Systematic deficiencies in ocean transport impact land and ocean carbon sinks

Laure Resplandy
Princeton University

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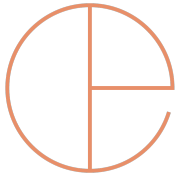
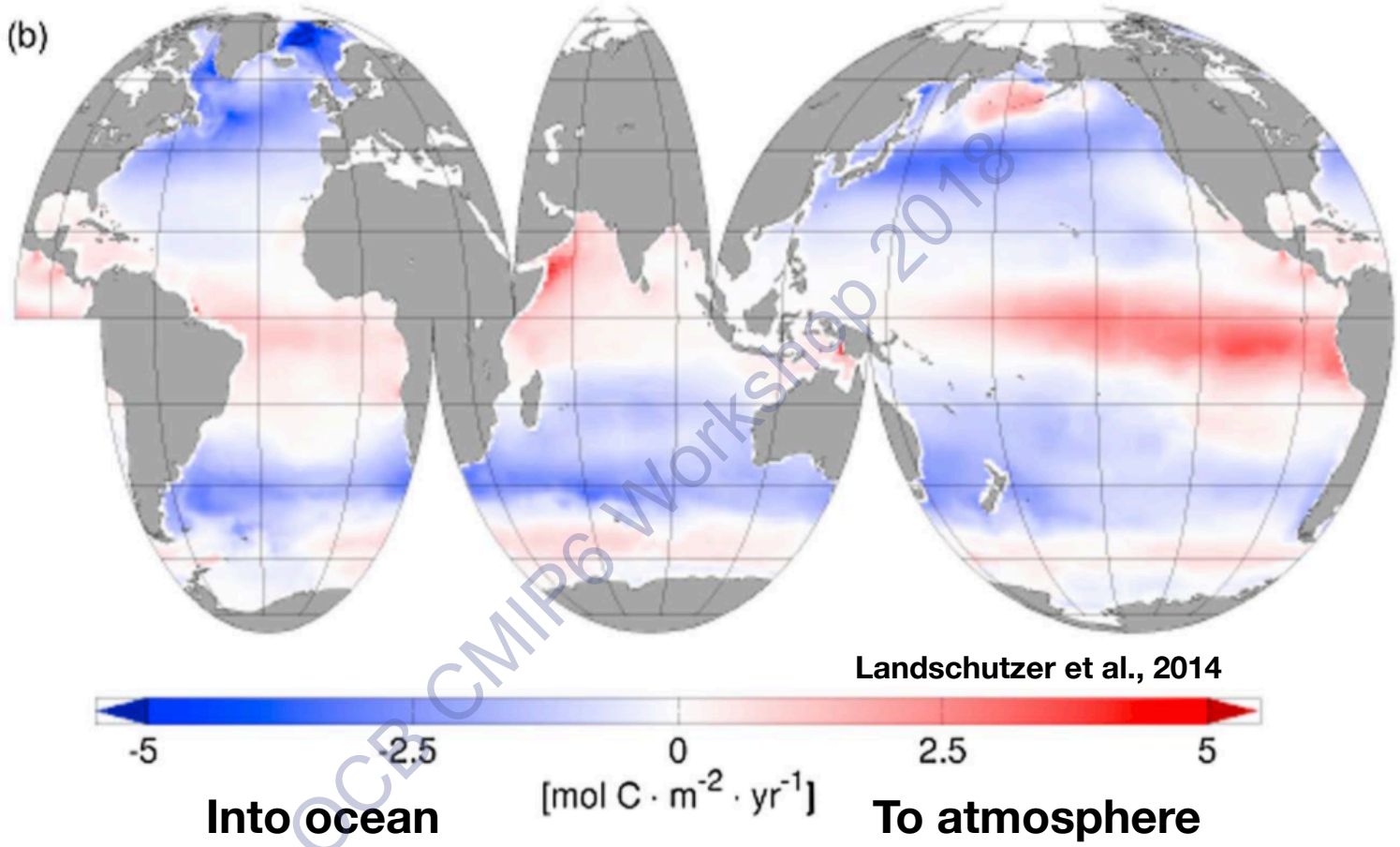
K. Rodgers (AOS); L. Bopp (IPSL); C. Rödenbeck (MPI, Germany);
S. Khatiwala (Oxford, UK); P. Tans (NOAA)



Princeton
Environmental
Institute

Ocean carbon fluxes

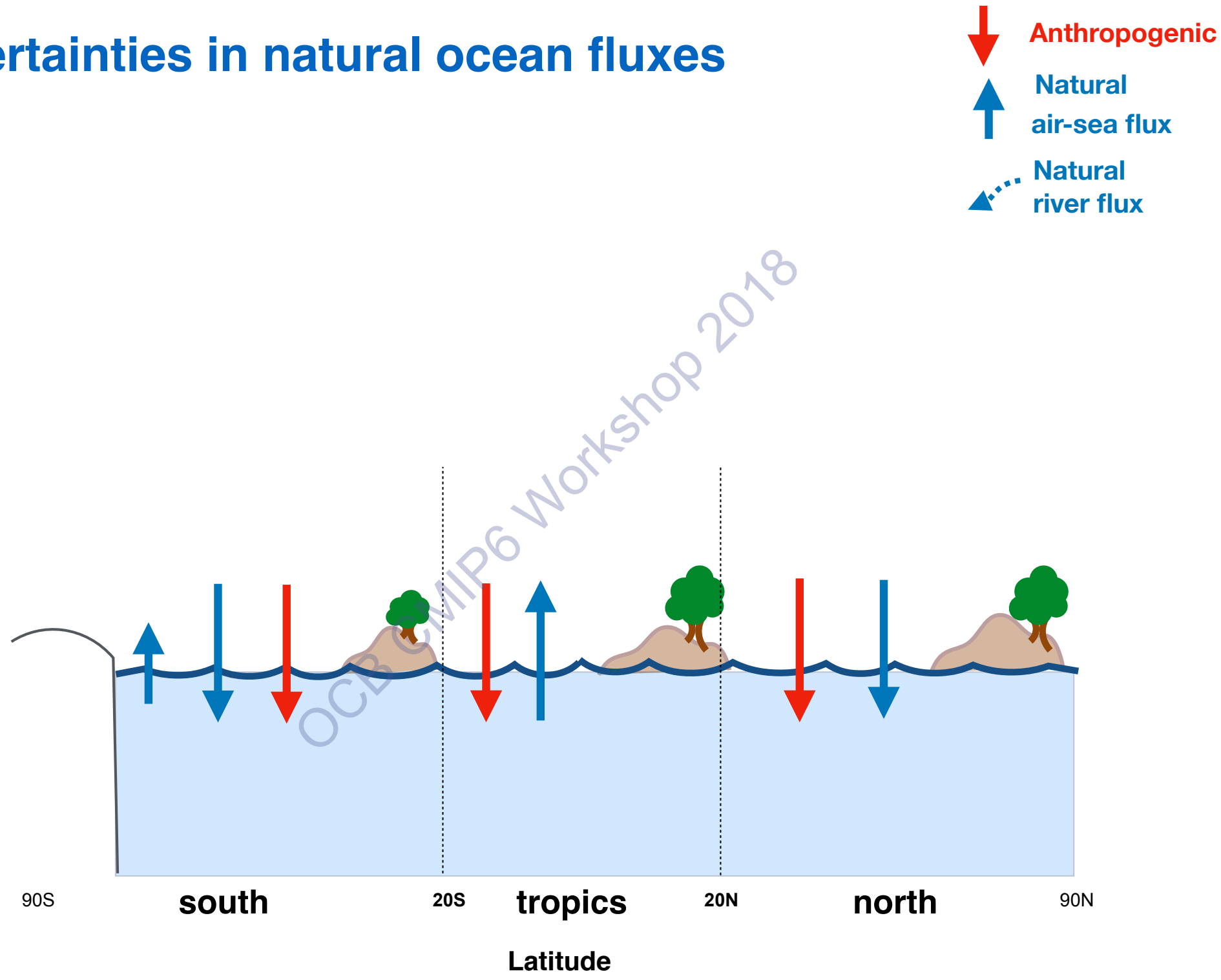


pCO_2-based SOCAT shipboard data

- Rödenbeck Jena mixed-layer scheme (update of Rödenbeck et al., 2014)
- Landchützer neural network (update of Landschützer et al., 2014)

Ocean Inversions (e.g. Mikaloff Fletcher et al, 2006 2007; Gruber et al, 2009)

Uncertainties in natural ocean fluxes



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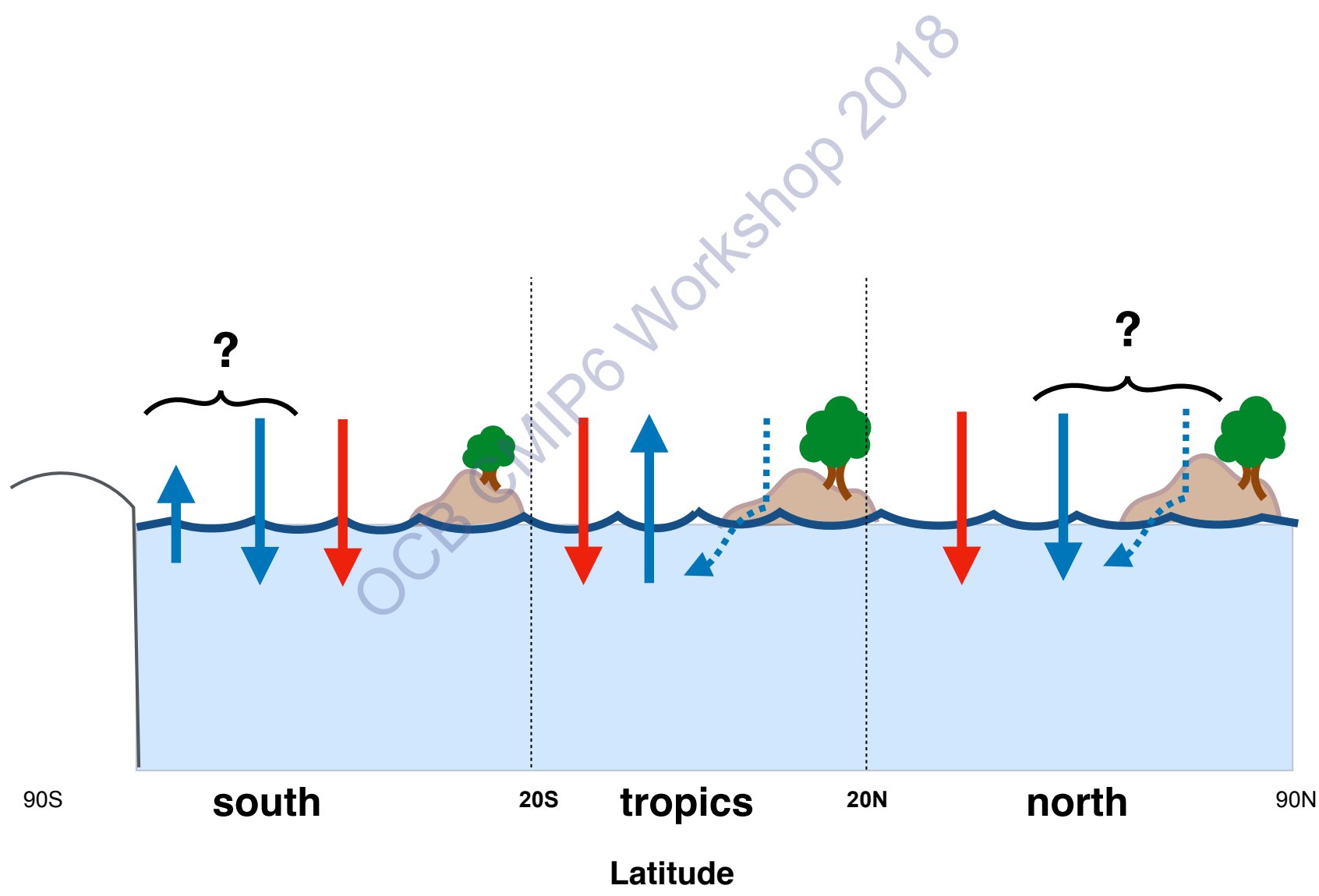
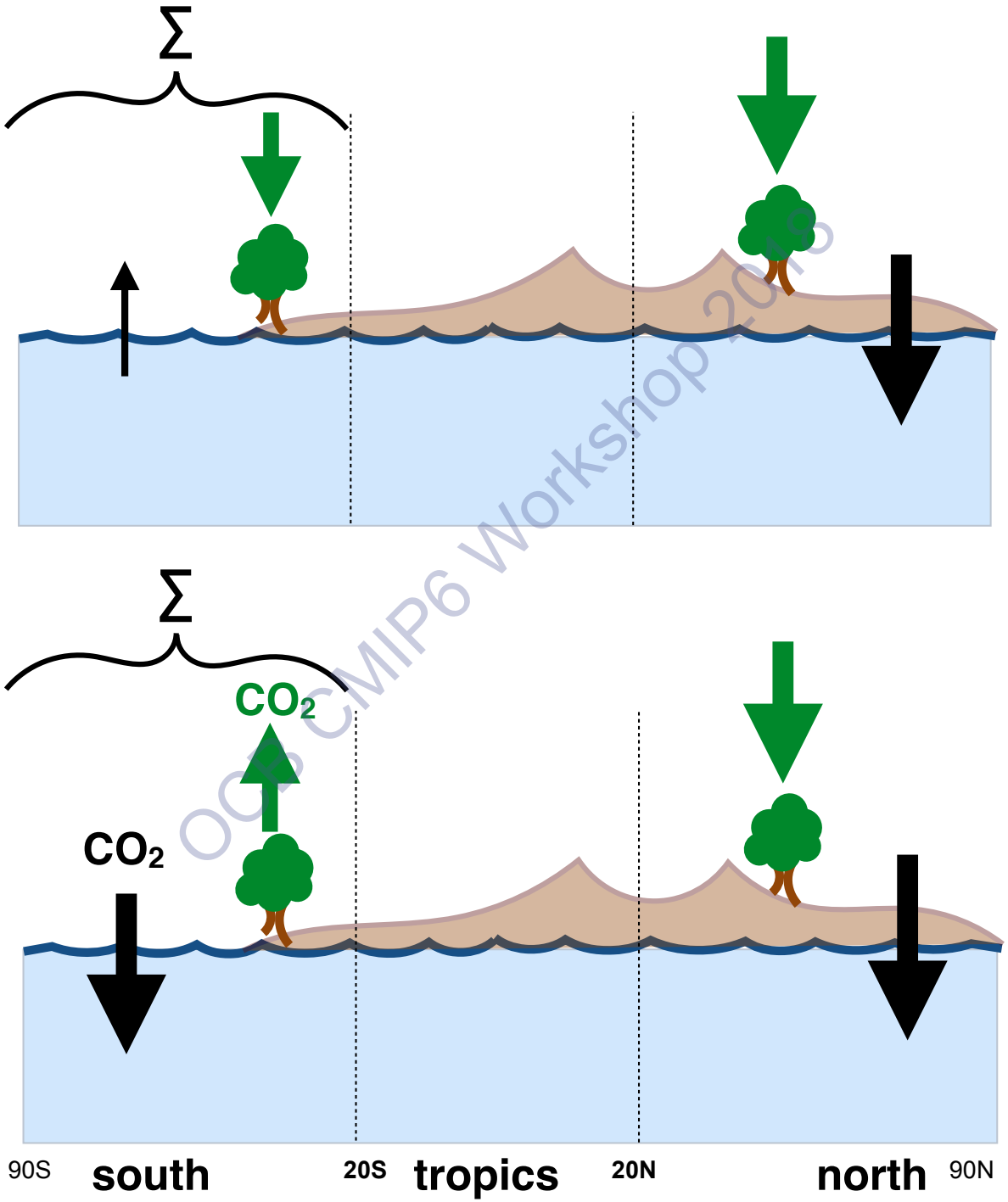


Implications for the land sink



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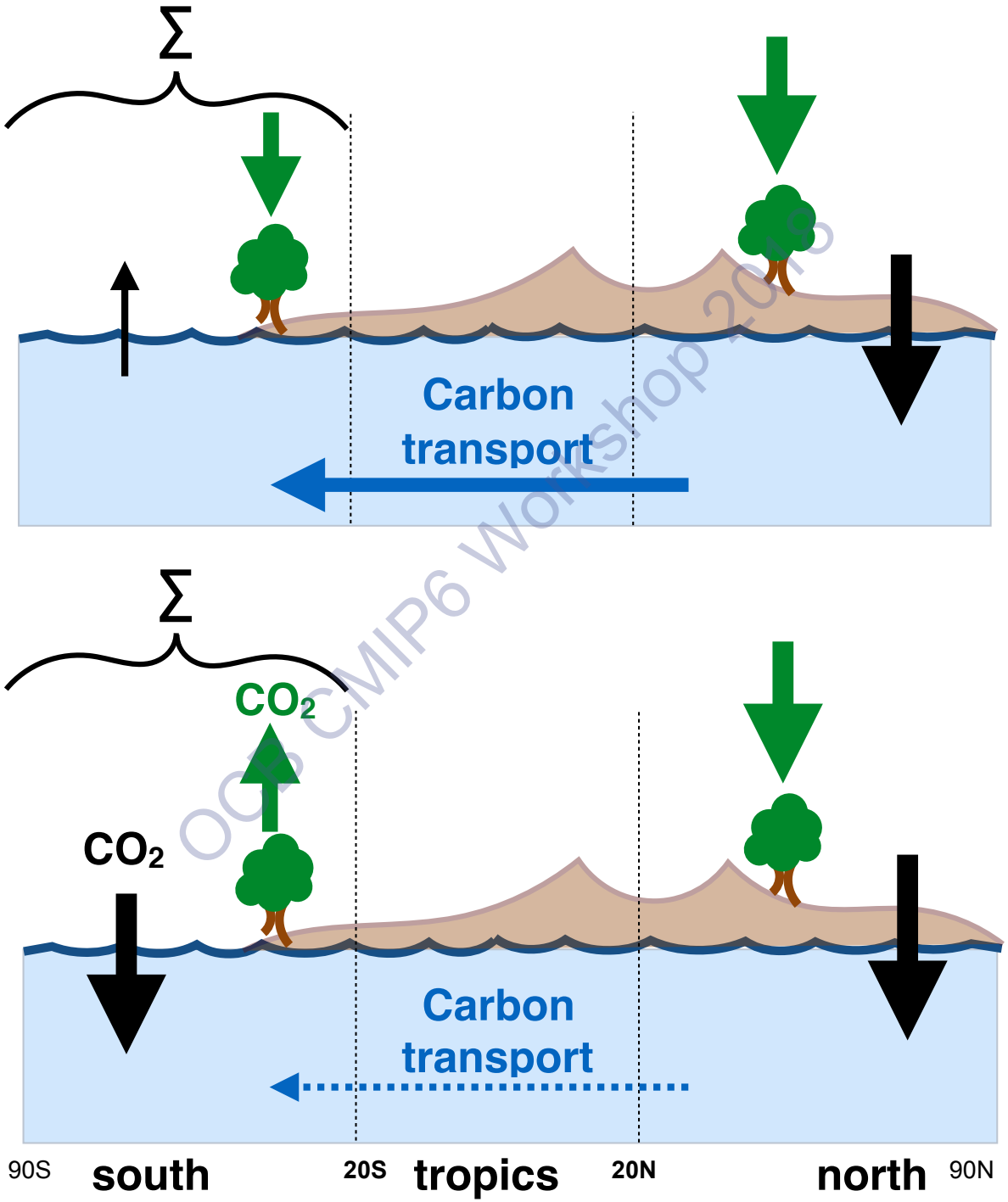
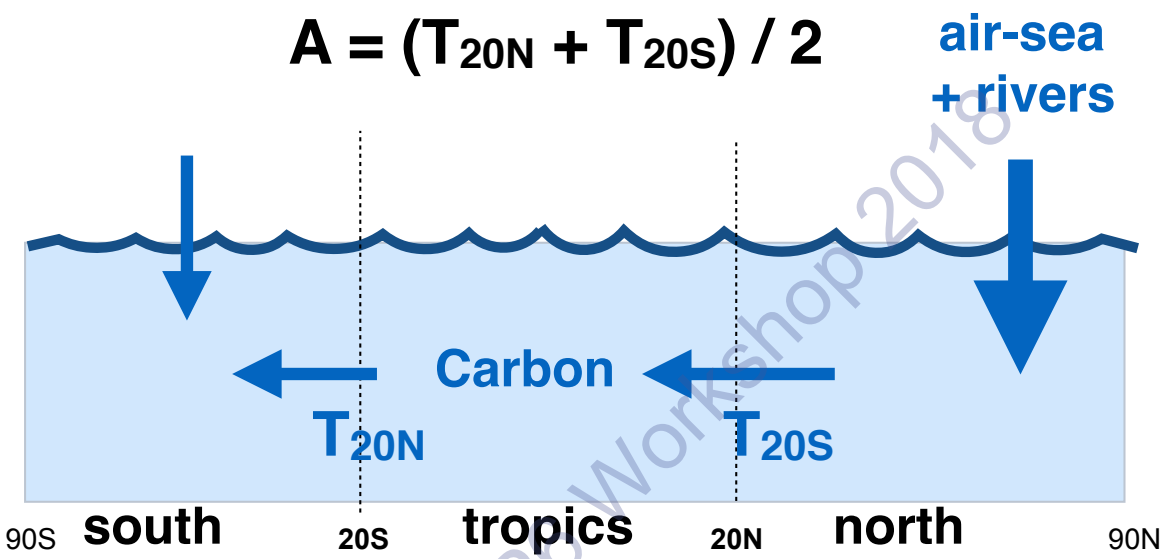
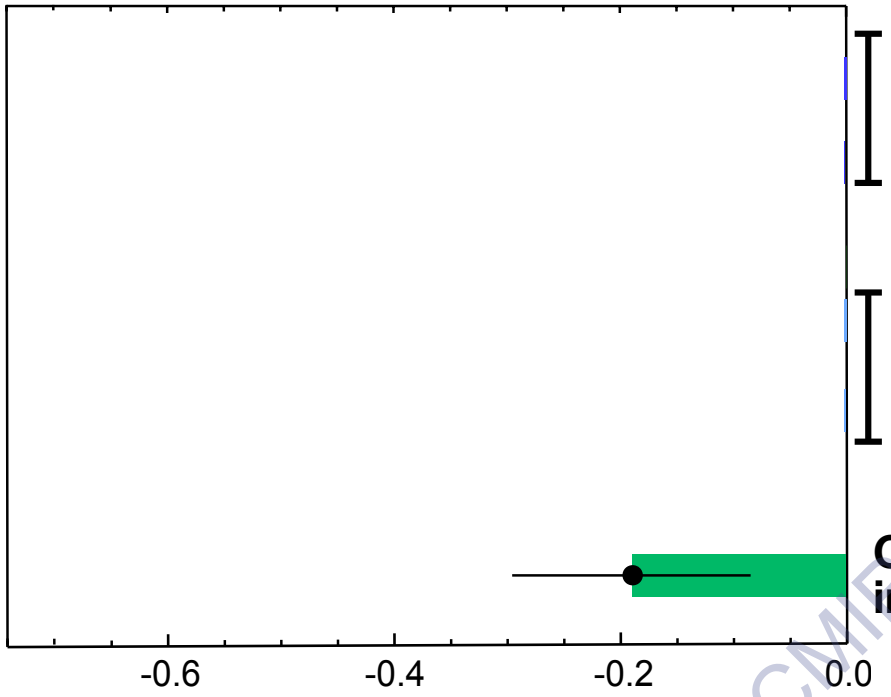


Hemispheric transport asymmetry



Do we know the ocean southward carbon transport?



pCO_2-based corrected for C_{ant} using Khatiwala et al., 2012
+ river loop = 0.78 PgC/y (Resplandy et al., 2018)

pCO_2-based
+ river loop = 0.45 PgC/y (Jacobson et al., 2007)

Ocean inversions
incl. rivers (e.g. Mikaloff Fletcher, 2007; Gruber et al., 2009)

Resplandy et al., Nat Geo 2018

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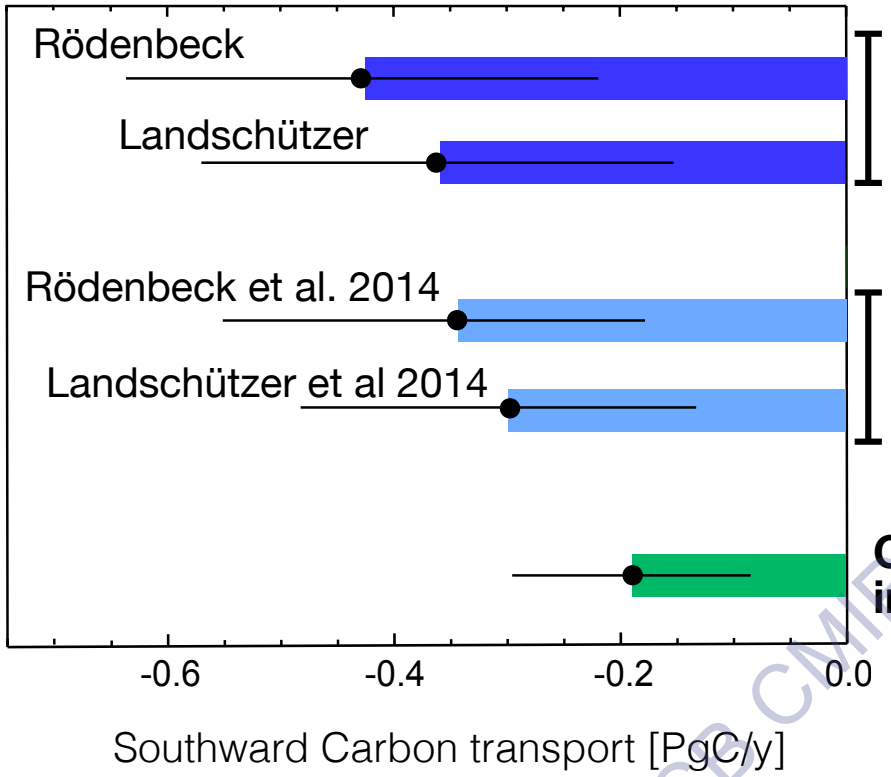

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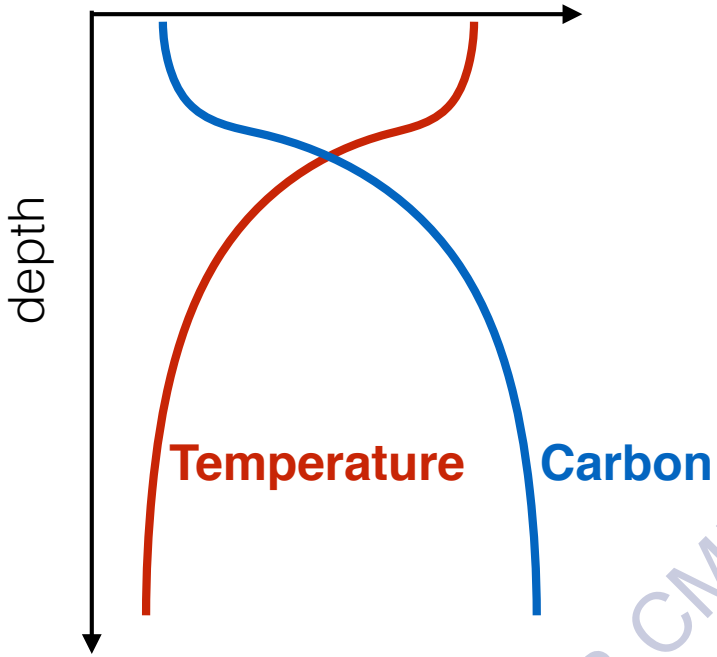
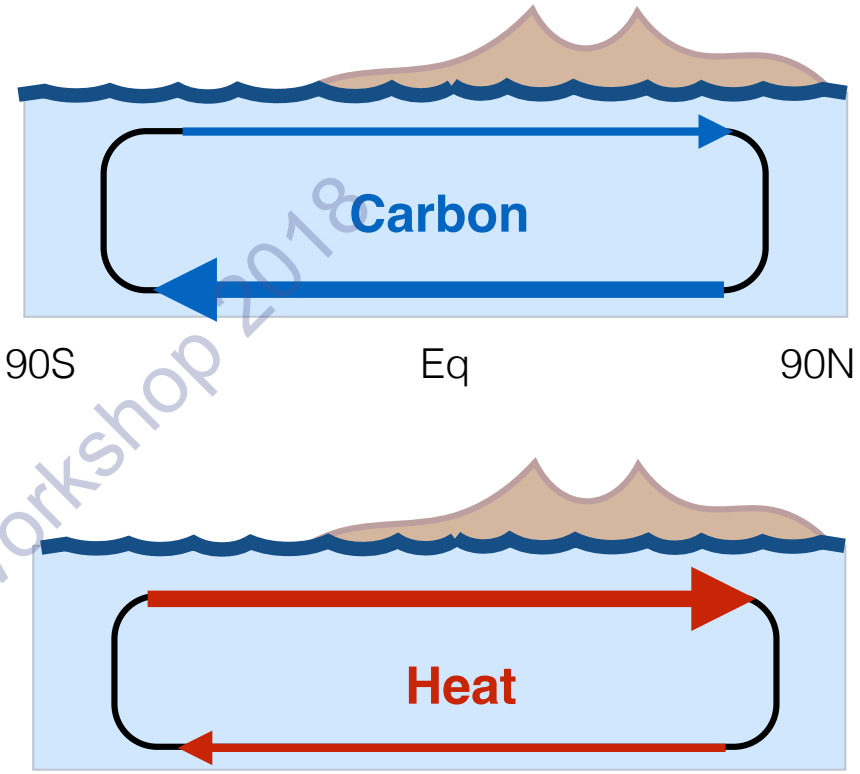
- **Estimates agree within large uncertainties but systematic differences in north-south balance**

Resplandy et al., Nat Geo 2018

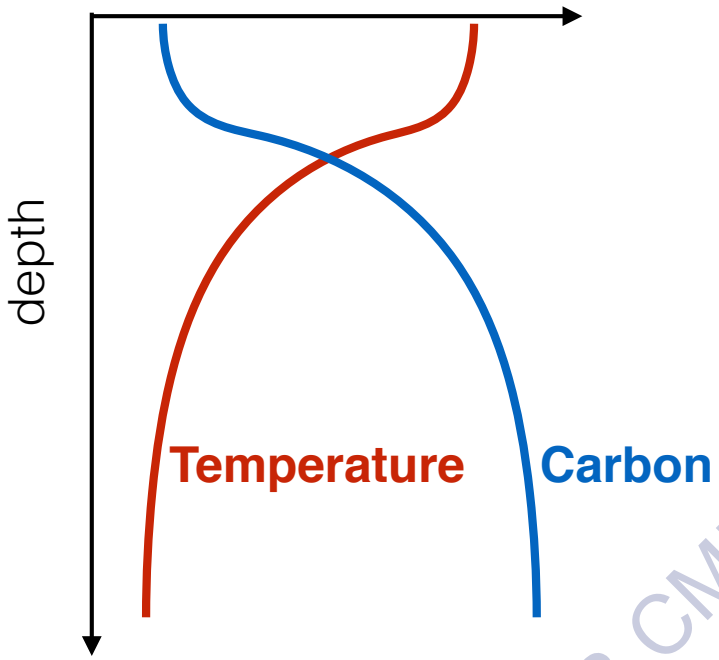
Heat an indicator of carbon transport?

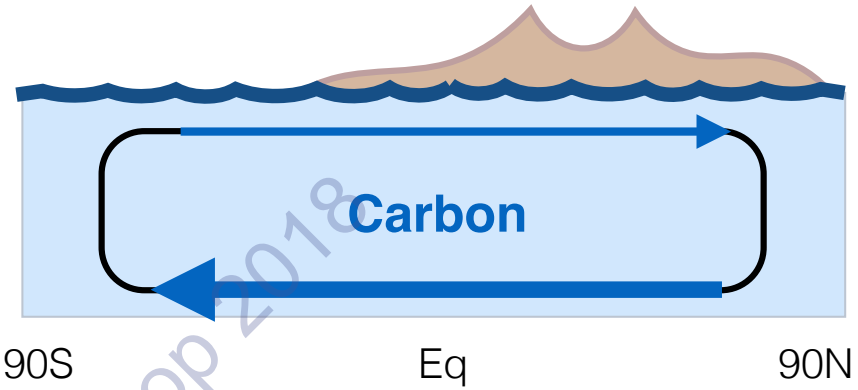


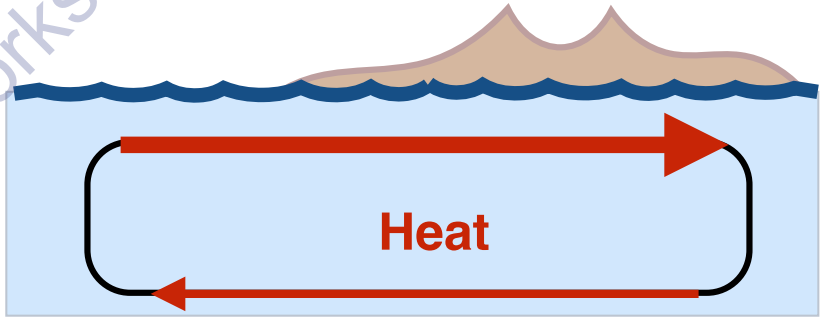


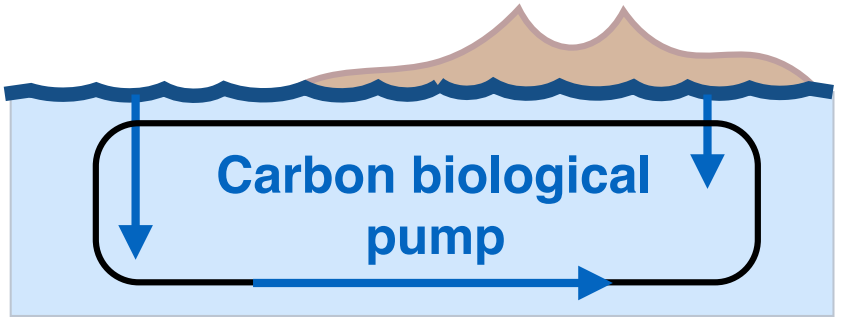
Tight carbon-temperature link arises from thermally driven fluxes (solubility) and biological pump (vertical exchange of respired carbon)

Heat an indicator of carbon transport?





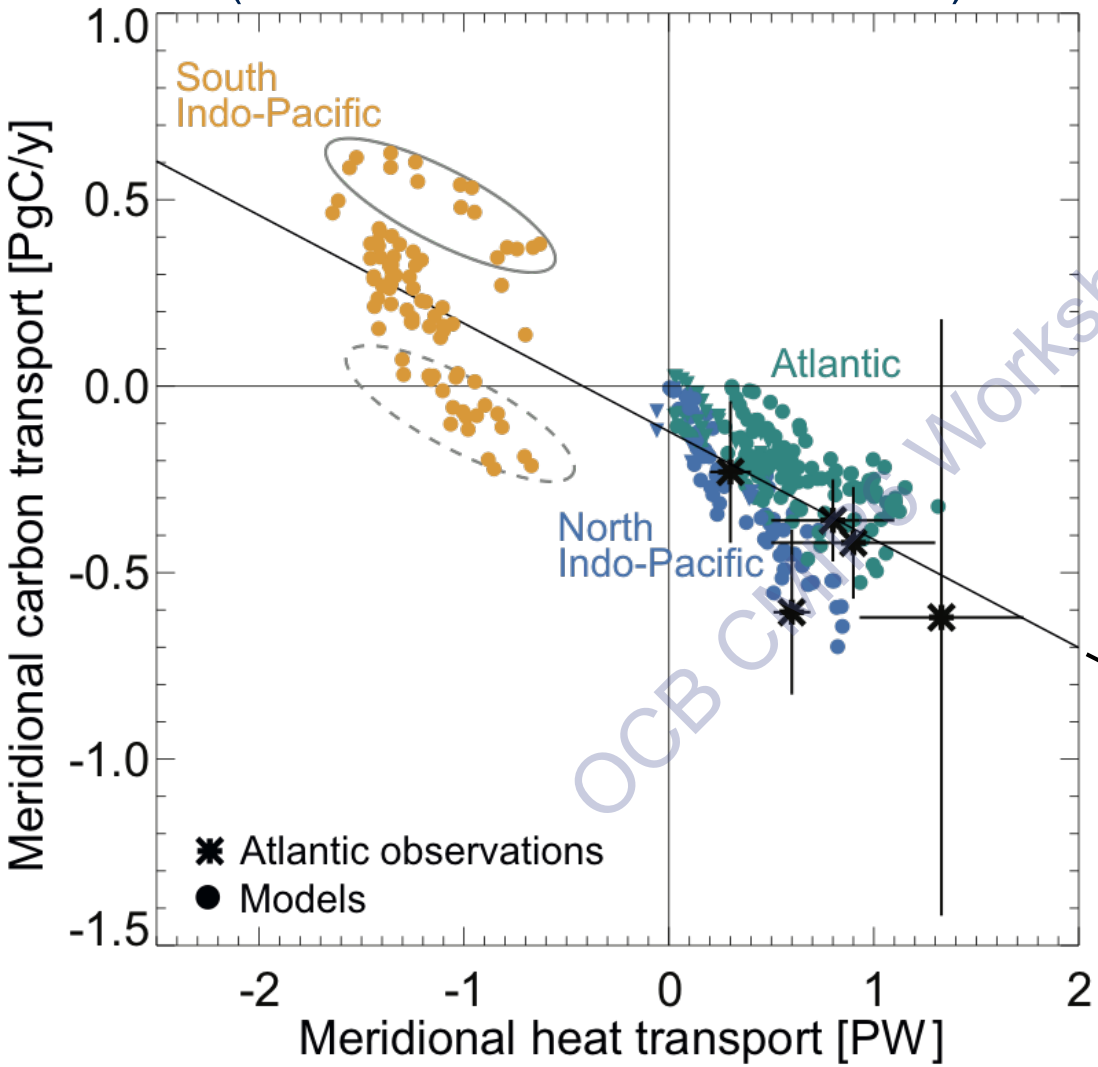




Not uniform biological pump still introduces decoupling between carbon and heat

Carbon transport linked to heat transport

Hydrographic data + 11 models
(ESMs & ocean forward models)



Ocean carries more carbon southward & heat northward
-0.3 PgC/y per PW

Solubility effect (-0.9 PgC/y per PW) dampened by vertical exchange of respired carbon

Data: Lundberg et al., 1996; Holfort et al., 1998; Alvarez et al., 2003; MacDonald et al. 2003, Ganachaud and Wunsch, 2003

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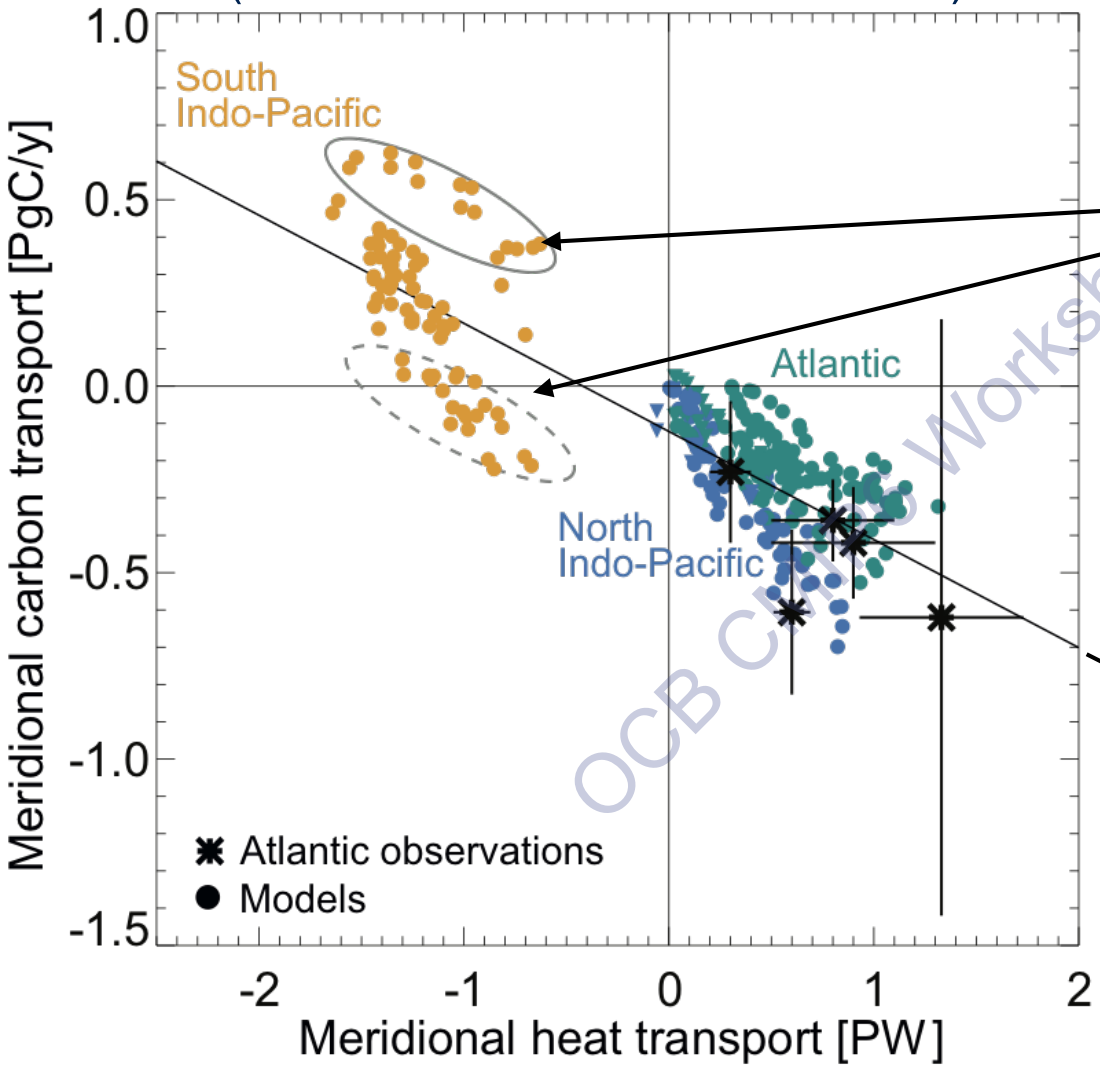

Biological pump decoupling varies across models

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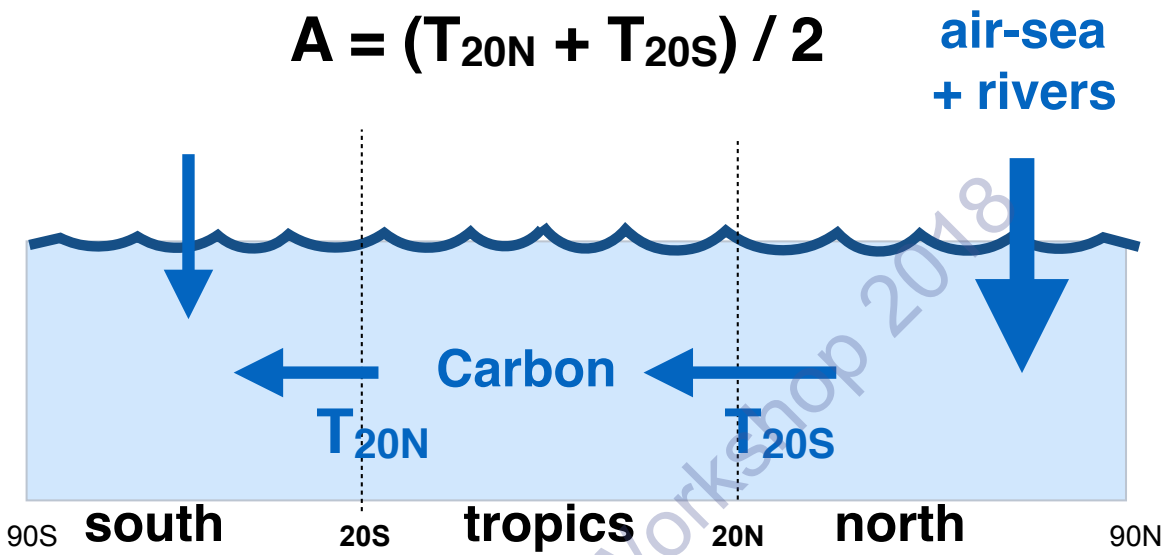
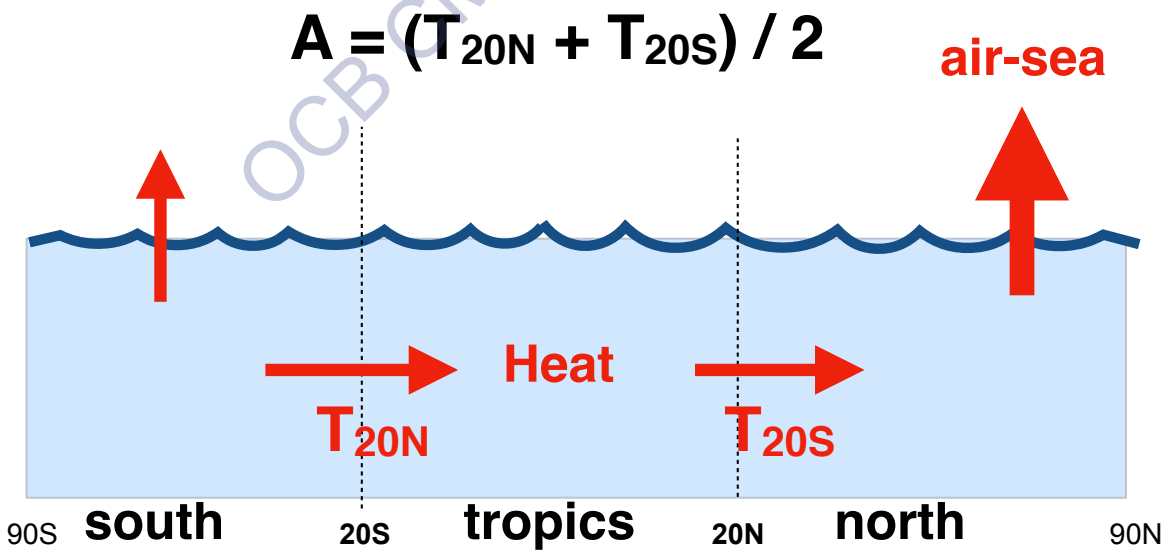
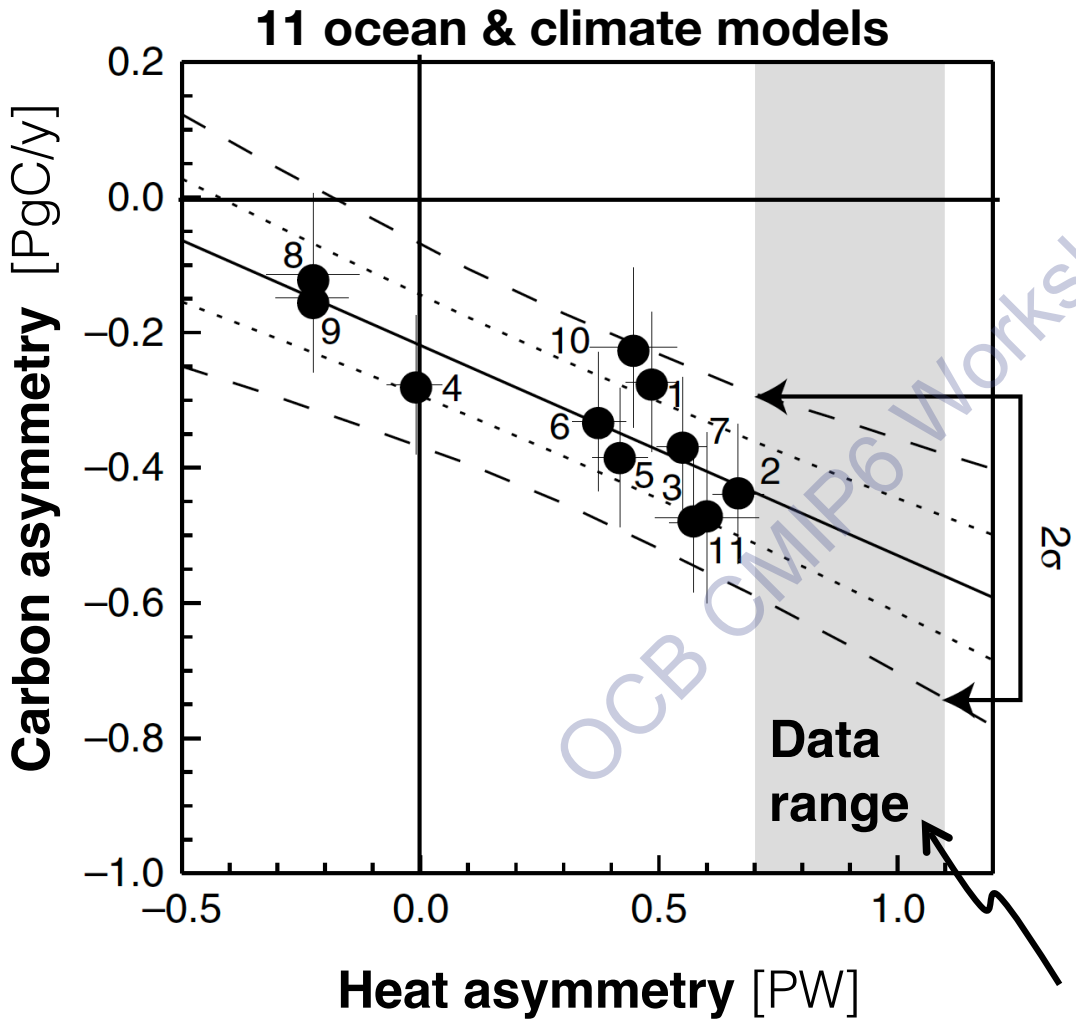




Heat an indicator of carbon transport?

Heat asymmetry explains **60%** of carbon transport
Heat + Bio pump asymmetry explain **85%** of carbon transport



Heat fluxes (Large and Yeager, 2009)
Atmospheric data (Resplandy et al., 2016)
Hydrography (Ganachaud and Wunsch, 2003)

Resplandy et al., Nat Geo 2018

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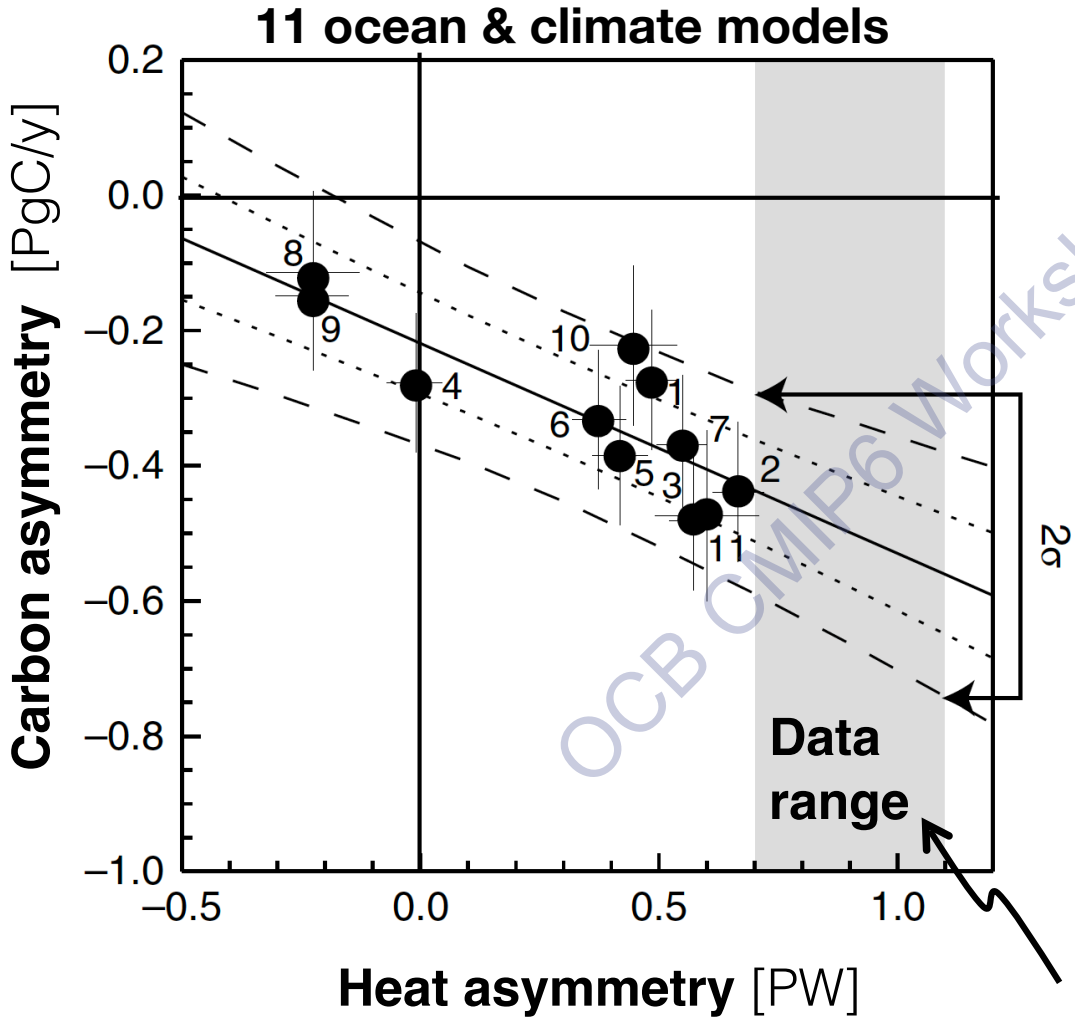


1) Models **biased low in heat** transport, **expected** biased **low in carbon** transport

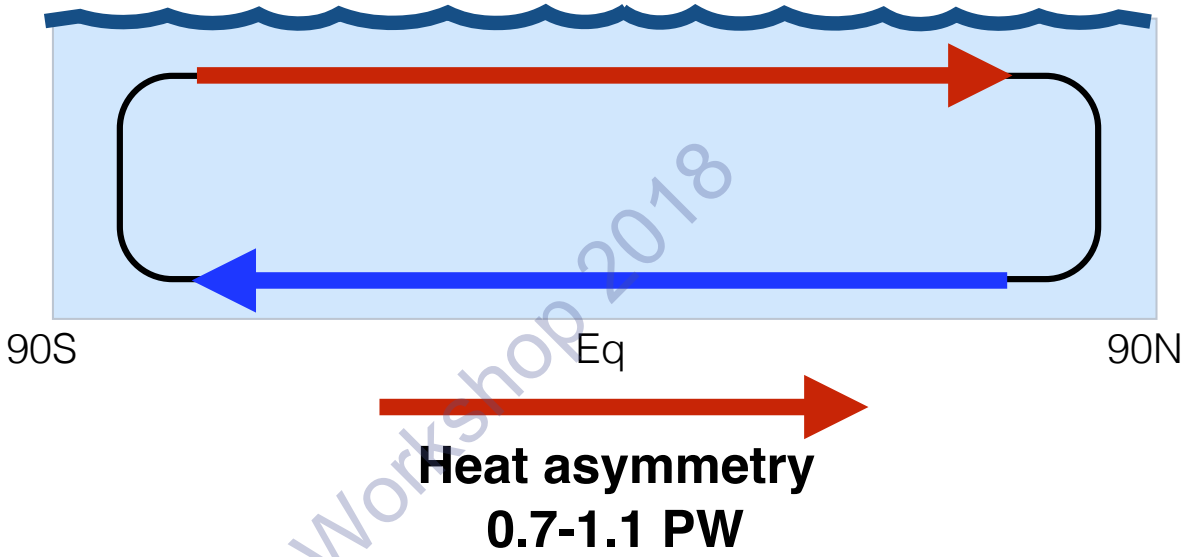
2) Southward carbon transport **= 0.30 to 0.75 PgC/y**

Heat fluxes (Large and Yeager, 2009)
Atmospheric data (Resplandy et al., 2016)
Hydrography (Ganachaud and Wunsch, 2003)

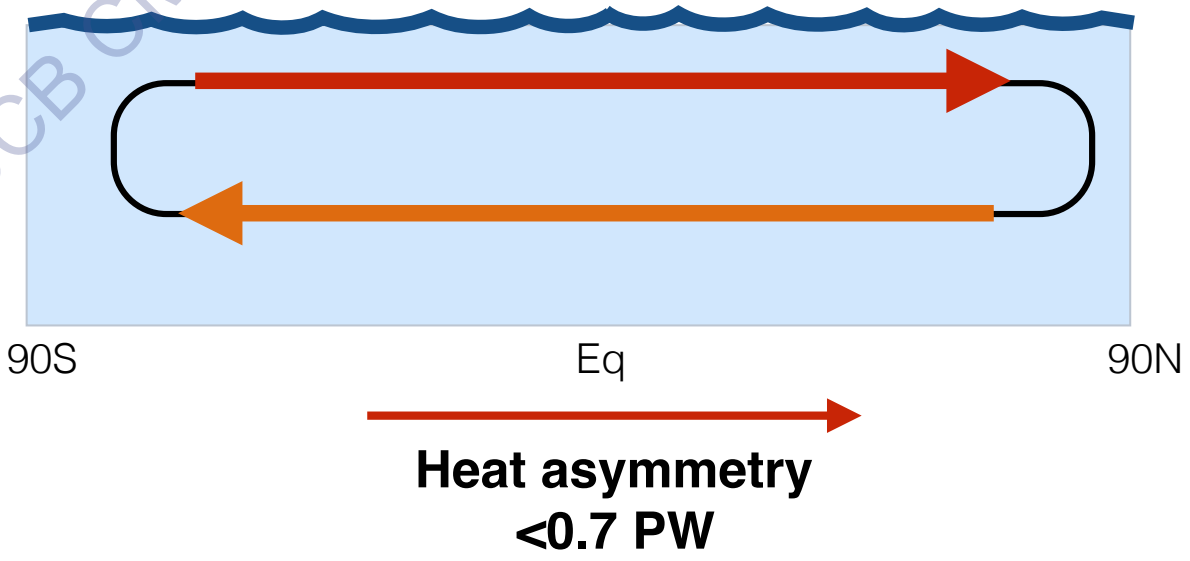
Resplandy et al., Nat Geo 2018

Too shallow overturning circulation in models?

what we expect



in models



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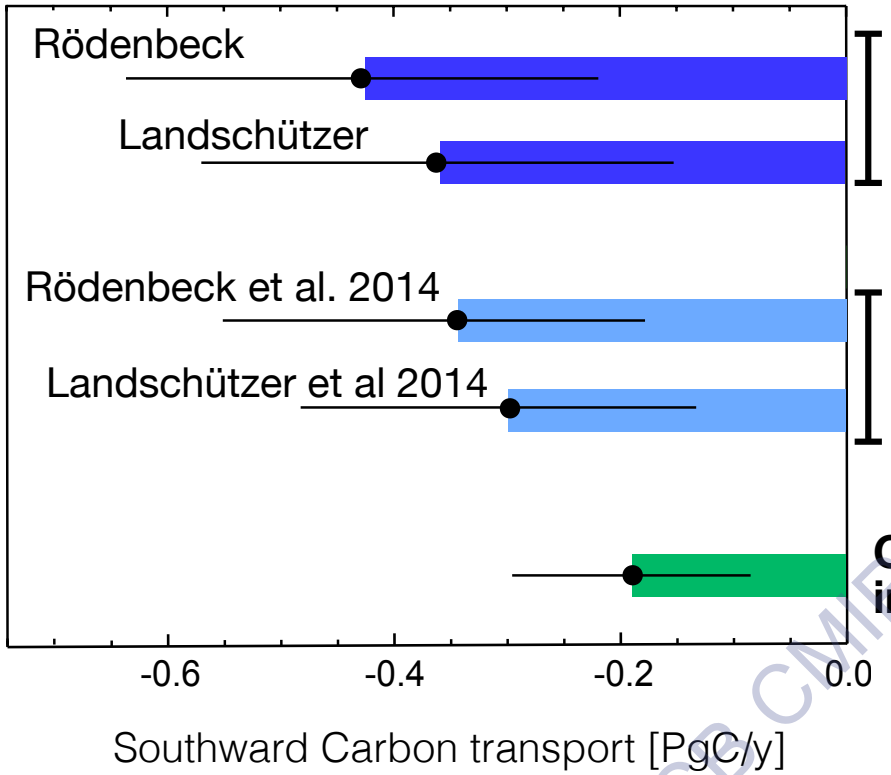

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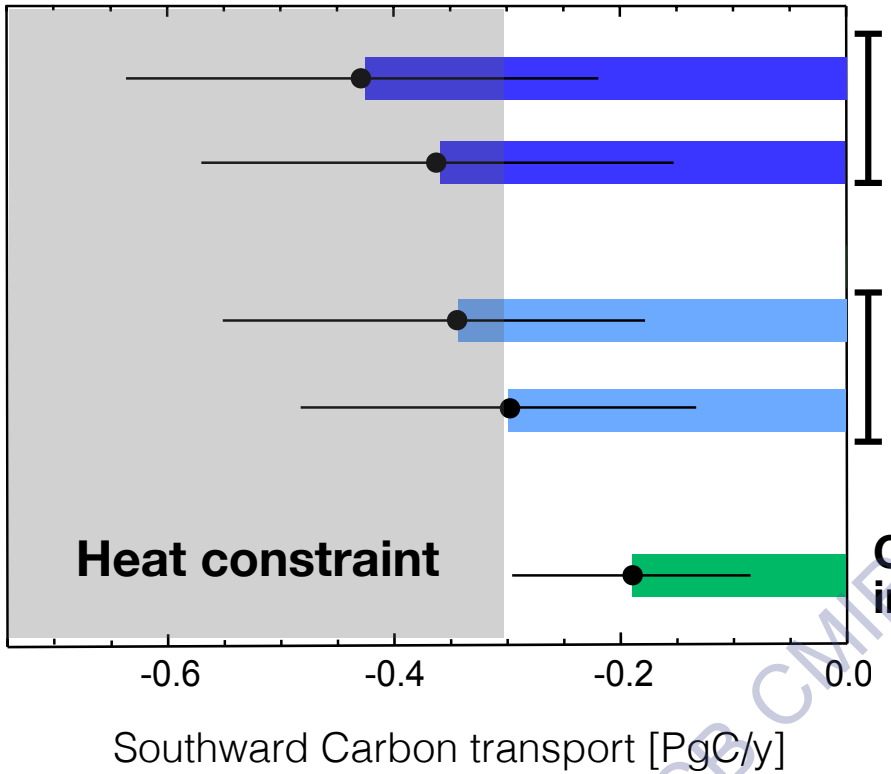
Ocean inversions
incl. rivers (e.g. Mikaloff Fletcher, 2007; Gruber et al., 2009)

- **Estimates agree within large uncertainties but systematic differences in north-south balance**

Resplandy et al., Nat Geo 2018

Heat constraint on ocean carbon flux estimates



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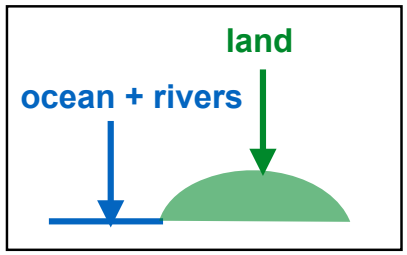
- **Estimates agree within large uncertainties but …**
- **Ocean inversions incompatible with heat constraint**
- **"best estimate":** update of Rödenbeck + stronger river loop

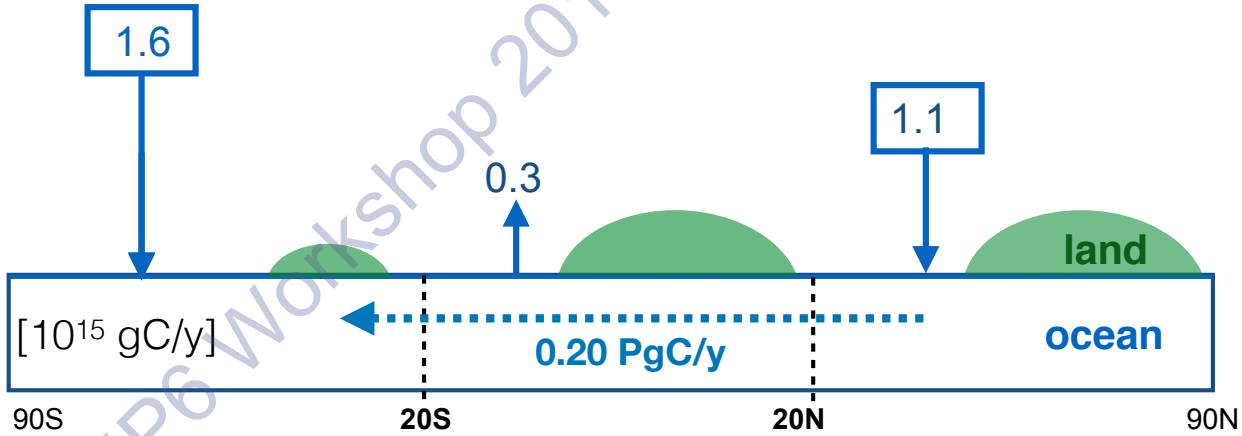
Resplandy et al., Nat Geo 2018

Implications for land sink?

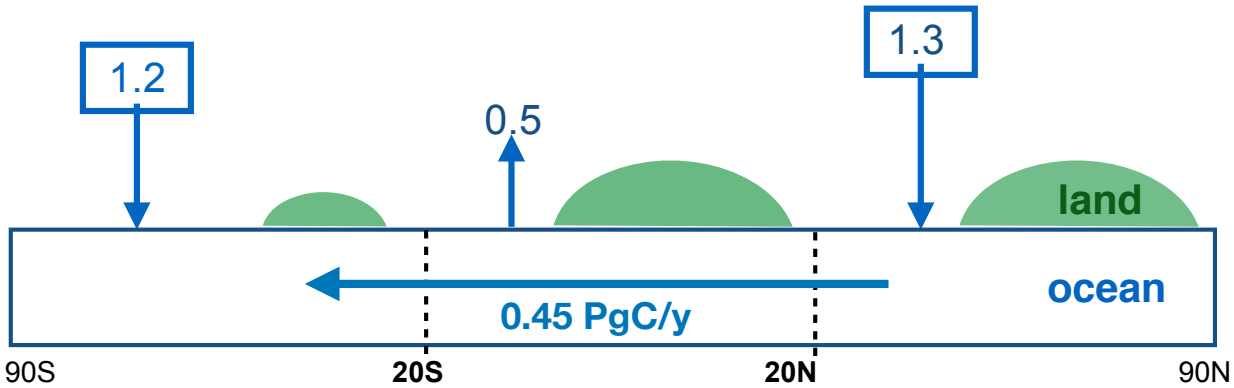
Atmospheric CO_2 inversion
Jena Carboscope - C. Roedenbeck
Same C_{ant} from Khatiwala et al 2012



Ocean inversion
Gruber et al., 2009
(1990-2010 period)



Revised ocean Roedenbeck + strong river loop
(1990-2010 period)



Resplandy et al., Nat Geo 2018

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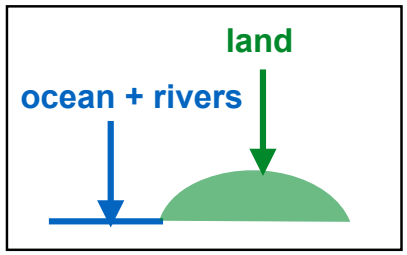

Ocean inversion
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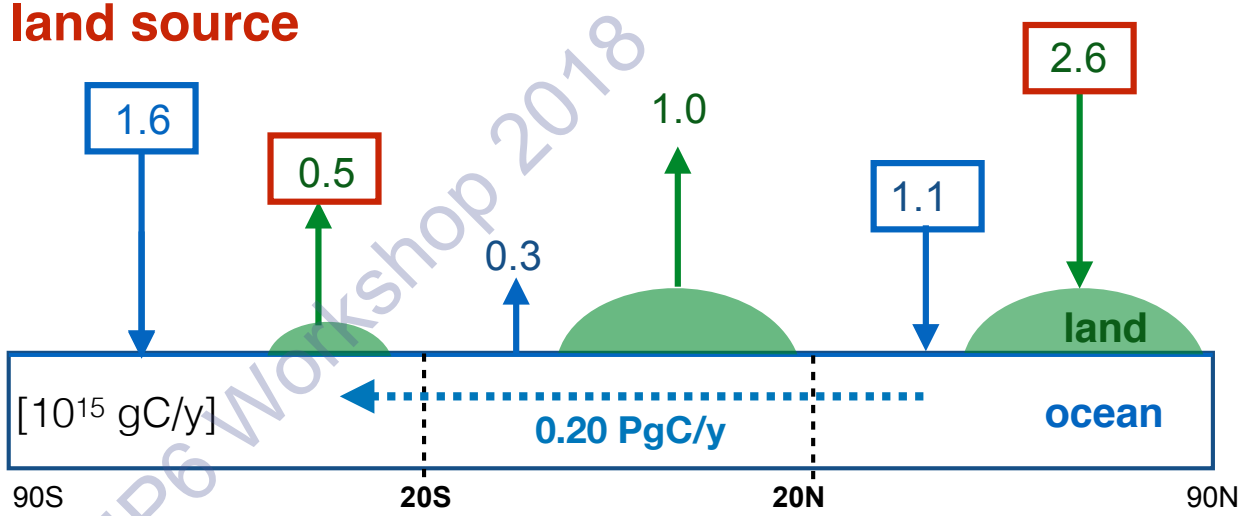
spurious southern land source

strong northern sink



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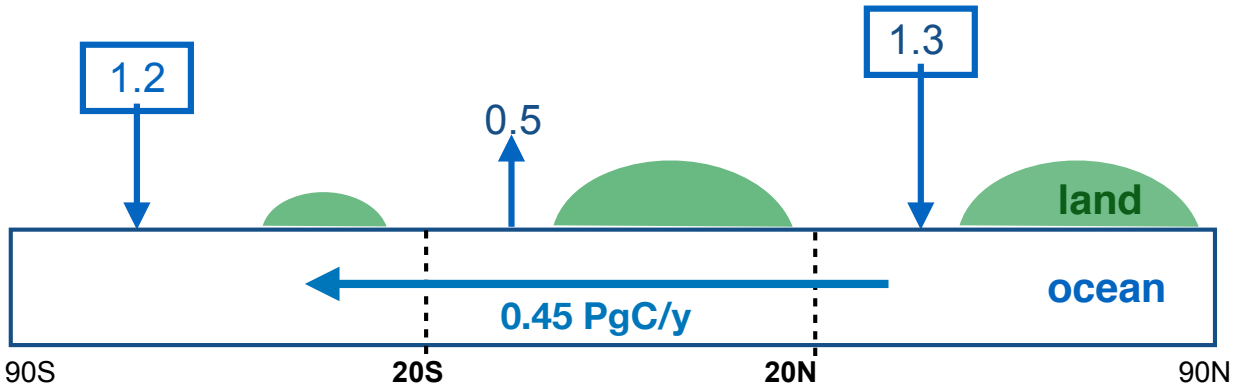

Resplandy et al., Nat Geo 2018

Implications for land sink?

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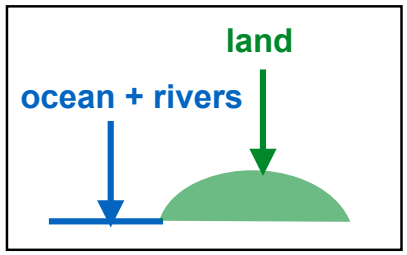

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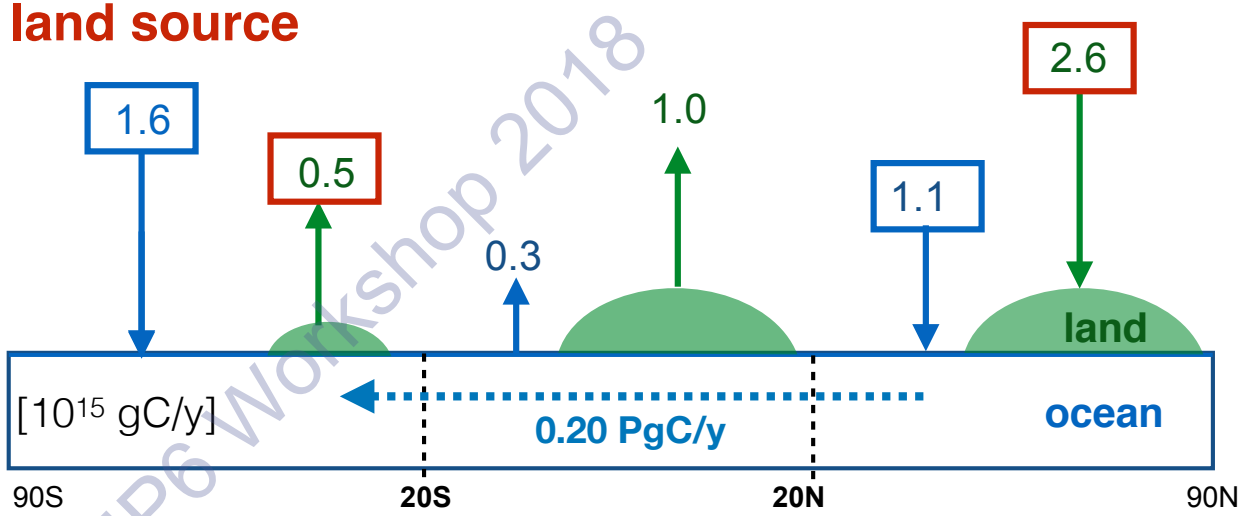

Revised ocean Roedenbeck + strong river loop
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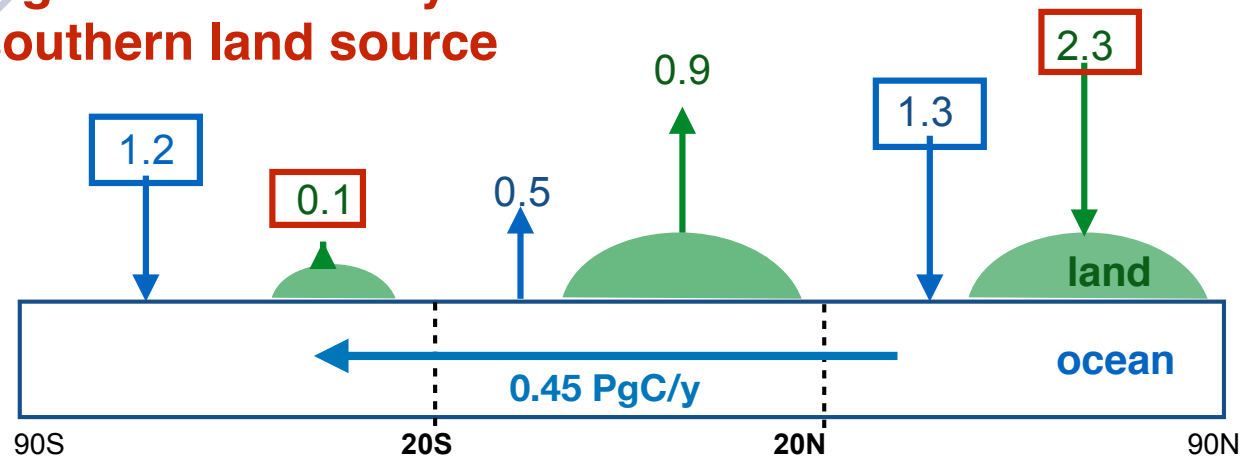
get rid of unlikely southern land source

weakens northern land sink



Resplandy et al., Nat Geo 2018

Implications for land sink?

Atmospheric CO_2 inversion
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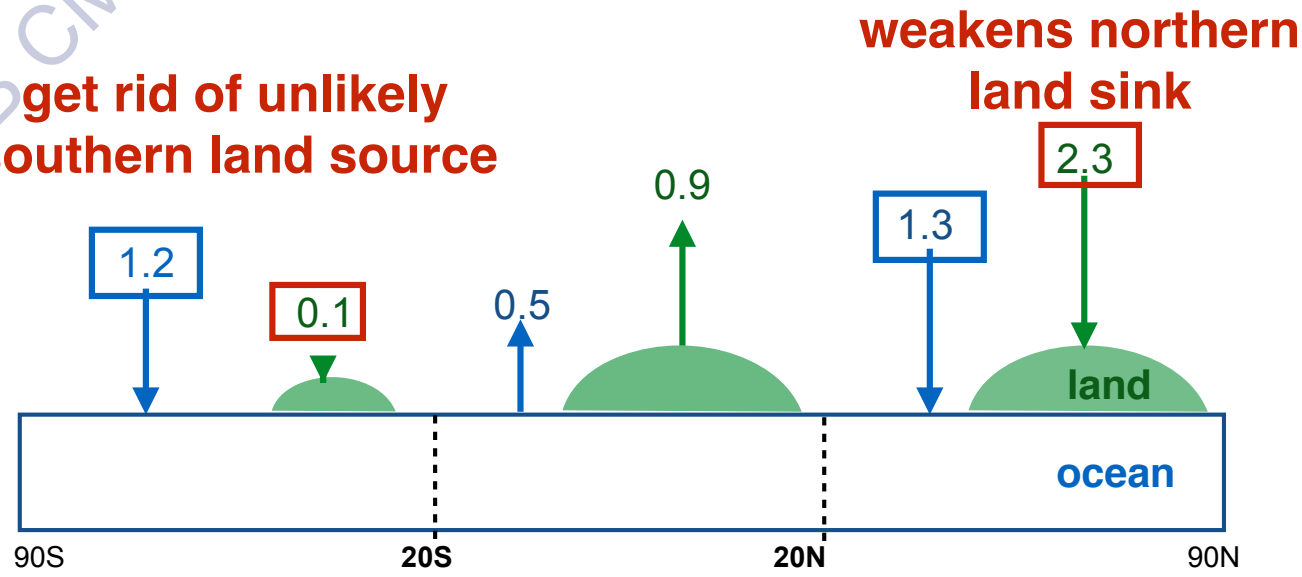
Same C_{ant} from Khatiwala et al 2012

Redistributes **40%** of the land sink

Reduce gap between atmospheric inversions & ecosystem models/ inventories

Revised ocean pCO_2-based + rivers
(1990-2010 period)



Resplandy et al., Nat Geo 2018

Summary

Heat observational constraint on carbon budget

Rivers probably overlooked & underestimated in global carbon budgets

Models underestimate heat & carbon transport asymmetry

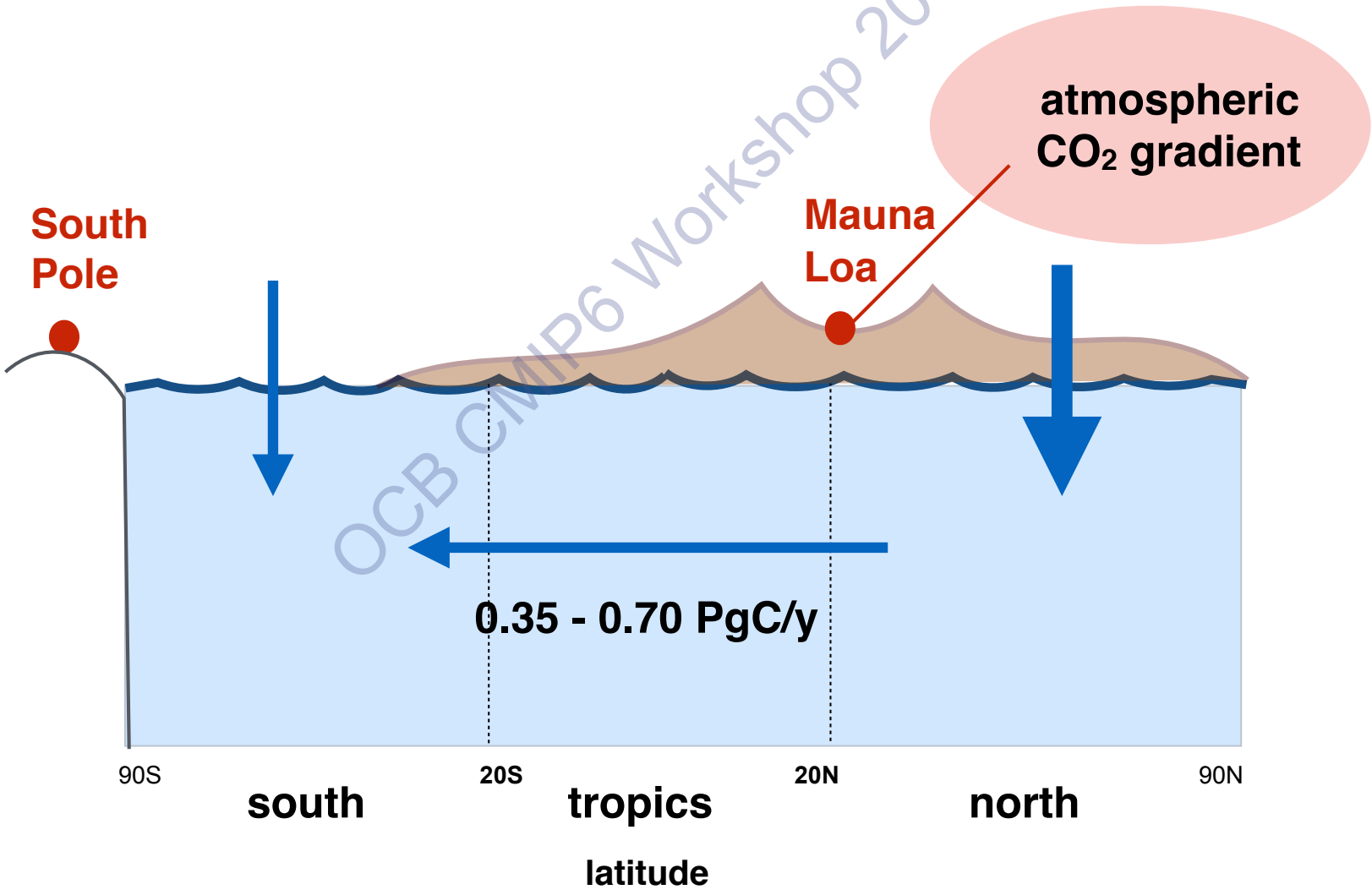
Implications for climate system

- ocean/land sinks magnitude and partition
- tropical precipitations, Arctic sea ice etc.

Resplandy et al., Climate Dyn. 2016
Resplandy et al., Nat Geo 2018

Carbon asymmetry consistent with pre-industrial hemispheric gradients in atmospheric CO_2

Scripps atmospheric data since 1959



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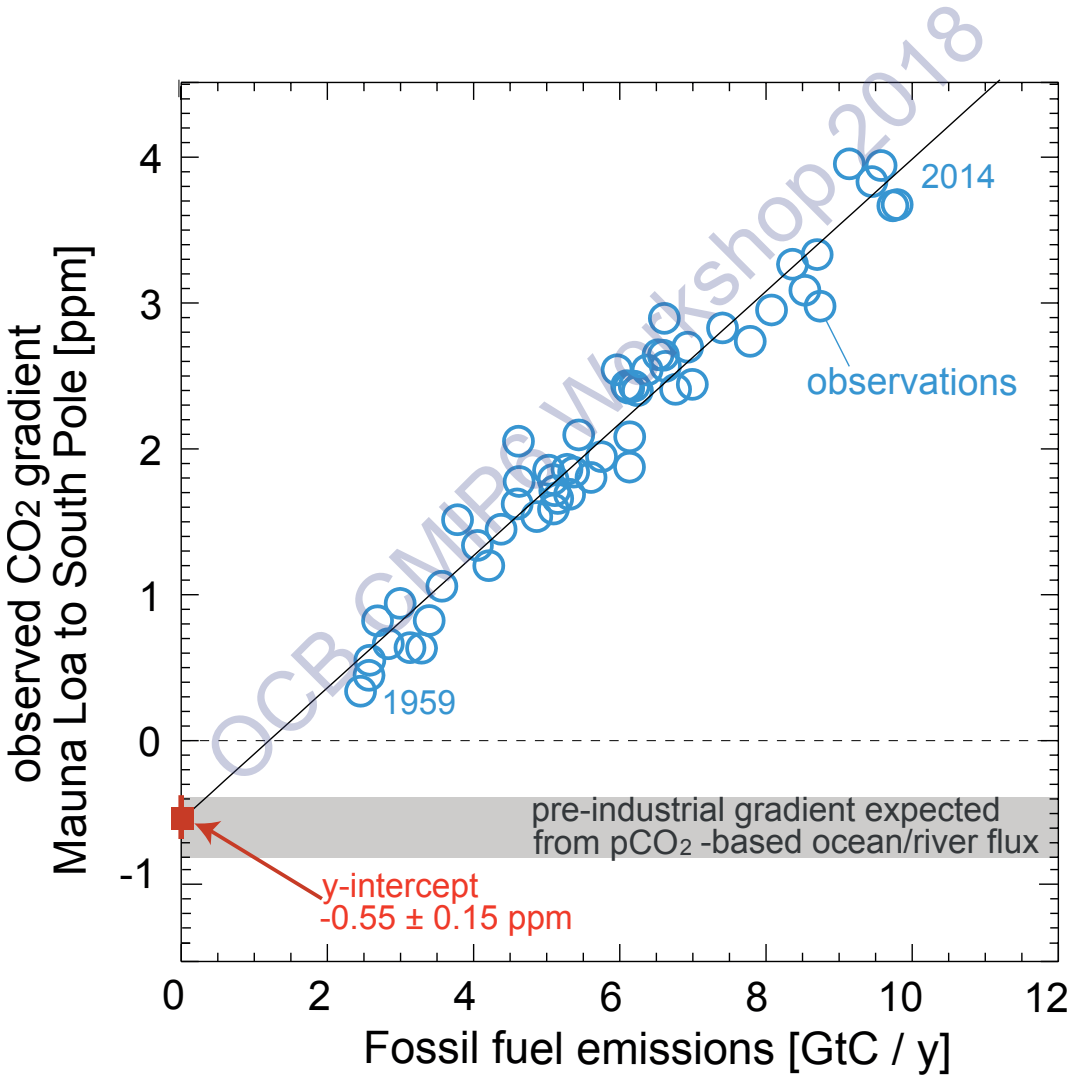

Keeling et al. (1989); Keeling et al. (2011)