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Understanding Arctic Ocean changes
with
emerging modeling capabilities

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Thanks to my collaborators
Sergey Danilov, Thomas Jung, Nikolay Koldunov, Xinyue Li, Vasco Müller, Dmitry Sidorenko & Claudia Wekerle (AWI)
Qi Shu, Shizhu Wang (FIO)

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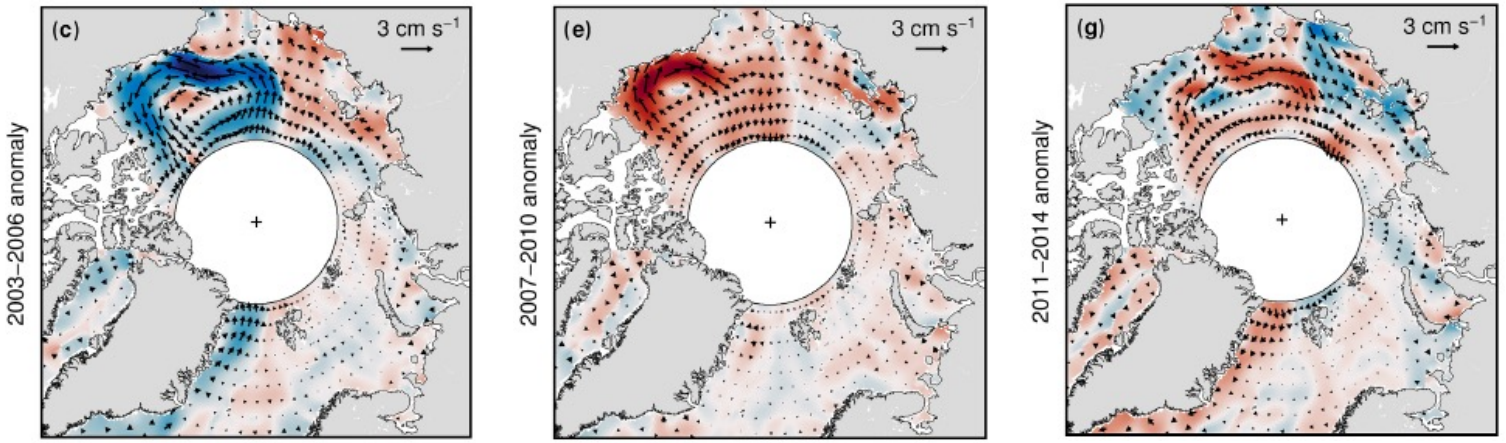
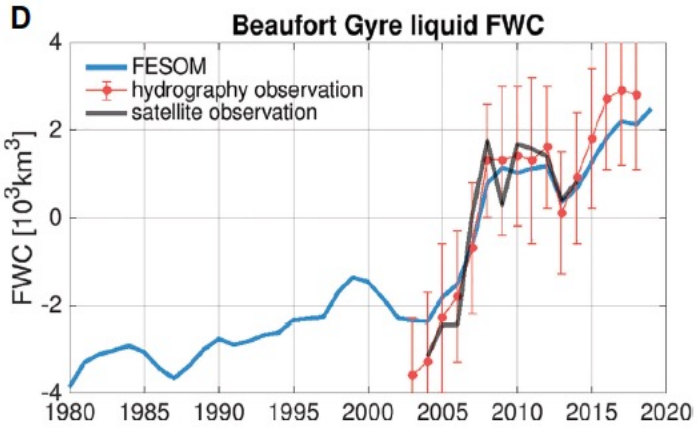
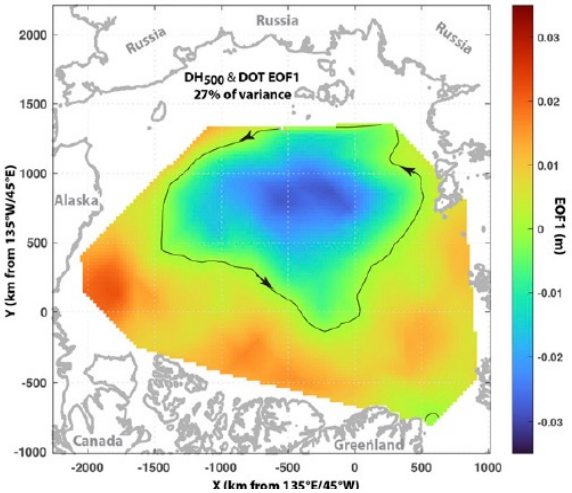
Background: decadal change vs. variability



Armitage et al., 2017, TC



Observational data taken from Proshutinsky et al., 2019, JGR



Morison et al. 2021, JPO

Background: warming & Arctic Atlantification

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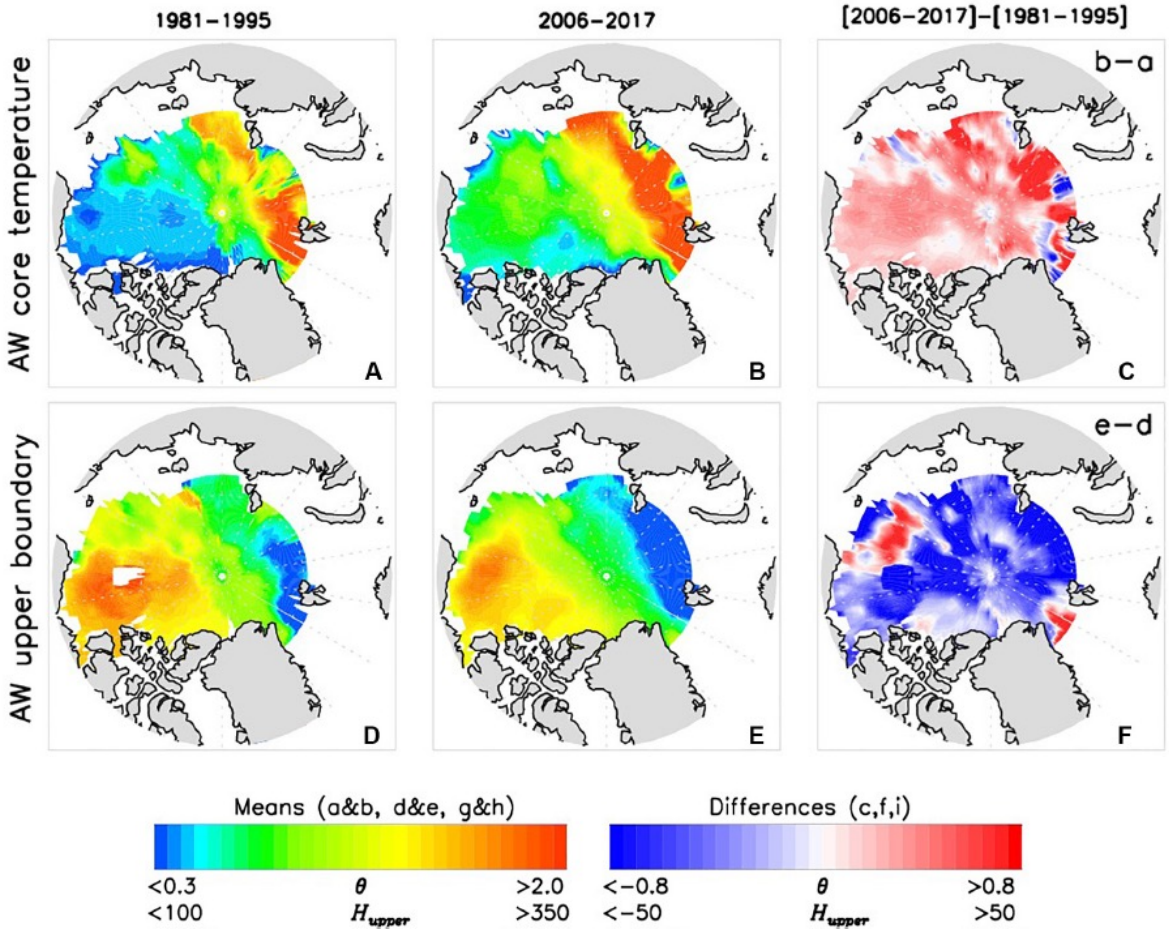
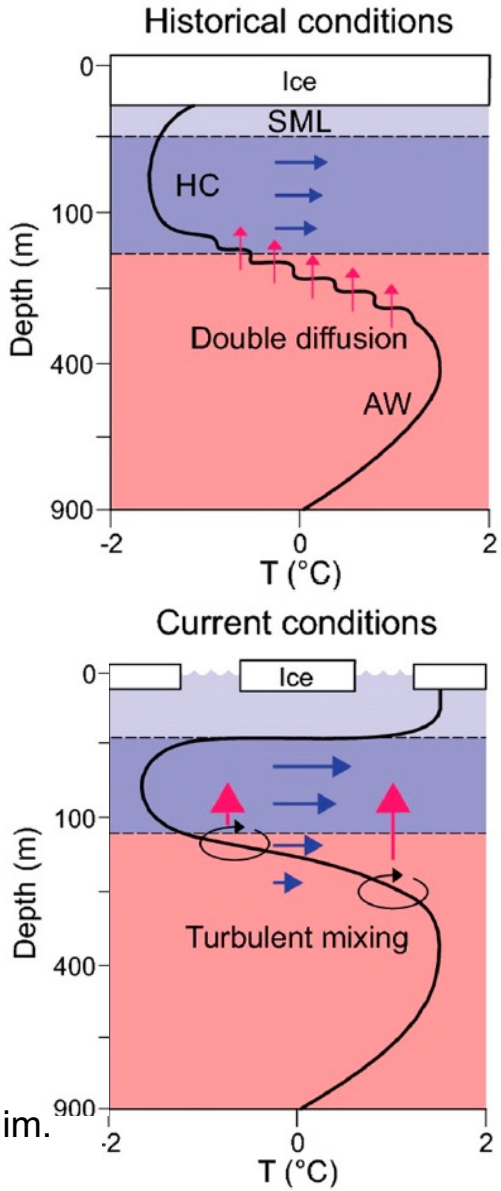


Polyakov et al. 2020, FMS



Polyakov et al. 2020, J. Clim.

Outline

- Idealized simulations to understand Arctic Ocean response to wind forcing and sea ice decline
- Recent changes in the upper Arctic Ocean
- Changes of the Arctic Ocean in future warming climate
- Arctic Ocean modeling: status and prospect

Ocean response to *winds*

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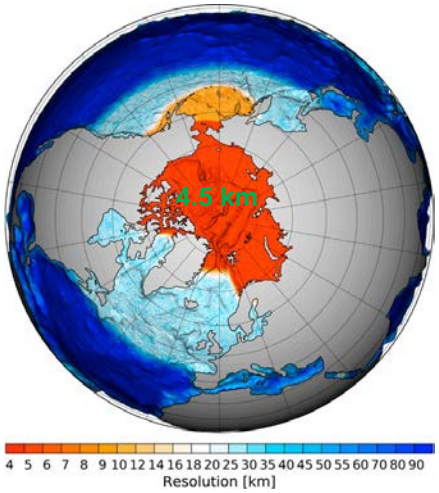
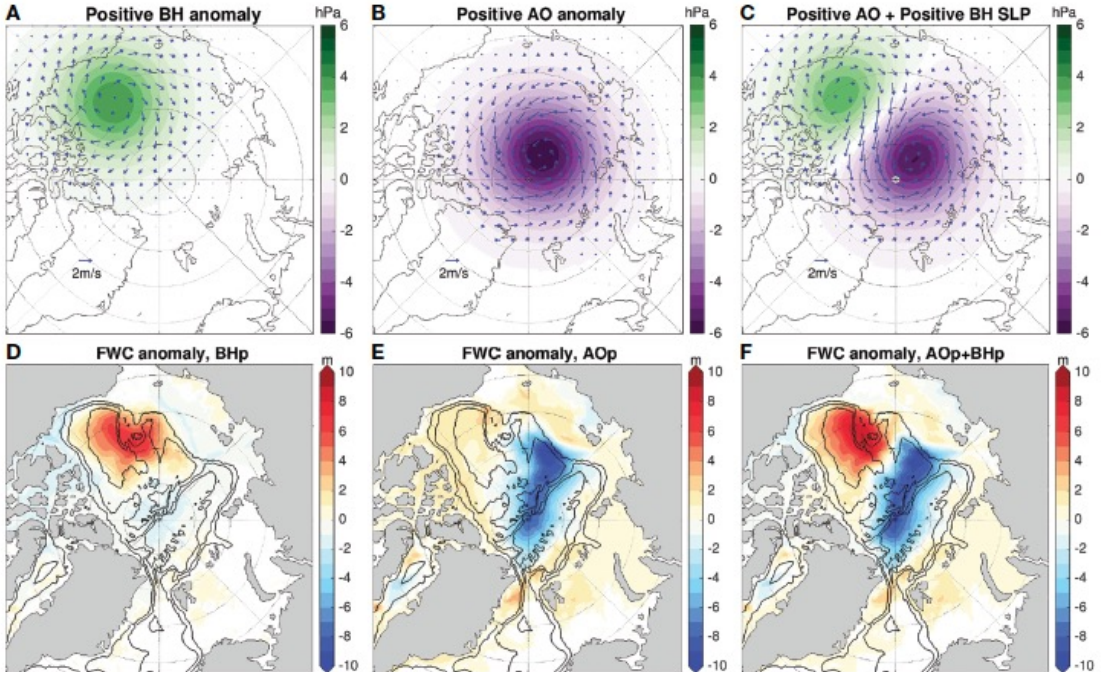
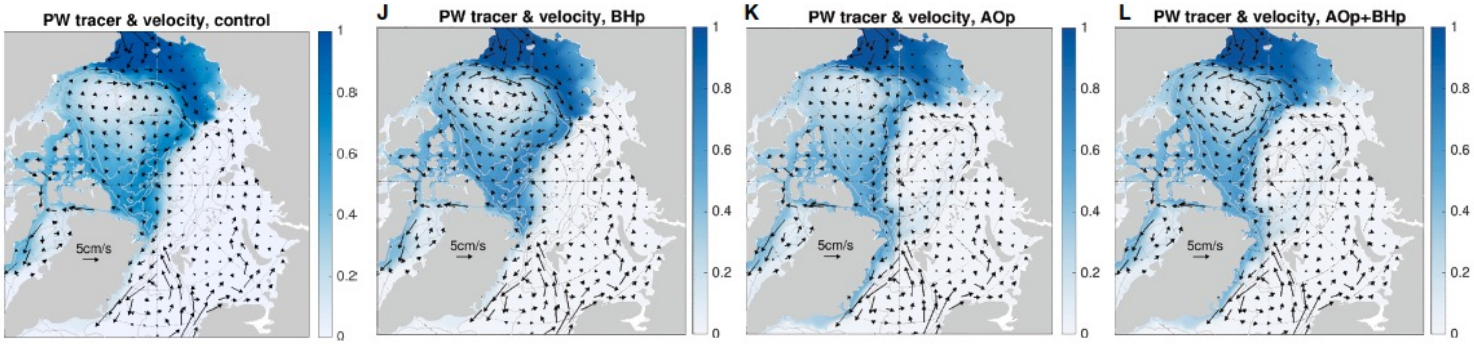


Global FESOM with multi-resolution;
Perturbation experiments



$$\mathrm{FWC} = \int_D^0 (S_{ref} - S)/S_{ref}\, \mathrm{d}z,$$



Circulation changes associated with the halosteric height changes

Wang et al. 2022, FMS

Sea ice condition influences the ocean response

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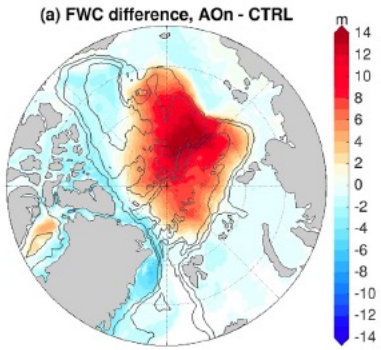
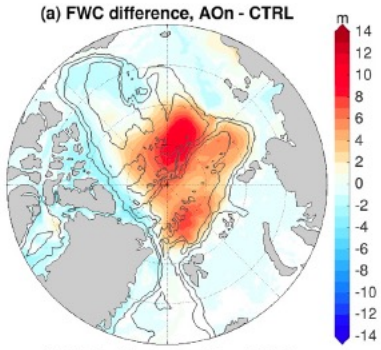
Wind perturbation experiments with different sea ice conditions
Arctic Oscillation forcing as an example

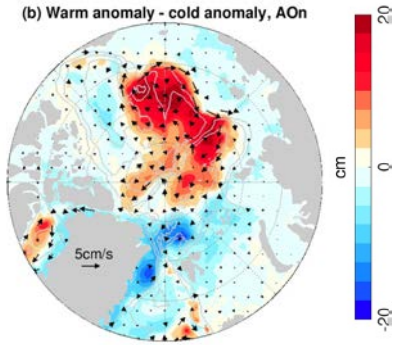
2010s condition

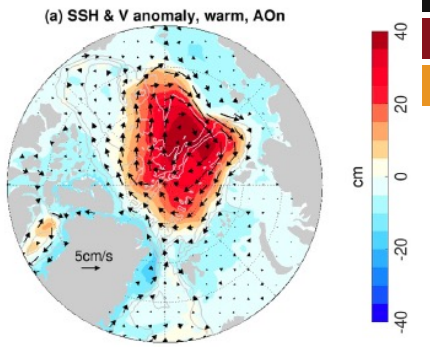


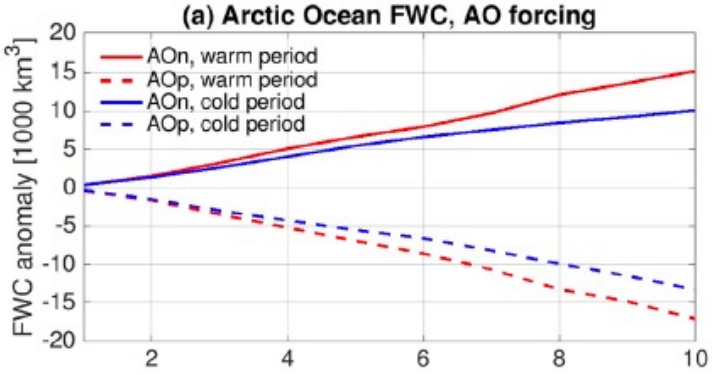
1980s condition



Difference in SSH & velocity







Wang 2021, JGR

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Outline

- Idealized simulations to understand Arctic Ocean response to wind forcing and sea ice decline
- Recent changes in the upper Arctic Ocean
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Wind variability in the early 21st century

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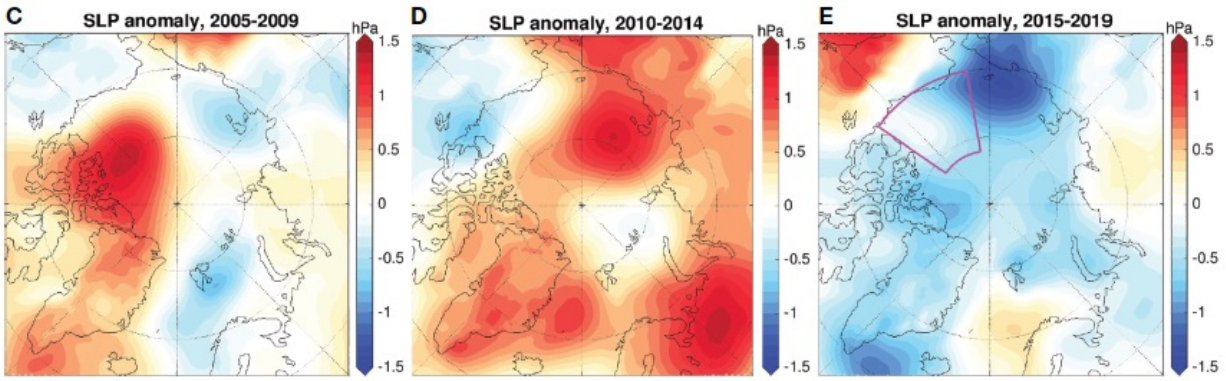
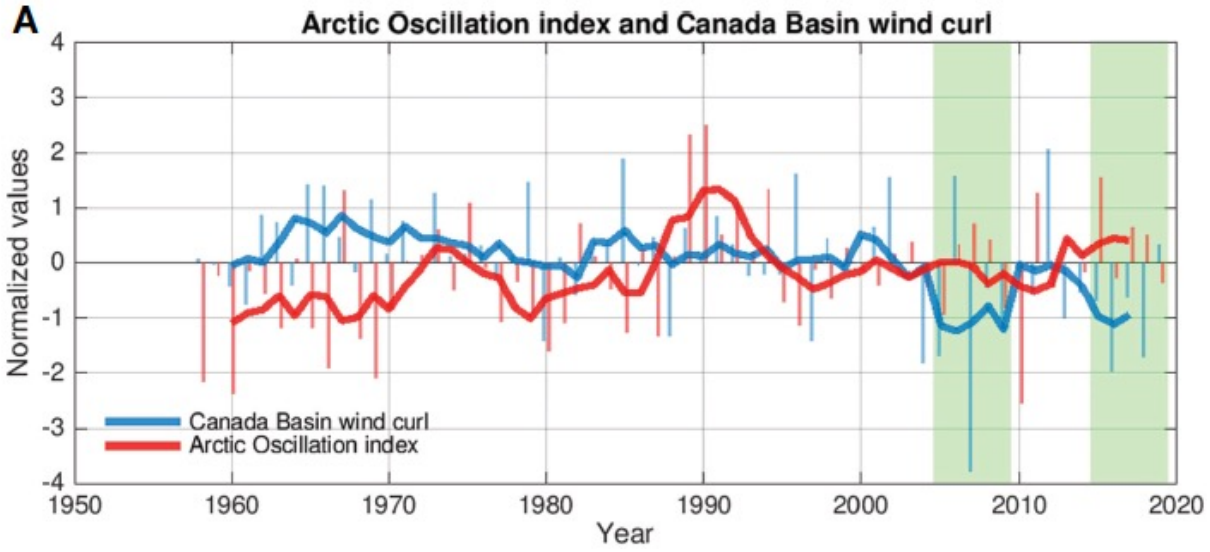
SLP





Wang et al. 2022, FMS

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Impact of sea ice decline: Sensitivity experiments

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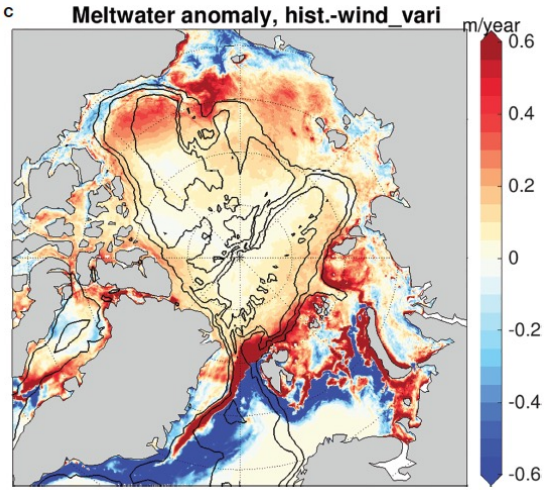
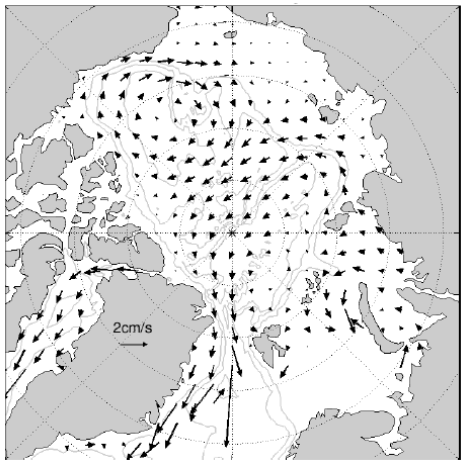


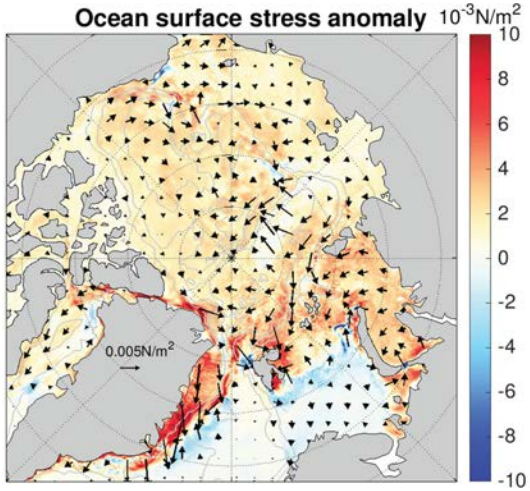
Two simulations:

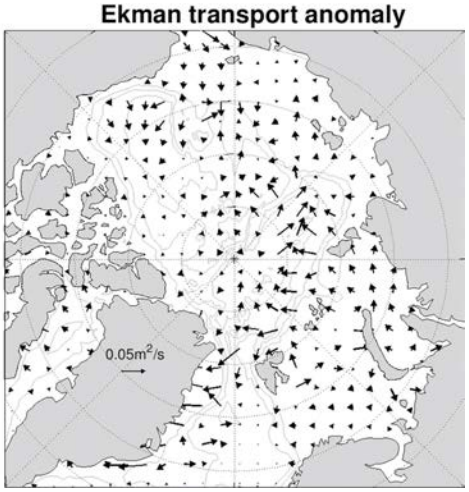
1. **Historical simulation (hindcast)**
2. **Thermal forcing over the Arctic Ocean: climatology**

Sea ice decline →

- **Freshwater source (relative to climatological condition)**
- **Mediating ocean surface stress**







Wang et al. 2022, FMS

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Impact of sea ice decline: decadal changes

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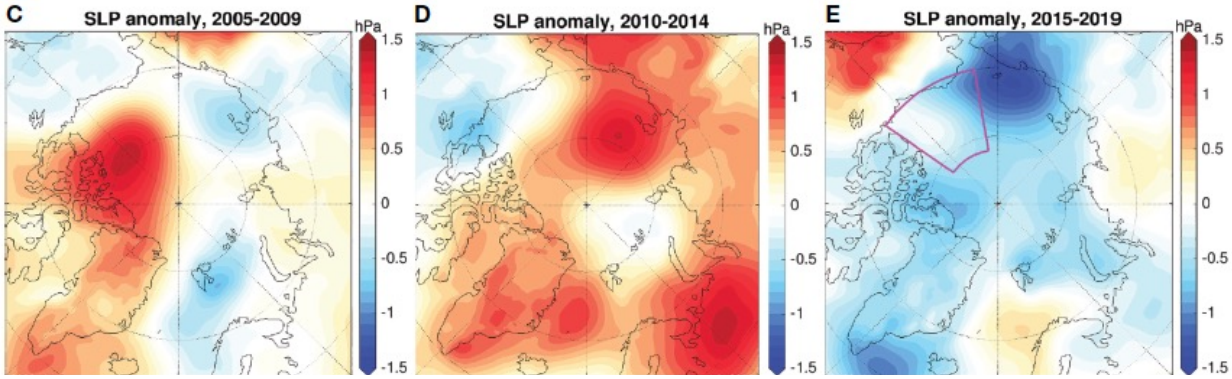
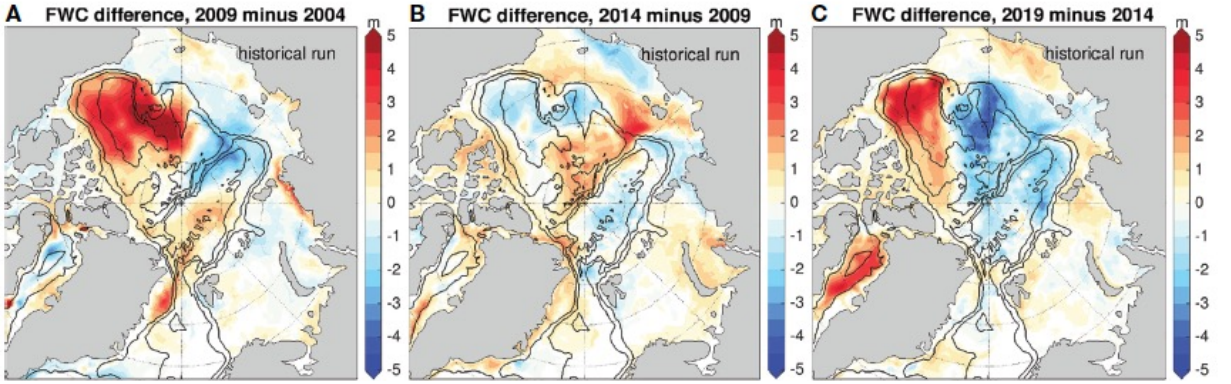
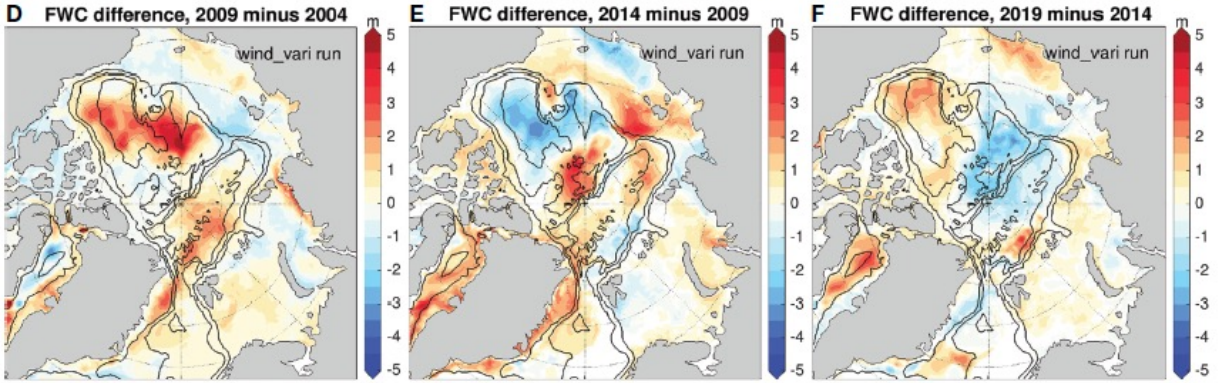
SLP



FWC, historical simulation



FWC, when sea ice decline eliminated



Anomalies are shown

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Impact of sea ice decline: circulation modes

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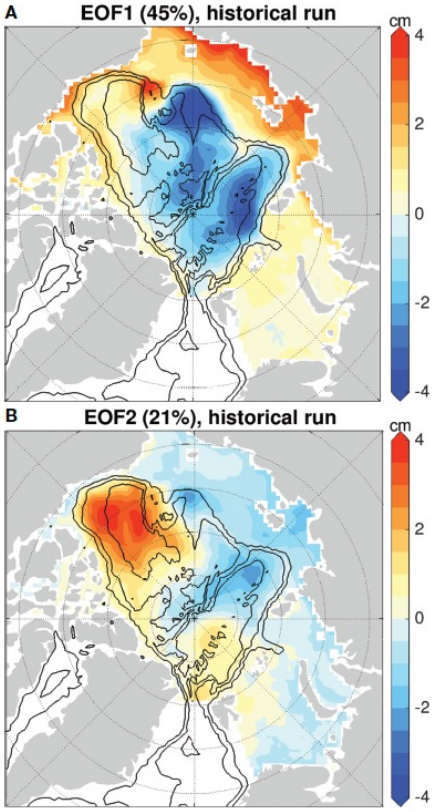
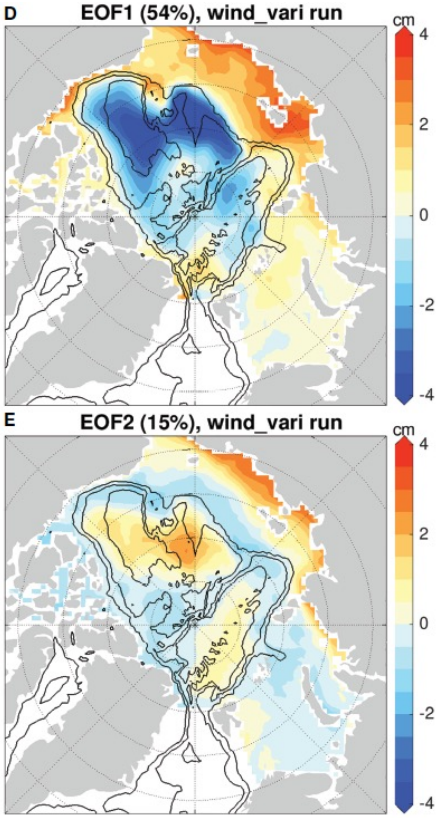
EOF of annual SSH in the Arctic (for 2004-2019)

historical simulation





When sea ice decline eliminated

Wang et al. 2022, FMS

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Impact of sea ice decline: Atlantification

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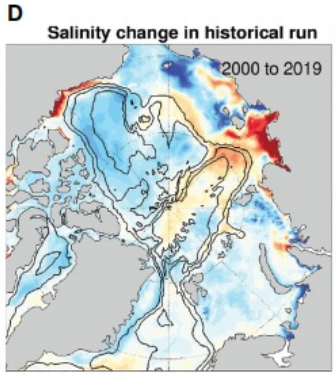
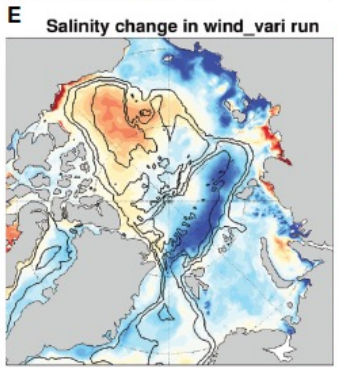
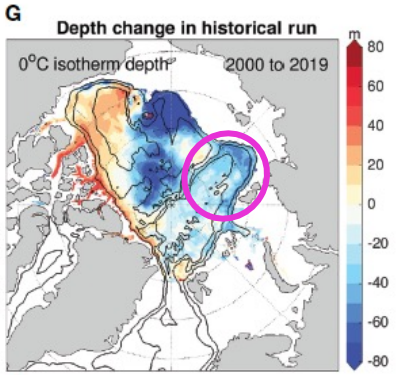
2000 to 2019 change

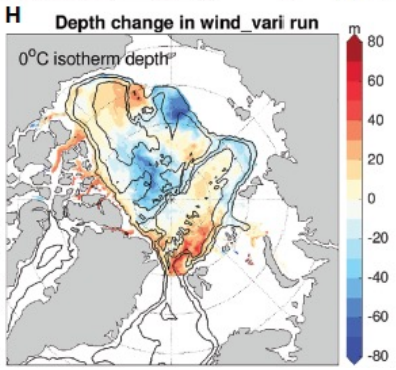
Upper ocean salinity





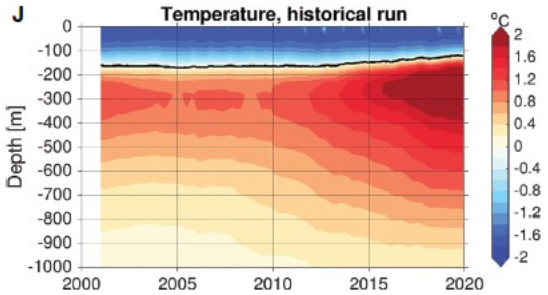
Halocline lower boundary

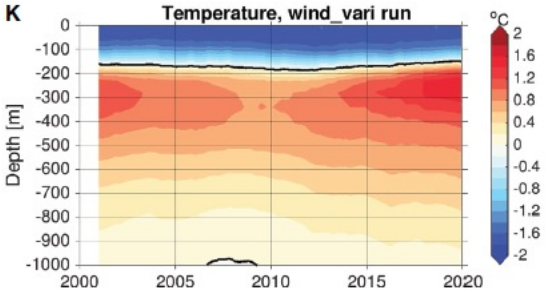




Wang et al. 2022, FMS

Eastern EB temperature





Wang et al. 2020, GRL
(Period updated)

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Sea ice dynamic effect continues in the future

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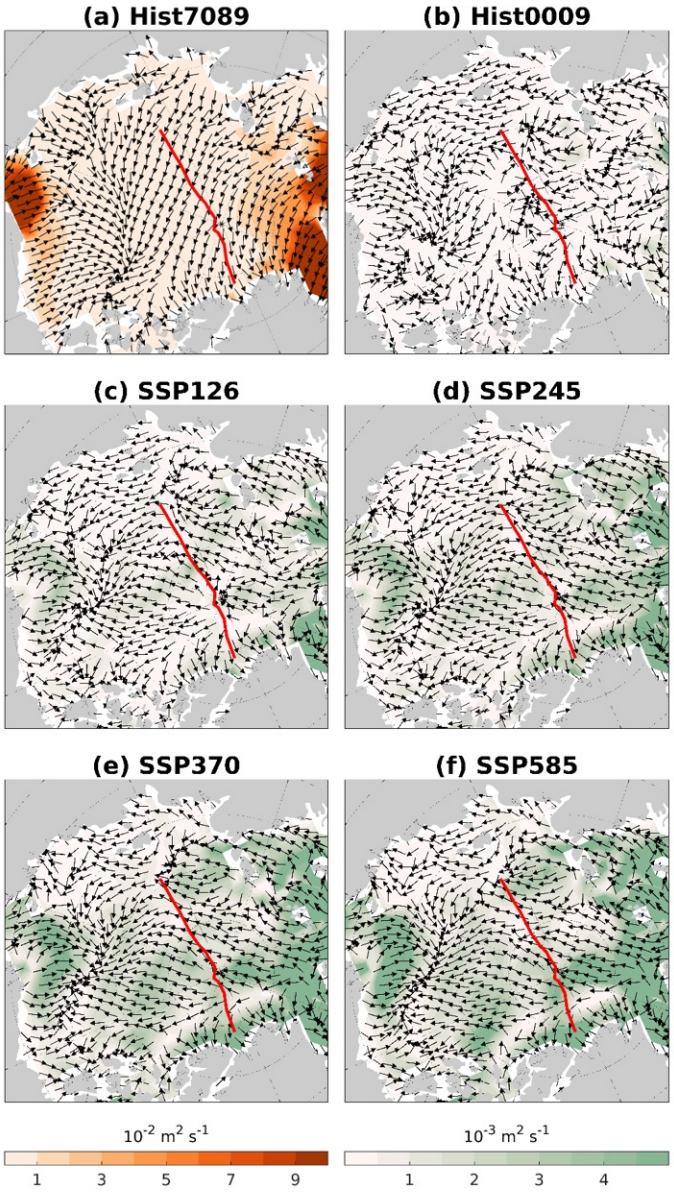

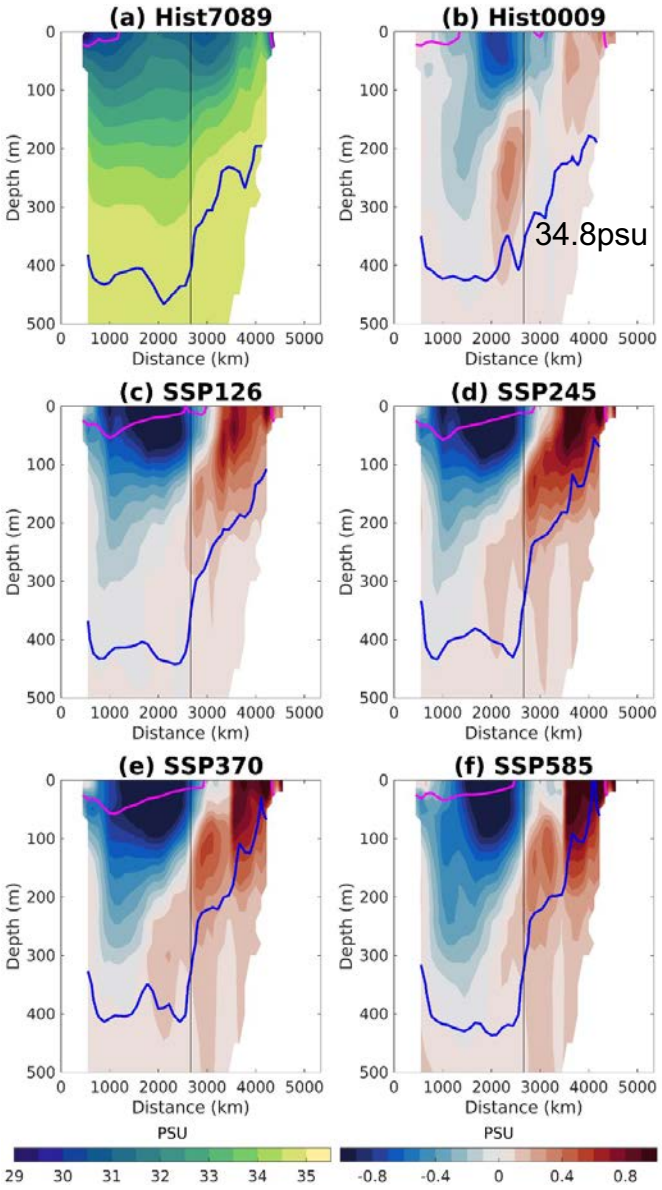

S. Wang et al., 2021, GRL

Arctic “Ocean” amplification

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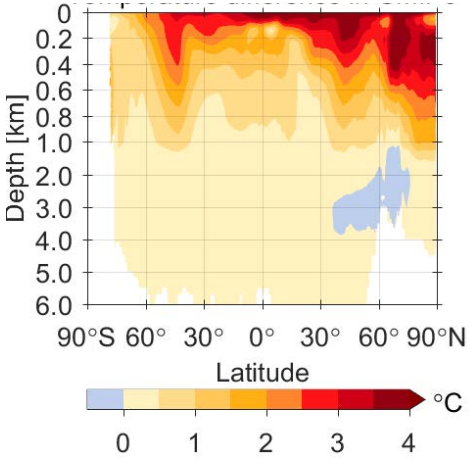
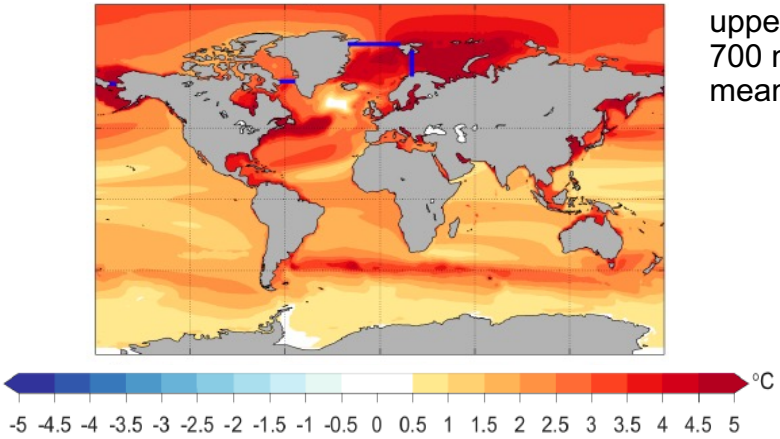
Temperature difference, 2081-2100 minus 1981-2000, SSP585

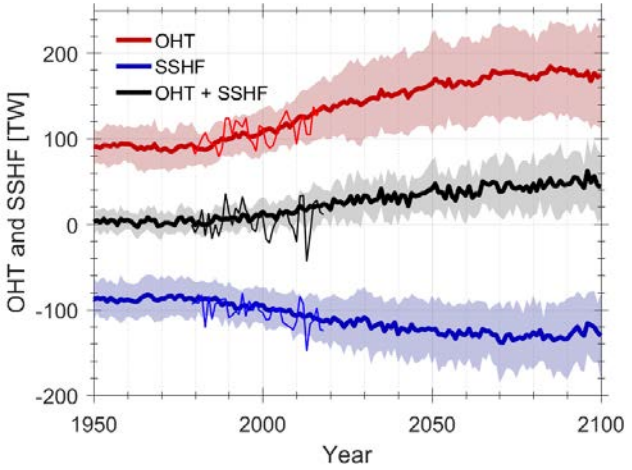


zonal mean



upper 700 m mean

Depth ranges (m)	Global Ocean (°C)	Arctic Ocean (°C)	AOAF
0–150	2.86 ± 0.58	3.15 ± 1.55 (Polar Surface Water)	1.0 ± 0.4
0–300	2.46 ± 0.50	3.26 ± 1.50	1.3 ± 0.4
0–700	1.80 ± 0.31	3.11 ± 1.36	1.7 ± 0.6
150–900	1.27 ± 0.21	2.89 ± 1.25 (Atlantic Water)	2.3 ± 0.9
0–2000	0.90 ± 0.14	2.00 ± 0.88	2.3 ± 1.0



Shu et al., in press, Science Advances

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Arctic “Ocean” amplification

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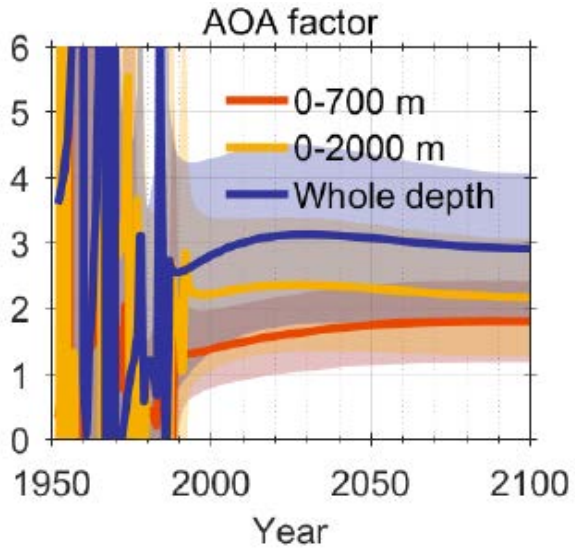
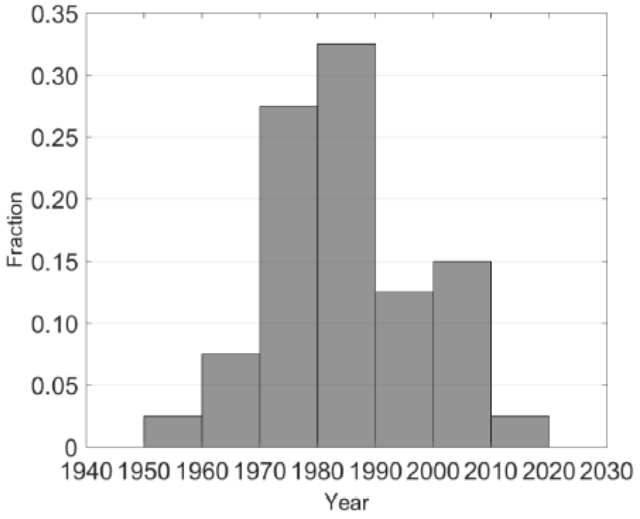
Time of Emergence (ToE) of AOA



CMIP6 models



CESM large ensemble

Shu et al., in press, Science Advances

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Arctic Ocean in CMIP6 vs. CMIP5

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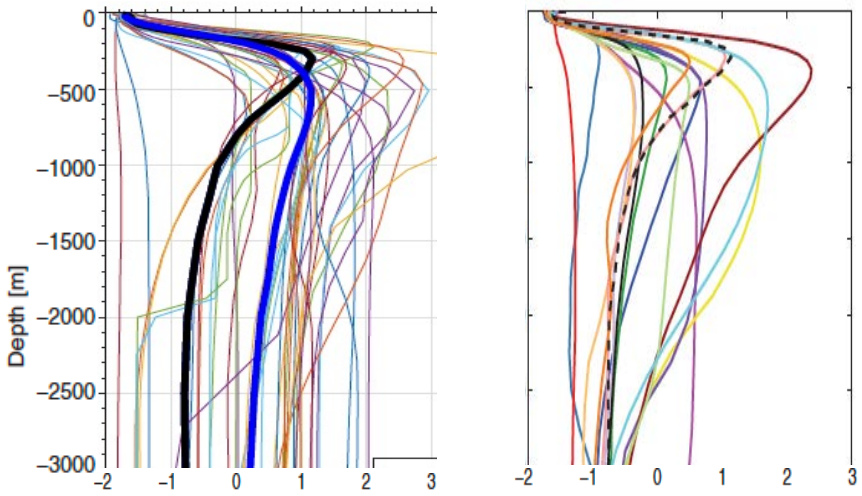
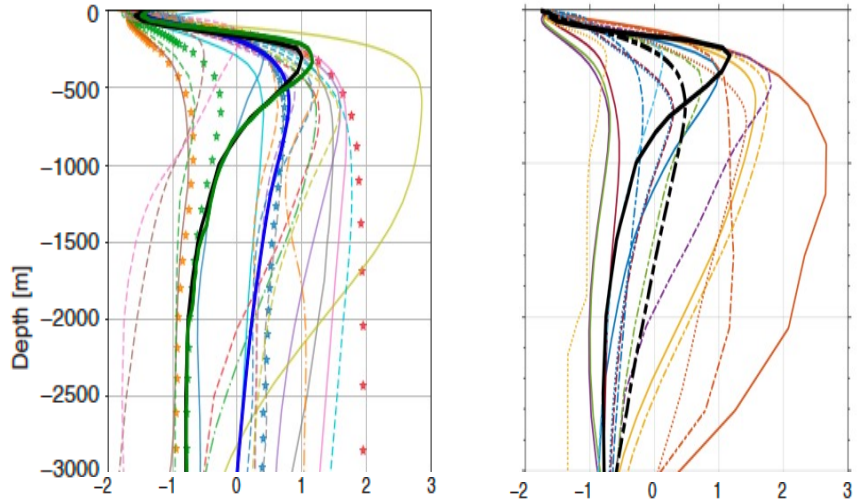
Coupled models | OMIP models

CMIP5



CMIP6



Temperature profiles
in CMIP6 and CMIP5

show that there is no clear improvement from CMIP5 to CMIP6, in both coupled and ocean-alone simulations.

- Large model spread
- The layer of warm Atlantic Water remains too deep and thick in most of the models in CMIP6.

Ilicak et al, 2016; Shu et al, 2019; Khosravi et al, 2022; Shu et al, in preparation

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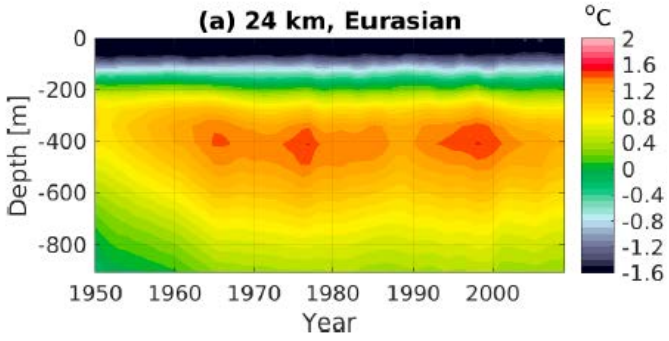
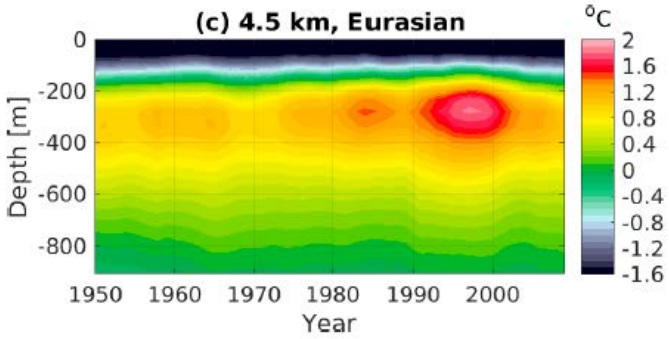
Benefit of using high resolution: example

Depth-time plot of temperature

24 km



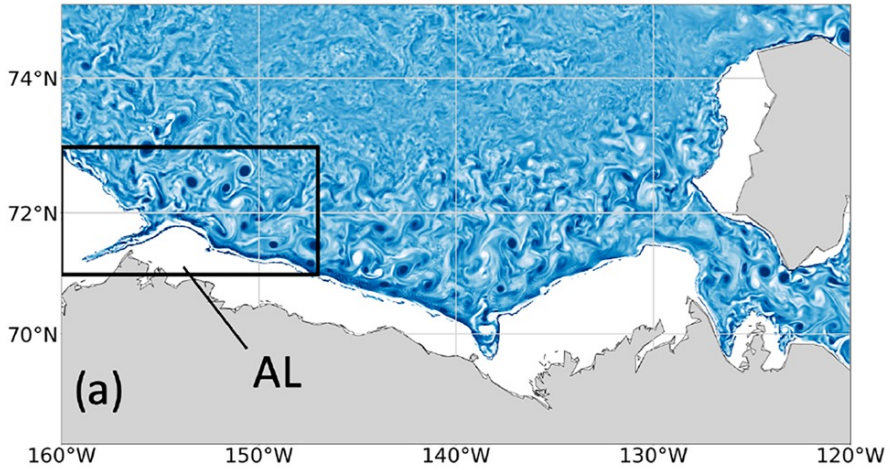
4.5 km



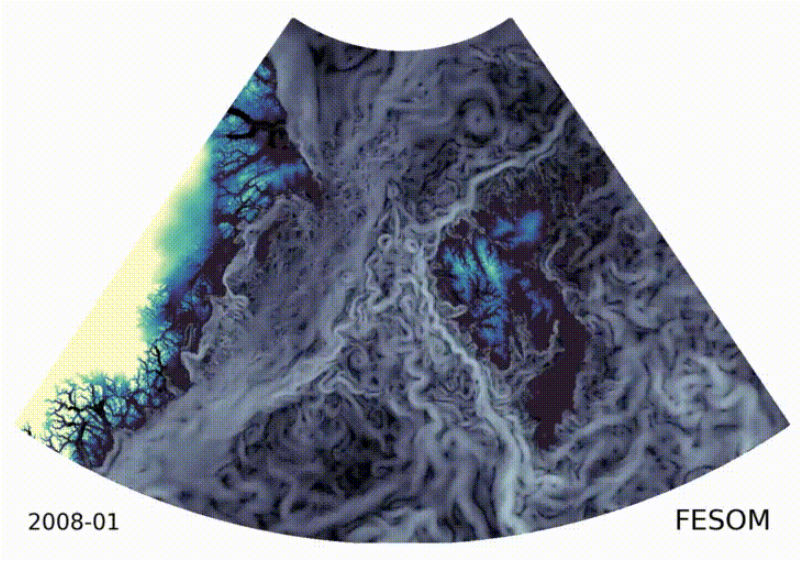
Increasing horizontal resolution from 24km to 4.5km reduces the deepening trend of **Atlantic Water layer**

Wang et al, 2018, GMD

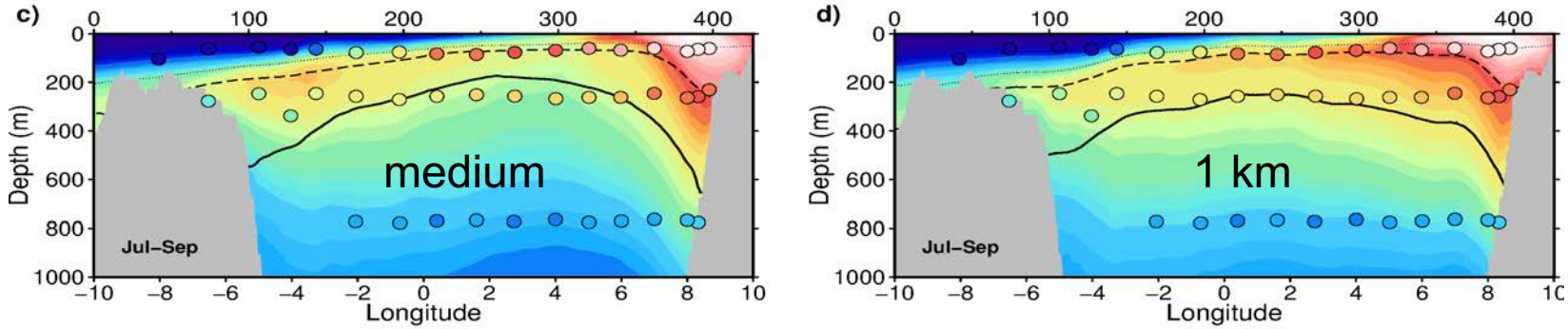
Resolving Arctic Ocean with km scale



Vorticity (only Canada Basin is shown here),
From **FESOM** 1km resolution simulation



Wang et al, 2020, GRL



Fram Strait T

Wekerle et al, 2017, JGR

Summary

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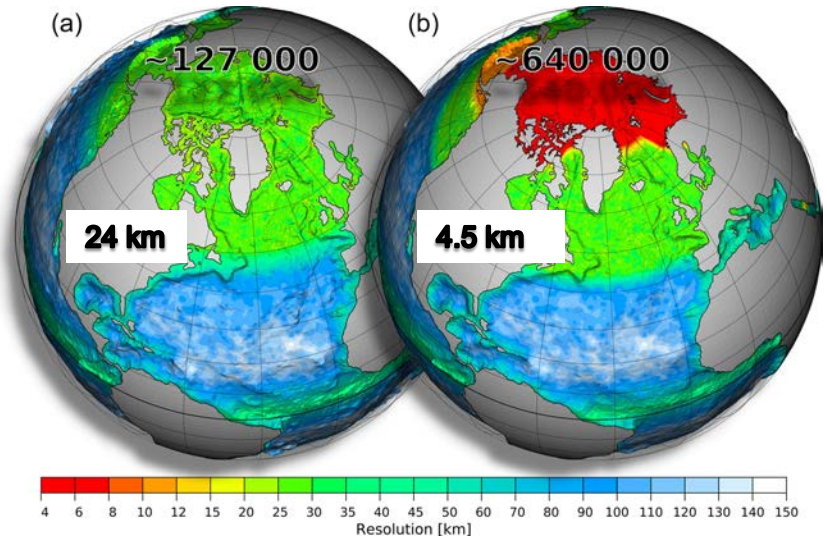
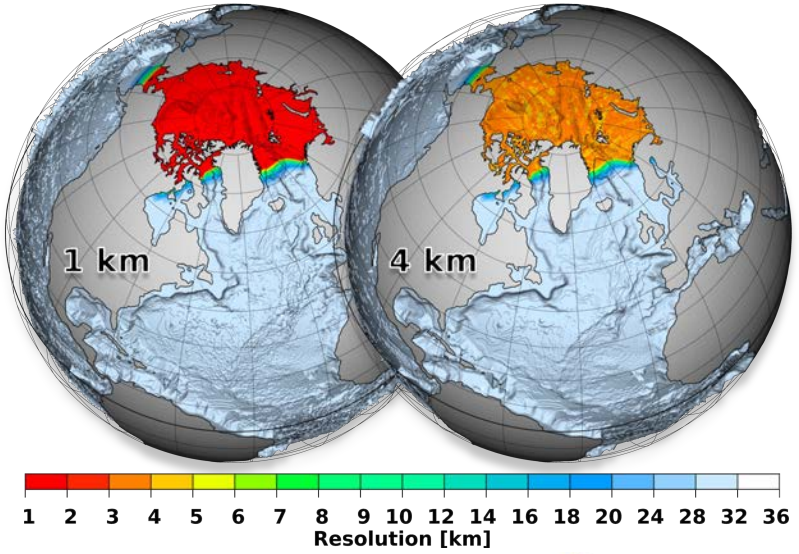
- Sea ice decline → strengthens the Arctic Ocean decadal changes
- Sea ice decline → strengthens the circulation variability (*circulation modes*)
- Arctic Ocean Amplification (AOA) has emerged
- km–scale simulations became available and showed promising results.





2000s 2015 2020

Sea ice condition influences the ocean response

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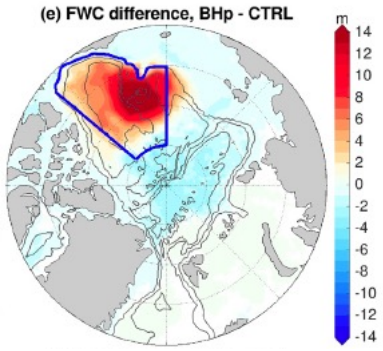
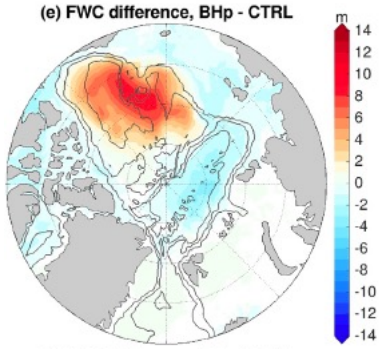
Beaufort High forcing

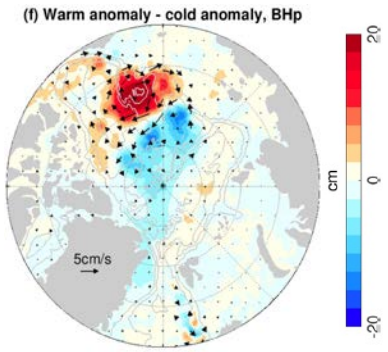
2010s condition

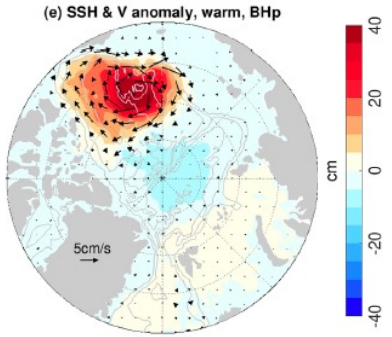


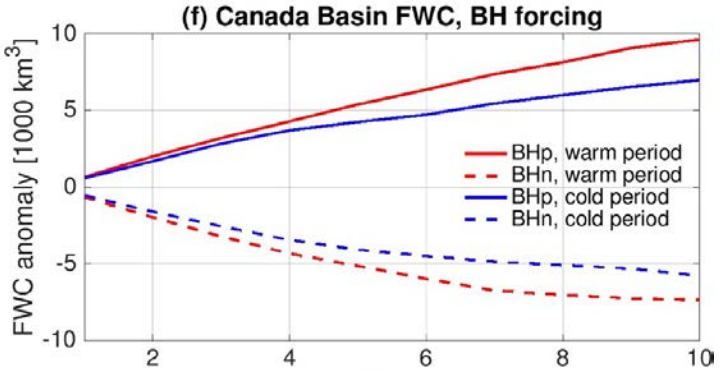
1980s condition



Difference in SSH & velocity







Wang 2021, JGR

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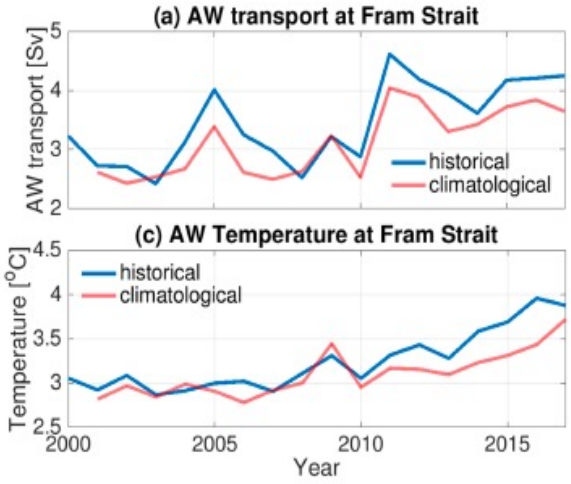
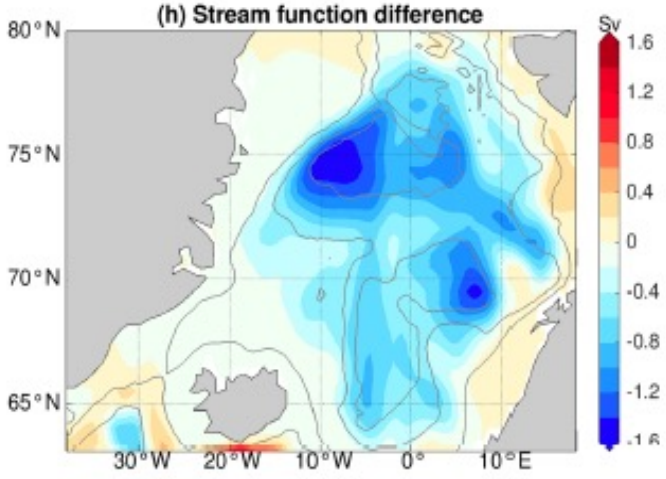
Atlantification due to sea ice decline





Wang et al. 2020, GRL

Warming continues in the future

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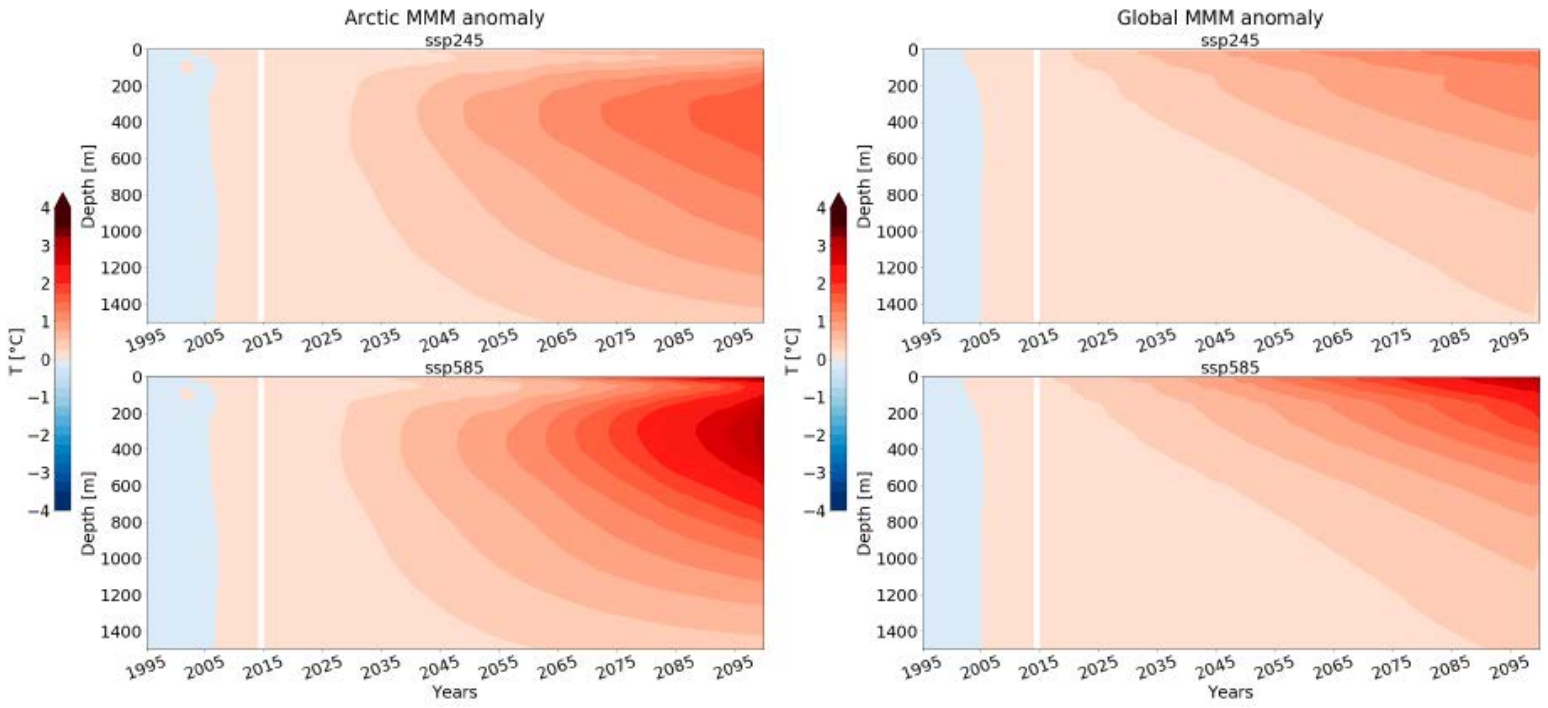

Khosravi et al., 2022, Earth‘s Future

Projections with large *uncertainties*

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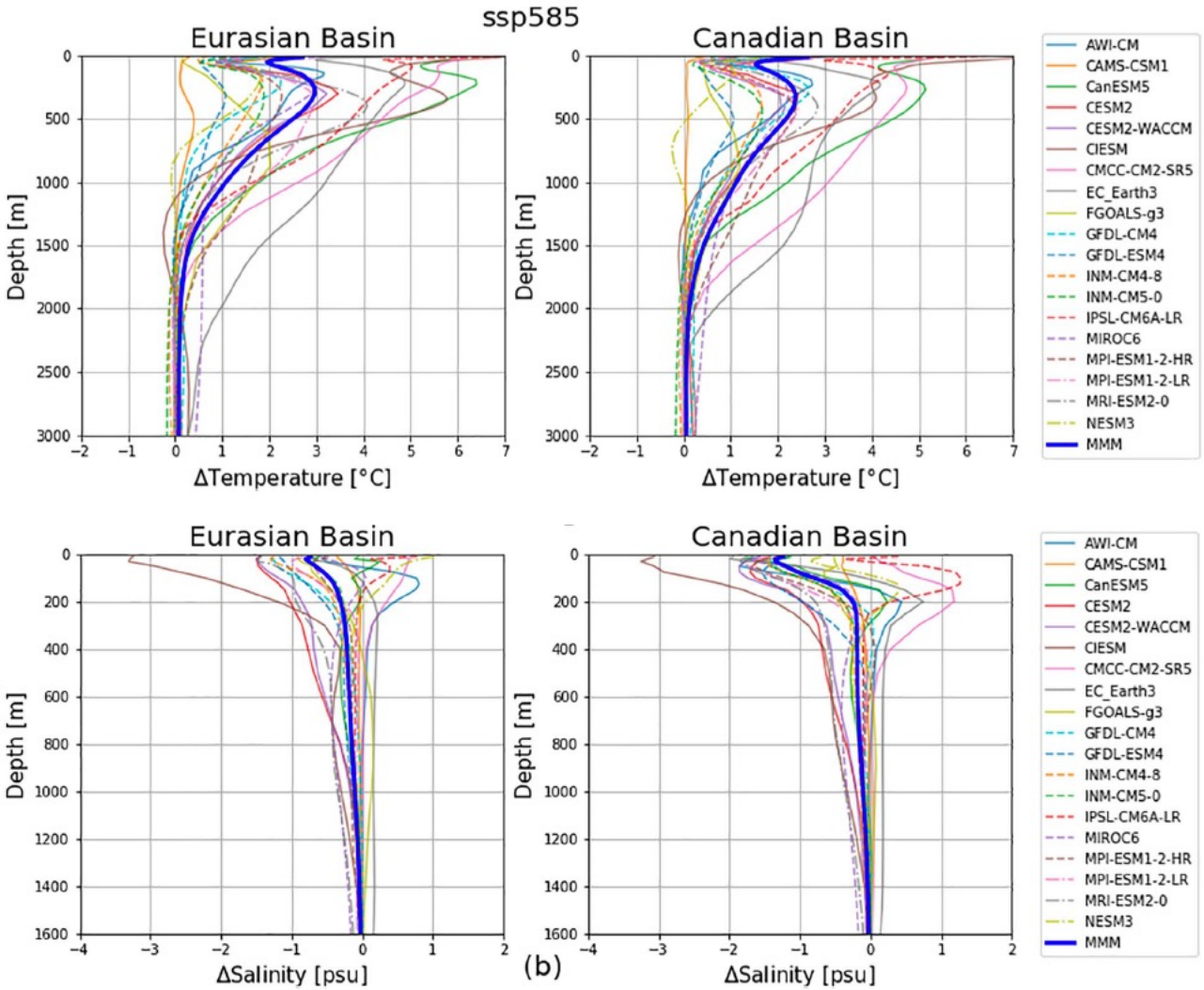
Temperature climate change signal

Salinity climate change signal



Khosravi et al., 2022, Earth's Future
S. Wang et al., under review, Earth's Future

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