Sources of the Arctic Atlantic Water Biases in CESM2

Who M. Kim
** NSF National Center for Atmospheric Research*

Gokhan Danabasoglu*, Young-Oh Kwon (WHOI), Steve Yeager*, Claude Frankignoul (LOCEAN/IPSL), & Dylan Oldenburg*

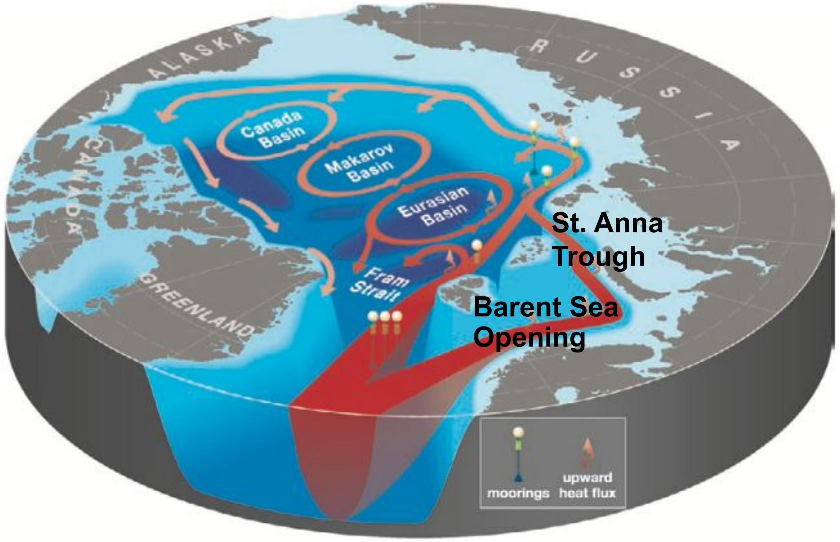
OMWG Winter Meeting 2025

February 27, 2025

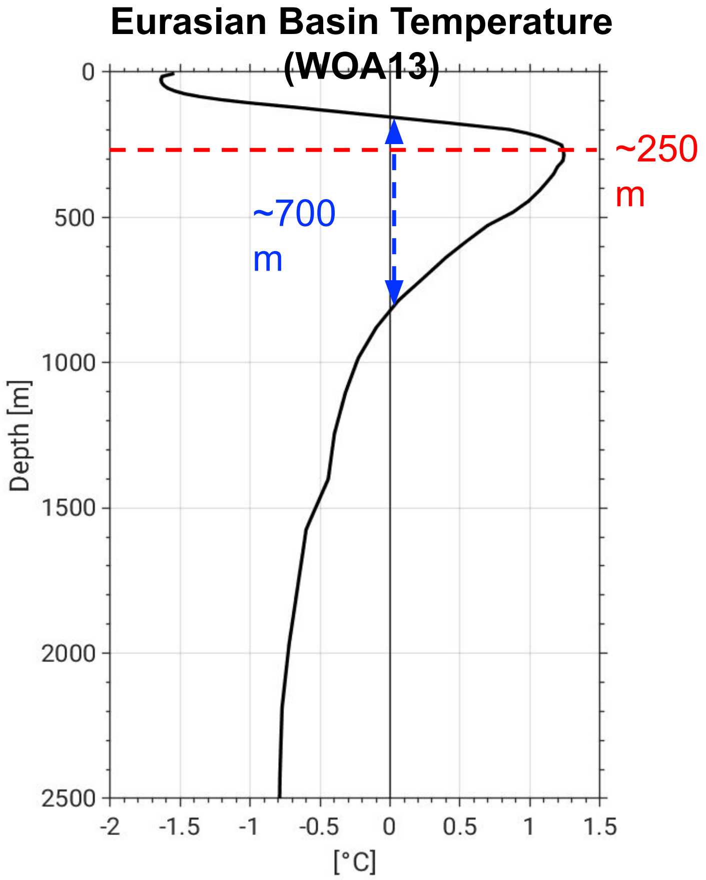
NCAR

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Arctic Atlantic Water (AW)



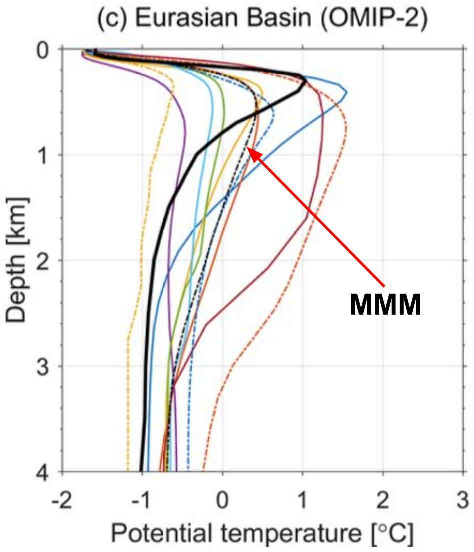
Polyakov et al. (2011)

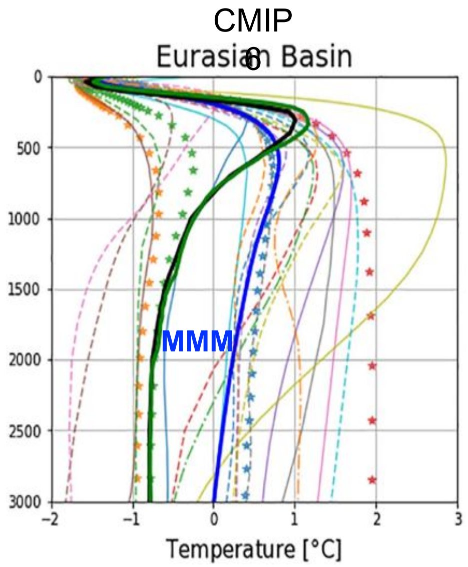


AW inflow to the Arctic Ocean

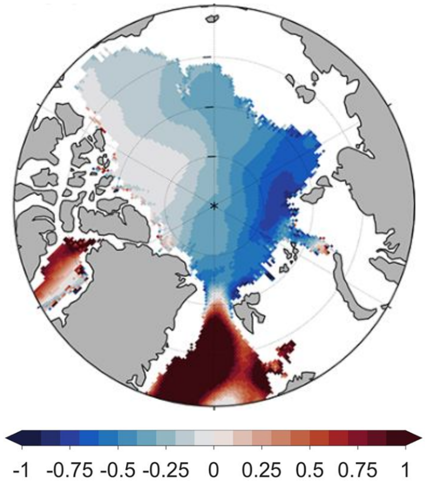
- Fram Strait branch (~2 Sv): relatively warmer and saltier
- Barents Sea branch (~2 Sv): relatively colder and fresher due to heat loss and mixing, entering the Arctic Ocean mainly through the St. Anna Trough
- Flows cyclonically along the continental slope
- AW in the interior Arctic Ocean: $\theta > 0$°C

Atlantic Water Biases



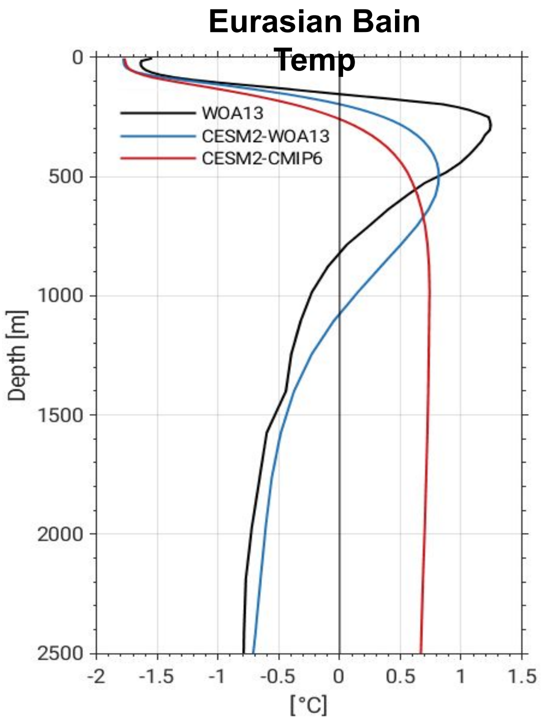


Khosravi et al.
(2022)

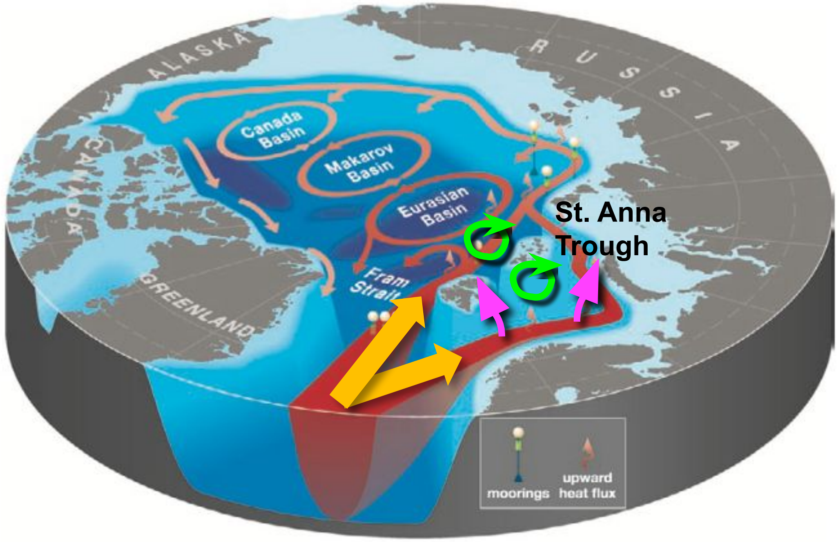


Shu et al.
(2023)

- Too deep and thick
- Too cold around the observed AW core and too warm below
- Salinity: a fresh bias in the AW layer
- **Short-term** vs. long-term biases



Potential Sources of the Biases



Polyakov et al.
(2011)

- Biased AW inflow from the GIN Seas
- Incorrect water mass transformation, due to surface fluxes and/or mixing, over the shelf of Barents and Kara Seas and/or within the troughs and channels
- Inaccurate or misrepresented horizontal and vertical mixing processes along the slope and in the interior
- **No study systematically examining the bias sources using a single model**

Model and Experiments

Forced ocean–sea-ice simulations

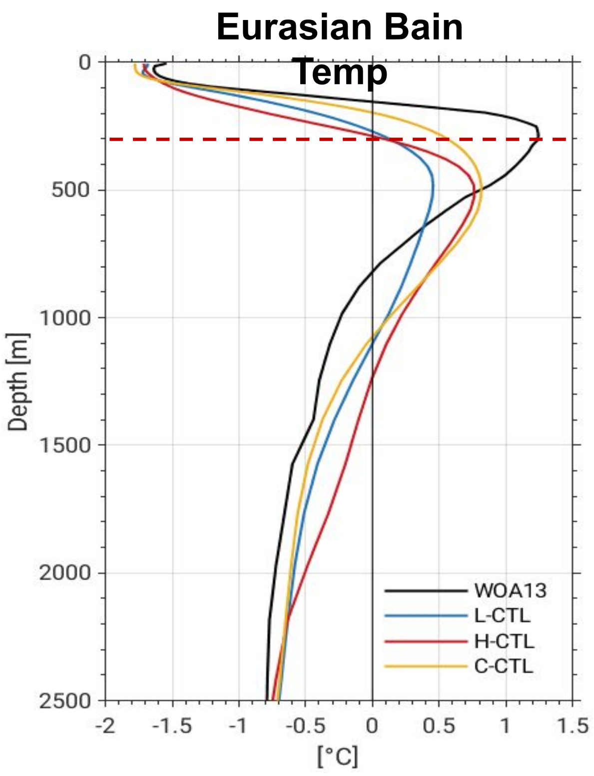
- Both low- (LR) and high-resolution (HR) configurations of CESM2
- **Sensitivity experiments (L-*Exp_Name*)**
  1) Interior T&S restoring experiments
  2) Mixing parameter experiments
  3) Combinations of (1) and (2)
- Selected experiments repeated using HR (H-*Exp_Name*)
- 2003-2004 Repeat Year Forcing (RYF), starting from WOA13 ICs
  – *Similar biases appear whether IAF or different RYFs are used*

Fully Coupled simulations

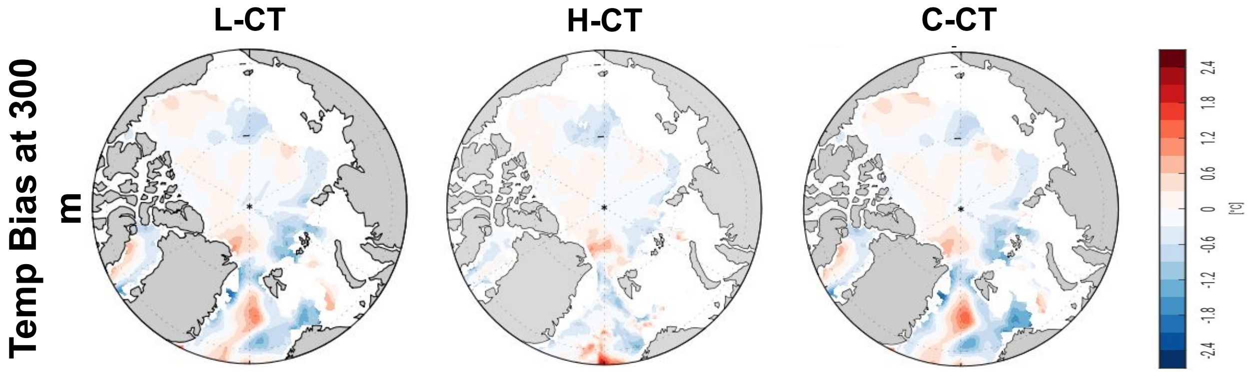
- Standard, LR configuration of CESM2
- New pi-control, starting from WOA13 ICs
- Selected experiments repeated (C-*Exp_Name*)

- All simulations run for 30 years
- Last 5-year averages used to examine biases, focusing on the temperature and circulation in the Eurasian Basin (EB)

AW Biases in the Control Simulations



- AW core found at deeper depths
  - ~450-500 m vs. 250 m in WOA13
  - Deepest in H-CTL
- AW layer thicker
  - ~800-900 m vs. 700 m in WOA13
  - Thickest in H-CTL
- Colder at the observed core depth and warmer below
- Max temperature is coldest in L-CTL (<0.5°C vs. 1.2 °C in WOA13)
- Biases initially developing quickly along the slope



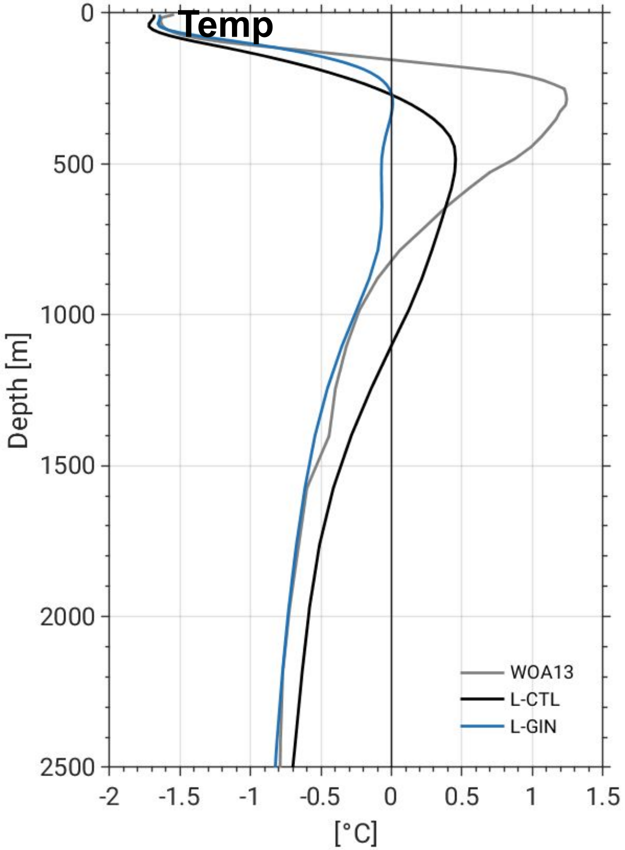
Bias at year 1

Restoring Experiments (L-GIN)

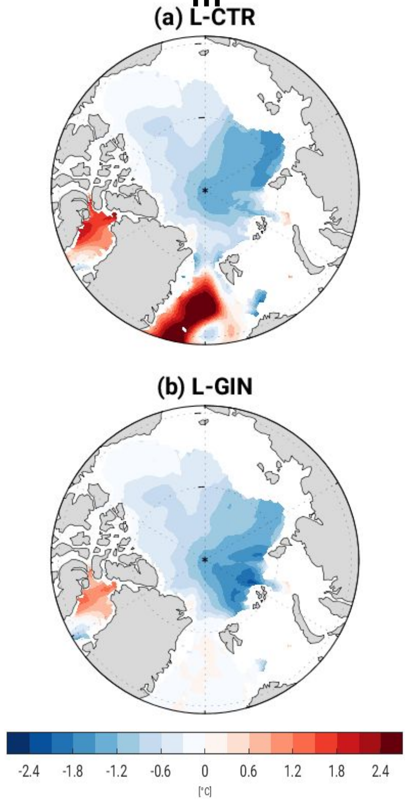
L-GIN

10 m < z < bottom

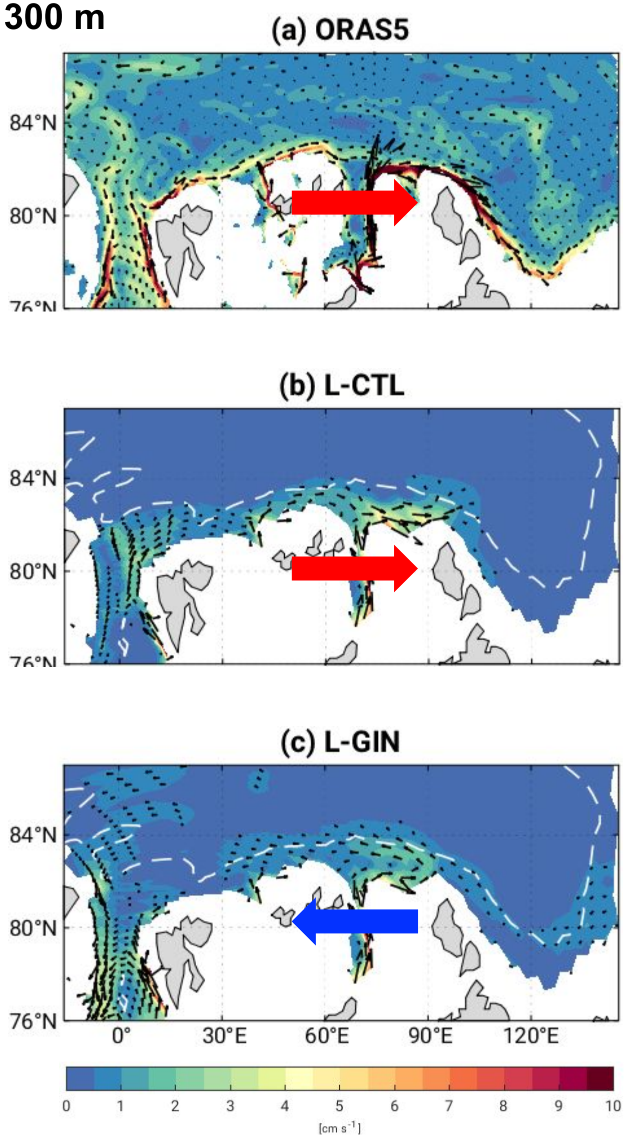
Eurasian Basin Temp



Temp Bias at 300 m



U_o at 300 m



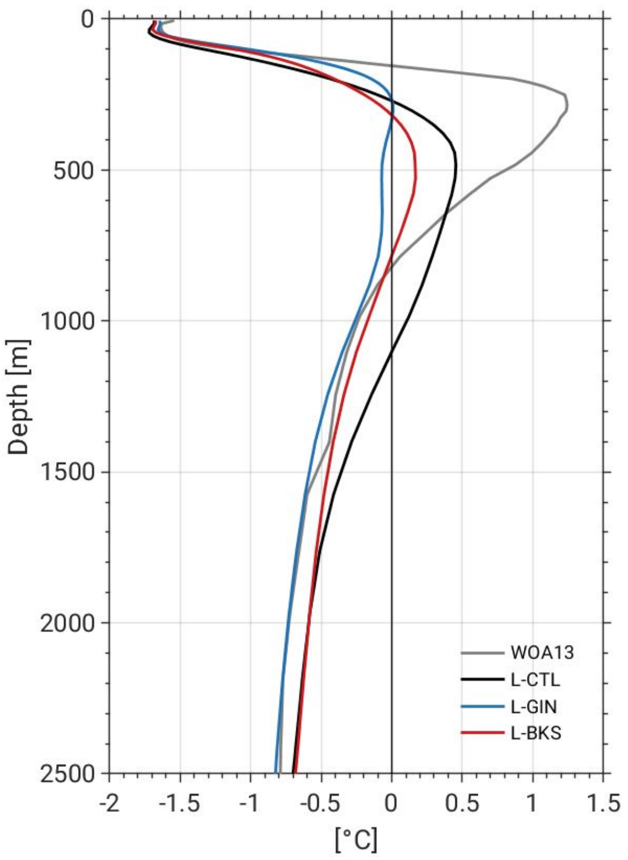
- Inflow from the SAT is cold-biased in both L-CTL and L-GIN
- Too weak circulation in the eastern EB

Restoring Experiments (L-BKS)

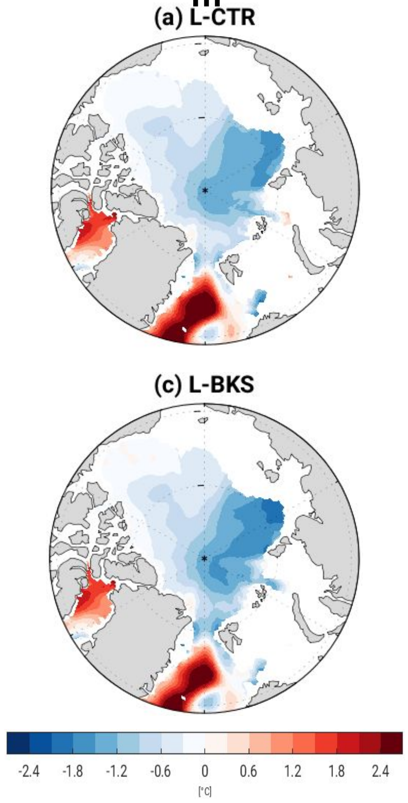
L-BKS

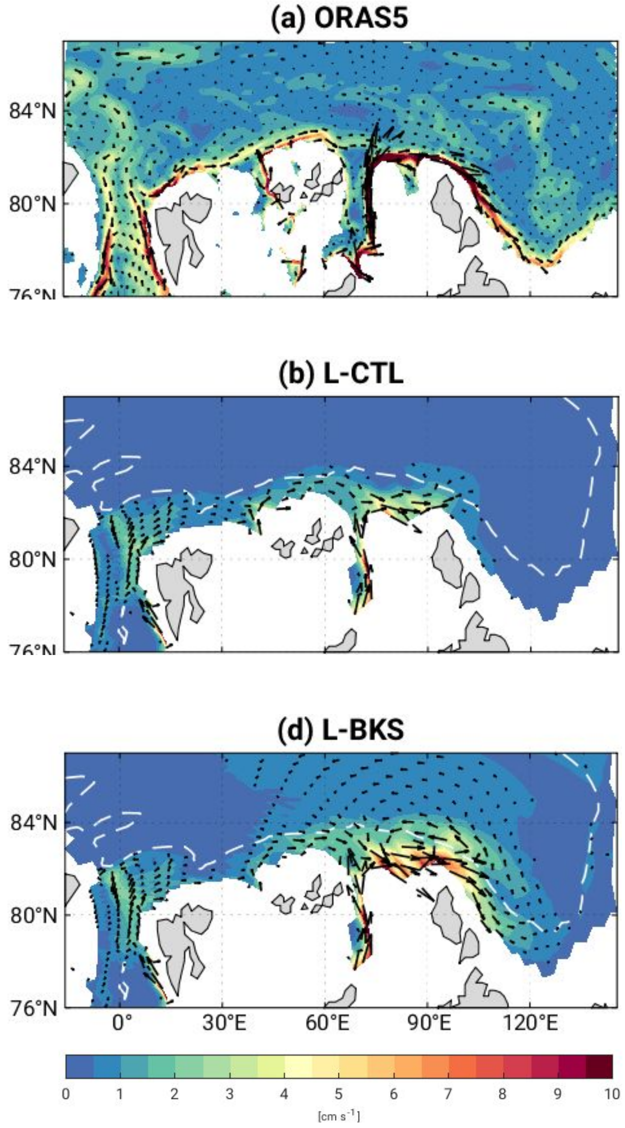
10 m < z < bottom or 500 m

Eurasian Basin



Temp Bias at 300 m



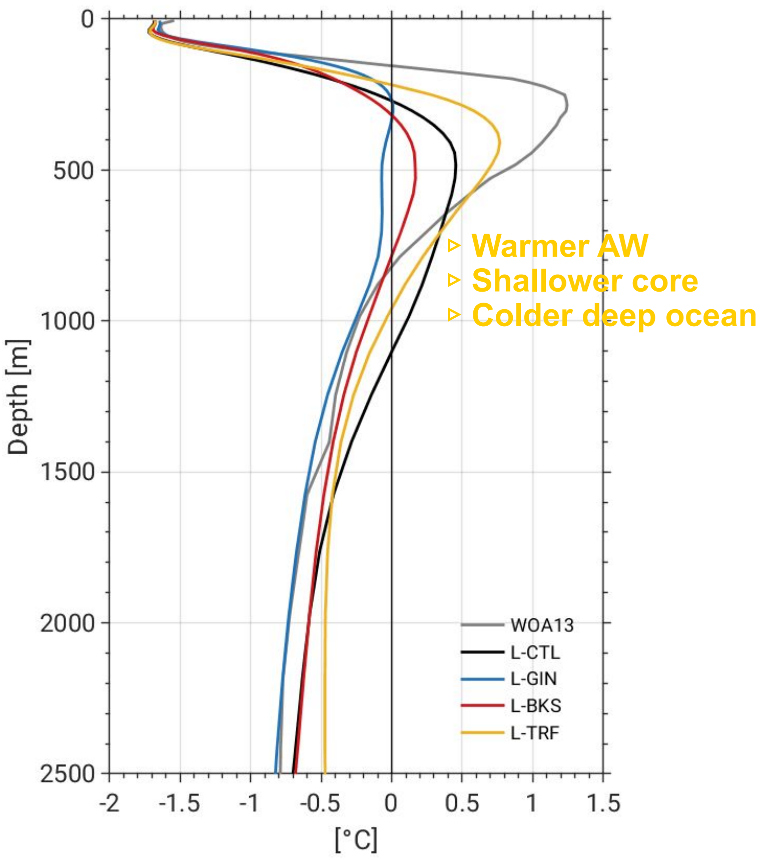


- Inflow from the SAT is still cold-biased in L-BKS
- Getting right over the shelf is not enough

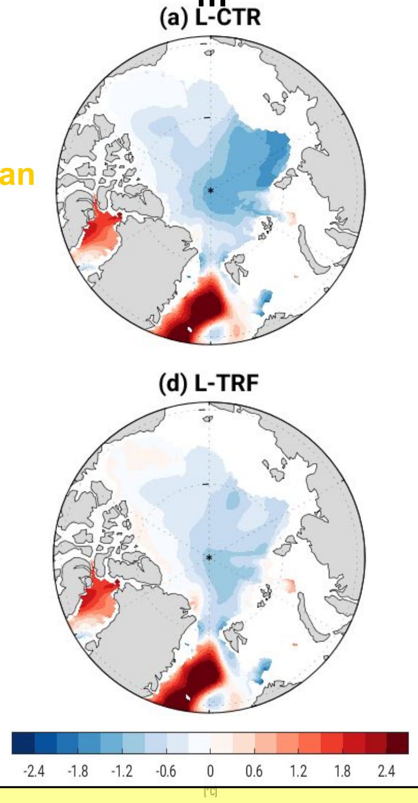
Restoring Experiments (L-TRF)

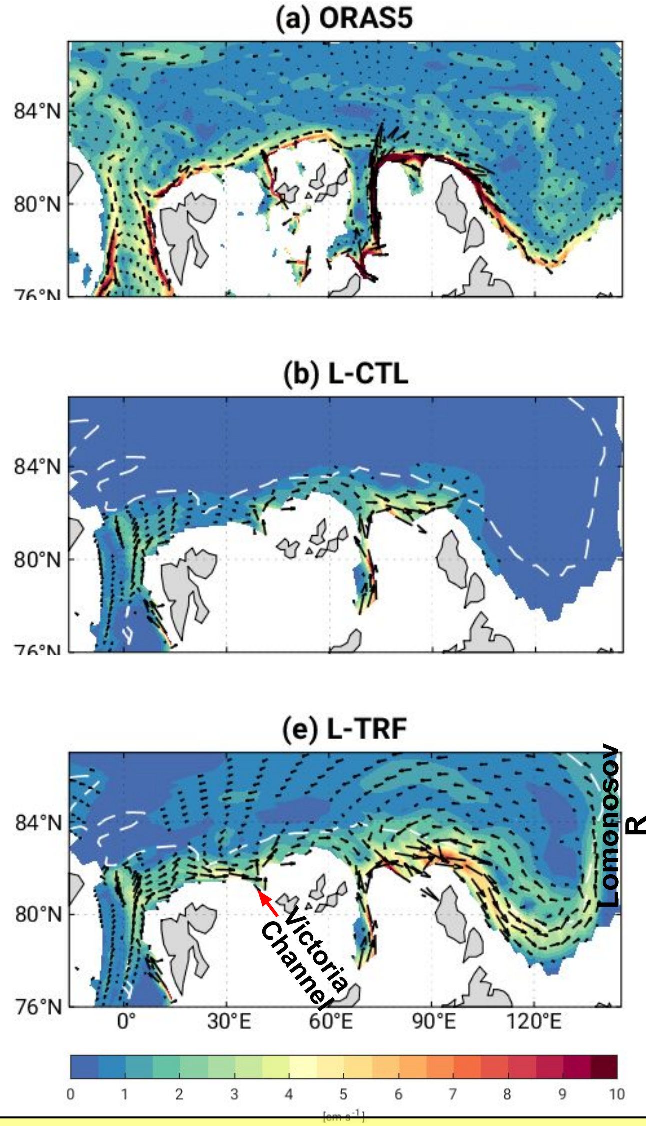
L-TRF

250 m < z < bottom



Temp Bias at 300 m



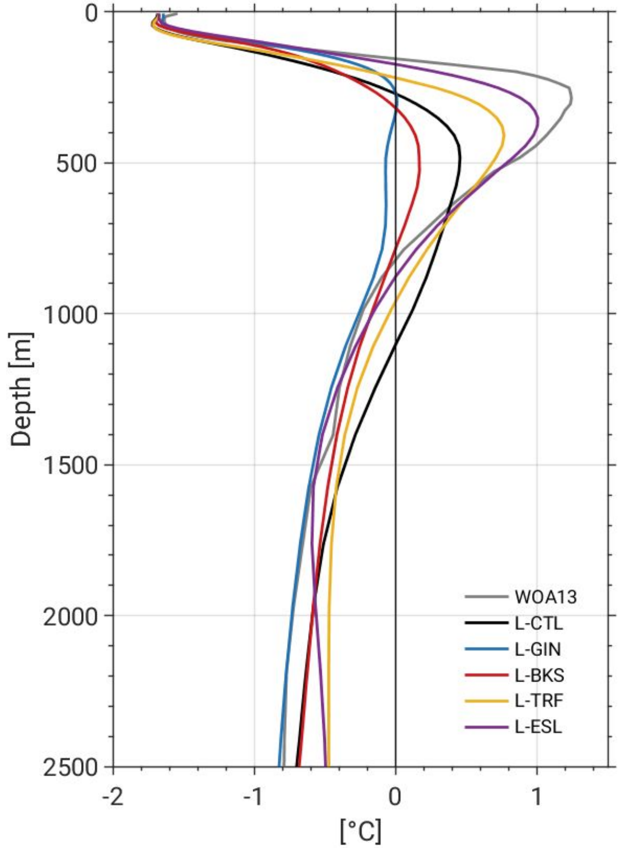


- Stronger cyclonic circulation in the eastern EB and along the Lomonosov Ridge with a stronger recirculation interior
- Suggesting the importance of the inflow from the troughs in simulating the the properties and circulation of the AW

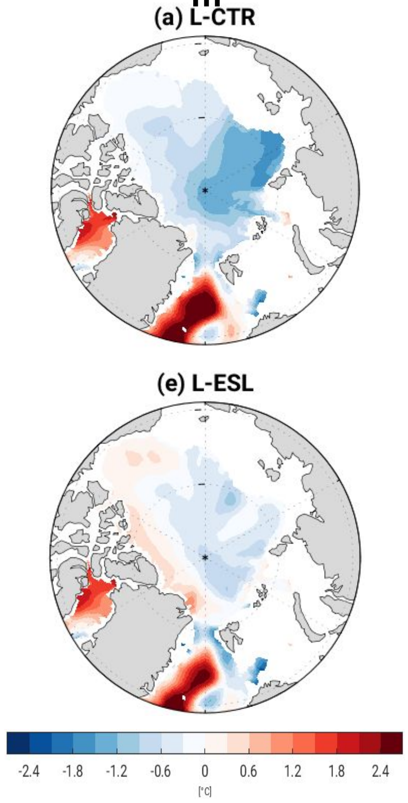
Restoring Experiments (L-ESL)

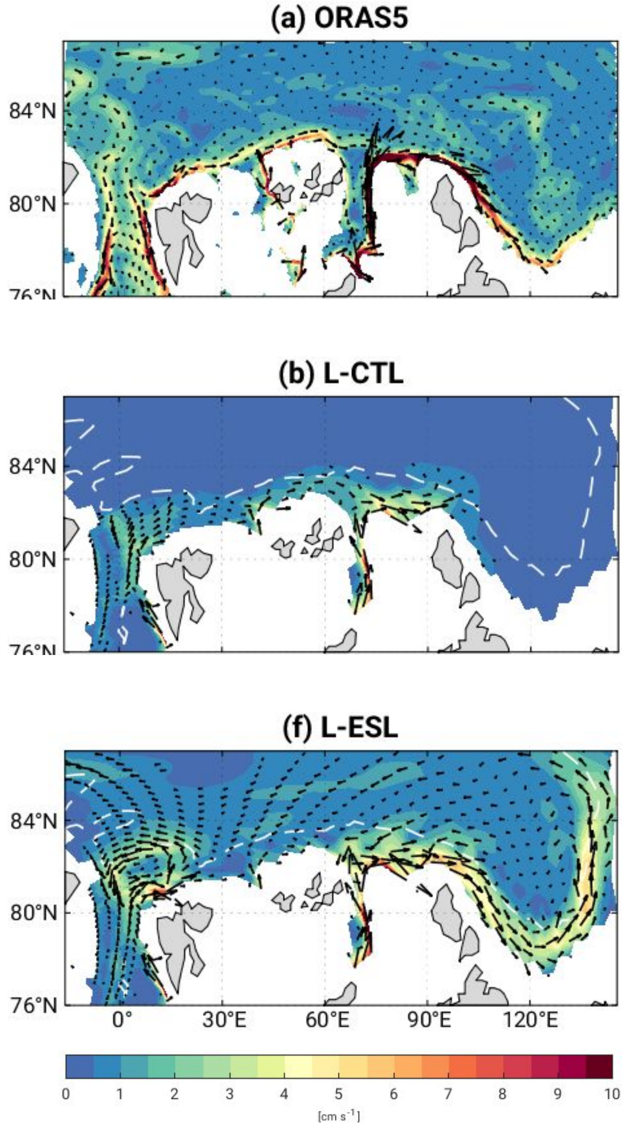
[L-ESL]

500 m < z < 2000 m



Temp Bias at 300 m

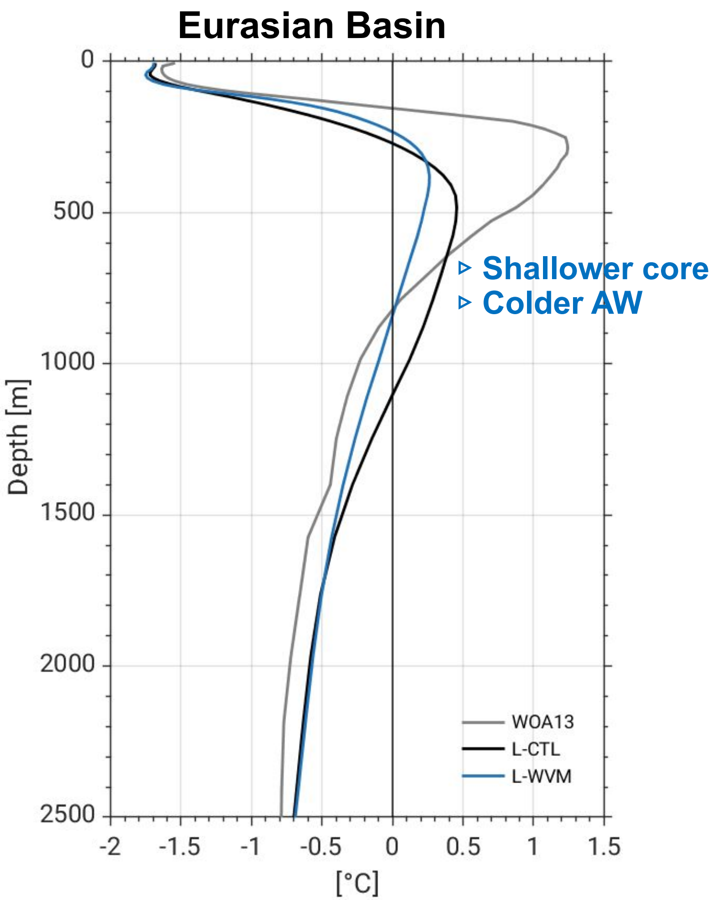


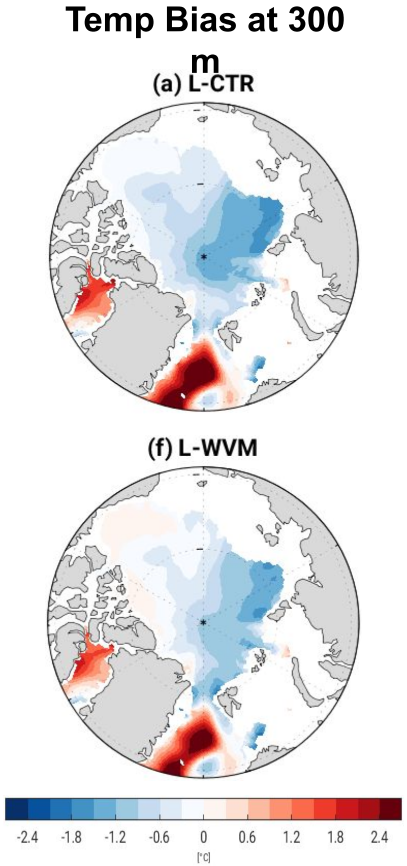


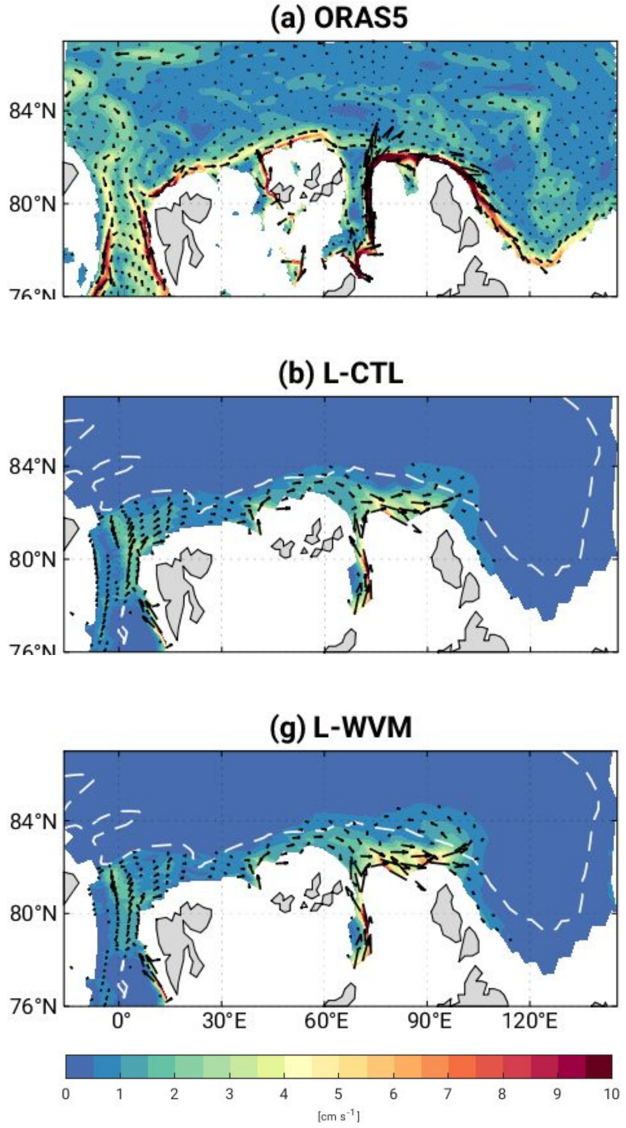
Mixing Experiments (L-WVM)

L-WVM

κ_{v_bg} = 1.4 x 10^{-5} → 0.1 x 10^{-5} m^2 s^{-1} in the Arctic





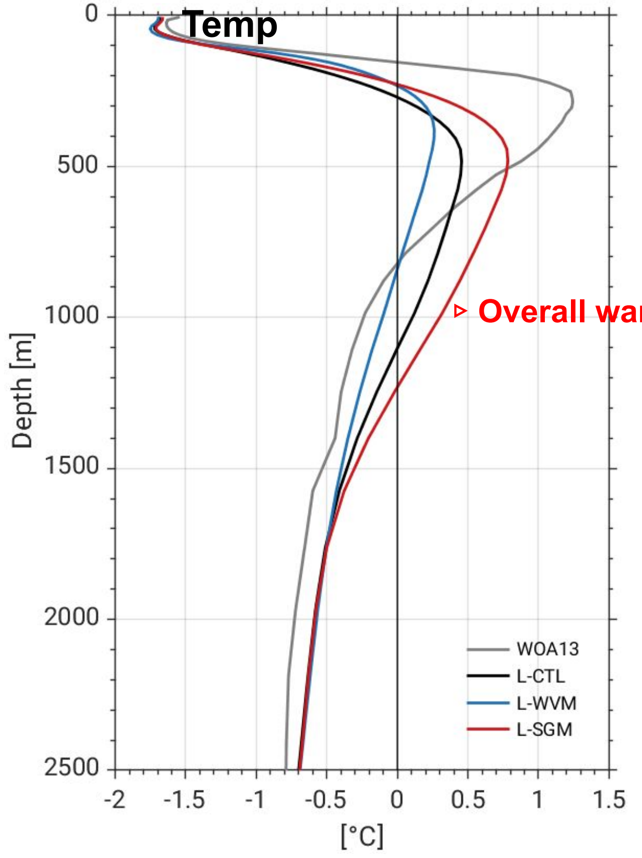


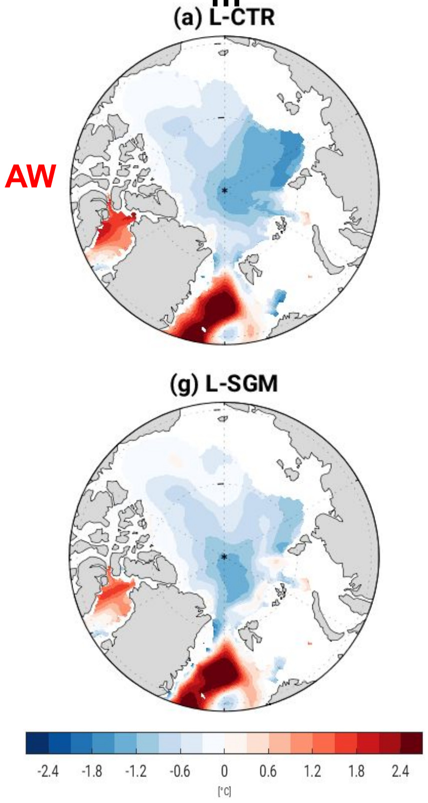
Mixing Experiments (L-SGM)

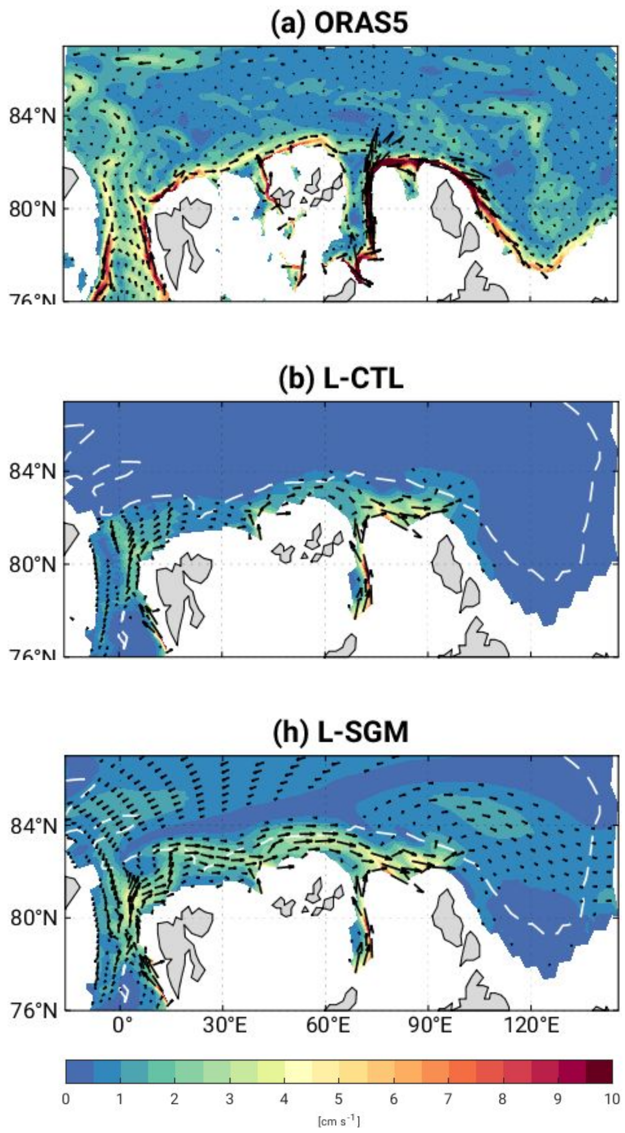
L-SGM

$\kappa_{GM\_isop,thic}$ scaled by area/max(area), suggested by Hunk et al. (2008)

→ **smaller $\kappa_{GM\_isop,thic}$ in the Arctic**



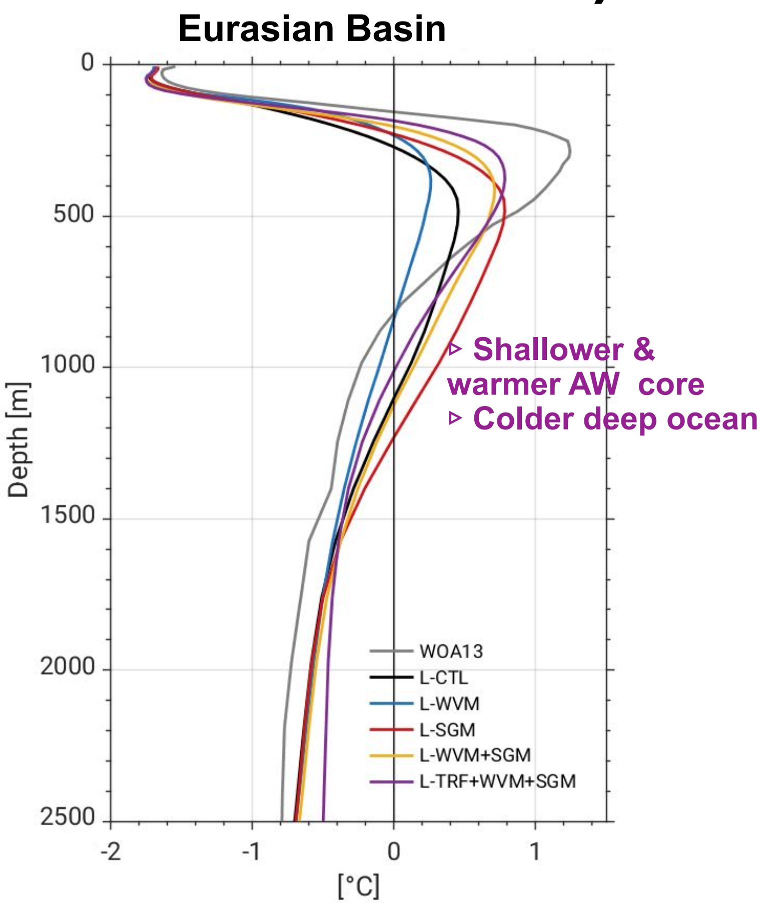


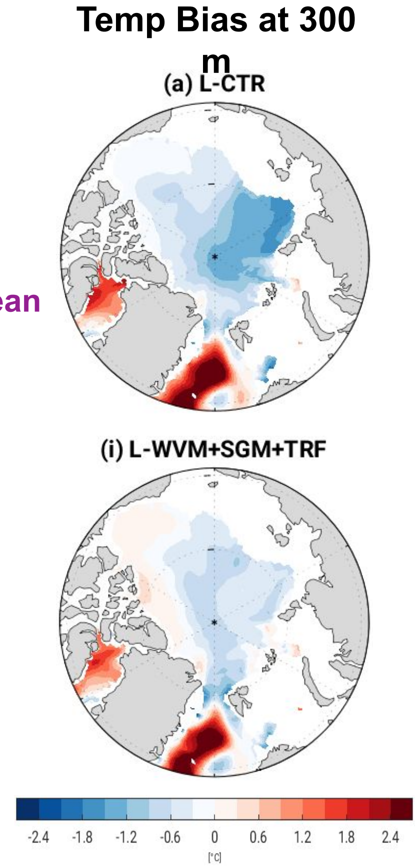


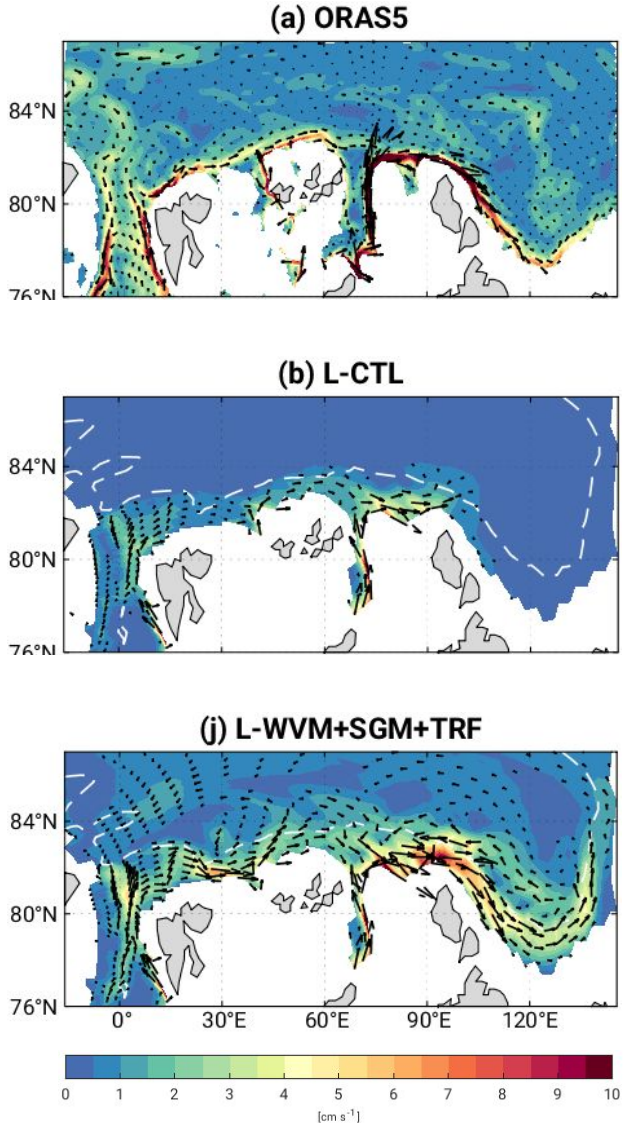
- Stronger cyclonic circulation in the western EB; still weak in eastern EB
- More heat (warm-biased) entering through FS; cold-biased inflow from the SAT

Combined Experiments (L-WVM+SGM+TRF)

L-WVM+SGM+TRF





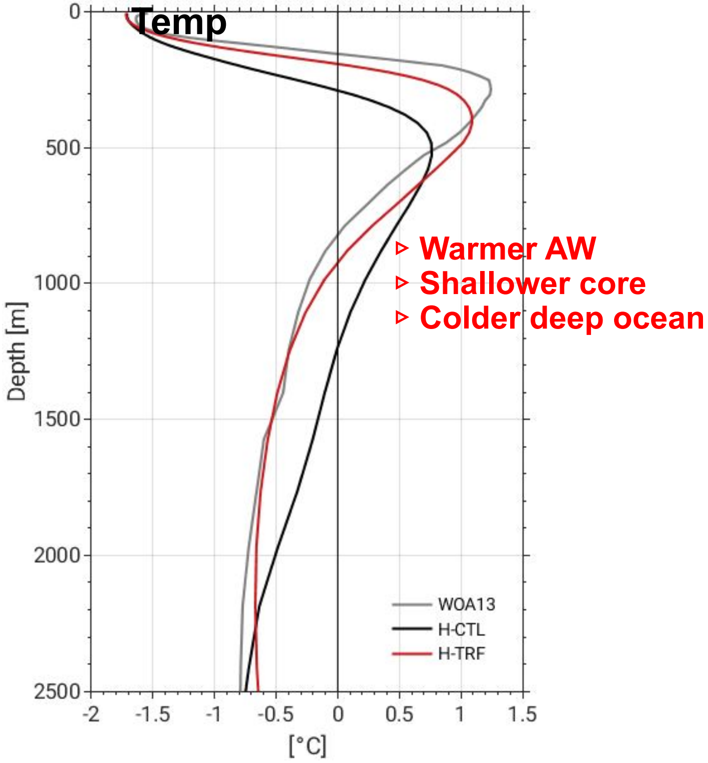


- Least biased AW core (other than L-ESL)
- Deep ocean still too warm

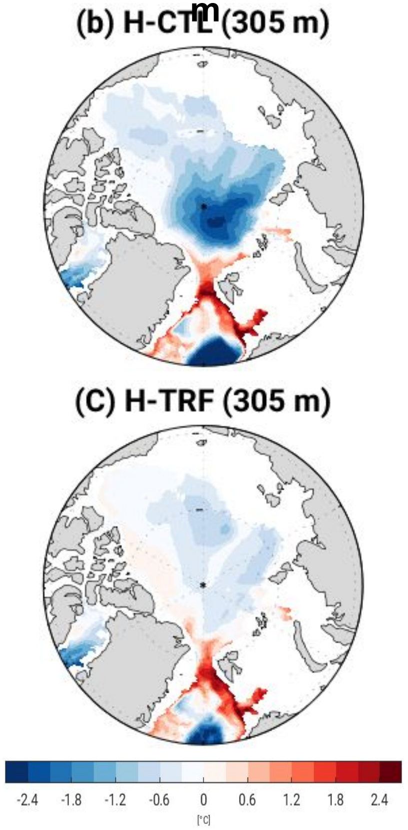
HR Experiments (H-TRF)

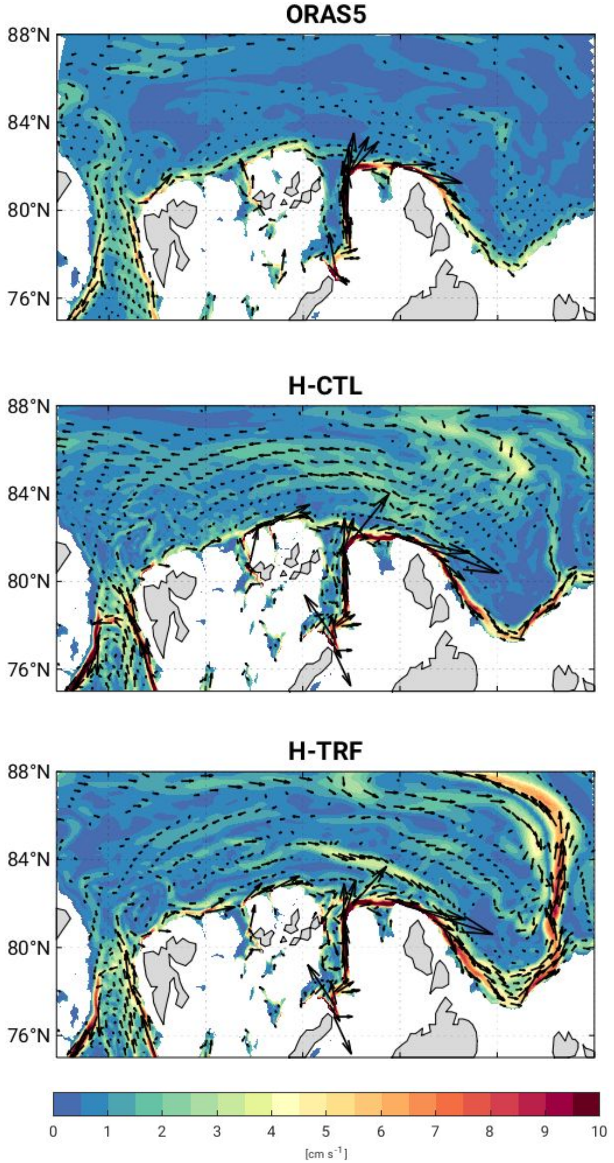
[H-TRF](#)

Eurasian Basin Temp



Temp Bias at 300 m

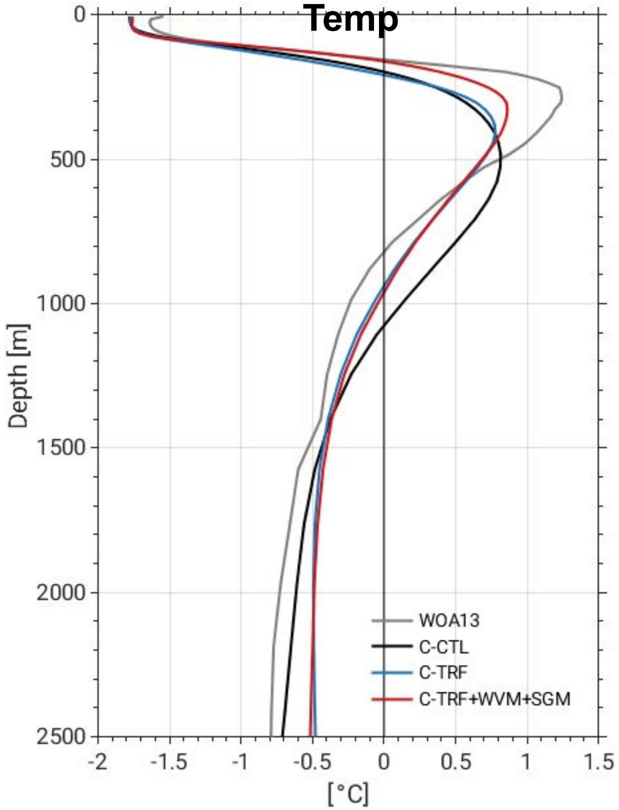




- Similar improvement as in L-TRF – shallower, thinner, warmer AW with a stronger cyclonic circulation in the eastern EB

Coupled Experiments

Eurasian Basin
Temp



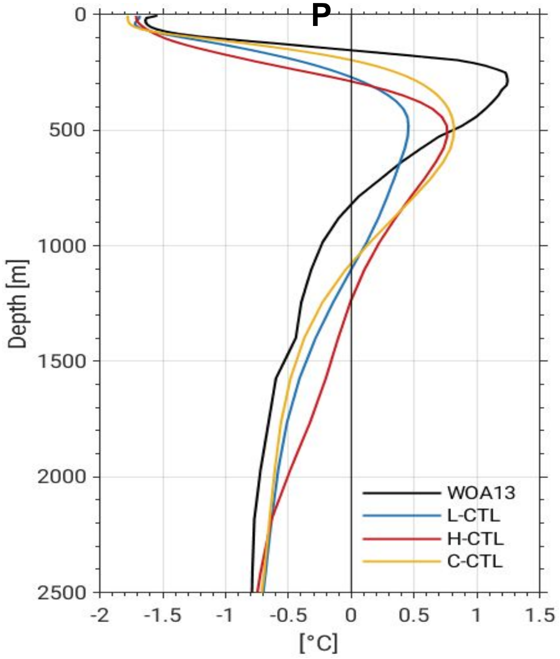
Summary

1) **Important role of the inflow from the troughs and channels** in setting up the hydrographic properties and circulation of the AW
   - The AW biases are substantially reduced (warmer, shallower, and thinner)
   - The cyclonic circulation becomes substantially stronger in the eastern EB, which feeds recirculation in the interior
   - **Calls for the development of an overflow parametrization (even in HR)**

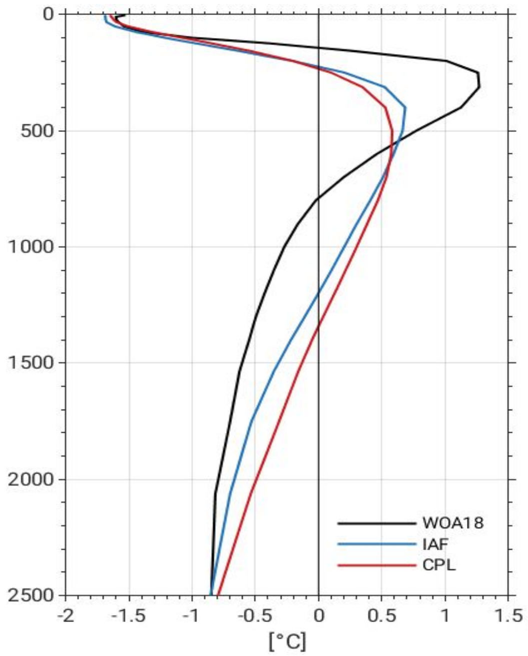
2) **Tunning of mixing parameters** (more relevant to LR)
   - Scaling GM diffusivity coefficients to grid area (i.e., weaker mixing in the Arctic) substantially strengthens the circulation in the western EB
   - Flow pattern becomes less organized
   - Biases in the GIN Seas become more matter (too warm in the deep ocean)

Is MOM better than POP?

PO
P



MOM

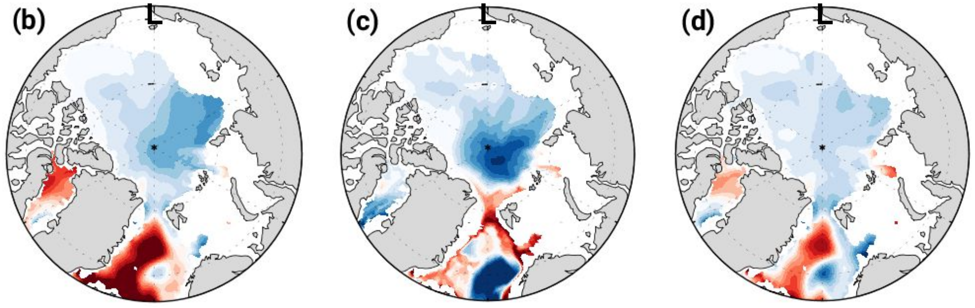


Temp Bias at 300
m

L-CT
L

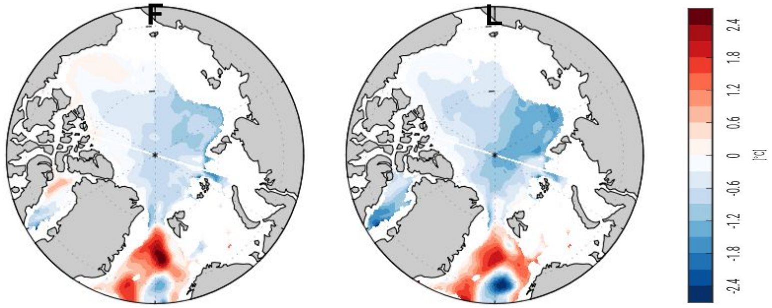
H-CT
L

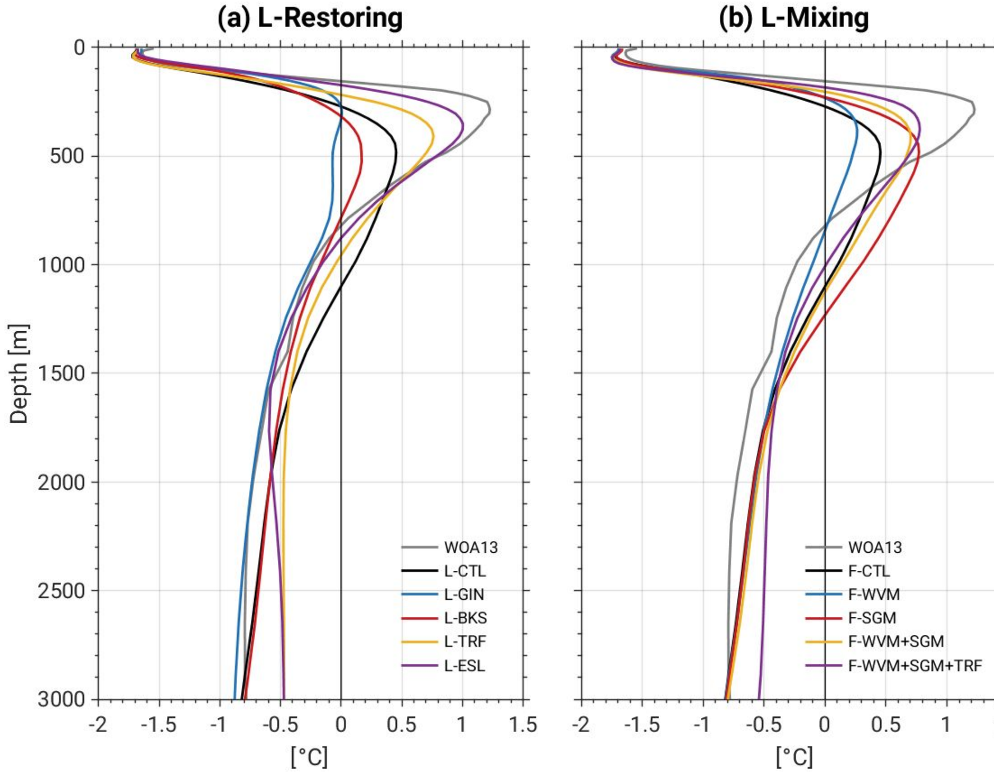
C-CT
L



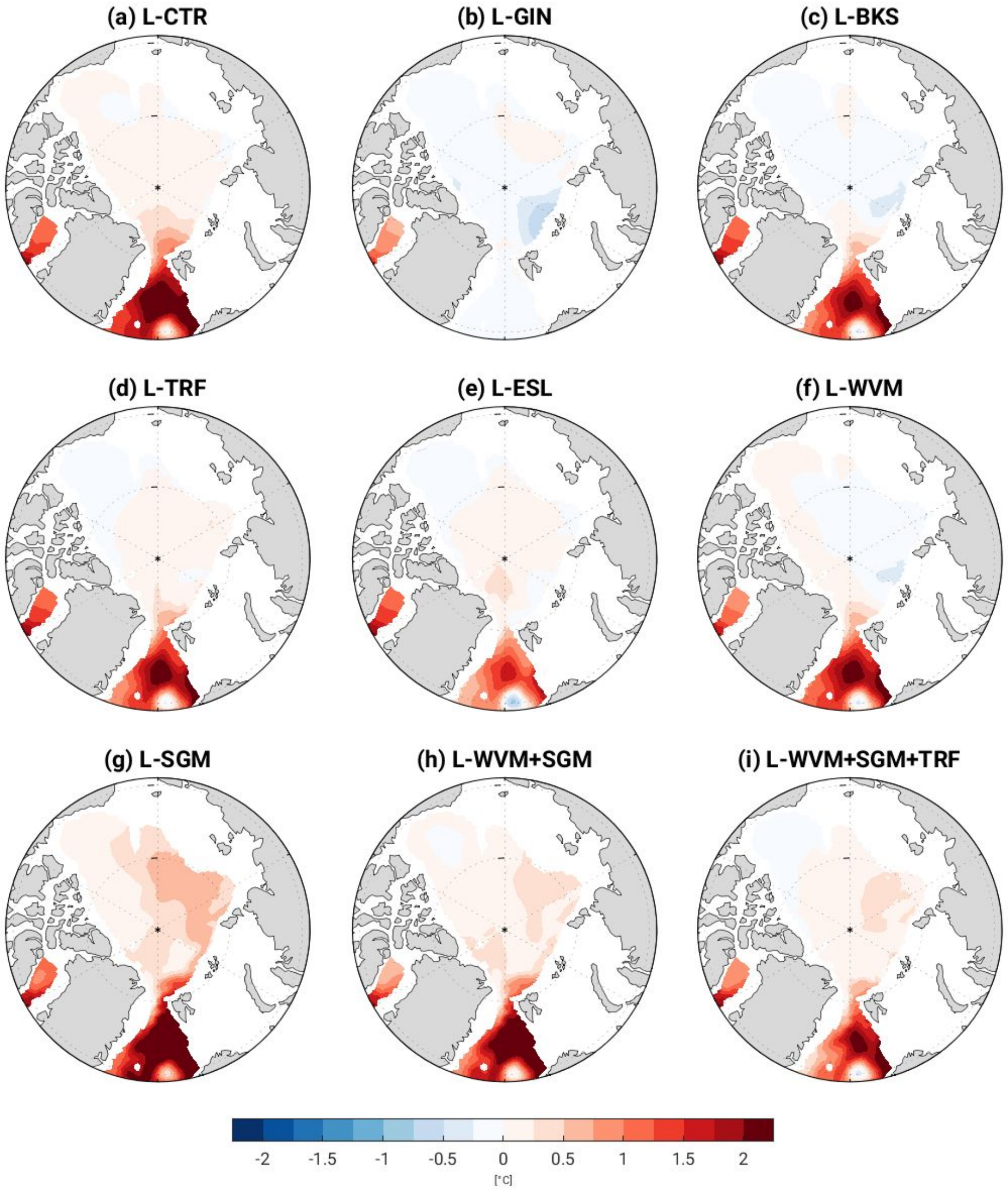
IA
F

CP
L

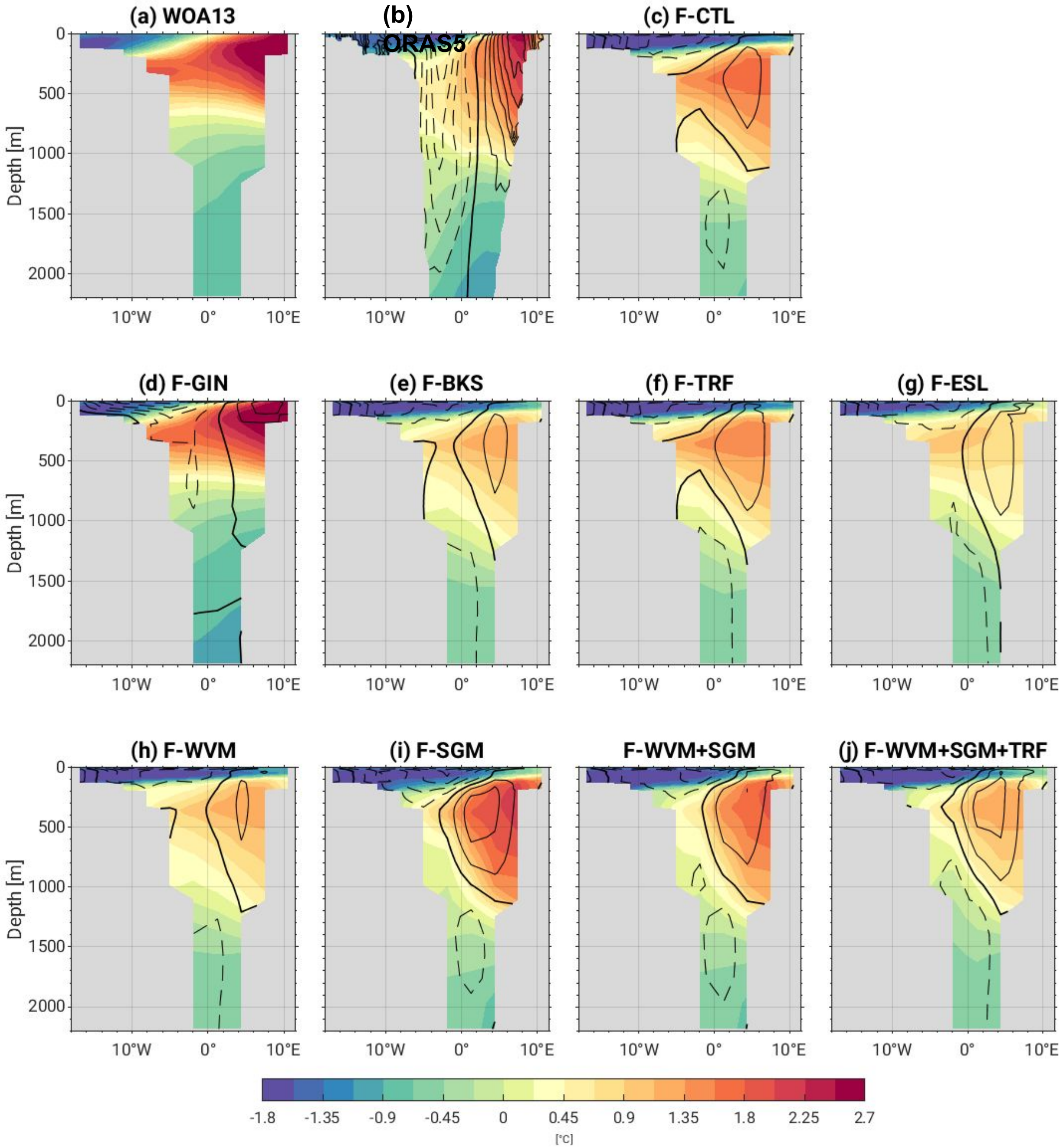




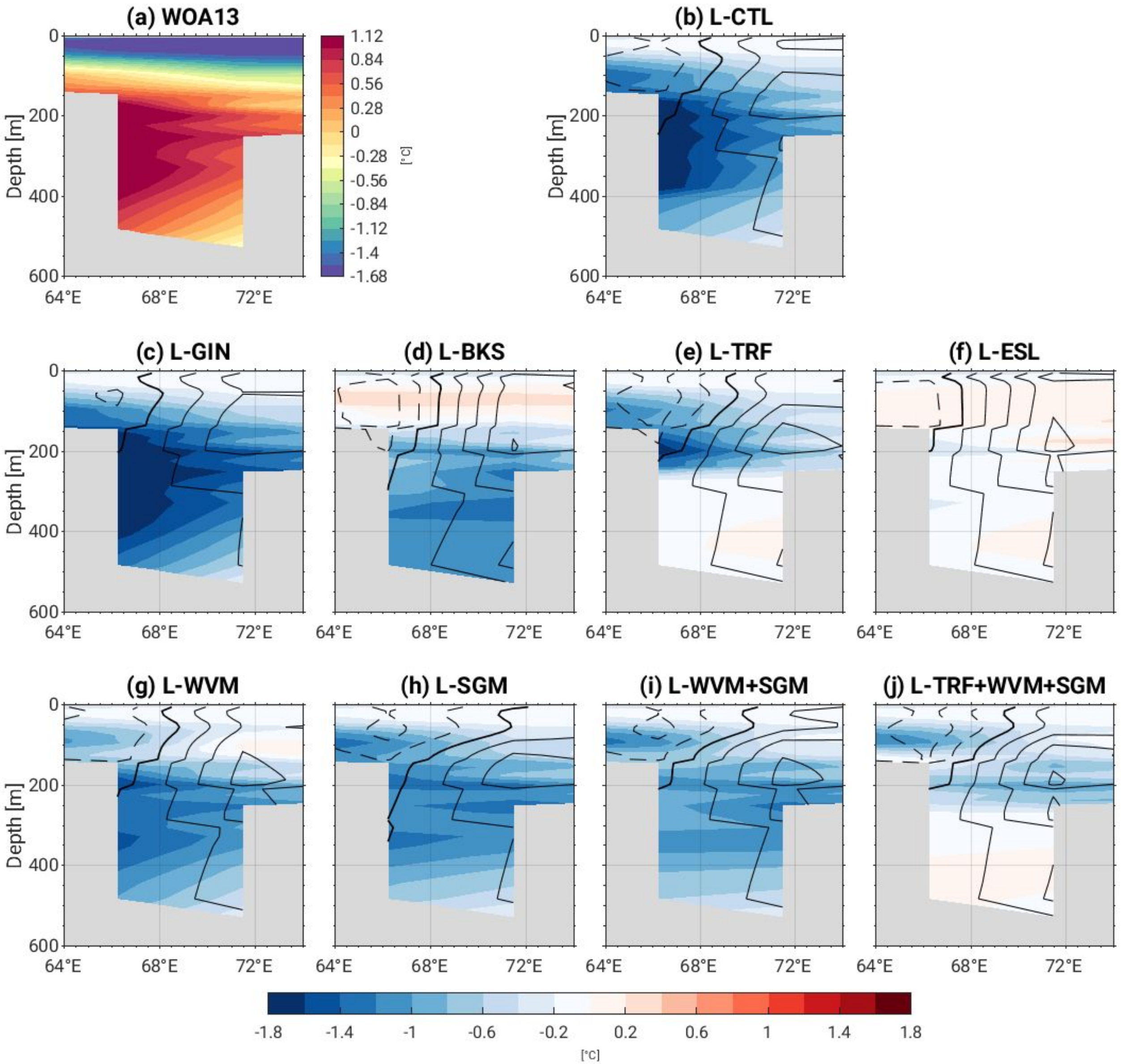
(a) L-Restoring
(b) L-Mixing
Depth [m]
0
500
1000
1500
2000
2500
3000
-2
-1.5
-1
-0.5
0
0.5
1
1.5
[°C]
WOA13
L-CTL
L-GIN
L-BKS
L-TRF
L-ESL
WOA13
F-CTL
F-WVM
F-SGM
F-WVM+SGM
F-WVM+SGM+TRF



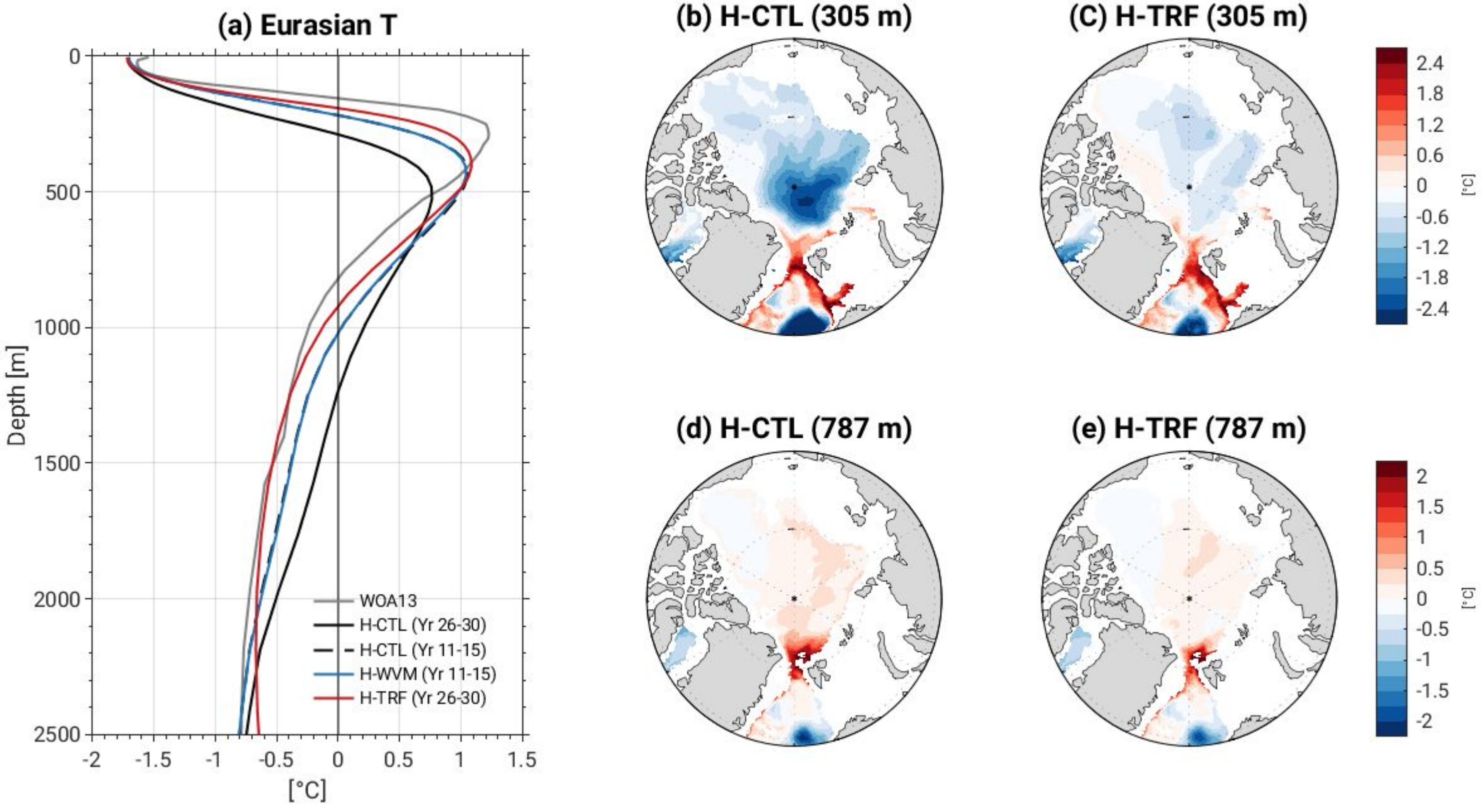
(a) L-CTR
(b) L-GIN
(c) L-BKS
(d) L-TRF
(e) L-ESL
(f) L-WVM
(g) L-SGM
(h) L-WVM+SGM
(i) L-WVM+SGM+TRF
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
[°C]



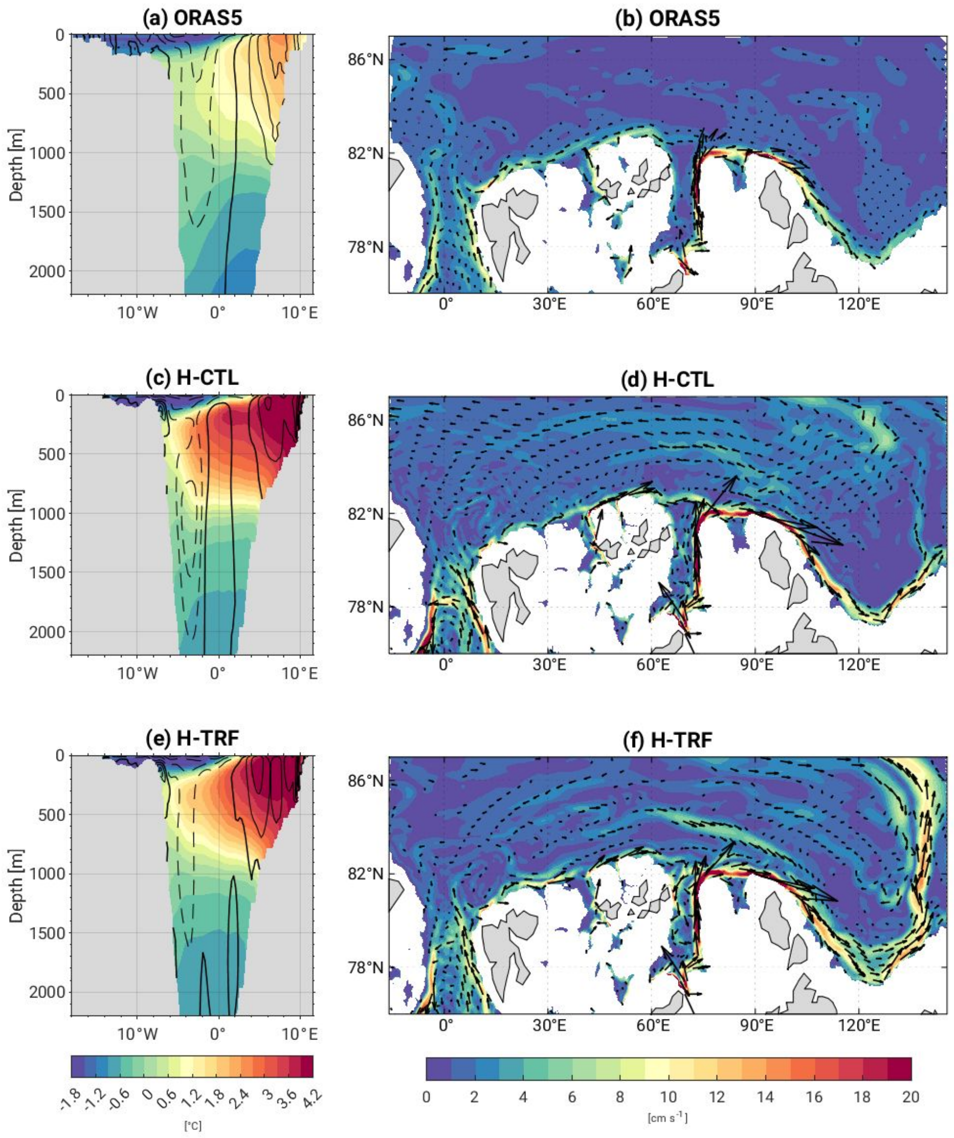
(a) WOA13
(b)
ORAS5
(c) F-CTL
(d) F-GIN
(e) F-BKS
(f) F-TRF
(g) F-ESL
(h) F-WVM
(i) F-SGM
F-WVM+SGM
(j) F-WVM+SGM+TRF
Depth [m]
0
500
1000
1500
2000
10°W
0°
10°E
-1.8
-1.35
-0.9
-0.45
0
0.45
0.9
1.35
1.8
2.25
2.7
[°C]



(a) WOA13
(b) L-CTL
(c) L-GIN
(d) L-BKS
(e) L-TRF
(f) L-ESL
(g) L-WVM
(h) L-SGM
(i) L-WVM+SGM
(j) L-TRF+WVM+SGM
Depth [m]
0
200
400
600
64°E
68°E
72°E
1.12
0.84
0.56
0.28
0
-0.28
-0.56
-0.84
-1.12
-1.4
-1.68
[°C]
-1.8
-1.4
-1
-0.6
-0.2
0.2
0.6
1
1.4
1.8
[°C]



(a) Eurasian T
Depth [m]
[°C]
WOA13
H-CTL (Yr 26-30)
H-CTL (Yr 11-15)
H-WVM (Yr 11-15)
H-TRF (Yr 26-30)
(b) H-CTL (305 m)
(C) H-TRF (305 m)
(d) H-CTL (787 m)
(e) H-TRF (787 m)
[°C]


(a) ORAS5
(b) ORAS5
(c) H-CTL
(d) H-CTL
(e) H-TRF
(f) H-TRF
Depth [m]
0
500
1000
1500
2000
10°W
0°
10°E
86°N
82°N
78°N
30°E
60°E
90°E
120°E
-1.8 -1.2 -0.6 0 0.6 1.2 1.8 2.4 3 3.6 4.2
[°C]
0 2 4 6 8 10 12 14 16 18 20
[cm s⁻¹]

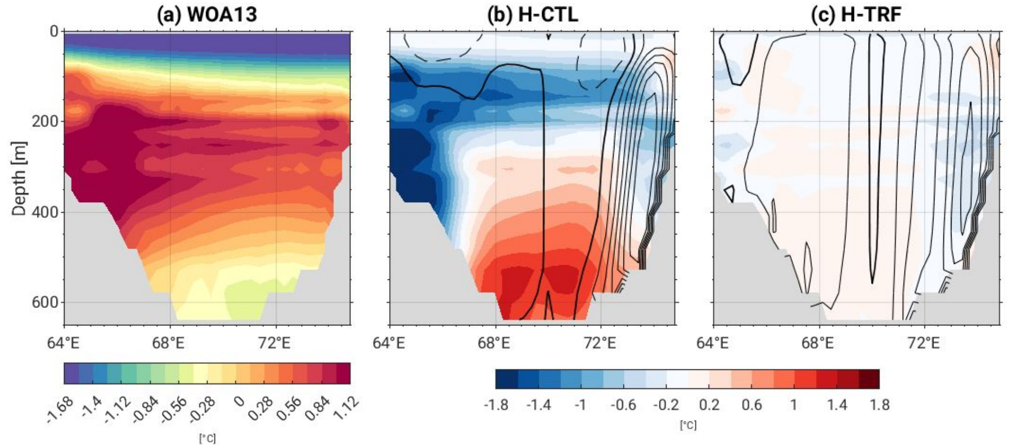
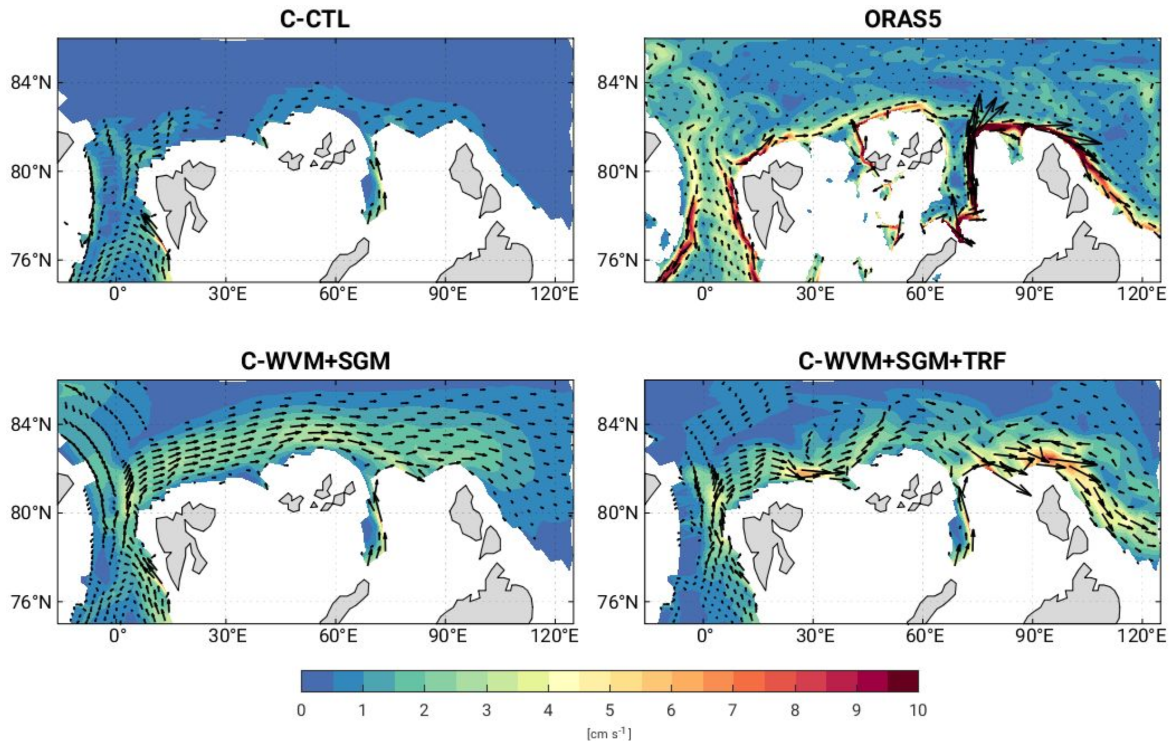

(a) WOA13
(b) H-CTL
(c) H-TRF
Depth [m]
0
200
400
600
64°E
68°E
72°E
-1.68 -1.4 -1.12 -0.84 -0.56 -0.28 0 0.28 0.56 0.84 1.12
[°C]
-1.8 -1.4 -1 -0.6 -0.2 0.2 0.6 1 1.4 1.8
[°C]

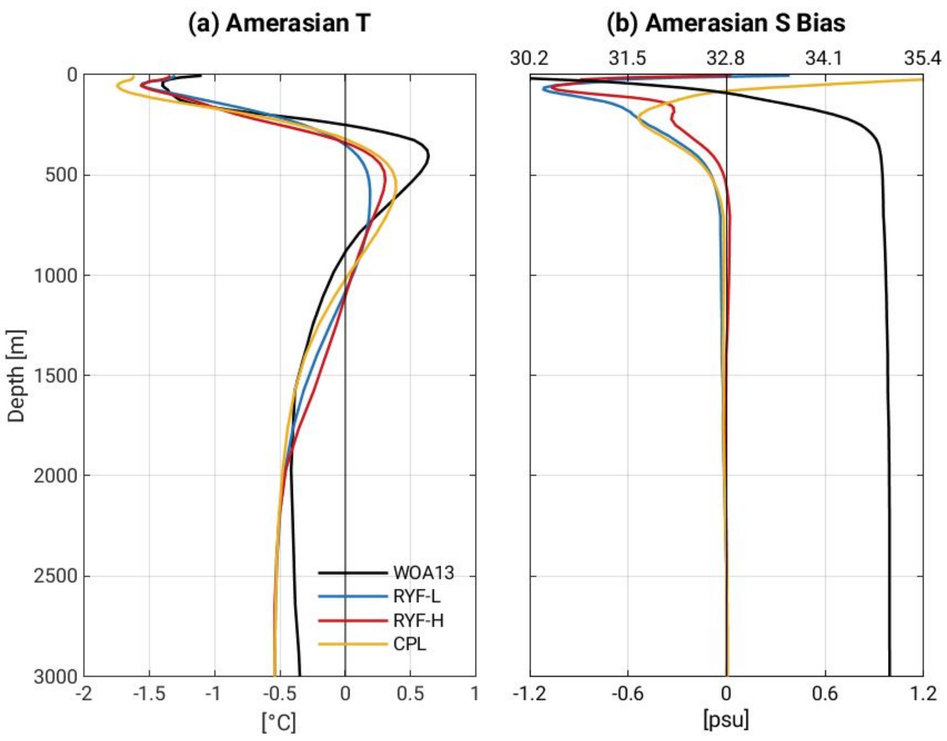
Fig. 11. Hovmoller diagram of T bias in EB and spatial map of T bias at 300 m from coupled experiments

- Blah

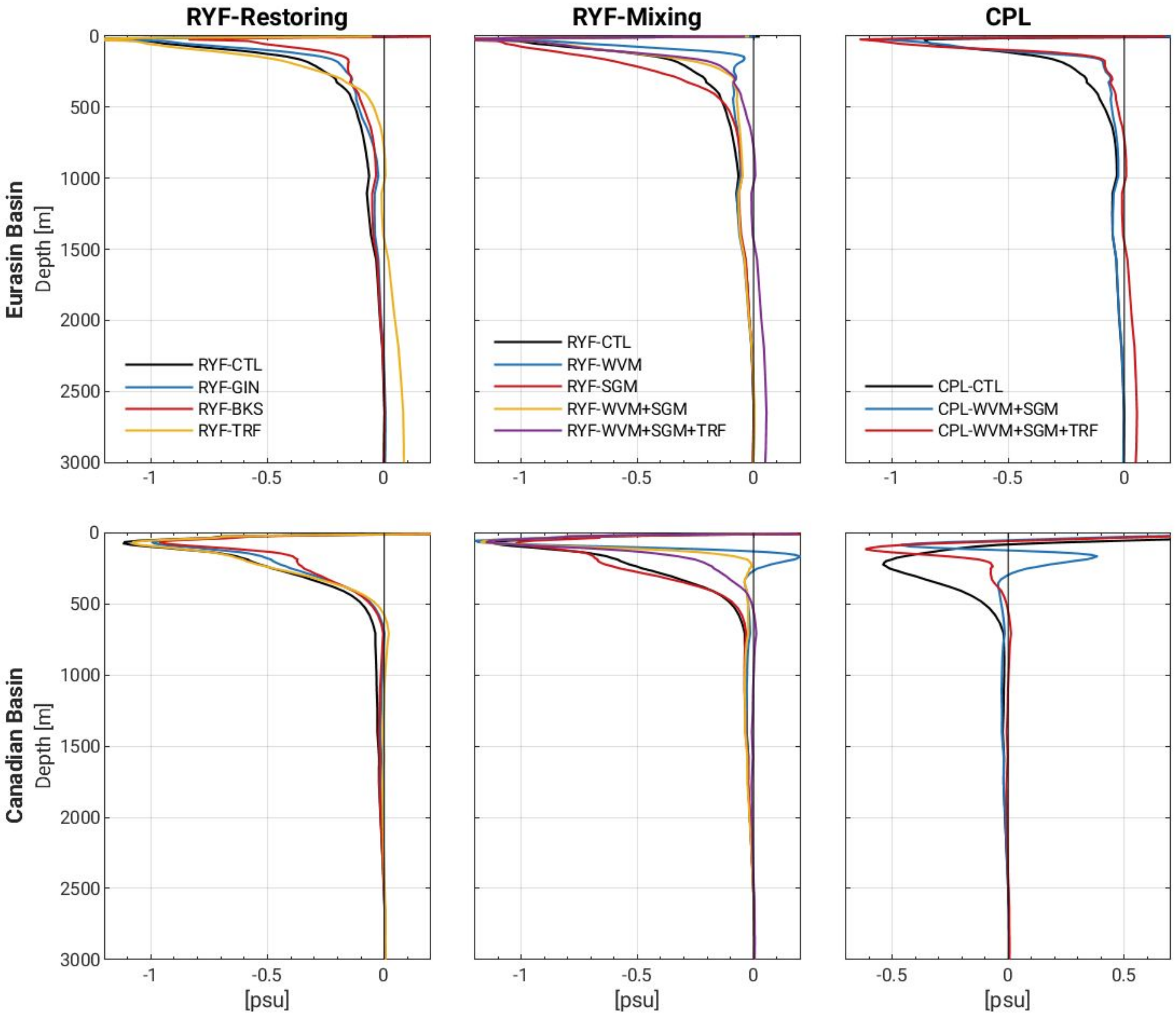


Tentative Conclusions:

- Both lateral mixing and waters entering the Arctic Ocean through channels (esp., St. Anna Trough) appear to be significant sources of the AWL temperature layer bias
- TRF is most effective in reducing both cold and warm biases at the observed AW core and bottom, respectively.
- TRF also enhance the cyclonic circulation substantially
- SGM also reduce the cold bias at the AW core and enhance the cyclonic circulation substantially
- However, SGM makes the warm bias worse at depths
- Need to optimize lateral mixing
- Need to improve water properties that exit the troughs (overflow parameterization?)



(a) Amerasian T
(b) Amerasian S Bias
Depth [m]
0
500
1000
1500
2000
2500
3000
-2
-1.5
-1
-0.5
0
0.5
1
[°C]
WOA13
RYF-L
RYF-H
CPL
30.2
31.5
32.8
34.1
35.4
-1.2
-0.6
0
0.6
1.2
[psu]



RYF-Restoring
RYF-Mixing
CPL
Eurasin Basin
Depth [m]
Canadian Basin
Depth [m]
RYF-CTL
RYF-GIN
RYF-BKS
RYF-TRF
RYF-CTL
RYF-WVM
RYF-SGM
RYF-WVM+SGM
RYF-WVM+SGM+TRF
CPL-CTL
CPL-WVM+SGM
CPL-WVM+SGM+TRF
0
500
1000
1500
2000
2500
3000
-1
-0.5
0
0.5
[psu]