

Maurice Huguenin

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ETHzürich



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WOODS HOLE
OCEANOGRAPHIC
INSTITUTION

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WOODS HOLE
OCEANOGRAPHIC
INSTITUTION

Disclaimer: It was more like this



Acknowledgment of Country



Acknowledgment of Country



- **Bedegal people**
- sovereignty has never been ceded
- climate justice for First Nations people





ACEAS

Australian Centre for Excellence
in Antarctic Science





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in Antarctic Science



Australian Government
Australian Research Council

The Australian Centre for Excellence in Antarctic Science is a
Special Research Initiative funded by the Australian Research Council



UNIVERSITY OF TASMANIA
IMAS
Institute for Marine and Antarctic Studies



Australian National
University



This research was supported by the Australian Research Council Special Research
Initiative, Australian Centre for Excellence in Antarctic Science (Project Number
SR200100008)



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Drivers and distribution of global ocean heat uptake over the last half century

Maurice F. Huguenin, Ryan M. Holmes and Matthew H. England

Nature Communications



Australian Government
Australian Research Council

The Australian Centre for Excellence in Antarctic Science is a
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MELBOURNE



Curtin University



University of
South Australia



THE UNIVERSITY OF
WESTERN AUSTRALIA

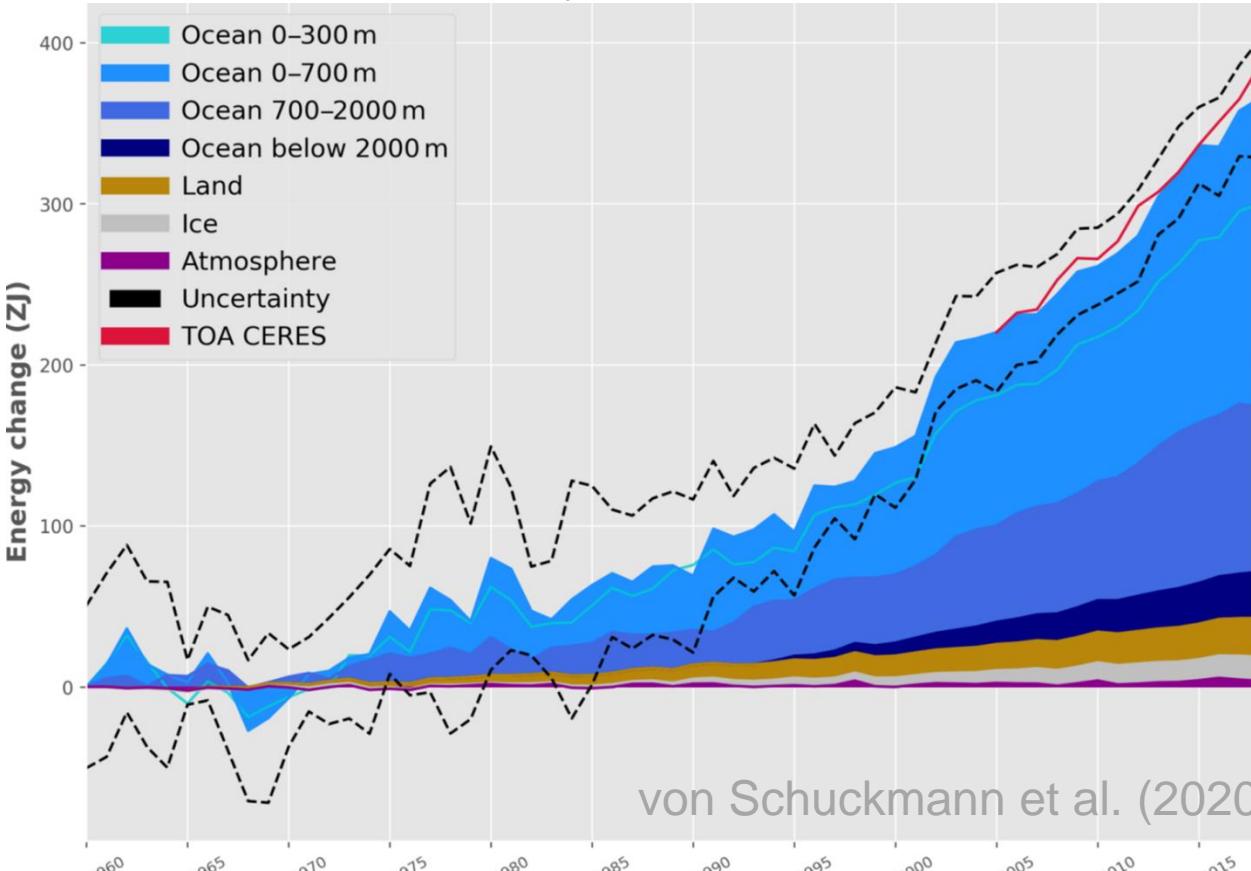


UNIVERSITY OF
CANBERRA

This research was supported by the Australian Research Council Special Research Initiative, Australian Centre for Excellence in Antarctic Science (Project Number SR200100008)

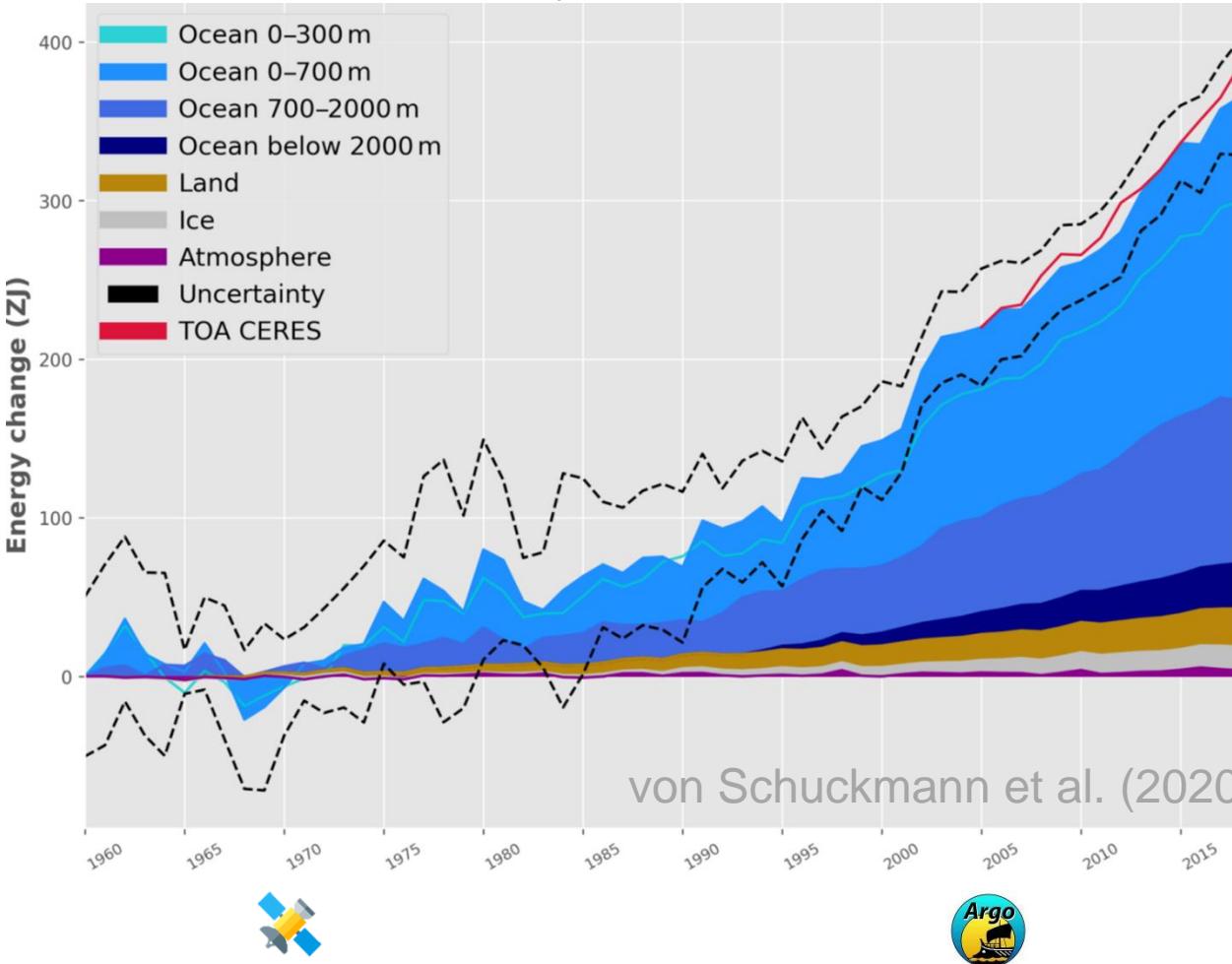
Importance of ocean heat content

Earth heat inventory relative to 1960 ($ZJ = 10^{21} J$)



Importance of ocean heat content

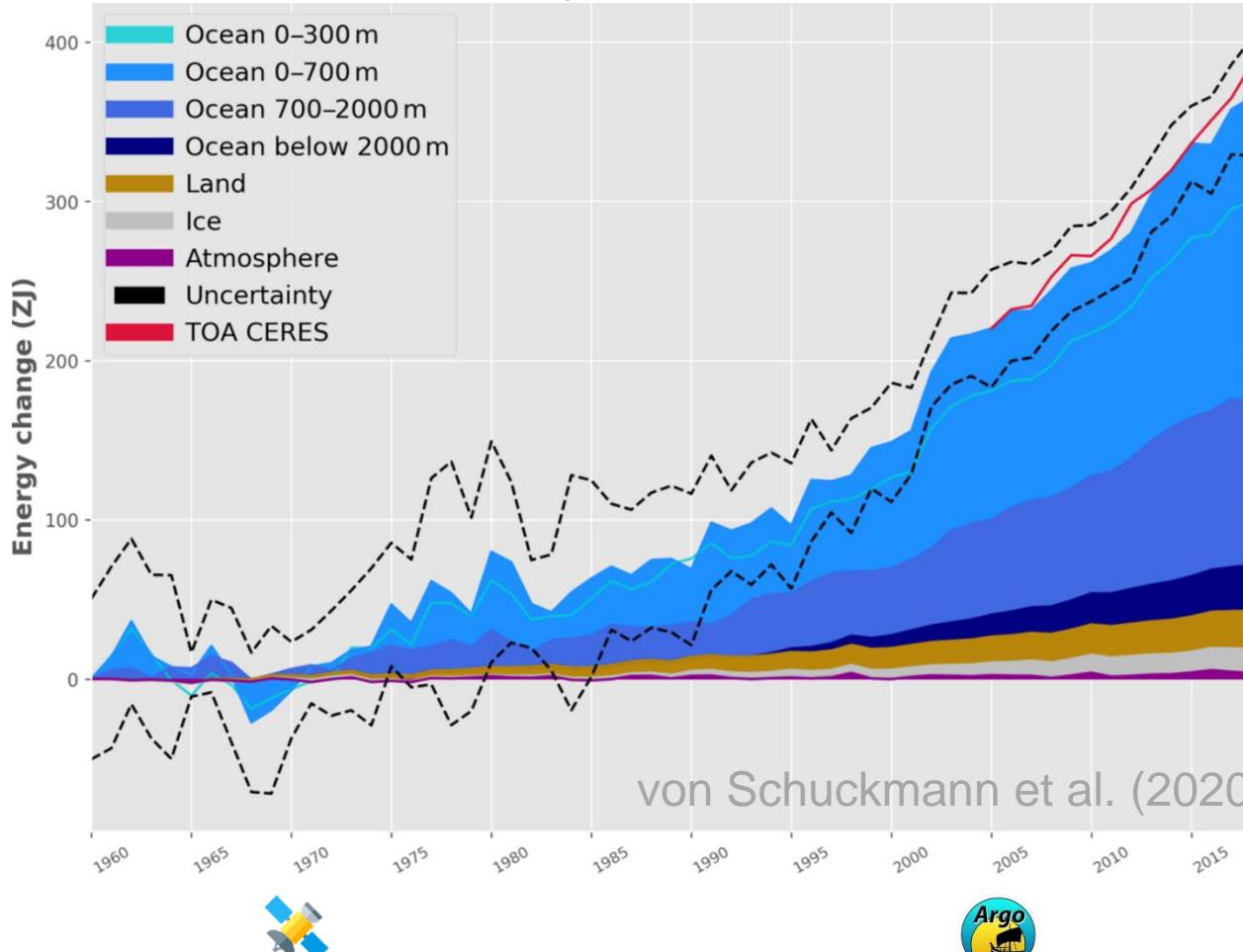
Earth heat inventory relative to 1960 ($ZJ = 10^{21} J$)



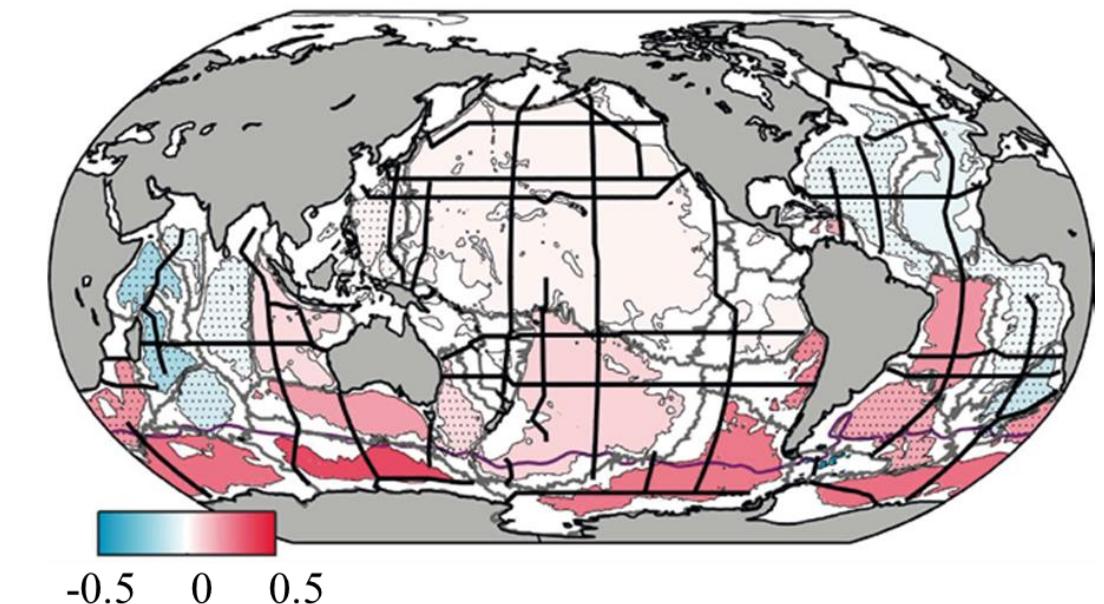
- Where has heat entered the ocean?
- Where is it today?
- What are the roles of wind and thermal forcing?

Importance of ocean heat content

Earth heat inventory relative to 1960 ($ZJ = 10^{21} J$)



Warming rate ($^{\circ}\text{C century}^{-1}$) below 4000 m



IPCC SROCC, Ch. 5, Fig. 5.4b, Allison et al. (2019)

- Where has heat entered the ocean?
- Where is it today?
- What are the roles of wind and thermal forcing?

Global ocean-sea ice model



- ACCESS-OM2 ([Kiss et al., 2019](#))
- MOM5.1, CICE5.1.2
- Input: atmospheric reanalysis JRA55-do ([Tsujino et al., 2018](#))

Global ocean-sea ice model



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ARC linkage grant funds ~2 positions

Global ocean-sea ice model

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COSIMA



access-hive.org.au



ARC linkage grant funds ~2 positions



Welcome to ACCESS-Hive Docs!

Documentation for ACCESS users: getting set up, running models and model evaluation



New ACCESS user?

Get Started on NCI



Models

Need help?

FAQ / Support



Run a Model



Data and Model Evaluation

Want to collaborate?

Contribute



Community Resources

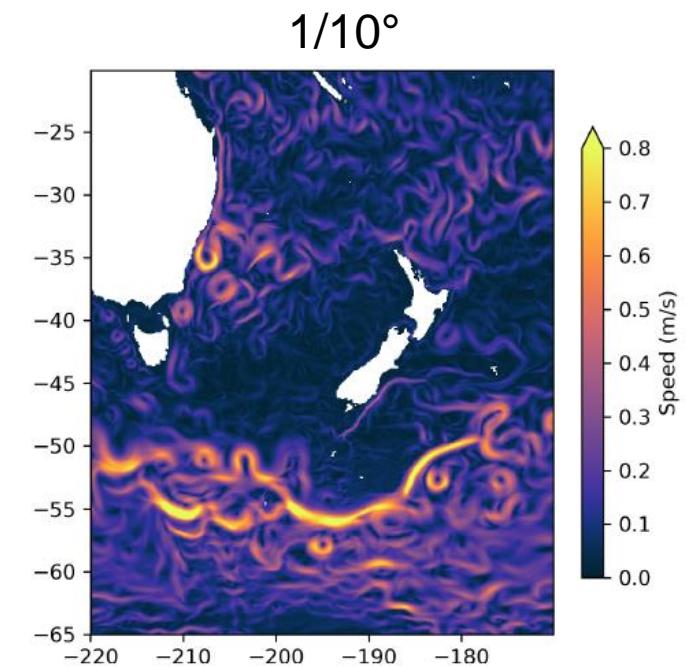
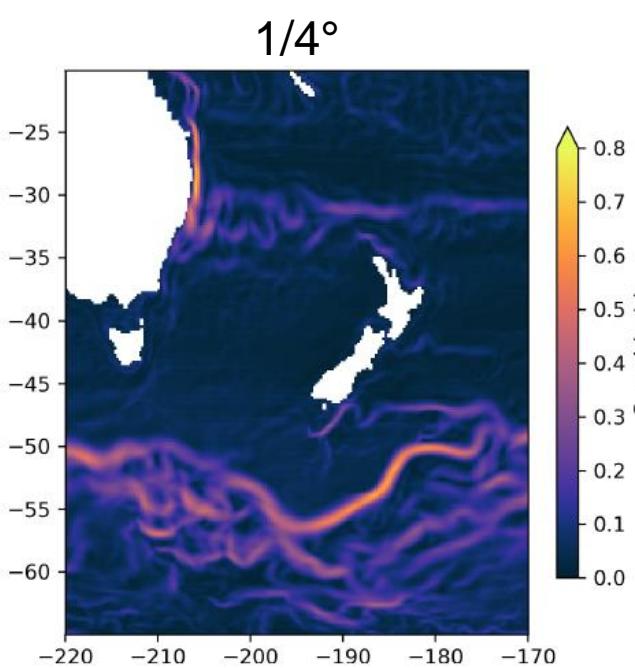
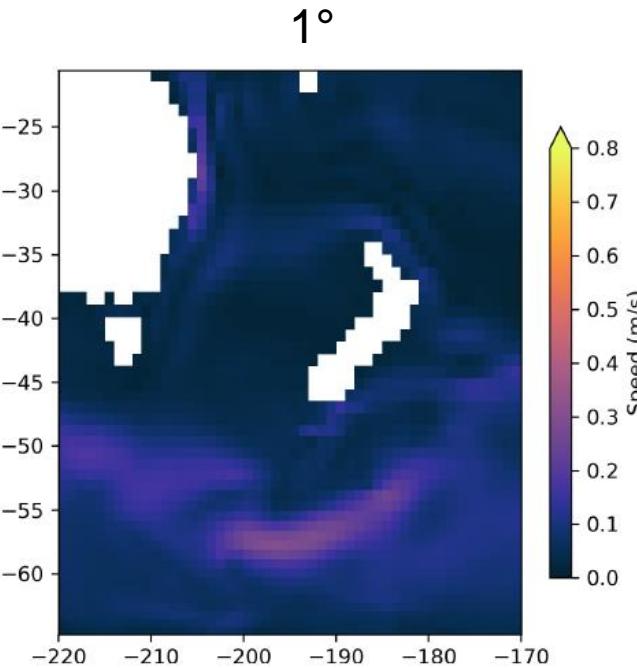
Acknowledgement of Country

We at ACCESS-NRI acknowledge the Traditional Owners of the land on which our research infrastructure and community operate across Australia and pay our respects to Elders past and present. We recognise the thousands of years of accumulated knowledge and deep connection they have with all the Earth systems we simulate.

Global ocean-sea ice model

- ACCESS-OM2 ([Kiss et al., 2019](#))
- MOM5.1, CICE5.1.2
- Input: atmospheric reanalysis JRA55-do ([Tsujino et al., 2018](#))

COSIMA



Kiss et al. (2019)





COSIMA Cookbook

Welcome to the COSIMA Cookbook!

This repository is a Cookbook of Recipes 🍳cookbooks.

We explain: a “recipe” here is an example an analysis of some ocean-sea ice model output or some ocean-related observational datasets. Each “recipe” comes in a self-contained and well-documented Jupyter notebook. All the recipes combined form a cookbook 📜!

Happy cooking! 😊cook 🥧oven 🍪oven 🍫oven

To get started have a look at the [tutorials](#) and then browse through the available [recipes](#) to find something the better suits your ‘taste’ (i.e., your needs)!

Contents:

- [Tutorials](#)
- [Recipes](#)
- [Notebook Guidelines](#)
- [Contributing to the Cookbook](#)
- [GitHub Repository](#)



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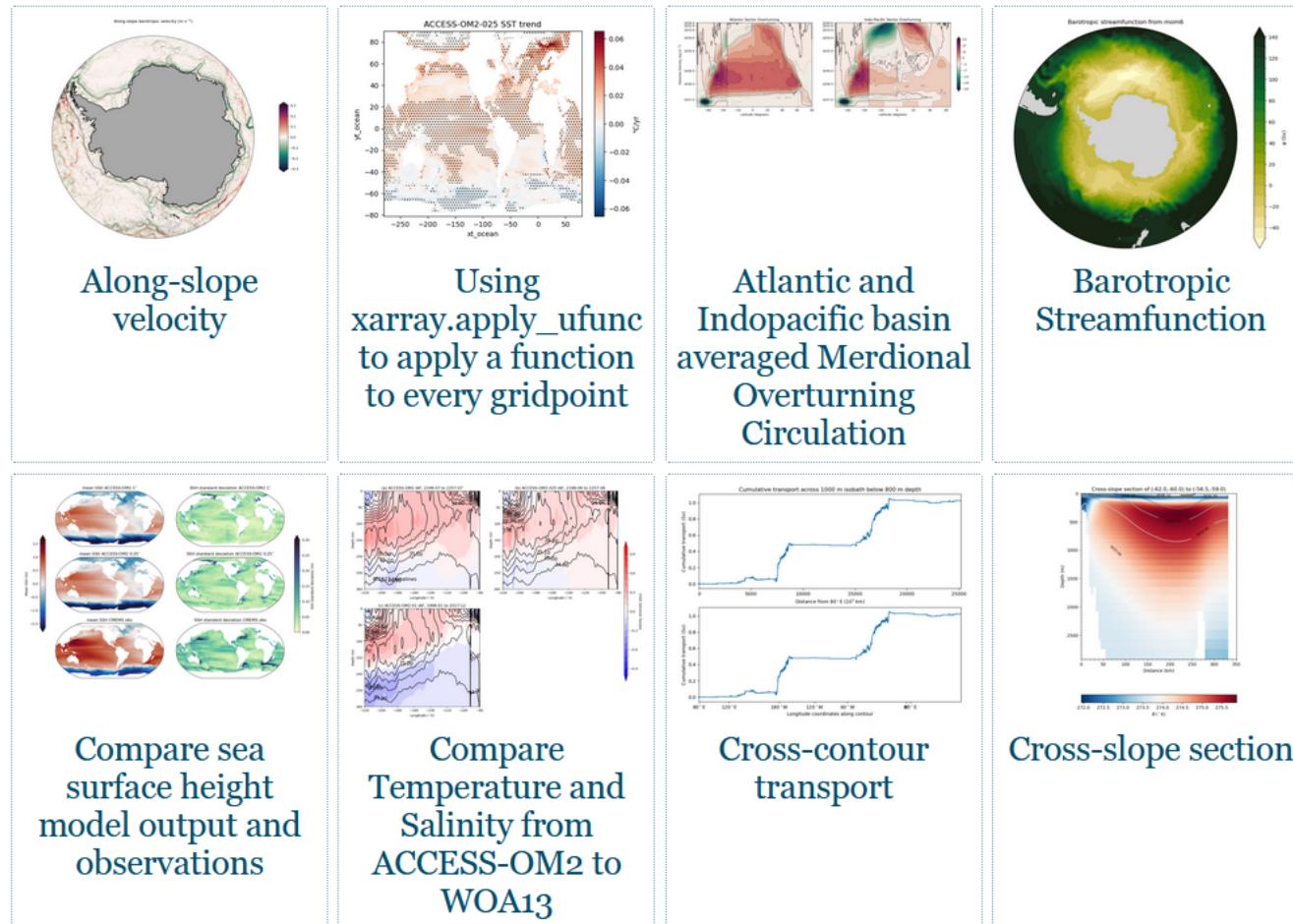
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Recipes

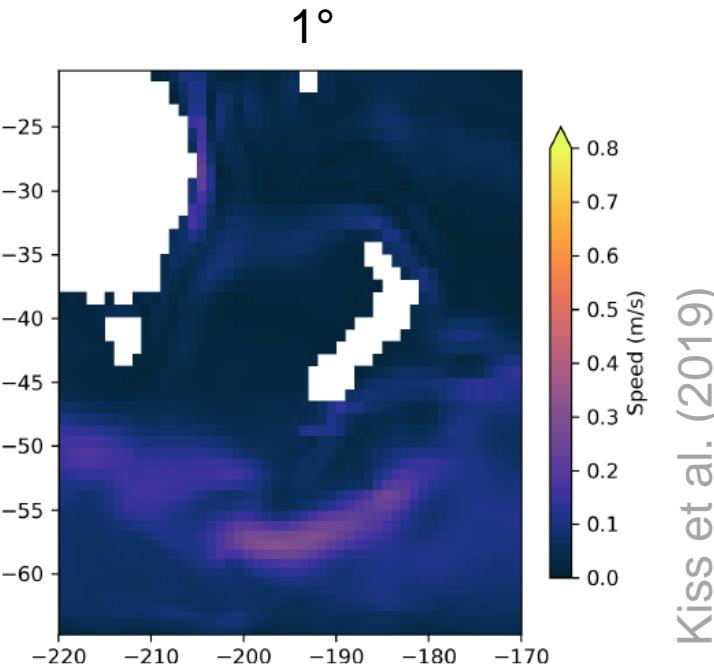
Recipes



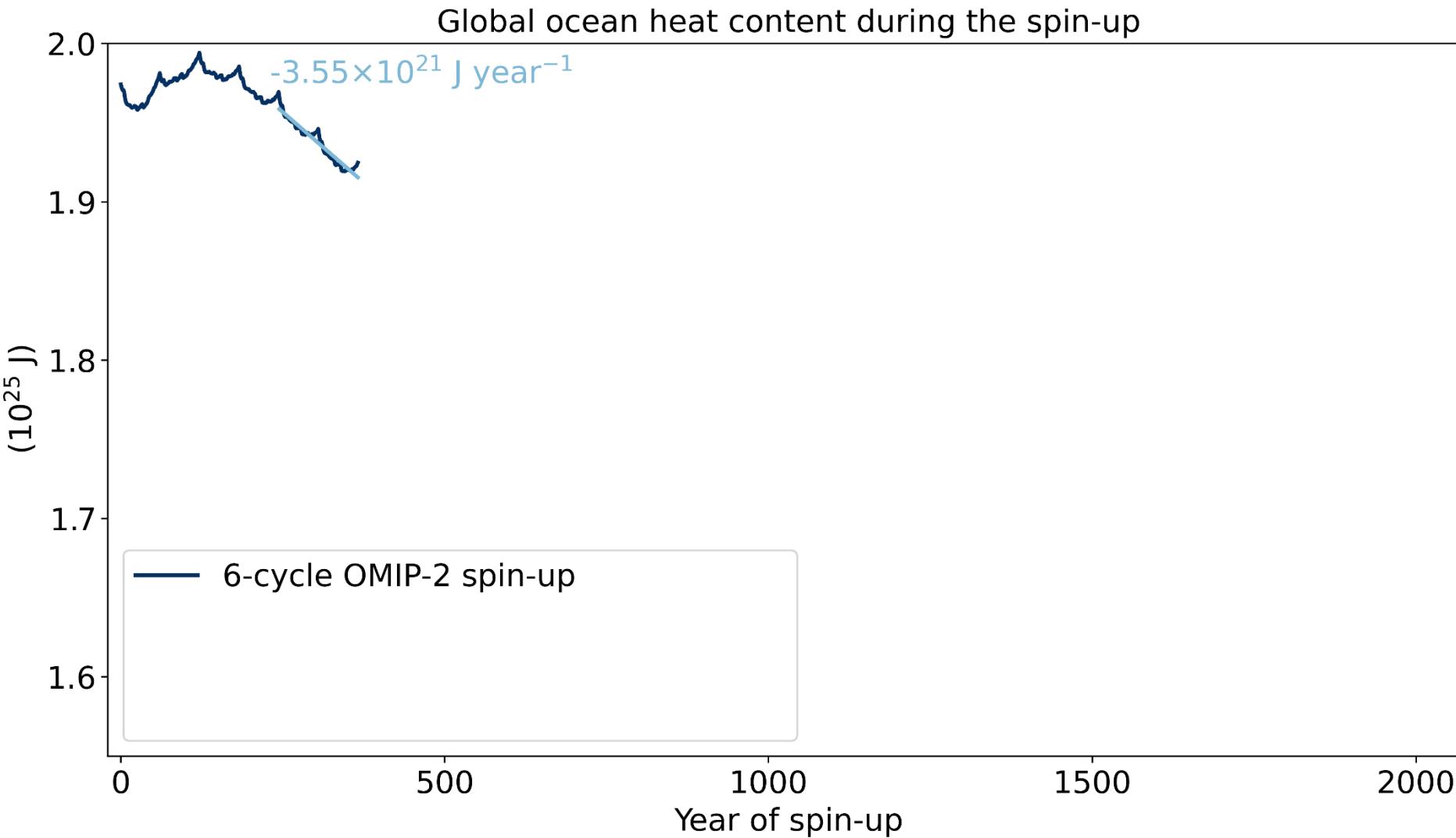
Global ocean-sea ice model



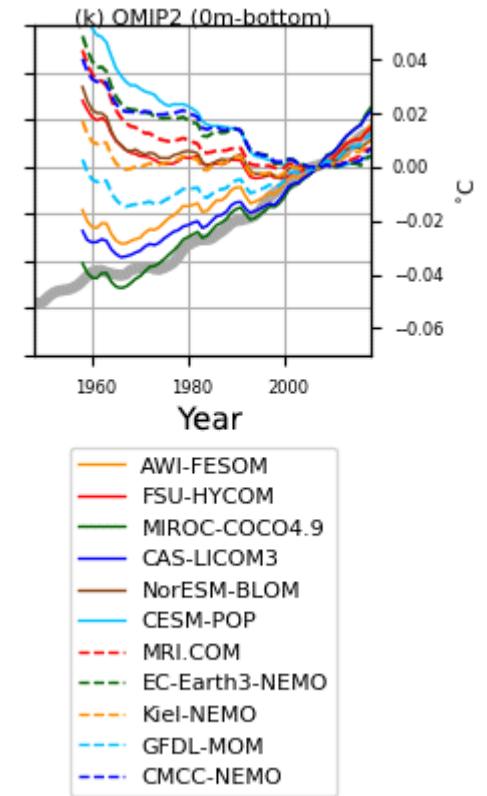
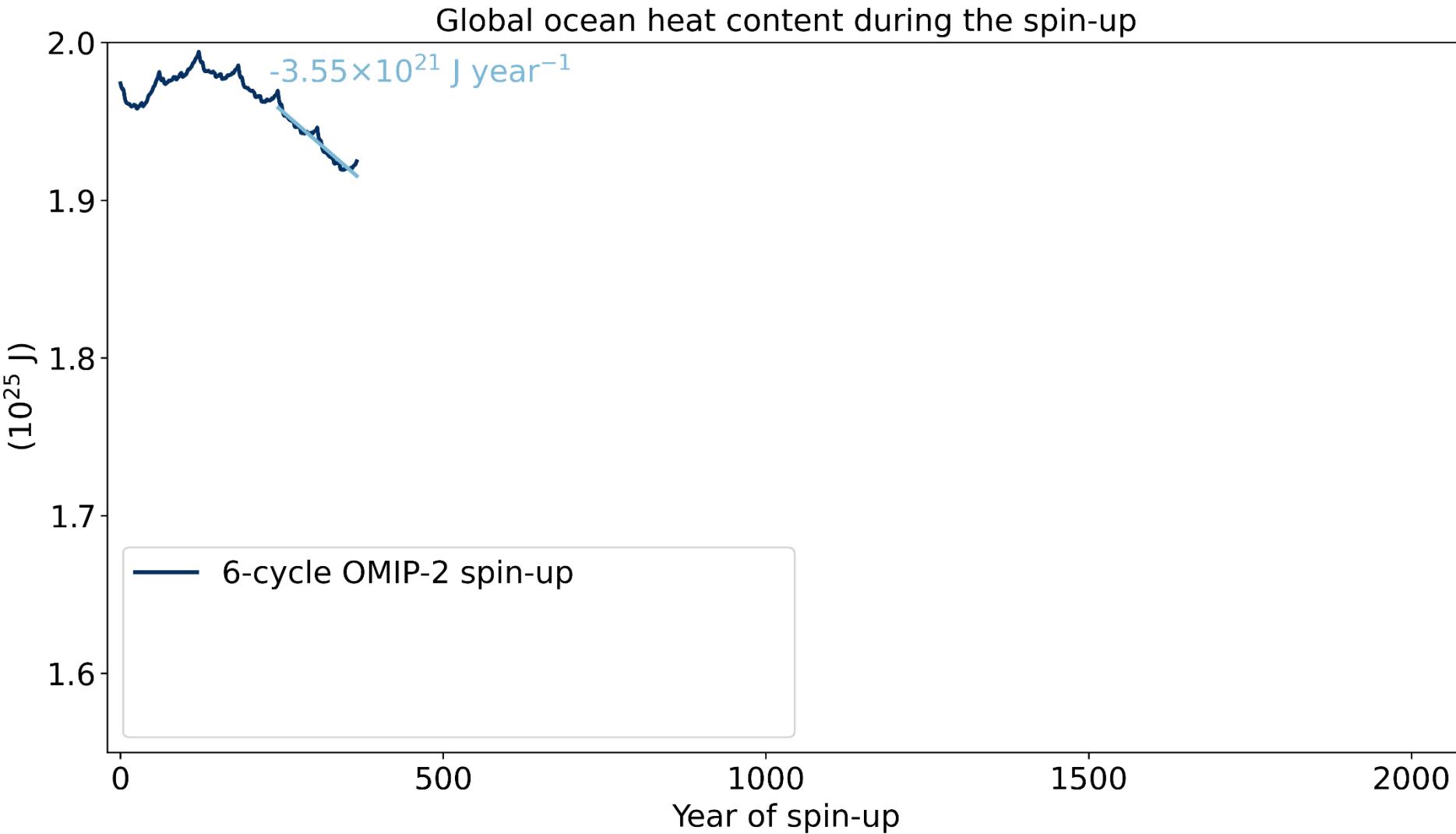
- ACCESS-OM2 ([Kiss et al., 2019](#))
- MOM5.1, CICE5.1.2
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Spin-up for ocean-sea ice models

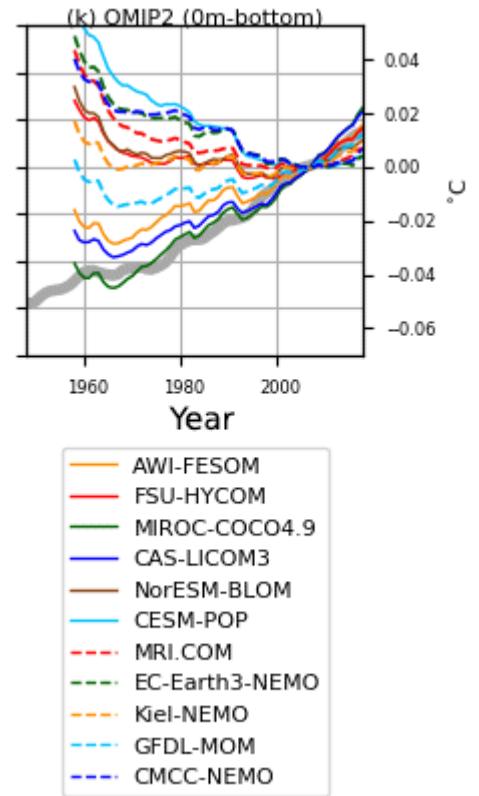
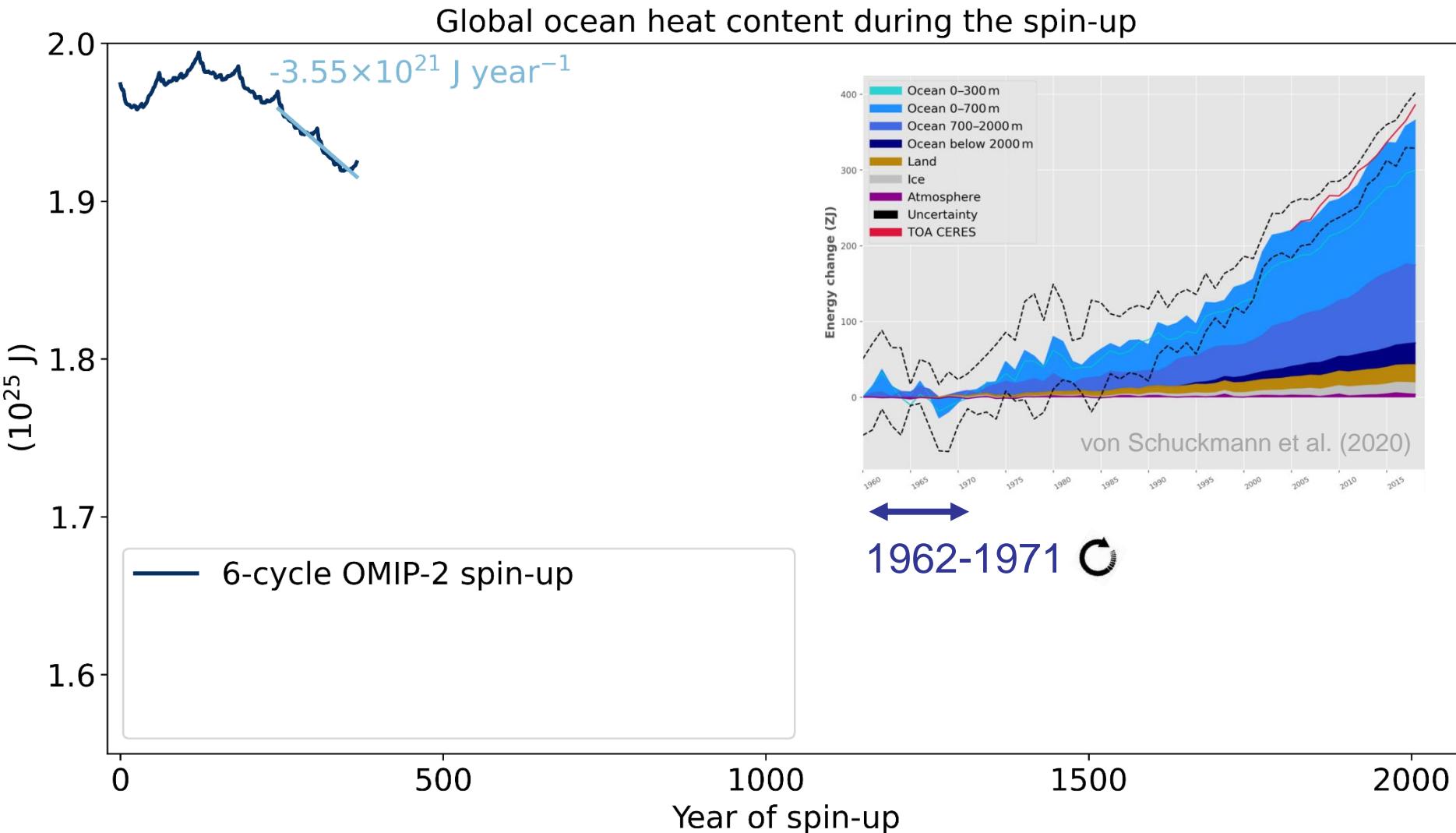


Spin-up for ocean-sea ice models



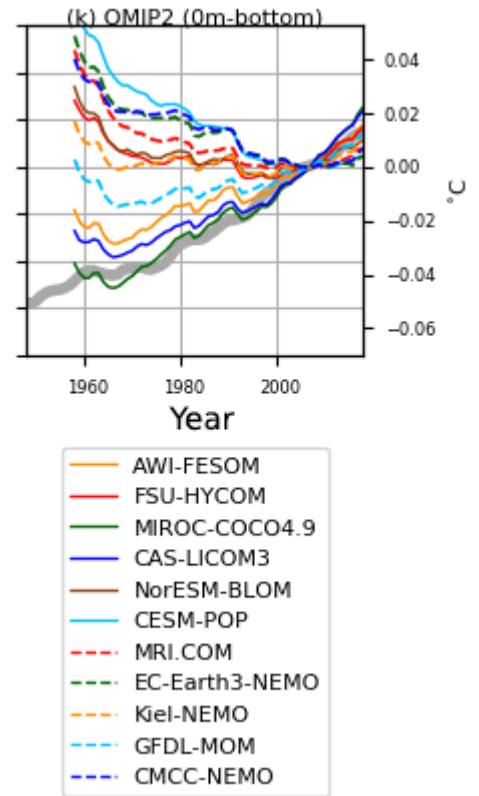
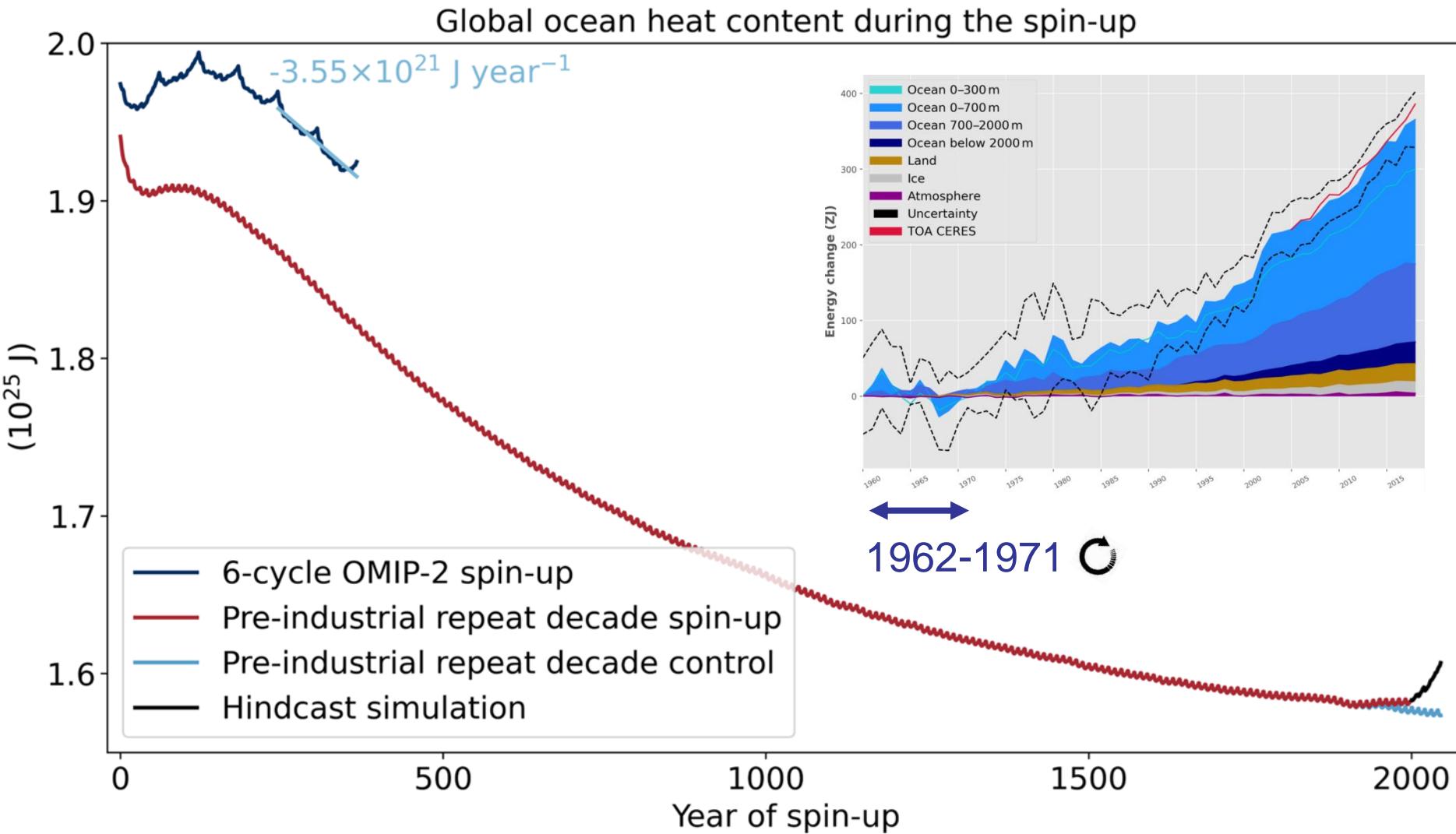
Tsujino et al. (2020)

New spin-up for ocean-sea ice models



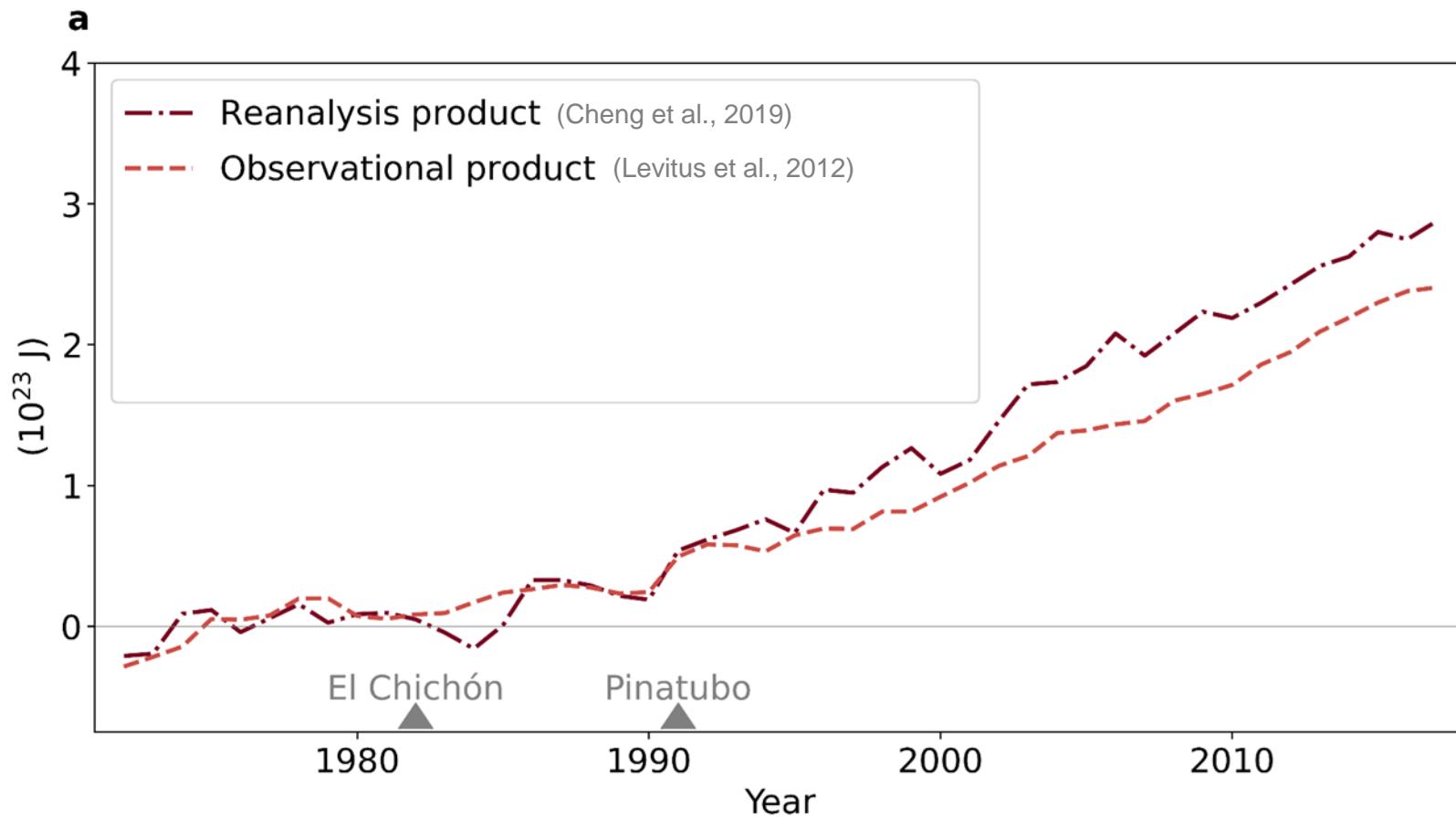
Tsujino et al. (2020)

New spin-up for ocean-sea ice models

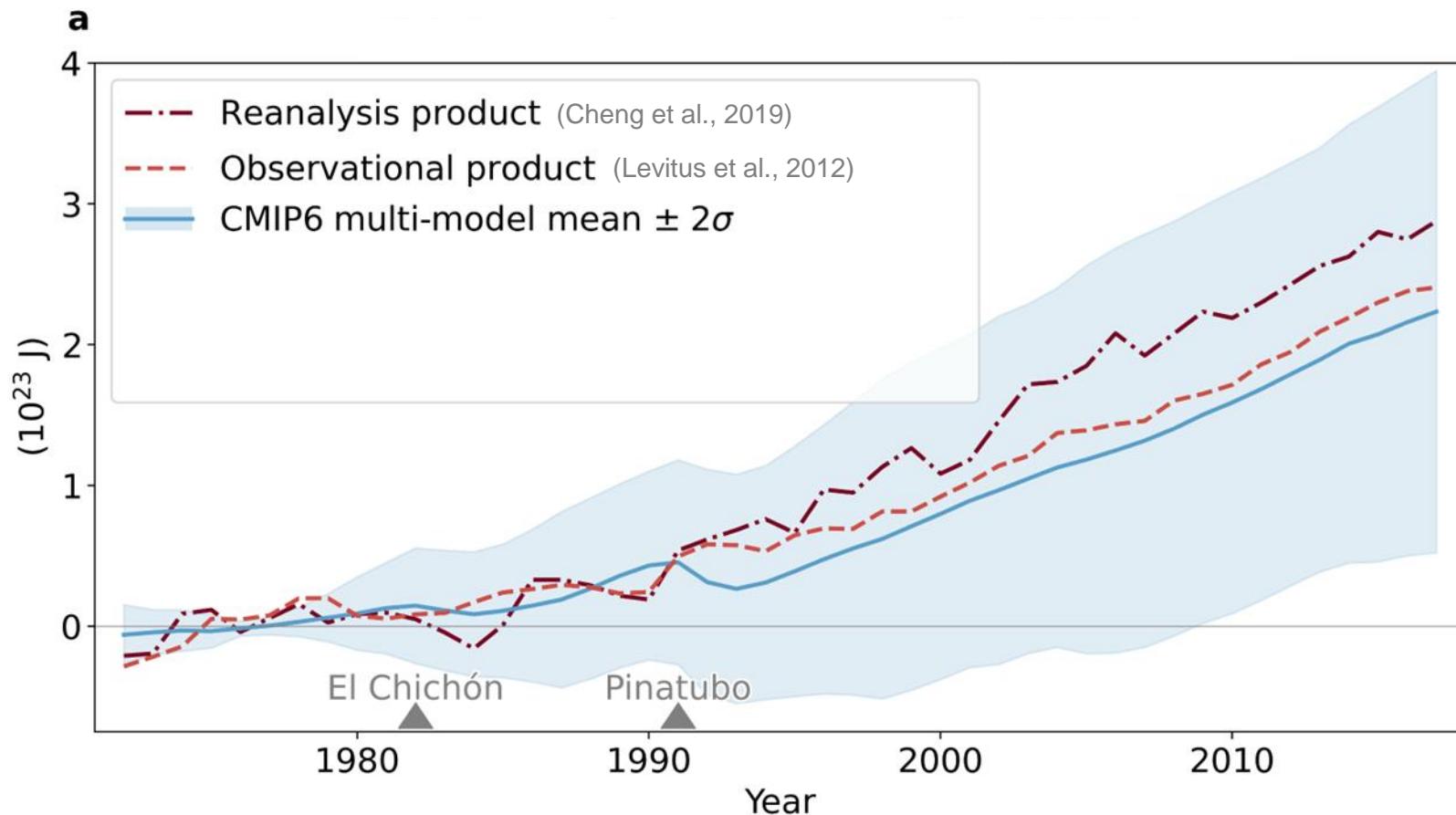


Tsujino et al. (2020)

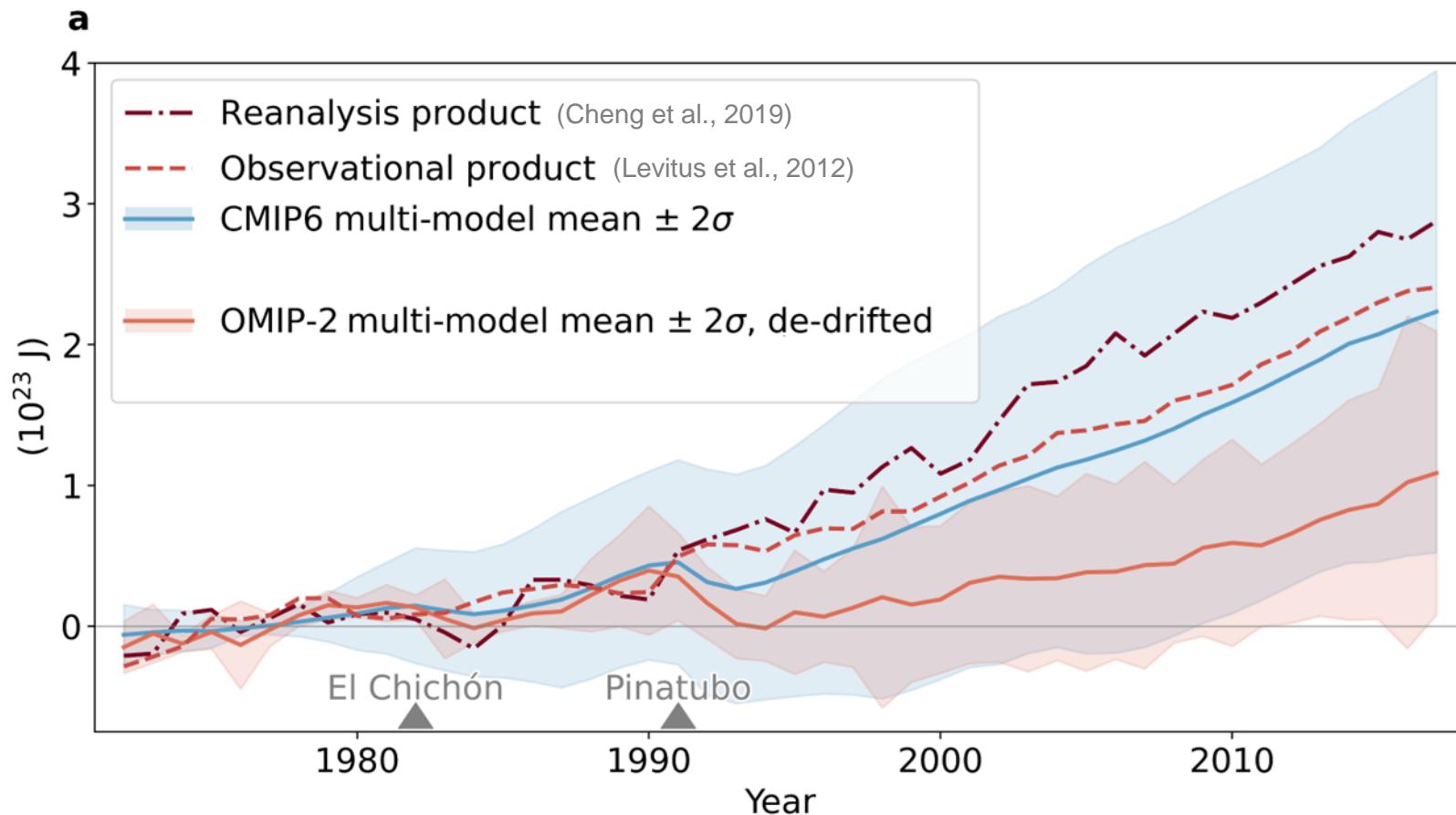
Global ocean heat content anomalies, 0-2000 m



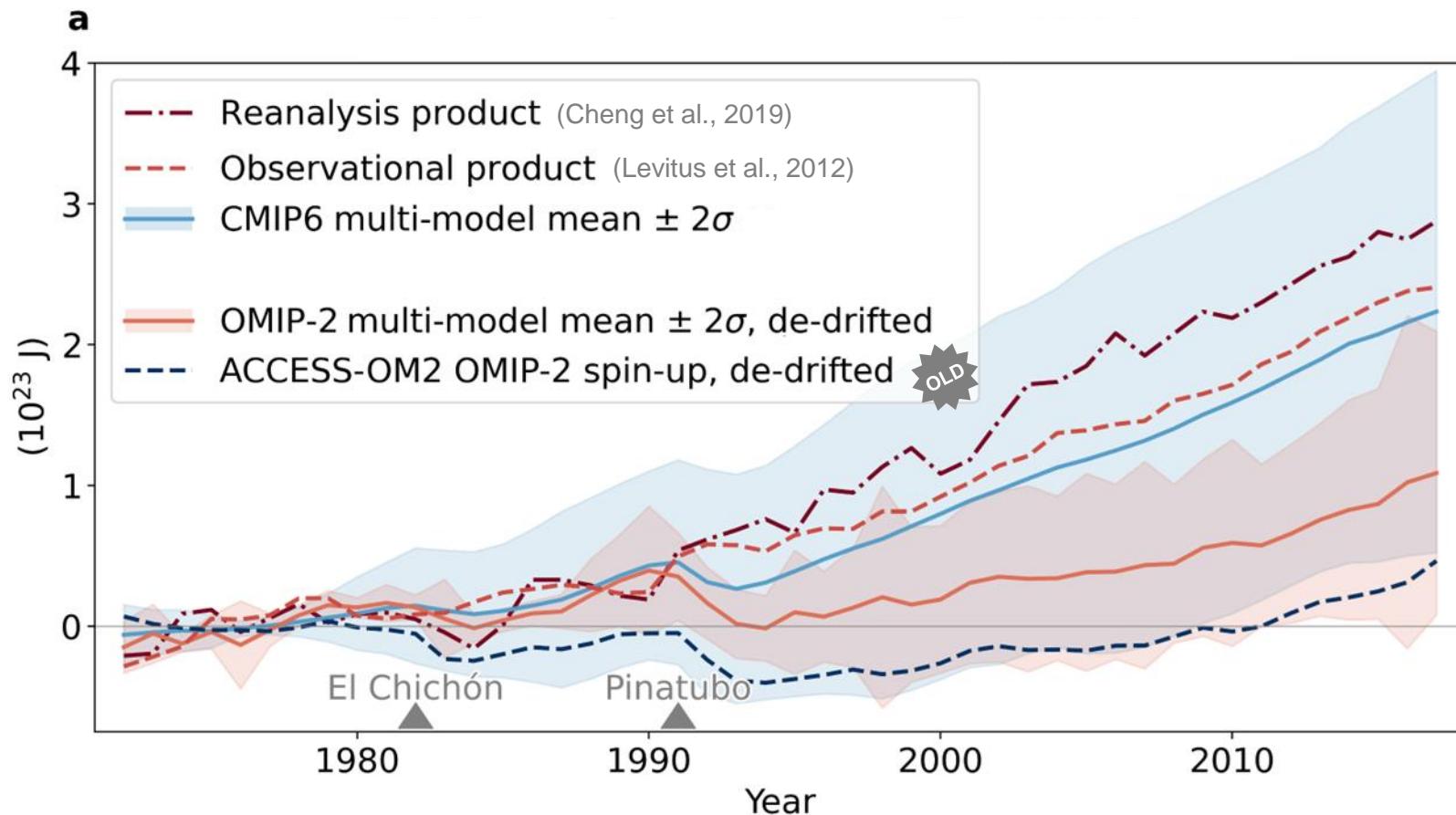
Global ocean heat content anomalies, 0-2000 m



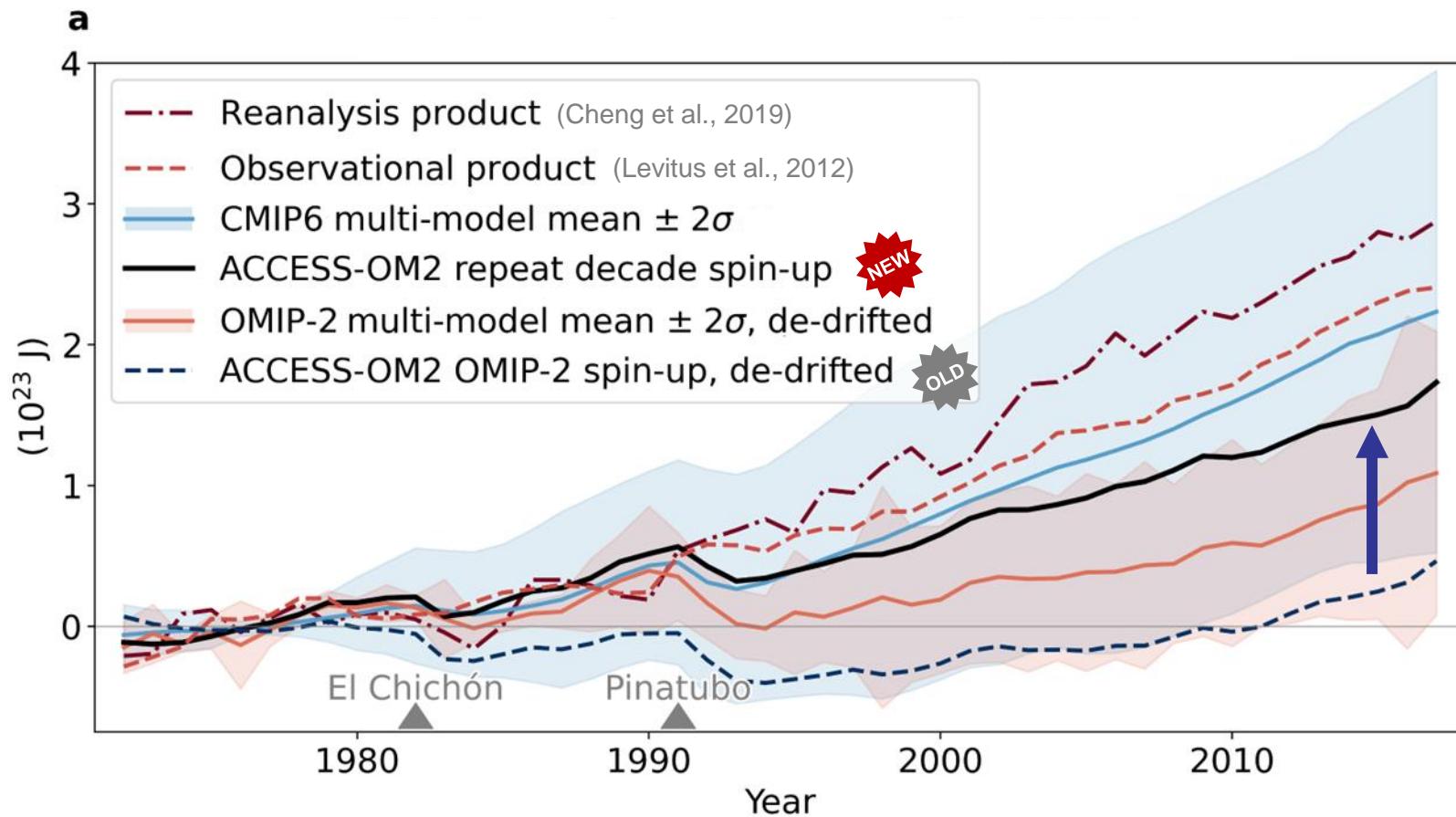
Global ocean heat content anomalies, 0-2000 m



Global ocean heat content anomalies, 0-2000 m

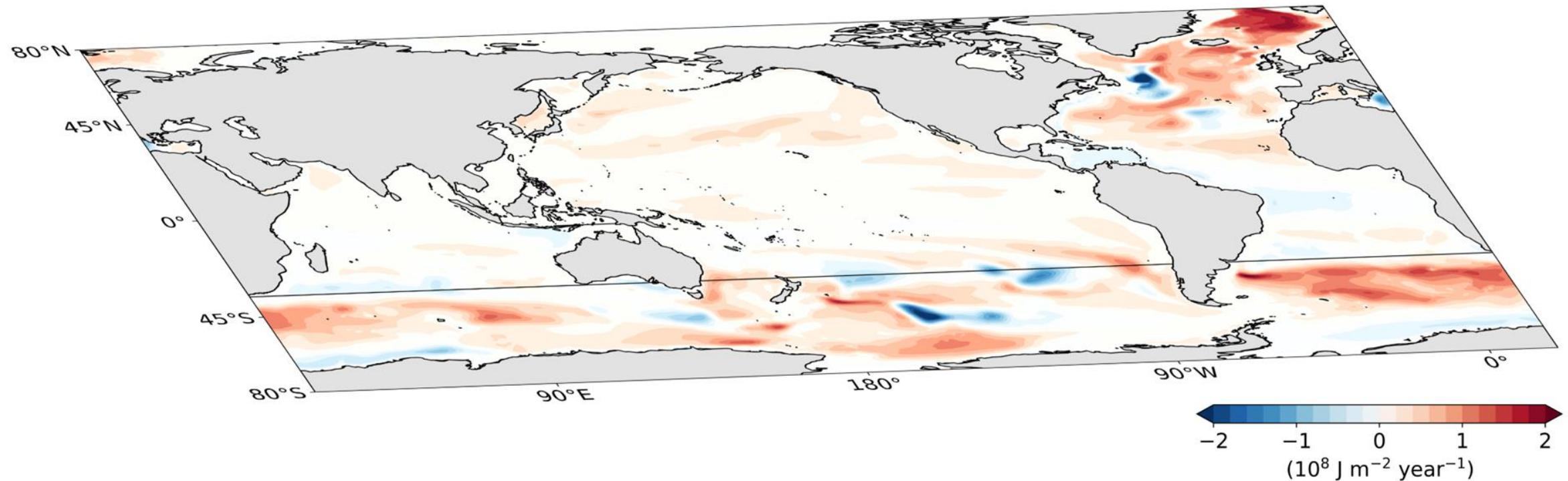


Global ocean heat content anomalies, 0-2000 m

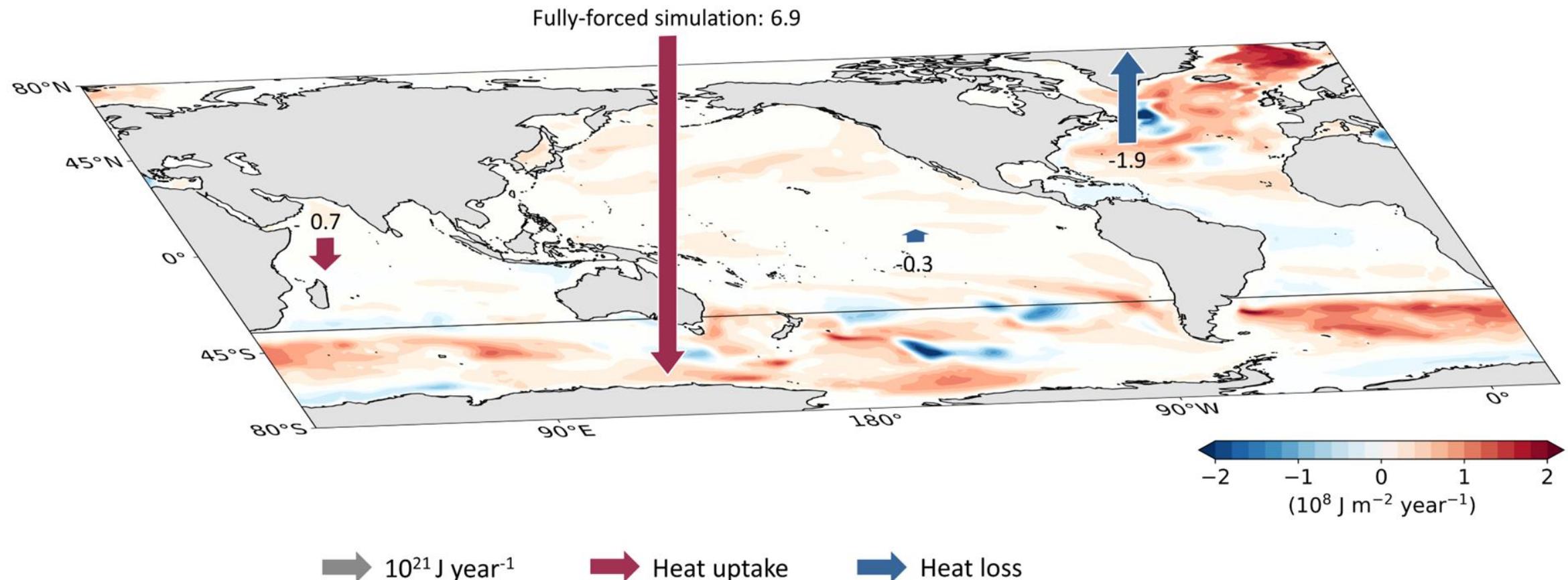


Schematic

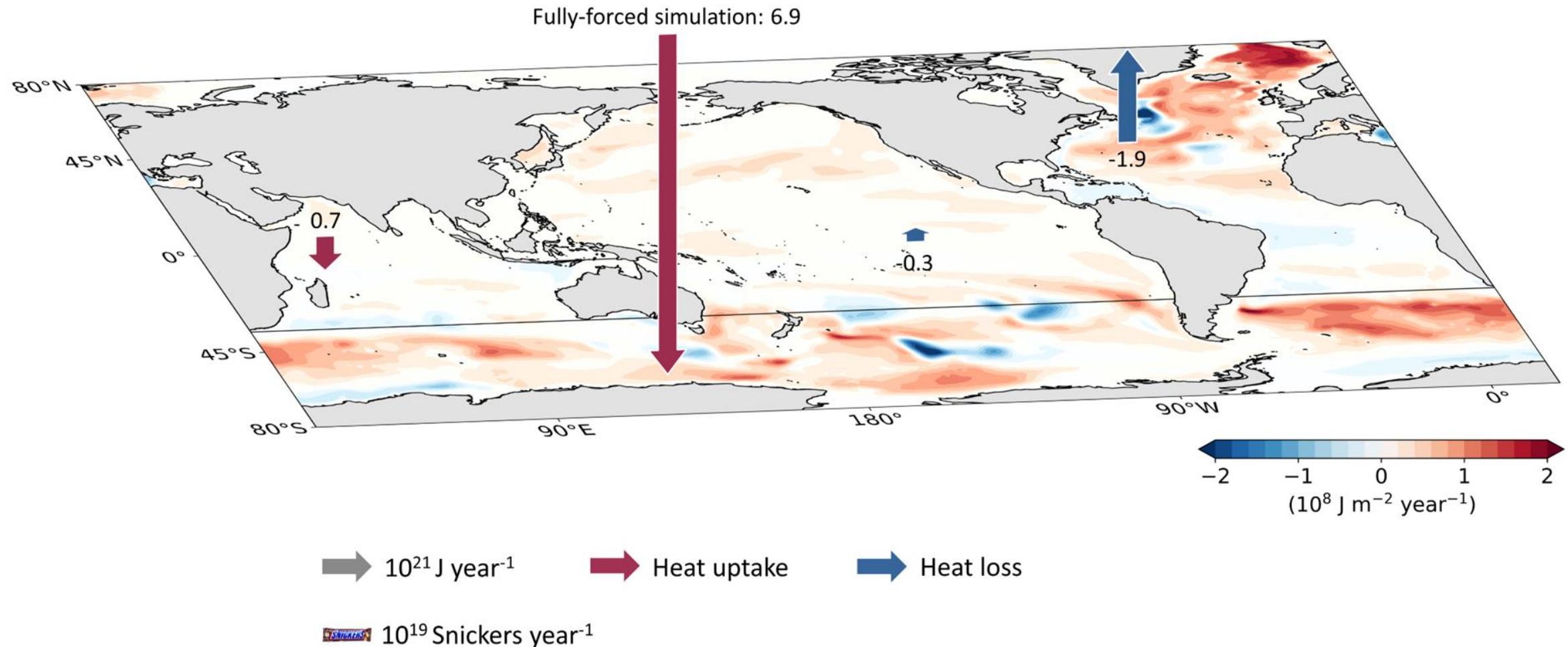
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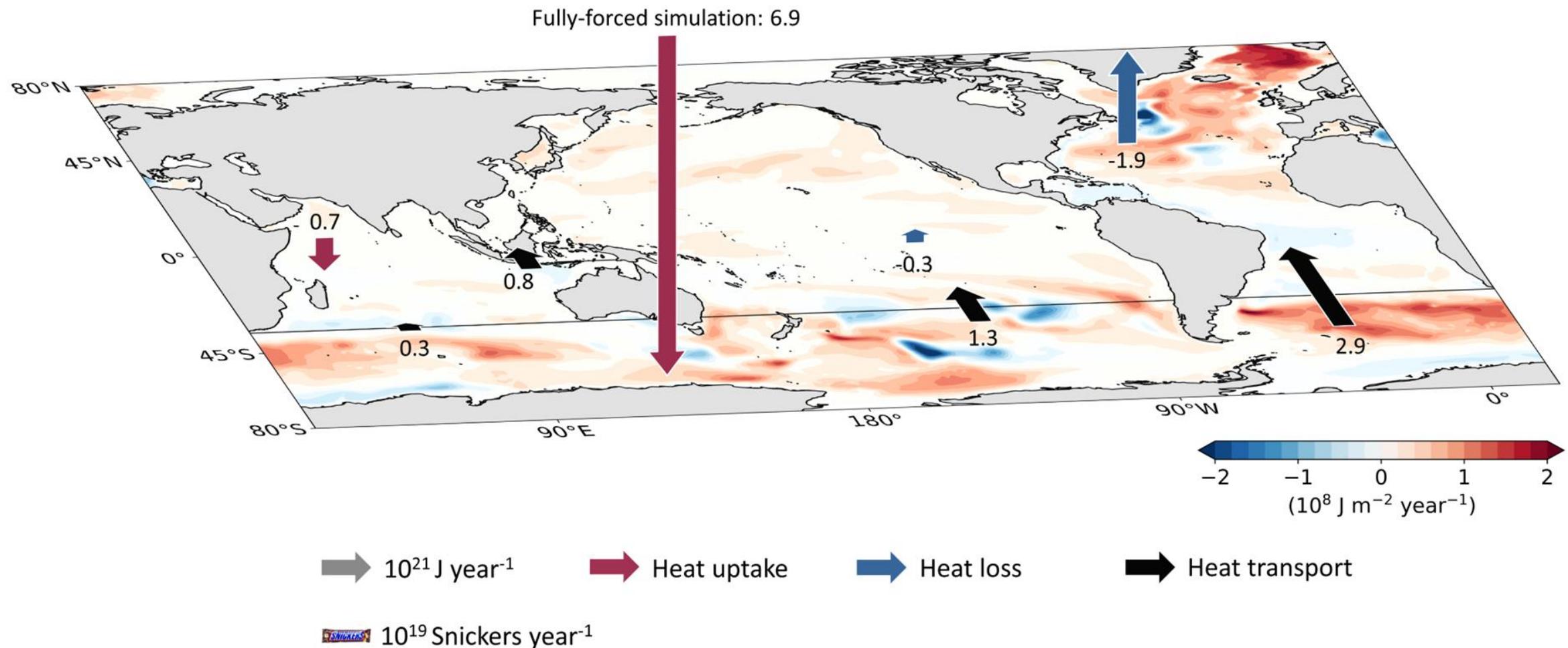
Schematic



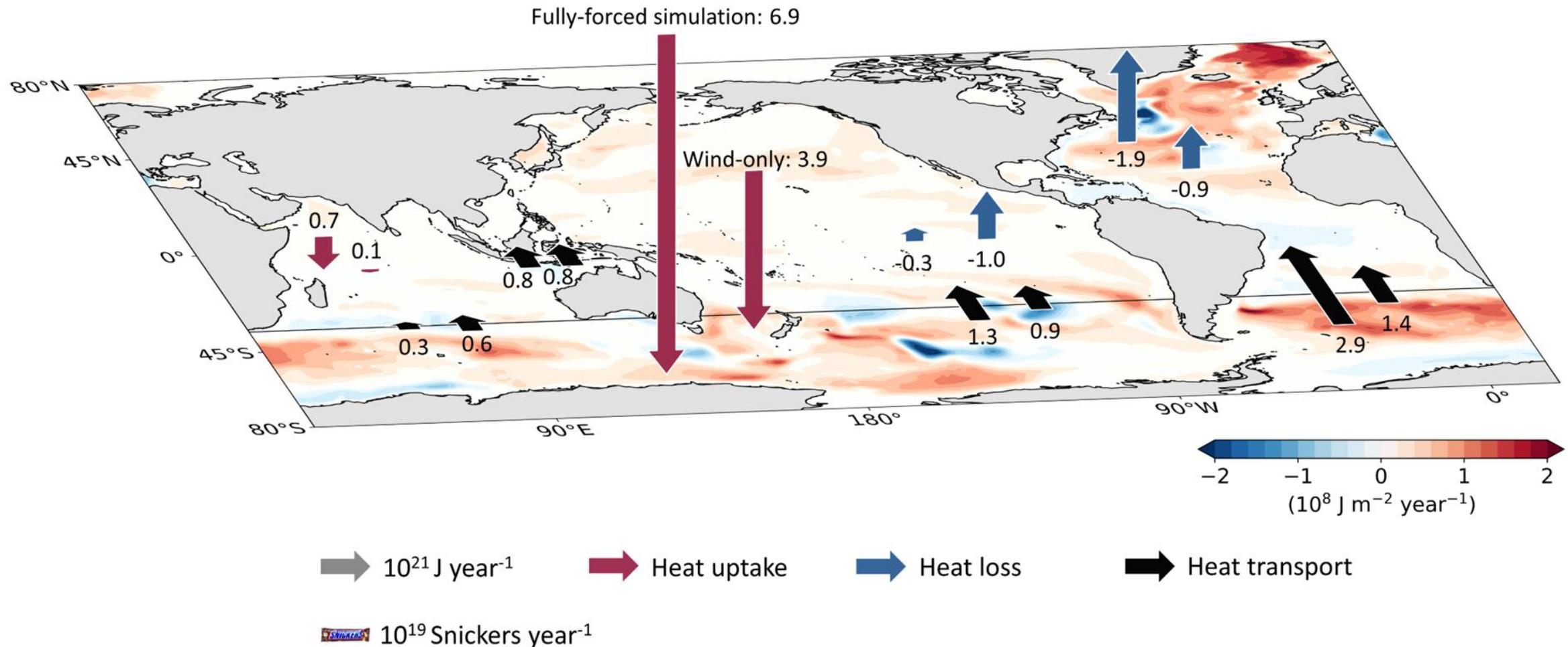
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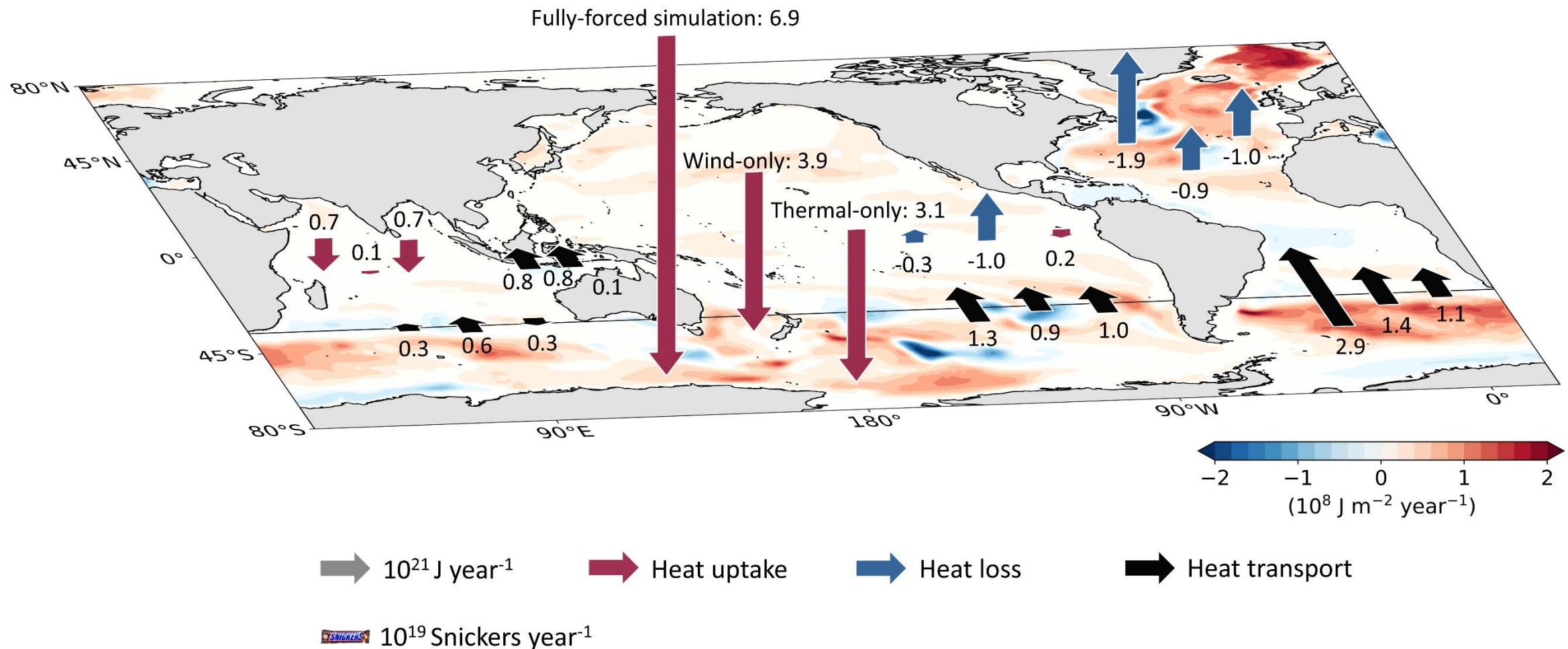
Schematic



Schematic



Schematic



7 April 2022

7 April 2022

```
rm -rf *
```

- deleted 12 TB of data
- everything from every project

7 April 2022

rm -rf *

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It's such a horrible feeling when you realise what you've done - but it's so common!

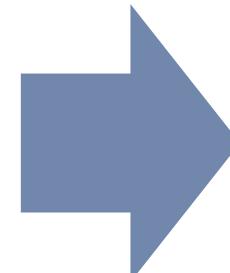
In addition to deleting a control run during my PhD, I also incorrectly ran an ensemble of runs last year. Luckily ESM1.5 is (relatively) cheap and fast to re-run...
but I felt ridiculous and like a modelling imposter who has no idea what they're doing. I messaged a friend (who's much better at running models than me!) and she was like "oh, don't worry, once I did something similar and ran a whole simulation with X set as -1 instead of 1" and I felt so much better! Hearing these stories make it so much more bearable I think!

Great to hear that you have got things going already and that your results are reproducible. I hope the run completes easily.

7 April 2022

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It's such a horrible feeling when you realise what you've done - but it's so common! In addition to deleting a control run during my PhD, I also incorrectly ran an ensemble of runs last year. Luckily ESM1.5 is (relatively) cheap and fast to re-run... but I felt ridiculous and like a modelling imposter who has no idea what they're doing. I messaged a friend (who's much better at running models than me!) and she was like "oh, don't worry, once I did something similar and ran a whole simulation with X set as -1 instead of 1" and I felt so much better! Hearing these stories make it so much more bearable I think!

Great to hear that you have got things going already and that your results are reproducible. I hope the run completes easily.

[Menu](#)

THE CONVERSATION



Shutterstock

The Southern Ocean absorbs more heat than any other ocean on Earth, and the impacts will be felt for generations

Published: September 7, 2022 7.18pm AEST

 Maurice Huguenin, UNSW Sydney, Matthew England, UNSW Sydney, Ryan Holmes, University of Sydney

 46,342  0   

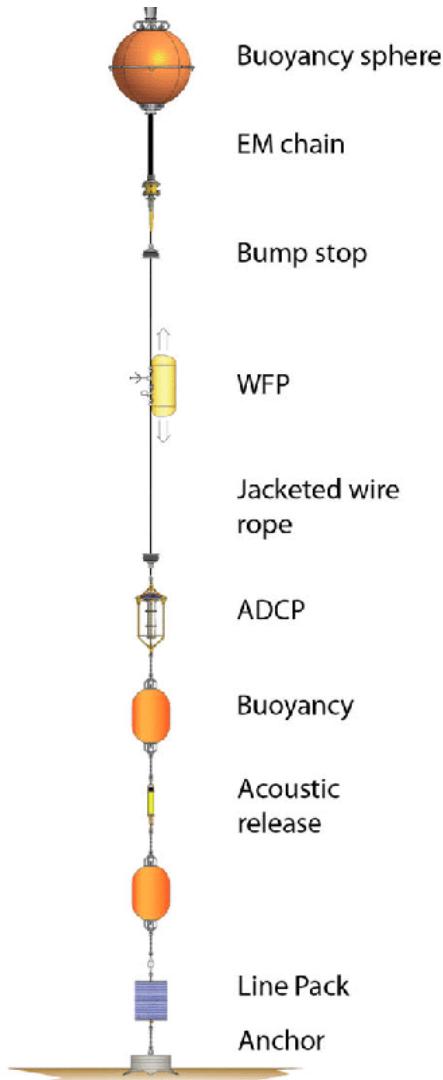
Cruise break



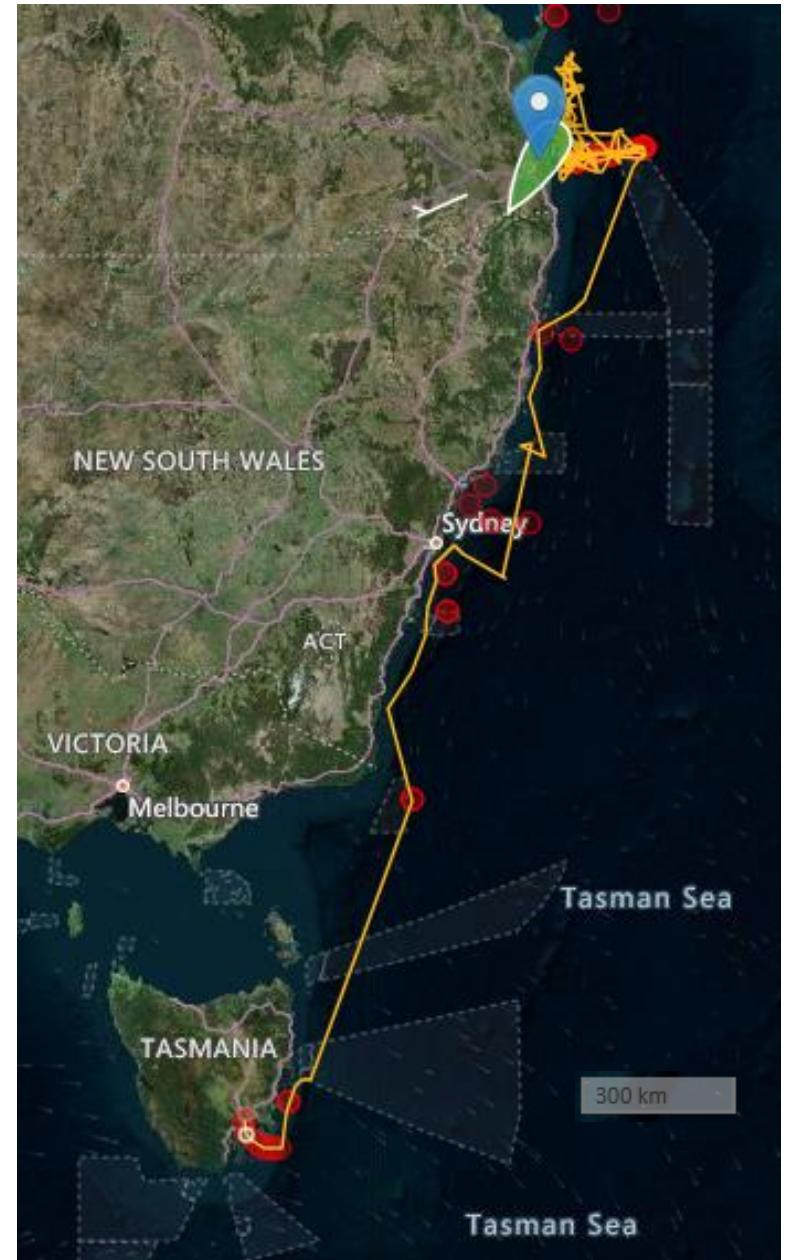


UNSW
SYDNEY

Cruise break



Thanks Amandine Schaeffer,
Chris Chapman & Iain Suthers





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in Antarctic Science

Subsurface warming of the West Antarctic continental shelf linked to El Niño events

Maurice F. Huguenin, Ryan M. Holmes, Paul Spence and
Matthew H. England

Geophysical Research Letters

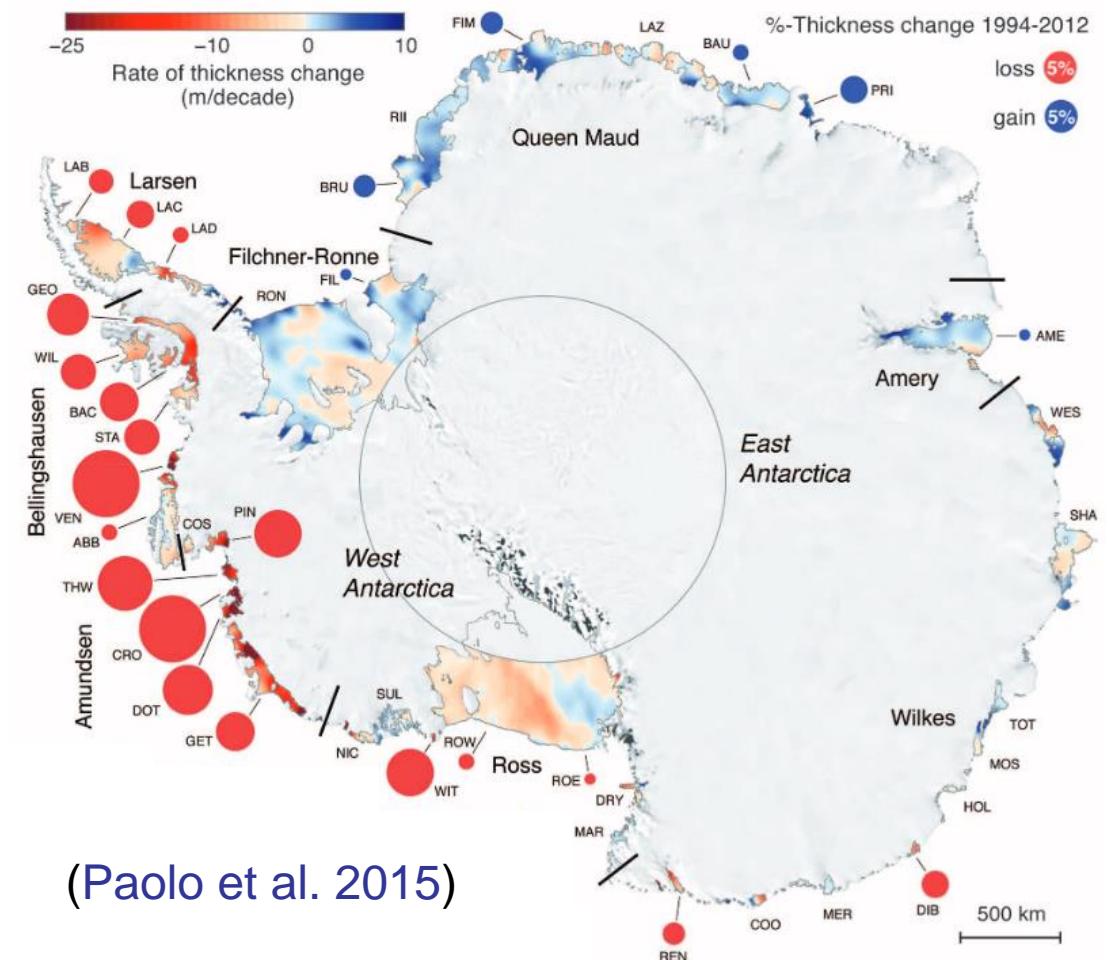


The Australian Centre for Excellence in Antarctic Science is a
Special Research Initiative funded by the Australian Research Council



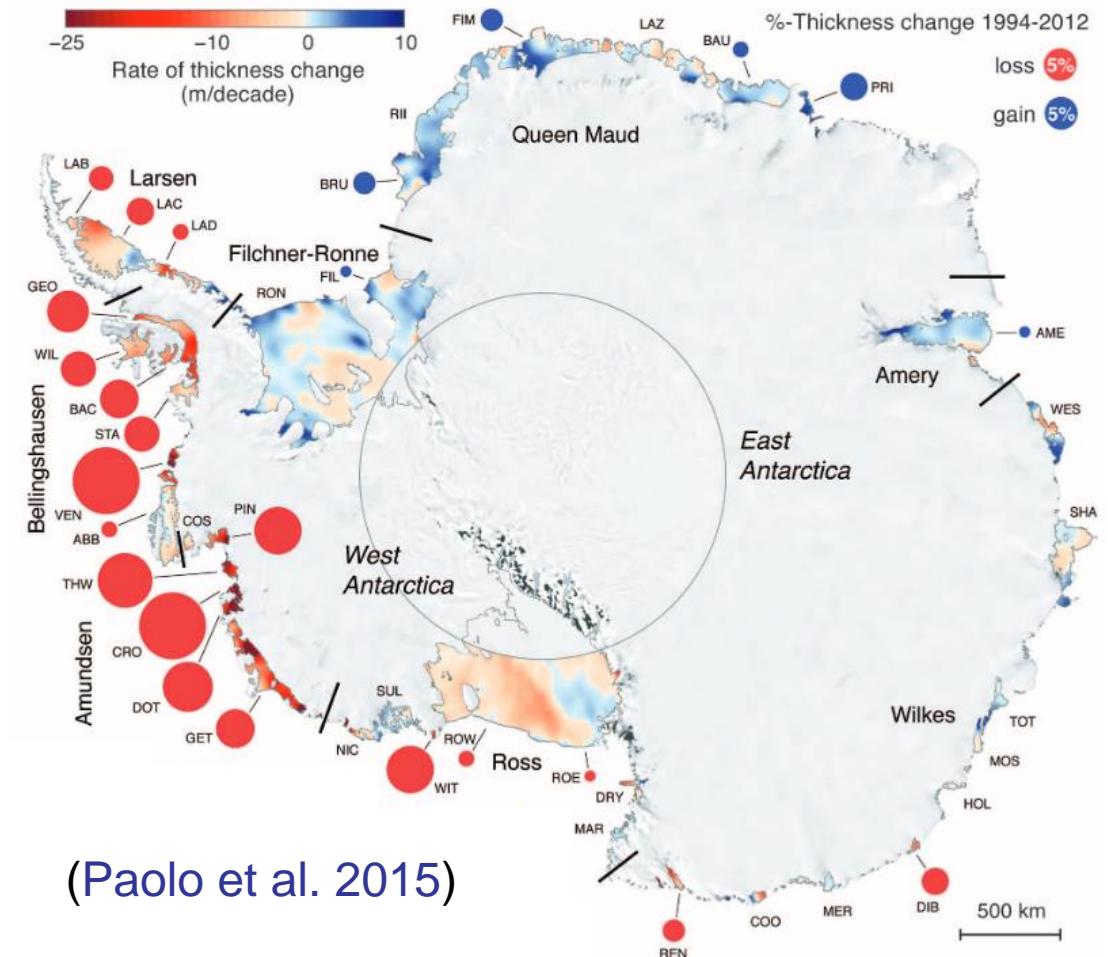
This research was supported by the Australian Research Council Special Research
Initiative, Australian Centre for Excellence in Antarctic Science (Project Number
SR200100008)

Background



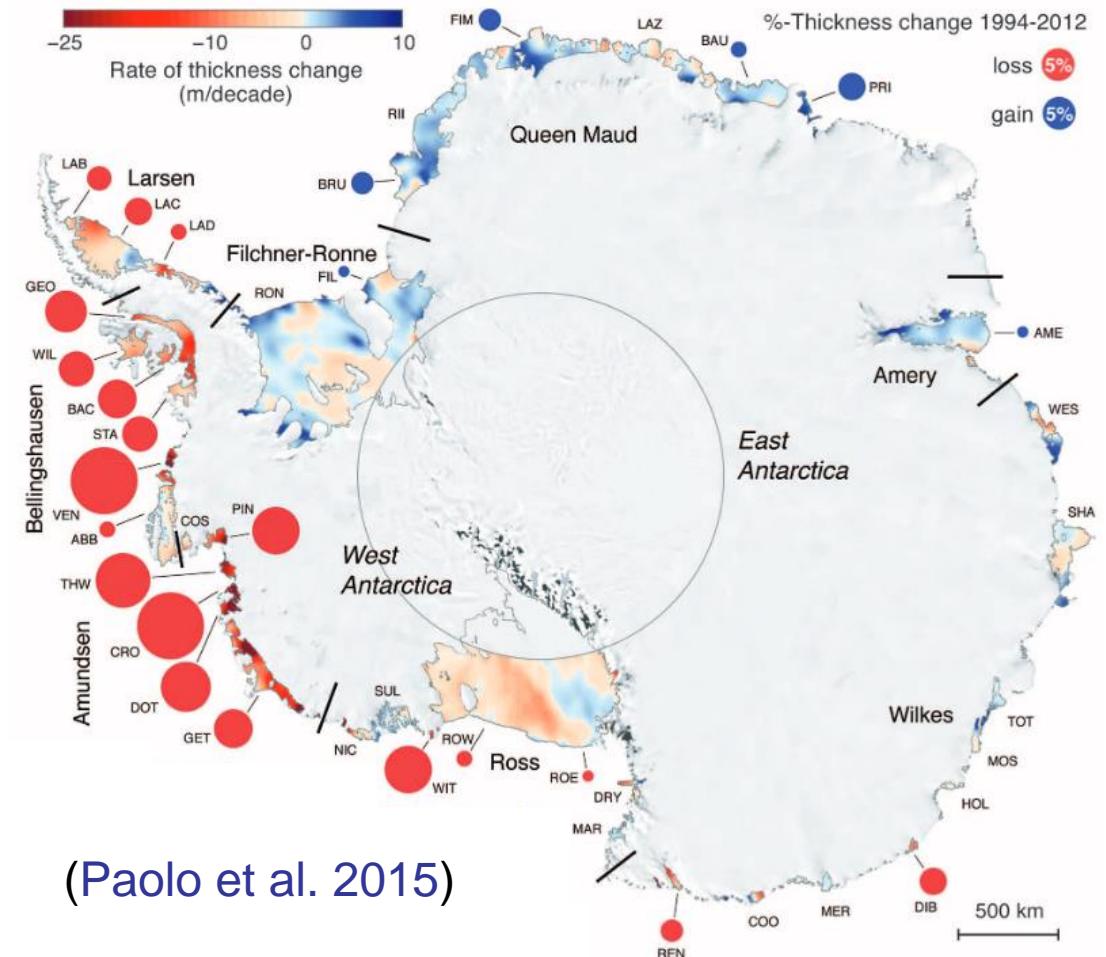
Background

- Volume loss from Antarctic ice shelves is accelerating ([Paolo et al. 2015](#))



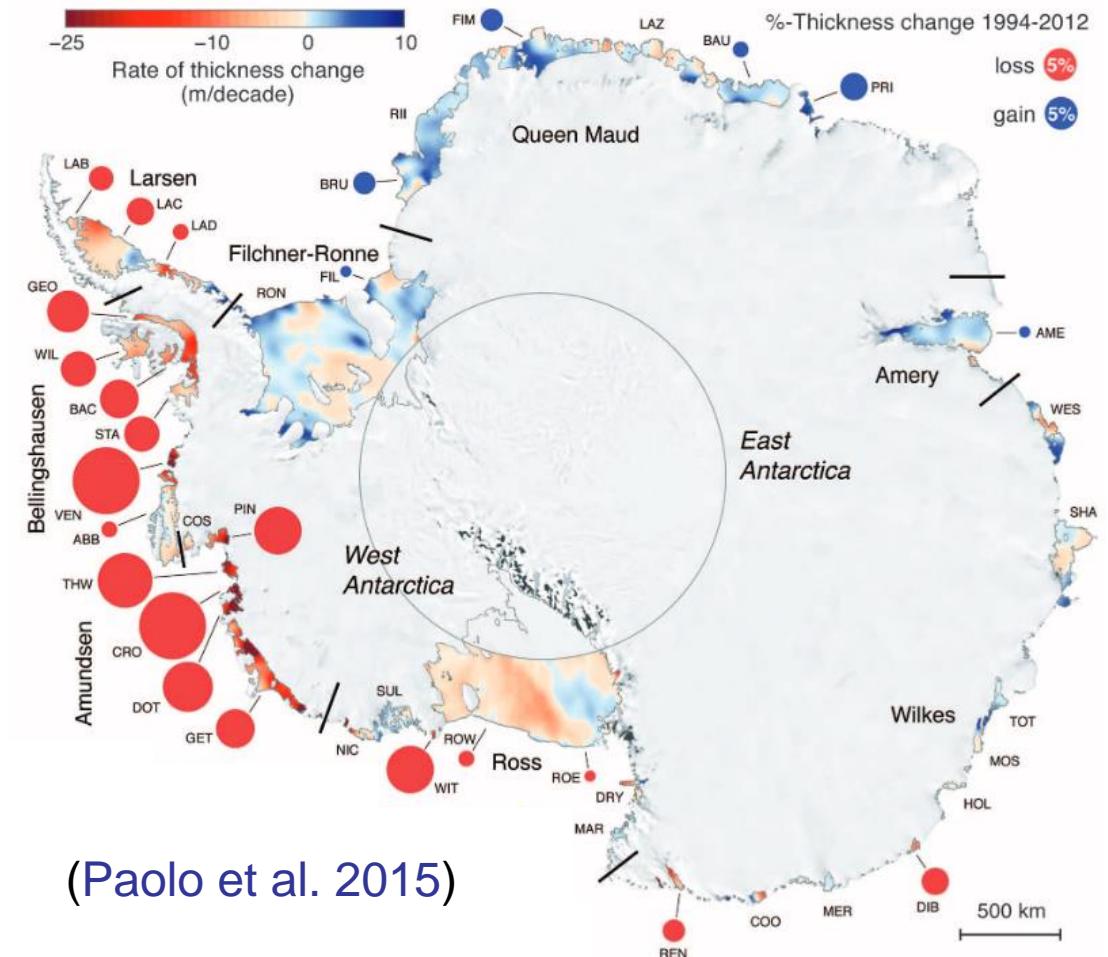
Background

- Volume loss from Antarctic ice shelves is accelerating ([Paolo et al. 2015](#))
- Ice loss influenced by internal climate variability and anthropogenic forcing ([Holland et al. 2019](#))



Background

- Volume loss from Antarctic ice shelves is accelerating (Paolo et al. 2015)
- Ice loss influenced by internal climate variability and anthropogenic forcing (Holland et al. 2019)
- El Niño: ↑height but ↓mass of West Antarctic ice shelves (Paolo et al. 2018)



The questions

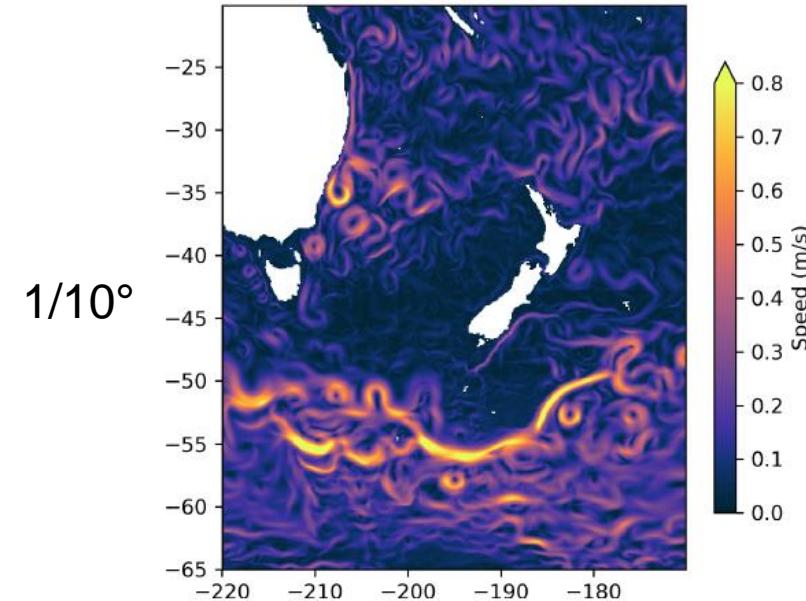
- How do El Niño & La Niña impact the West Antarctic shelf circulation?
- What processes are responsible for warming and cooling on the shelf?

The questions

- How do El Niño & La Niña impact the West Antarctic shelf circulation?
- What processes are responsible for warming and cooling on the shelf?

The method

- ACCESS-OM2 ([Kiss et al. 2020](#))
 - 1/10° configuration
 - JRA55-do reanalysis ([Tsujino et al. 2018](#))



Kiss et al. (2019)

- Repeat-year forcing spin-up
- ENSO anomalies on top

Forcing for the idealised simulations

Repeat-year forcing [t , x , y]

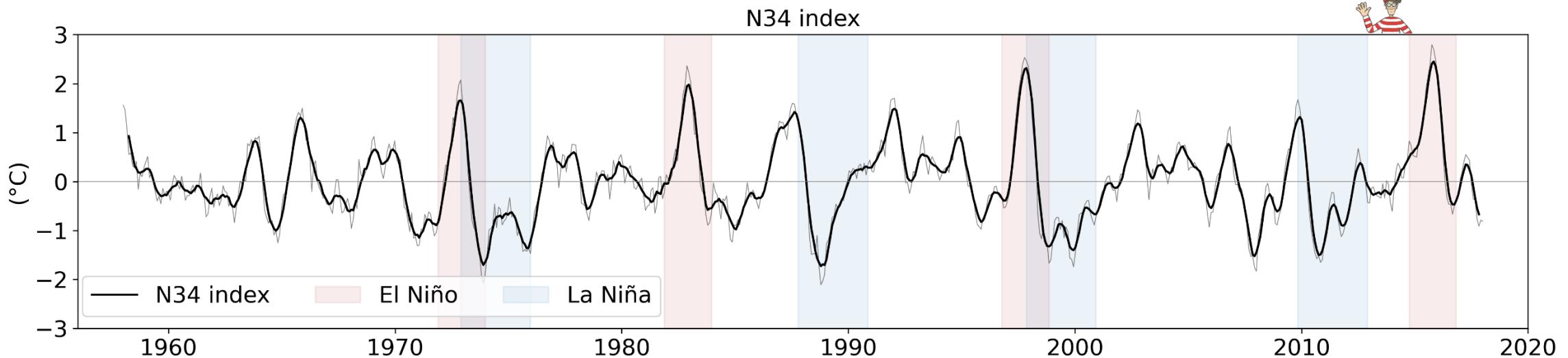
Forcing for the idealised simulations

Repeat-year forcing [t, x, y]

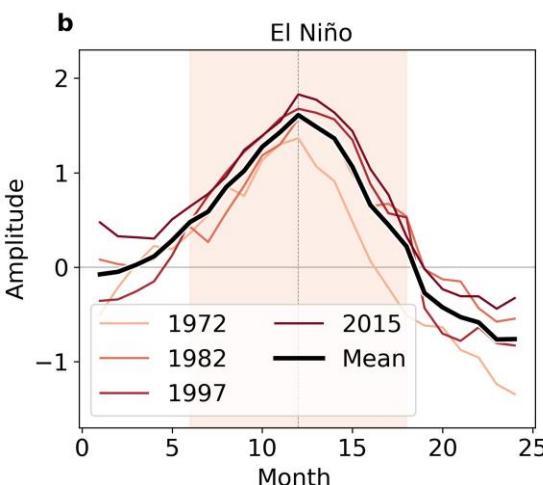
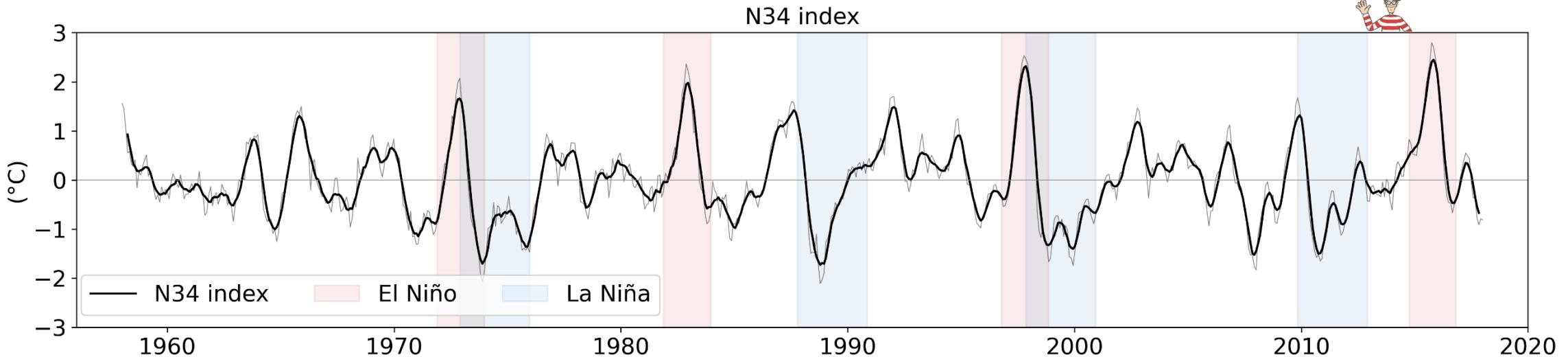
+

ENSO anomalies (time series [t] \times spatial pattern [x,y])

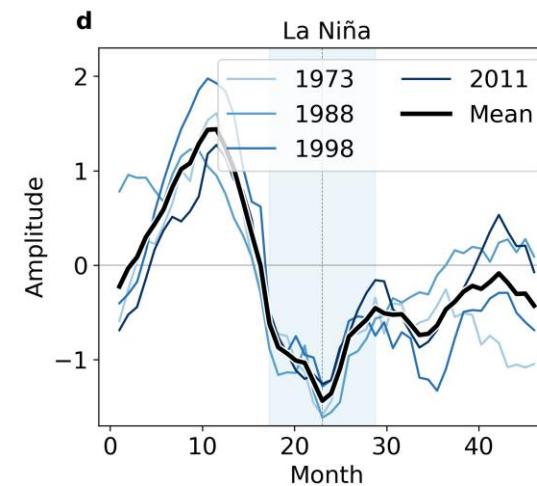
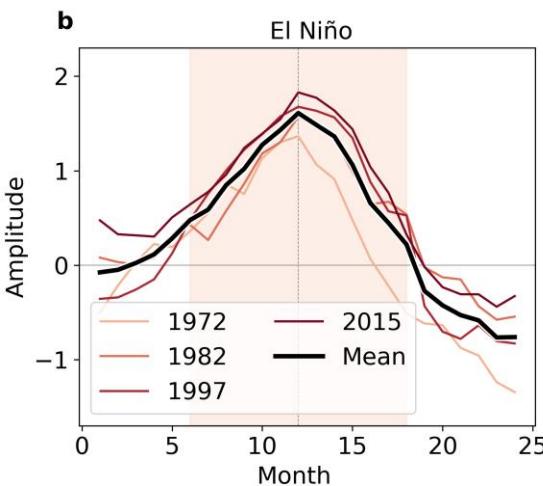
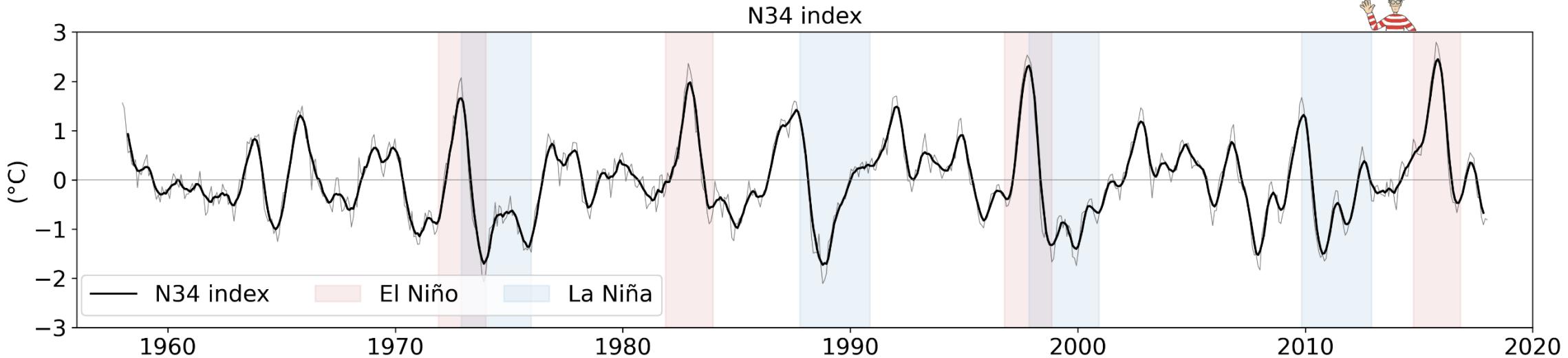
Forcing for the idealised simulations



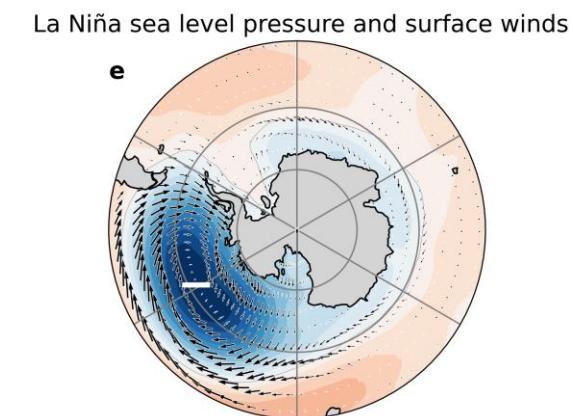
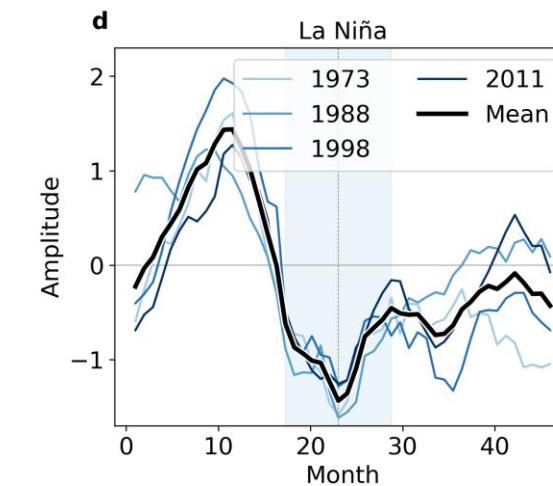
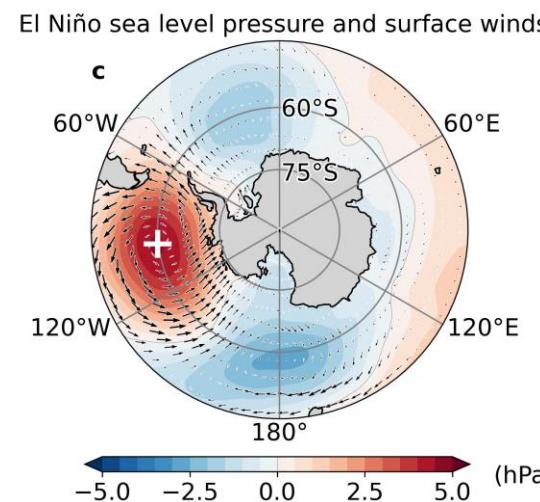
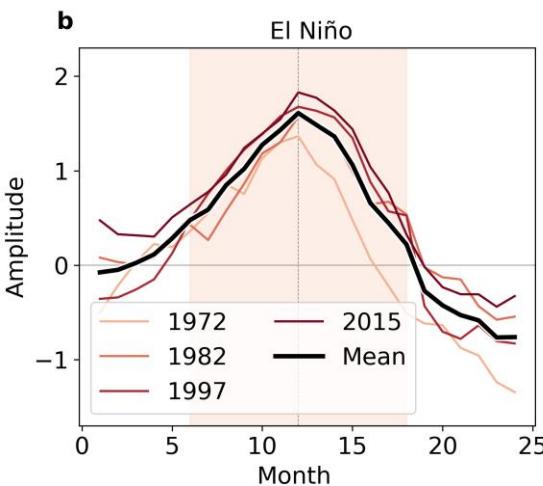
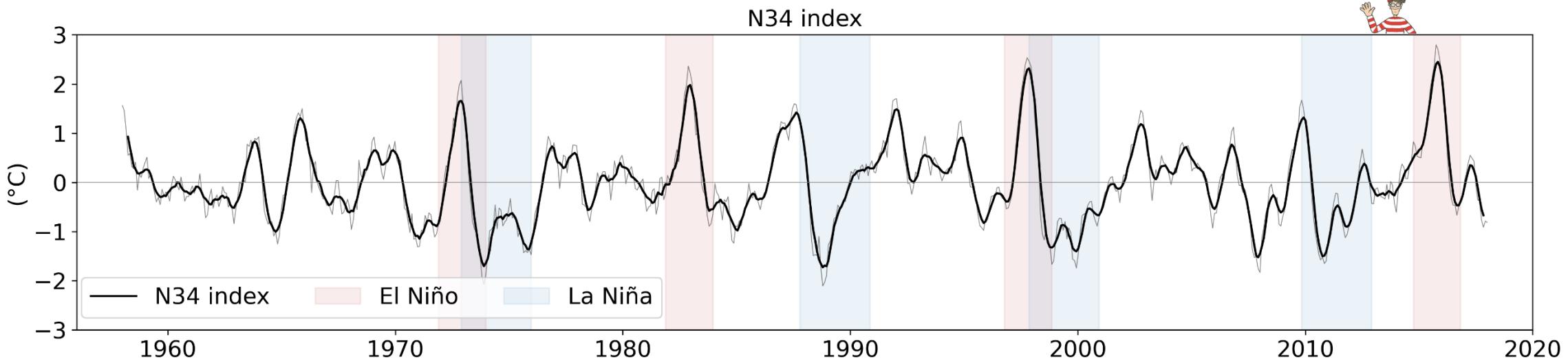
Forcing for the idealised simulations



Forcing for the idealised simulations

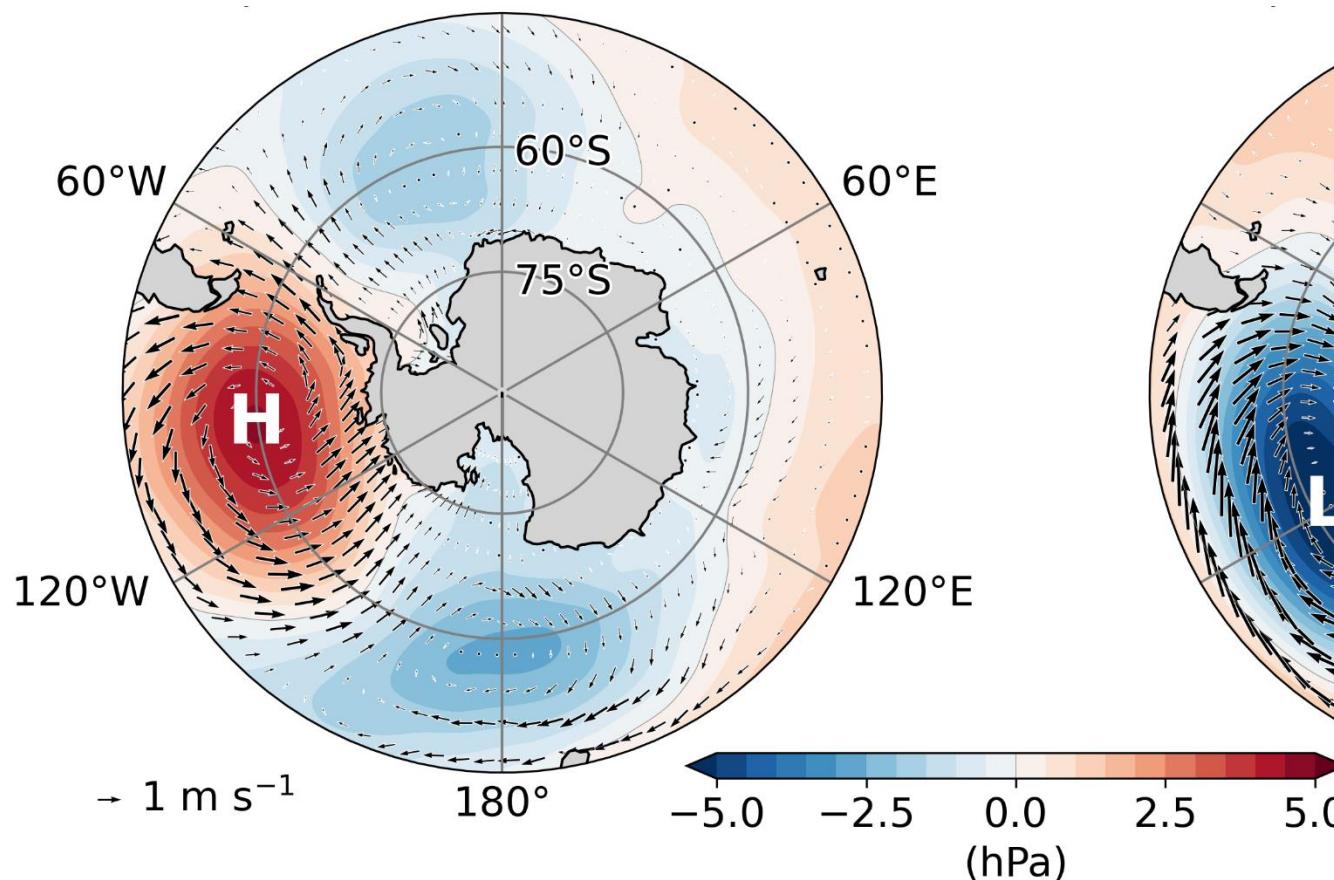


Forcing for the idealised simulations

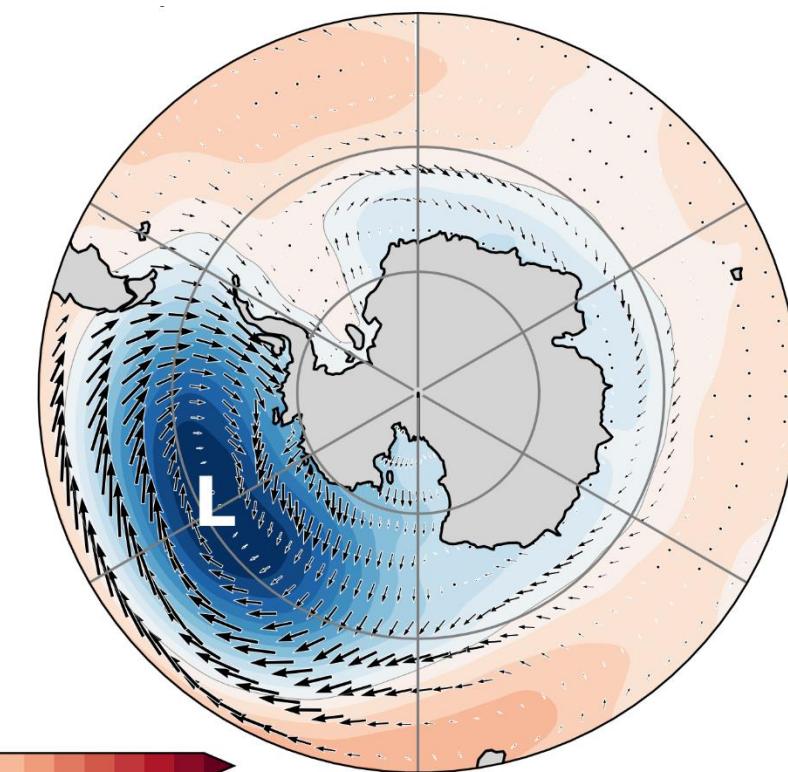


Forcing for the idealised simulations

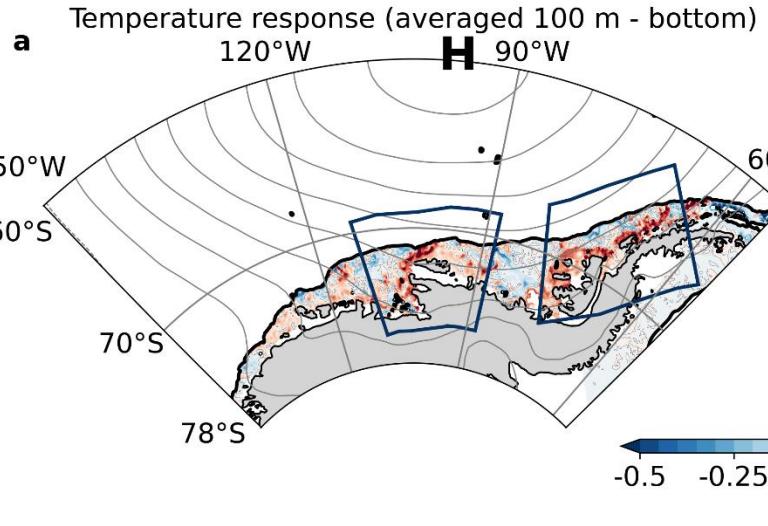
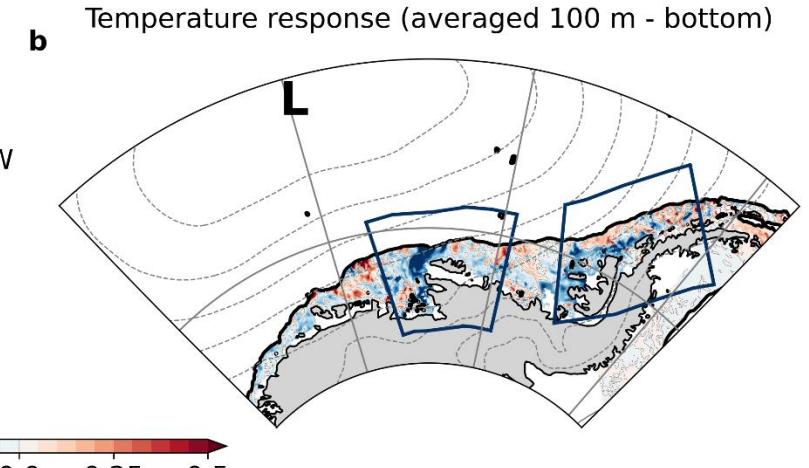
El Niño sea level pressure and surface winds



La Niña



Shelf response to ENSO forcing

El Niño simulation**La Niña simulation**

isopycnals

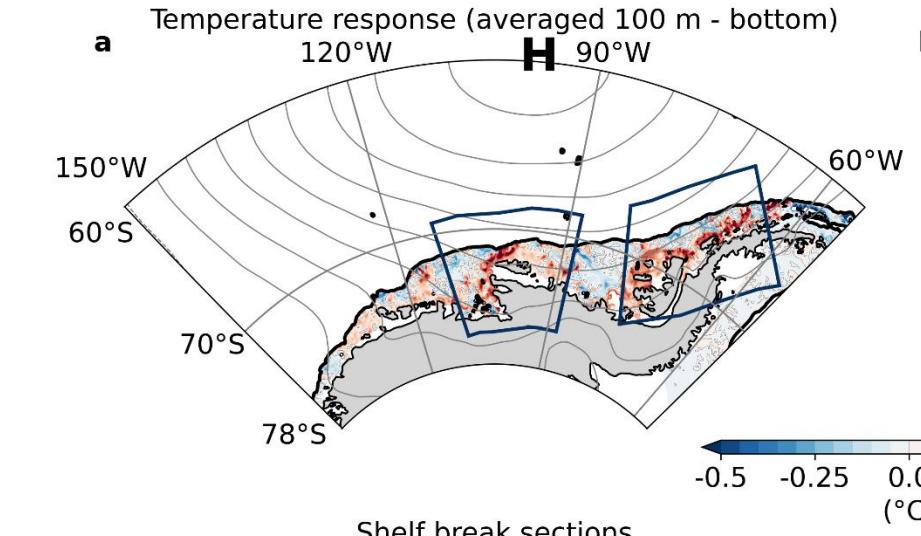
0°C isotherm

Shelf response to ENSO forcing

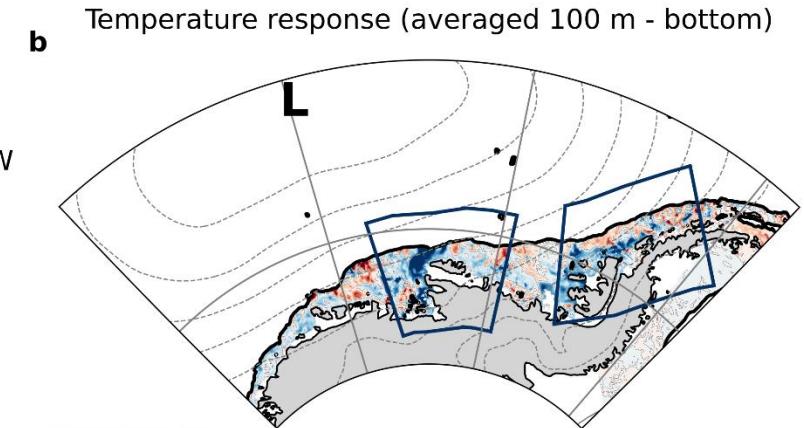
isopycnals

0°C isotherm

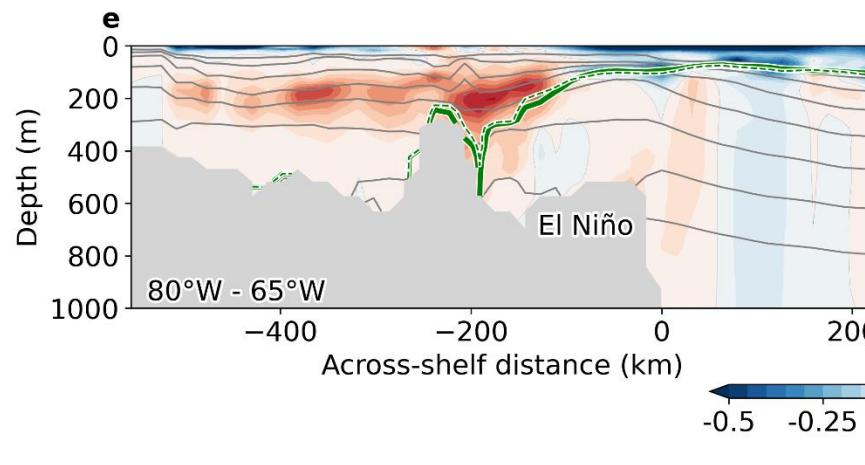
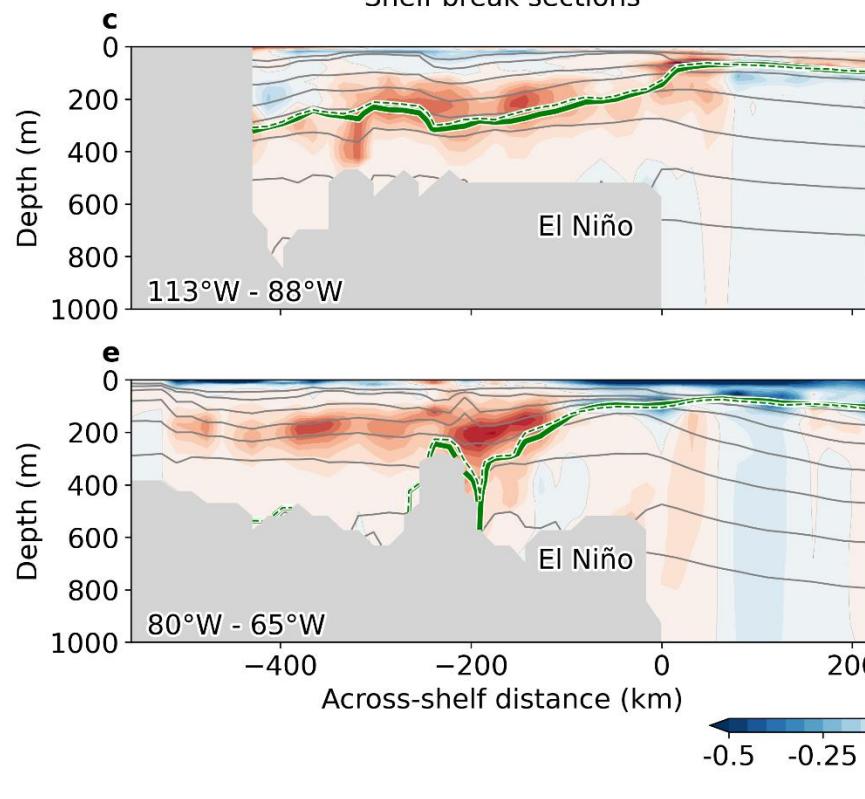
El Niño simulation



La Niña simulation



Shelf break sections

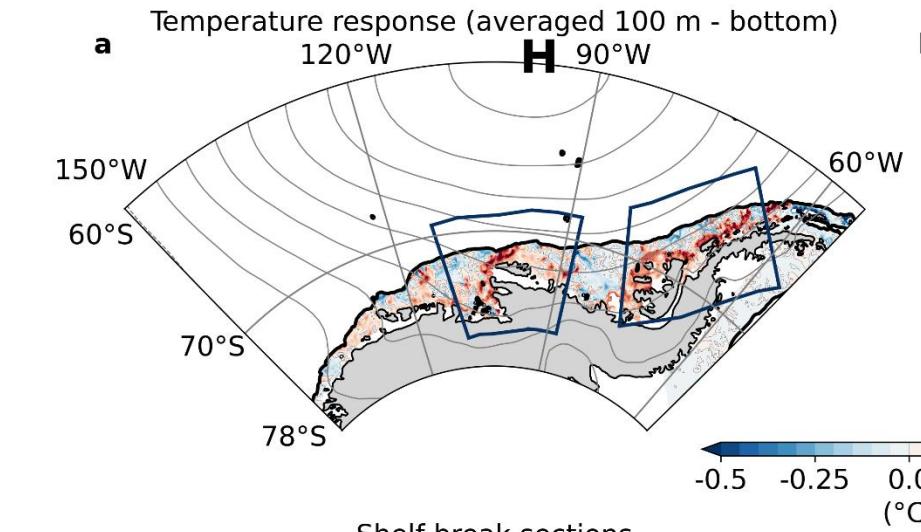


Shelf response to ENSO forcing

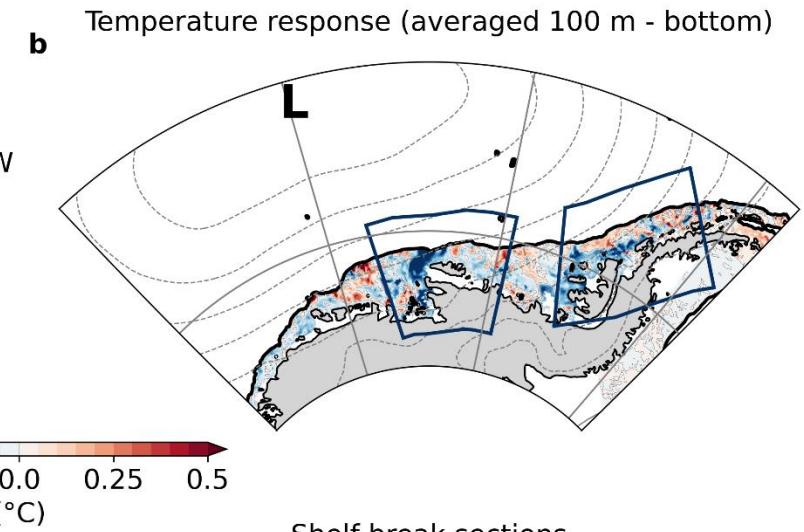
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0°C isotherm

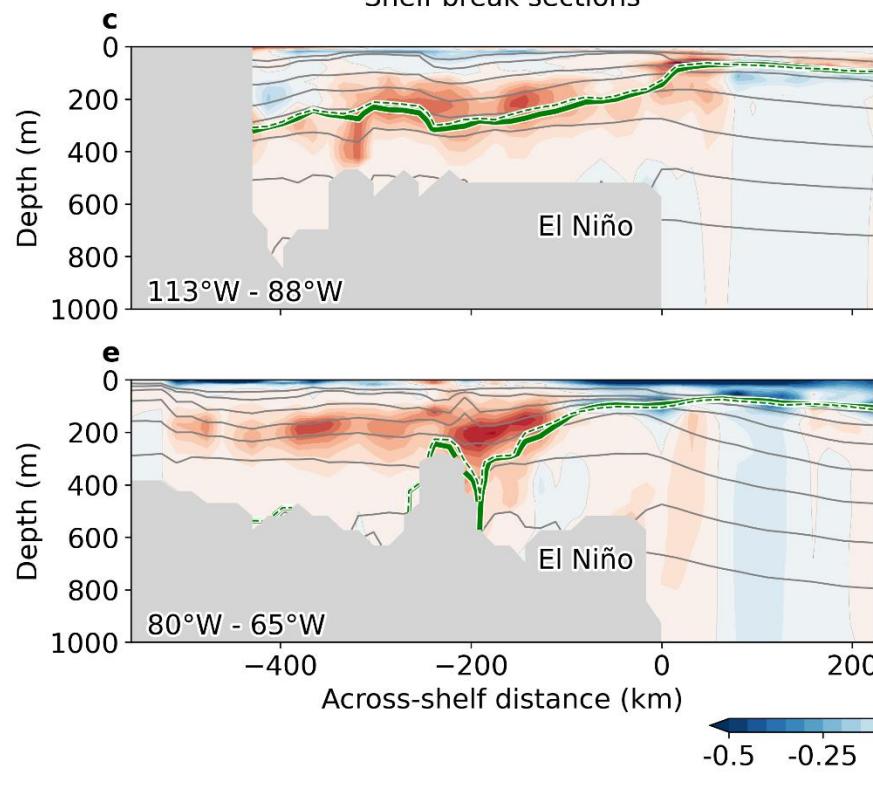
El Niño simulation



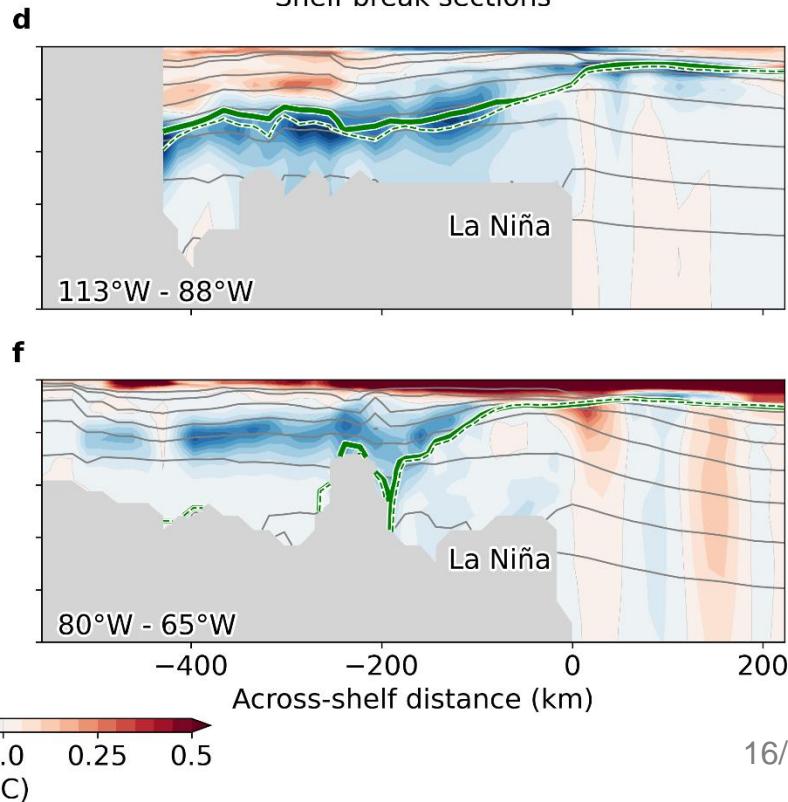
La Niña simulation



Shelf break sections



Shelf break sections

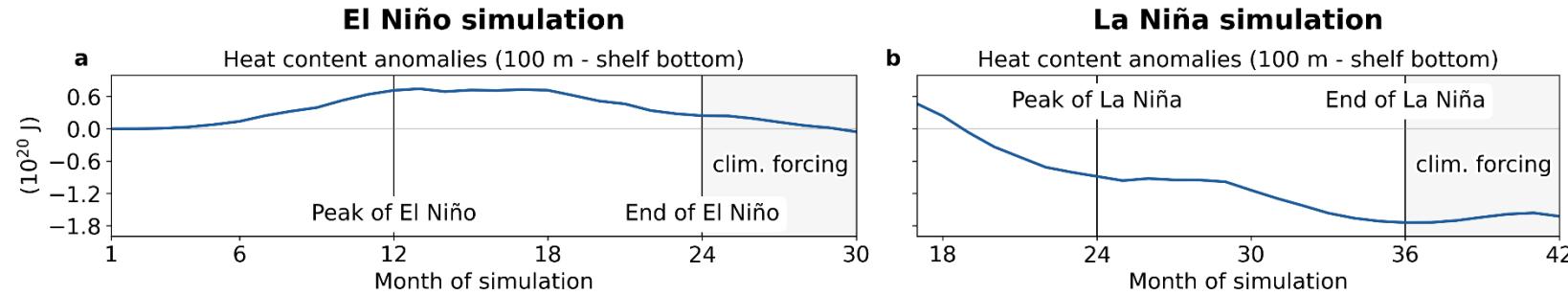
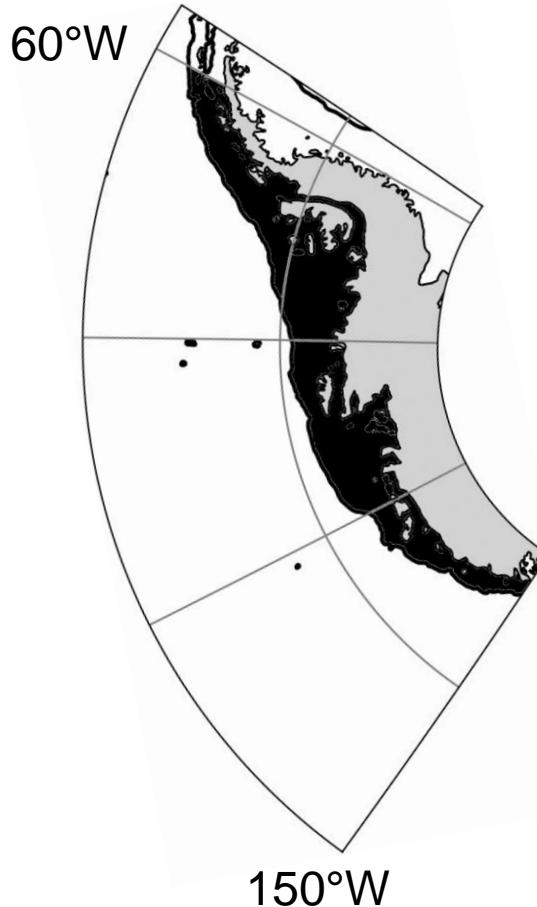


El Niño

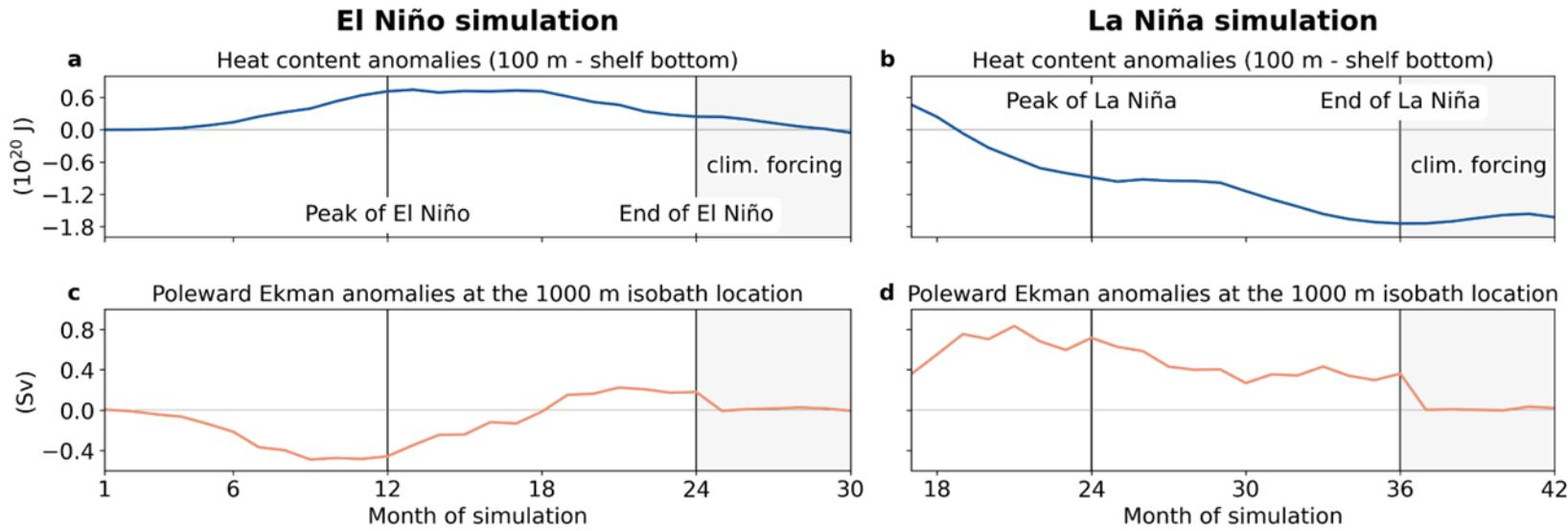
La Niña

The subsurface heat budget

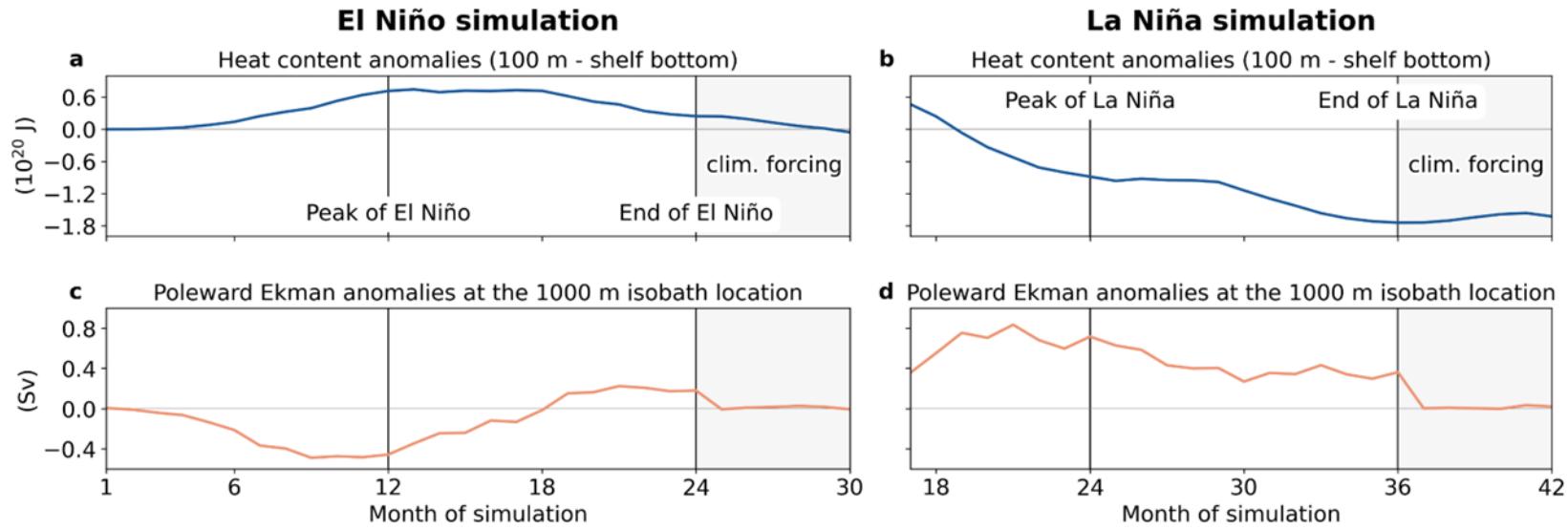
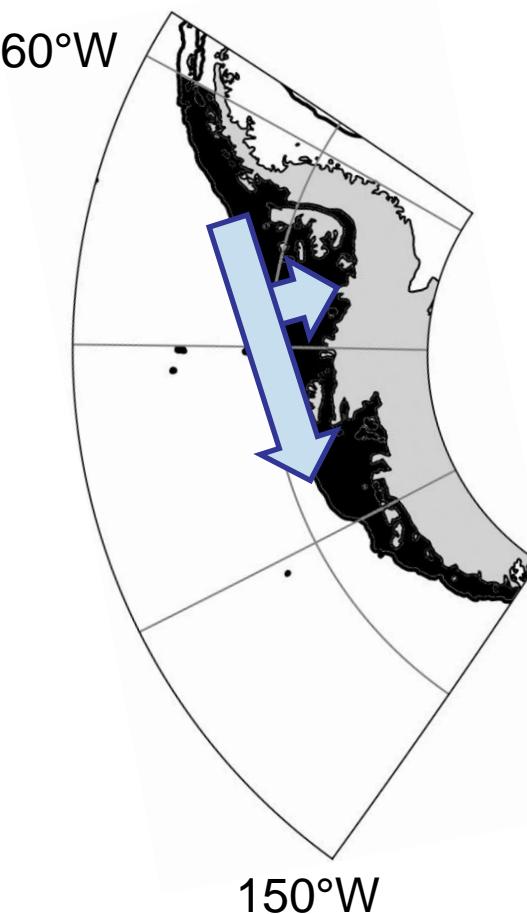
The subsurface heat budget



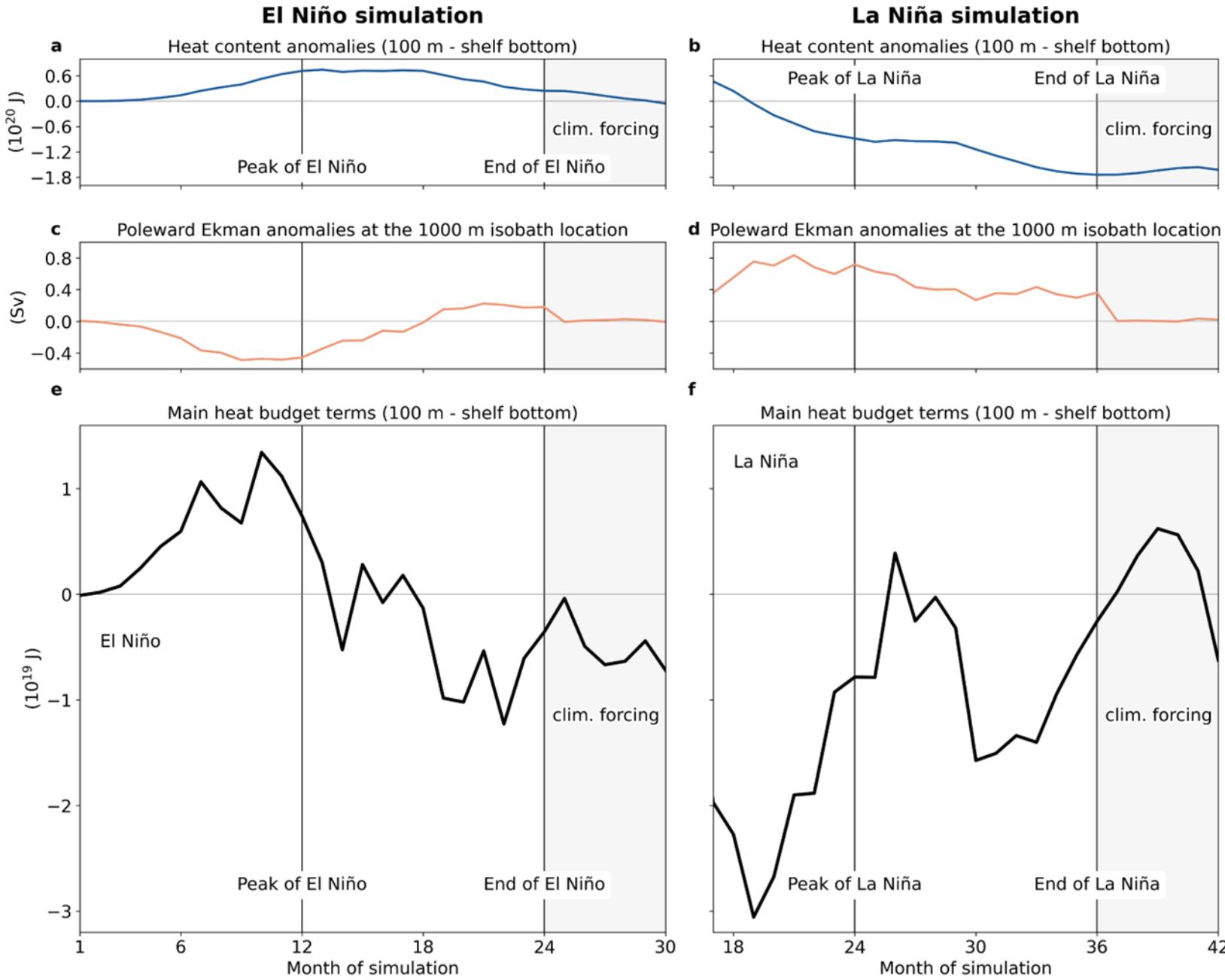
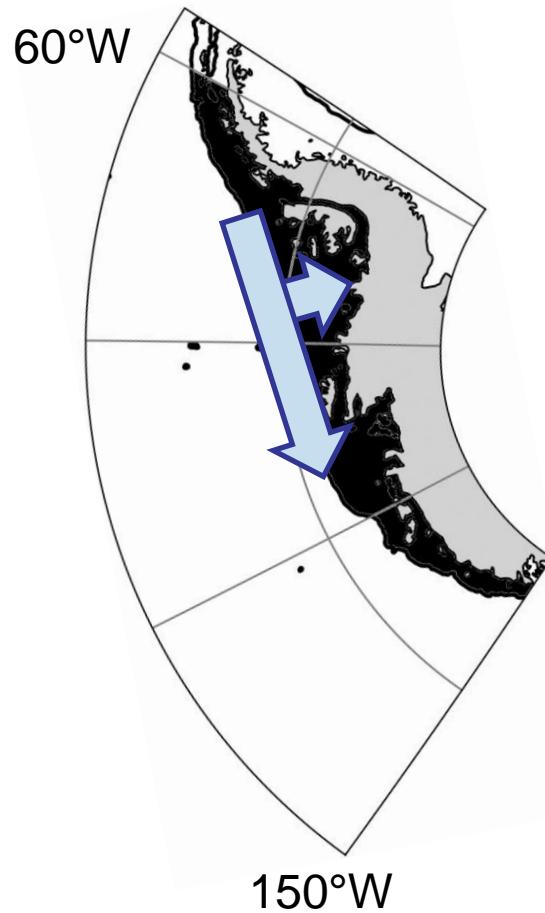
The subsurface heat budget



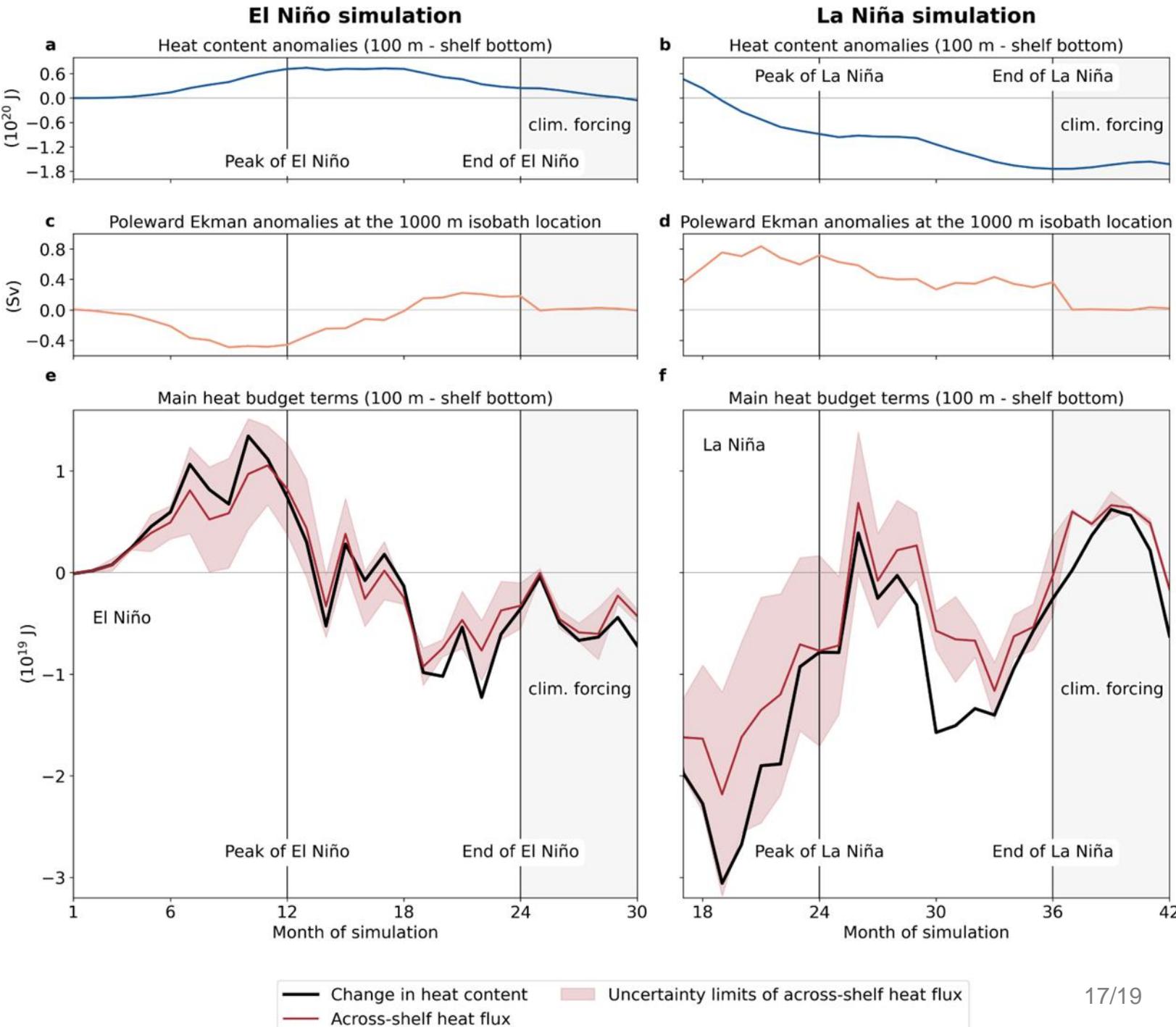
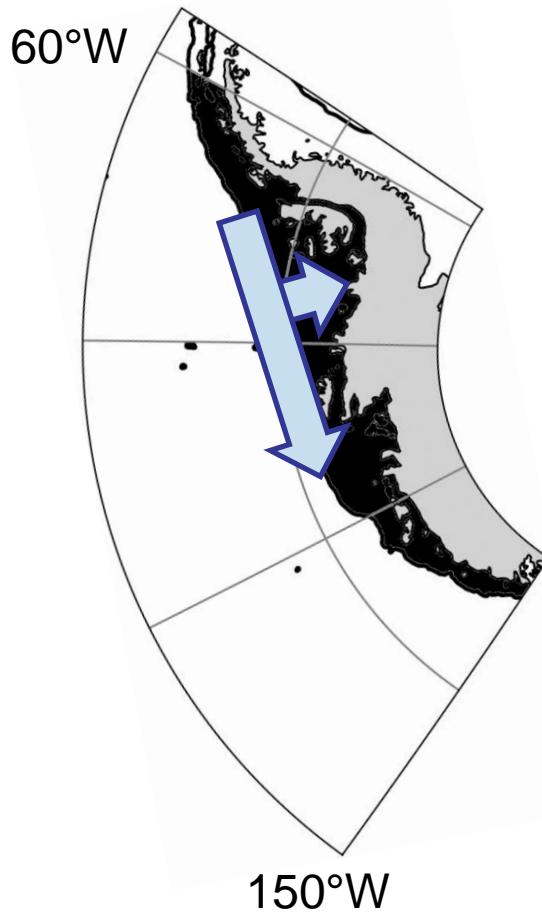
The subsurface heat budget



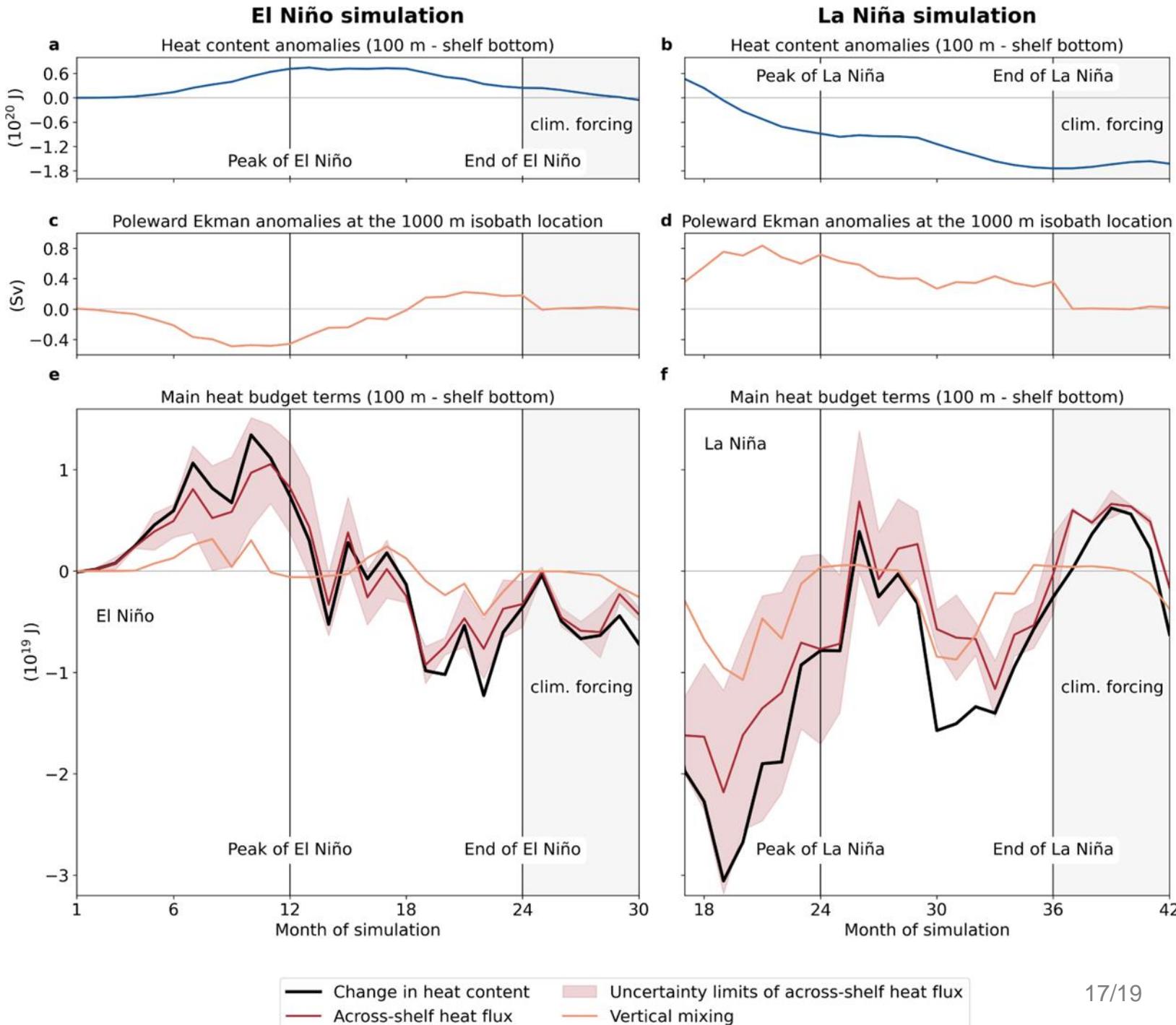
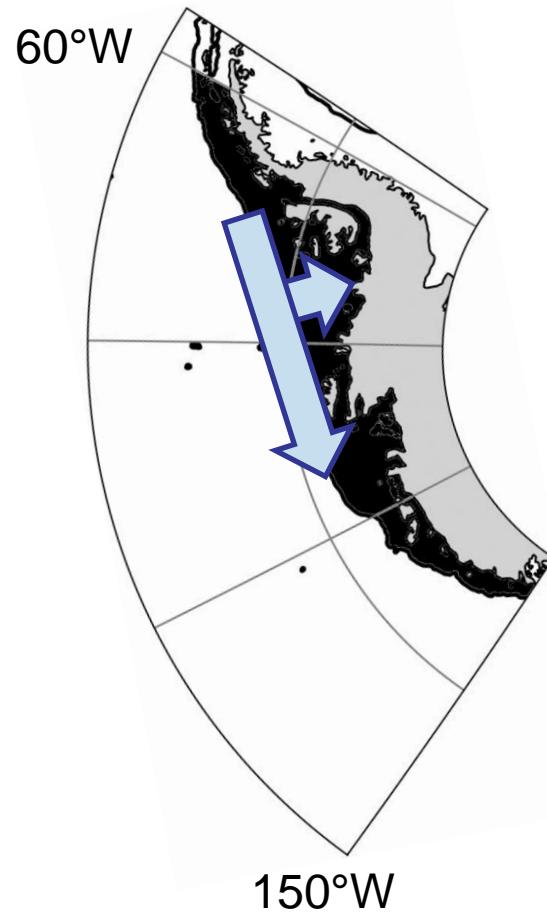
The subsurface heat budget



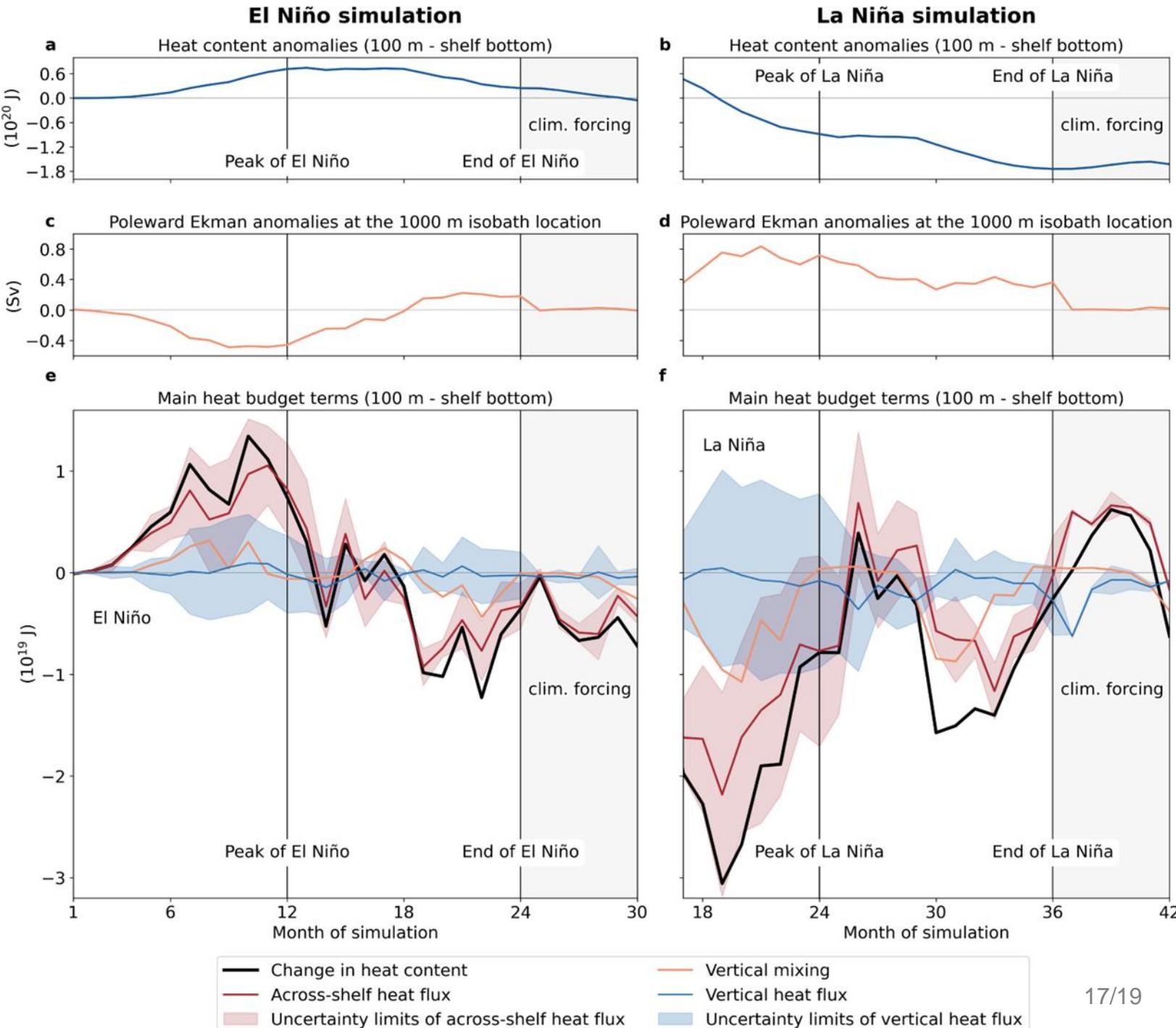
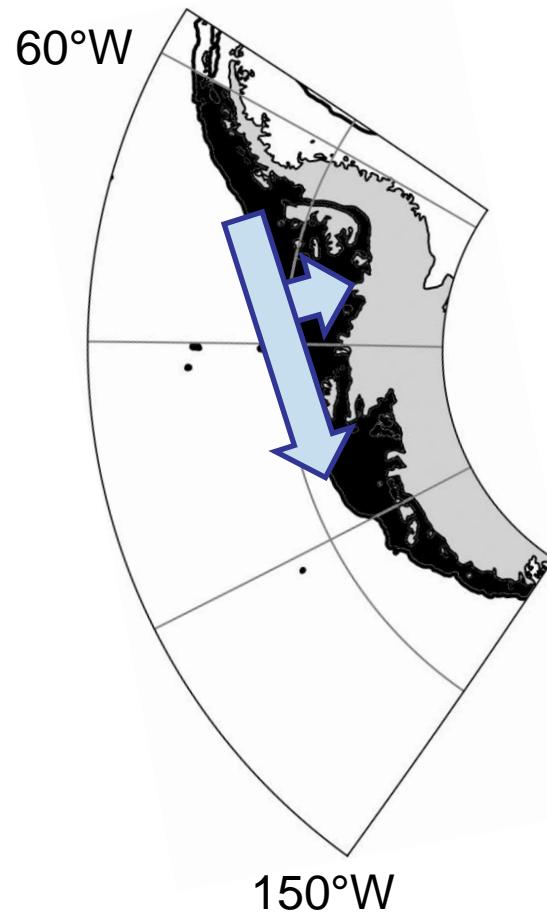
The subsurface heat budget



The subsurface heat budget



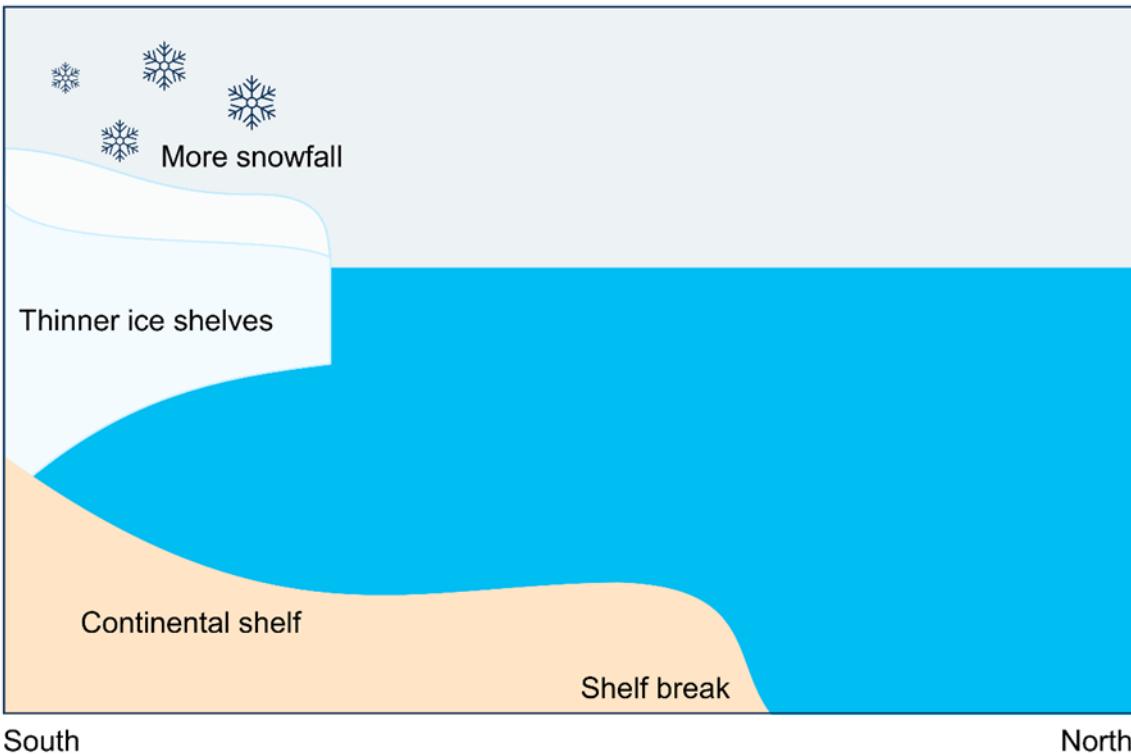
The subsurface heat budget



Schematic

a

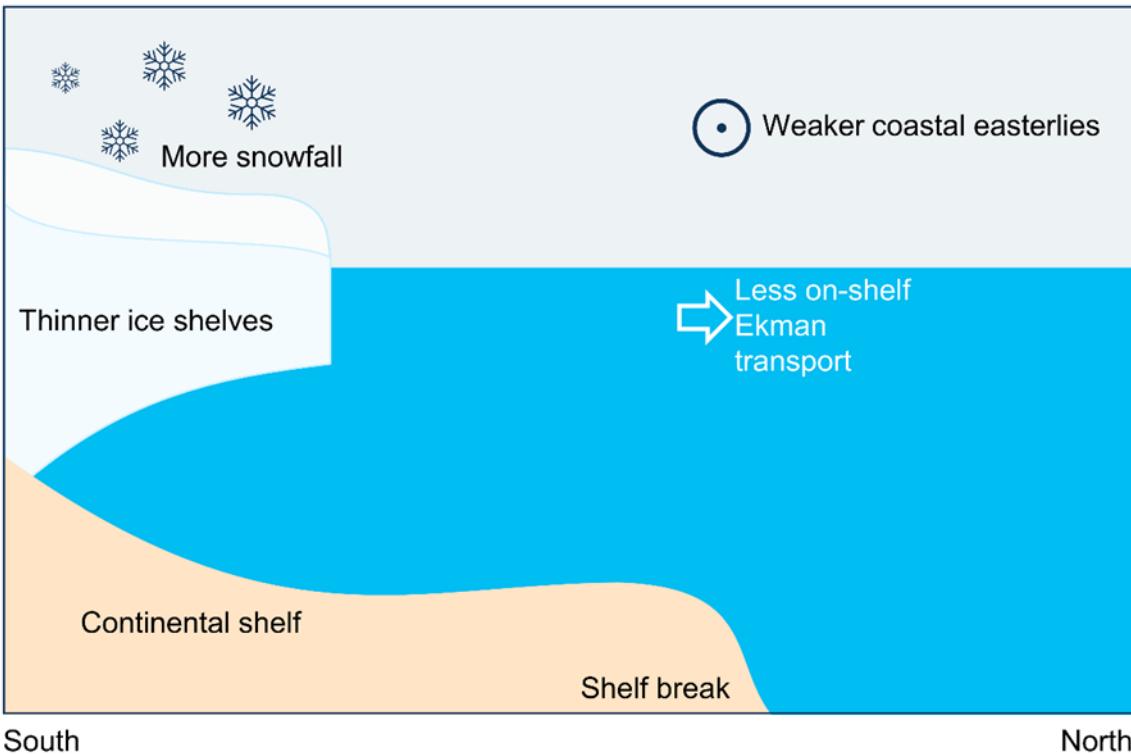
El Niño



Schematic

a

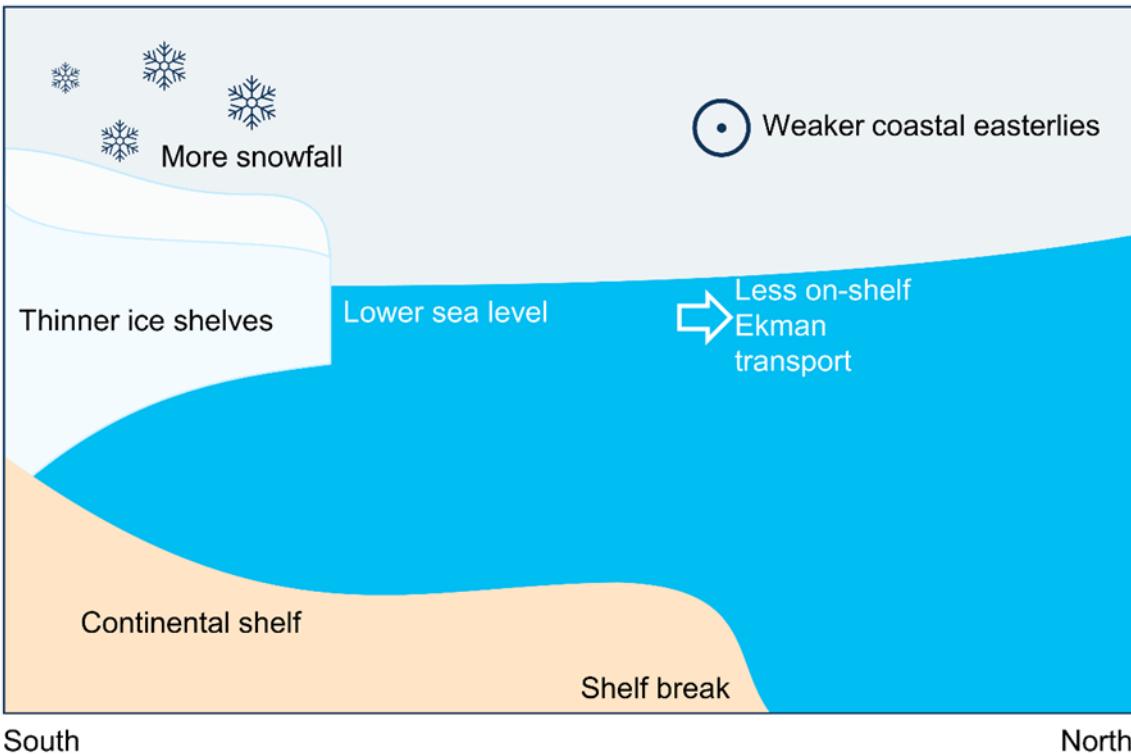
El Niño



Schematic

a

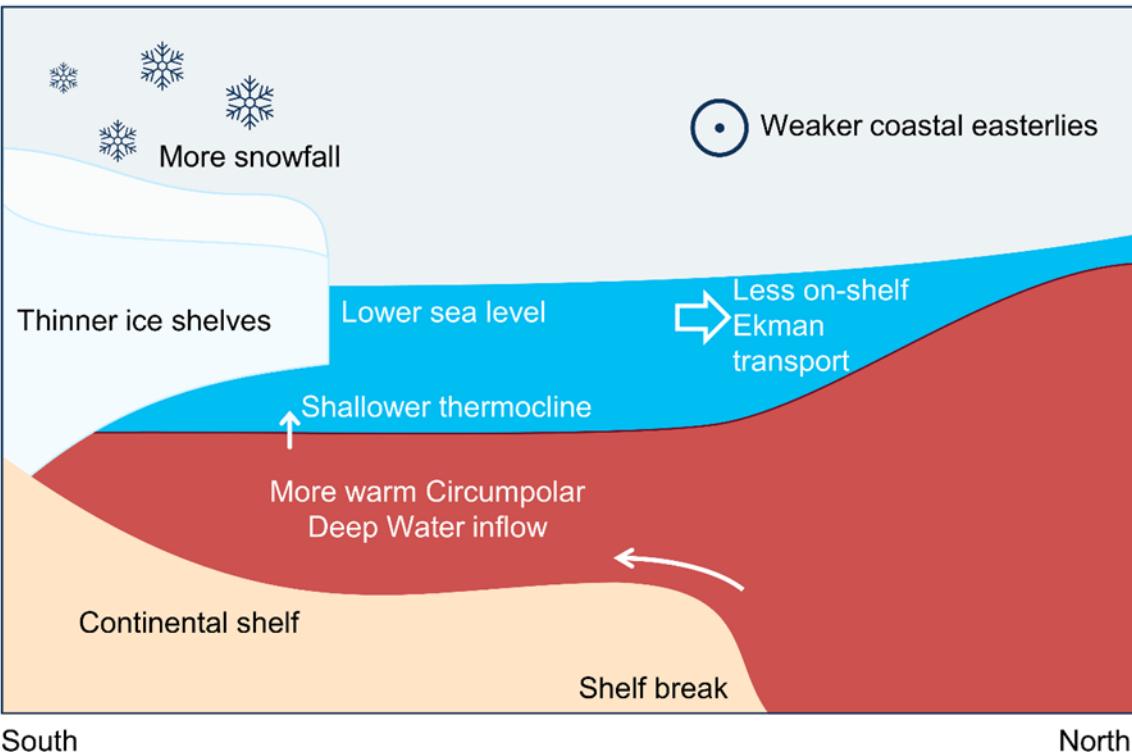
El Niño



Schematic

a

El Niño

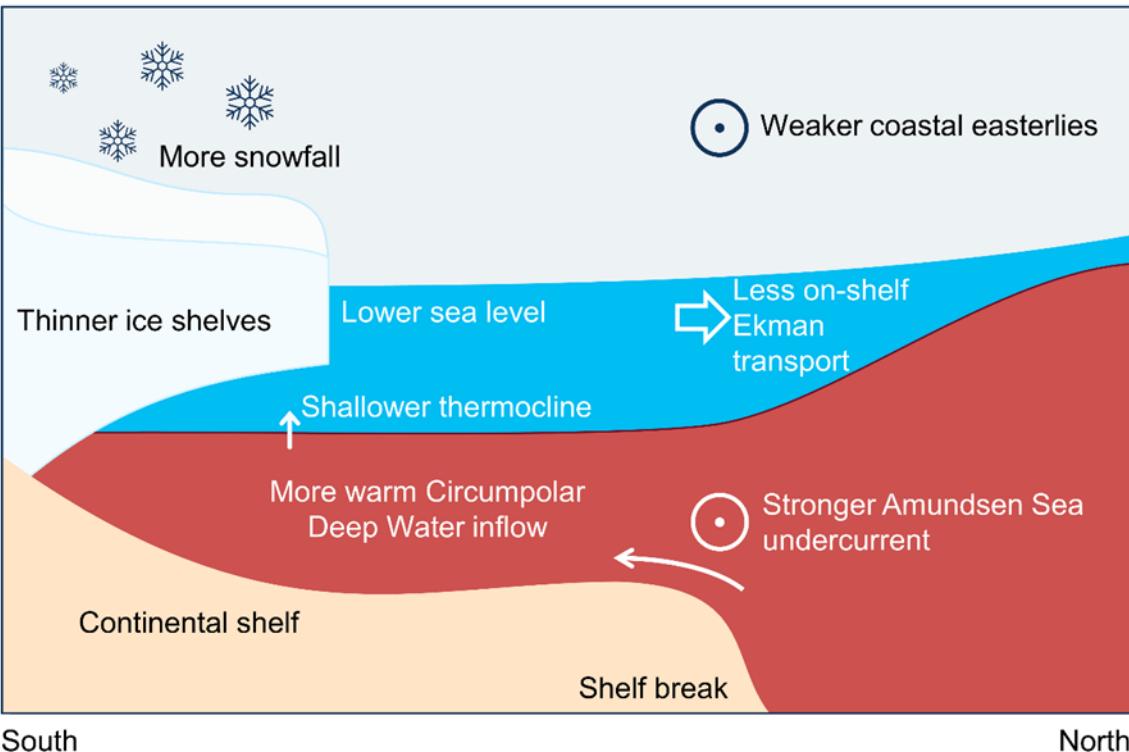


- *bottom Ekman response*
- *baroclinic adjustment*
- *Amundsen Sea undercurrent*
- *eddies*

Schematic

a

El Niño



South

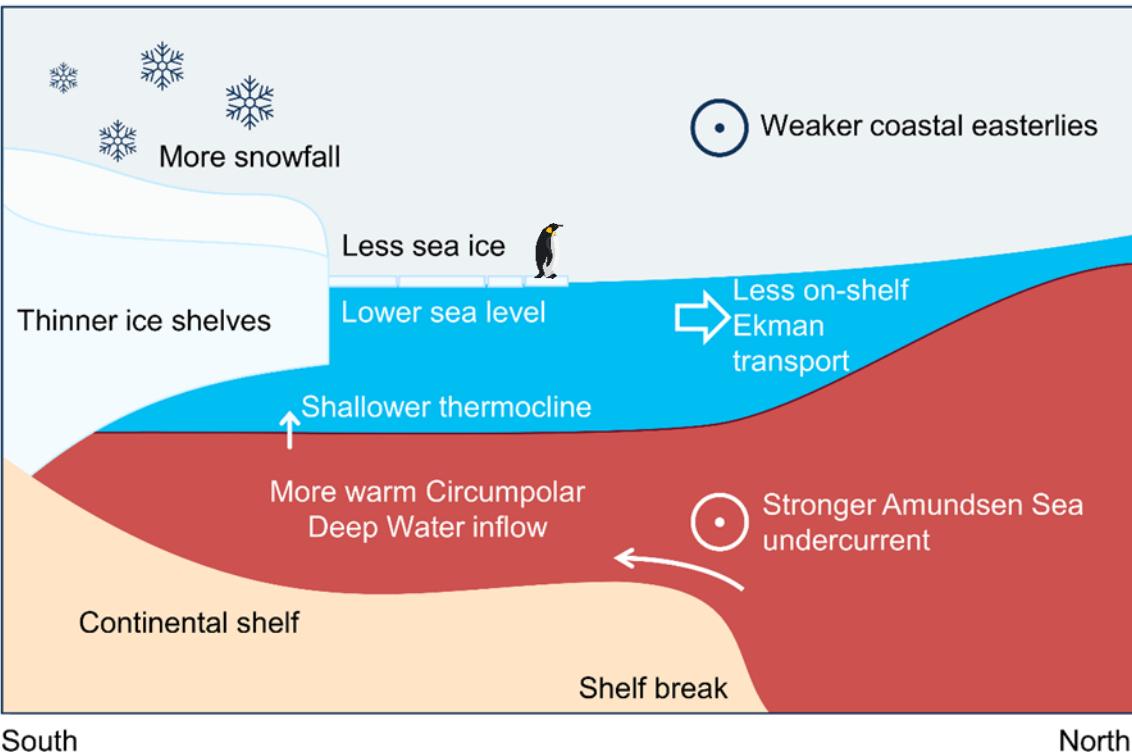
North

- *bottom Ekman response*
- *baroclinic adjustment*
- *Amundsen Sea undercurrent*
- *eddies*

Schematic

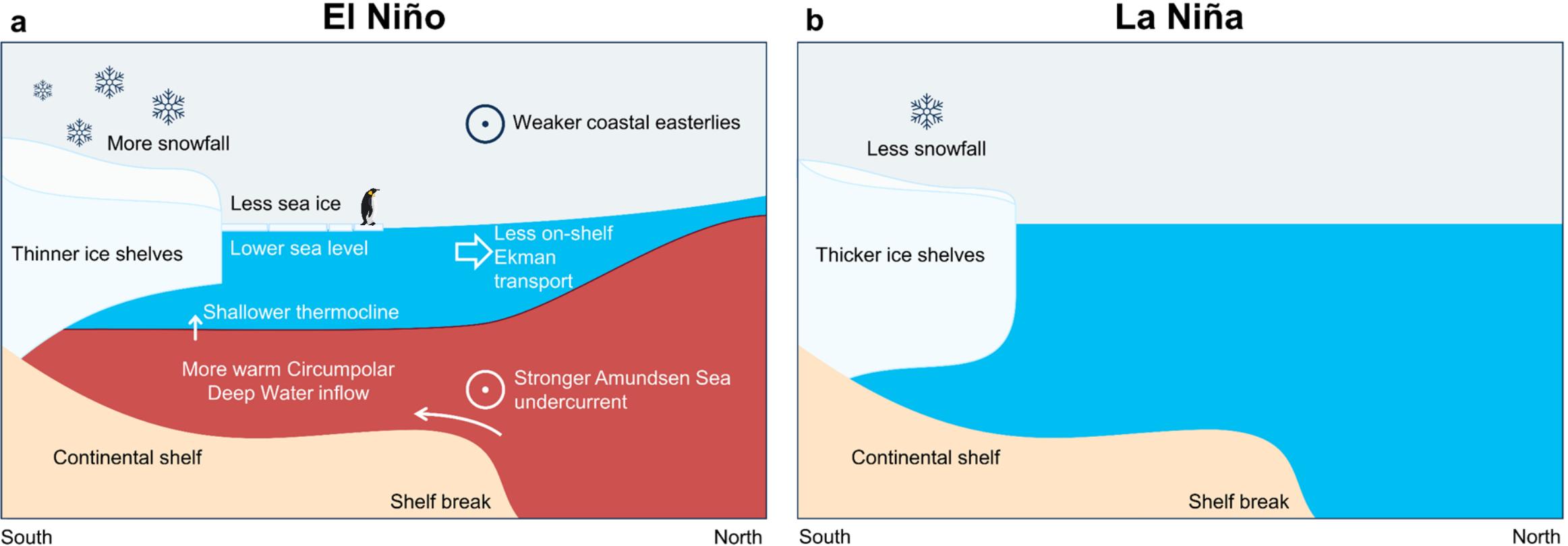
a

El Niño



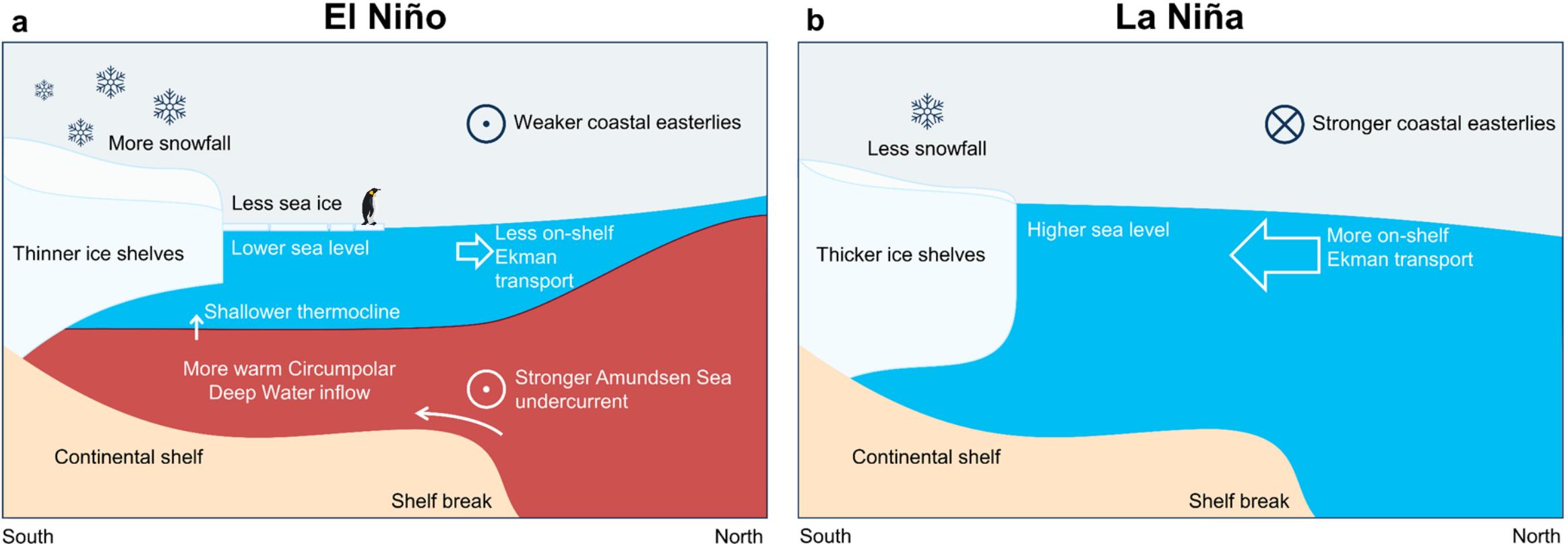
- *bottom Ekman response*
- *baroclinic adjustment*
- *Amundsen Sea undercurrent*
- *eddies*

Schematic



- *bottom Ekman response*
- *baroclinic adjustment*
- *Amundsen Sea undercurrent*
- *eddies*

Schematic



South

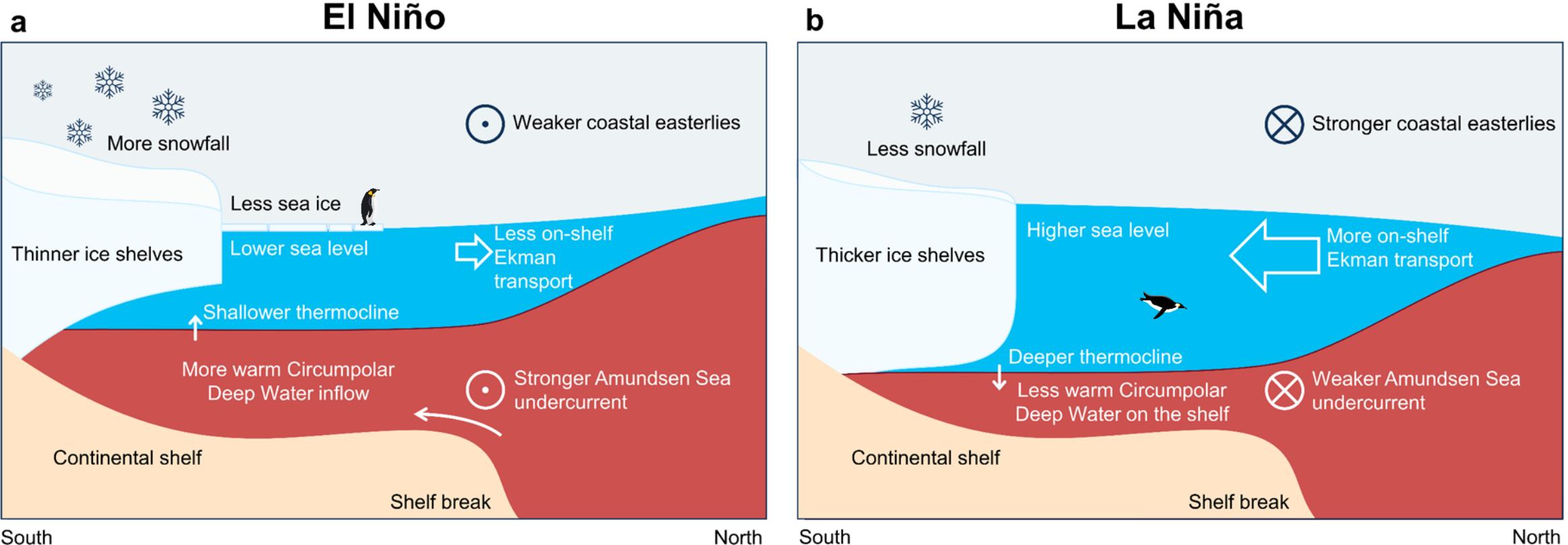
North

South

North

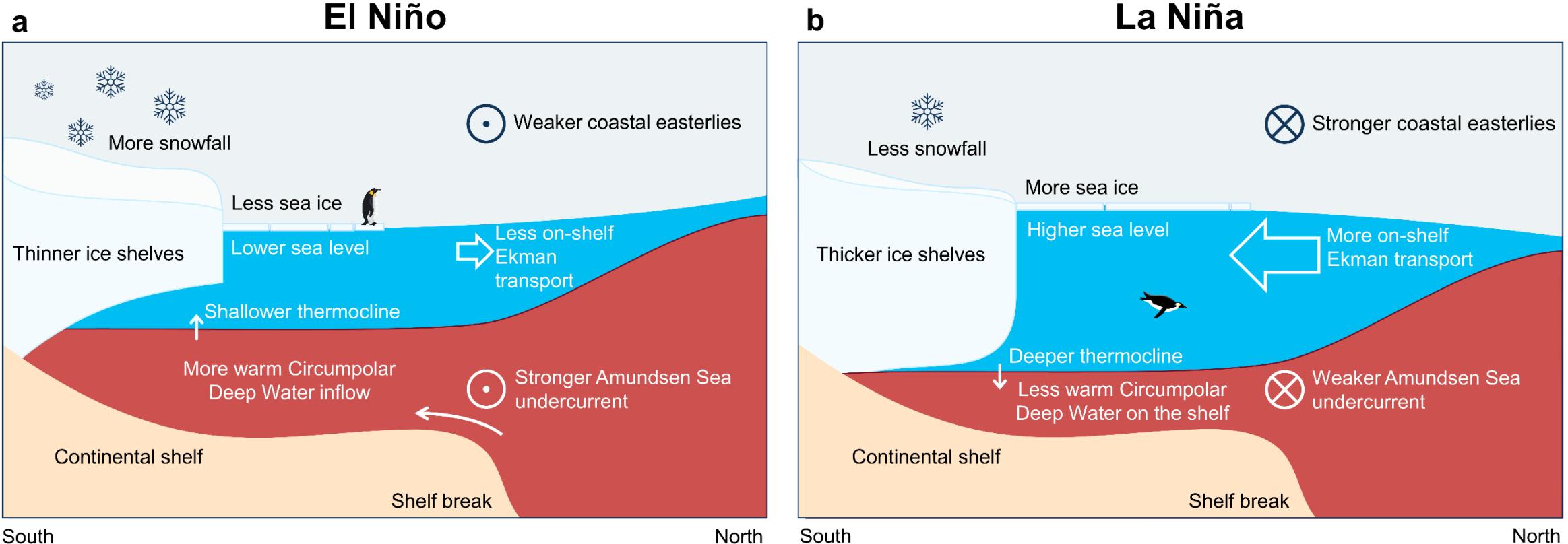
- *bottom Ekman response*
- *baroclinic adjustment*
- *Amundsen Sea undercurrent*
- *eddies*

Schematic



- *bottom Ekman response*
- *baroclinic adjustment*
- *Amundsen Sea undercurrent*
- *eddies*

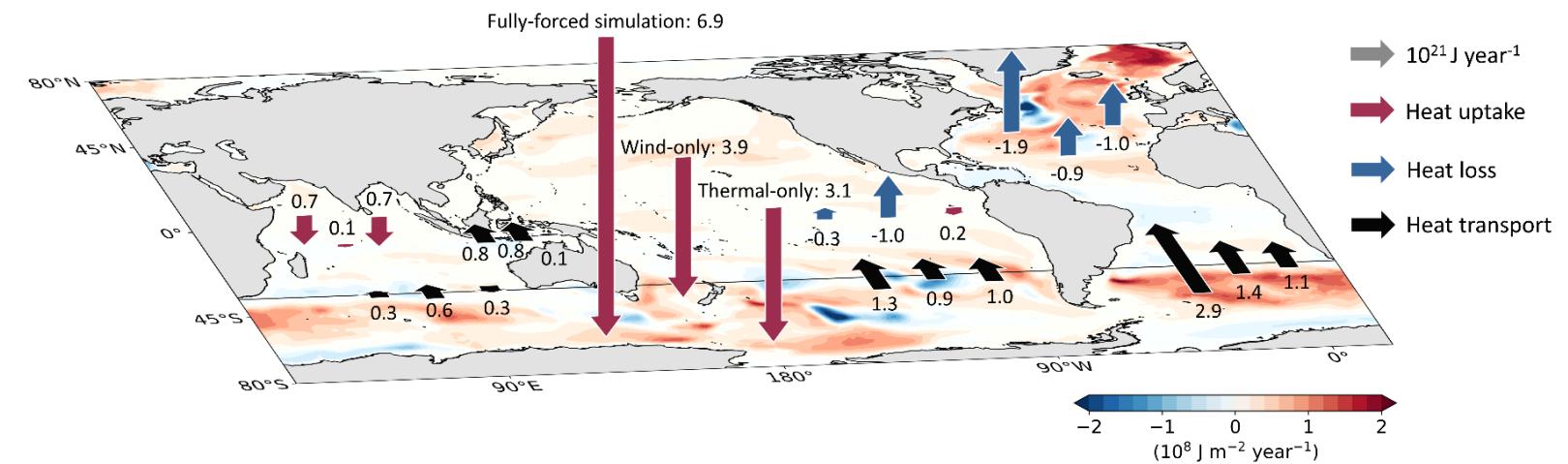
Schematic



- *bottom Ekman response*
- *baroclinic adjustment*
- *Amundsen Sea undercurrent*
- *eddies*

A journey through two research projects

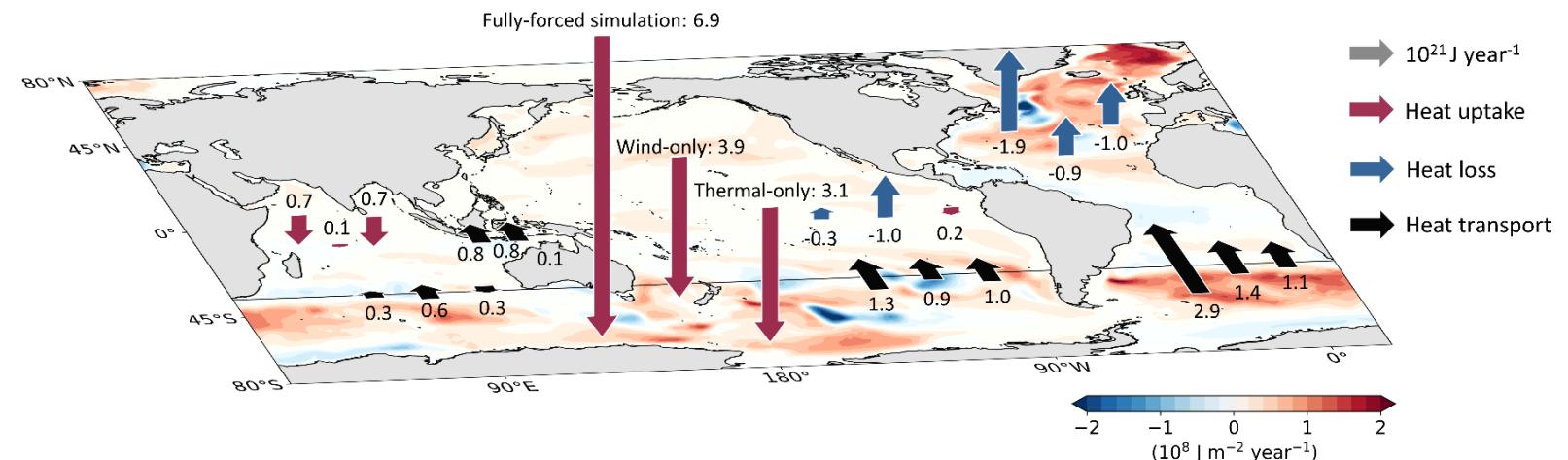
1. Drivers and distribution of global ocean heat uptake over the last half century



A journey through two research projects

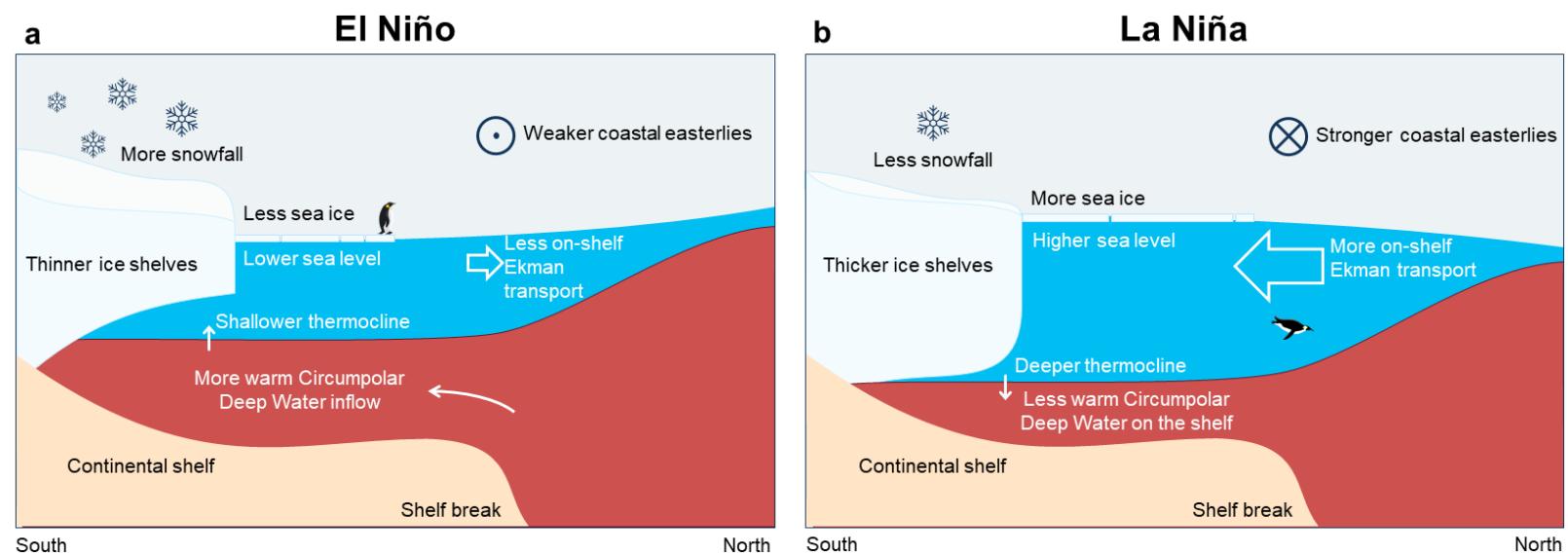
1. Drivers and distribution of global ocean heat uptake over the last half century

(Huguenin et al. 2022, Nat. Comms.)



2. Subsurface warming of West Antarctic coastal waters linked to El Niño events

(Huguenin et al., 2020, J. Clim.)



...but wait, there's more!

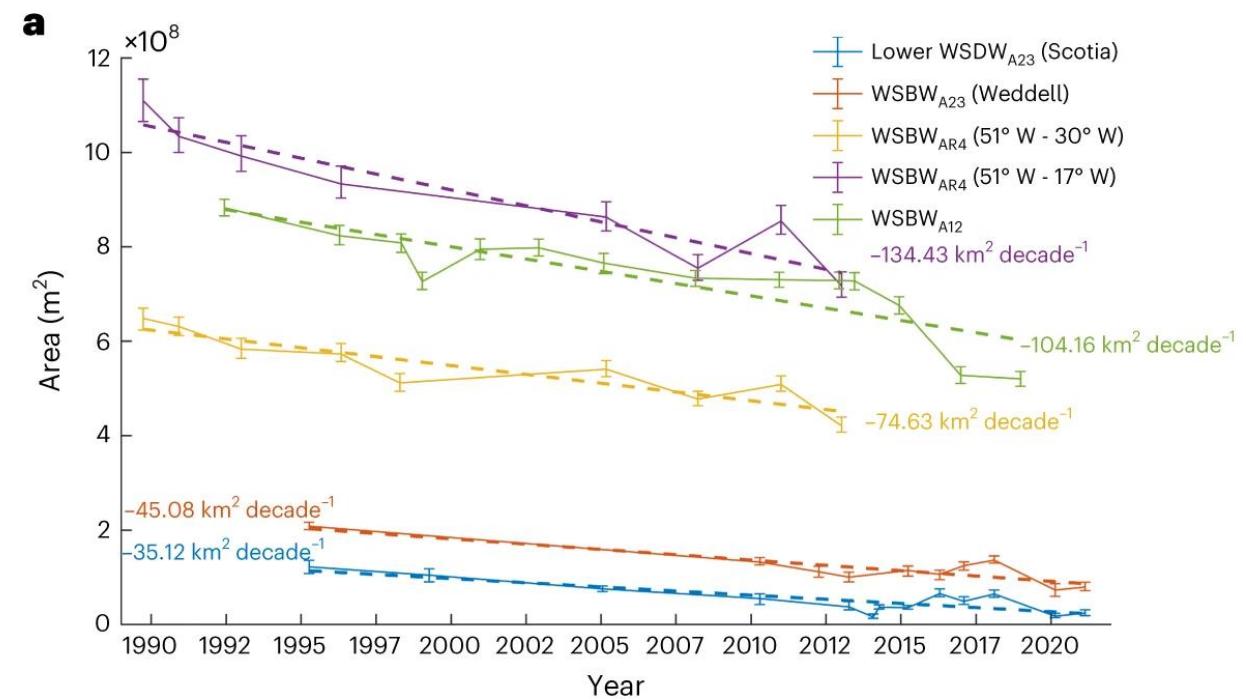
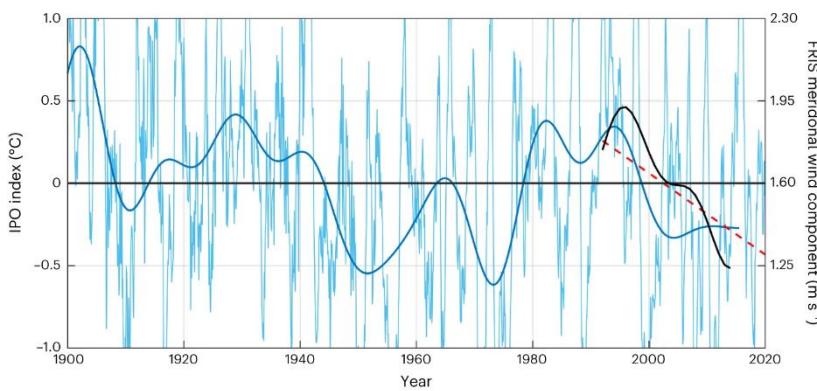
Linking the recent decrease in Weddell Sea dense shelf water to changes in the IPO

Maurice F. Huguenin, Svenja Ryan, Caroline Ummenhofer and Matthew H. England, *in preparation.*

Linking the recent decrease in Weddell Sea dense shelf water to changes in the IPO

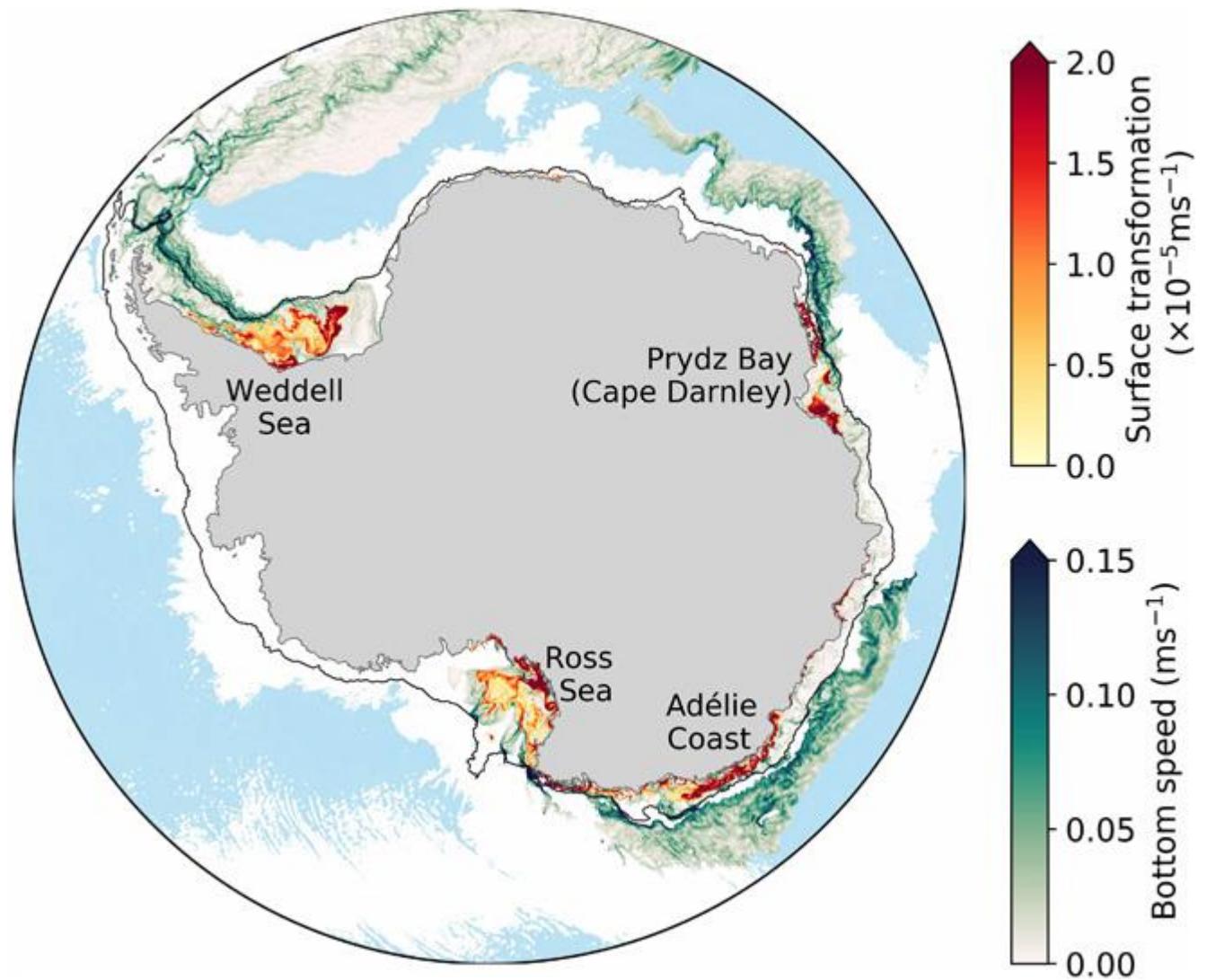
Maurice F. Huguenin, Svenja Ryan, Caroline Ummenhofer and Matthew H. England, *in preparation.*

- Zhuo et al. (2023)
- water-mass area along three hydrographic transects
- observed 30% reduction of Weddell Sea Bottom Water volume since 1992





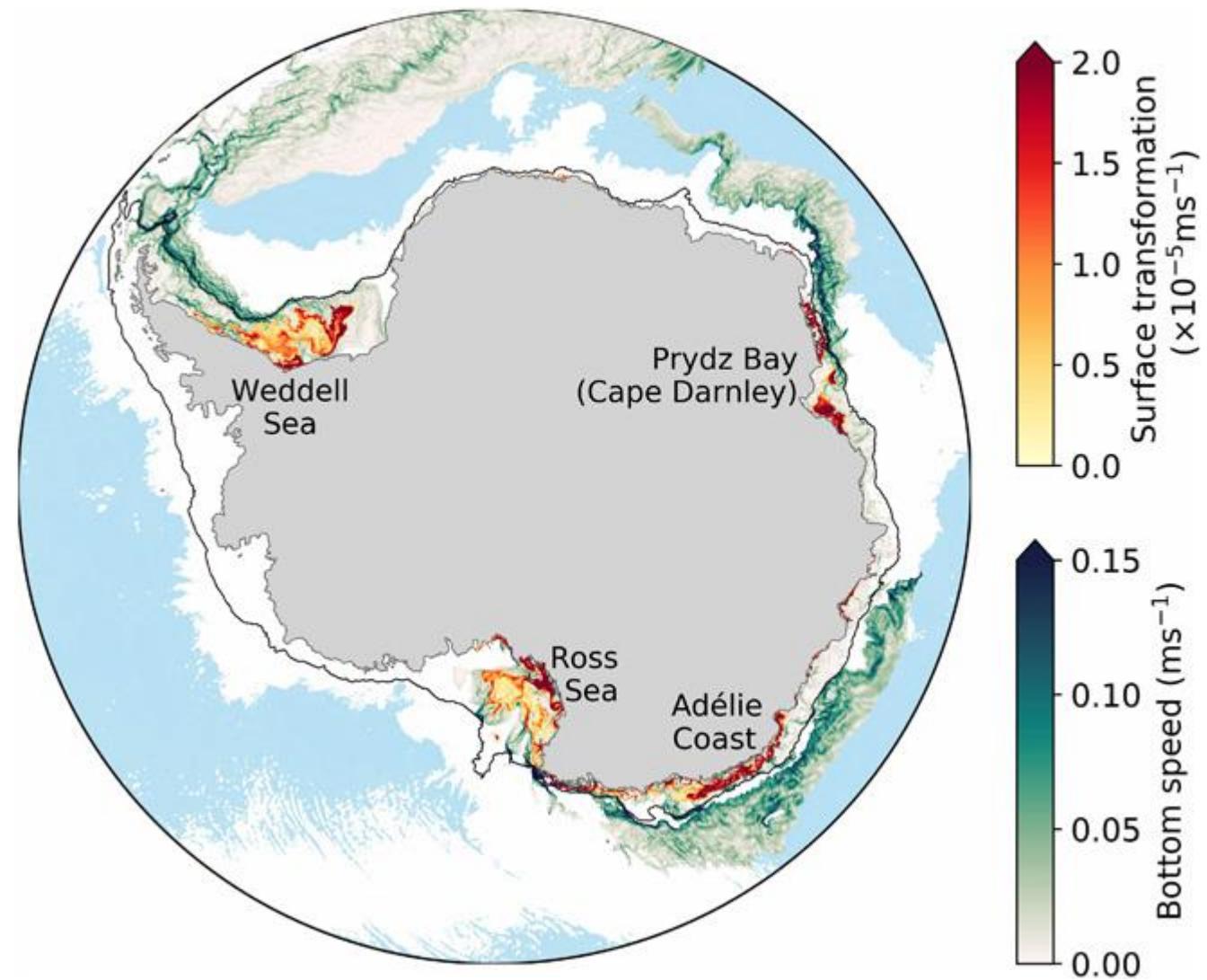
Surface water mass transformation



Morrison et al. (2019)

Surface water mass transformation

Surface water-mass transformation may be defined as the volume flux into a given density class (σ) from lighter density classes ($\sigma' < \sigma$) due to surface buoyancy forcing.

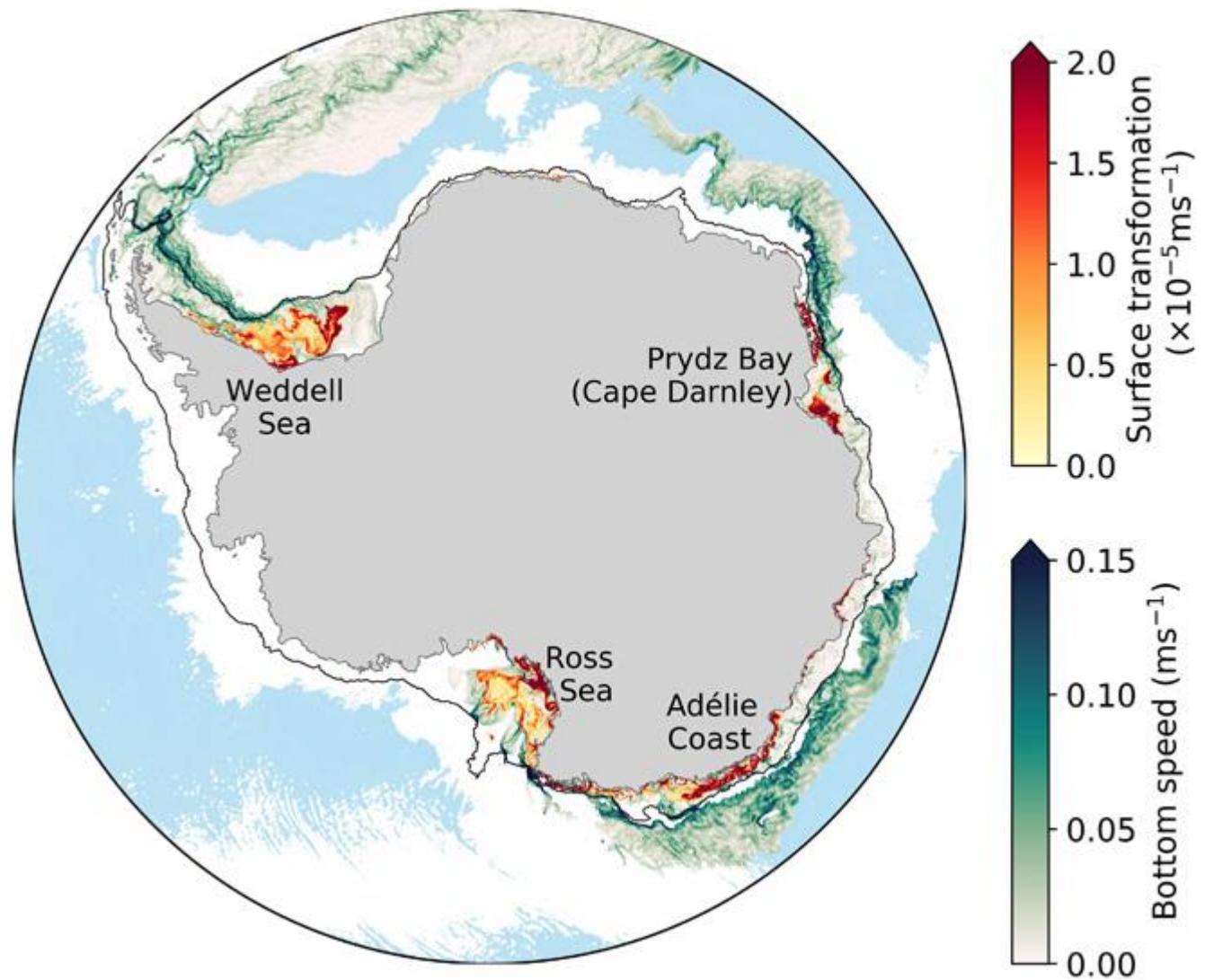


Morrison et al. (2019)

Surface water mass transformation

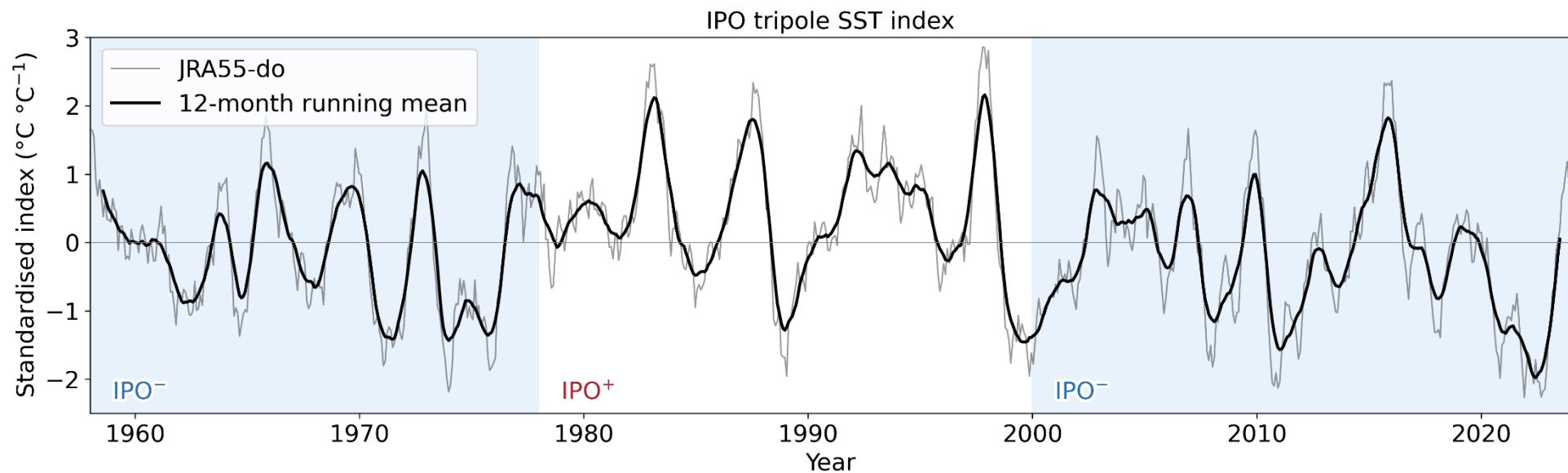
Surface water-mass transformation may be defined as the volume flux into a given density class (σ) from lighter density classes ($\sigma' < \sigma$) due to surface buoyancy forcing.

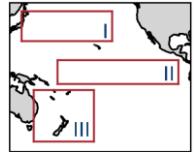
<https://cosima-recipes.readthedocs.io/en/latest/index.html>



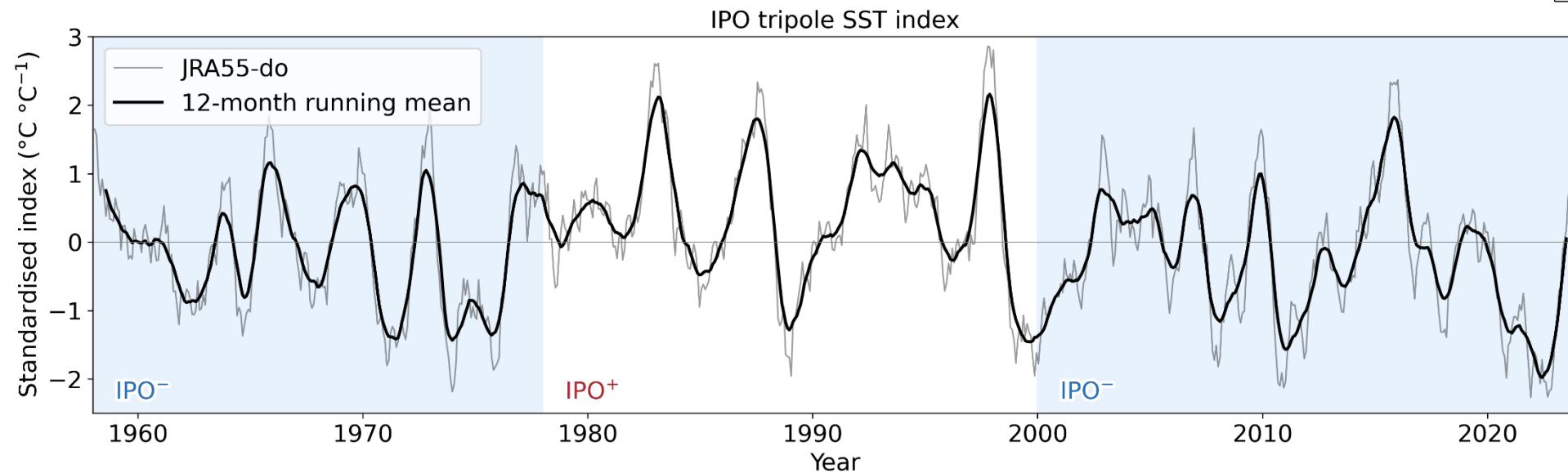
Morrison et al. (2019)

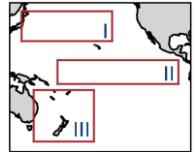
Experimental setup

a

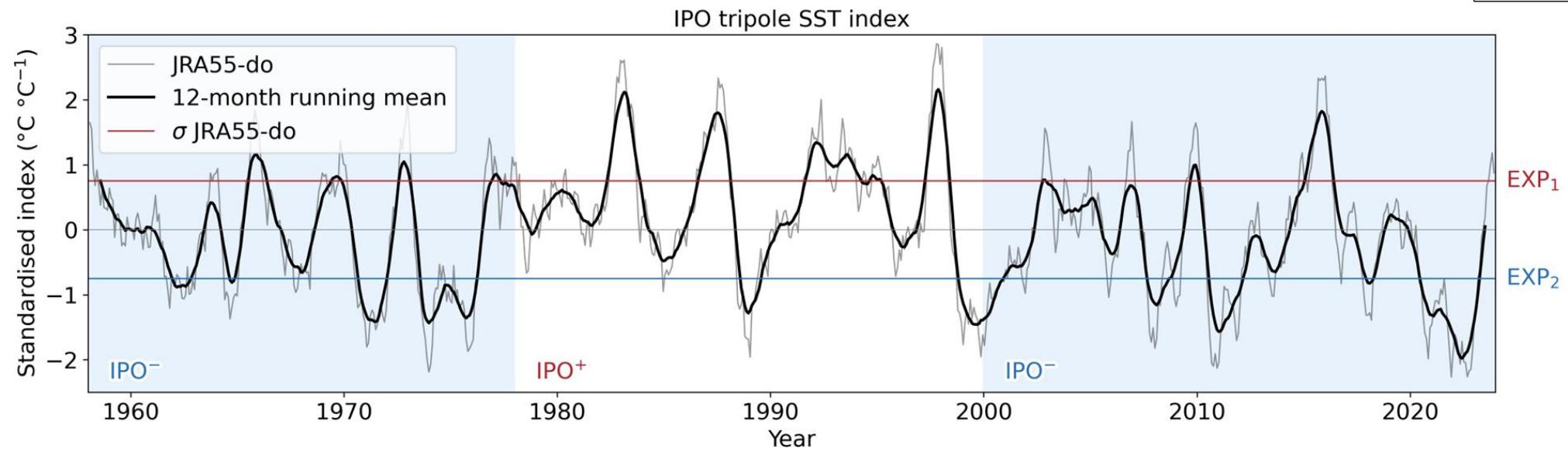


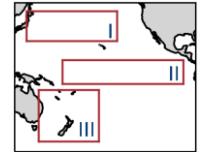
Experimental setup

a




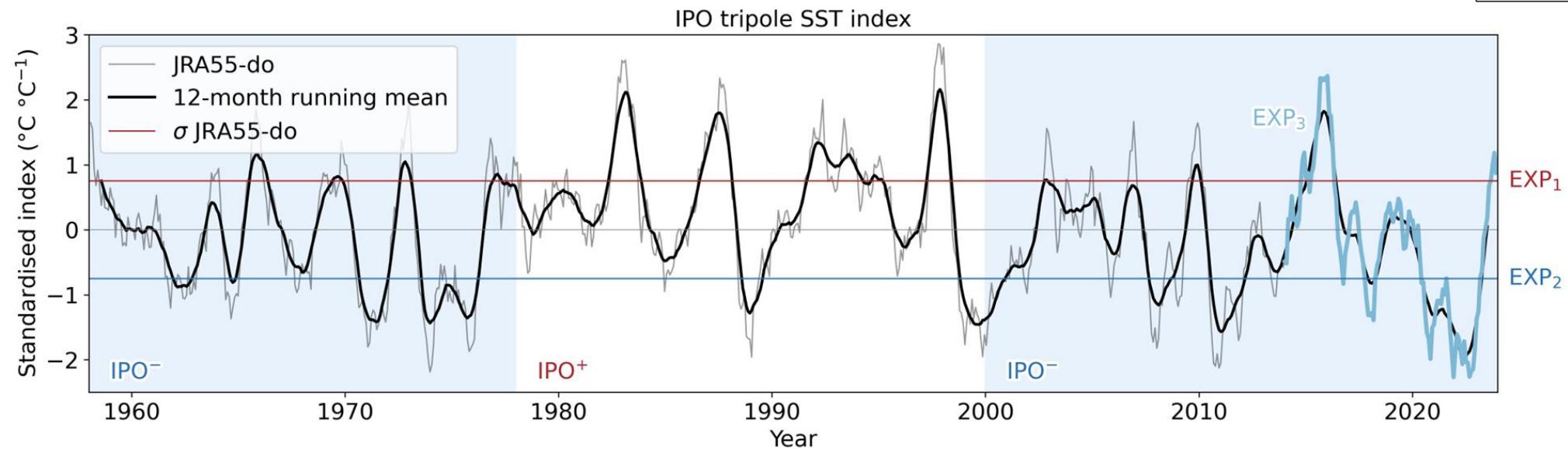
Experimental setup

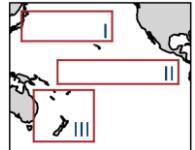
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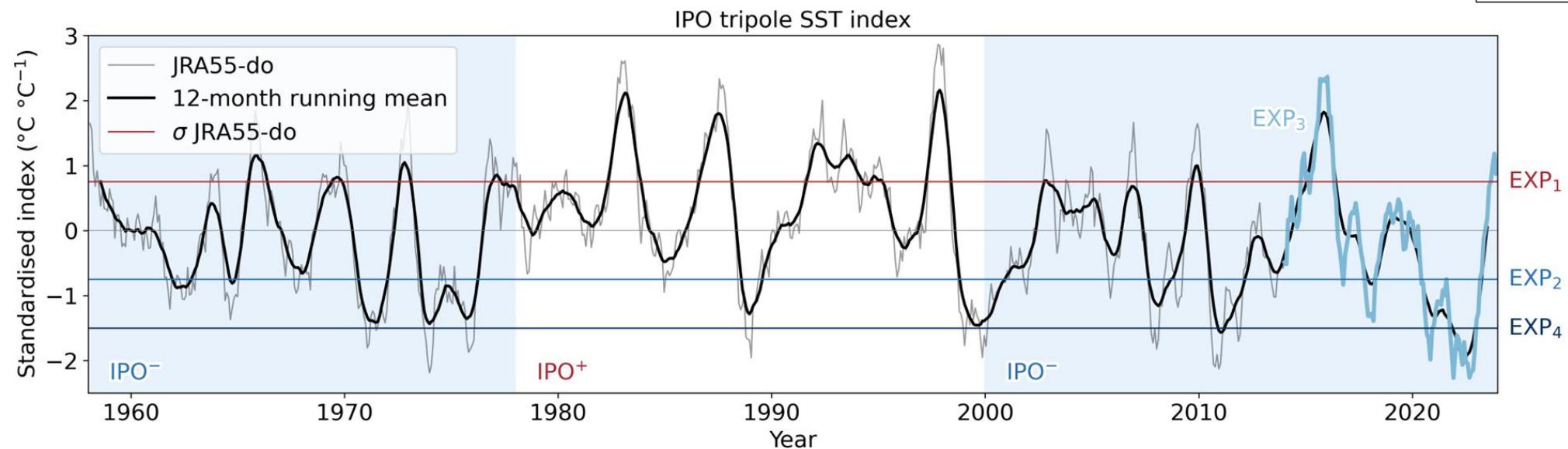
Experimental setup

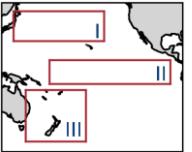
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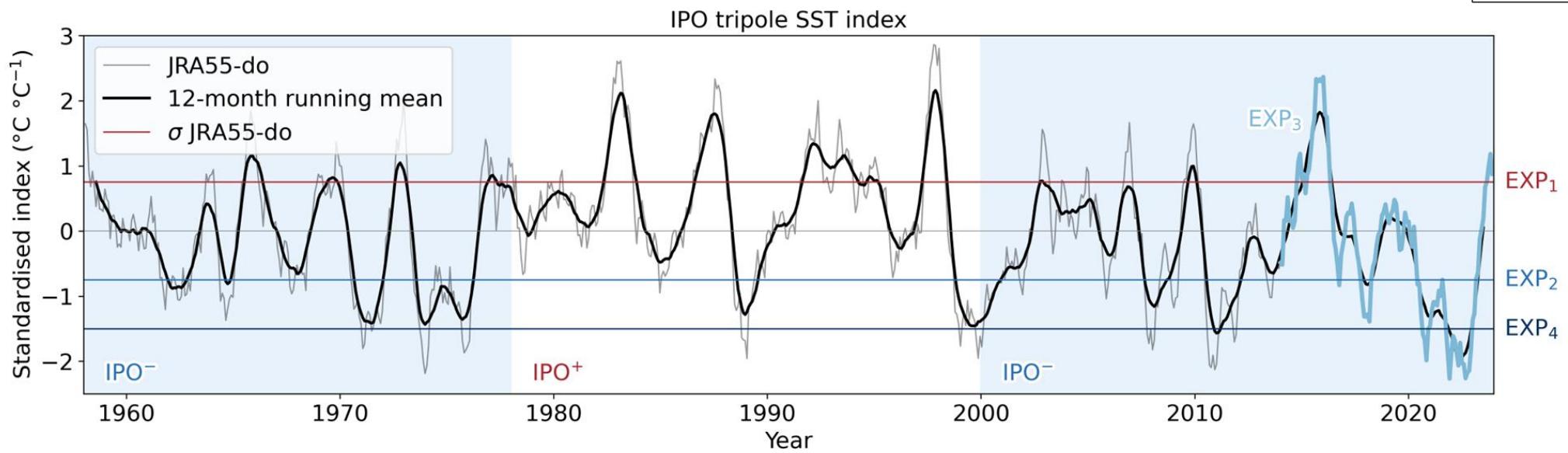
Experimental setup

a


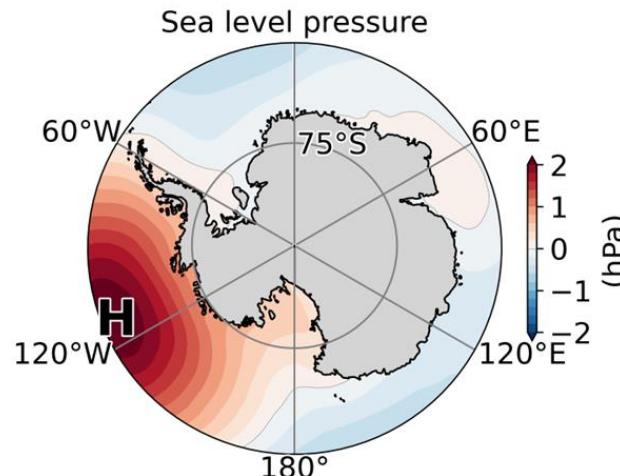


Experimental setup

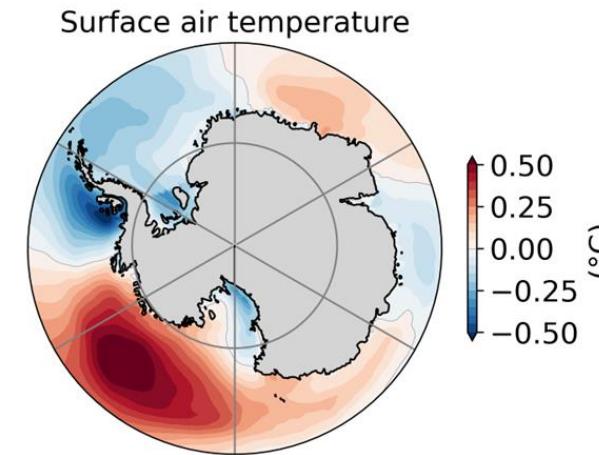
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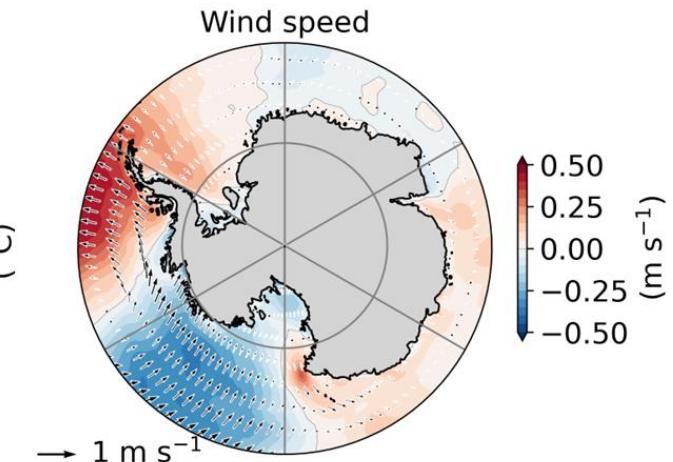
c



d

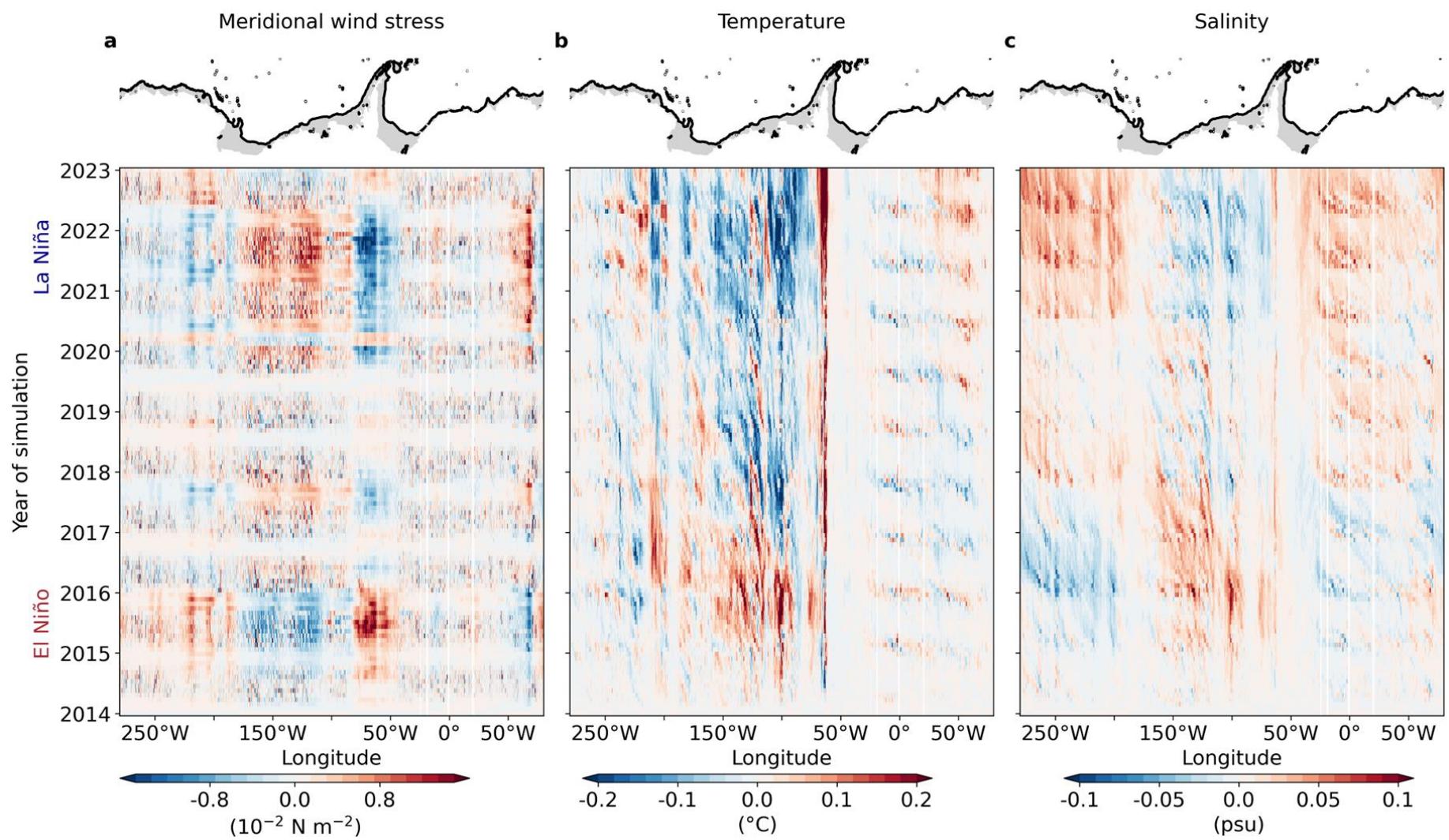


e

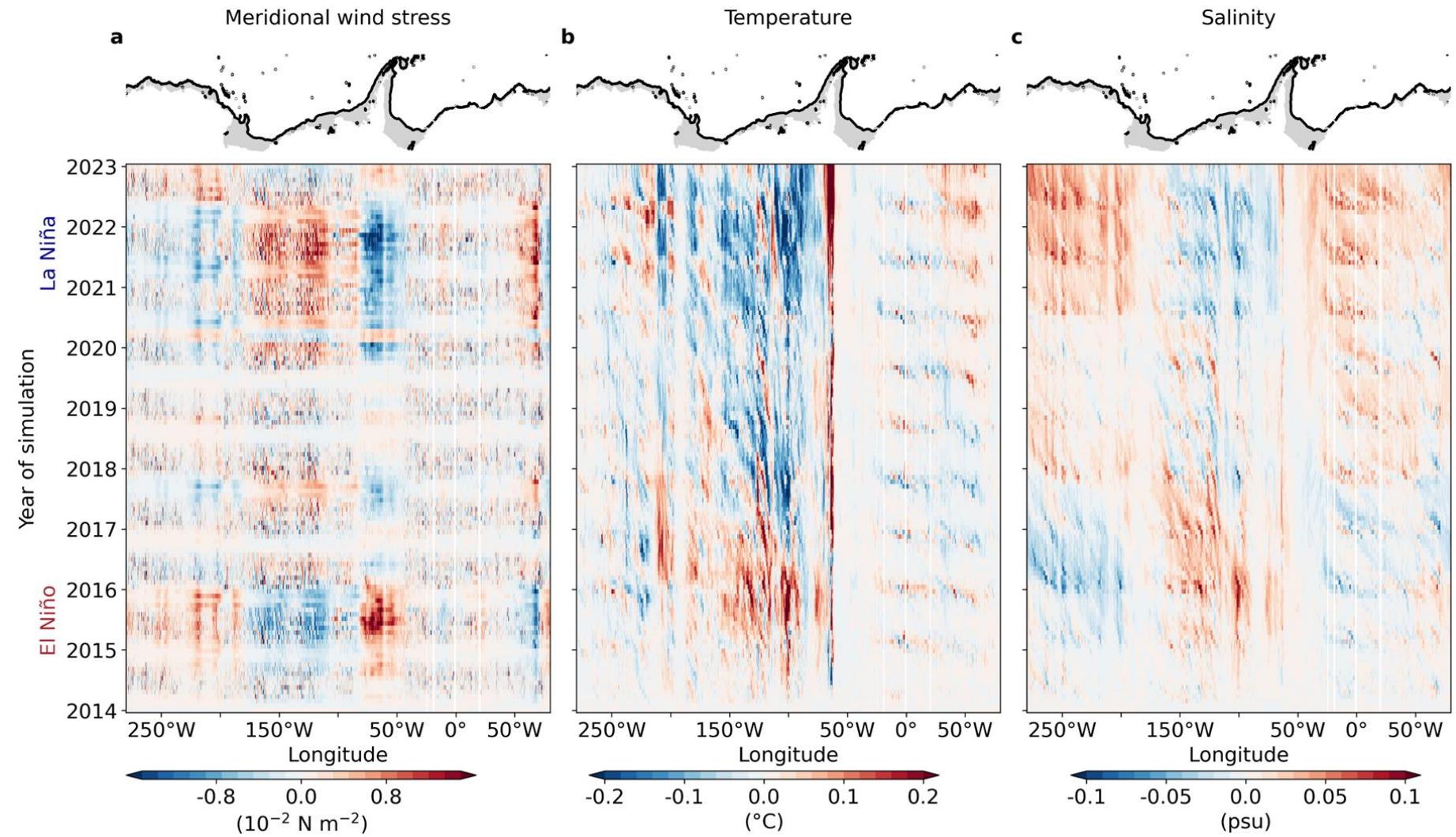
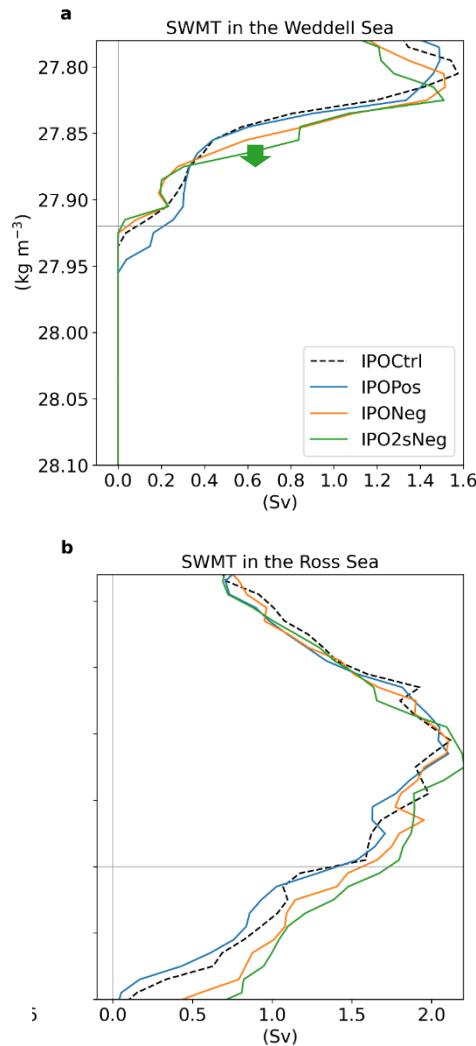


IPO changes in dense shelf water formation

IPO changes in dense shelf water formation

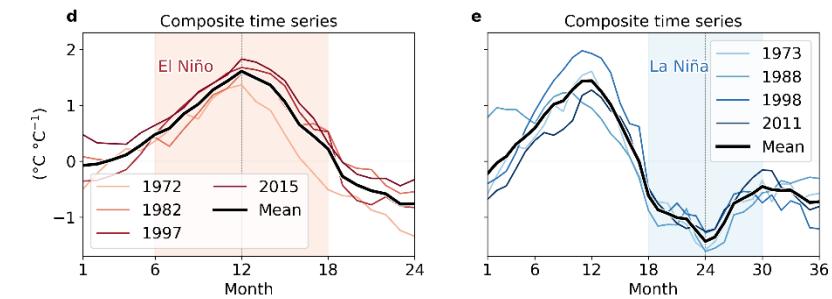


IPO changes in dense shelf water formation

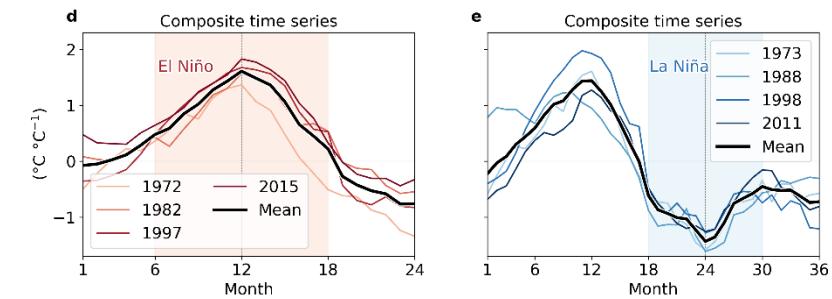


... but wait, there is more!

ENSOAntarctica project

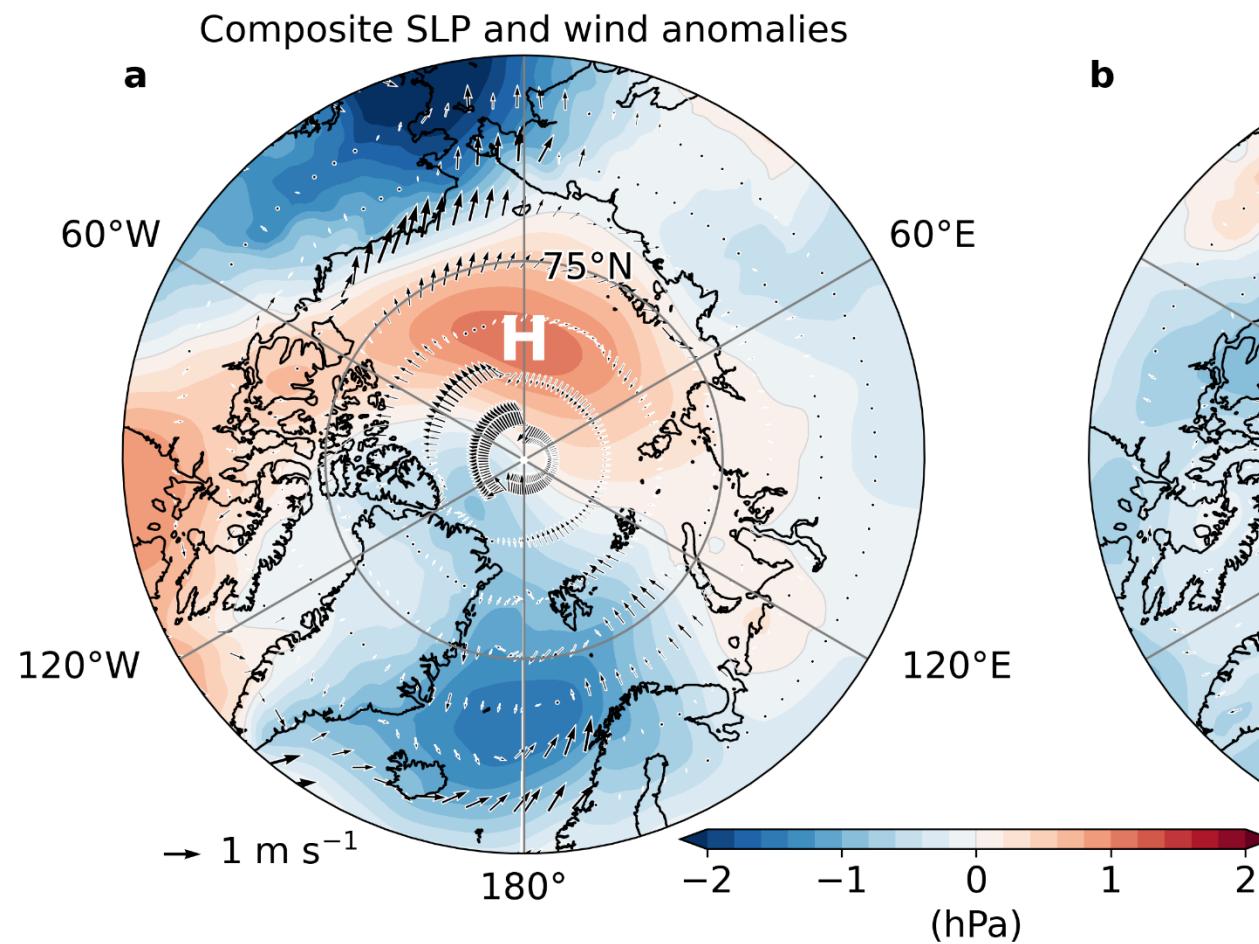


ENSOAntArctic project!

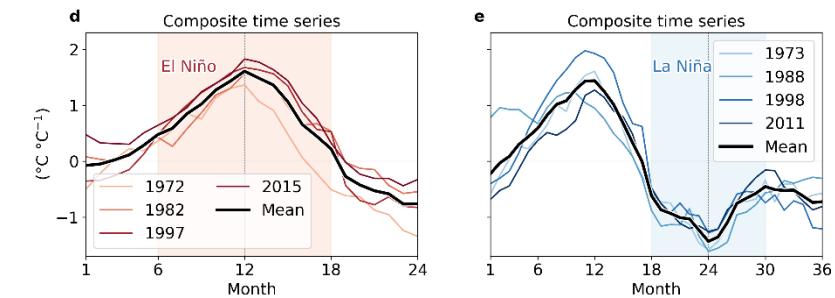


ENSOAntArctic project!

El Niño



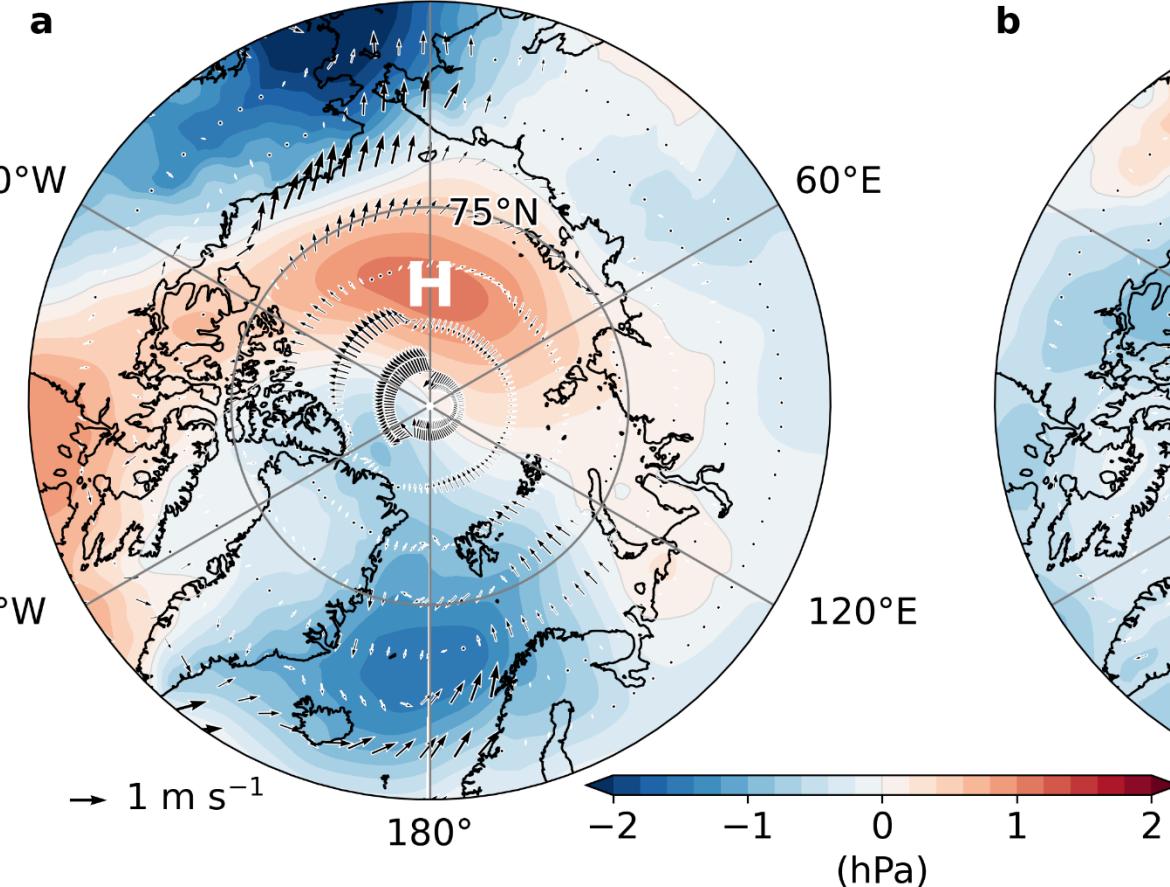
La Niña



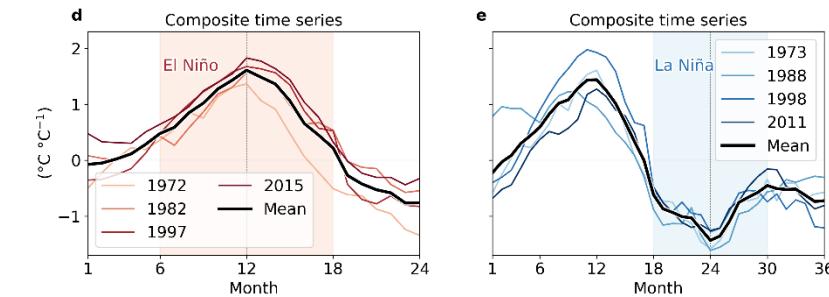
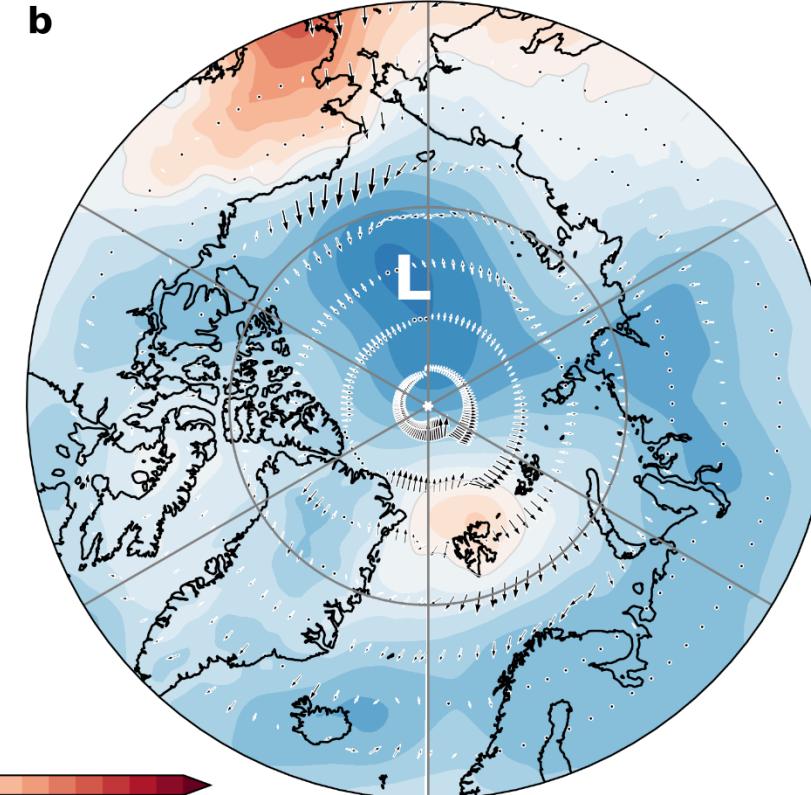
ENSOAntArctic project!

El Niño

Composite SLP and wind anomalies



La Niña

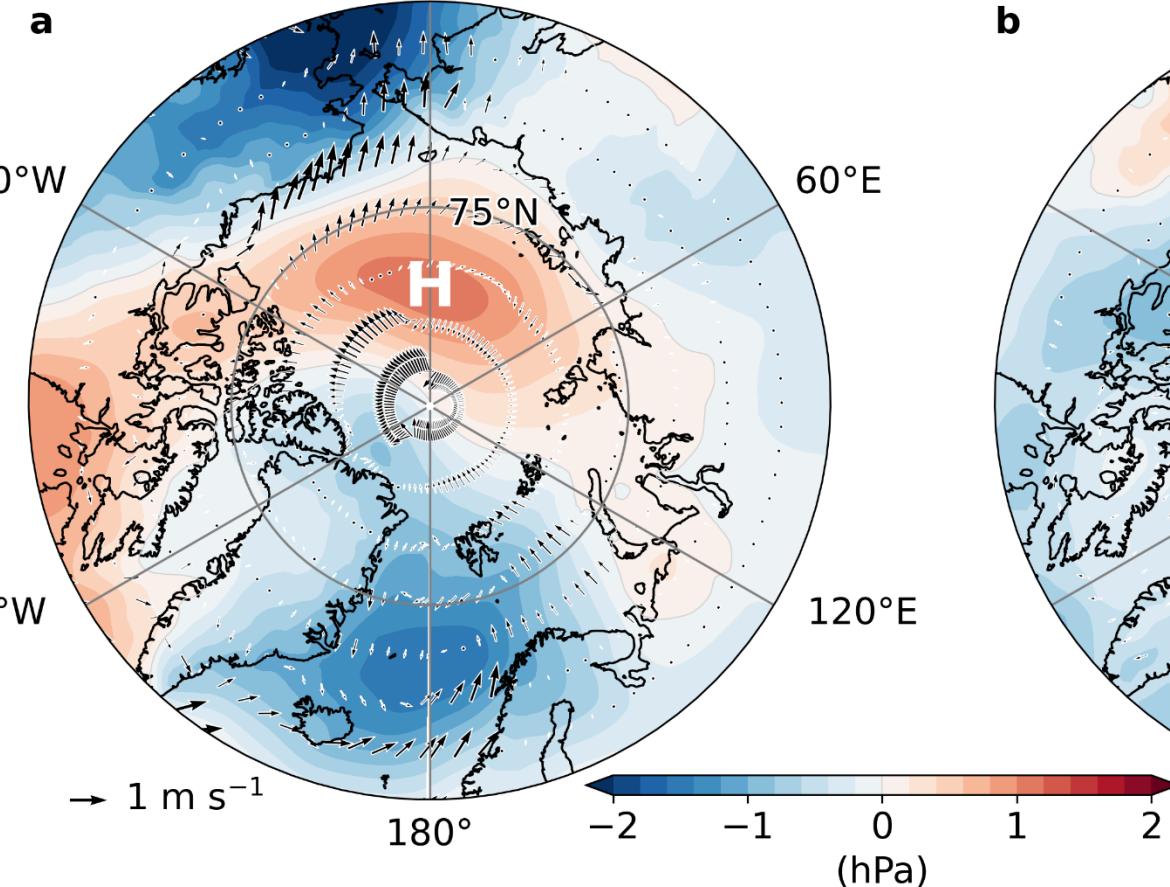


- Impacts on sea ice?
- Impacts on heat budget?
- More heat advection through Spitsbergen current?
- What happens to the Greenland coastal current?
- Are the anomalies too weak?

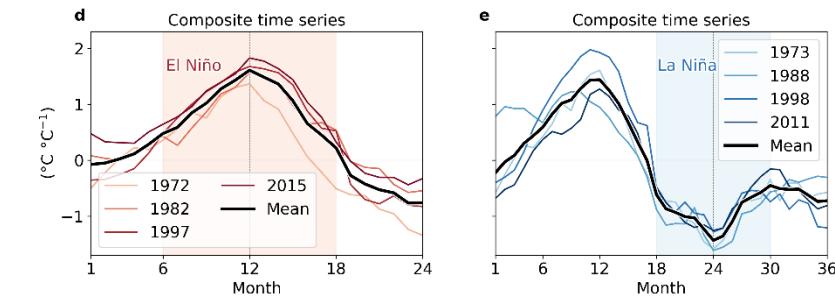
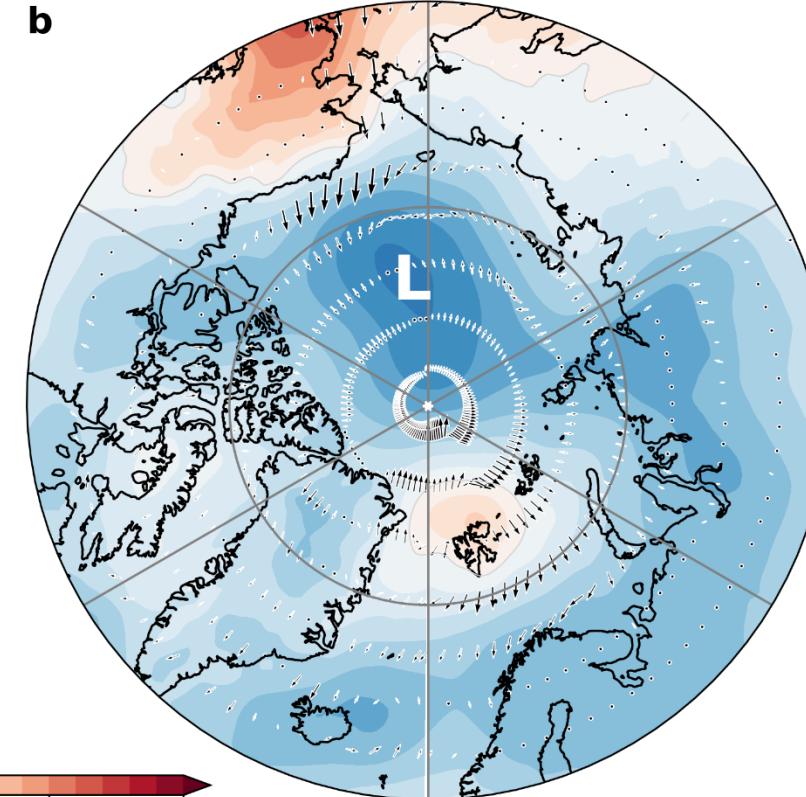
ENSOAntArctic project!

El Niño

Composite SLP and wind anomalies



La Niña



- Impacts on sea ice?
- Impacts on heat budget?
- More heat advection through Spitsbergen current?
- What happens to the Greenland coastal current?
- Are the anomalies too weak?

Come chat with me!
Clark 349

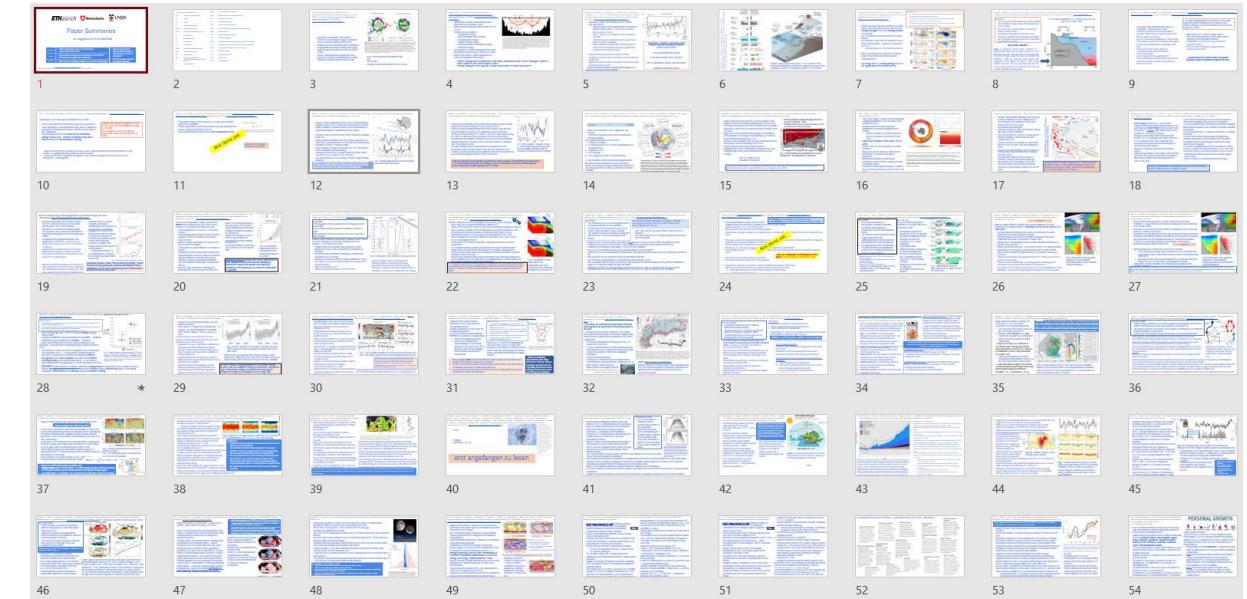
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|----------|----------|----------|----------|----------|
| 48:20.46 | 37:17.17 | 37:31.56 | 37:26.94 | 39:48.61 |
| 39:26.58 | | | | |
| | | | | |
| | | | | |

... but wait, there is more!

4 habits that helped me in my PhD

4 habits that helped me in my PhD

1. One paper, one powerpoint slide



Anna Merrifield's idea

4 habits that helped me in my PhD

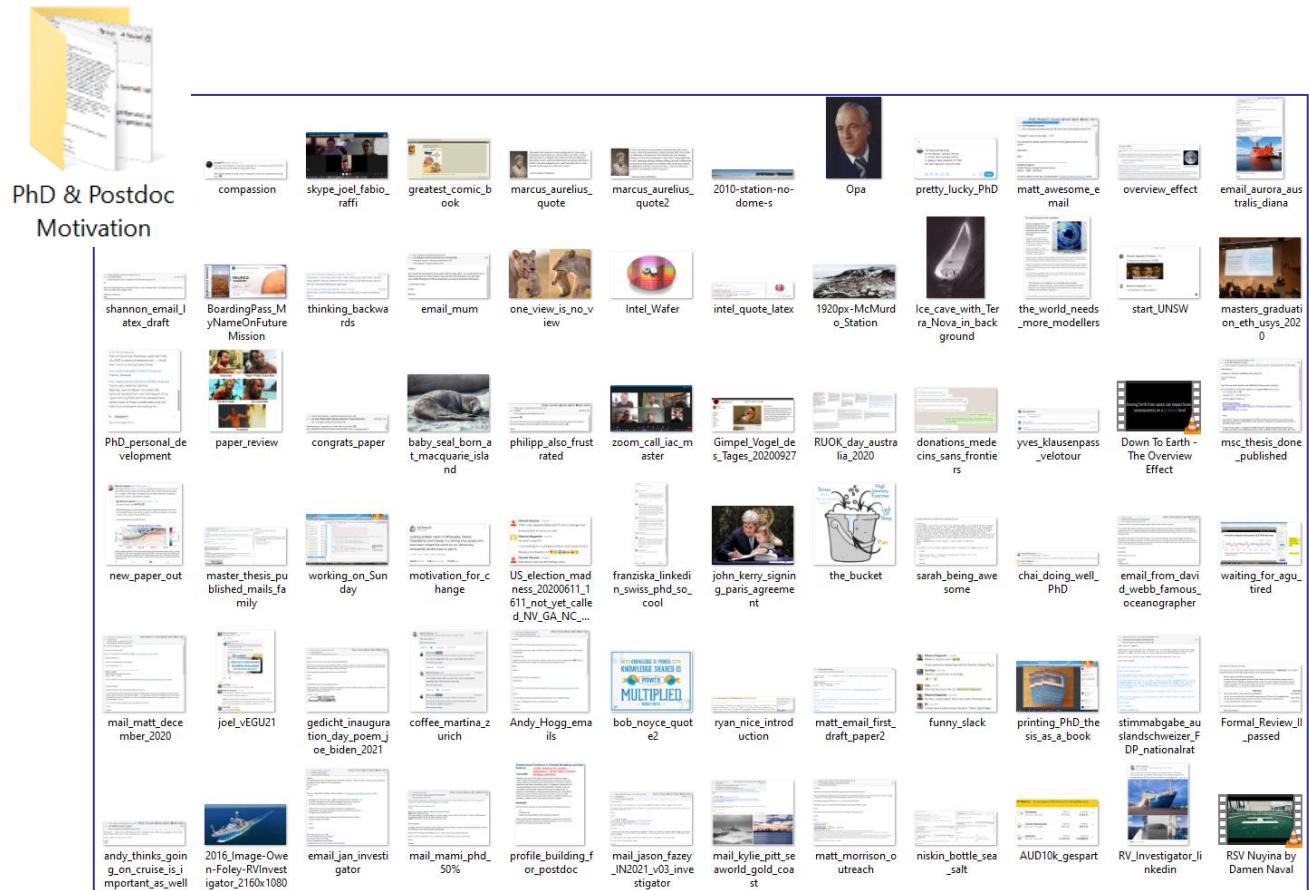
1. One paper, one powerpoint slide

2. Chocolate countdown



4 habits that helped me in my PhD

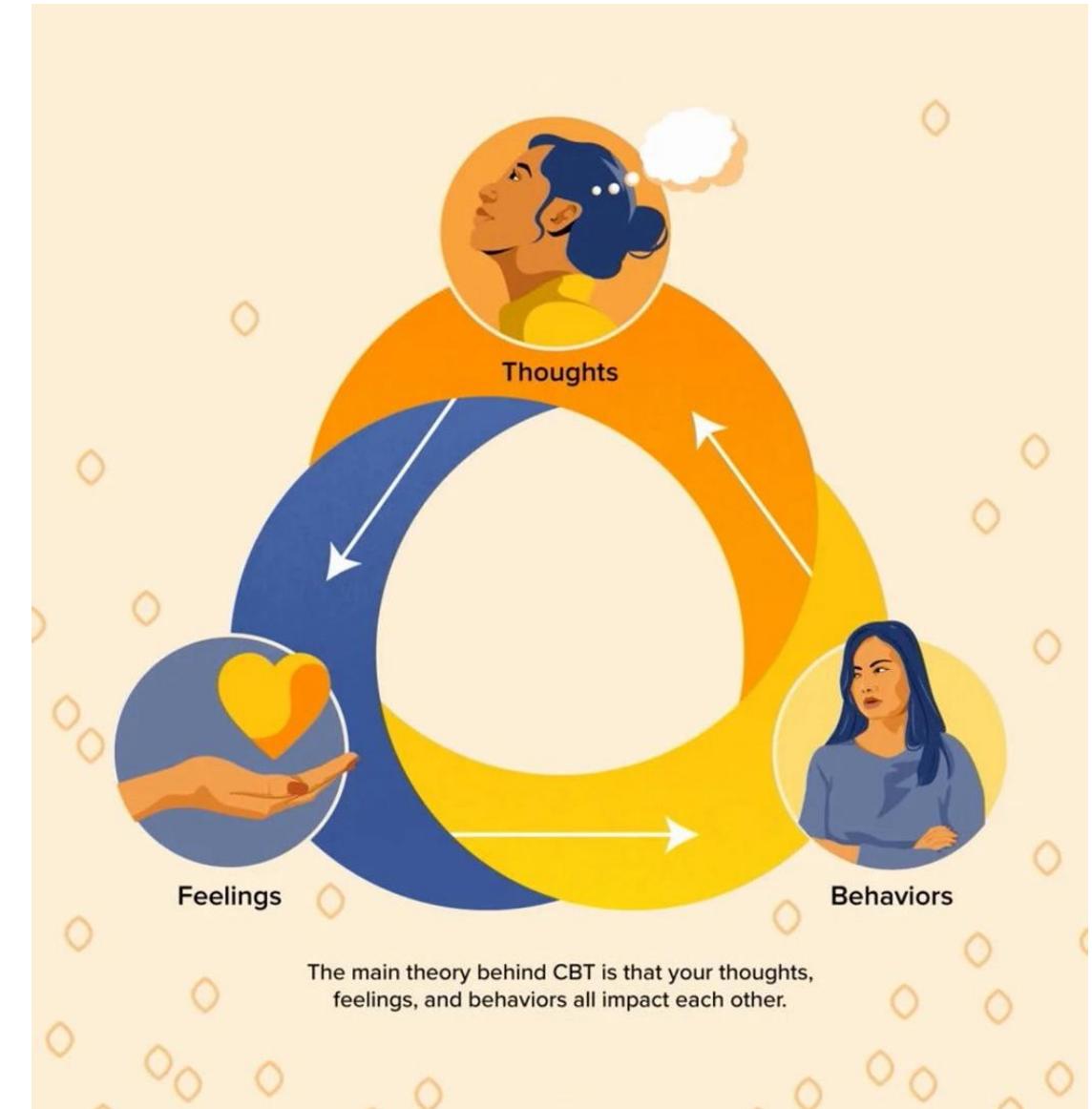
1. One paper, one powerpoint slide
 2. Chocolate countdown
 3. PhD Motivation folder



4 habits that helped me in my PhD

1. One paper, one powerpoint slide
2. Chocolate countdown
3. PhD Motivation folder
4. CBT

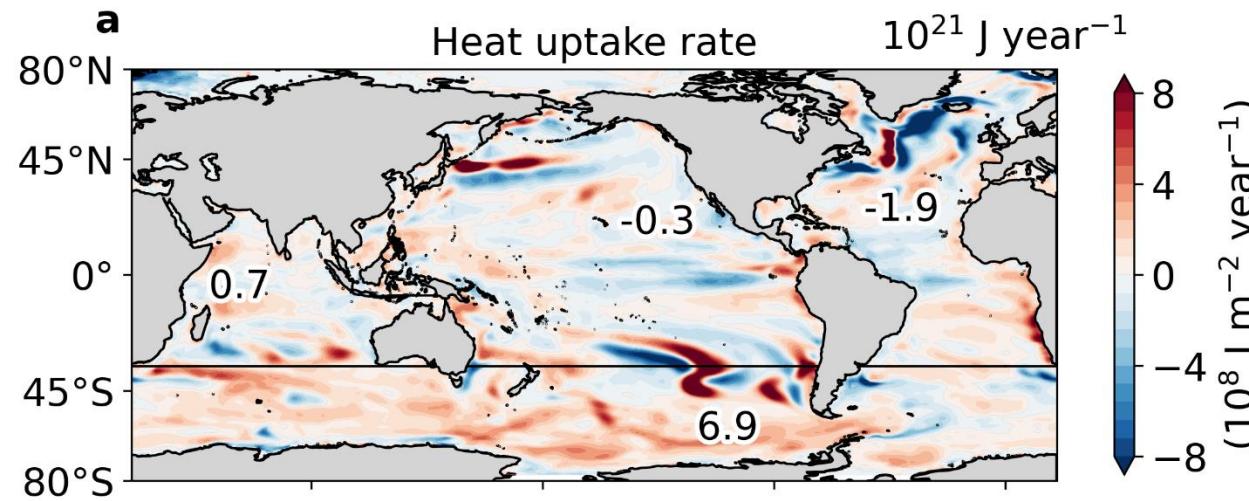
“Come talk to me about the other six habits.”



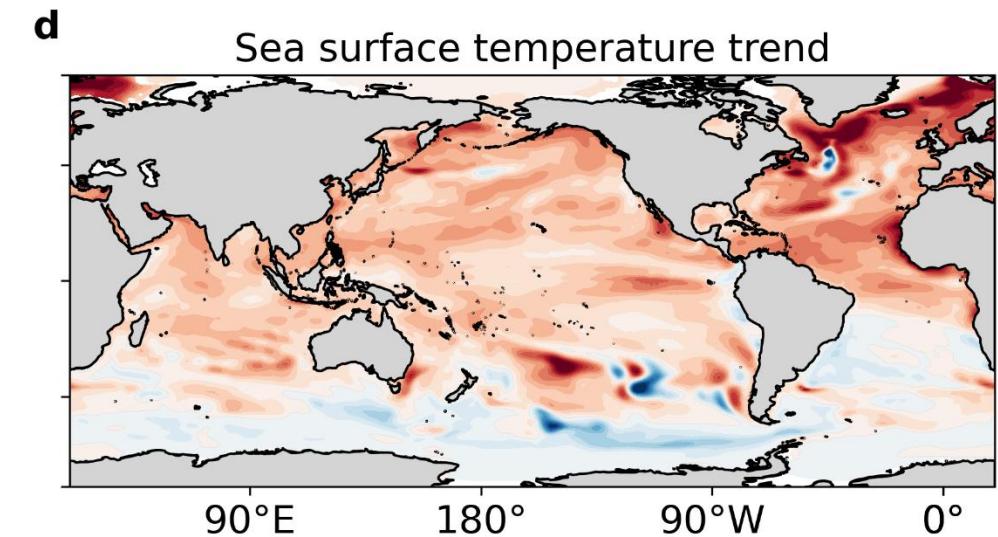
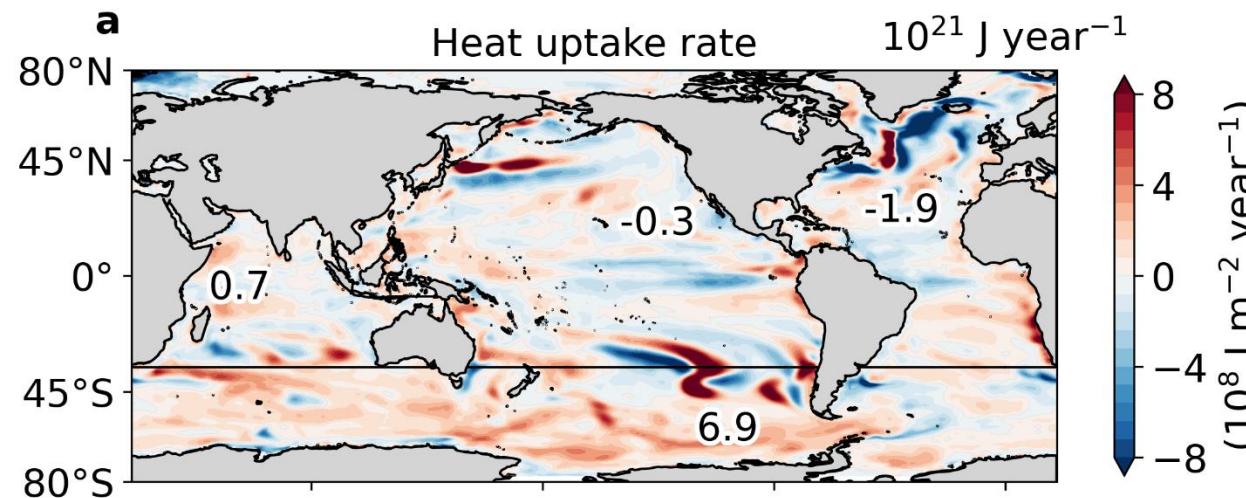
old slides

Ocean heat uptake, transport and storage

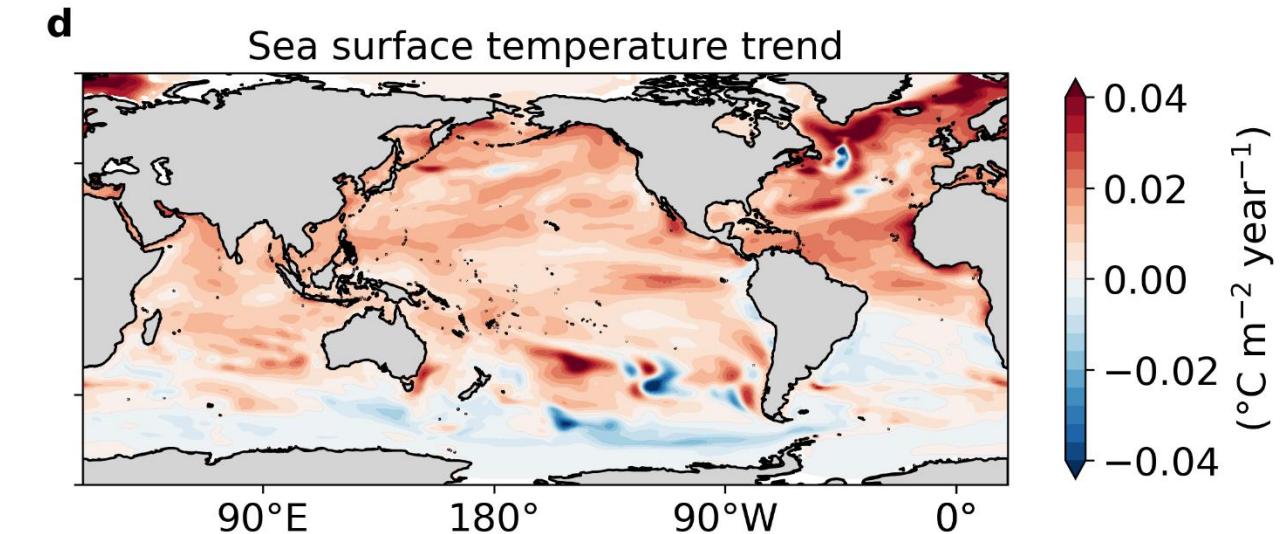
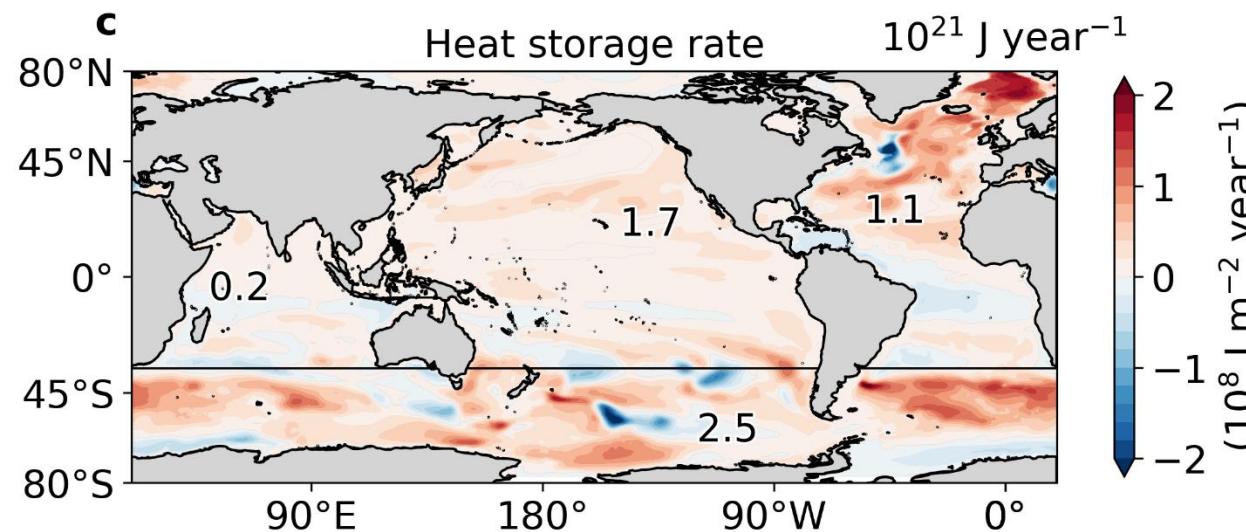
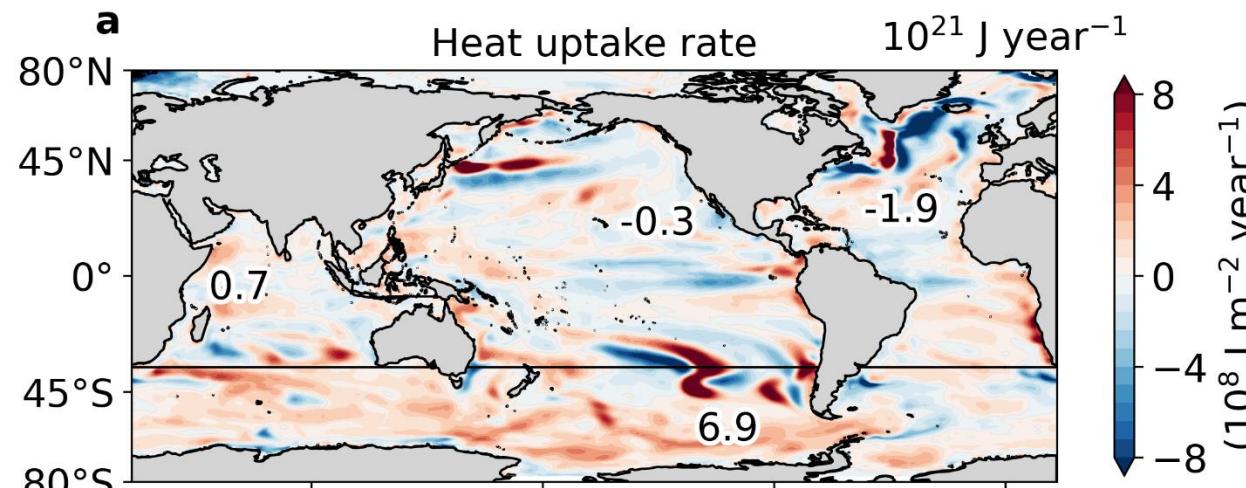
Ocean heat uptake, transport and storage



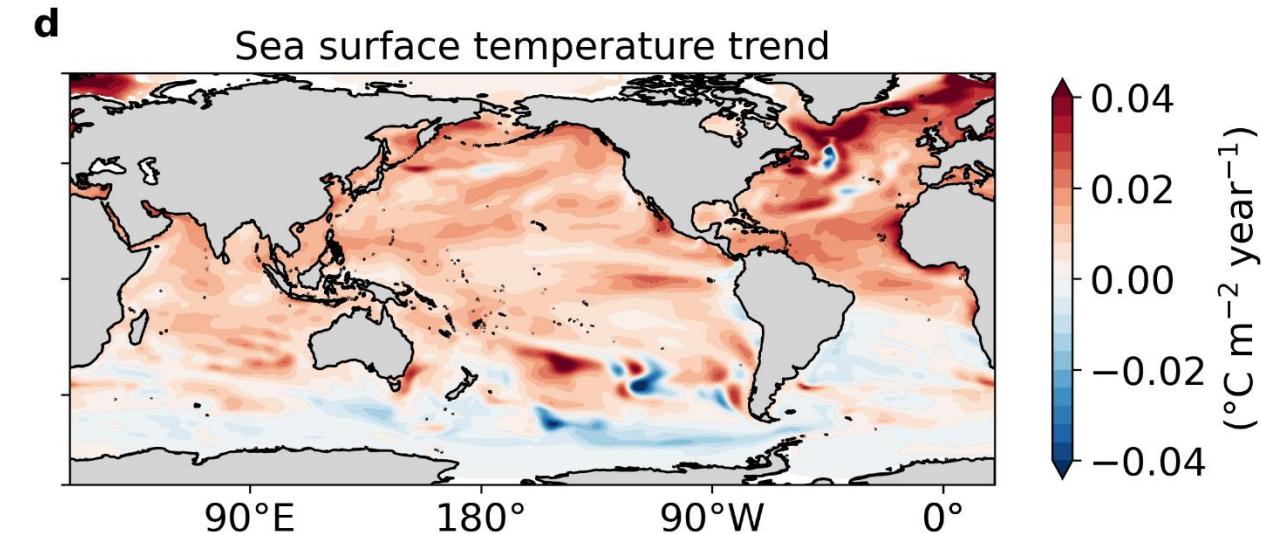
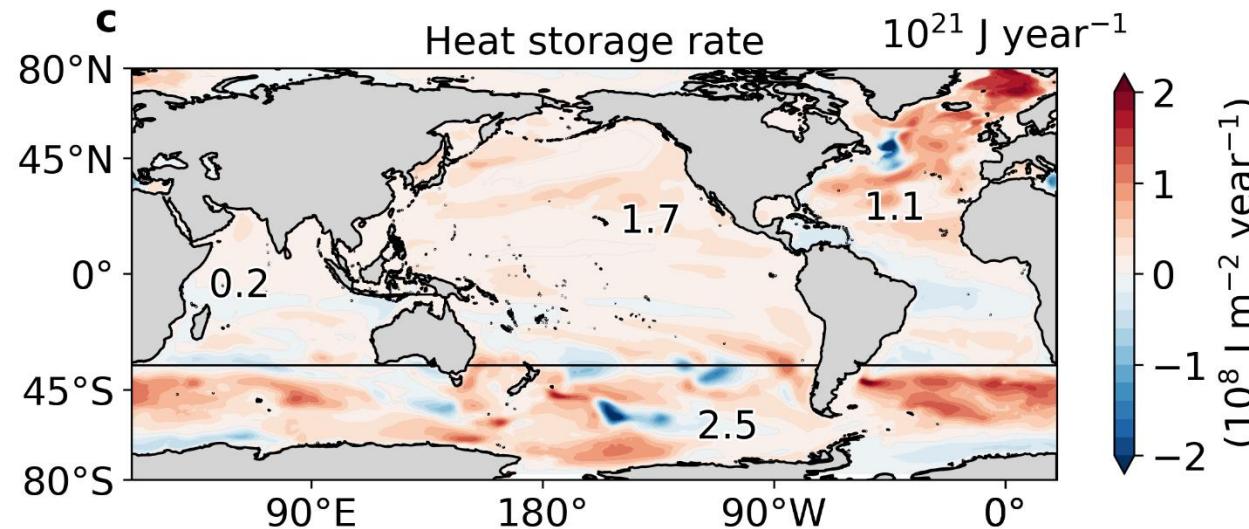
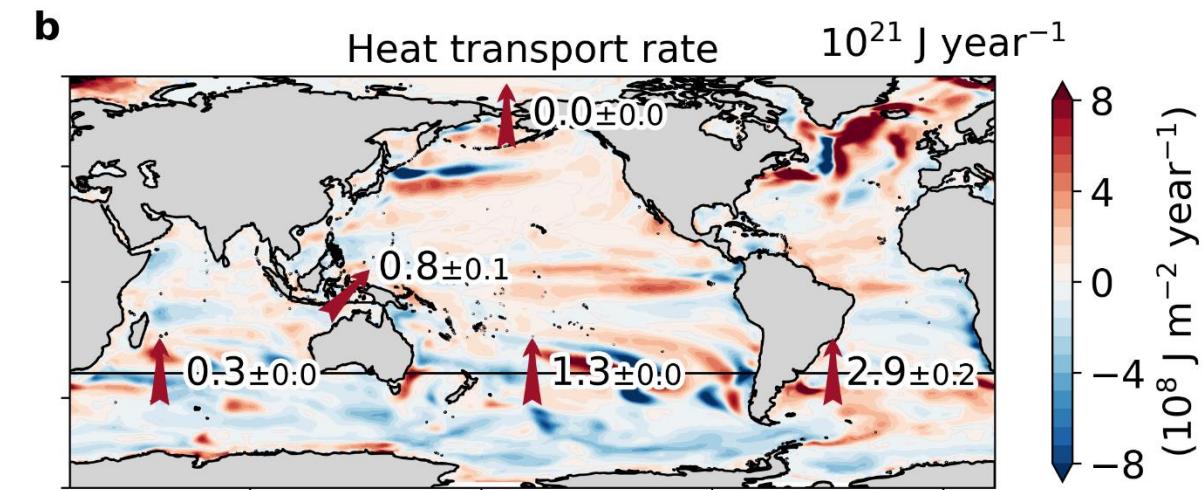
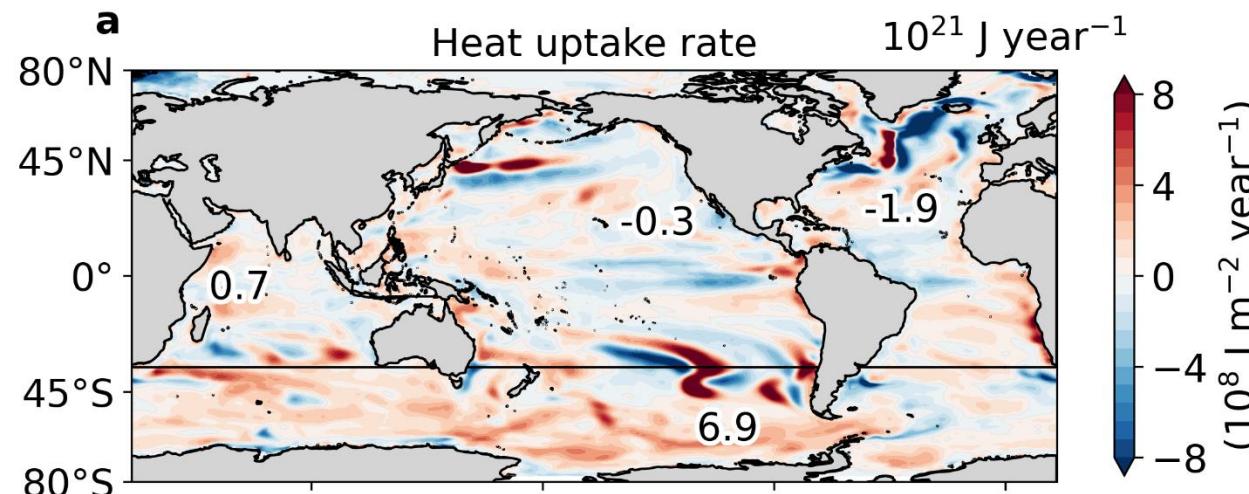
Ocean heat uptake, transport and storage



Ocean heat uptake, transport and storage



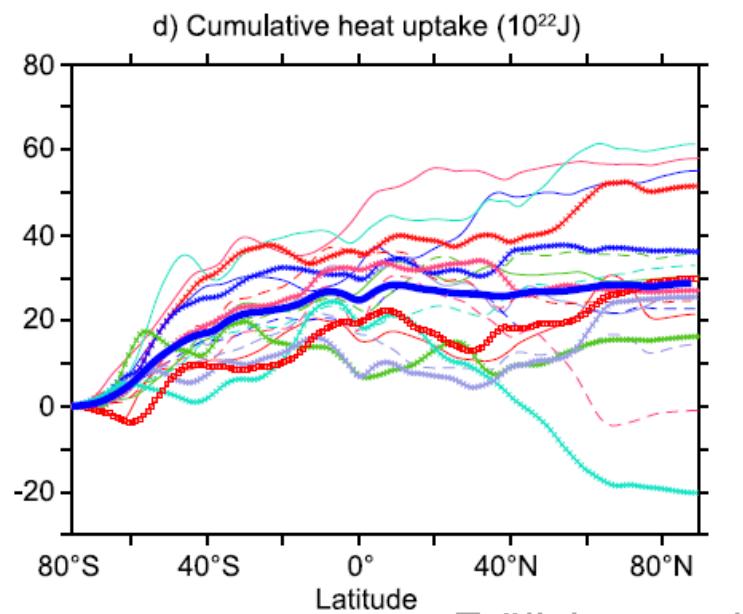
Ocean heat uptake, transport and storage



Take Home

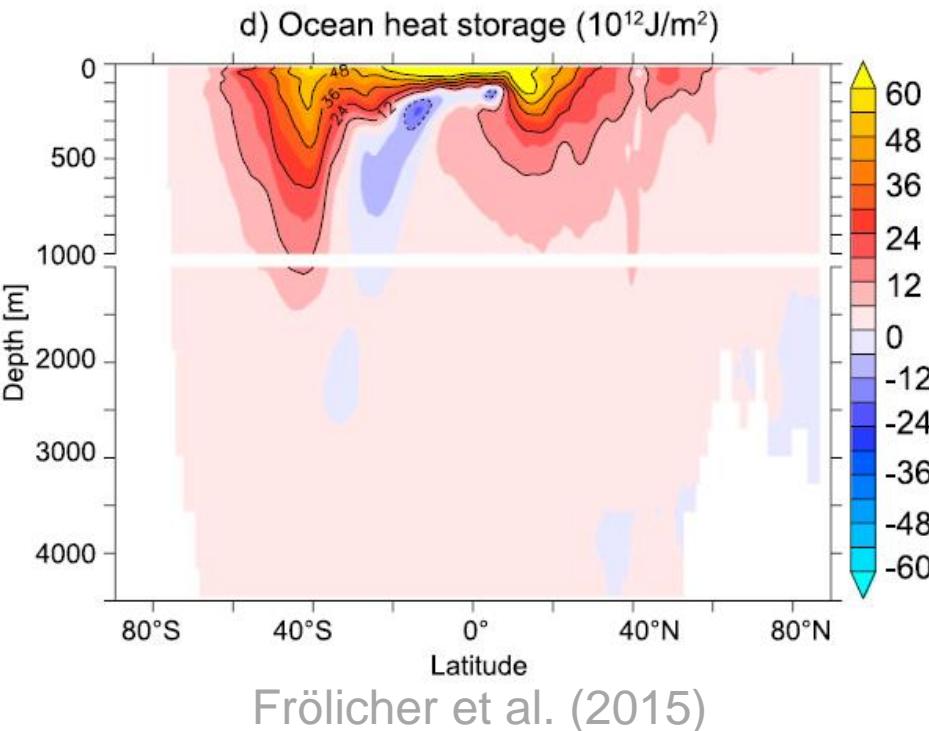
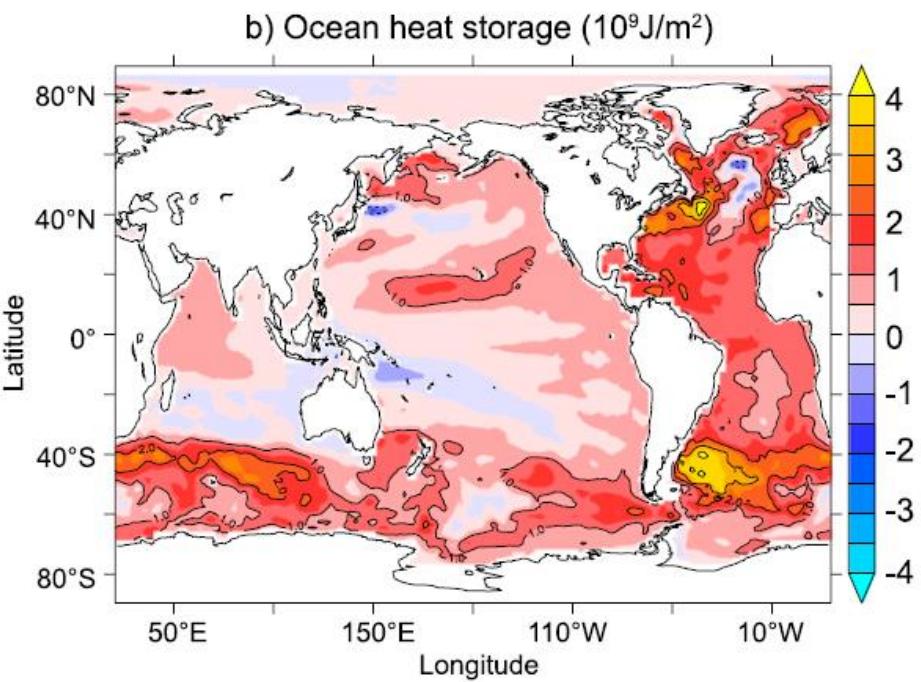
1. **Isolated strong ENSO** simulations illustrate how they modulate subsurface West Antarctic shelf temperatures
2. **El Niño weakens** coastal **easterlies**, **reduced** cold poleward **Ekman** transport & causes cross-shelf **upwelling** of warm **CDW**
3. **La Niña** shelf circulation **response** largely **opposite** & inhibits cross-shelf upwelling of CDW

Importance of ocean heat content



Frölicher et al. (2015)

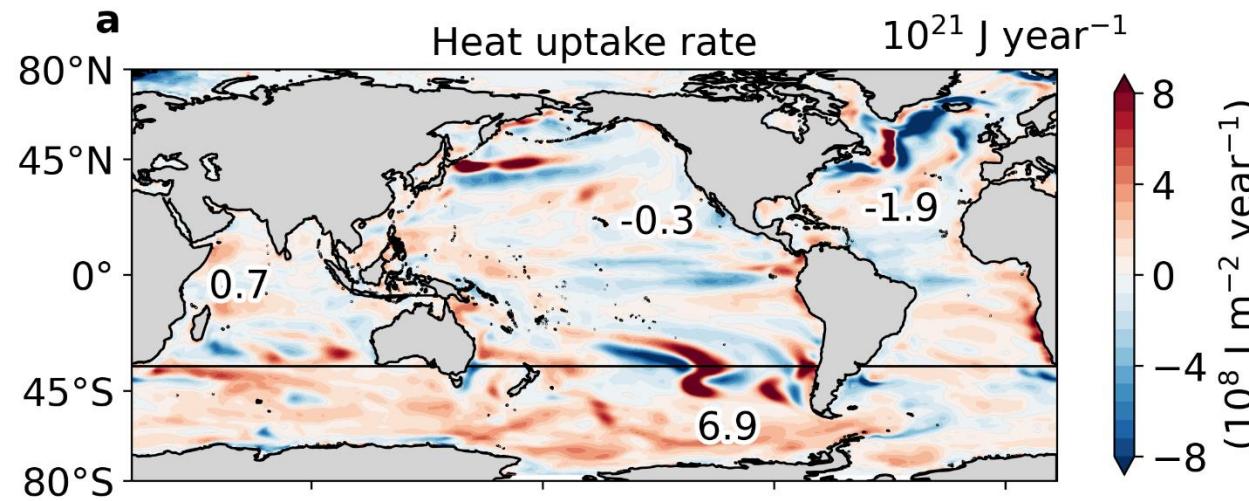
- CNRM-CM5
- IPSL-CM5A-LR
- IPSL-CM5A-MR
- IPSL-CM5B-LR
- FGOALS-s2
- MRI-CGCM3
- GISS-E2-R
- CCSM4
- MIROC-ESM-CHEM
- NorESM1-M
- NorESM-ME
- MIROC-ESM
- MIROC5
- HadGEM2-CC
- MPI-ESM-LR
- Ensemble mean



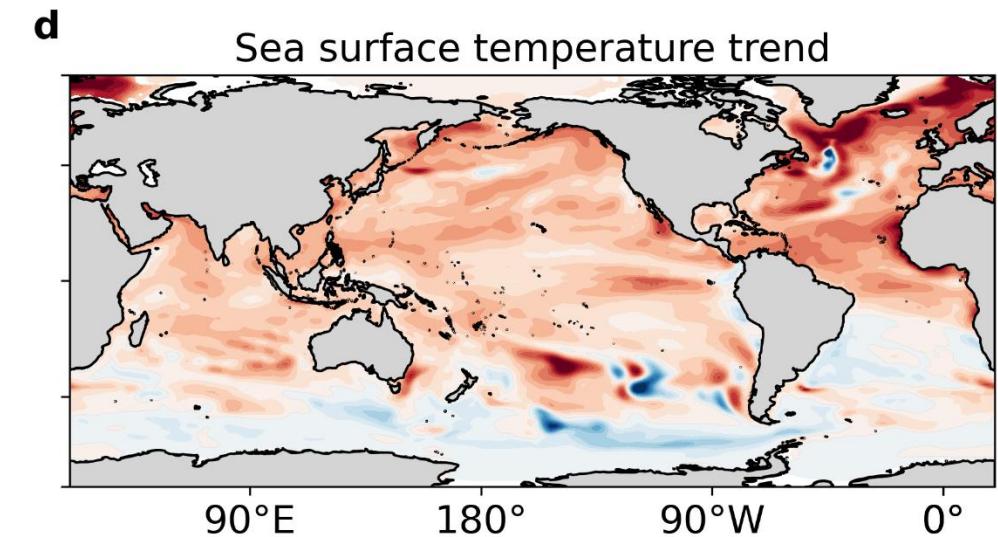
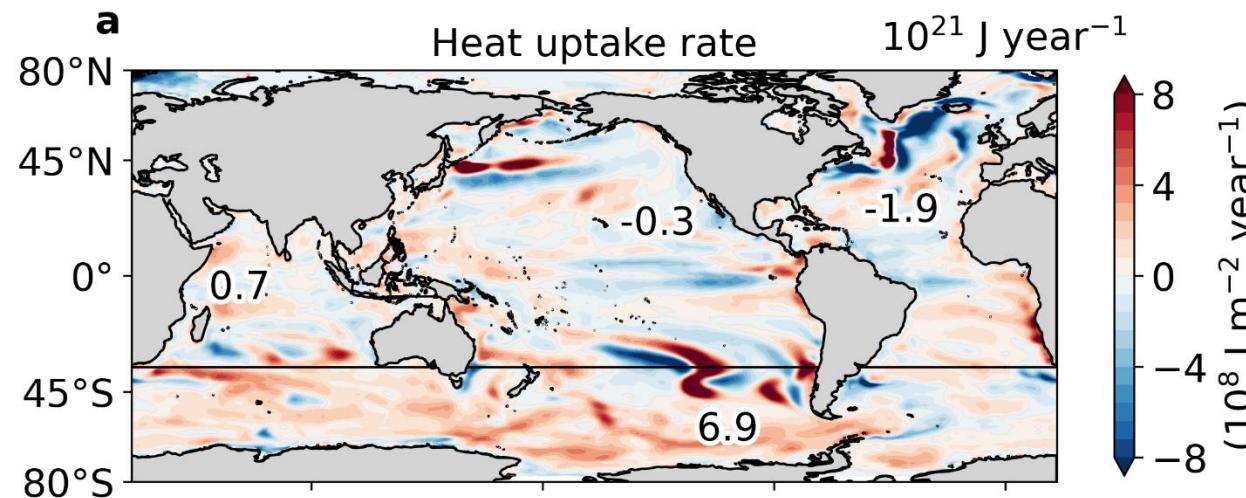
Frölicher et al. (2015)

Ocean heat uptake, transport and storage

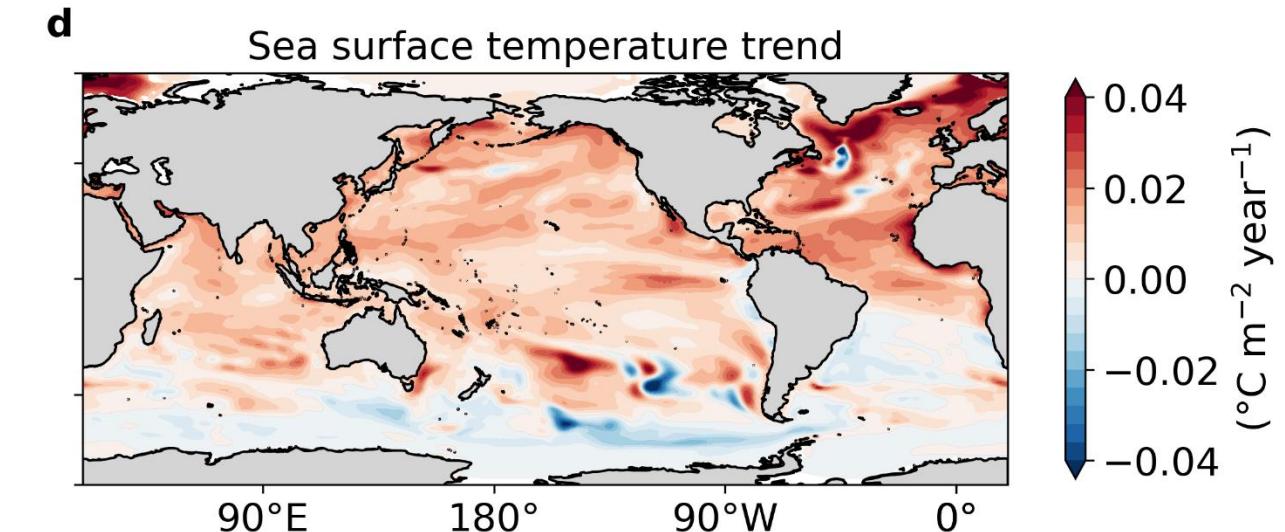
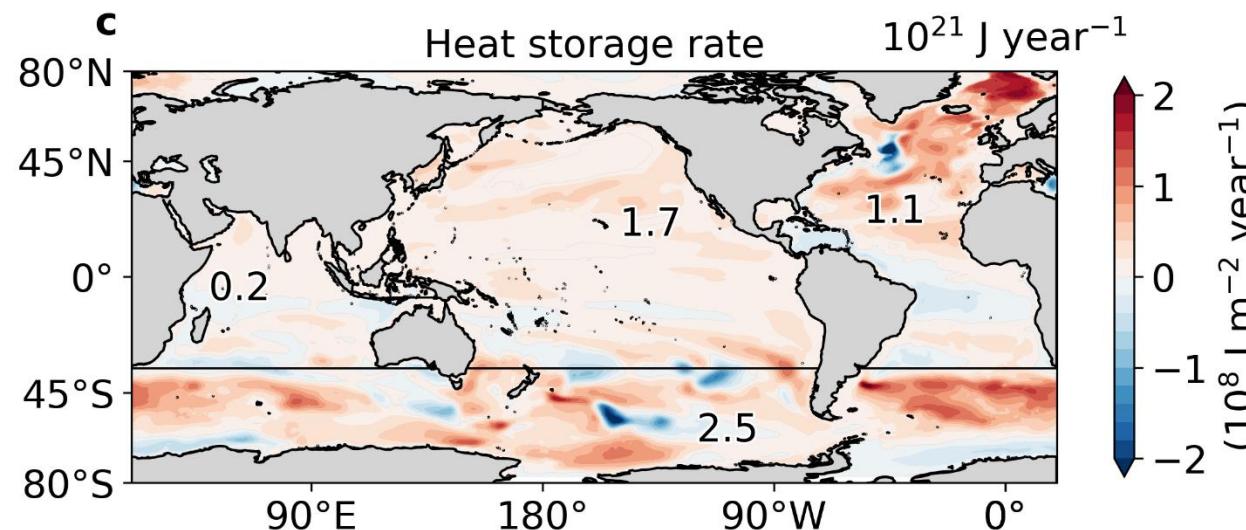
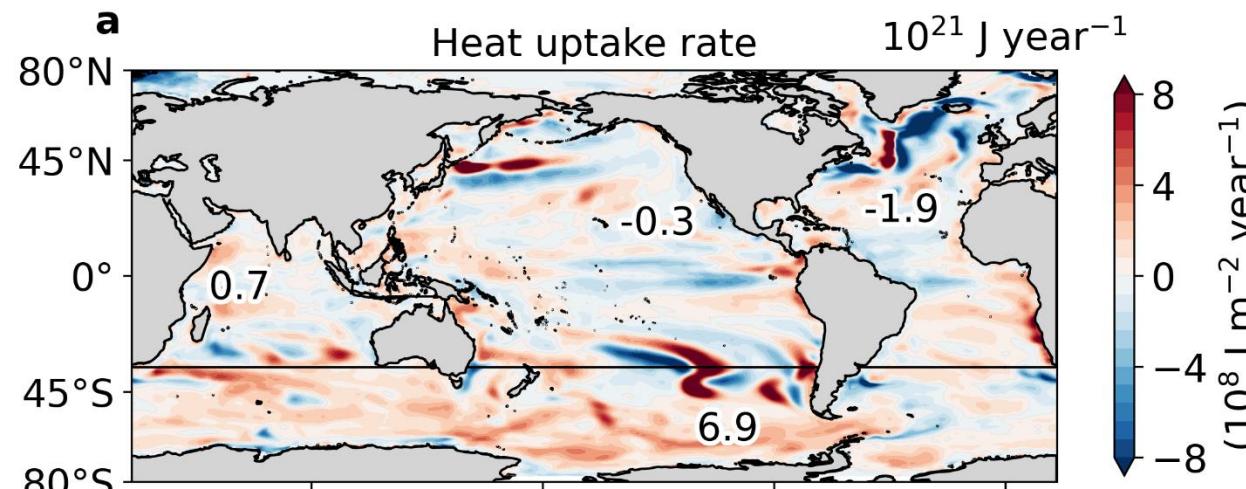
Ocean heat uptake, transport and storage



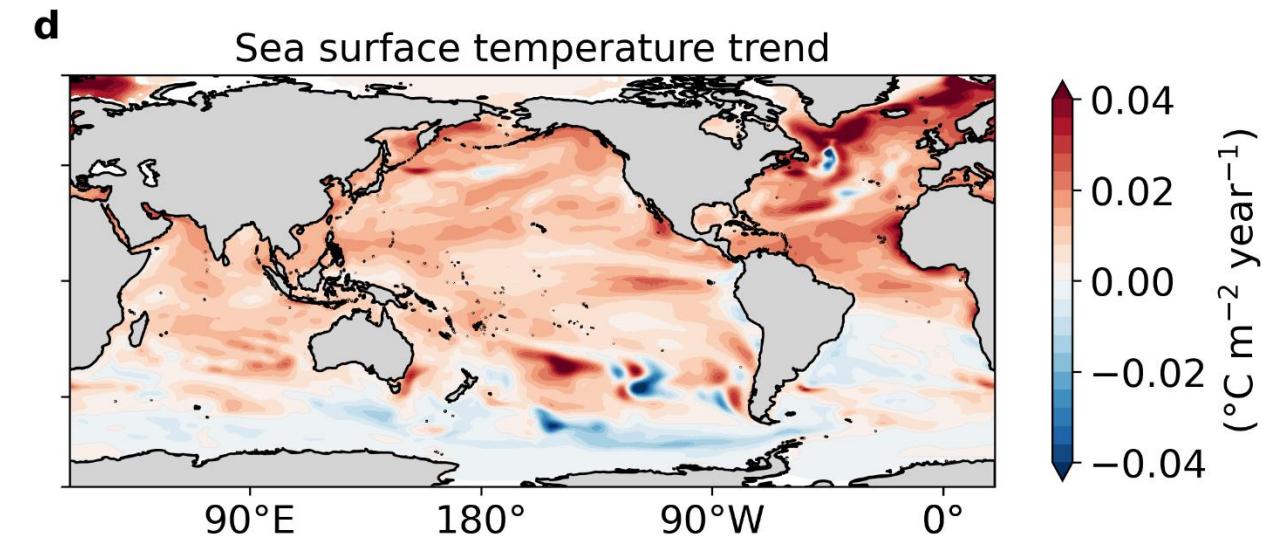
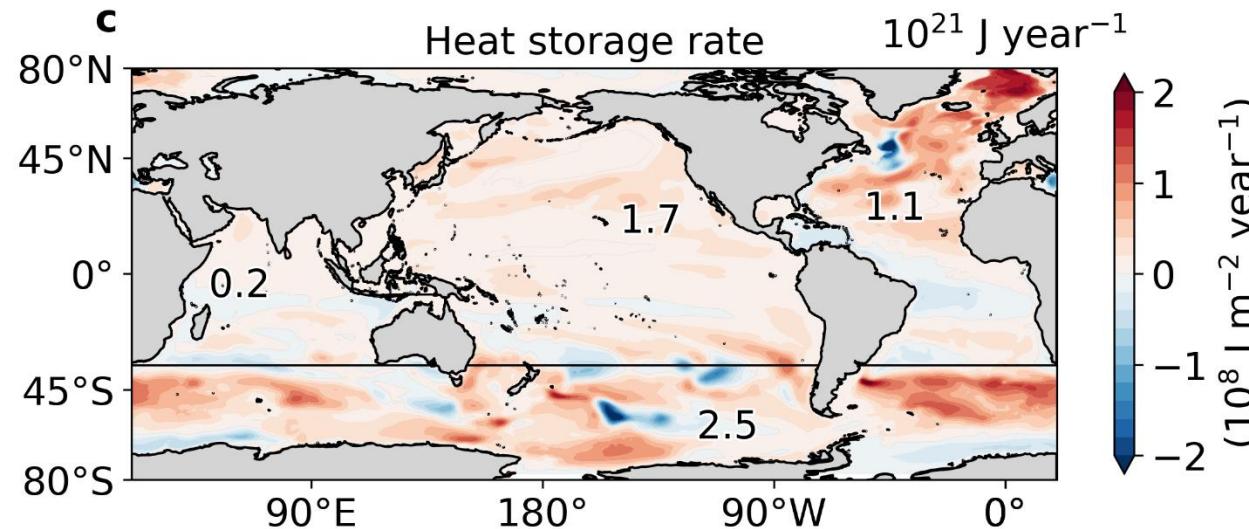
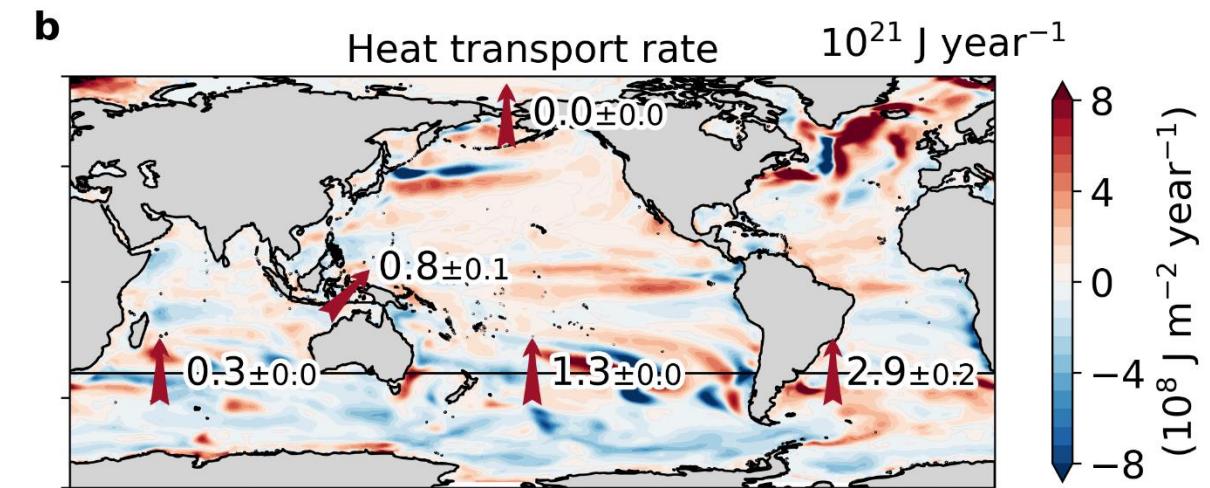
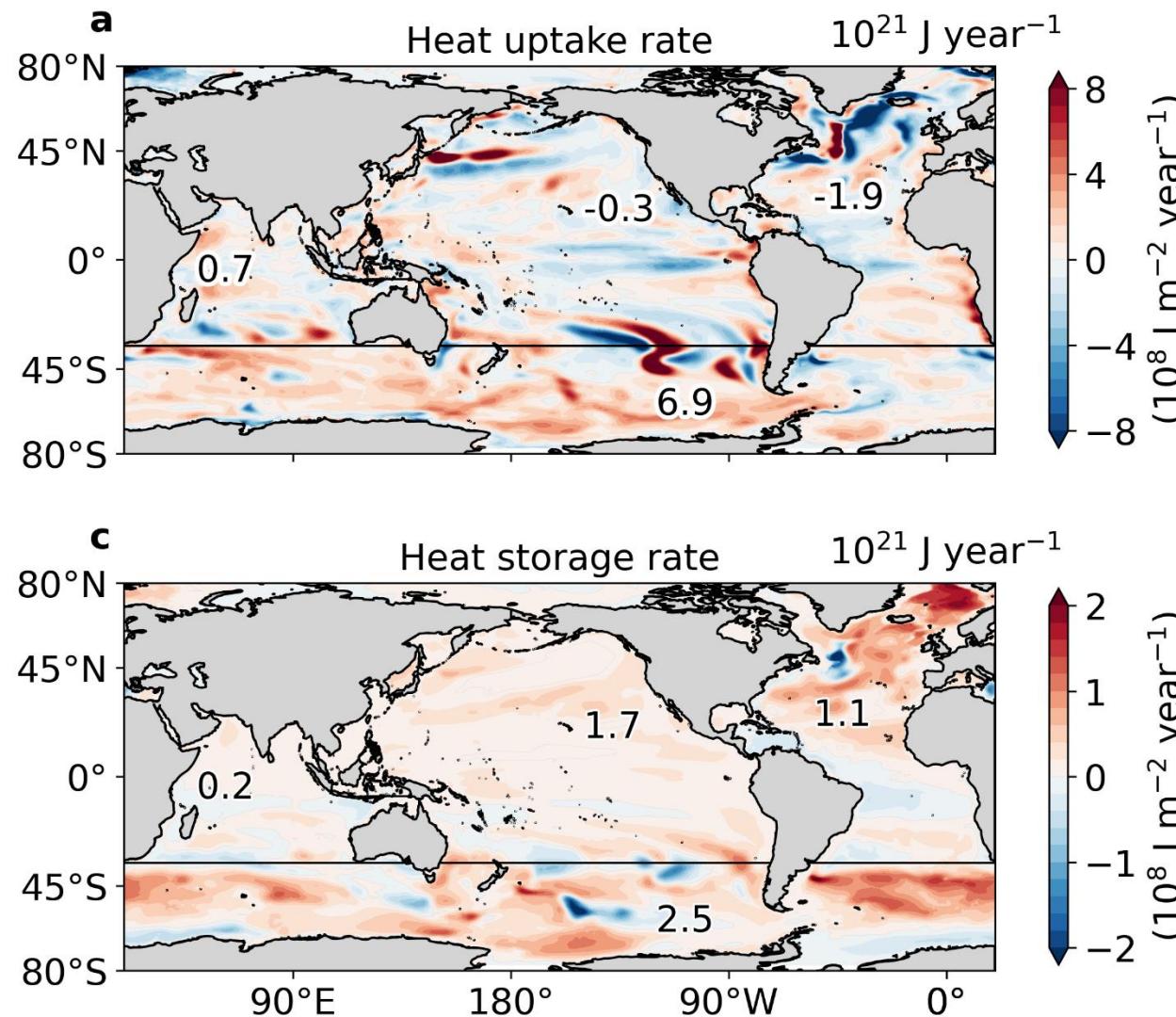
Ocean heat uptake, transport and storage



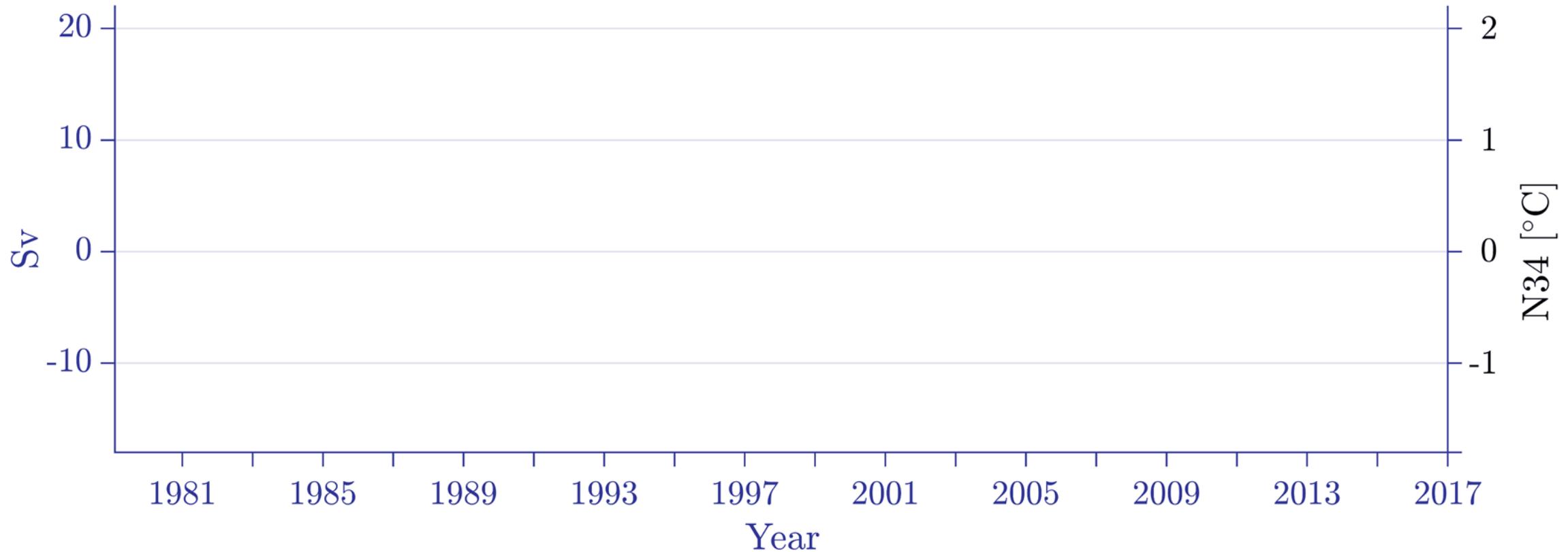
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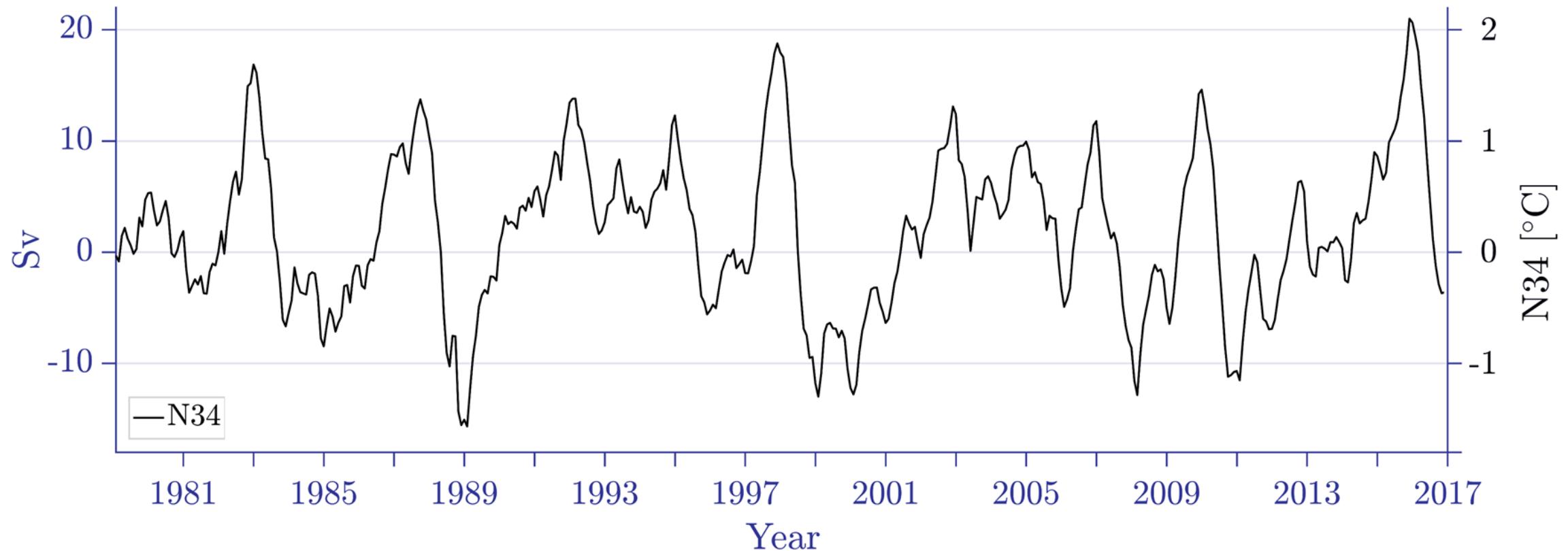
Ocean heat uptake, transport and storage



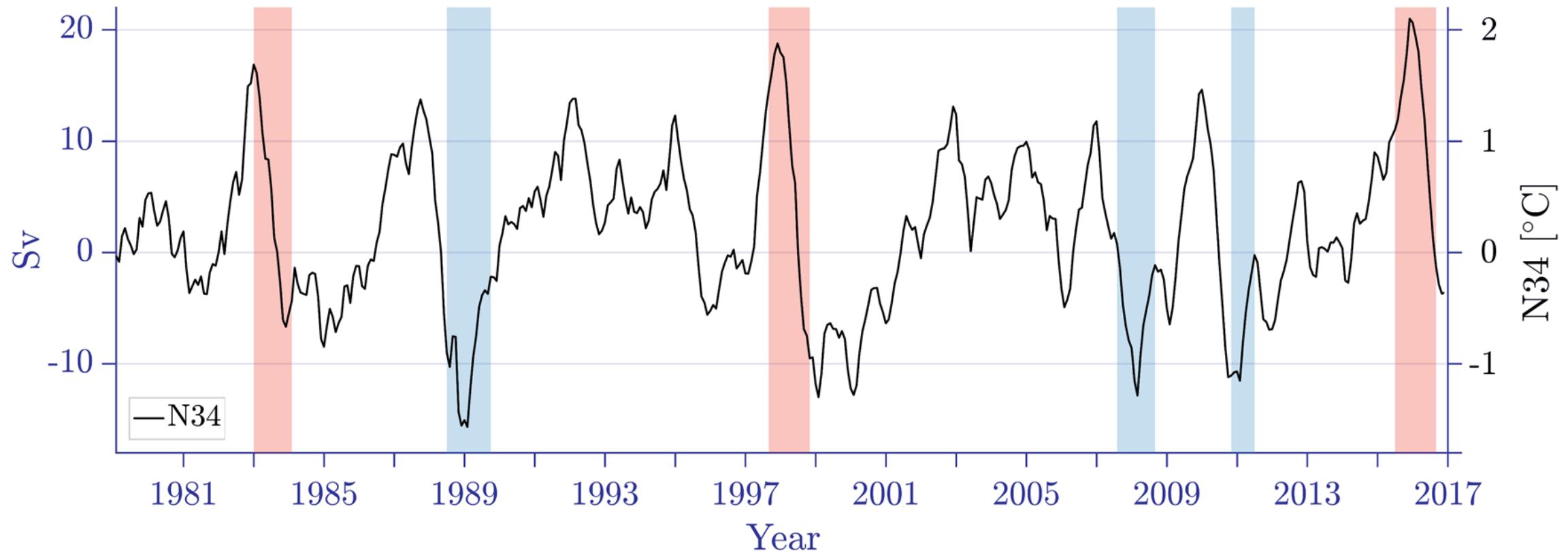
Interannual Variability of the Diabatic Fluxes



Interannual Variability of the Diabatic Fluxes



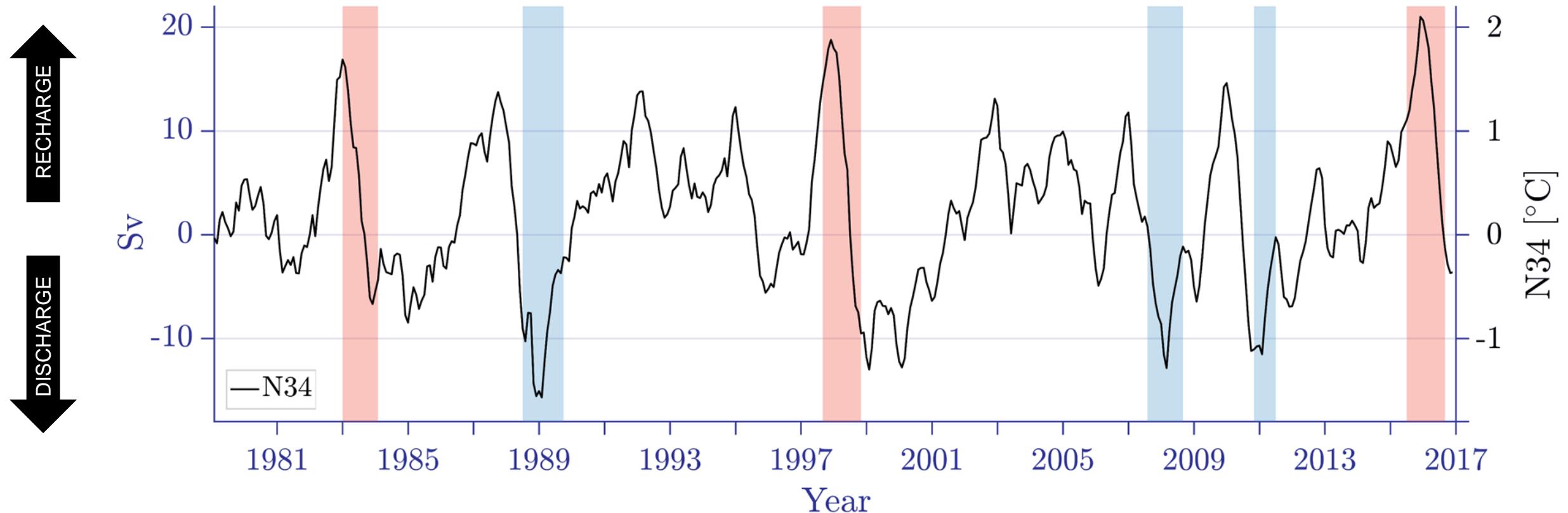
Interannual Variability of the Diabatic Fluxes



El Niño: discharge

La Niña: recharge

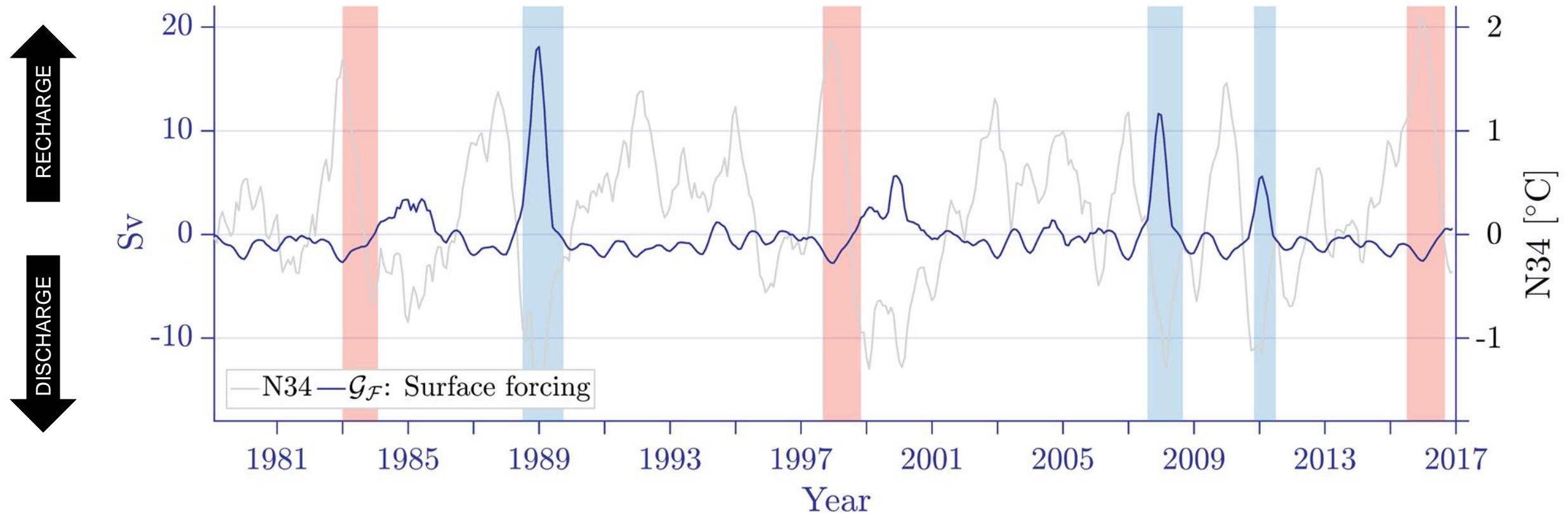
Interannual Variability of the Diabatic Fluxes



El Niño: discharge

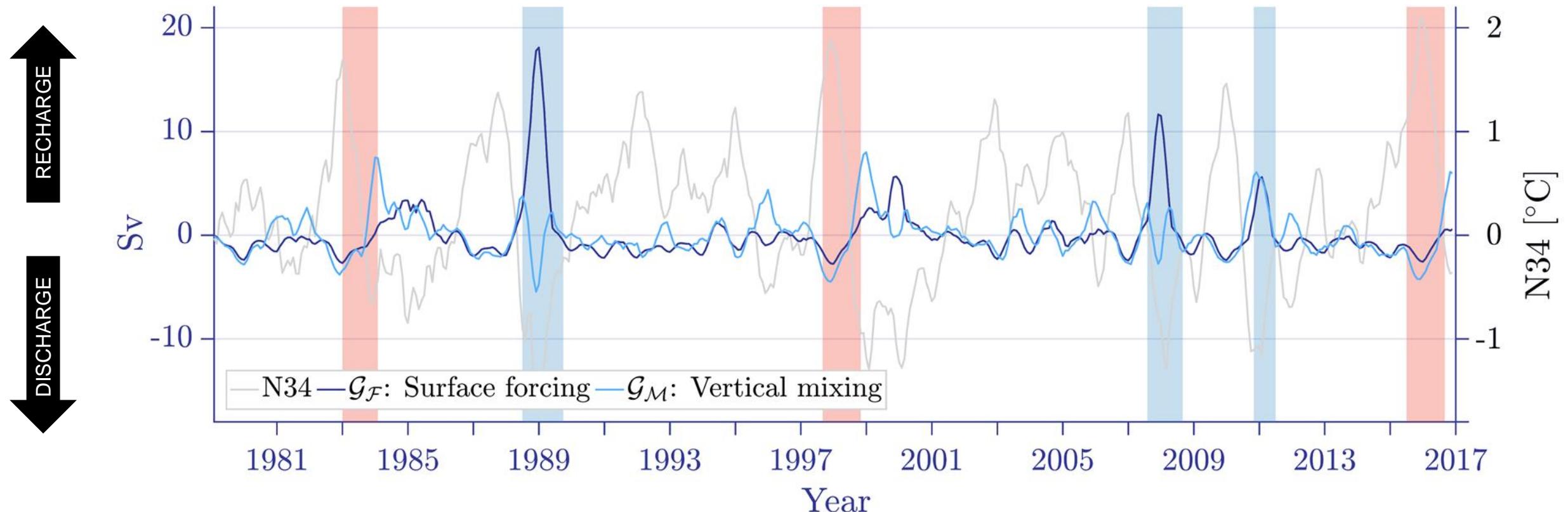
La Niña: recharge

Interannual Variability of the Diabatic Fluxes



La Niña: large positive contribution of surface forcing

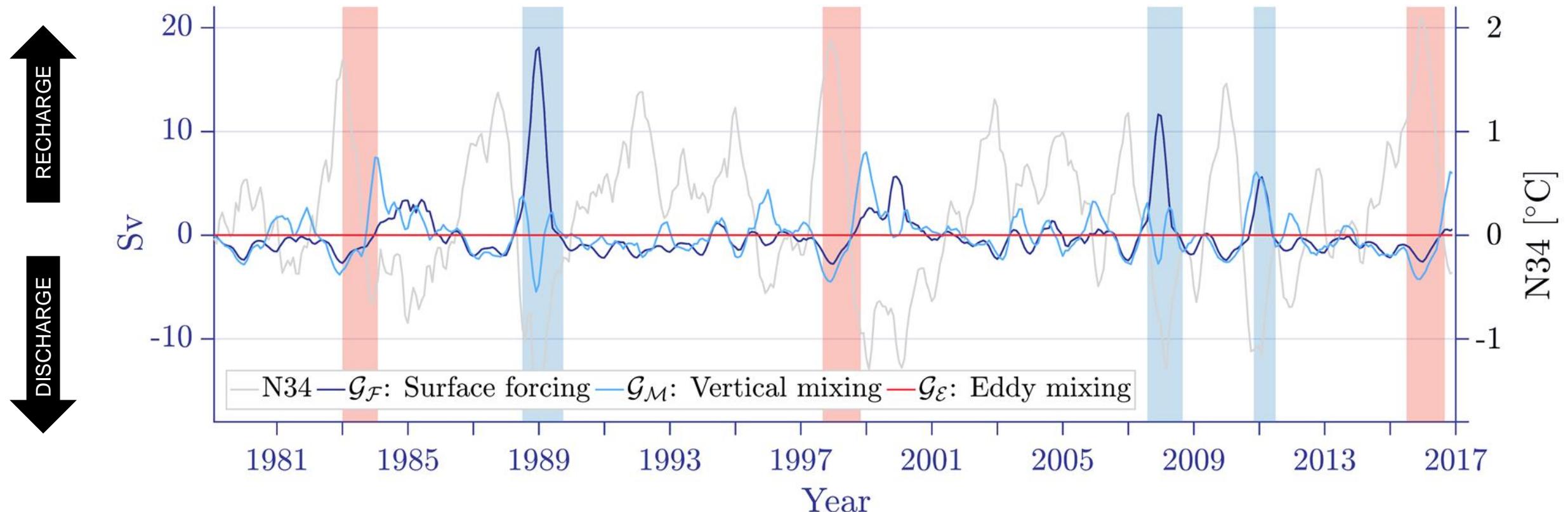
Interannual Variability of the Diabatic Fluxes



El Niño:
La Niña:

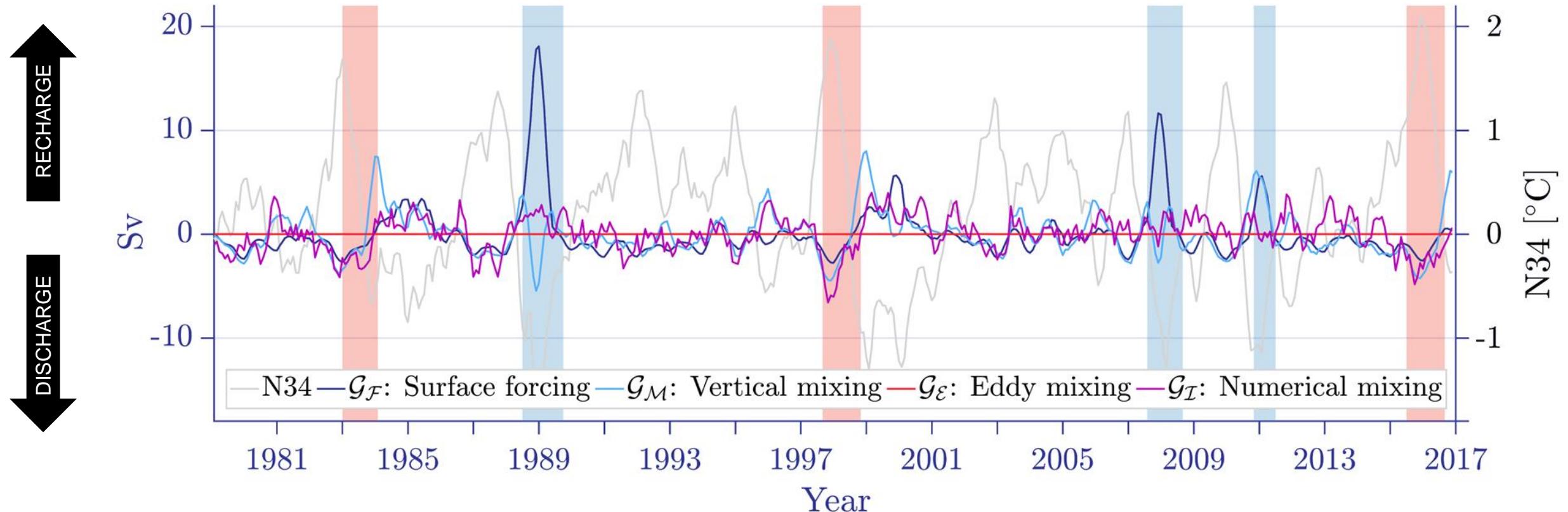
both surface forcing & vertical mixing deplete WWV
large positive contribution of surface forcing

Interannual Variability of the Diabatic Fluxes



El Niño: both surface forcing & vertical mixing deplete WWV
La Niña: large positive contribution of surface forcing

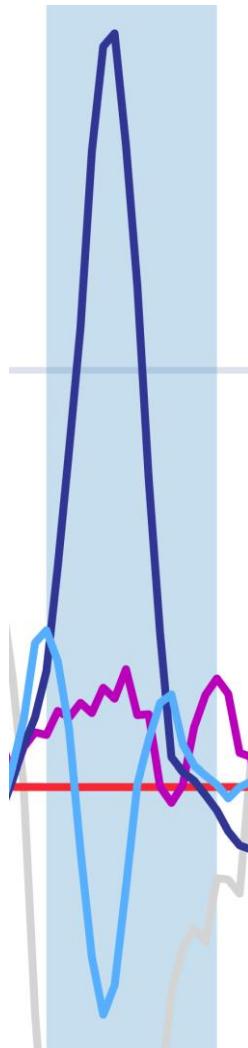
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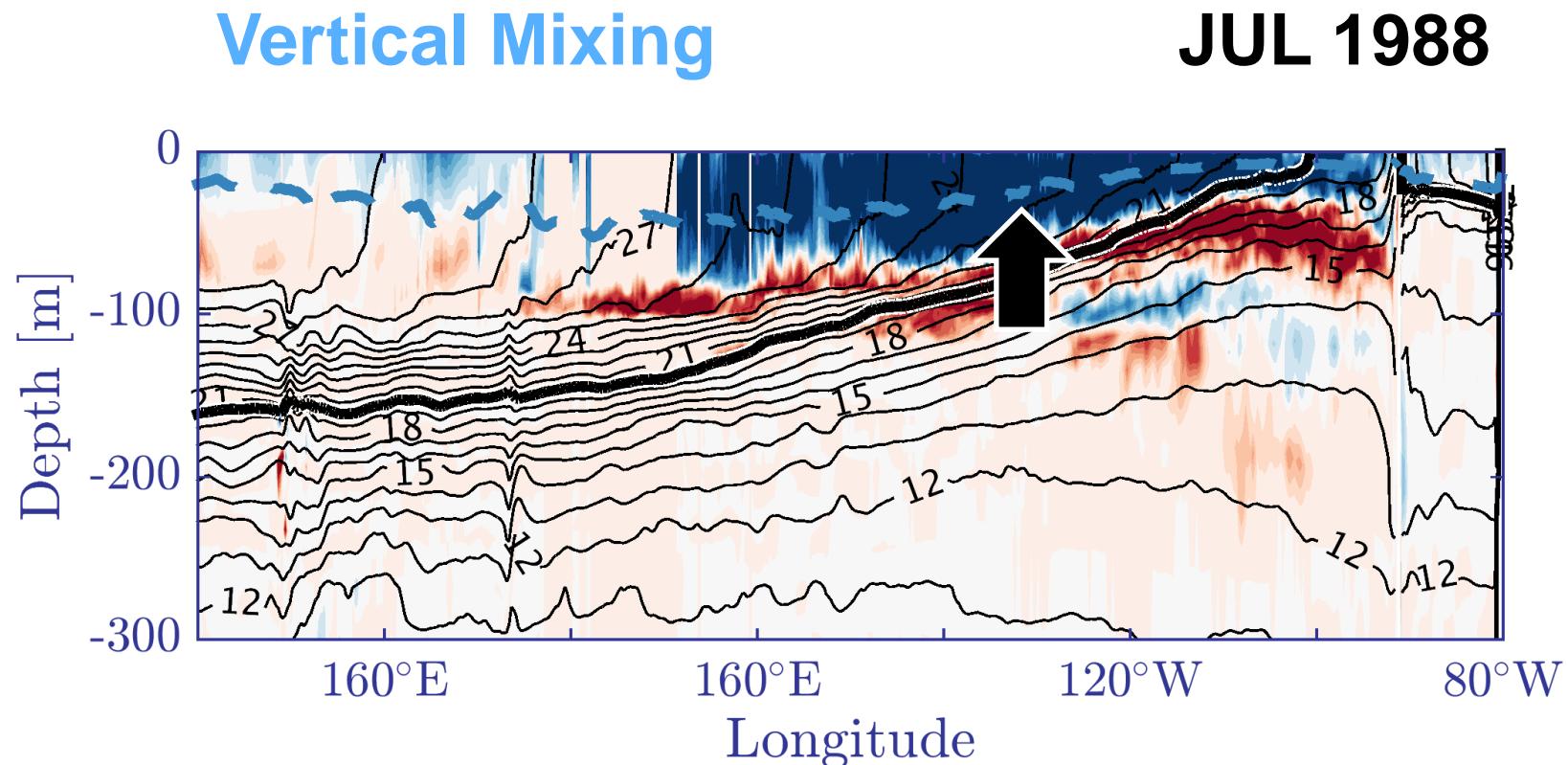
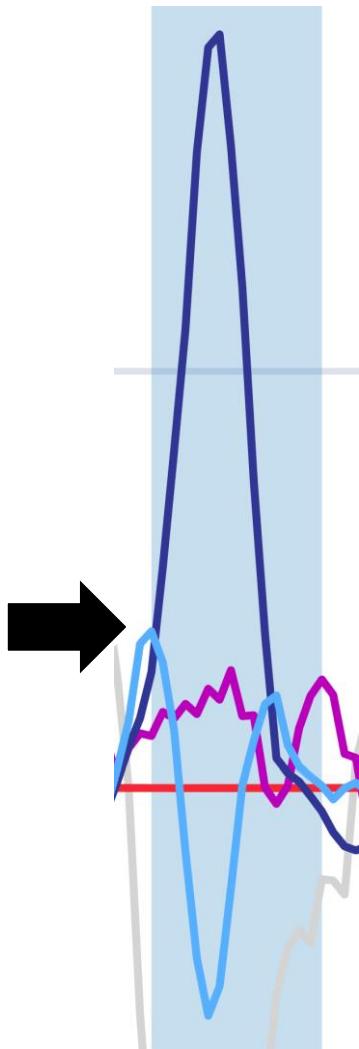
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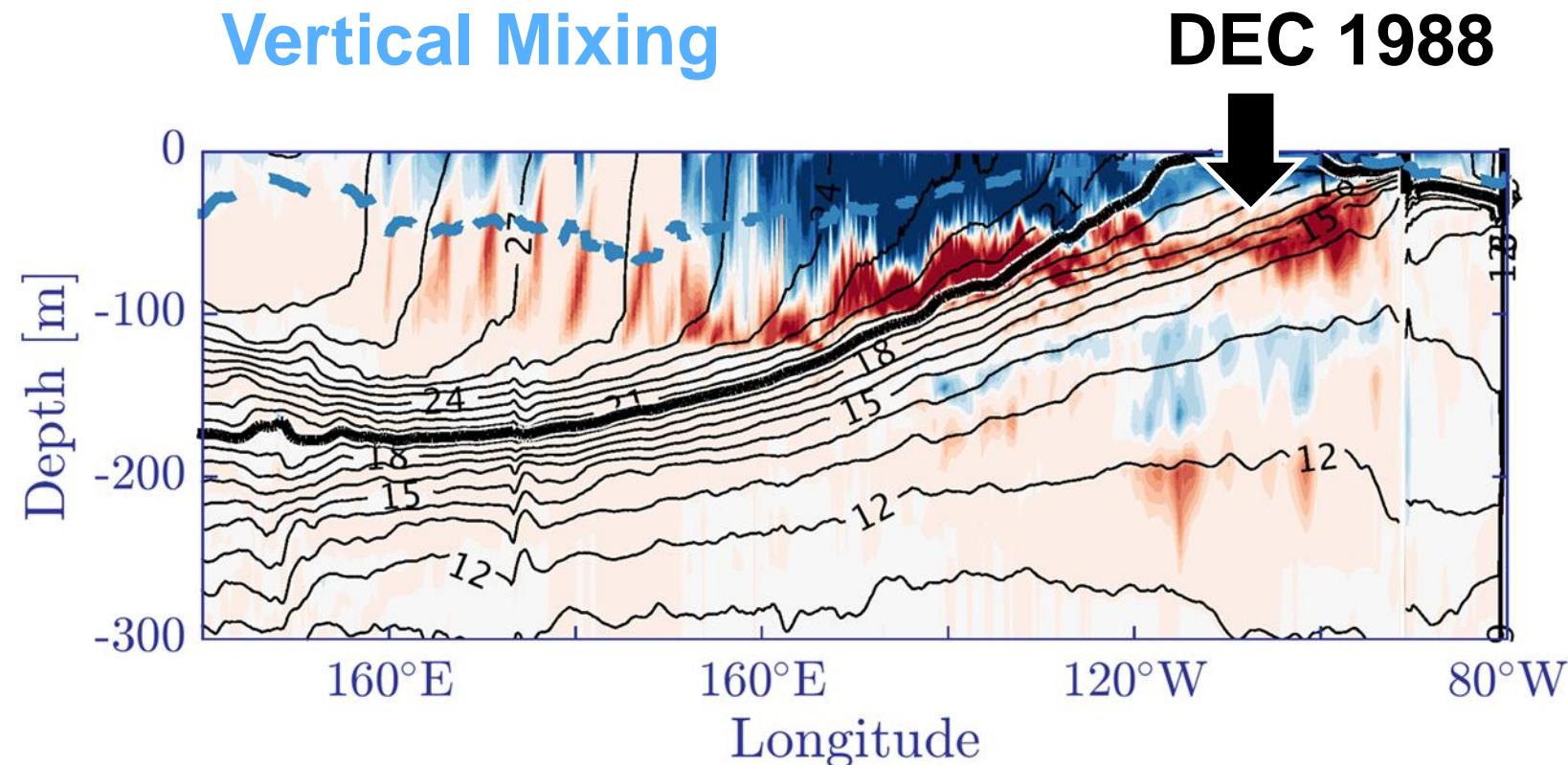
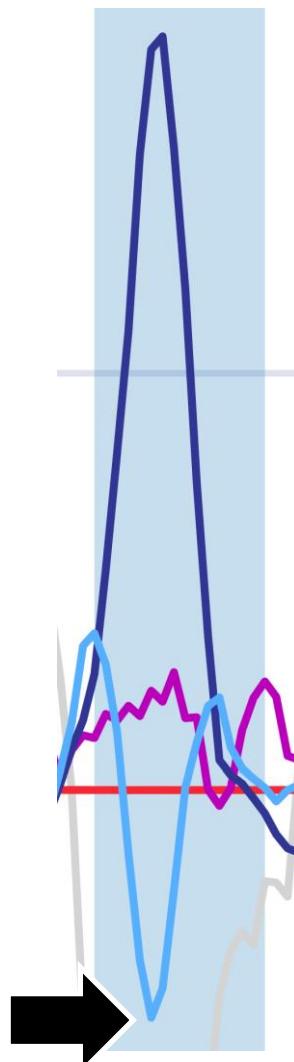
Diabatic Fluxes during La Niña 1988/89



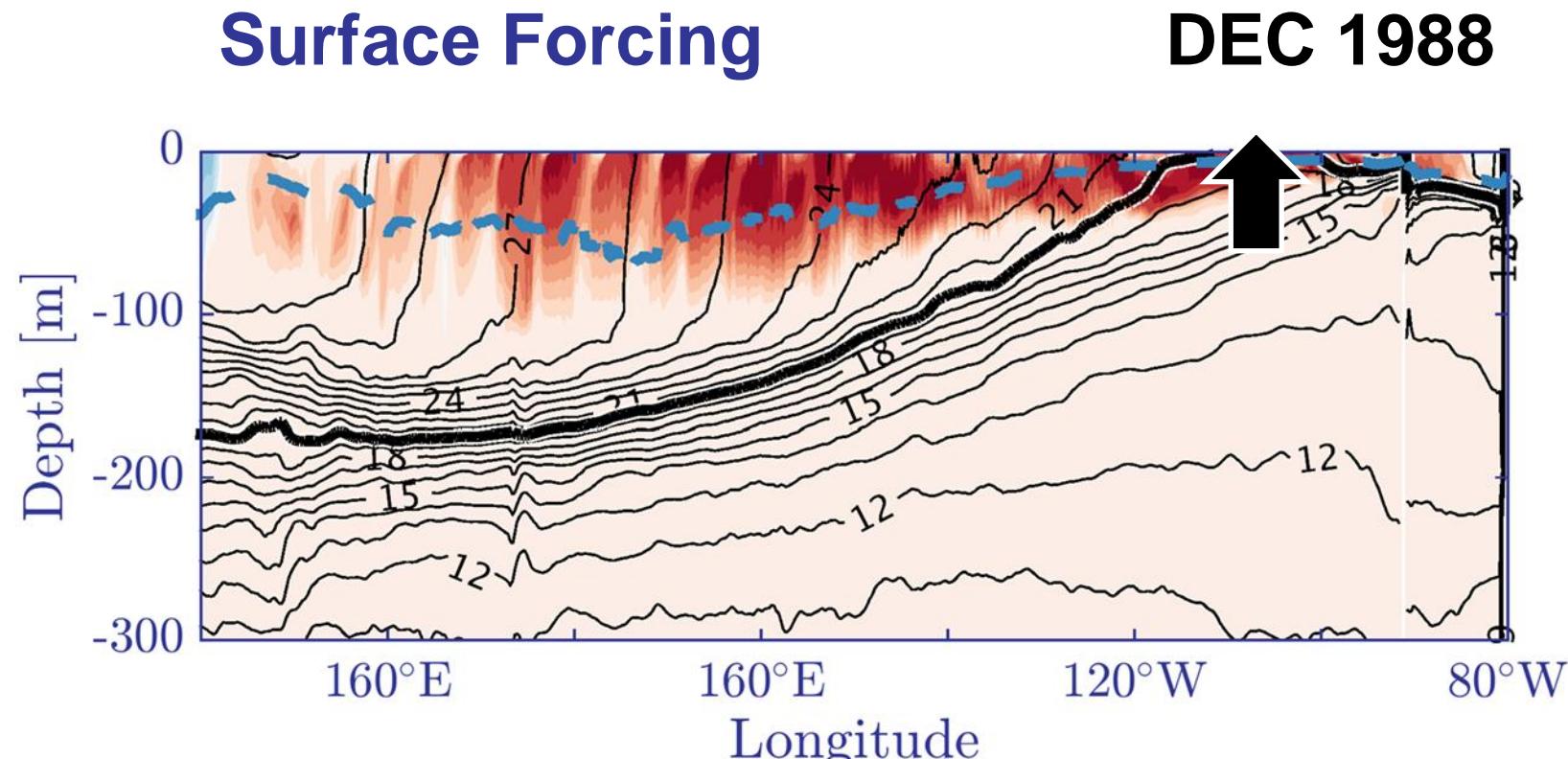
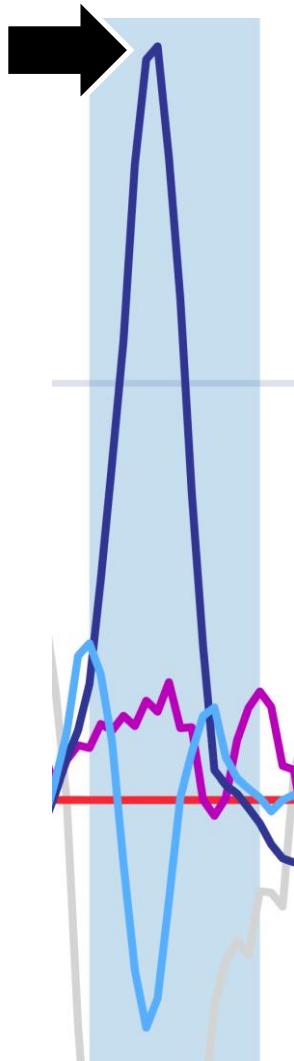
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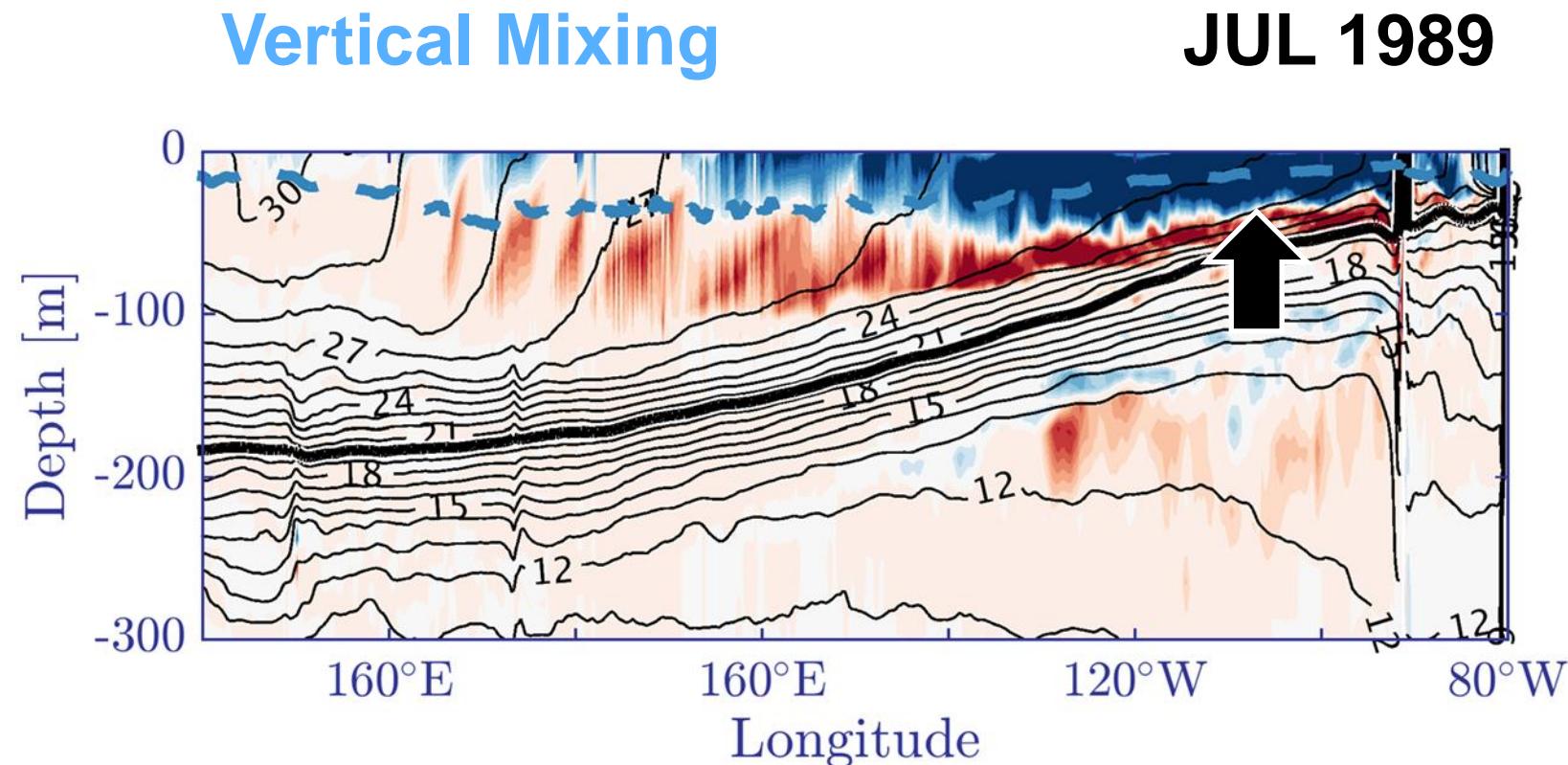
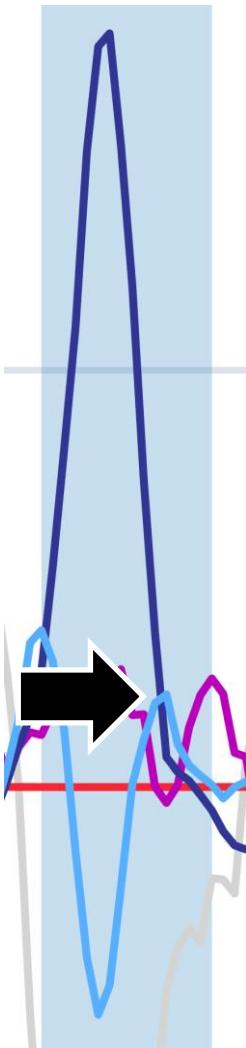
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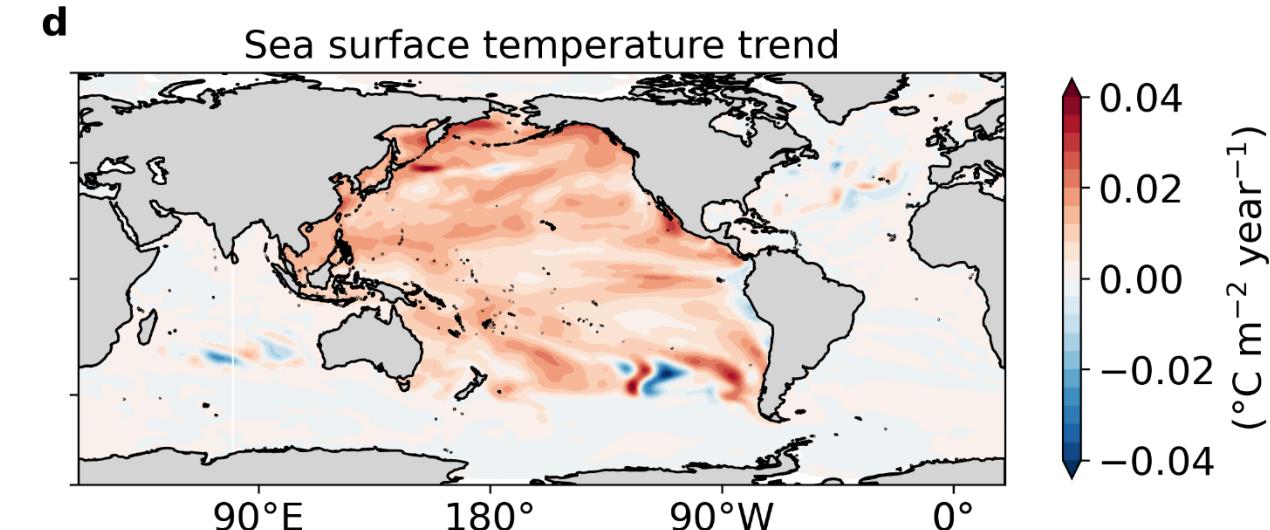
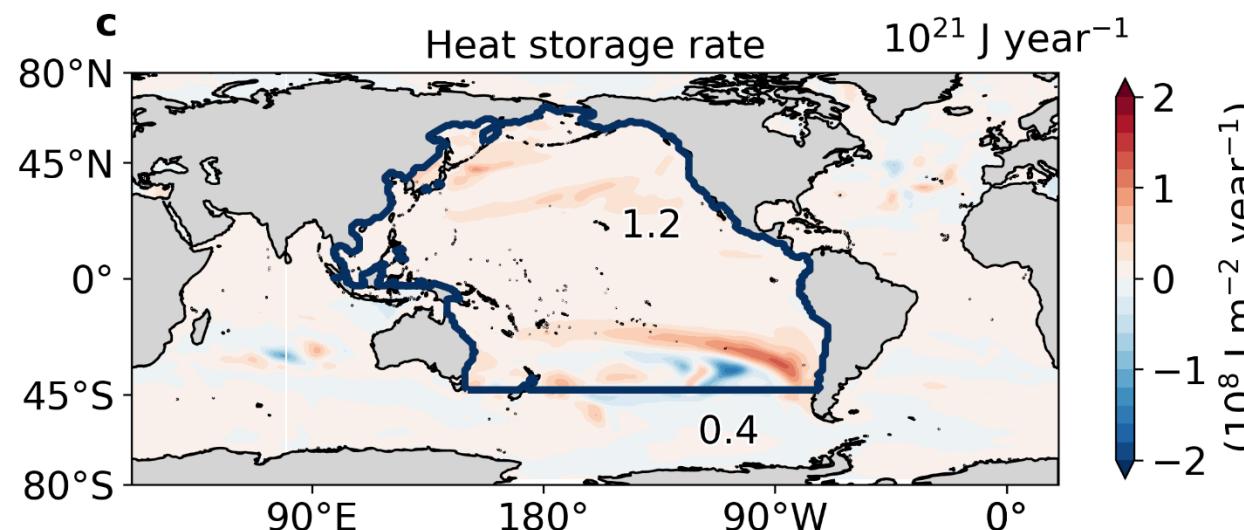
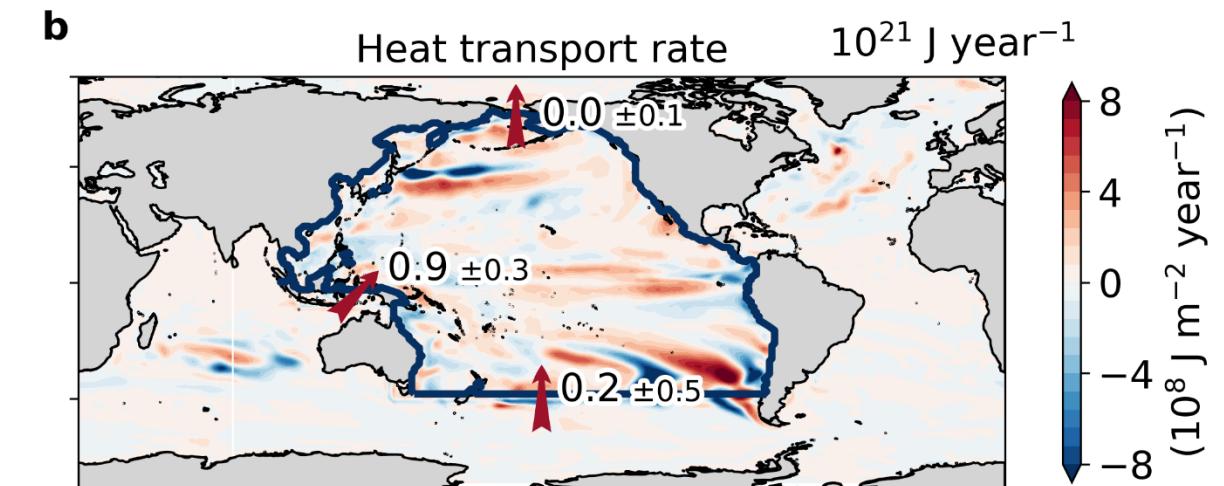
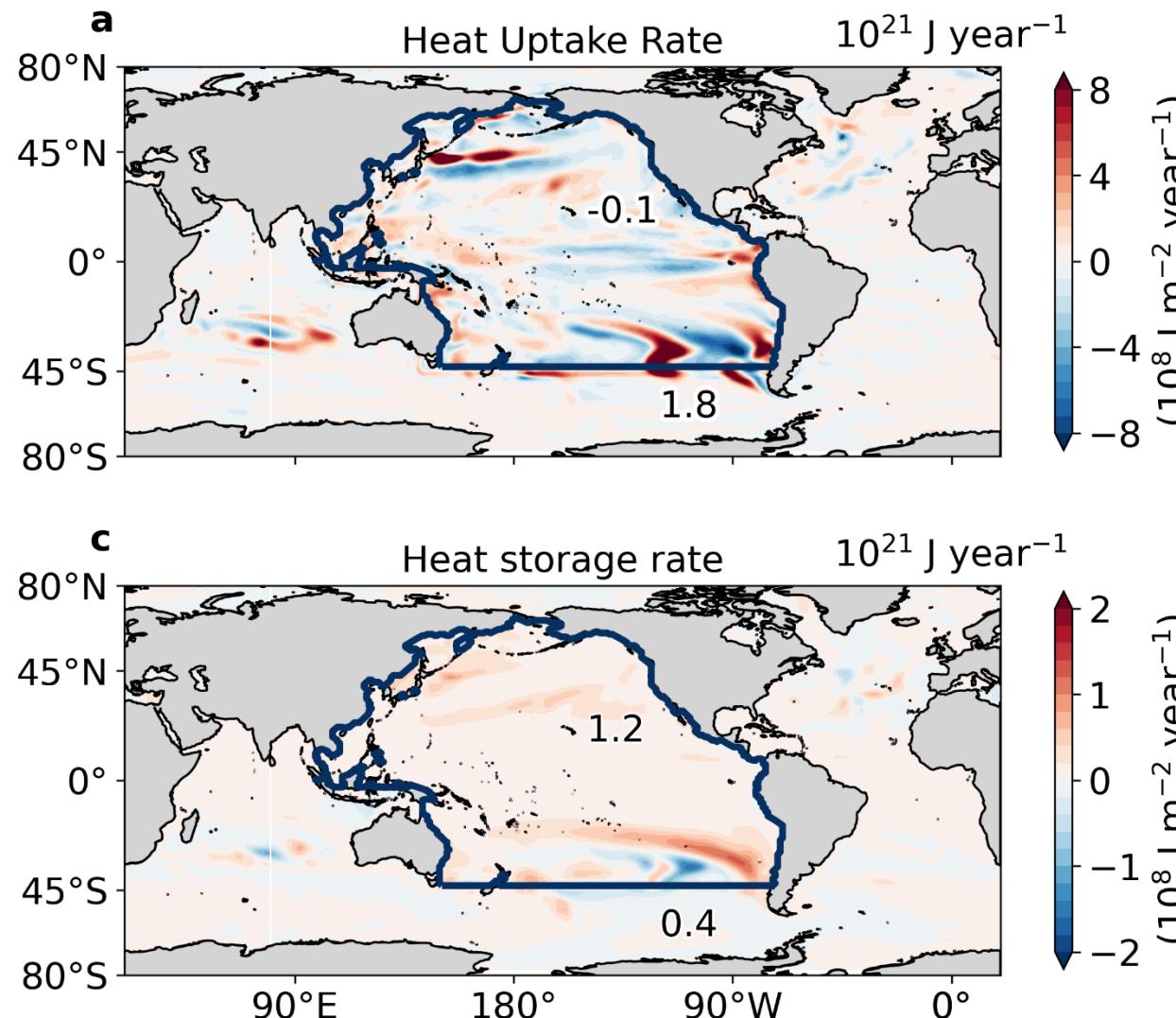
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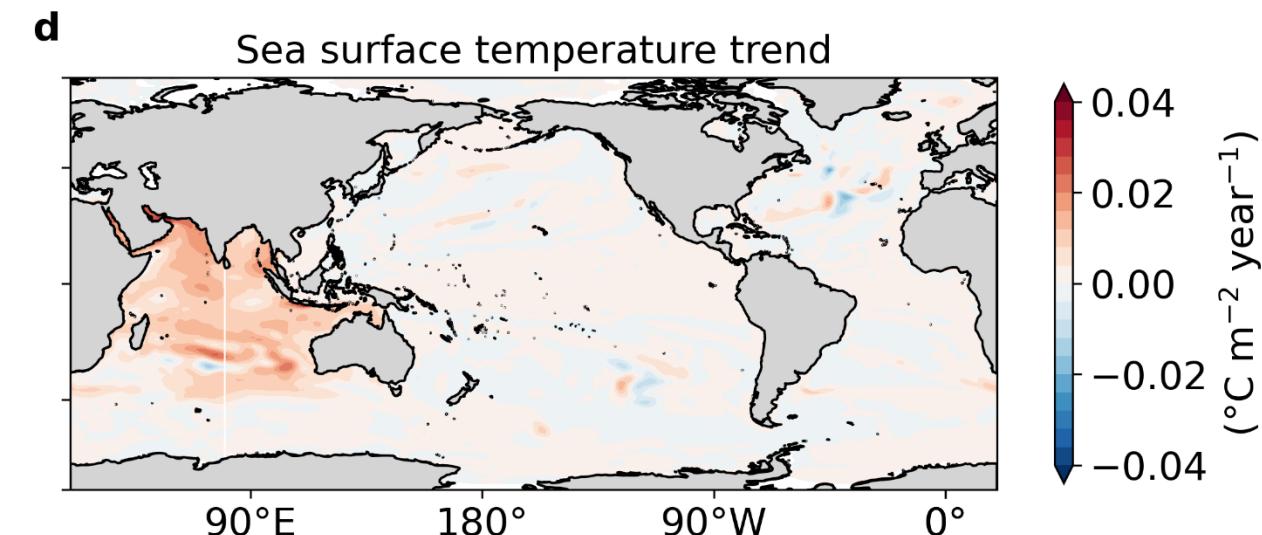
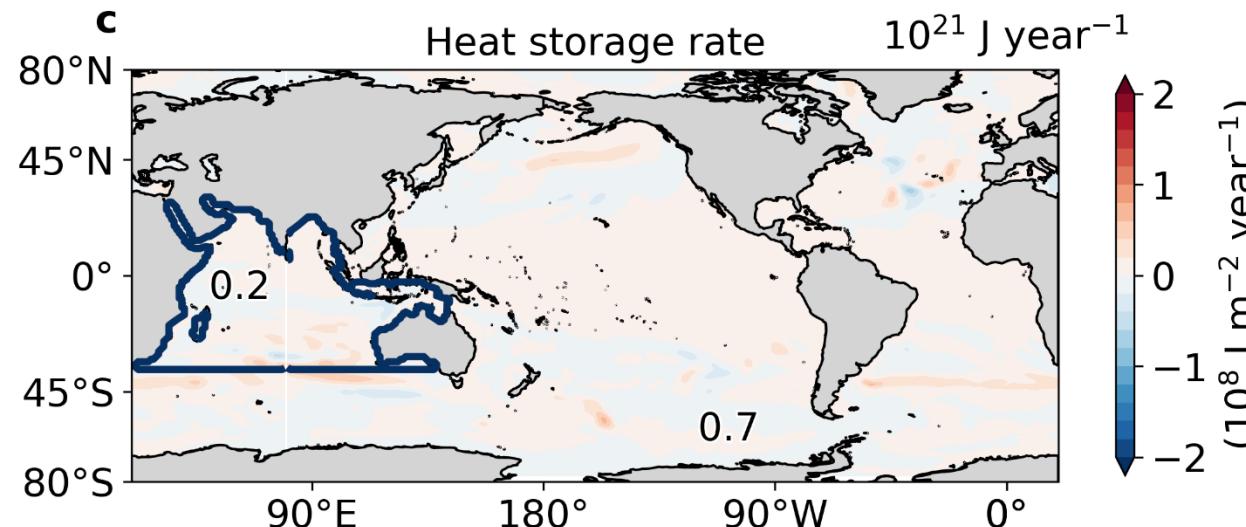
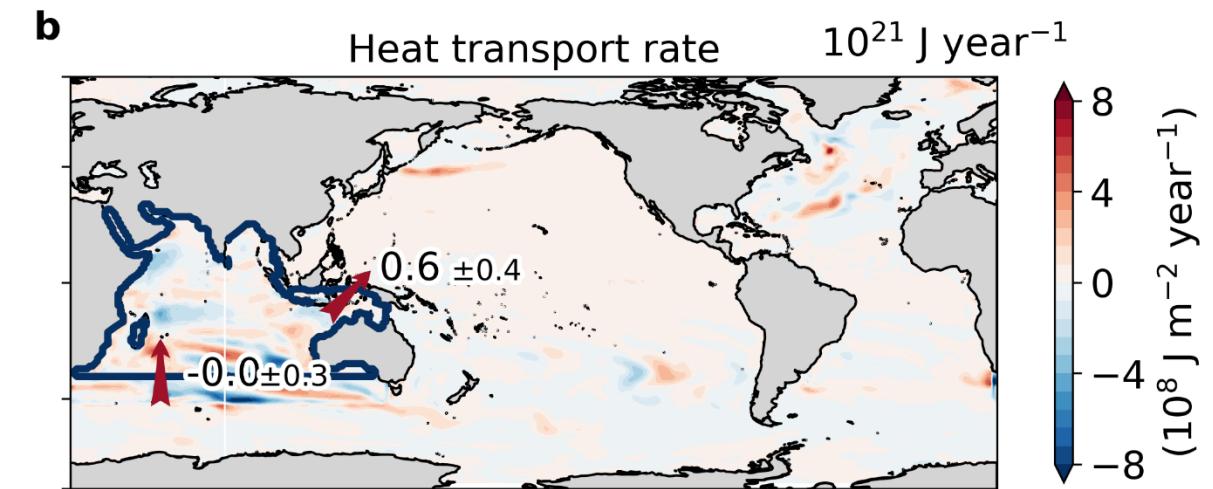
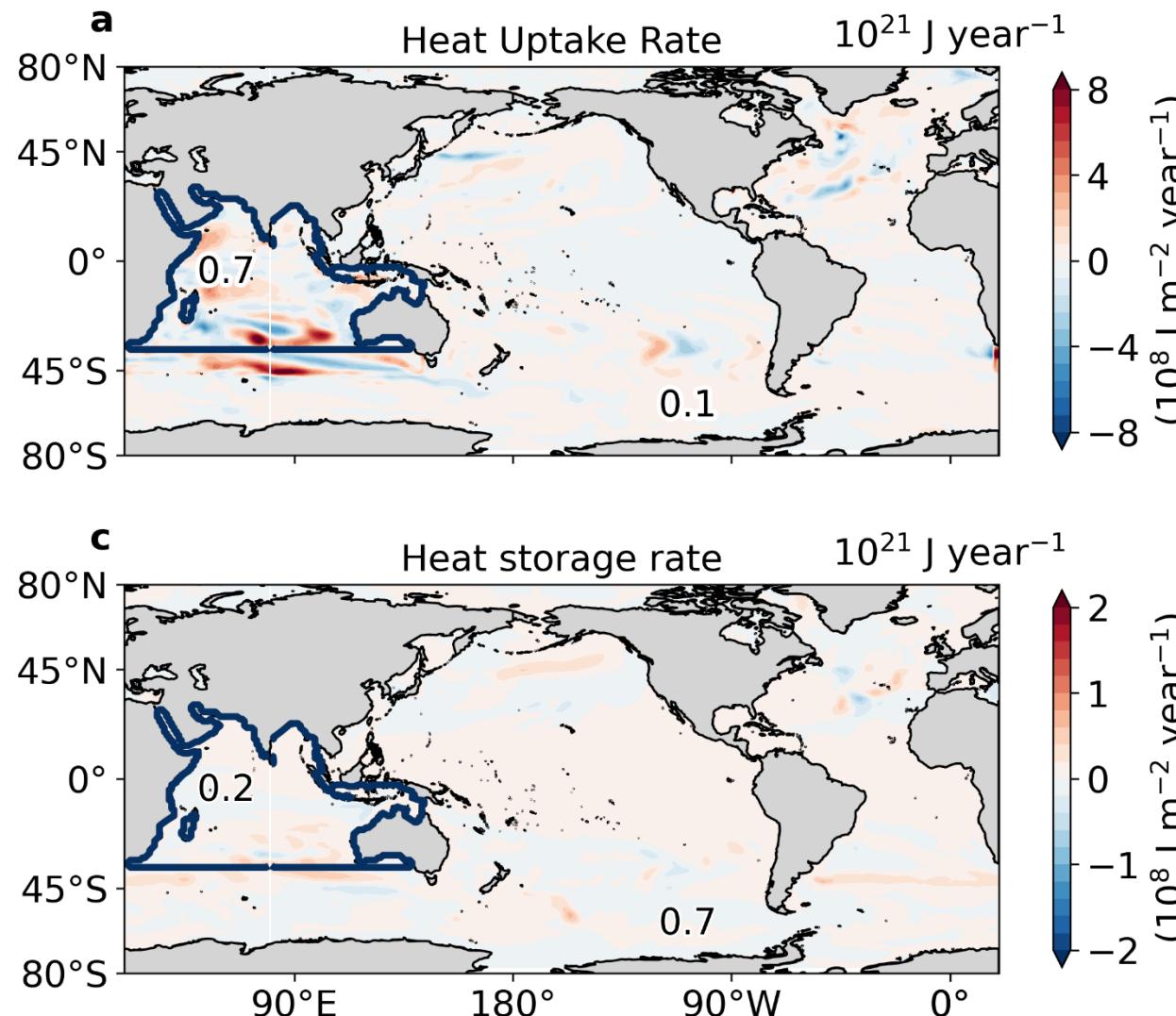
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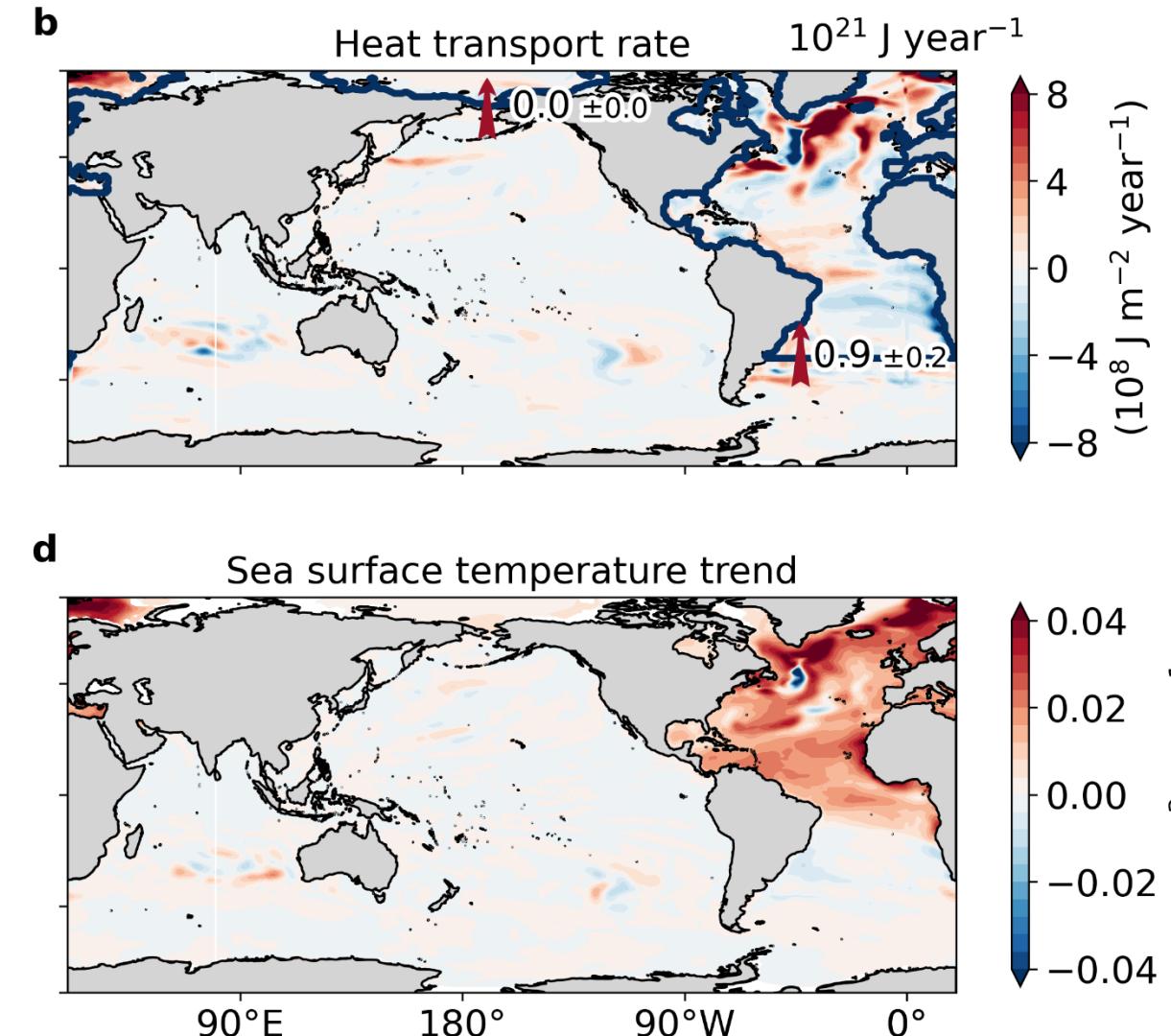
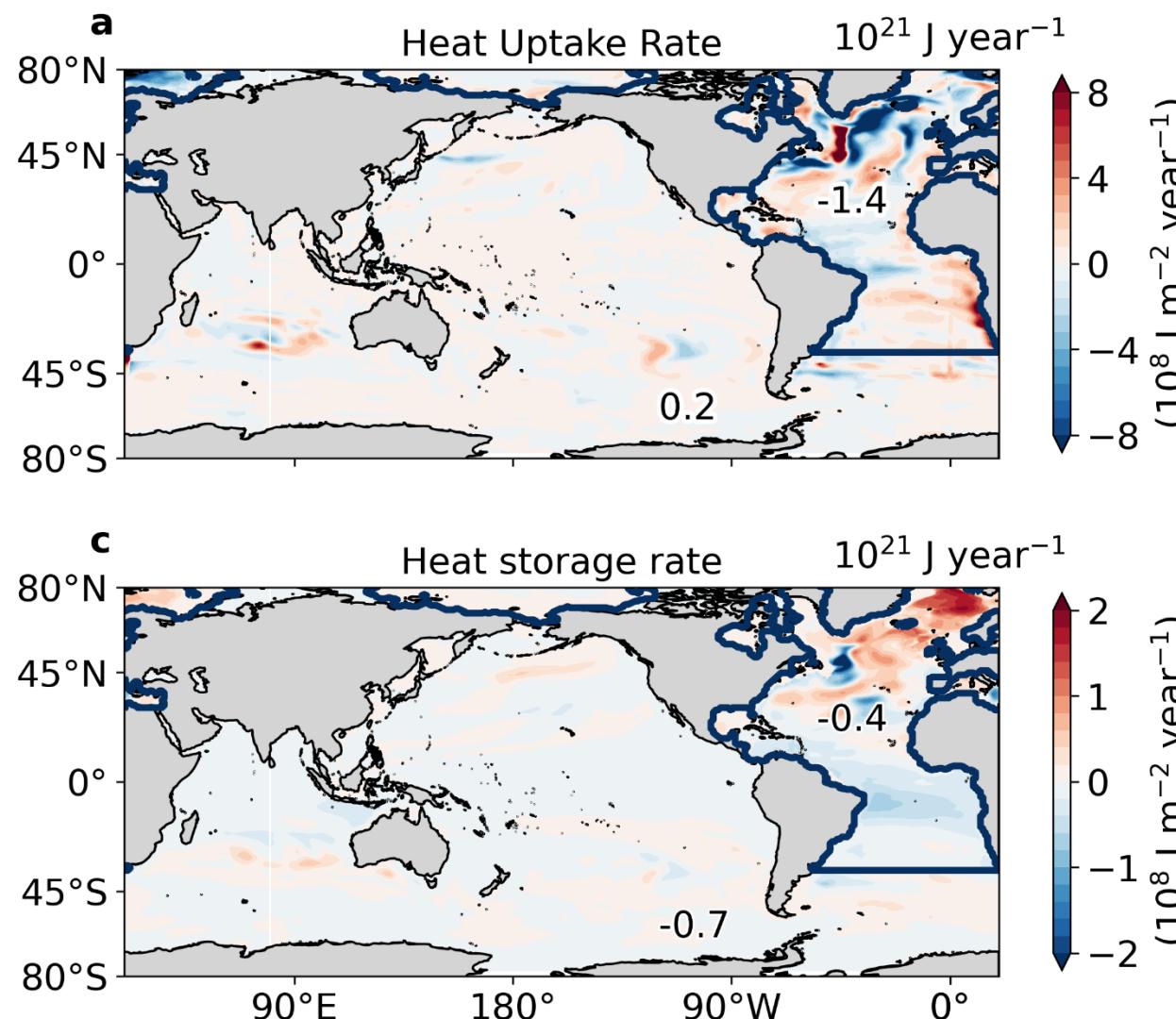
Pacific Ocean-only



Indian Ocean-only

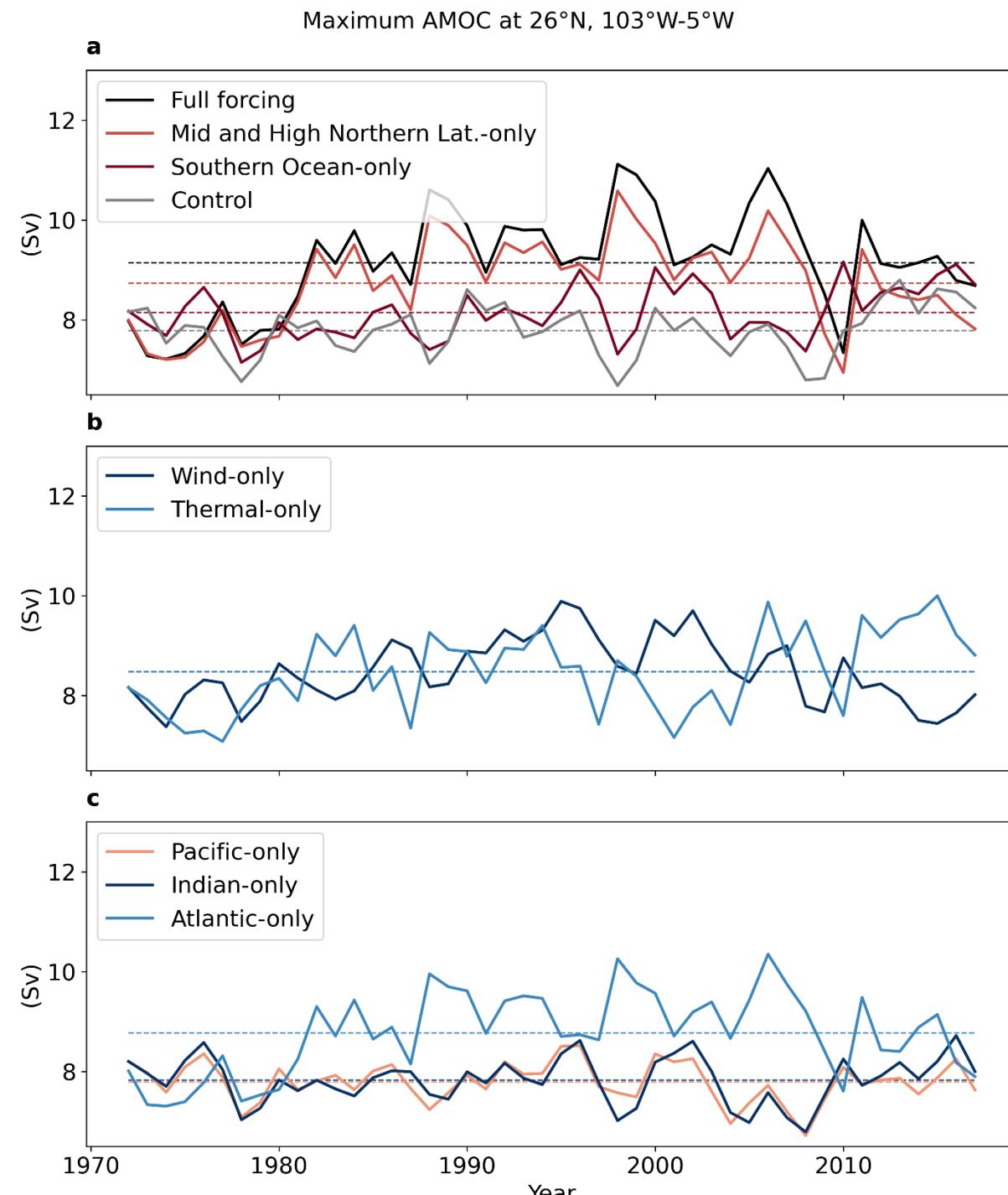
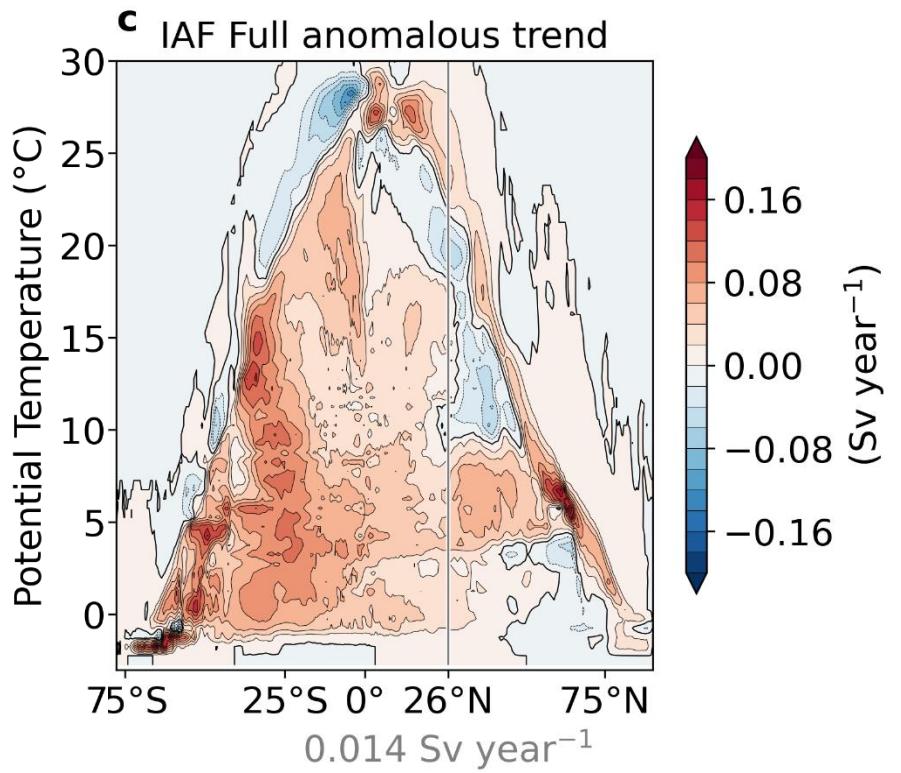


Atlantic Ocean-only

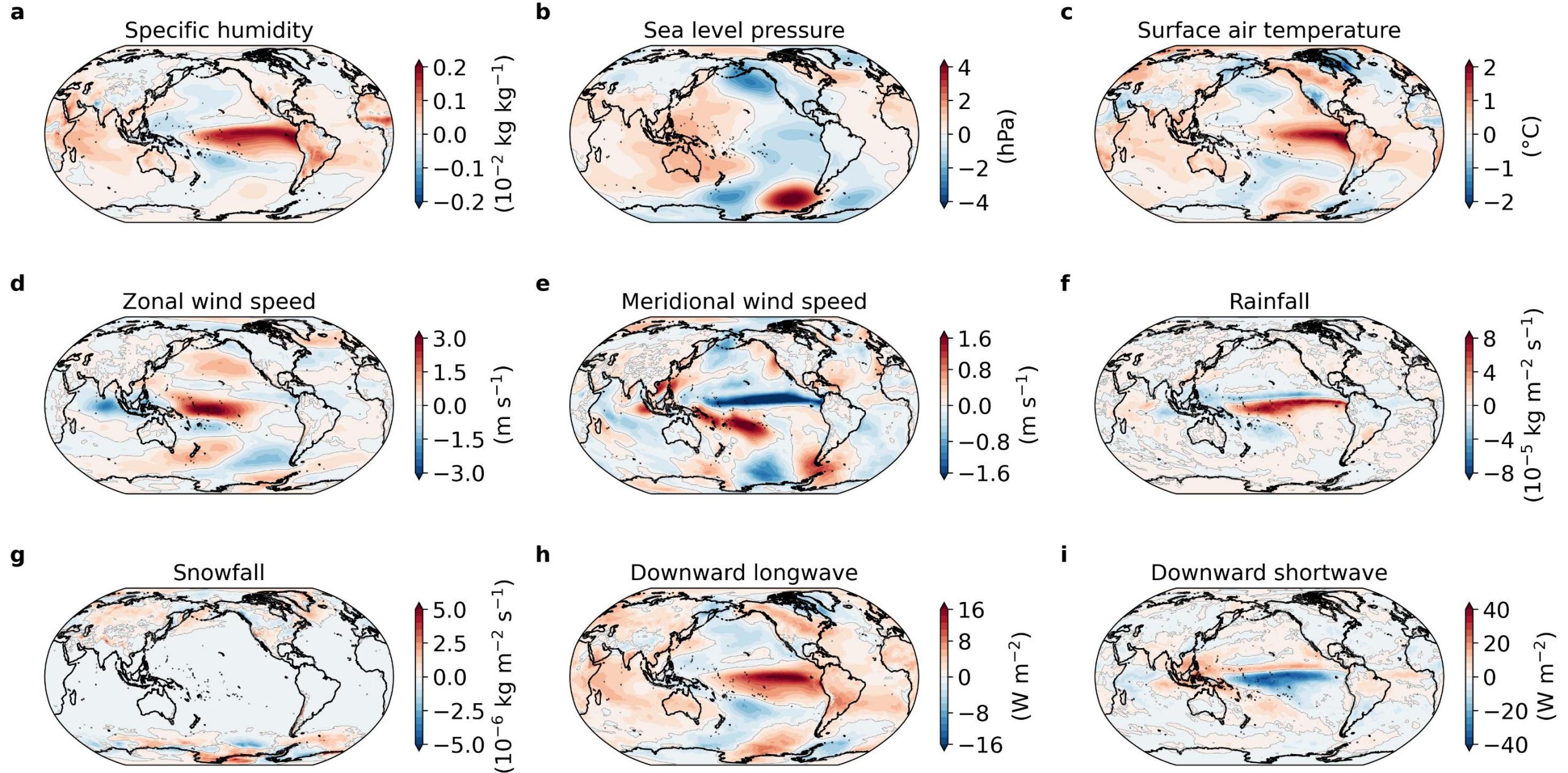




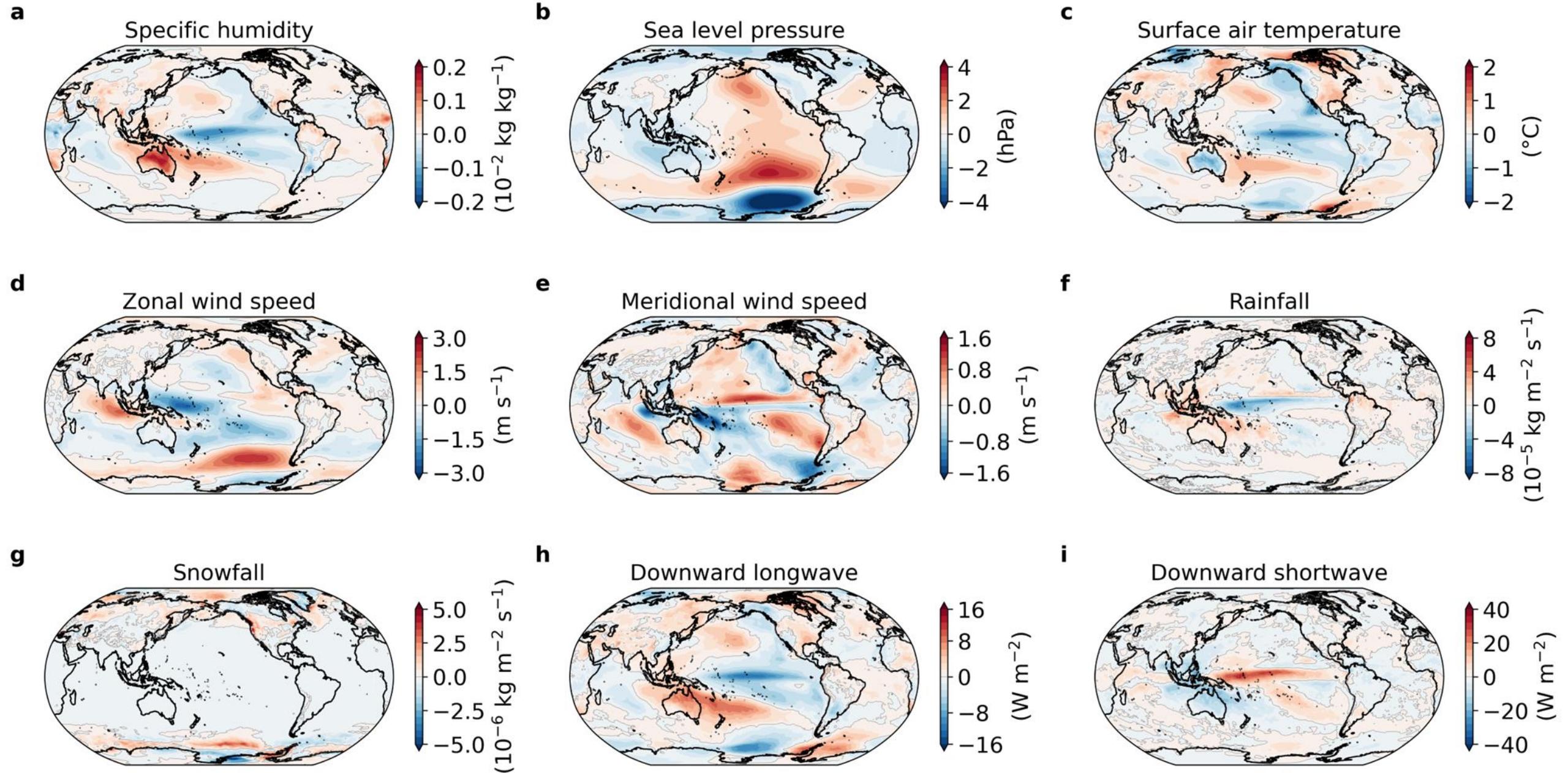
AMOC changes



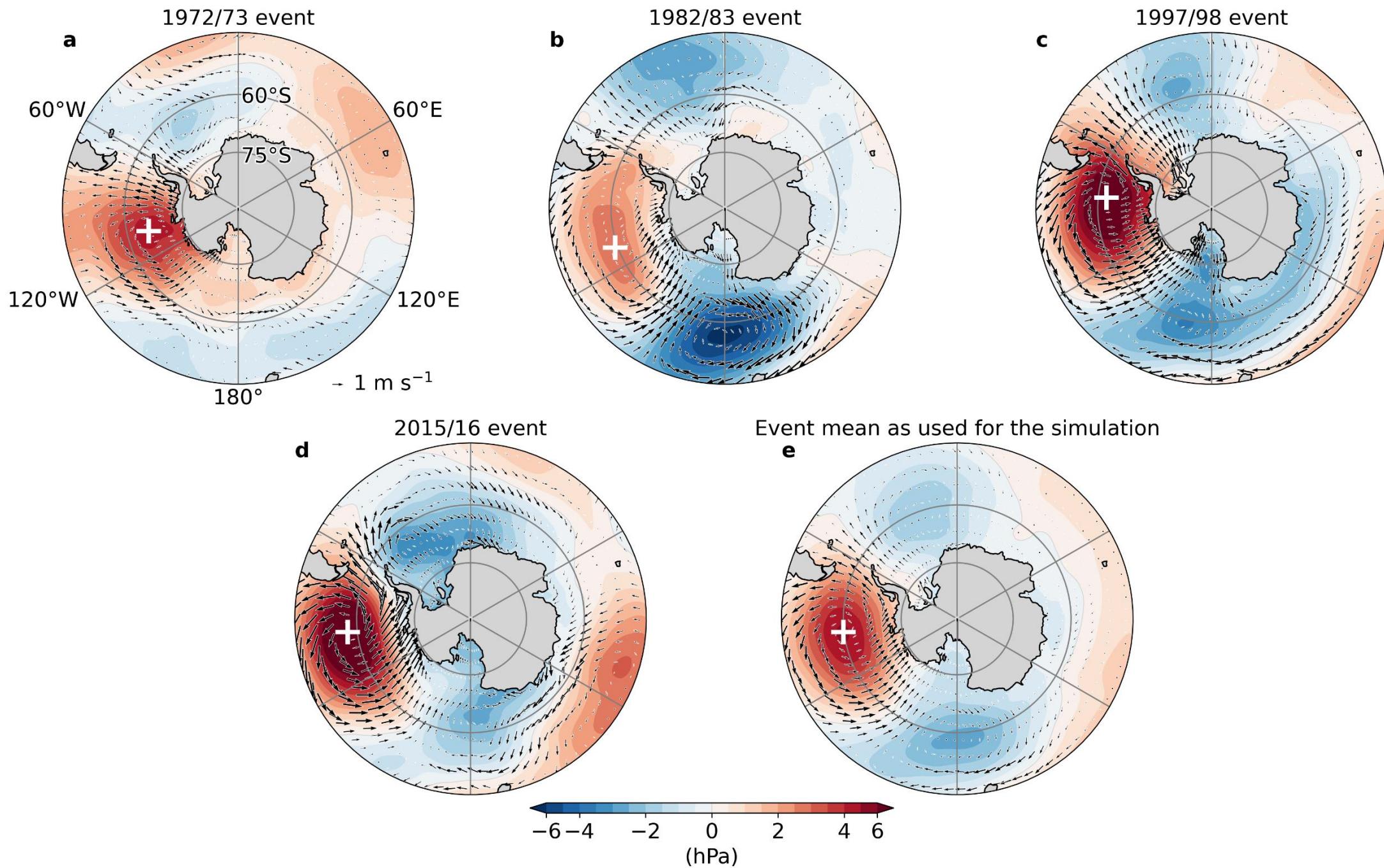
Spatial maps of El Niño anomalies



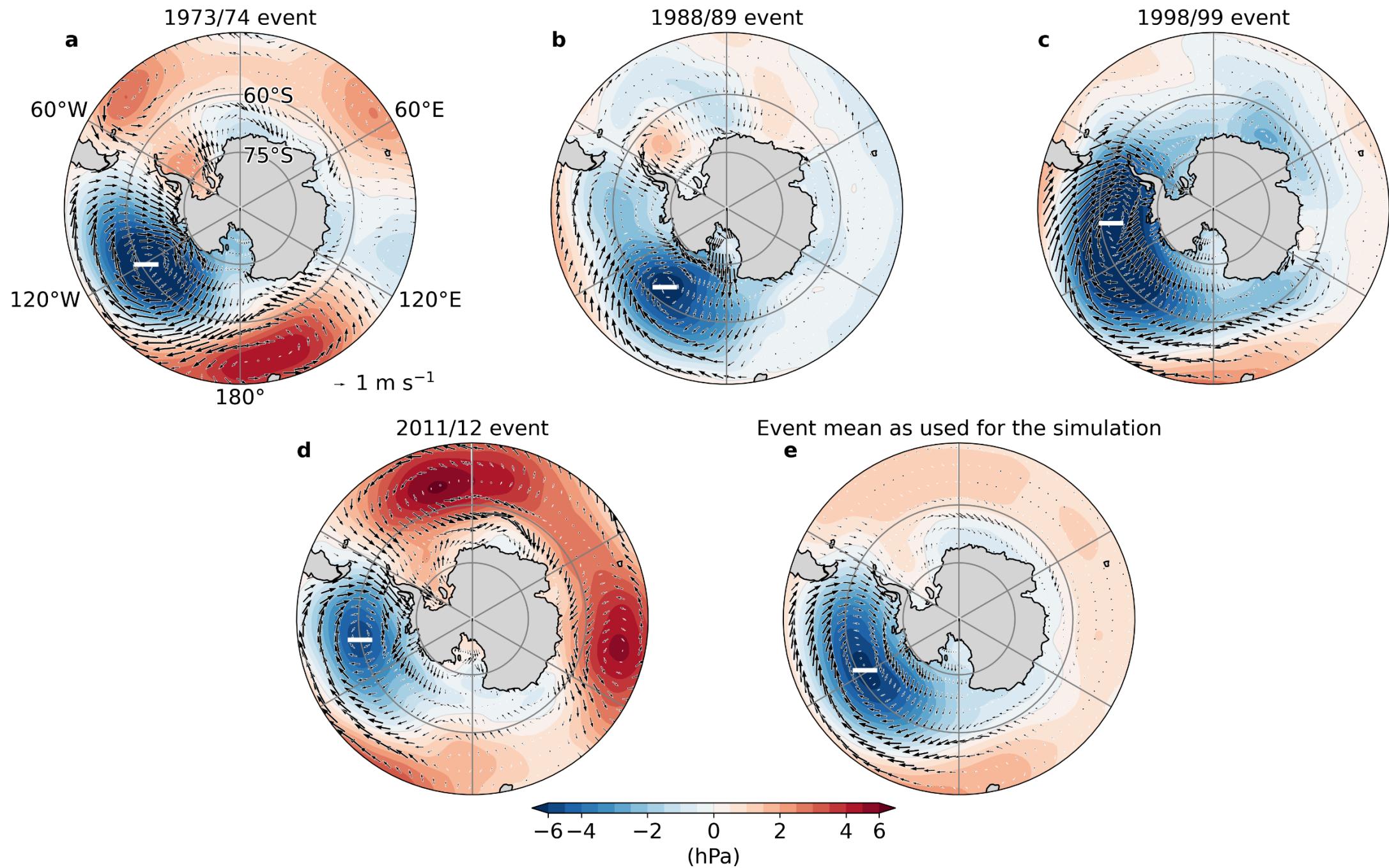
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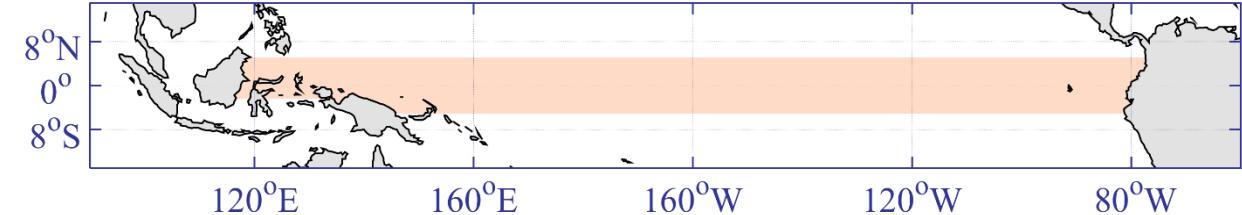
El Niño sea level pressure and surface wind anomalies



La Niña sea level pressure and surface wind anomalies



The warm water volume budget



$$\frac{dWWV}{dt} = \underbrace{\mathcal{T}_{5^\circ N + 5^\circ S} + \mathcal{T}_{ITF} + P - E + R}_{\text{adiabatic fluxes}} + \dots$$

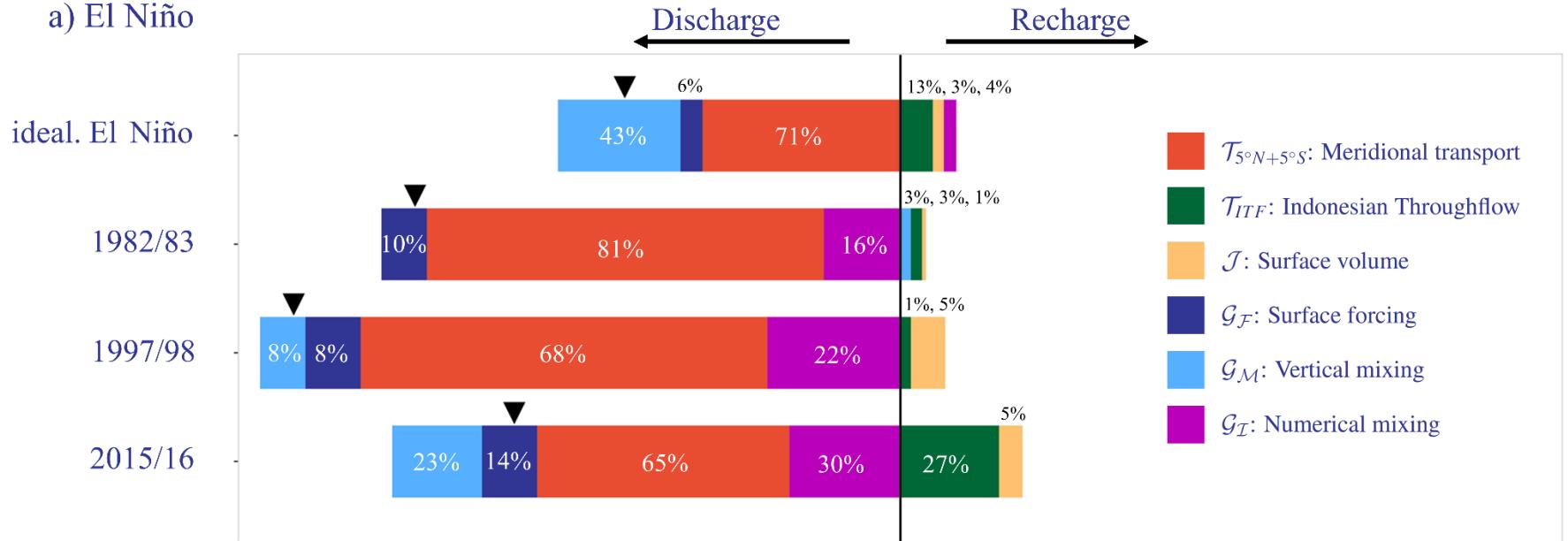
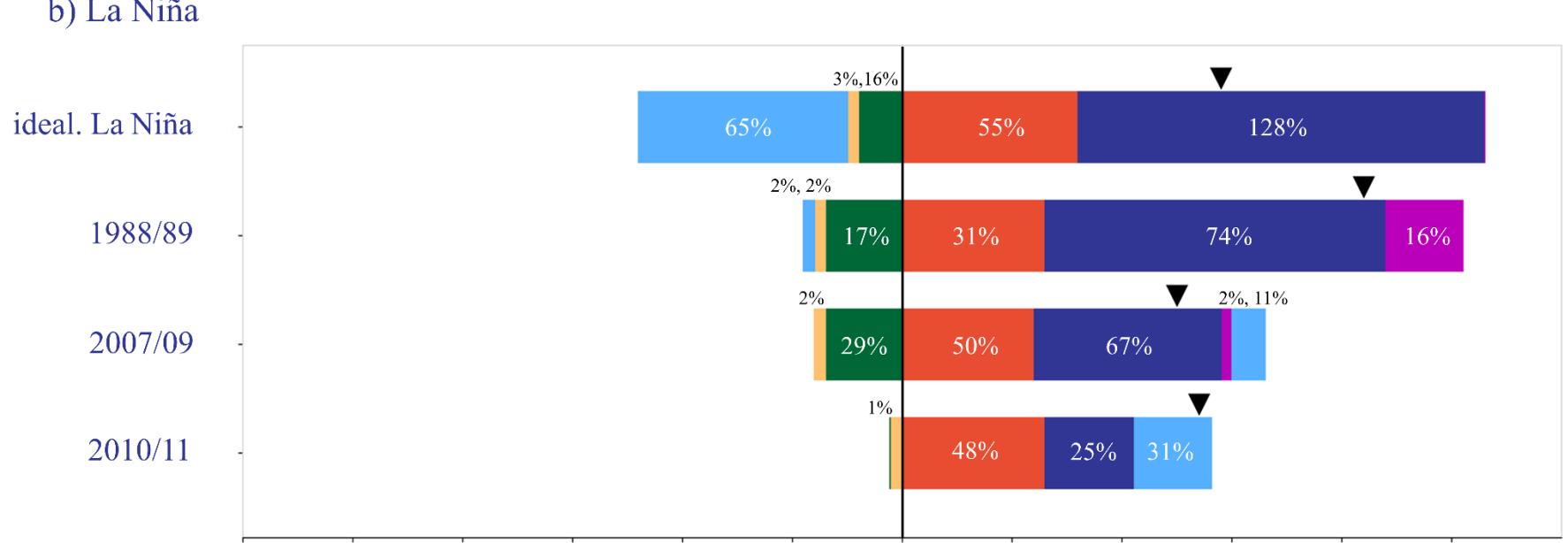
Eddy Mixing

Numerical Mixing

Surface Forcing

Vertical Mixing

$$\underbrace{\frac{1}{\rho_0 \cdot C_p} \cdot \iint \frac{\partial \mathcal{F}}{\partial \Theta} \Big|_{20^\circ C} dA}_{\text{diabatic fluxes}} + \underbrace{\frac{1}{\rho_0 \cdot C_p} \cdot \iint \frac{\partial \mathcal{M}}{\partial \Theta} \Big|_{20^\circ C} dA}_{\text{diabatic fluxes}} + \mathcal{G}_{\mathcal{E}} + \mathcal{G}_{\mathcal{I}}$$

a) El Niño

b) La Niña


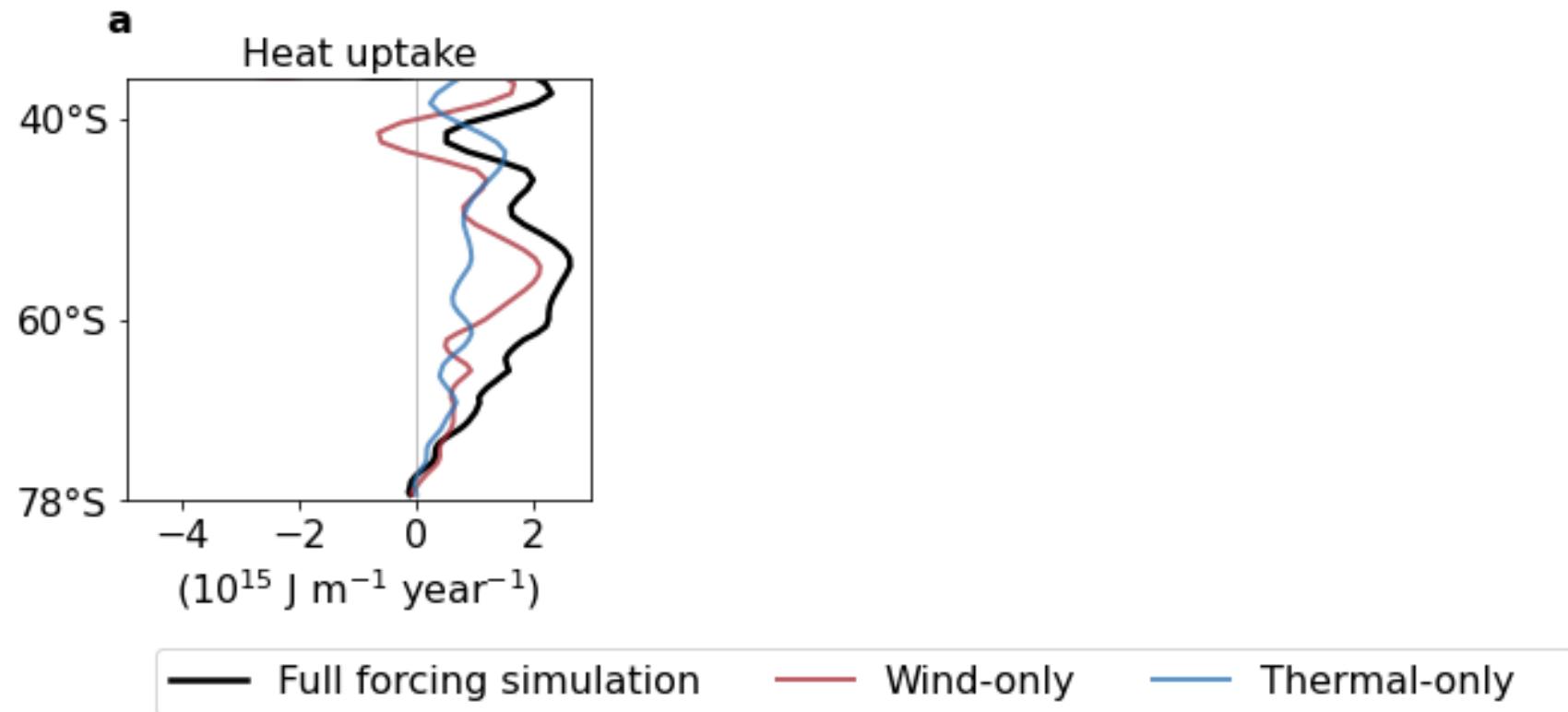
Take Home

1. Repeat decade **spin-up** → **better OHC evolution** than most OMIP-2 models
2. Recent surface **wind** and **thermal** property **trends**: ~50% of global OHC
→ **almost 100%** when applied only over **Southern Ocean**
3. Heat uptake facilitated by **cool SSTs** & dominant ...
... **sensible heat fluxes** with **thermal forcing** held **fixed**
... downward **longwave radiation** when **winds** are **fixed** & thermal properties evolve over time

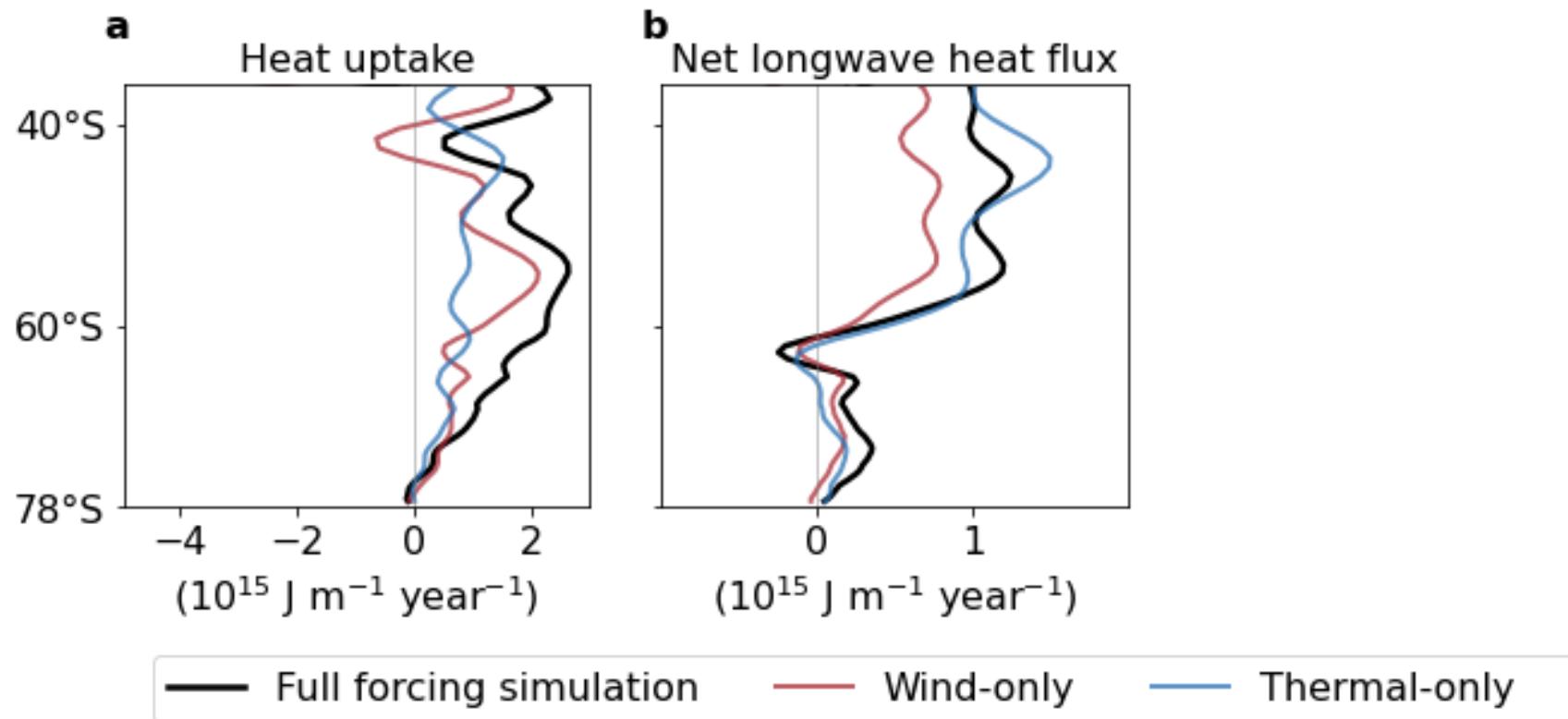
Project I: Take Home Messages

- In-depth analysis of individually calculated upper ocean heat/volume fluxes during ENSO in ACCESS-OM2
- Adiabatic volume fluxes mostly symmetric, diabatic fluxes show a strong asymmetry and peak three to six months earlier
- The large event-to-event variability in the surface forcing flux is linked to the shoaling of the 20°C isotherm in the eastern equatorial Pacific

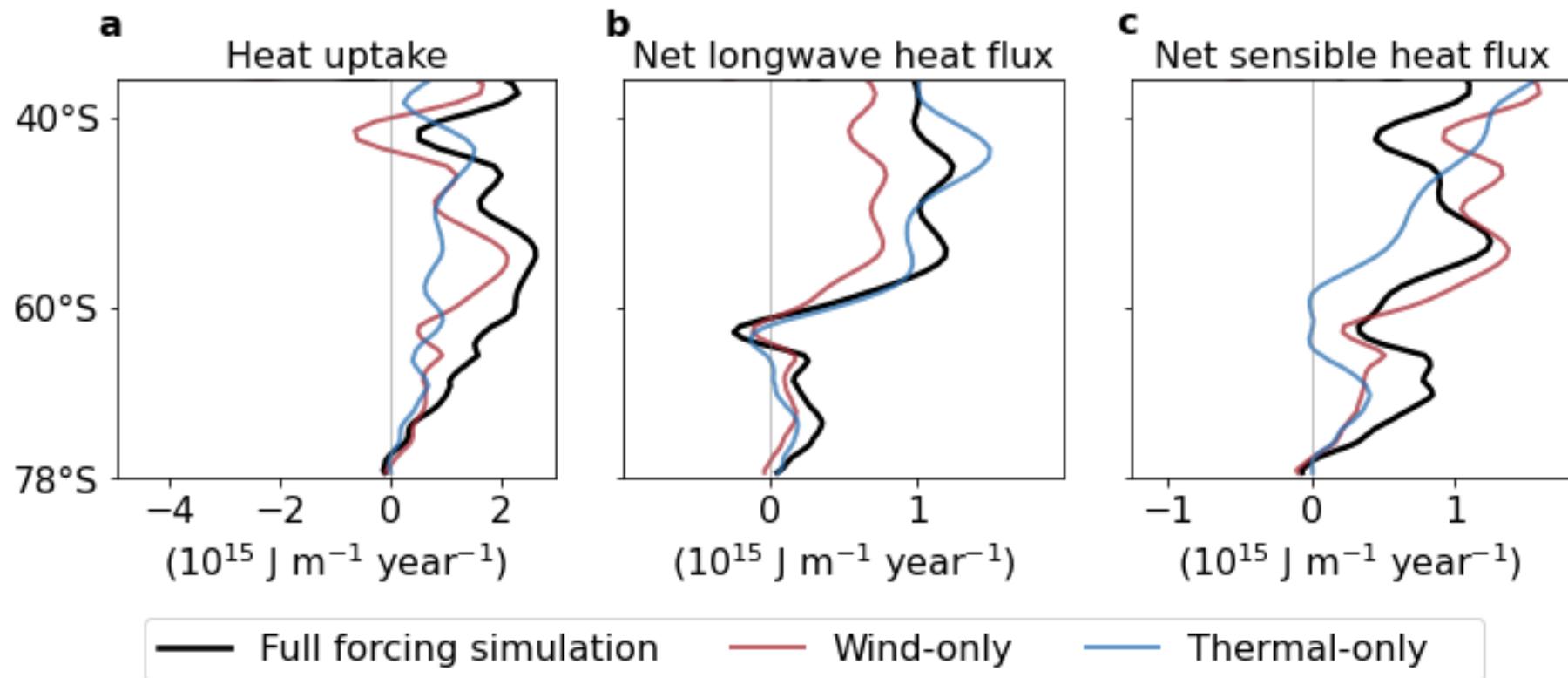
Zonally integrated heat fluxes



Zonally integrated heat fluxes



Zonally integrated heat fluxes



ENSOAnt



UNSW
SYDNEY

Climate Change Research Centre

School of Biological, Earth and Environmental Sciences

PROCESSES AND DYNAMICS OF
GLOBAL TO REGIONAL OCEAN HEAT
UPTAKE AND VARIABILITY

A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

MAURICE F. HUGUENIN

supervised by

Prof. Dr. Matthew H. England and Dr. Ryan M. Holmes

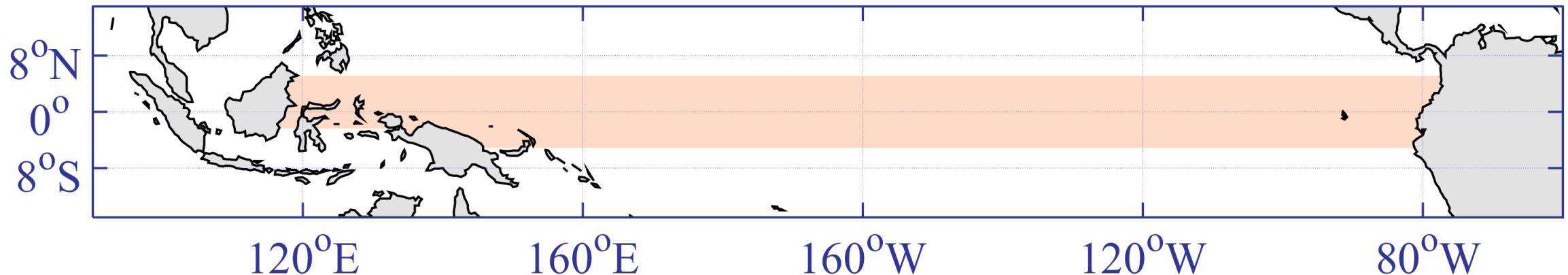
23rd May 2023

1. Drivers and distribution of global ocean heat uptake over the last half century
(Huguenin et al. 2022)

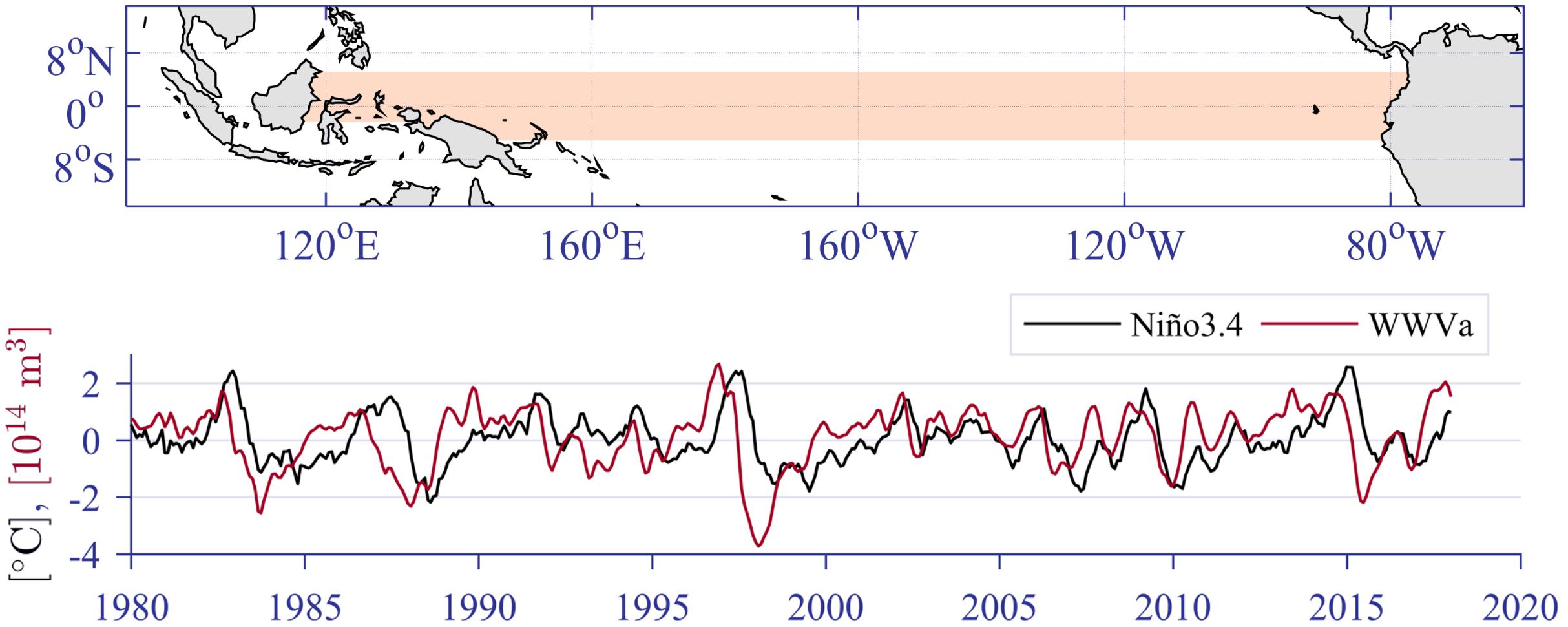
2. Key role of surface forcing and vertical mixing in changing warm water volume during ENSO (Huguenin et al. 2020b)

Motivation

Motivation



Motivation



Reynolds et al. (2007); Meinen & McPhaden (2000)

Motivation

- Focus on adiabatic exchange (Ekman, Sverdrup dynamics)
→ e.g. Jin (1997), McGregor et al. (2013, 2014), Neske and McGregor (2018), Izumo et al. (2018), ...

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- Diabatic fluxes account for ~50% of warm water volume discharge in 1997/98
Meinen and McPhaden (2001)

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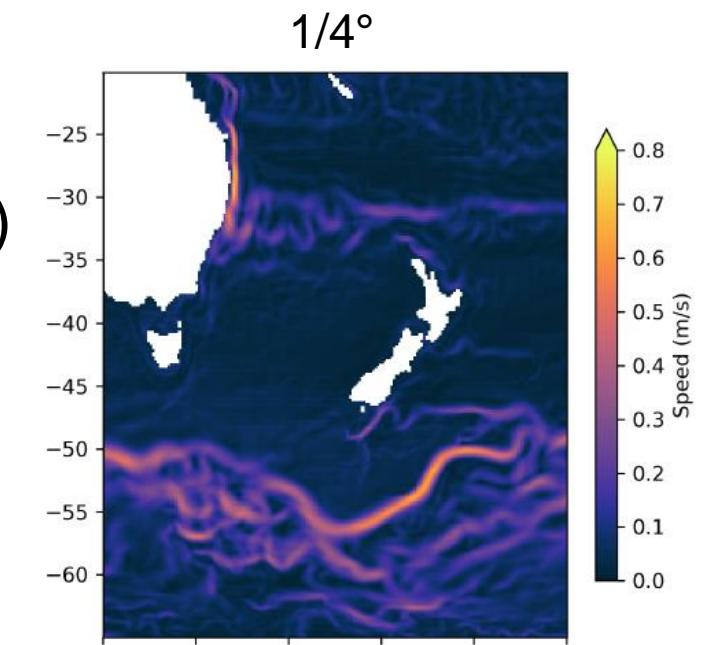
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- Diabatic fluxes account for ~50% of warm water volume discharge in 1997/98
Meinen and McPhaden (2001)
- Diabatic contribution to warm water volume changes varies
Lengaigne et al. (2012) model study
- Disagreement amongst studies: Brown and Fedorov (2010)

Part 2: Goals

1. Revisit the warm water volume budget using online calculated fluxes
2. Simulate ENSO variability over 1979-2016
3. Examine extreme El Niño/La Niña events and asymmetries

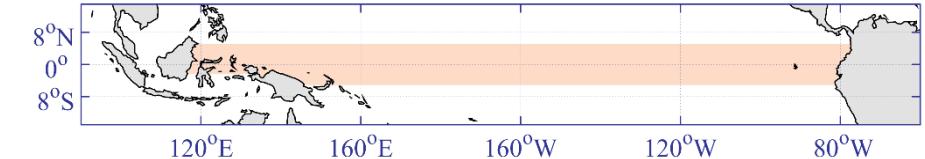
More ocean-sea ice modelling!

- 1/4° ACCESS-OM2 with 50 z^* levels
- Precise temperature-space water mass transformation diagnostics ([Holmes et al., 2019a](#))



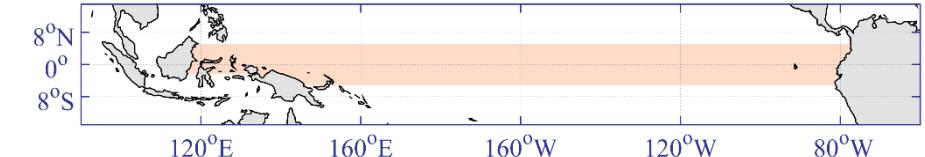
Kiss et al. (2019)

The warm water volume budget



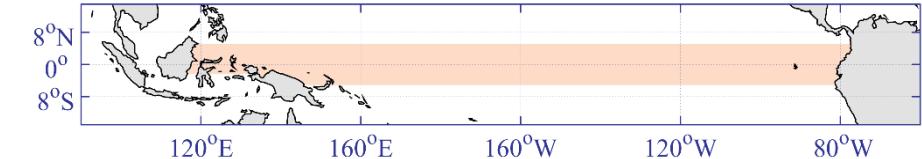
$$\frac{dWWV}{dt} = \underbrace{\dots}_{\text{adiabatic fluxes}} + \underbrace{\dots}_{\text{diabatic fluxes}}$$

The warm water volume budget



$$\frac{dWWV}{dt} = \underbrace{\mathcal{T}_{5^\circ N + 5^\circ S} + \mathcal{T}_{ITF} + P - E + R + \dots}_{\text{adiabatic fluxes}} + \underbrace{\dots}_{\text{diabatic fluxes}}$$

The warm water volume budget

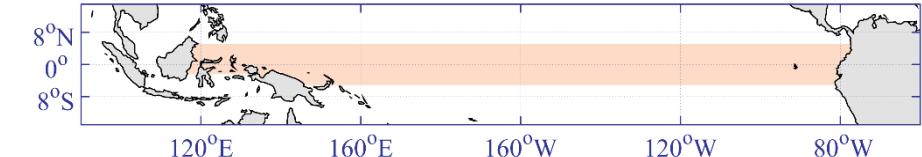


$$\frac{dWWV}{dt} = \underbrace{\mathcal{T}_{5^\circ N + 5^\circ S} + \mathcal{T}_{ITF} + P - E + R}_{adiabatic\ fluxes} + \dots$$

Surface Forcing

$$\underbrace{\frac{1}{\rho_0 \cdot C_p} \cdot \int \int \frac{\partial \mathcal{F}}{\partial \Theta} \Big|_{20^\circ C} dA}_{diabatic\ fluxes} +$$

The warm water volume budget



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Surface Forcing

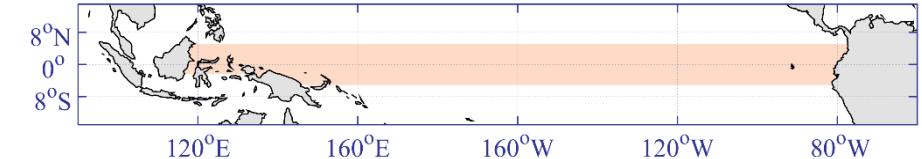
$$\frac{1}{\rho_0 \cdot C_p} \cdot \int \int \left. \frac{\partial \mathcal{F}}{\partial \Theta} \right|_{20^\circ C} dA$$

Vertical Mixing

$$\frac{1}{\rho_0 \cdot C_p} \cdot \int \int \left. \frac{\partial \mathcal{M}}{\partial \Theta} \right|_{20^\circ C} dA +$$

diabatic fluxes

The warm water volume budget



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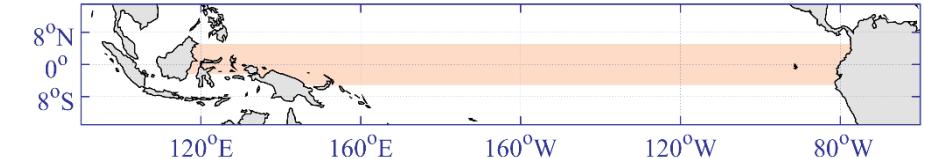
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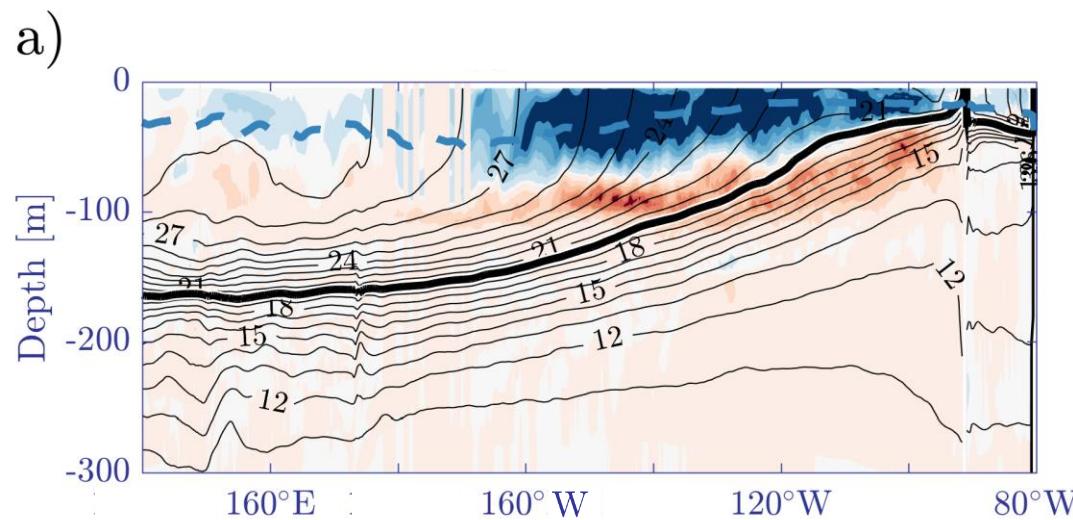
The diabatic volume fluxes: September-November

Vertical Mixing

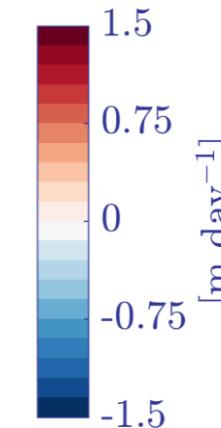
Surface Forcing

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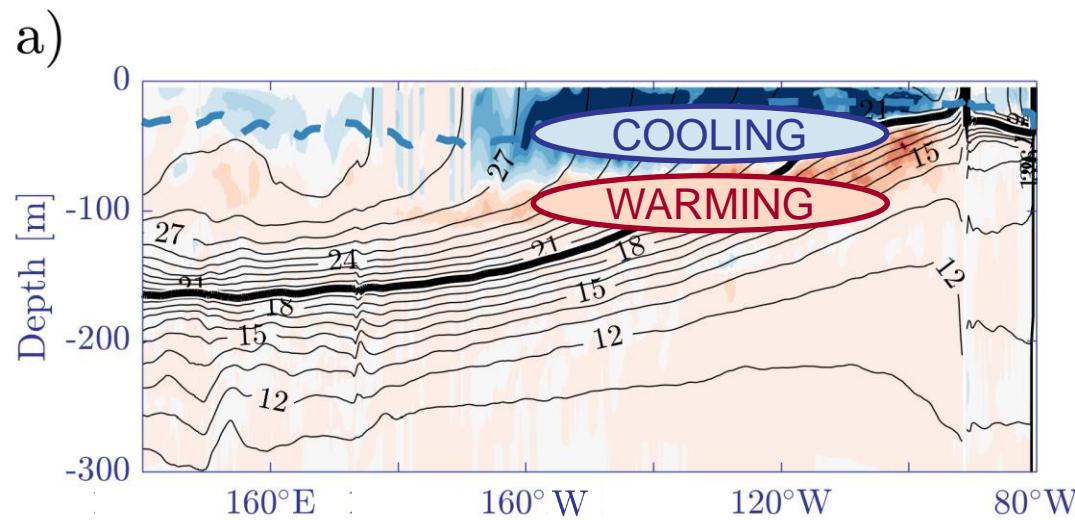


Surface Forcing

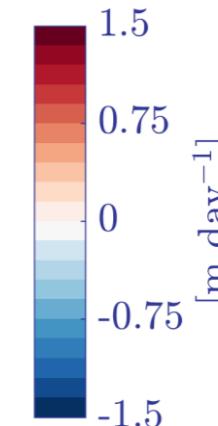


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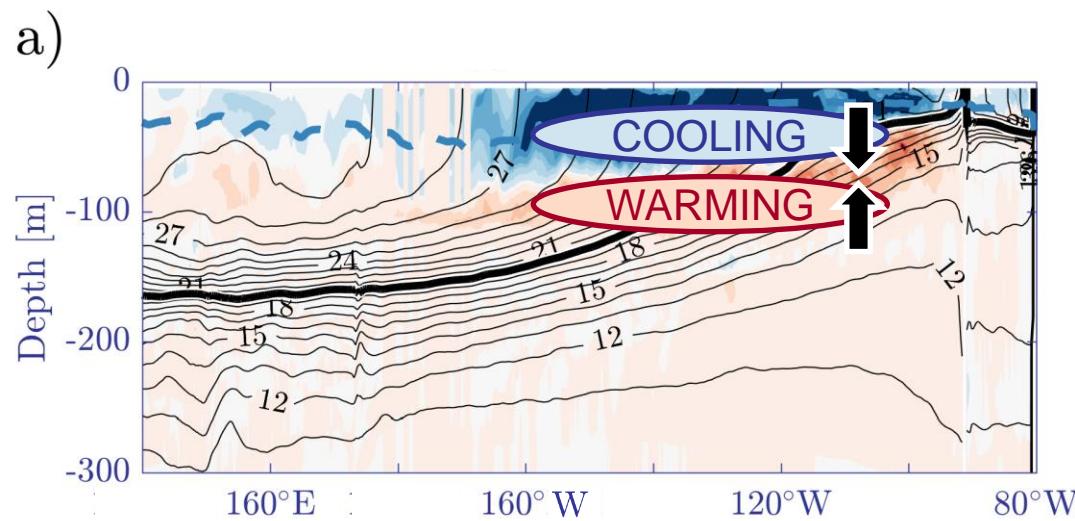


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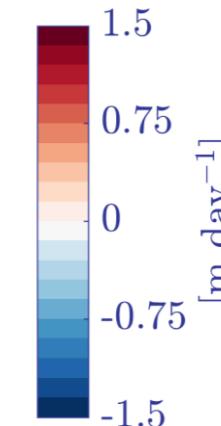


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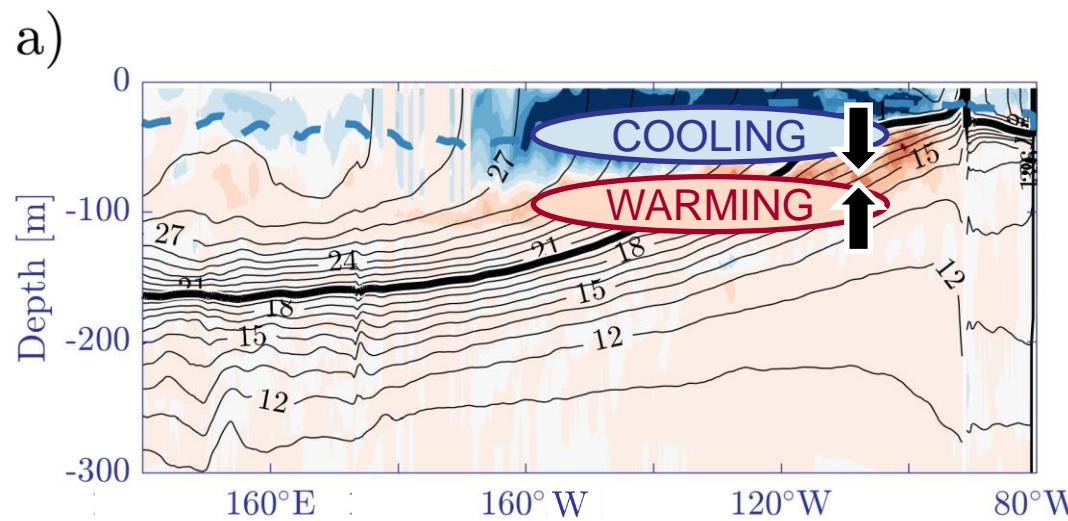


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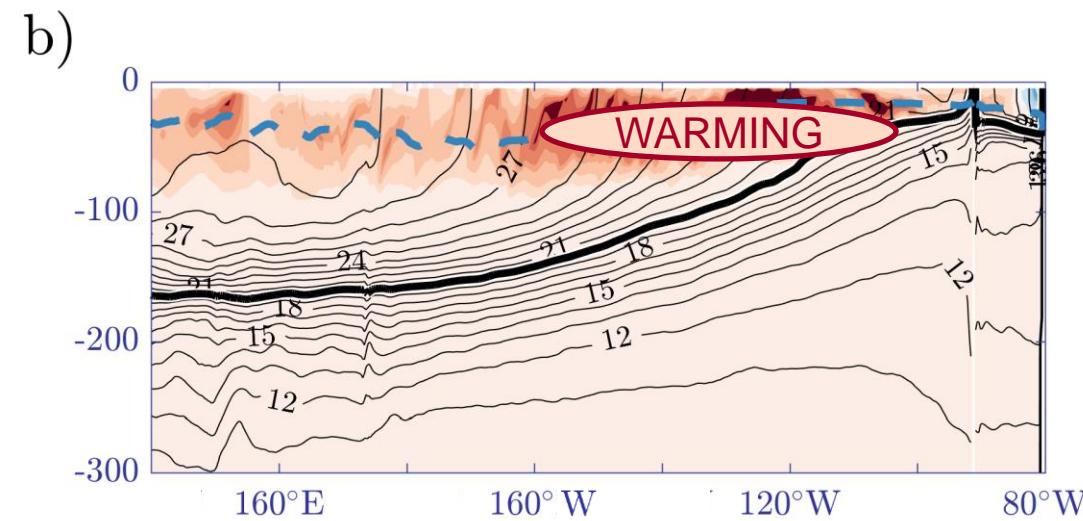


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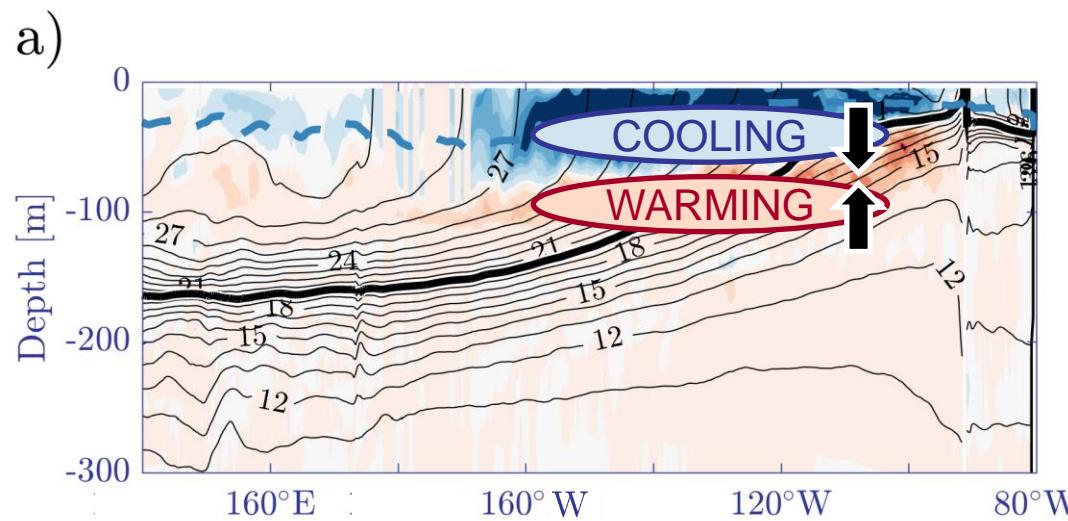


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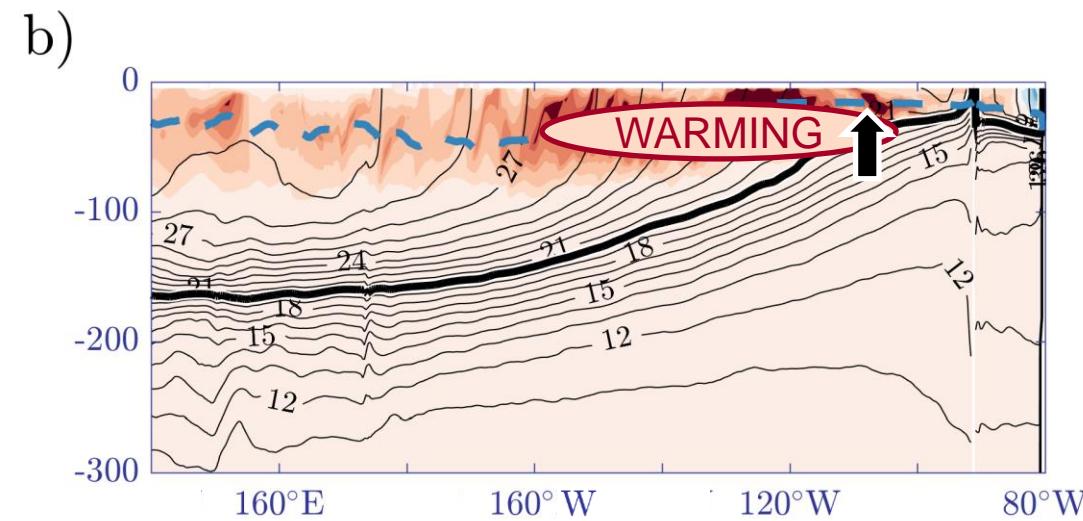


The diabatic volume fluxes: September-November

Vertical Mixing

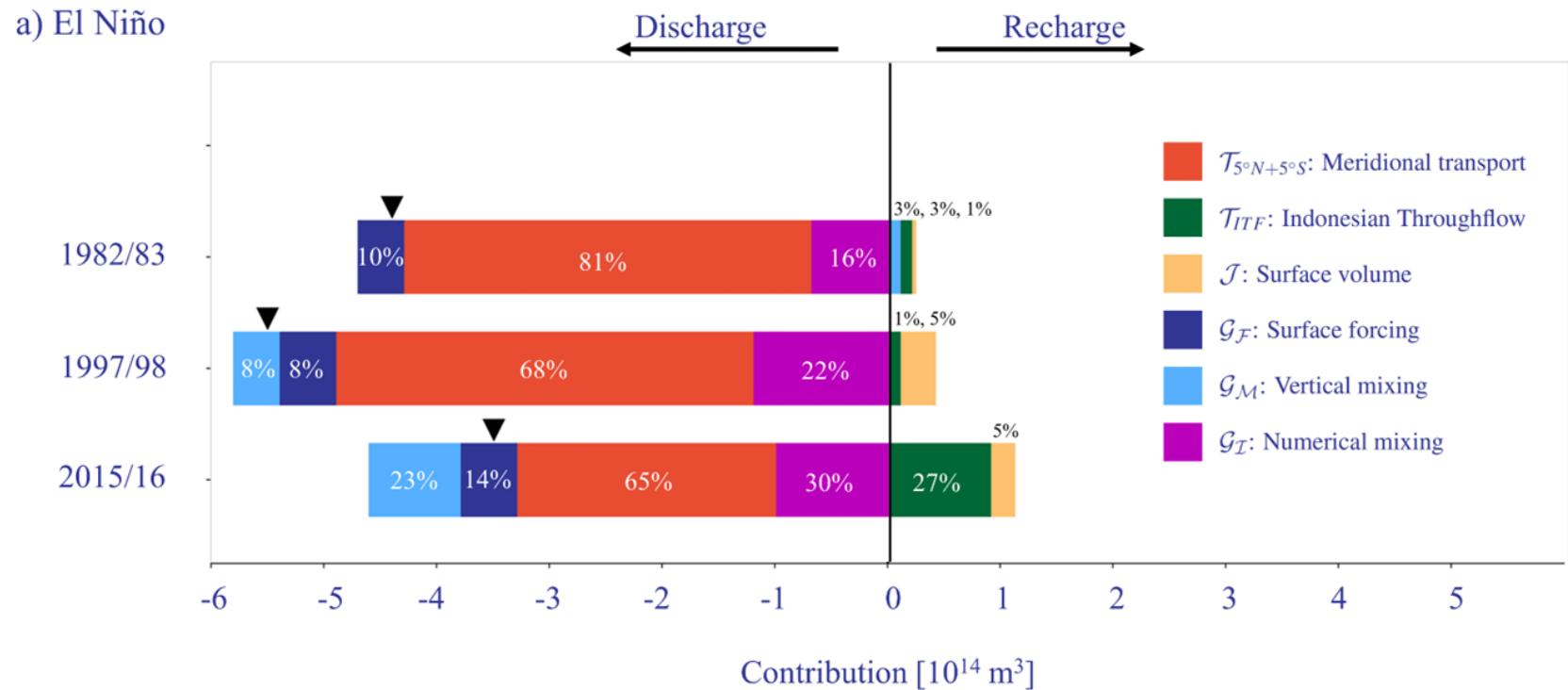


Surface Forcing

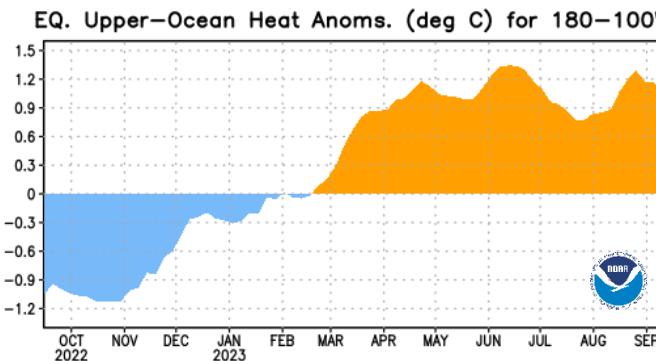
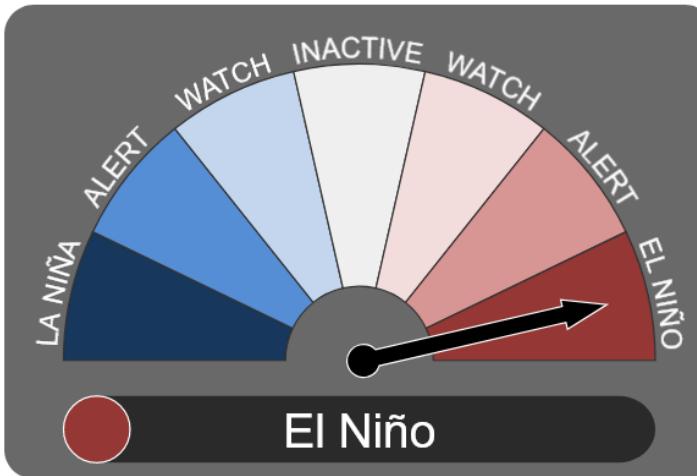


Summary figure

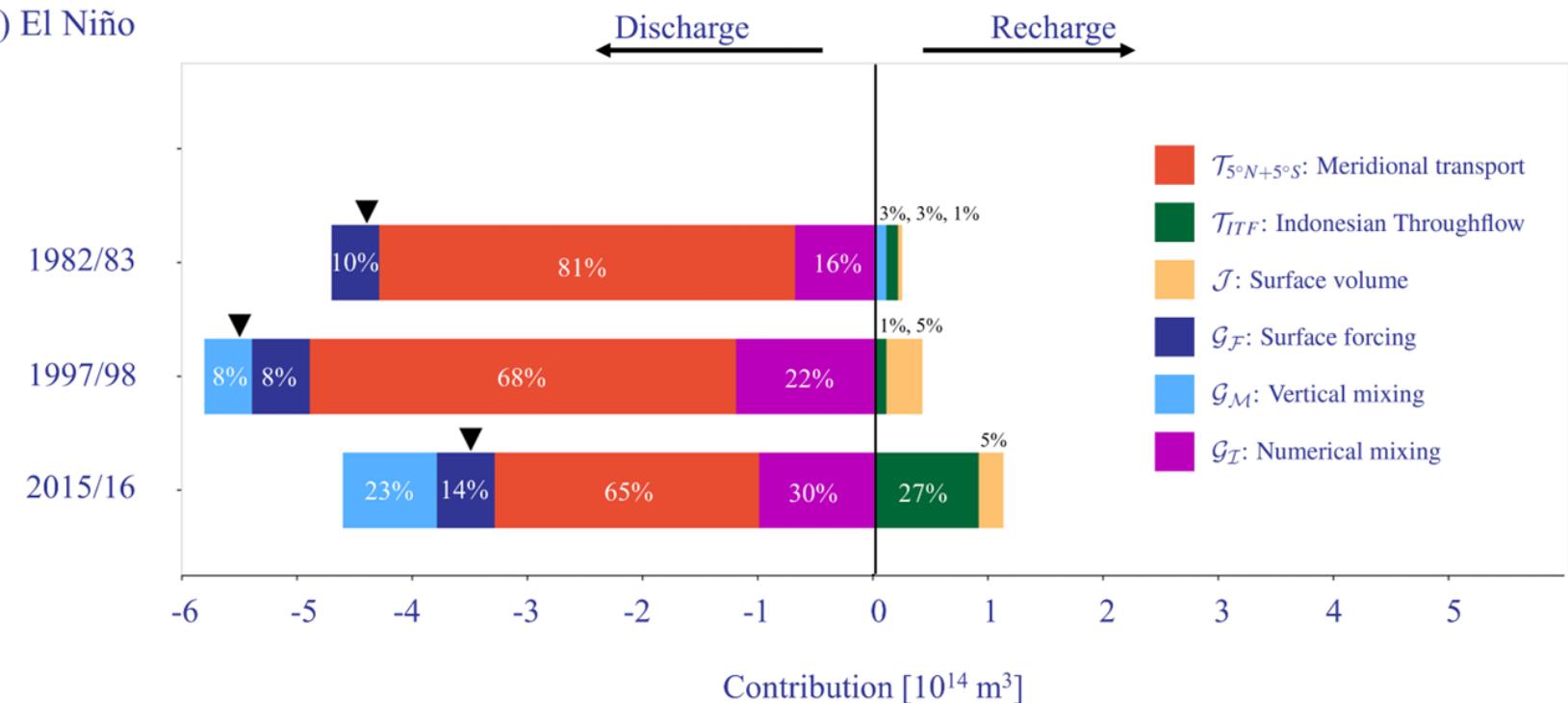
Summary figure



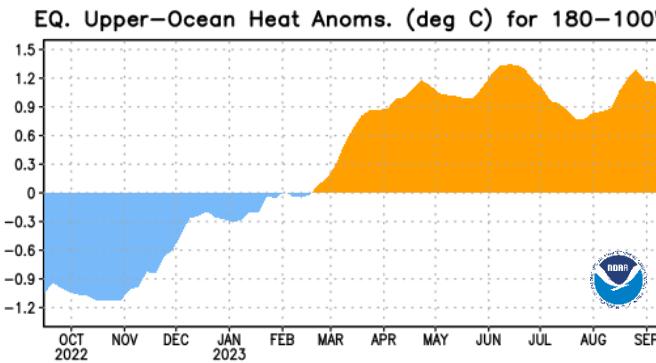
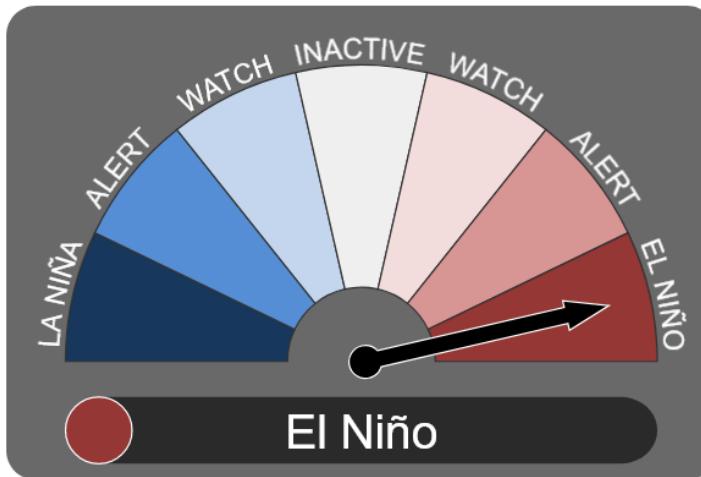
Summary figure



a) El Niño



Summary figure



a) El Niño

ideal. El Niño

1982/83

1997/98

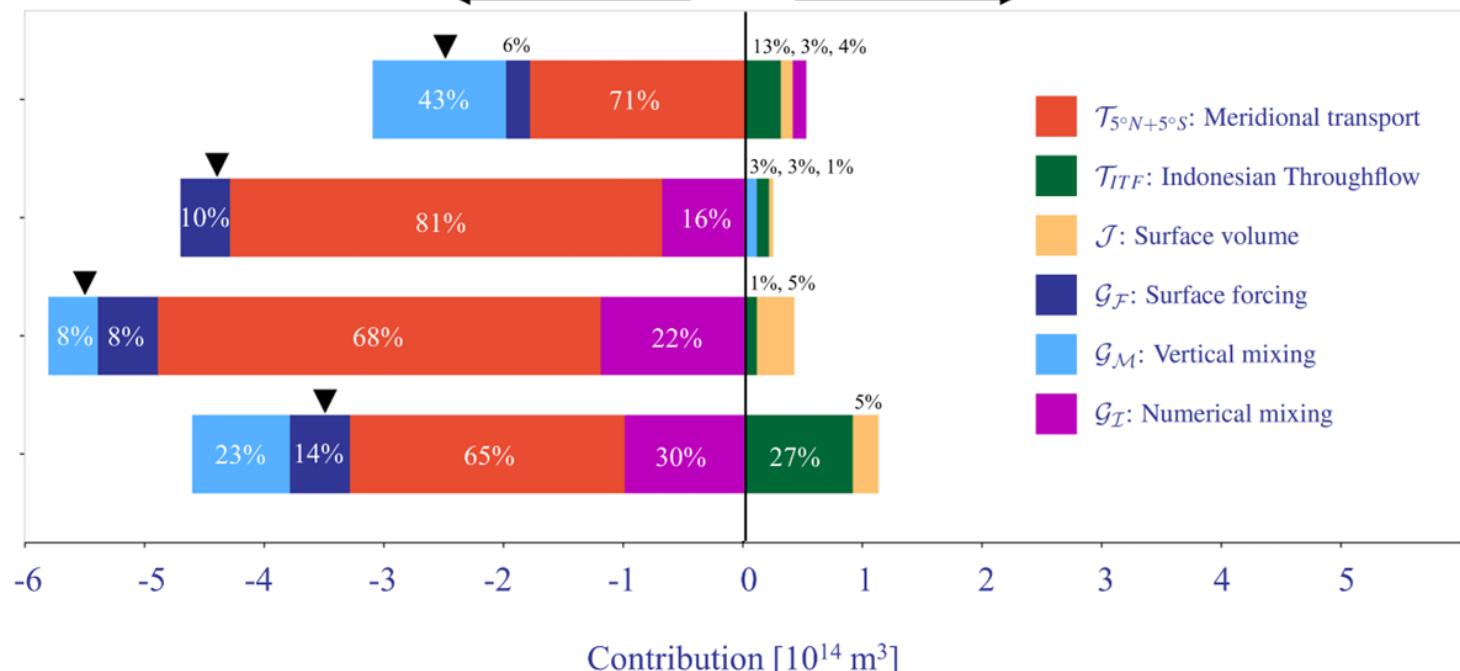
2015/16

Discharge

Recharge

Contribution [10^{14} m^3]

- █ $\mathcal{T}_{5^\circ N+5^\circ S}$: Meridional transport
- █ \mathcal{T}_{ITF} : Indonesian Throughflow
- █ \mathcal{J} : Surface volume
- █ \mathcal{G}_F : Surface forcing
- █ \mathcal{G}_M : Vertical mixing
- █ \mathcal{G}_L : Numerical mixing



Summary figure

a) El Niño

ideal. El Niño

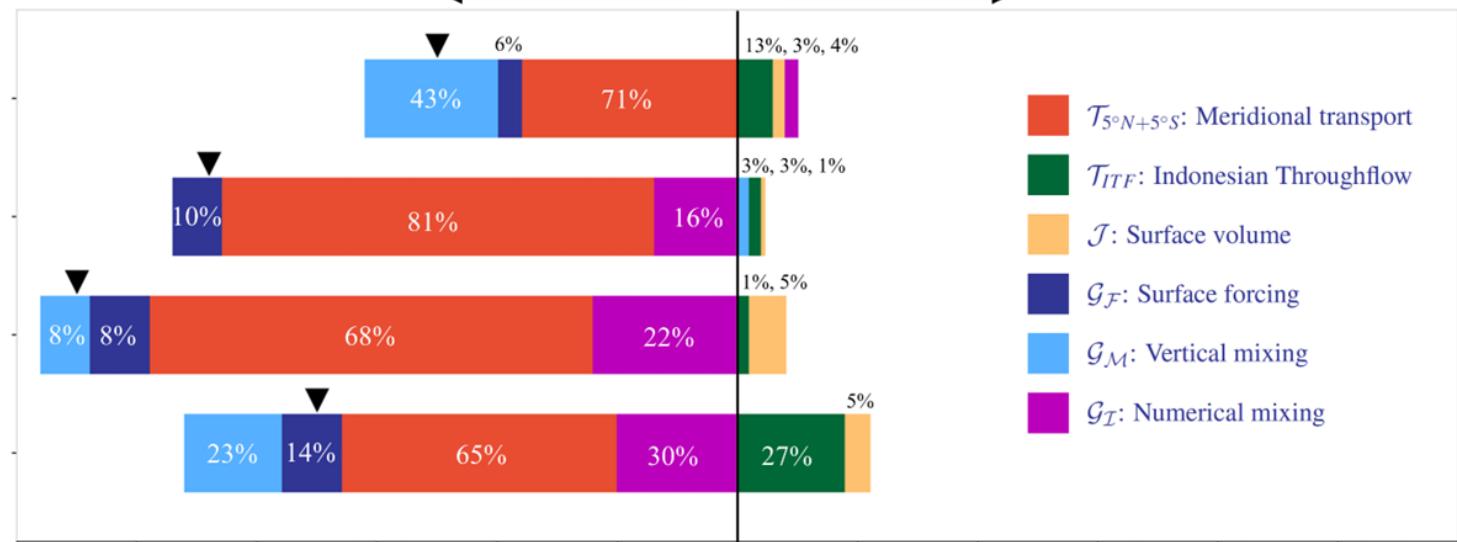
1982/83

1997/98

2015/16

Discharge

Recharge

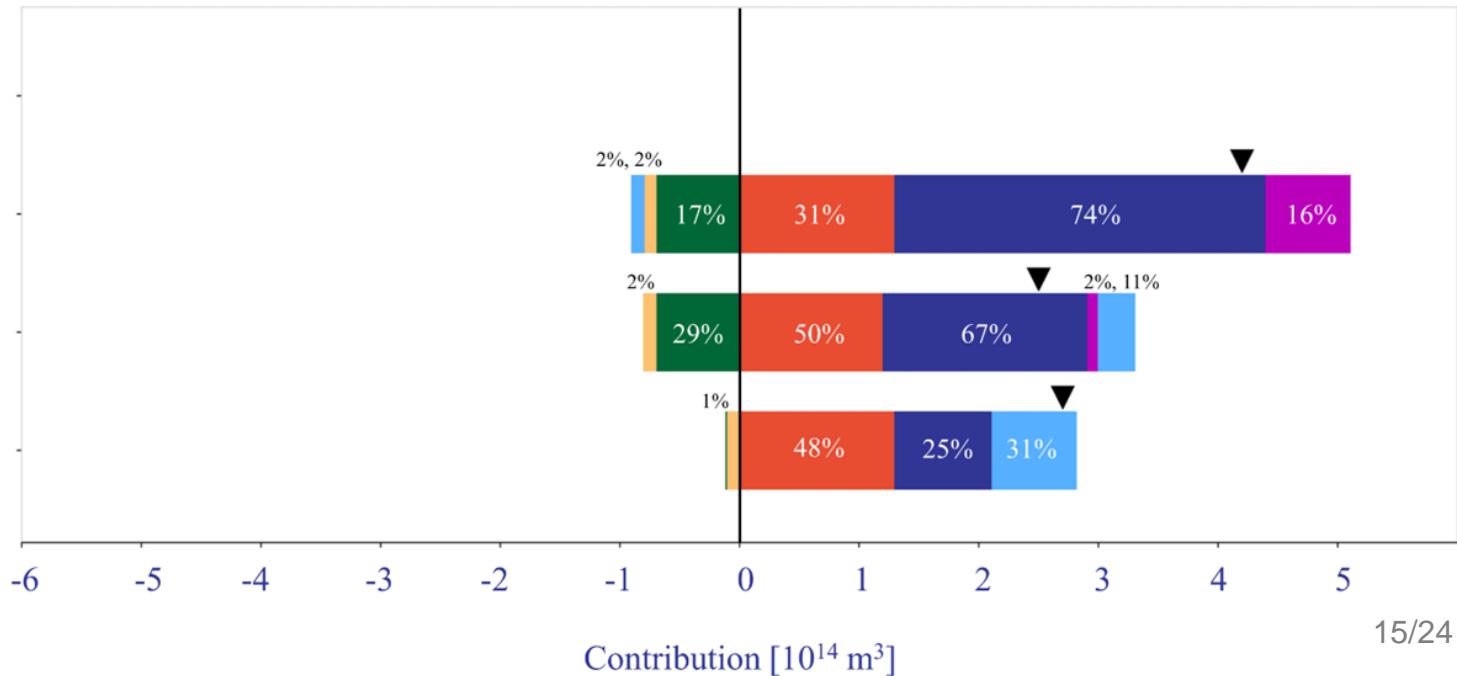


b) La Niña

1988/89

2007/09

2010/11



Summary figure

a) El Niño

ideal. El Niño

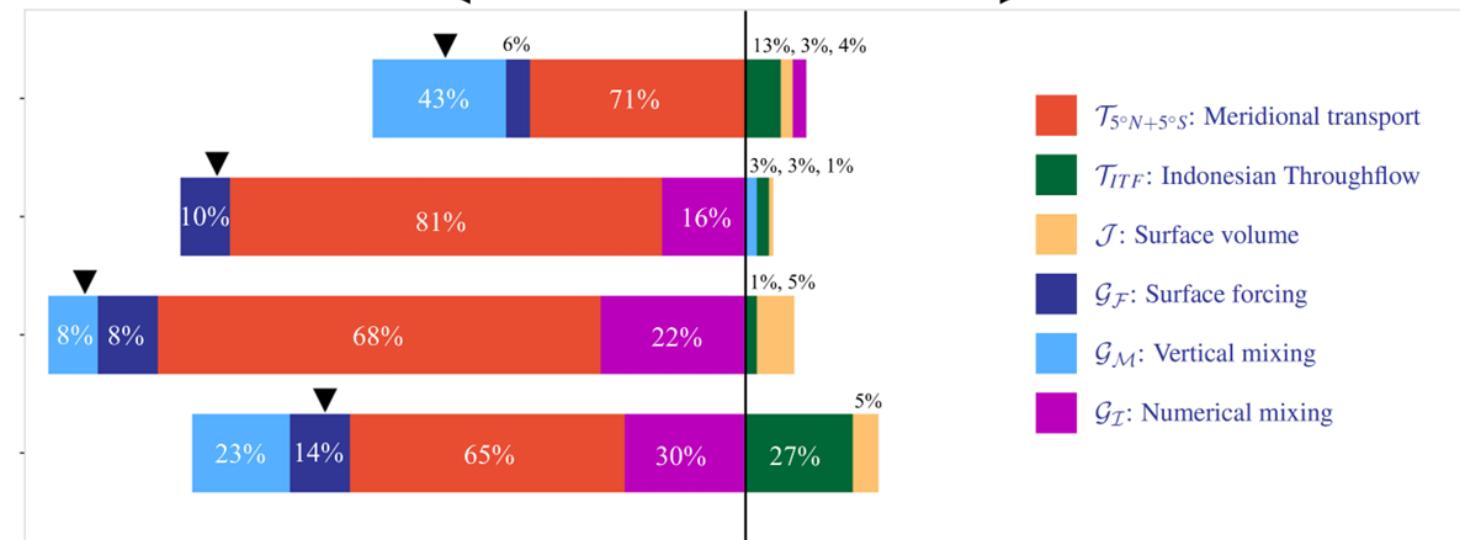
1982/83

1997/98

2015/16

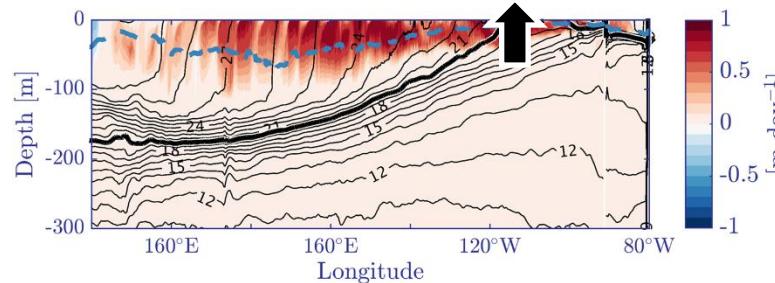
Discharge

Recharge



b) La Niña

Surface Forcing DEC 1988



1988/89

2007/09

2010/11

2%

2%

17%

2%

29%

1%

48%

31%

67%

2%

50%

25%

74%

2%

11%

16%

2%

11%

3%

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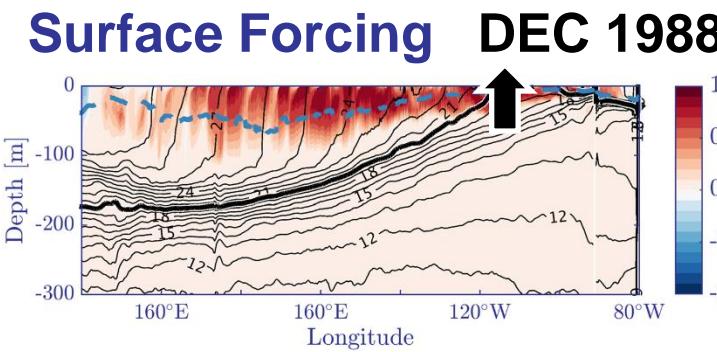
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Summary figure



a) El Niño

ideal. El Niño

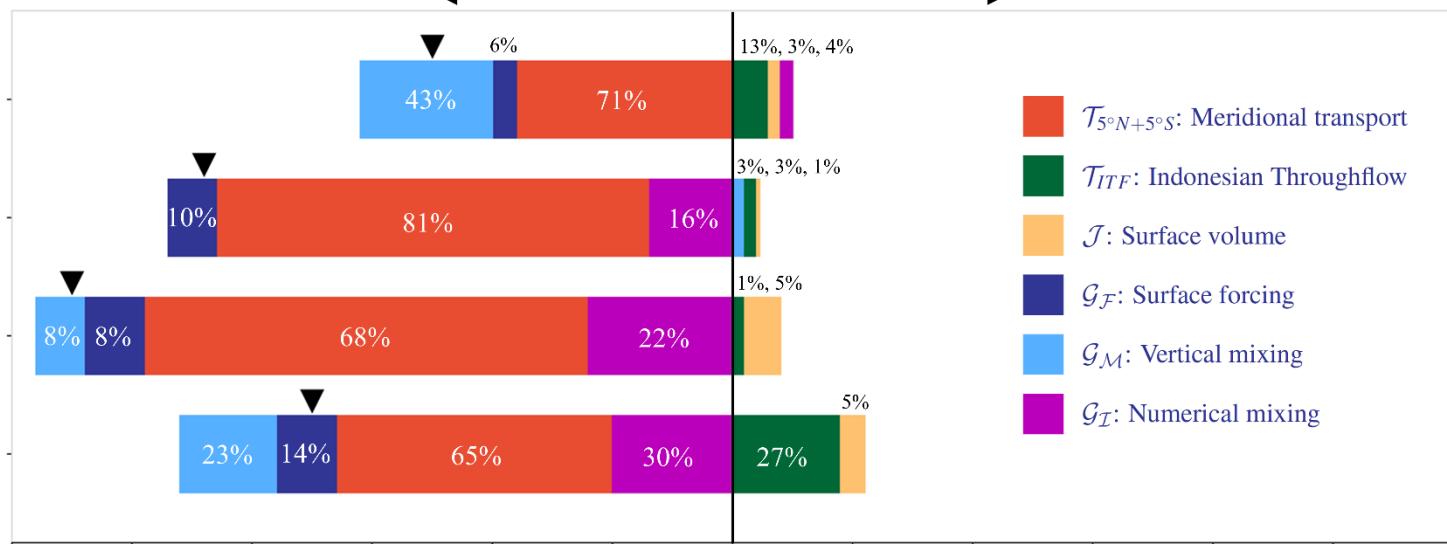
1982/83

1997/98

2015/16

Discharge

Recharge



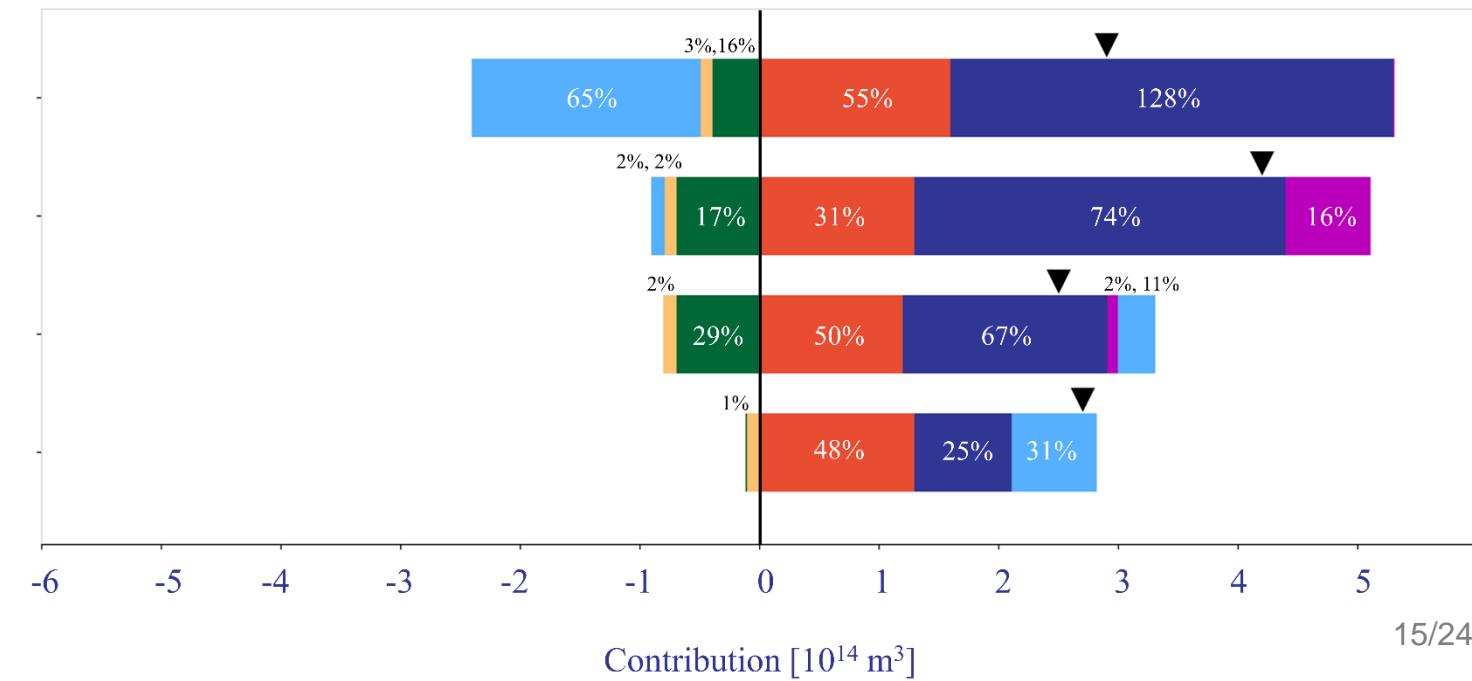
b) La Niña

ideal. La Niña

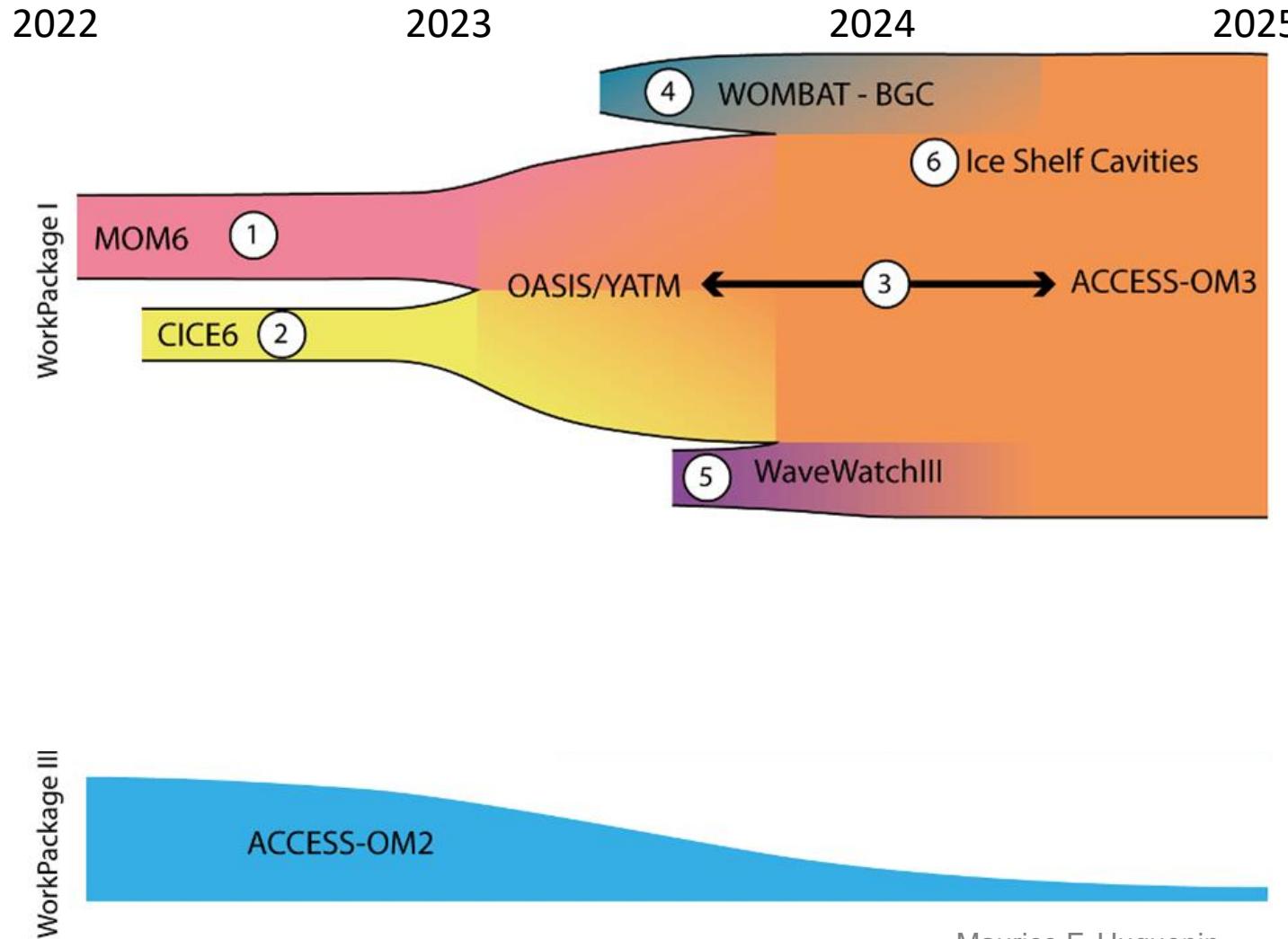
1988/89

2007/09

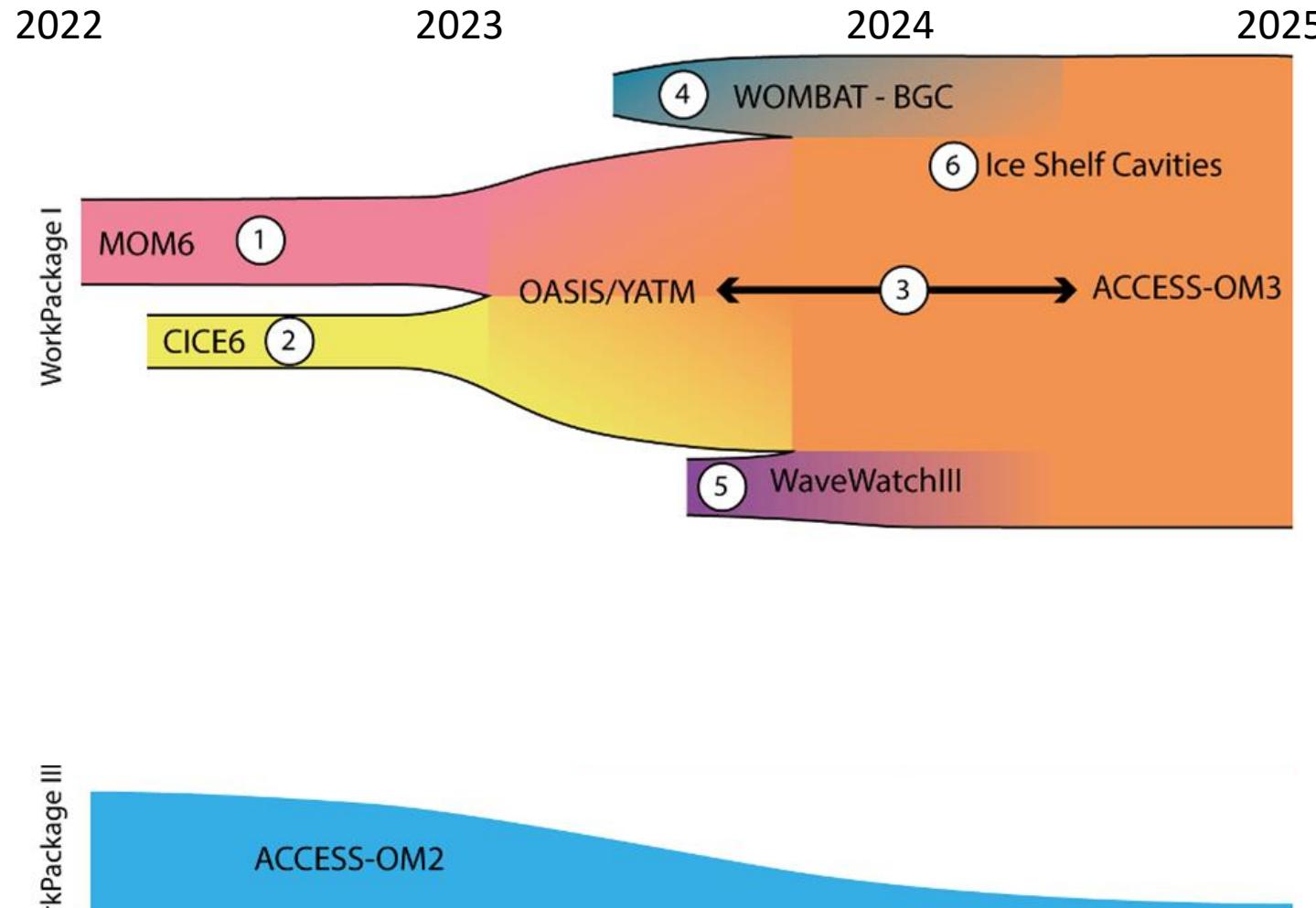
2010/11



Global ocean-sea ice model



Global ocean-sea ice model



Maurice F. Huguenin

COSIMA

Pan-Antarctic 1/20° & 1/40° model

