

Maurice Huguenin

how it started



how it's going



ETH zürich



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

MeteoSwiss



UNSW
SYDNEY



WOODS HOLE
OCEANOGRAPHIC
INSTITUTION

Disclaimer: It was more like this



Acknowledgment of Country



Mindil Beach, Darwin, AU

Acknowledgment of Country



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





ACEAS

Australian Centre for Excellence
in Antarctic Science





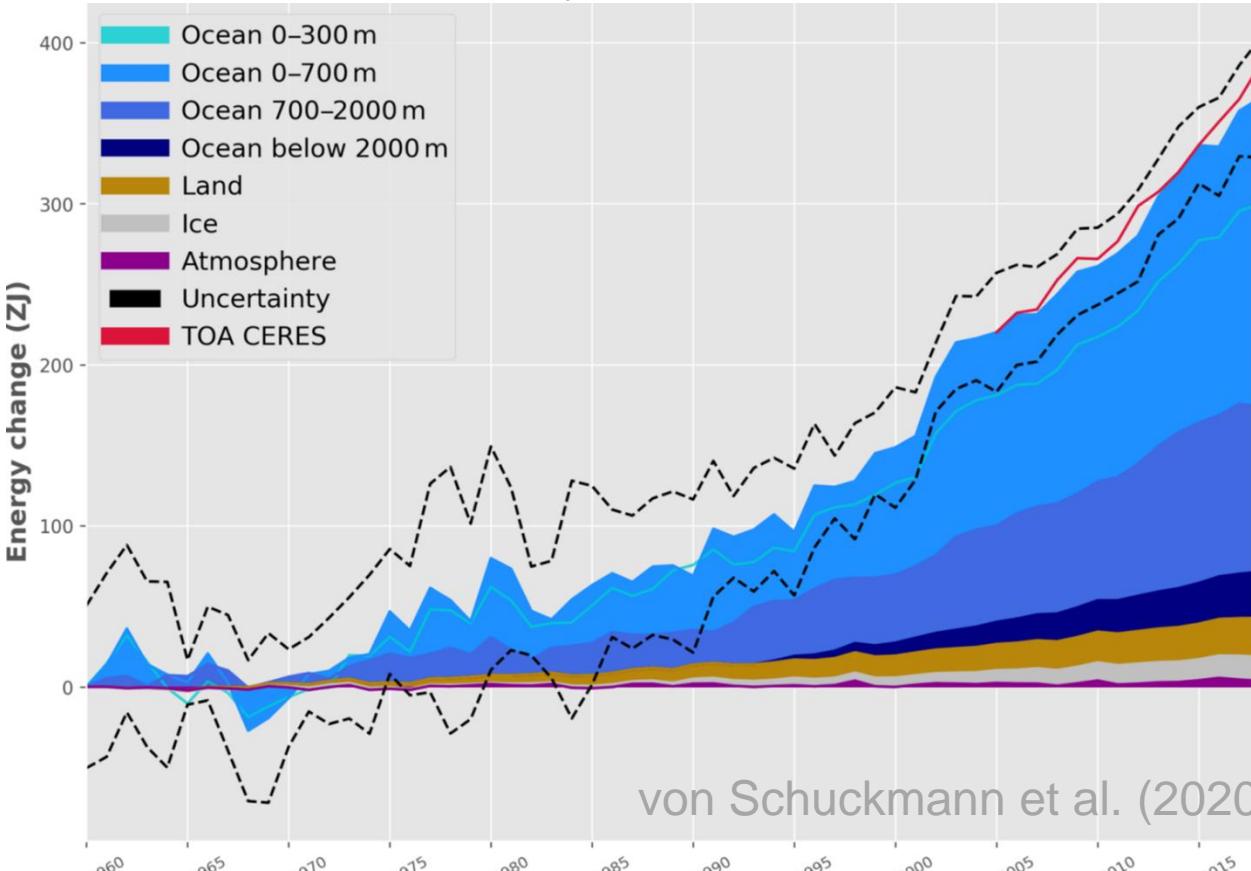
Drivers and distribution of global ocean heat uptake over the last half century

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

Nature Communications

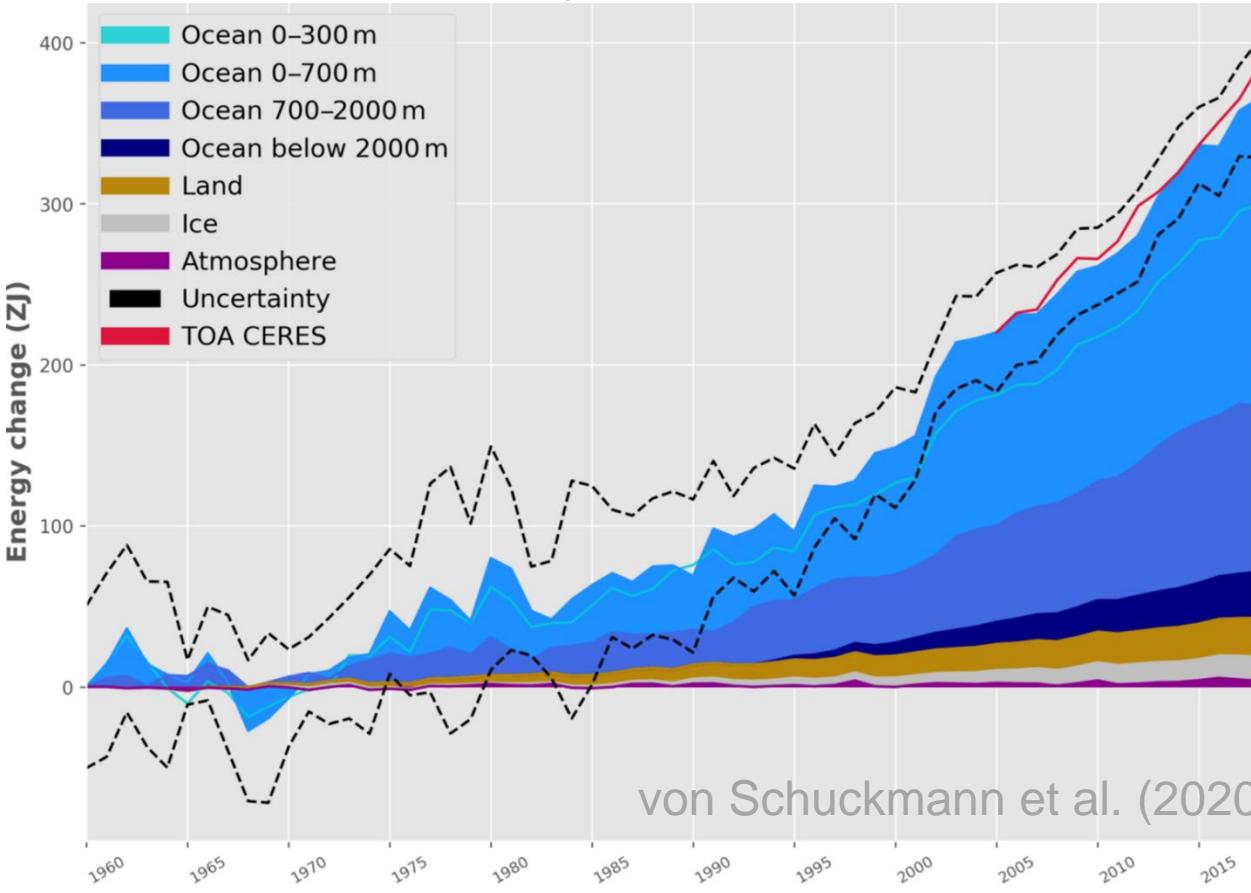
Importance of ocean heat content

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



Importance of ocean heat content

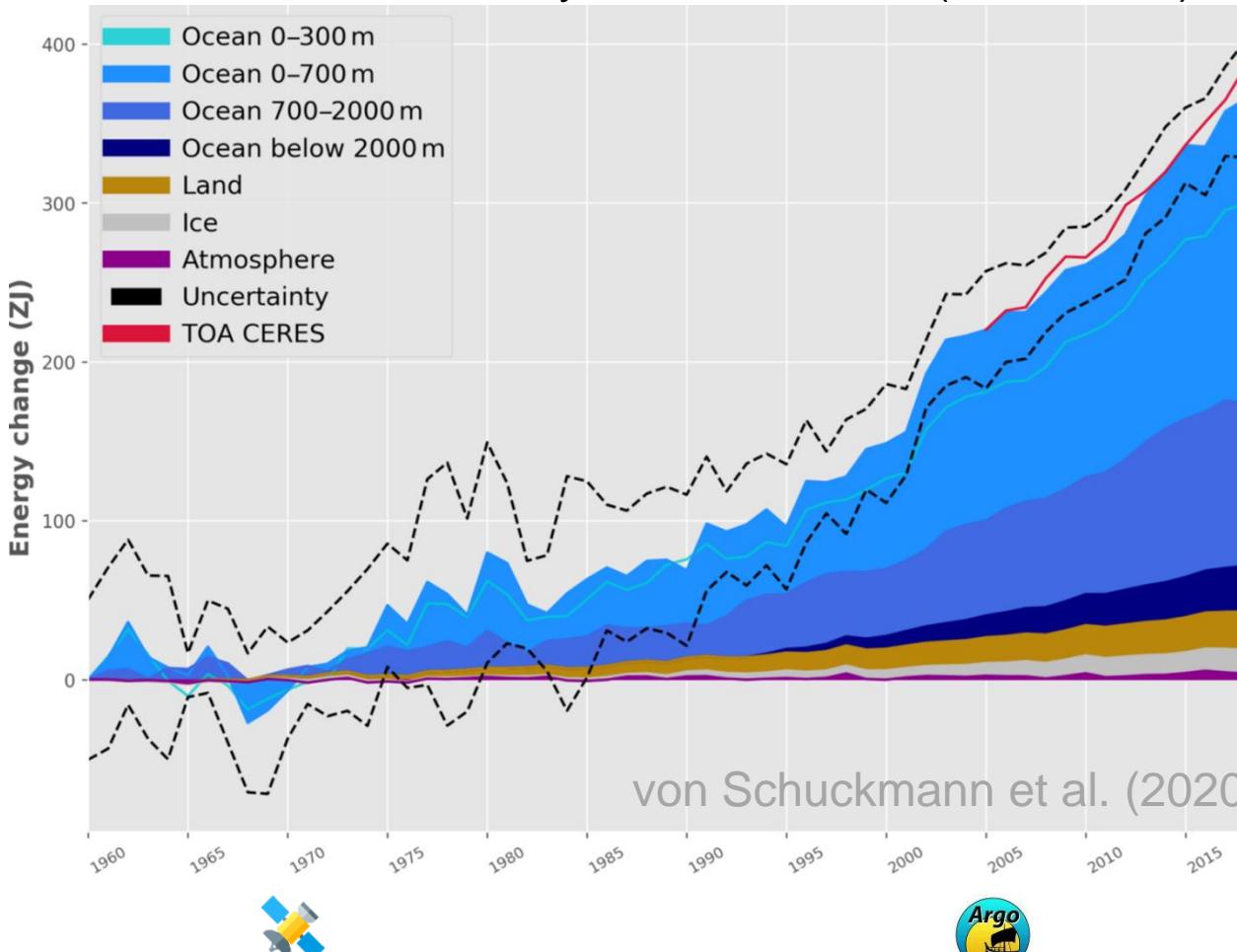
Earth heat inventory relative to 1960 ($ZJ = 10^{21} J$)



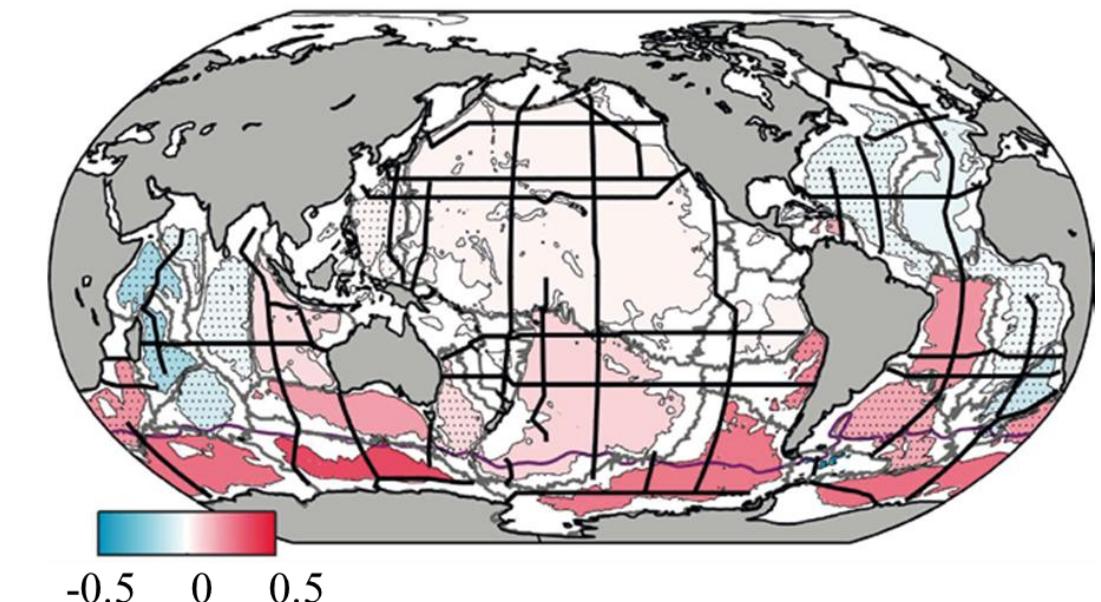
- Where has heat entered the ocean?
- Where is it today?
- What are the roles of wind and thermal forcing?

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

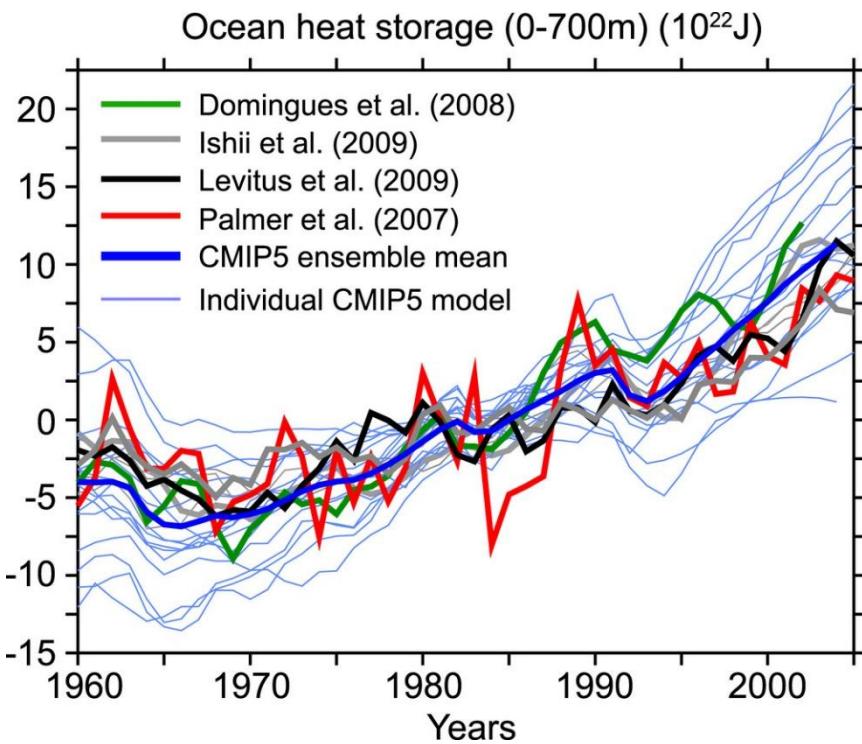


IPCC SROCC, Ch. 5, Fig. 5.4b, Allison et al. (2019)

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

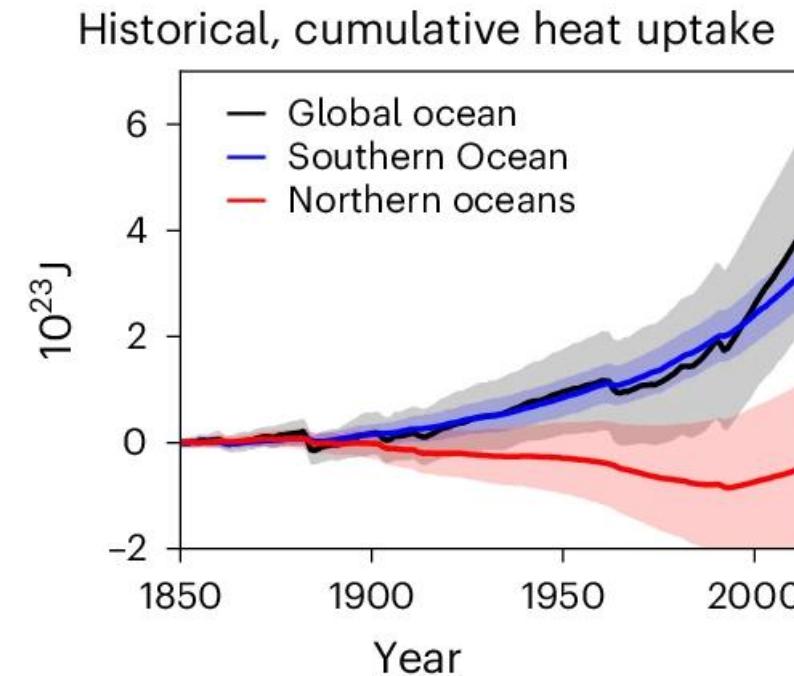
Modelling ocean heat storage

CMIP5



Frölicher et al. (2015)

CMIP6



Williams et al. (2024)

Global ocean-sea ice model

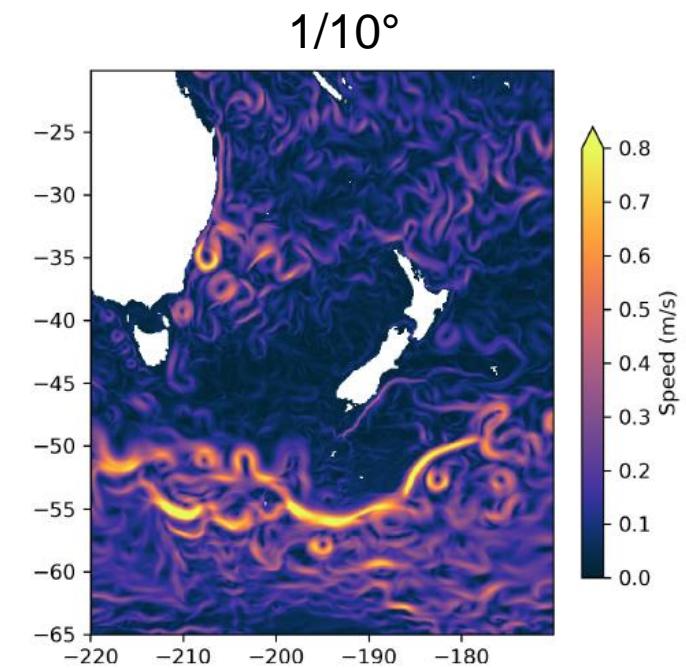
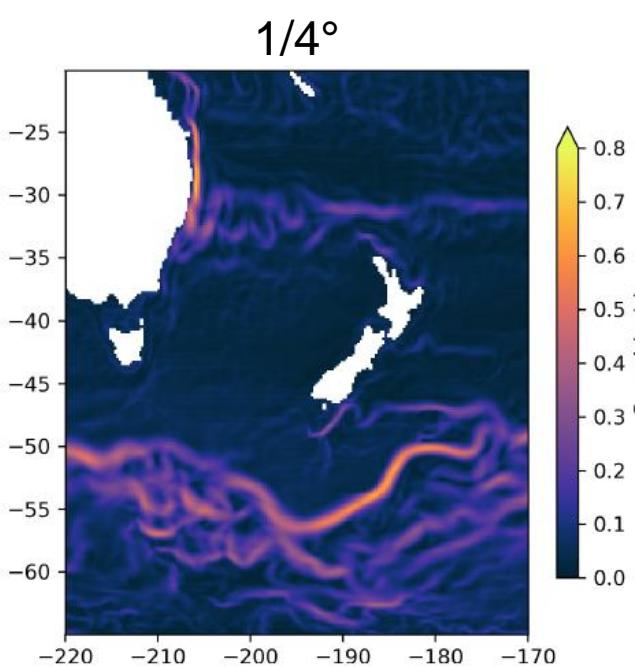
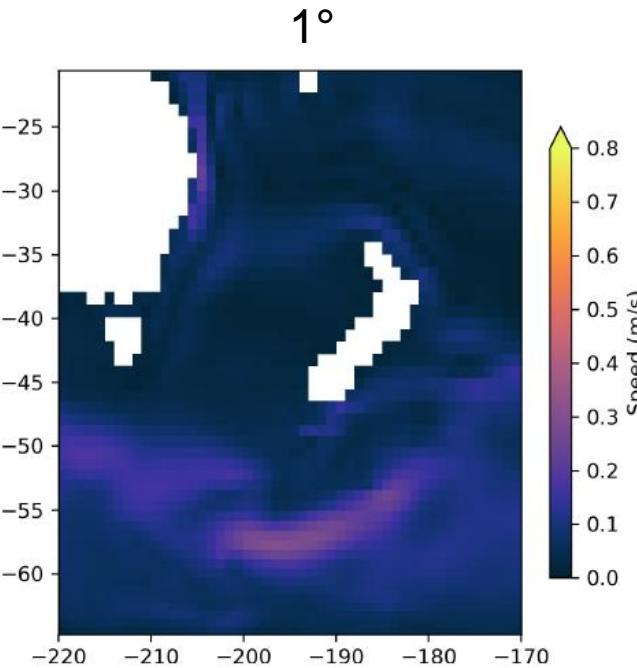


- ACCESS-OM2 ([Kiss et al., 2019](#))
- MOM5.1, CICE5.1.2
- Input: atmospheric reanalysis JRA55-do ([Tsujino et al., 2018](#))

Global ocean-sea ice model

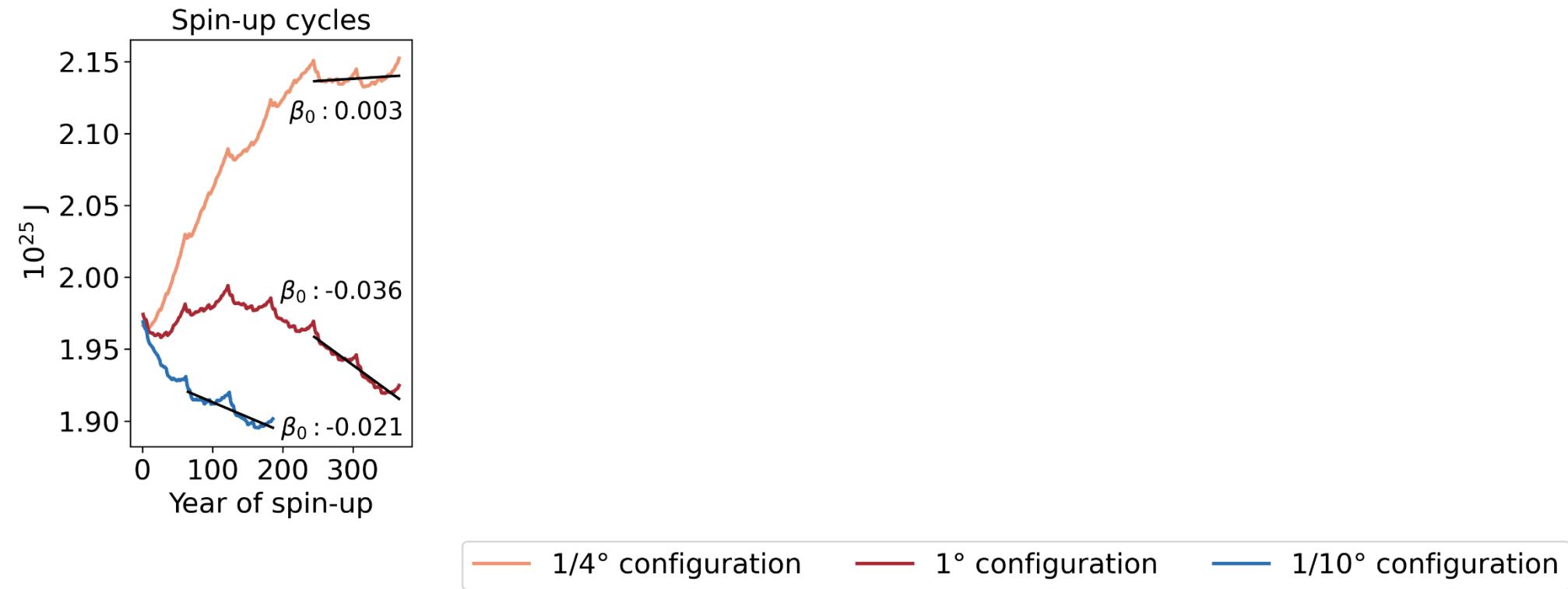
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COSIMA

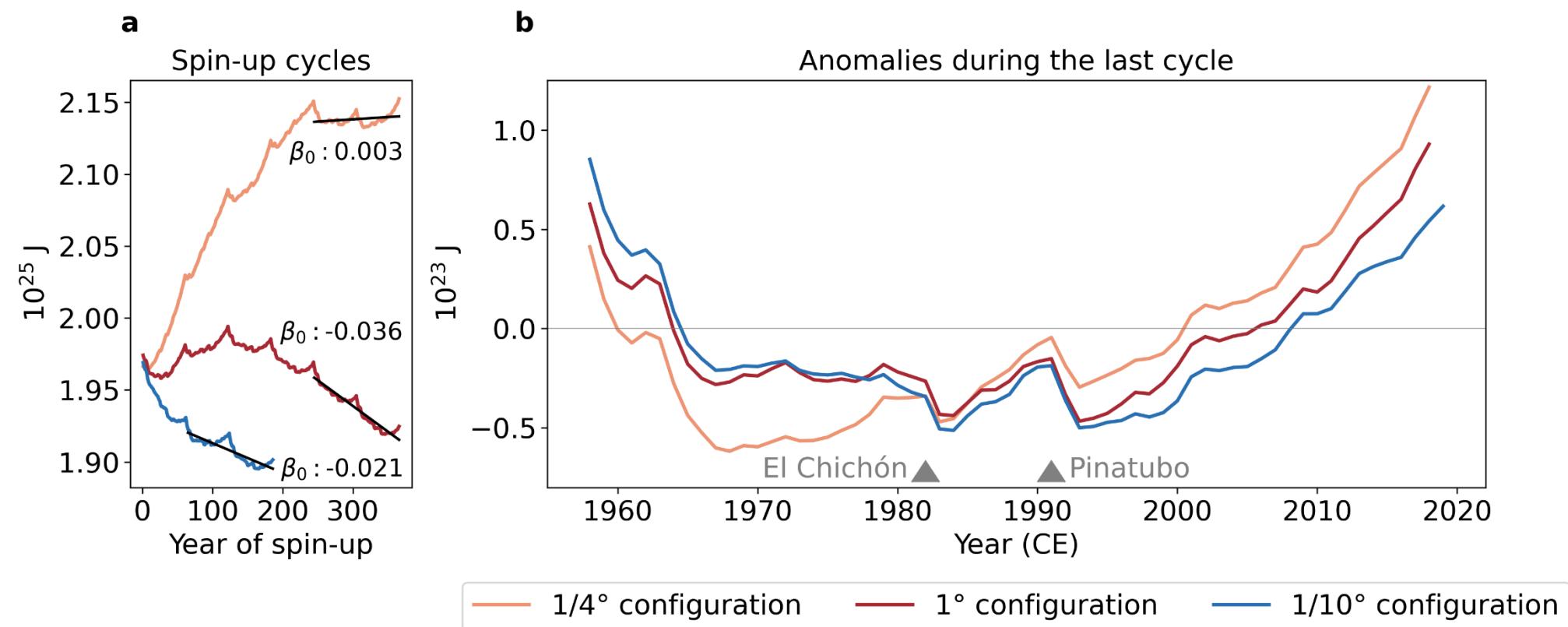


Kiss et al. (2019)

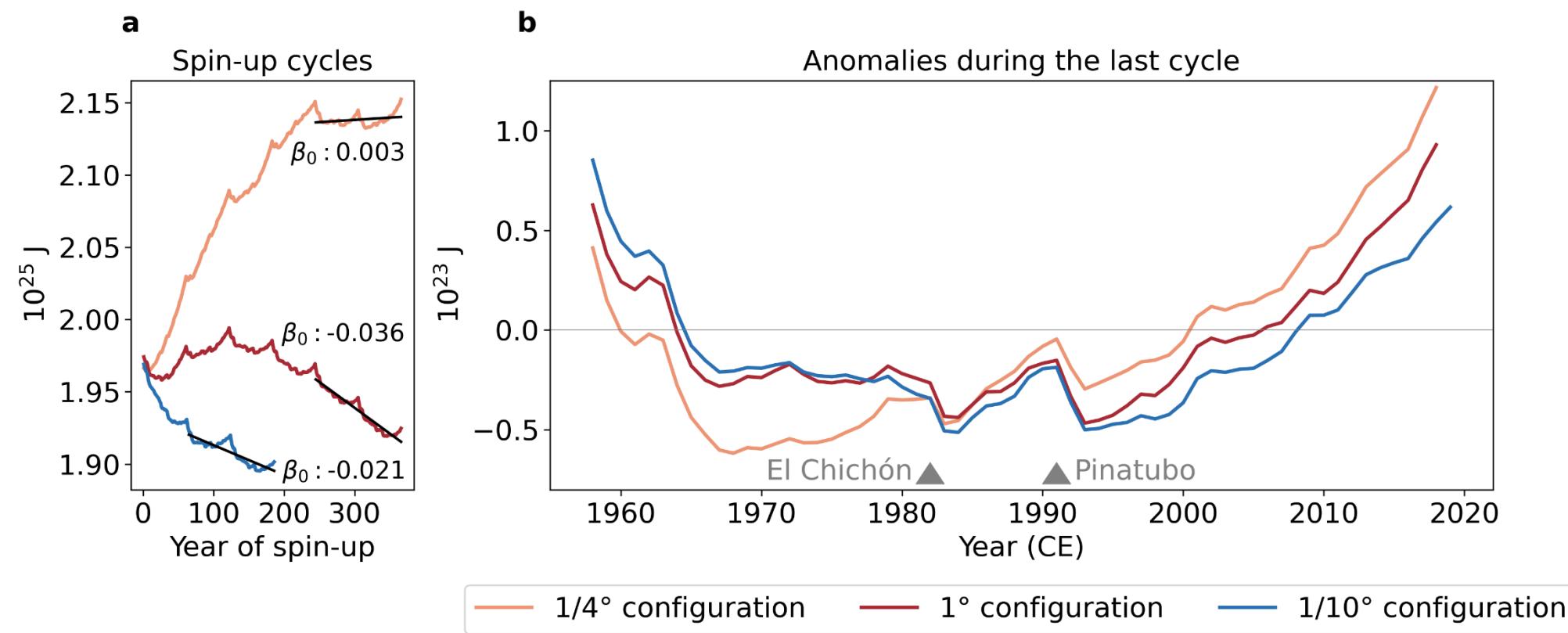
Spin-up in ocean-sea ice models

a

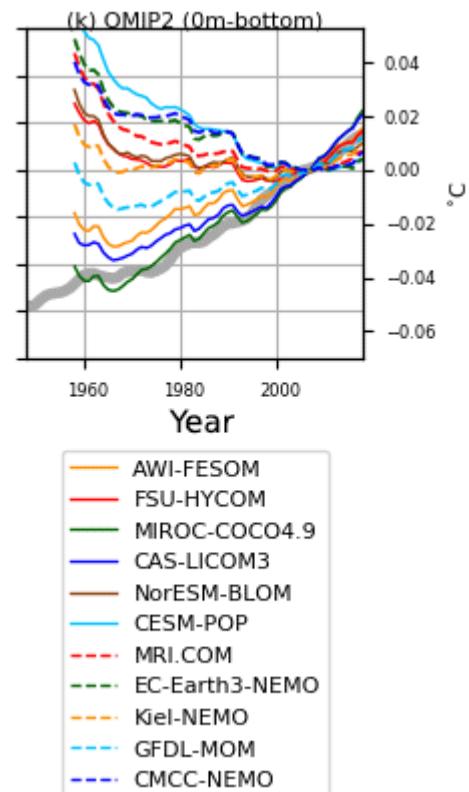
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Spin-up in ocean-sea ice models



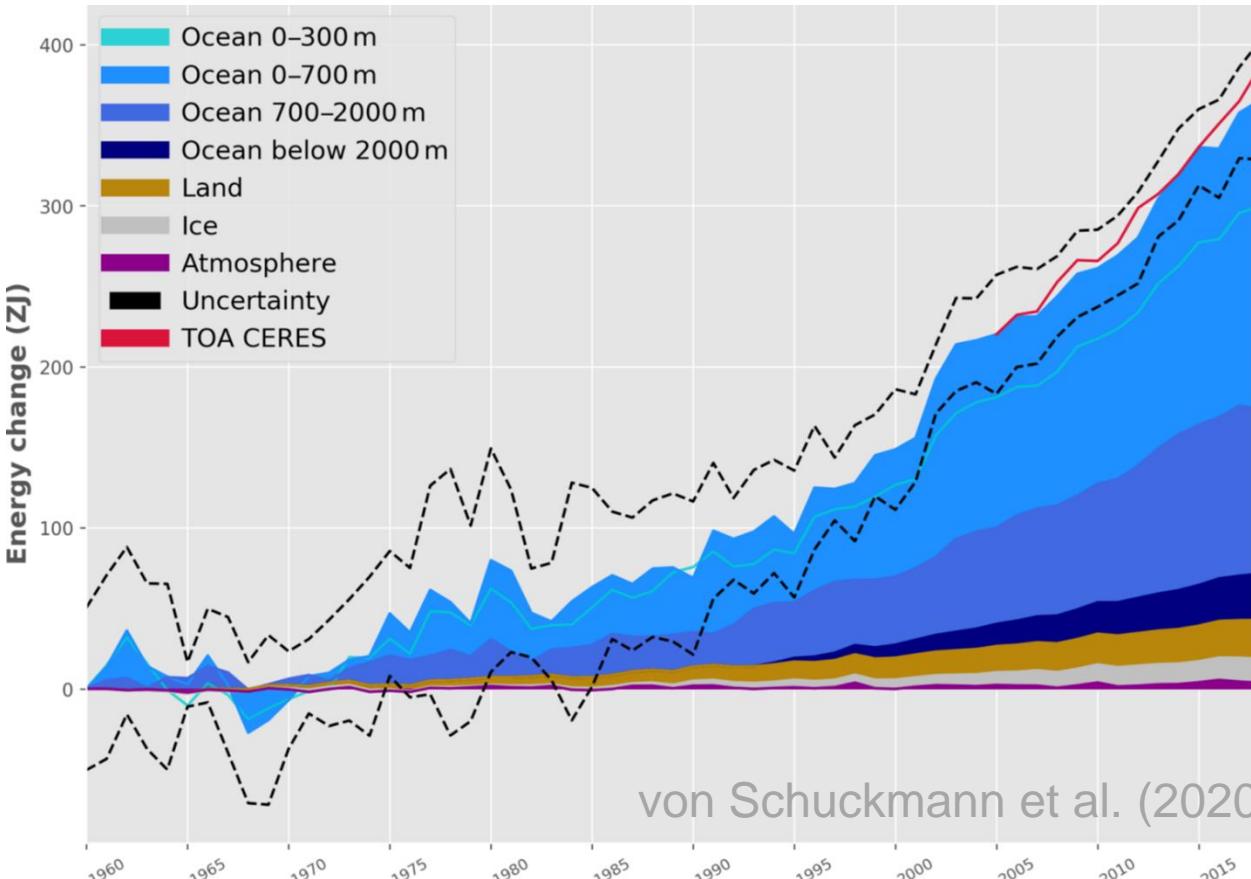
OMIP-2 models, anomalies relative to 2005-09



Tsujino et al. (2020)

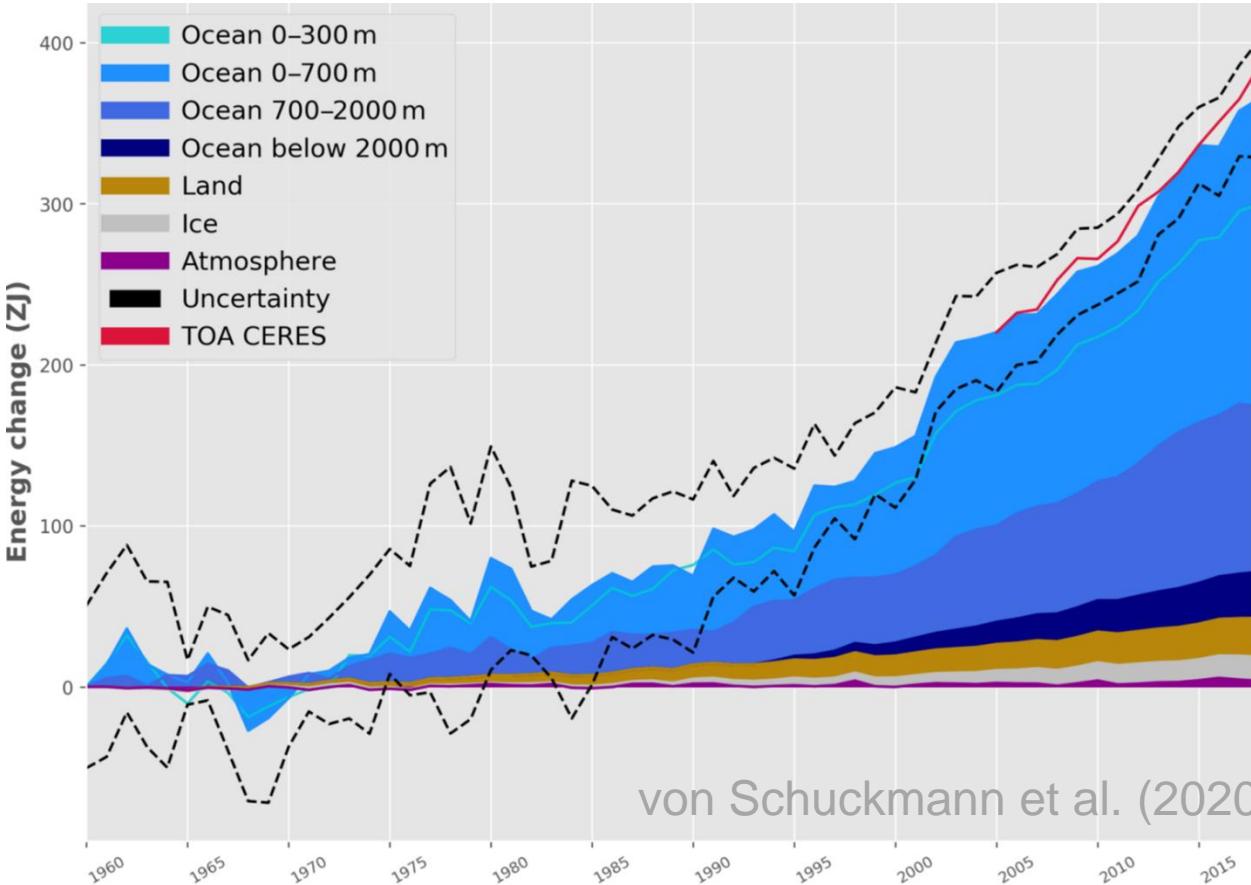
New spin-up for ocean-sea ice models

New spin-up for ocean-sea ice models



Maurice F. Huguenin

New spin-up for ocean-sea ice models



1962-1971

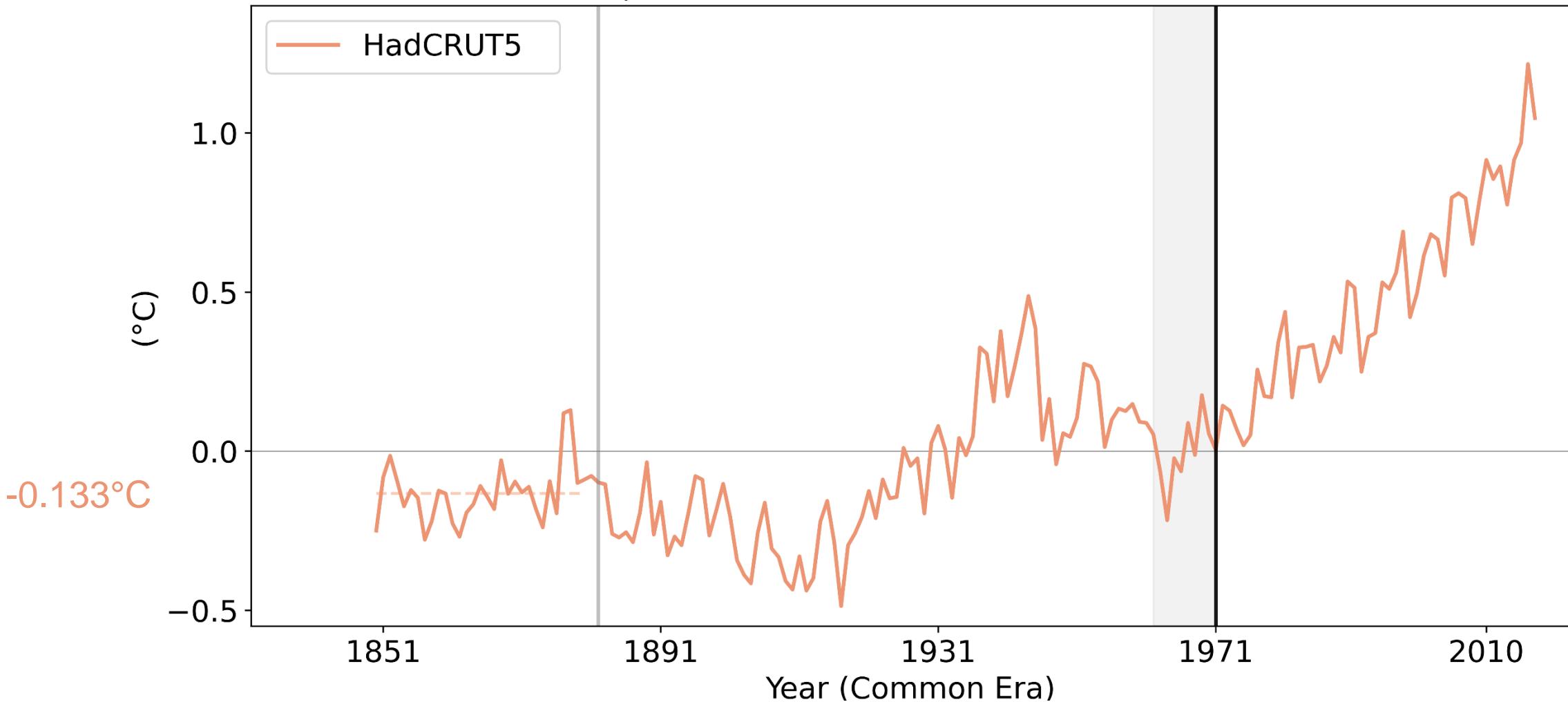


Maurice F. Huguenin

New spin-up for ocean-sea ice models

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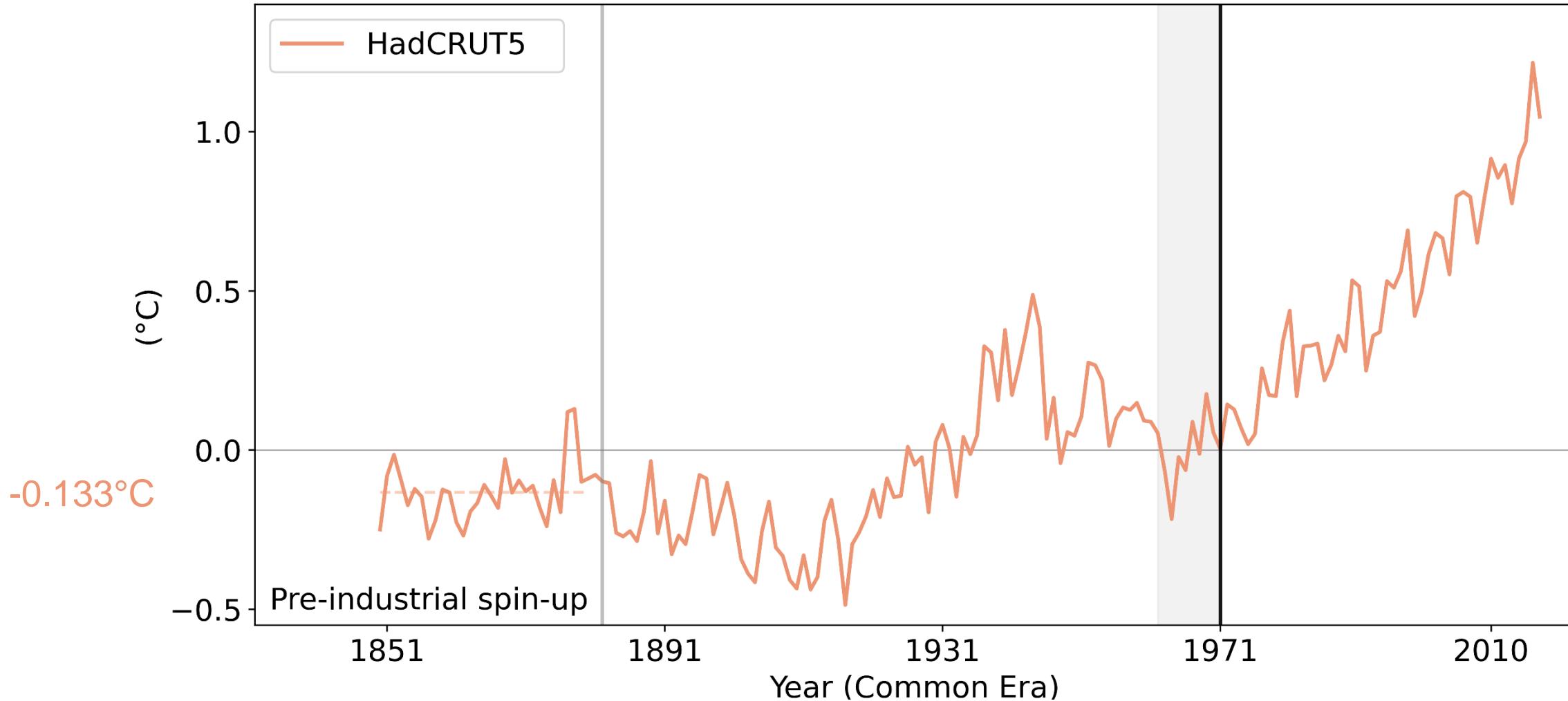
Surface air temperature anomalies



New spin-up for ocean-sea ice models

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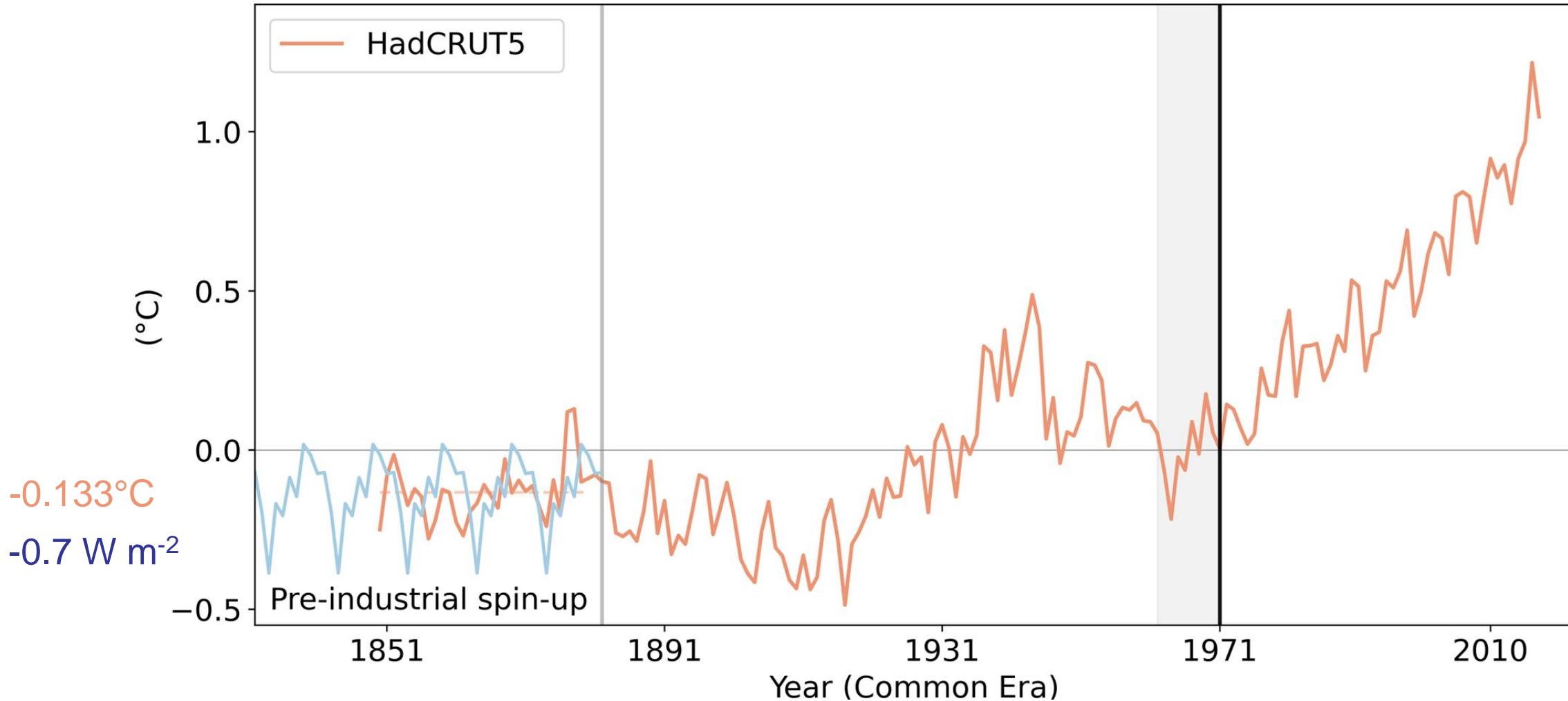
Surface air temperature anomalies during the last part of the spin-up



New spin-up for ocean-sea ice models

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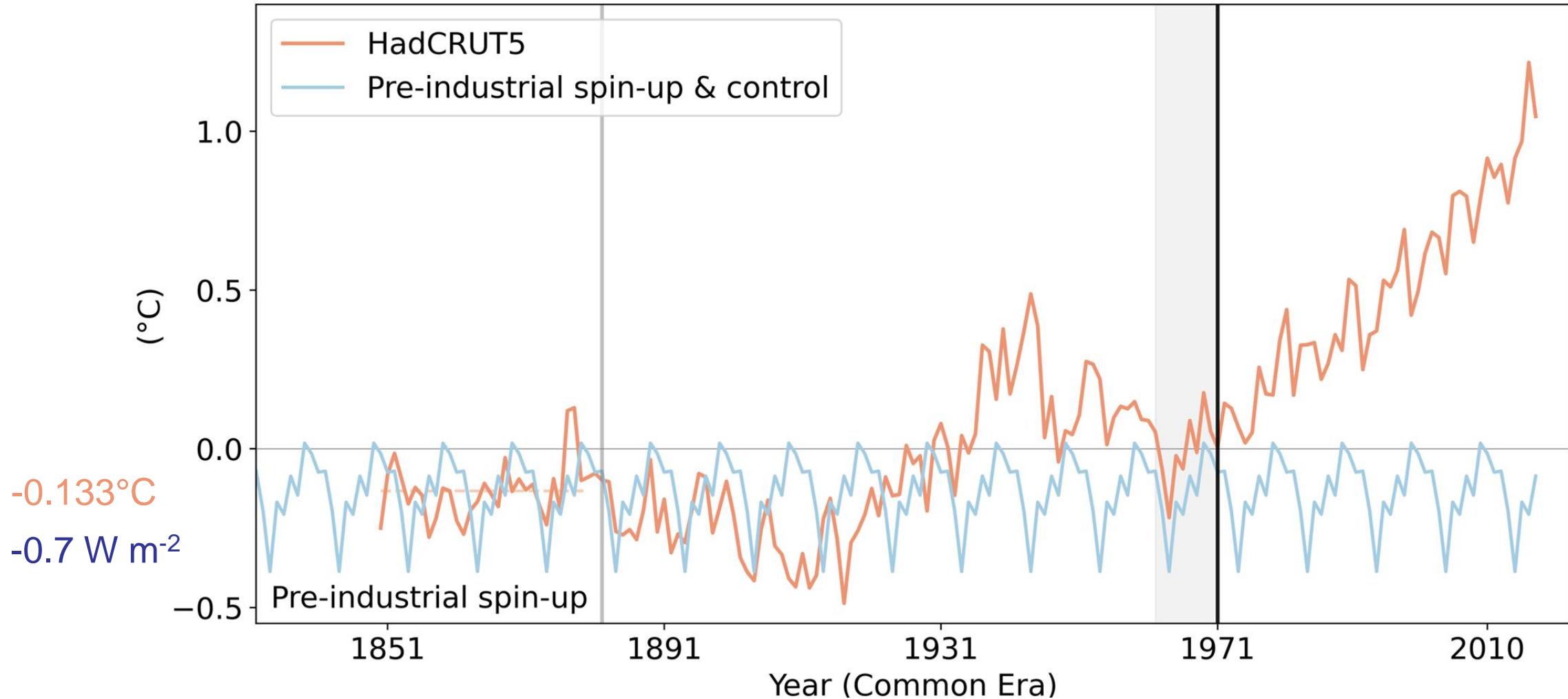
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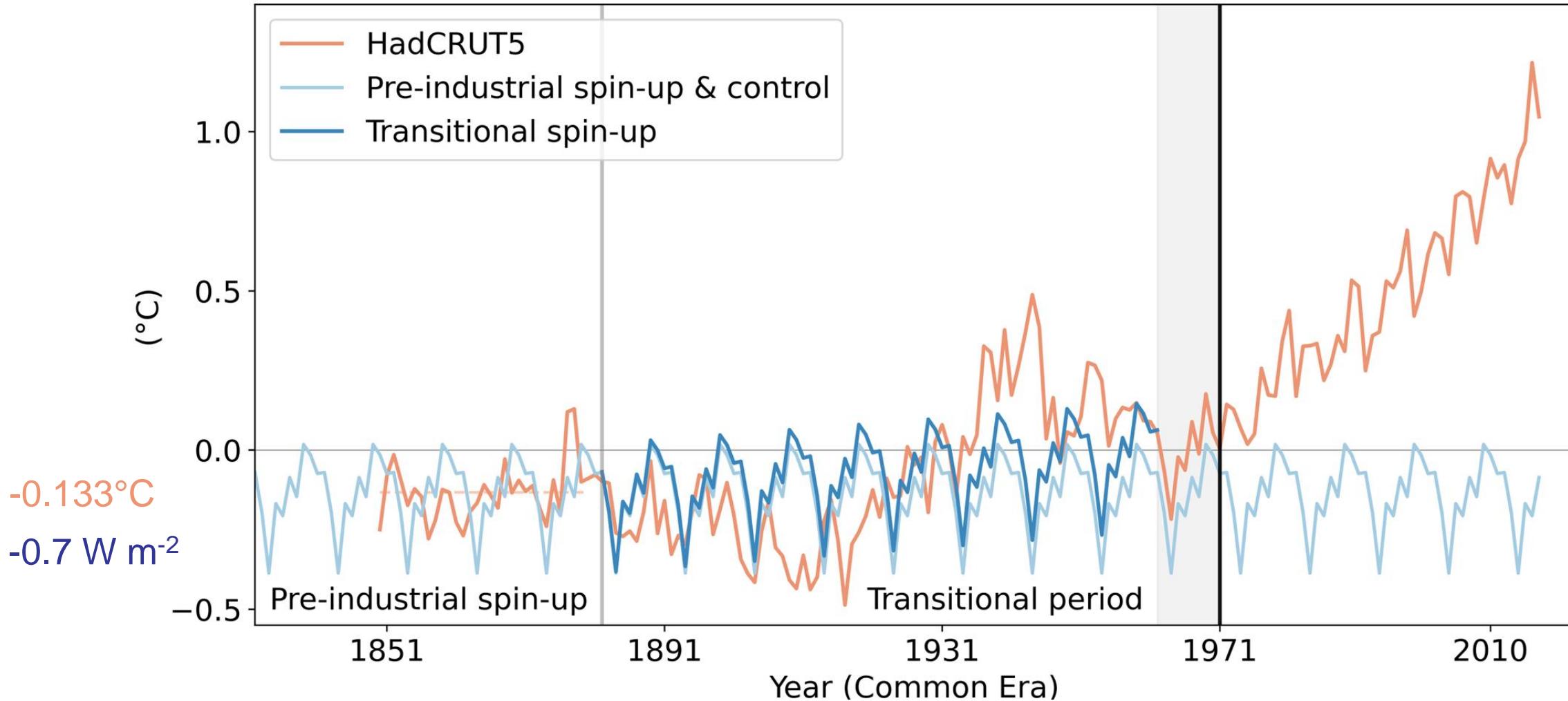
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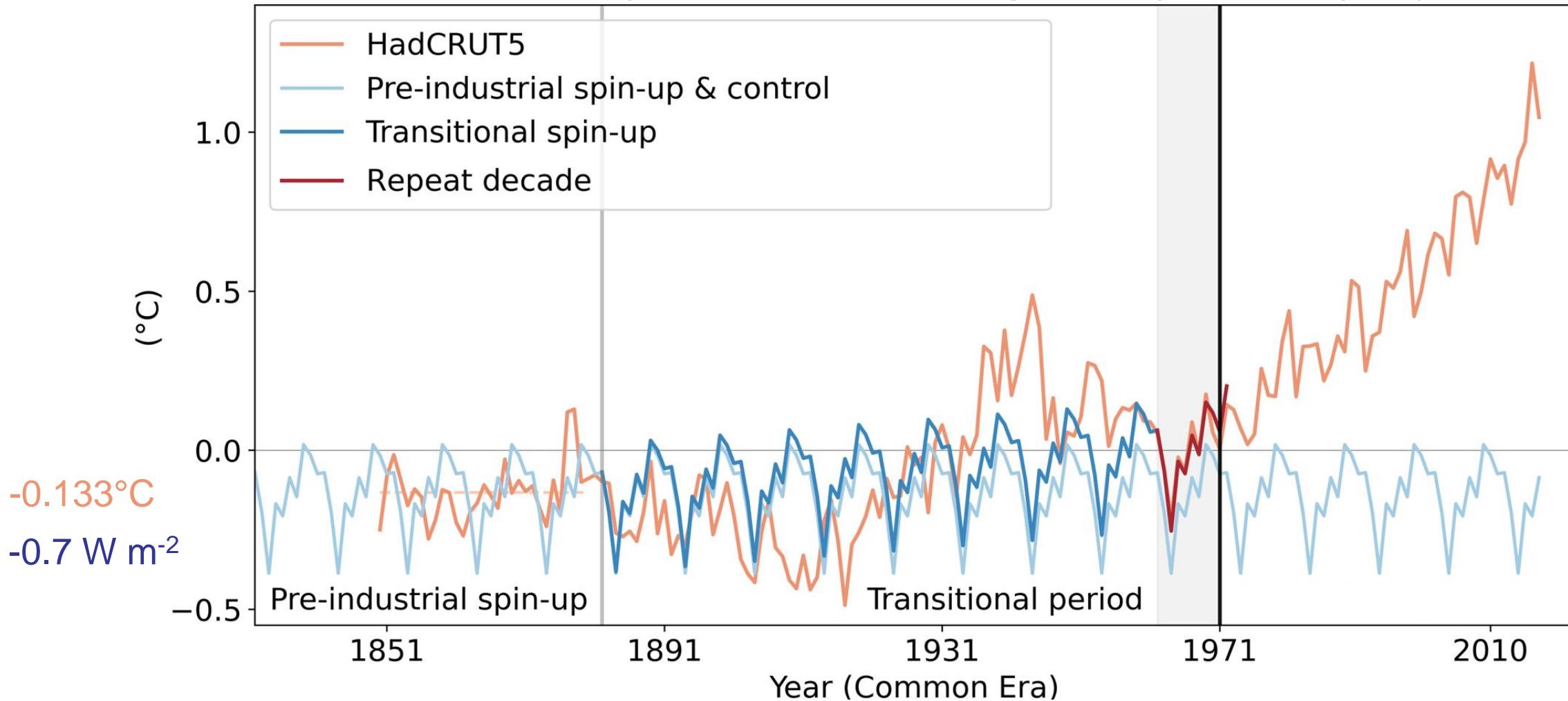
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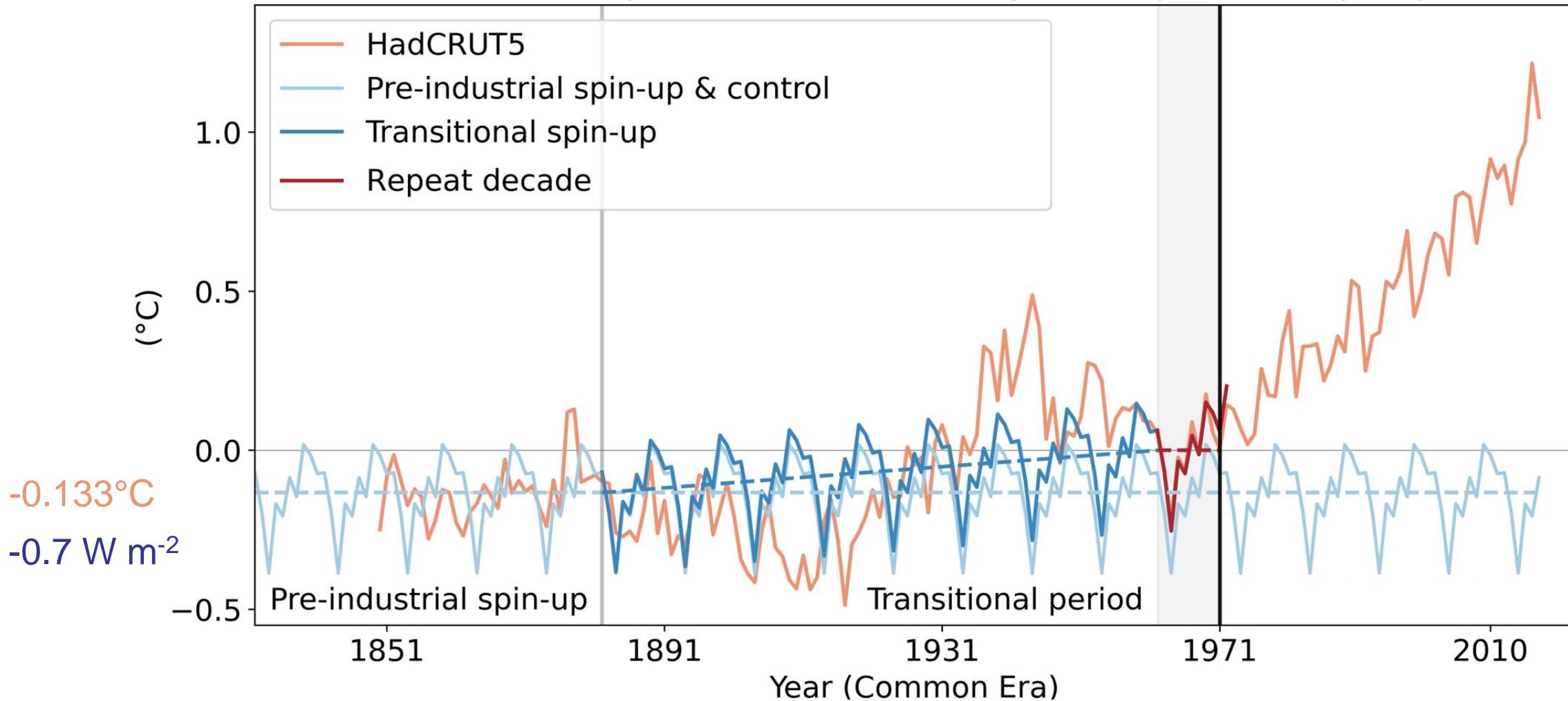
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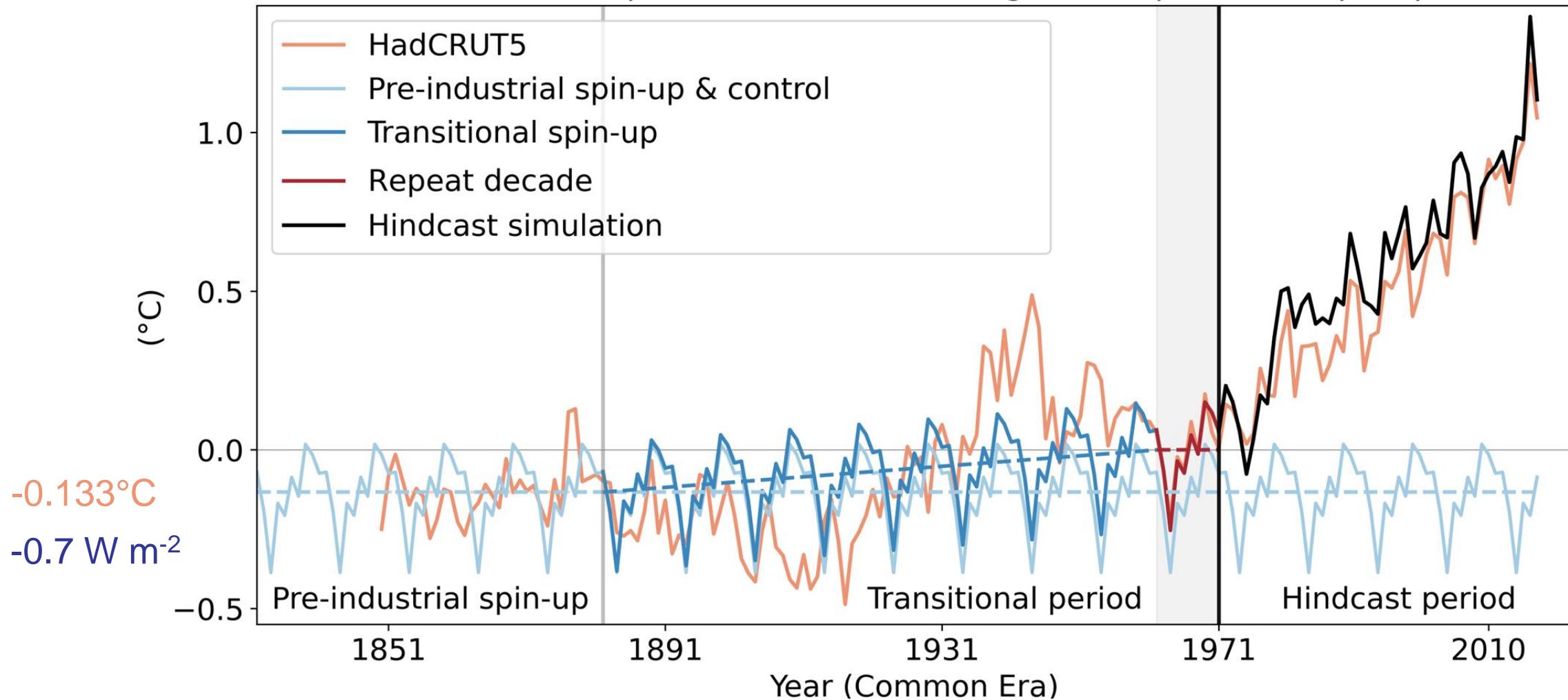
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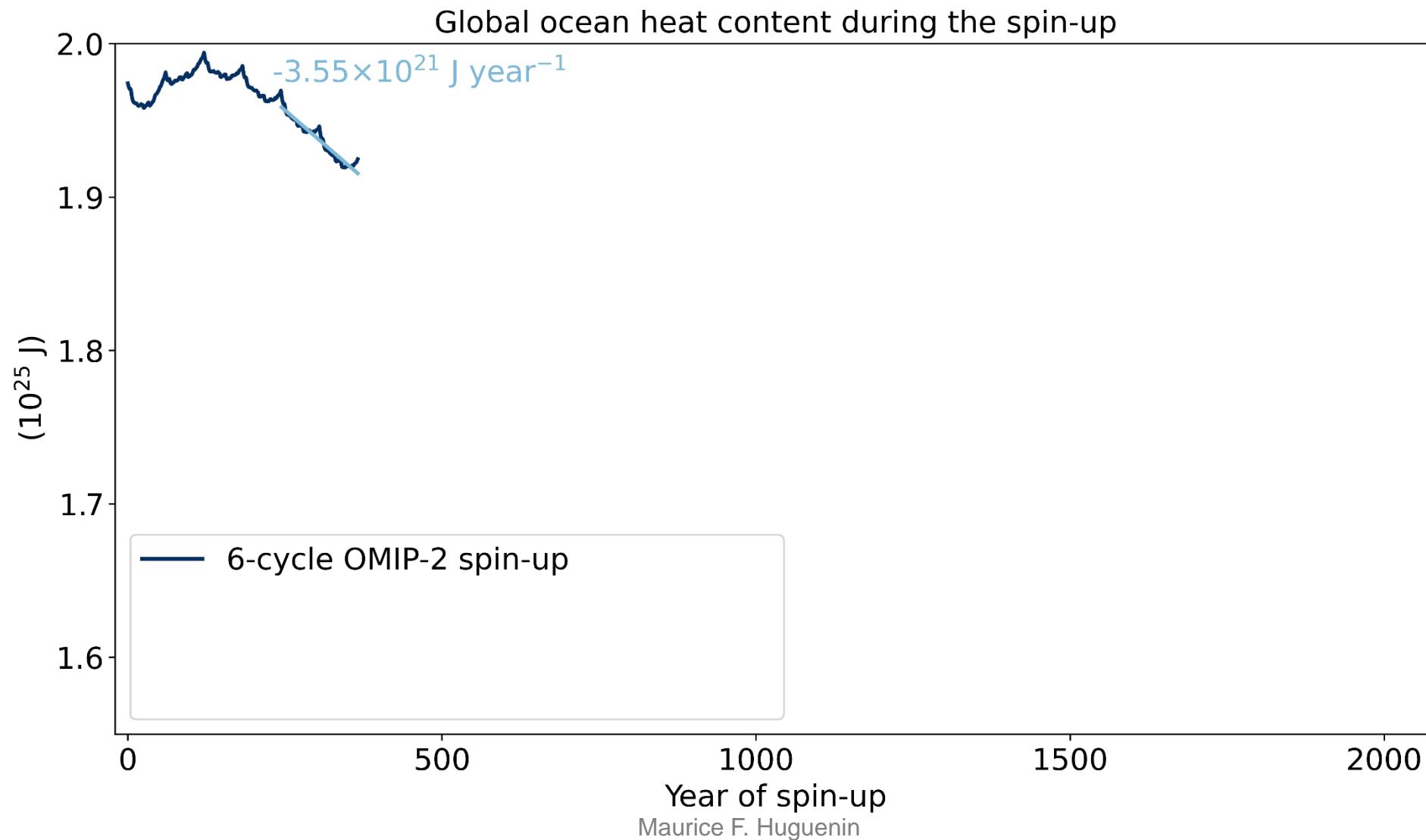
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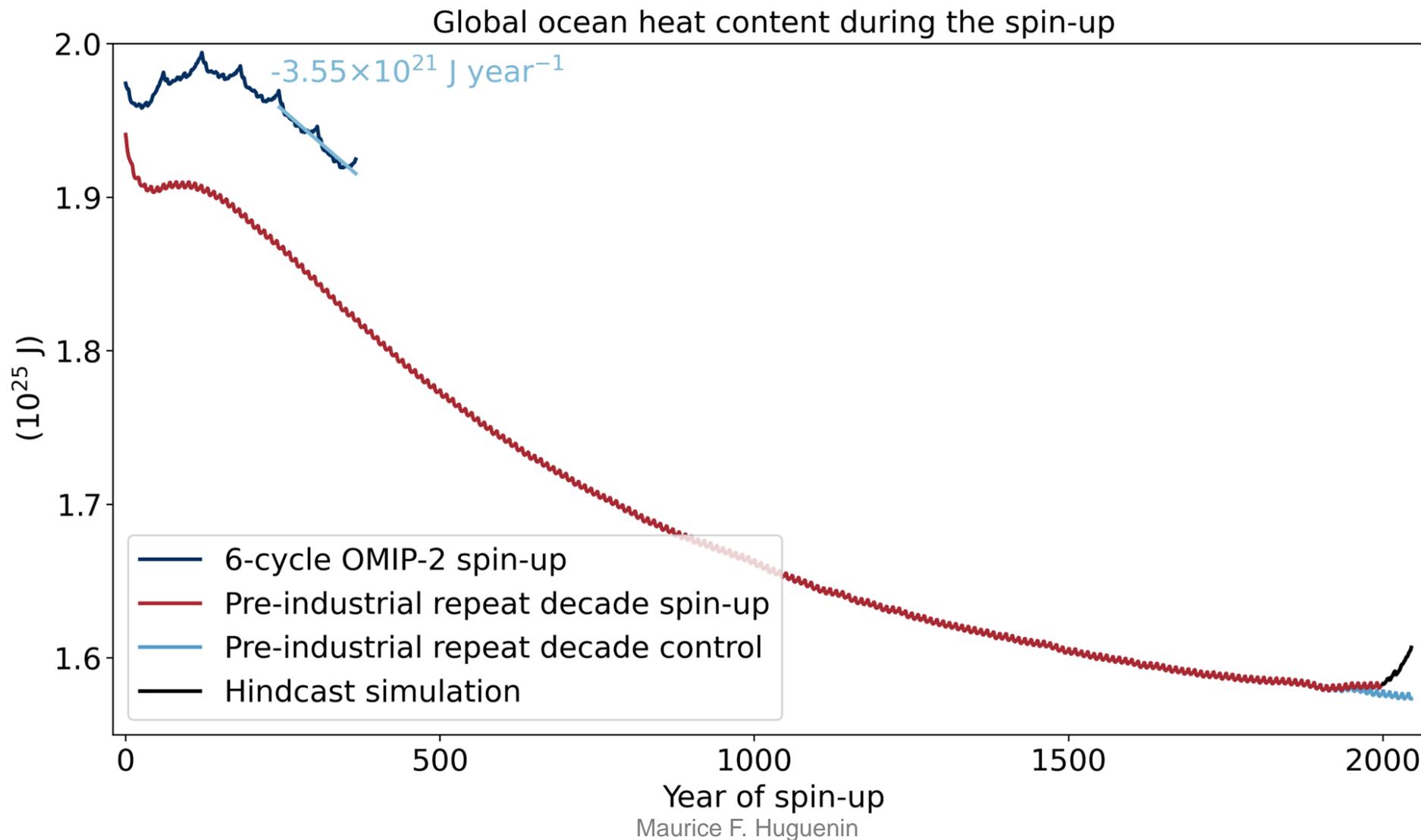
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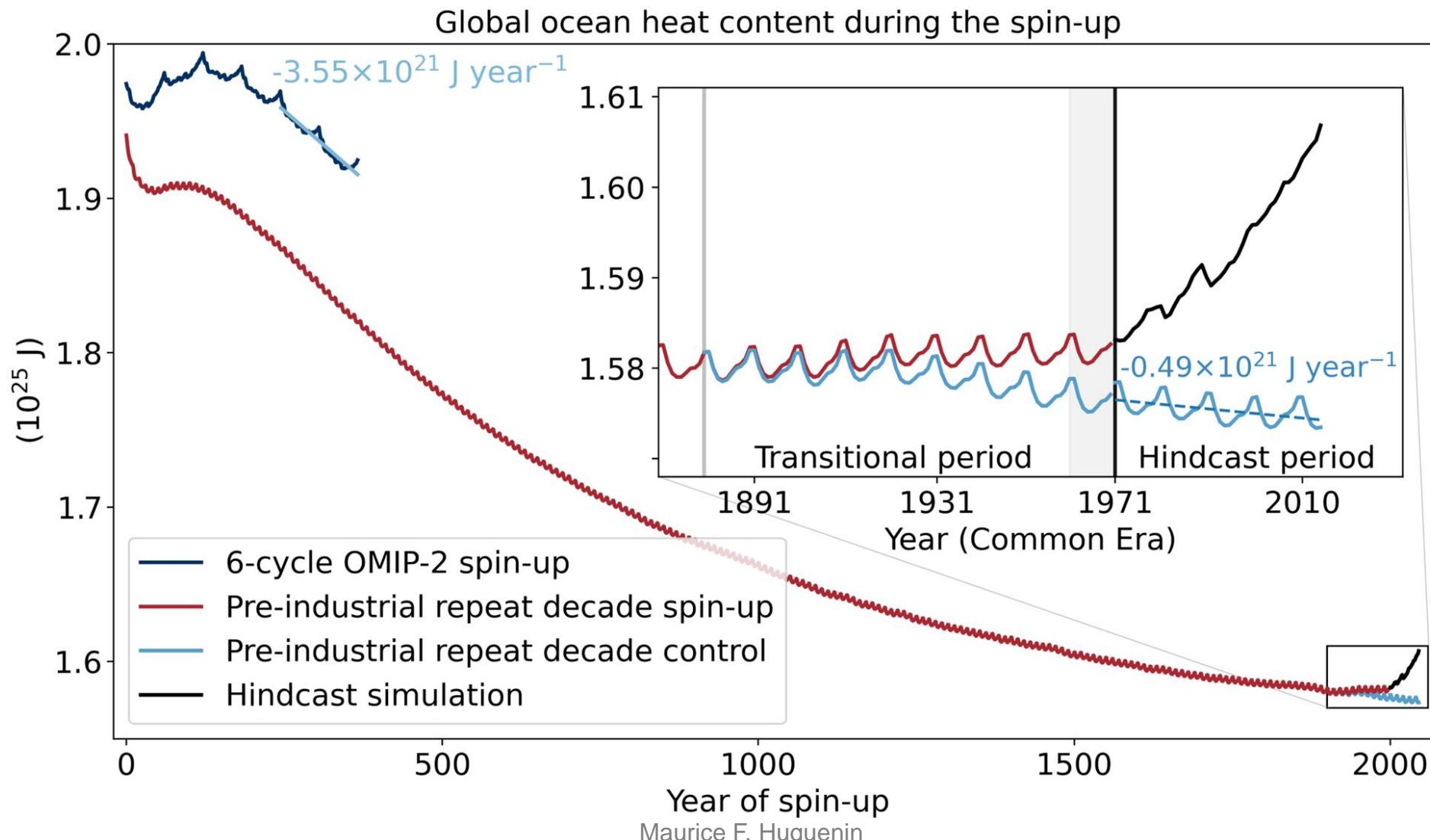
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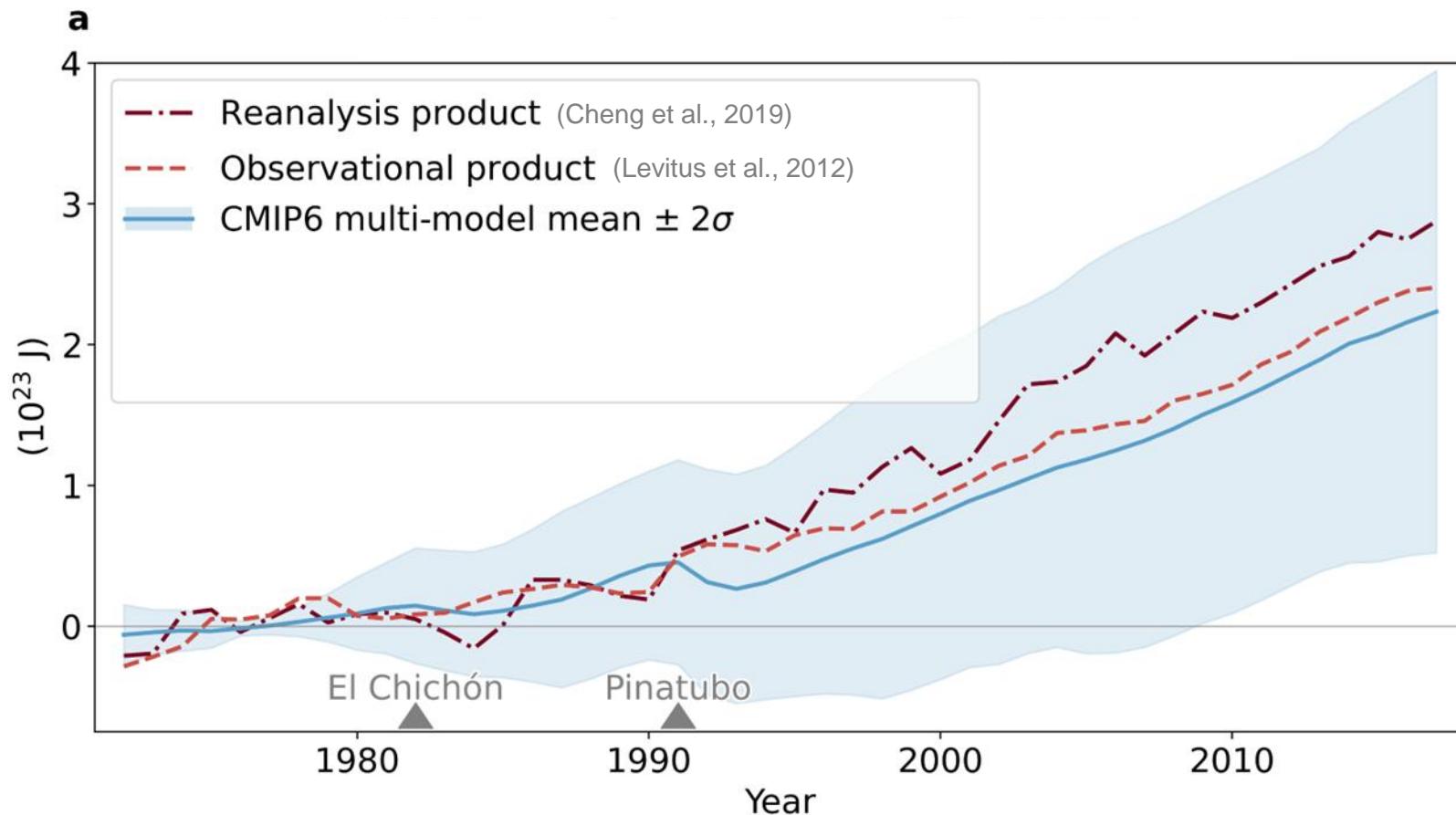


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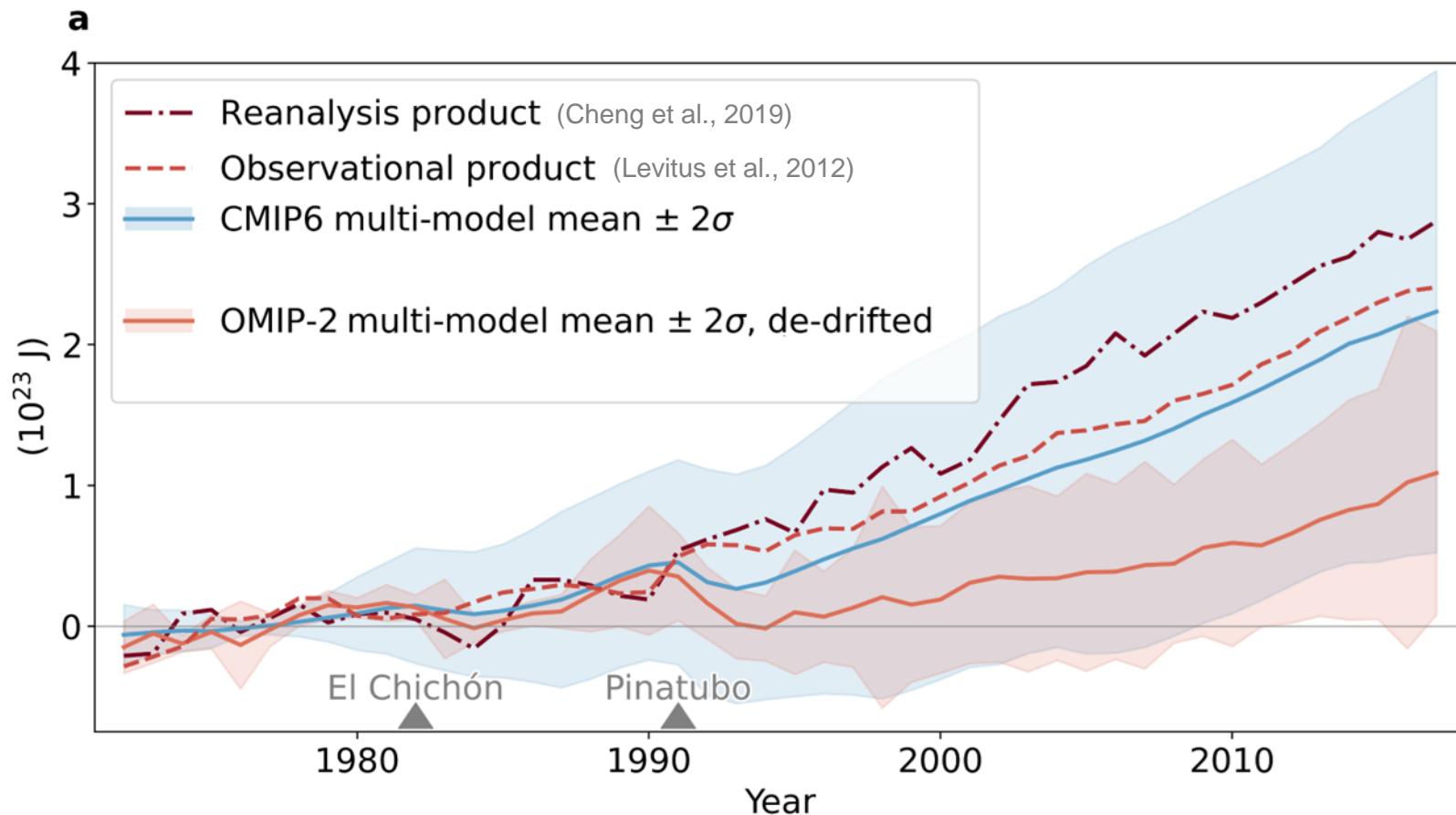


Global ocean heat content anomalies, 0-2000 m

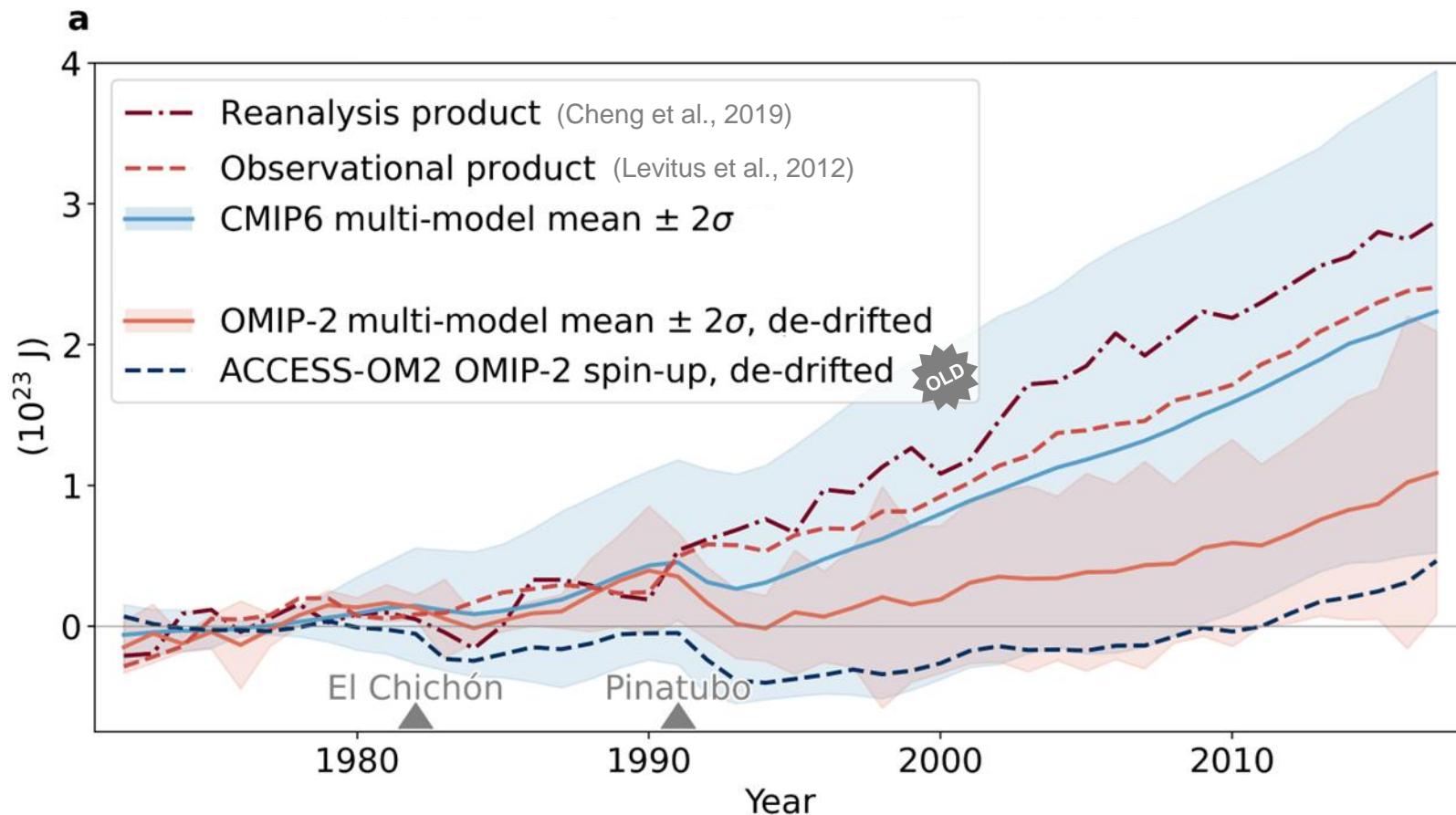
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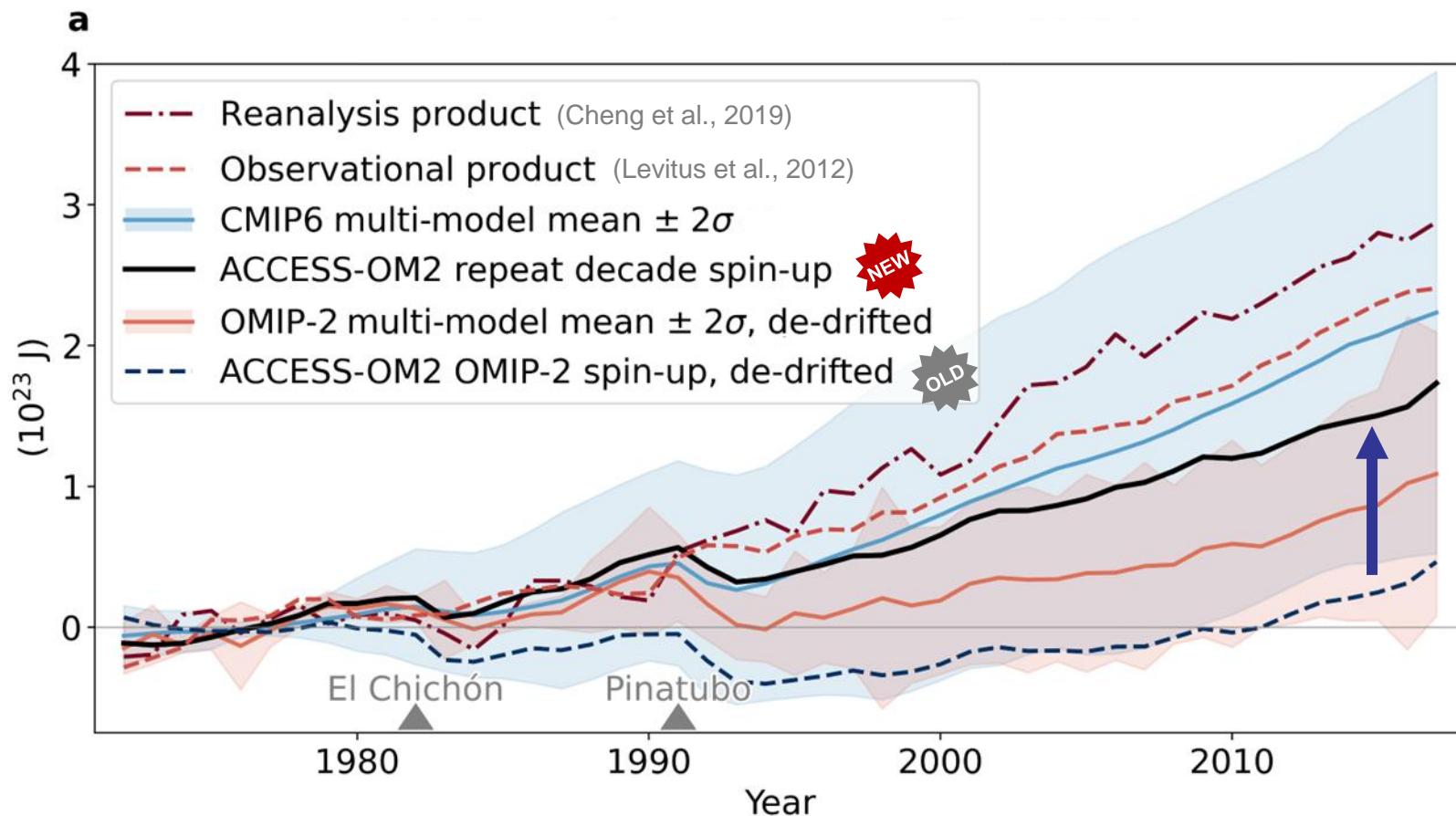
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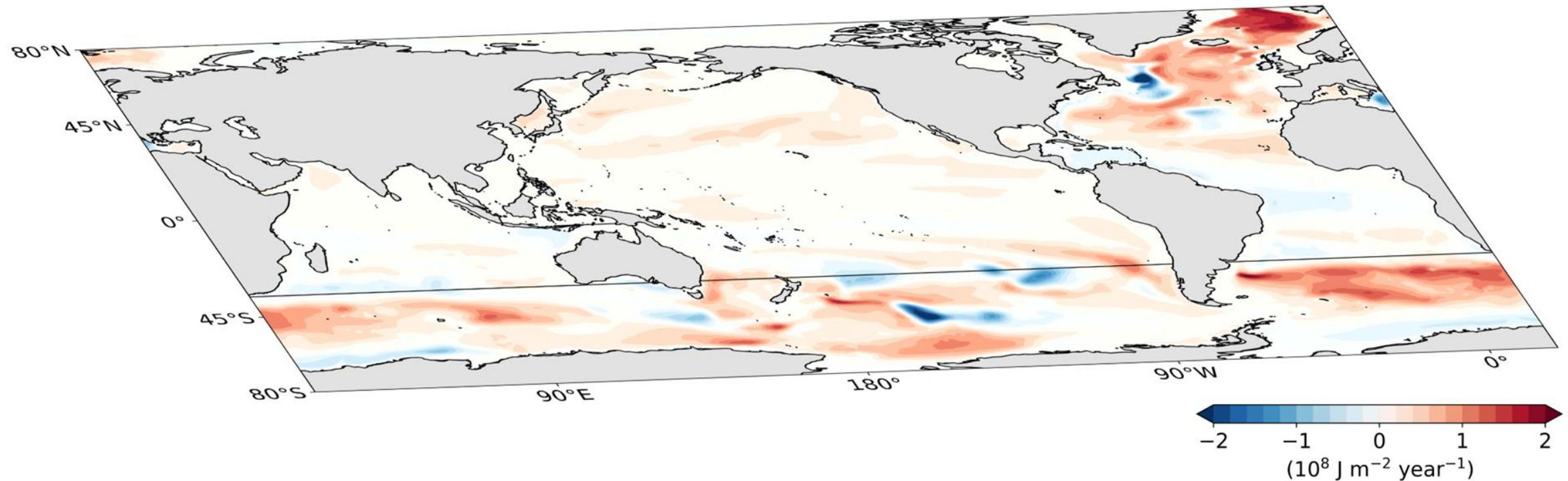


Global ocean heat content anomalies, 0-2000 m

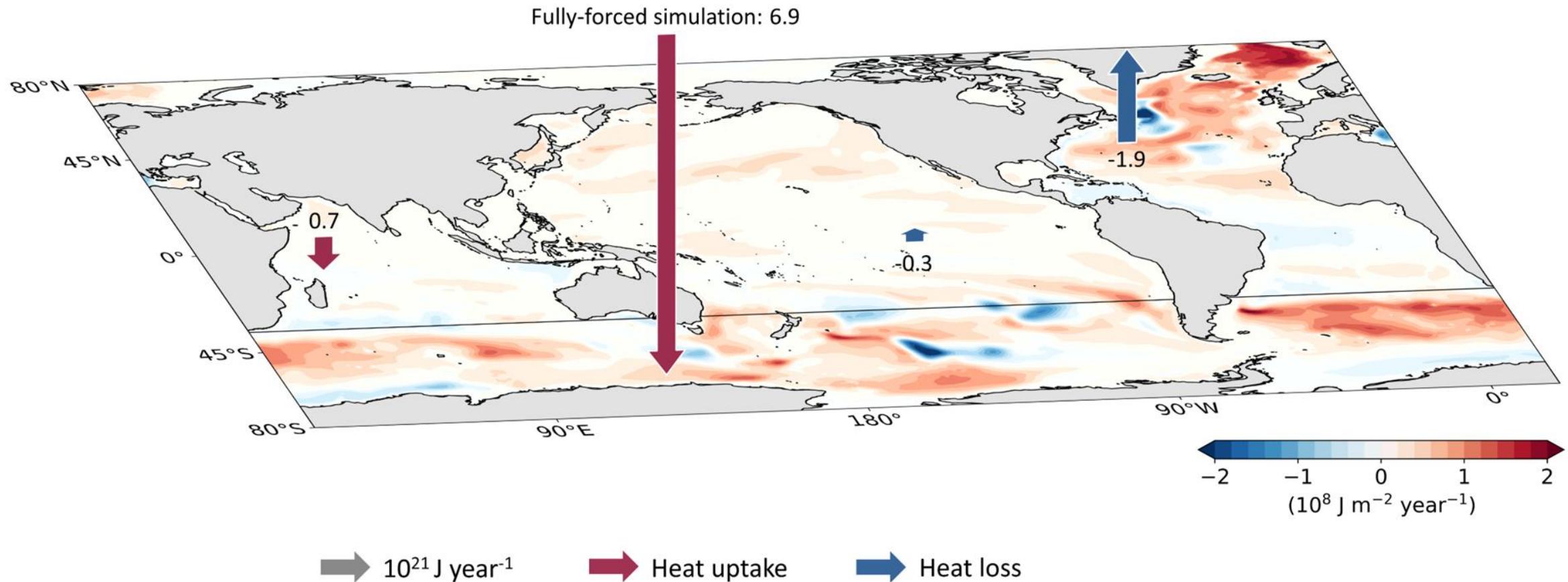


Schematic

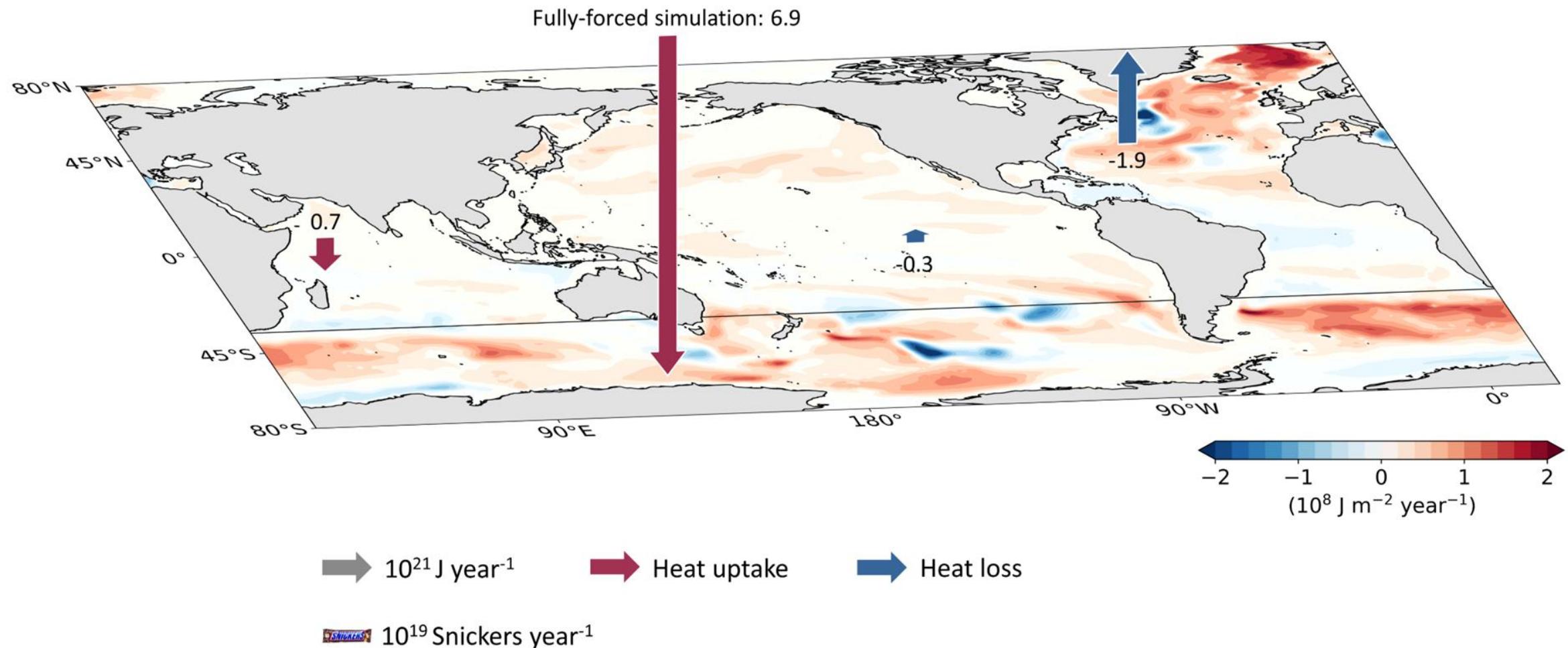
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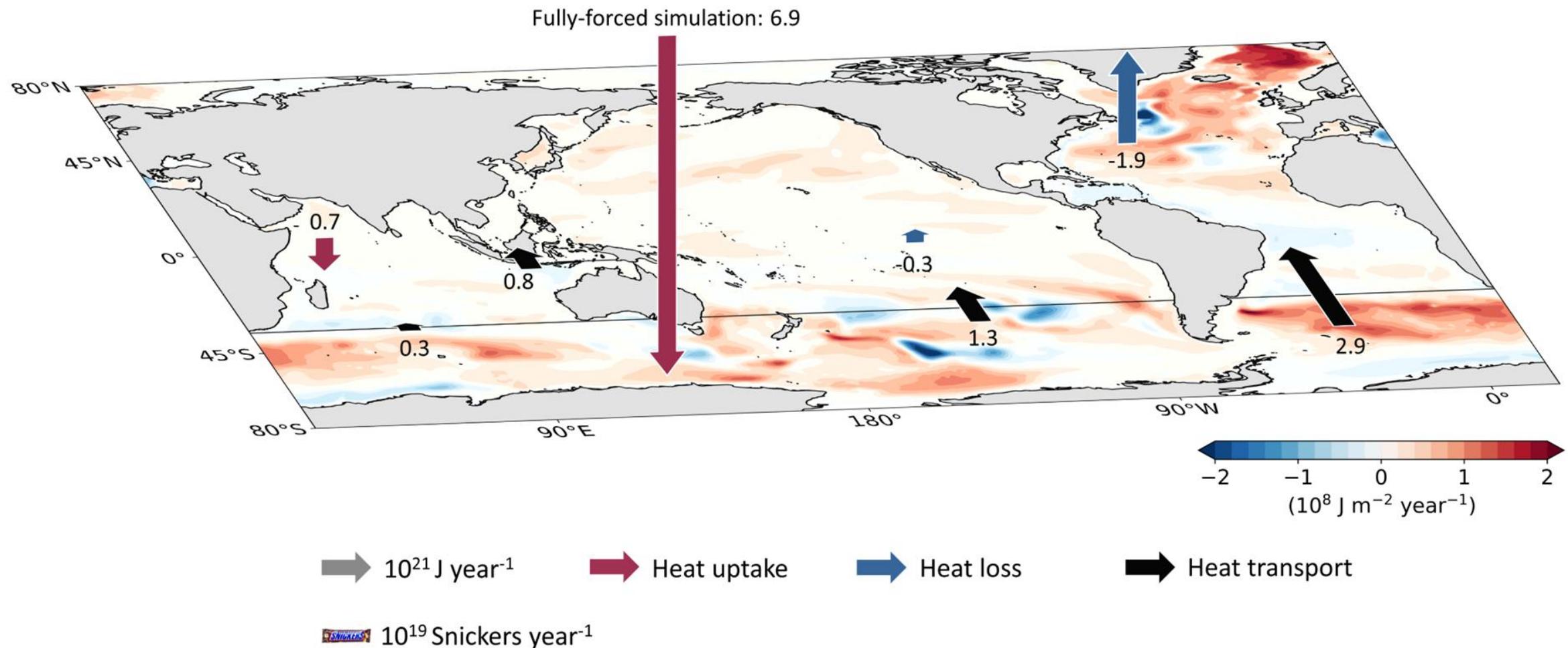
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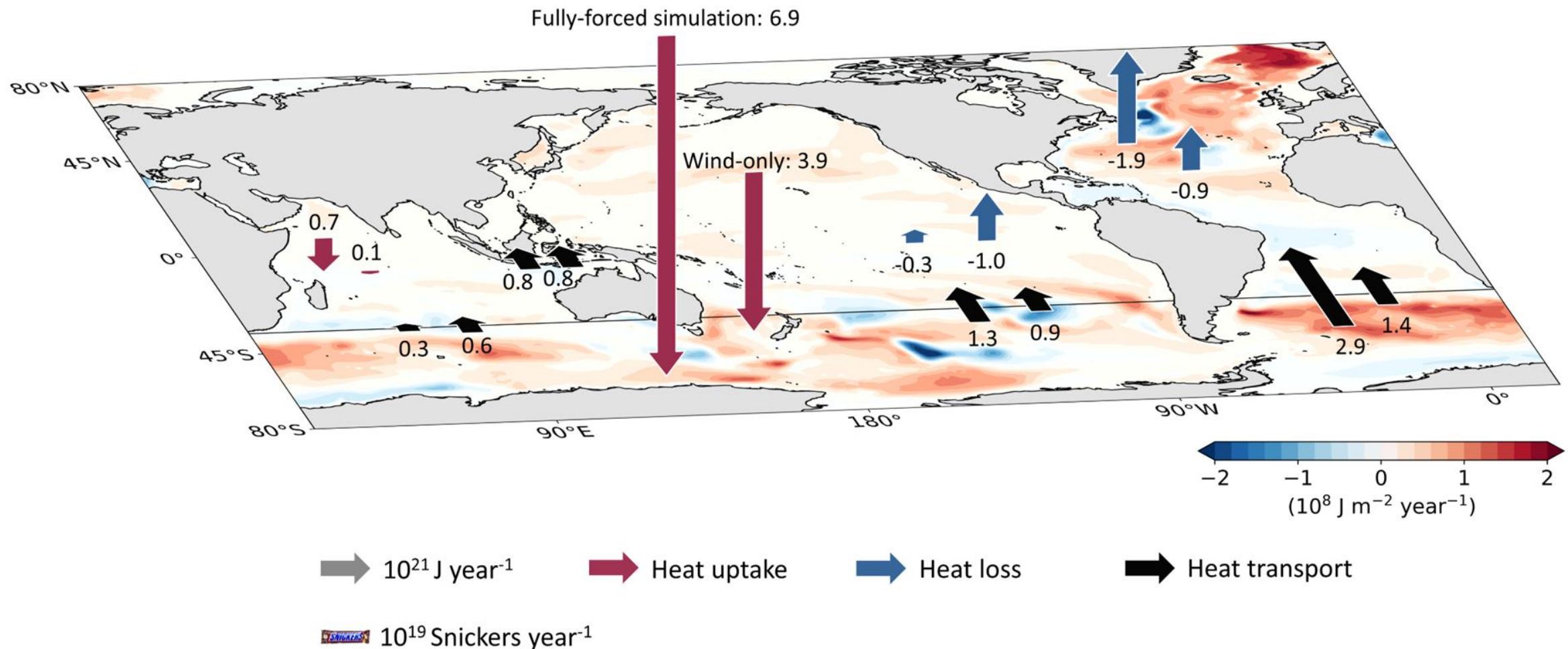
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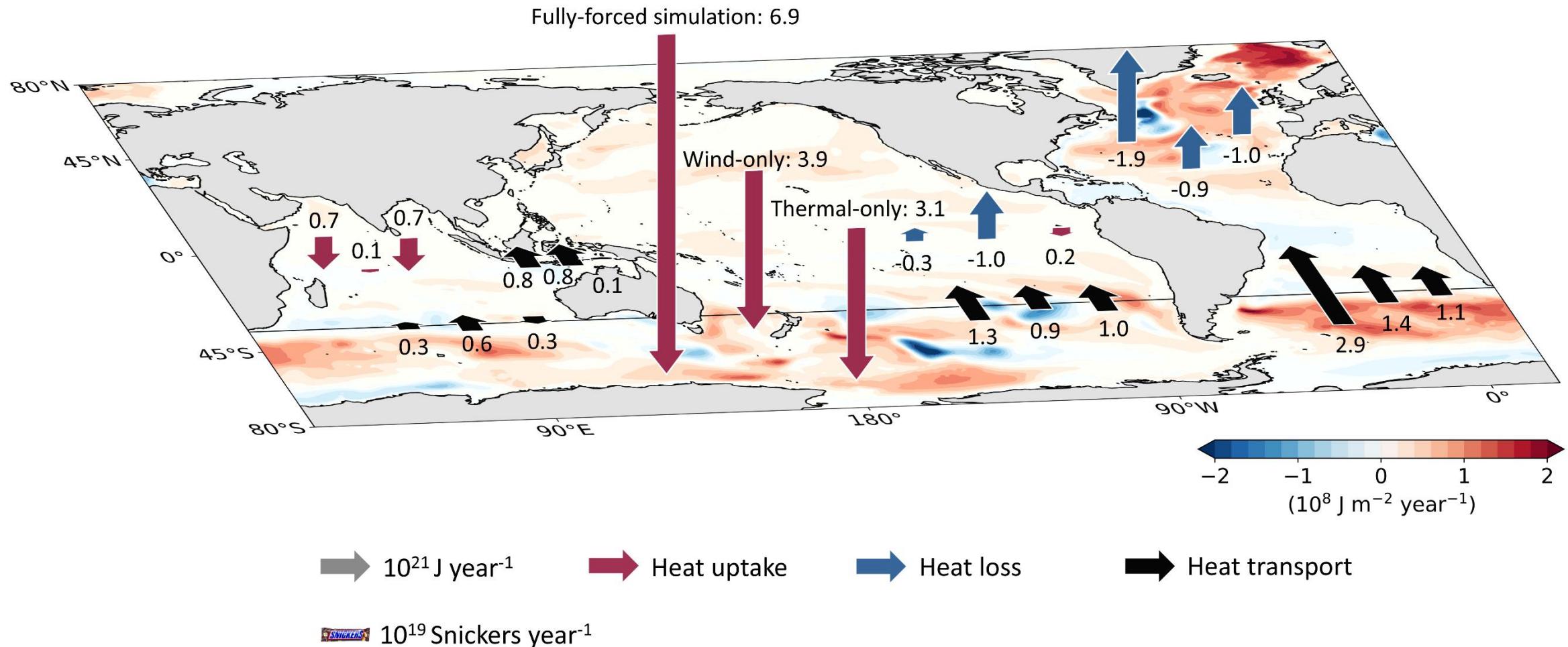
Schematic



Schematic



Schematic



7 April 2022

7 April 2022

```
rm -rf *
```

- deleted 12 TB of data
- everything from every project

7 April 2022

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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.

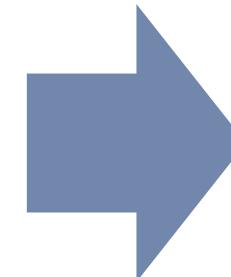
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[Menu](#)

THE CONVERSATION



Shutterstock

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

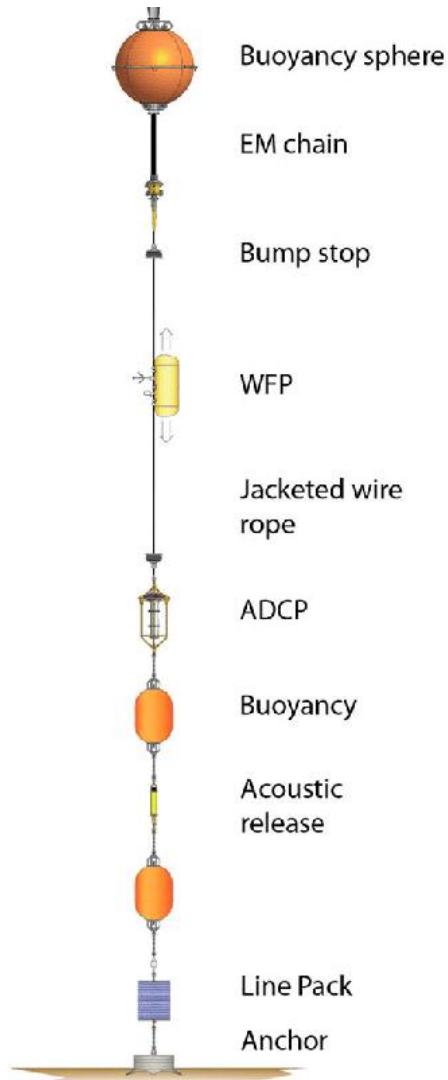
Published: September 7, 2022 7.18pm AEST

 Maurice Huguenin, UNSW Sydney, Matthew England, UNSW Sydney, Ryan Holmes, University of Sydney 46,342  0   

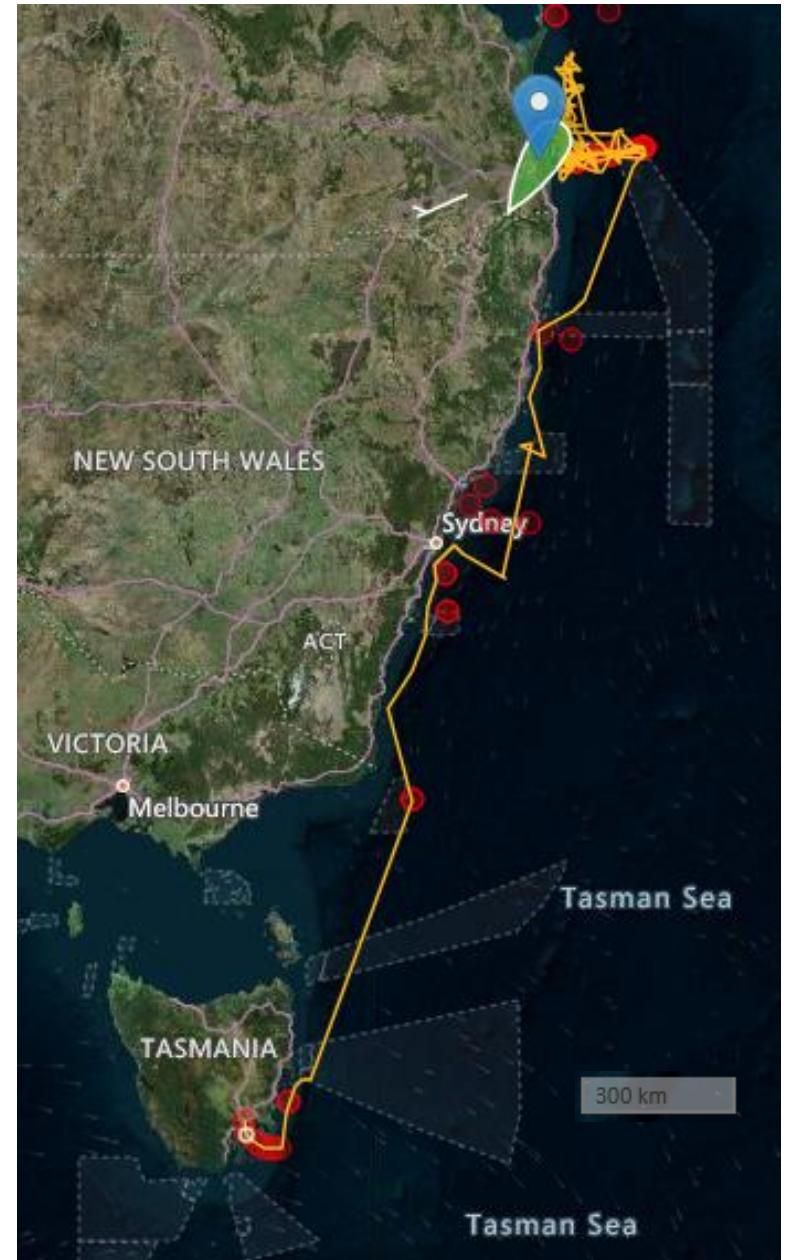
Cruise break



Cruise break



Thanks Amandine Schaeffer,
Chris Chapman & Iain Suthers





ACEAS

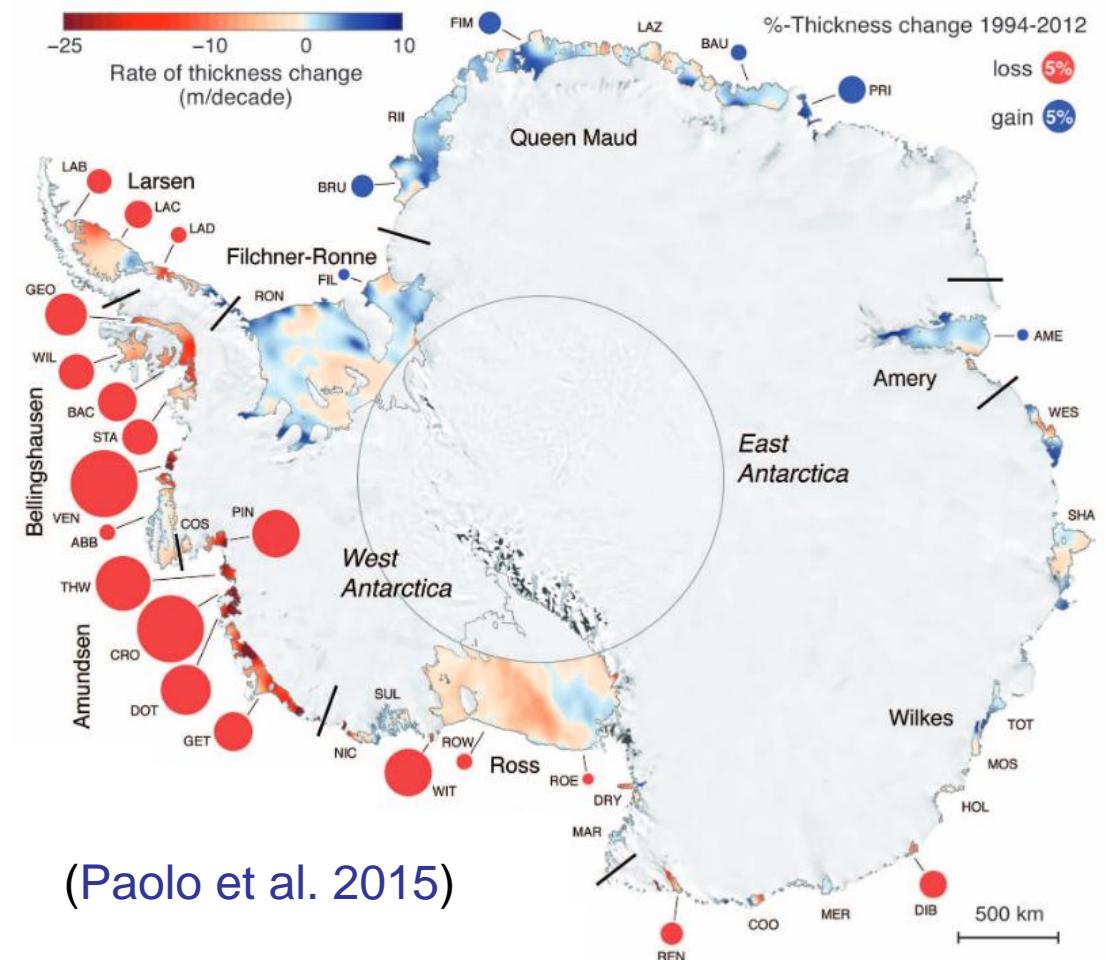
Australian Centre for Excellence
in Antarctic Science

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

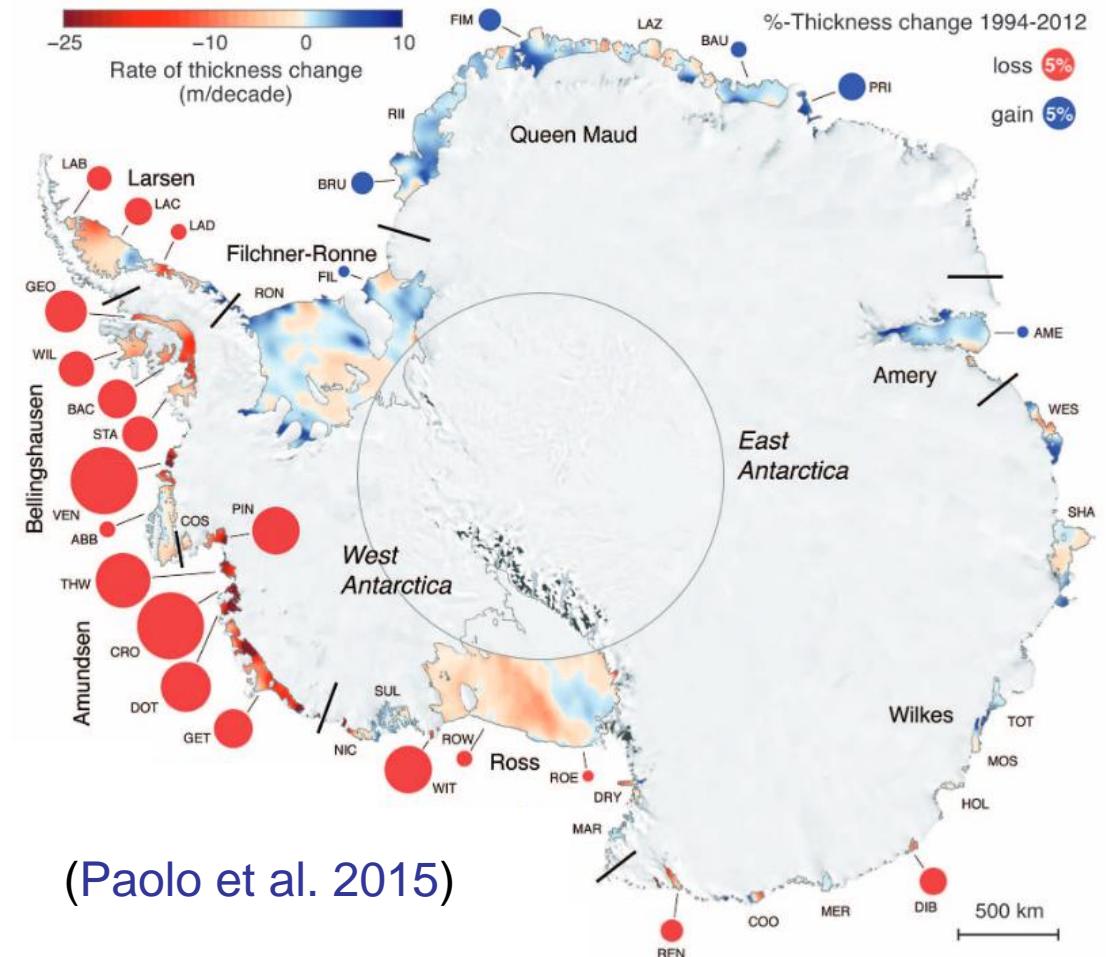
Geophysical Research Letters

Background



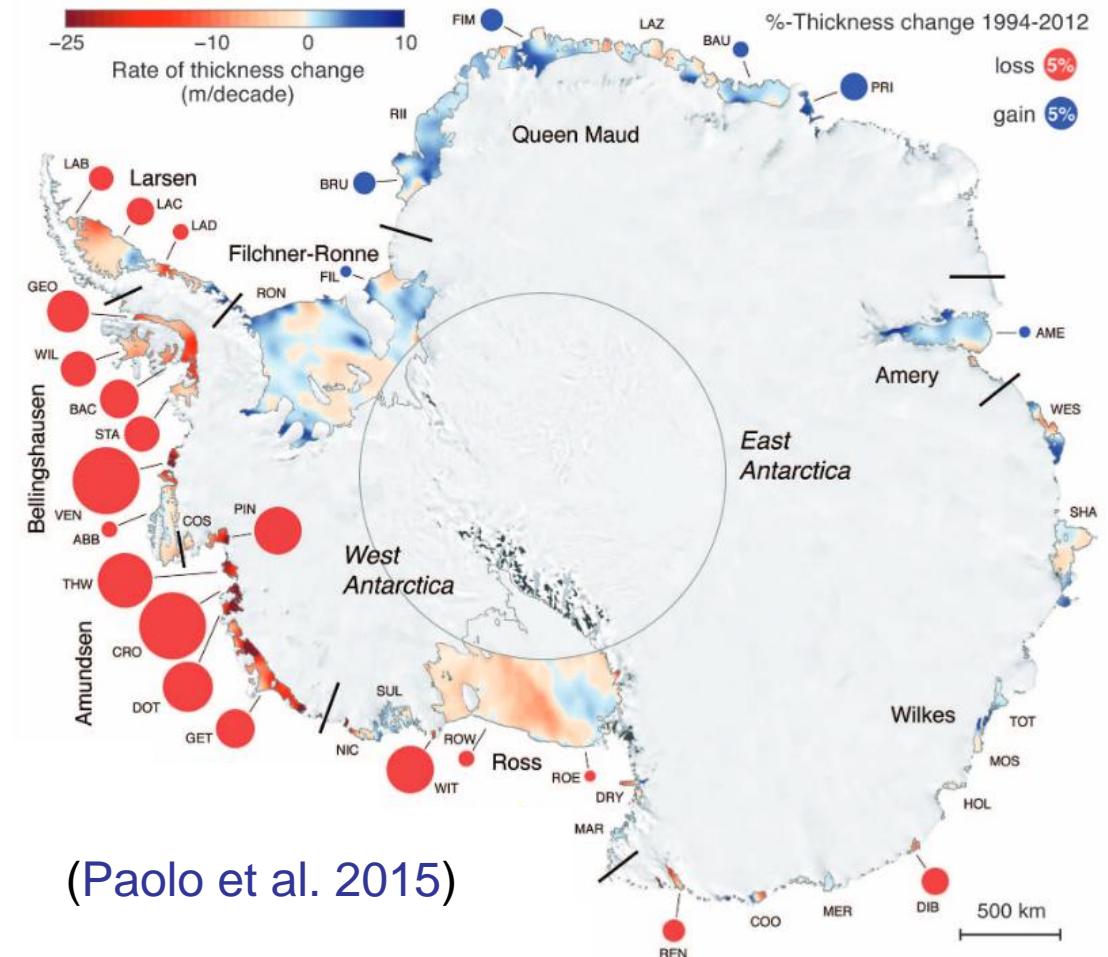
Background

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



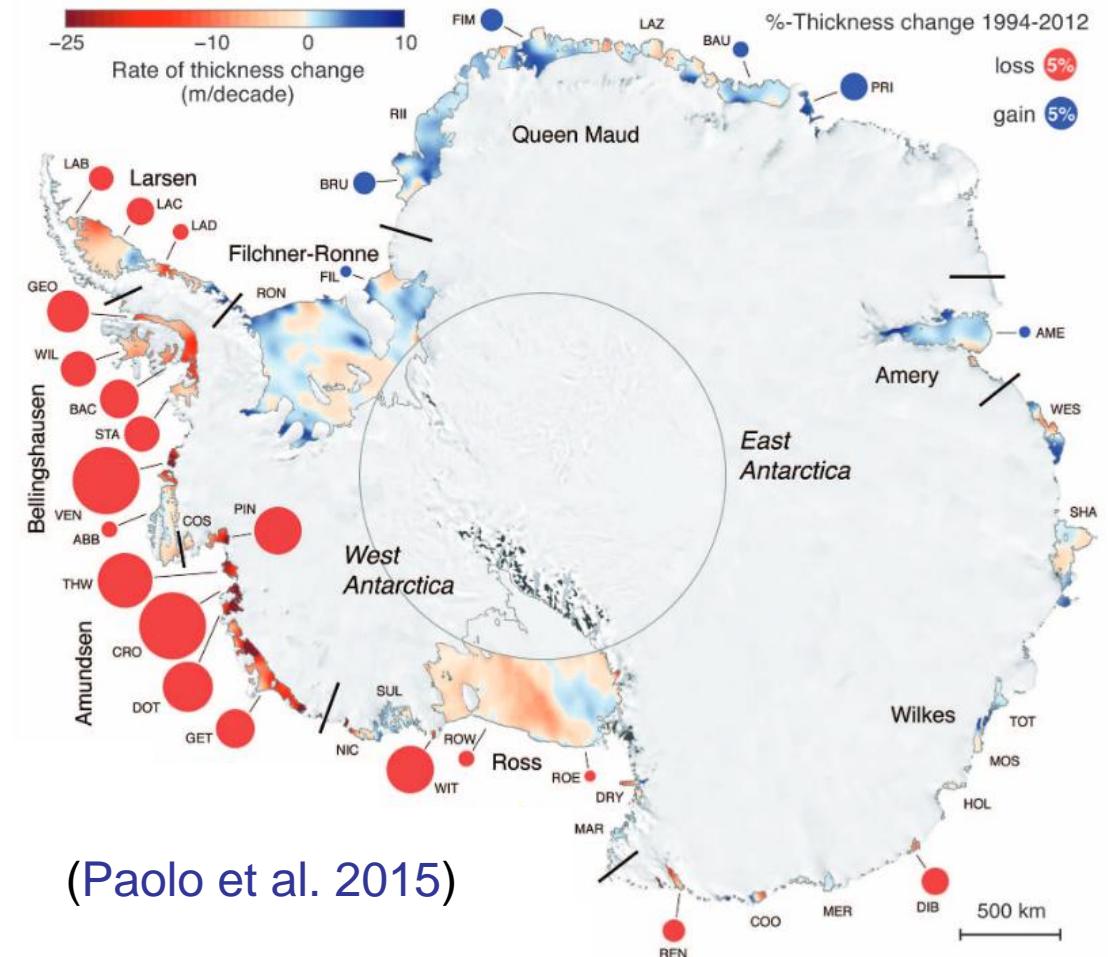
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- Volume loss from Antarctic ice shelves is accelerating ([Paolo et al. 2015](#))
- Ice loss influenced by internal climate variability and anthropogenic forcing ([Holland et al. 2019](#))



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

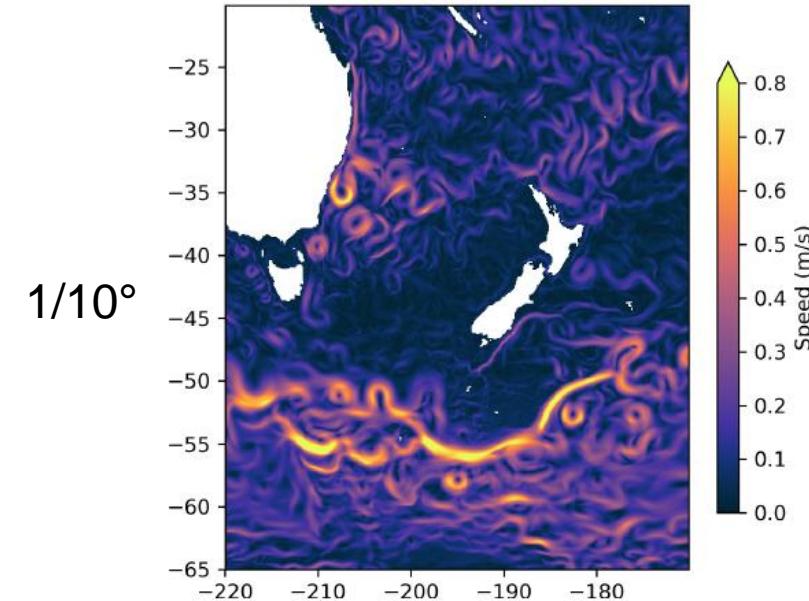
- How do El Niño & La Niña impact the West Antarctic shelf circulation?
- What processes are responsible for warming and cooling on the shelf?

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]

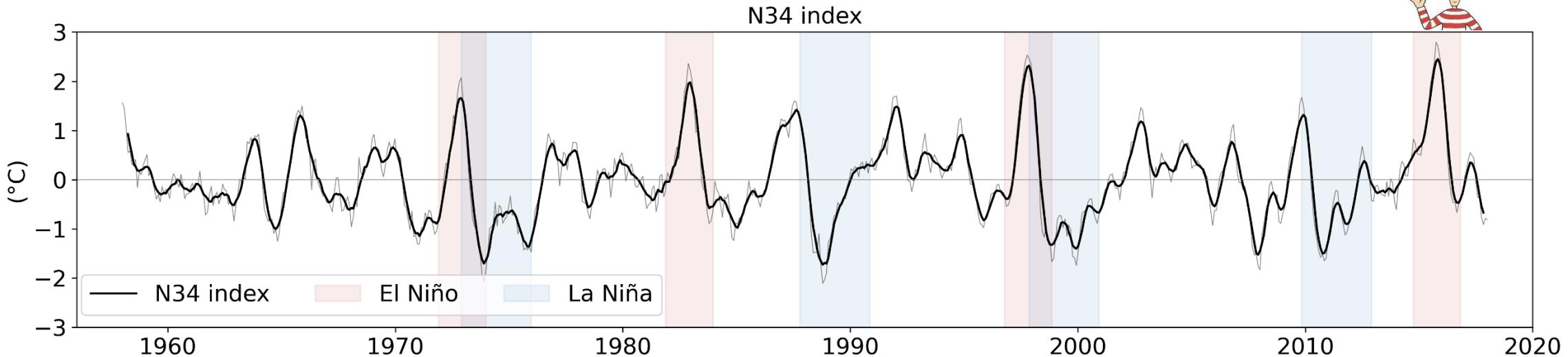
Forcing for the idealised simulations

Repeat-year forcing [t, x, y]

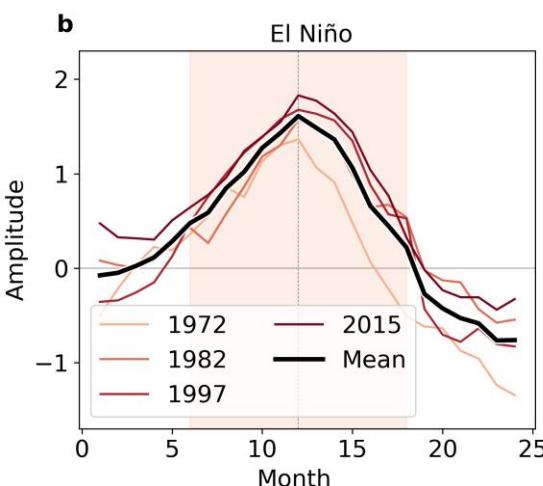
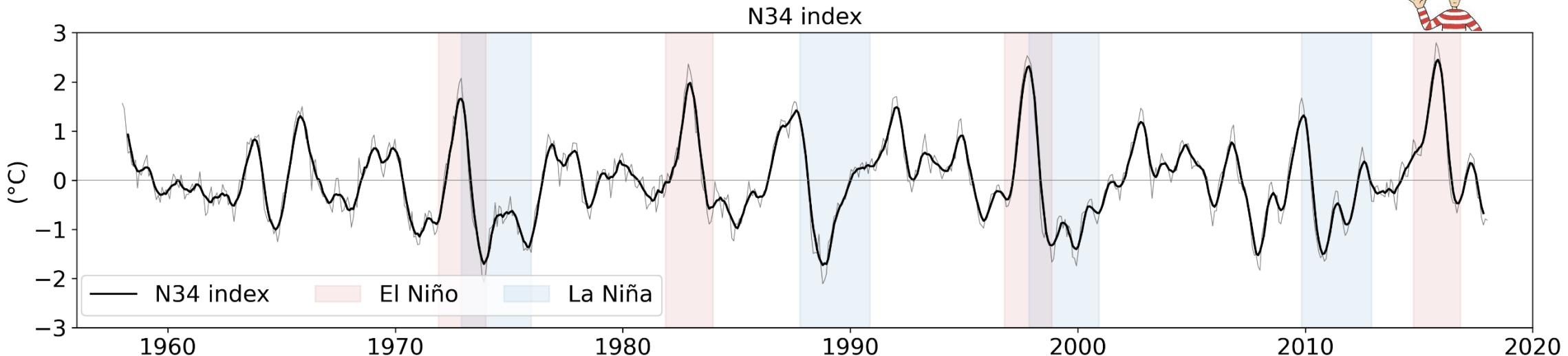
+

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

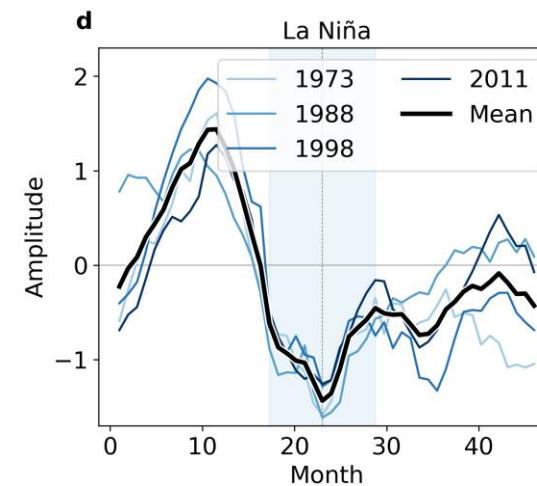
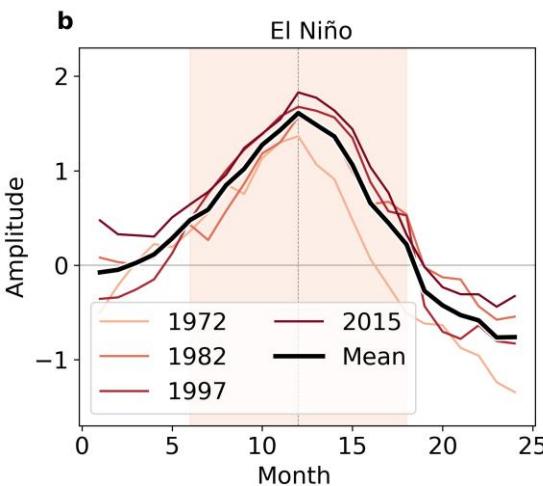
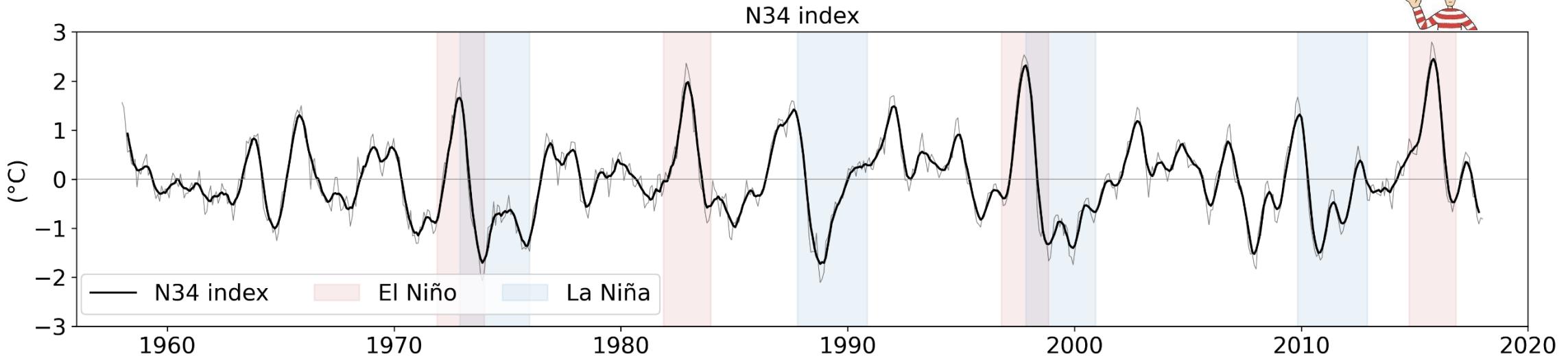
Forcing for the idealised simulations



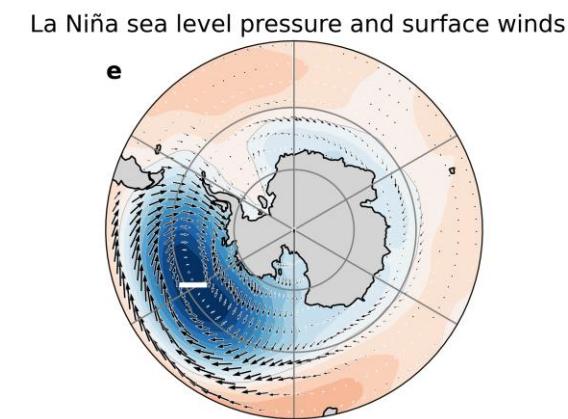
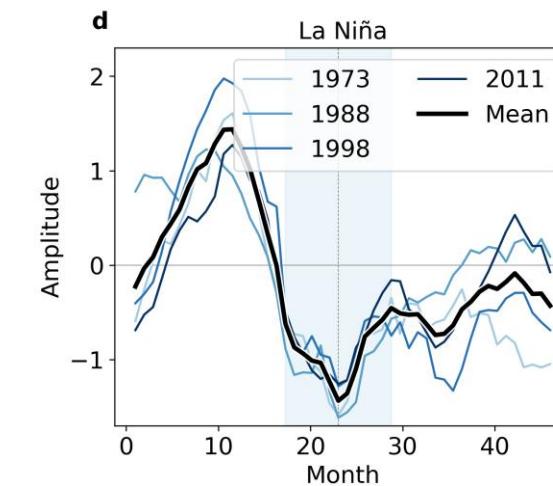
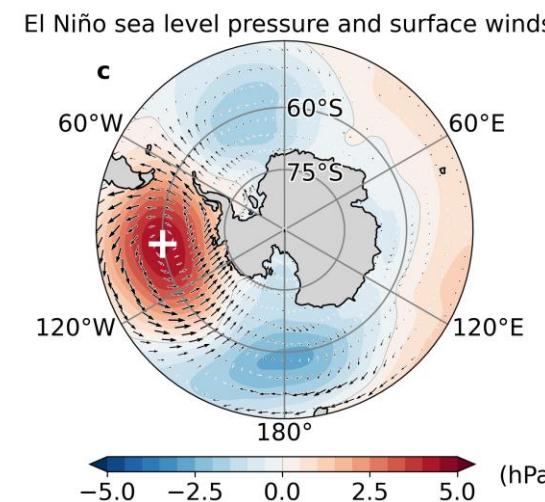
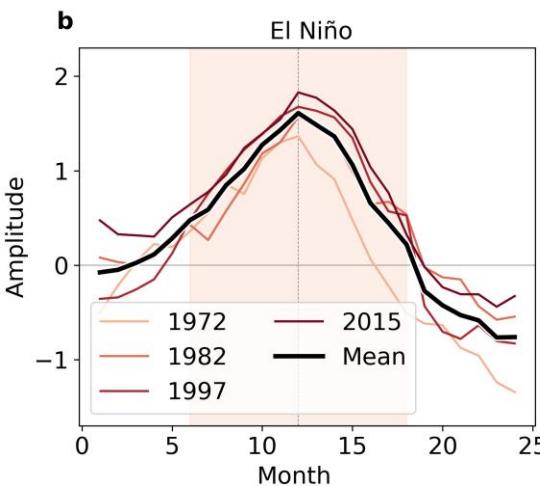
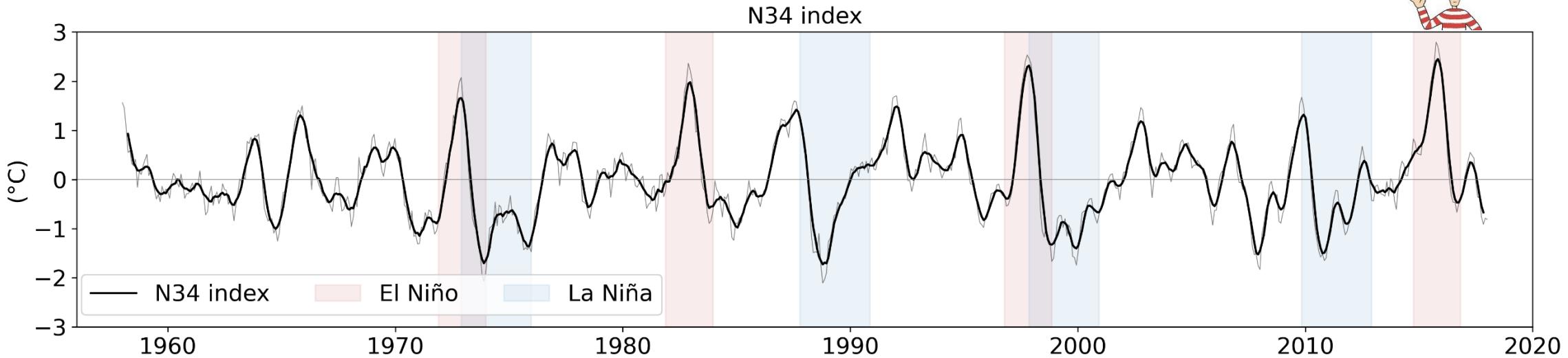
Forcing for the idealised simulations



Forcing for the idealised simulations

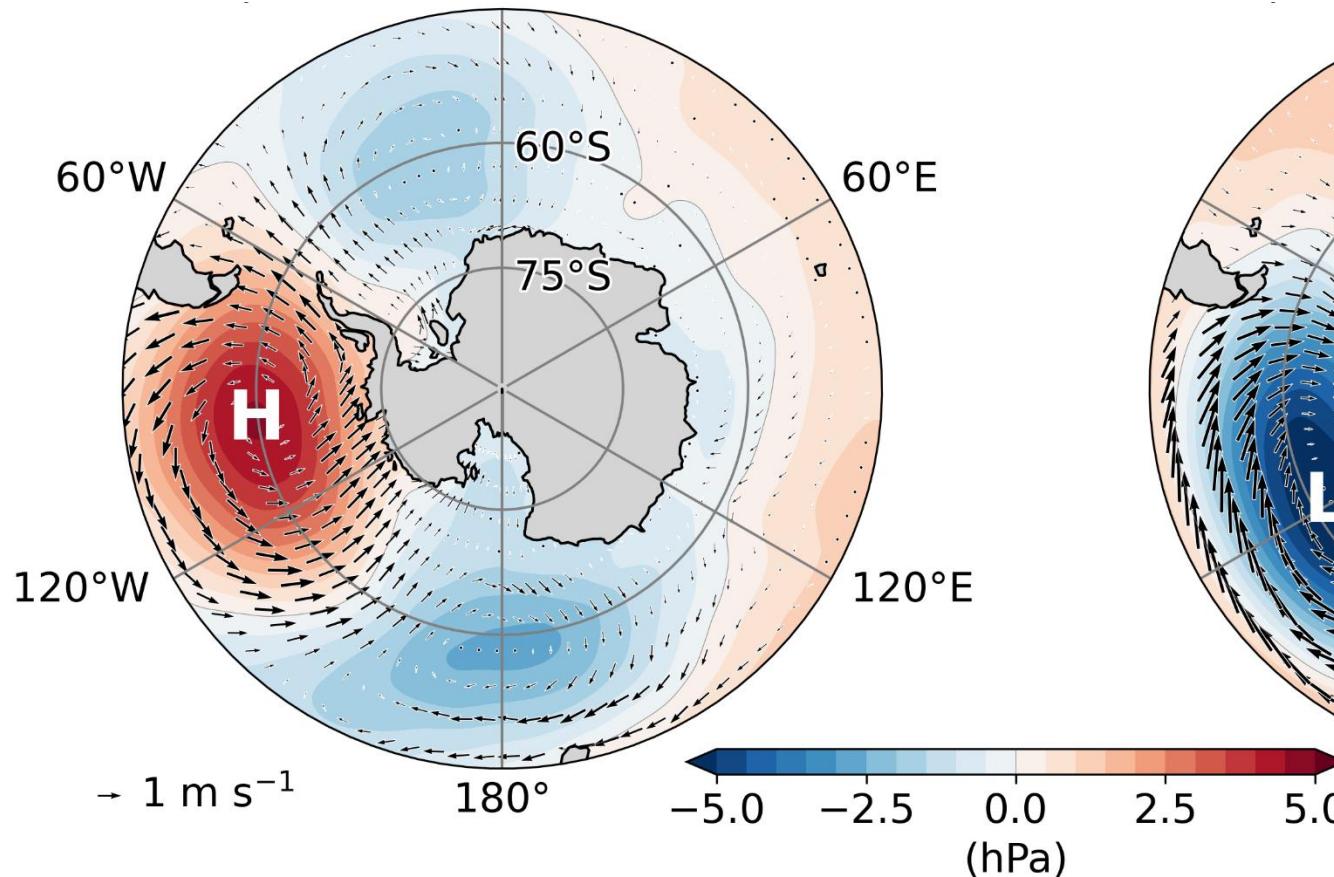


Forcing for the idealised simulations

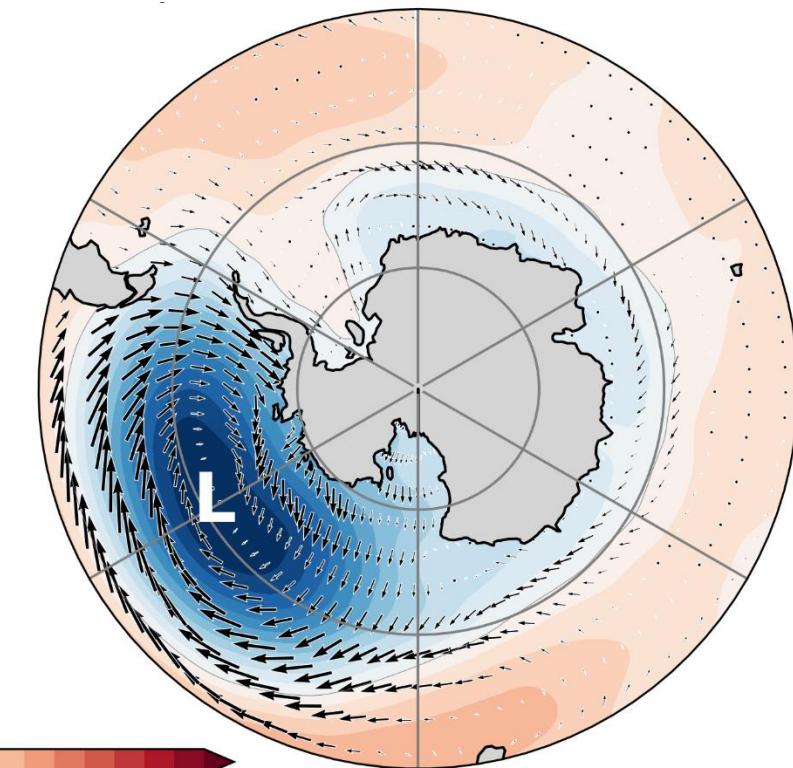


Forcing for the idealised simulations

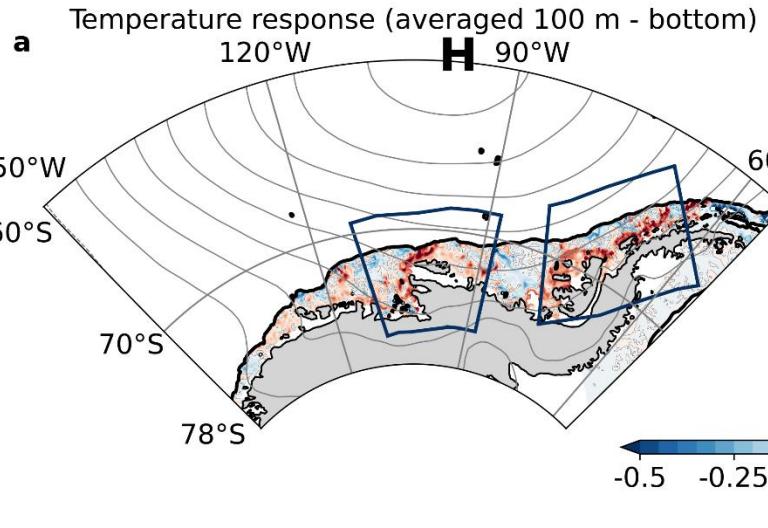
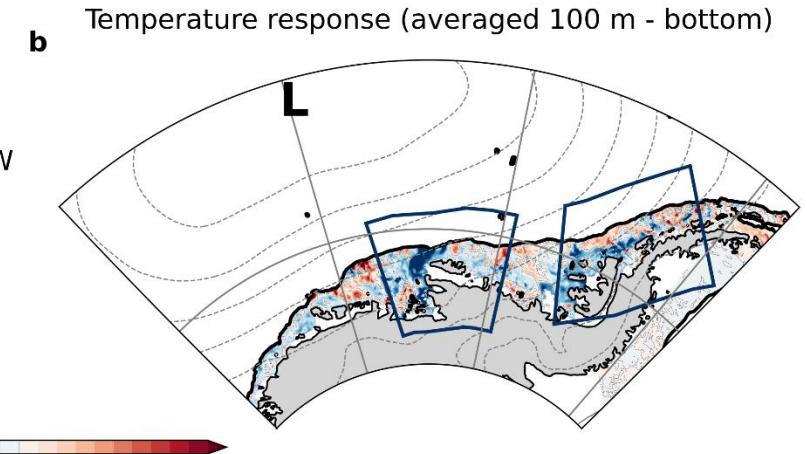
El Niño sea level pressure and surface winds



La Niña



Shelf response to ENSO forcing

El Niño simulation**La Niña simulation**

isopycnals

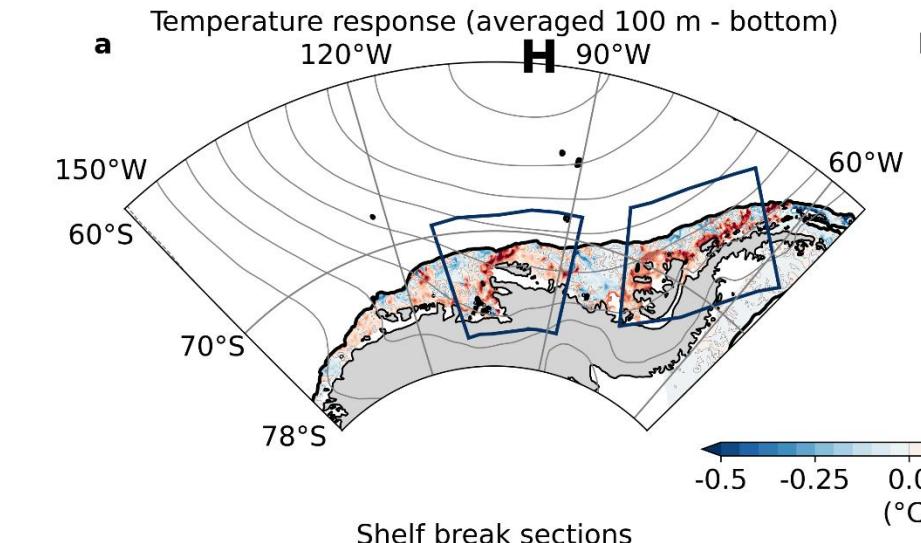
0°C isotherm

Shelf response to ENSO forcing

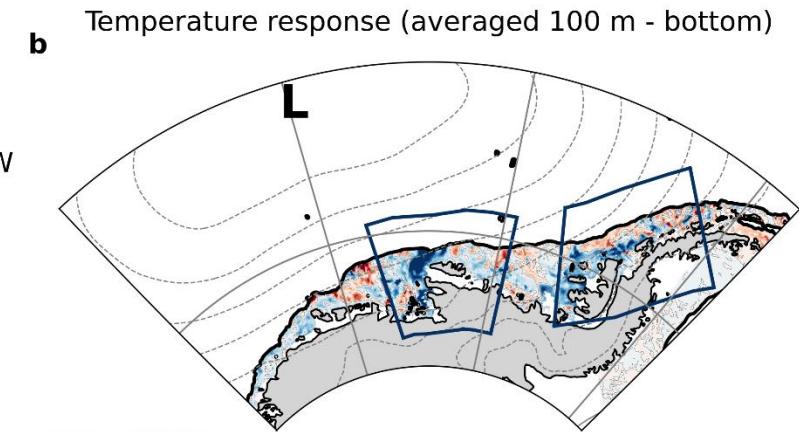
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0°C isotherm

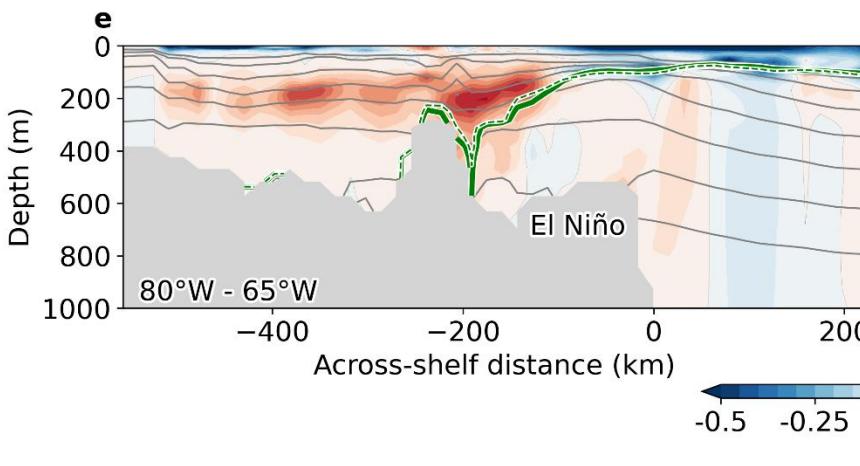
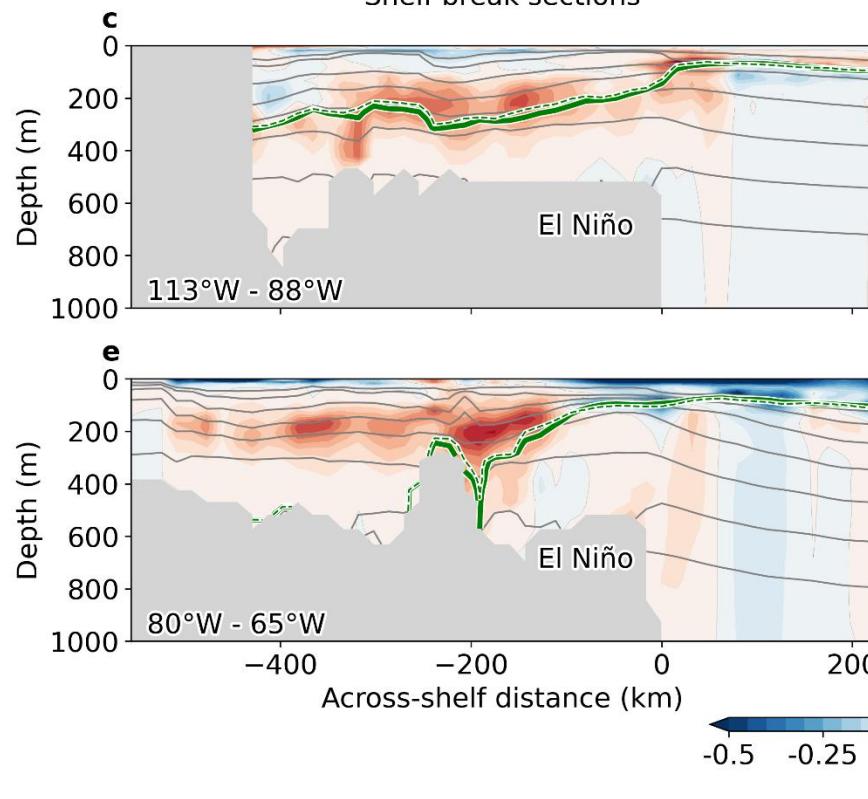
El Niño simulation



La Niña simulation



Shelf break sections

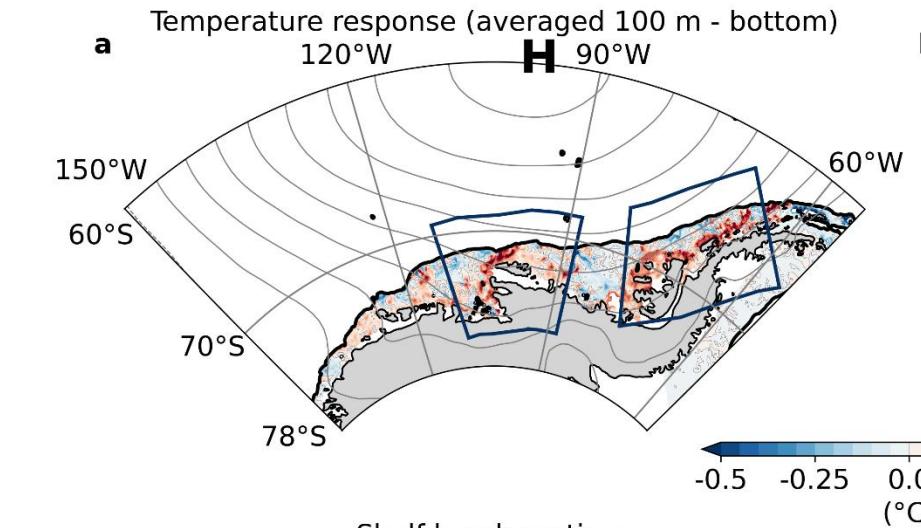


Shelf response to ENSO forcing

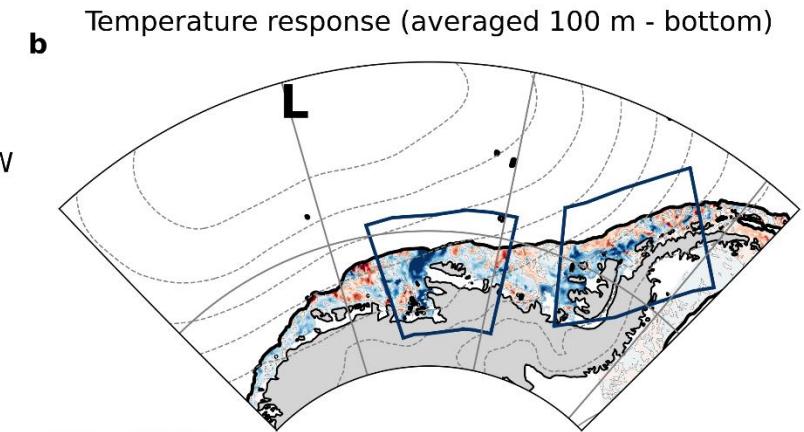
isopycnals

0°C isotherm

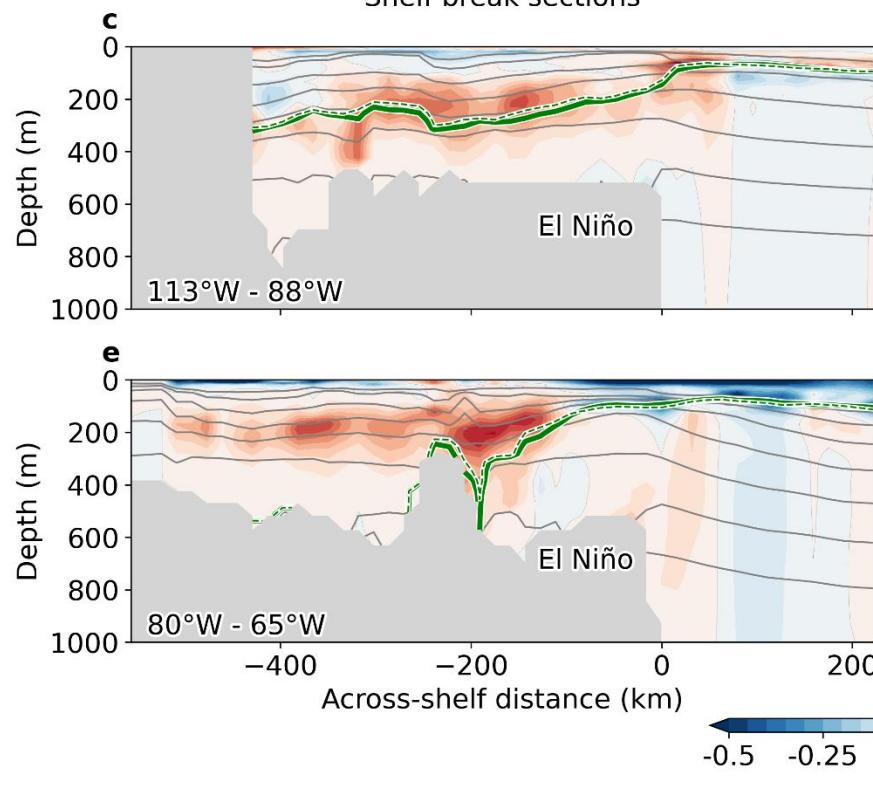
El Niño simulation



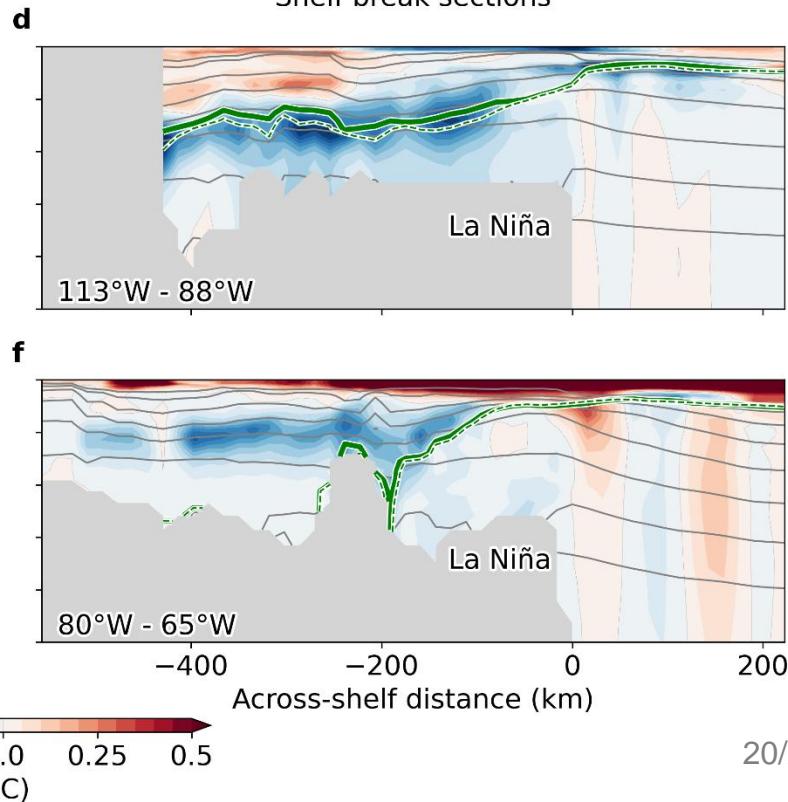
La Niña simulation



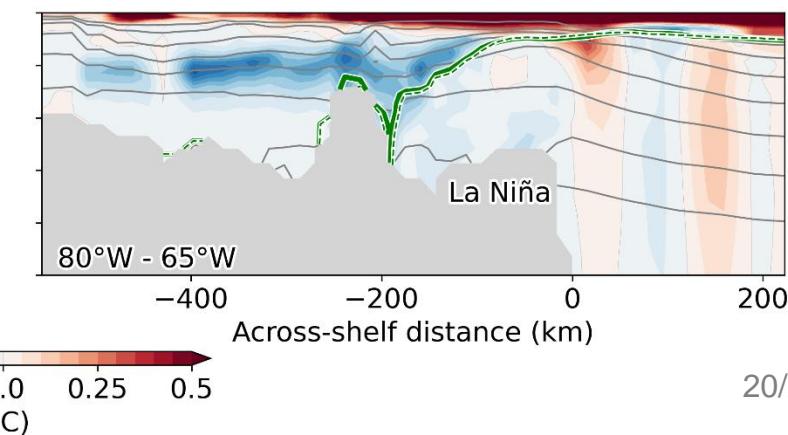
Shelf break sections



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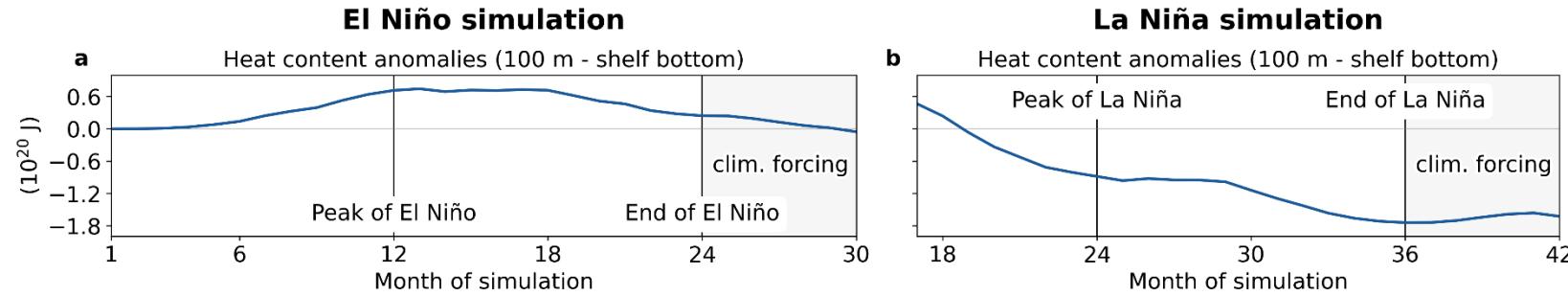


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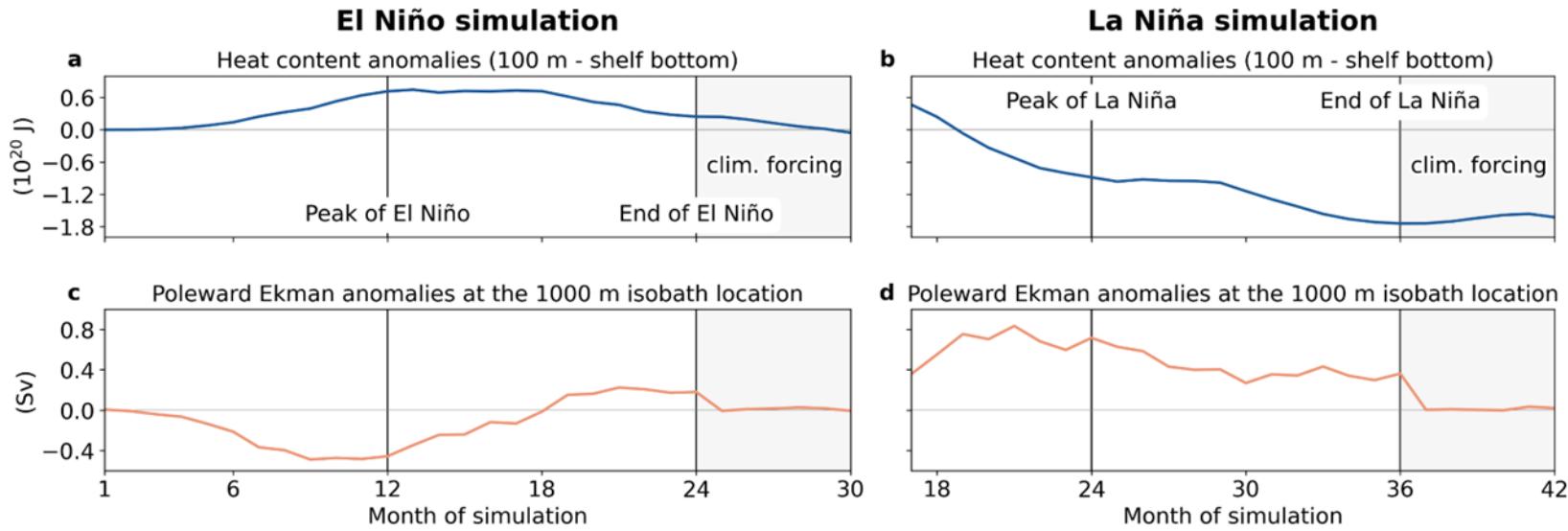
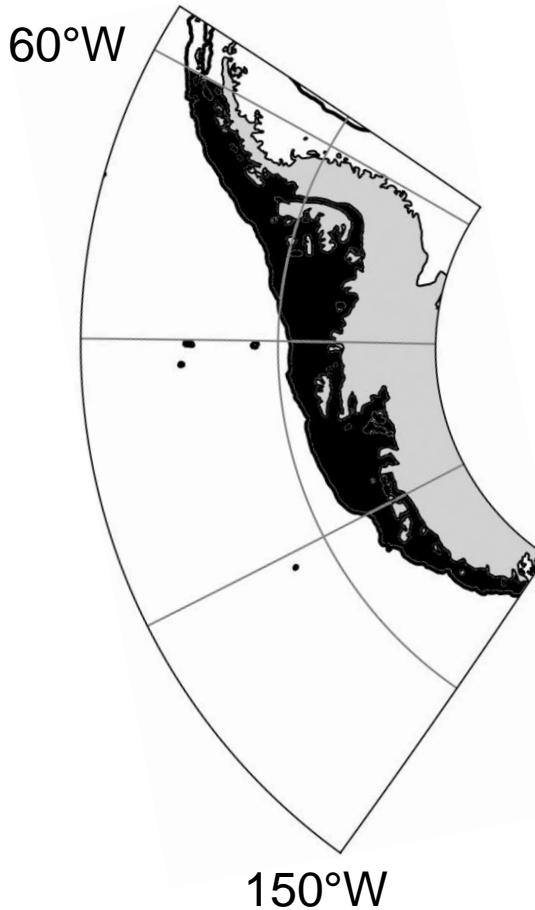


The subsurface heat budget

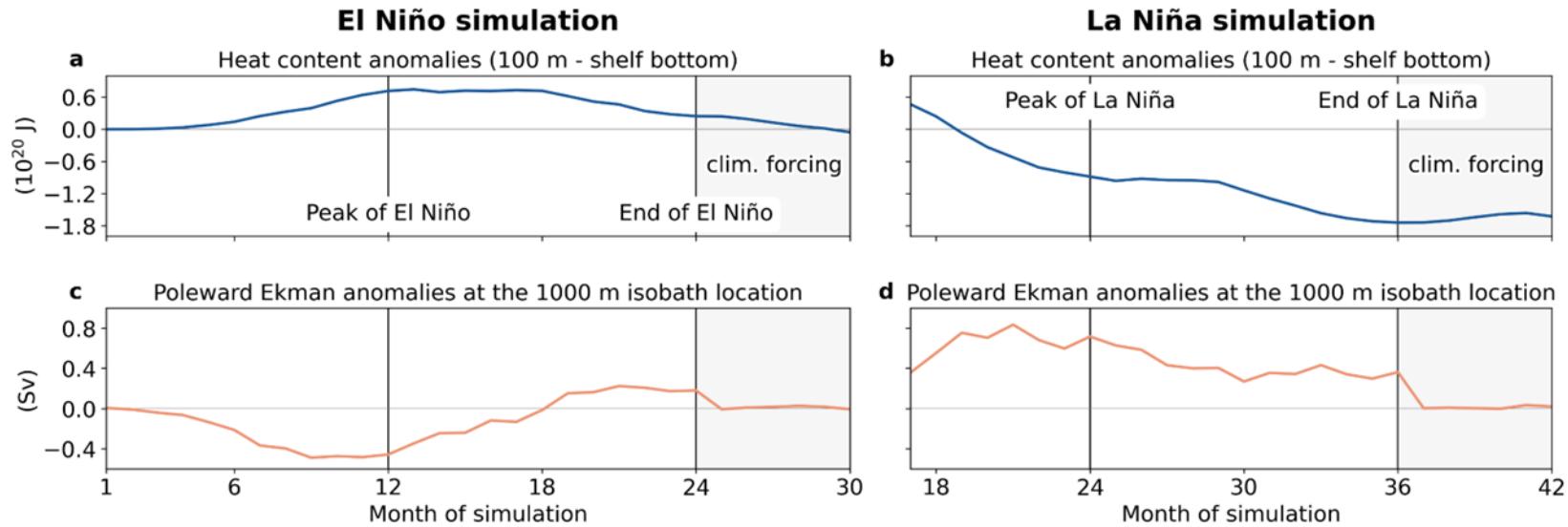
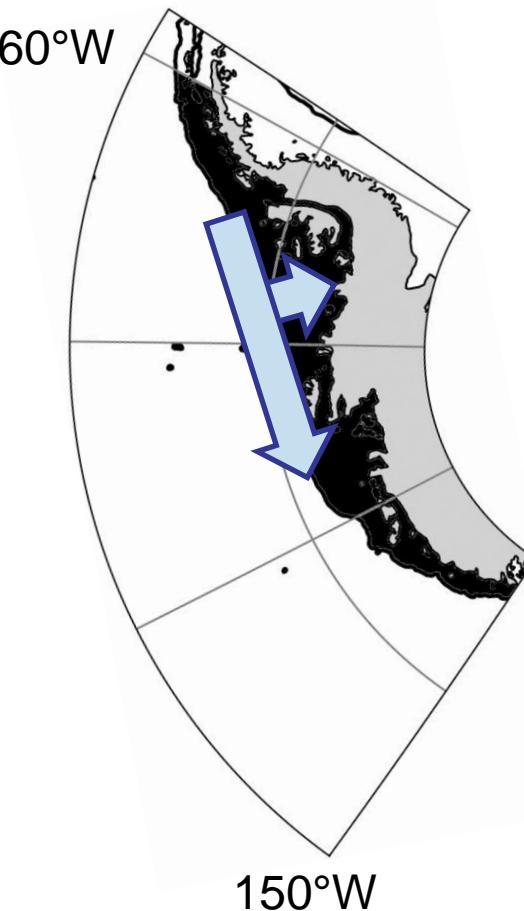
The subsurface heat budget



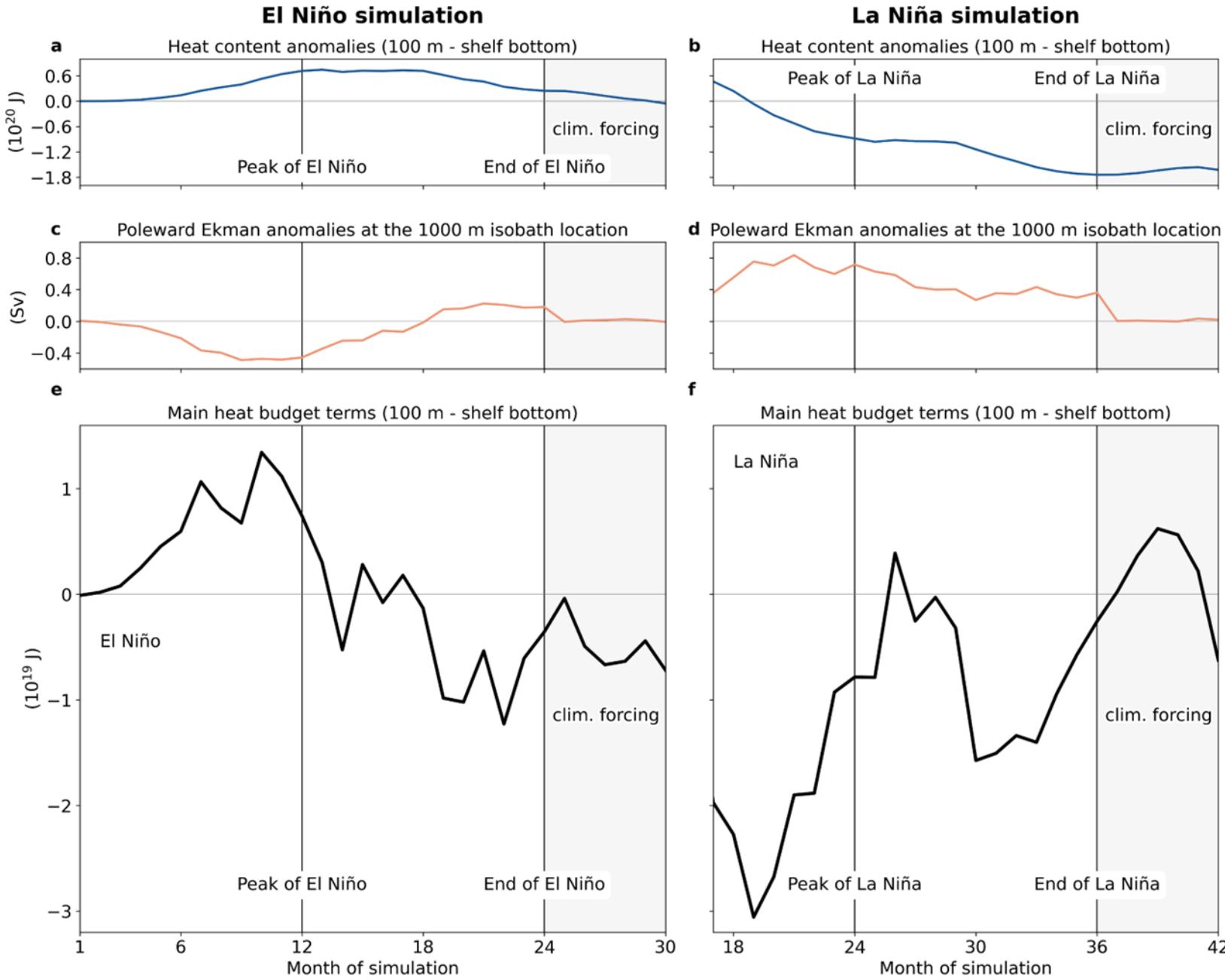
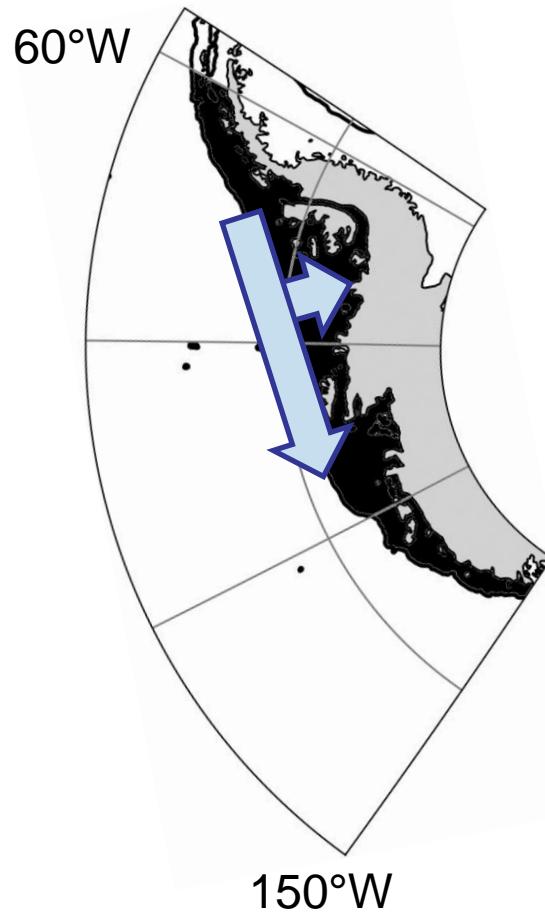
The subsurface heat budget



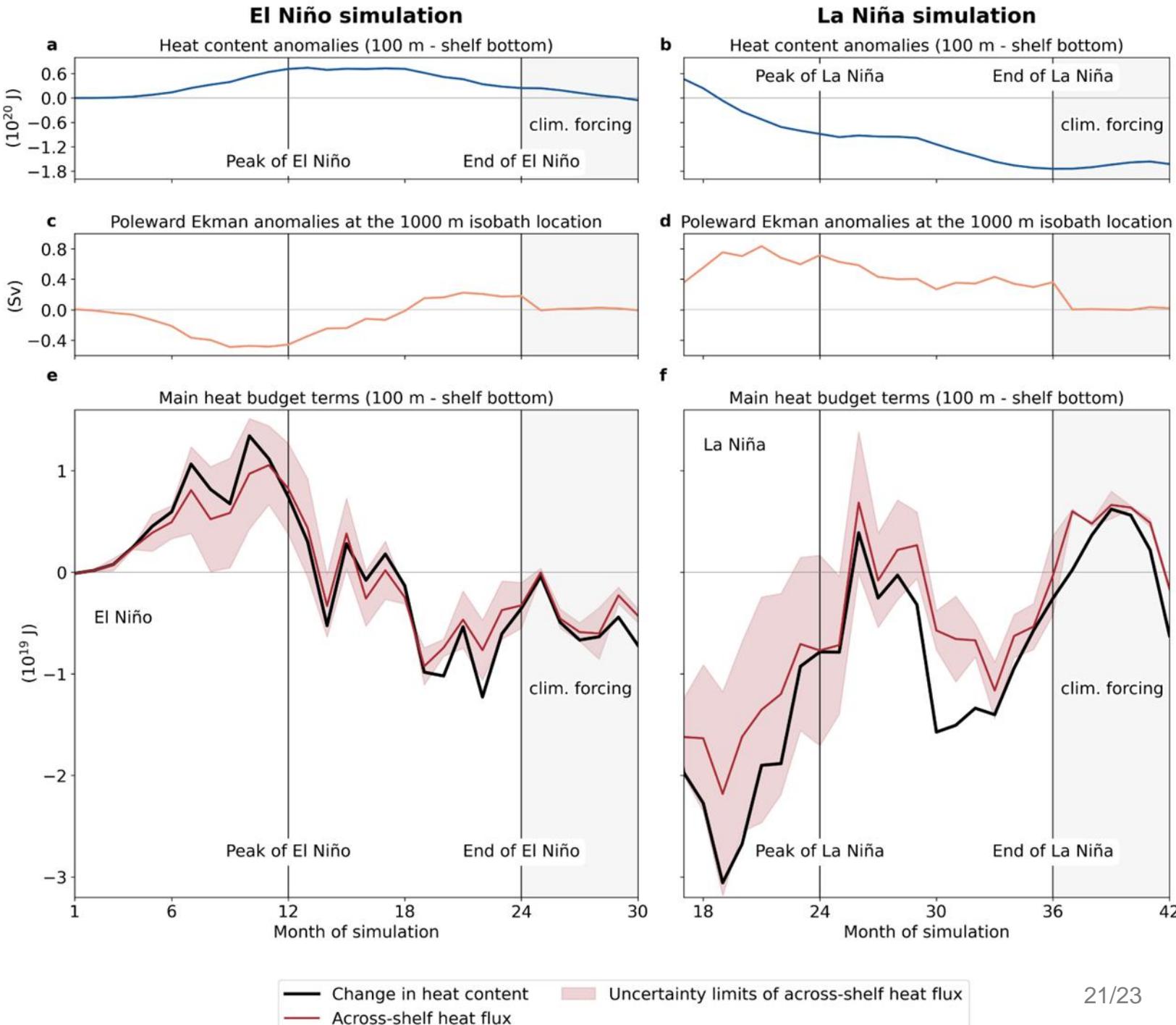
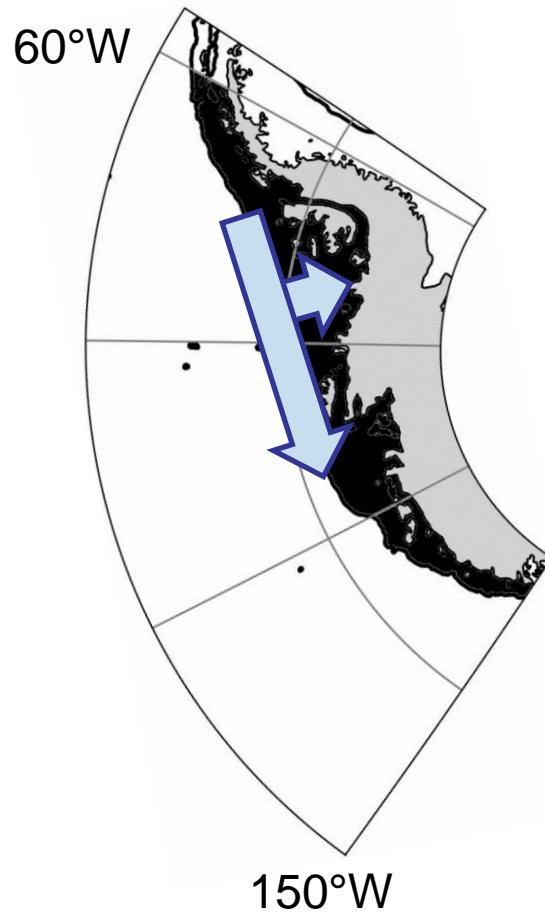
The subsurface heat budget



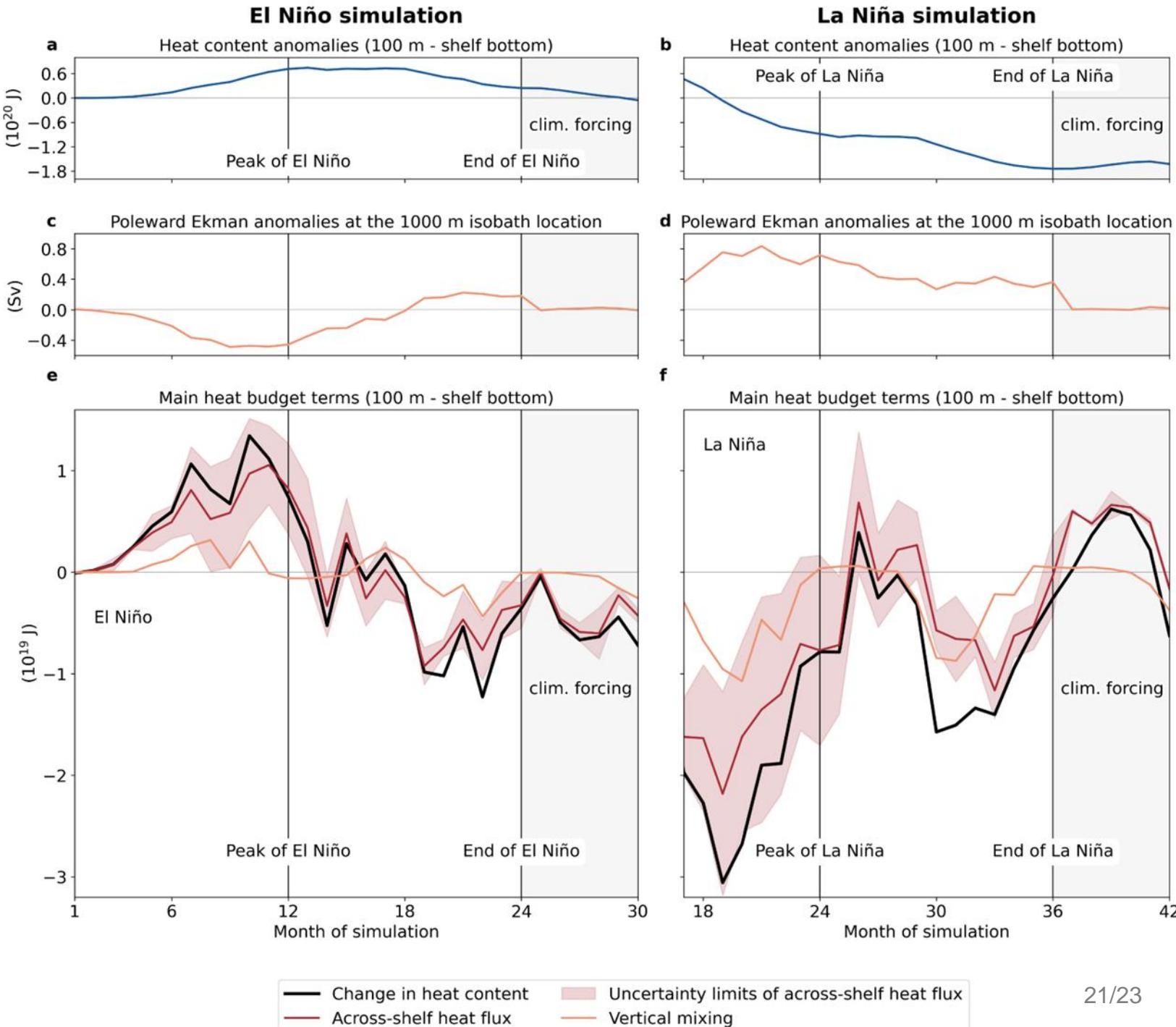
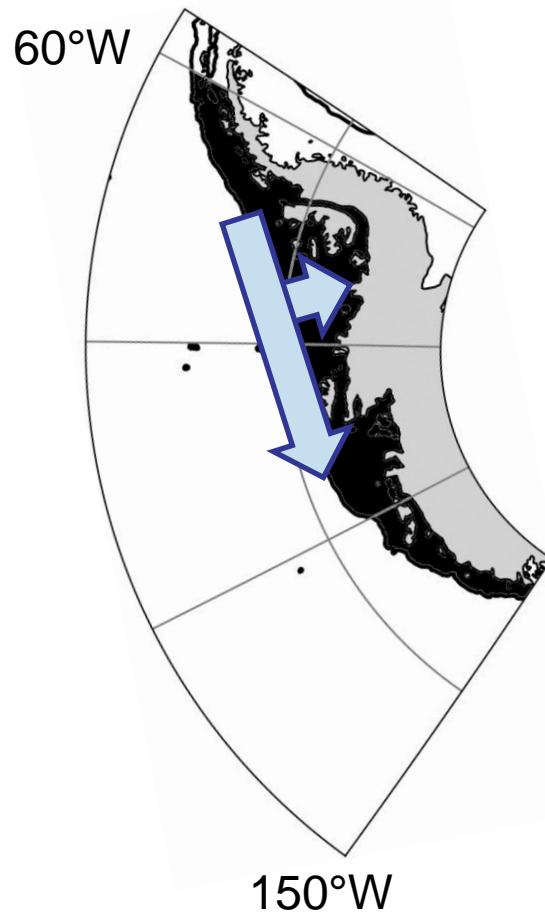
The subsurface heat budget



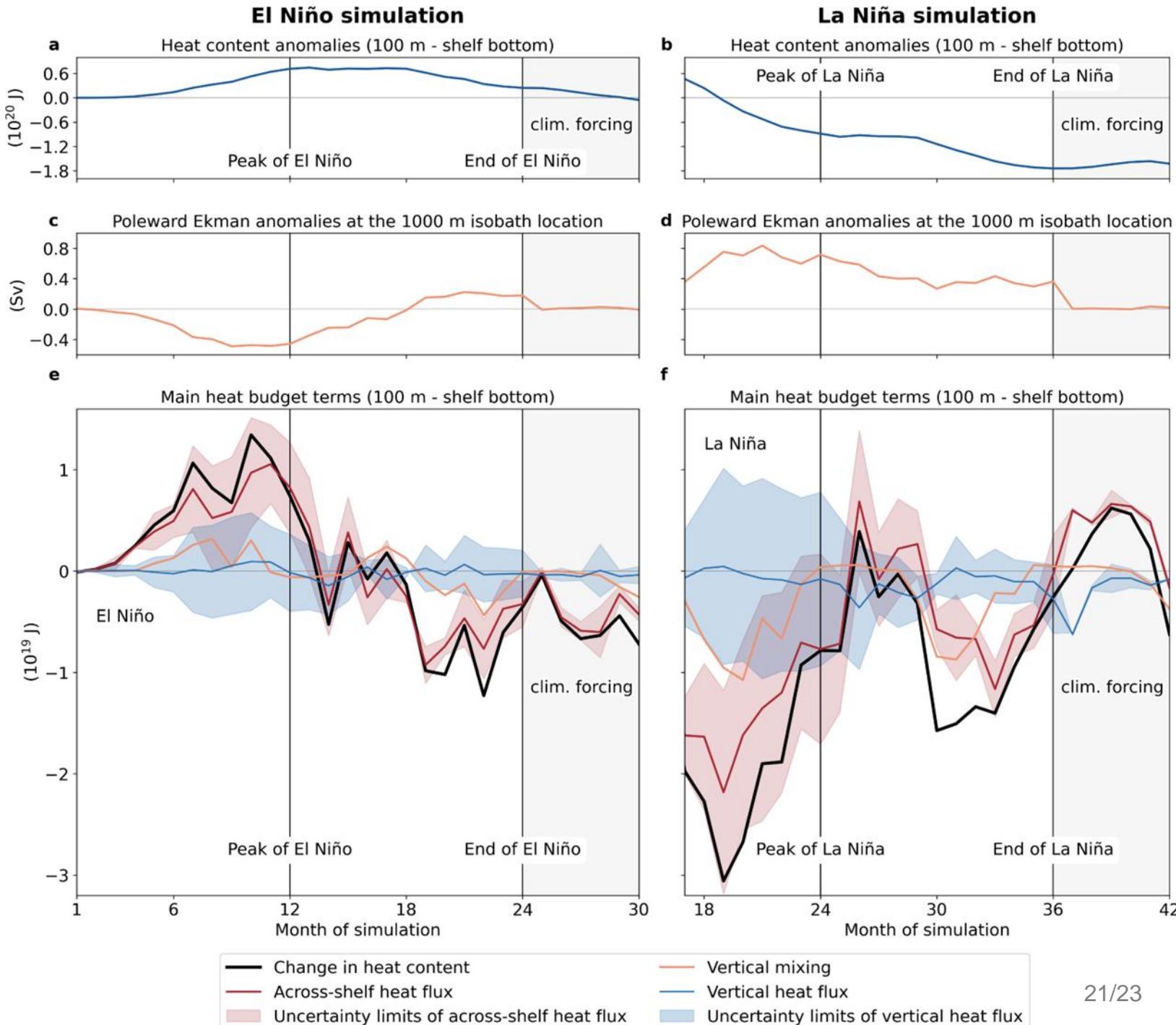
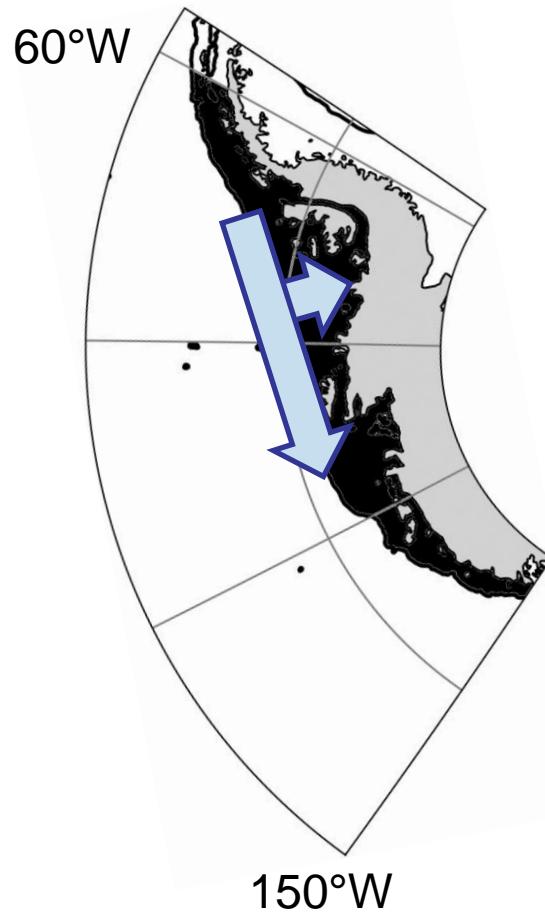
The subsurface heat budget



The subsurface heat budget



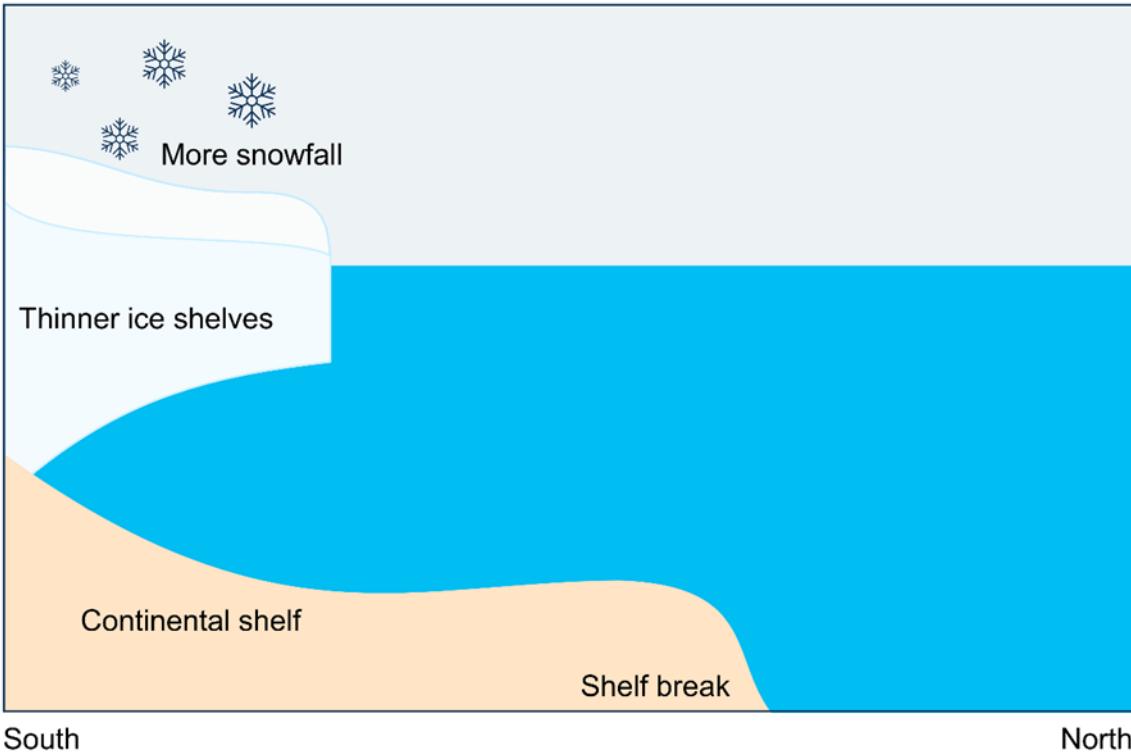
The subsurface heat budget



Schematic

a

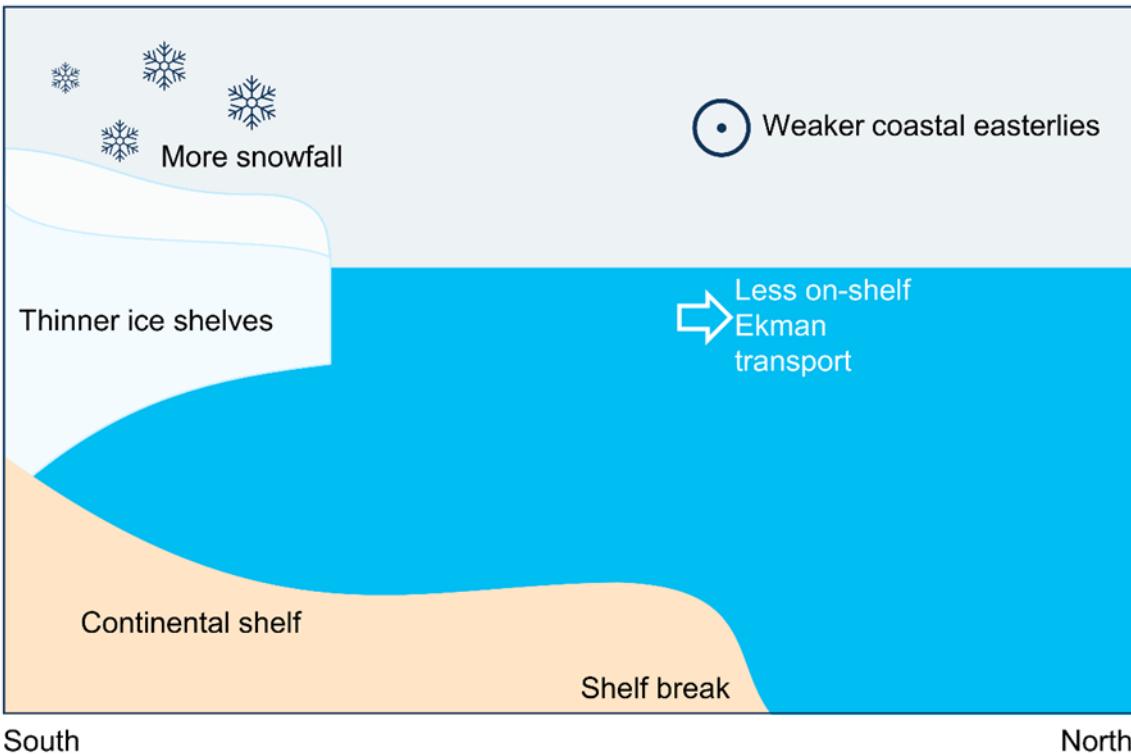
El Niño



Schematic

a

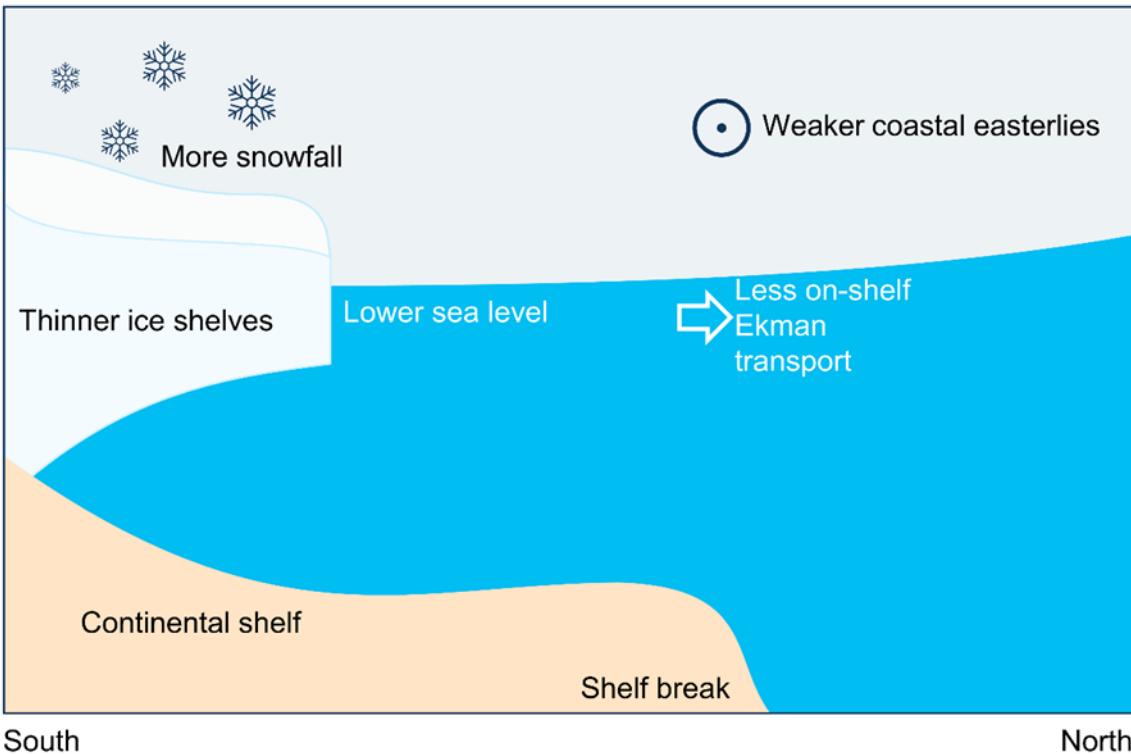
El Niño



Schematic

a

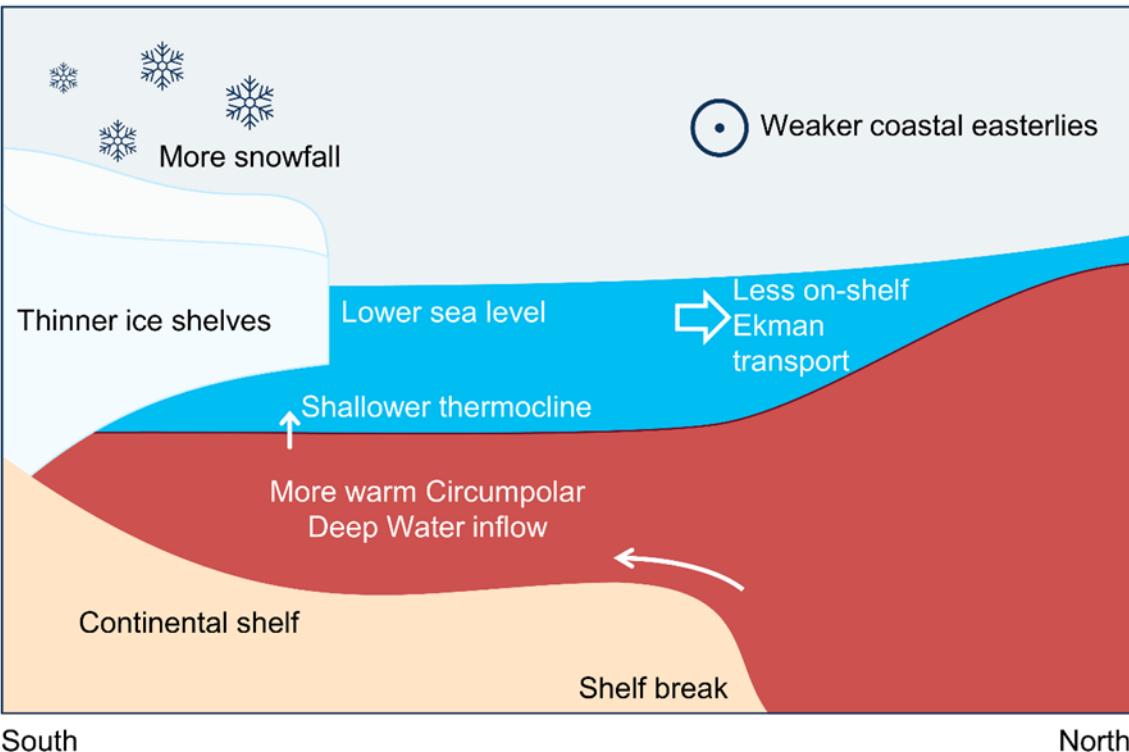
El Niño



Schematic

a

El Niño



South

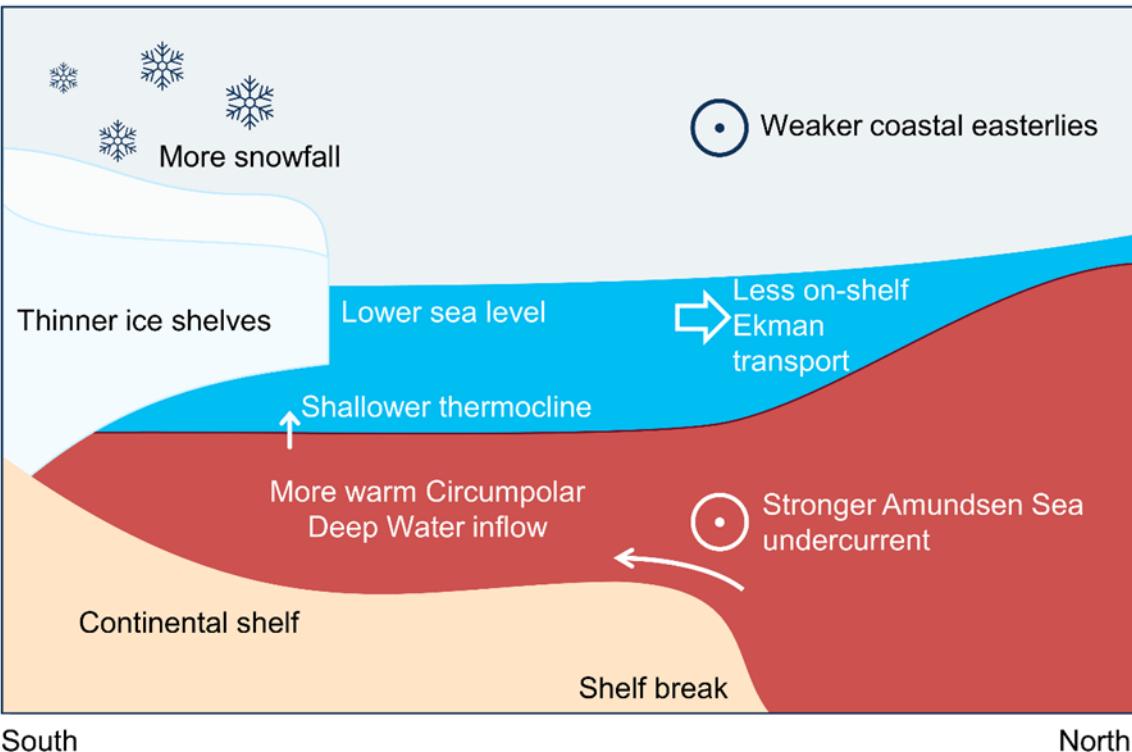
North

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

Schematic

a

El Niño



South

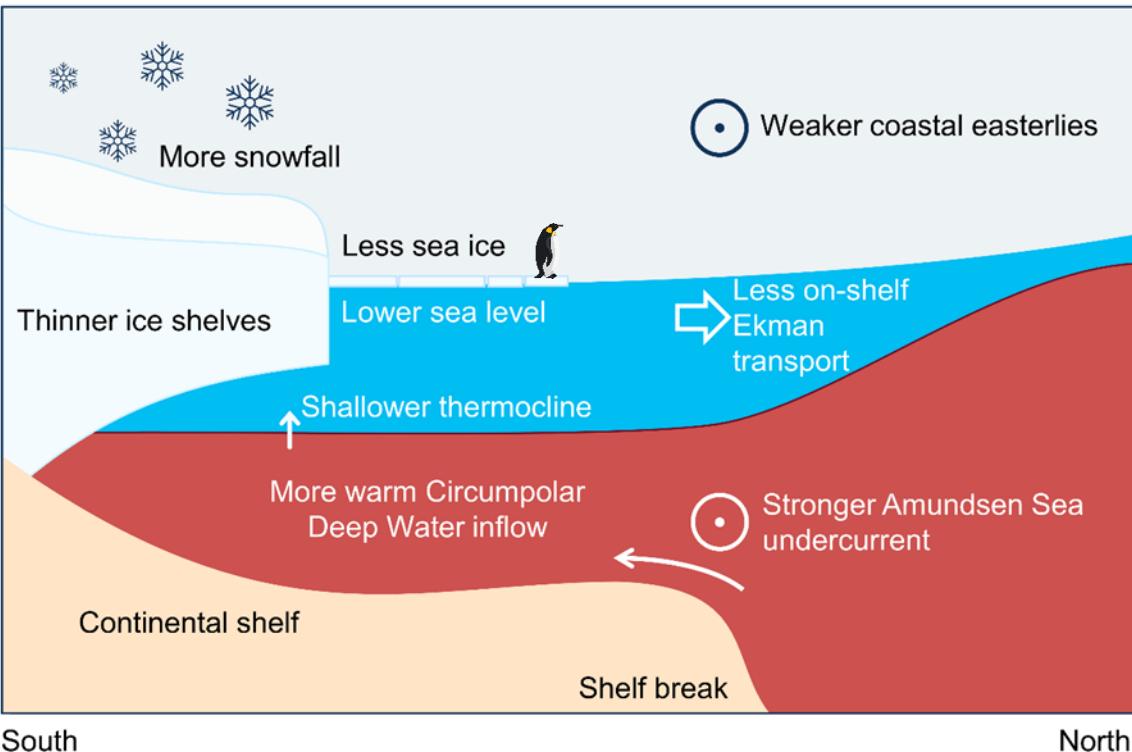
North

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Schematic

a

El Niño

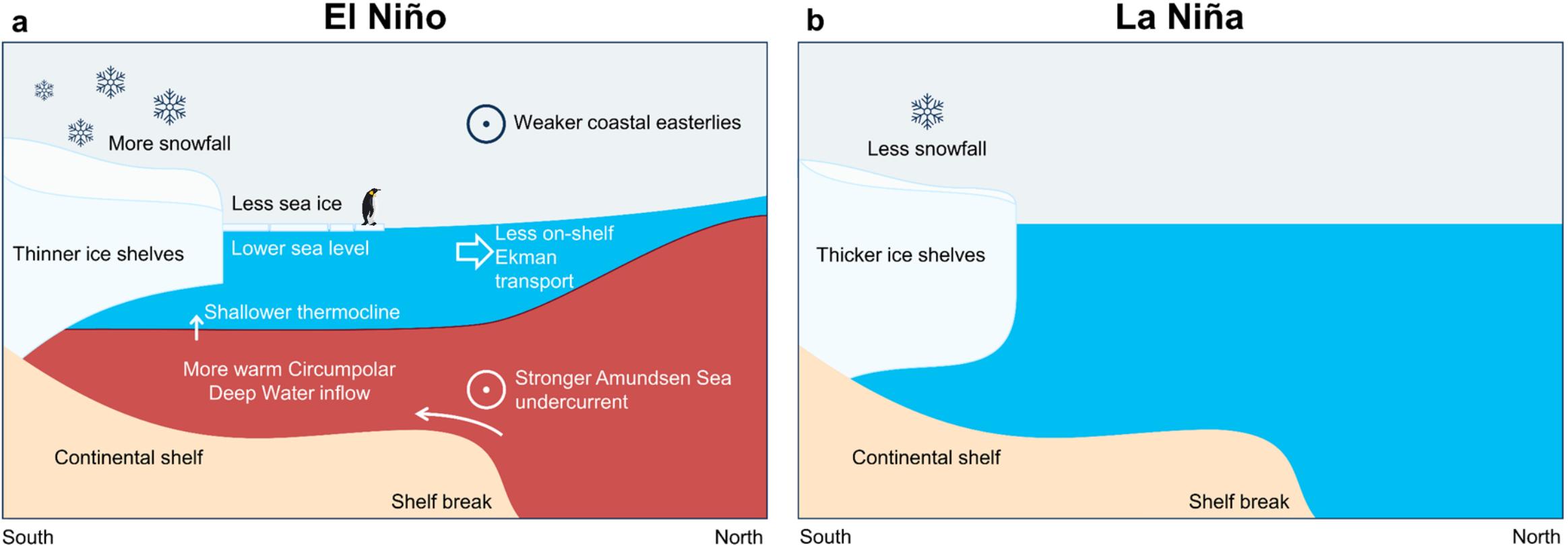


South

North

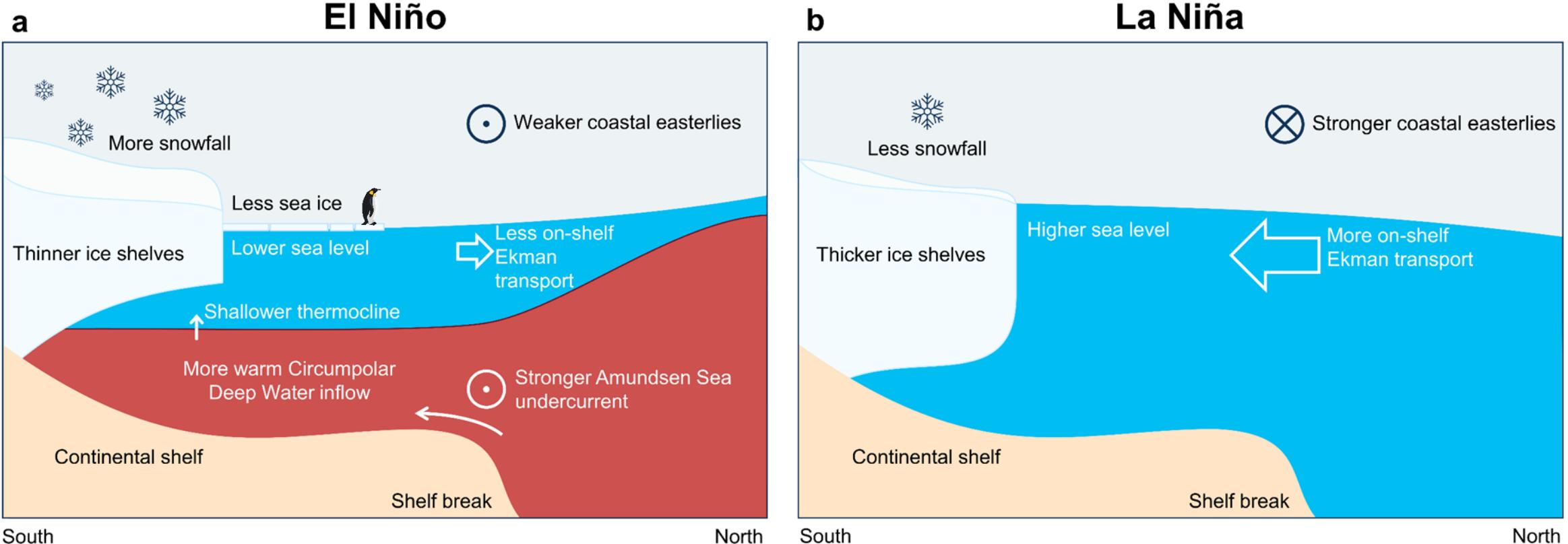
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Schematic



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Schematic



South

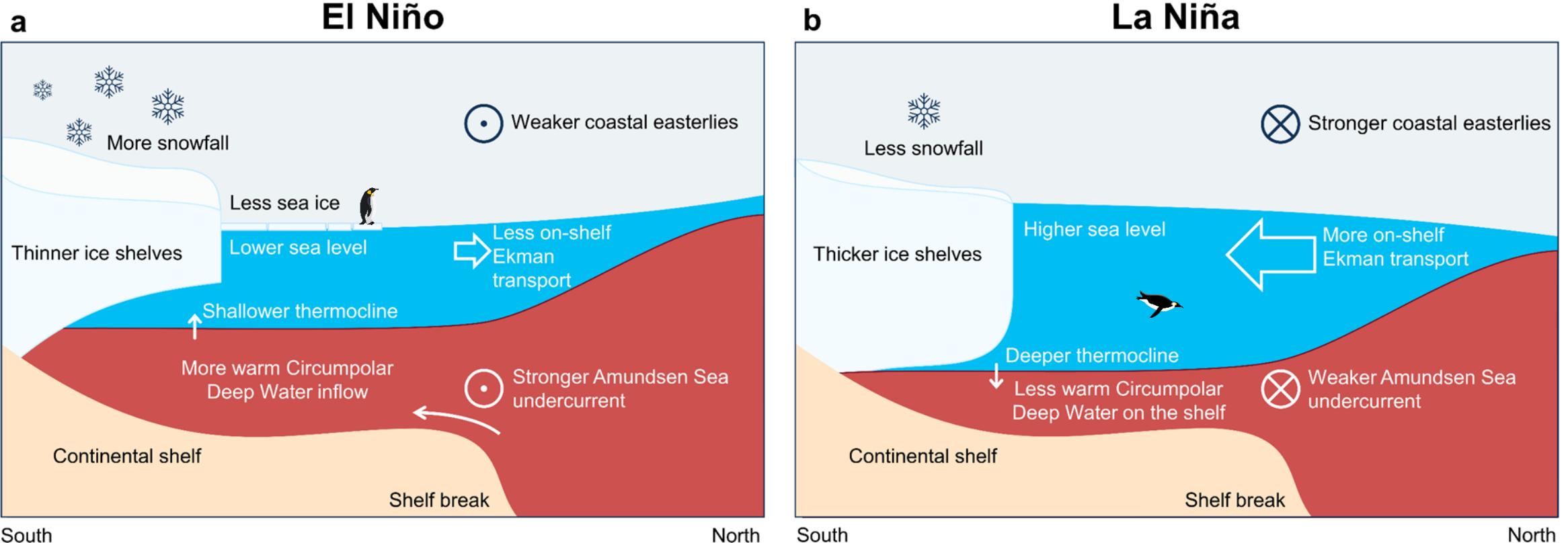
North

South

North

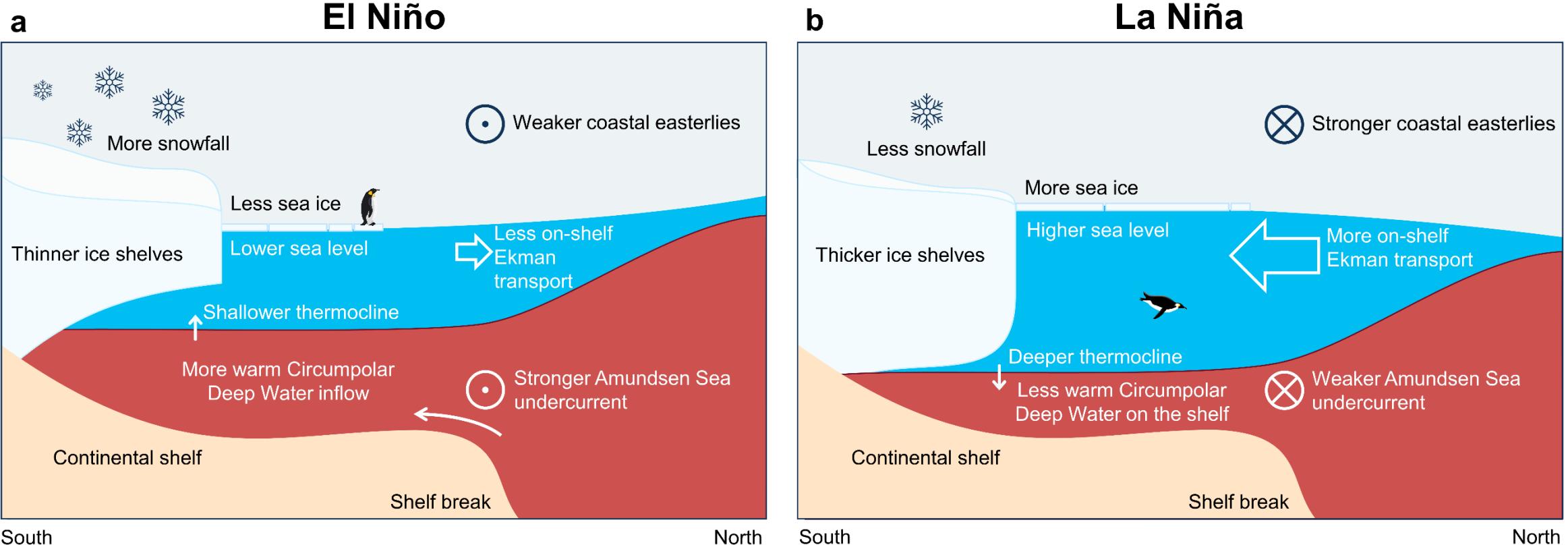
- *bottom Ekman response*
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Schematic



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- *eddies*

Schematic



South

North

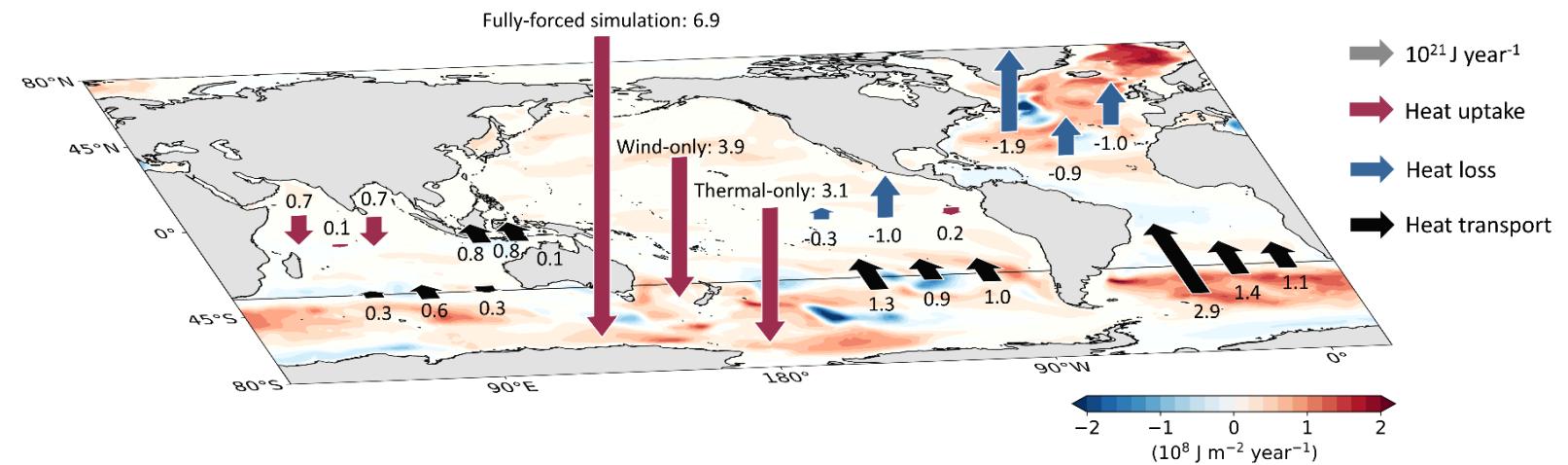
South

North

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A journey through two research projects

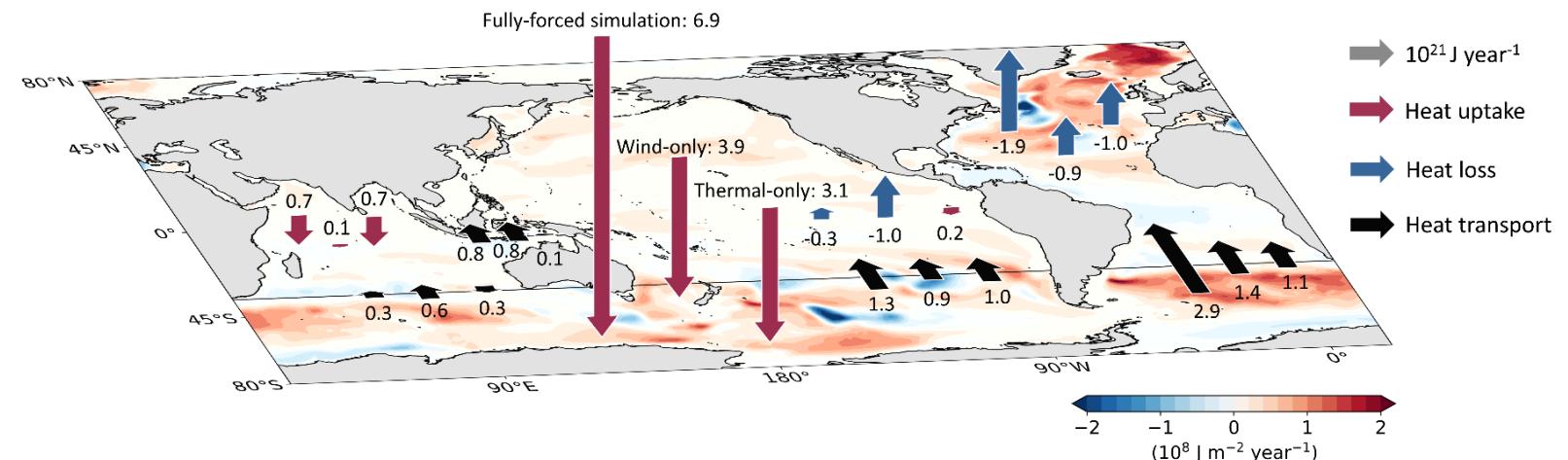
1. Drivers and distribution of global ocean heat uptake over the last half century (Huguenin et al. 2022, Nat. Comms.)



A journey through two research projects

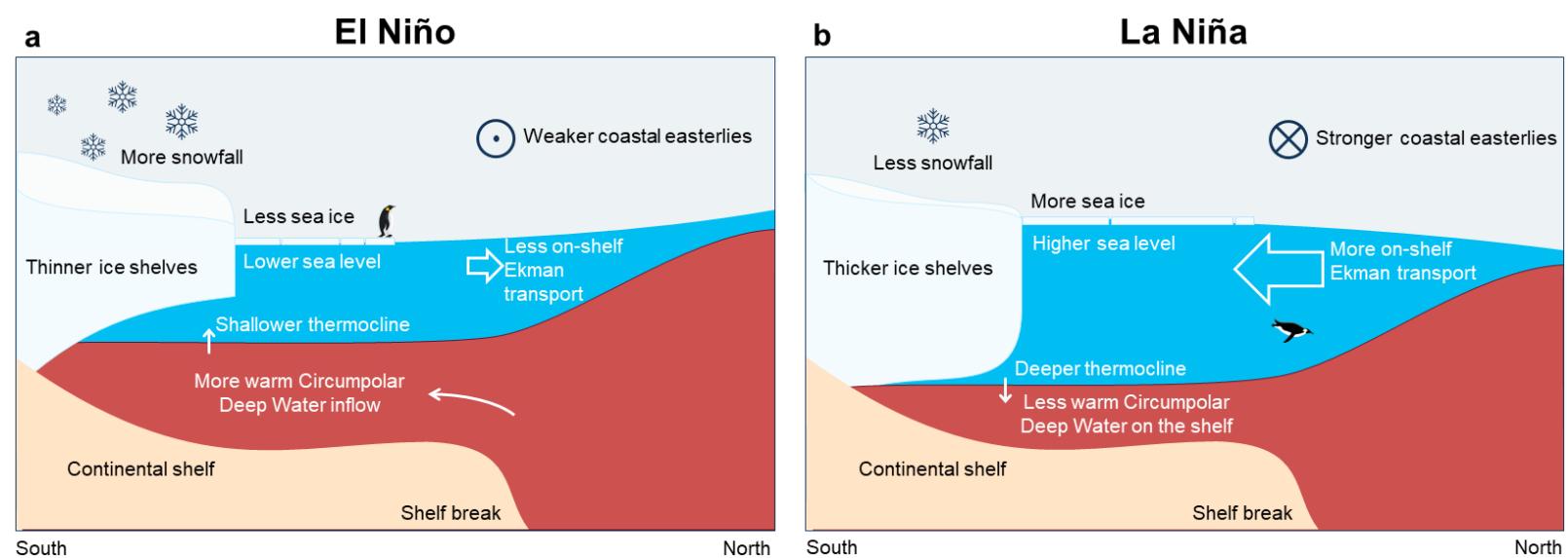
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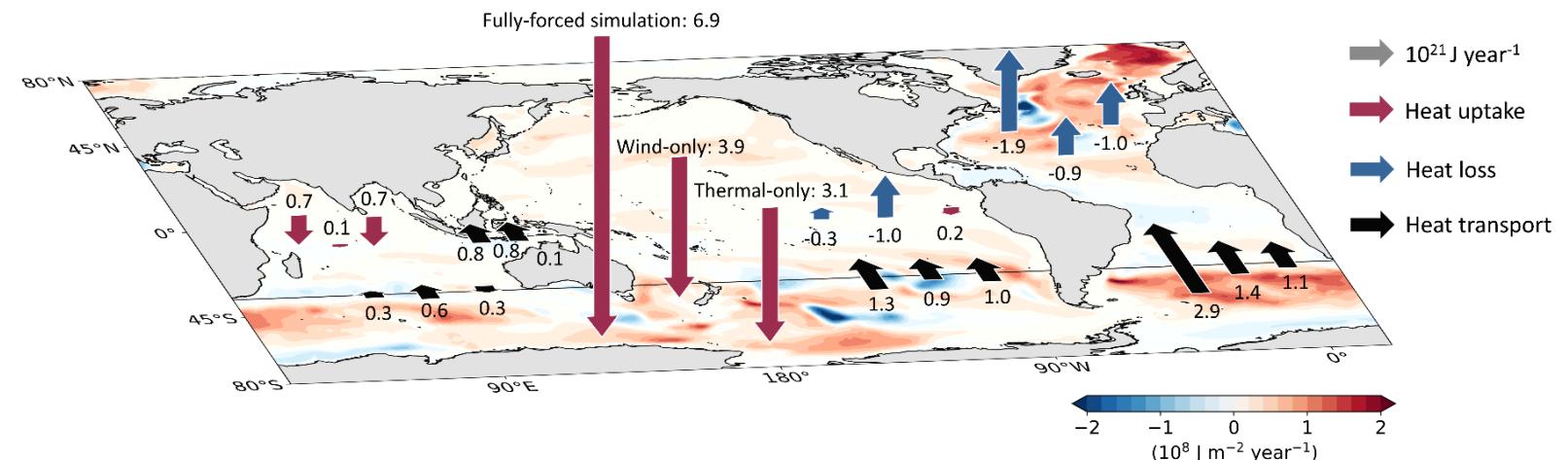
2. Subsurface warming of West Antarctic coastal waters linked to El Niño events

(Huguenin et al., 2024, GRL)

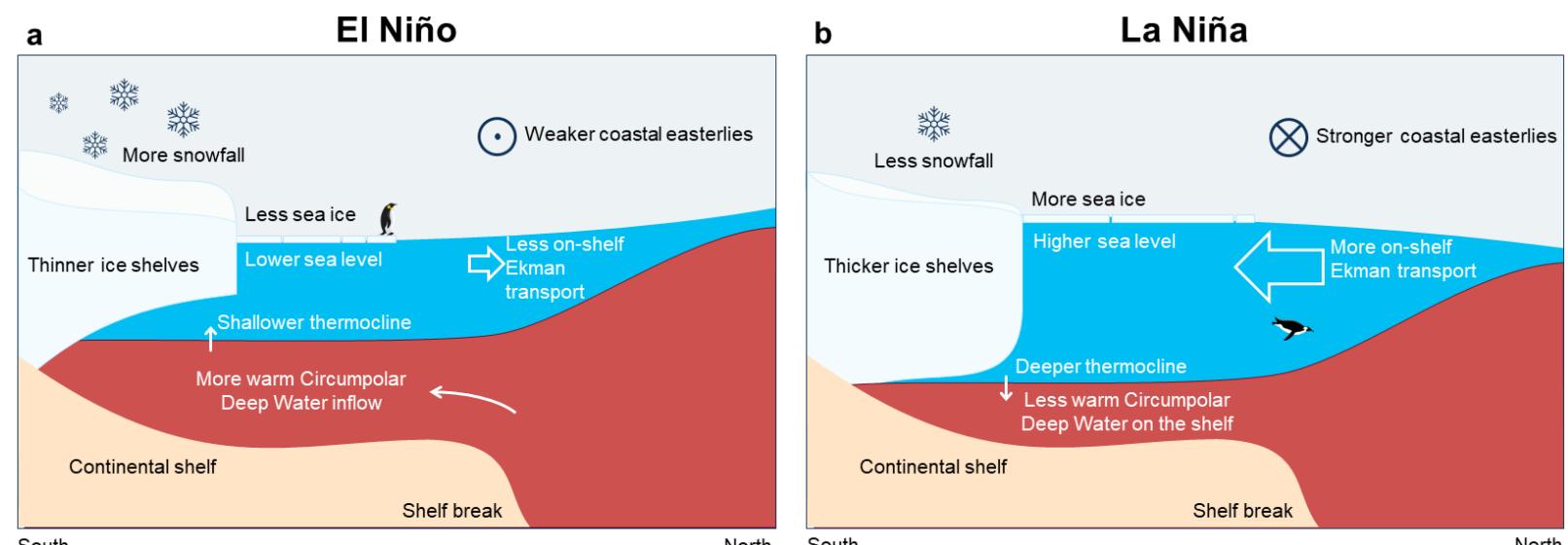


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 maurice.huguenin@whoi.edu

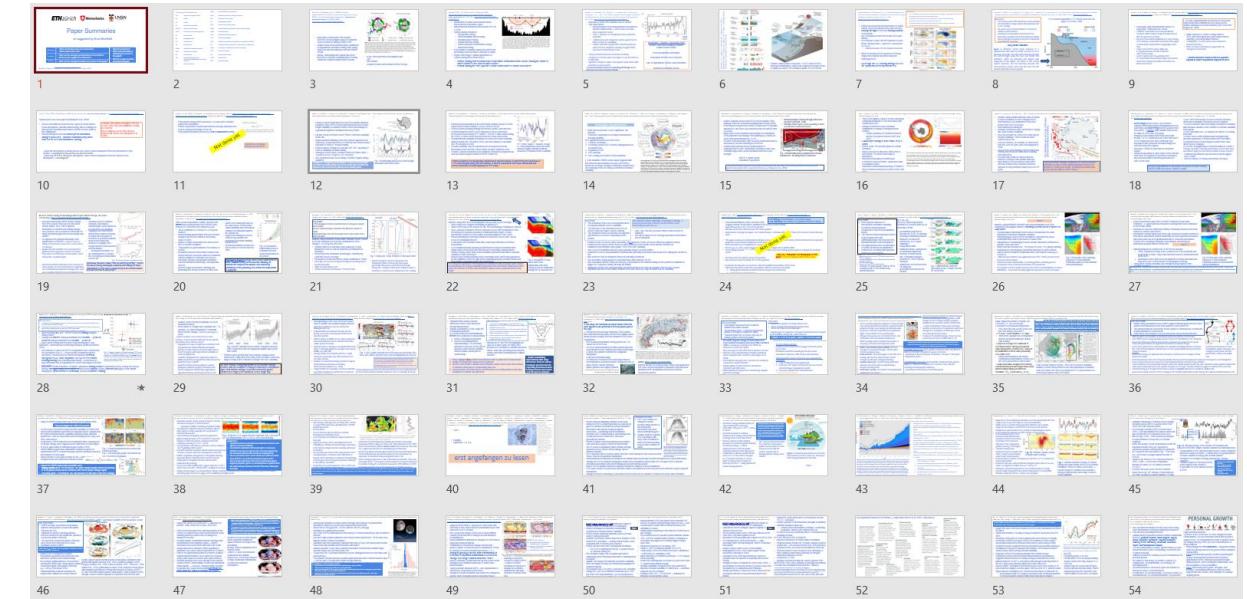
 @mauricehuguenin

...but wait, there's more!

A few habits that helped me in grad school

A few habits that helped me in grad school

1. One paper, one powerpoint slide



Anna Merrifield's idea

A few habits that helped me in grad school

1. One paper, one powerpoint slide

2. Chocolate countdown

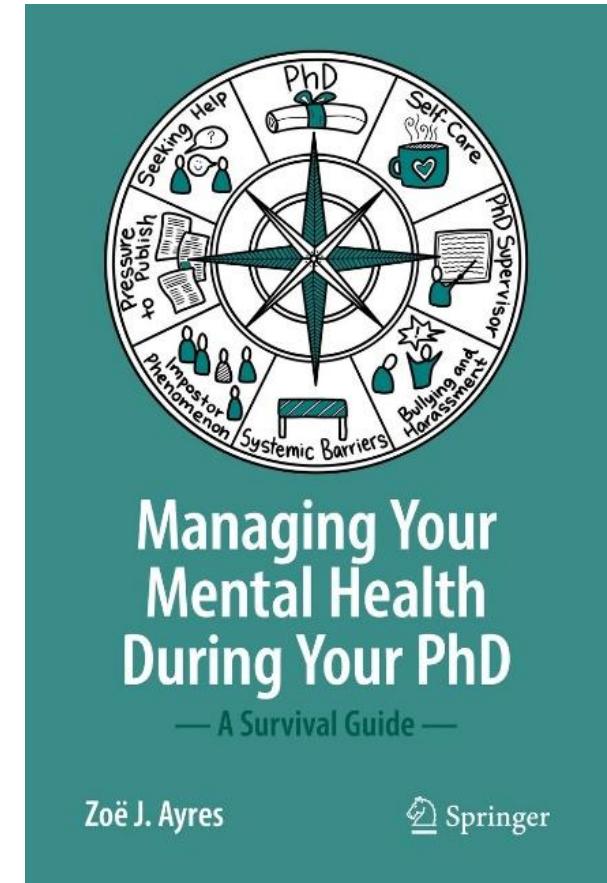
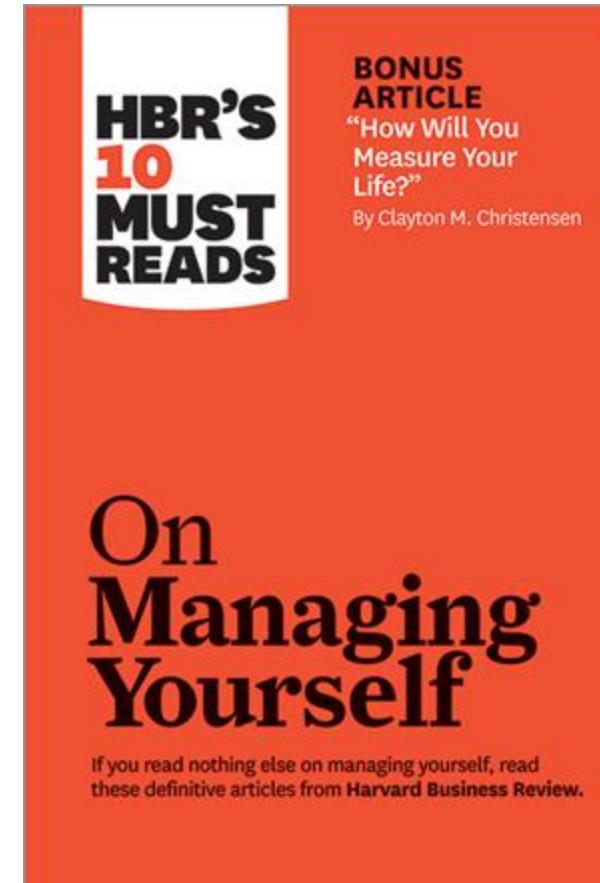


A few habits that helped me in grad school

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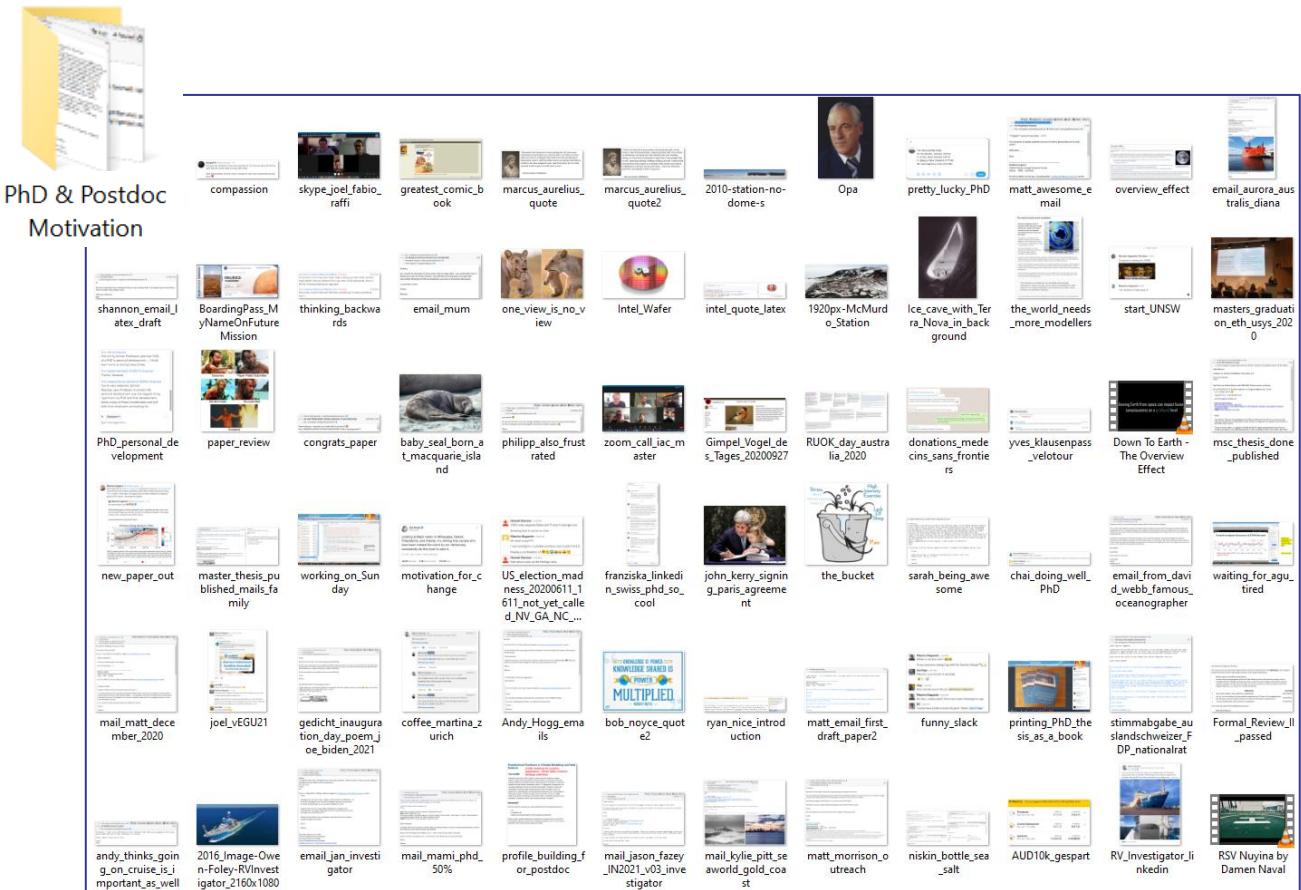
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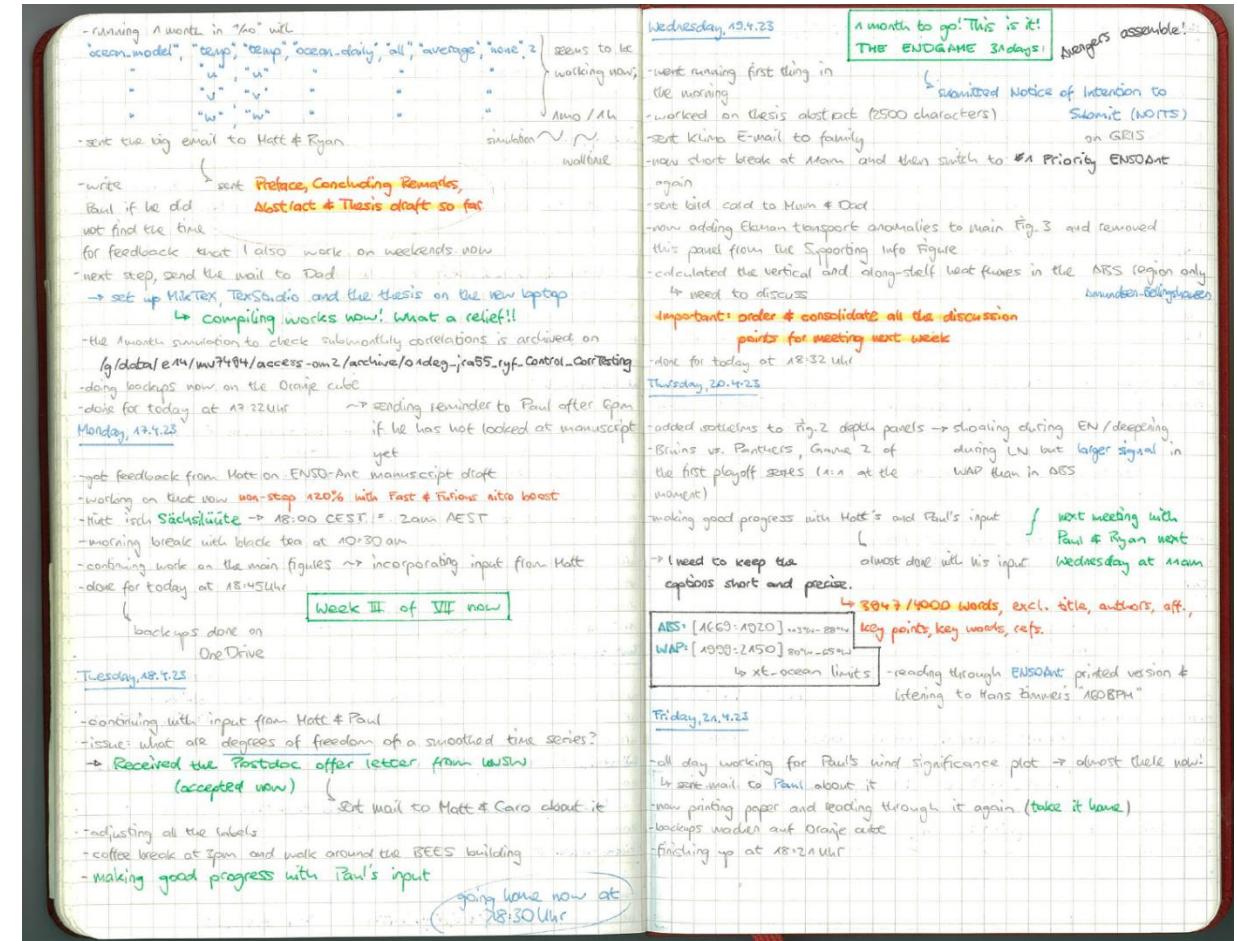
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Evidence for European presence in the Americas in AD 1021

[Margot Kuitem](#)✉, [Birgitta L. Wallace](#), [Charles Lindsay](#), [Andrea Scifo](#), [Petra Doeve](#), [Kevin Jenkins](#), [Susanne Lindauer](#), [Pınar Erdil](#), [Paul M. Ledger](#), [Véronique Forbes](#), [Caroline Vermeeren](#), [Ronny Friedrich](#) & [Michael W. Dee](#)✉

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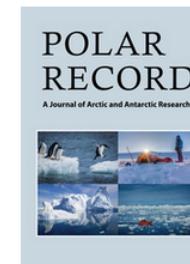
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The present location of the tent that Roald Amundsen left behind at the South Pole in December 1911

Published online by Cambridge University Press: 21 January 2011

Olav Orheim

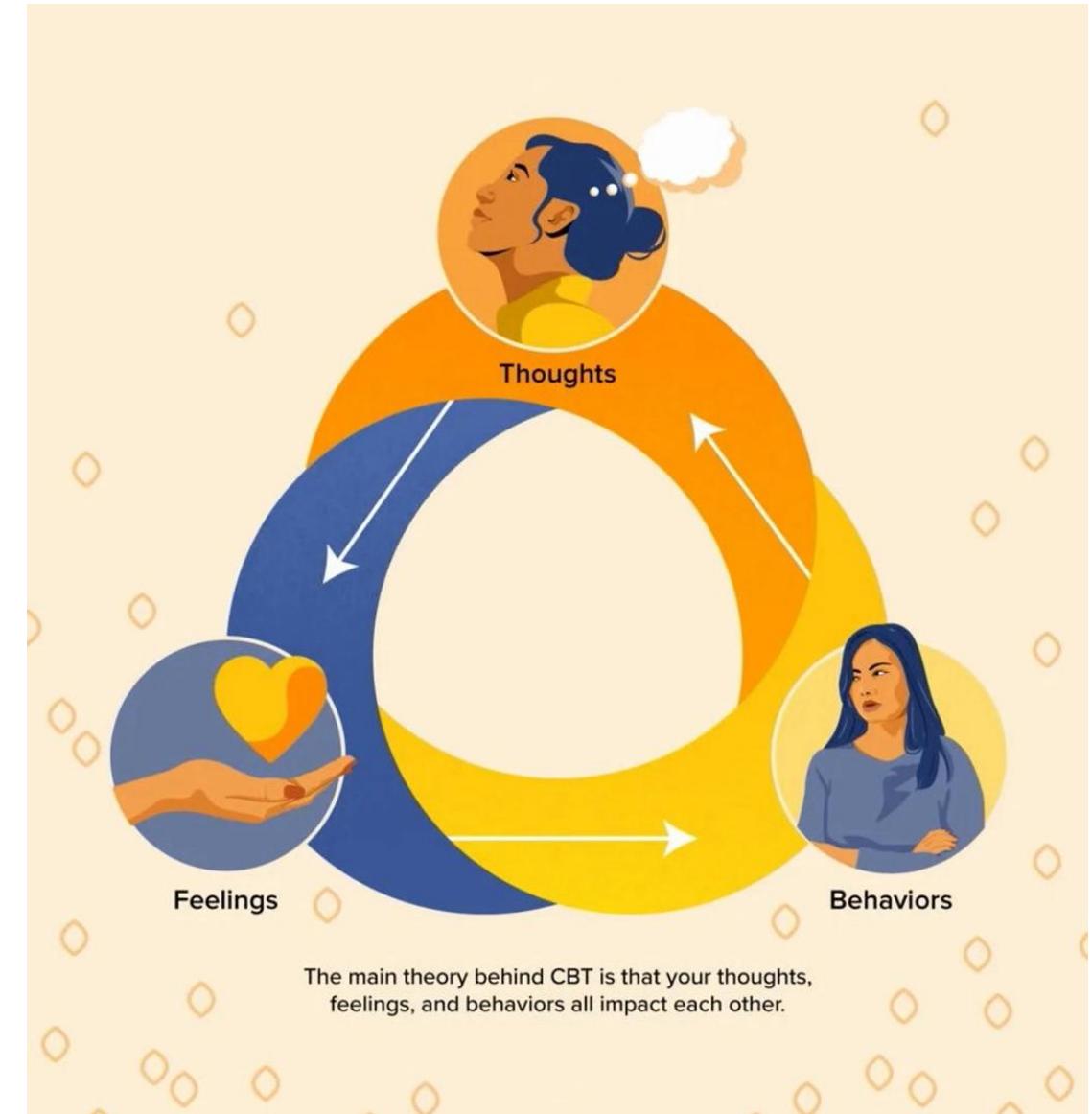
Show author details ▾

[Article](#) [Figures](#) [Metrics](#)

- $89^{\circ} 58' 51'' \text{ S}$, $17 \text{ m deep} \pm 3 \text{ km}$
- $1.8 \text{ km} < \text{tent} < 2.5 \text{ km from flag}$

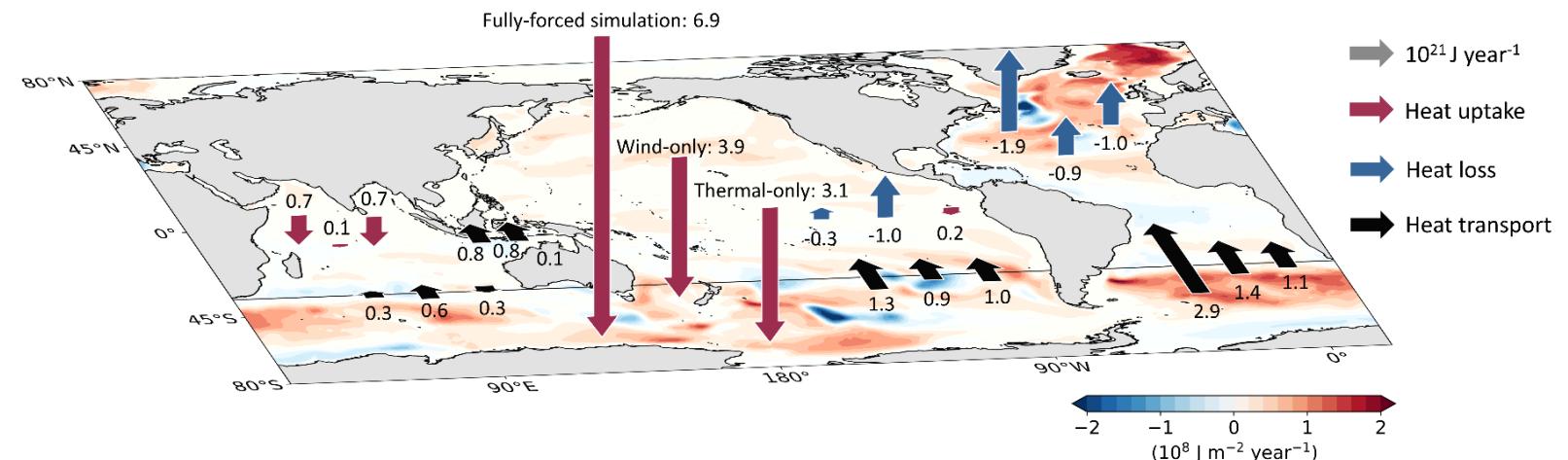
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7. CBT

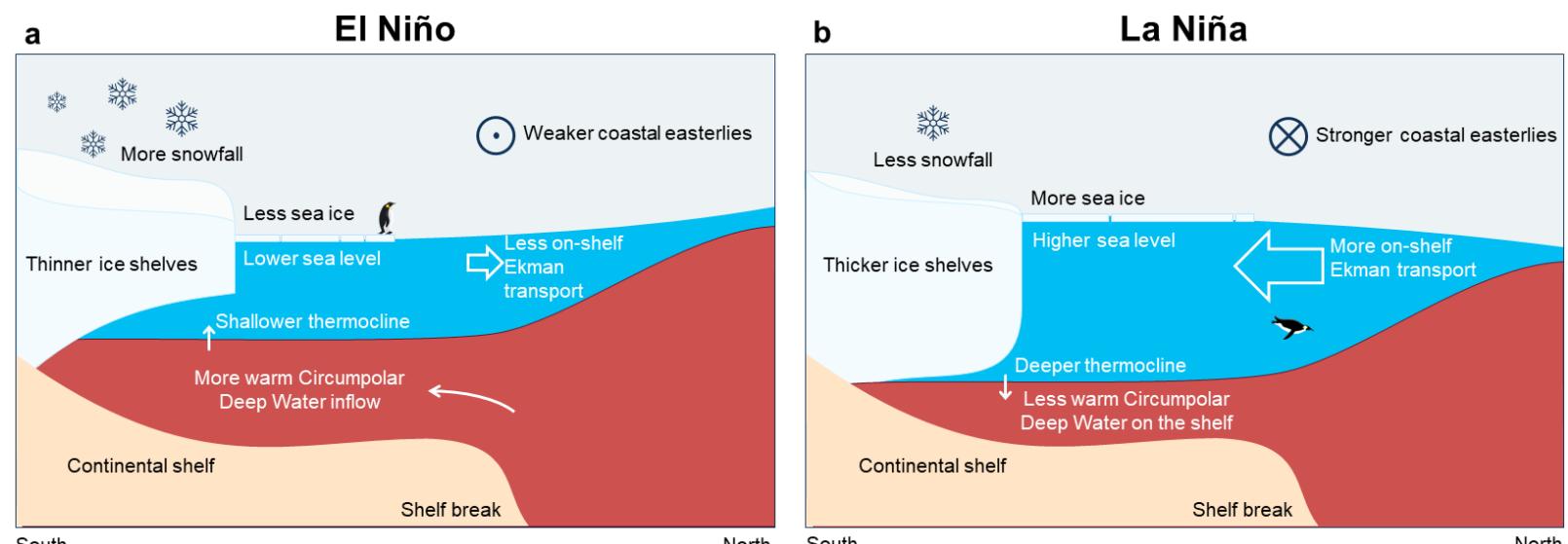


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 maurice.huguenin@whoi.edu

 @mauricehuguenin

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

...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.*

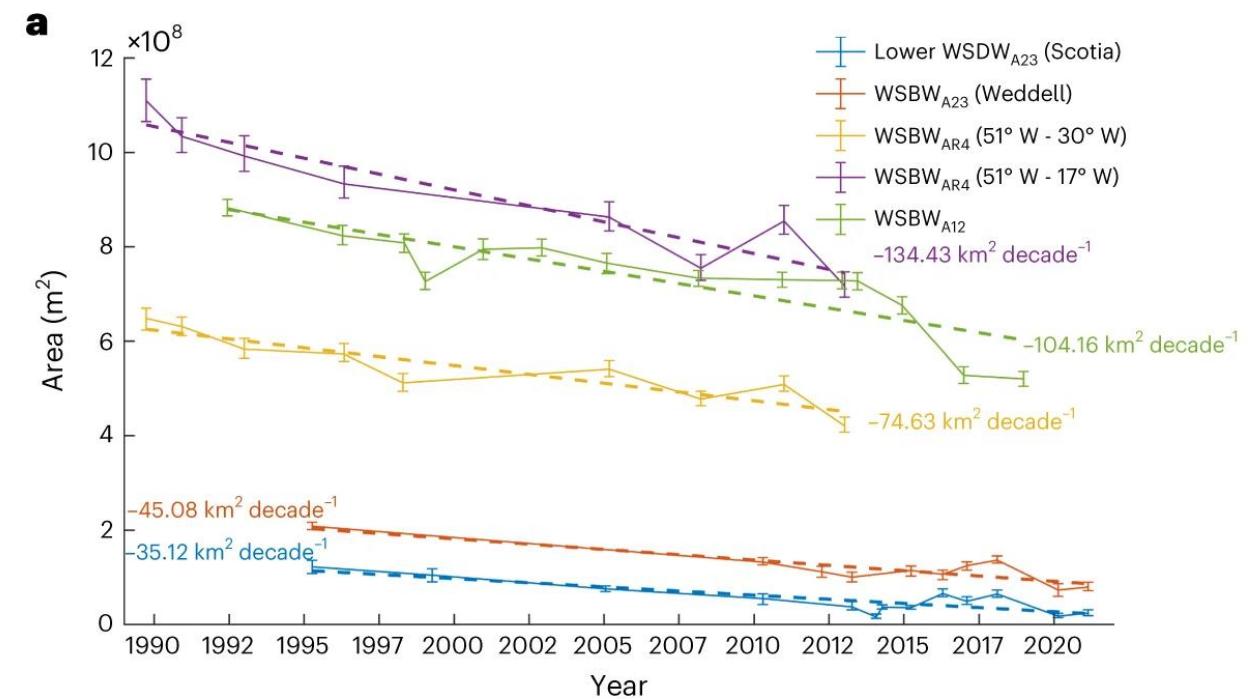
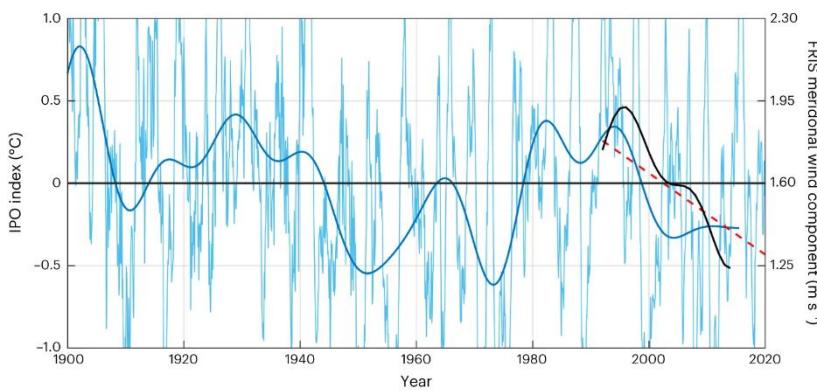
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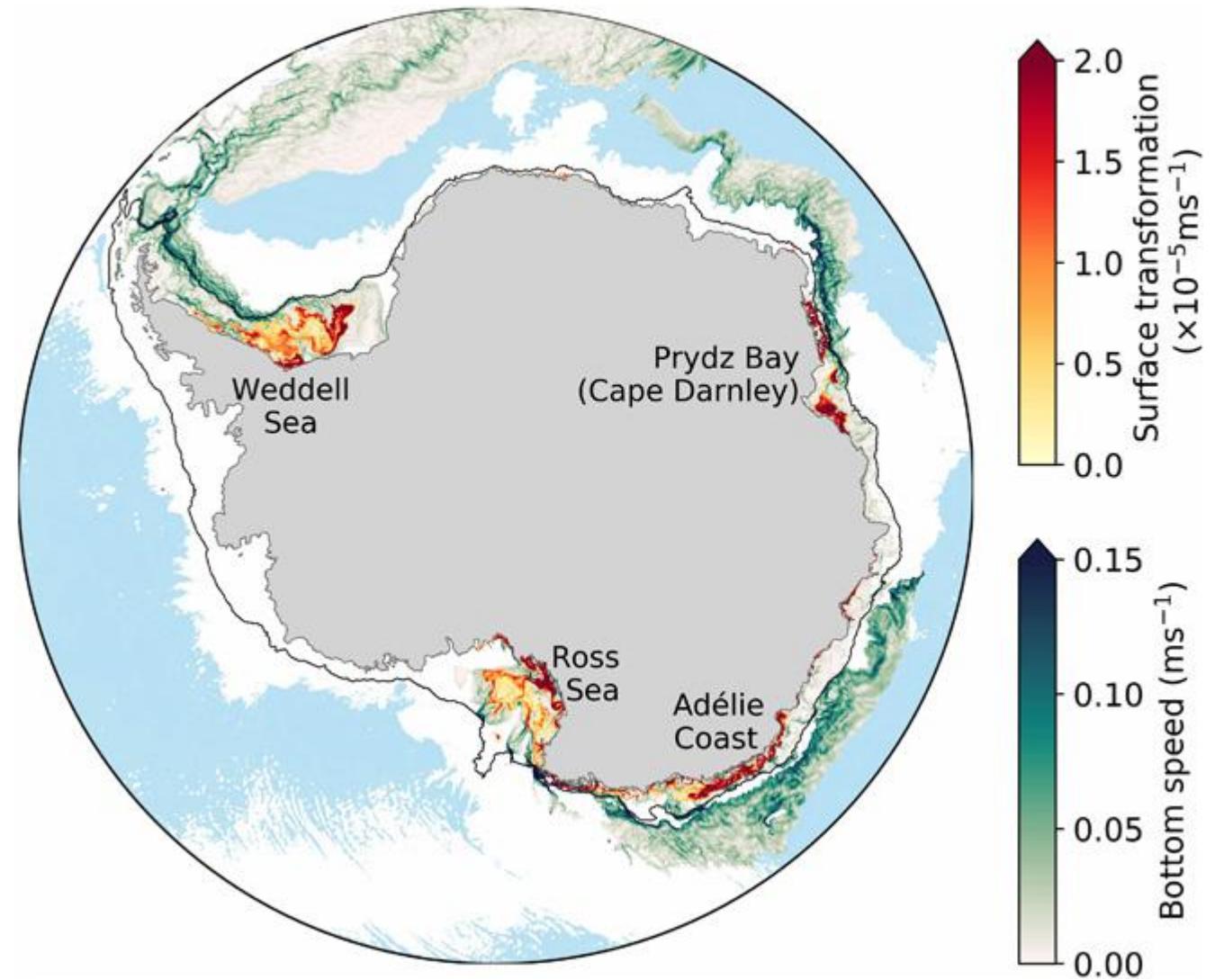
Maurice F. Huguenin, Svenja Ryan, Caroline Ummenhofer and Matthew H. England, *in preparation.*

- 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



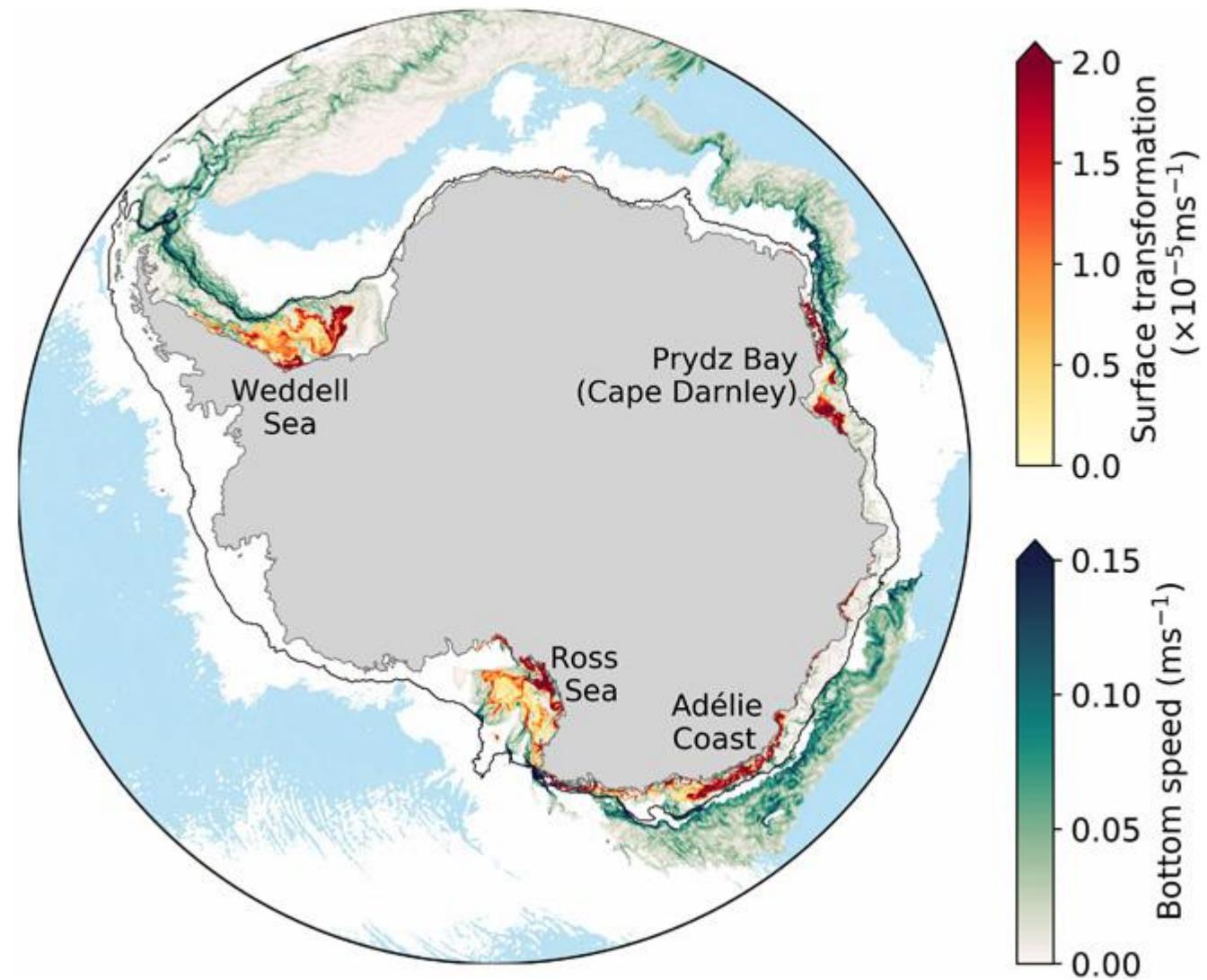
Morrison et al. (2019)

Maurice F. Huguenin

21/24

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)

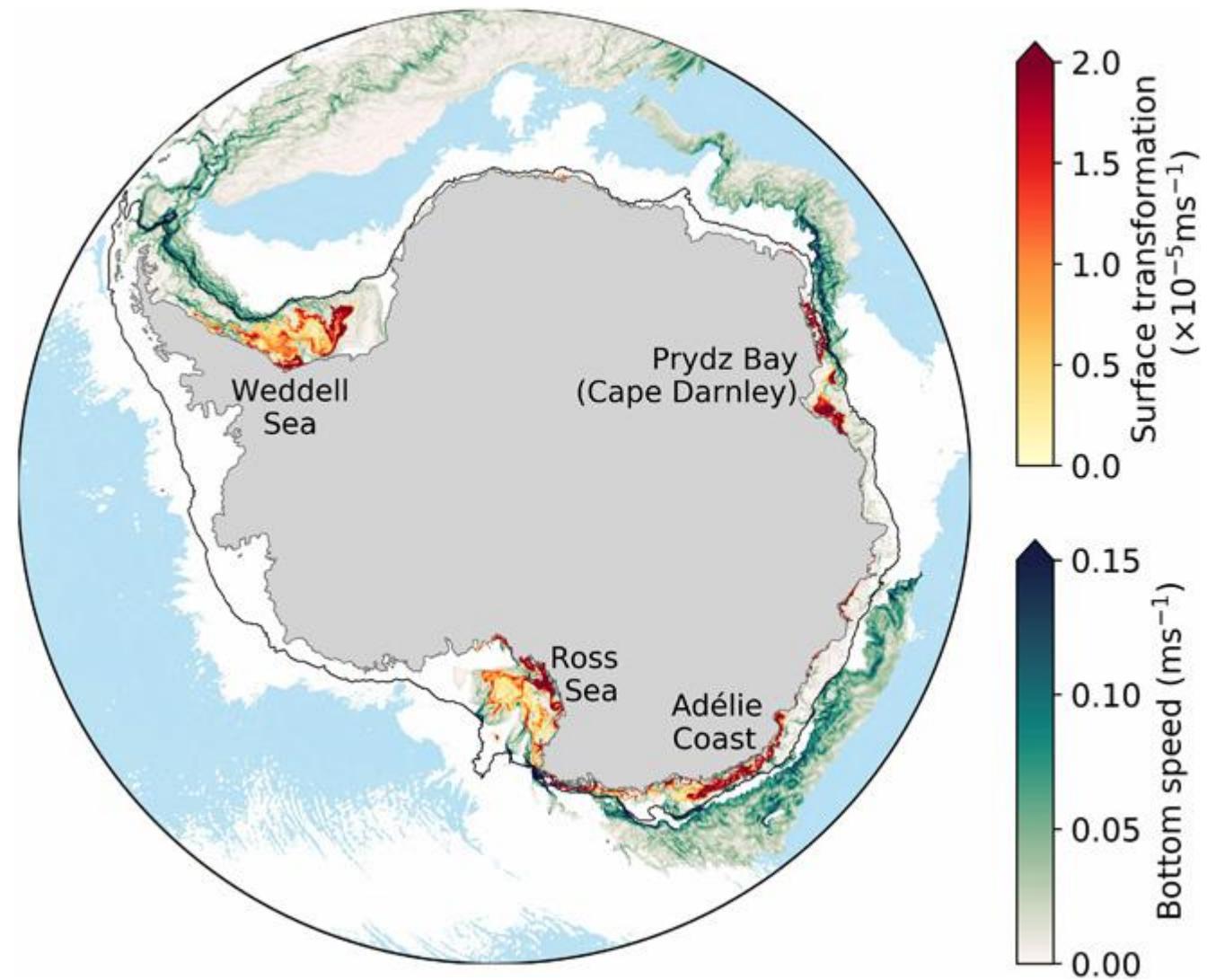
Maurice F. Huguenin

21/24

Surface water mass transformation

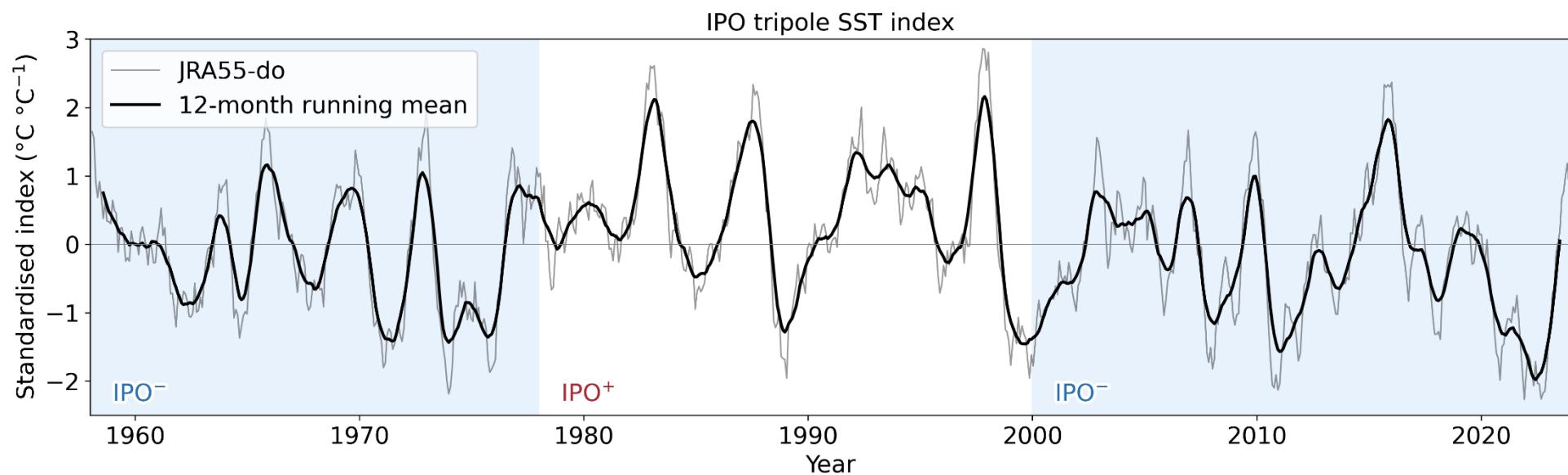
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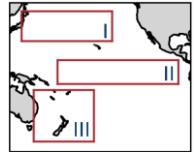
<https://cosima-recipes.readthedocs.io/en/latest/index.html>



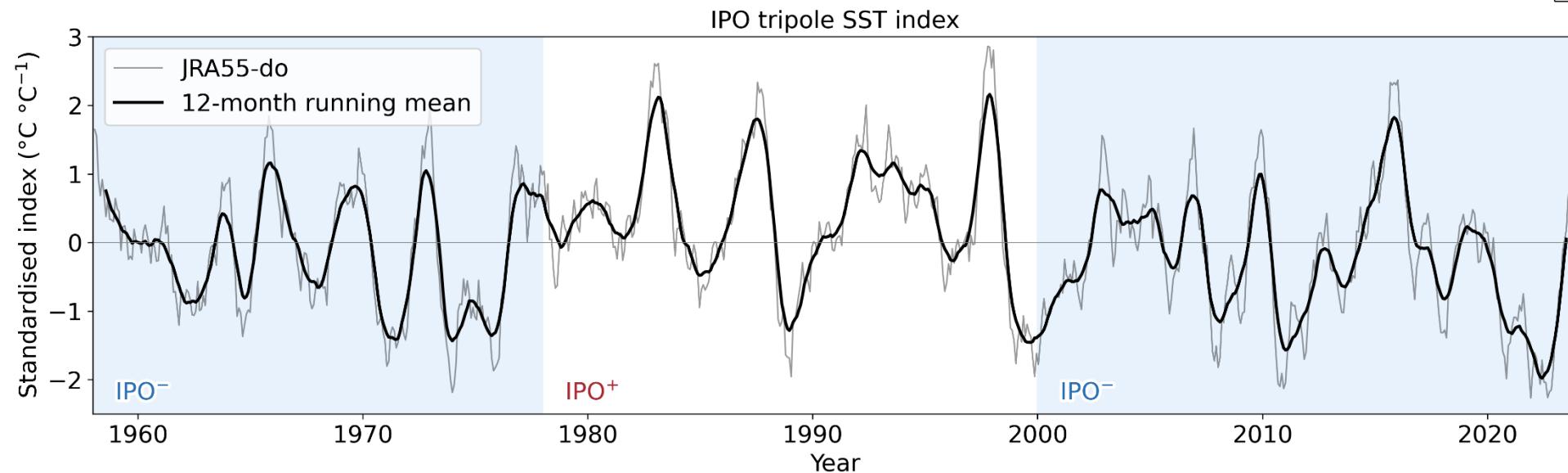
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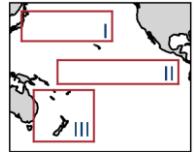
Experimental setup

a

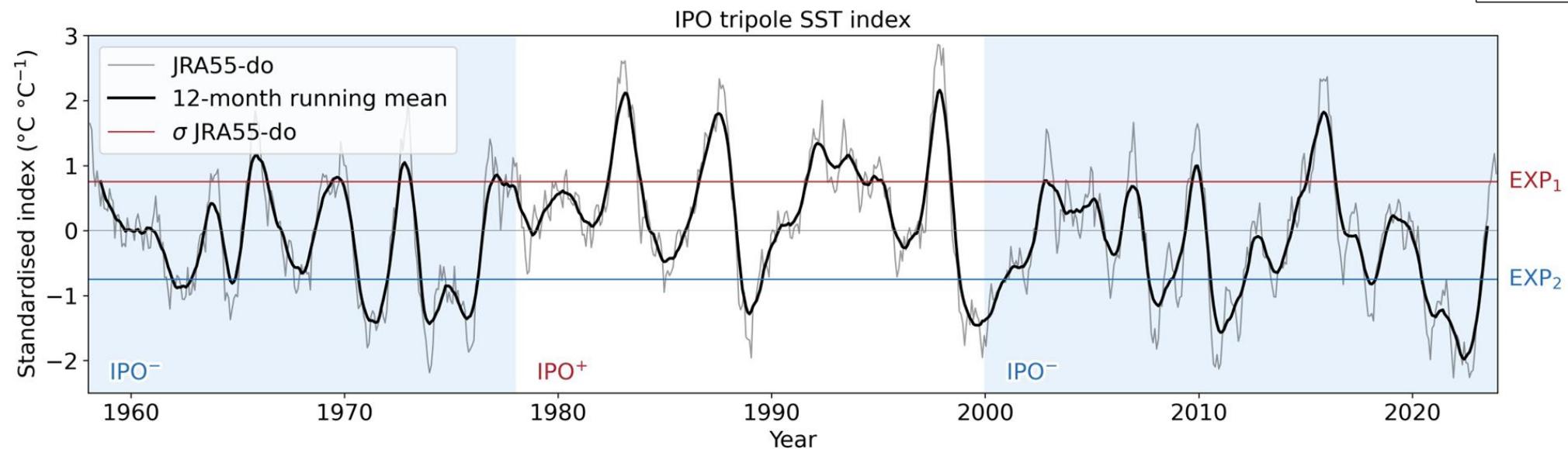


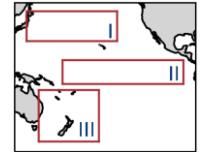
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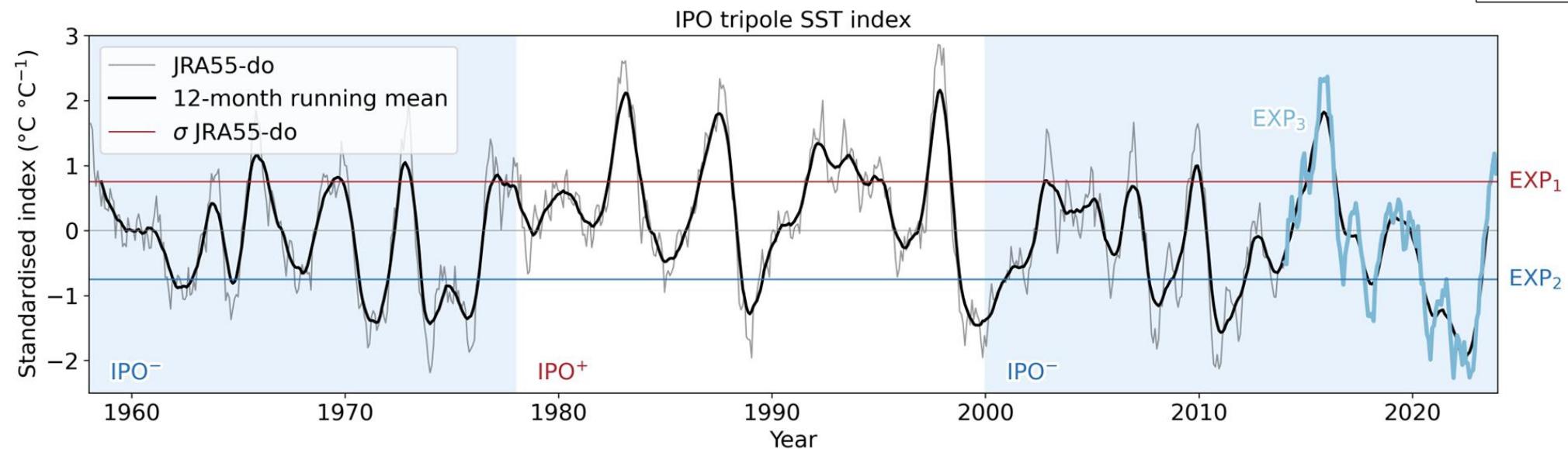


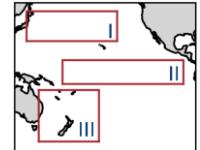
Experimental setup

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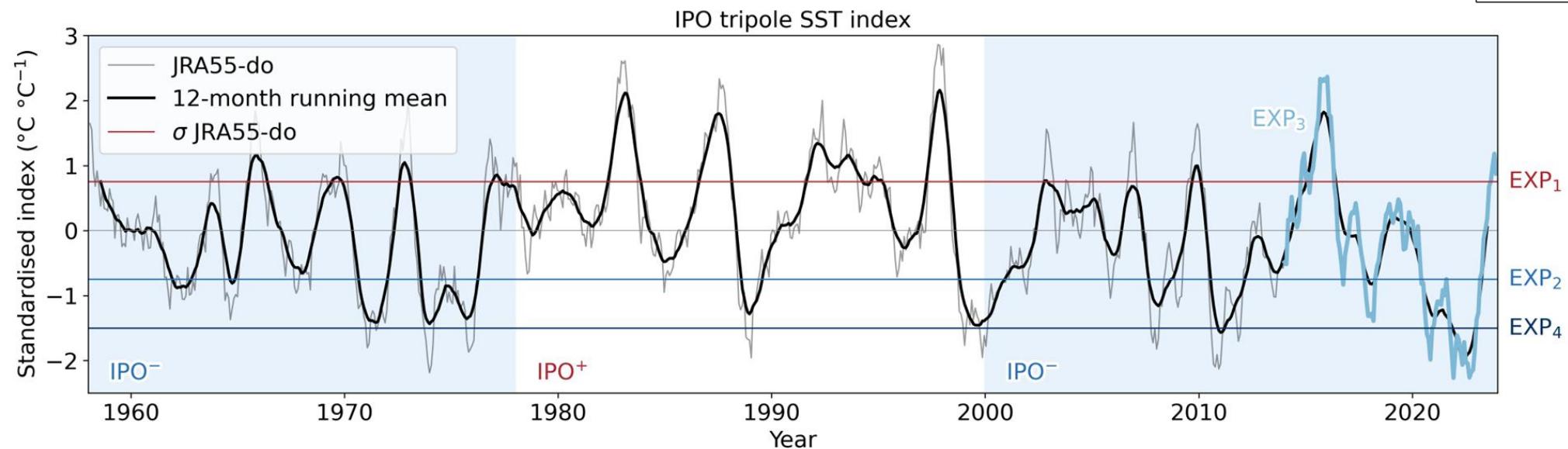


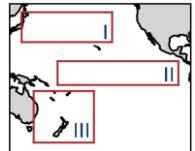
Experimental setup

a

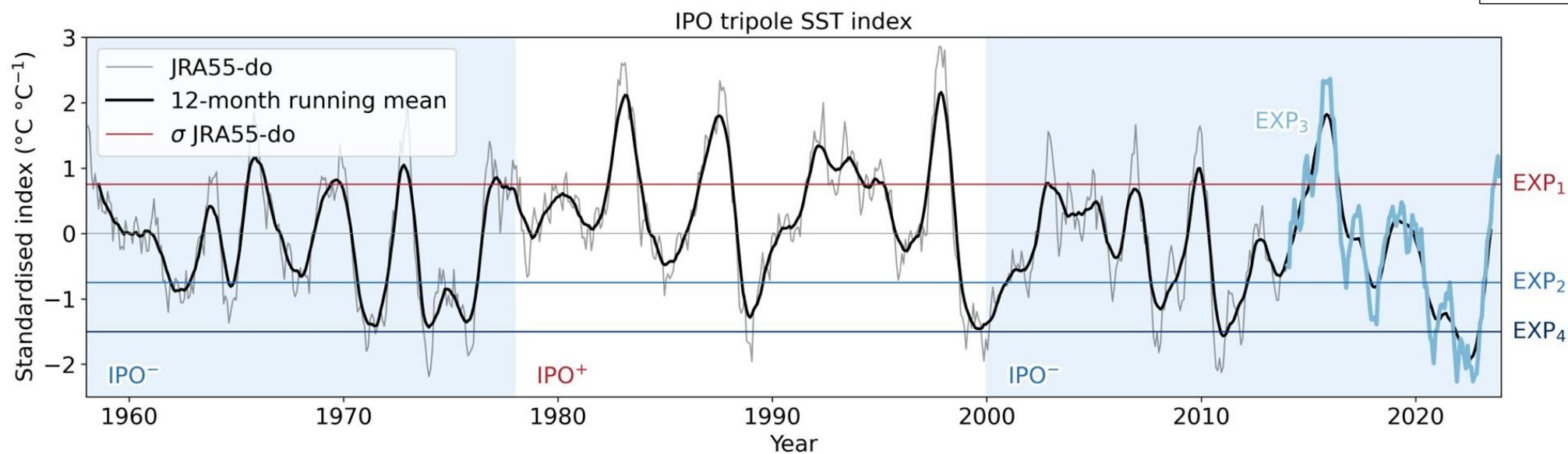
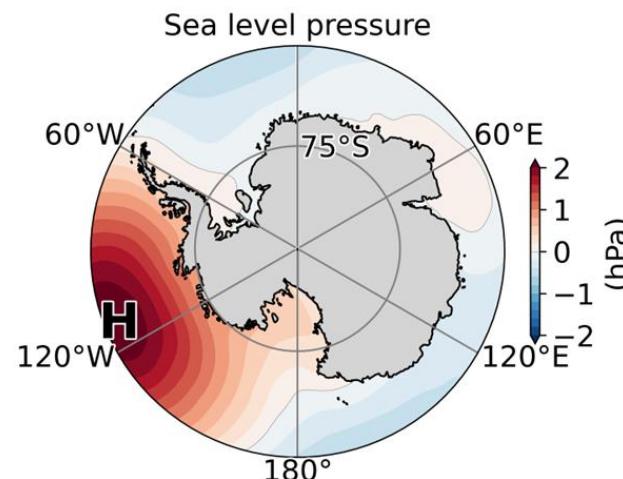
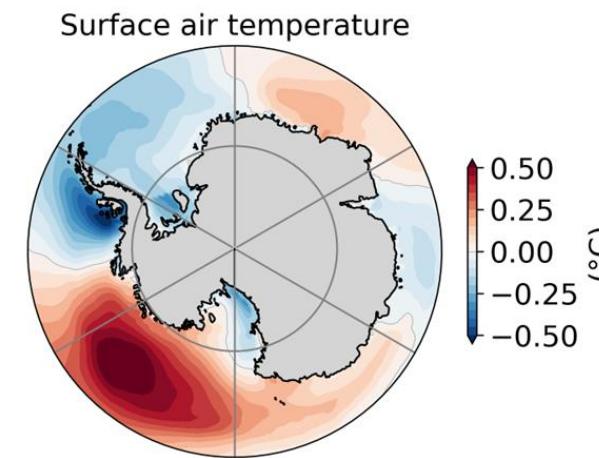
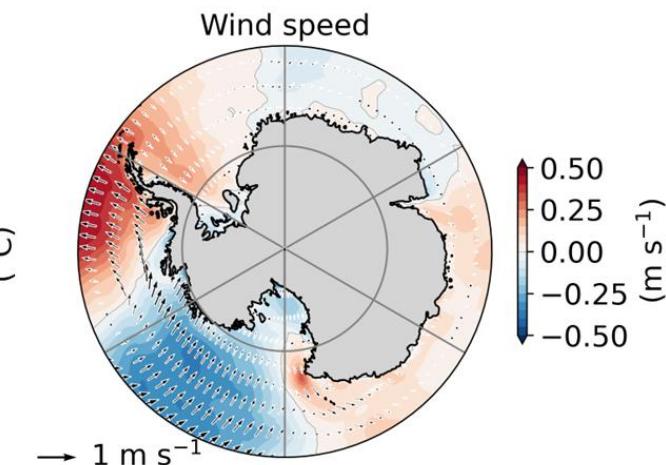


Experimental setup

a



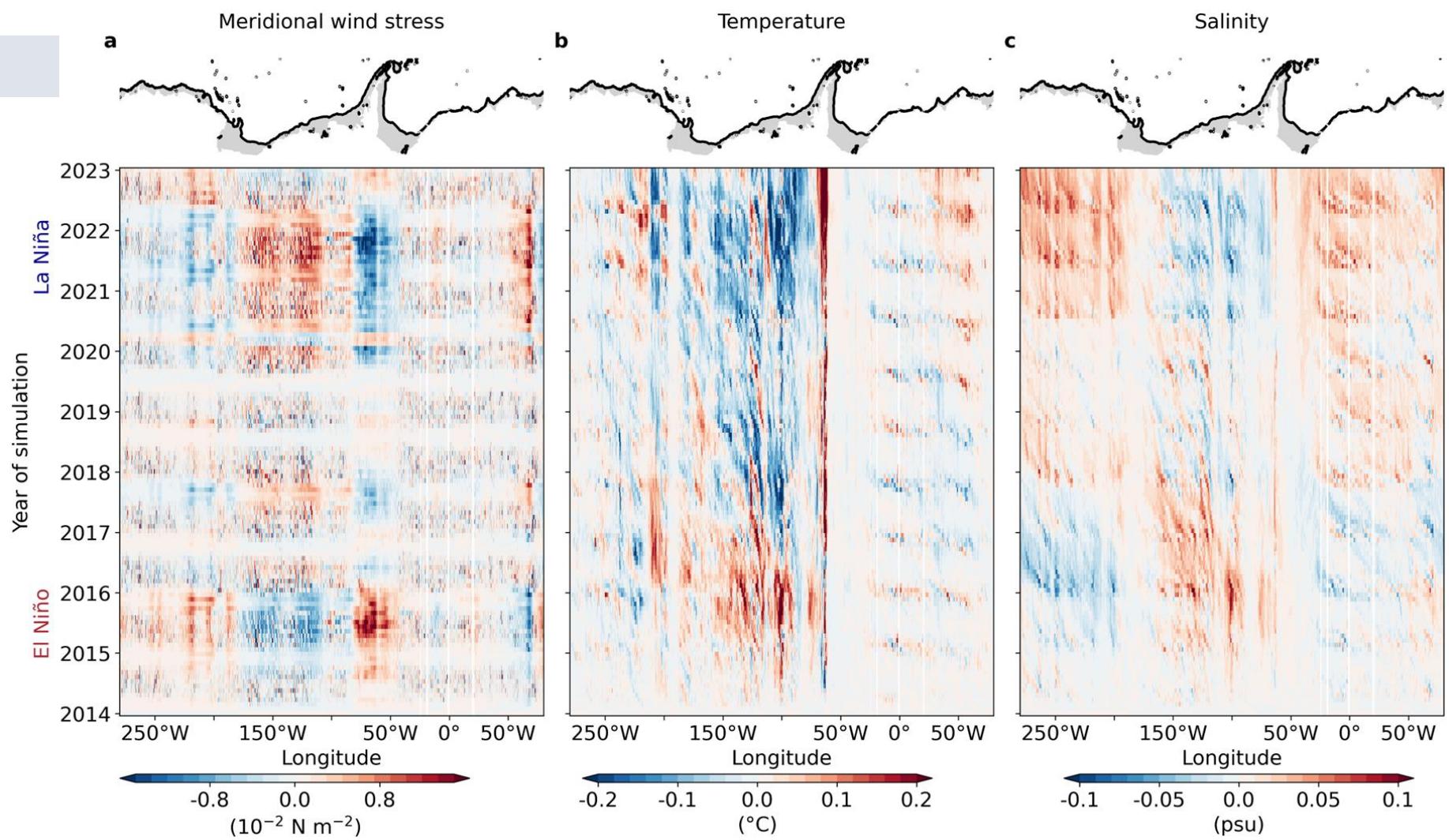
Experimental setup

a**c****d****e**

IPO changes in dense shelf water formation

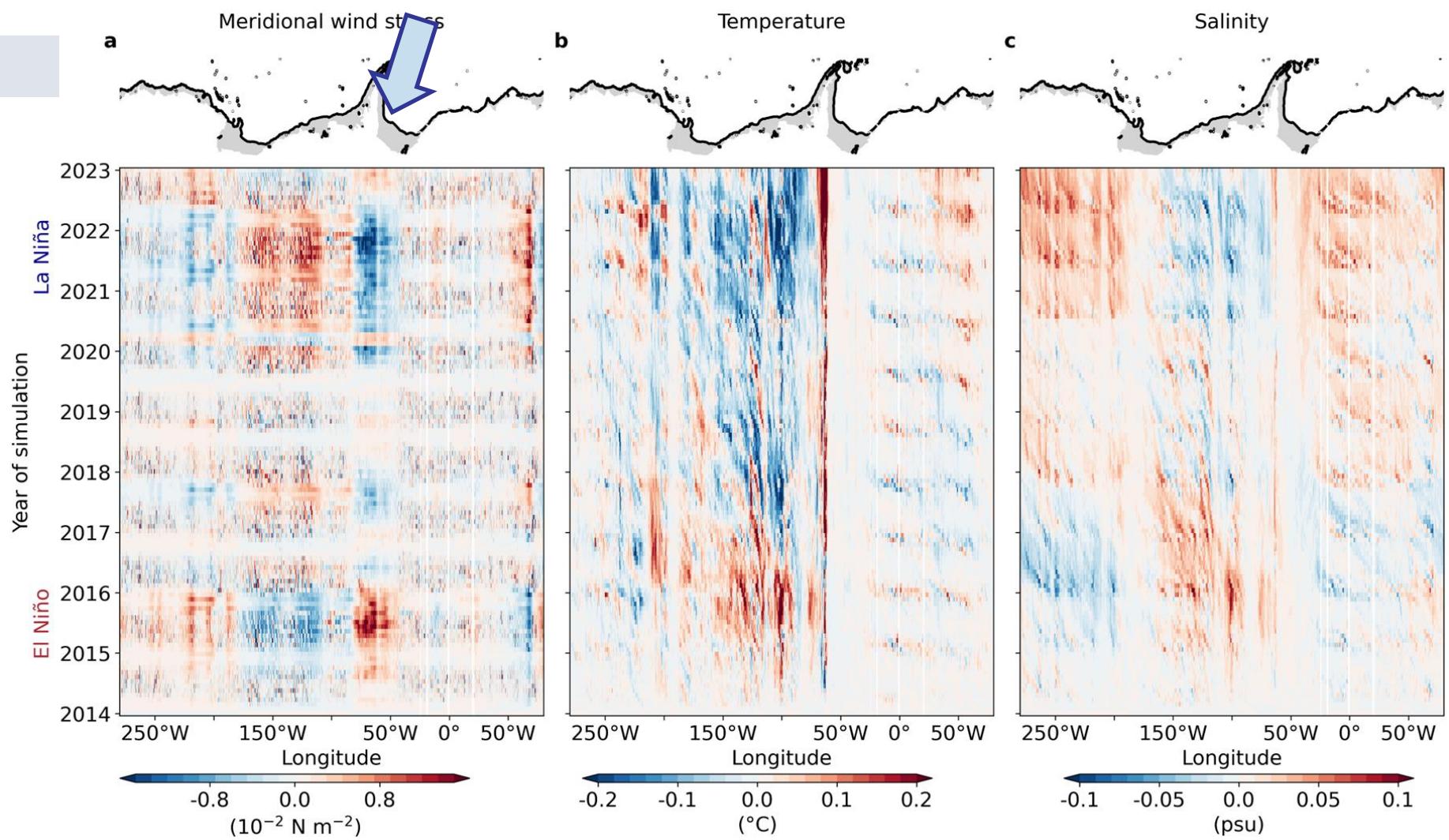
IPO changes in dense shelf water formation

Interannual simulation



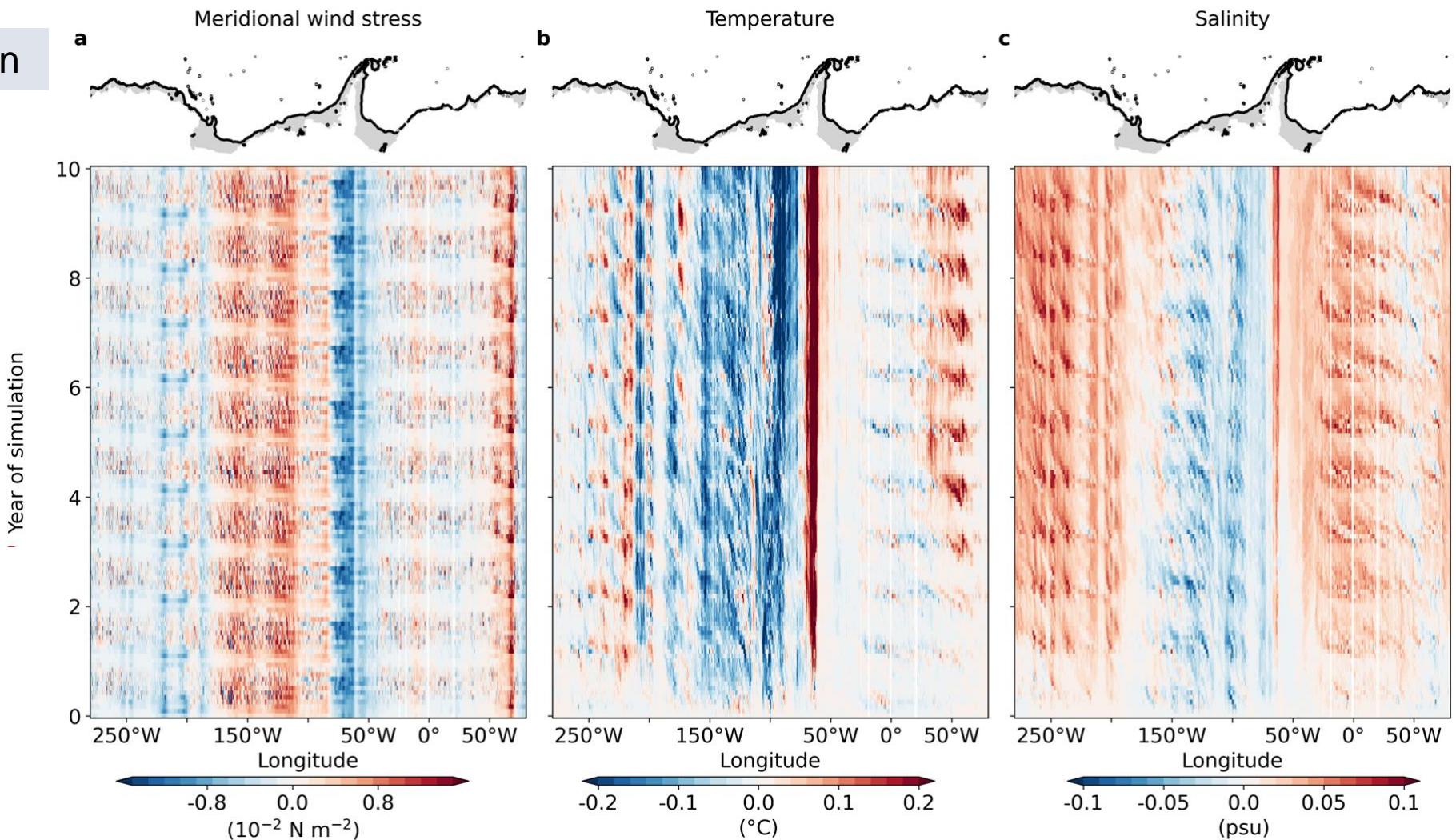
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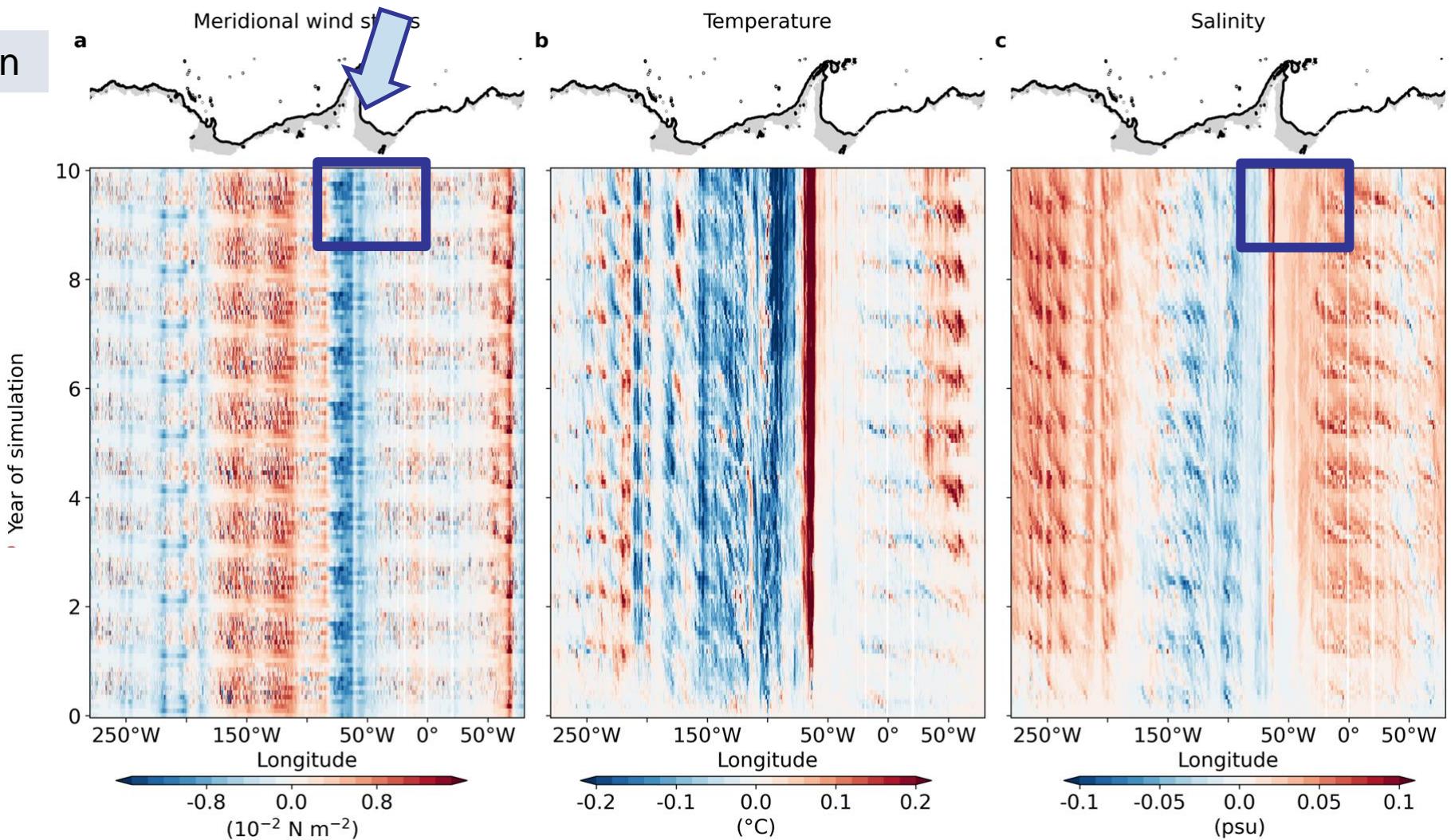
IPO changes in dense shelf water formation

2σ negative IPO simulation

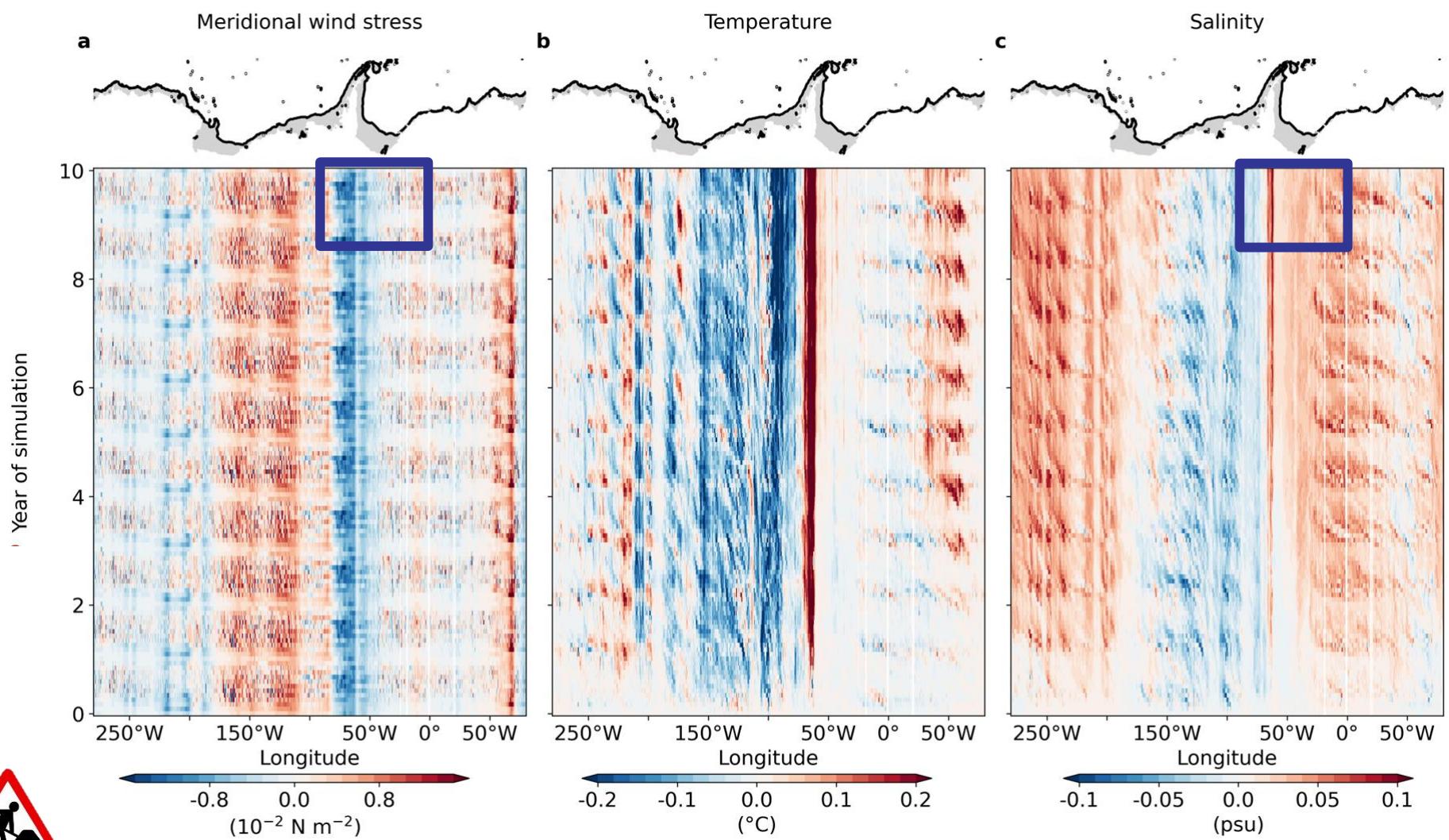
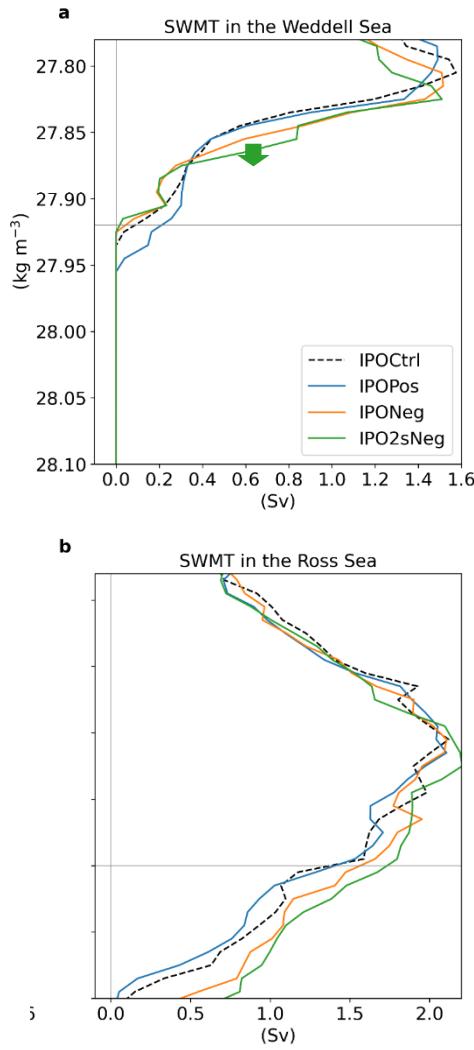


IPO changes in dense shelf water formation

2 σ negative IPO simulation

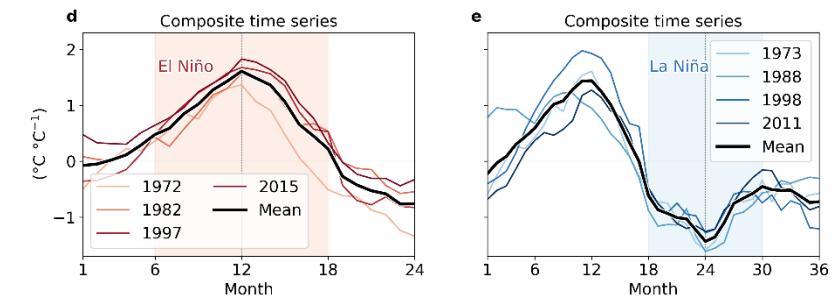


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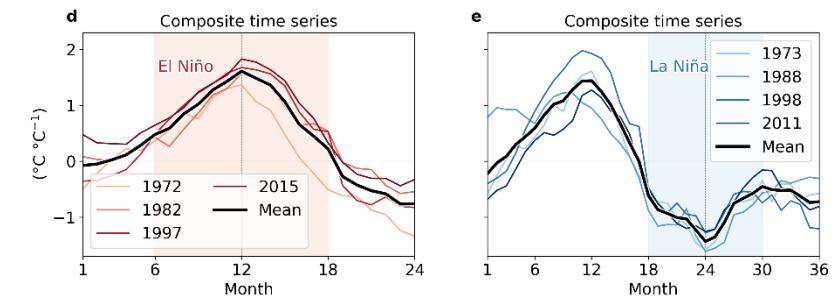


... but wait, there is more!

ENSOAntarctica project



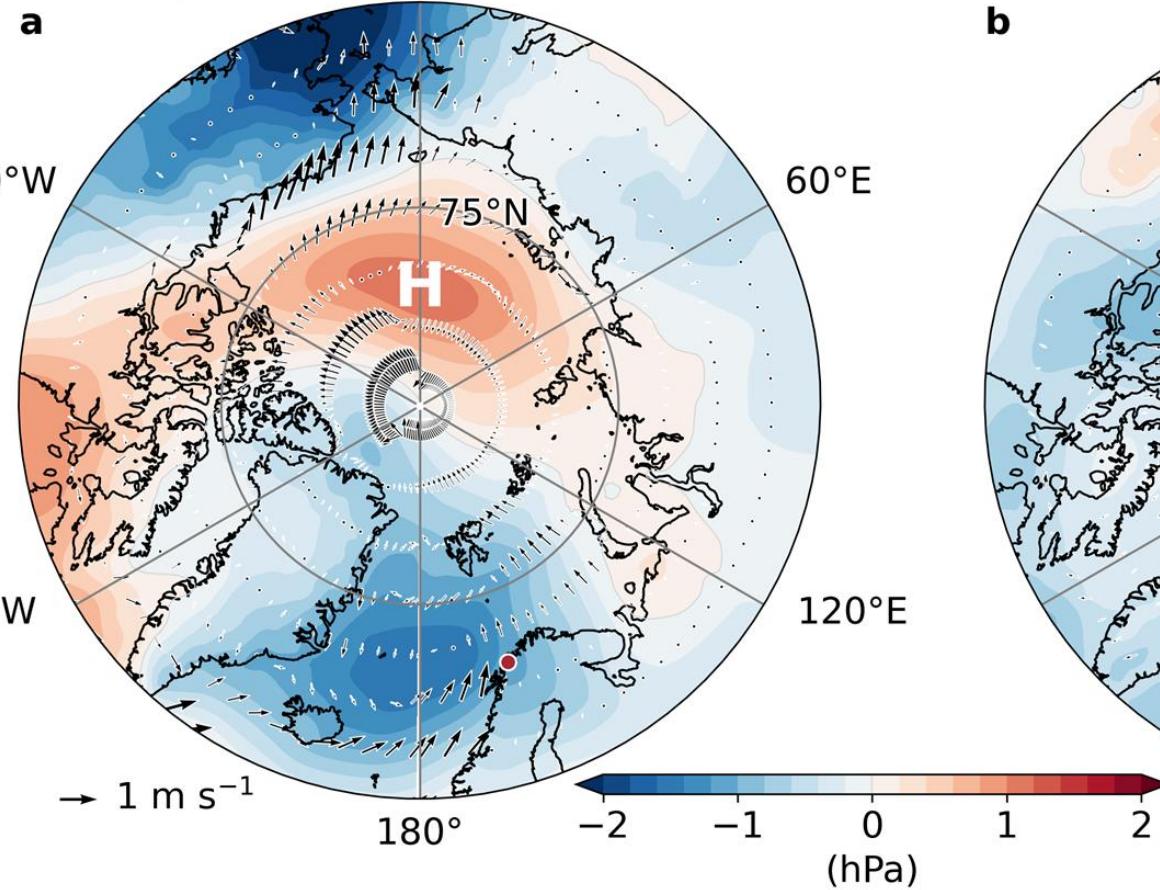
ENSOAntArctic project!



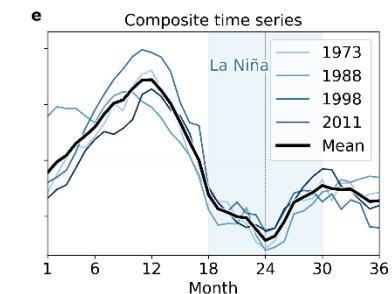
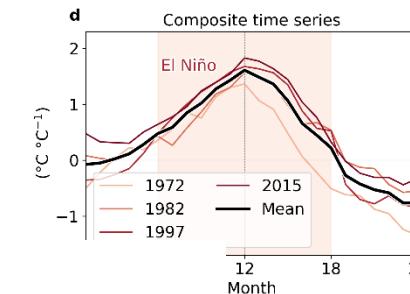
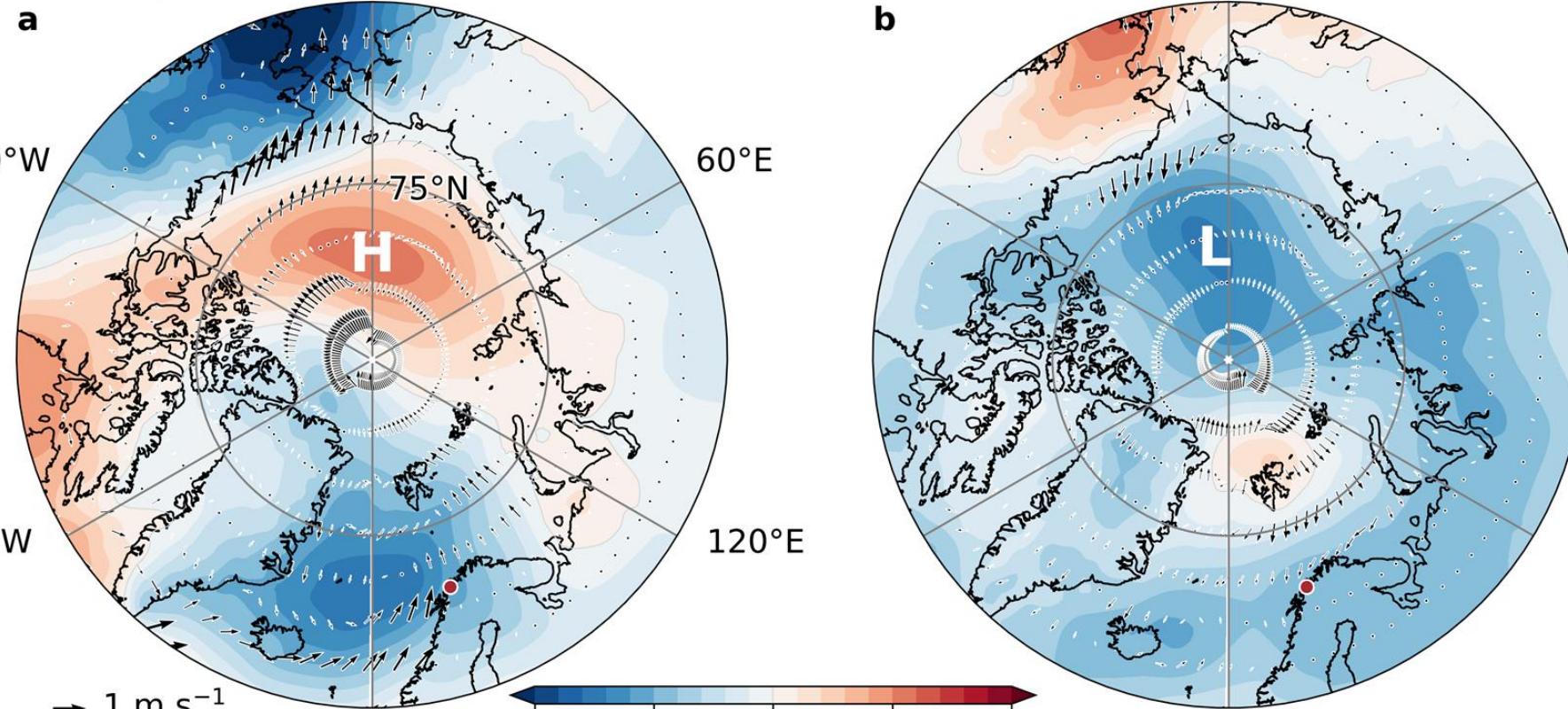
ENSOAntArctic project!

El Niño

Composite SLP and wind anomalies



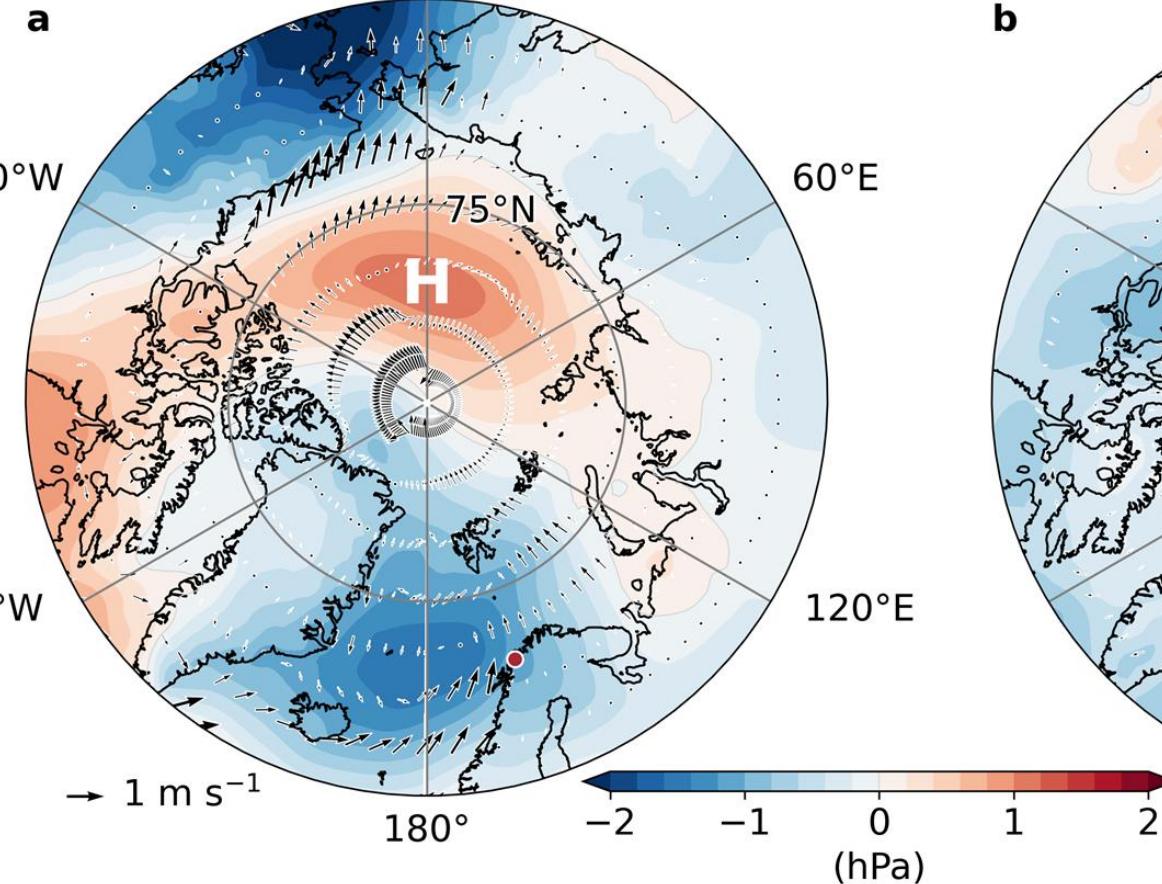
La Niña



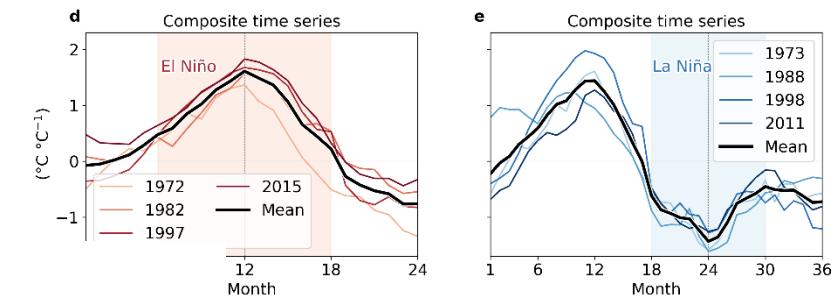
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La Niña

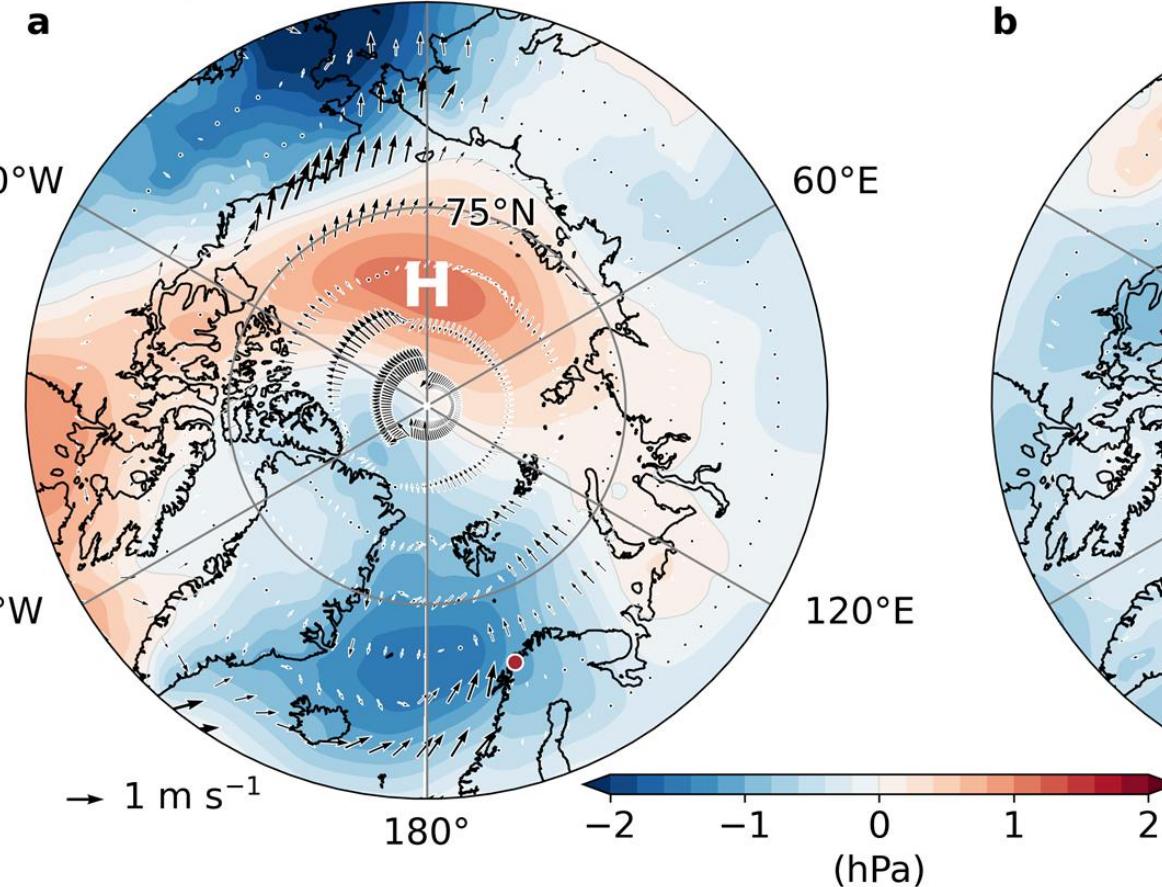


- Impacts on sea ice?
- Impacts on heat budget?
- More heat advection through Spitsbergen current?
- What happens to the Greenland coastal current?
- Are the anomalies too weak?

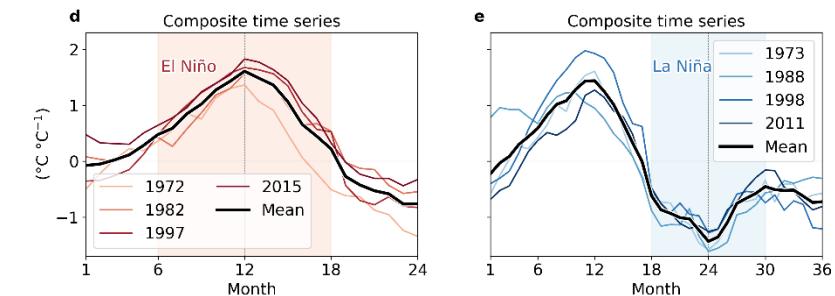
ENSOAntArctic project!

El Niño

Composite SLP and wind anomalies



La Niña



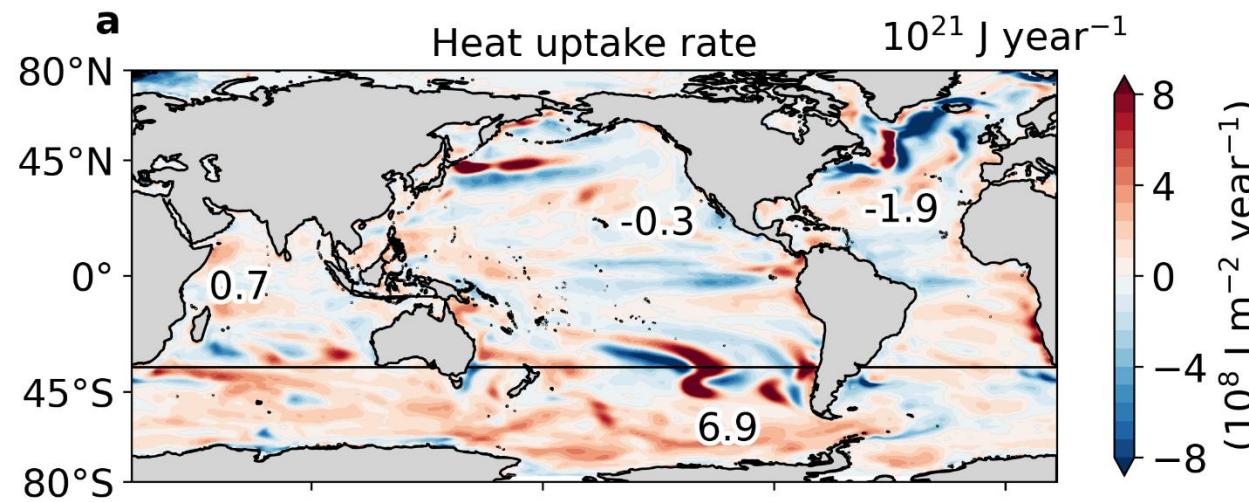
- Impacts on sea ice?
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Come chat with me!
Clark 349

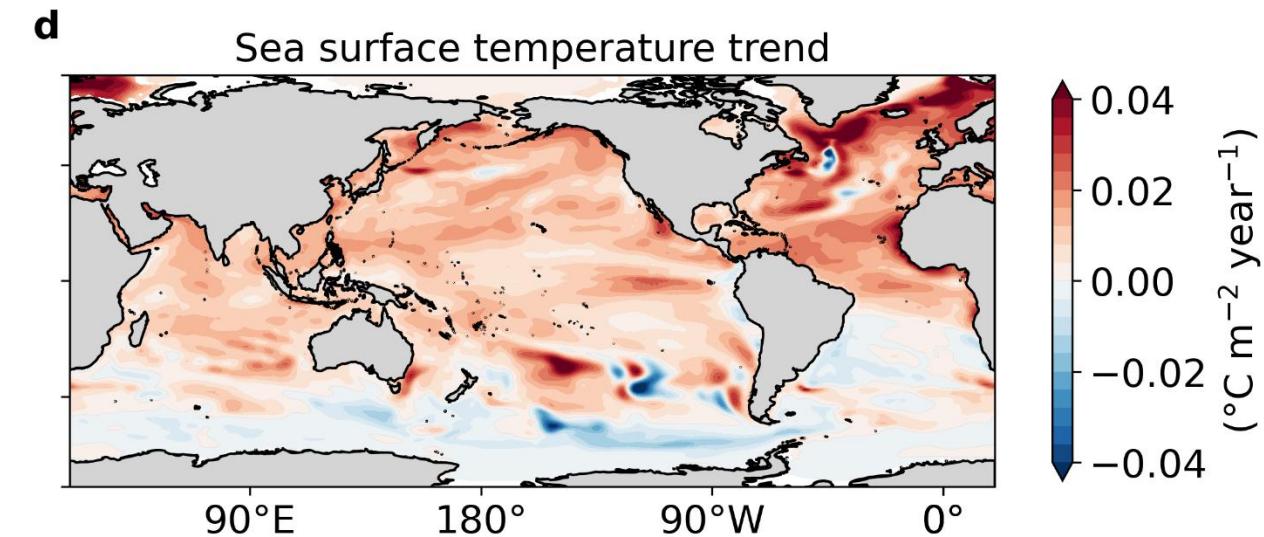
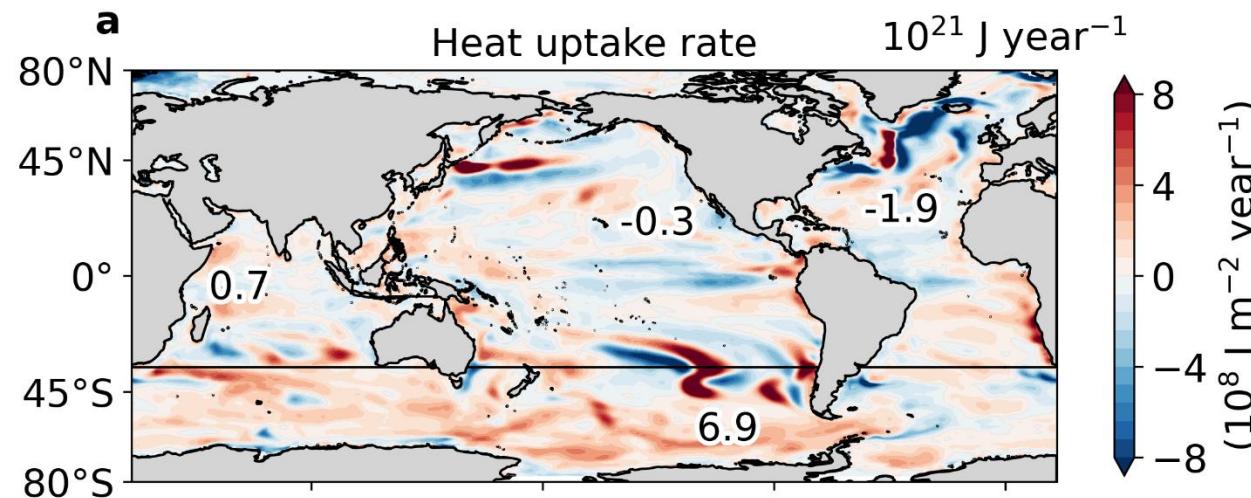
old slides

Ocean heat uptake, transport and storage

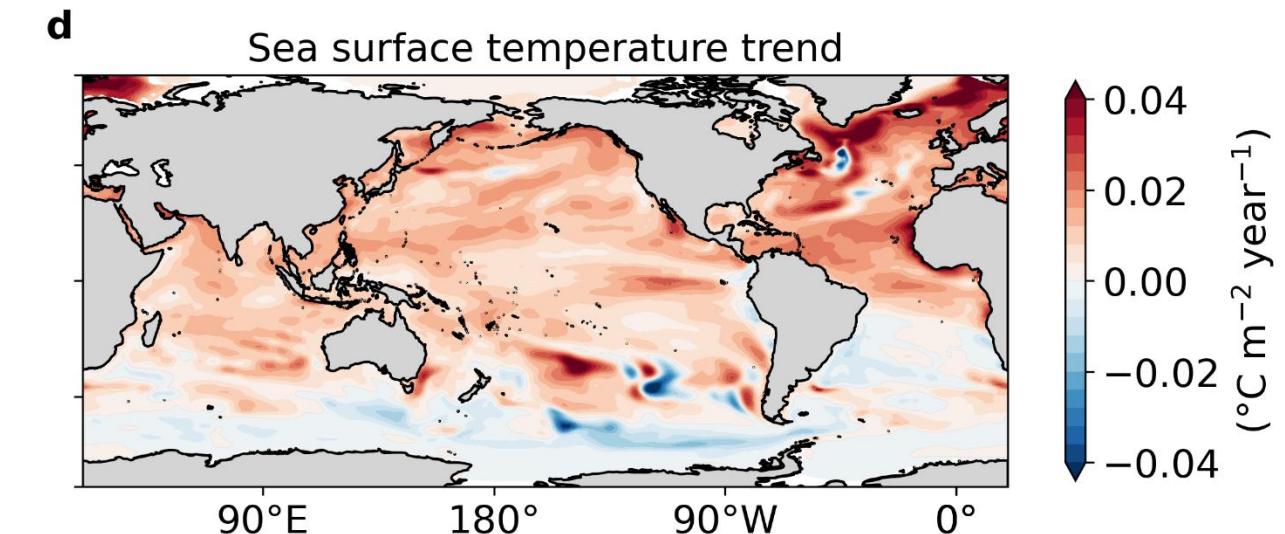
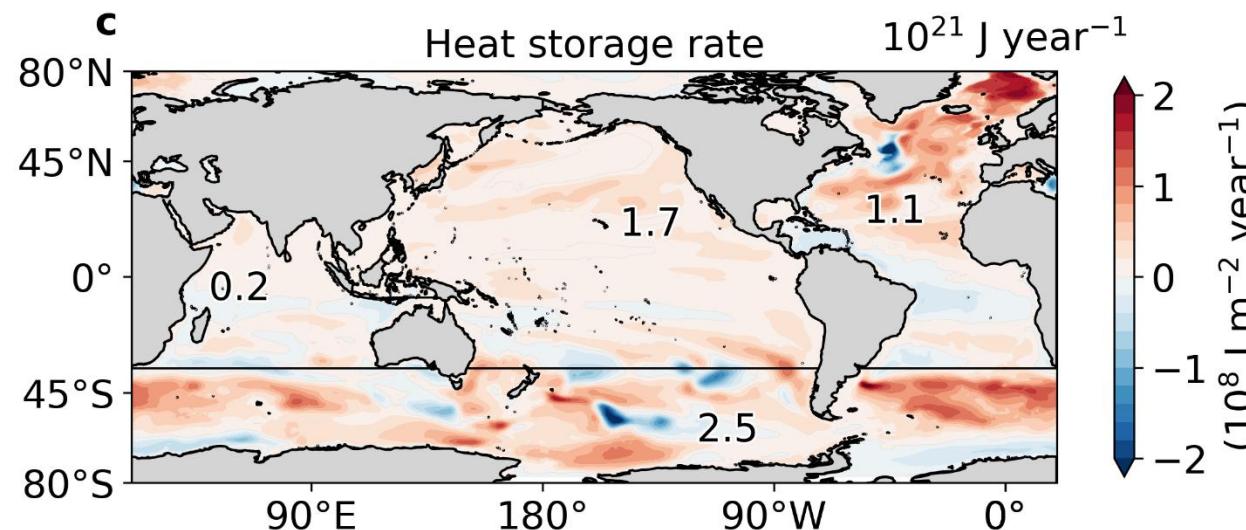
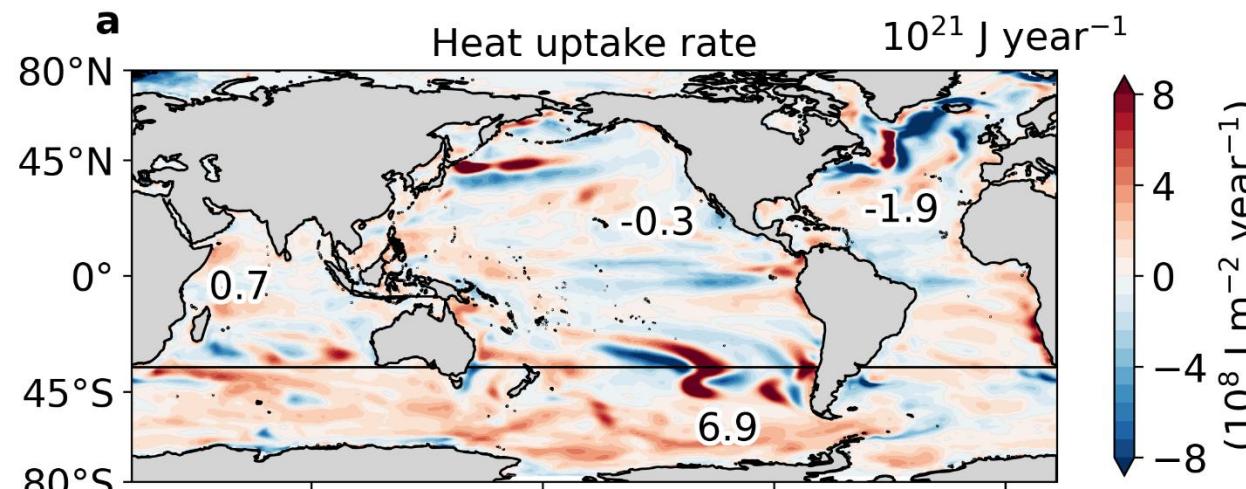
Ocean heat uptake, transport and storage



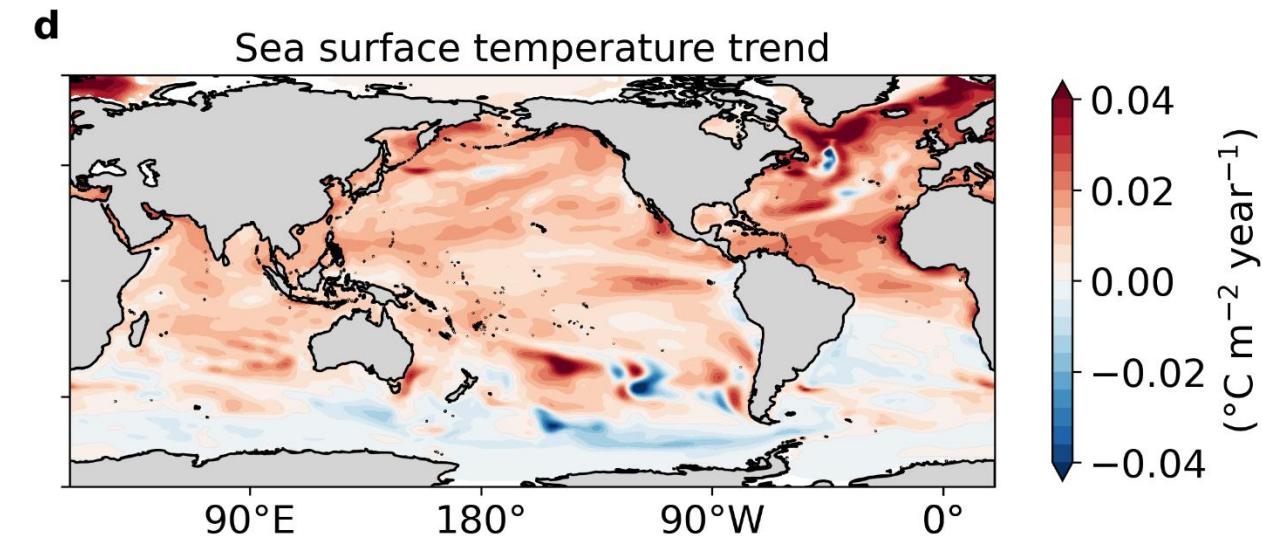
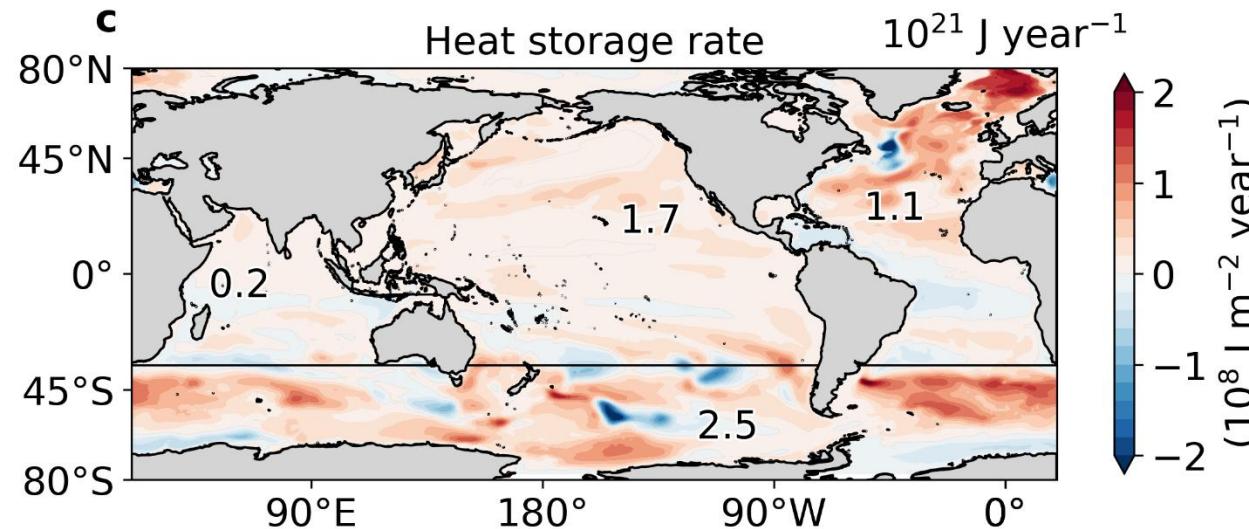
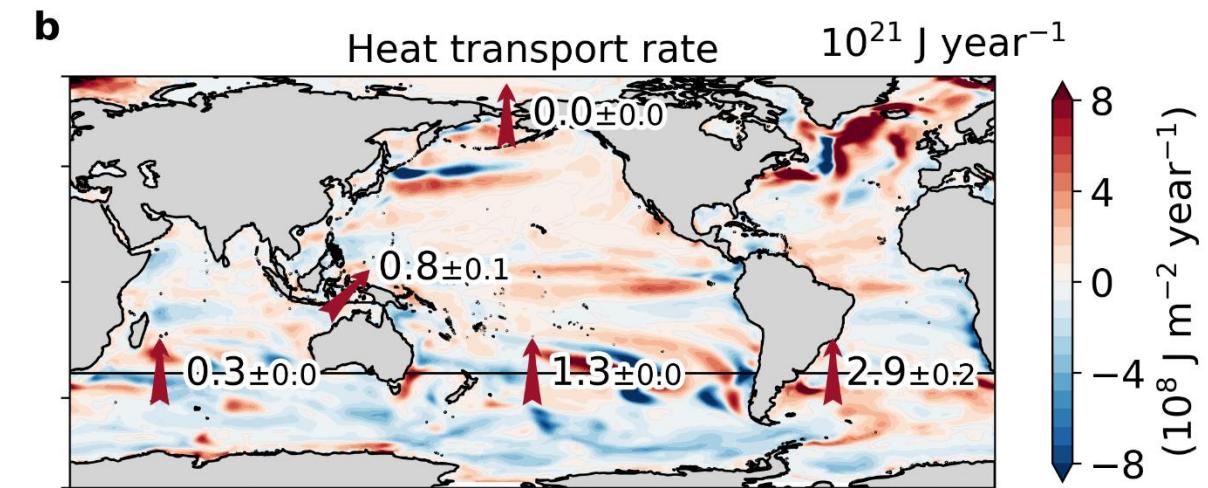
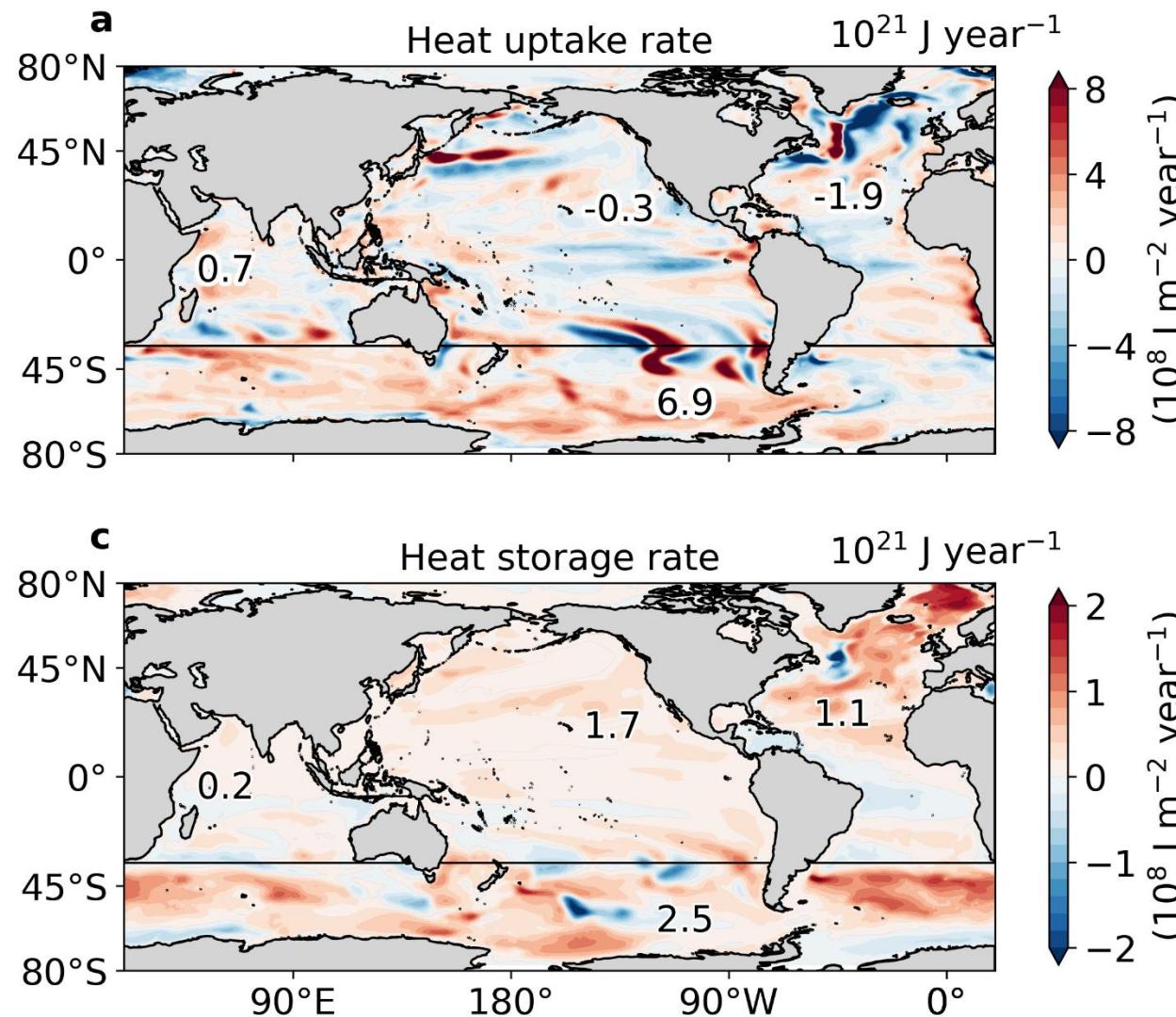
Ocean heat uptake, transport and storage



Ocean heat uptake, transport and storage



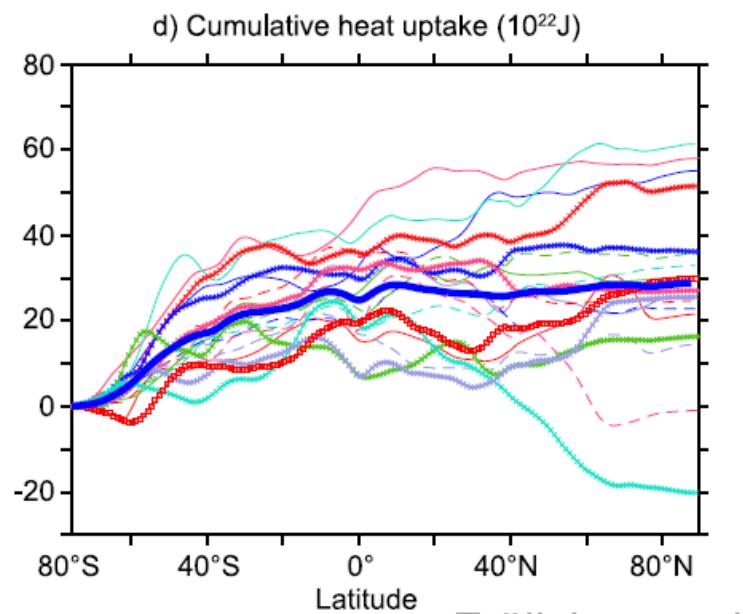
Ocean heat uptake, transport and storage



Take Home

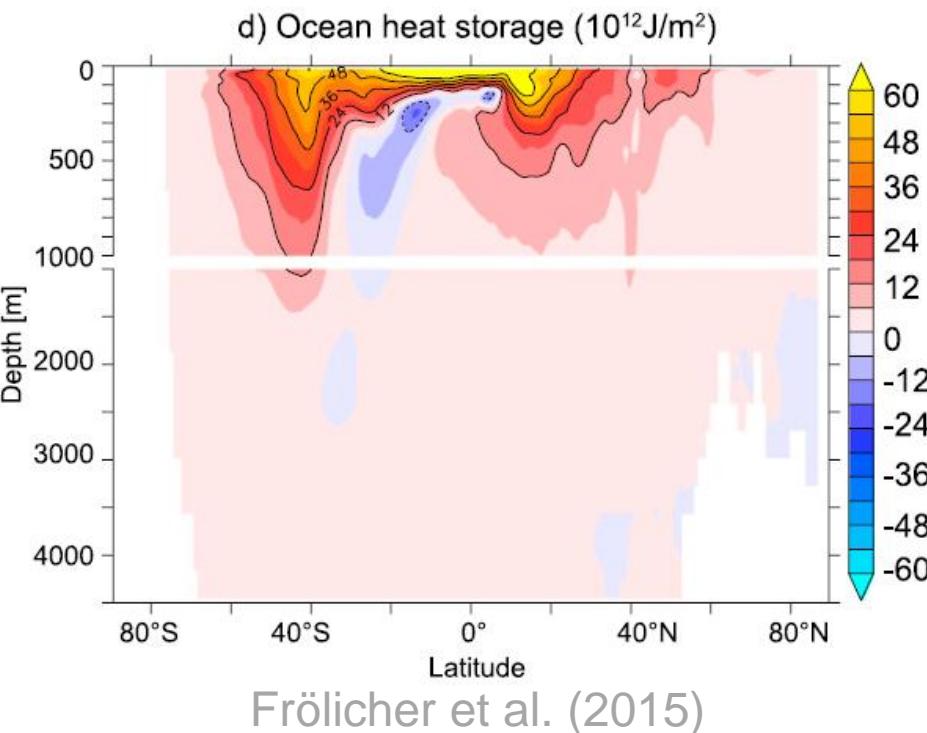
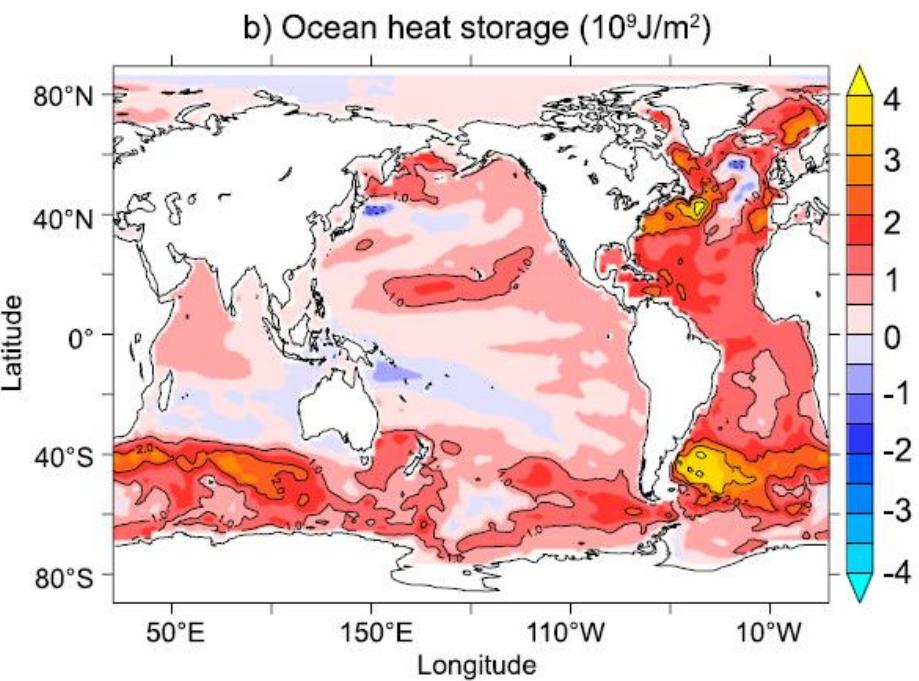
1. **Isolated strong ENSO** simulations illustrate how they modulate subsurface West Antarctic shelf temperatures
2. **El Niño weakens** coastal **easterlies**, **reduced** cold poleward **Ekman** transport & causes cross-shelf **upwelling** of warm **CDW**
3. **La Niña** shelf circulation **response**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

Importance of ocean heat content



Frölicher et al. (2015)

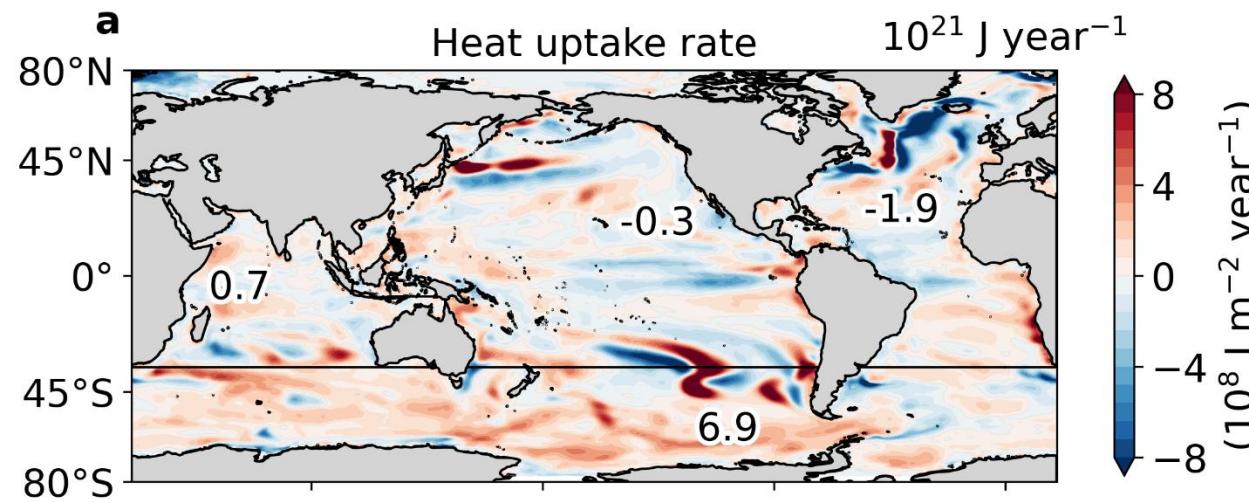
- CNRM-CM5
- IPSL-CM5A-LR
- IPSL-CM5A-MR
- IPSL-CM5B-LR
- FGOALS-s2
- MIROC-ESM-CHEM
- - - MIROC-ESM
- - - MIROC5
- - - HadGEM2-CC
- - - MPI-ESM-LR
- MPI-ESM-MR
- MRI-CGCM3
- x GISS-E2-R
- x CCSM4
- x NorESM1-M
- x NorESM-ME
- x GFDL-CM3
- x GFDL-ESM2M
- GFDL-ESM2G
- █ Ensemble mean



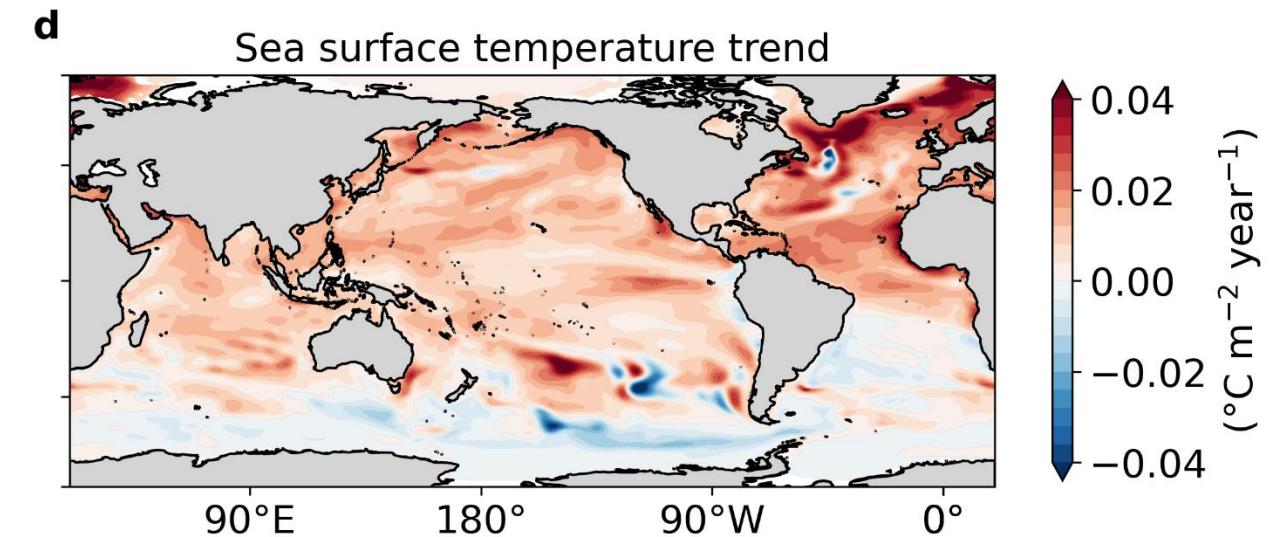
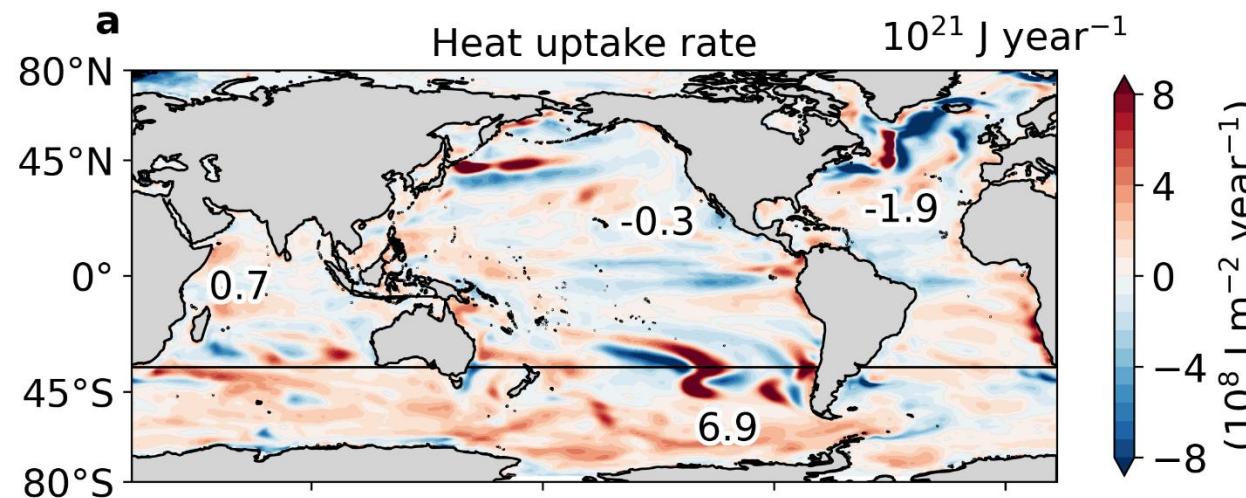
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Ocean heat uptake, transport and storage

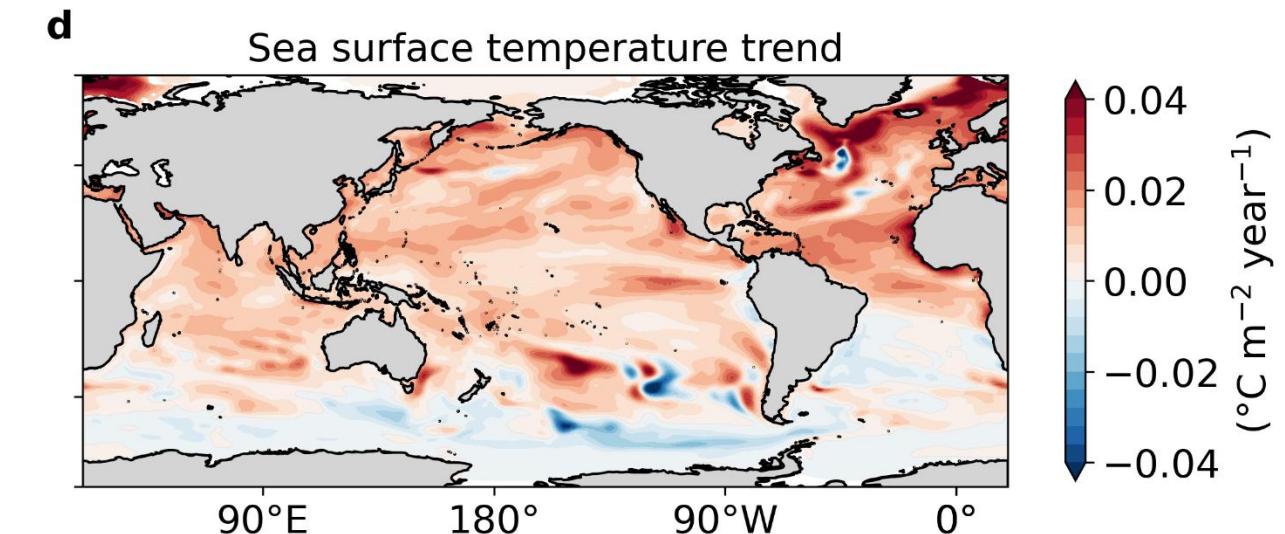
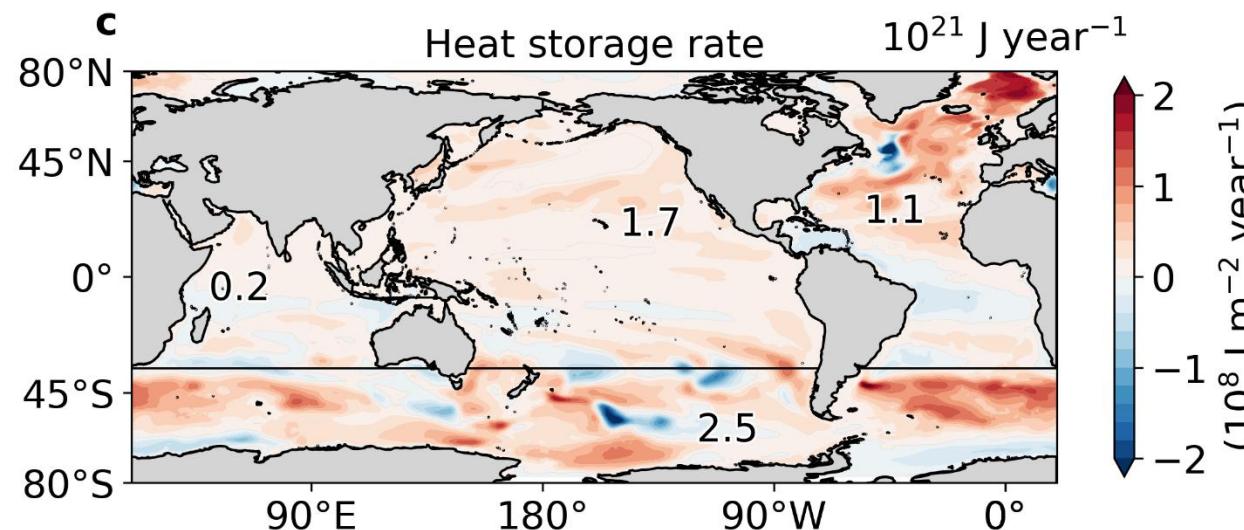
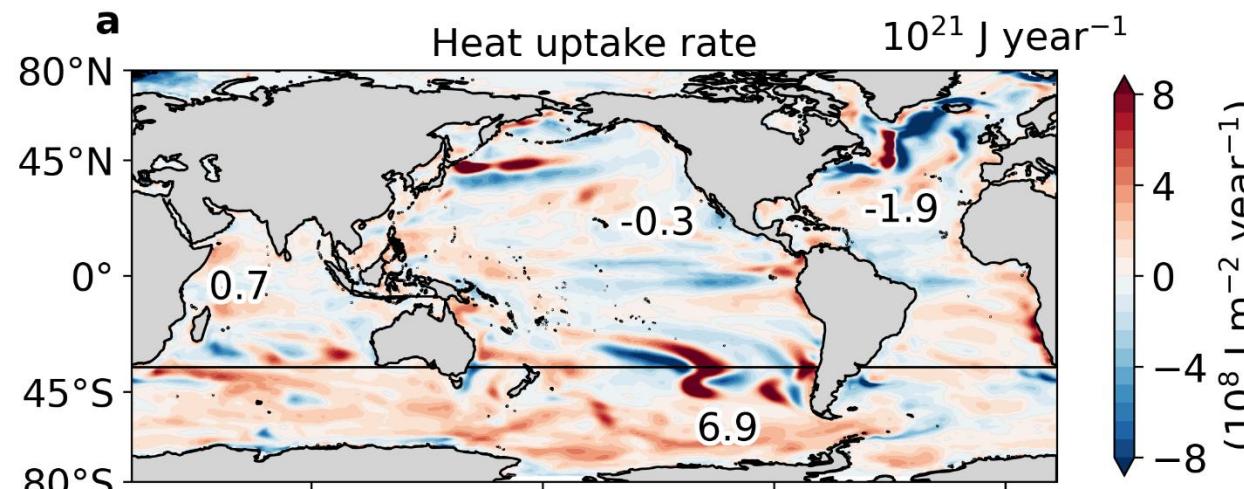
Ocean heat uptake, transport and storage



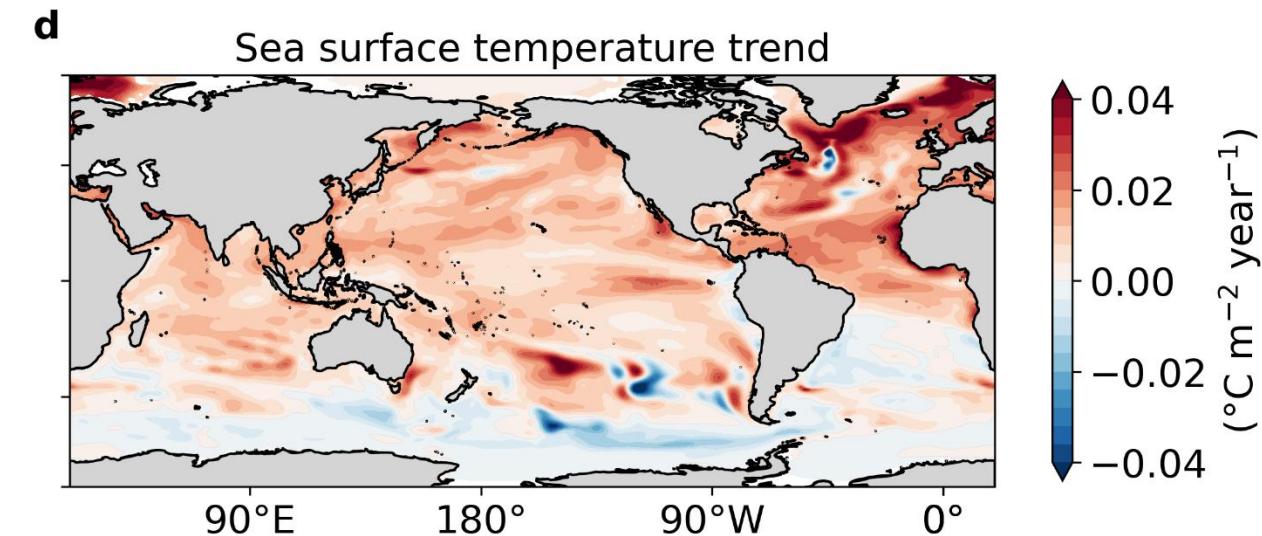
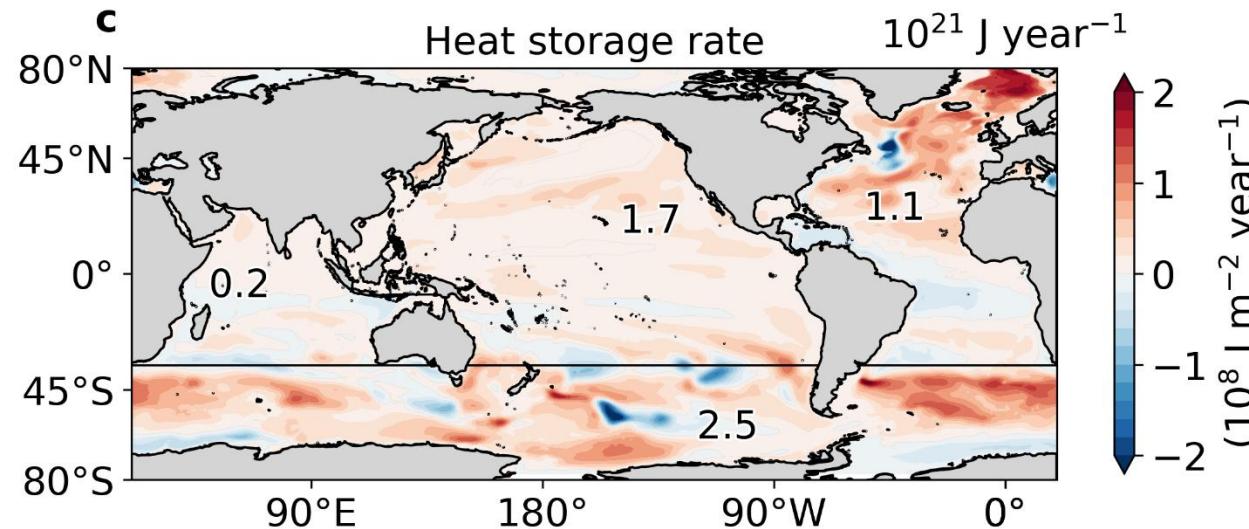
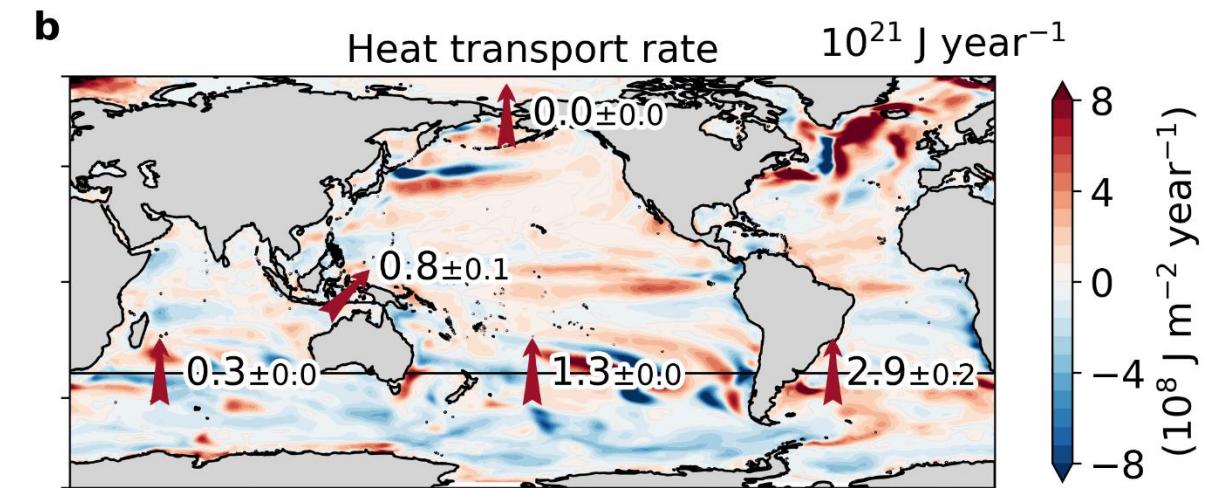
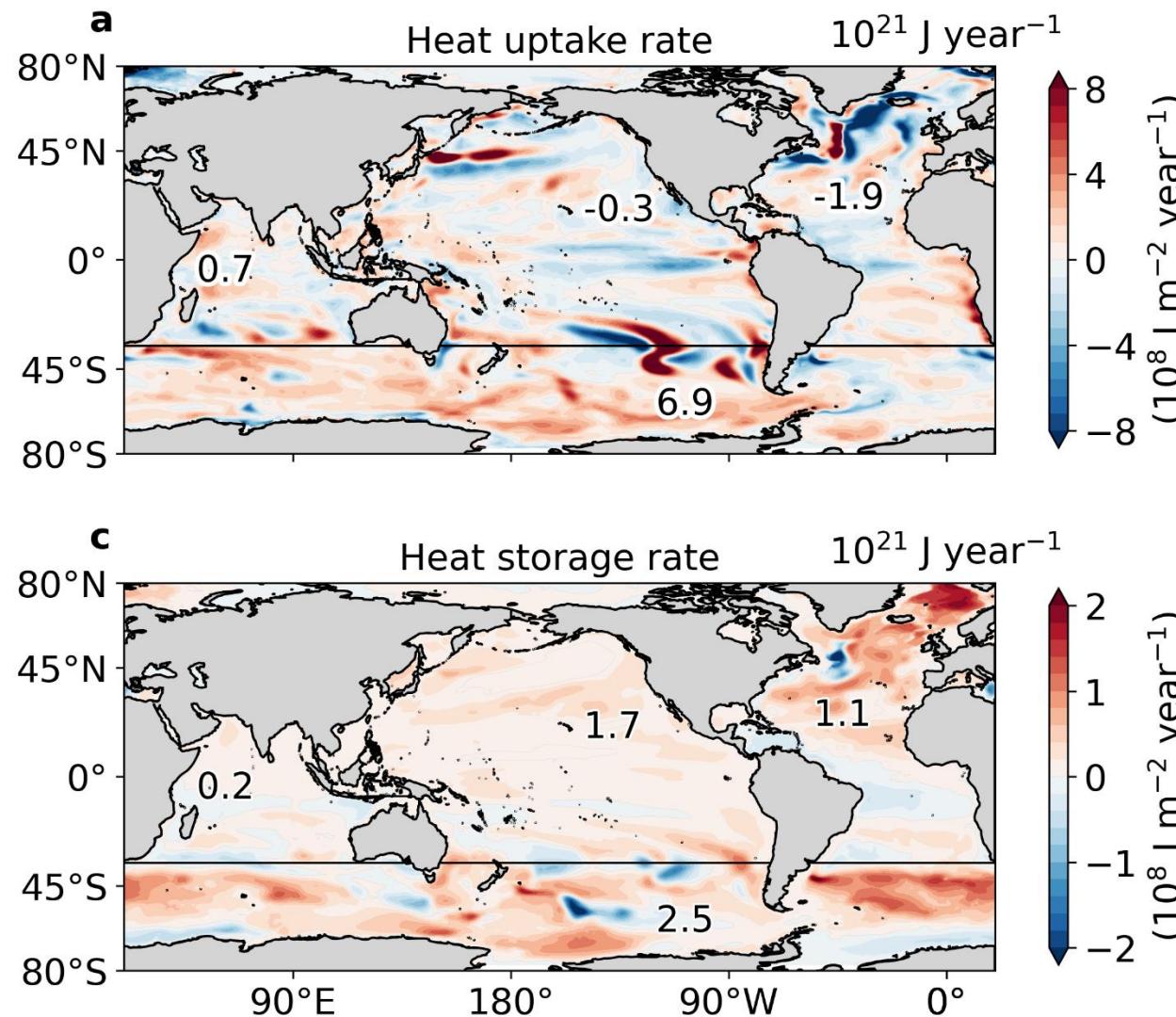
Ocean heat uptake, transport and storage



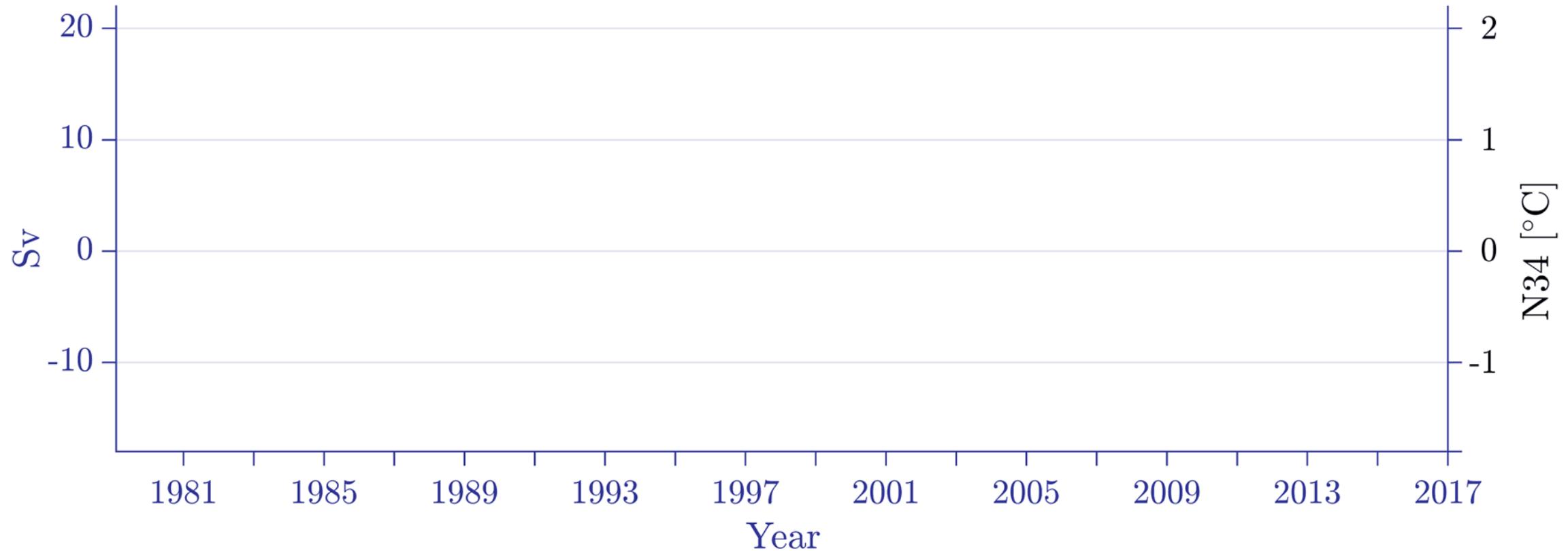
Ocean heat uptake, transport and storage



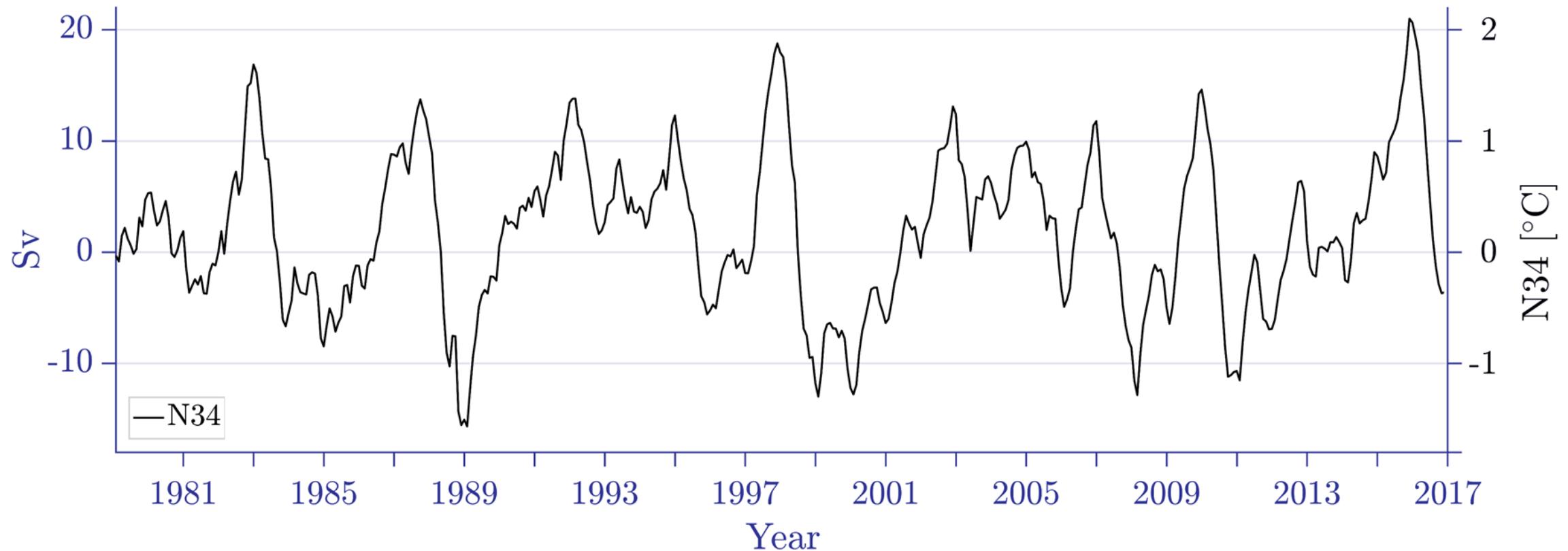
Ocean heat uptake, transport and storage



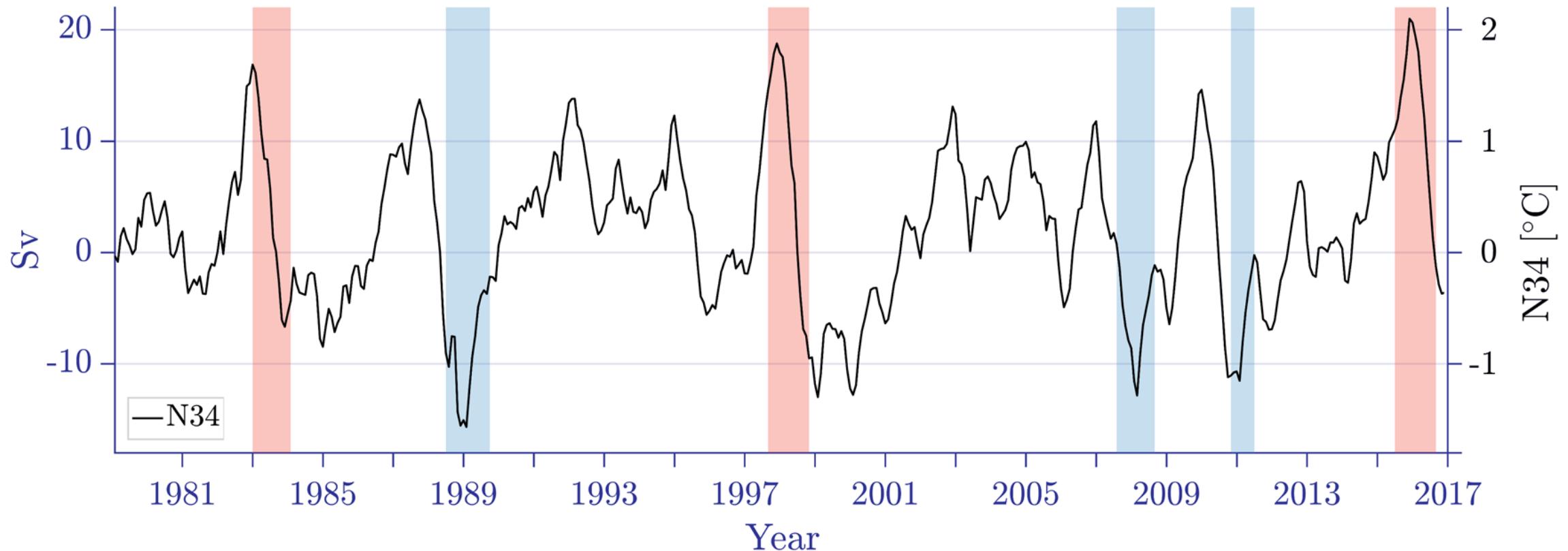
Interannual Variability of the Diabatic Fluxes



Interannual Variability of the Diabatic Fluxes



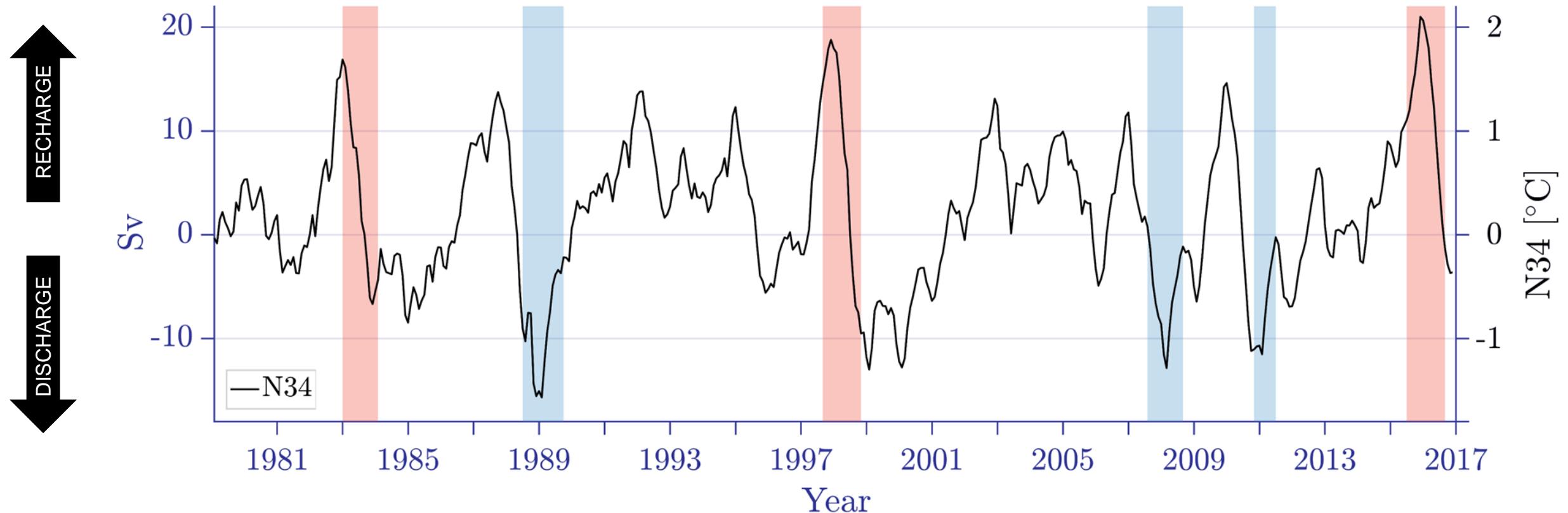
Interannual Variability of the Diabatic Fluxes



El Niño: discharge

La Niña: recharge

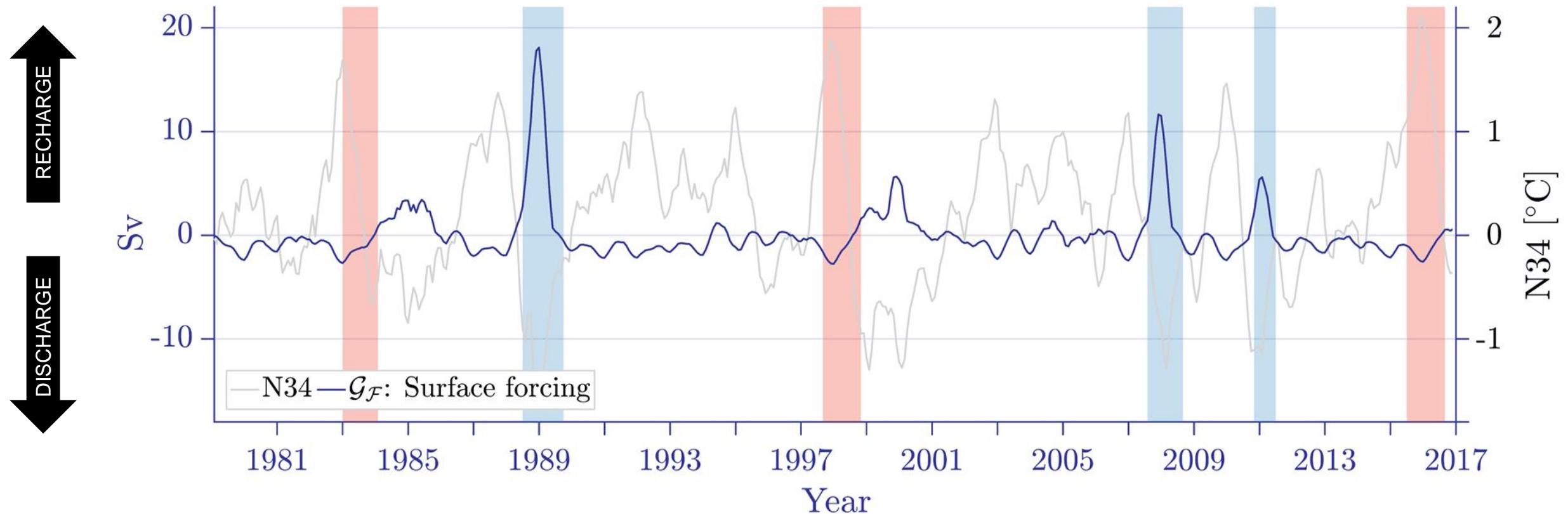
Interannual Variability of the Diabatic Fluxes



El Niño: discharge

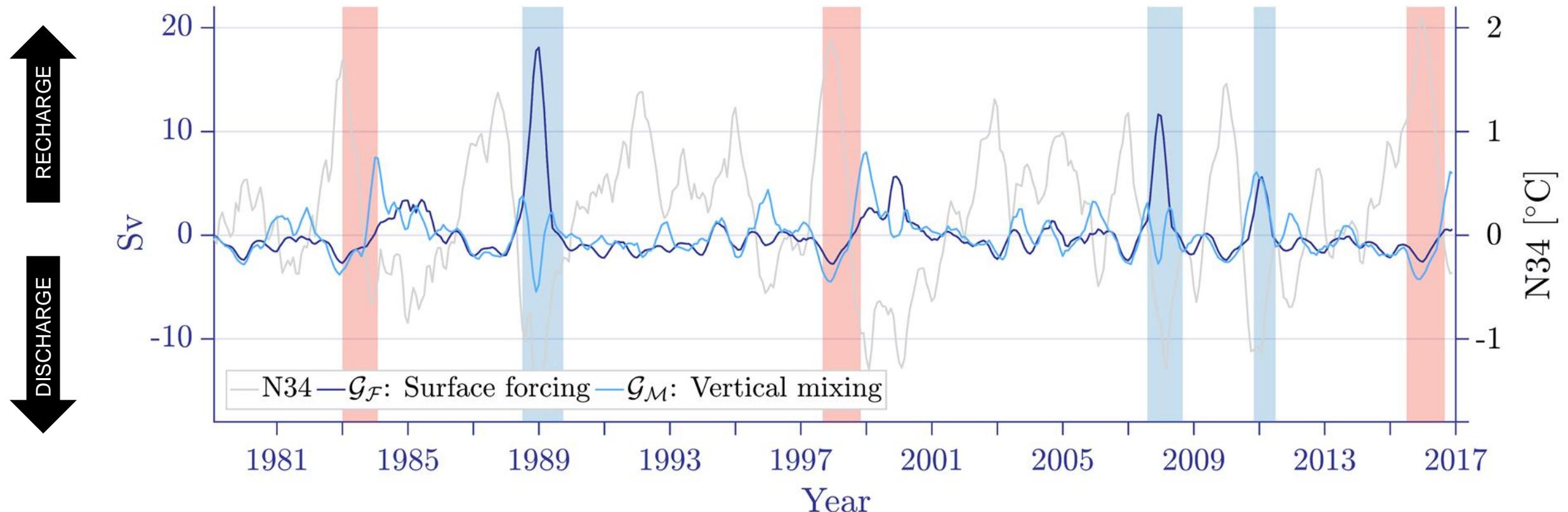
La Niña: recharge

Interannual Variability of the Diabatic Fluxes



La Niña: large positive contribution of surface forcing

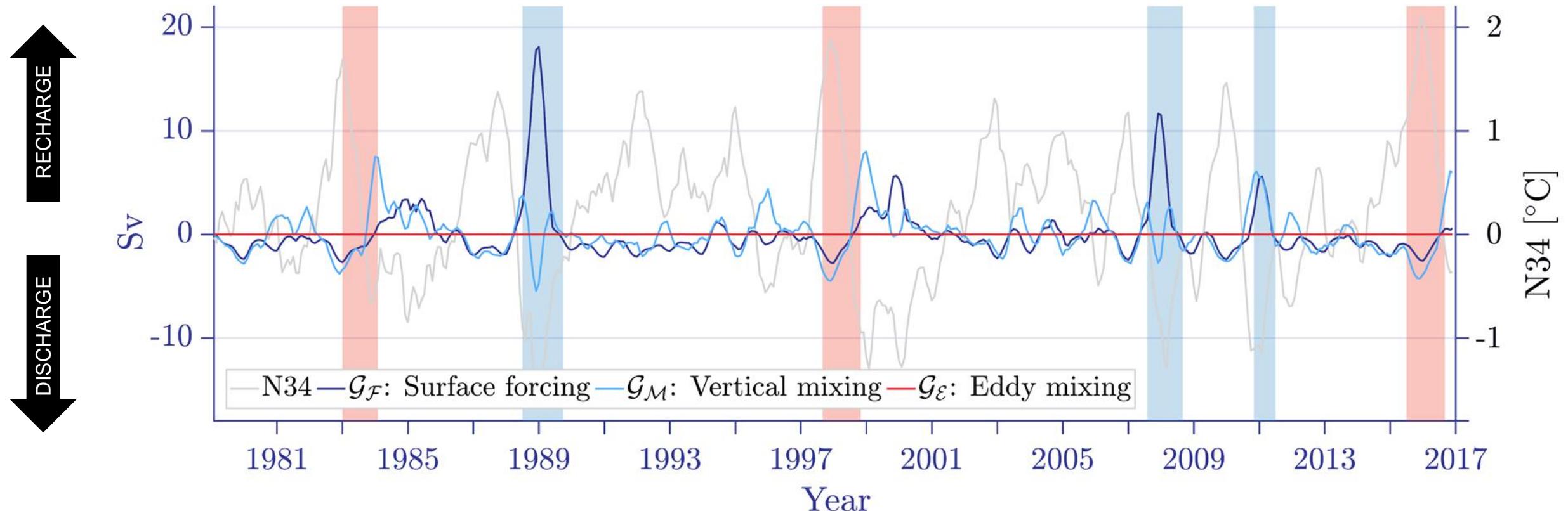
Interannual Variability of the Diabatic Fluxes



El Niño:
La Niña:

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

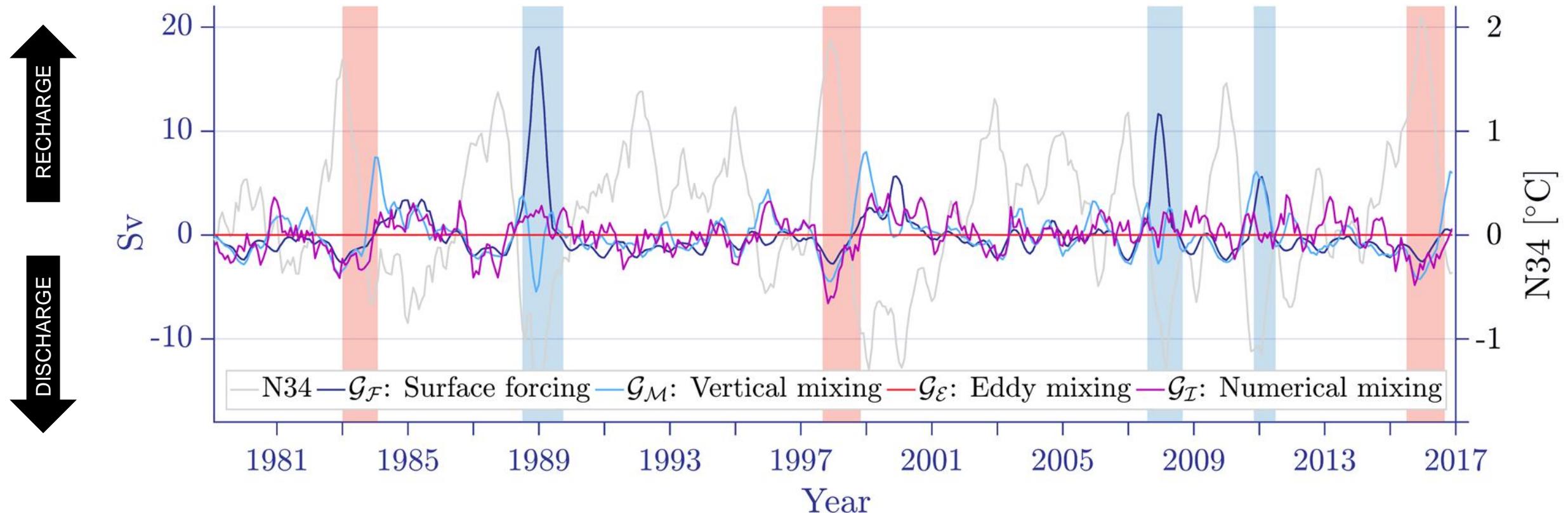
Interannual Variability of the Diabatic Fluxes



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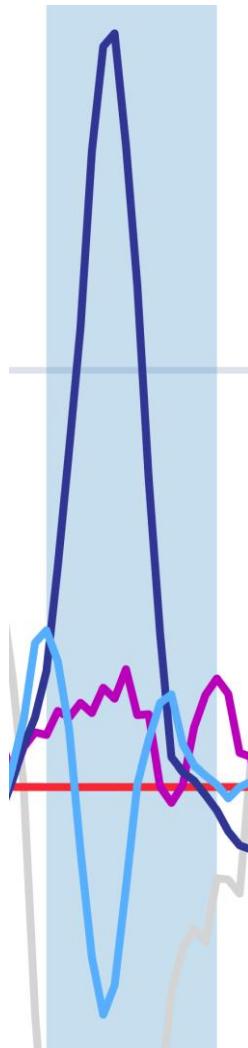
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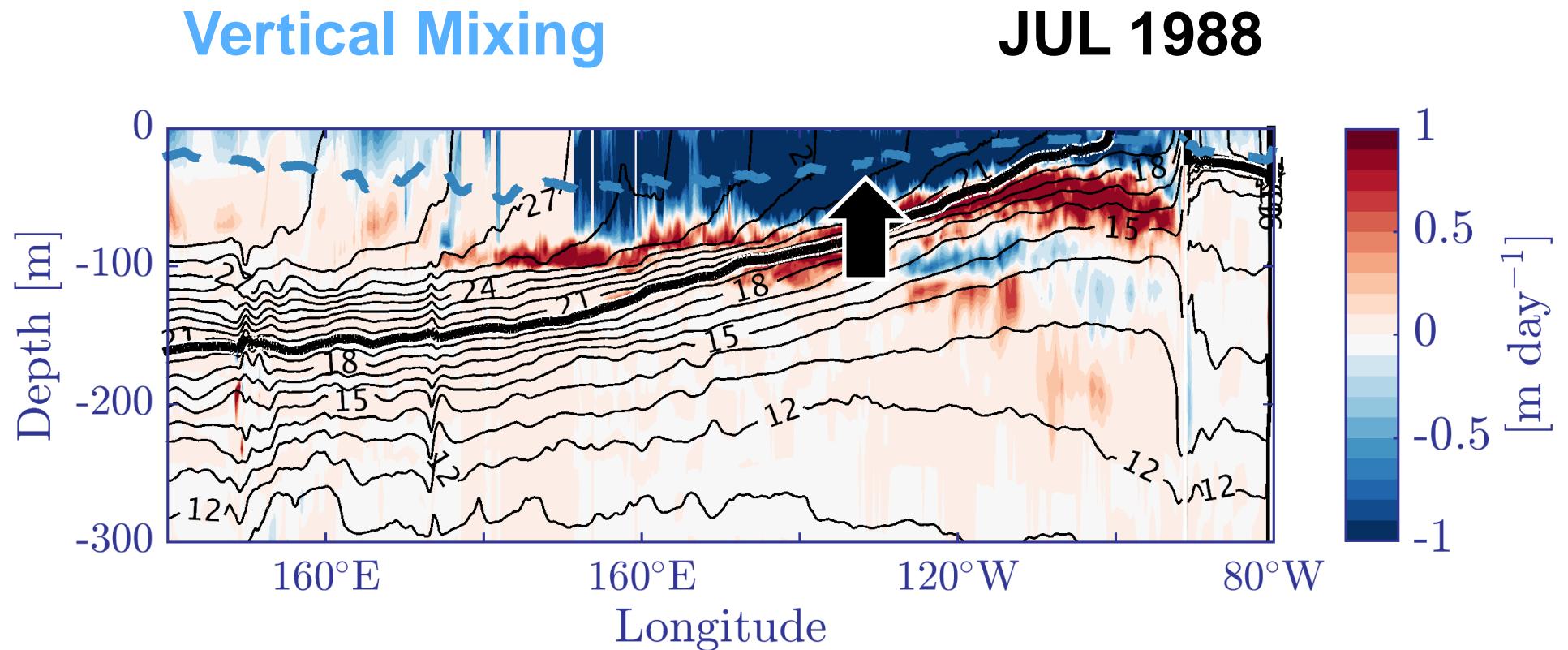
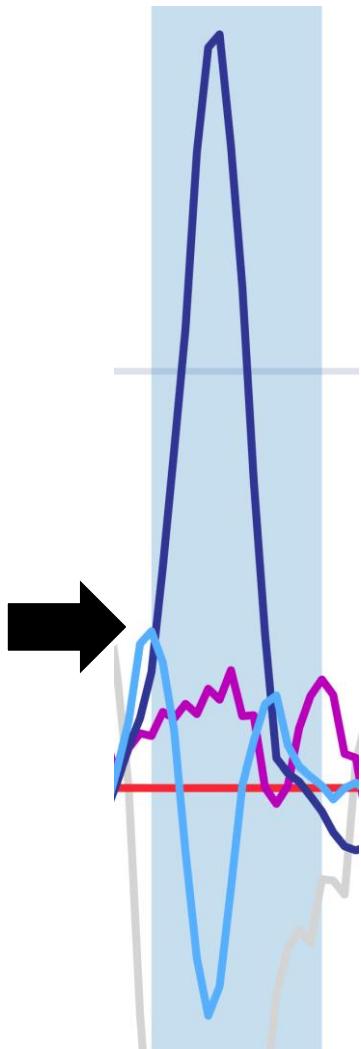
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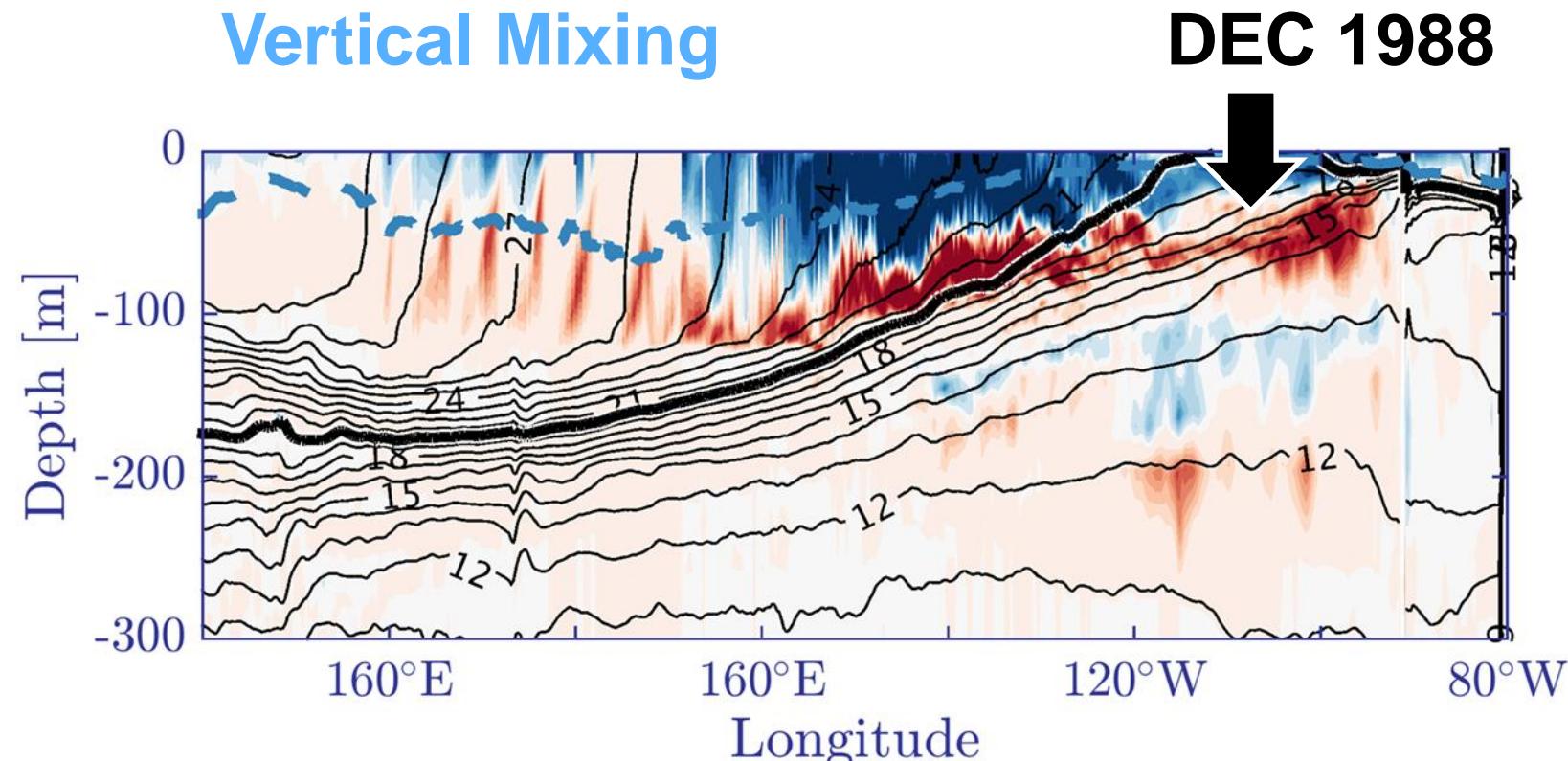
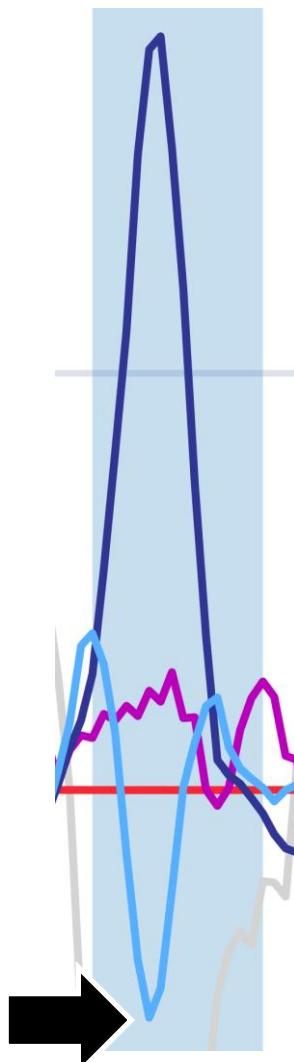
Diabatic Fluxes during La Niña 1988/89



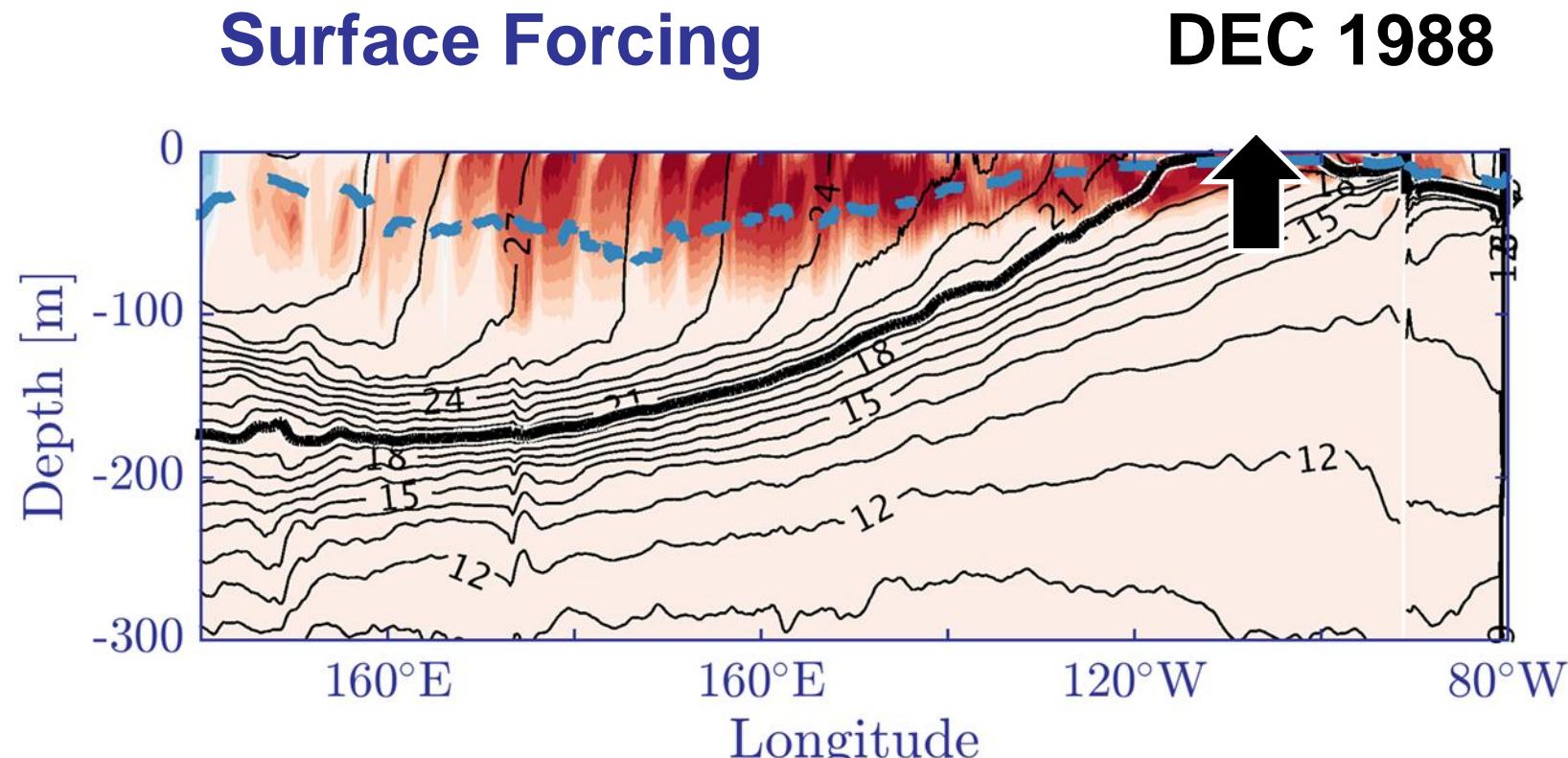
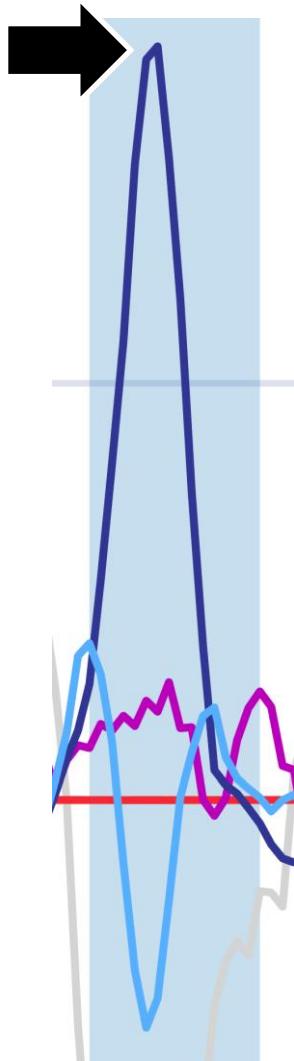
Diabatic Fluxes during La Niña 1988/89



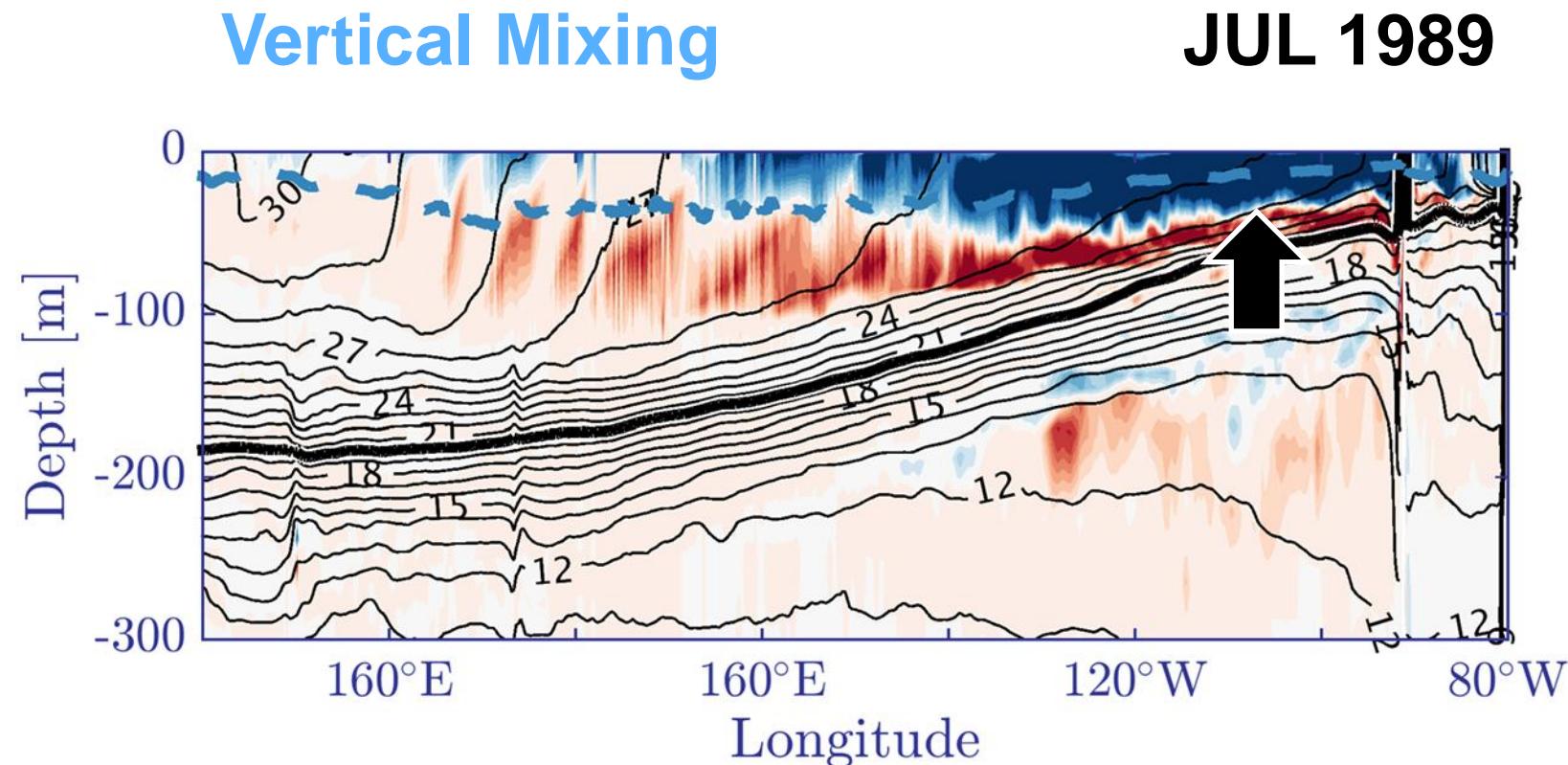
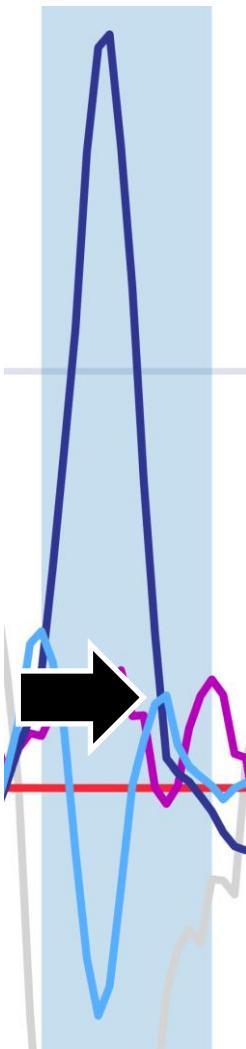
Diabatic Fluxes during La Niña 1988/89



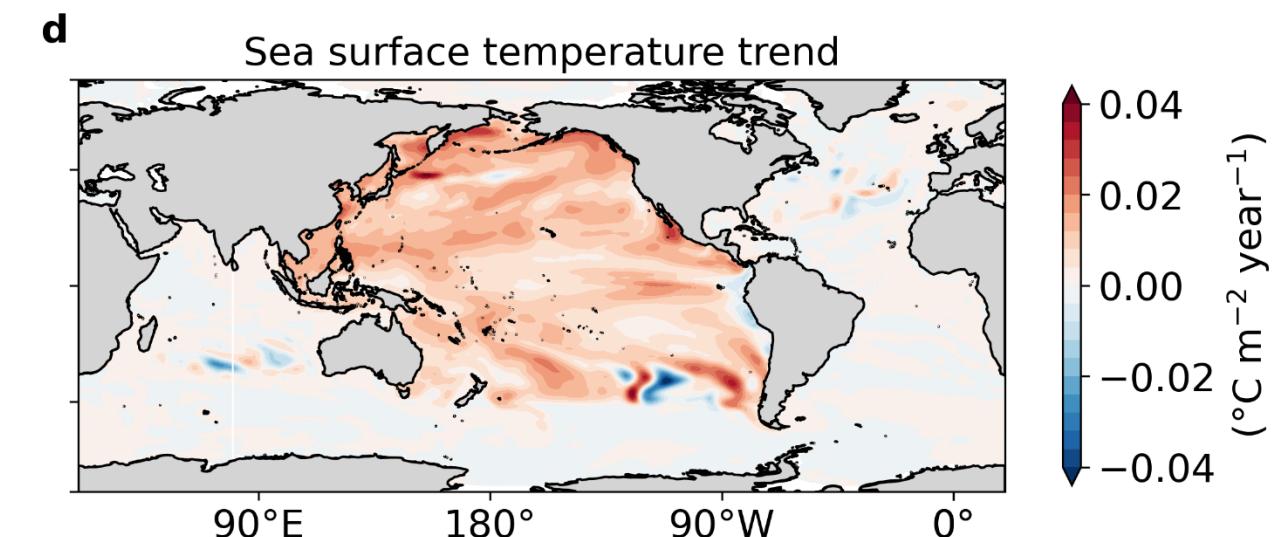
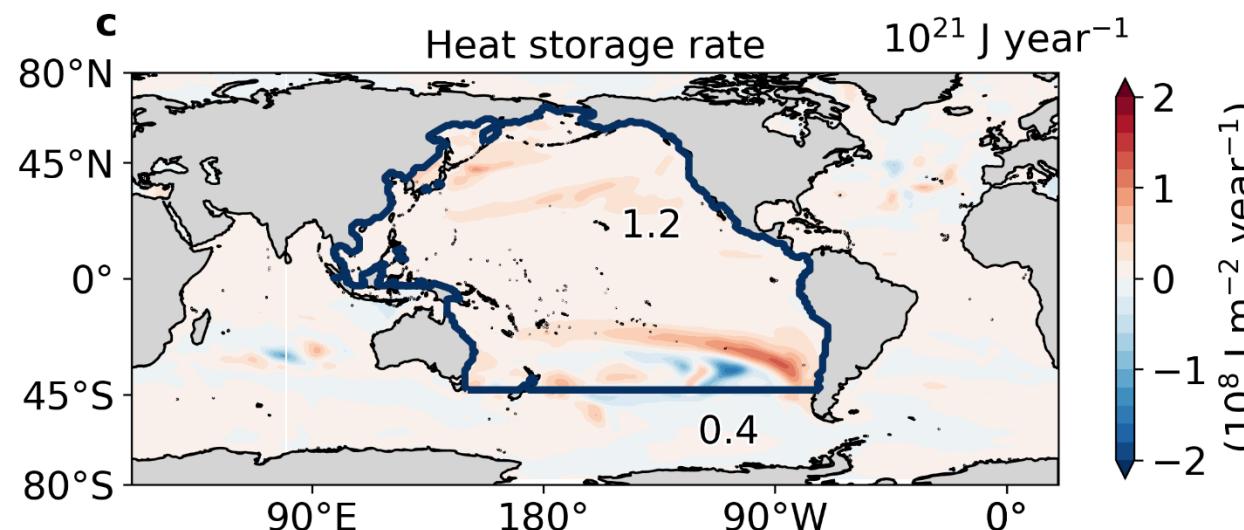
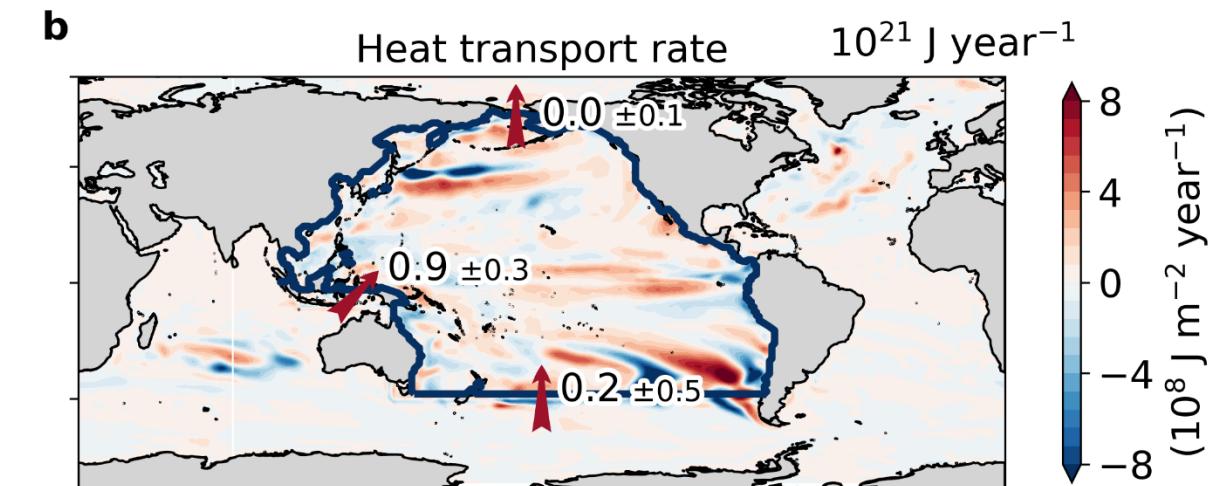
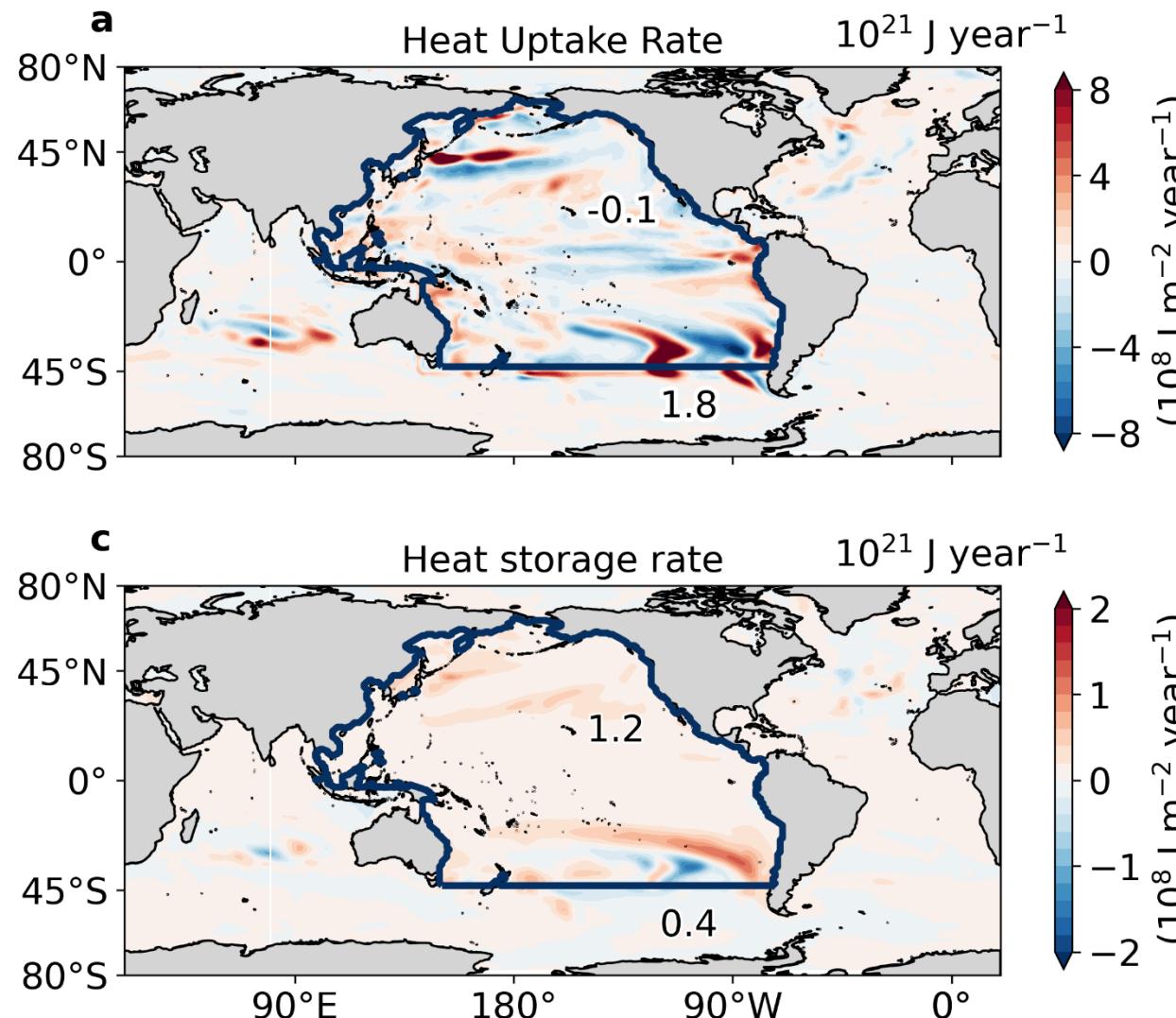
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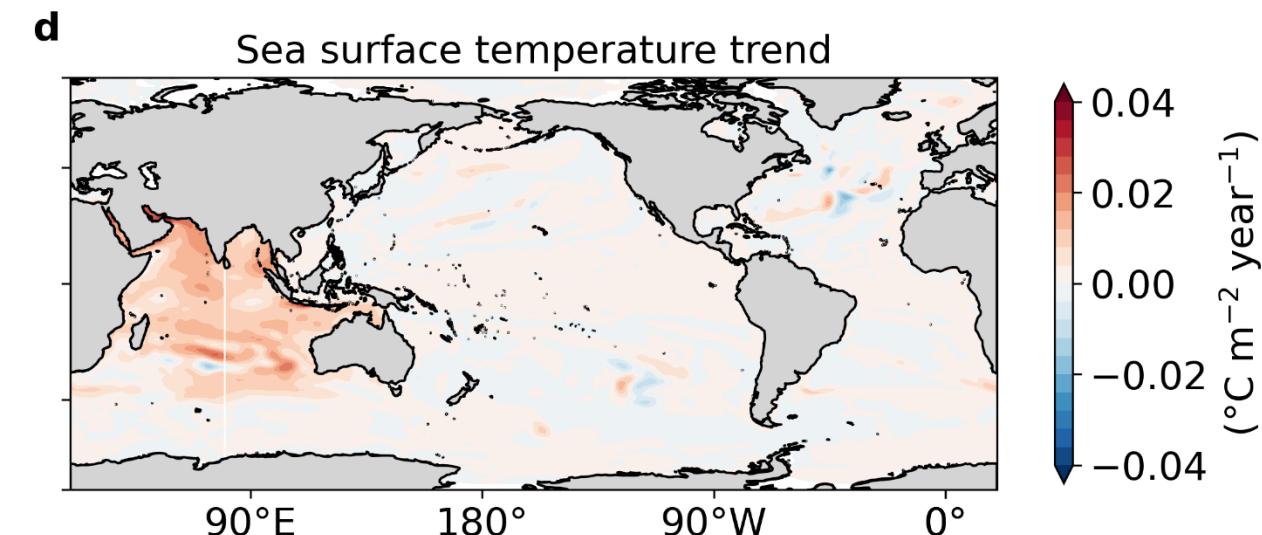
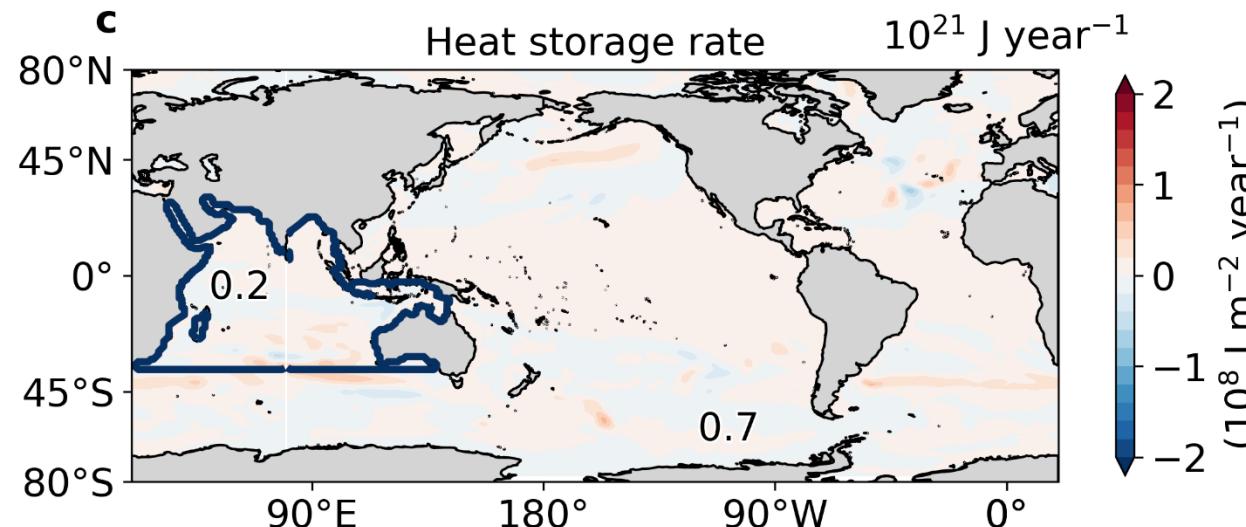
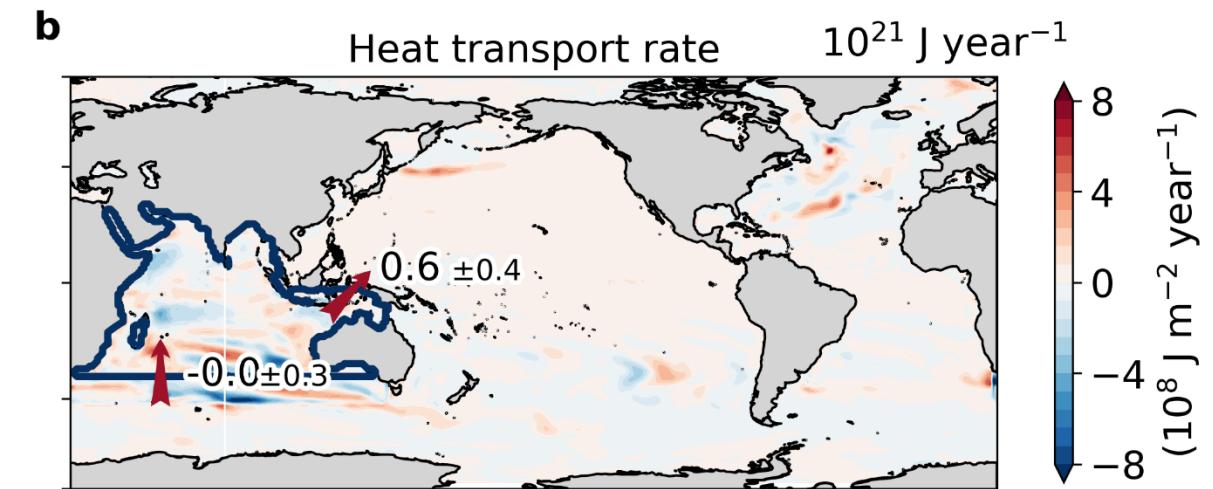
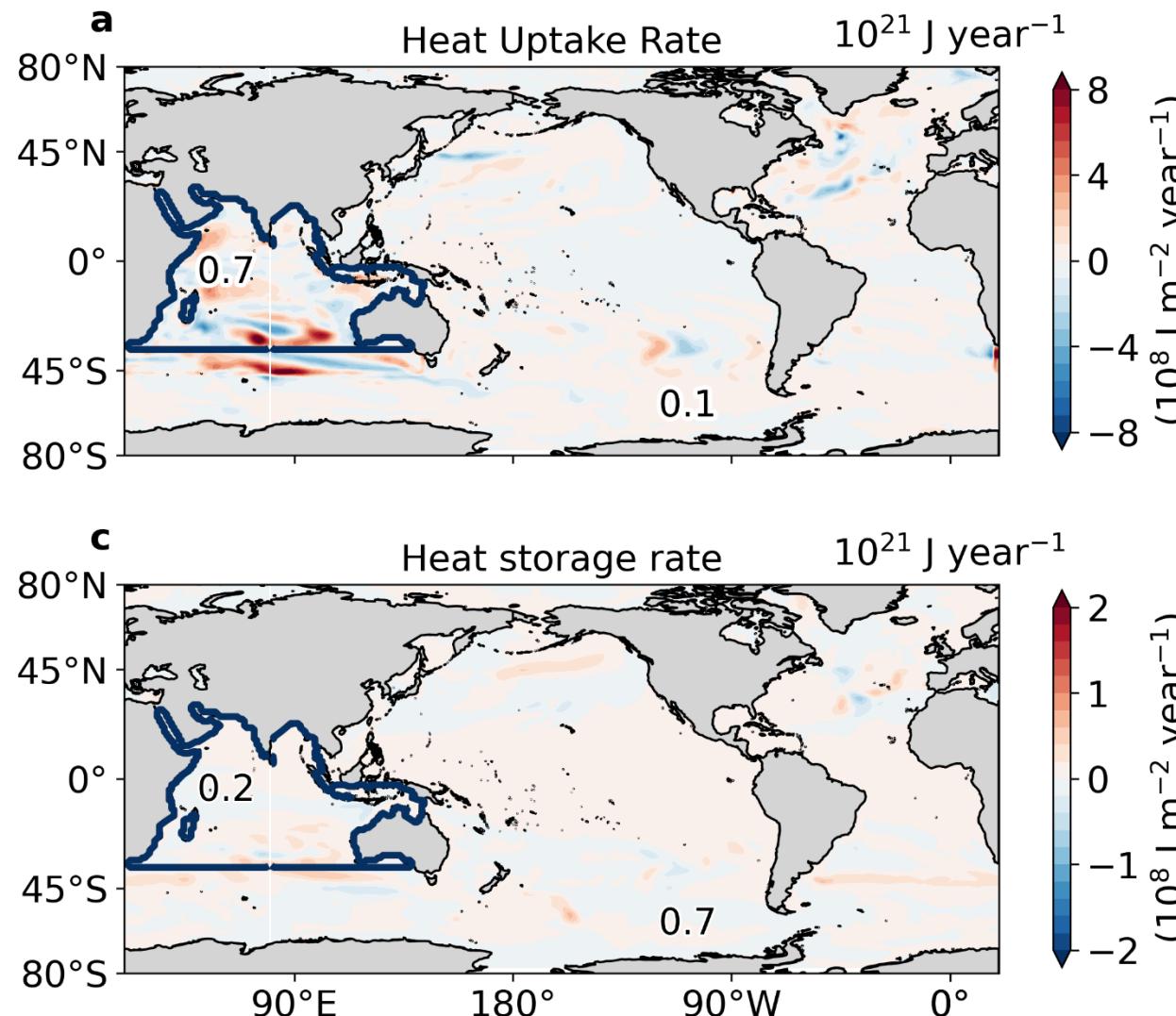
Diabatic Fluxes during La Niña 1988/89



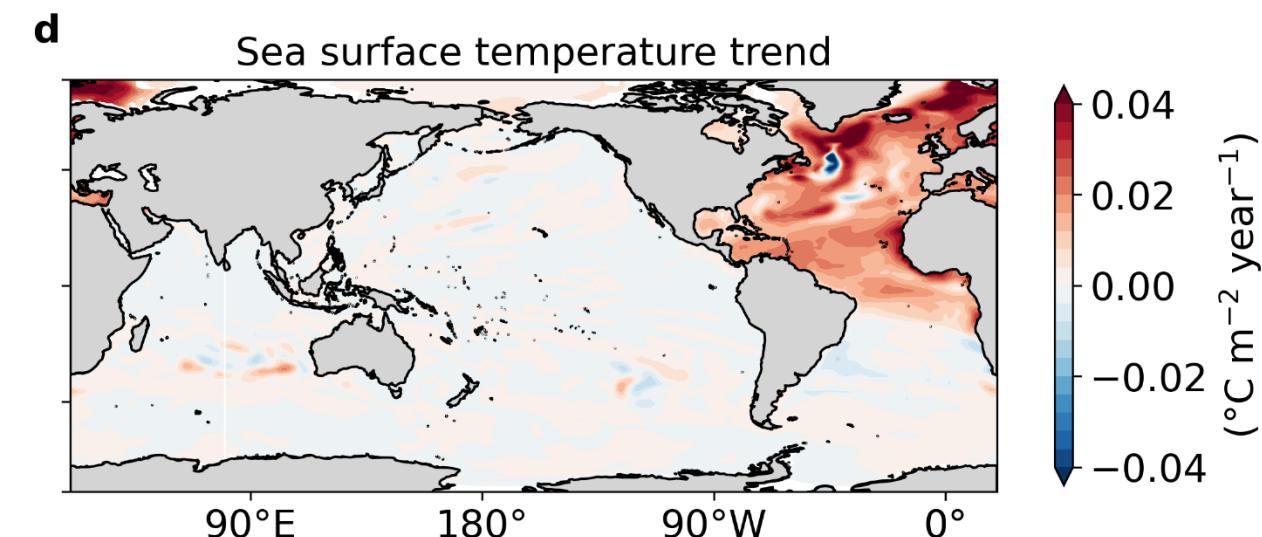
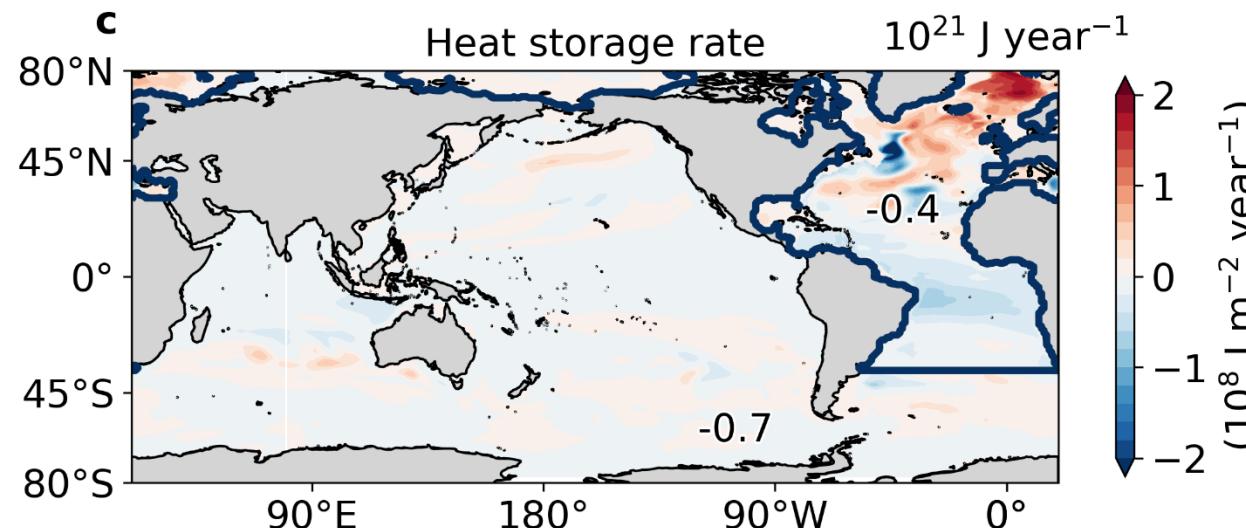
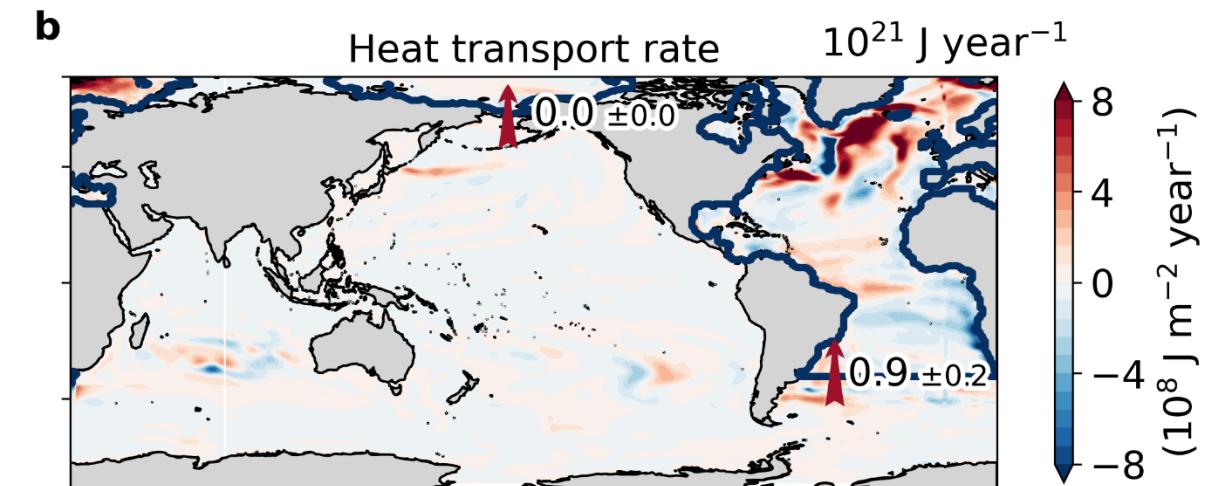
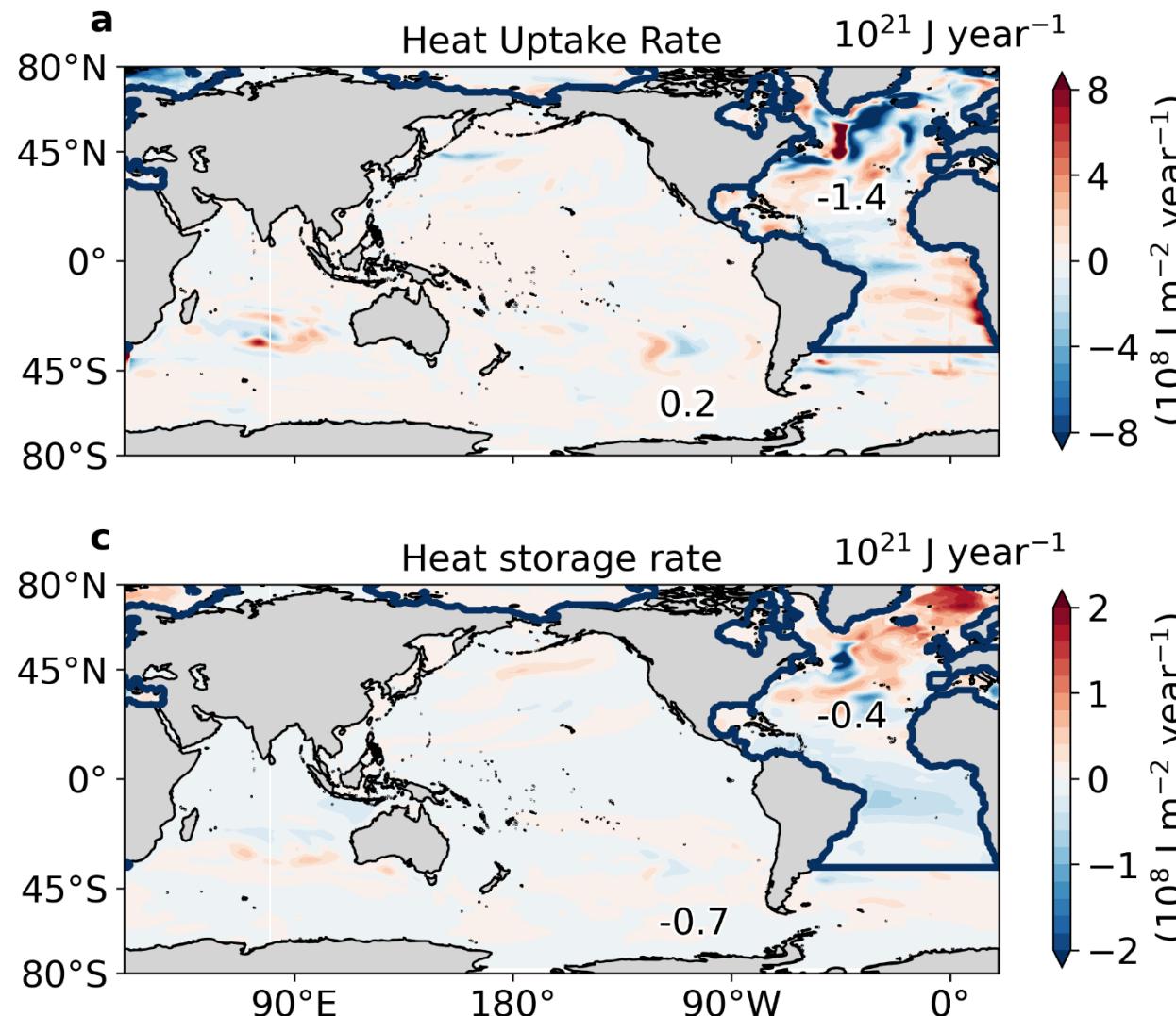
Pacific Ocean-only



Indian Ocean-only



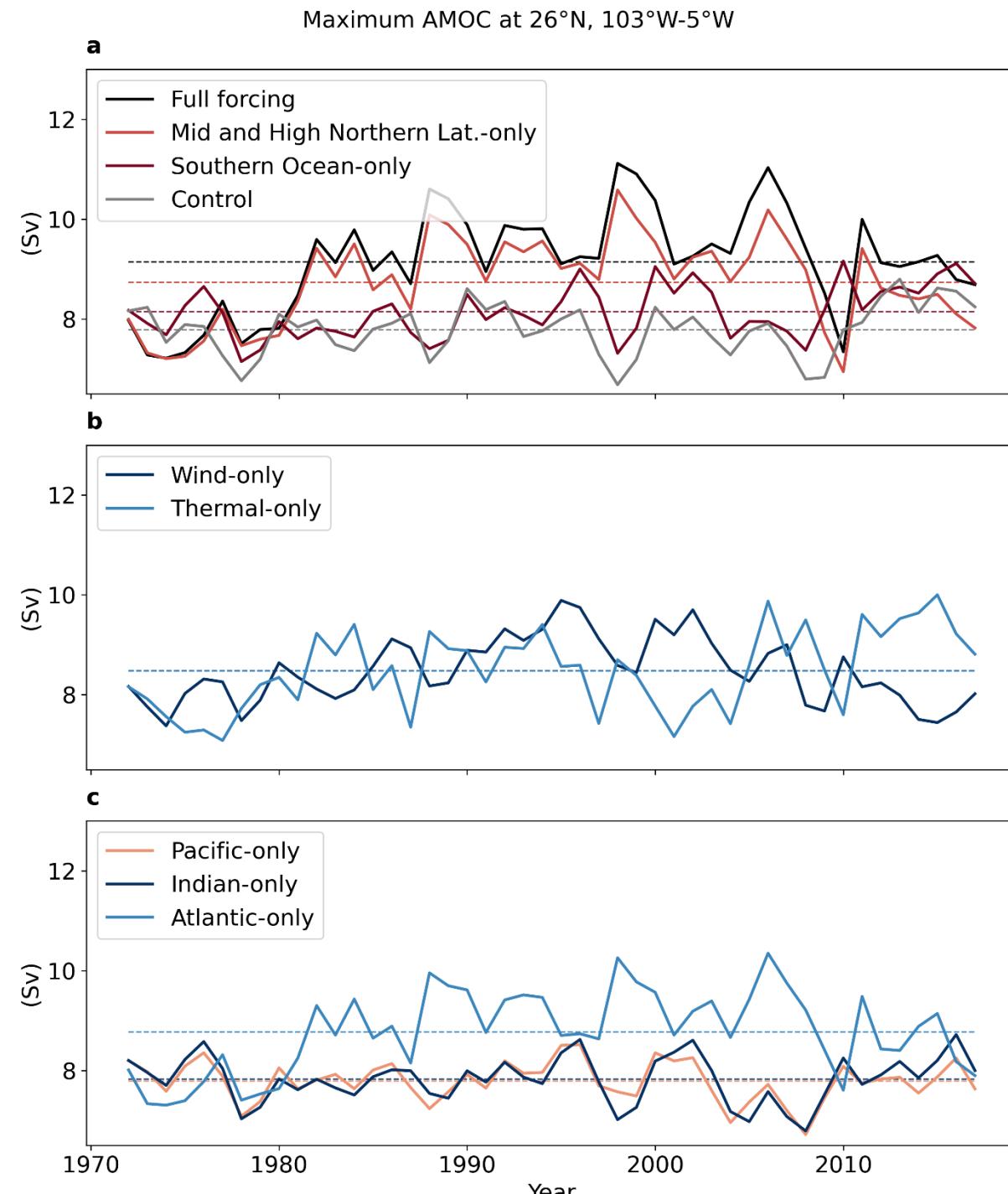
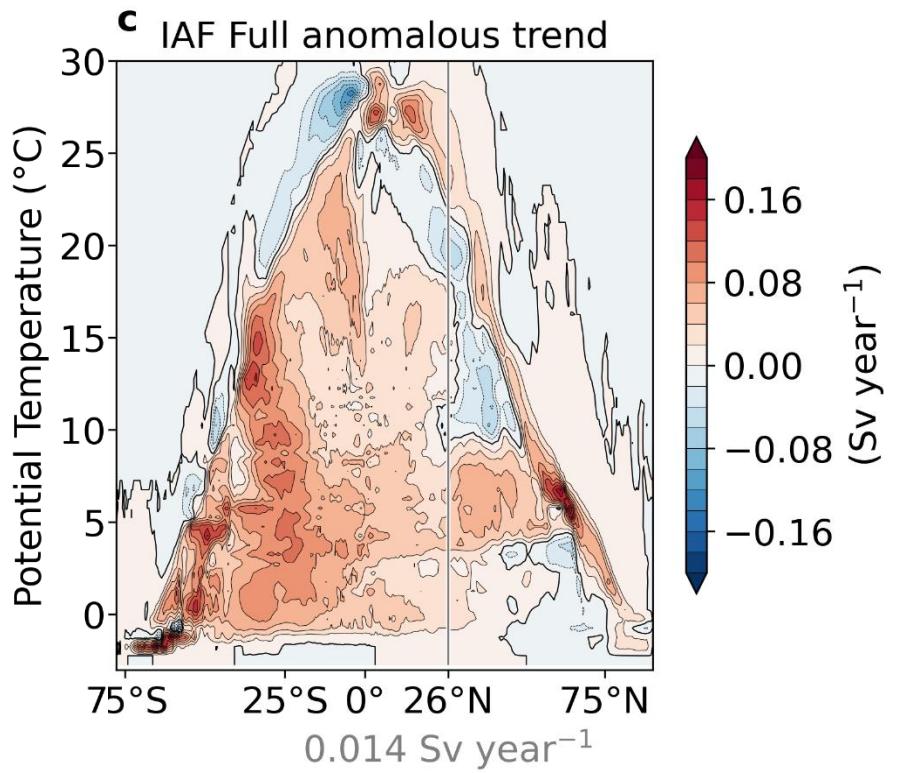
Atlantic Ocean-only



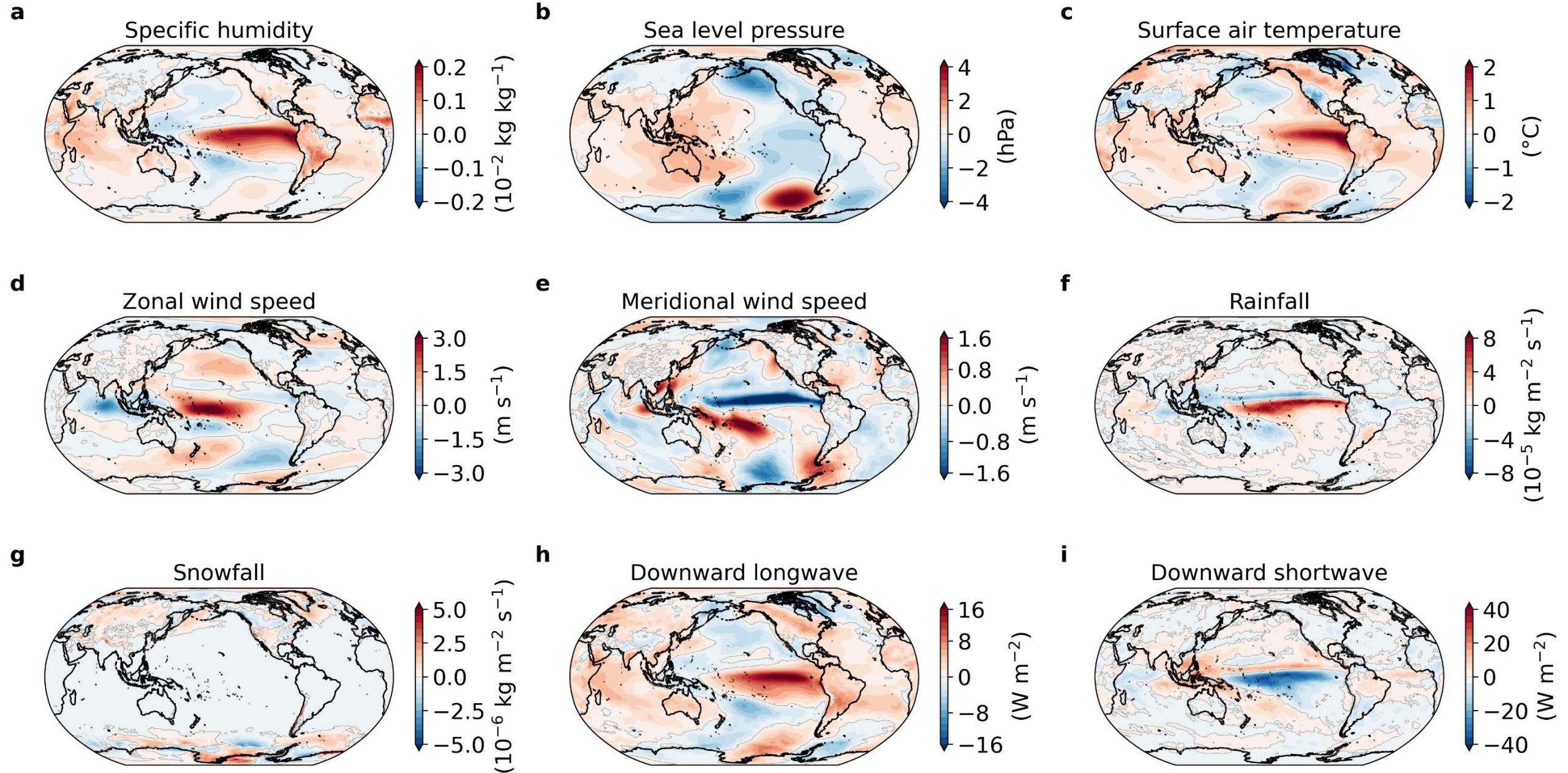


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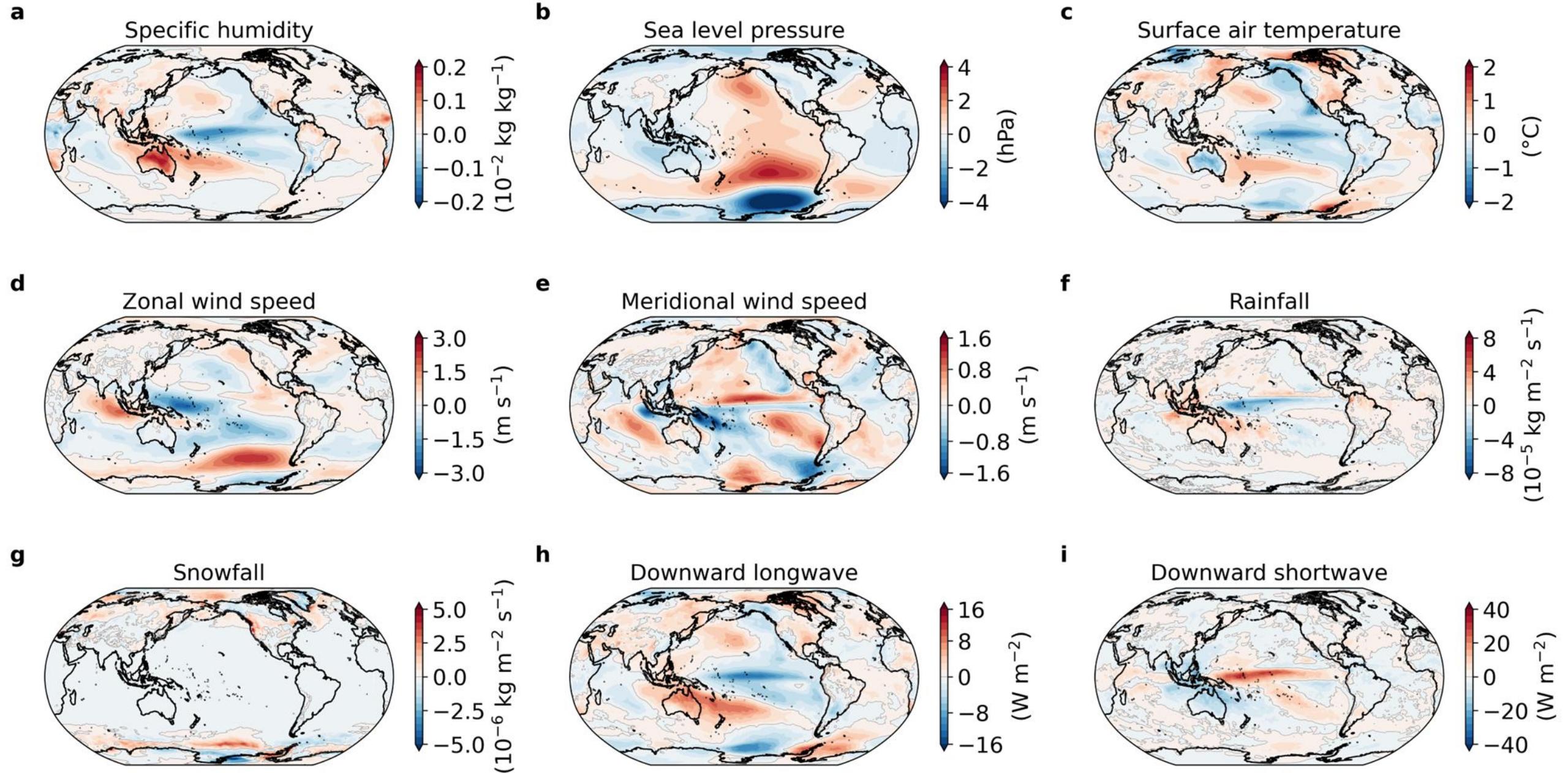
AMOC changes



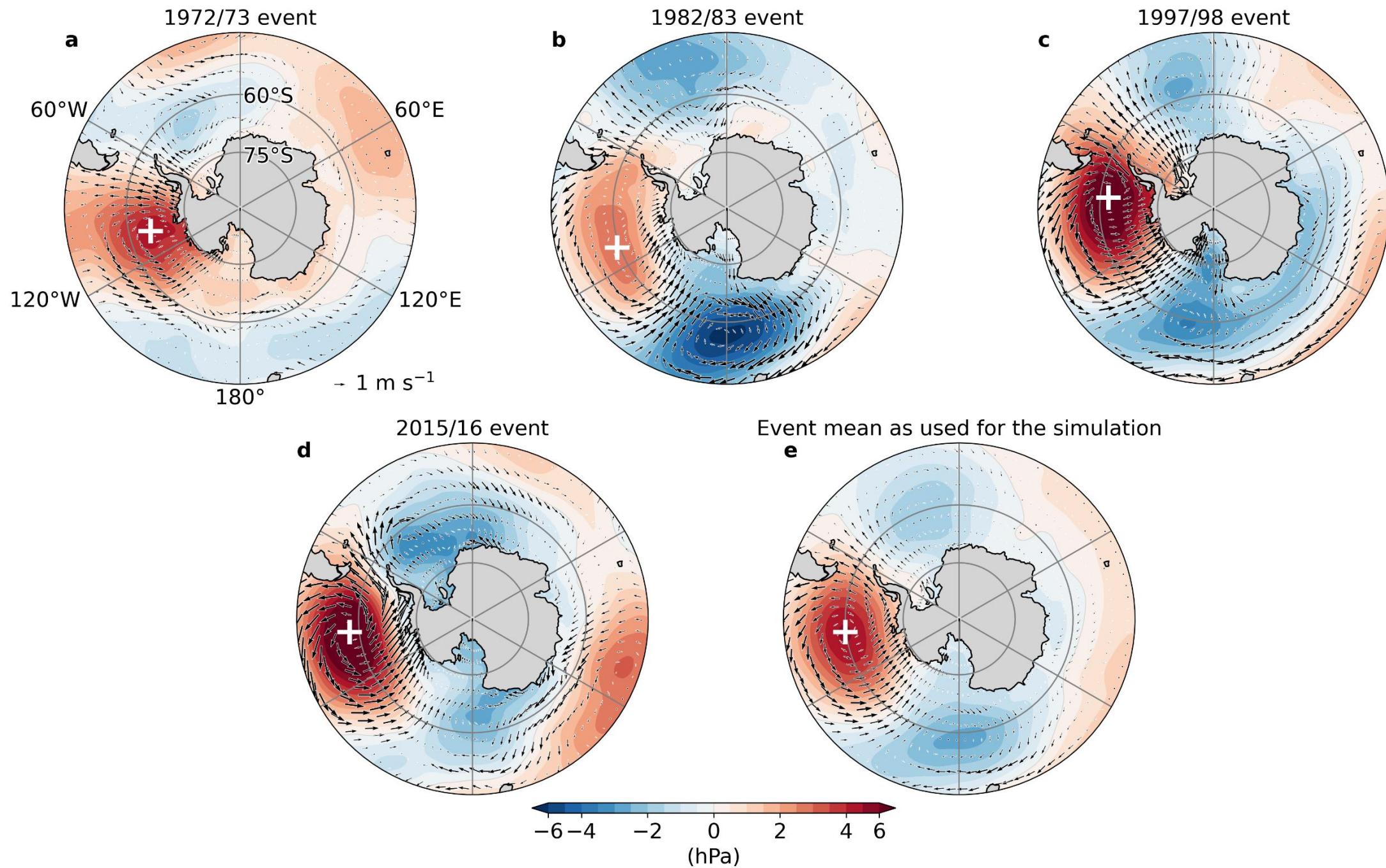
Spatial maps of El Niño anomalies



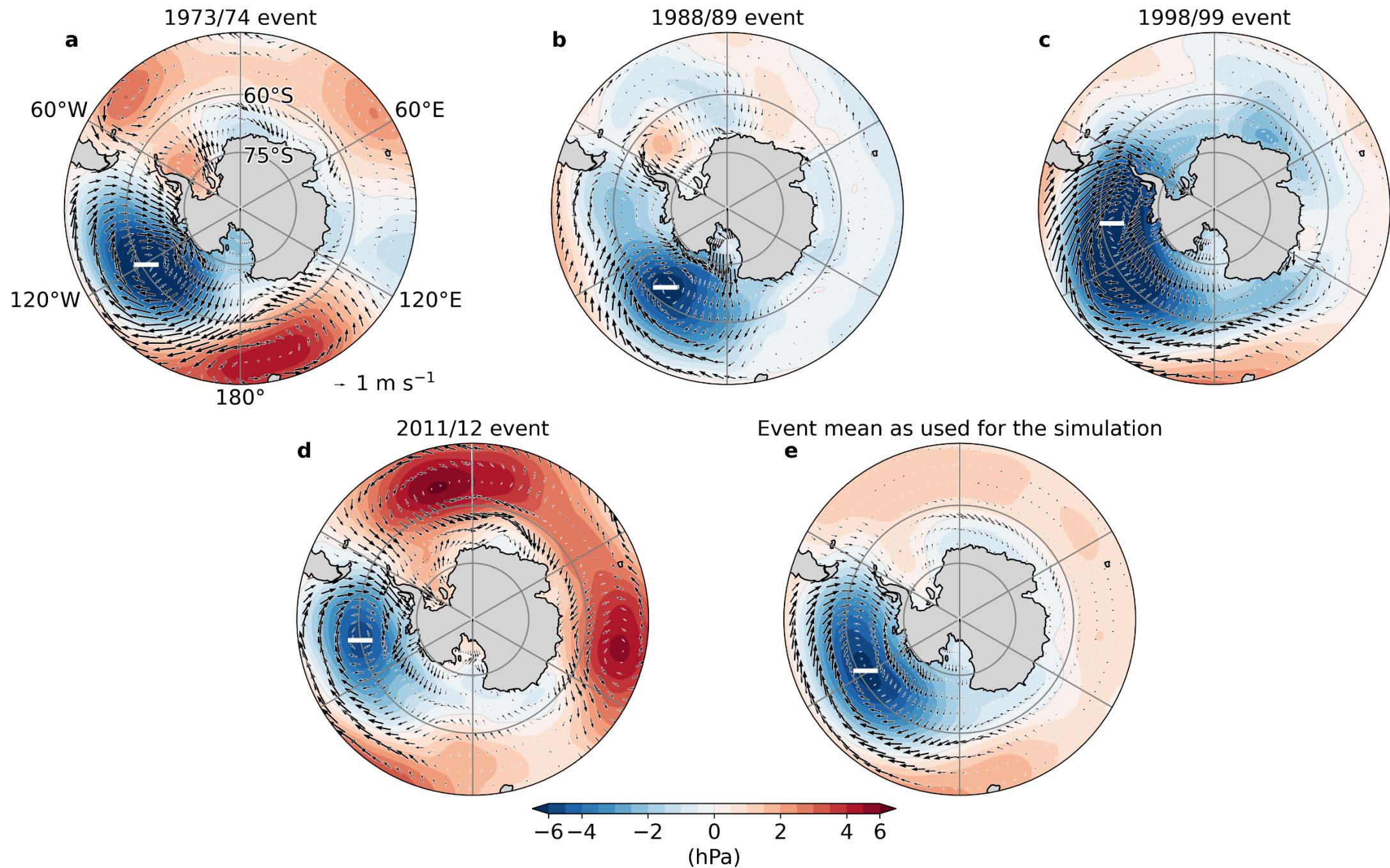
Spatial maps of La Niña anomalies



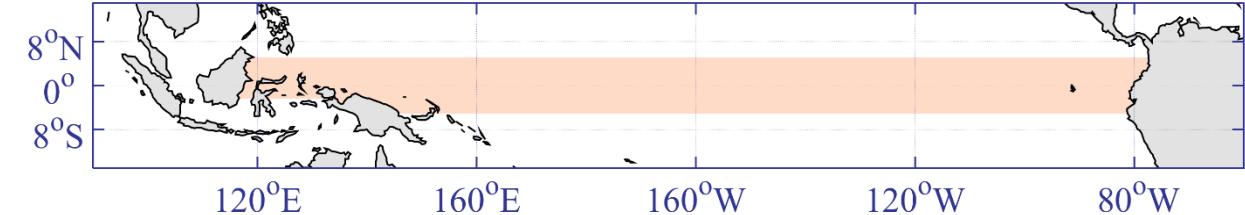
El Niño sea level pressure and surface wind anomalies



La Niña sea level pressure and surface wind anomalies



The warm water volume budget



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

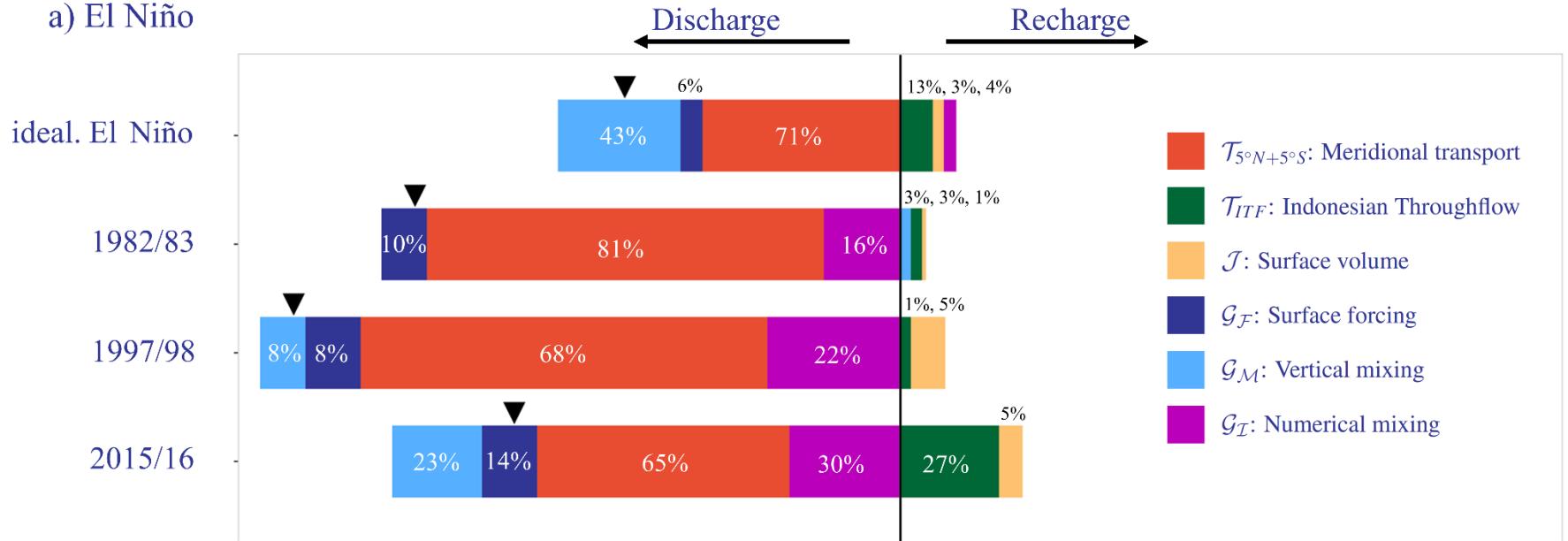
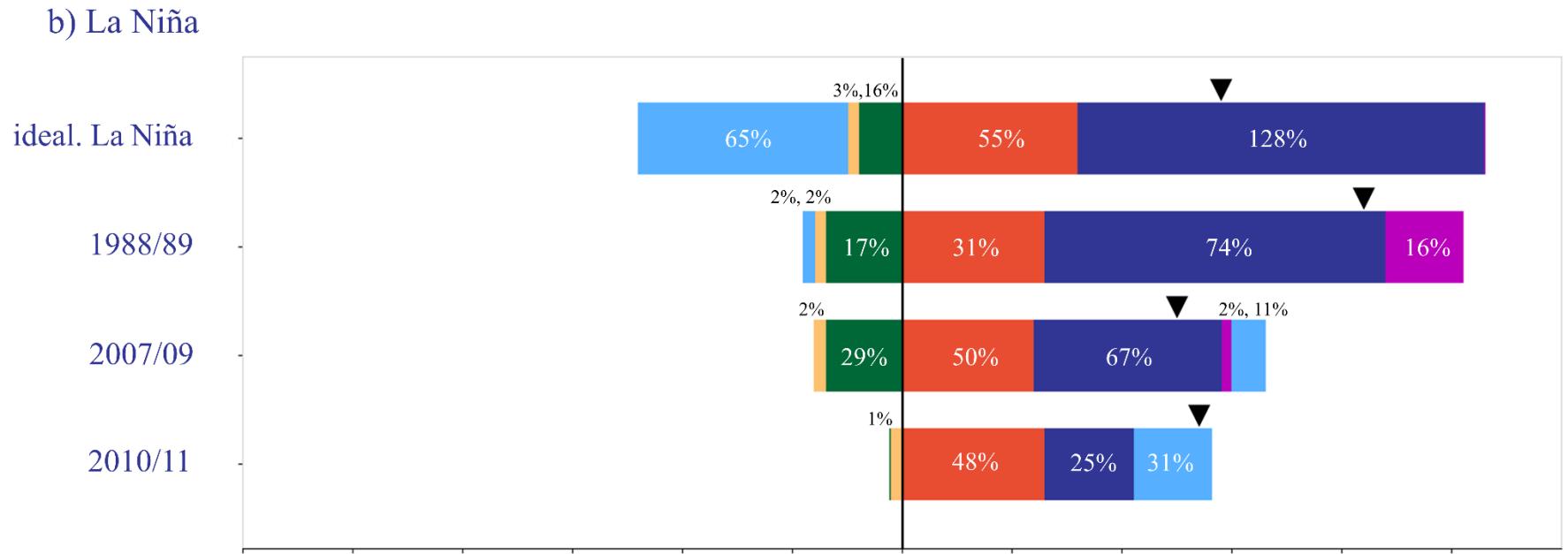
Eddy Mixing

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


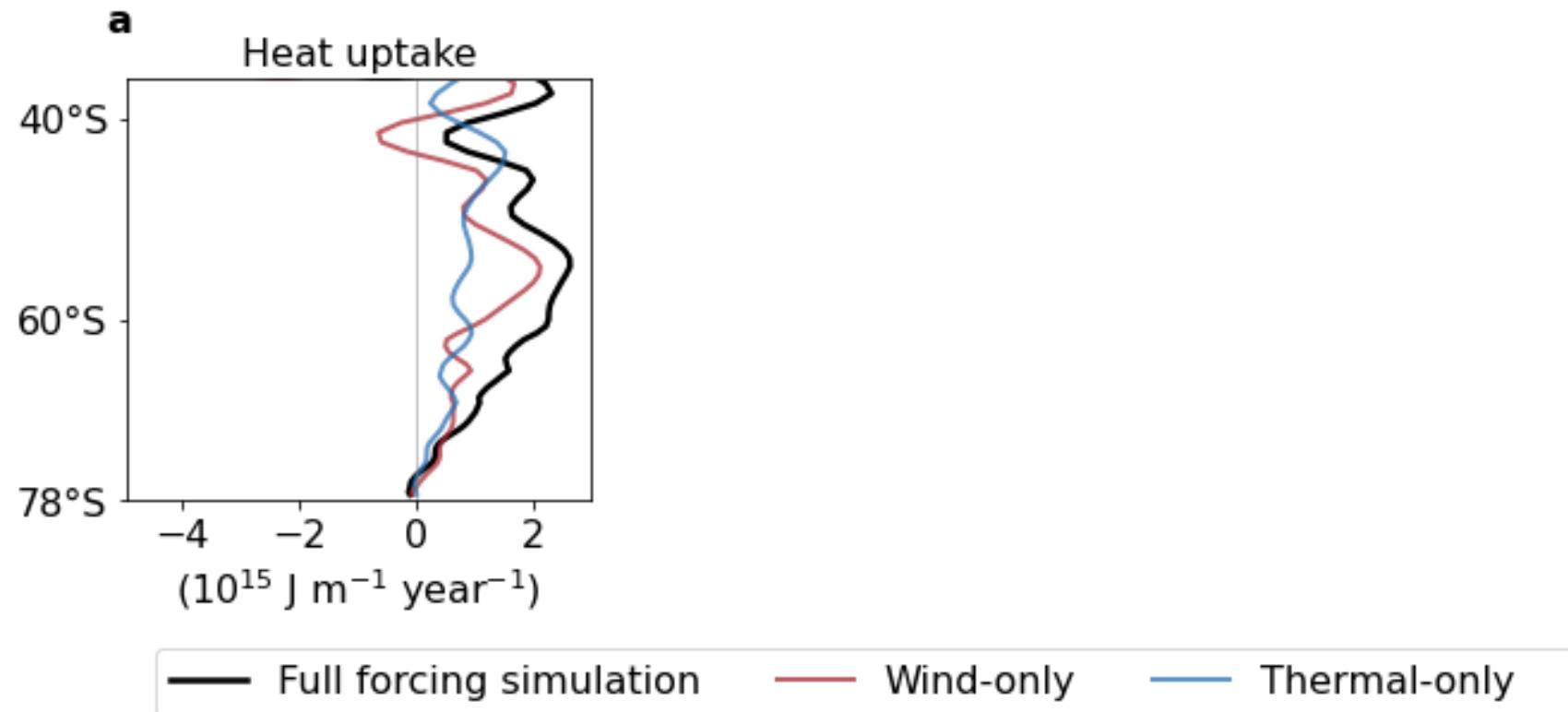
Take Home

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

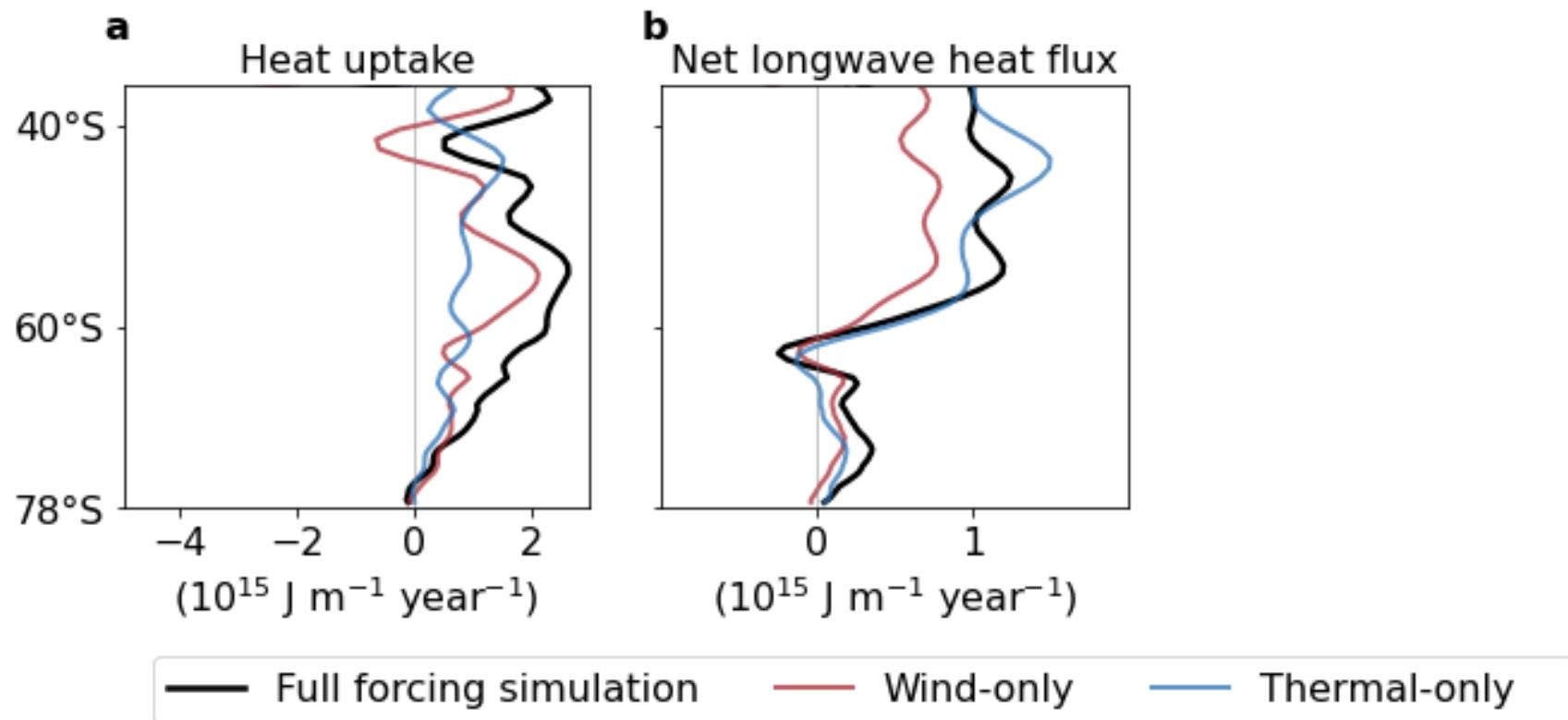
Project I: Take Home Messages

- 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

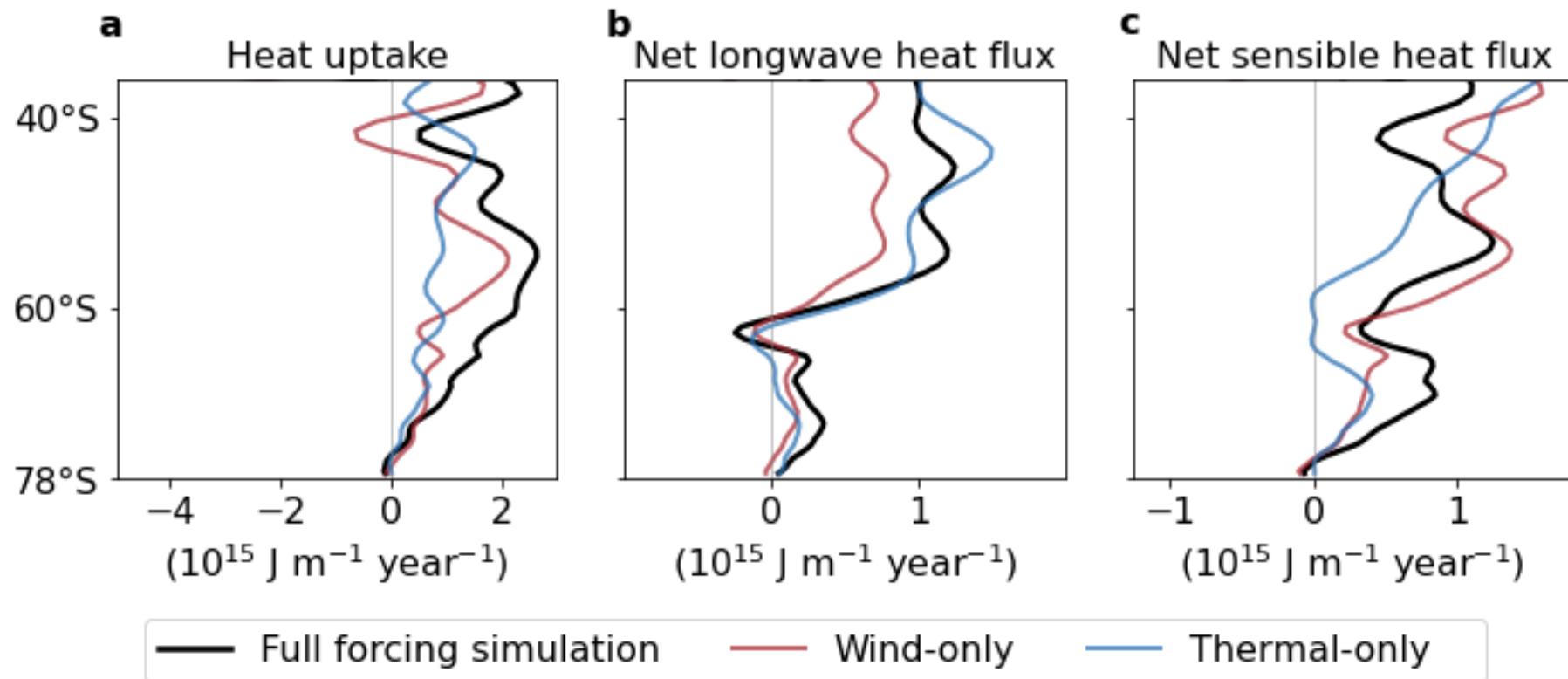
Zonally integrated heat fluxes



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

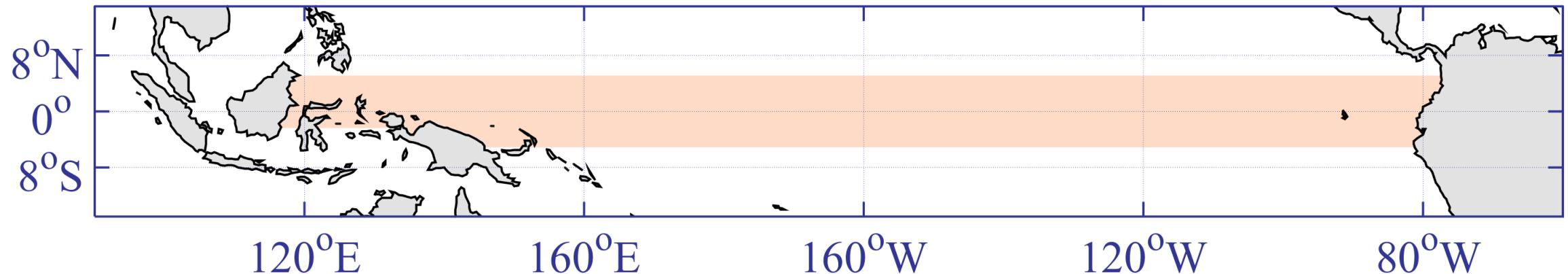
23rd May 2023

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

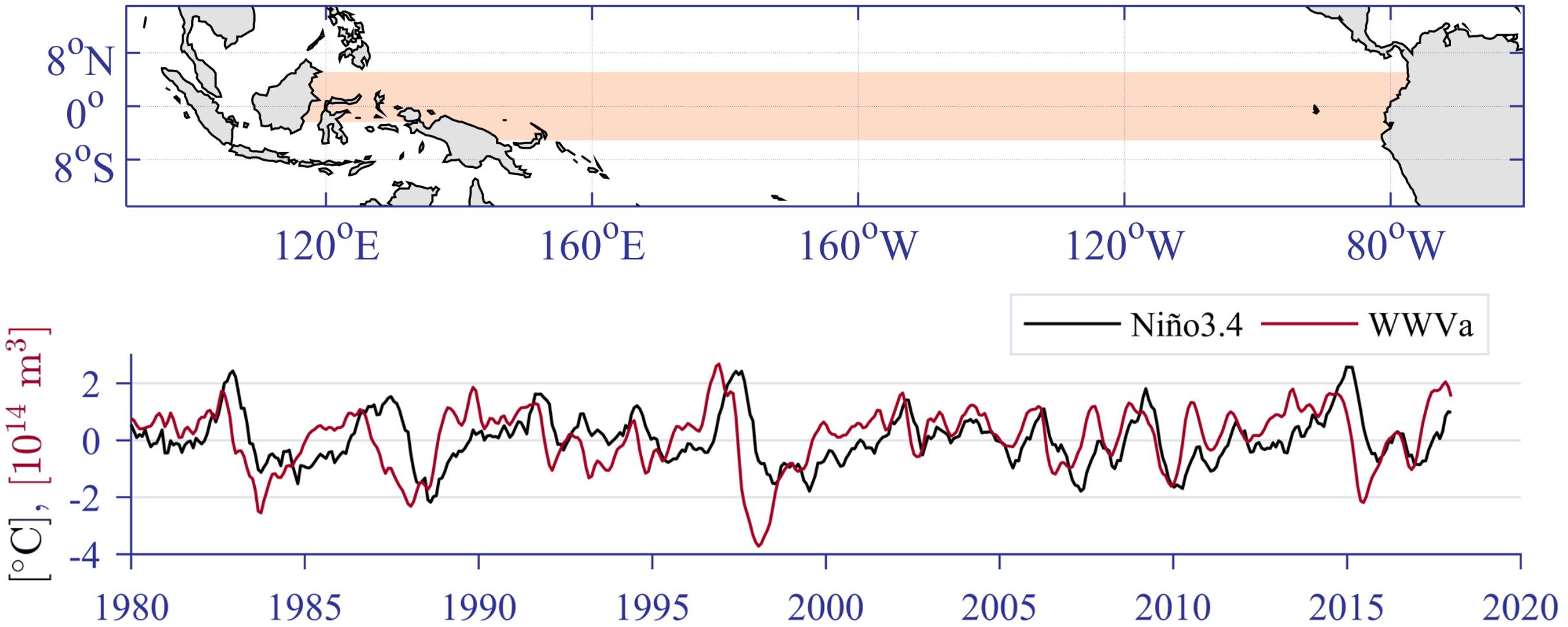
2. Key role of surface forcing and vertical mixing in changing warm water volume during ENSO (Huguenin et al. 2020b)

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
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Motivation

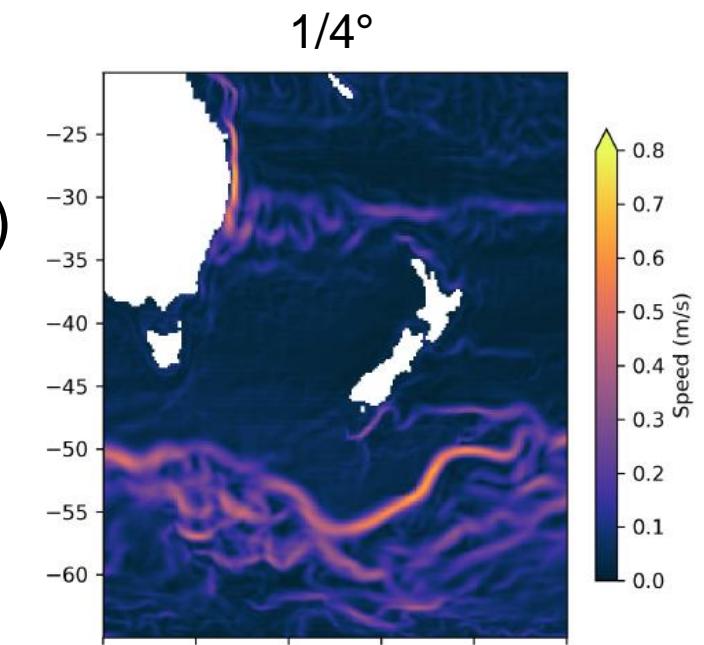
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- Diabatic fluxes account for ~50% of warm water volume discharge in 1997/98
Meinen and McPhaden (2001)
- Diabatic contribution to warm water volume changes varies
Lengaigne et al. (2012) model study
- Disagreement amongst studies: Brown and Fedorov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

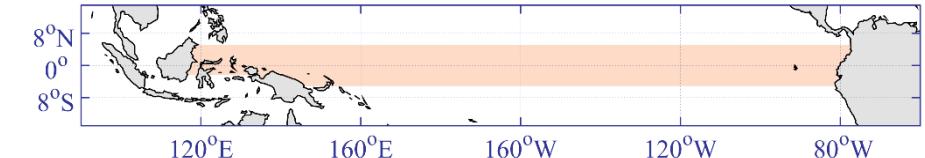
More ocean-sea ice modelling!

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



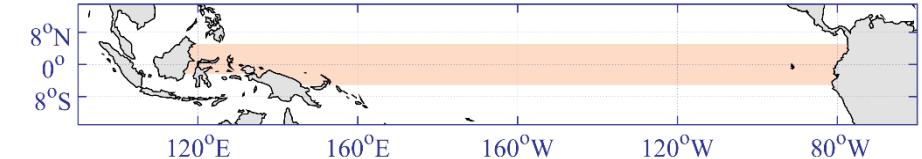
Kiss et al. (2019)

The warm water volume budget



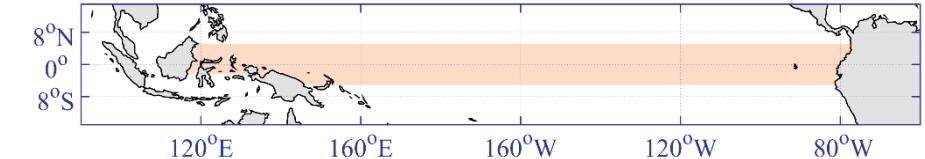
$$\frac{dWWV}{dt} = \underbrace{\dots}_{\text{adiabatic fluxes}} + \underbrace{\dots}_{\text{diabatic fluxes}}$$

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

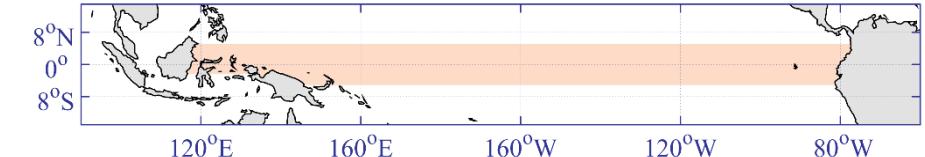


$$\frac{dWWV}{dt} = \underbrace{\mathcal{T}_{5^\circ N + 5^\circ S} + \mathcal{T}_{ITF} + P - E + R}_{adiabatic\ fluxes} + \dots$$

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



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

Surface Forcing

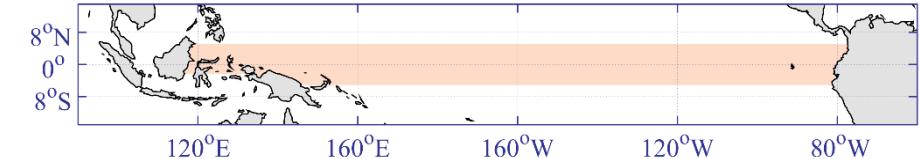
$$\frac{1}{\rho_0 \cdot C_p} \cdot \int \int \left. \frac{\partial \mathcal{F}}{\partial \Theta} \right|_{20^\circ C} dA$$

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



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

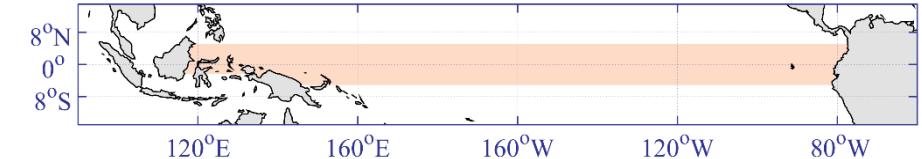
Eddy
Mixing

Surface Forcing

Vertical Mixing

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

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

Surface Forcing

Vertical Mixing

Numerical Mixing

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

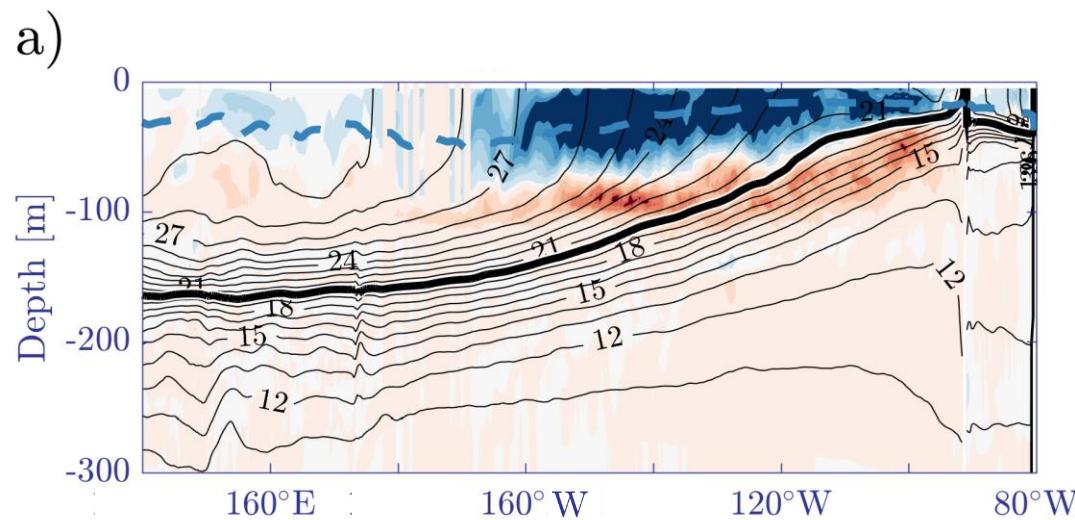
The diabatic volume fluxes: September-November

Vertical Mixing

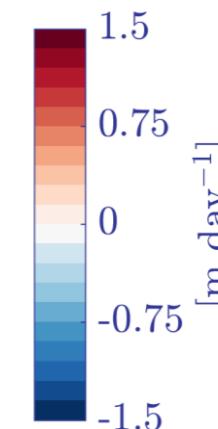
Surface Forcing

The diabatic volume fluxes: September-November

Vertical Mixing

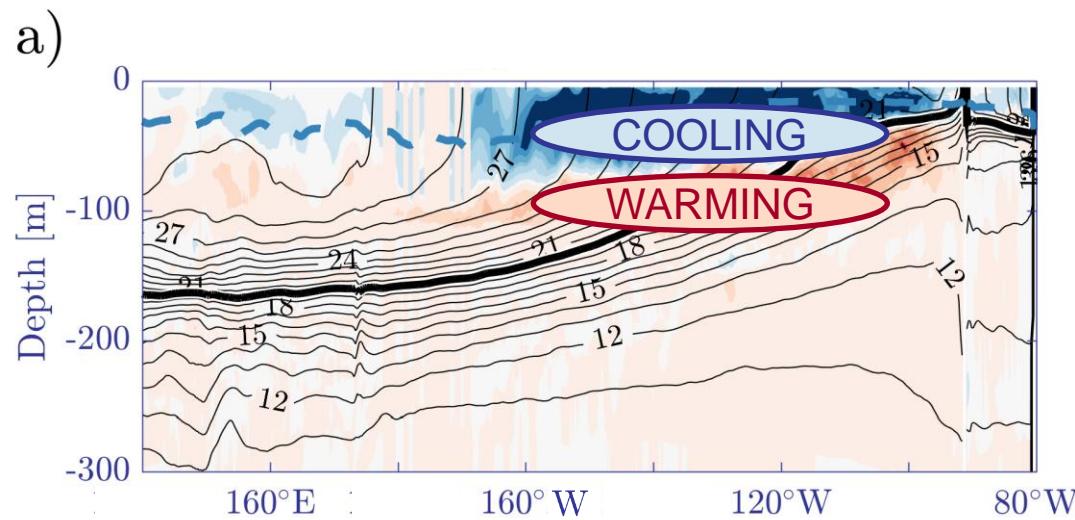


Surface Forcing

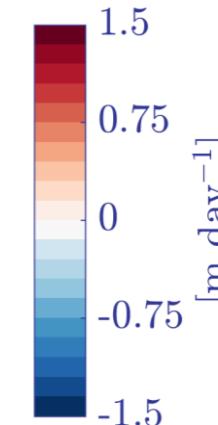


The diabatic volume fluxes: September-November

Vertical Mixing

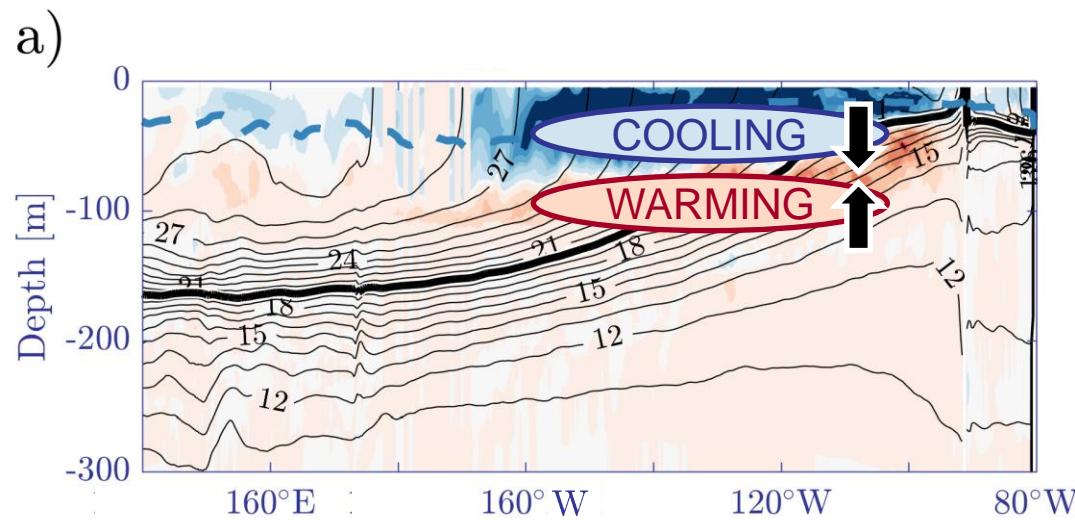


Surface Forcing



The diabatic volume fluxes: September-November

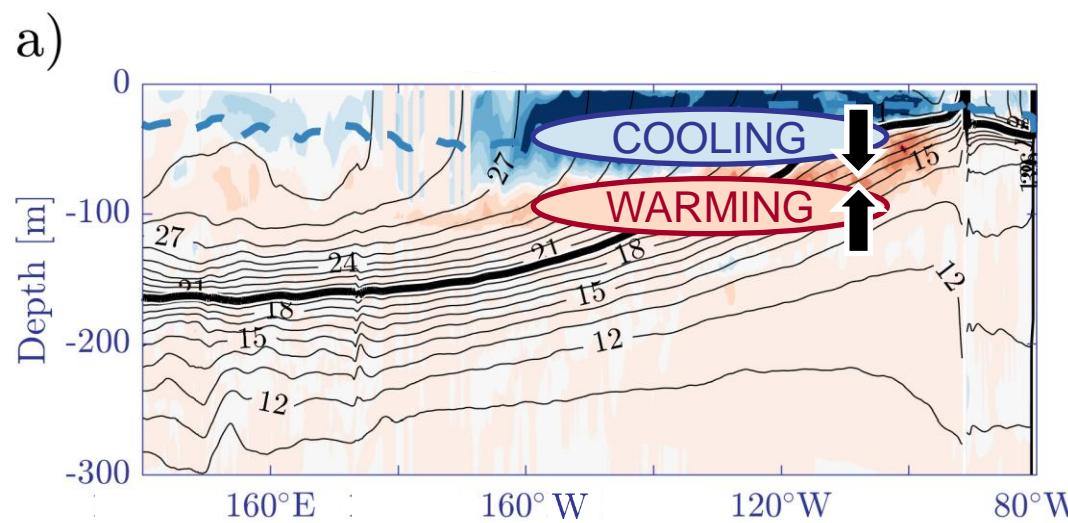
Vertical Mixing



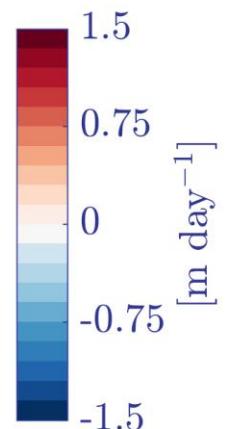
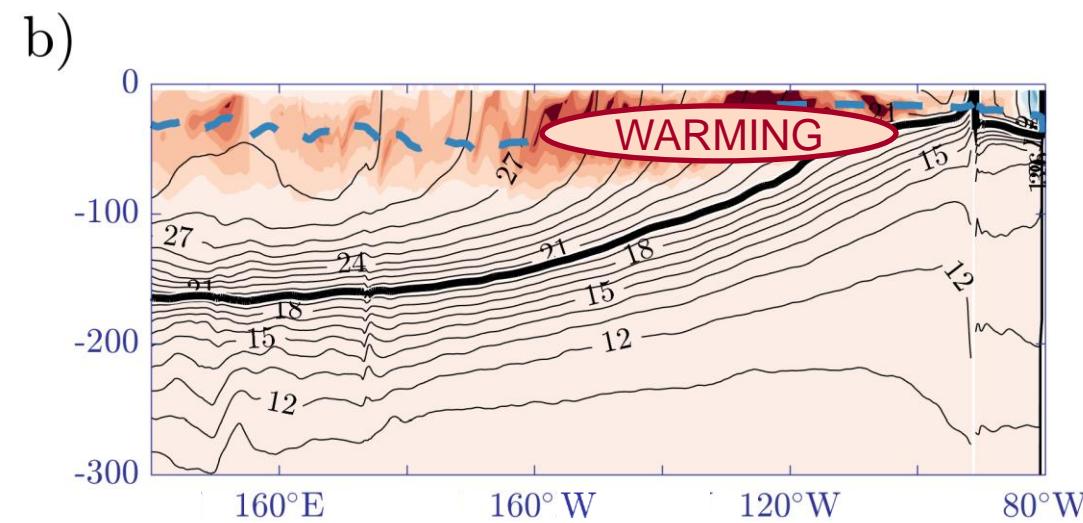
Surface Forcing

The diabatic volume fluxes: September-November

Vertical Mixing

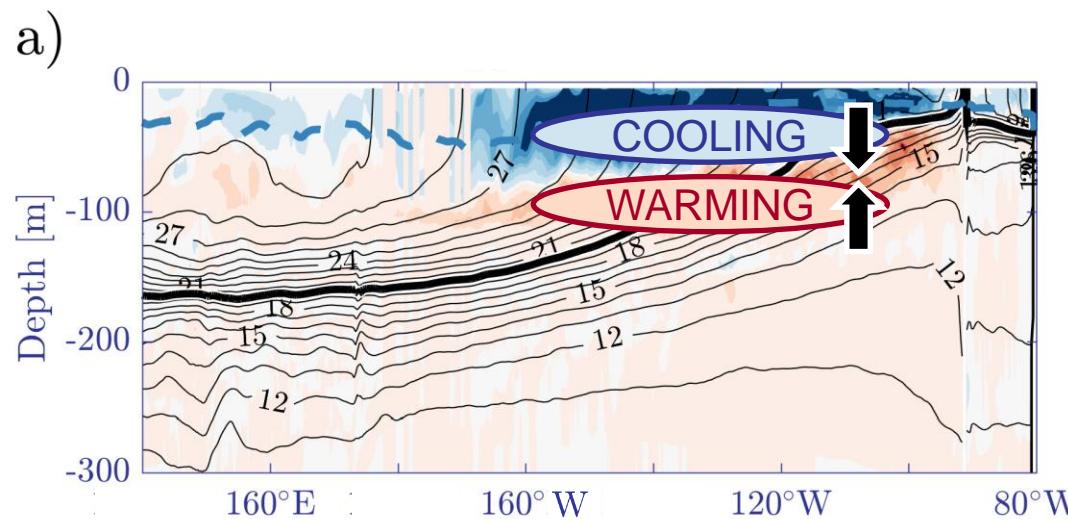


Surface Forcing

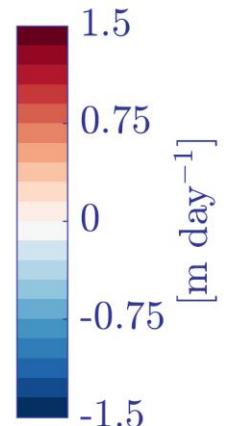
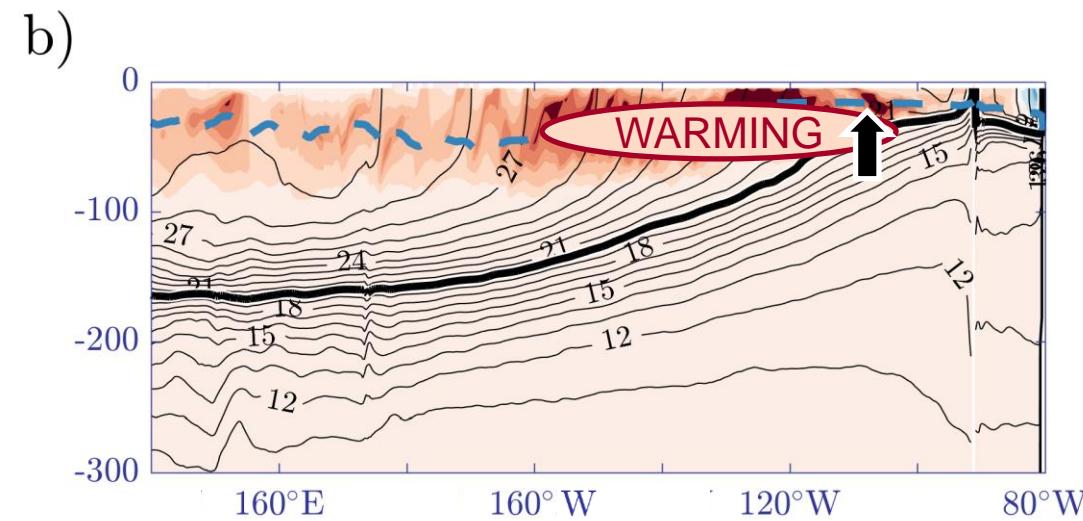


The diabatic volume fluxes: September-November

Vertical Mixing

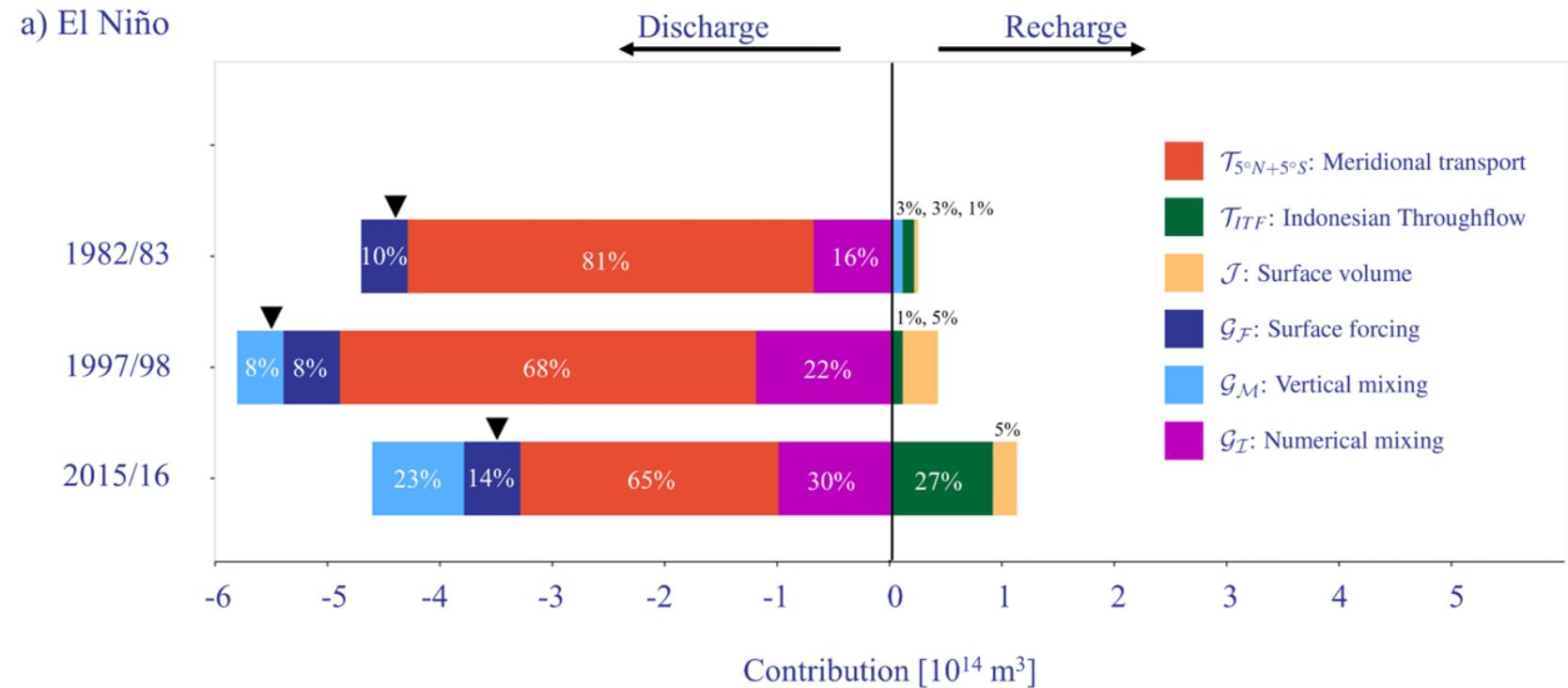


Surface Forcing

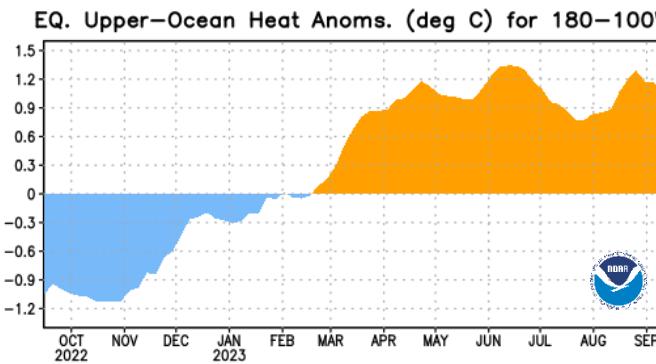
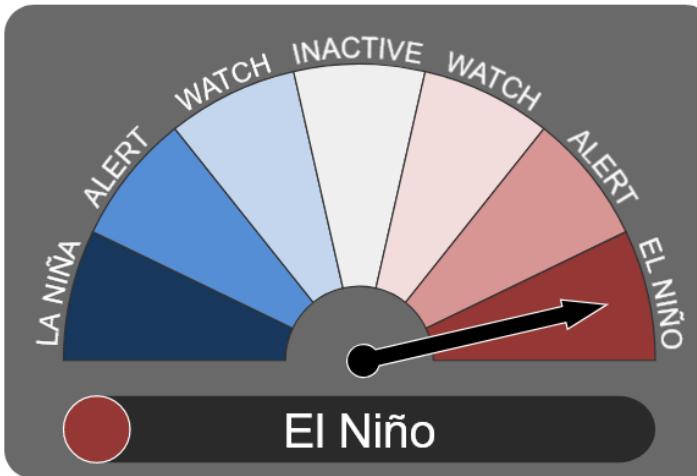


Summary figure

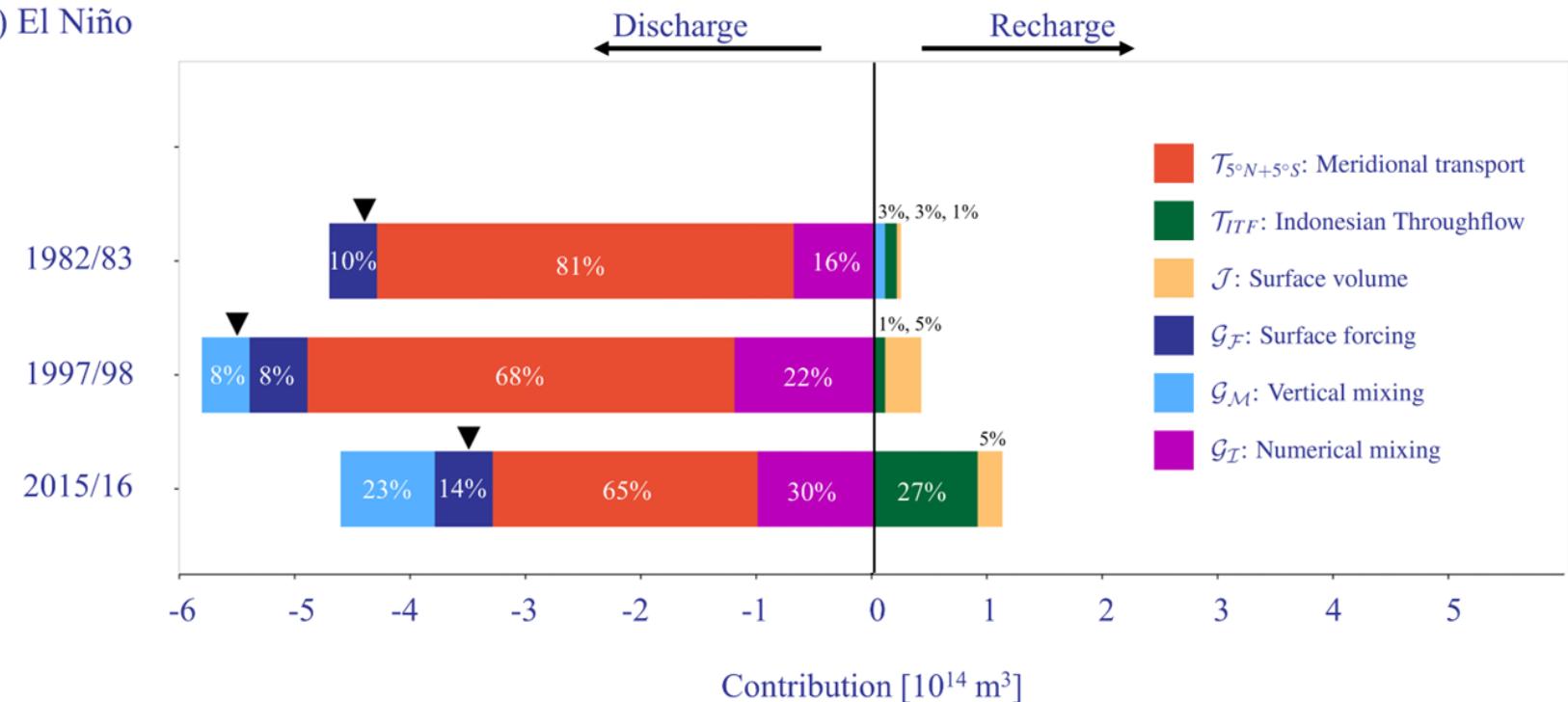
Summary figure



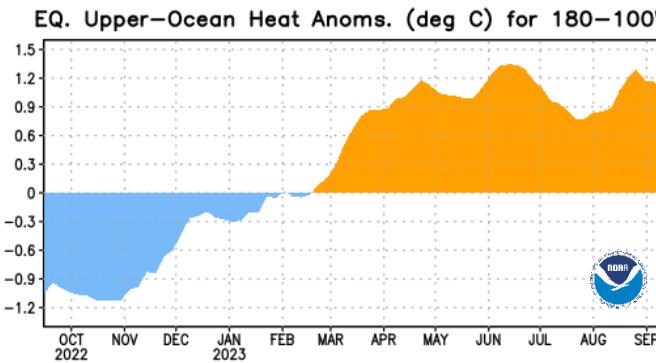
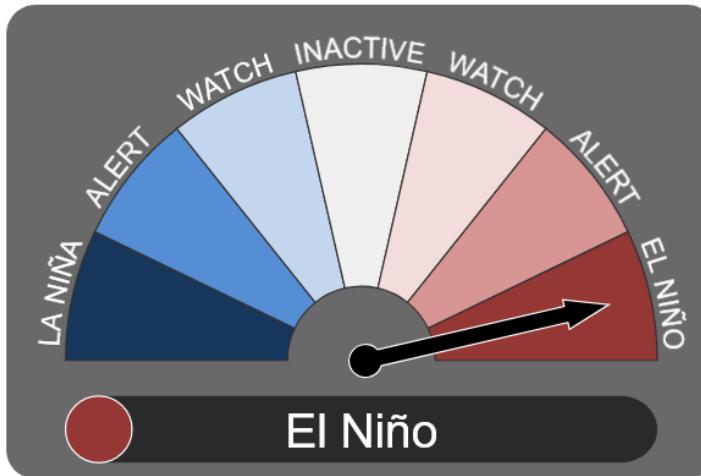
Summary figure



a) El Niño



Summary figure



a) El Niño

ideal. El Niño

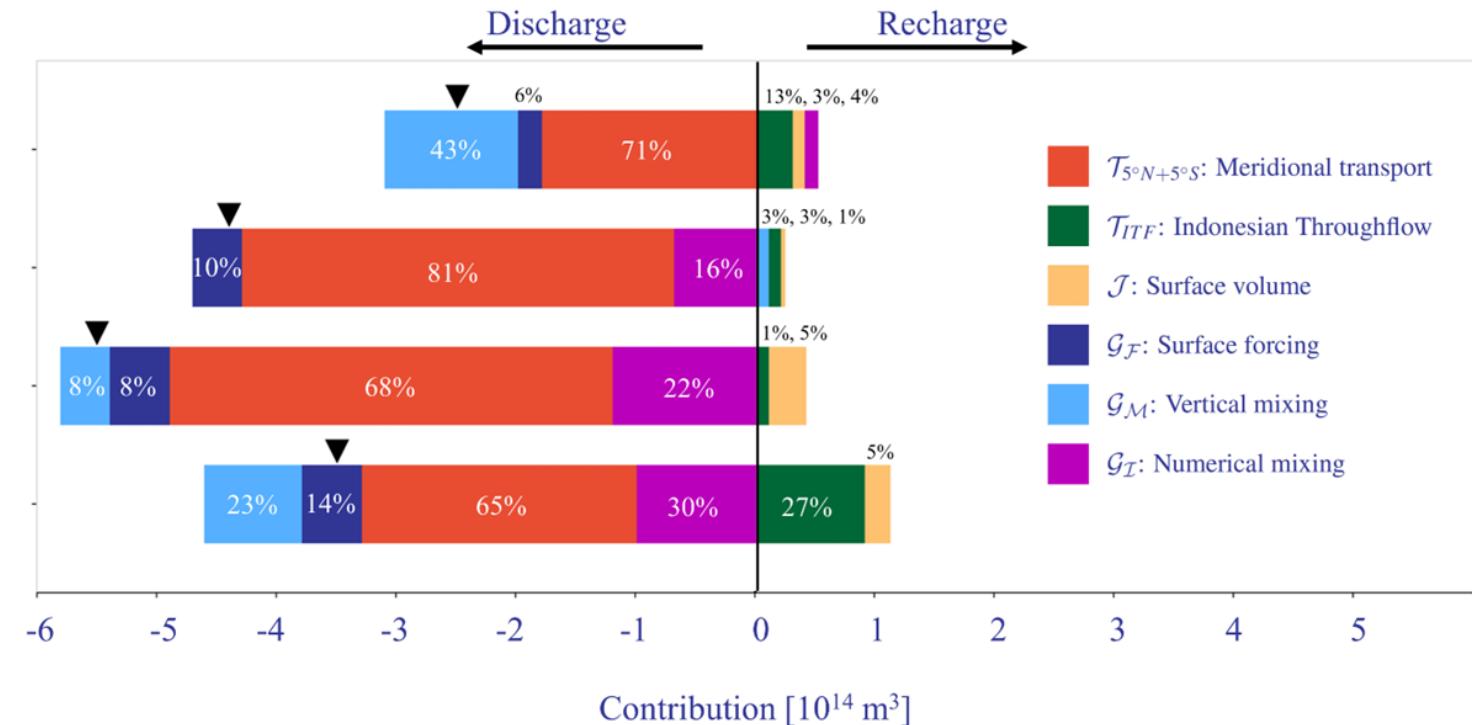
1982/83

1997/98

2015/16

Discharge

Recharge



Summary figure

a) El Niño

ideal. El Niño

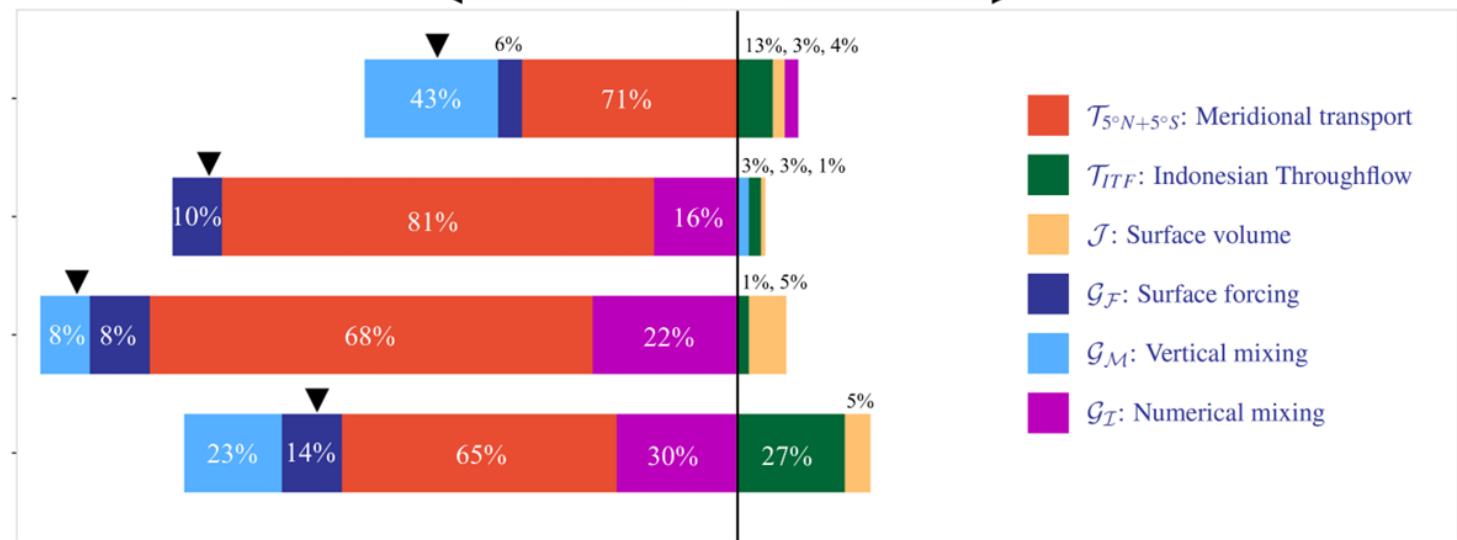
1982/83

1997/98

2015/16

Discharge

Recharge

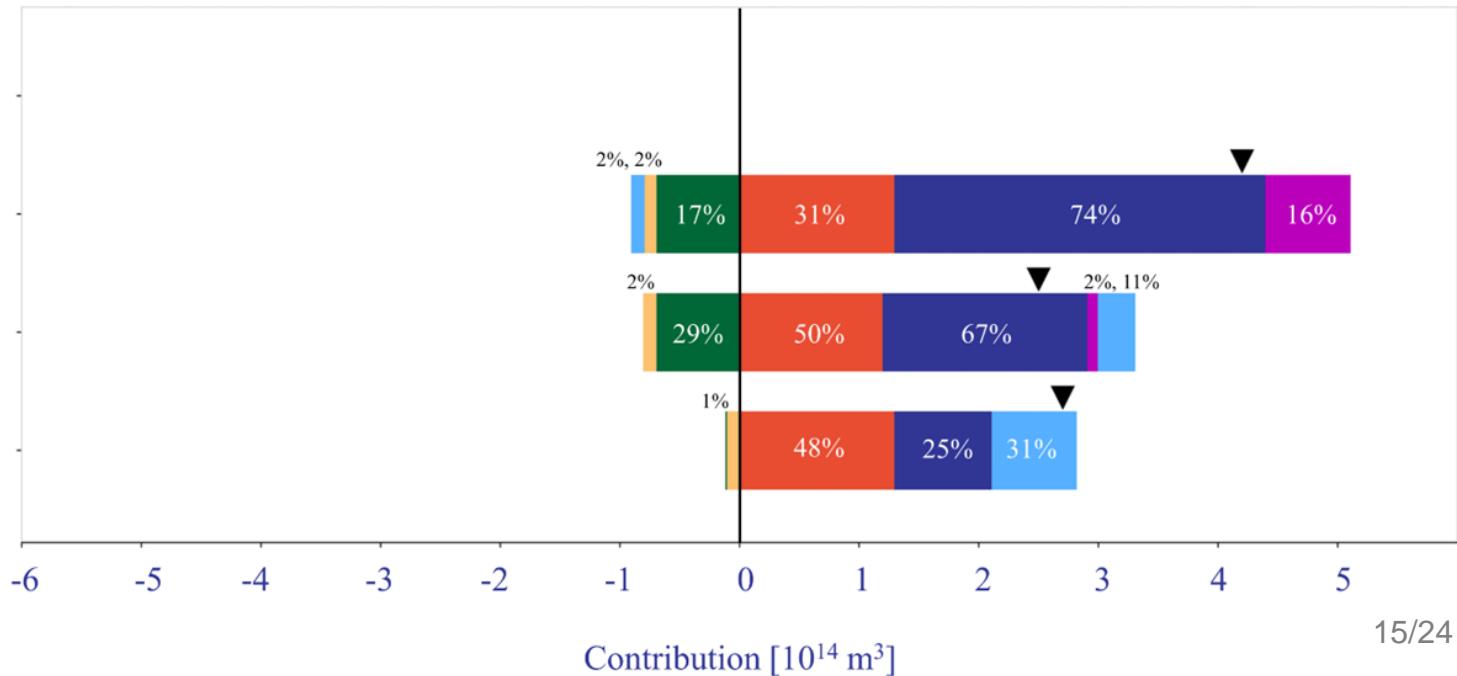


b) La Niña

1988/89

2007/09

2010/11



Summary figure

a) El Niño

ideal. El Niño

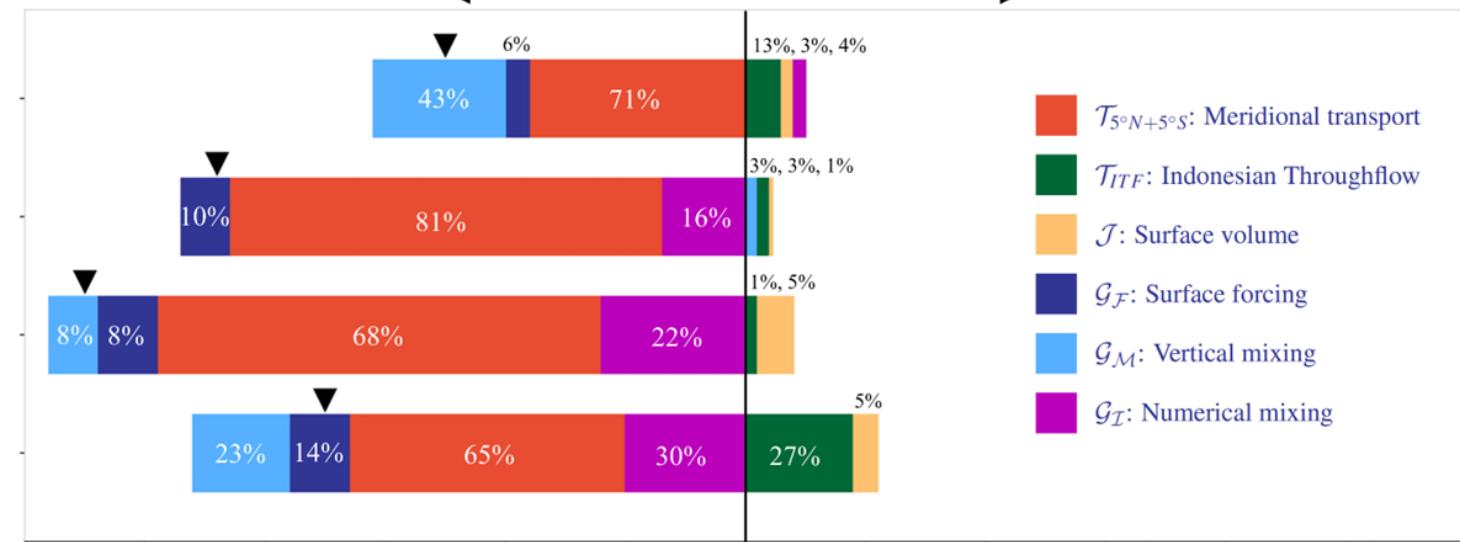
1982/83

1997/98

2015/16

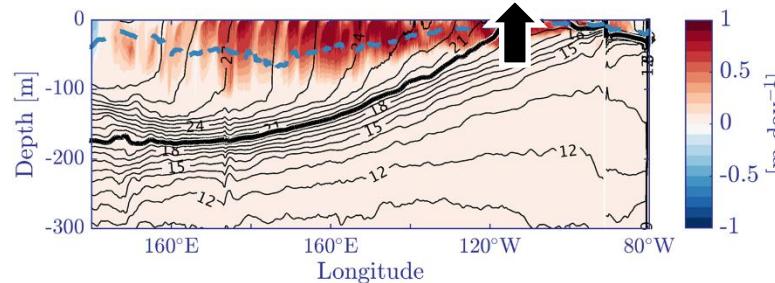
Discharge

Recharge



b) La Niña

Surface Forcing DEC 1988



1988/89

2007/09

2010/11

2%

2%

17%

31%

74%

16%

1%

29%

50%

67%

2%

11%

2%

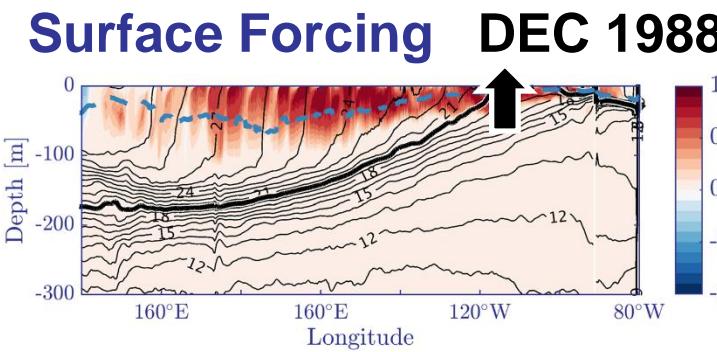
48%

25%

31%



Summary figure



a) El Niño

ideal. El Niño

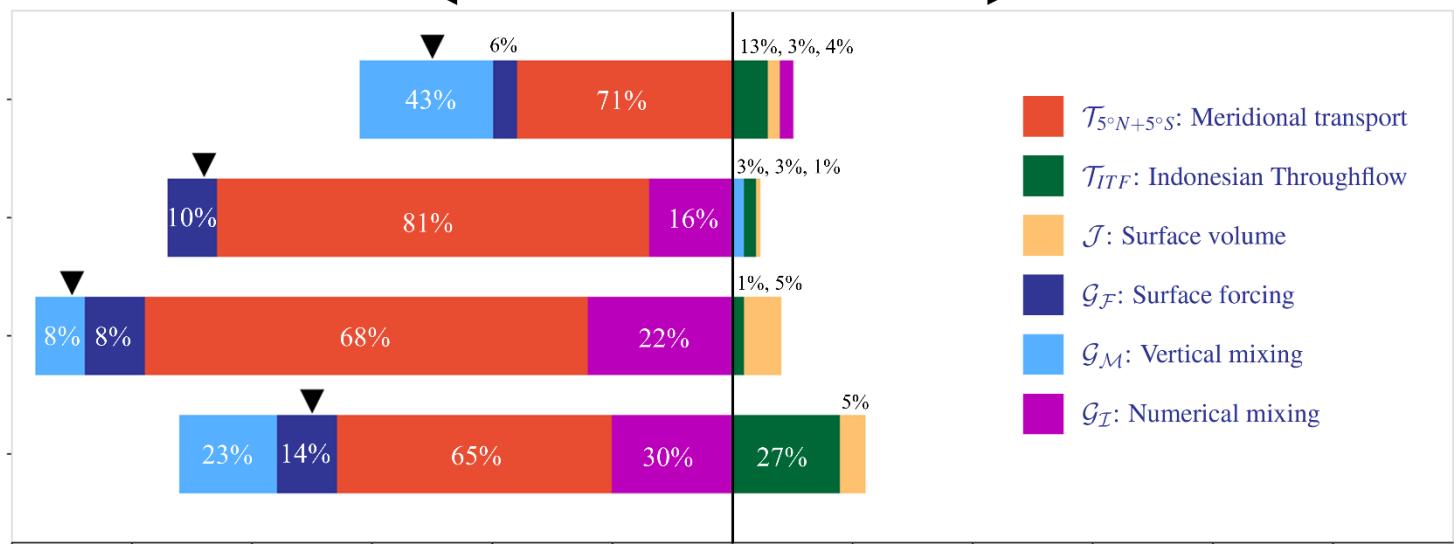
1982/83

1997/98

2015/16

Discharge

Recharge



b) La Niña

ideal. La Niña

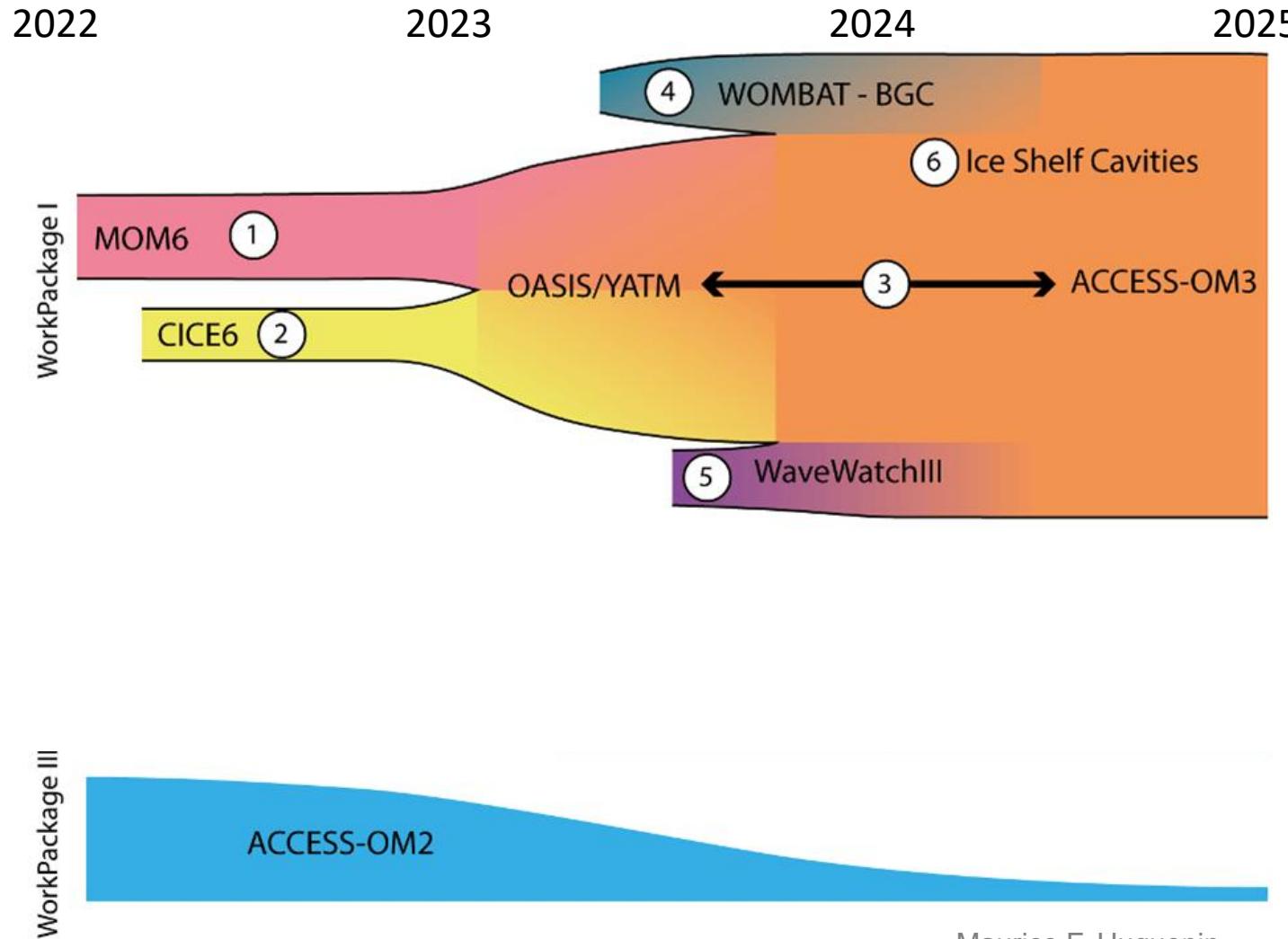
1988/89

2007/09

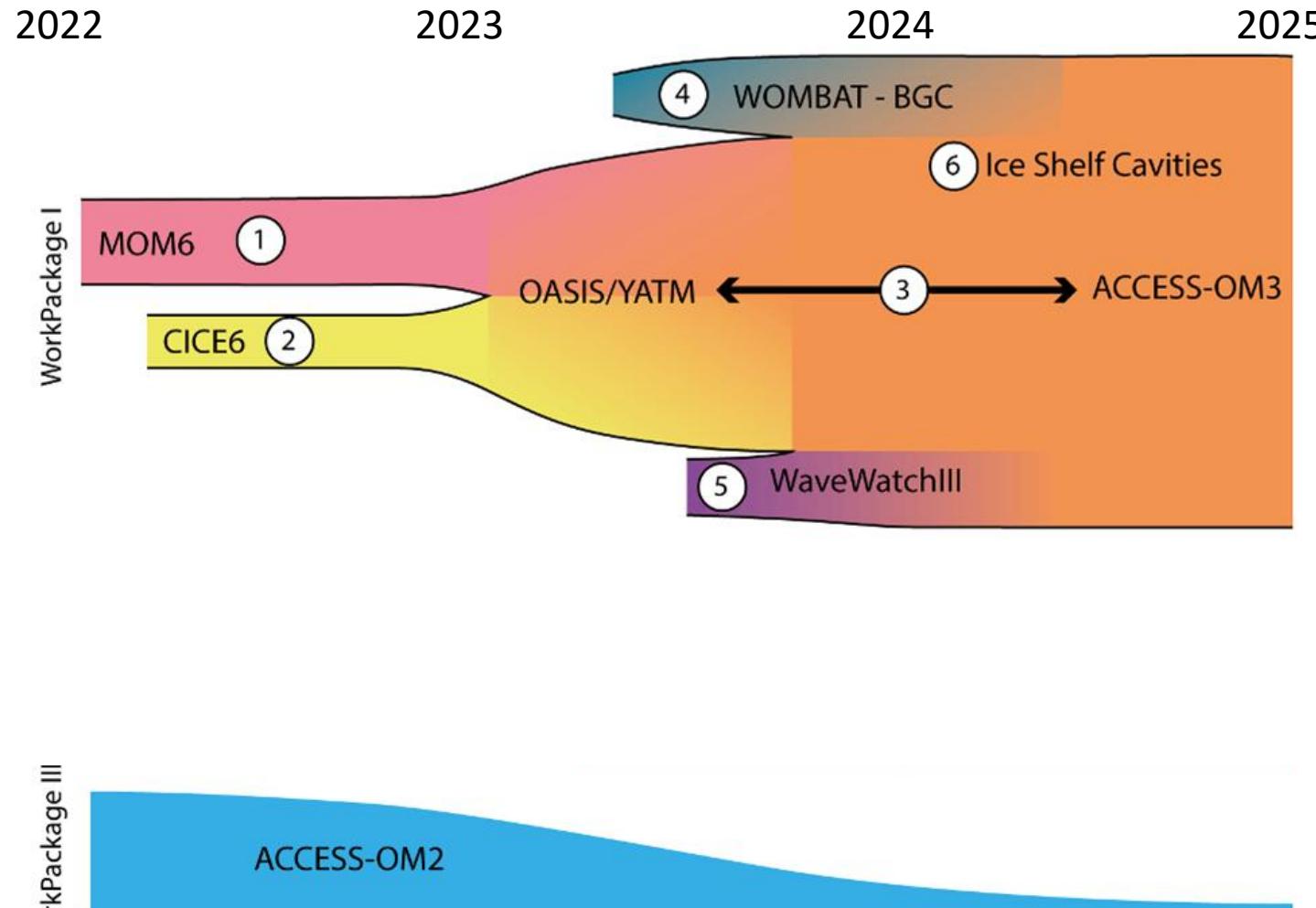
2010/11



Global ocean-sea ice model



Global ocean-sea ice model



Maurice F. Huguenin

COSIMA

Pan-Antarctic 1/20° & 1/40° model

