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Role of the Southern Ocean in climate: heat and carbon uptake

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December 13, 2014

Current state of knowledge of
model biases and uncertainties in CMIP5 models

US CLIVAR & OCB workshop on
Ocean's carbon and heat uptake: uncertainties and metrics

Nutrient cycle

Sarmiento et al. (2004)

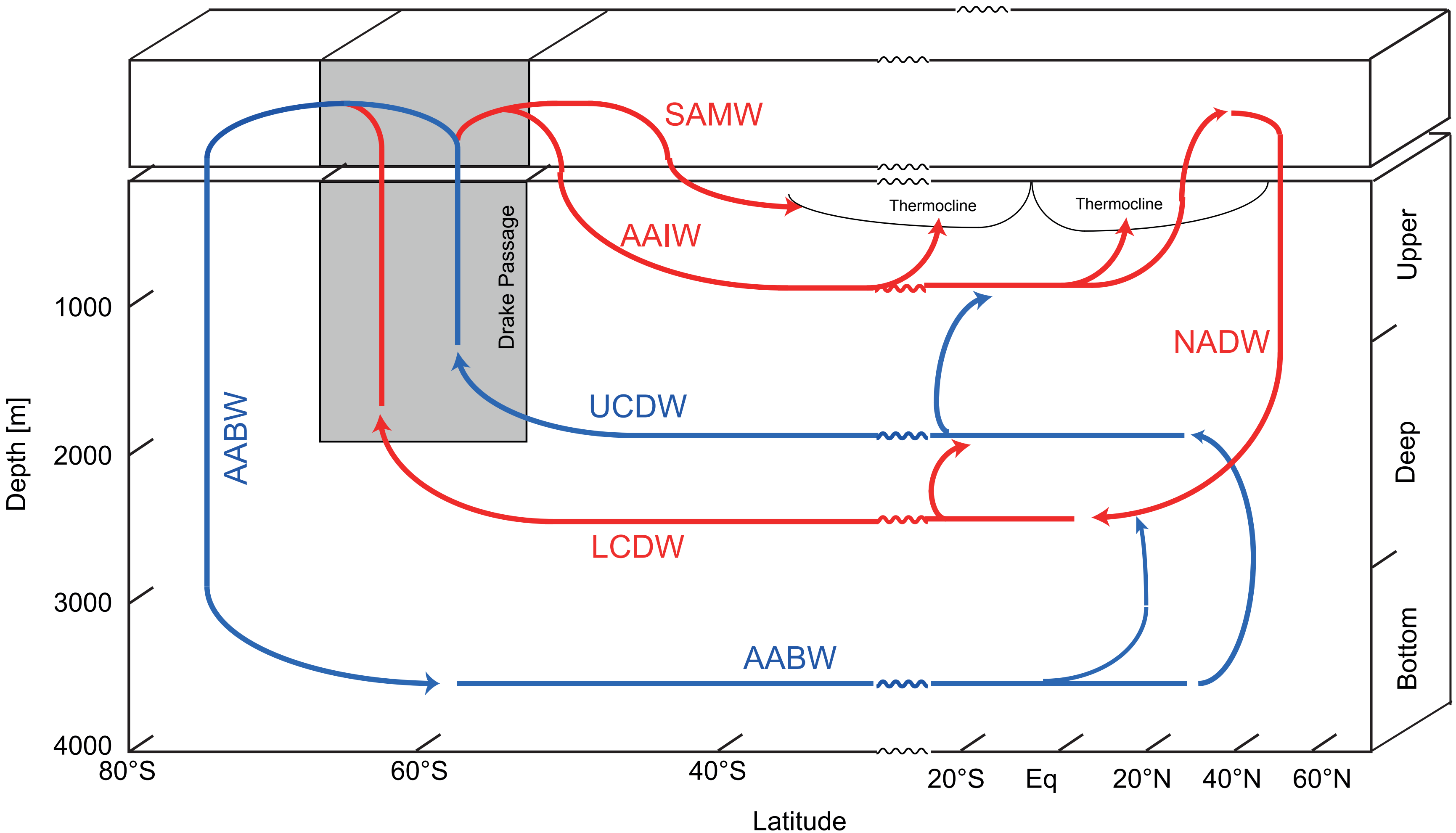
Marinov et al. (2006)

The Problem

- Sediment traps suggest that ~one-third of the particulate organic matter flux at 200 m continues past the base of the main thermocline (defined as σ_θ = 26.8)
- If nitrate lost by the above particle sinking were not replaced, the thermocline nitrate would be depleted within ~50 years!
- <u>QUERY</u>: How do nutrients return from the deep ocean to the thermocline and thence to the surface?

Sarmiento et al. (2004)

Deep ocean overturning circulation simplified



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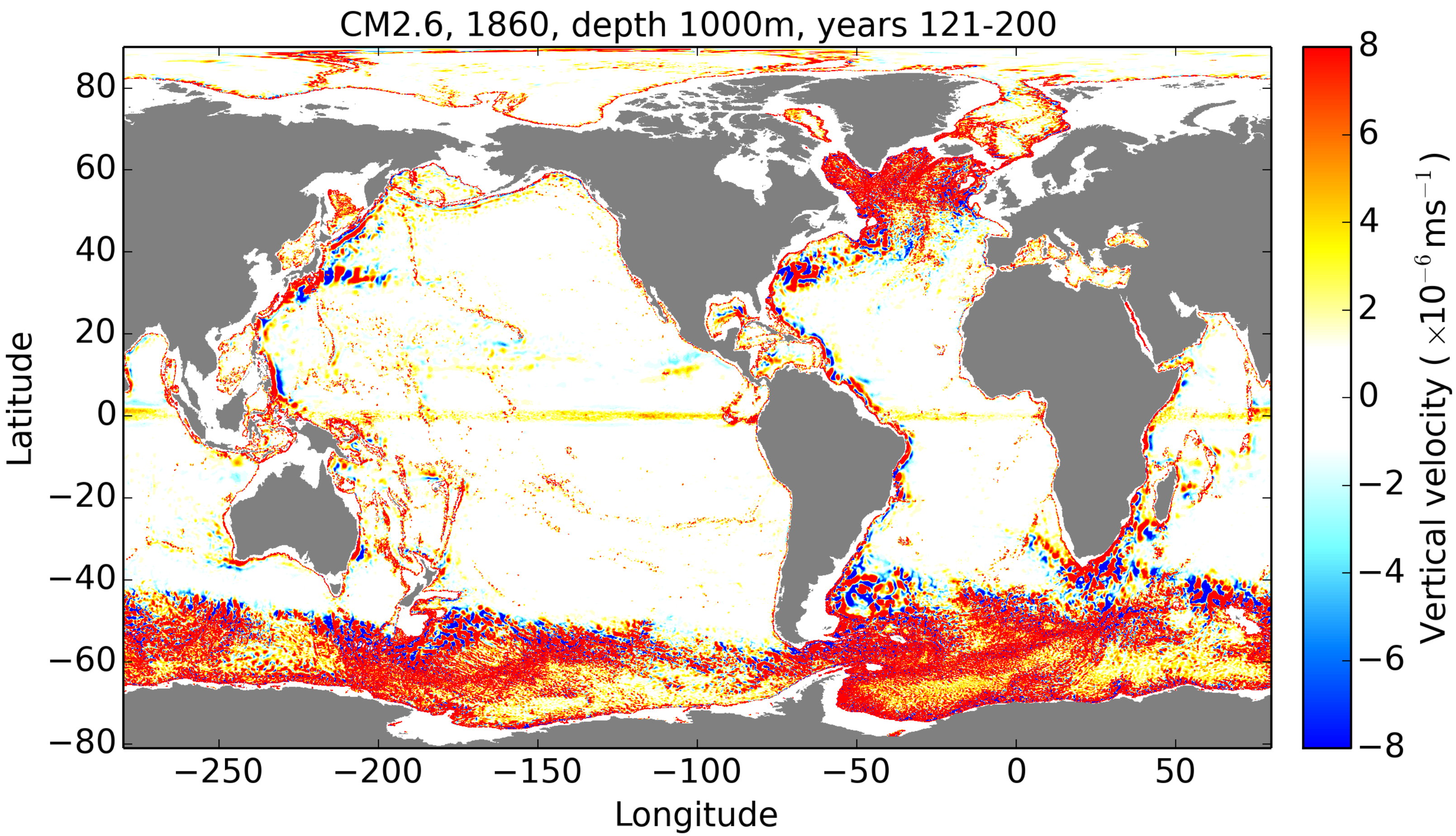
Based on Talley (2013)

Upwelling at 1000 m in GFDL CM2.6



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Morrison (pers. comm.)

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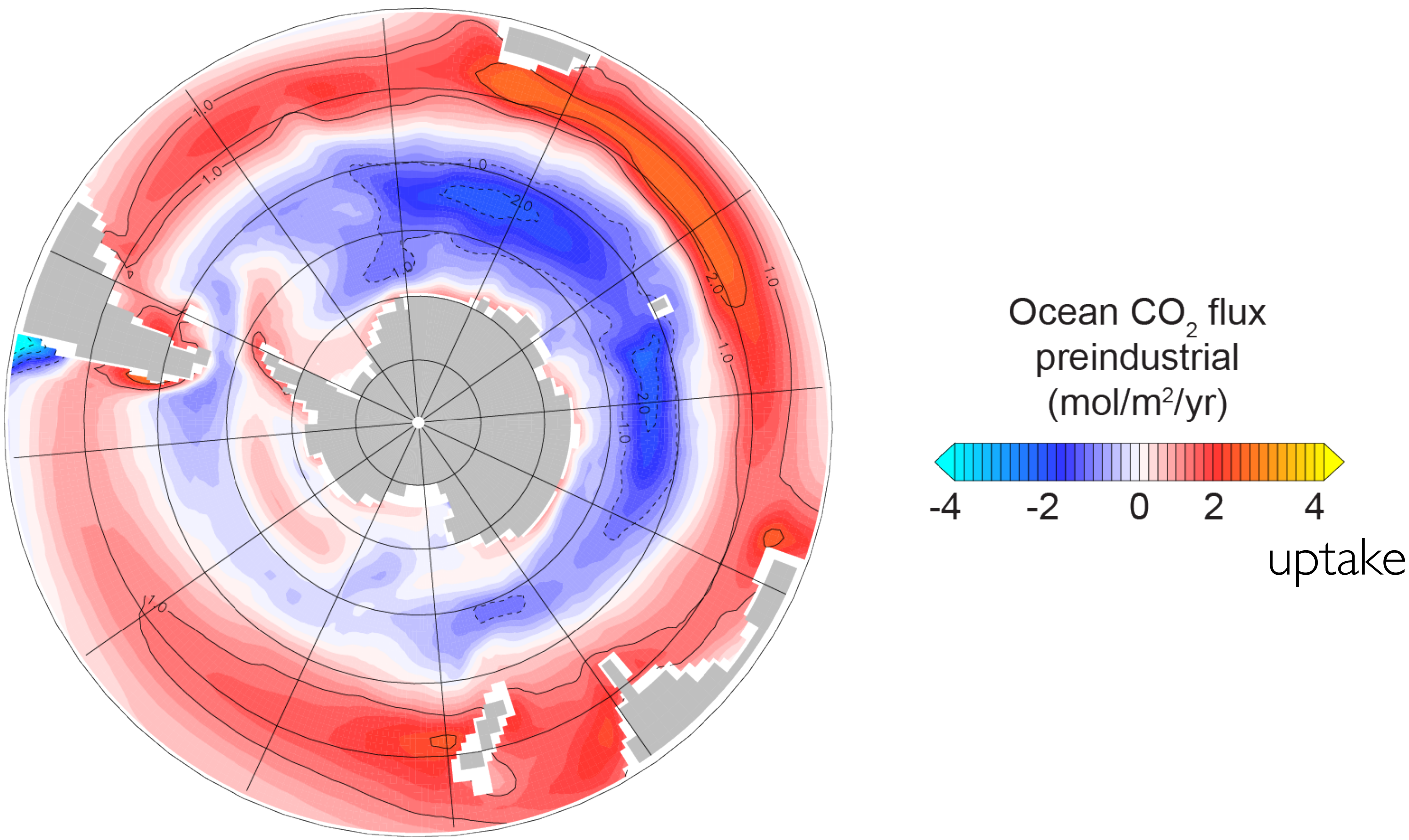
Air-sea CO_2 flux

An analysis based on CMIP5 models.

Froelicher et al. (in press, J. Climate)

Pre-industrial CO_2 flux in CMIP5

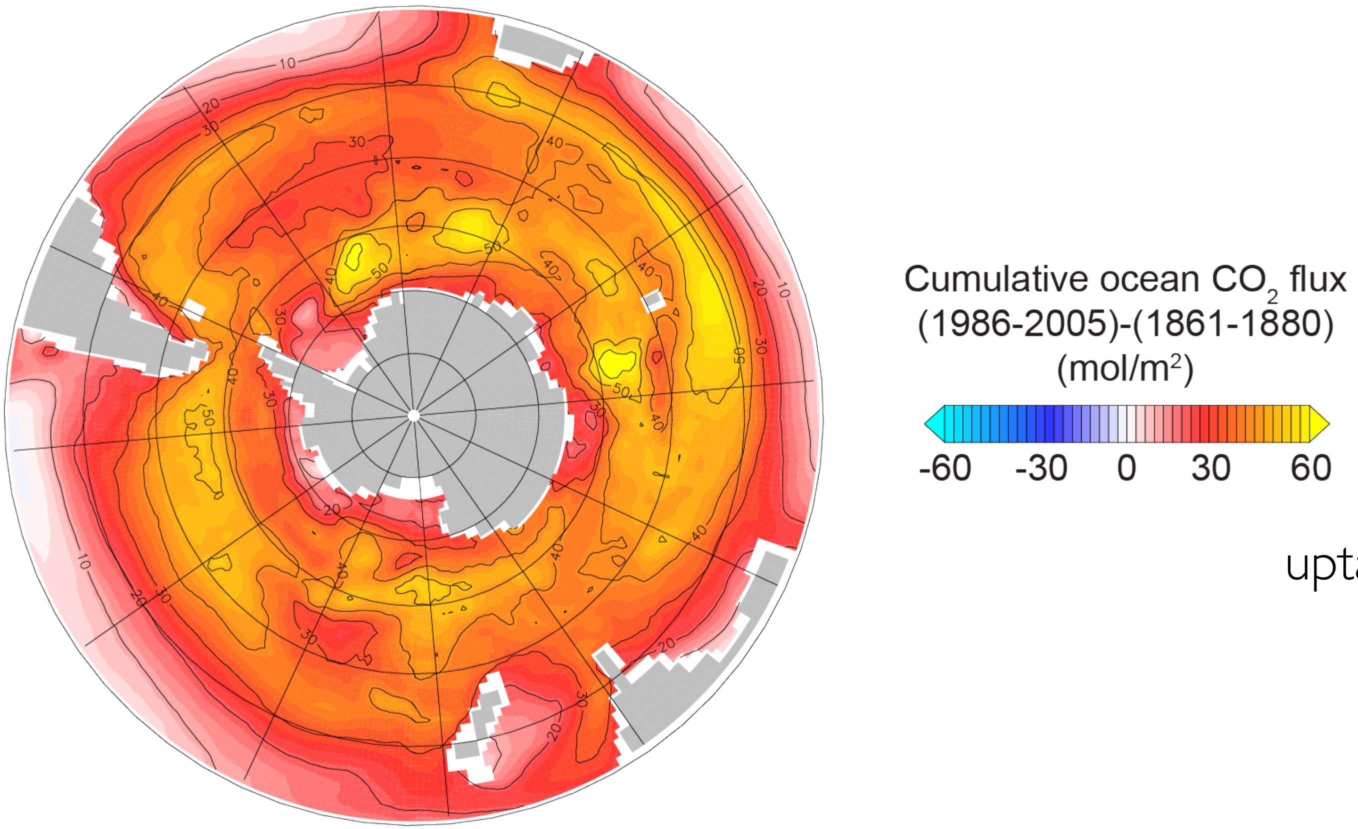
Multi-model mean (11 models)



Froelicher et al. (submitted)

Cumulative anthropogenic CO_2 uptake in CMIP5

Multi-model mean (11 models)



uptake

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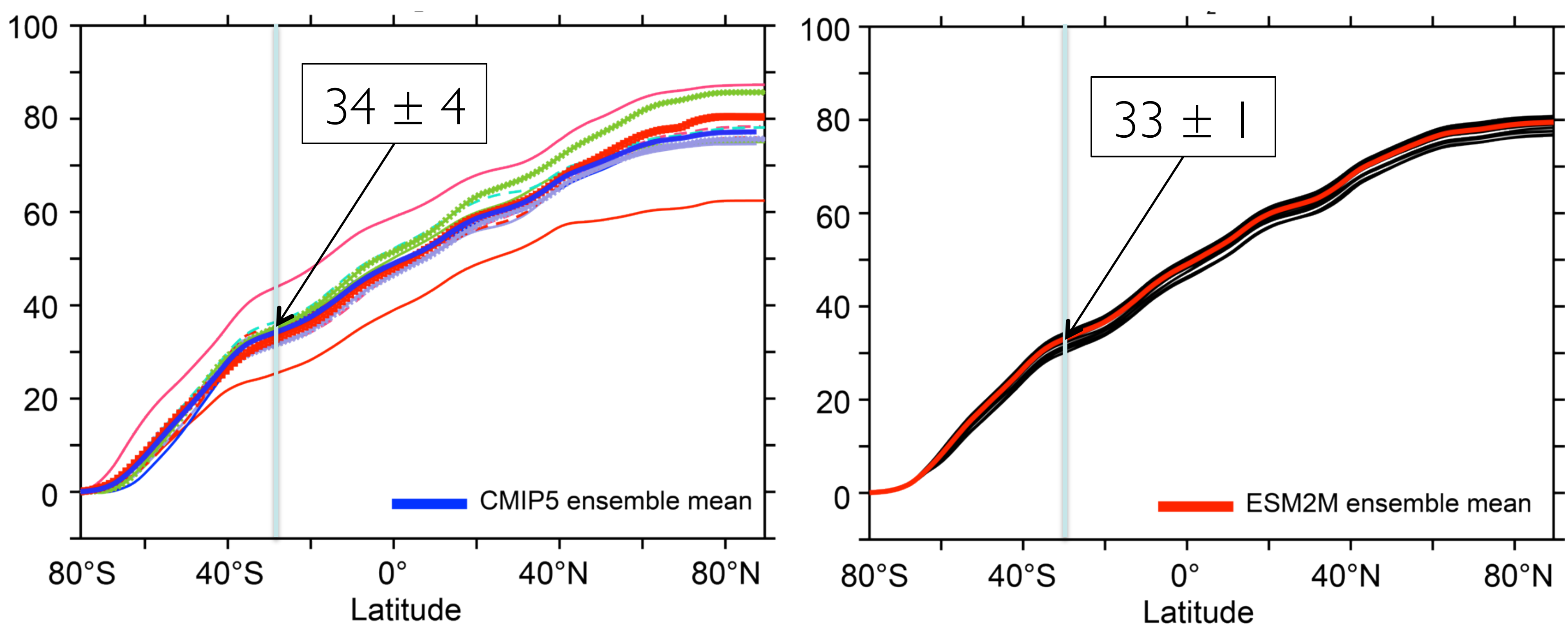
Froelicher et al. (submitted)

Cumulative CO_2 uptake in CMIP5 models & ESM2M ensemble in PgC (1950-2005)



- Southern Ocean accounts for 44% of global in models
- Observations (inverse model) give ~50%
- Most of the uncertainty comes from S. Ocean
- Internal variability accounts for ~24% of range.

Frölicher et al. (2014, in press)

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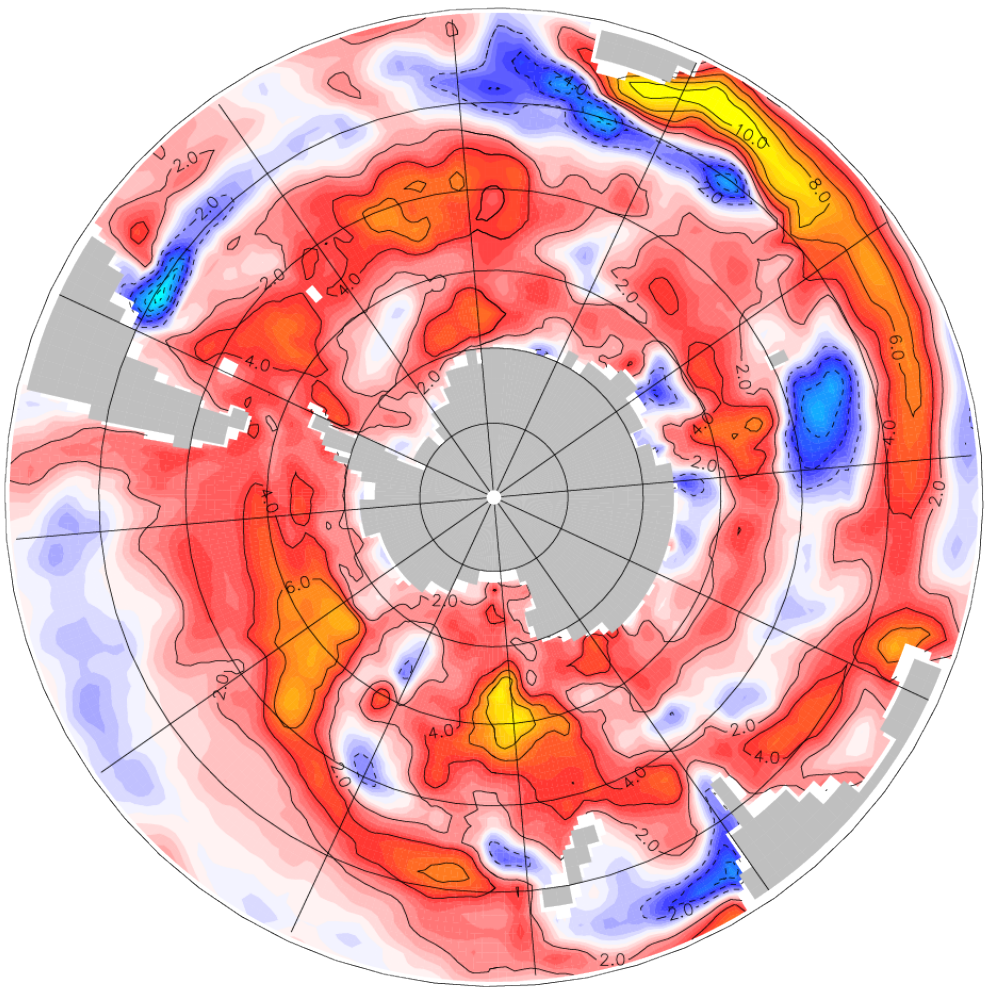
Excess heat uptake by ocean

An analysis based on CMIP5 models.

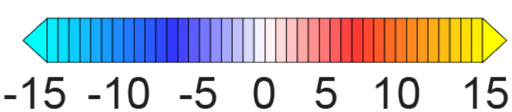
Froelicher et al. (in press, J. Climate)

Cumulative perturbation heat uptake in CMIP5

Multi-model mean (19 models)



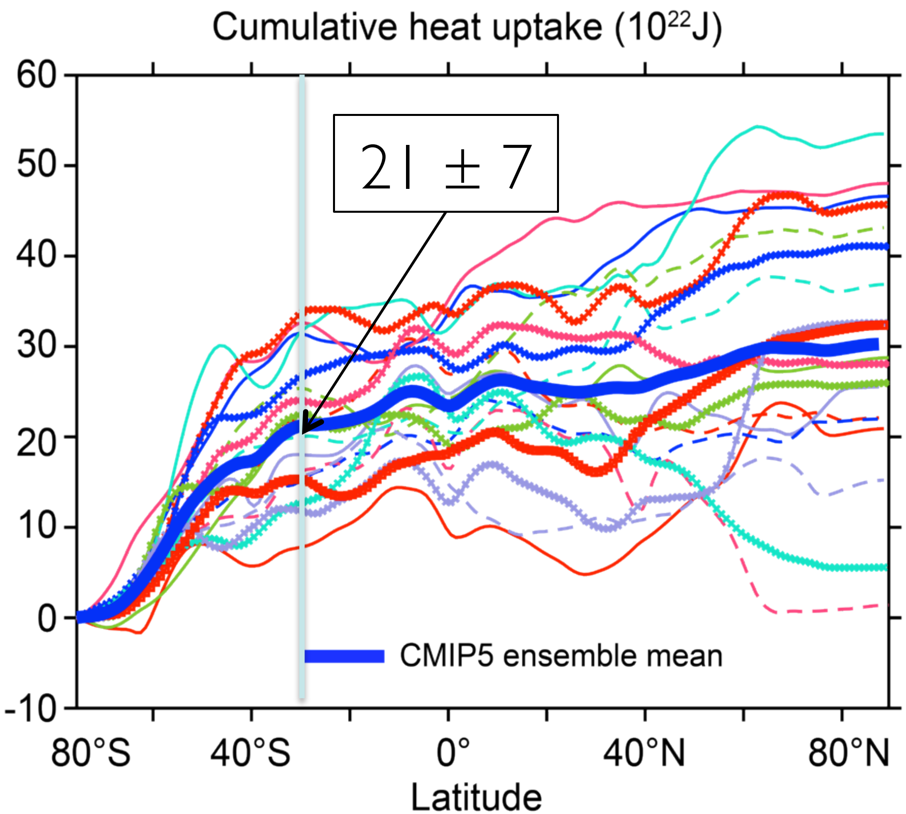
Cumulative ocean heat flux
(1986-2005) - (1861-1880)
(10^9J/m^2)

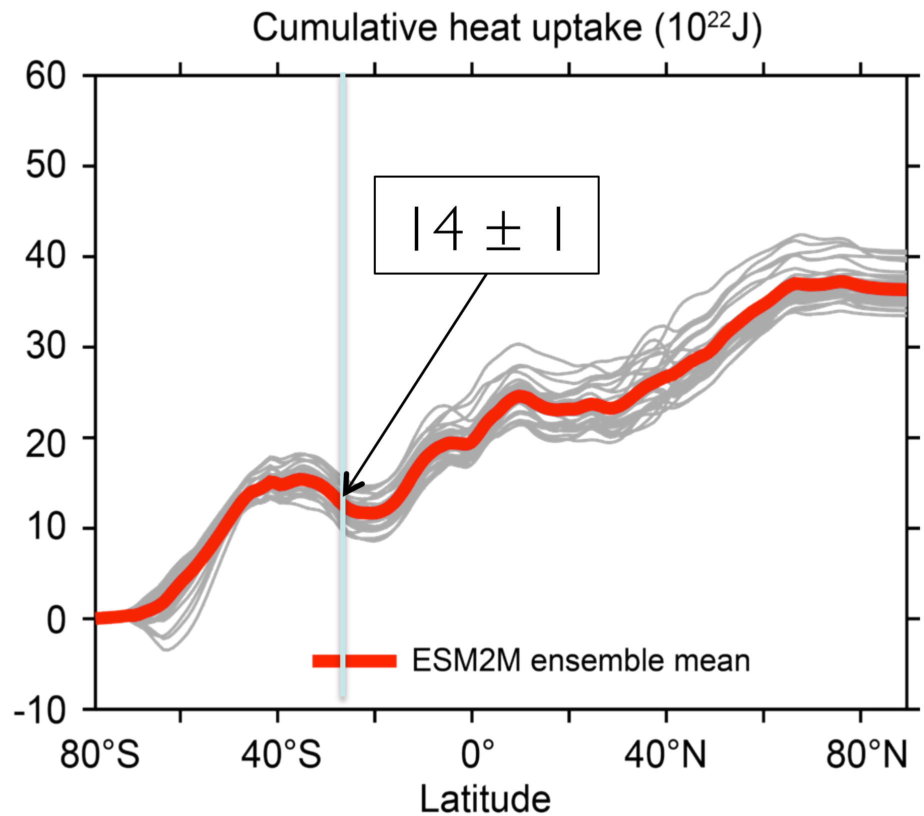


uptake

Froelicher et al. (submitted)

Cumulative heat uptake in CMIP5 models & ESM2M ensemble (1950-2005)





- Southern Ocean accounts for ~69% of global.
- Internal variability accounts for ~19% of range.

Frölicher et al. (2014, in press)

Role of WBCs

An analysis by Dufour et al., (in preparation)

based on GFDL CM2.6 climate model with 0.1° ocean & simple biogeochemistry

With acknowledgement to Iudicone et al. (2011), Talley (2013) and others

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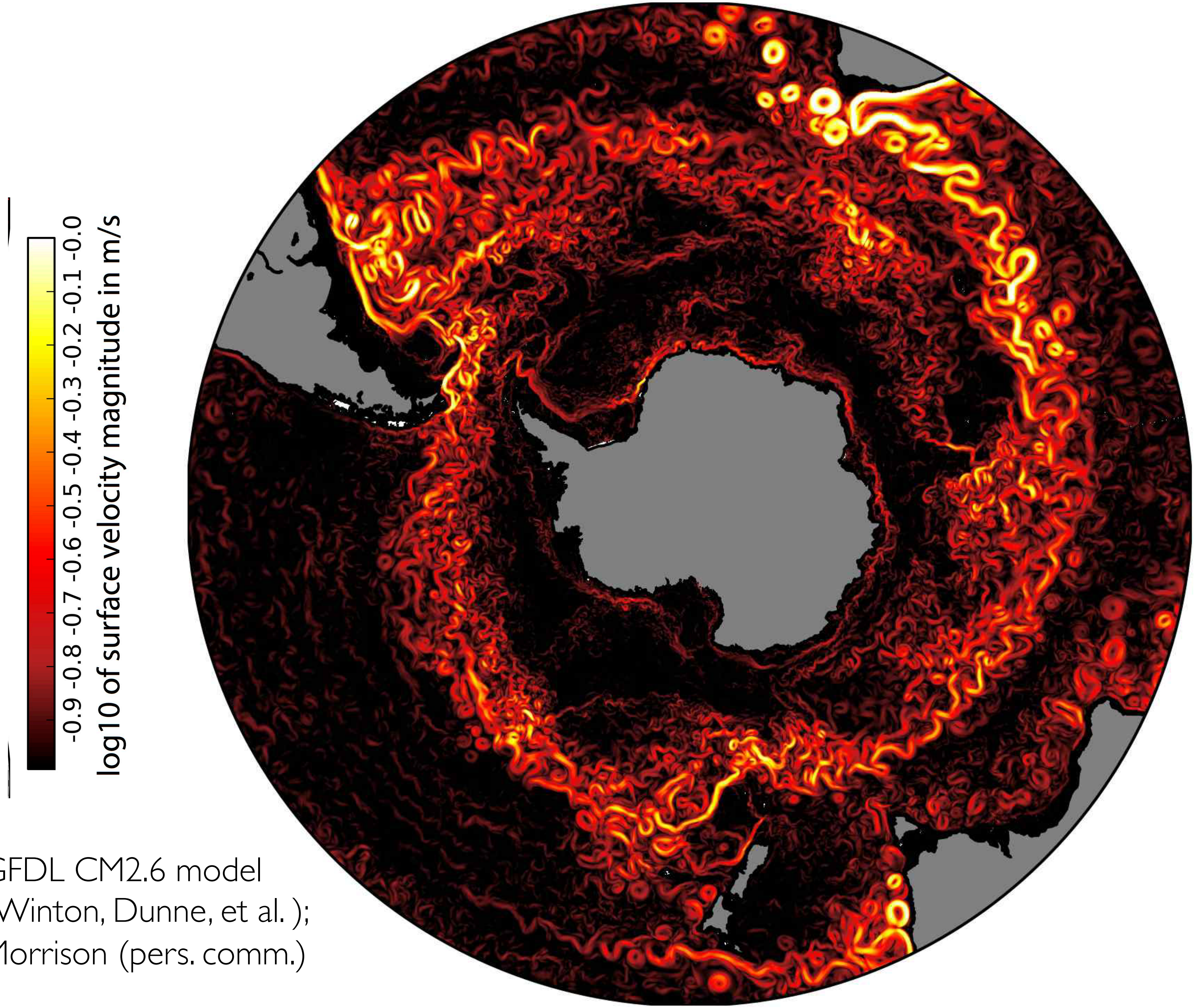
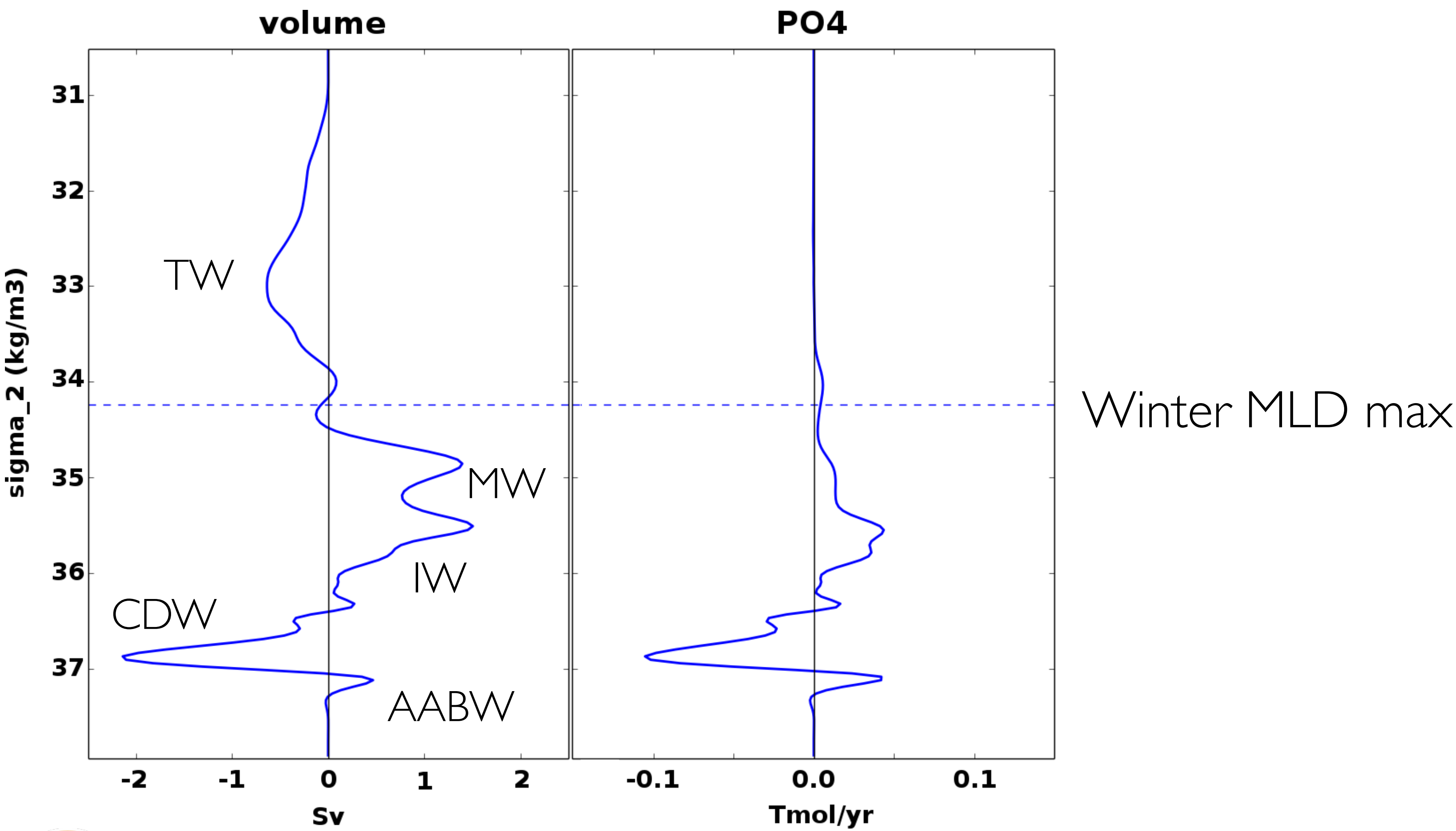


GFDL CM2.6 model
(Winton, Dunne, et al.);
Morrison (pers. comm.)

Volume and phosphate transport versus sigma-2



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Dufour et al. (in prep.)

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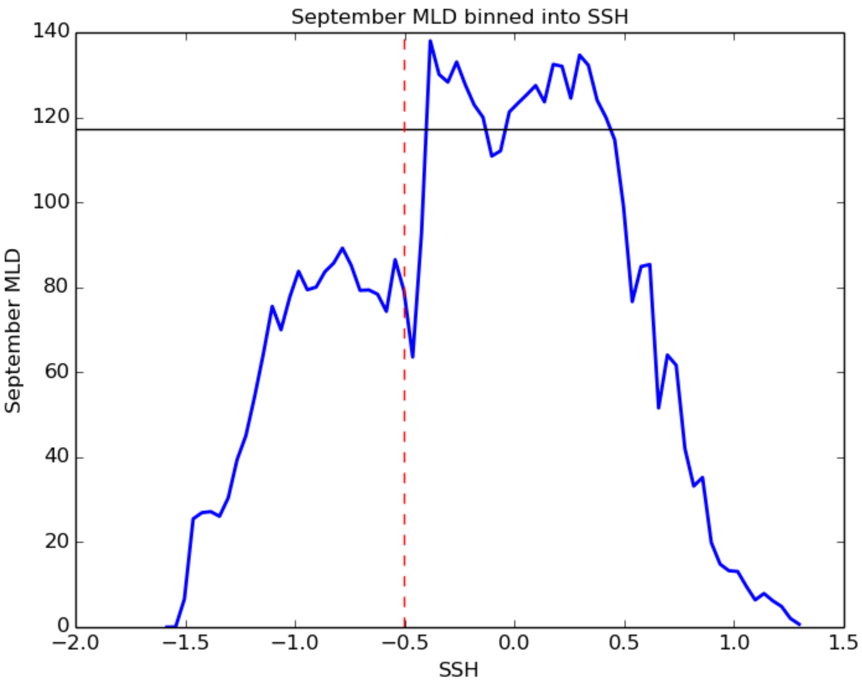
Focus on processes

- Goal: to separate surface ocean into regions dominated by
  - upwelling of ancient waters vs.
  - WBC cooling regions
- Strategy is based on the hypotheses that
  - Region to south of Subantarctic front is dominated by upwelling
  - Region to north of Subtropical front is dominated by WBC influence
  - Region between these fronts is influenced by both upwelling and WBC

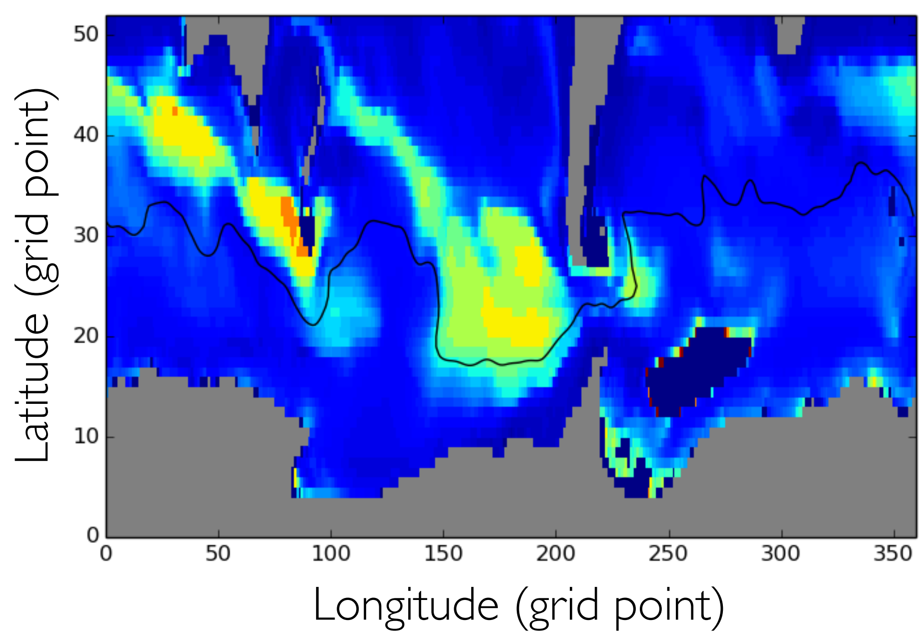
“Operational” definition for the Subantarctic front

- The SSH contour corresponding to the region just south of the deepest winter mixed layers.

Example with GFDL-ESM2M



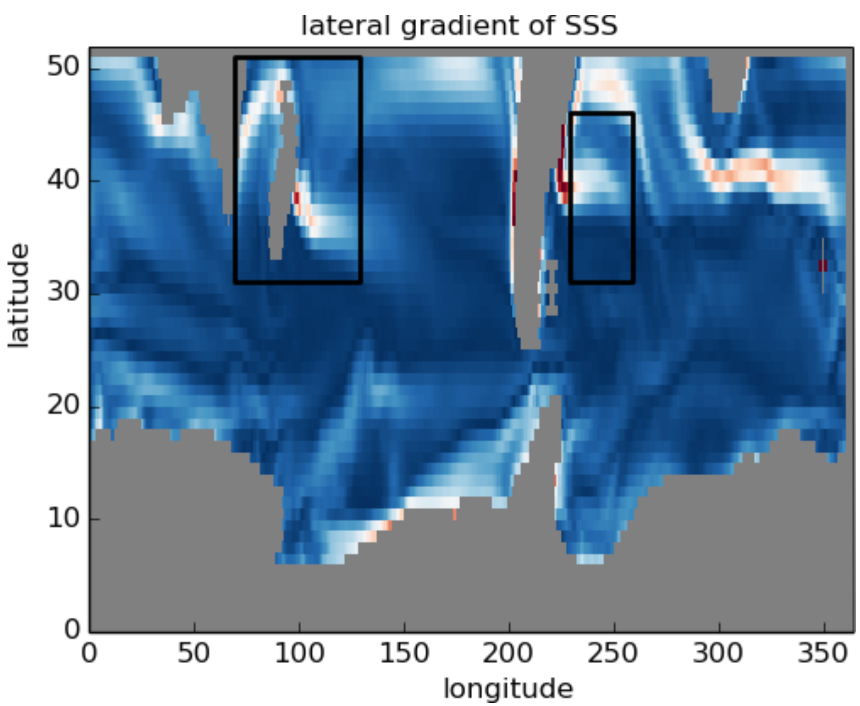
September MLD on model grid with SSH contour



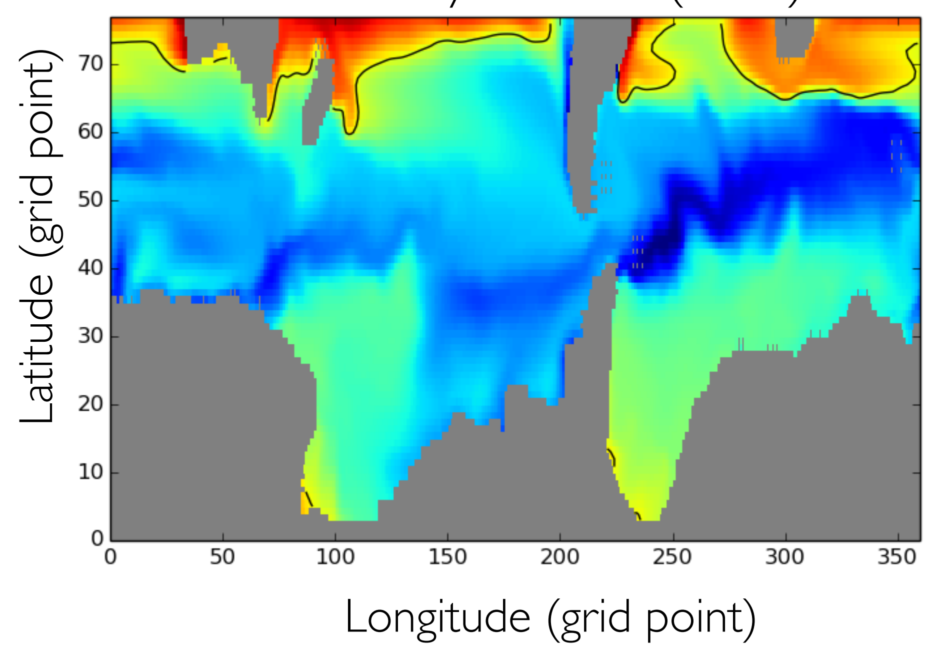
"Operational" definition for the Subtropical front

- The SSS contour that corresponds to the maximum lateral SSS gradient in the Western Boundary current regions

Example with GFDL-ESM2M



SSS (colors) and
SSS boundary contour (black)

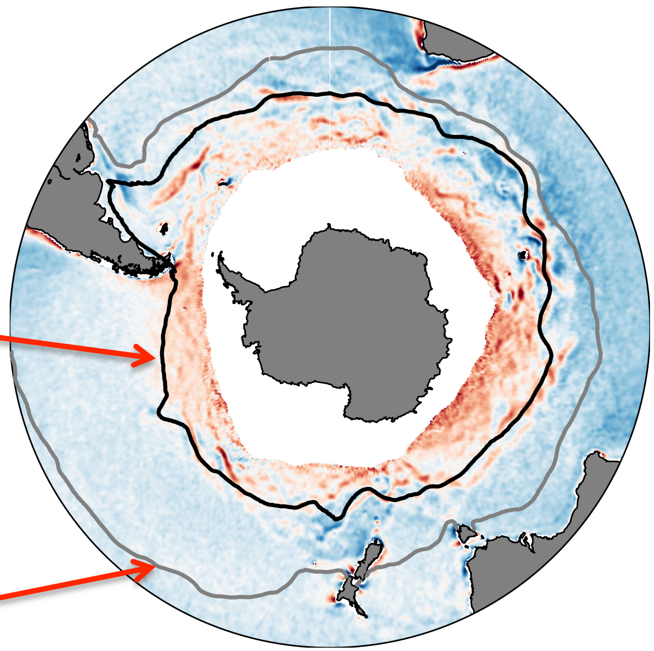


Ekman divergence

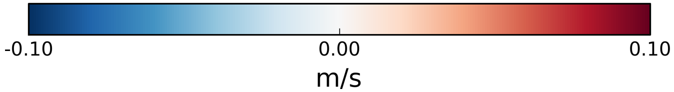
Note: *Upwelling region* is confined to south of Subantarctic Front

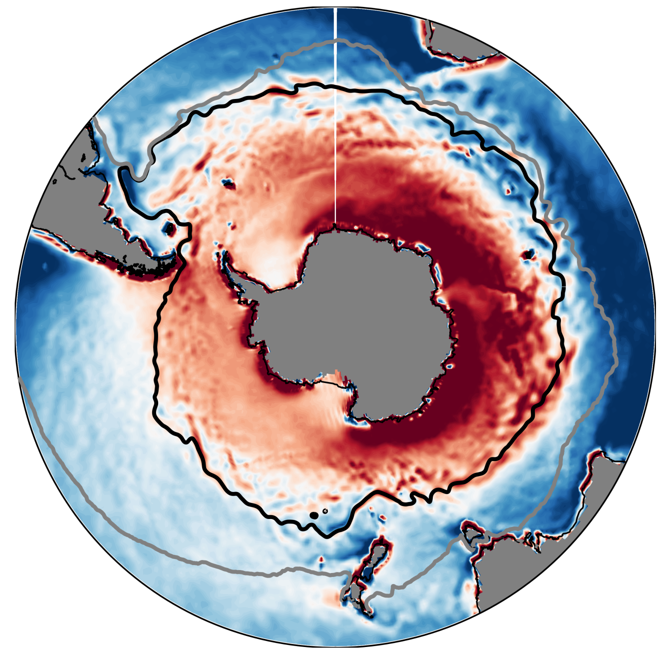
~Sub AA front
(SSH = -38 cm)

~Subtropical front
(S = 35)

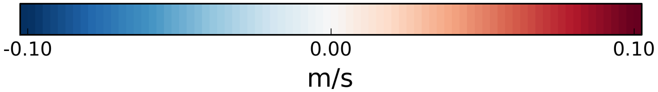


Observations
(SCOW; Risien & Chelton, 2008)



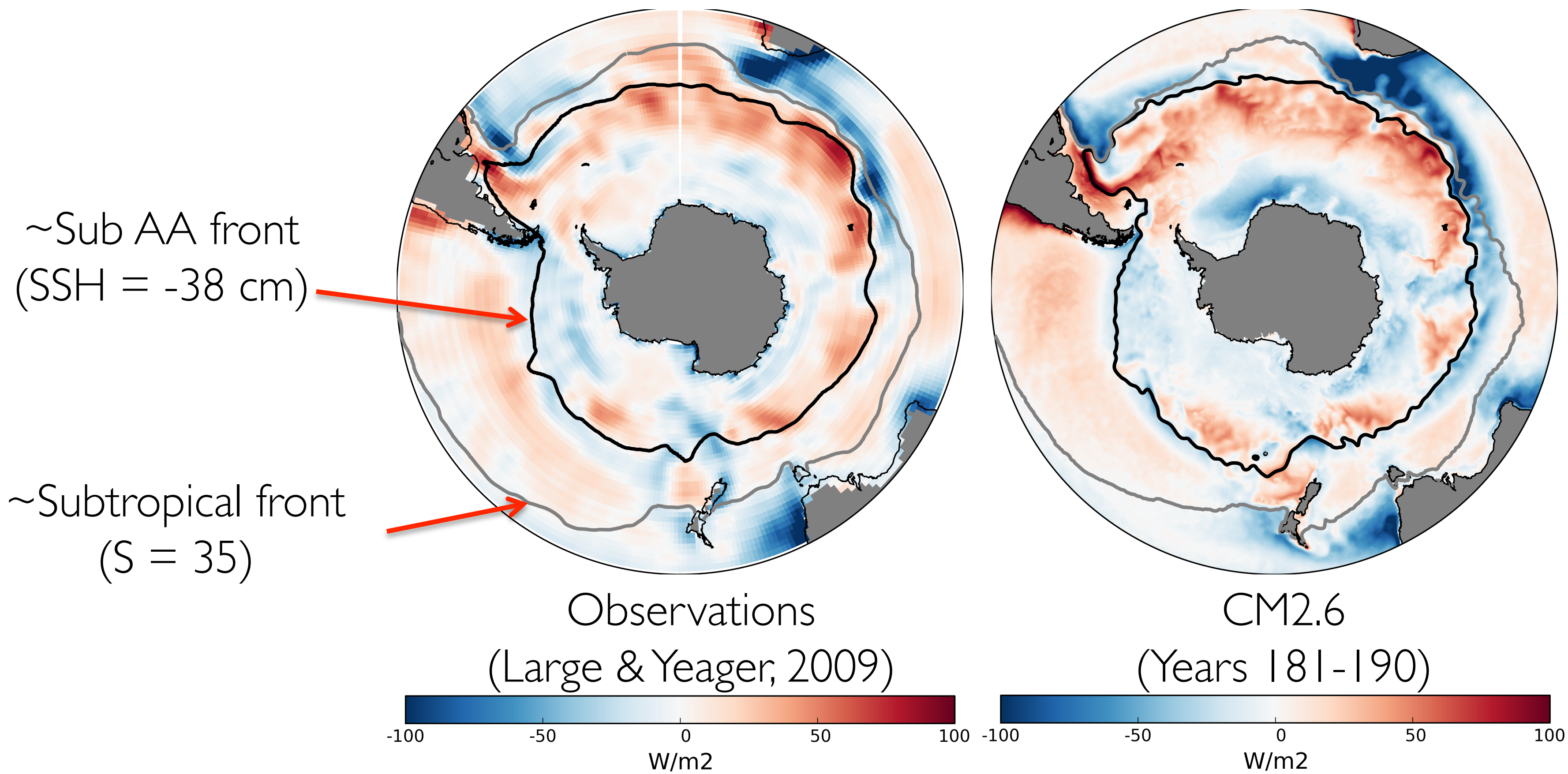


CM2.6
(Years 181-190)



Air-sea heat fluxes

Note: *Cooling regions* due to Western Boundary Current influence are confined largely to north of Subtropical Front



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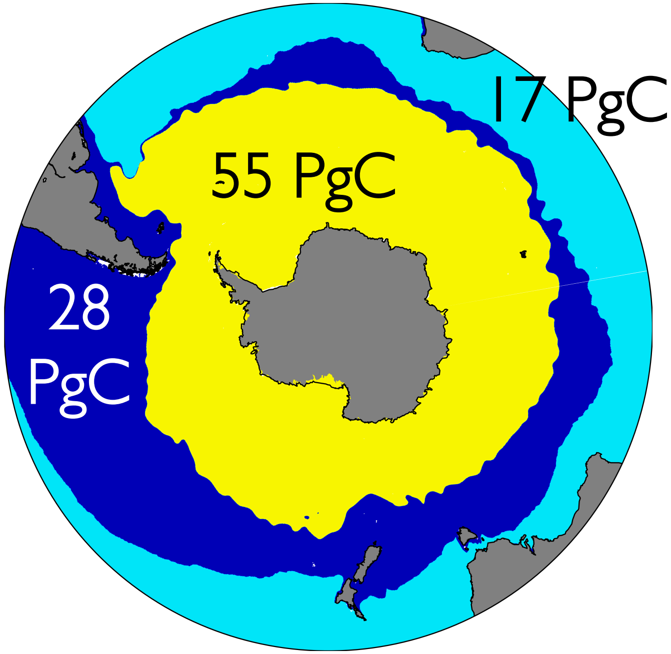
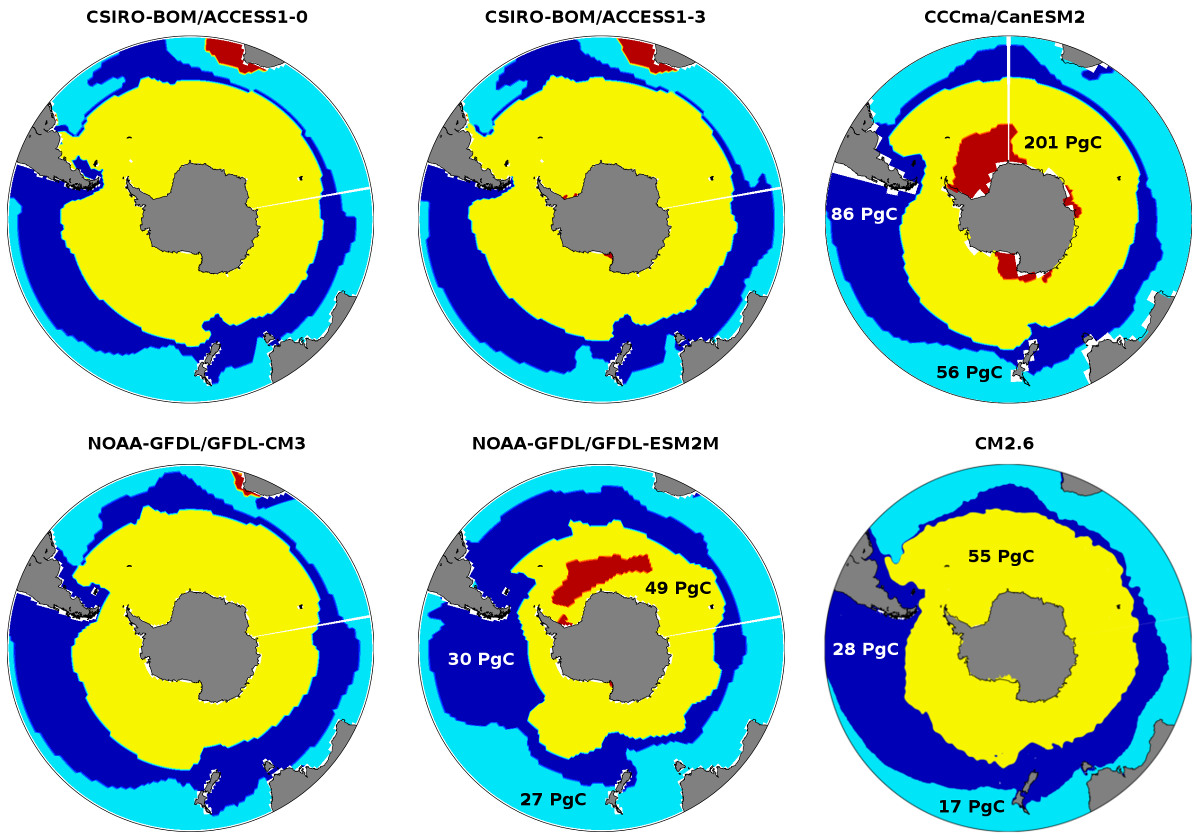
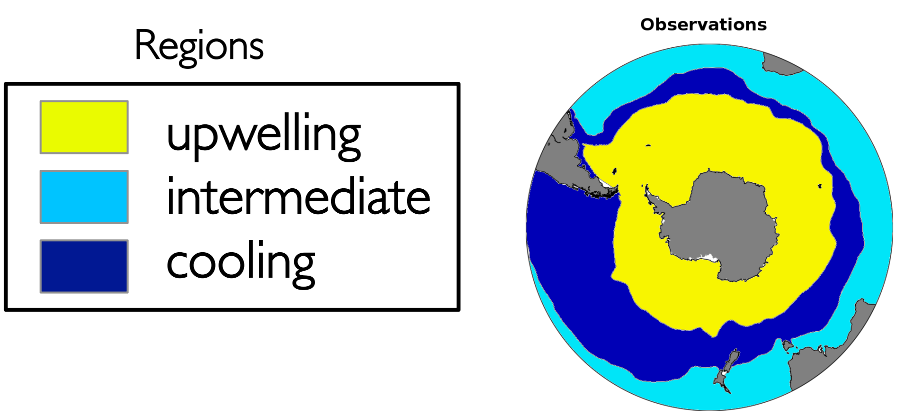
Cumulative anthropogenic CO_2 uptake (70 years) by region in CM2.6



	Upwelling region		Cooling region
Anthropogenic CO_2 uptake (%)	55	28	17

Application to some CMIP5 models and CM2.6





- Separation into 3 regions of the 70 year cumulative sum of anthropogenic CO_2 flux
- *Note:* in red regions the method does not work well (e.g. polynyas)

Conclusions

Process	Southern Ocean (south of 30°S) contribution to world	Upwelling + boundary region	Cooling region
Nutrient resupply	~3/4 biological production north of 30°S	~100%	~0%
Anthropogenic CO_2 uptake	Observations ~50% Models 40-45%	~70%	~30%
"Anthropogenic" heat uptake	~70 ± 20%	?	?