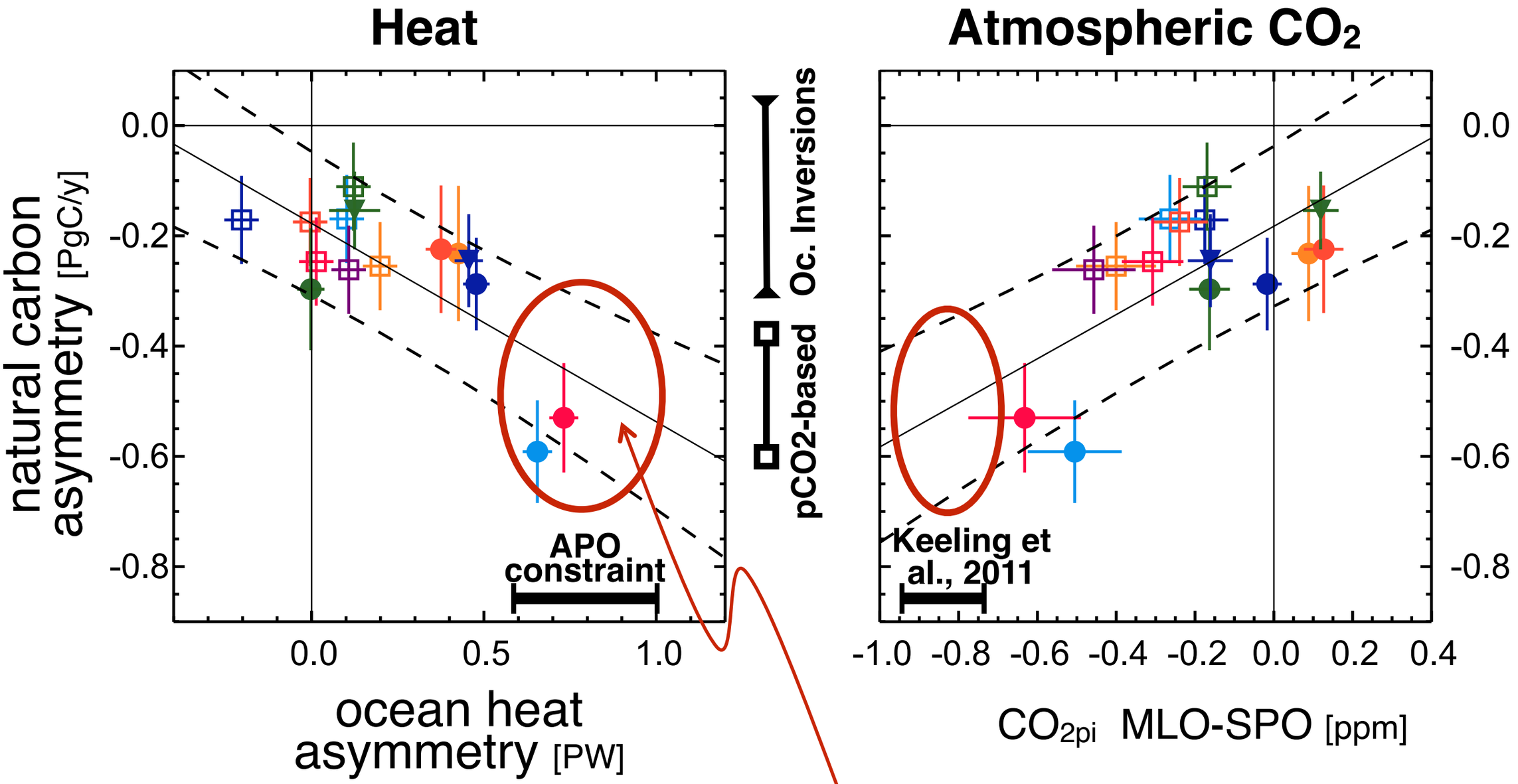
Independent constraints on natural carbon transport



Models

- □ 7 ocean inversions
- ● 6 climate models (CMIP5)
- x 2 ocean models (CESM, IPSL)

Independent constraints on natural carbon transport



Models

- ☐ 7 ocean inversions
- ● 6 climate models (CMIP5)
- x 2 ocean models (CESM, IPSL)

Previous estimates

Mikaloff Fletcher et al., 2007;
Gerber et al., 2010;
Takahashi et al., 2009

Discussion and prospects

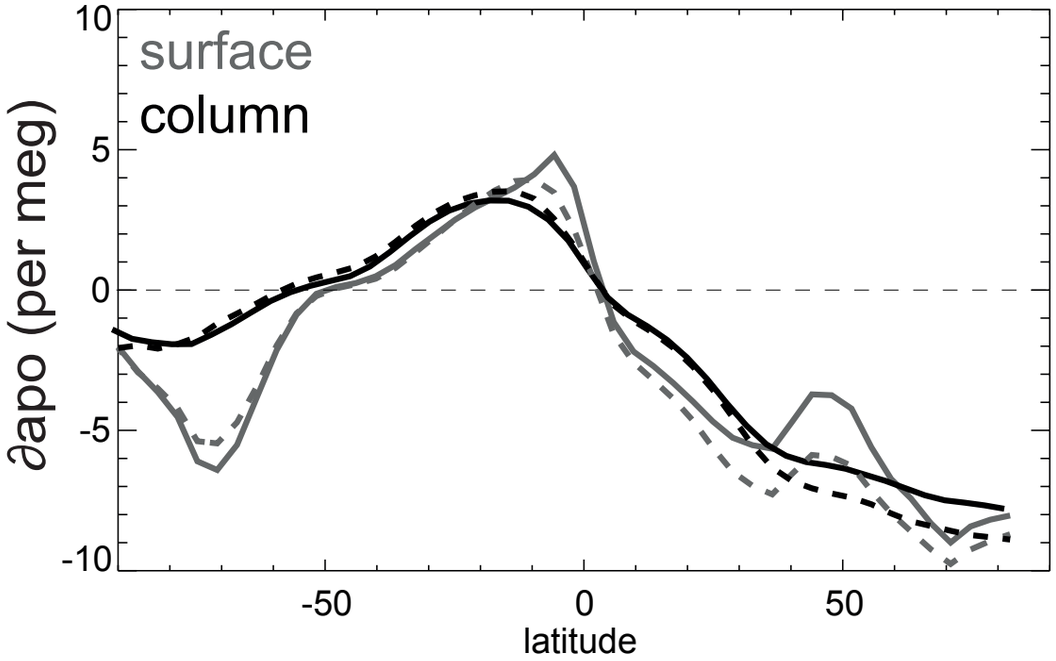
- Potential oxygen is a valuable new constraint on heat transport
  0.5-1 PW ≥ hydrographic data and consistent with surface flux.

- Atmospheric data supports strong asymmetry in natural carbon
  0.2-0.8 PgC/y ≥ ocean priors used in atmospheric inversions

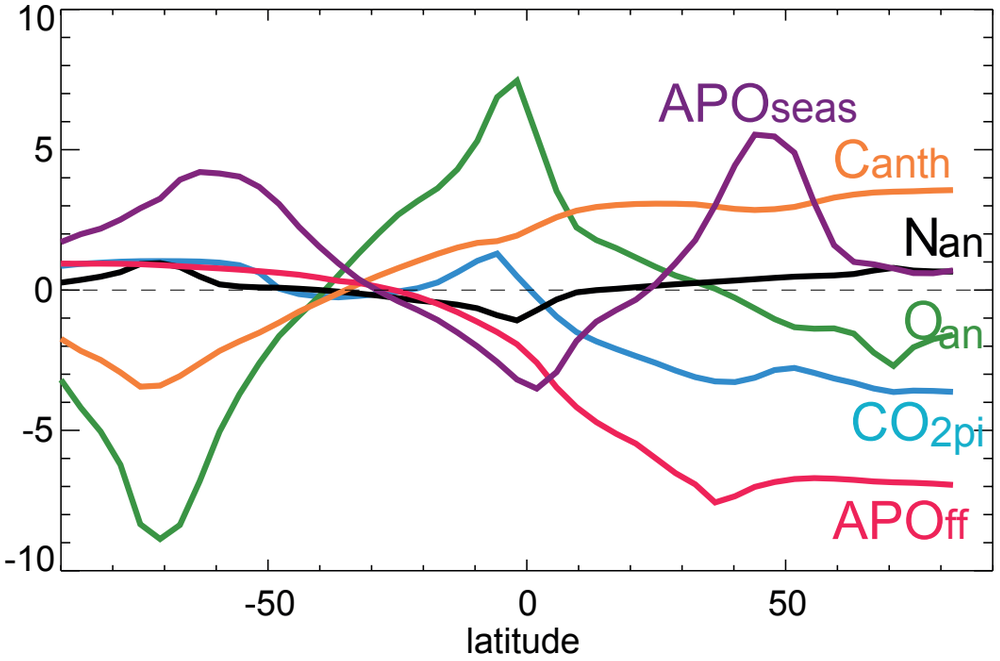
- Ocean/climate models underestimate heat and carbon transports

- Impacts on carbon sinks attribution & future climate projections…?

a) Simulated APO gradient



b) Surface components



c) Column components