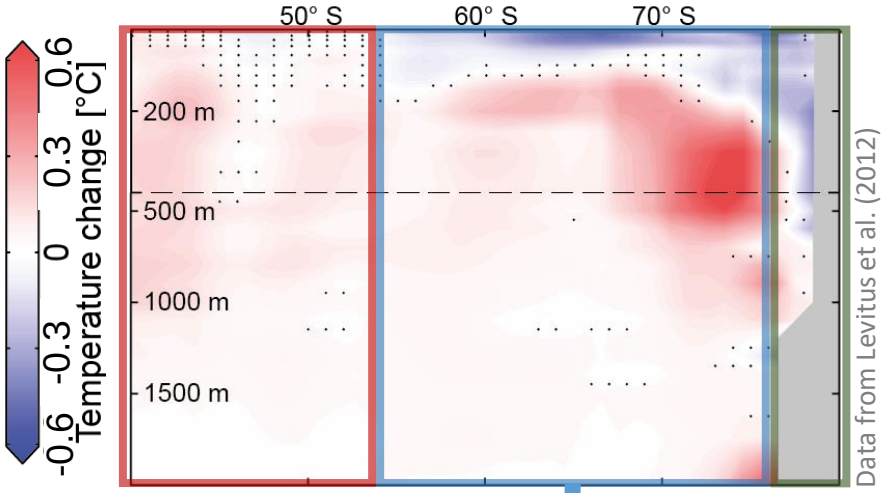
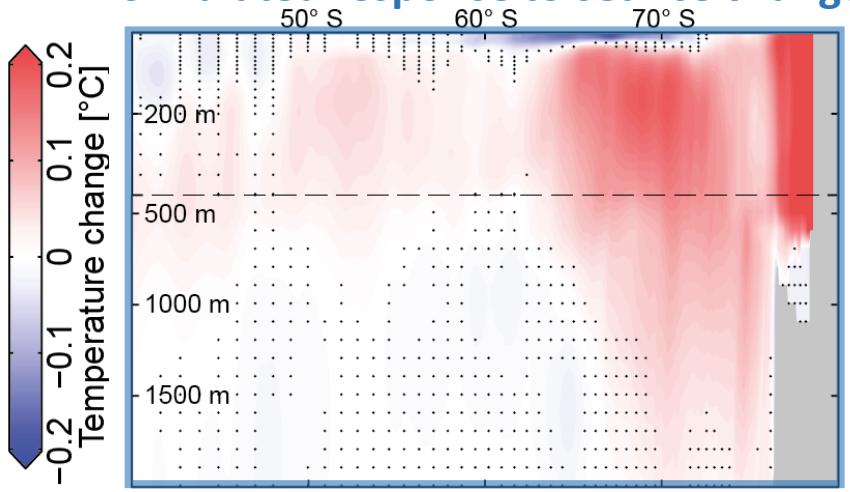
Summary

Why has the high-latitude Southern Ocean been cooling at the surface and warming at the subsurface between 1982 and 2011?

Observed changes 1982-2011:



Simulated response to sea-ice changes:



Factorial model experiments show:

→ **Sea-ice** freshwater flux changes due to enhanced northward transport caused **surface cooling and freshening** and **subsurface warming** south of the Subantarctic Front

→ **Glacial meltwater** changes are confined to the **coastal** ocean

→ **Ocean circulation** (Ekman transport) induced changes in temperature and salinity are opposite to observed changes in high latitudes, but might contribute north of the Subantarctic Front

Implications:

→ Sea-ice related **strengthened surface stratification** in high latitudes led to a **subsurface warming** around West Antarctica, potentially affecting **ice-shelf melt**

→ This subsurface warming contributed to the **slowdown of global warming** by increasing the **global ocean heat content (8%)** over this period

F. Alexander Haumann (alexander.haumann@gmail.com), Nicolas Gruber & Matthias Münnich

Overview (click to reach section)

Summary

Introduction

Methods

Conclusions

Results:

- ❑ Surface salinity changes
- ❑ Surface temperature changes
- ❑ Stratification & mixing changes
- ❑ Zonal mean vertical cross-sections
- ❑ Subsurface heat content changes

Haumann, F. A., Gruber, N., & Münnich, M. (2020): **Sea-ice induced Southern Ocean subsurface warming and surface cooling in a warming climate**. *AGU Advances*, 1, e2019AV000132. https://doi.org/10.1029/2019AV000132 (available May 6, 2020)

Sea-ice Induced Southern Ocean Subsurface Warming and Surface Cooling in a Warming Climate

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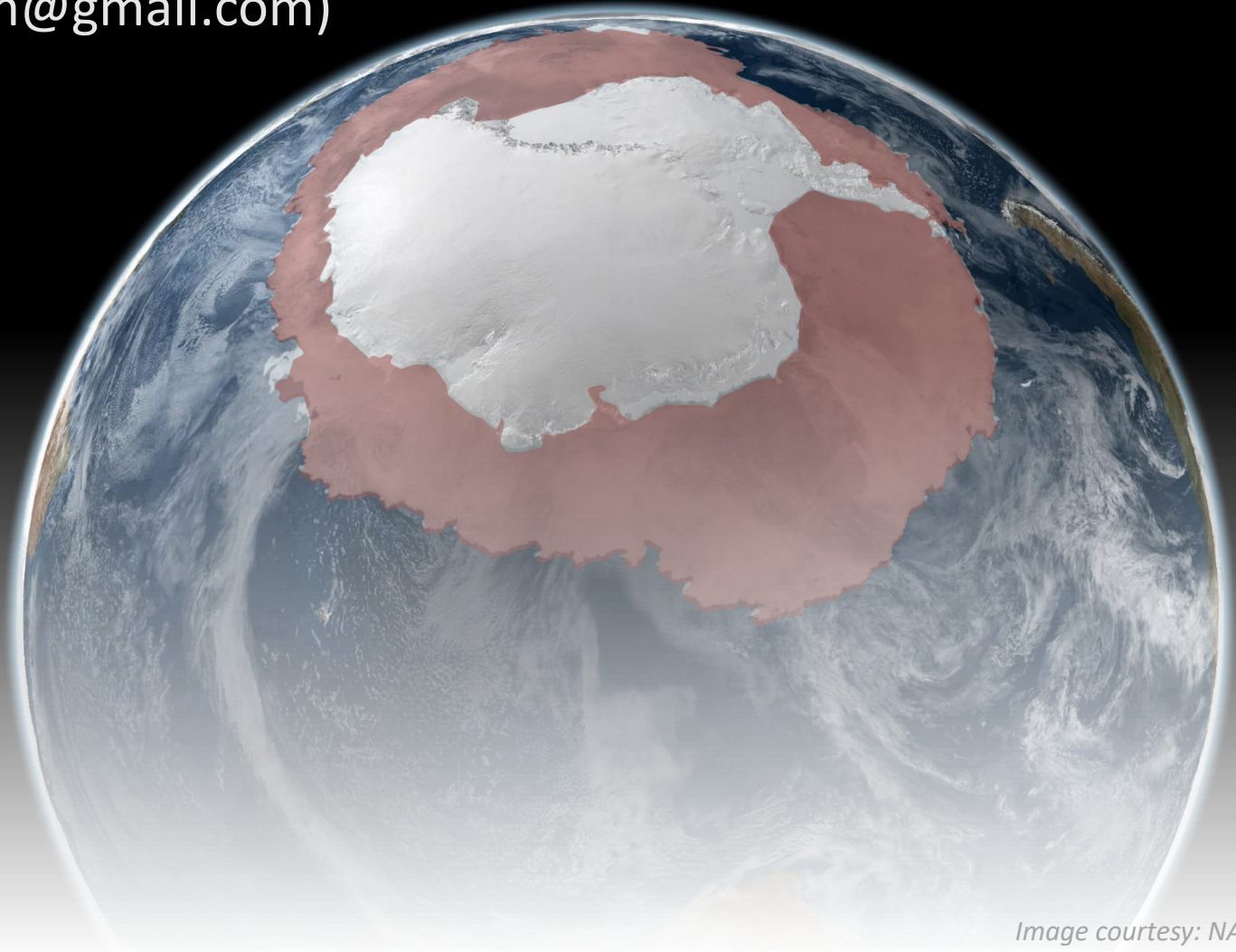
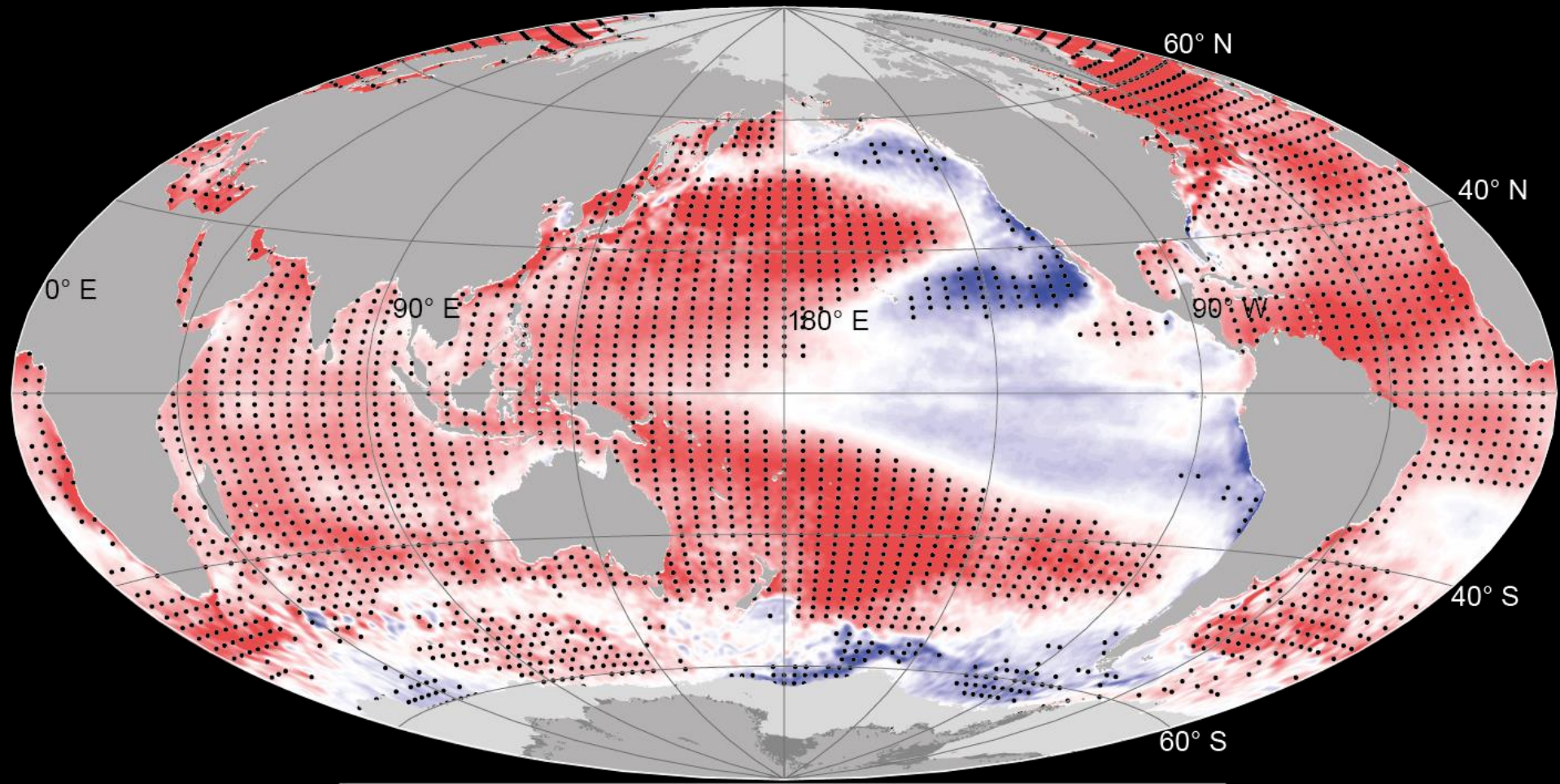
Nicolas Gruber & Matthias Münnich
ETH Zurich



Related publication:
Haumann, F. A., Gruber, N., & Münnich, M. (2020): **Sea-ice induced Southern Ocean subsurface warming and surface cooling in a warming climate**. *AGU Advances*, 1, e2019AV000132. https://doi.org/10.1029/2019AV000132 (available May 6, 2020)

Image courtesy: NASA

Motivation:
Multi-decadal Southern Ocean high-latitude surface cooling despite global surface ocean warming



data from AVHRR, Reynolds et al. (2007)

Recent Southern Ocean hydrographic changes (1982–2011)

- Surface cooler & fresher
- Subsurface saltier & warmer
- AAIW/SAMW fresher & warmer

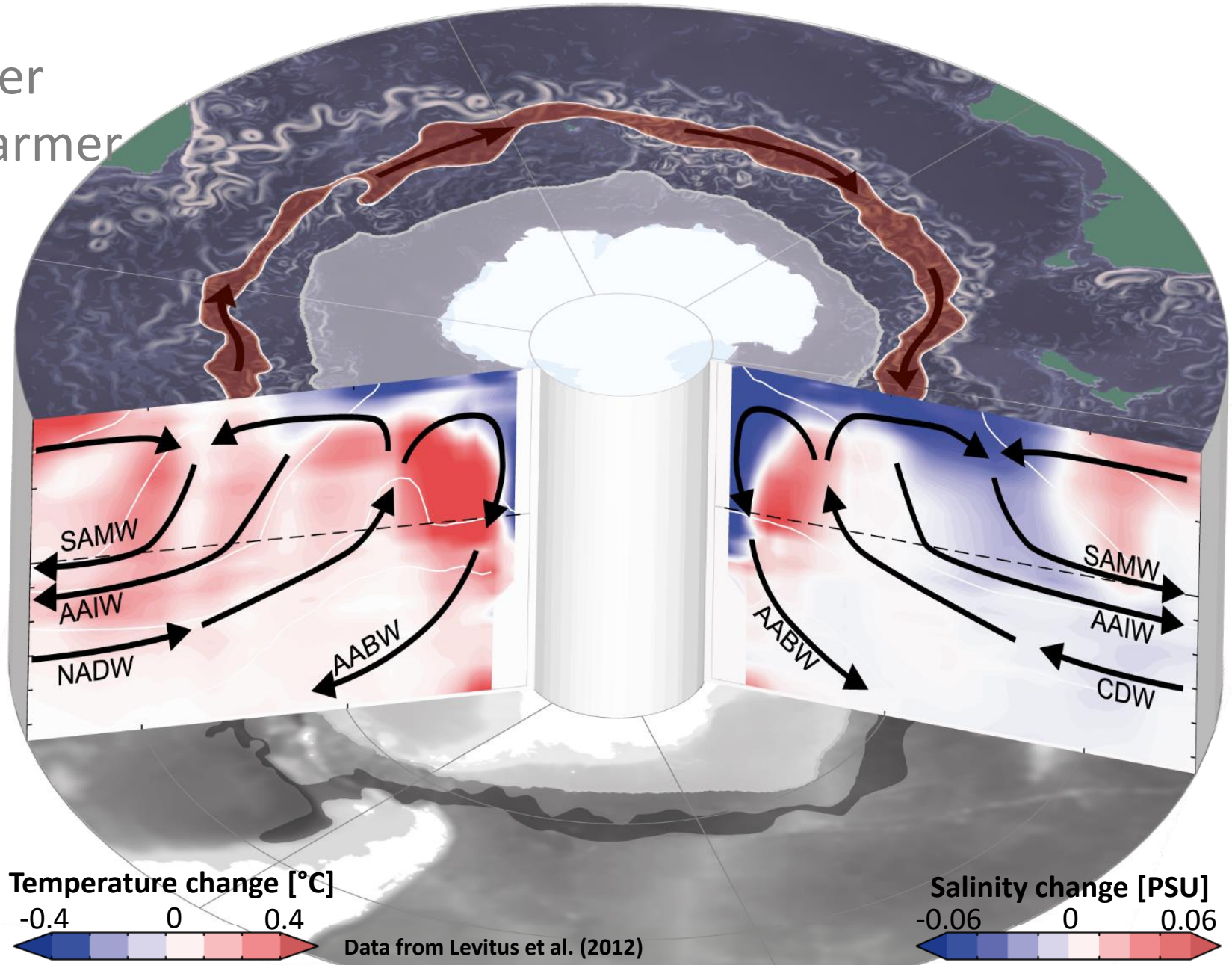
e.g. Gille (2002); Jacobs et al. (2002); Durack et al. (2012); Jones et al. (2013)

Possible explanations:

→ **Delayed Southern Ocean warming due to mean ocean circulation**
(e.g. Manabe et al., 1990, 1991; Stouffer, 2004; Armour et al., 2016)

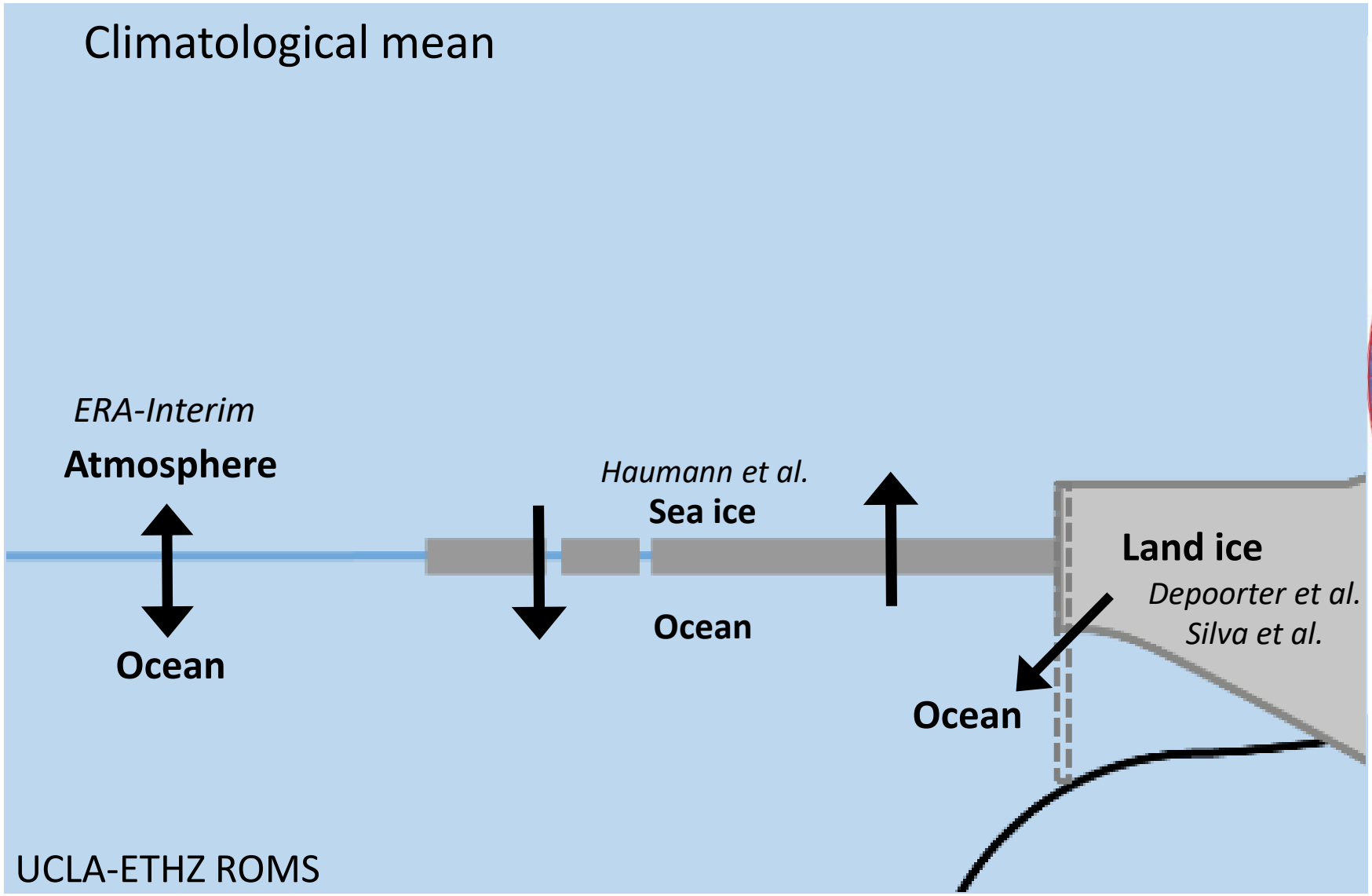
→ **Increasing zonal wind /SAM**
(e.g. Sen Gupta et al., 2009; Thompson et al., 2011; Kostov et al., 2016; Seviour et al., 2016)

→ **Increased freshwater flux**
(e.g. Stouffer et al., 2007; Swingedouw et al., 2009; Hansen et al., 2016; Purich et al. 2018)

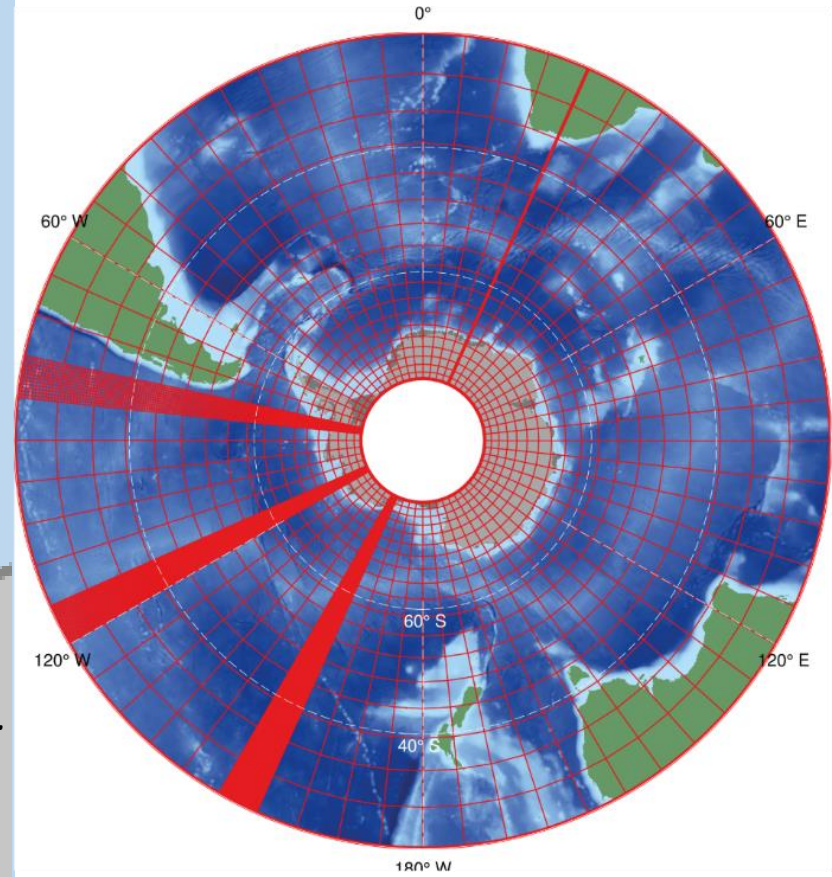


Methods: A flux-forced model of the Southern Ocean

Regional Ocean Modeling System forced with observed fluxes (atmosphere, sea ice, land ice)



24°S / 25 km



Antarctica / 5 km

For more details on the model:
Haumann (2016), PhD thesis

Model sensitivity experiments I

Enhanced northward sea-ice transport

Climatological mean + perturbation

Atmosphere

Ocean

+0.027 Sv

Sea ice

Ocean

Land ice

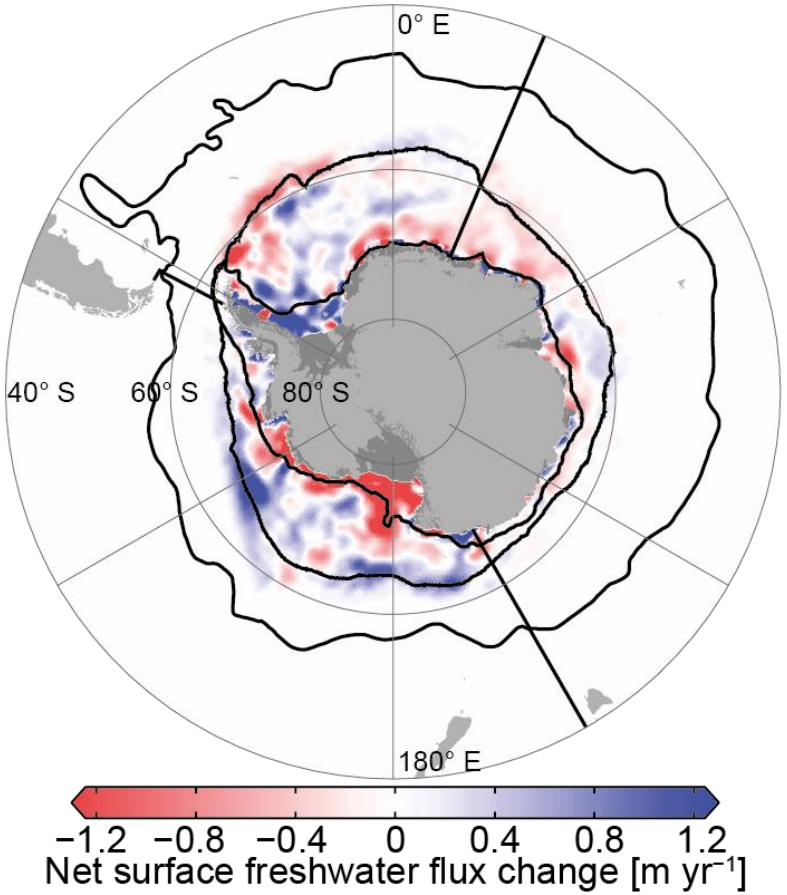
Ocean

UCLA-ETHZ ROMS

24°S / 25 km

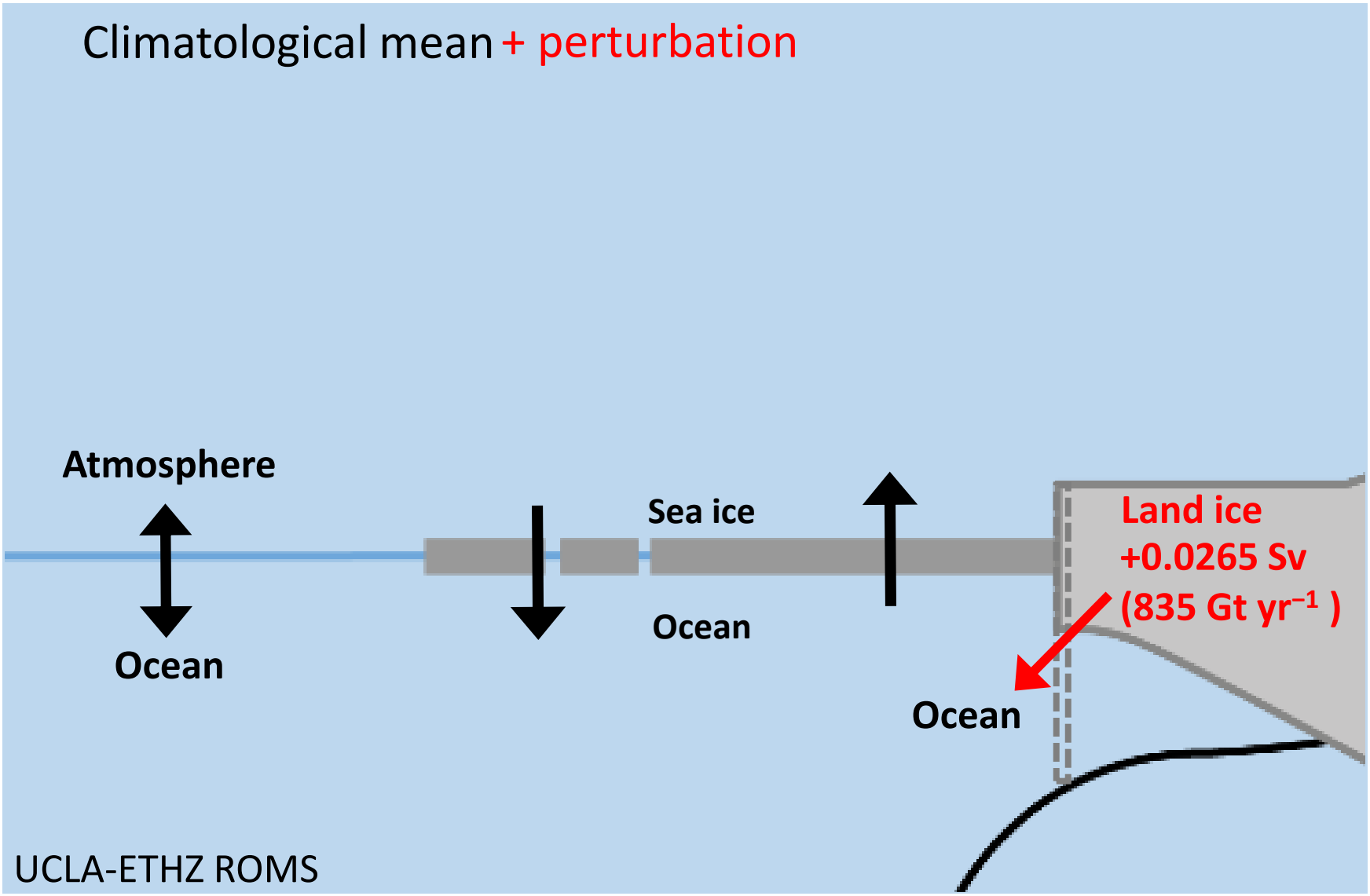
Antarctica / 5 km

Sea-ice flux changes from Haumann et al. (2016):



Model sensitivity experiment II

Enhanced glacial meltwater input from the Antarctic continent

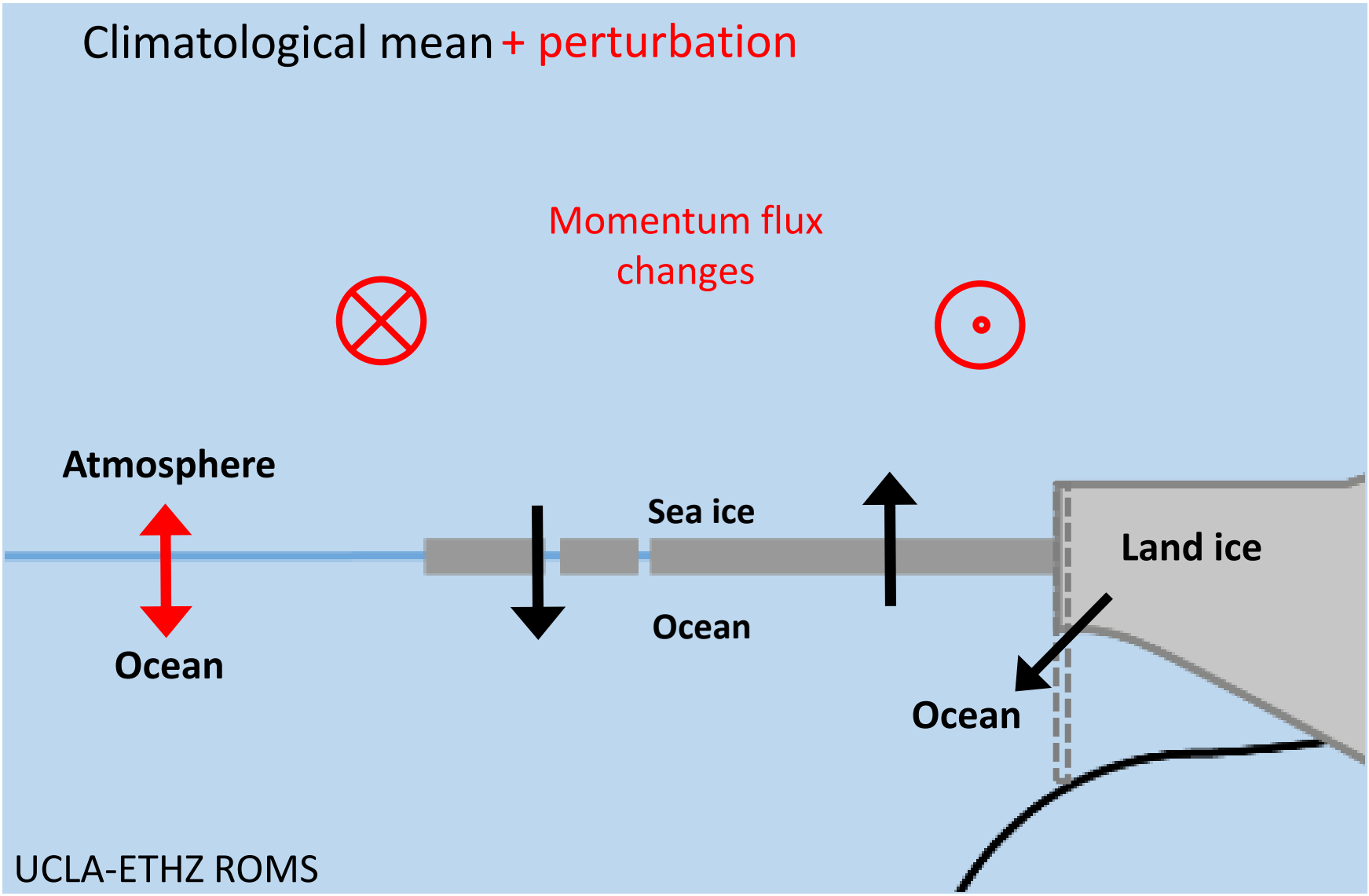


Glacial meltwater flux changes estimated from
Paolo et al. (2015)
Sutterley et al. (2014)

Model sensitivity experiment III Changes in atmosphere-ocean momentum flux due to changing winds (affecting ocean circulation and mixing, but not sea ice)

Climatological mean + perturbation

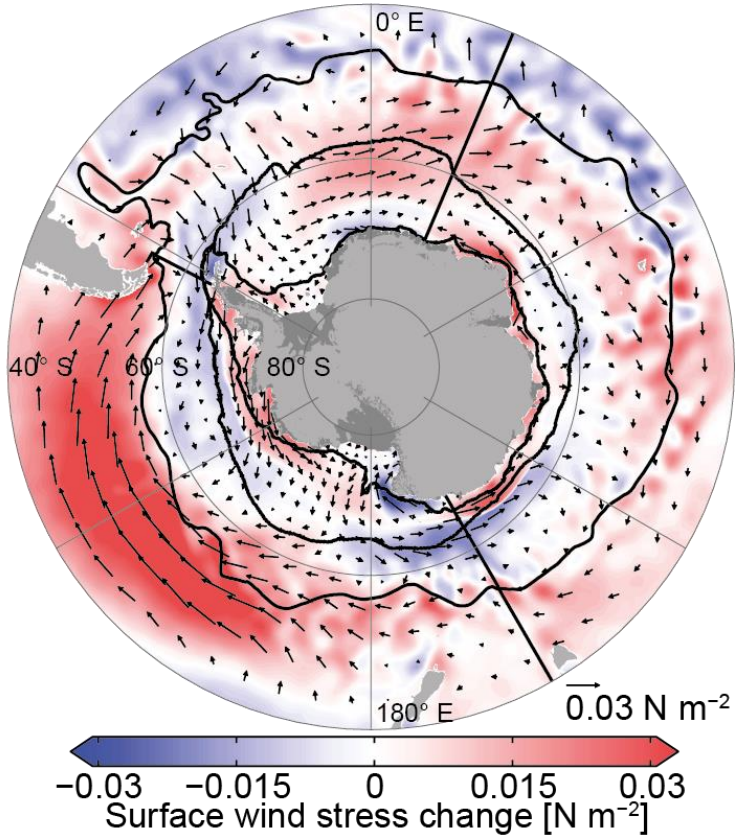
Momentum flux changes



UCLA-ETHZ ROMS

24°S / 25 km

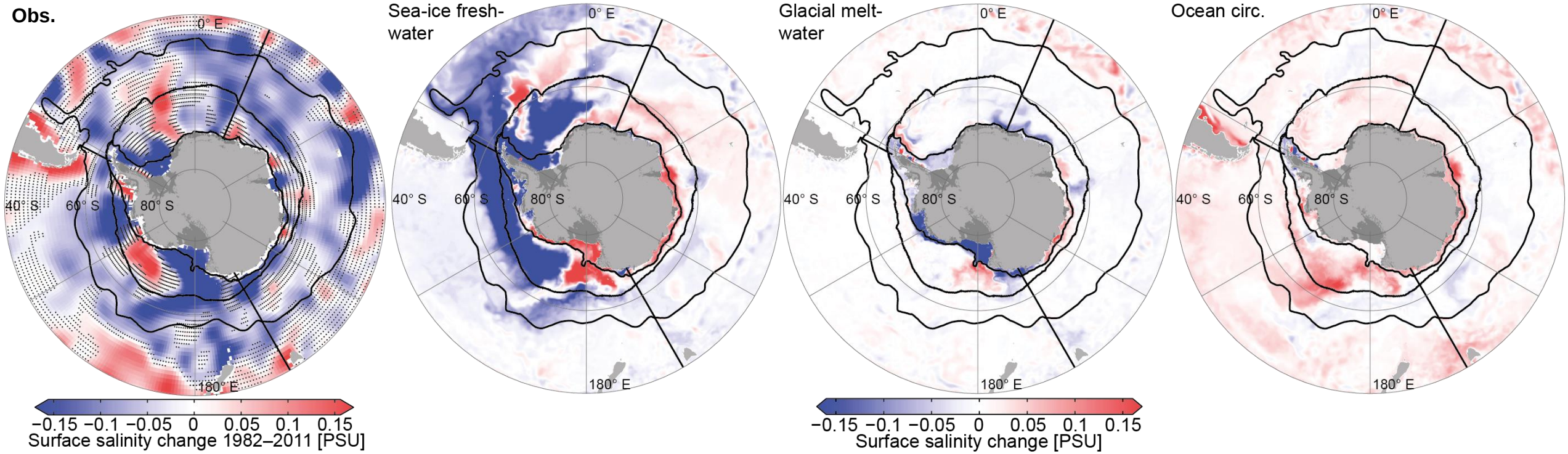
Surface wind stress changes from ERA-I (Dee et al., 2011)



Antarctica / 5 km

Simulated surface salinity response to surface flux changes

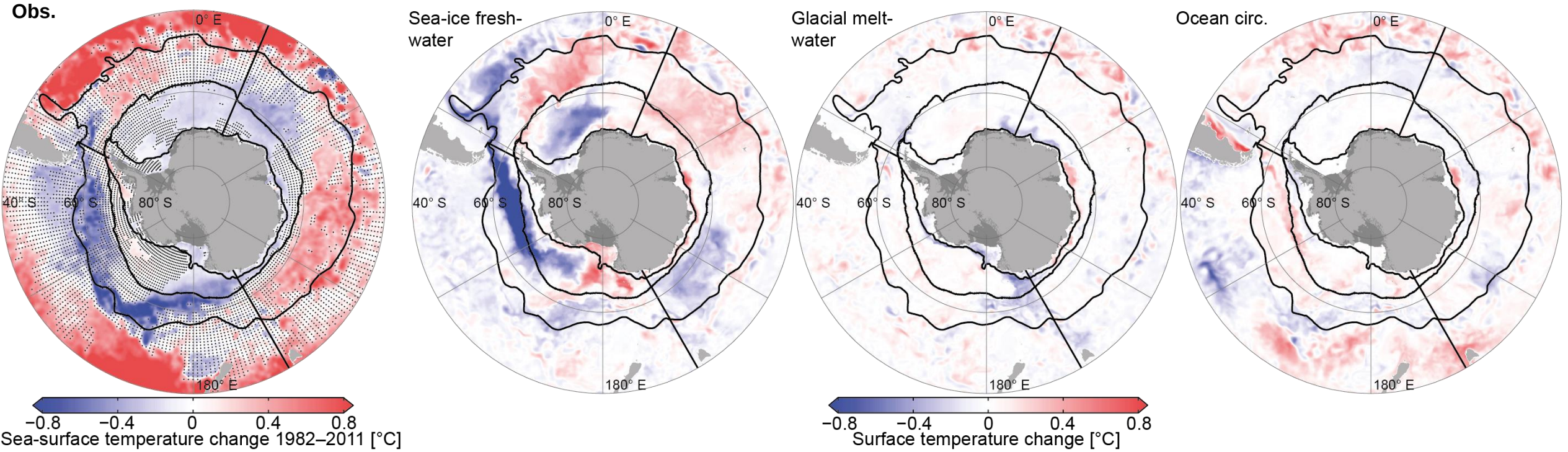
Freshening due to sea ice and land ice freshwater fluxes & salinification due to momentum fluxes



Data from Levitus et al. (2012)

Simulated surface temperature response to surface flux changes

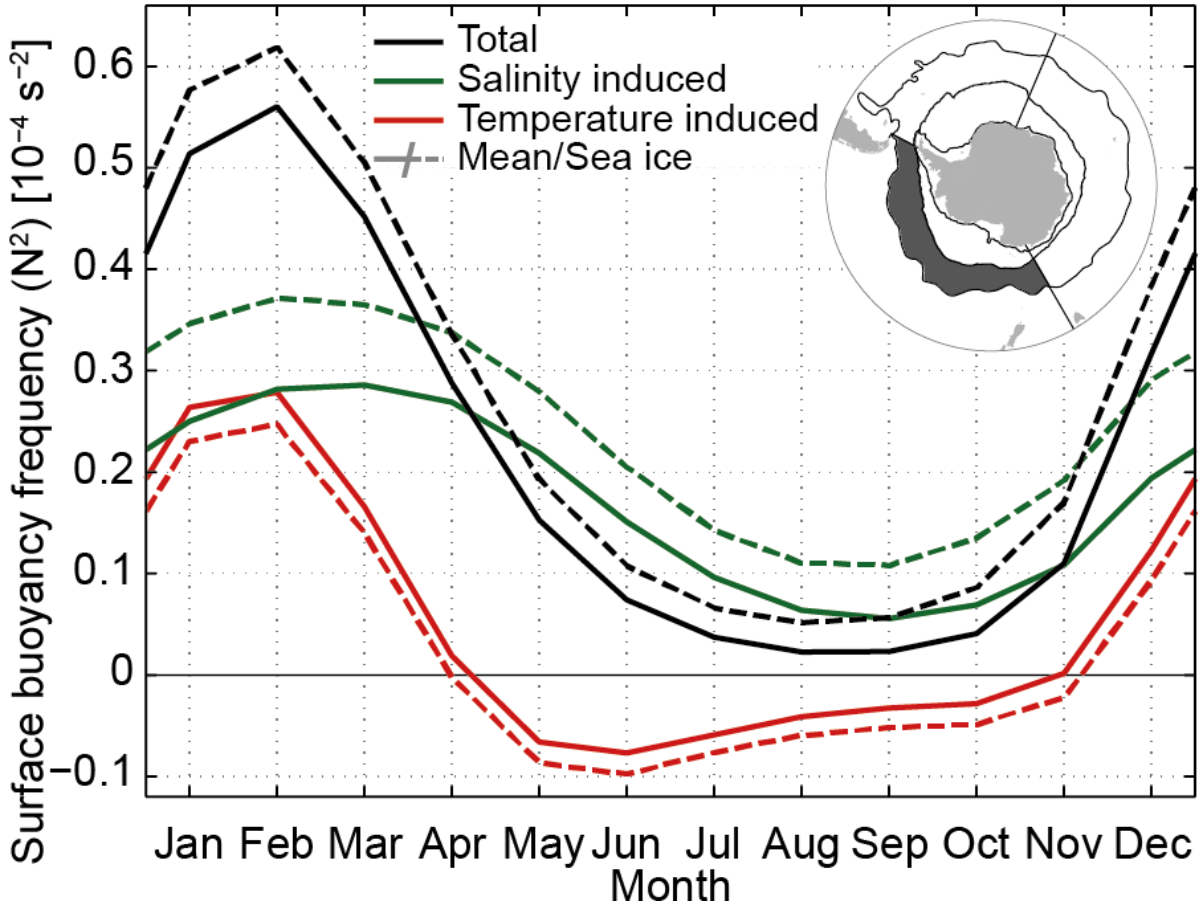
Cooling due to sea ice and land ice freshwater fluxes & warming due to momentum fluxes

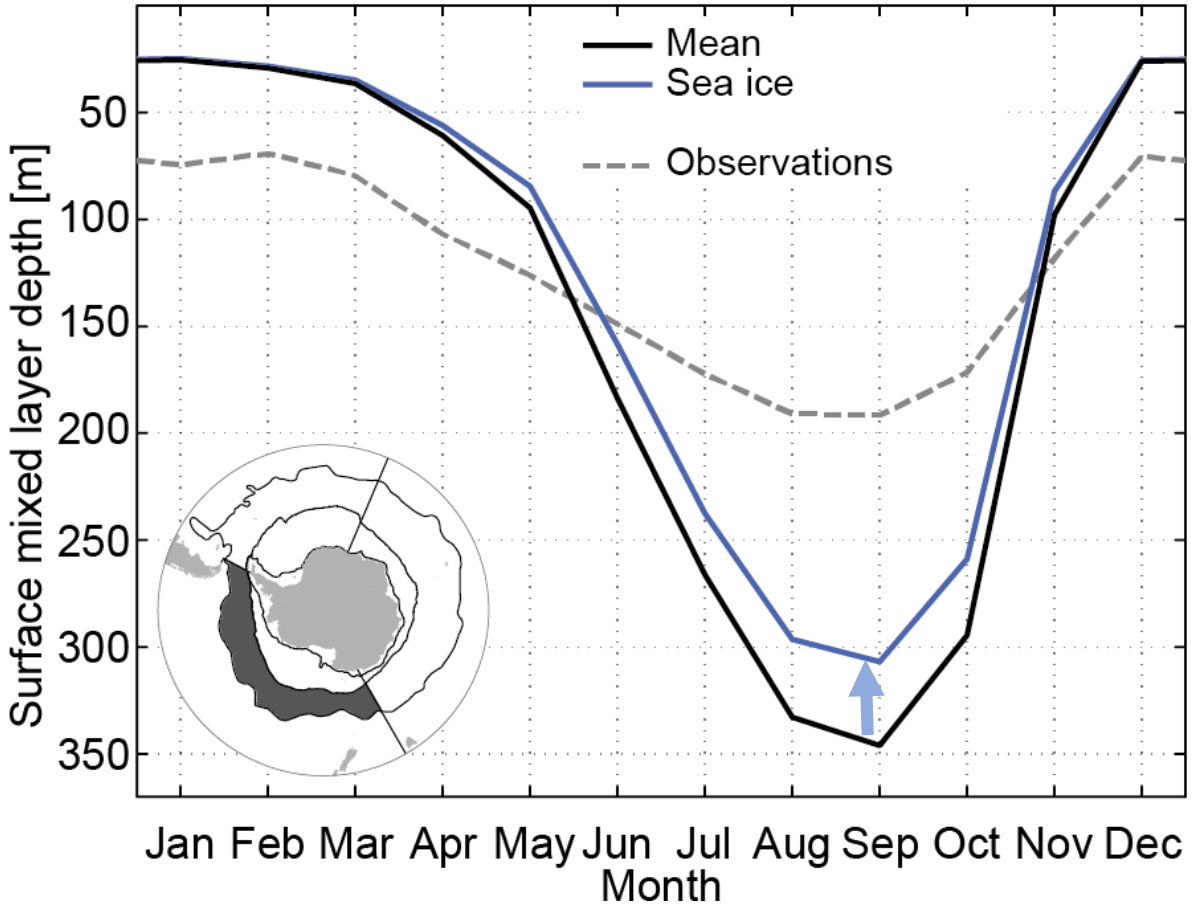


Data from Reynolds et al. (2007)

Surface stratification response to sea-ice freshwater flux changes

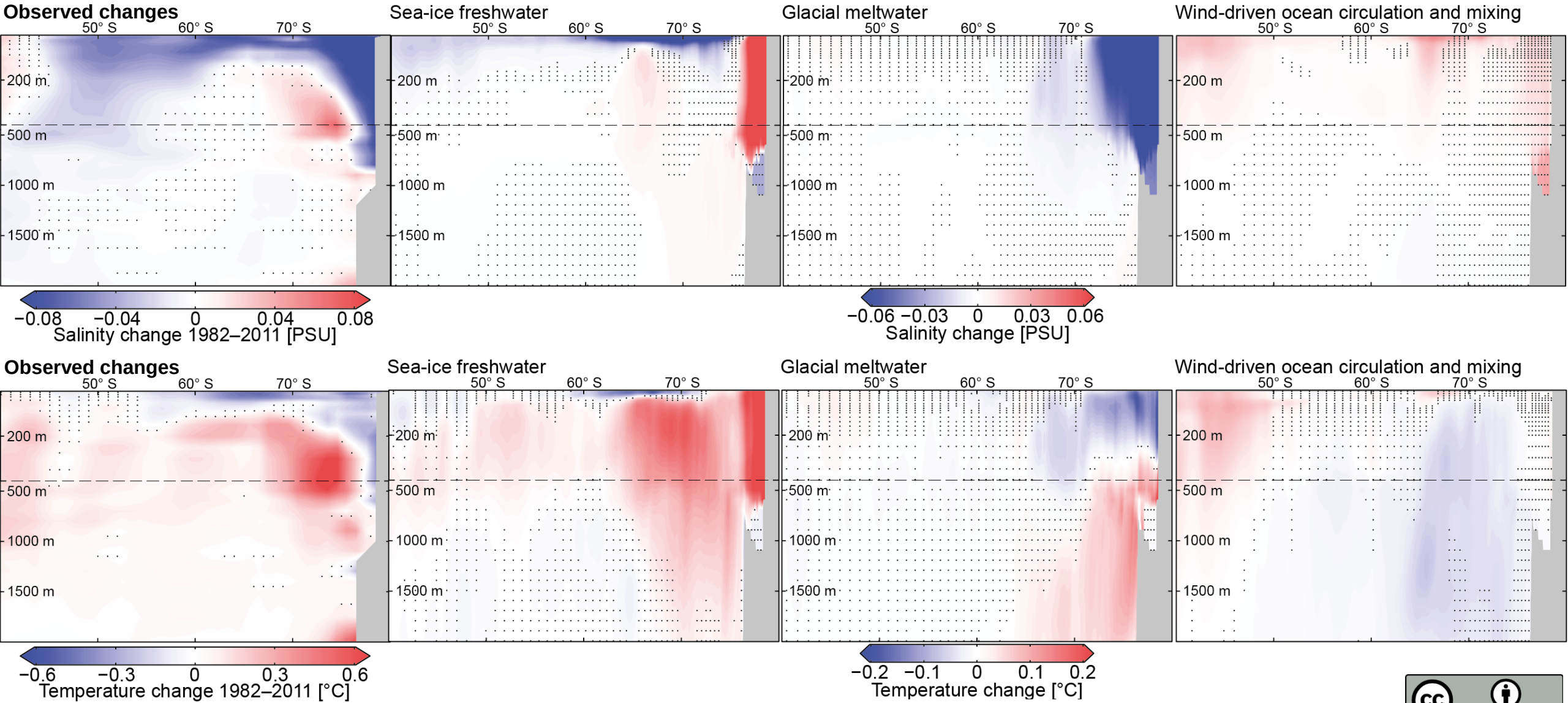
Surface stabilization and reduced mixing mostly in the open ocean Pacific





Subsurface temperature response to surface flux changes

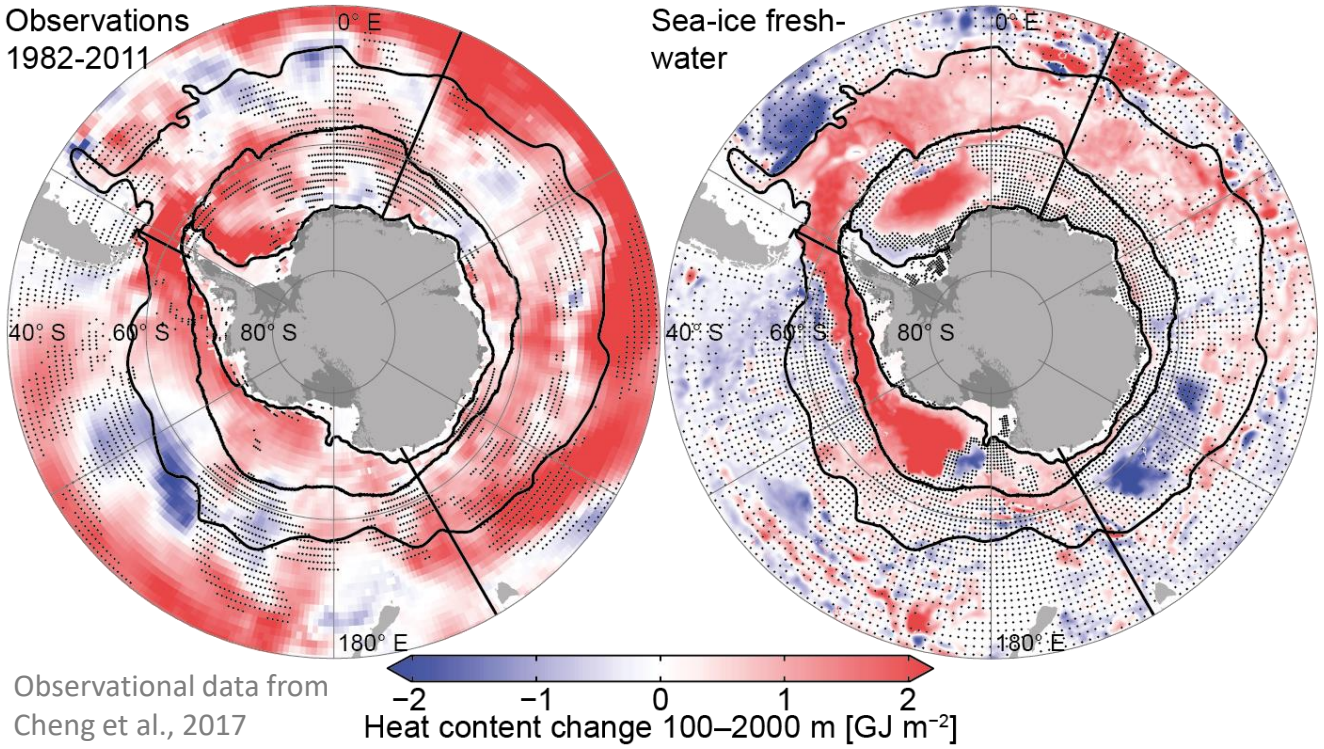
Freshwater fluxes consistent with observed changes in Southern Ocean hydrography



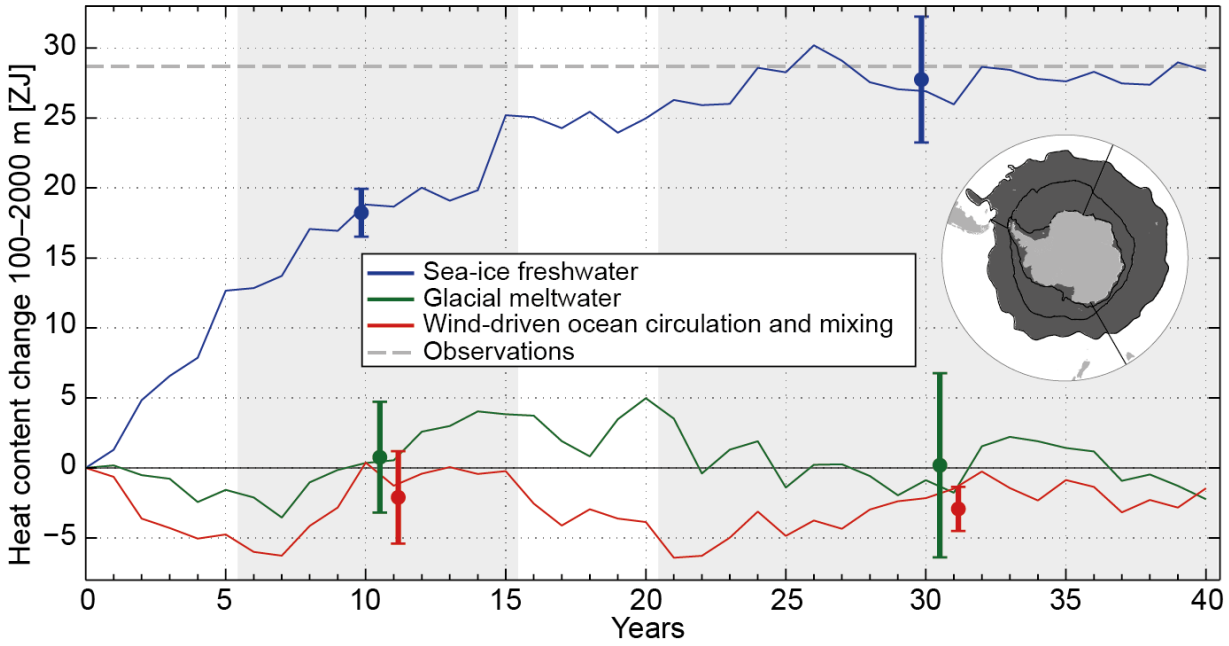
Observational data from Levitus et al. (2012)

Subsurface heat content response to sea-ice freshwater flux changes

Subsurface warming mostly around West Antarctica consistent with some of the observed high-latitude warming



Observational data from Cheng et al., 2017

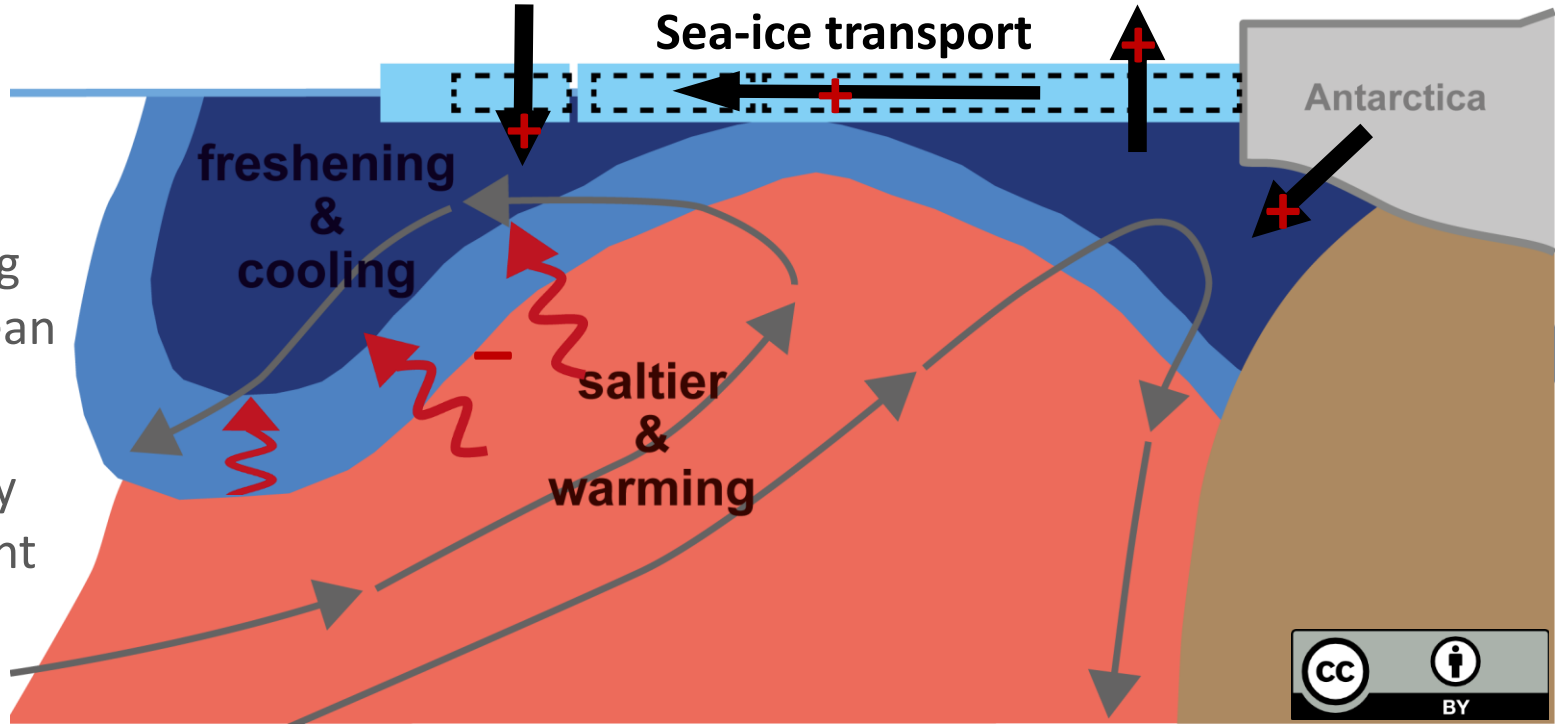


→ Sea-ice changes potentially affecting **ice-shelf melt**

→ Sea-ice changes contributed to the **slowdown of global warming** by retaining heat at depth & increasing the **global ocean heat content (8%)**

Conclusions

- Open-ocean surface **freshening** through increased northward **sea-ice transport** & coastal freshening due to **land-ice melting**, most likely driven by atmospheric circulation changes
- Freshening **increases** density **stratification** and **reduces mixing**
- Resulting in **surface cooling** & **subsurface warming**
- **Freshwater induced** simulated hydrographic changes **agree with observed changes**
- Patterns of hydrographic change due to **ocean circulation changes (Ekman transport)** are **opposite** to the observed changes in high latitudes and can therefore not explain the observed changes
- Sea-ice induced subsurface warming potentially affected **ice-shelf melt**
- Sea-ice changes contributed to the **slowdown of global warming** by retaining heat at depth & increasing the global ocean heat content (8%)
- **Global climate models** need to accurately simulate sea-ice changes to capture recent changes in Southern Ocean hydrography



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