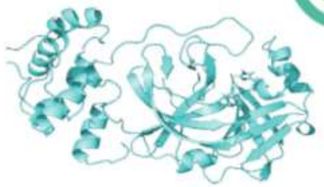
Feeling under the weather: Untangling future ocean warming in West Antarctica

K. A. Turner [1,2], K. A. Naughten [1], P. R. Holland [1], A. C. Naveira Garabato [2]

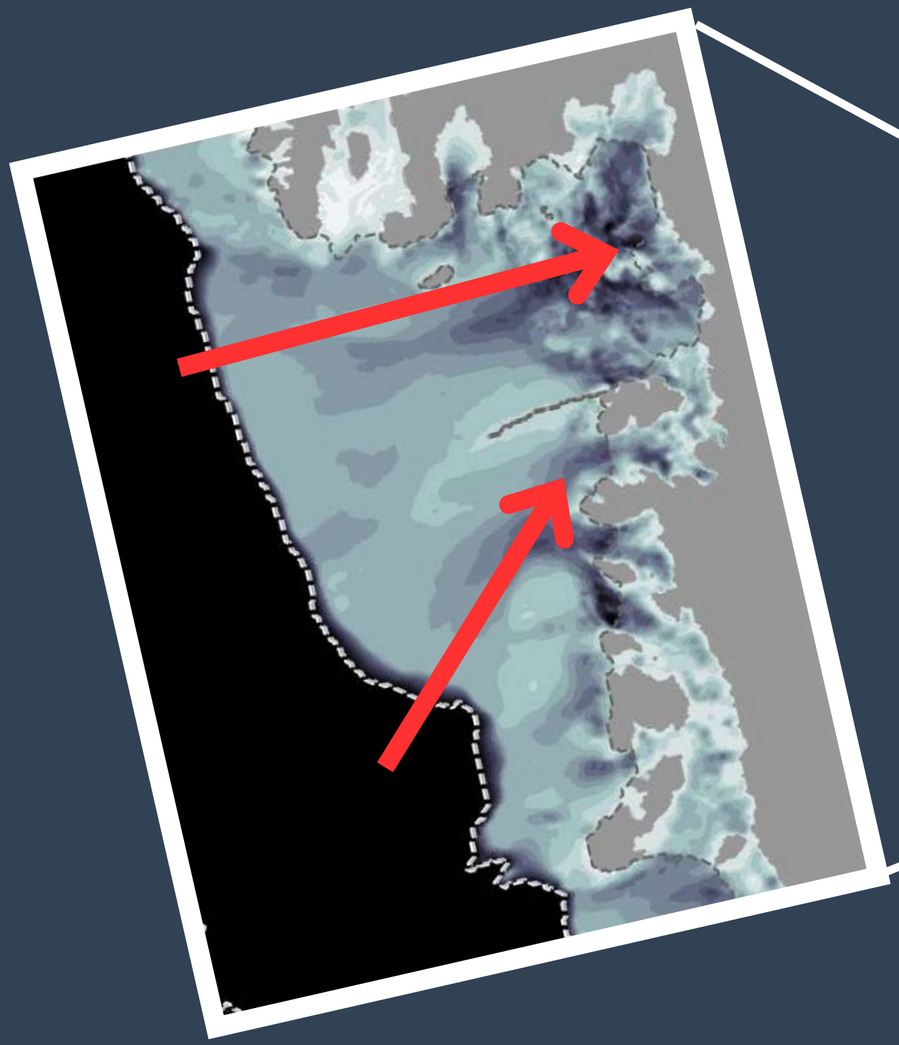
University of Southampton

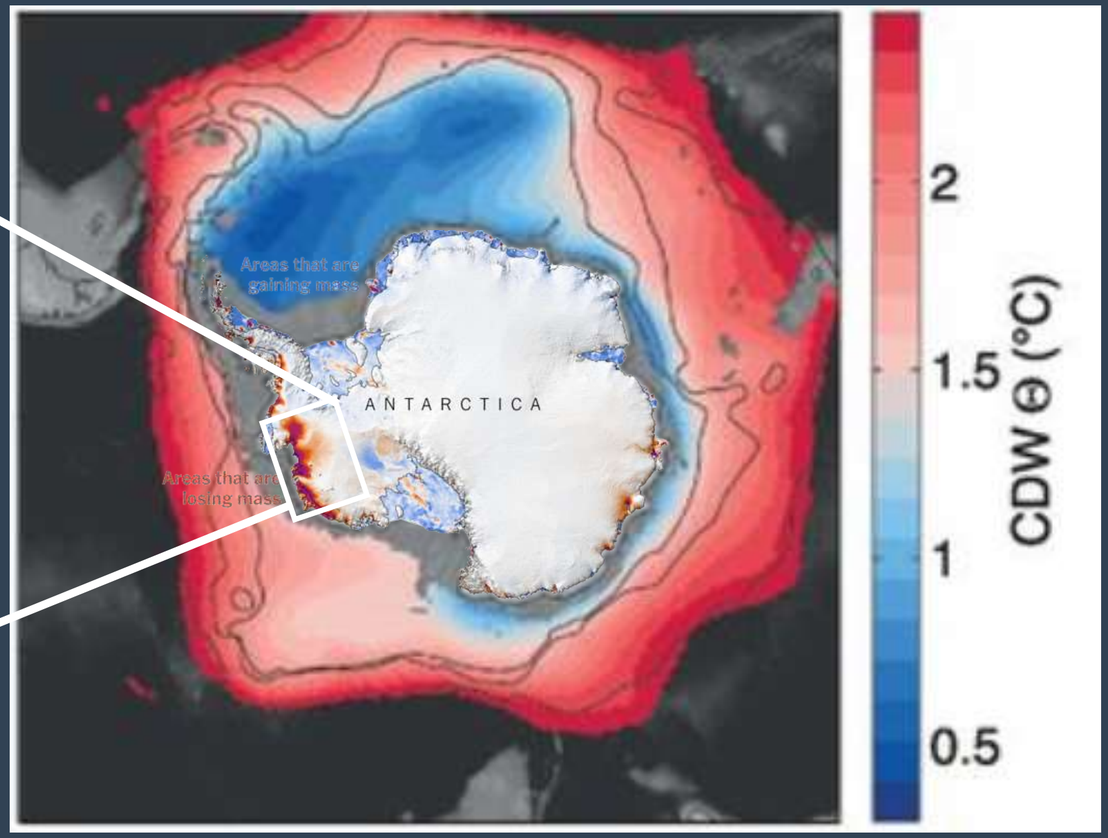
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

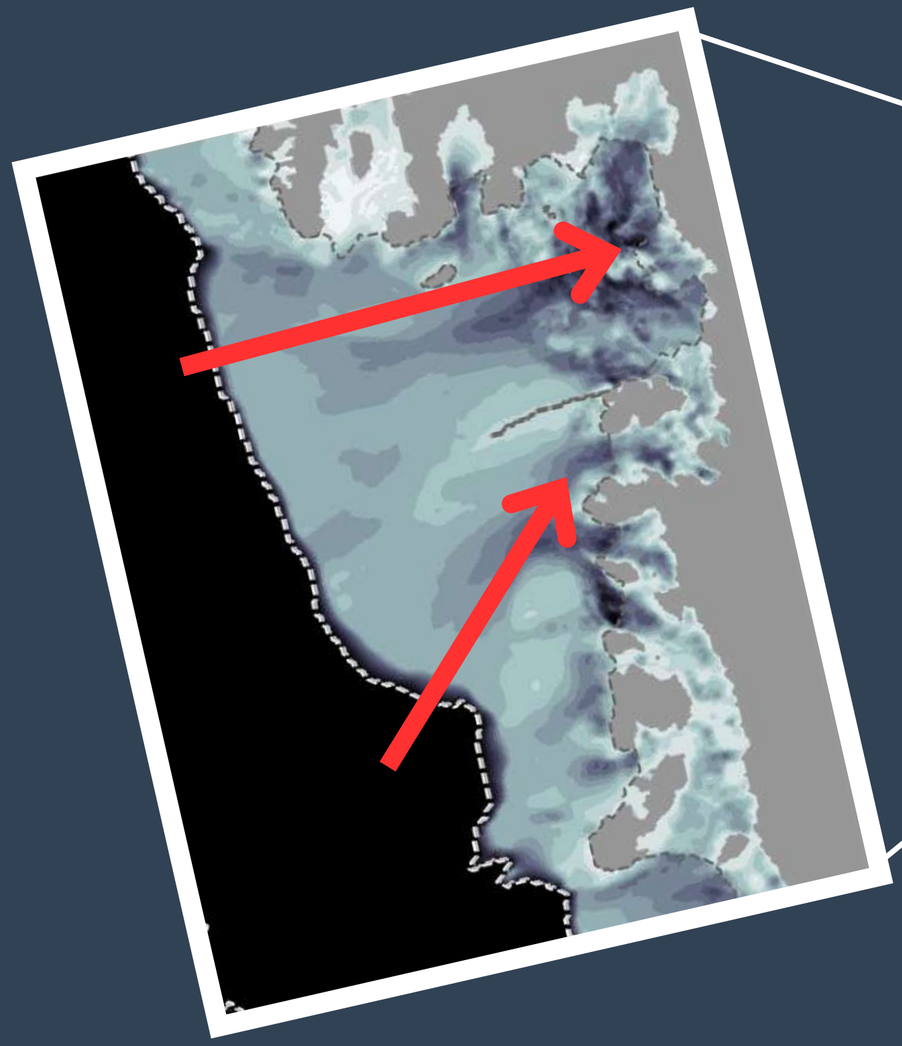


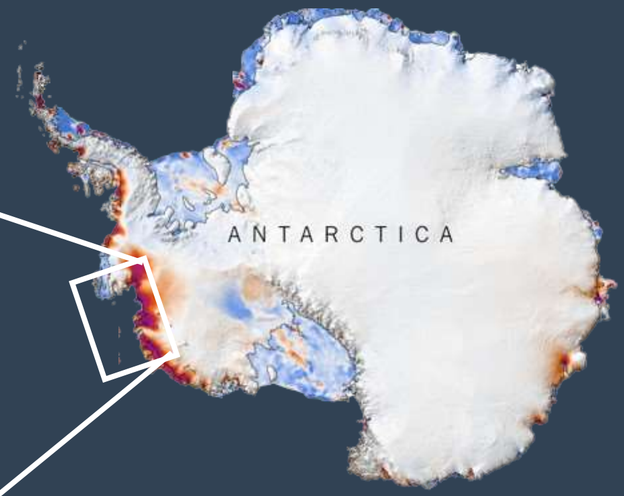
archer2
Celebration of Science

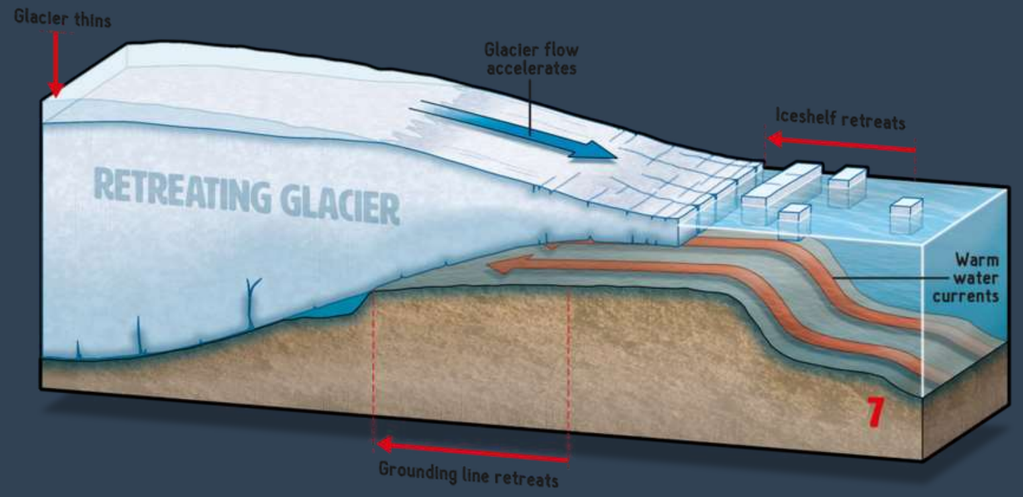

Areas that are gaining mass
ANTARCTICA
Areas that are losing mass
Amundsen Sea




Areas that are gaining mass
ANTARCTICA
Areas that are losing mass
2
1.5
1
0.5
CDW Θ (°C)




ANTARCTICA


Glacier thins
Glacier flow accelerates
Iceshelf retreats
RETREATING GLACIER
Warm water currents
Grounding line retreats

CLIMATE IN CRISIS

'Doomsday' glacier could melt faster than previously thought

A new study of Thwaites Glacier suggests it might retreat at twice its recent rate in the future, threatening to cause a substantial rise in sea level.

tgi THE GARDEN ISLAND

Friday, Dec. 2, 2022 | Today's Paper | 68.765°

News

Ice shelf protecting Antarctic glacier is breaking up faster

By Associated Press | Friday, June 11, 2021, 9 a.m.

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iews

'Doomsday Glacier' is teetering even closer to disaster than scientists thought, new seafloor map shows

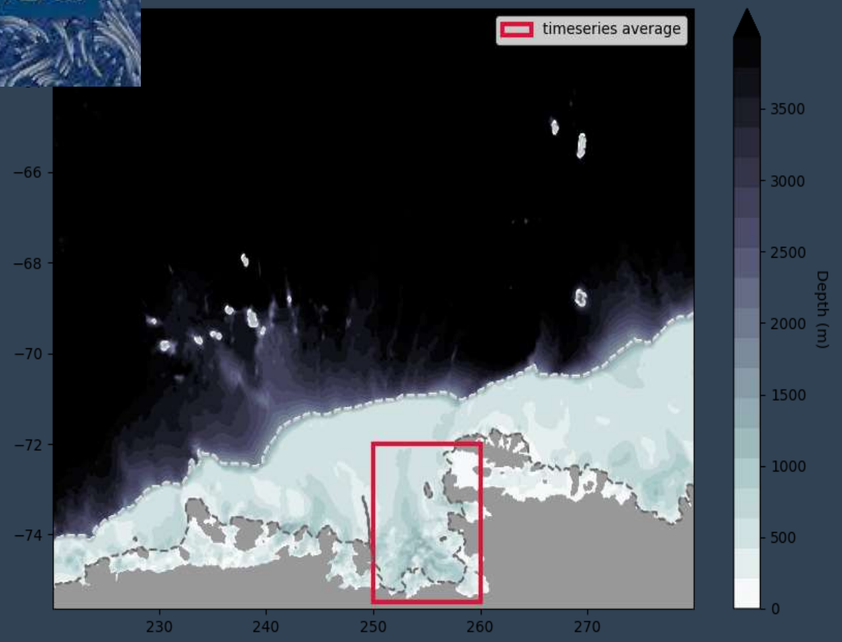
By Harry Baker published September 08, 2022

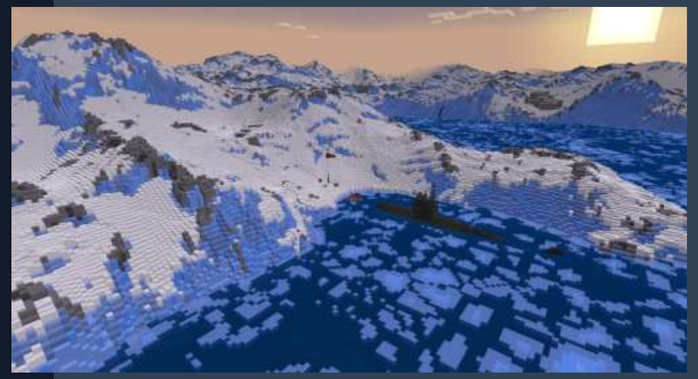
Researchers say the icy mass is "holding on by its fingernails."

The researcher onboard the R/V Nathaniel B. Palmer as it sits in front of Thwaites Glacier in Antarctica. (Image credit: Alexandra Mazur/University of Gothenburg)

But what will the future look like??

METHODS





We use MITgcm (MIT General Circulation Model), a **numerical model** designed for study of the atmosphere, ocean, and climate.

1 year takes about 2 hours using 4CU

We run a number of **climate scenarios** to look at the evolution of ocean warming in the area

nature climate change

Article

https://doi.org/10.1038/s41558-023-01818-x

Unavoidable future increase in West Antarctic ice-shelf melting over the twenty-first century

Received: 13 April 2023

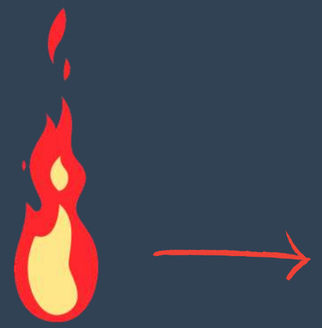
Accepted: 23 August 2023

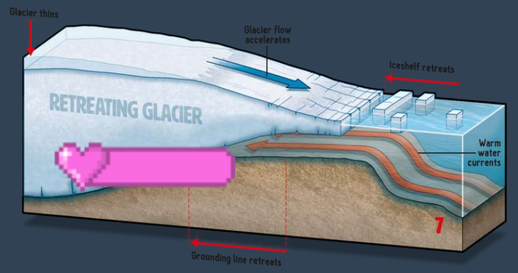
Published online: 23 October 2023

Check for updates

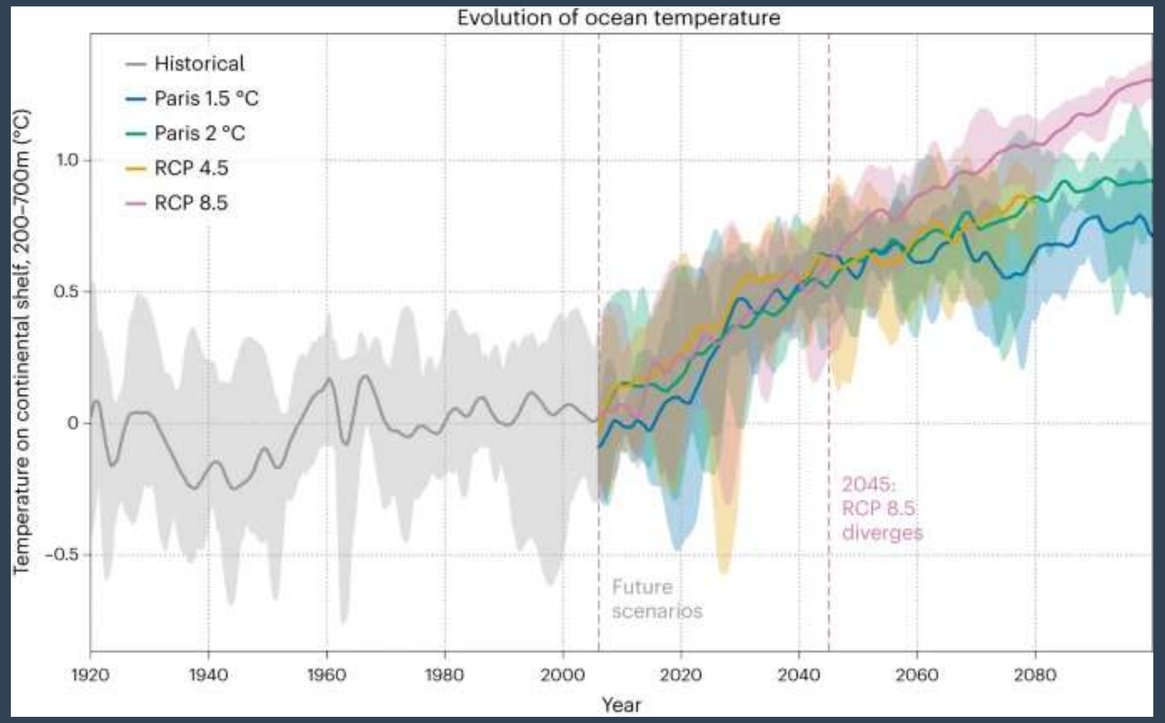
Kaitlin A. Naughten [1], Paul R. Holland [1] & Jan De Rydt [2]

Ocean-driven melting of floating ice-shelves in the Amundsen Sea is currently the main process controlling Antarctica's contribution to sea-level rise. Using a regional ocean model, we present a comprehensive suite of future projections of ice-shelf melting in the Amundsen Sea. We find that rapid ocean warming, at approximately triple the historical rate, is likely committed over the twenty-first century, with widespread increases in ice-shelf melting, including in regions crucial for ice-sheet stability. When internal climate variability is considered, there is no significant difference between mid-range emissions scenarios and the most ambitious targets of the Paris Agreement. These results suggest that mitigation of greenhouse gases now has limited power to prevent ocean warming that could lead to the collapse of the West Antarctic Ice Sheet.





WHAT HAPPENS IN THE FUTURE?

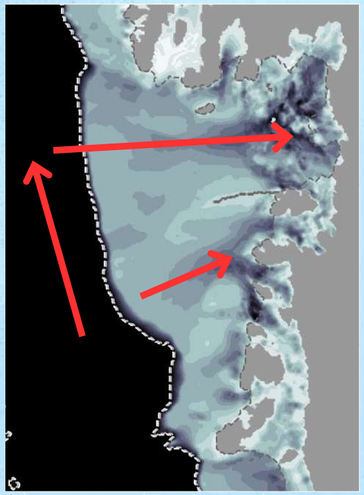


THE OCEAN IS SET TO CONTINUE WARMING ... BUT WHAT IS CAUSING THIS WARMING?

i.e. the question that took up the last two years of my PhD!

Oceanography 101

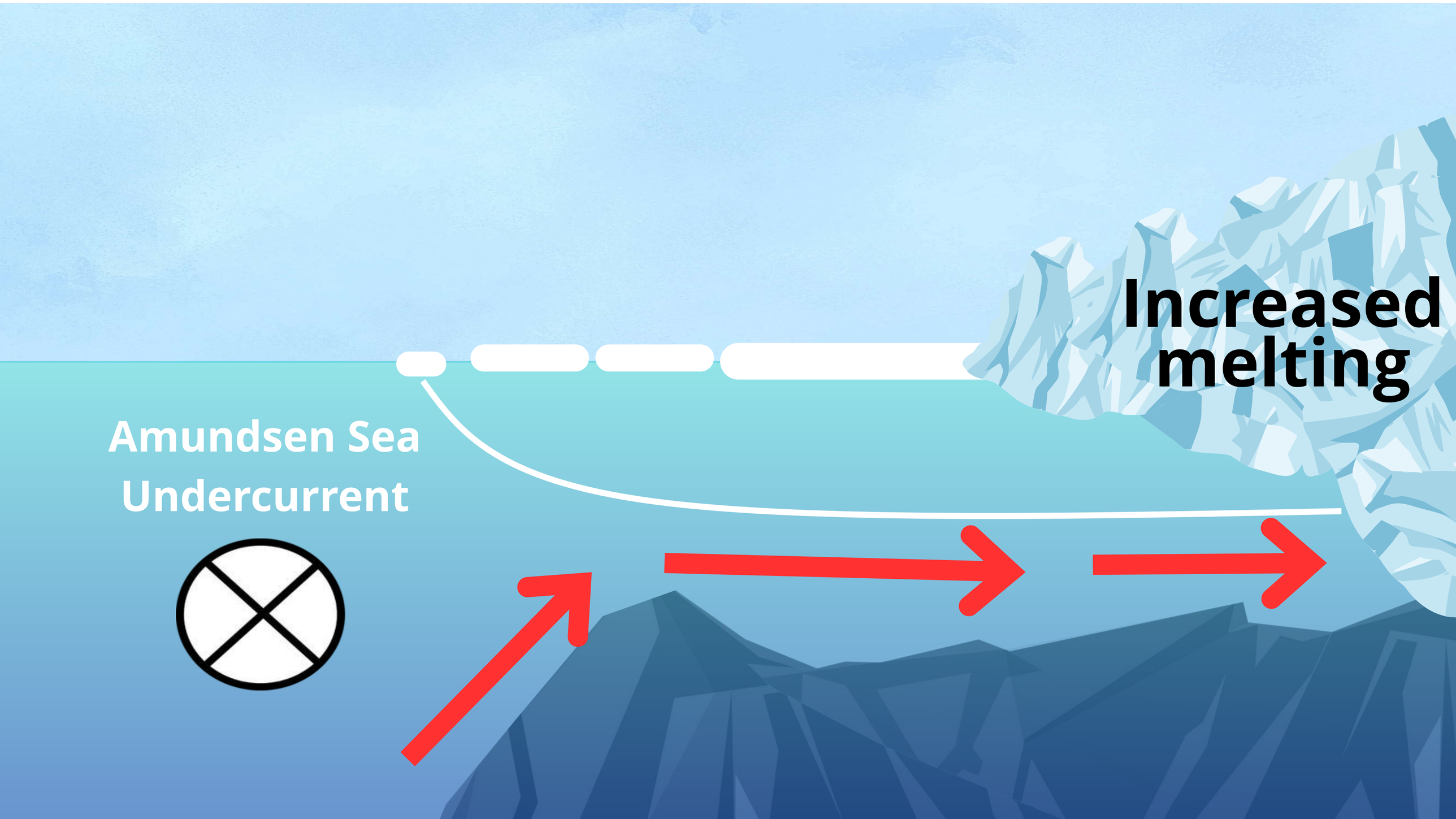
(fluid mechanics with a *ton* of approximations)



Cold fresh water

Amundsen Sea Undercurrent

Warm salty water


Increased melting
Amundsen Sea Undercurrent

He who controls the spice controls the universe

He who controls the ~~spice~~ controls the ~~universe~~

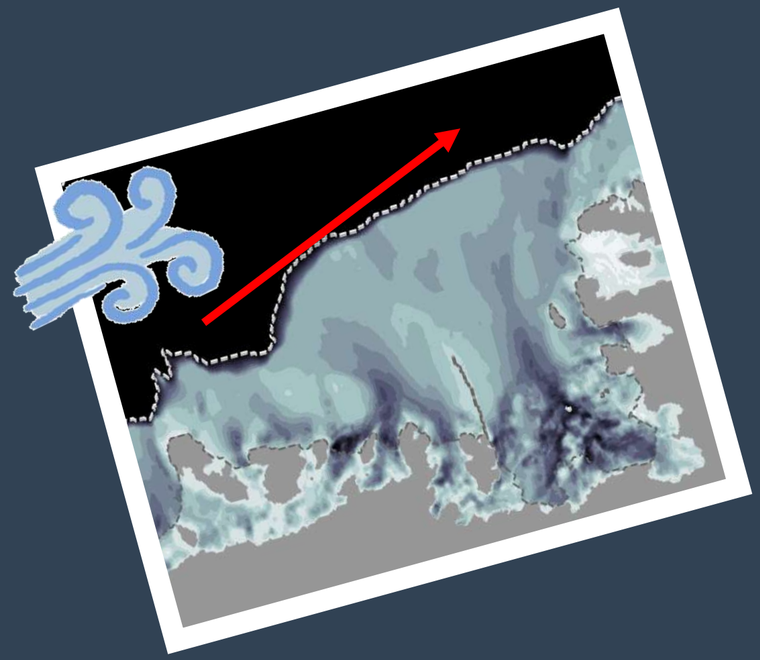
Undercurrent

Amundsen Sea Warming

QUESTION

THE OCEAN IS SET TO CONTINUE WARMING ... BUT WHAT IS CONTROLLING THE UNDERCURRENT?

WINDS



Observations show that when these eastward winds decrease, ice shelf melting also decreases

REPORT

Strong Sensitivity of Pine Island Ice-Shelf Melting to Climatic Variability

PIERRE DUTRIEUX , JAN DE RYDT, ADRIAN JENKINS, PAUL R. HOLLAND, HO KYUNG HA, SANG HOON LEE, ERIC J. STEIG, QINGHUA DING, E. POVL ABRAHAMSEN, AND MICHAEL SCHRÖDER Authors Info & Affiliations

We know shelf break winds are set to increase in the future, potentially explaining the predicted warming

THERMODYNAMICS

We expect temperature and precipitation (atmospheric thermodynamics) to also increase in the future.

JGR Oceans

Research Article | Open Access

Drivers and Reversibility of Abrupt Ocean State Transitions in the Amundsen Sea, Antarctica

Justine Caillet, Nicolas C. Jourdain, Pierre Mathiot, Hartmut H. Hellmer, Jérémie Mouginot

First published: 20 December 2022 | https://doi.org/10.1029/2022JC018929 | Citations: 4

Geophysical Research Letters

Research Letter | Open Access

Decadal Variability of Ice-Shelf Melting in the Amundsen Sea Driven by Sea-Ice Freshwater Fluxes

Michael Haigh, Paul R. Holland

QUESTION

ON CENTENNIAL TIMESCALES WHAT IS THE MAIN DRIVER OF WARMING?

Winds

Future scenarios predict stronger, poleward - shifted winds

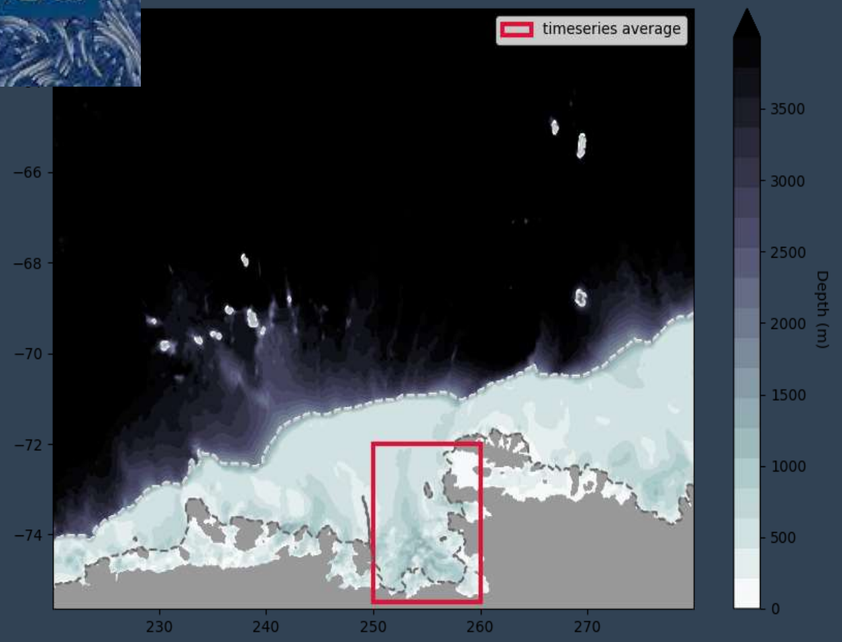
Atmospheric Thermodynamics

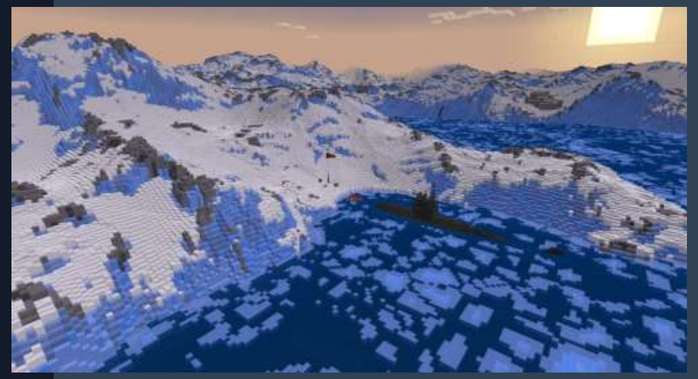
What will be the effects of a warmer, wetter atmosphere?

How do we untangle the effects of winds from those of a wetter and warmer atmosphere?

We use models!

METHODS



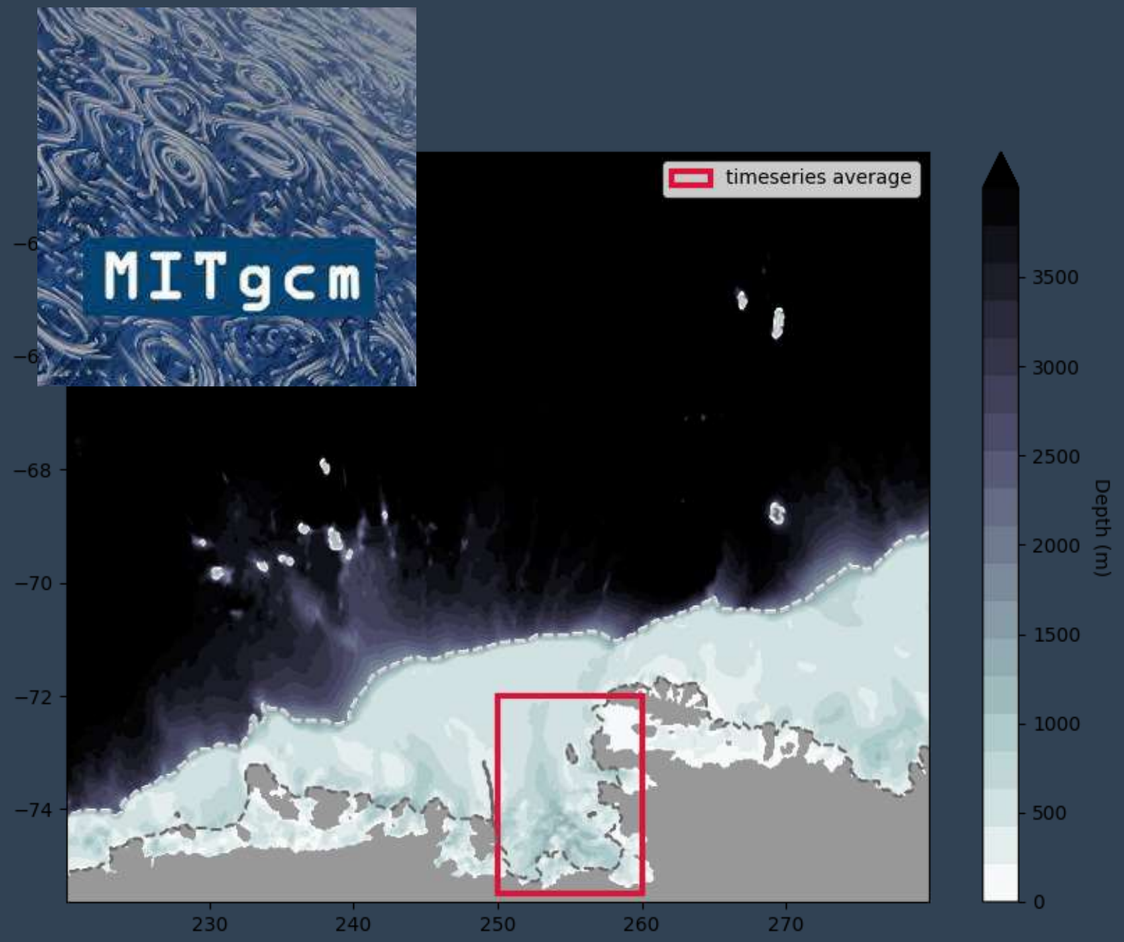


I use MITgcm (MIT General Circulation Model), a **numerical model** designed for study of the atmosphere, ocean, and climate.

1 year takes about 2 hours using 4CU

4 experiments
9 ensemble members each
From 1920 to 2100

METHODS



ATMOSPHERIC FORCING:

ALL

model is forced with high man-made change

NONE

What would the Amundsen Sea look like if the industrial revolution had never happened?

WIND

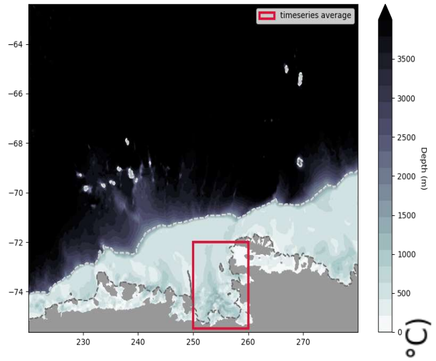
Future worst-case winds and pre-industrial thermodynamics

THERMO

Future worst case atmospheric thermodynamics pre-industrial winds

QUESTION

WHAT HAPPENS TO OCEAN WARMING UNDER THESE DIFFERENT EXPERIMENTS?


timeseries average
−64
−66
−68
−70
−72
−74
230
240
250
260
270
3500
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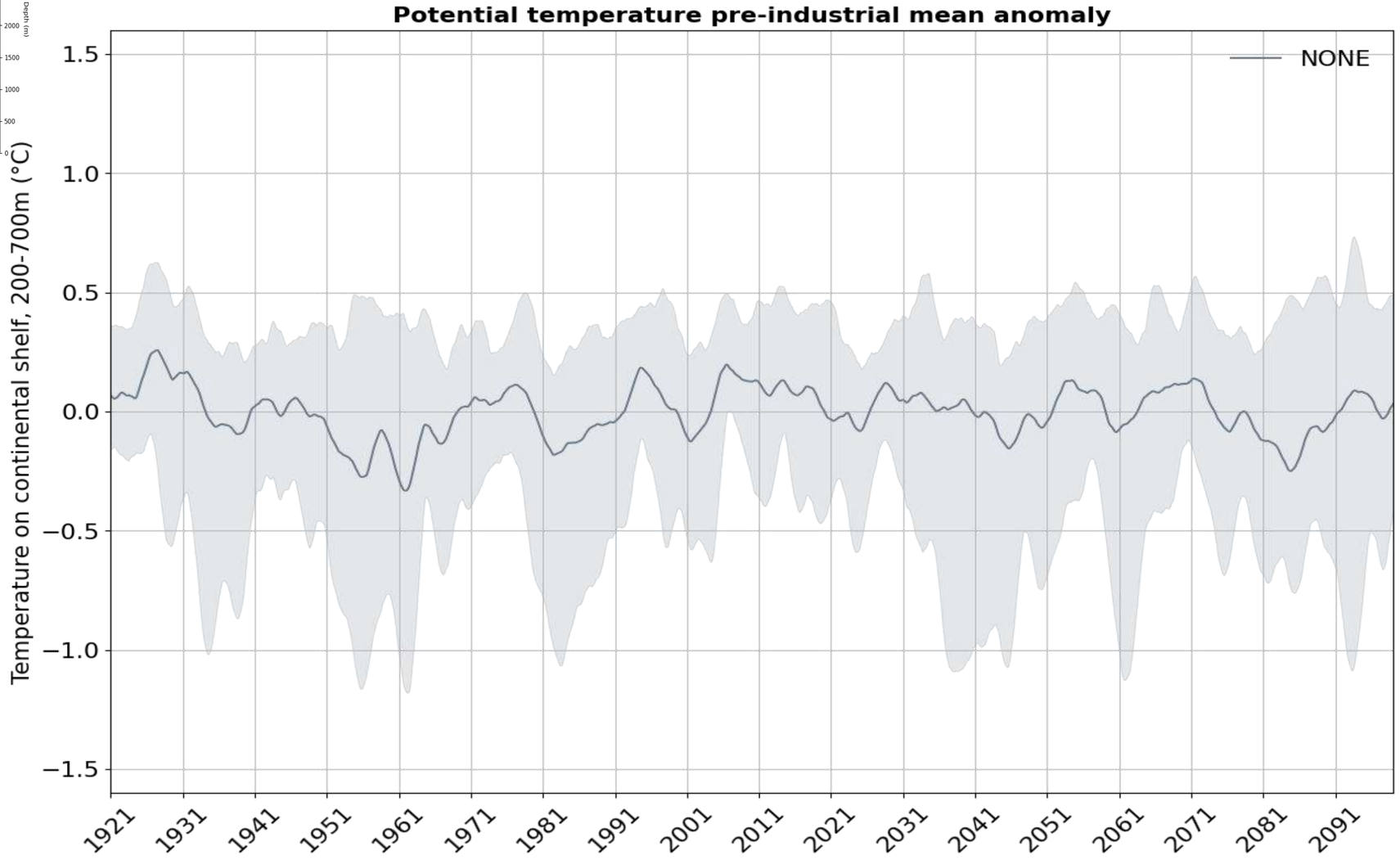
2500
2000
1500
1000
500
0
Depth (m)


Potential temperature pre-industrial mean anomaly
NONE
Temperature on continental shelf, 200-700m (°C)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
1921
1931
1941
1951
1961
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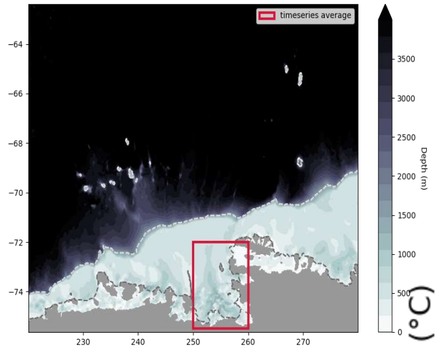
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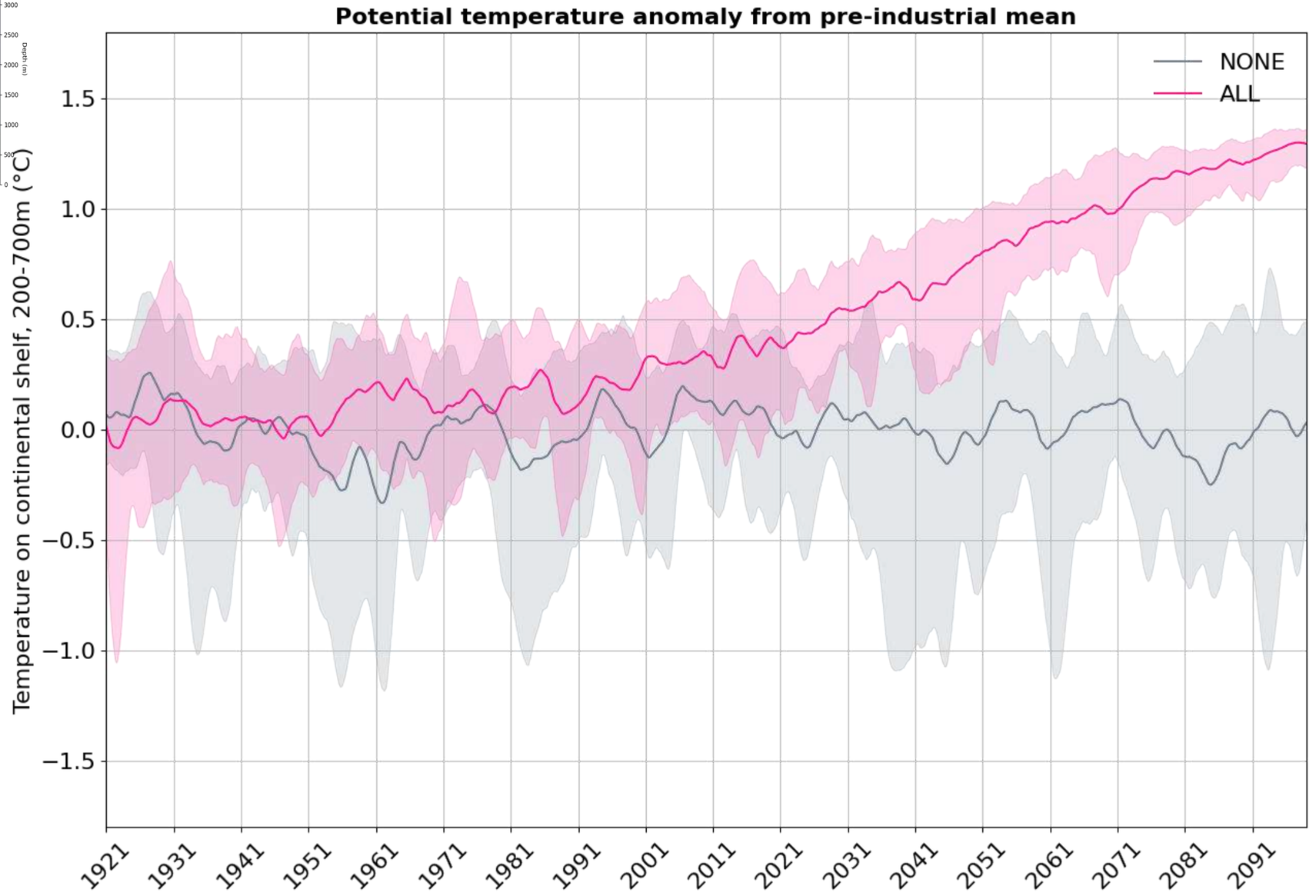
Potential temperature anomaly from pre-industrial mean
NONE
ALL
Temperature on continental shelf, 200-700m (°C)
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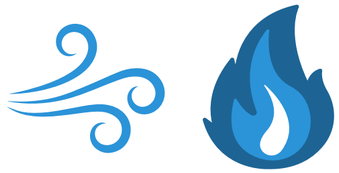
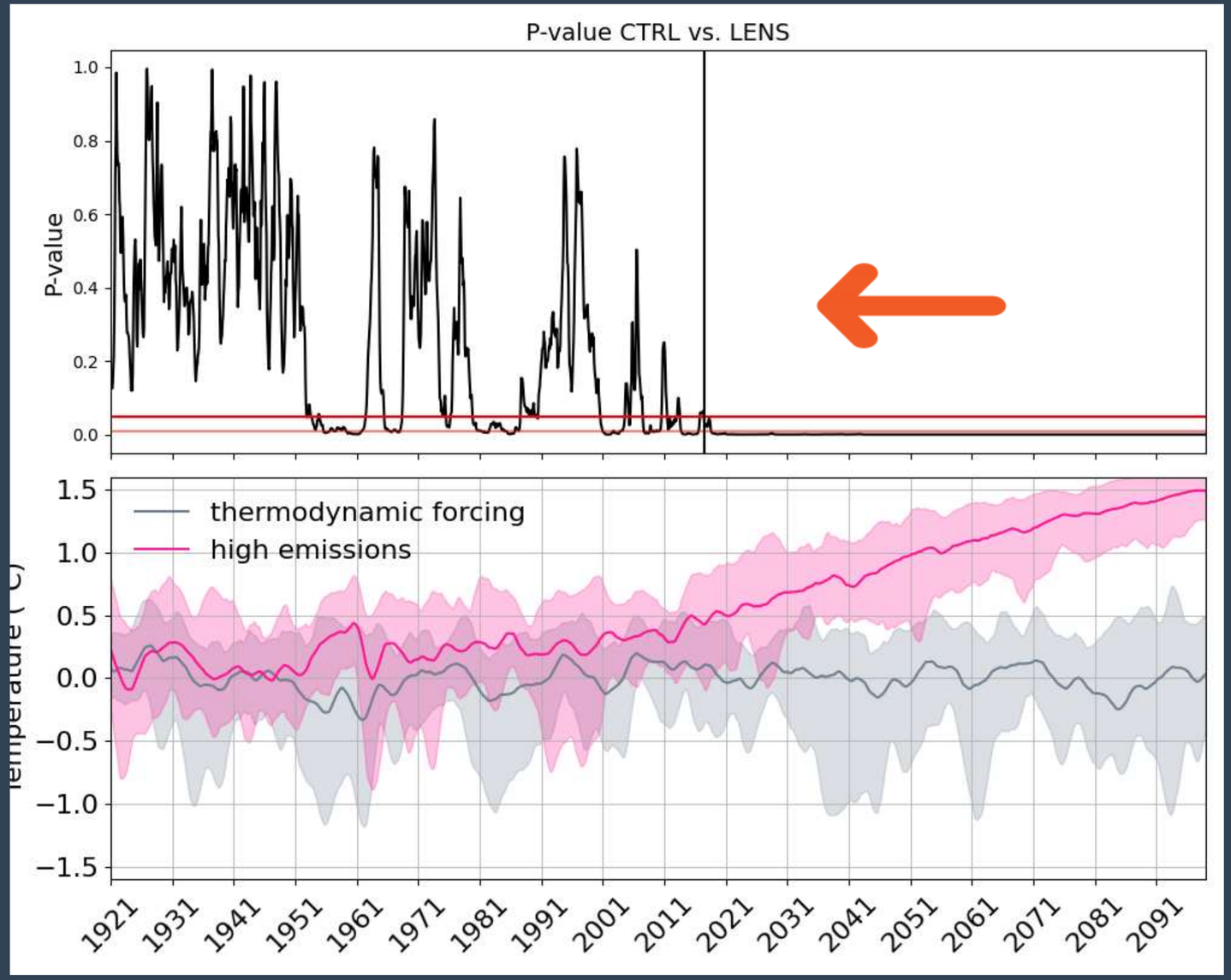
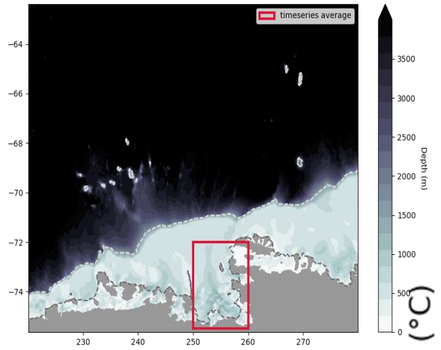


EFFECT ON WARMING

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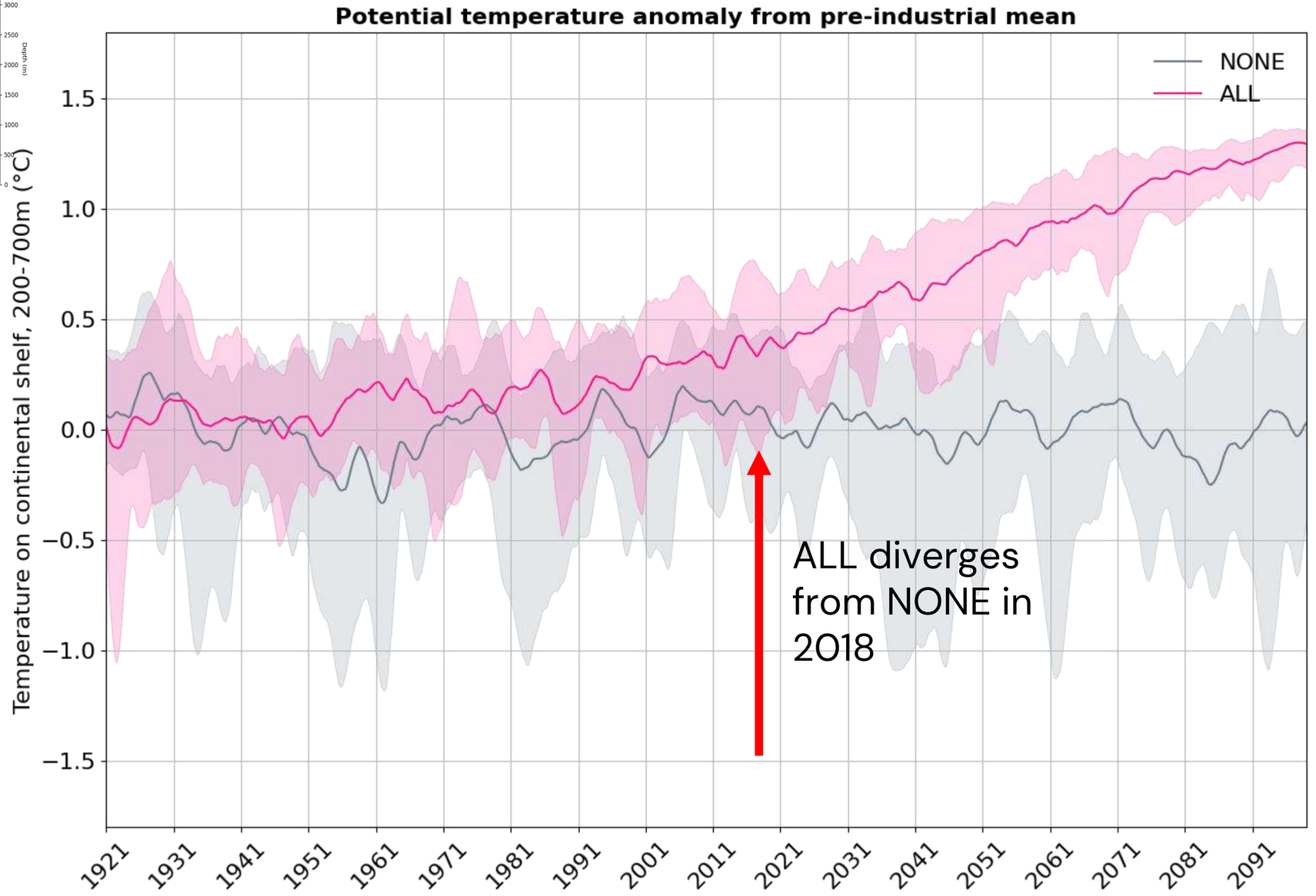
Depth (m)


Potential temperature anomaly from pre-industrial mean
NONE
ALL
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1.0
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−1.0
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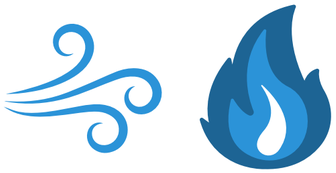
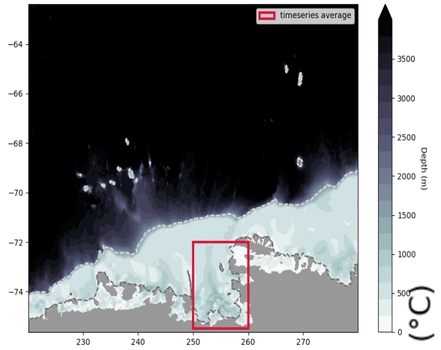
2091
ALL diverges from NONE in 2018

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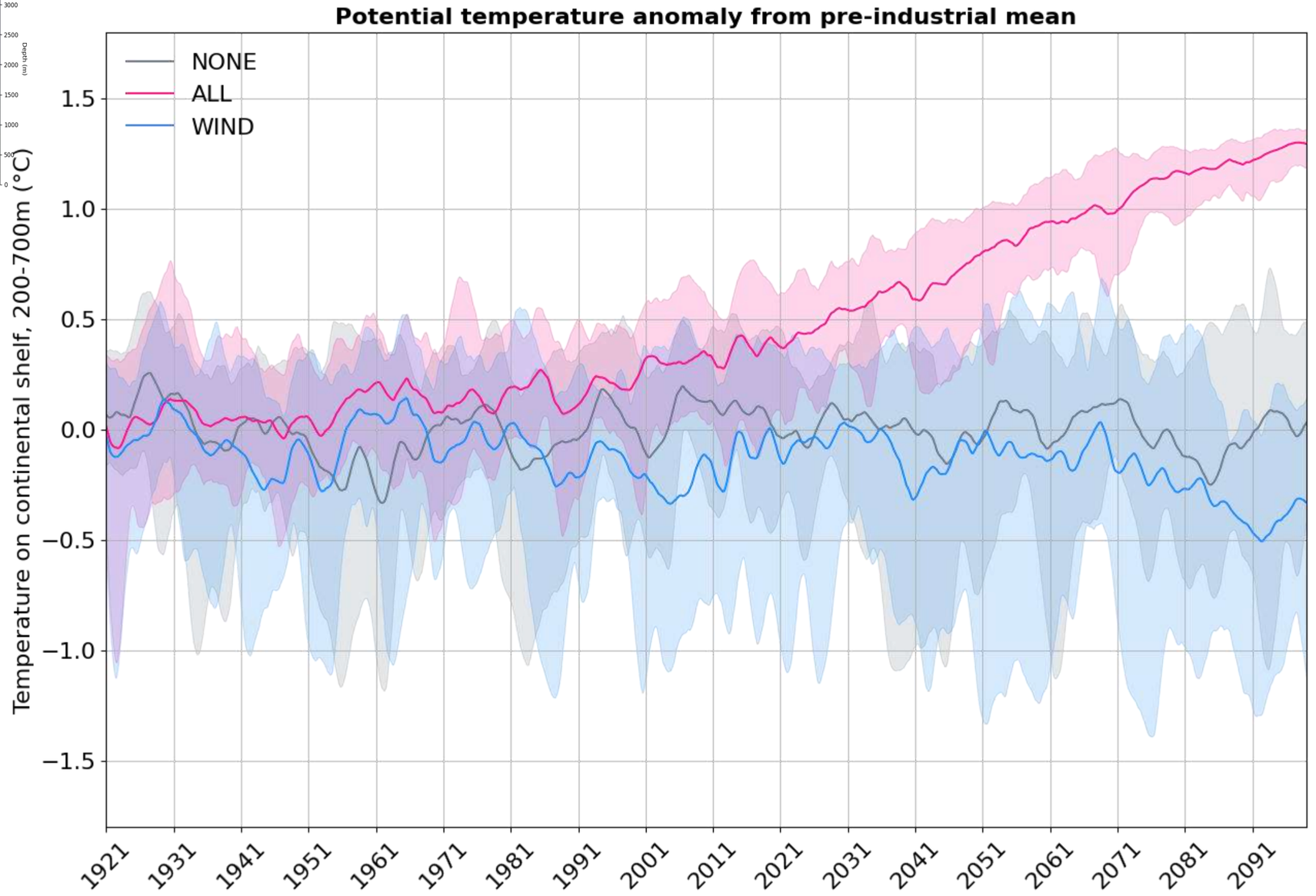
Potential temperature anomaly from pre-industrial mean
NONE
ALL
WIND
Temperature on continental shelf, 200-700m (°C)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
1921
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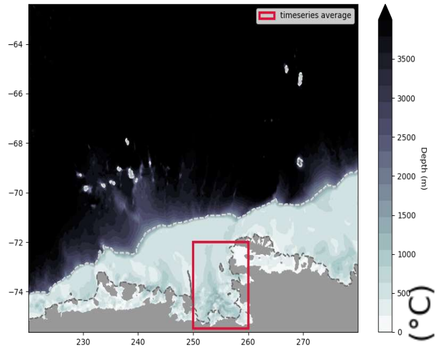
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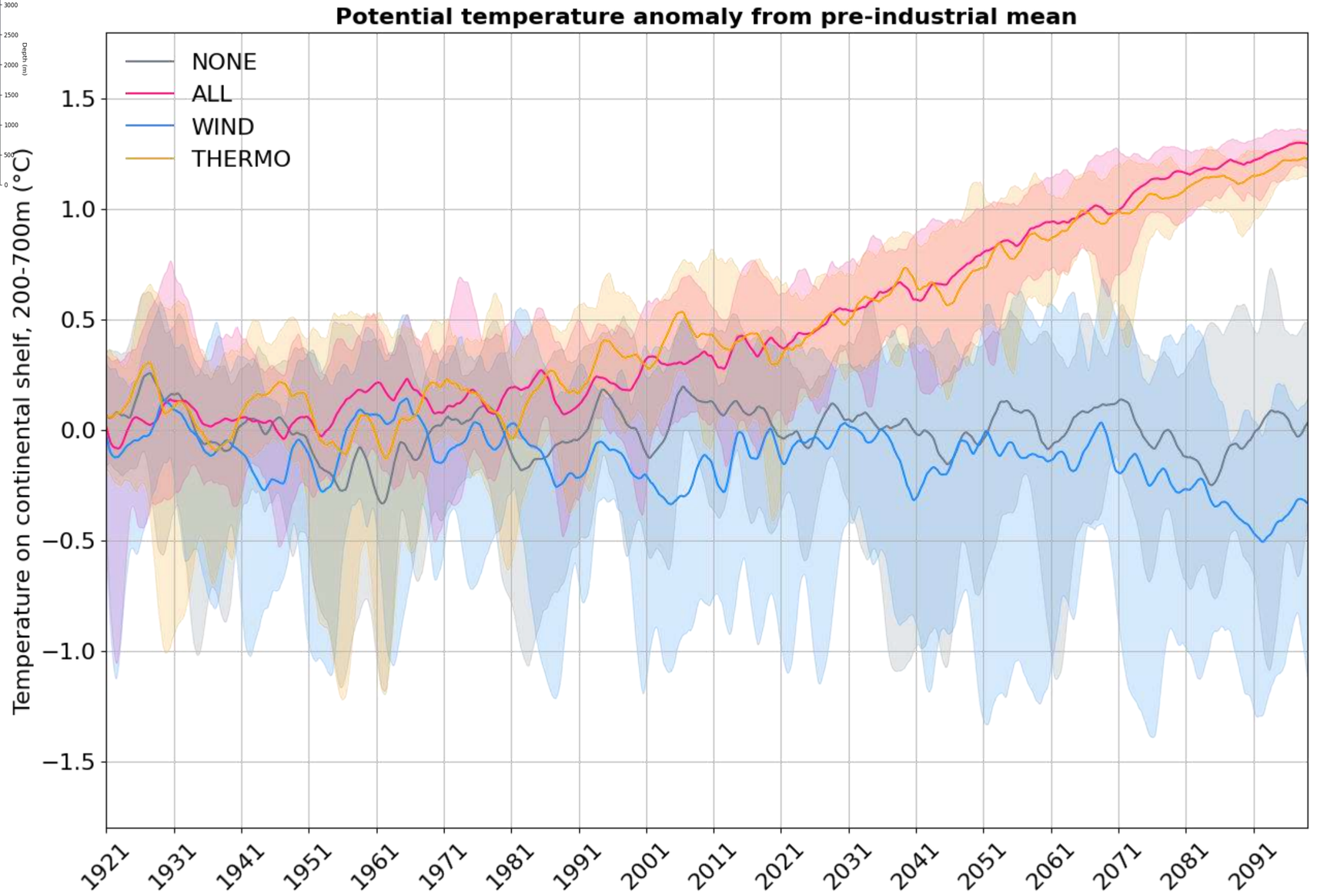
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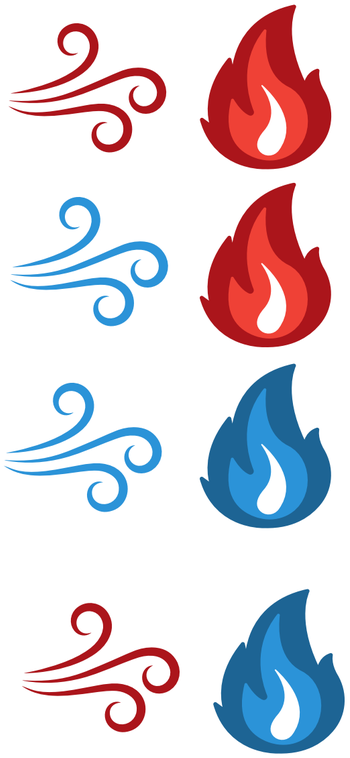
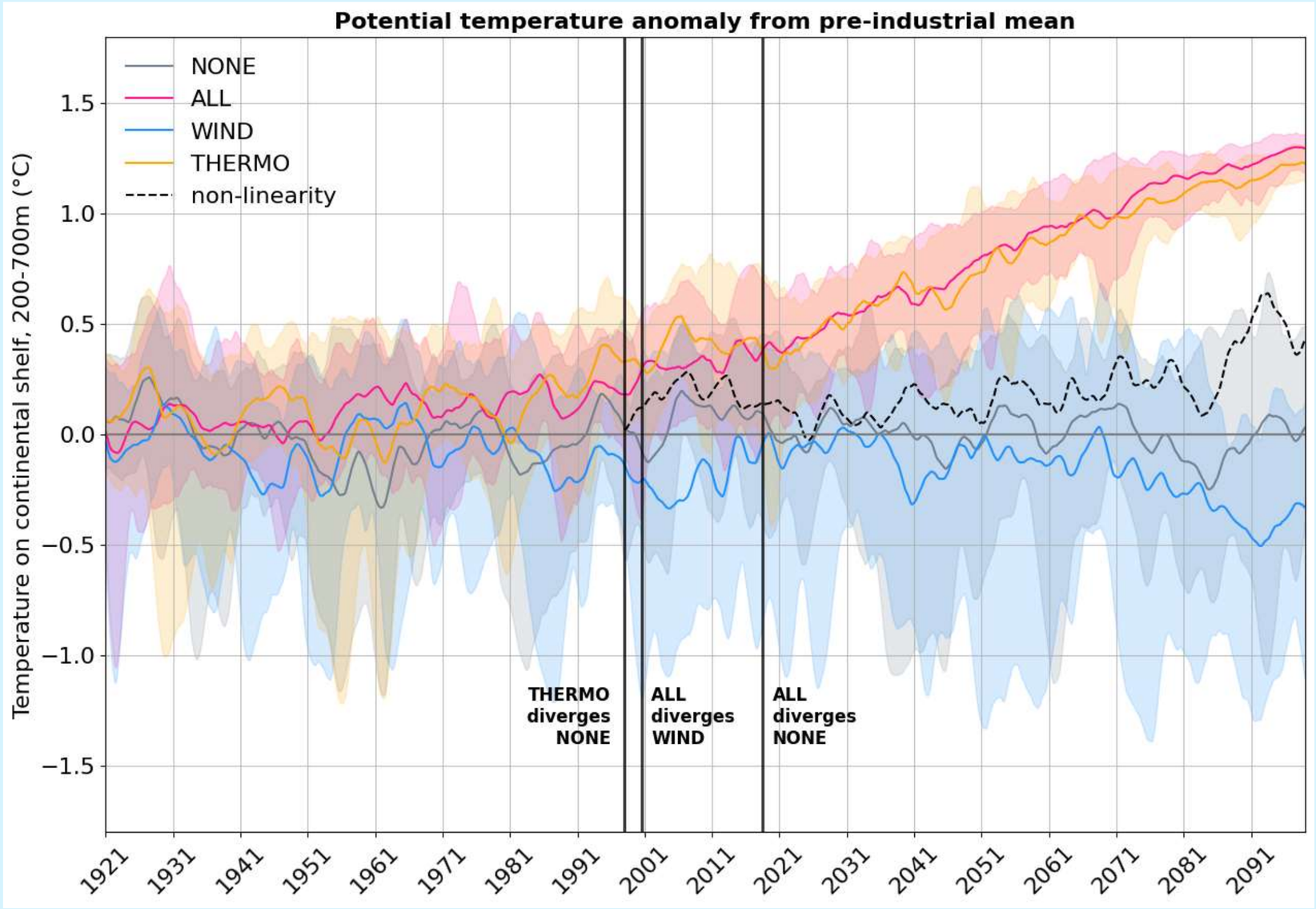


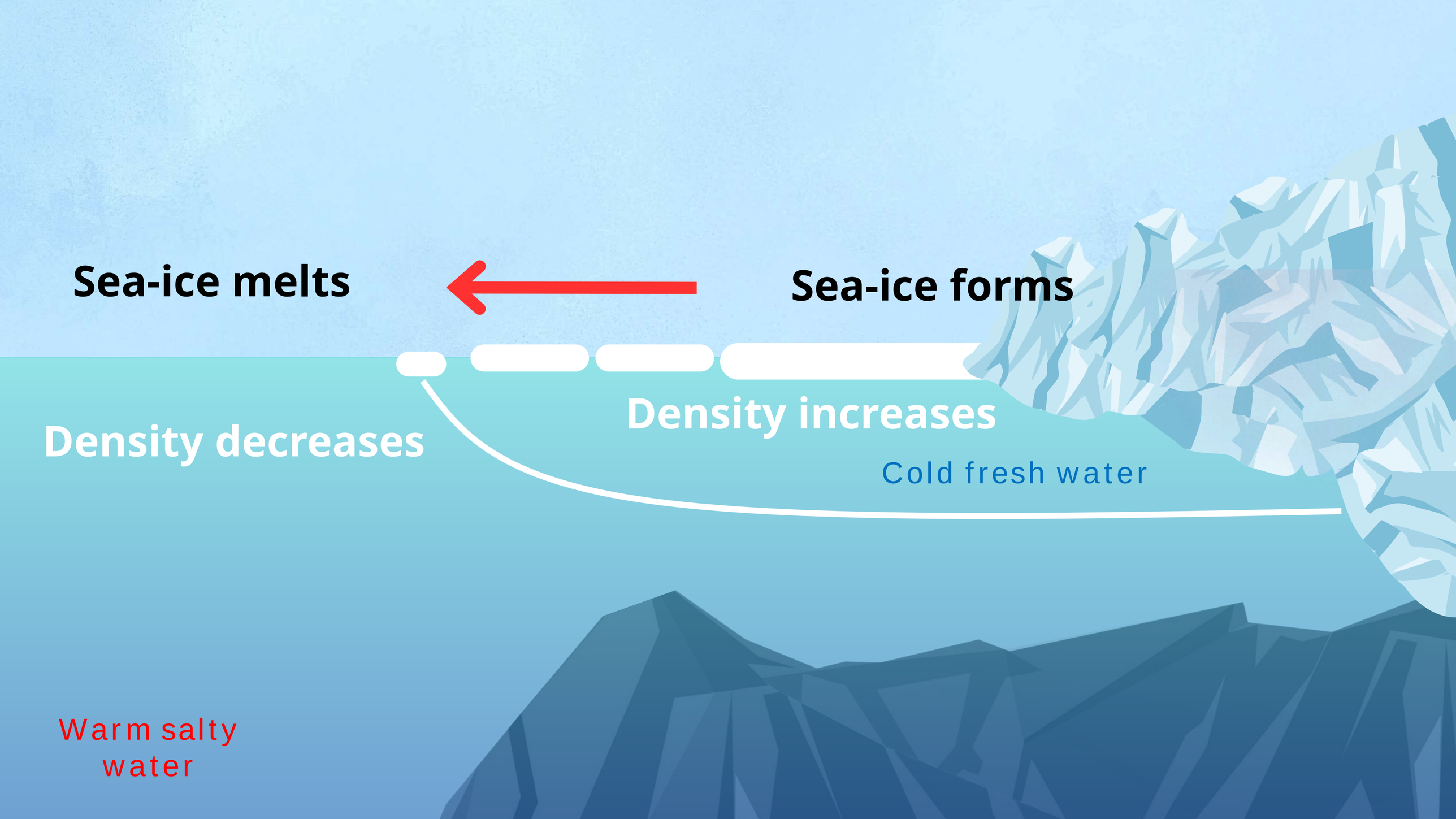


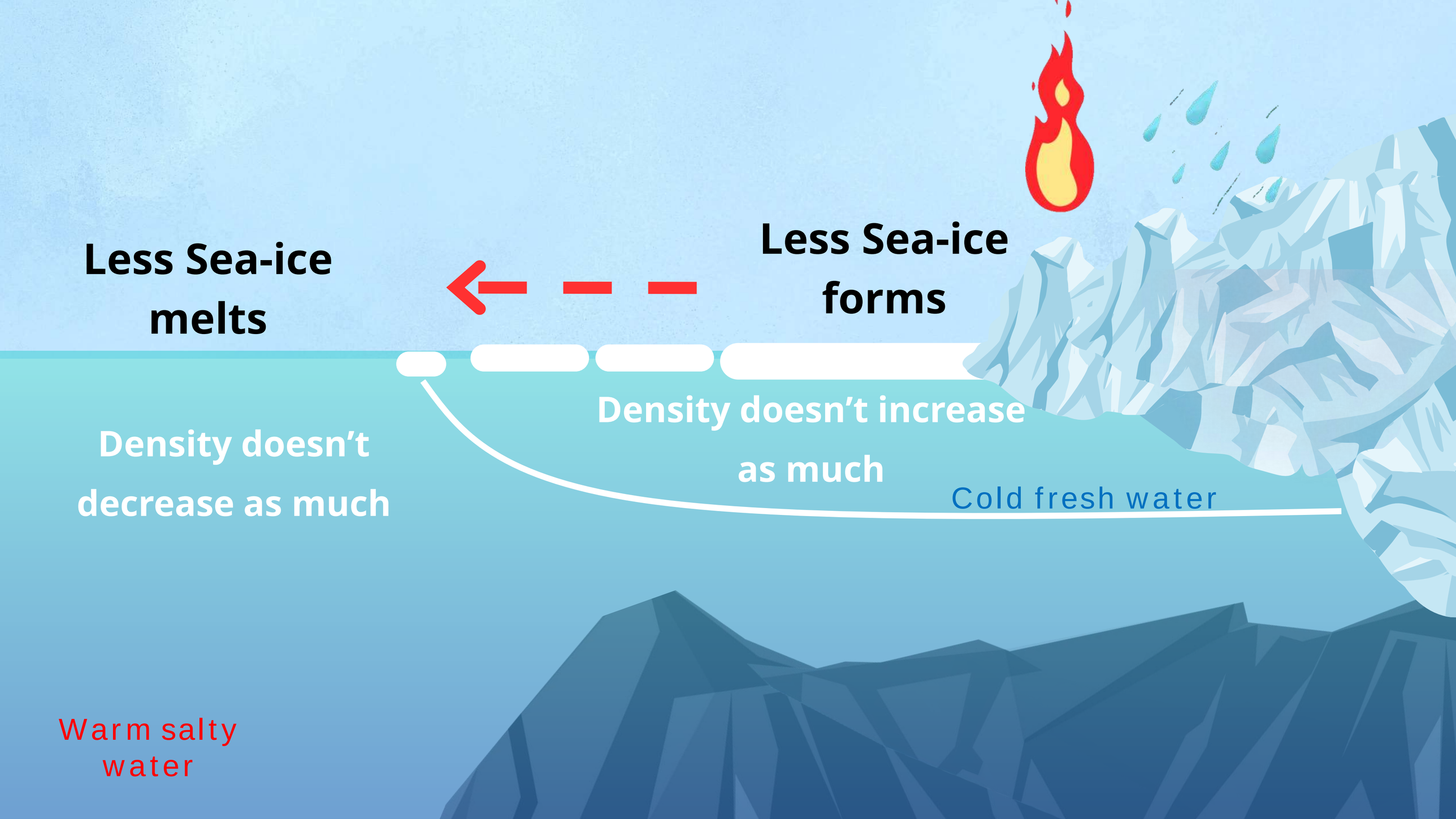
NON-LINEARITY CALCULATED AS: (ALL - NONE) - (THERMO - NONE) - (WIND - NONE)

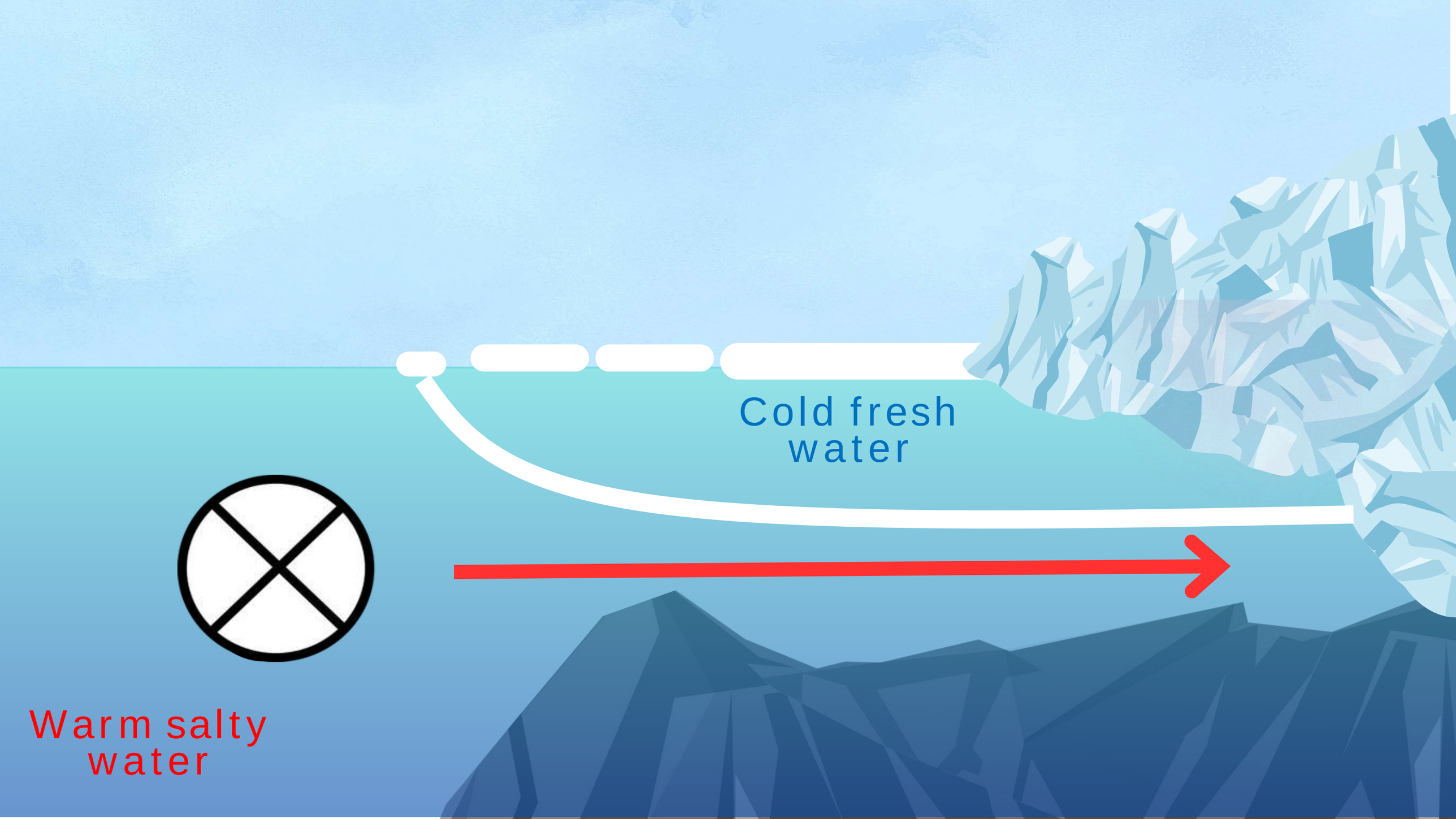
QUESTION

IF THE WINDS AREN'T

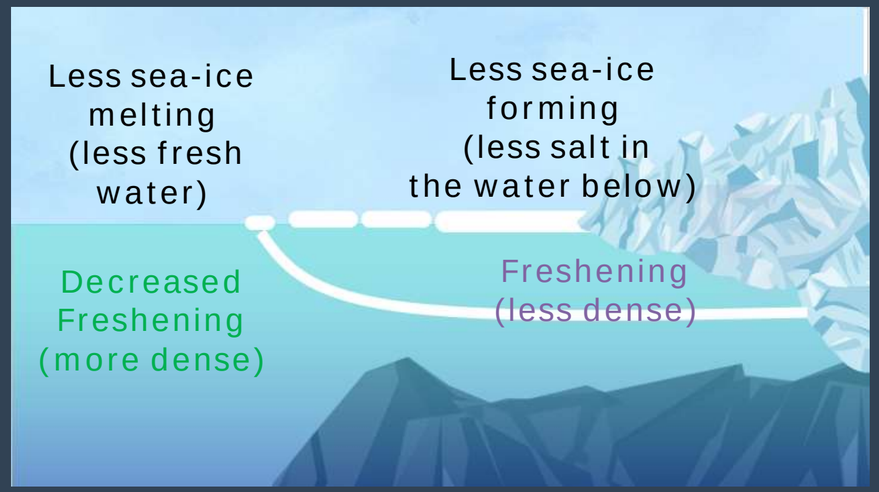
THE CAUSE OF OCEAN WARMING, WHAT IS?


Sea-ice melts
Sea-ice forms
Density increases
Density decreases
Cold fresh water
Warm salty water


Less Sea-ice melts
Less Sea-ice forms
Density doesn’t decrease as much
Density doesn’t increase as much
Cold fresh water
Warm salty water

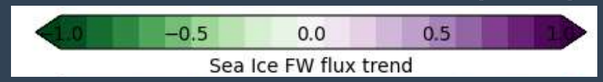

Cold fresh water
Warm salty water

Freshening trends on the continental shelf

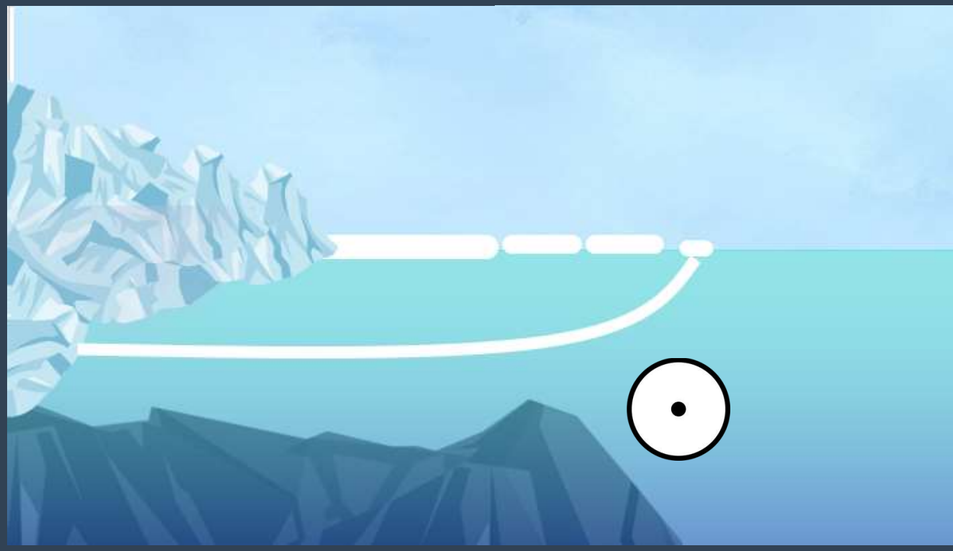


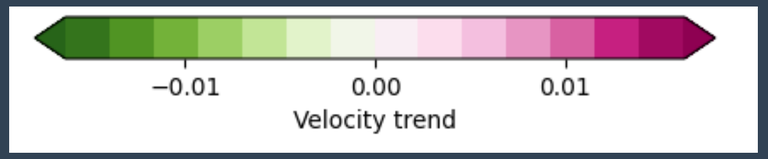
Decreased freshening

Increased freshening (m/yr/century)



Undercurrent acceleration





Eastward acceleration (m/s/century)

Next steps? Using ARCHER to run a coupled ice sheet-ocean model

Northumbria University NEWCASTLE

Separating the effects of ice shelf melt and sea-ice melt

Contributing to MISOMIP 2

Reproducing Naughten et al., 2023 with ice shelf response and continuing simulations up to 2300

RESULTS

Result 1

The effect of human activity can only be separated from un-forced scenarios from 2018

Result 2

The effects from a wetter and warmer atmosphere account for most of ocean warming in the Amundsen Sea on centennial scales

Result 3

Future warming can be attributed to changes related to changes in the trends in sea-ice production

Turner et al (2025) "Modelled centennial ocean warming in the Amundsen Sea driven by thermodynamic atmospheric changes, not winds" - GRL ***[in review]***

Questions?

Get in Touch!

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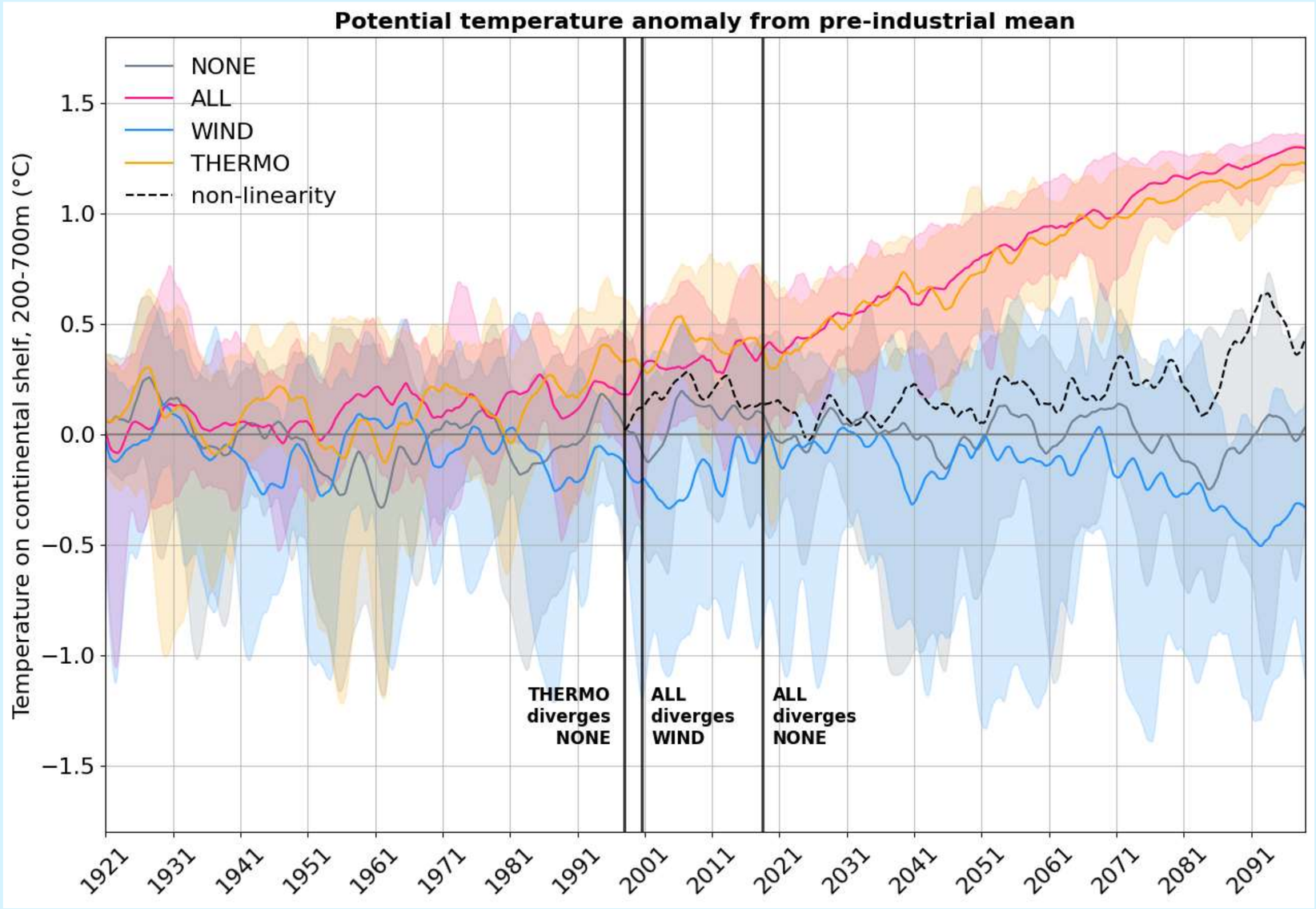
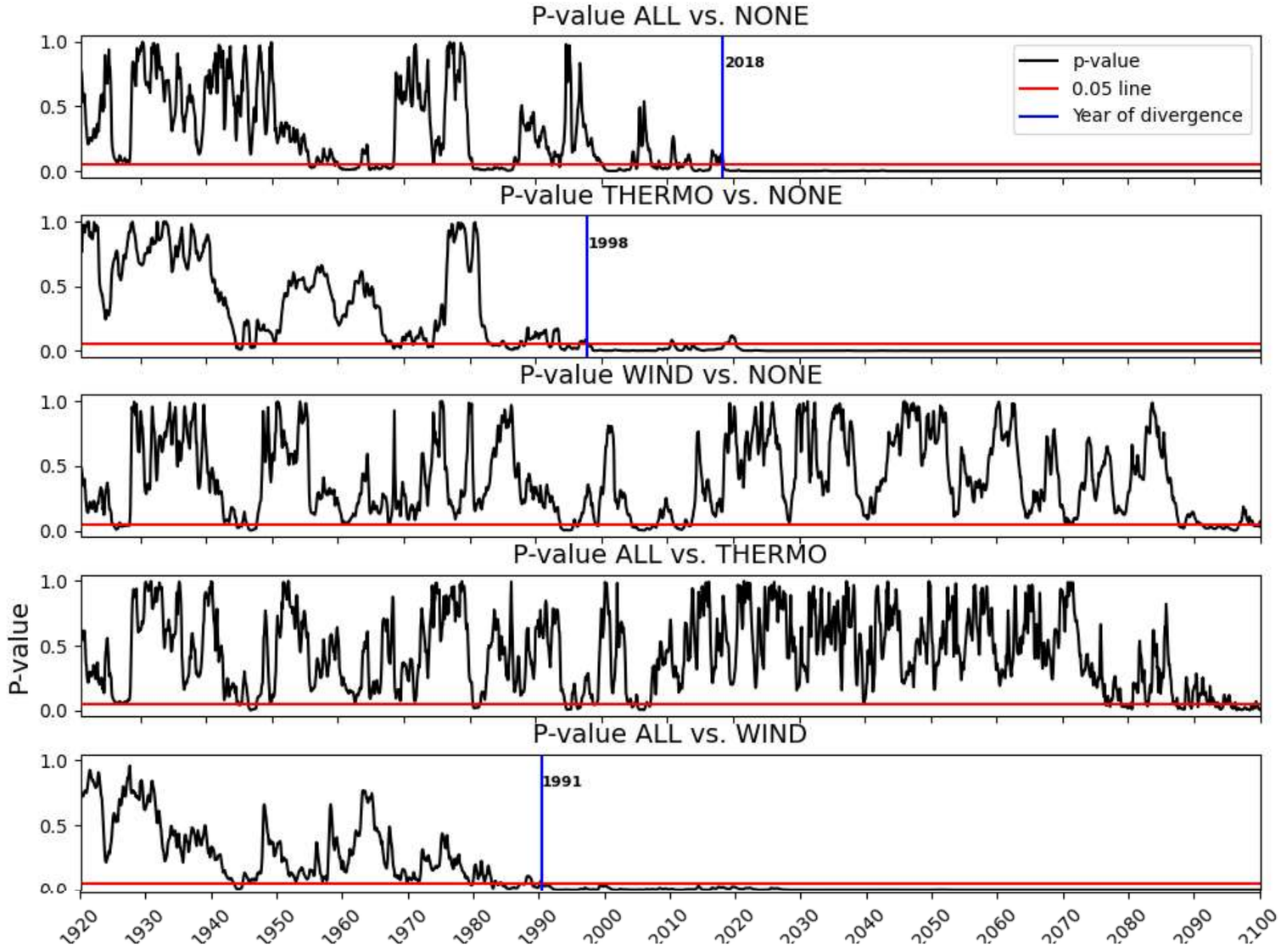
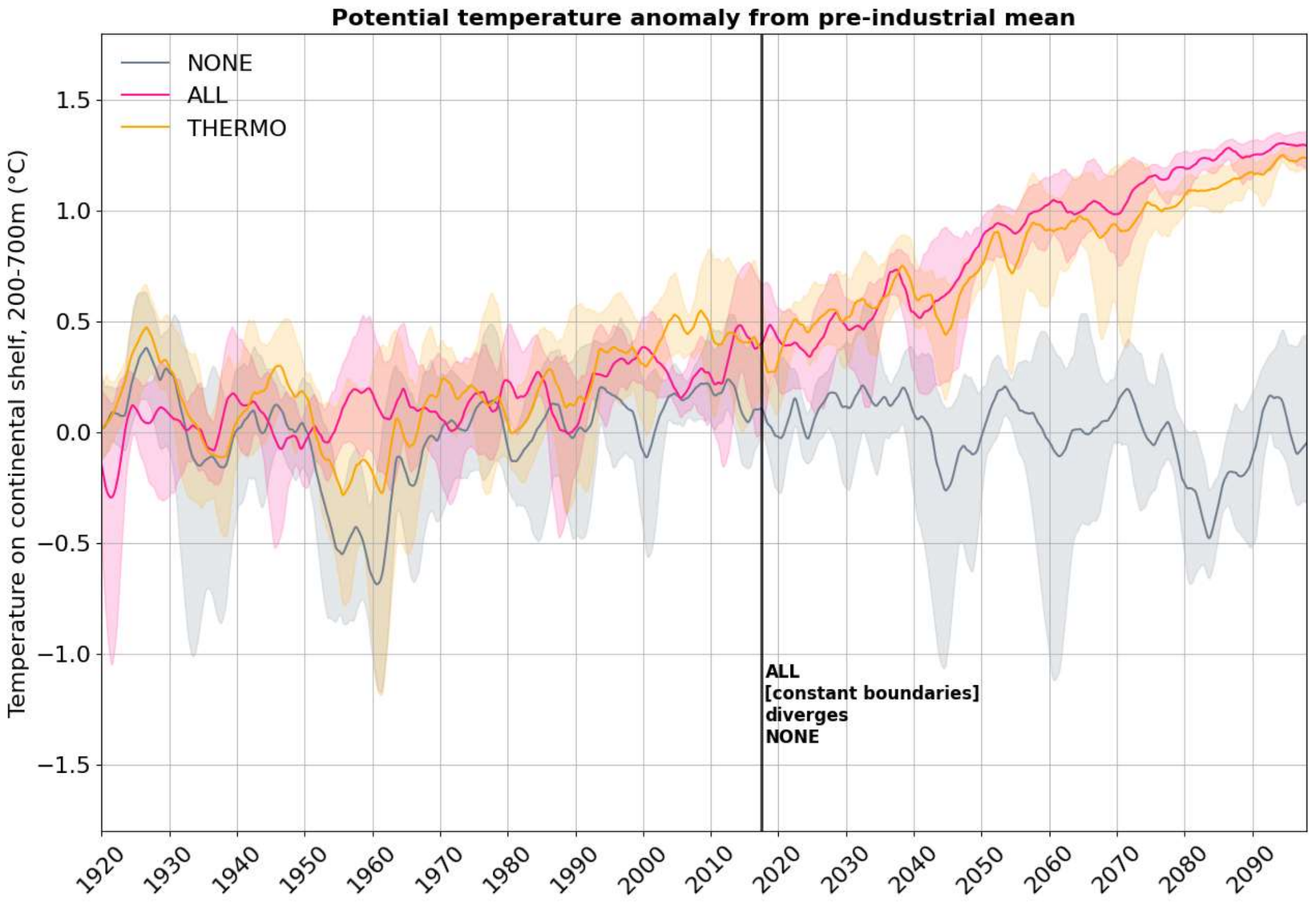
EXTRAS
(for the curious)

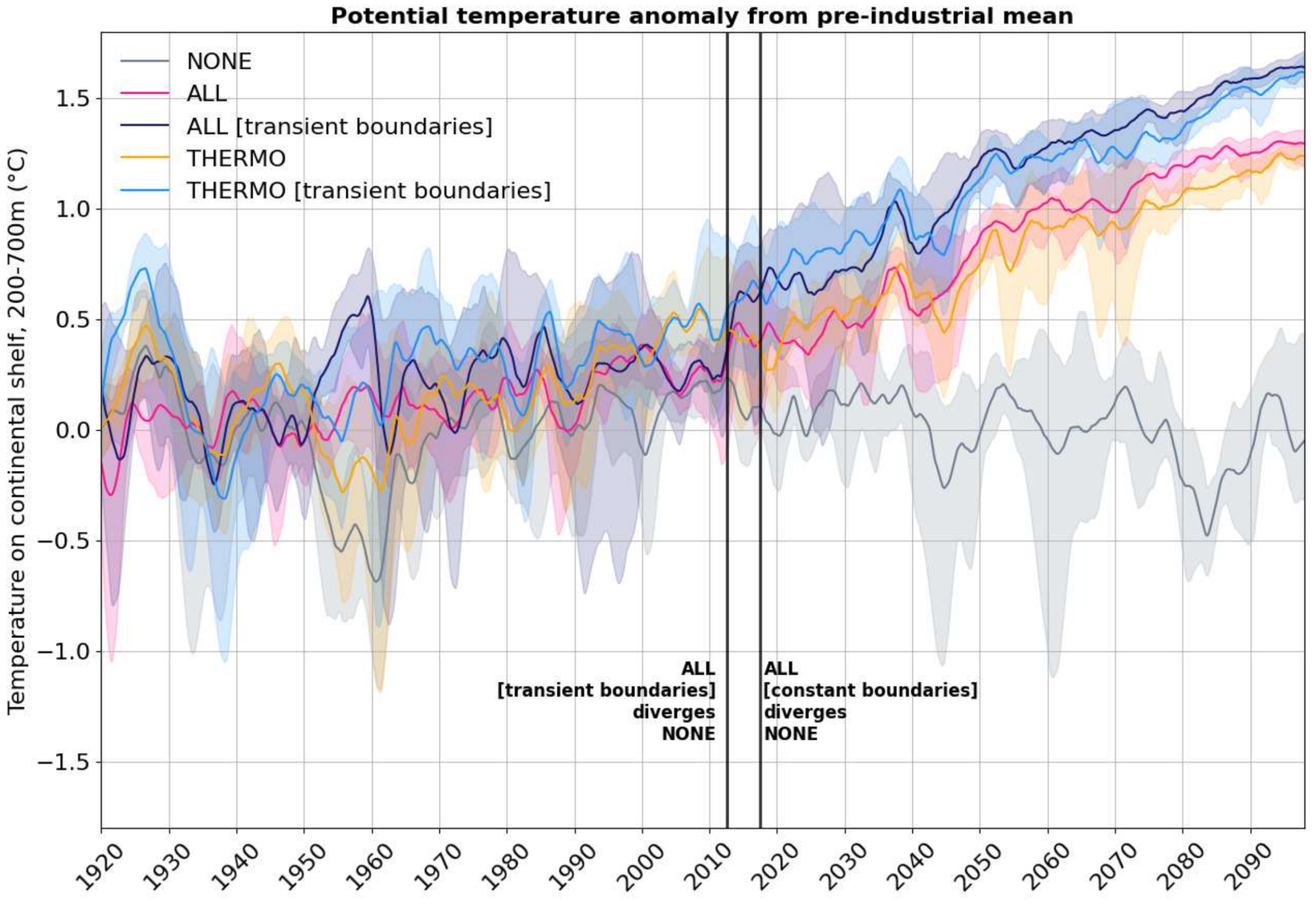
	Priority	Ens num	years	CU	Memory	Simulations	Time (d)	Jobs
Check compiler	High	1	30	120	224	2	17.5	
Run present-day climatology	High	3	30	360	1008	3	17.5	
Kaitlin's transient boundary (180 years)	High	3	210	2520	7056	3	17.5	18
Pre-industrial transient boundary (180 years)	High	3	210	5040	9408	4	17.5	
Run using trend trend on the thermodynamic var	Medium	3	30	720	672	2	2.5	
Run using trend trend on the wind var	Low	3	30	720	1008	3	2.5	
Kaitlin's transient boundary more members	Low	6	210	5040	14112	3	17.5	

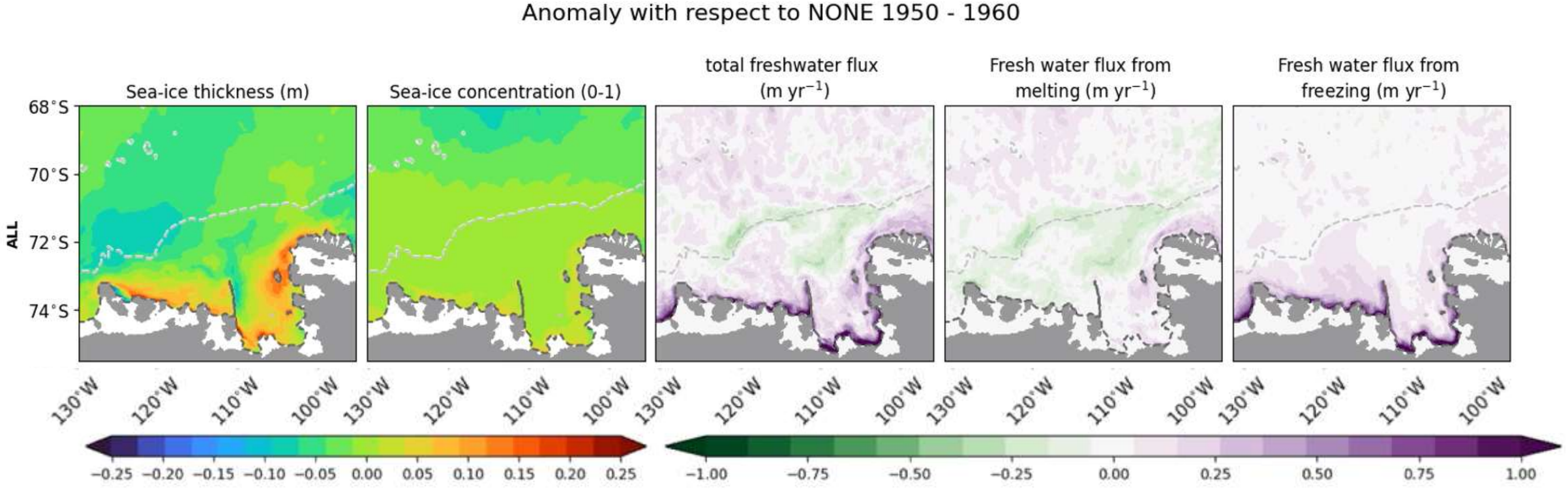


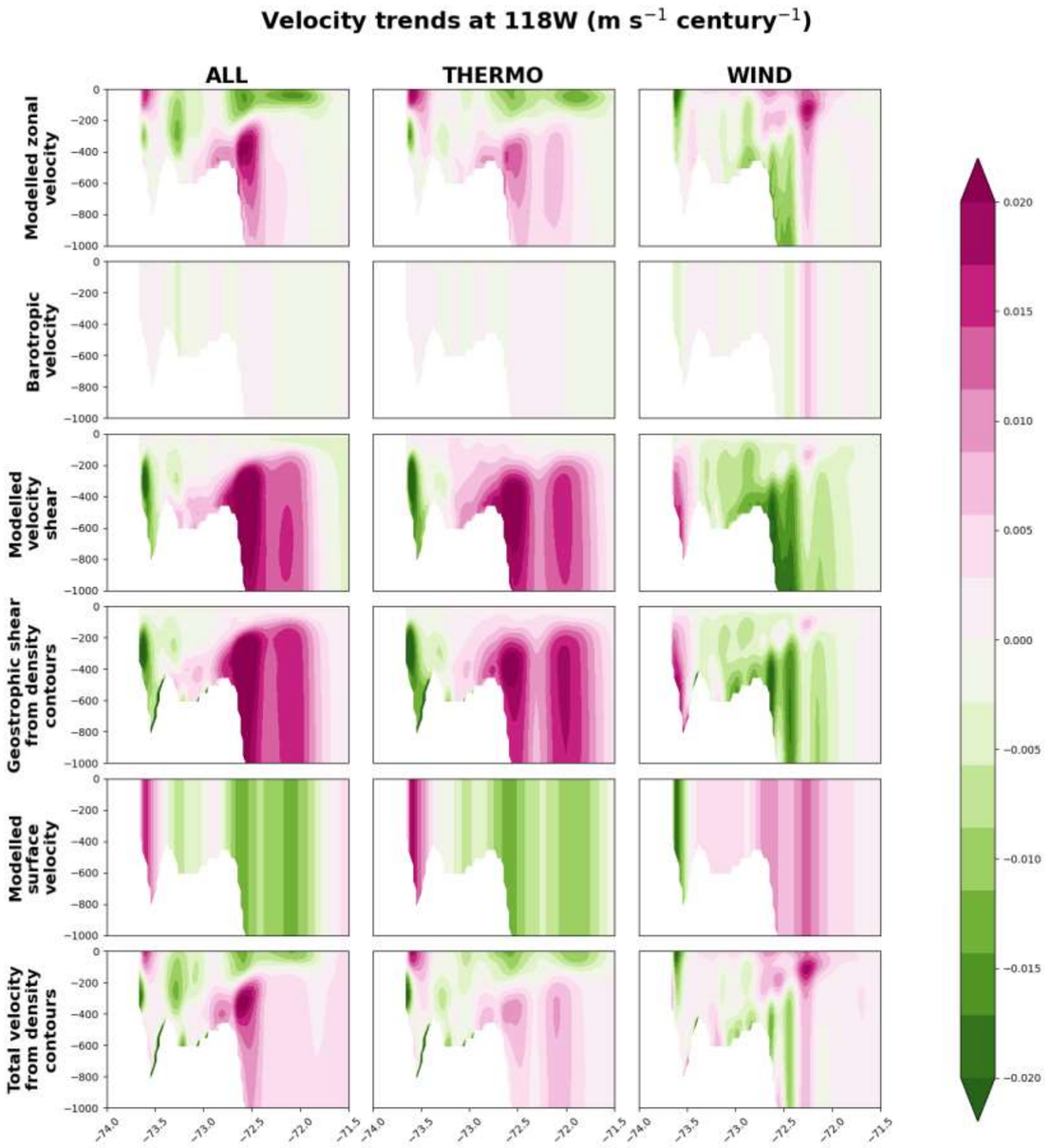
NON-LINEARITY CALCULATED AS: (ALL - NONE) - (THERMO - NONE) - (WIND - NONE)

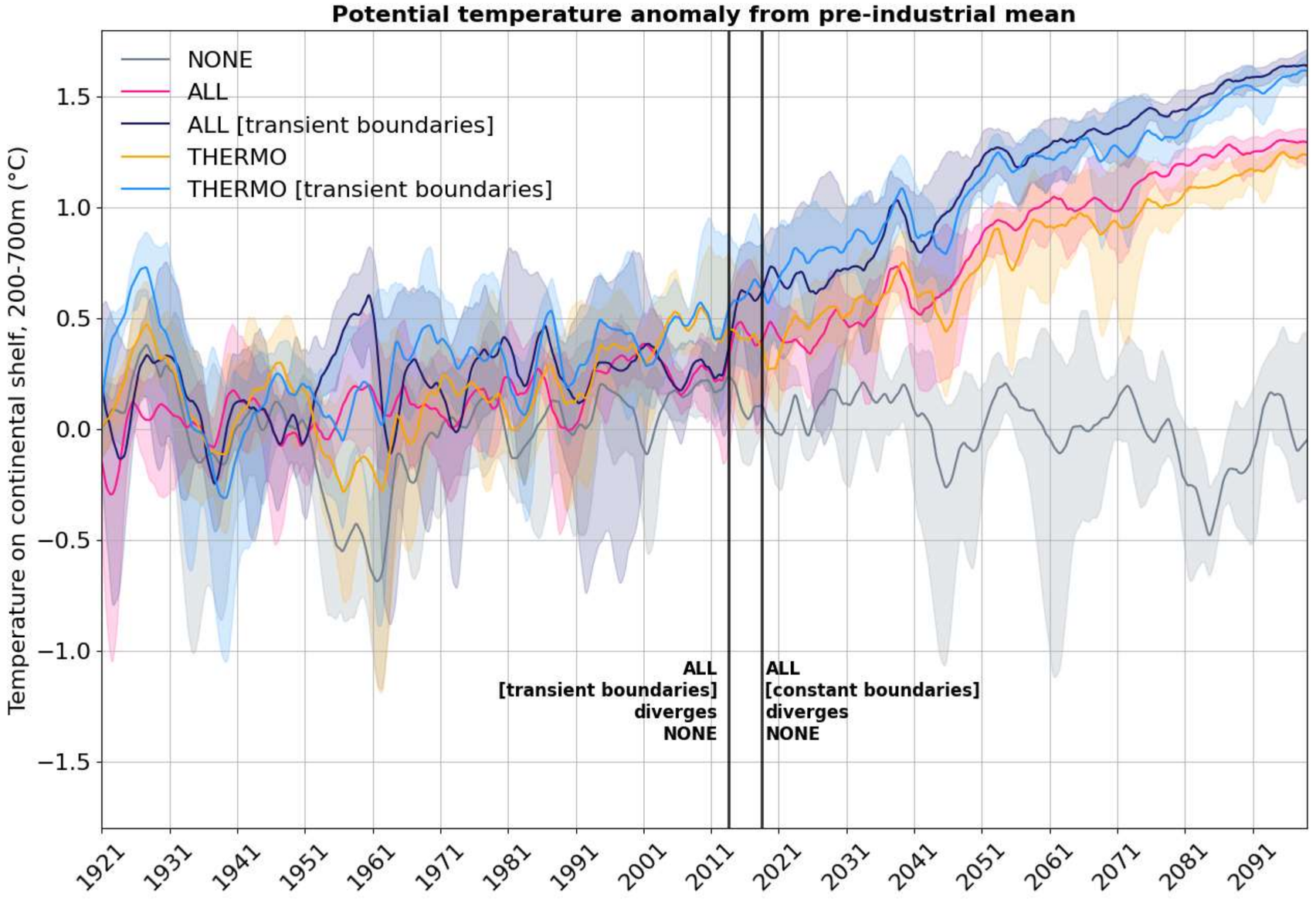

P-value ALL vs. NONE
P-value THERMO vs. NONE
P-value WIND vs. NONE
P-value ALL vs. THERMO
P-value ALL vs. WIND
P-value
p-value
0.05 line
Year of divergence
2018
1998
1991
1.0
0.5
0.0
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

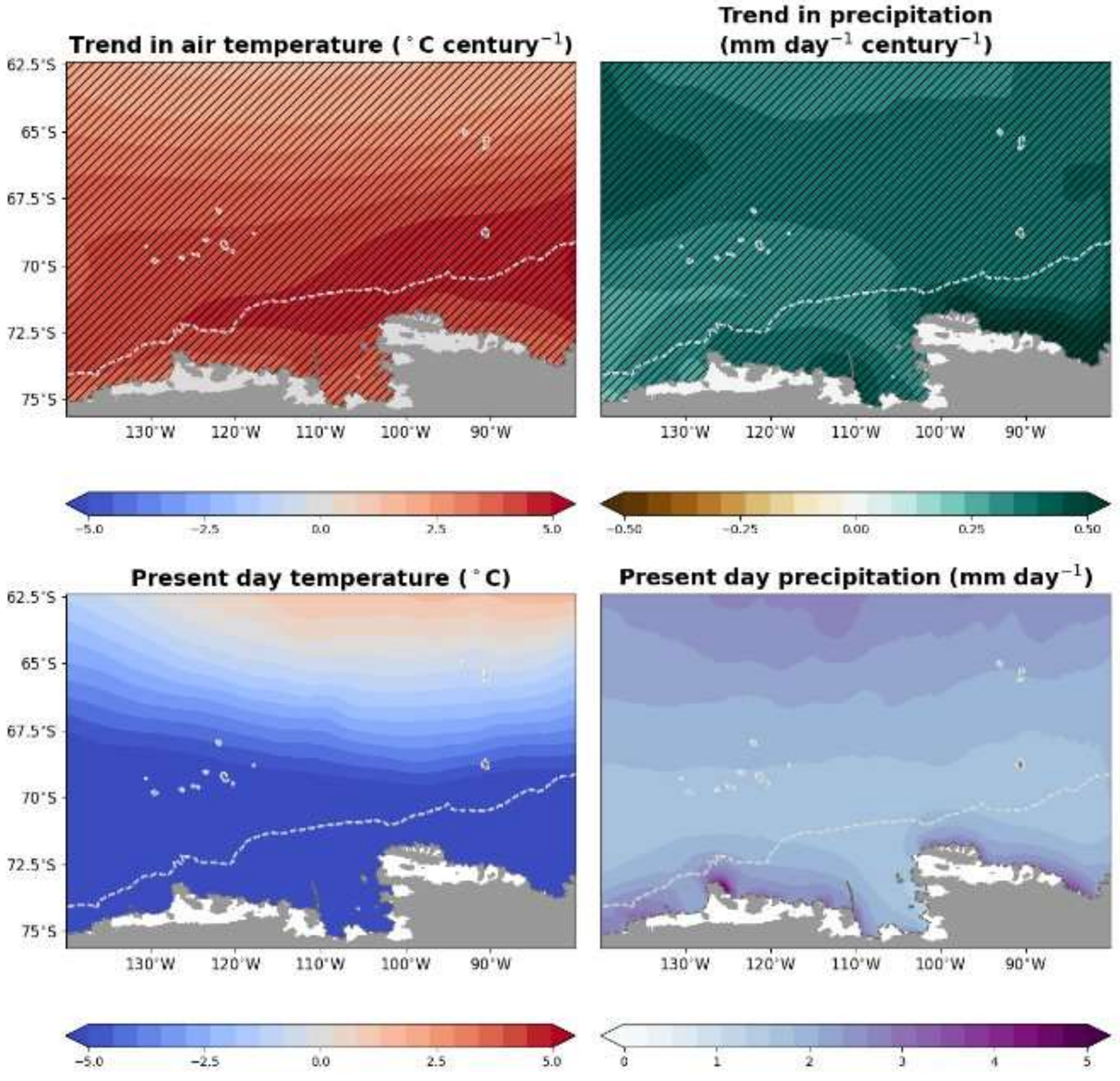

Potential temperature anomaly from pre-industrial mean
NONE
ALL
THERMO
Temperature on continental shelf, 200-700m (°C)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
ALL
[constant boundaries]
diverges
NONE


Potential temperature anomaly from pre-industrial mean
NONE
ALL
ALL [transient boundaries]
THERMO
THERMO [transient boundaries]
Temperature on continental shelf, 200-700m (°C)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
ALL
[transient boundaries]
diverges
NONE
ALL
[constant boundaries]
diverges
NONE


Anomaly with respect to NONE 1950 - 1960
Sea-ice thickness (m)
Sea-ice concentration (0-1)
total freshwater flux (m yr^{-1})
Fresh water flux from melting (m yr^{-1})
Fresh water flux from freezing (m yr^{-1})
ALL
68°S
70°S
72°S
74°S
130°W
120°W
110°W
100°W
−0.25 −0.20 −0.15 −0.10 −0.05 0.00 0.05 0.10 0.15 0.20 0.25
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00


Velocity trends at 118W (m s^{-1} century^{-1})
ALL
THERMO
WIND
Modelled zonal velocity
Barotropic velocity
Modelled velocity shear
Geostrophic shear from density contours
Modelled surface velocity
Total velocity from density contours
0
−200
−400
−600
−800
−1000
−74.0
−73.5
−73.0
−72.5
−72.0
−71.5
0.020
0.015
0.010
0.005
0.000
−0.005
−0.010
−0.015
−0.020


Potential temperature anomaly from pre-industrial mean
NONE
ALL
ALL [transient boundaries]
THERMO
THERMO [transient boundaries]
Temperature on continental shelf, 200-700m (°C)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
ALL
[transient boundaries]
diverges
NONE
ALL
[constant boundaries]
diverges
NONE
1921
1931
1941
1951
1961
1971
1981
1991
2001
2011
2021
2031
2041
2051
2061
2071
2081
2091


Trend in air temperature (°C century^{-1})
Trend in precipitation (mm day^{-1} century^{-1})
Present day temperature (°C)
Present day precipitation (mm day^{-1})
62.5°S
65°S
67.5°S
70°S
72.5°S
75°S
130°W
120°W
110°W
100°W
90°W
−5.0
−2.5
0.0
2.5
5.0
−0.50
−0.25
0.00
0.25
0.50
0
1
2
3
4
5