Thermal and silicate fronts in the Southern Ocean using the CESM LE simulations

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Antarctic Polar Front is a biogeochemical front

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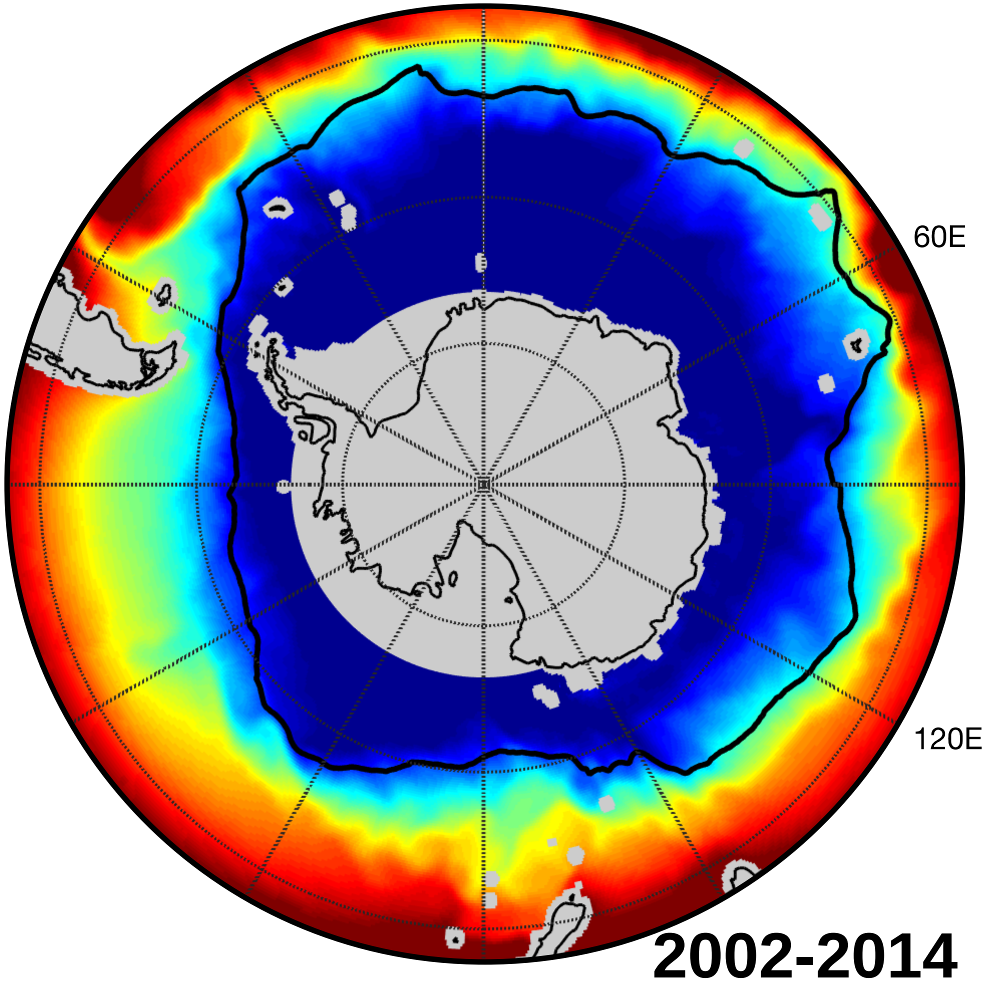


°C

Freeman & Lovenduski (2016)

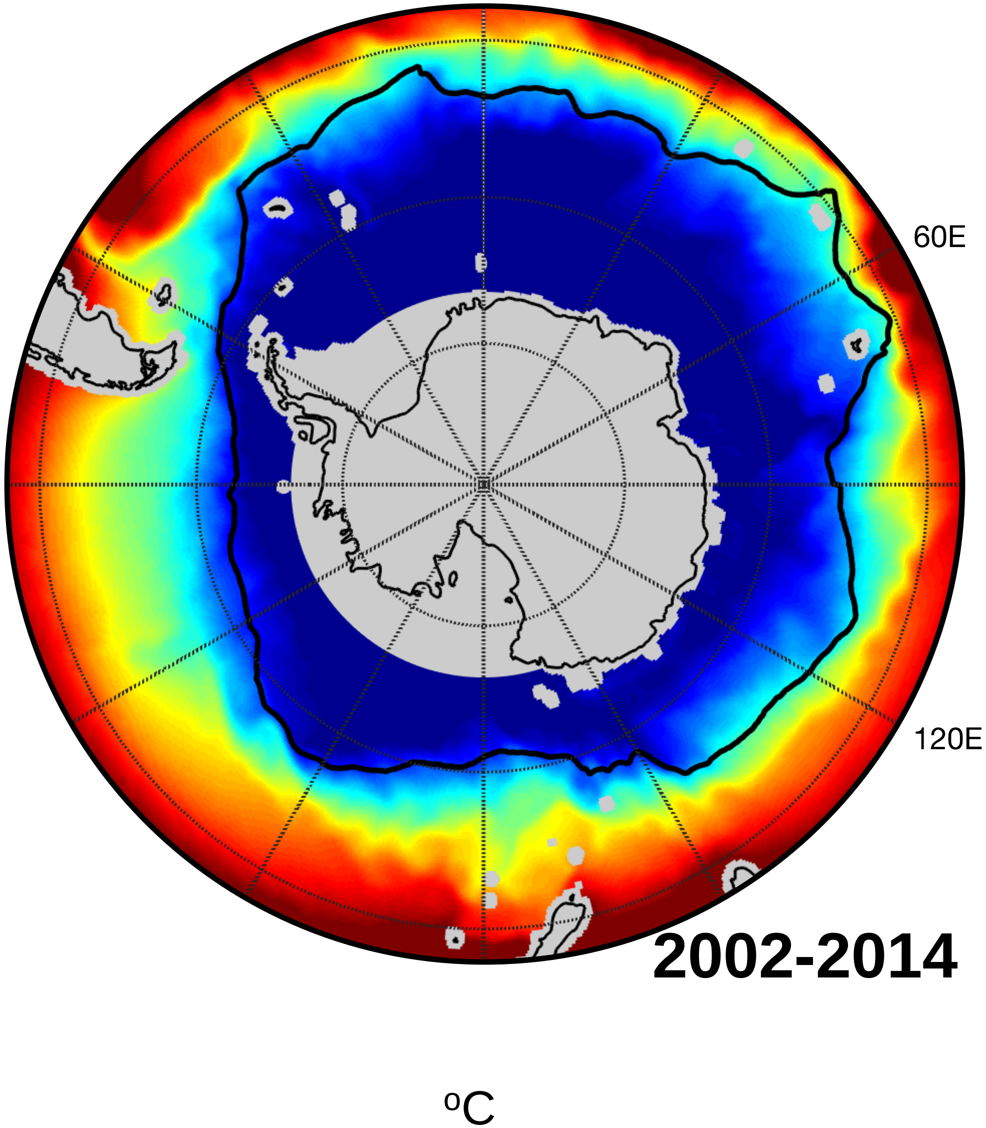
Antarctic Polar Front is a biogeochemical front

Subduction, transition zone

South of Polar Front:

- salinity-dominated stratification
- high [macronutrients]
- low [micronutrients]

Implications: local physical, biogeochemical processes



Freeman & Lovenduski (2016)

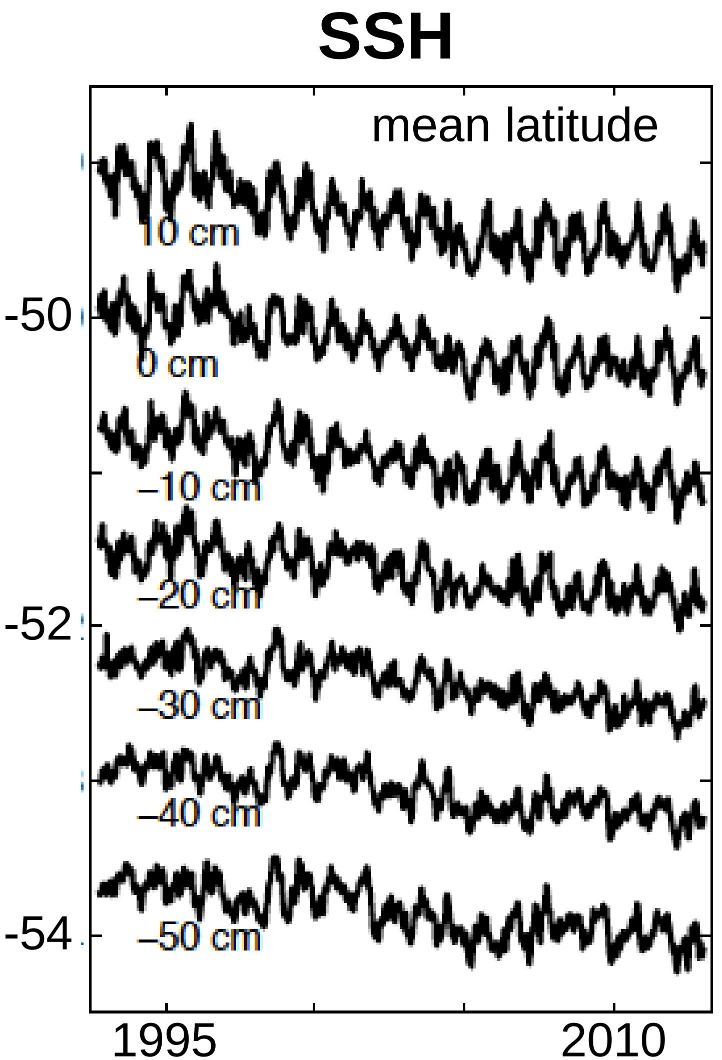
Southern Ocean change

Observed change
- warmed, freshened
- carbon sink strengthened
- westerlies strengthened, shifted poleward

Predicted change
- continued poleward shift in westerlies
- ACC system to mirror westerlies

How has the Antarctic Polar Front (PF) changed over this period of substantial Southern Ocean change?

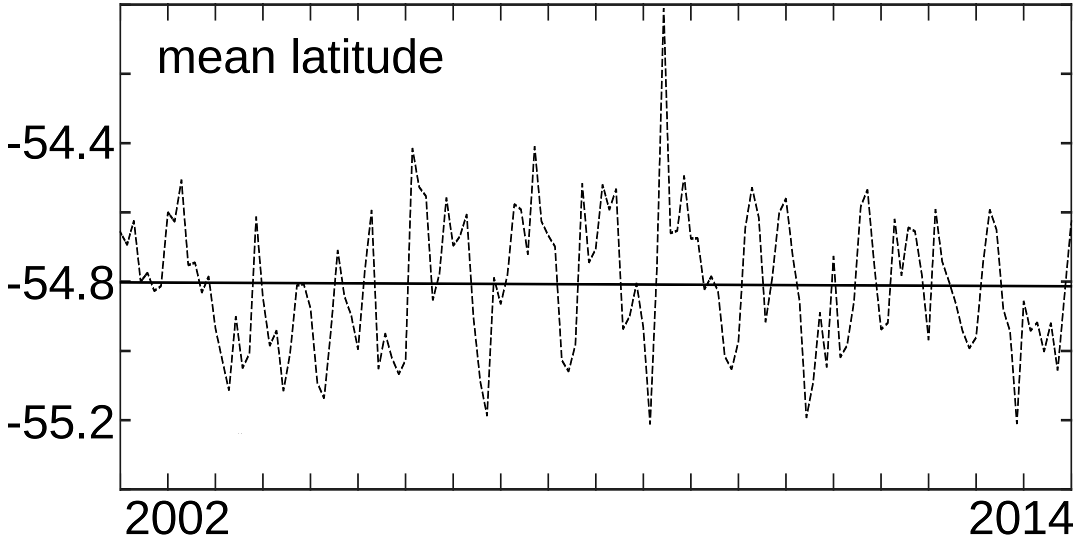
Has the PF moved?



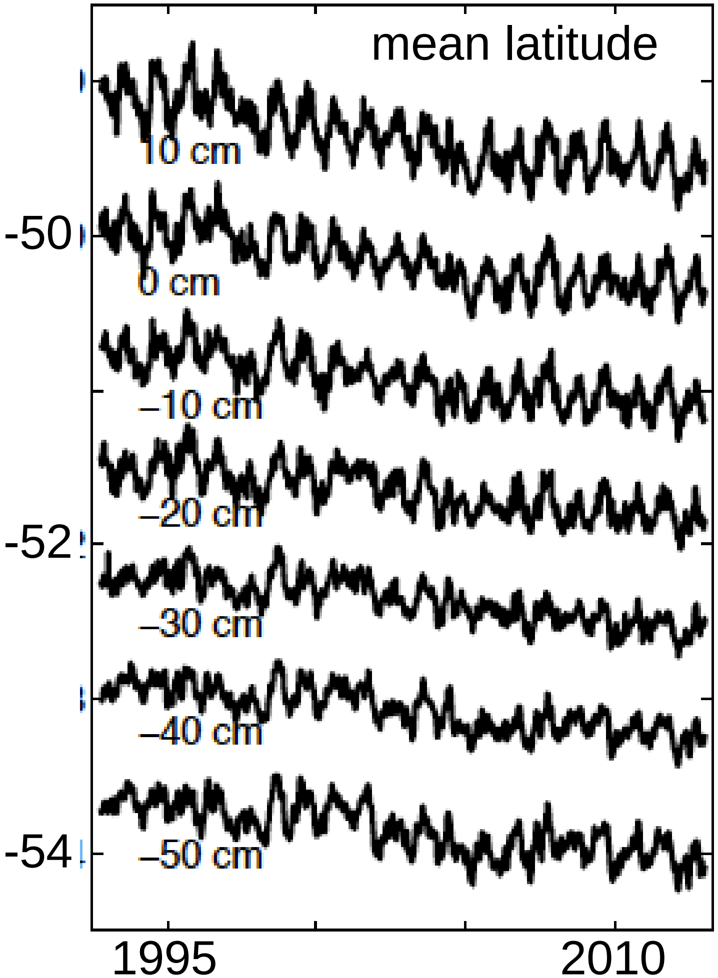
Sokolov & Rintoul (2009); Sallee et al. (2008)

Has the PF moved?

SST



SSH



Freeman & Lovenduski (2016)
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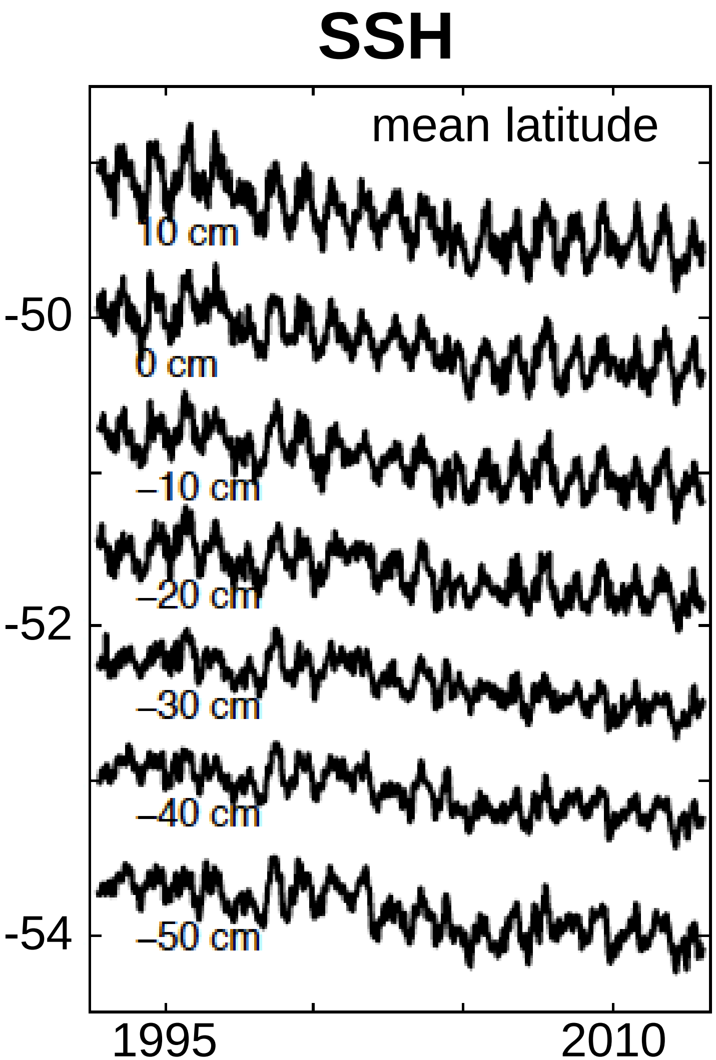

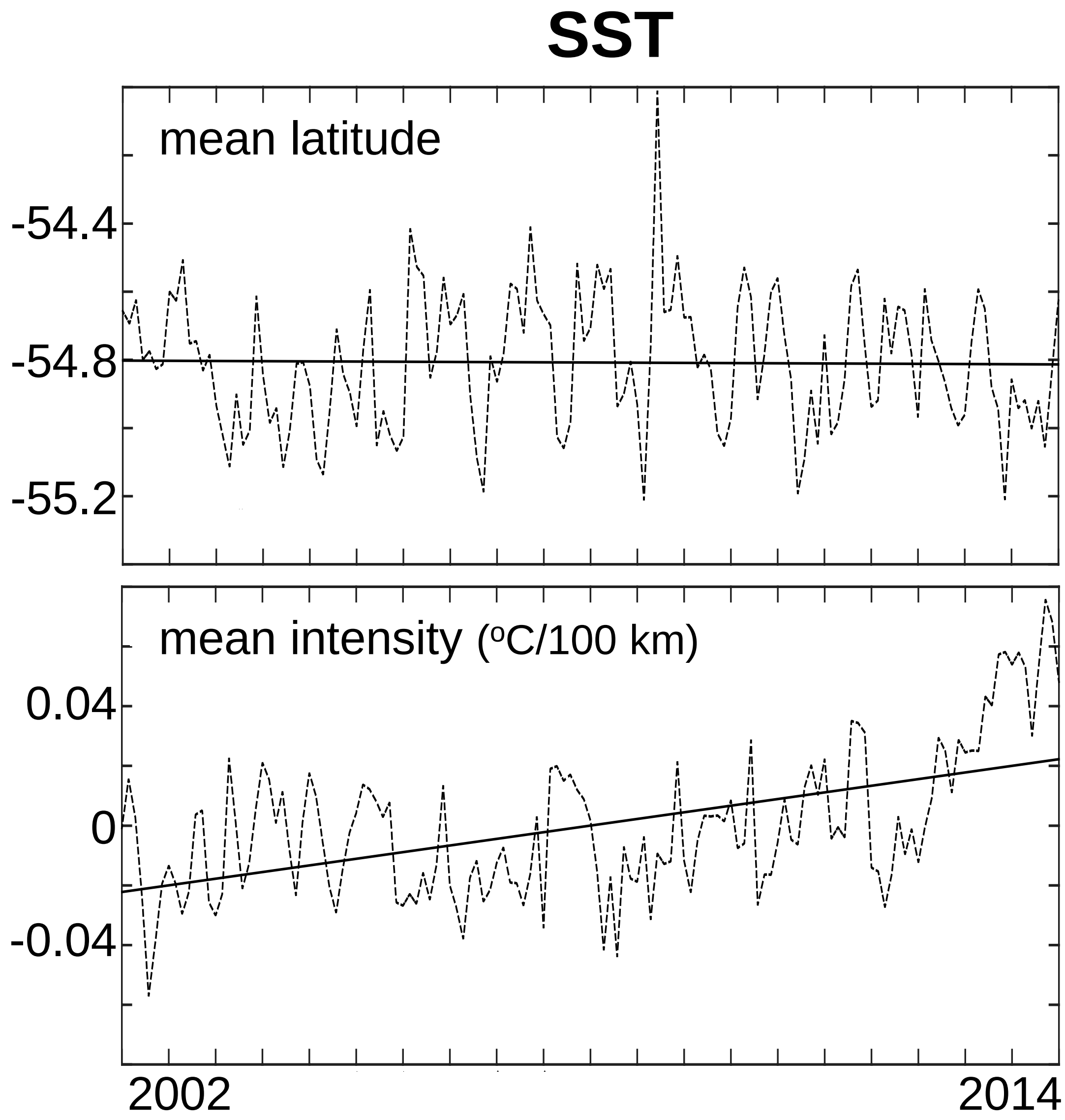

Freeman & Lovenduski (2016)
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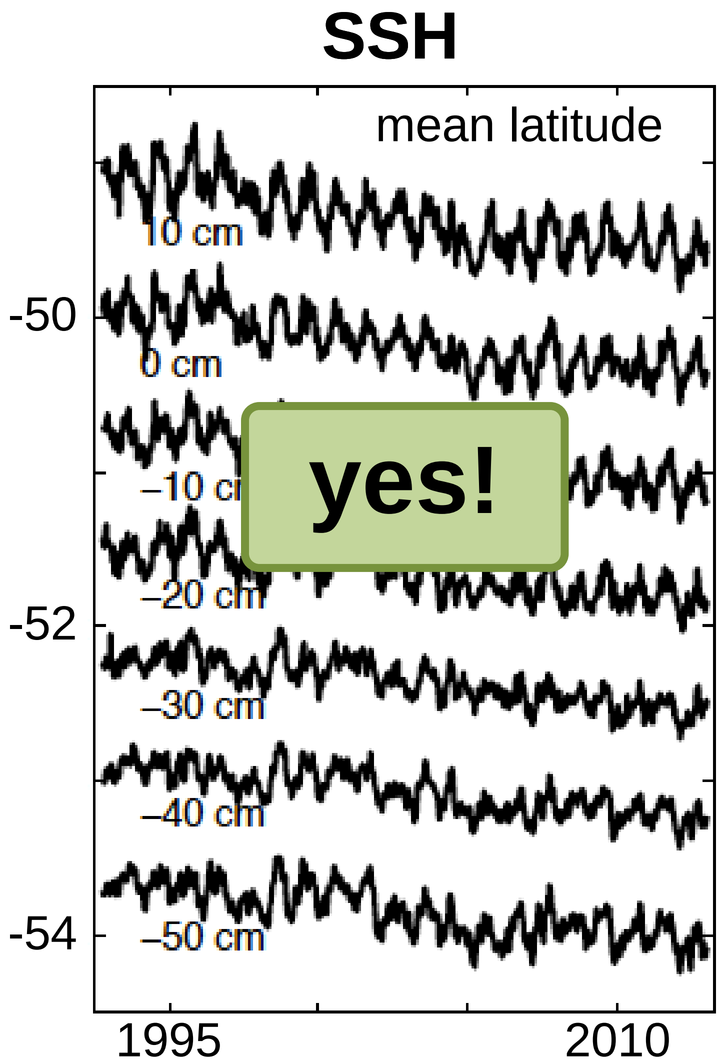

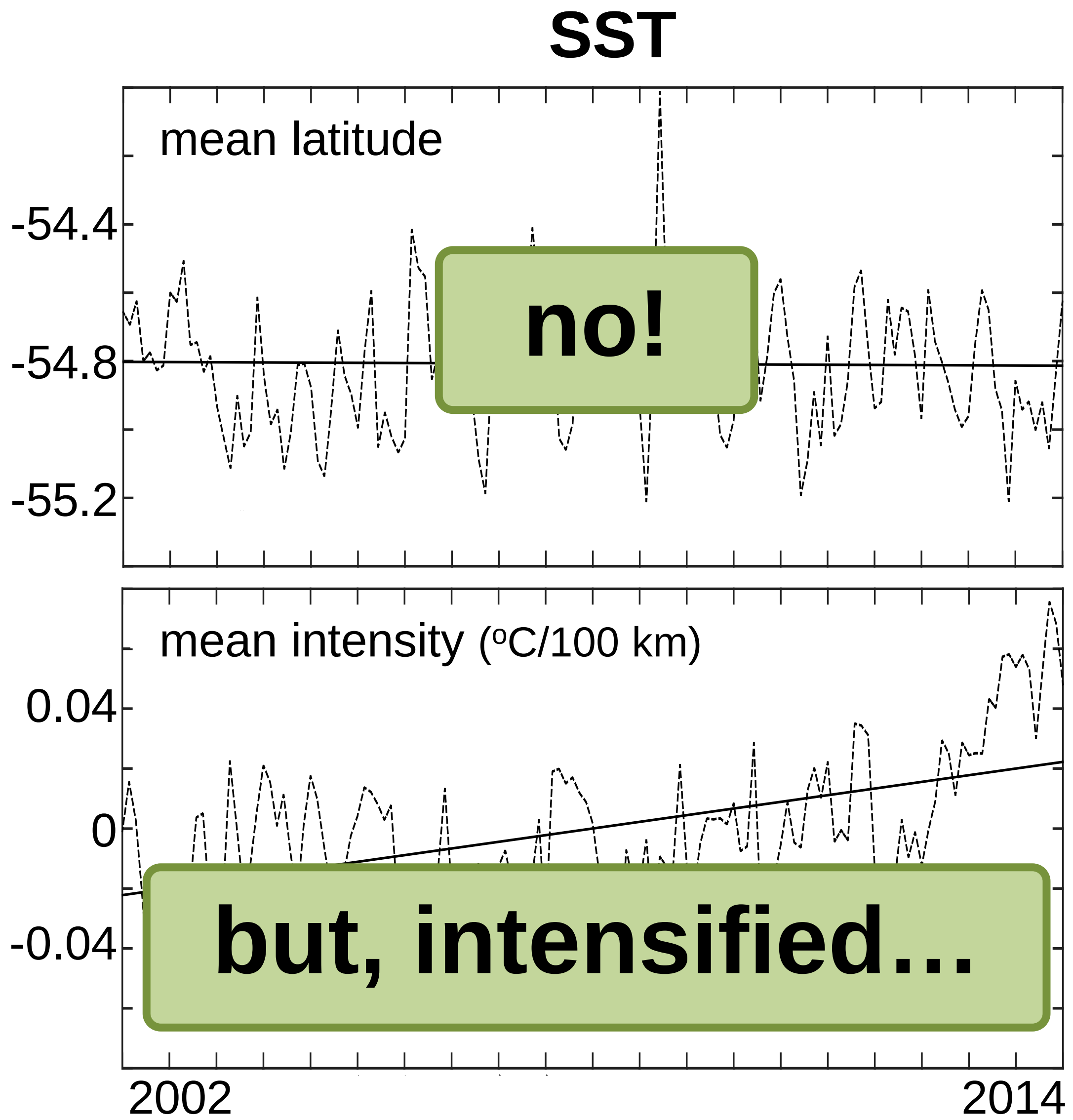

Freeman & Lovenduski (2016)
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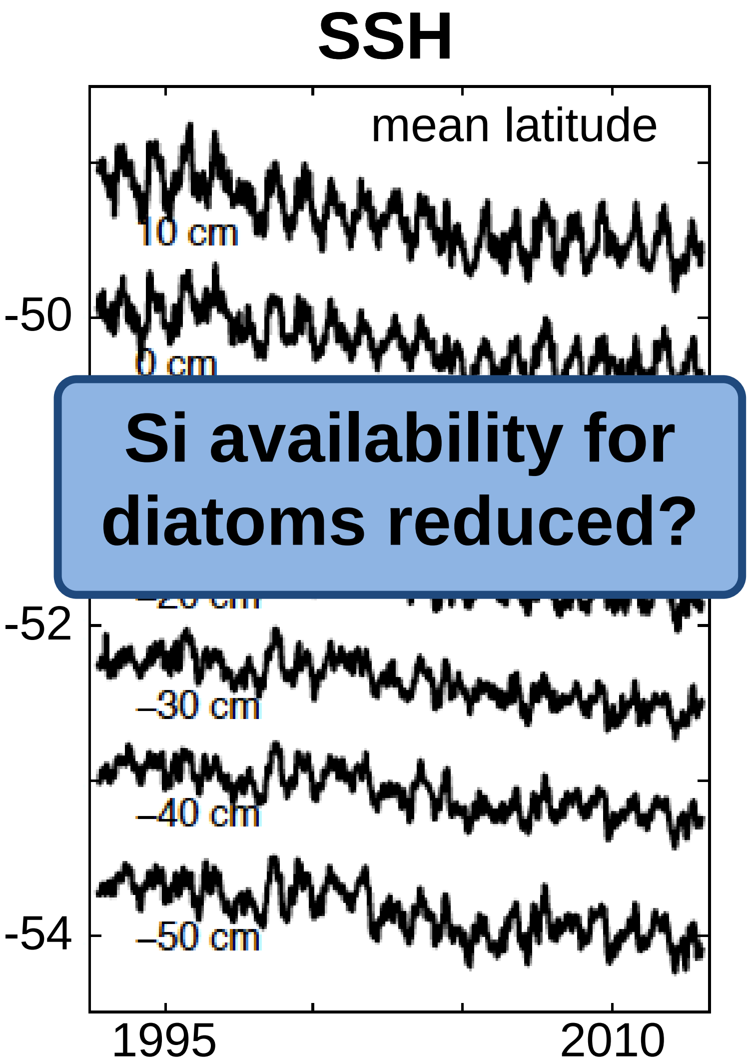
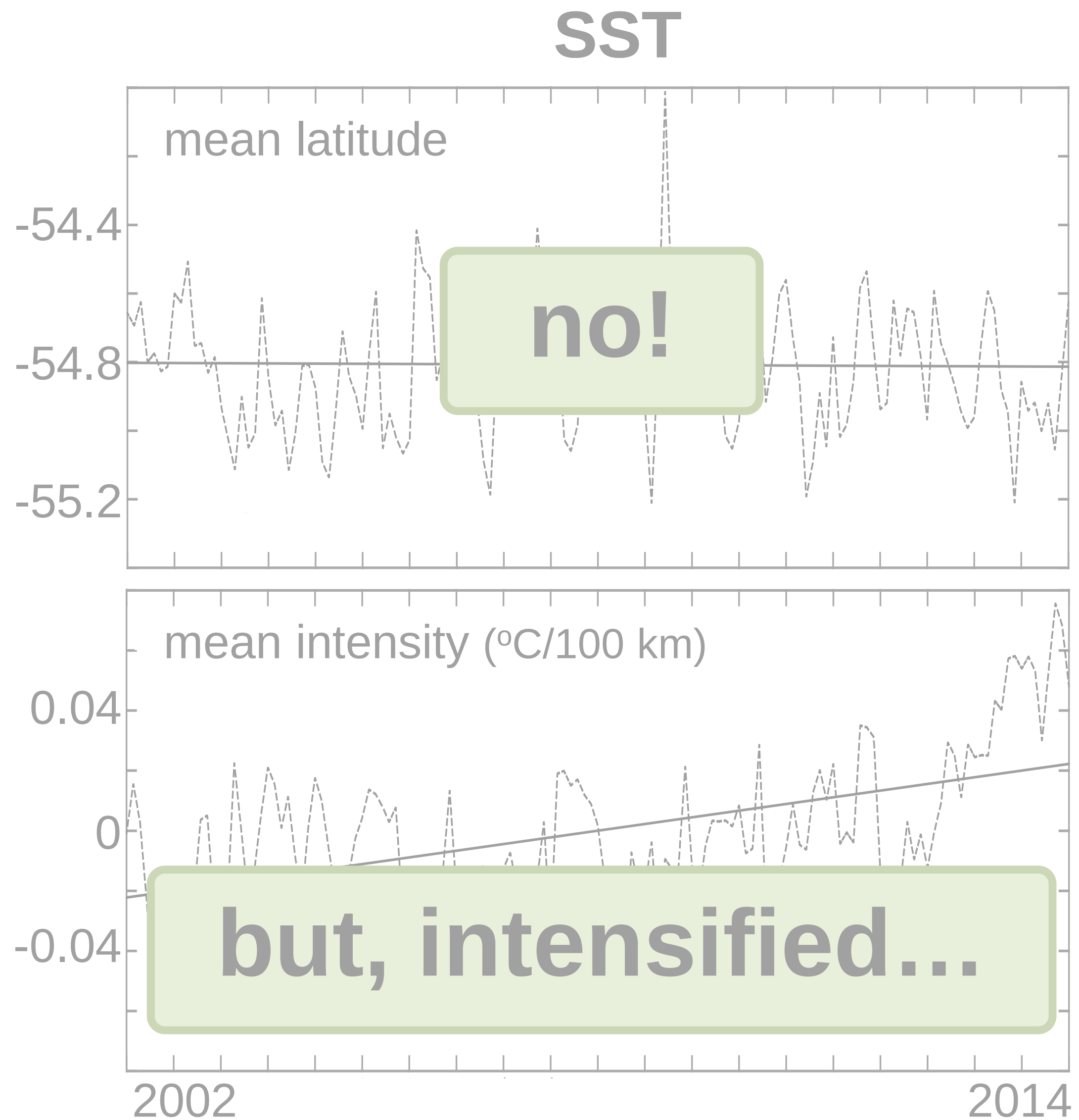
What does this mean for BGC?





Freeman & Lovenduski (2016)
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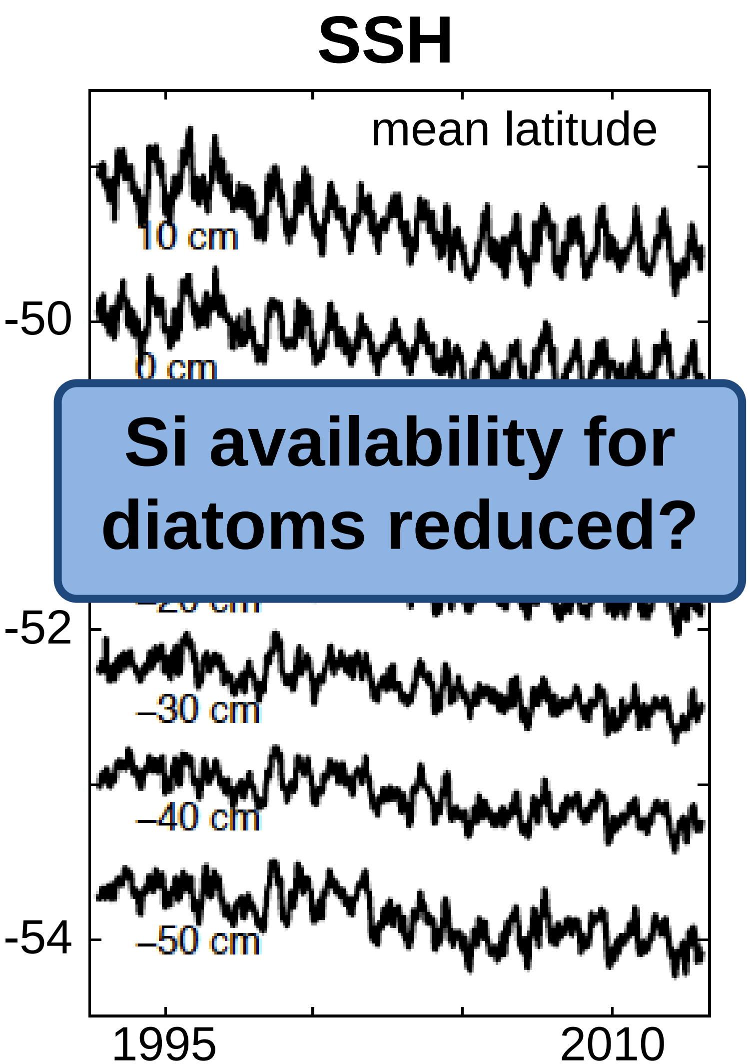

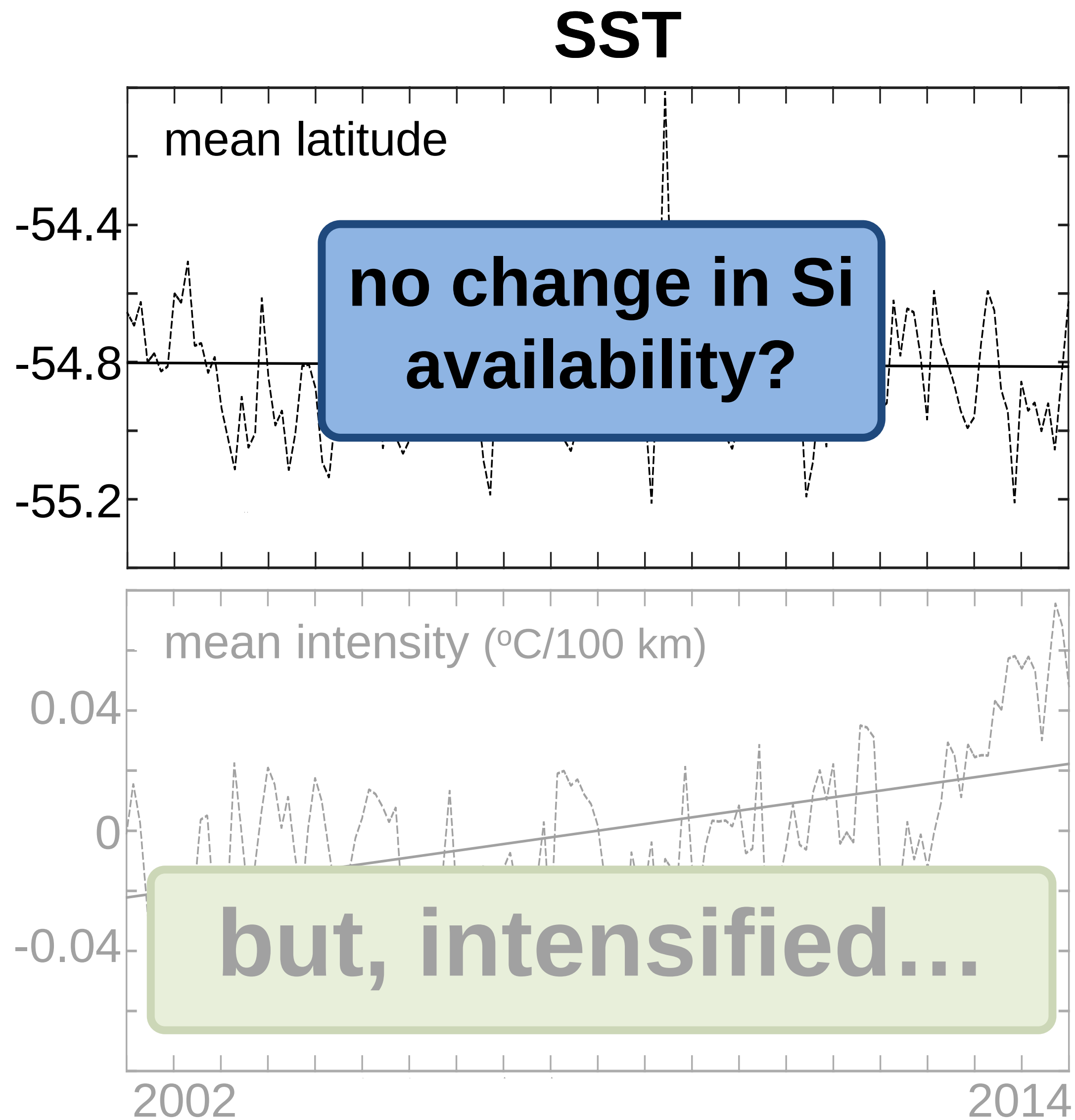

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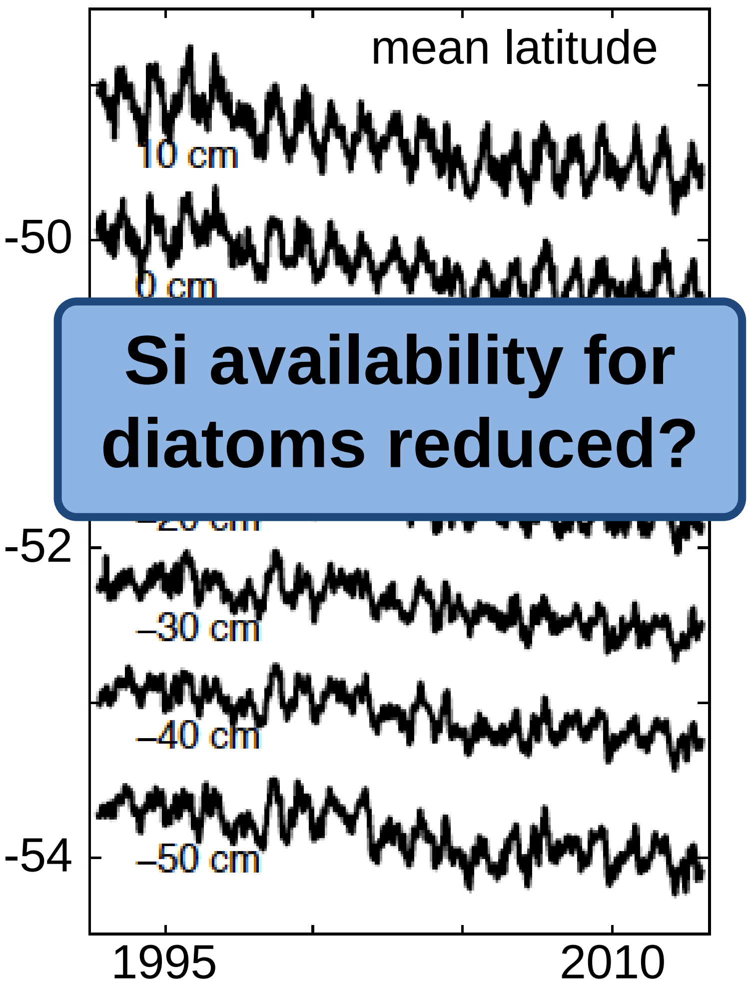
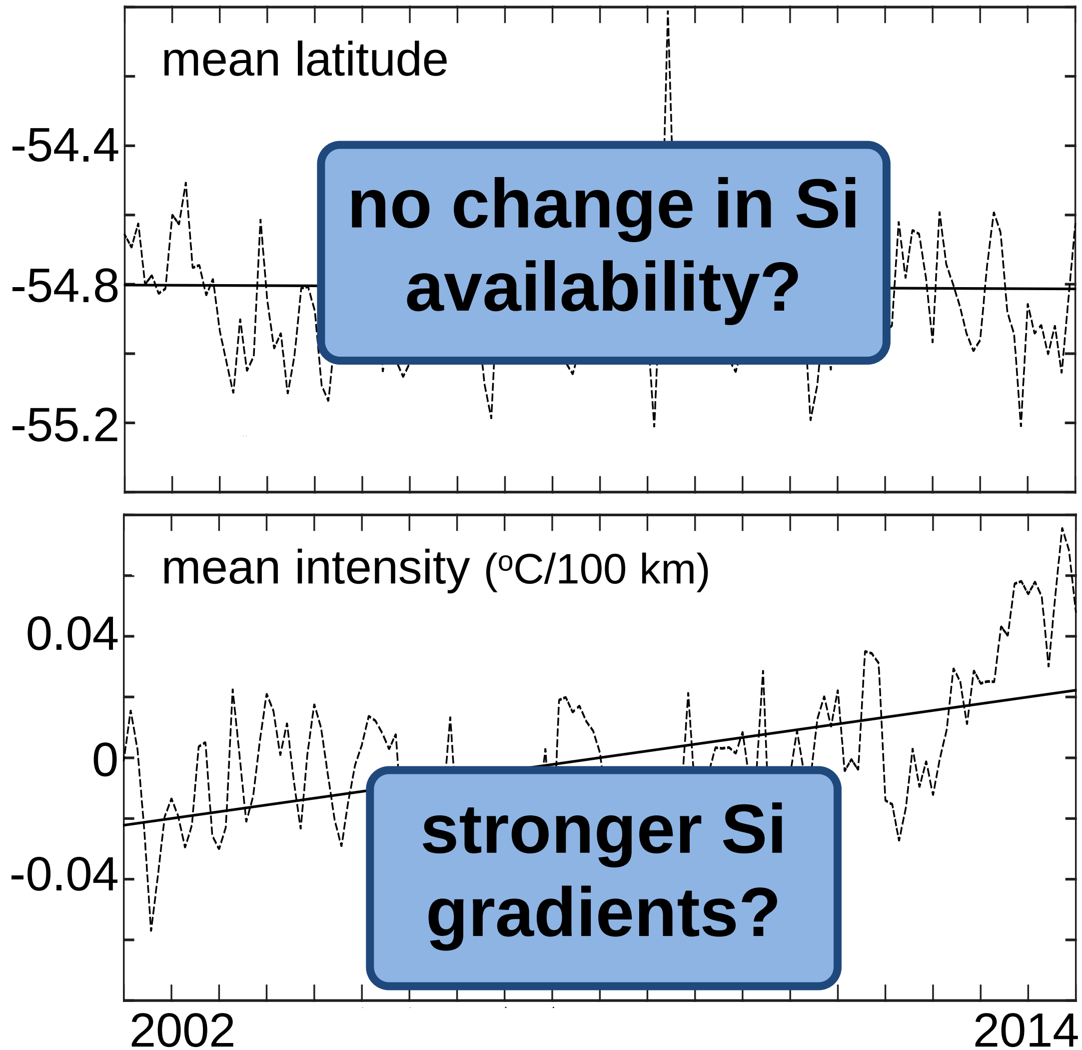


SST



Sokolov & Rintoul (2009); Sallee et al. (2008)

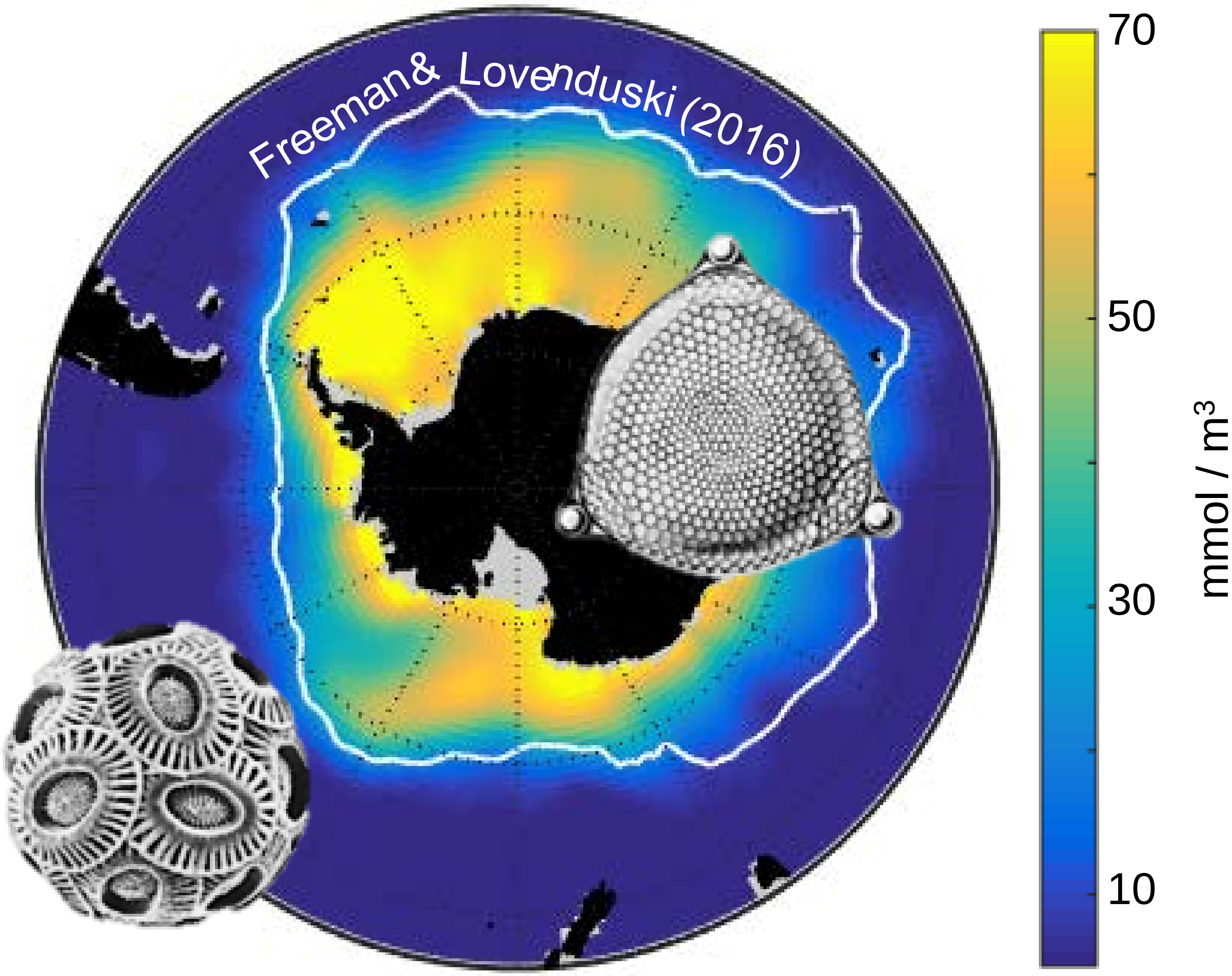
Freeman & Lovenduski (2016)
Freeman et al. (2016)

The PF and the Silicate Front (SF)

World Ocean Atlas: annual mean surface silicate

sharp meridional Si gradients at the PF

relationship important in terms of **biogeography**



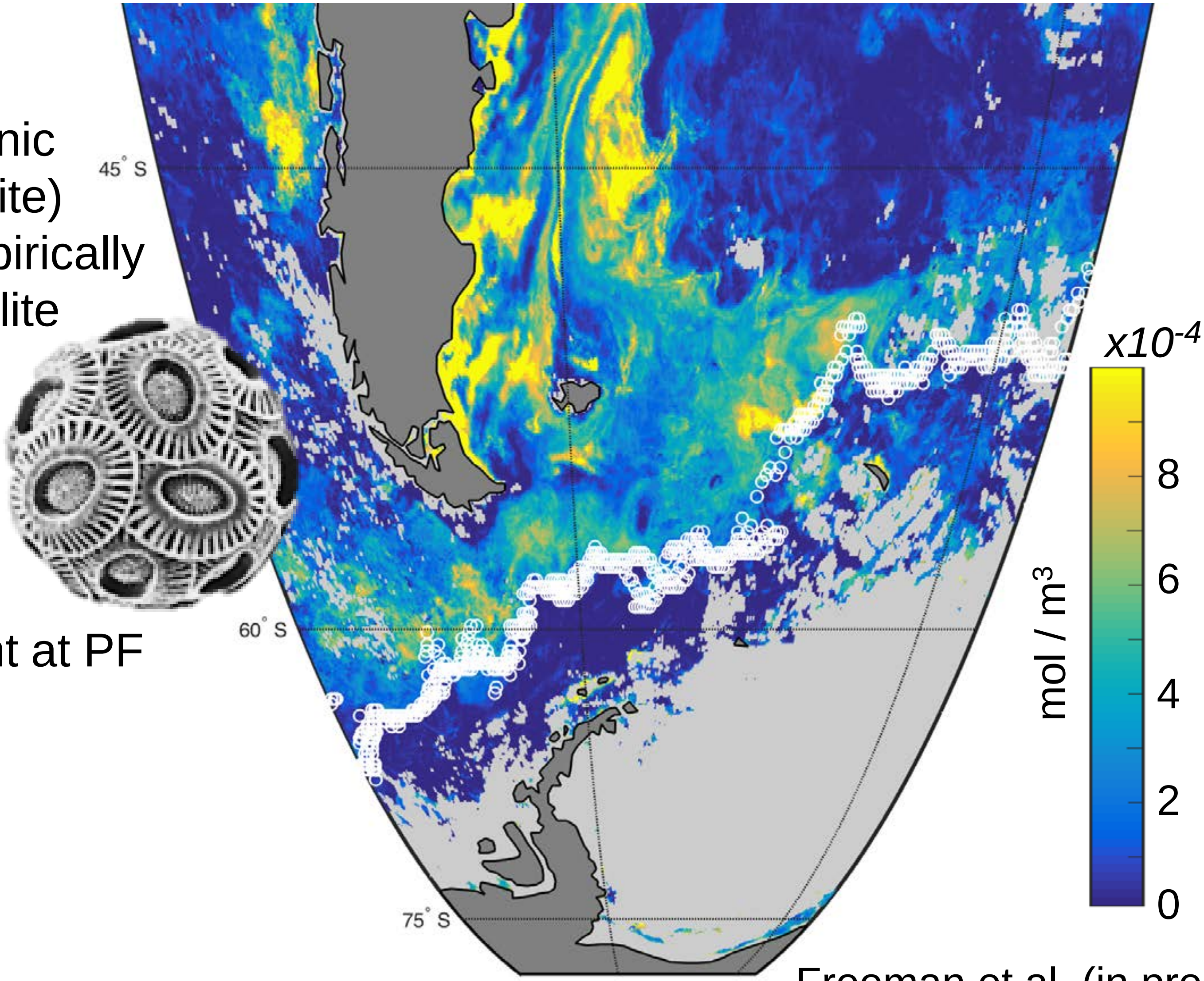
phytoplankton drawings: Sally Bensusen, NASA EOS Project Science Office

PF-BGC relationship apparent in Drake Passage

Particulate Inorganic Carbon (PIC; calcite) concentration empirically derived from satellite

sharp PIC gradient at PF

MODIS Aqua [PIC] (December 2002)



Freeman et al. (in prep)

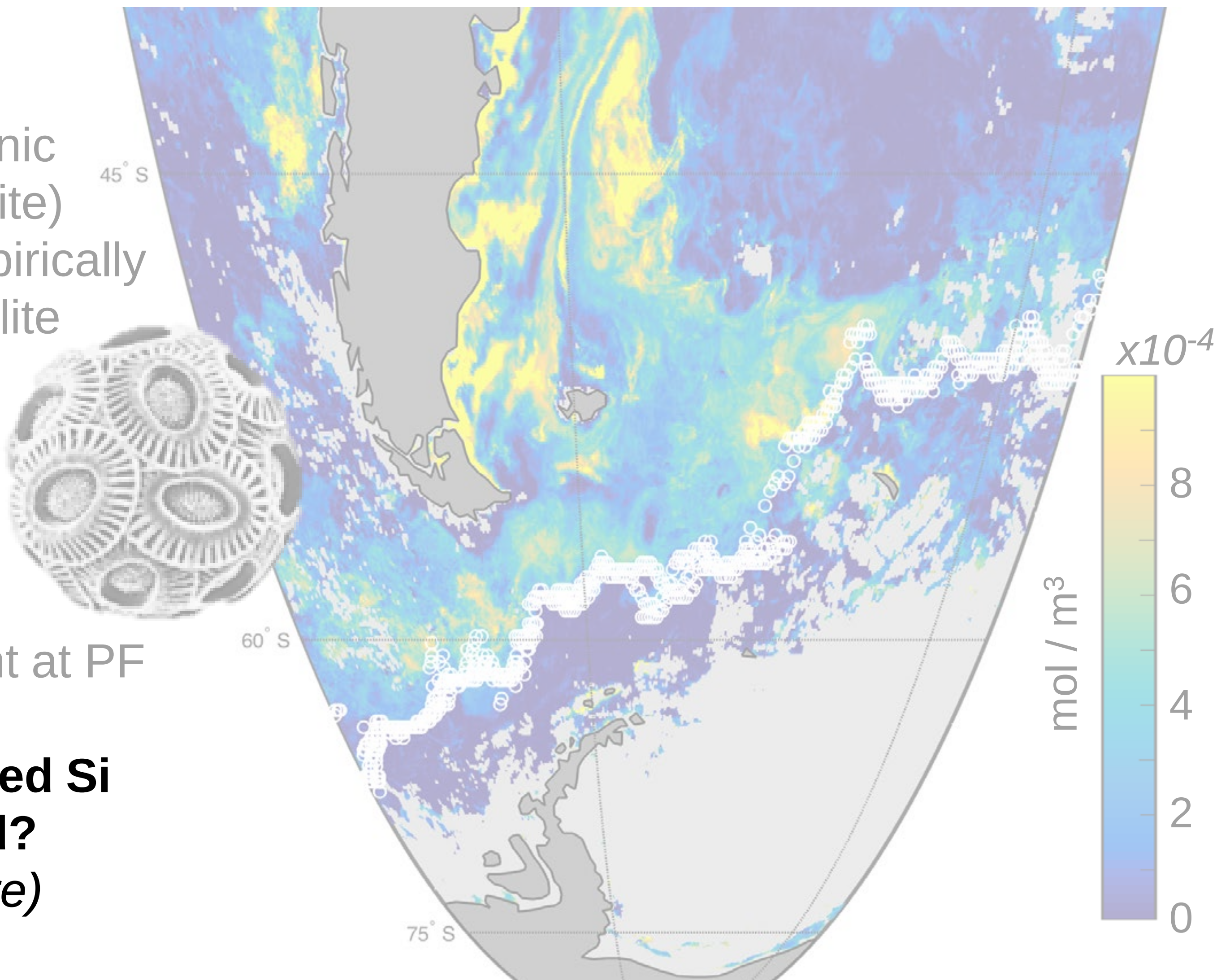
PF-BGC relationship apparent in Drake Passage

Particulate Inorganic Carbon (PIC; calcite) concentration empirically derived from satellite

sharp PIC gradient at PF

Has the associated Si boundary shifted?
(invoke model here)

MODIS Aqua [PIC] (December 2002)



Freeman et al. (in prep)

Exploring BGC fronts in CESM LE

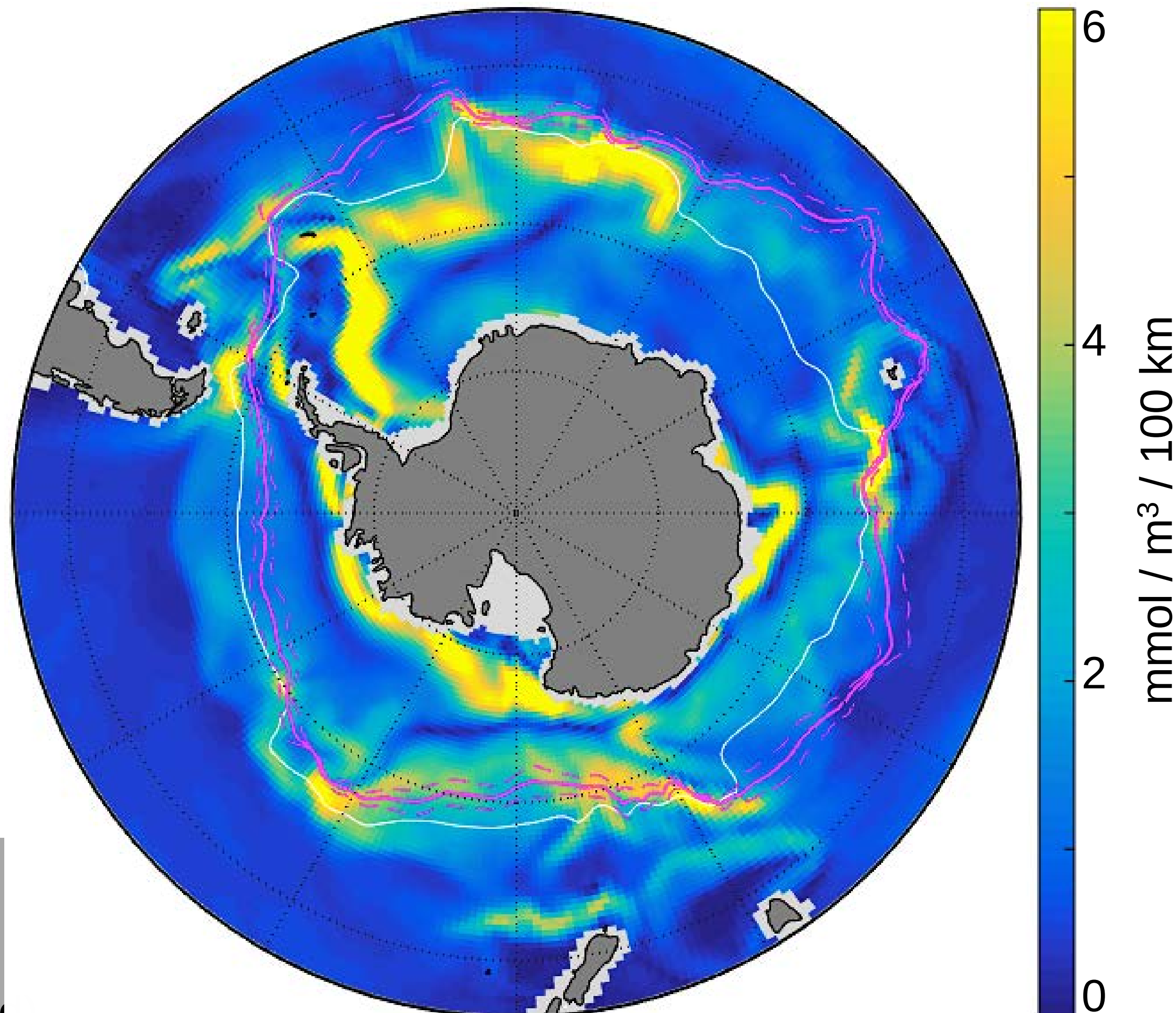
Thanks to CESM LE Community Project (Kay et al., 2015) & NSF/CISL/Yellowstone

Exploring BGC fronts in CESM LE

diatoms *generally* take up nutrients at Si:N = 1 ratio
under adequate light, nutrient conditions

regional coincidence:
Si:N = 1
ΔSi
PF (ΔSST)

ΔSi (2002-2014)

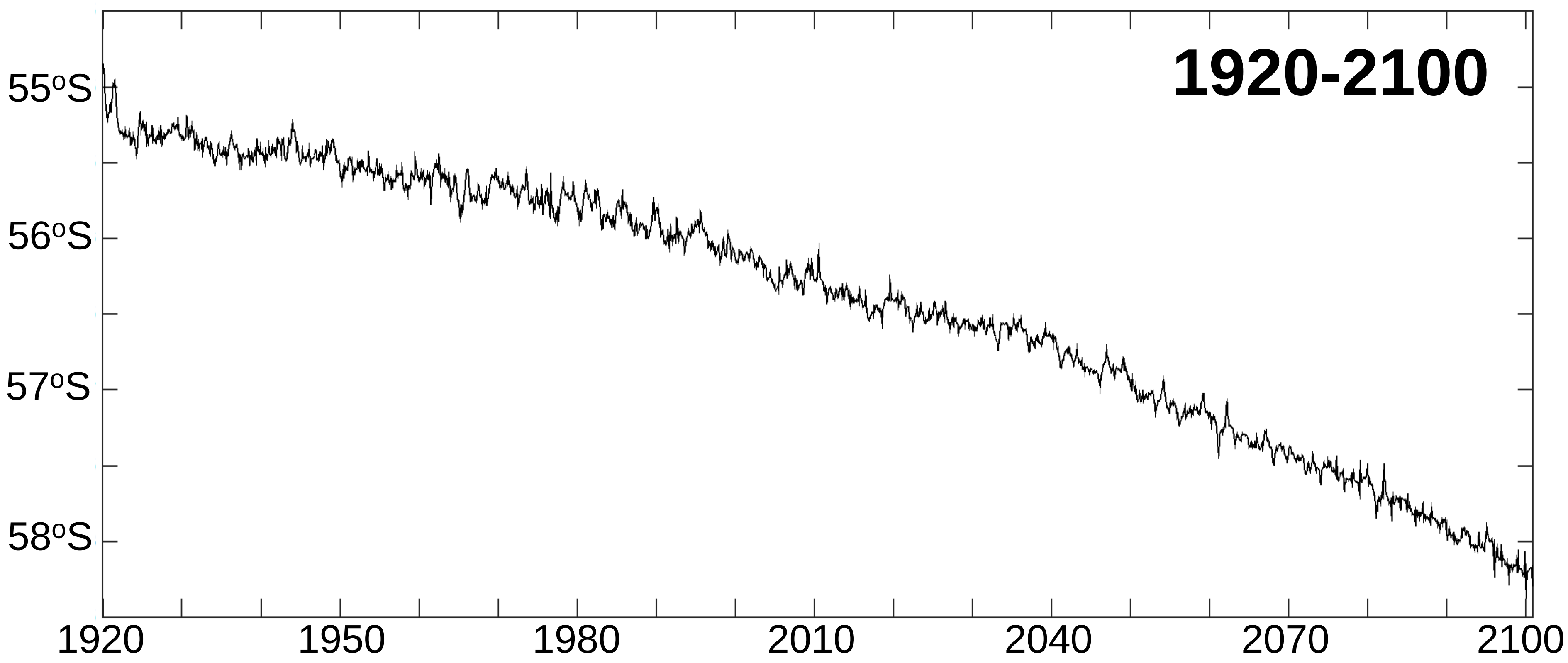


mean PF (observed)
±1σ monthly mean PF
mean Si:N = 1 (modeled

Freeman et al. (in prep)

SF shifts poleward

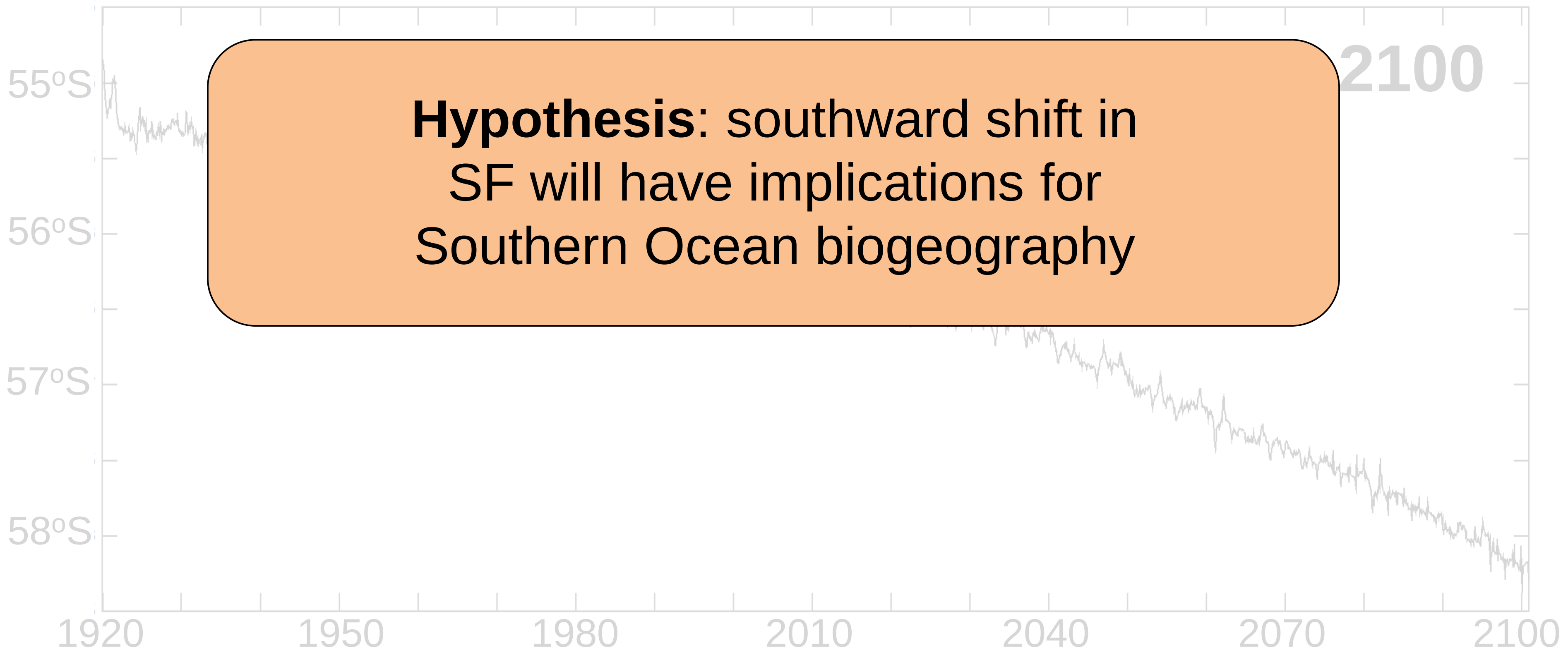
mean **latitude where Si:N = 1** at the surface displaced southward both in historical record and in future climate scenario (RCP8.5)



Freeman et al. (in prep)

Silicate Front (SF) shifts poleward

mean **latitude where Si:N = 1** displaced southward both in historical record and in future climate scenario (RCP8.5)



Hypothesis: southward shift in SF will have implications for Southern Ocean biogeography

Freeman et al. (in prep)

Defining long-term change

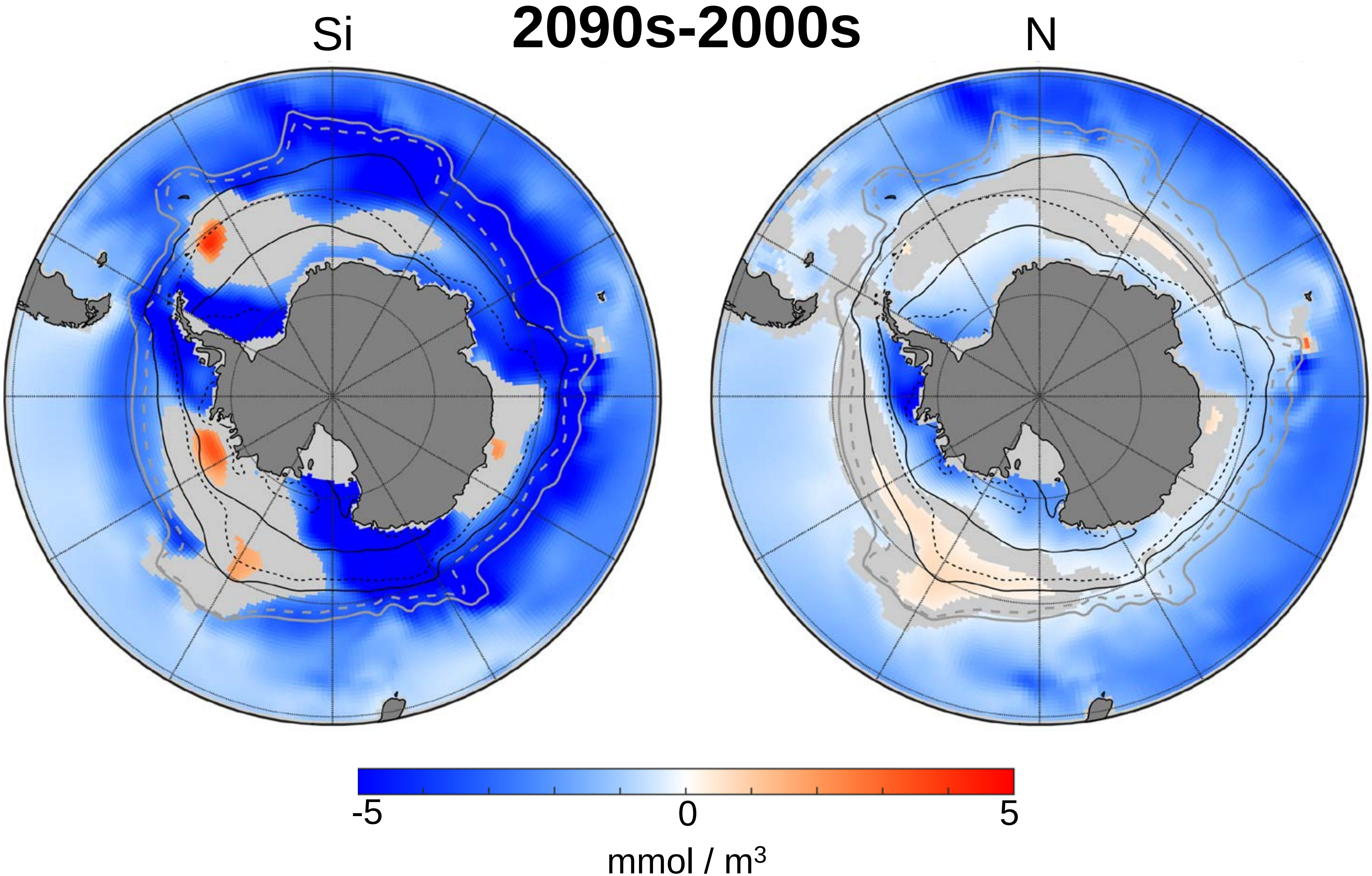
Present: **2000s**
2000-2009 decadal average

Future: **2090s**
2090-2099 decadal average

Long-term change: **2090s – 2000s**
Future – Present

Ensemble Member spread: **1σ**
Significant change in Ens. Mean: **long-term change > 1σ**

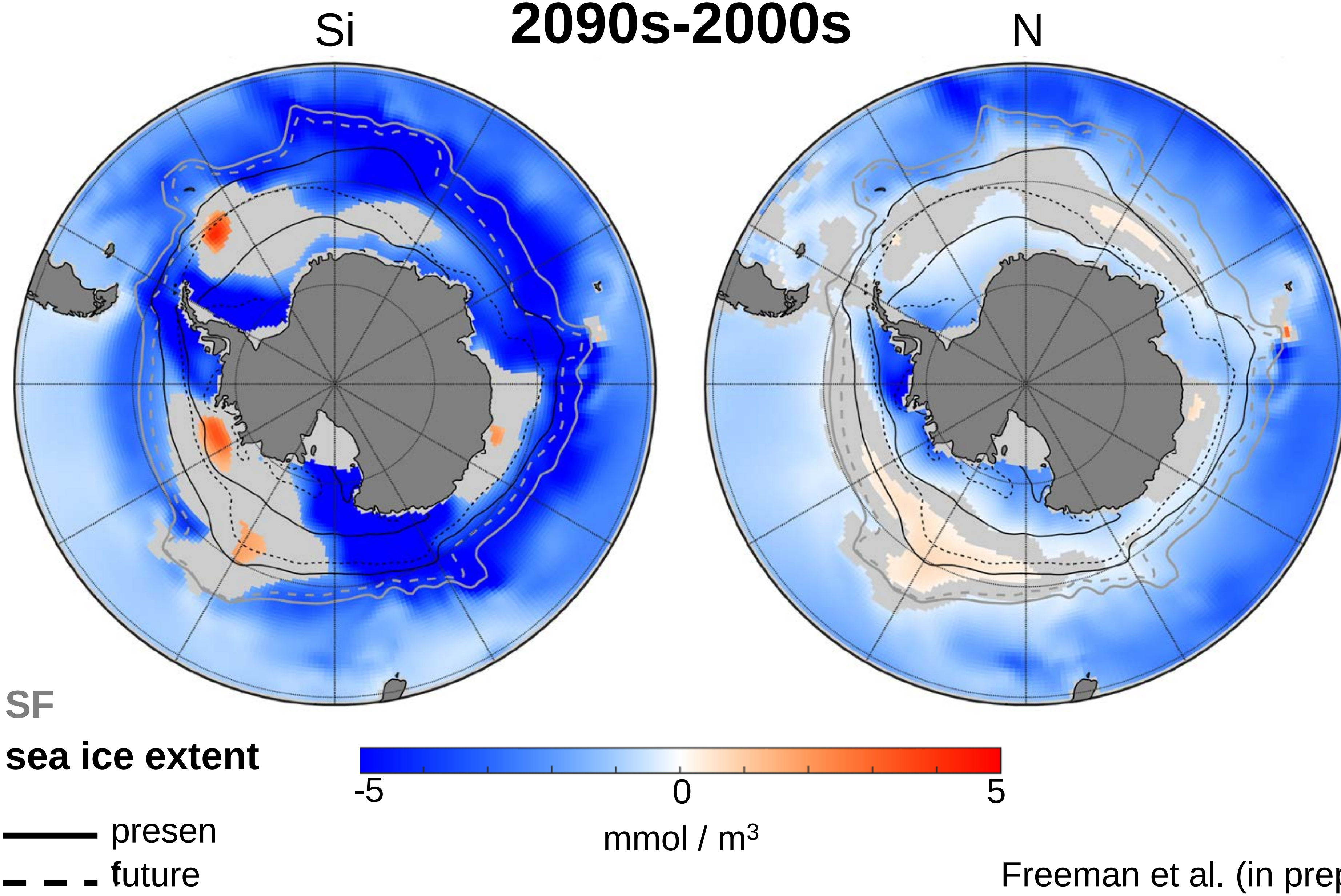
Long-term decreases in surface Si, N



Freeman et al. (in prep)

Long-term decreases in surface Si, N

2090s-2000s



Freeman et al. (in prep)

Long-term decreases in surface Si, N

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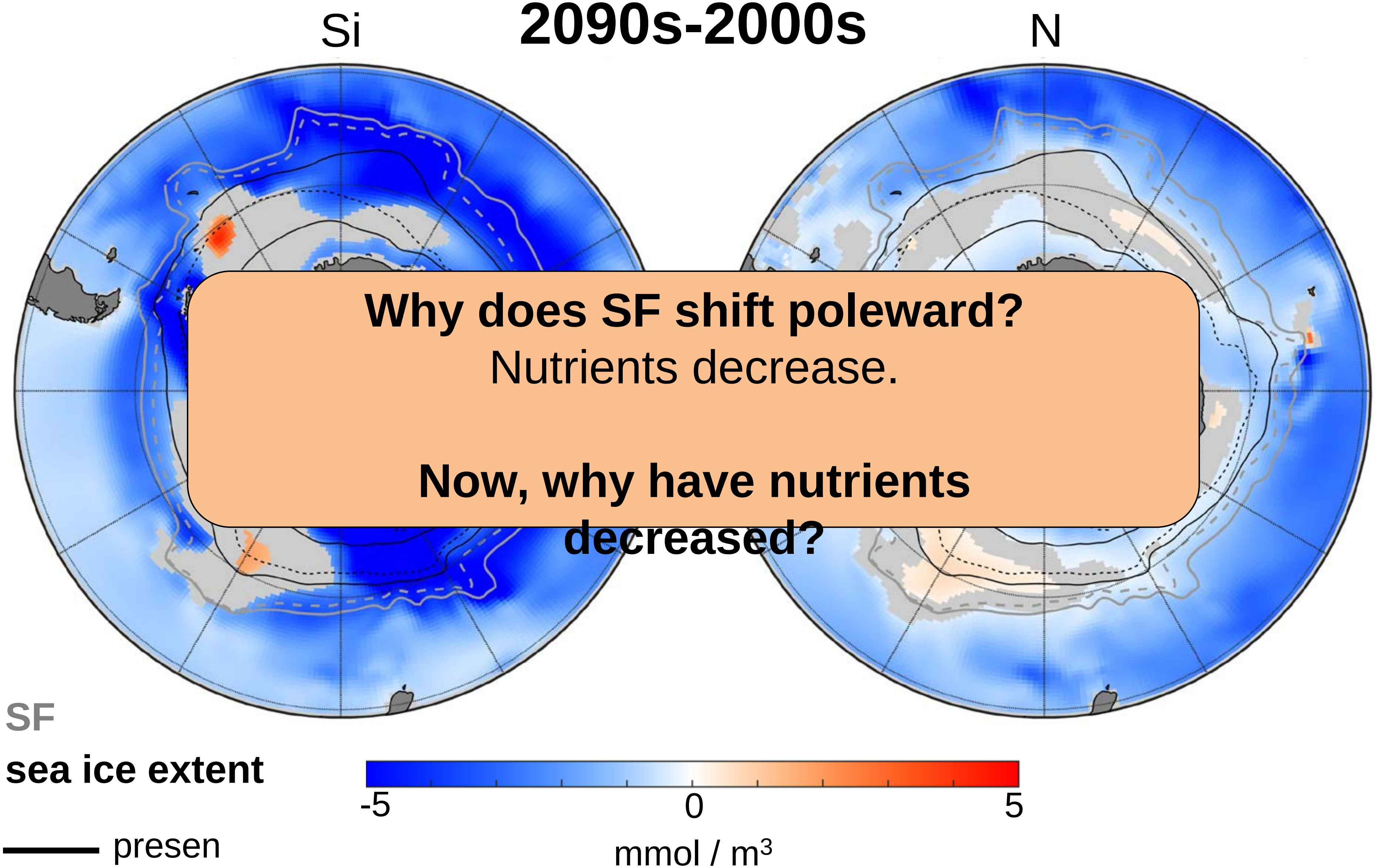

Why does SF shift poleward?

Nutrients decrease.

Now, why have nutrients decreased?

SF

sea ice extent

presen

future

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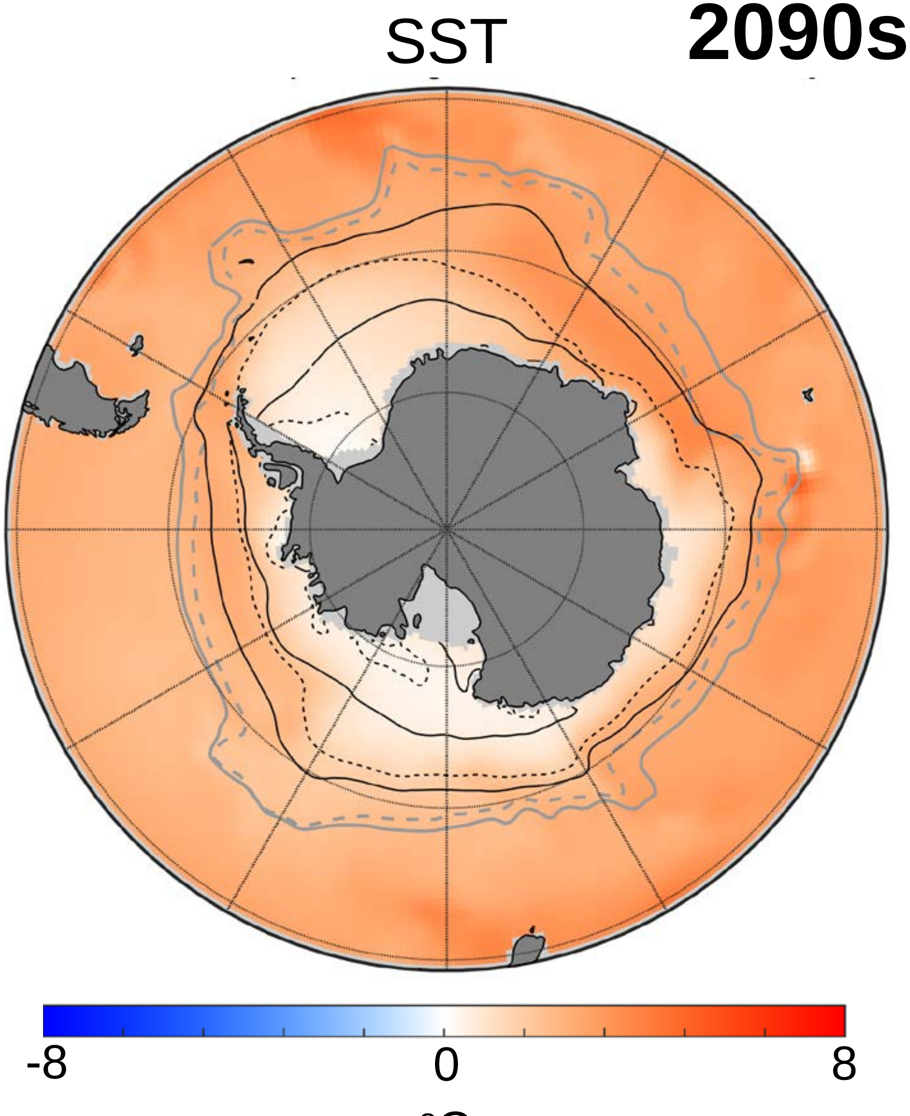
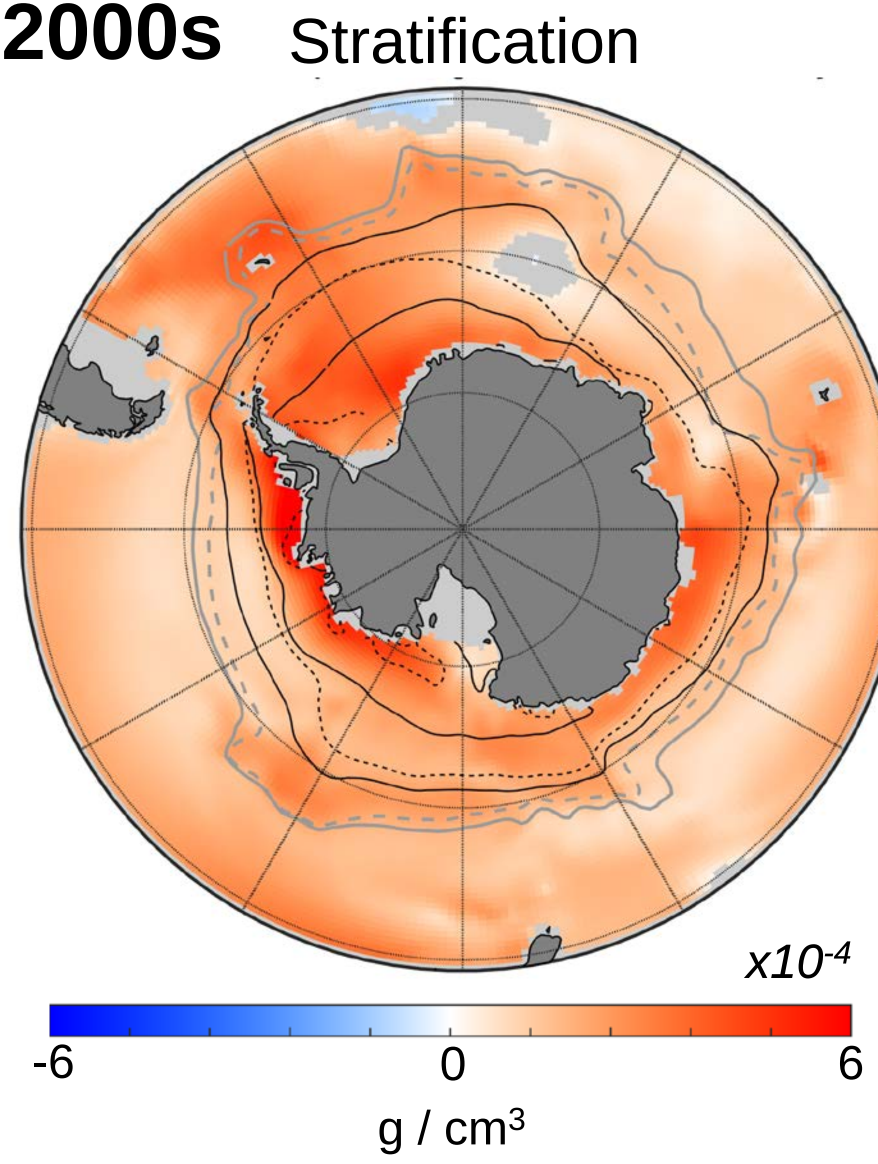
Warming and increased stratification

2090s-2000s





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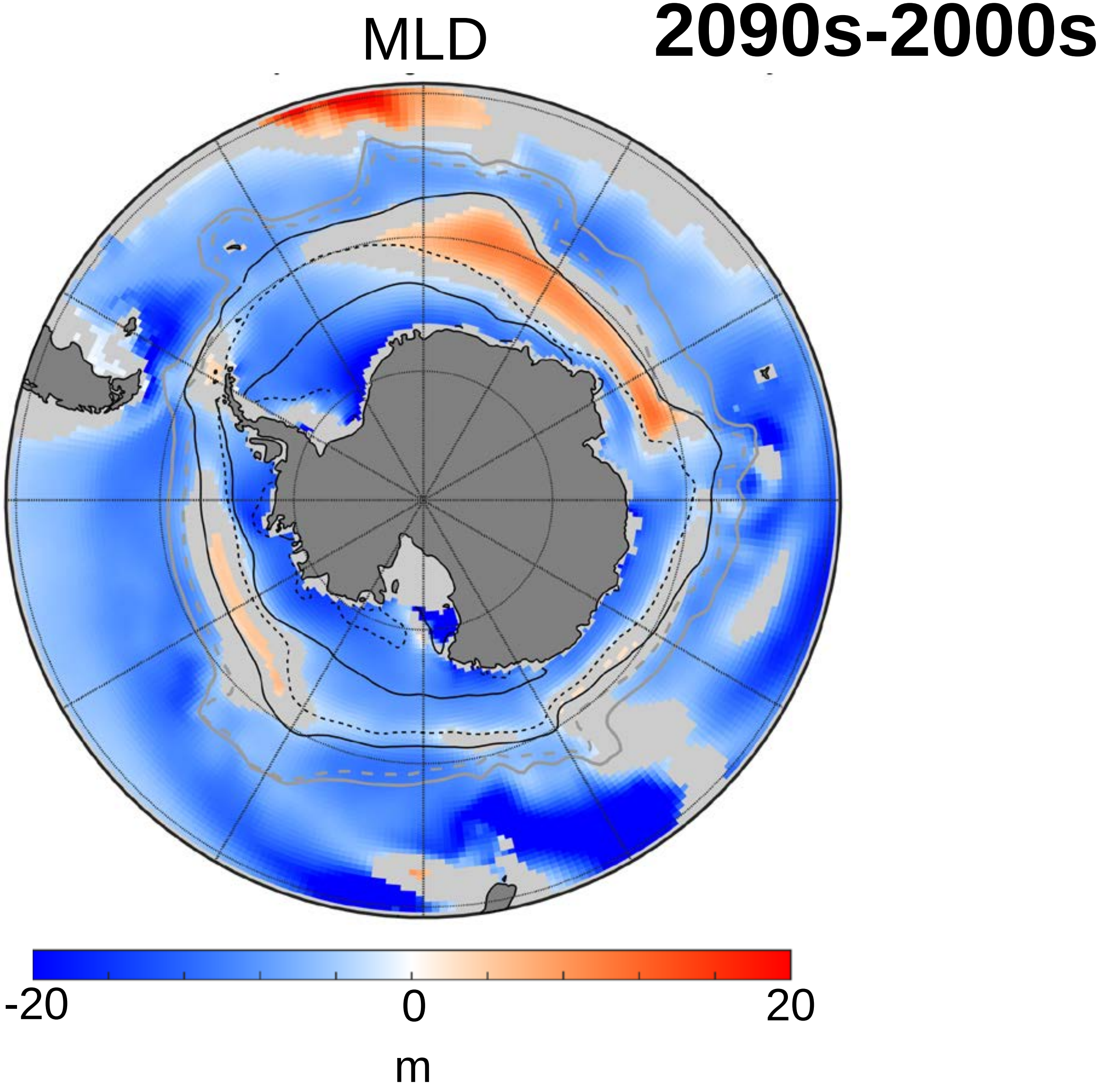
Shallower MLDs



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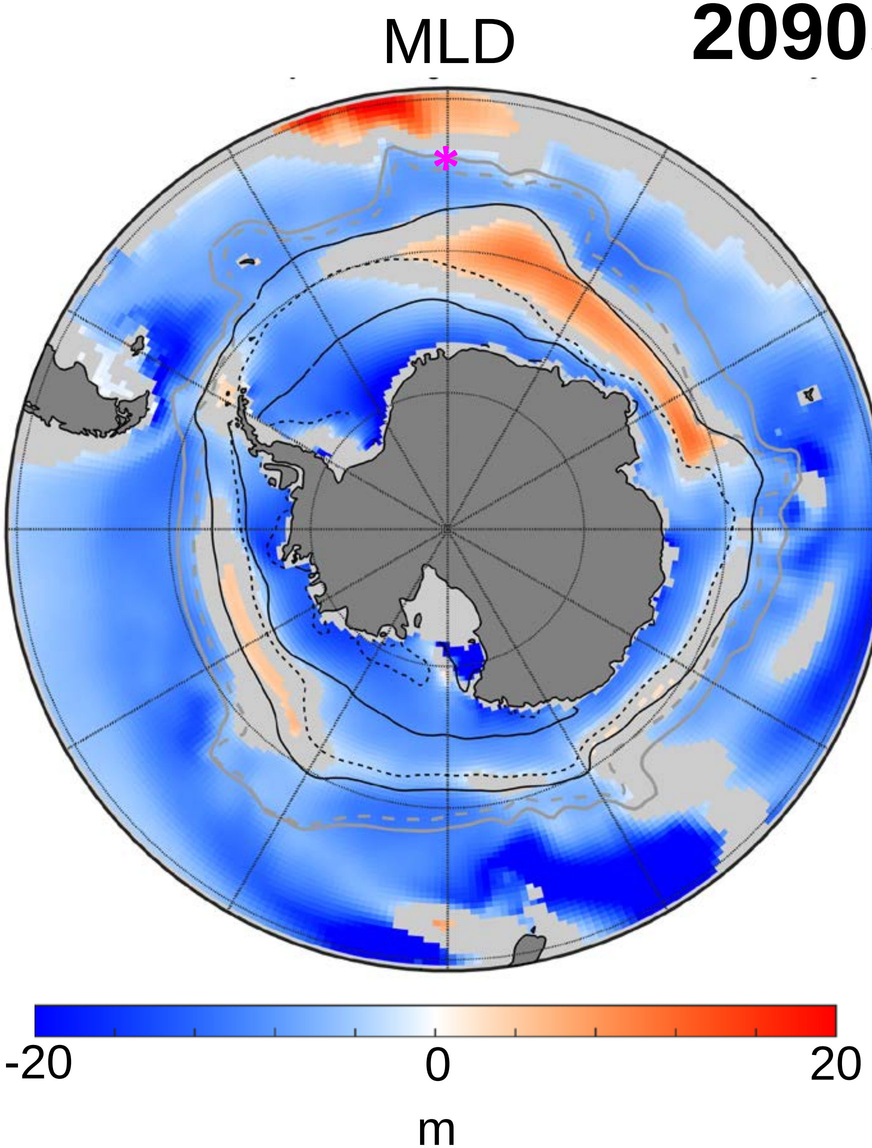
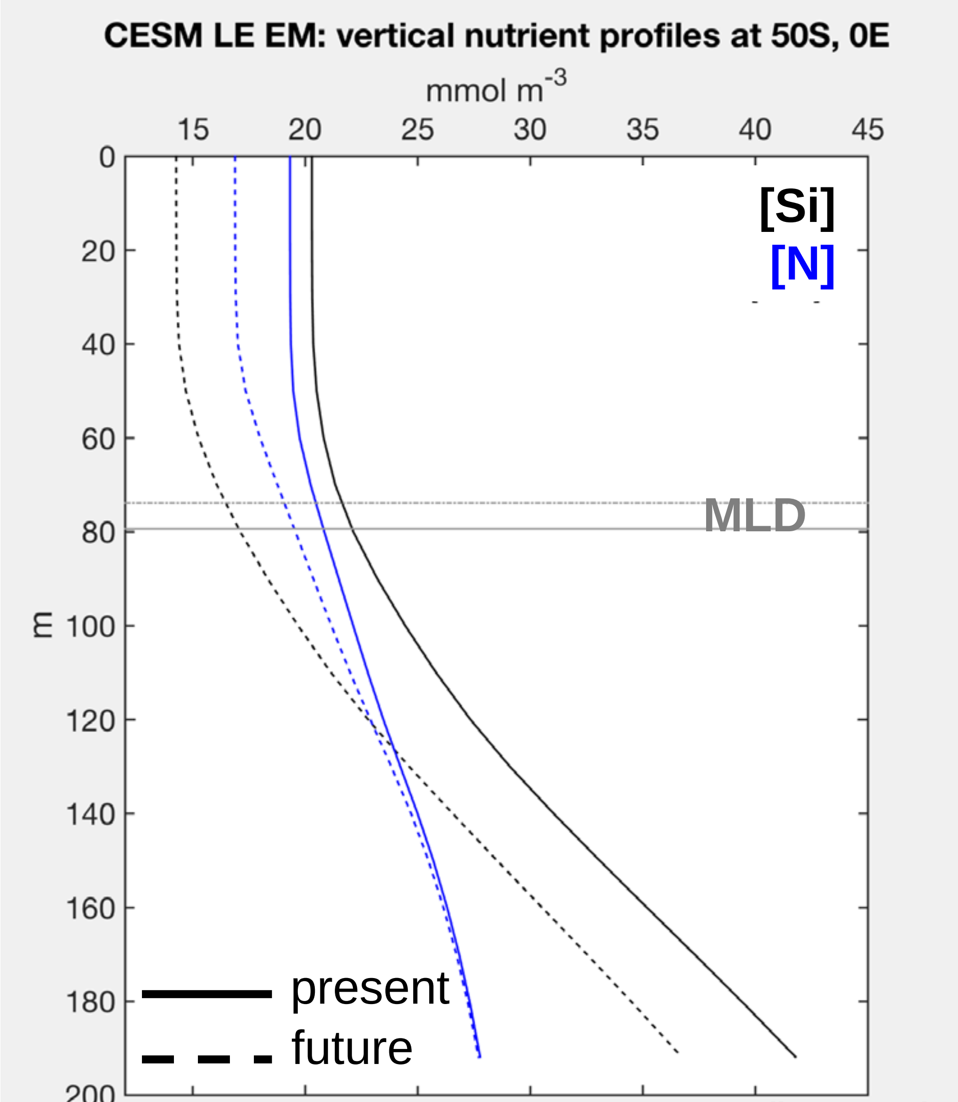
Si vs. N at depth

2090s-2000s

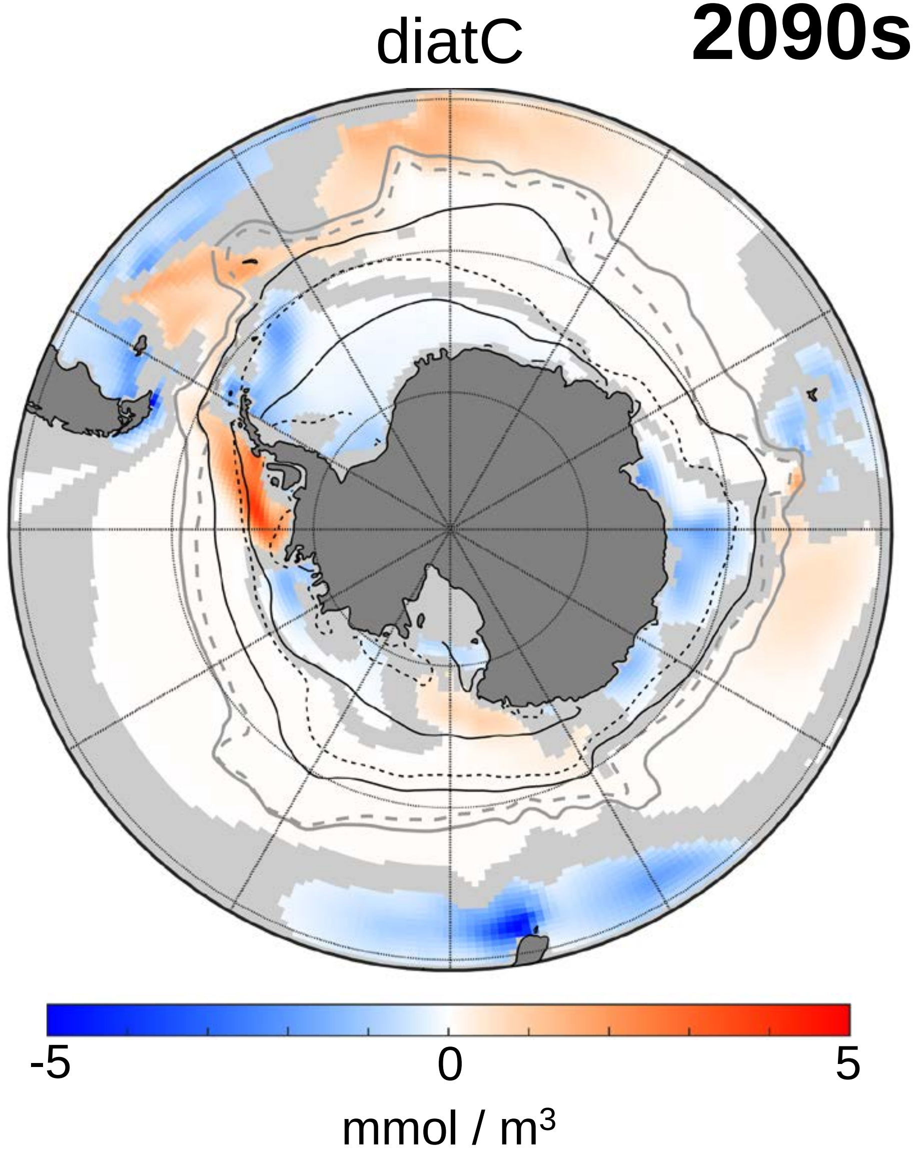




Freeman et al. (in prep)

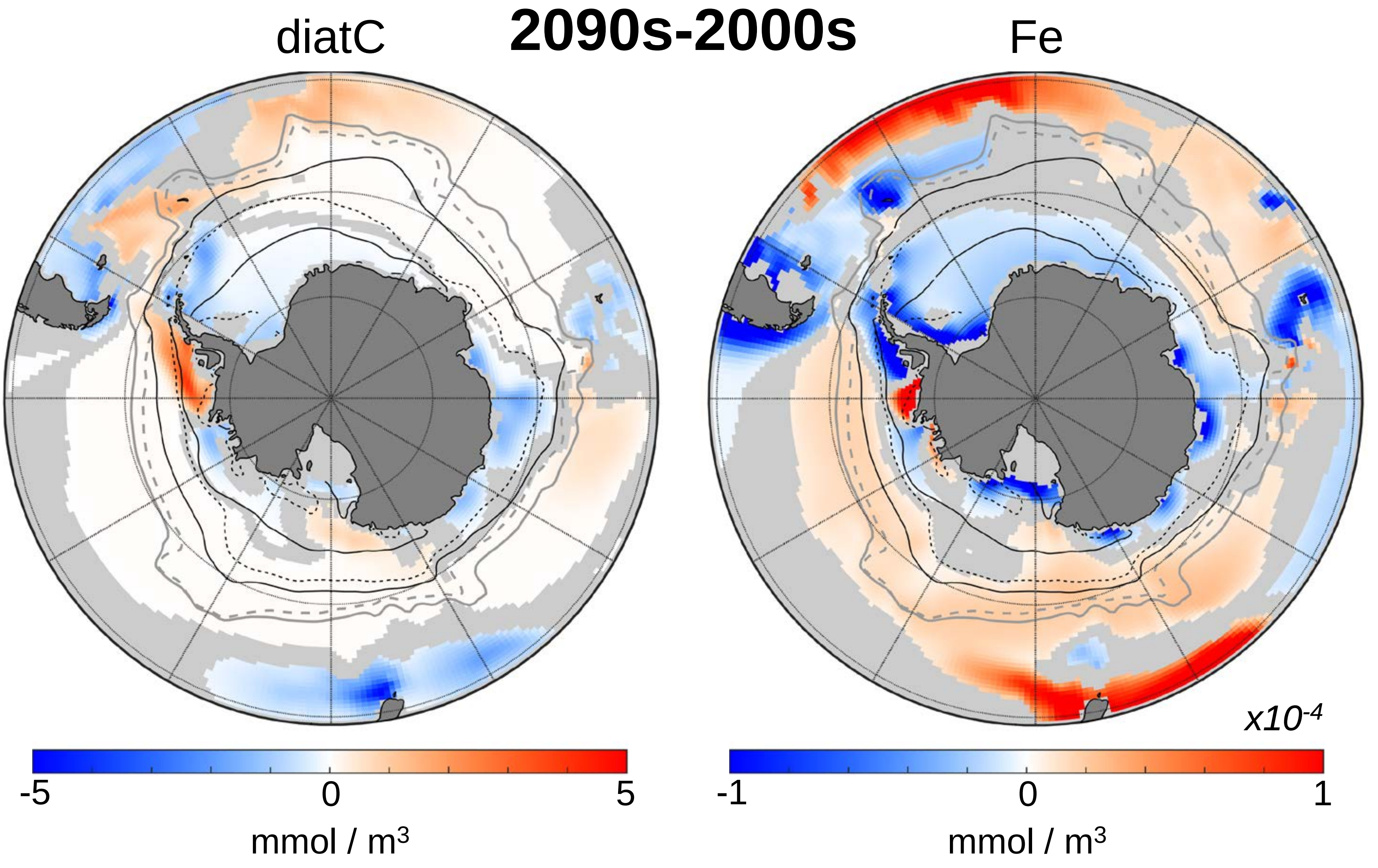
Long-term changes in biomass

2090s-2000s



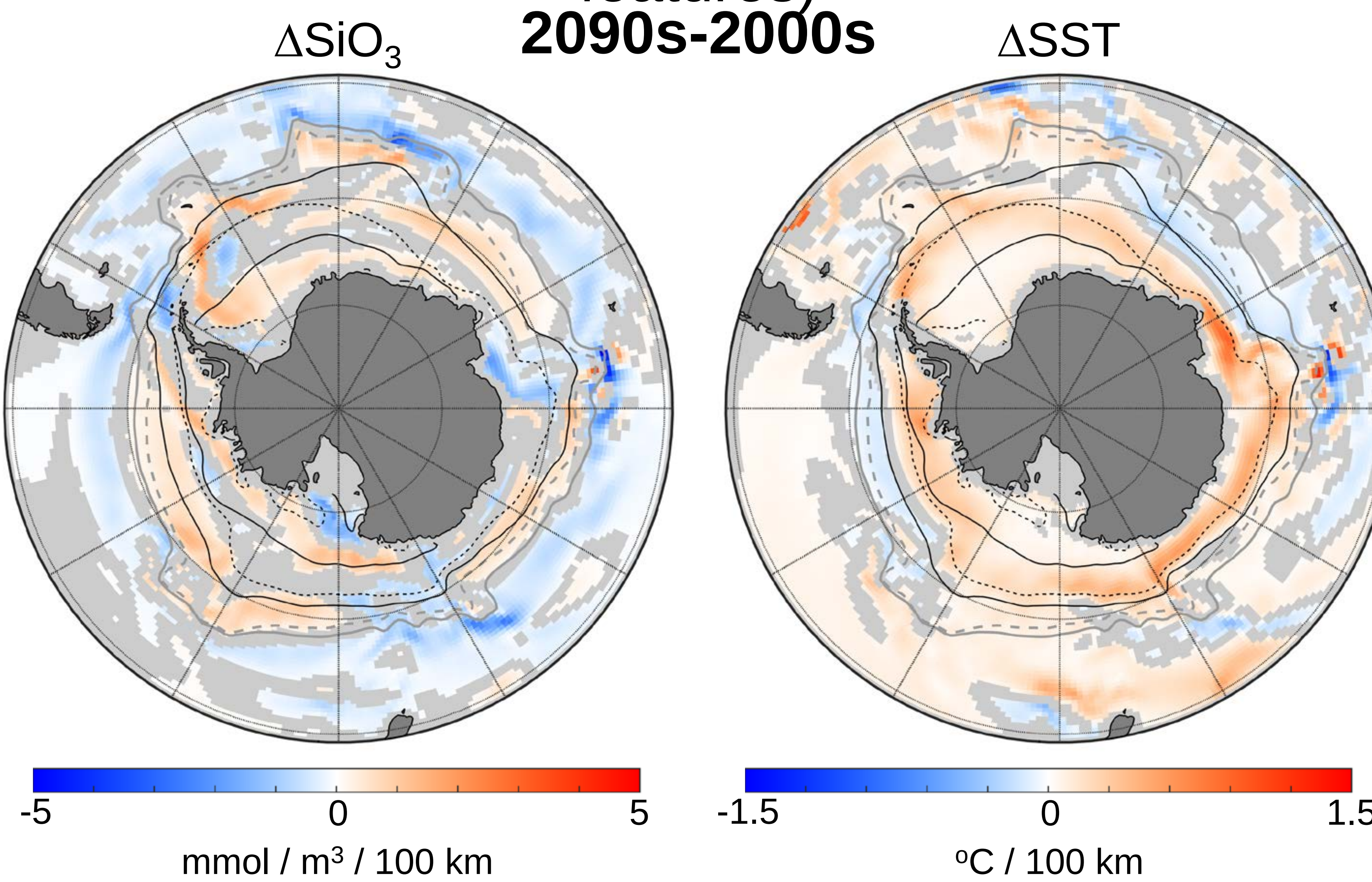
Freeman et al. (in prep)

Changes in biomass driven by Fe increase?



Freeman et al. (in prep)

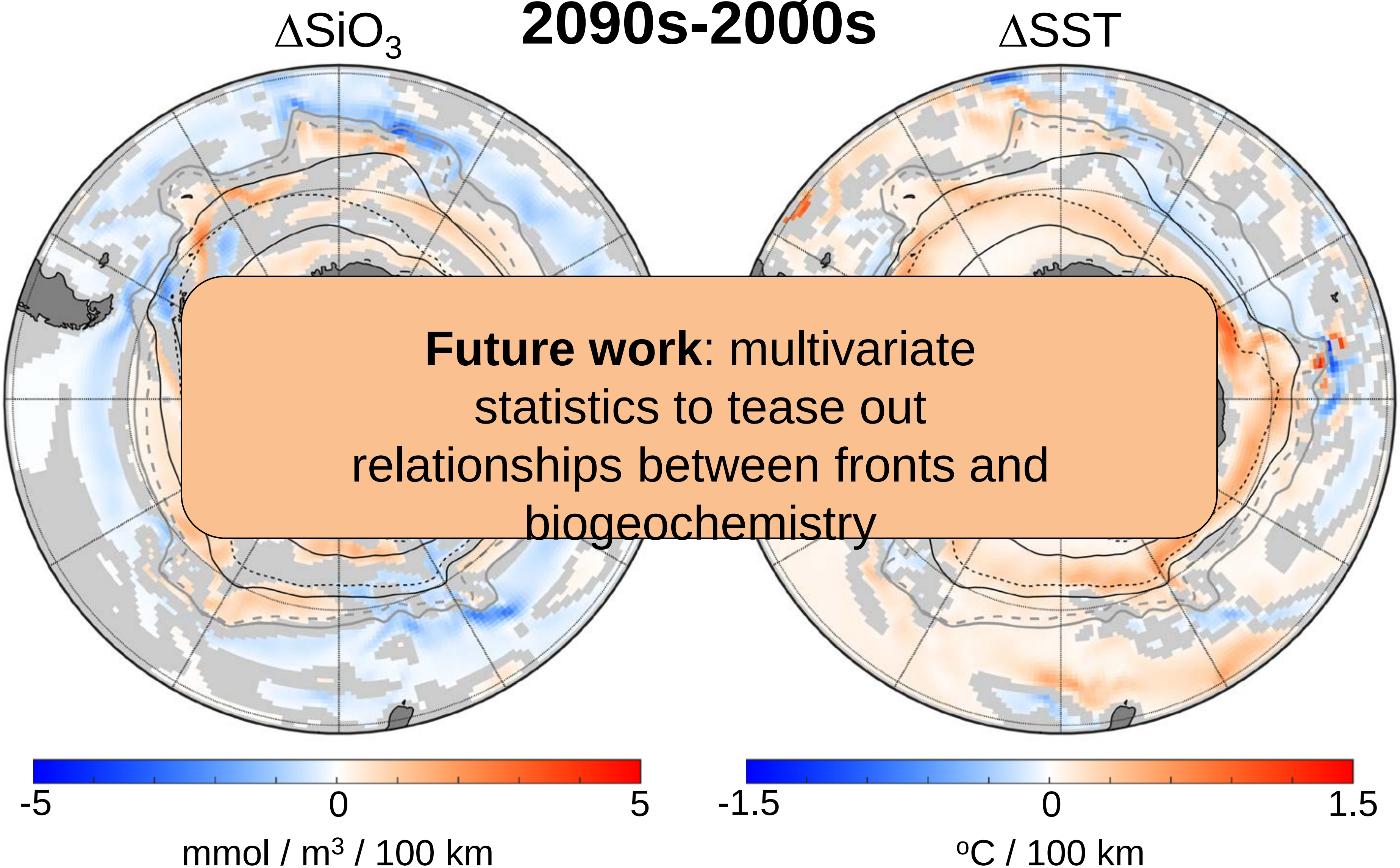
Long-term changes in ΔSiO3, ΔSST (i.e., frontal features)



Freeman et al. (in prep)

Long-term changes in ΔSiO3, ΔSST (i.e., frontal features)

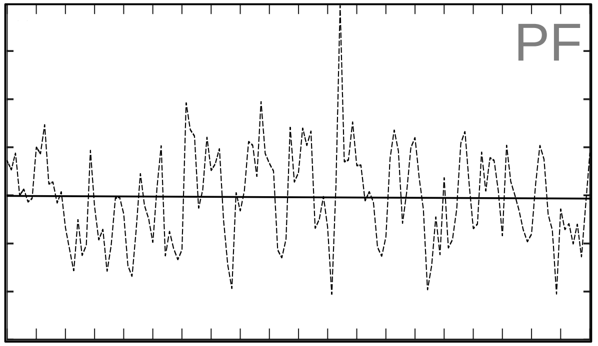
2090s-2000s



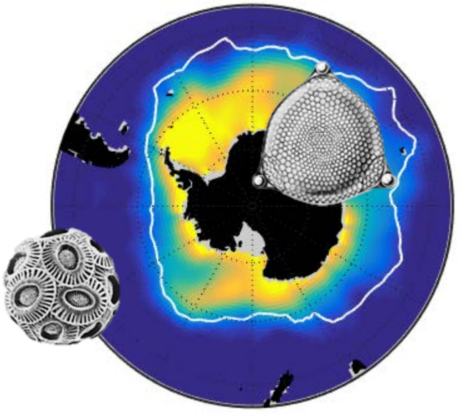
Future work: multivariate statistics to tease out relationships between fronts and biogeochemistry

Freeman et al. (in prep)

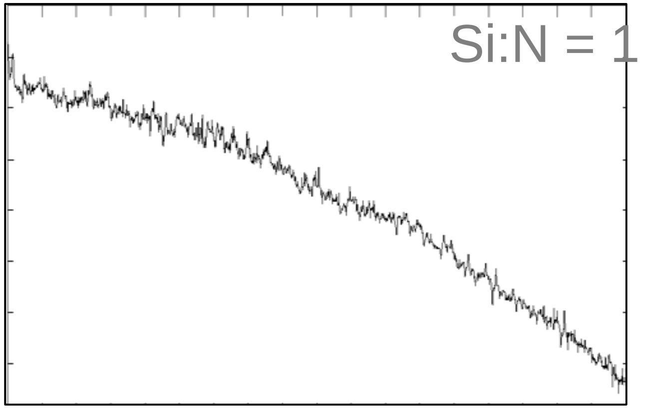
Conclusions



Observed frontal variability results depend on methods



Motivated by the observed biogeochemical significance of the PF



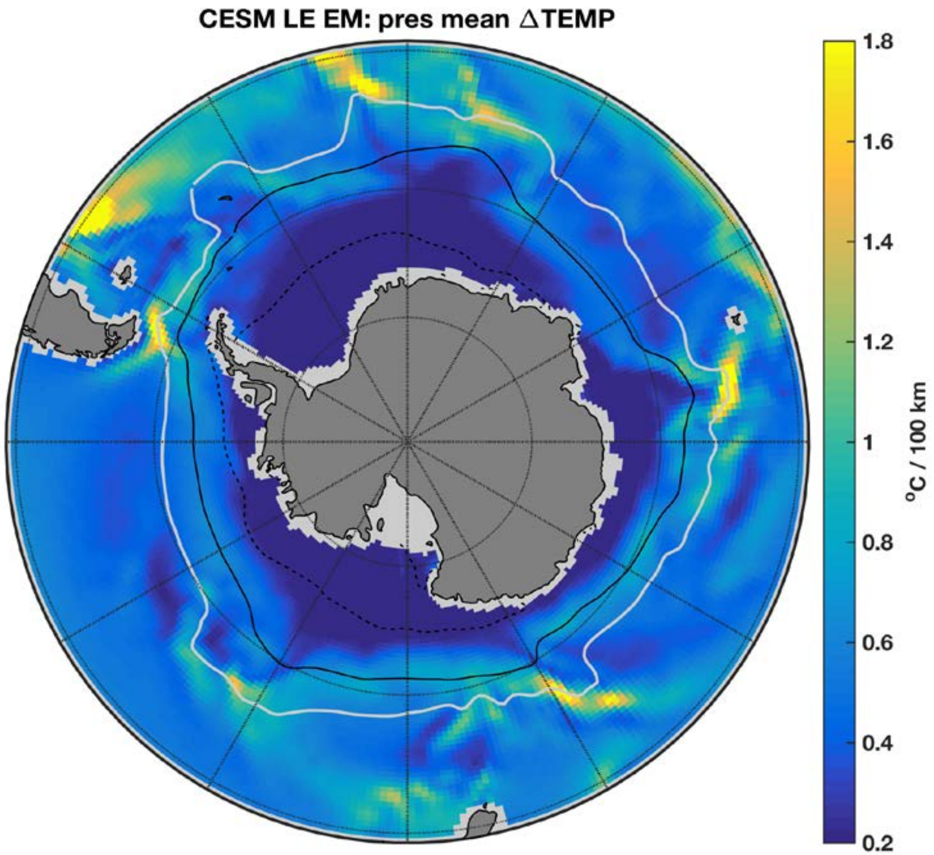
CESM LE suggests a poleward contraction of the "SF"

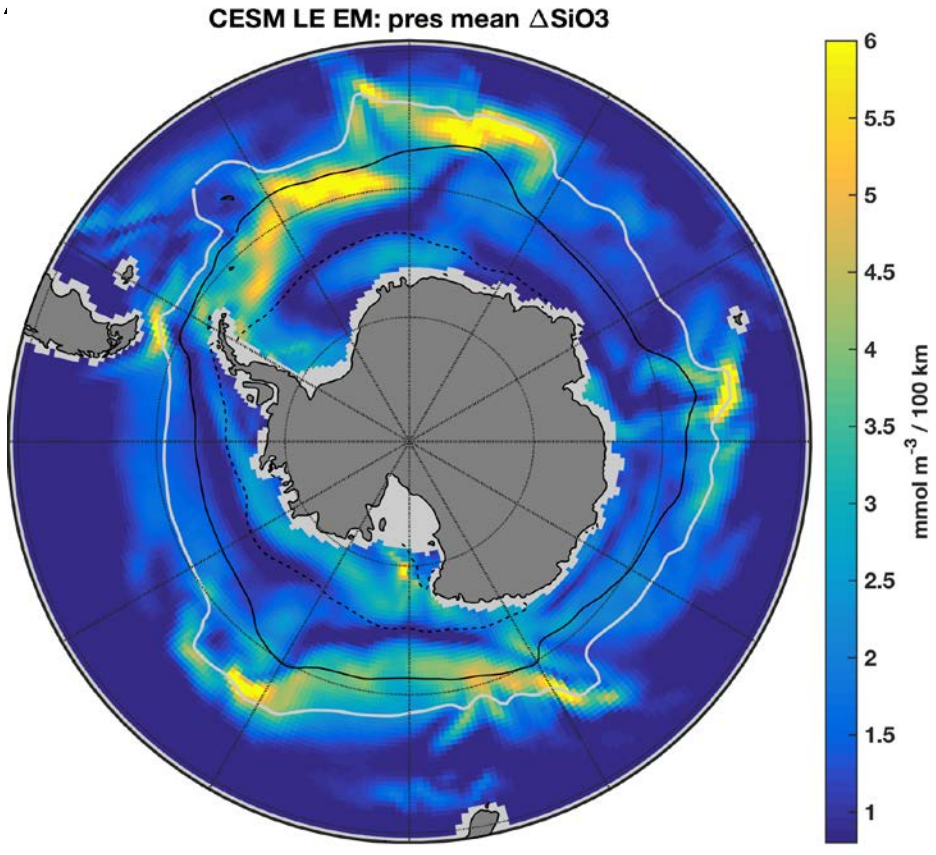
Thanks for your attention.

Questions? Feedback?

Contact me at natalie.freeman@colorado.edu

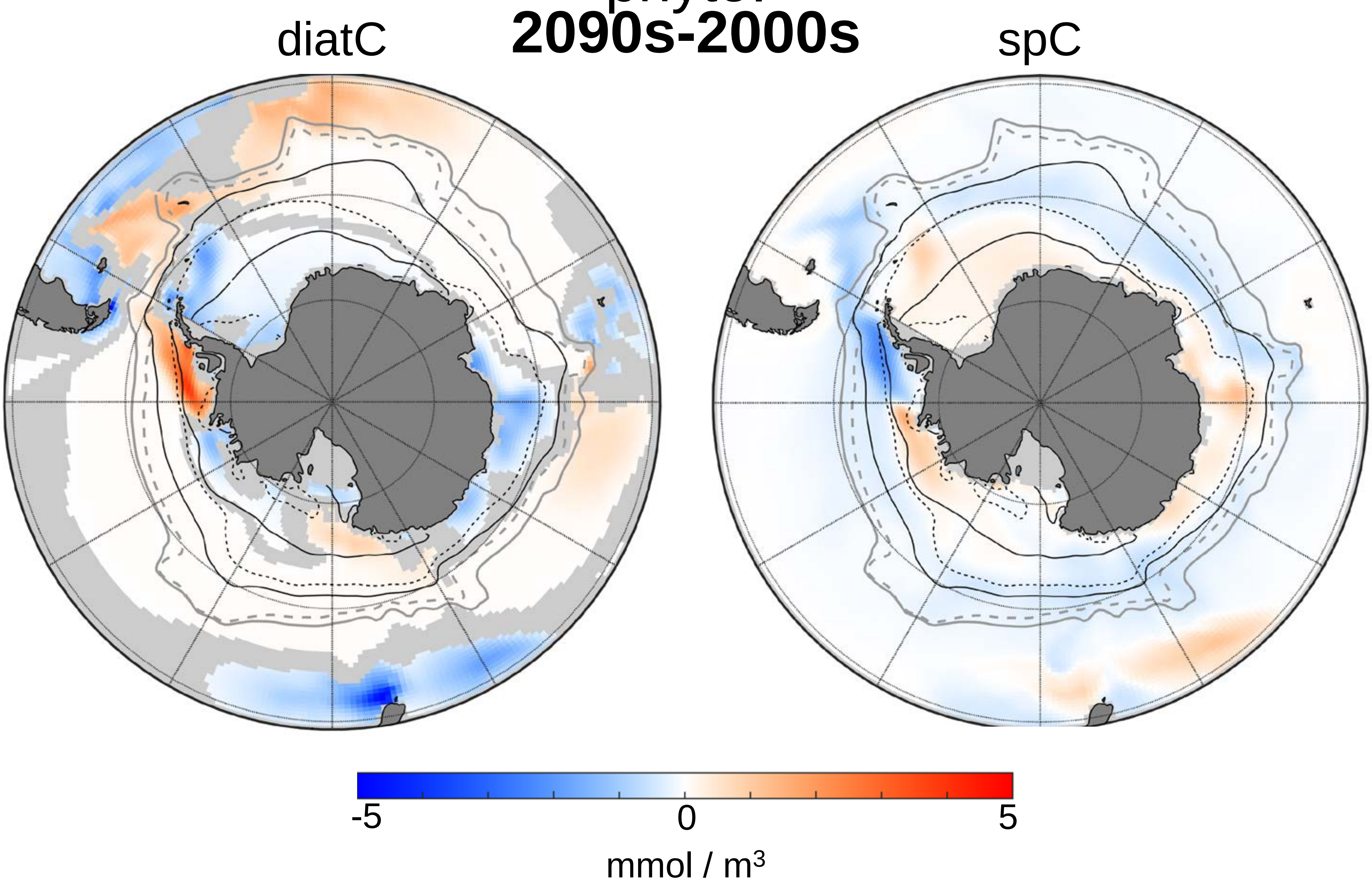
Exploring BGC fronts in CESM LE





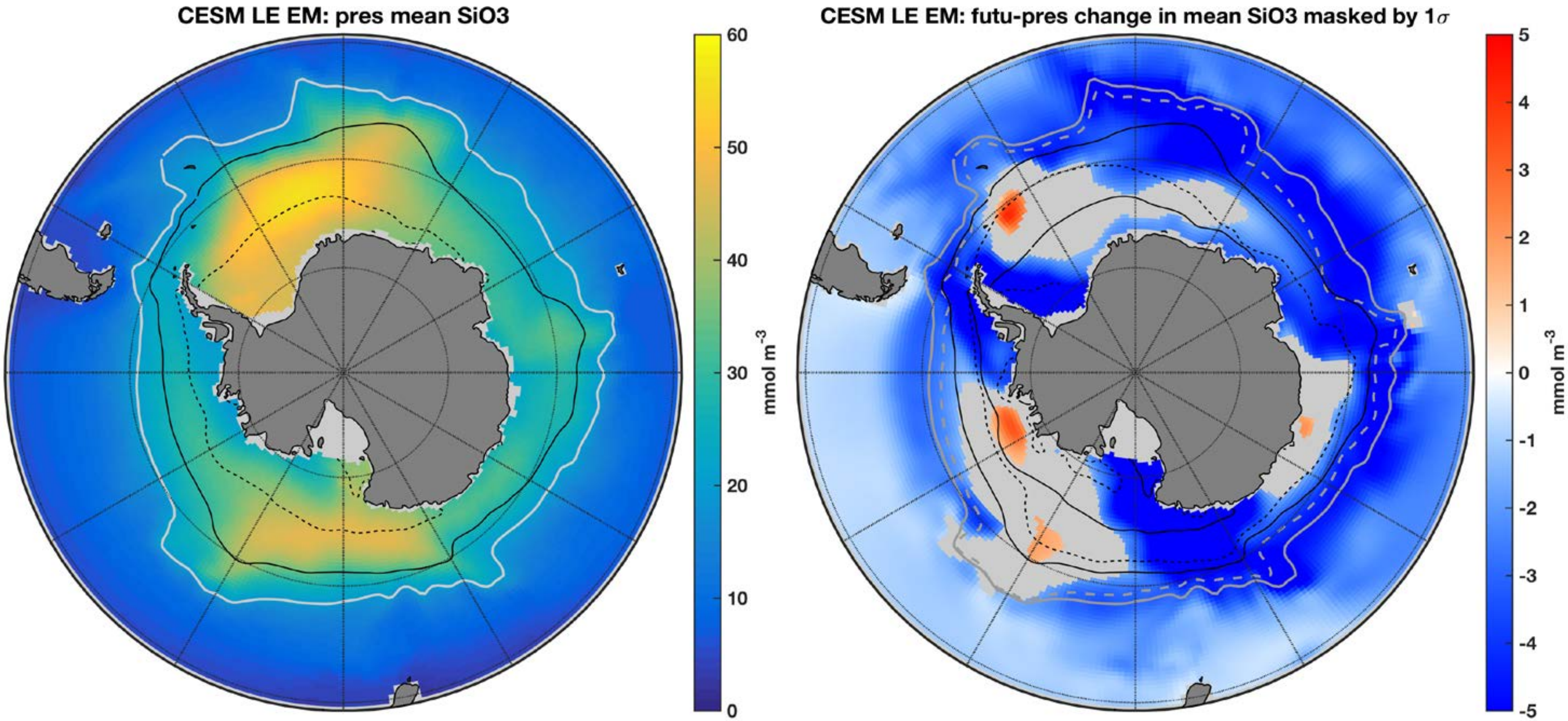
Freeman et al. (in prep)

Long-term change in biomass: diatoms vs. small phyto.



Freeman et al. (in prep)

SF seasonal cycle



Silica cycle

Surface waters receive considerable amounts of silicic acid from the rest of the world ocean through the upwelling of the CDW, fed by contributions of deep waters of the Atlantic, Indian, and Pacific Oceans.

The SO exports a considerable flux of the silicic acid that is not used by diatoms in surface waters through the northward pathways of the SAMW, AAIW, and ABW.

**The question of the steady state of the Si cycle in the modern ocean remains an open question.

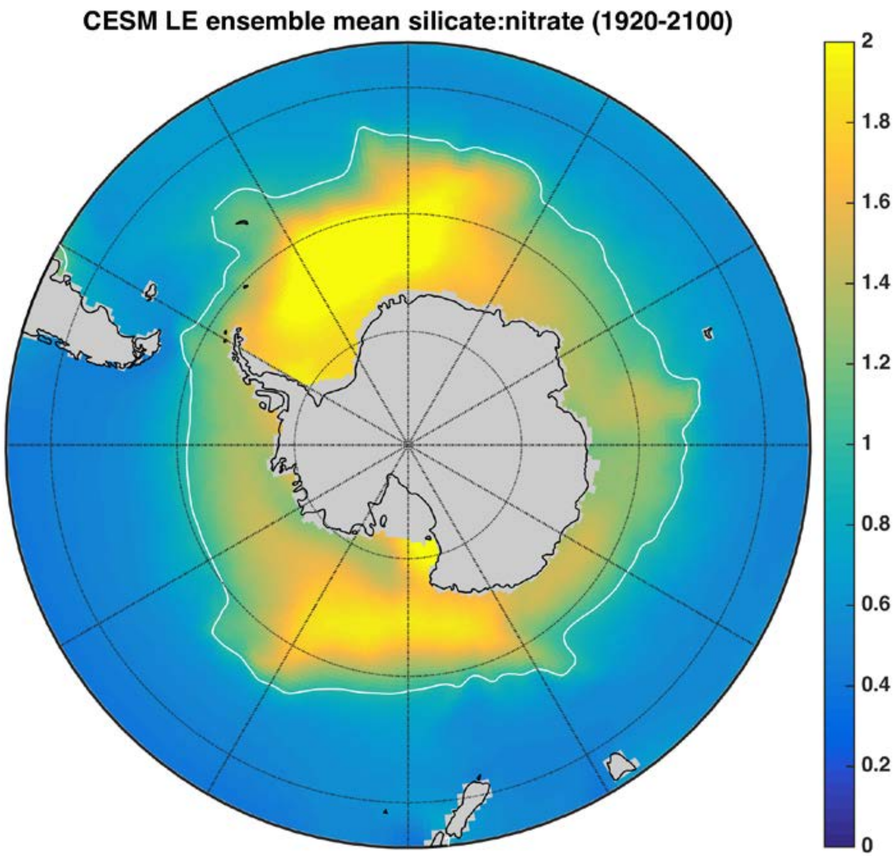
Location Relative to Polar Front

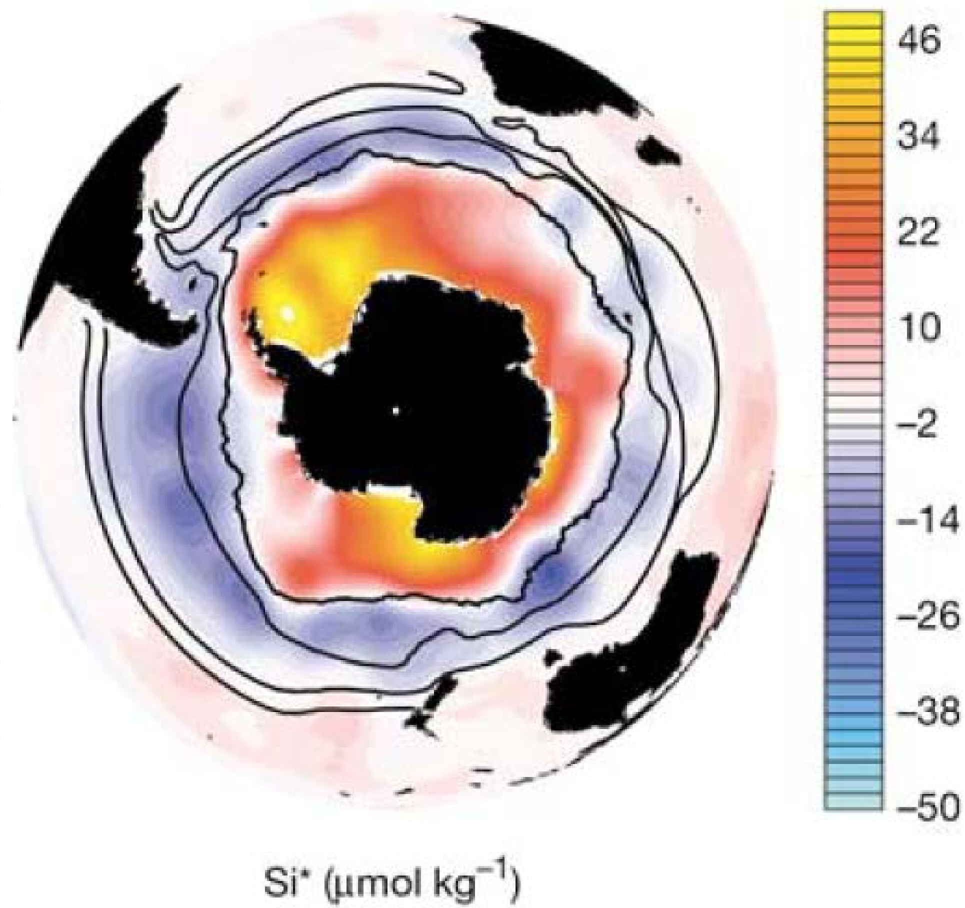
Iron Availability	South	North	
High	Big, well-silicified diatoms outcompete nano-, pico-phytopl., coccos. and dinos; Low Calcification; CO_2 drawdown (NCP>NCC); High export flux; Low transfer eff.;(e.g. South of Polar Front near islands)	Coccos outcompete diatoms, nano-, pico-phytopl., dinos ; High calcification; CO_2 source (NCC>NCP); Moderate export flux; High transfer eff. (e.g. Patagonian Shelf; SAF [Indian sector], south of ARC, near islands)	**Strong shear; enhanced Ekman pumping**
Low	Small diatoms (e.g. *Fragillariopsis sp.*); few coccos; nano-, pico-phytopl., dinos coexist and covary; No net impact on pCO_2 (moderate NCP:NCC); Moderate export flux; Low-to-moderate transfer eff.; (e.g. south of Polar front, Indian sector, away from islands)	Coccos, dinos, nano-, pico-phytopl.coexist and covary; Low to moderate calcification; Neutral to slight pCO_2 source (NCC=>NCP); Moderate export flux; Moderate transfer eff.; (e.g. north of ARC and STF, Atlantic and Indian sectors, away from islands)	**Low shear; reduced Ekman pumping**
	Negative	**Zero to Positive**	

RNPG (μ_N-μ_{Si}; d^{-1})

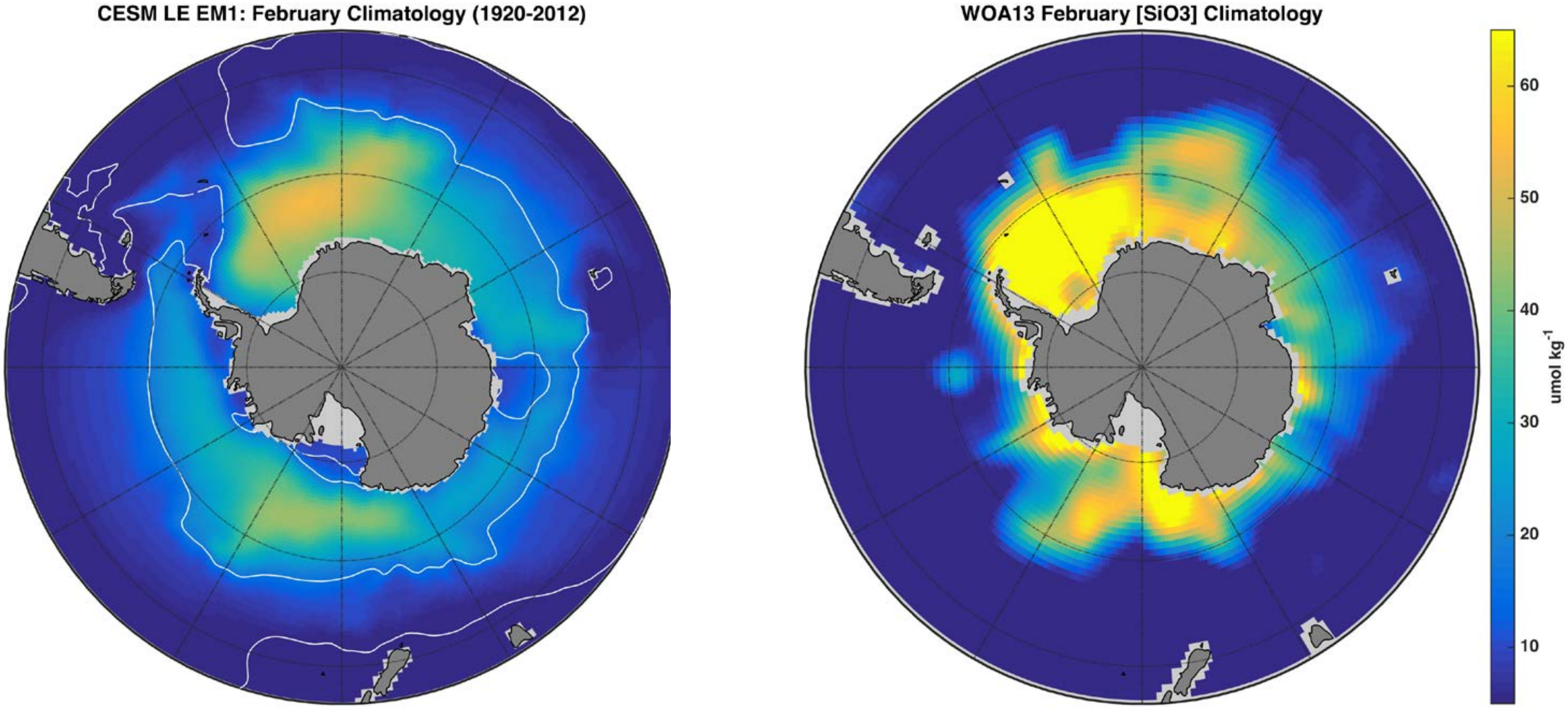
Figure 11. Conceptual model for balance of coccolithophores and noncalcifying phytoplankton growth in GCB versus diatom growth (determined as RNPG) and effects on CO_2 source/sink dynamics and sinking particle fluxes. Abbreviations used in table: coccos = coccolithophores; dinos = dinoflagellates; nanophytopl. = nanophytoplankton; picophytopl. = picophytoplankton; eff. = efficiency; ARC = Agulhas Return Current.

(Si:N = 1) ~ (Si*)

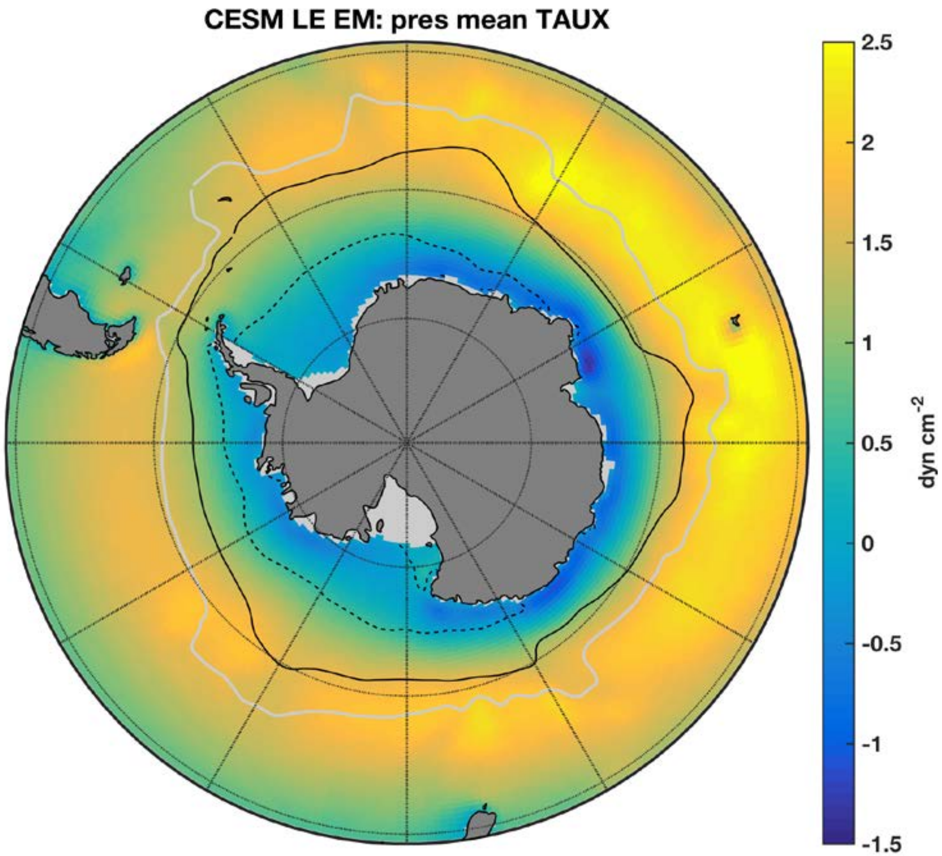

CESM LE ensemble mean silicate:nitrate (1920-2100)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

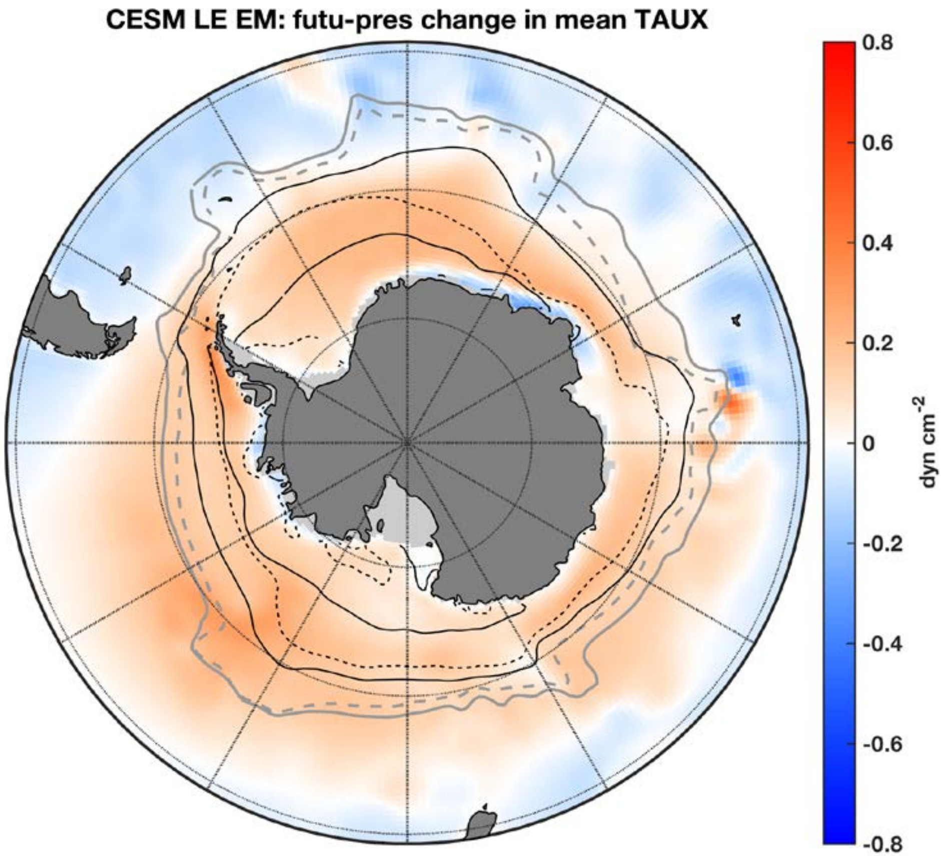

46
34
22
10
−2
−14
−26
−38
−50
Si* (µmol kg^{-1})

CESM LE vs. WOA13



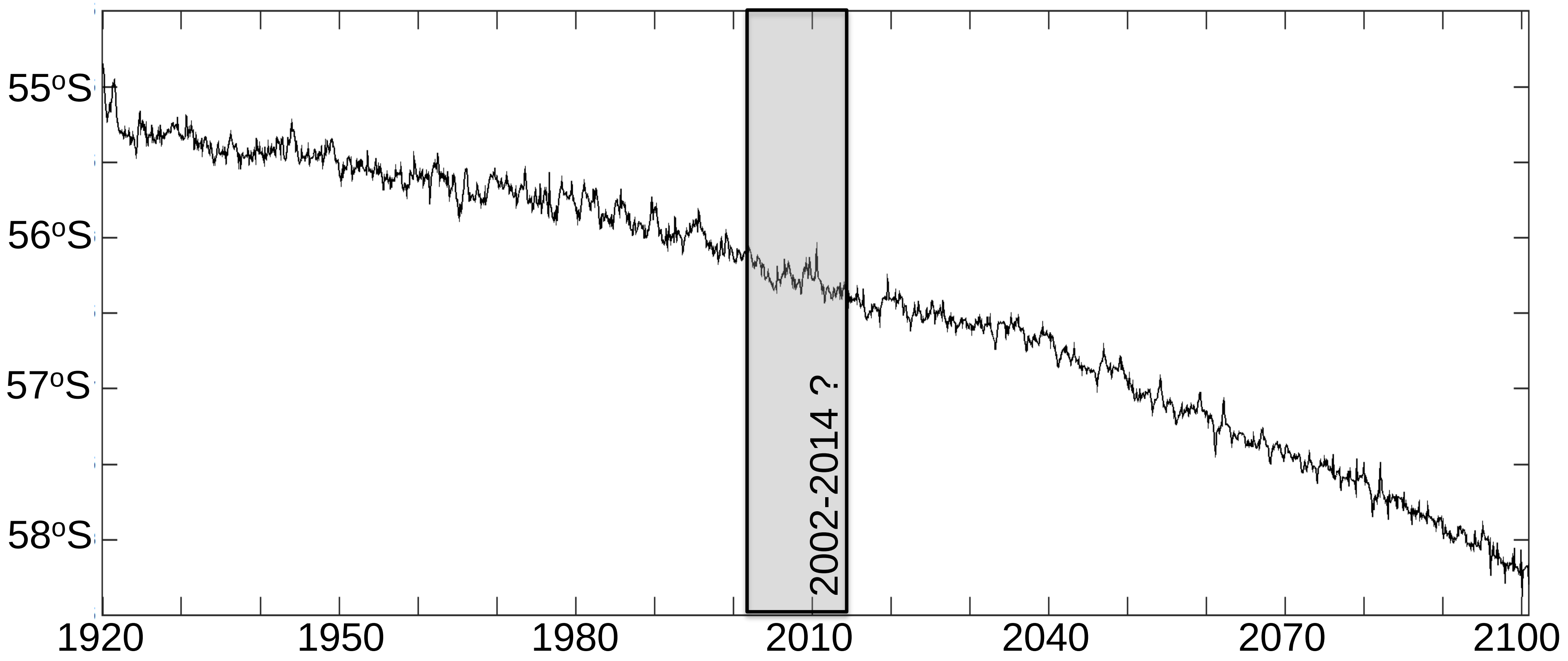
τ_x: present-day mean and long-term change





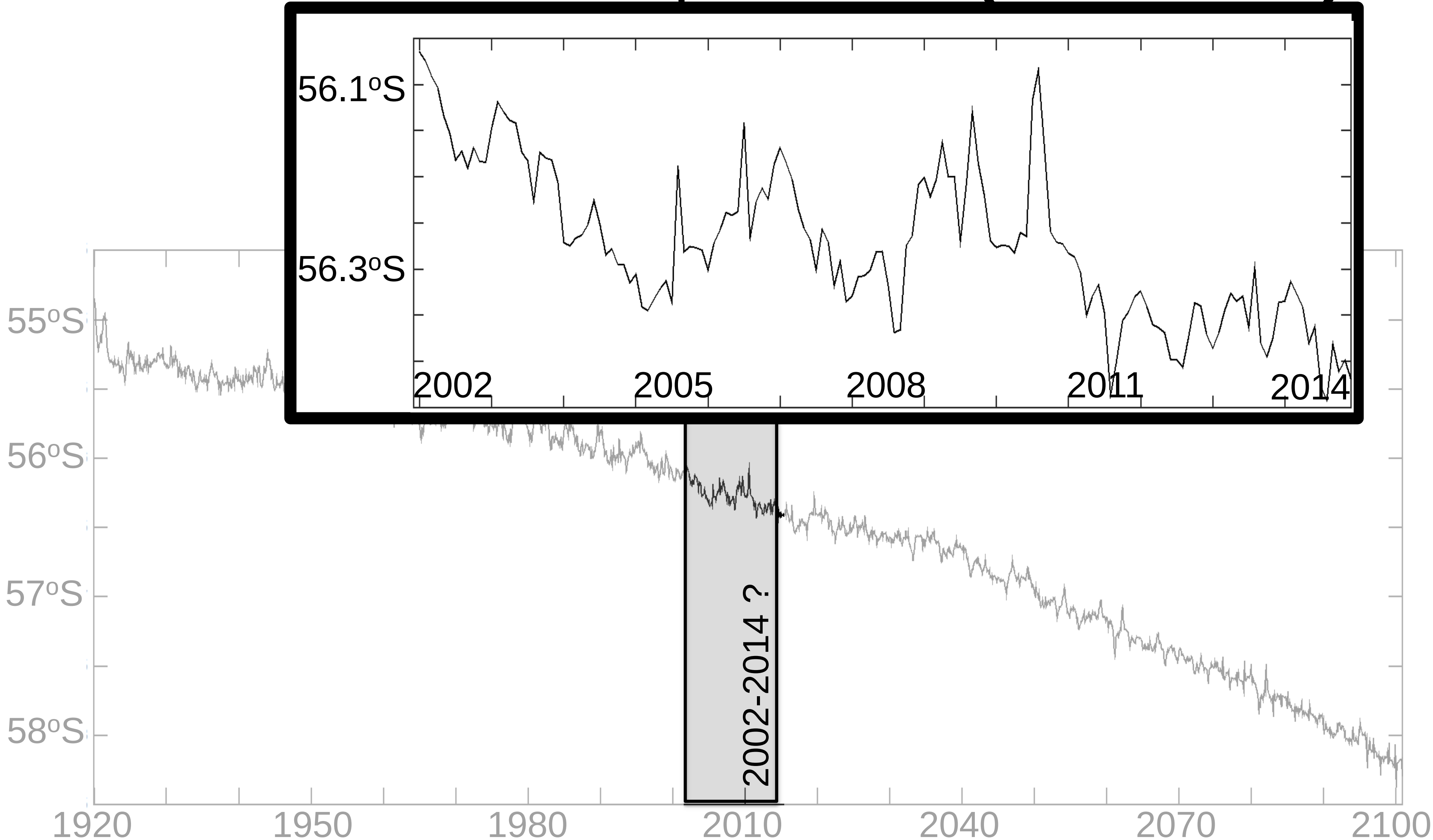
Freeman et al. (in prep)

Silicate Front shifts poleward **(1920-2100)**



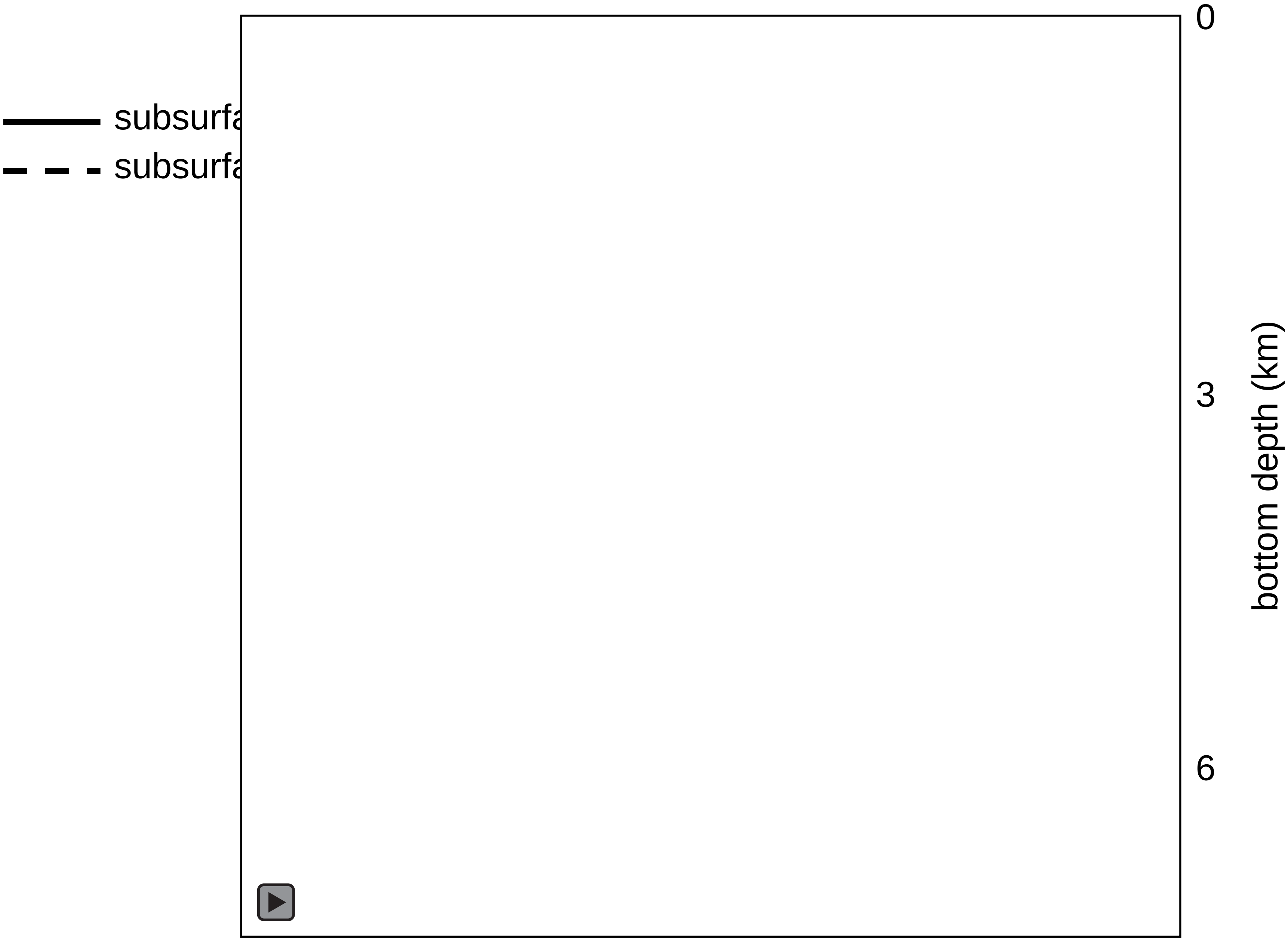
Freeman et al. (in prep)

Silicate Front shifts poleward **(2002-2014)**



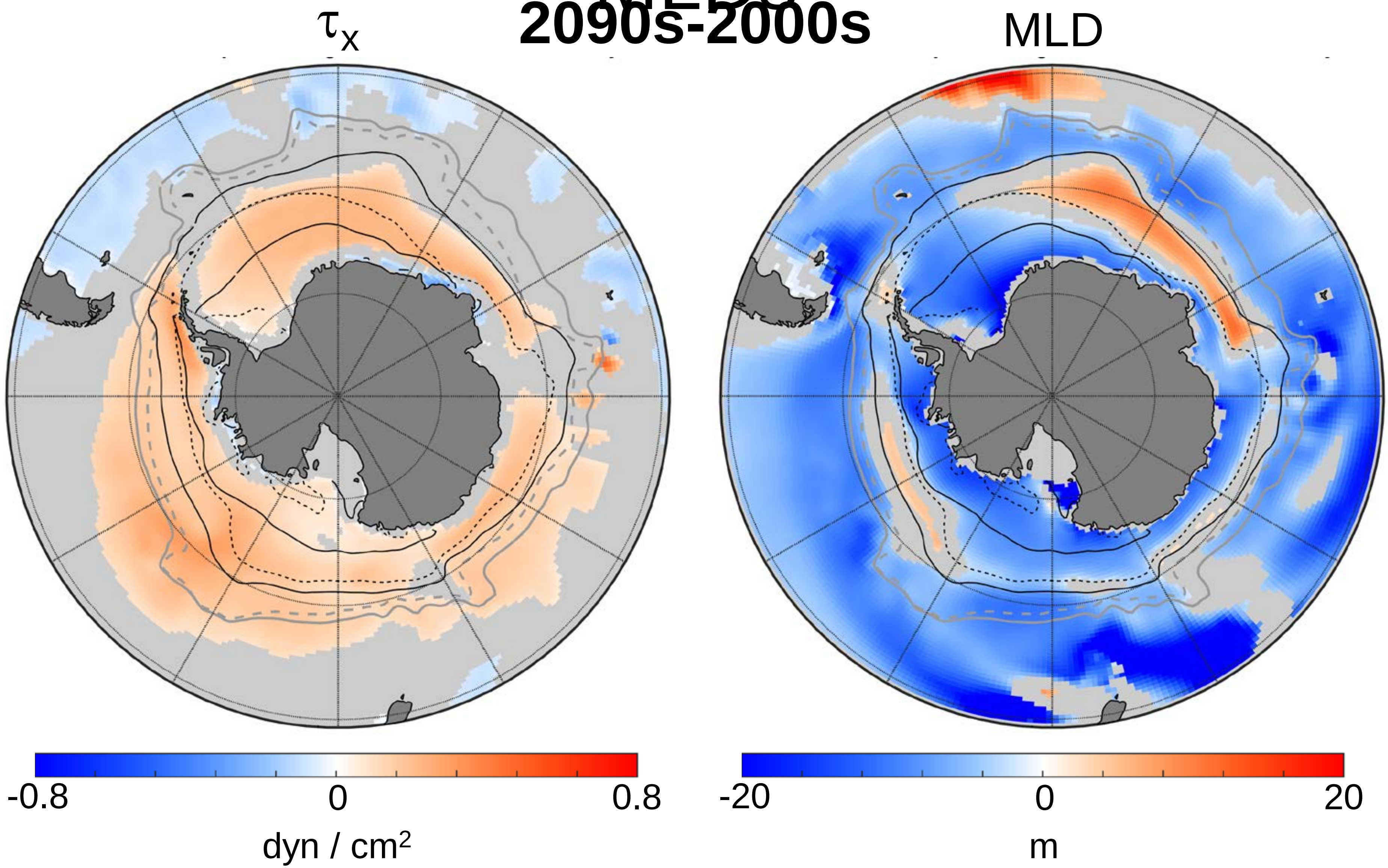
Freeman et al. (in prep)

CESM LE: PF vs. SF at 200 m



Increased wind stress and shallower MLDs

2090s-2000s



Freeman et al. (in prep)

NPP
changes in marine NPP can thus result only from
(i) changes in the phytoplankton growth rate and
(ii) changes in phytoplankton biomass