COMMODORE
Community for the numerical modeling of the global, regional and coastal ocean

# COMMODORE conference
Hamburg, 28-31 Jan.

# FESOM2.0

## Progress, Performance and Scalability

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**Energy Transfer in Atmo-sphere and Ocean, Topic S2:** Improved parameterisations and numerics in climate models

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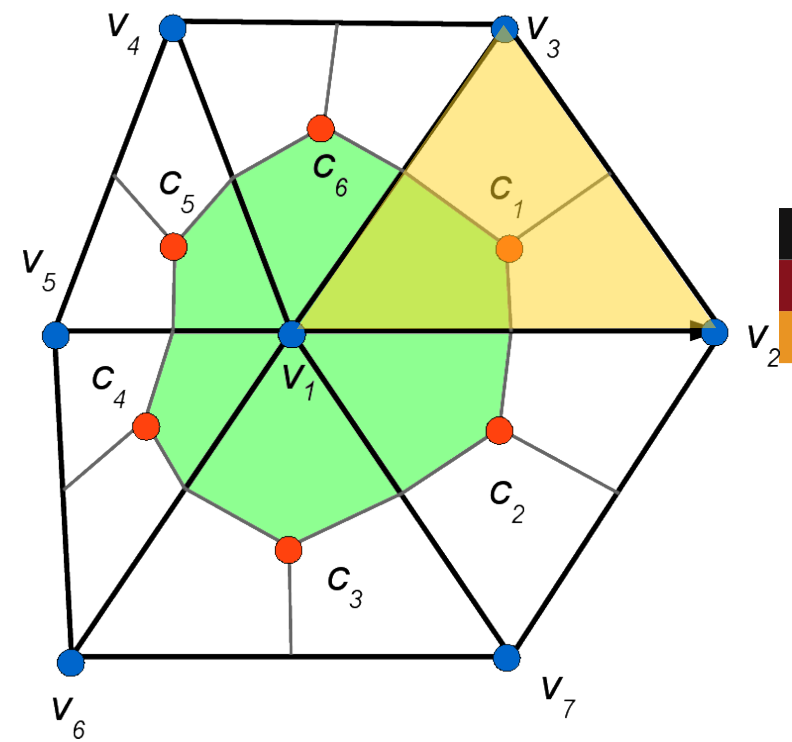
# FESOM 2.0 (Finite Volume)

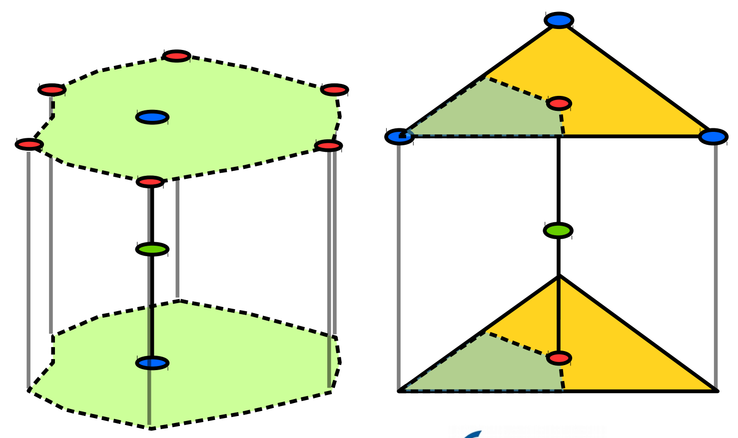
- Finite VolumE Sea Ice Ocean Model **(FESOM2.0)**
- Global triangular unstructured grid ocean sea-ice model, that solves the primitive equations under boussinesq approximation
- In FESOM2.0 switched from Finite-Elements to Finite-Volumes this allows for:
  - → More efficient data structure due to the switch from tetrahedral elements (FESOM1.4) to prismatic elements (FESOM2.0)
  - → More efficient use of computational resources
  - → Clearly defined fluxes trough faces of the control volume
  - → The possibility to introduce via Arbitrary Lagrangian-Eulerian **(ALE)** approach plenty of different vertical discretisations

# FESOM 2.0 (Finite Volume)

## Placement of variables:

- FESOM2.0  B-Grid (FESOM1.4 A-Grid)
- U,V horizontally defined at triangle centroids, in vertical placed at mid levels
- Scalar are defined at triangle vertices
- Scalar control volume formed by connecting cell centroids with edge mid-points
- Vector control volume formed by prisms based on mesh surface cells
- In the vertical all quantities except vertical velocity are placed at mid depth levels



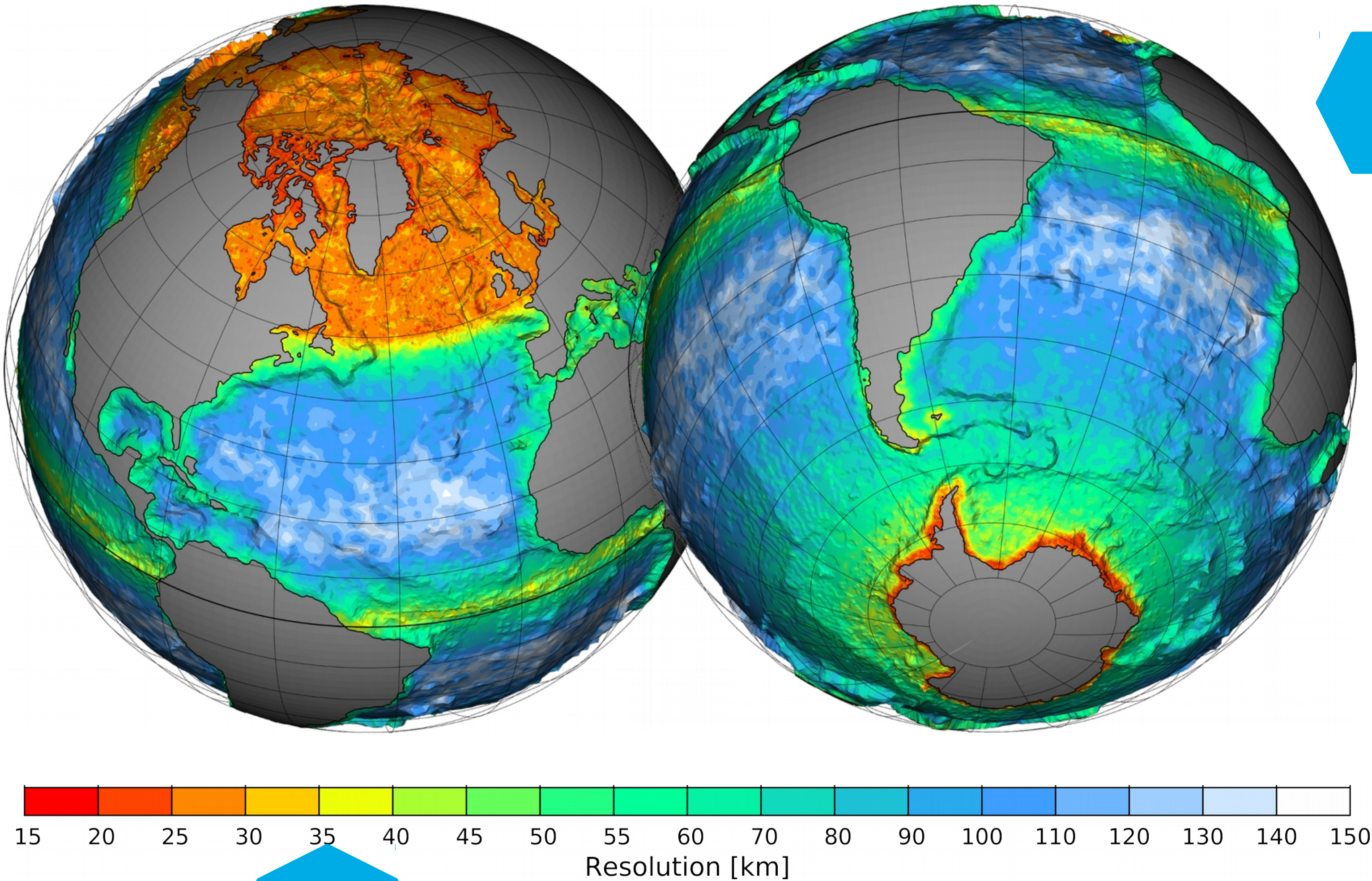
# Implementation of ALE vertical coordinates

## Why we want to use ALE ?

S. Danilov et al. 2017

- vertical levels can be fixed in time (Eulerian) or move with the flow (Lagrangian) or something in between
- has the potential to reduce unwanted spurious cross isopycnal mixing effects
- allows a variety of different vertical discretisations (linfs, zlevel, zstar, ztilde...)
- allows easy implementation of floating ice and partial bottom cells
- allows for the implementation terrain-following-sigma coord., VQS hybrid coord., isopycnal following coord.

# Model Setup




**Forcing**
- Coordinated Ocean-ice Reference Experiments data set, version 2 (Large and Yeager 2009)
- Period 1948-2009
- Applied 3 spinup cycles

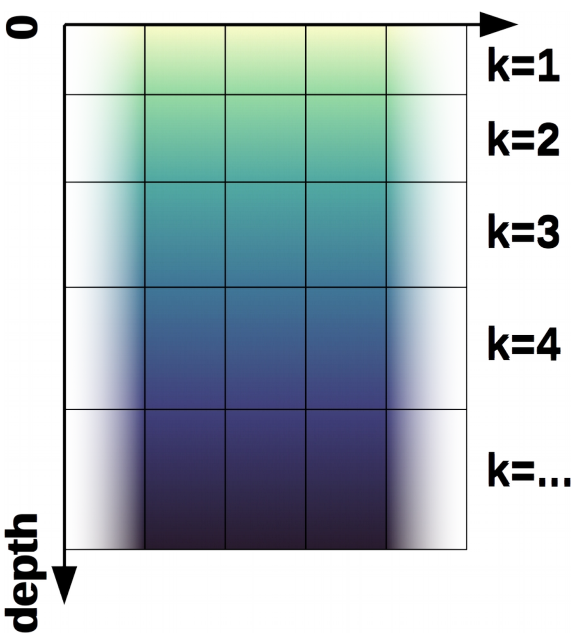
**Initialisation**
- Polar science center Hydrographic Climatology (PHC3.0)

**Mesh**
- CORE2 mesh, minimum resolution ~20 km (#surface vertices: 126858, #layers: 48)
- Also used for CORE2 intercomparison project with FESOM1.4

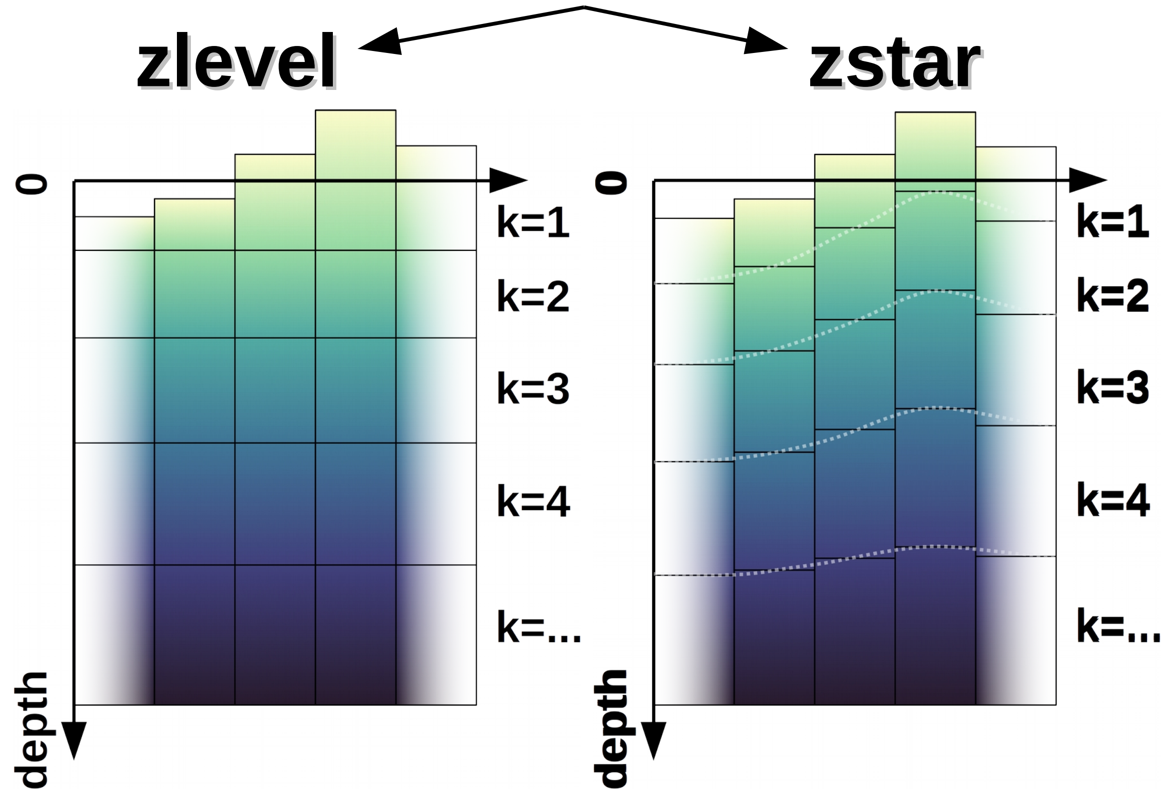
# ALE vertical coordinates

## Linear free surface

linfs




## Full (nonlinear) free surface

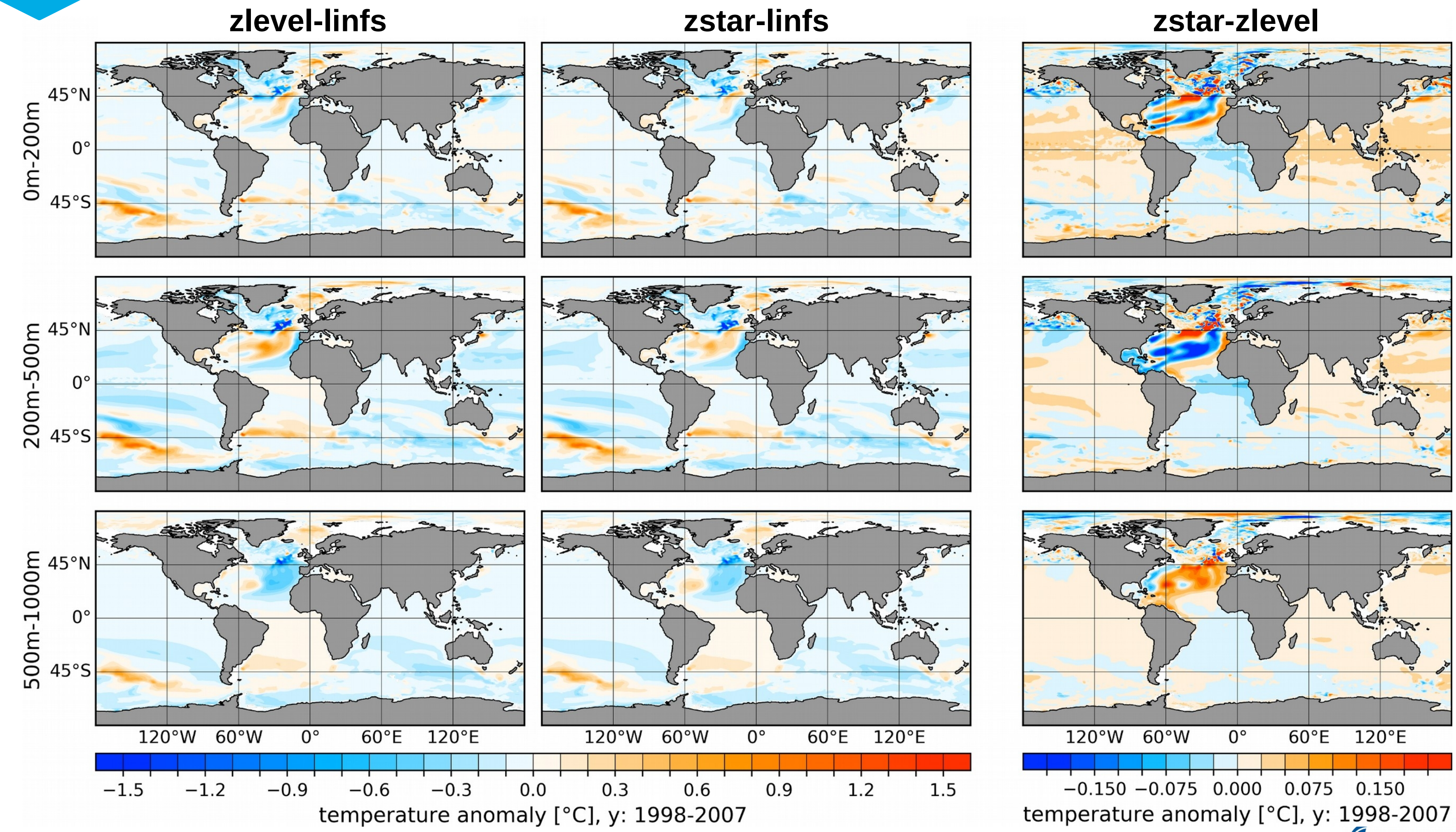



- Freshwater flux can not be taken into account contributes by virtual salinity flux

- Freshwater flux directly affects the volume of the first layer and thus alternates salinity

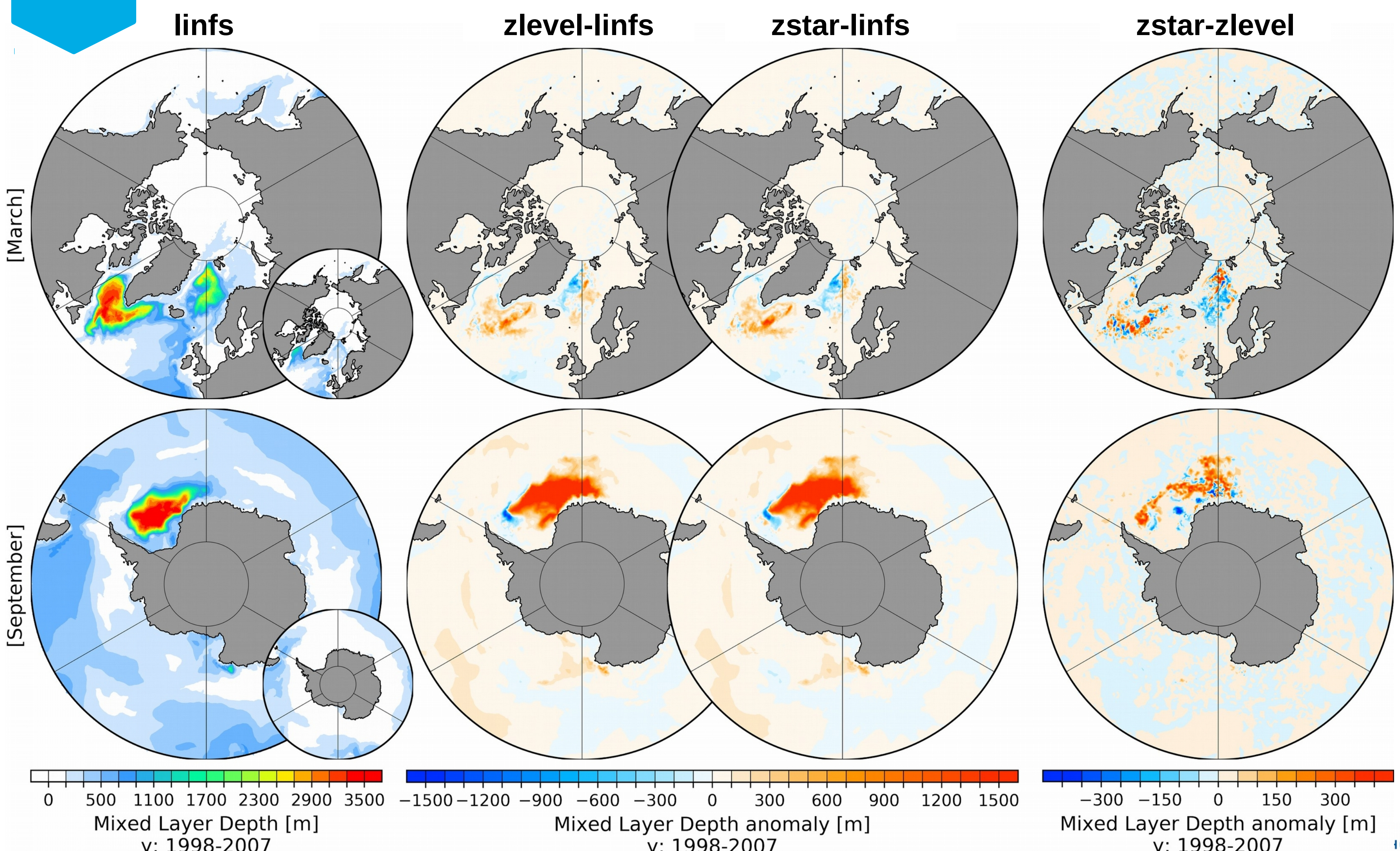
# ALE vertical coordinates

- Temperture bias of full free surface cases, zlevel and zstar, with respect to linfs (left + middle panel) and bias between zlevel and zstar(right panel, zstar-zlevel)



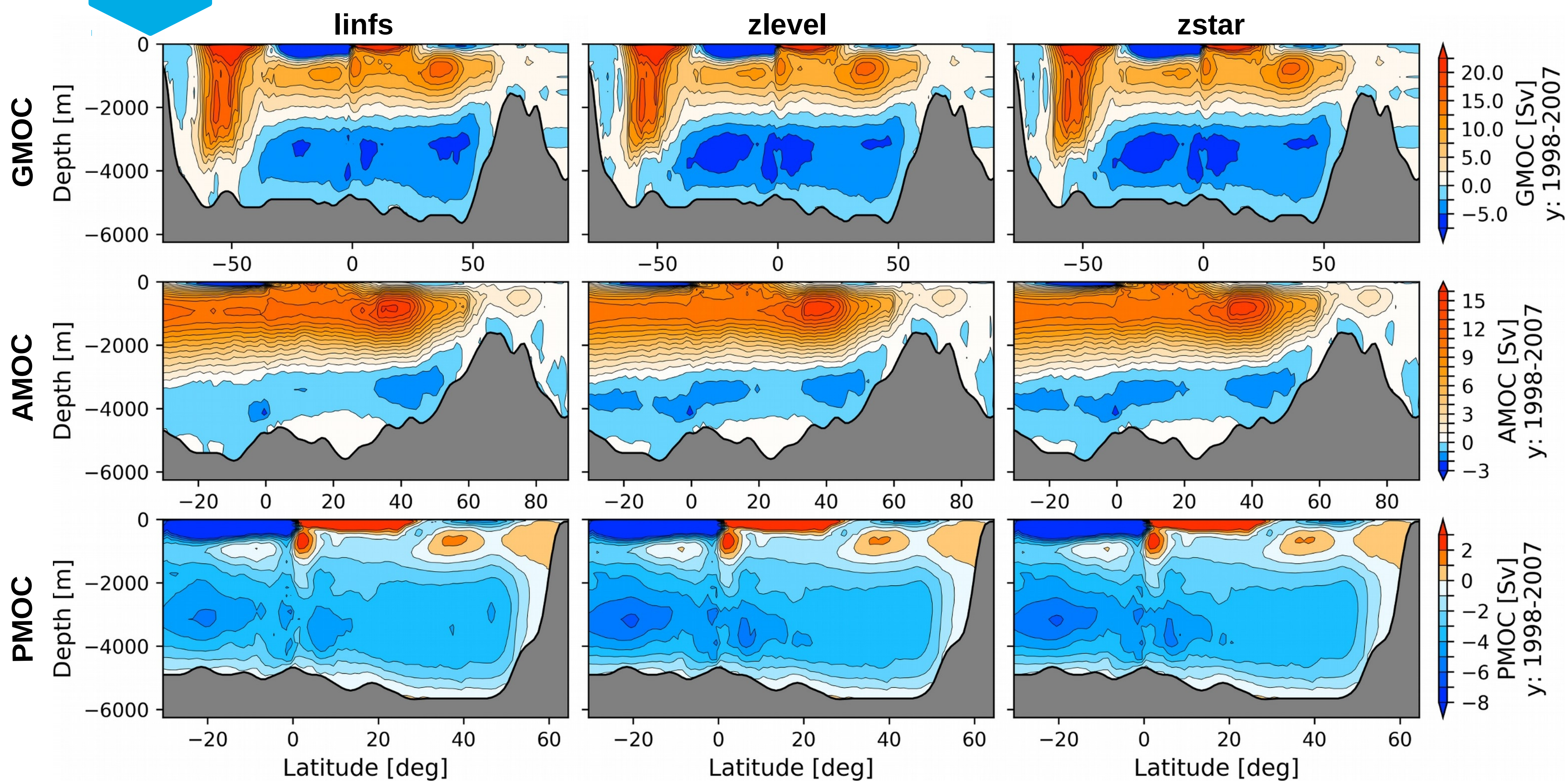
# ALE vertical coordinates

- Mixed layer depth (MLD) of linfs and MLD differences of full free surface cases, zlevel and zstar, with respect to linfs and MLD differences between zlevel and zstar



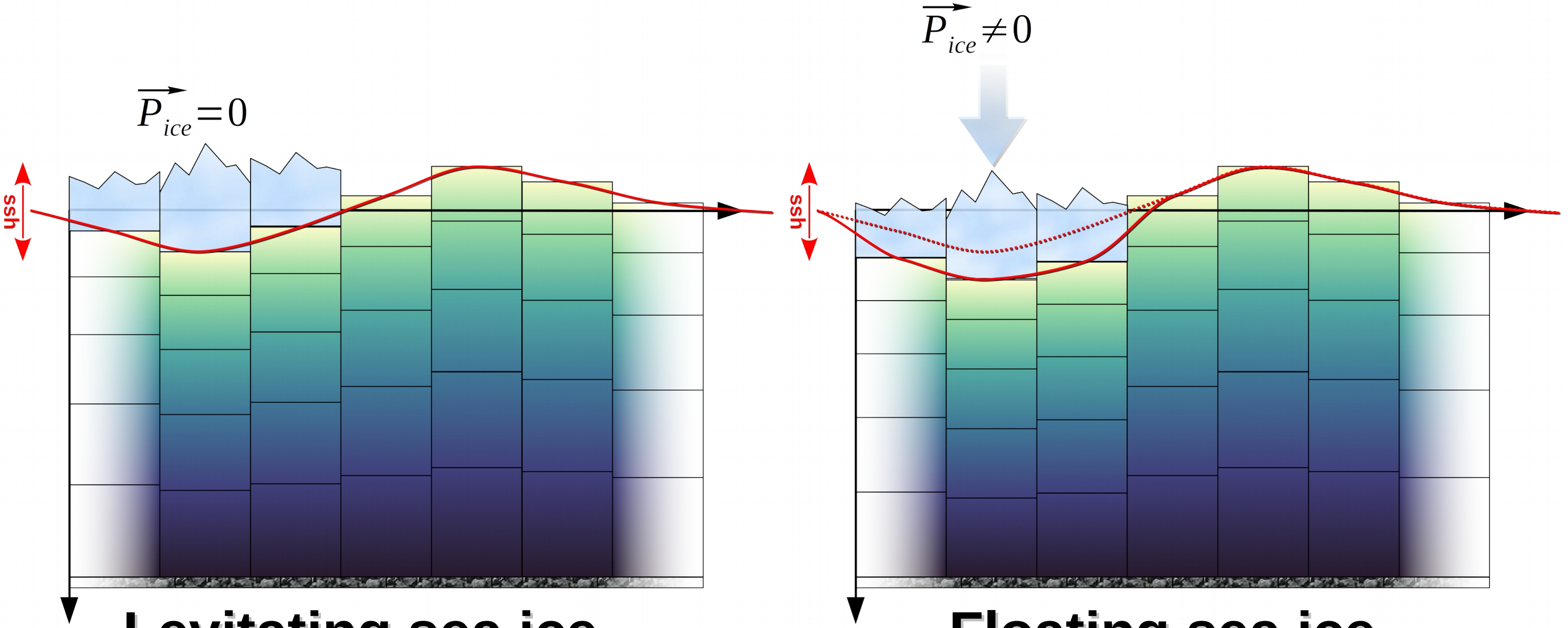
# ALE vertical coordinates

- Global (1st row ), Atlantic (2nd row) and Pacific (3rd row) Meridional Overturning Circulation (MOC) for linfs, zlevel and zstar



# ALE vertical coordinates

## Other features: Floating Sea Ice

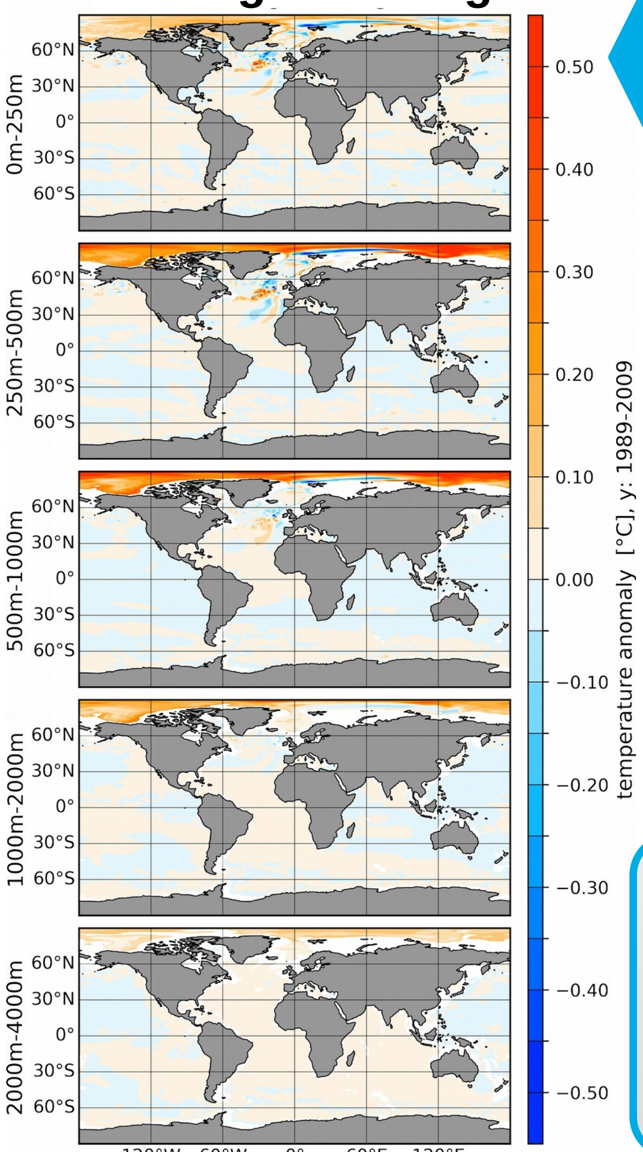



**Levitating sea ice** **Floating sea ice**

# ALE vertical coordinates

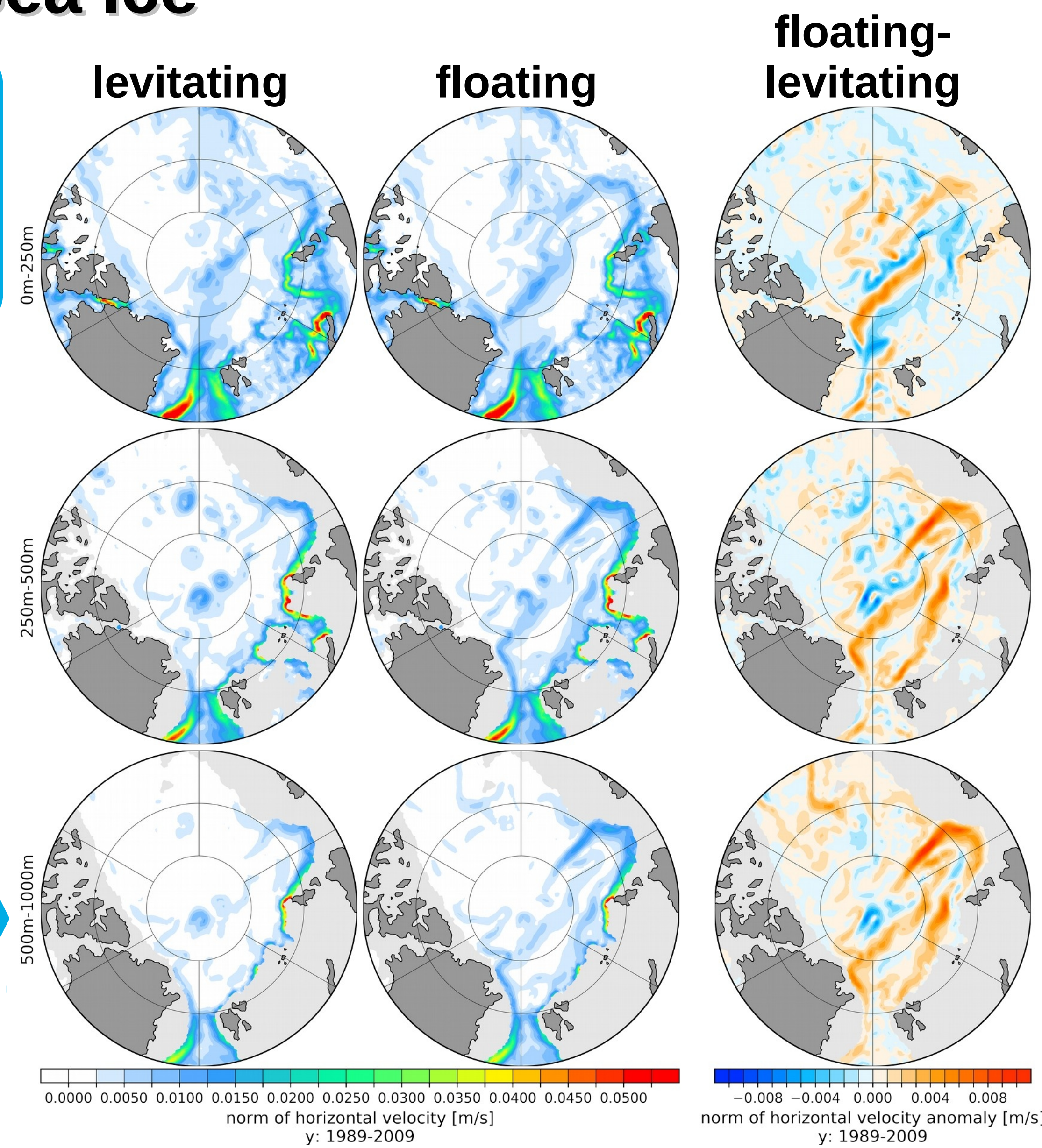
## Other features: Floating Sea Ice

floating-levitating



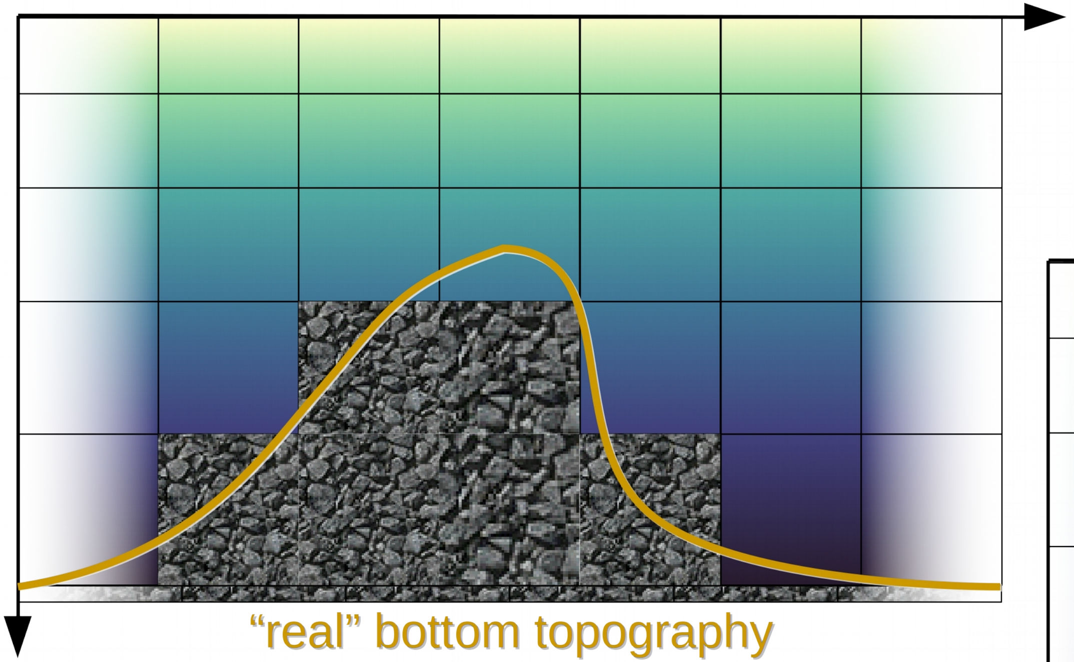

- Mean temp. difference between floating and levitating sea ice

- Norm of horiz. ocean velocity for levitating and floating sea ice

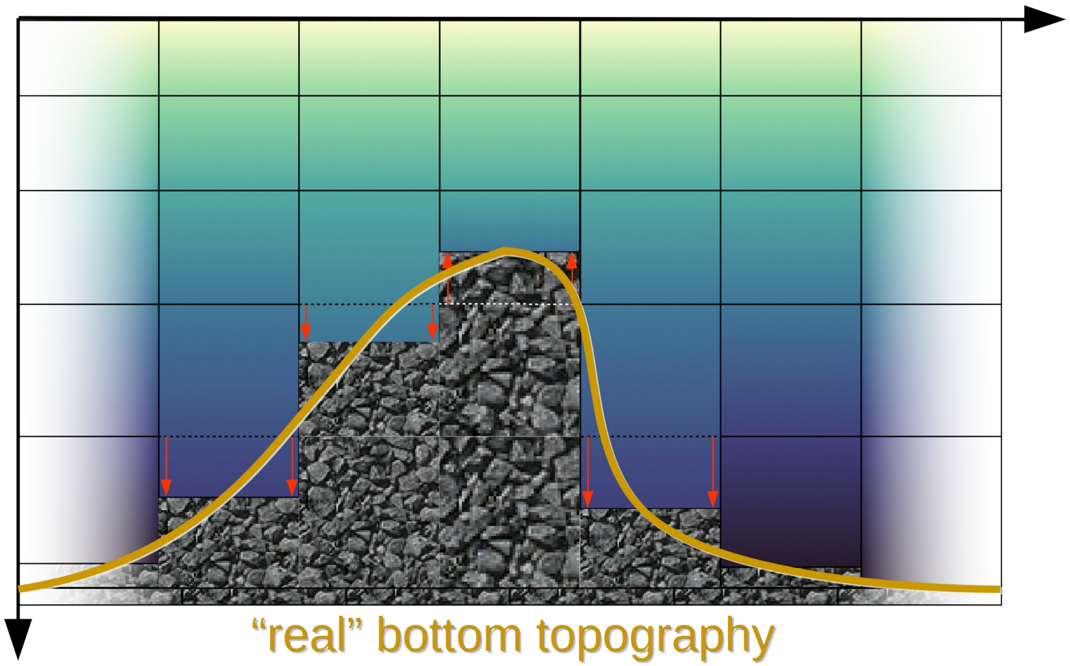


# ALE vertical coordinates

## ■ Other features: Partial Cells



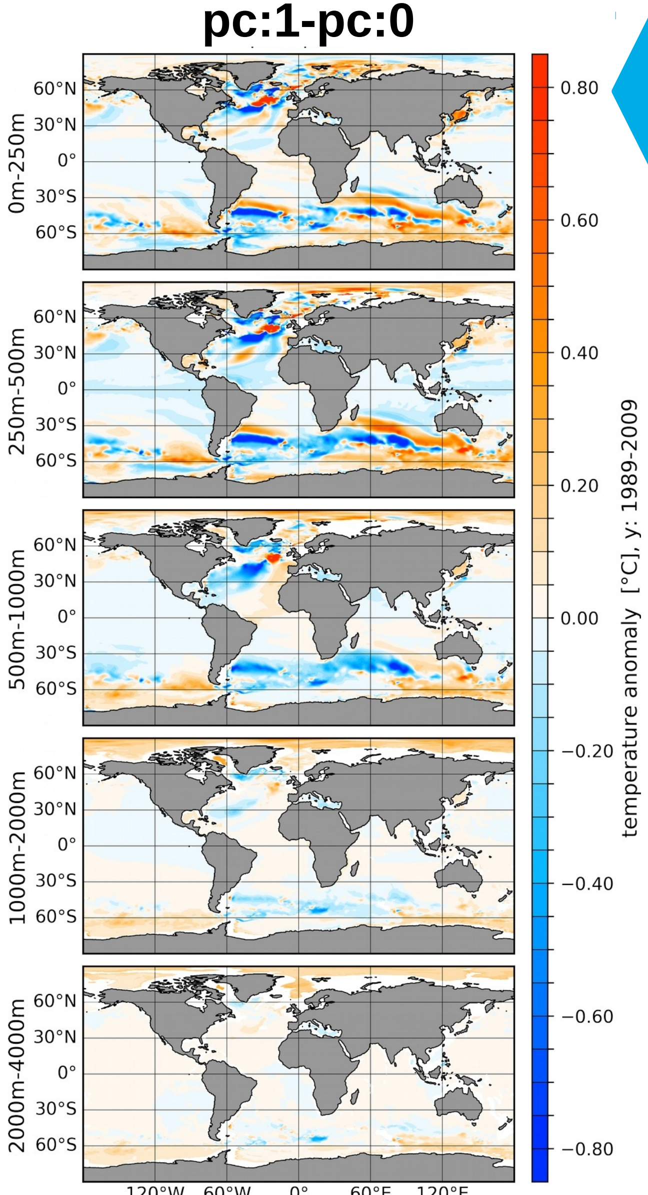

**Full bottom cell**




**Partial bottom cell**

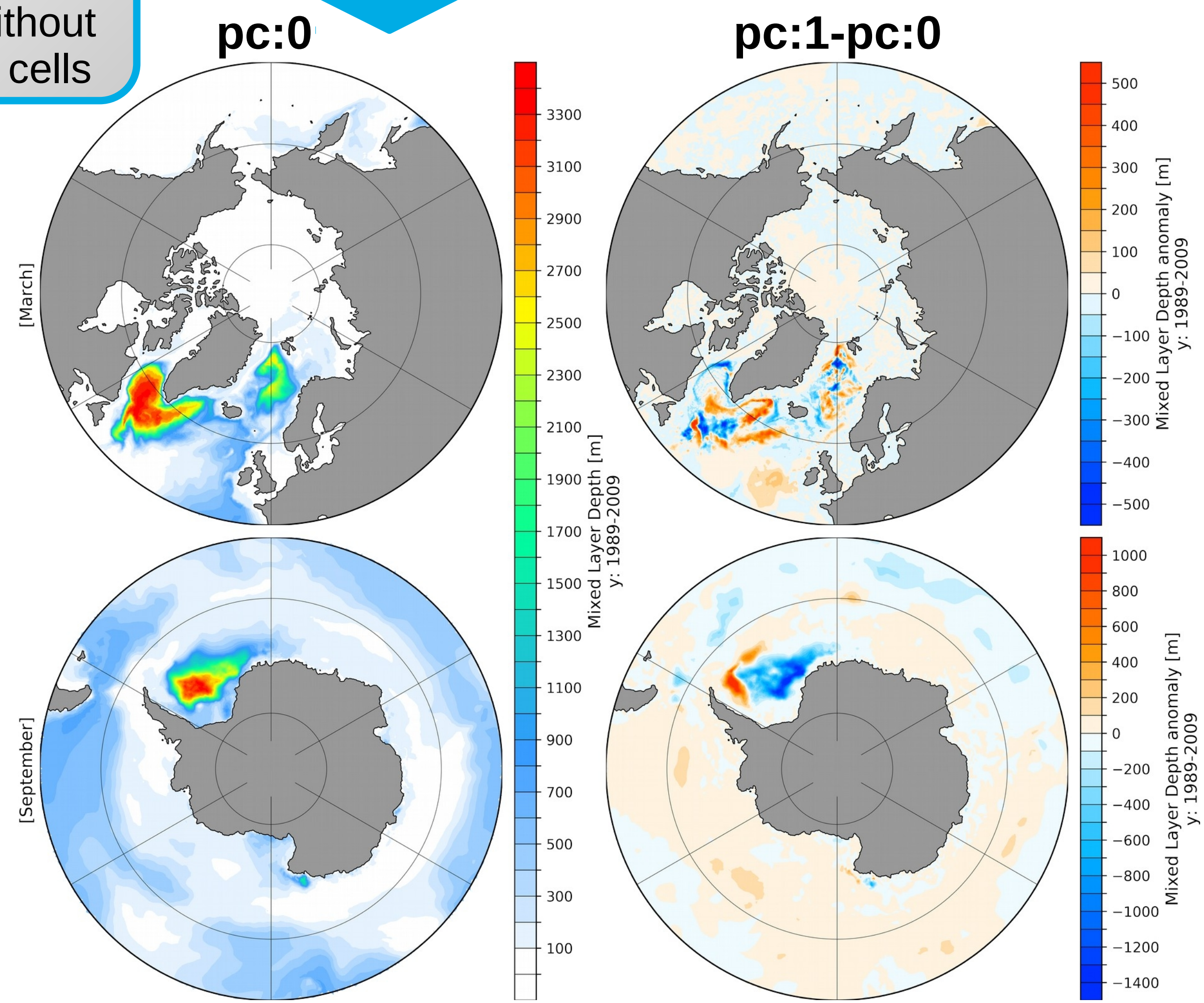
# ALE vertical coordinates

## Other features: Partial Cells




- Mean temp. difference between with and without partial cells

- Absolute mixed layer depth (MLD) without partial cells and MLD difference between with and without partial cells



# Implementation of CVMIX vertical mixing library

## Why we use CVMIX ?

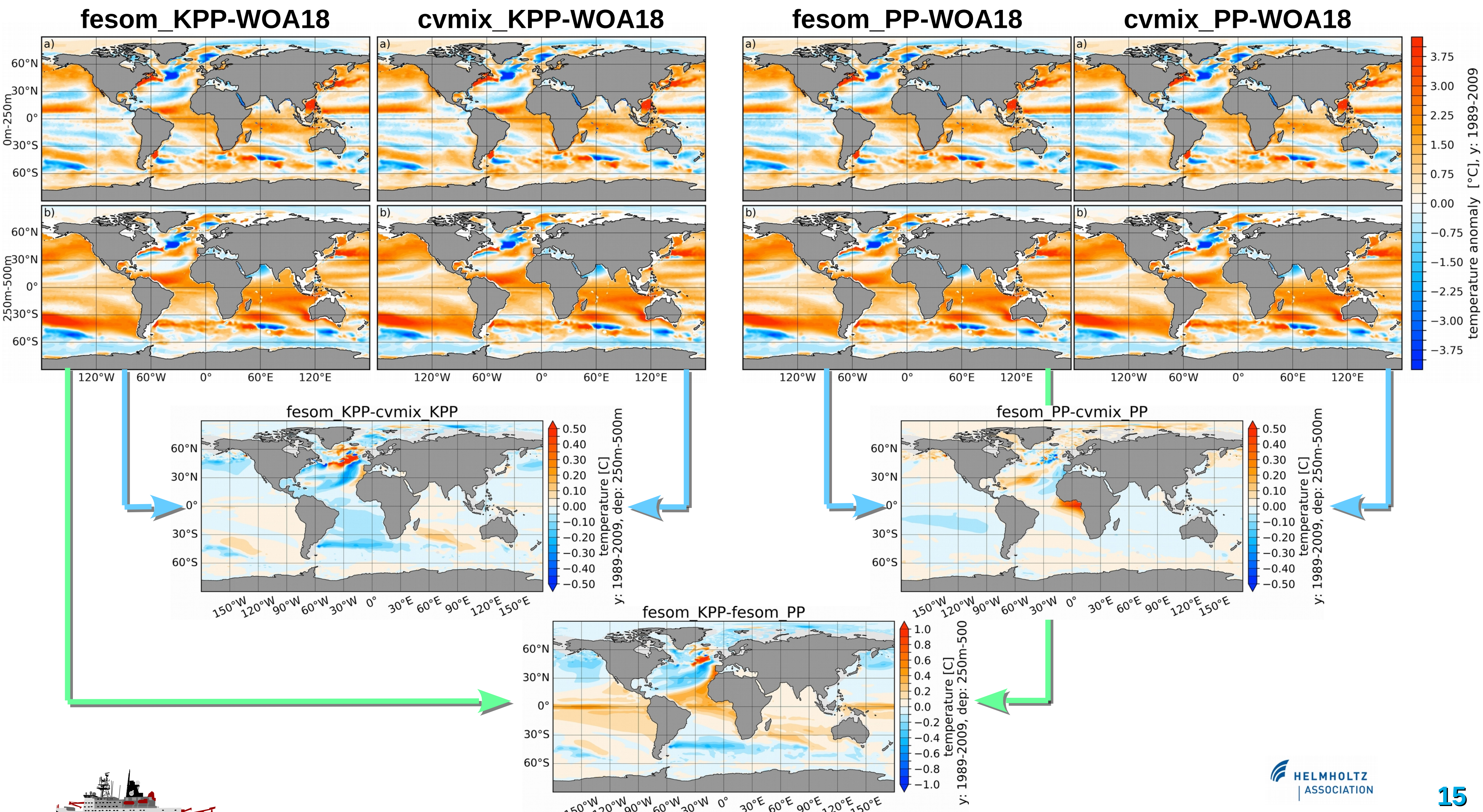
- Community Ocean Vertical Mixing Project (CVMIX) software package (https://github.com/CVMix)
- Provides transparent, robust, flexible, well documented Fortran source code for parameterizing vertical mixing in various ocean models (e.g. MPAS, MOM6, POP, MPIOM ...).

## What has been implemented from CVMIX ?

- Shear induces mixing of Pacanowski and Philander (1981) (**cvmix_PP**)
- K-profile parameterization (**cvmix_KPP**) of Large et al. (1994) (MOM6 style)
- tidally (**cvmix_TIDAL**) induced mixing of Simmons et. al. (2004)

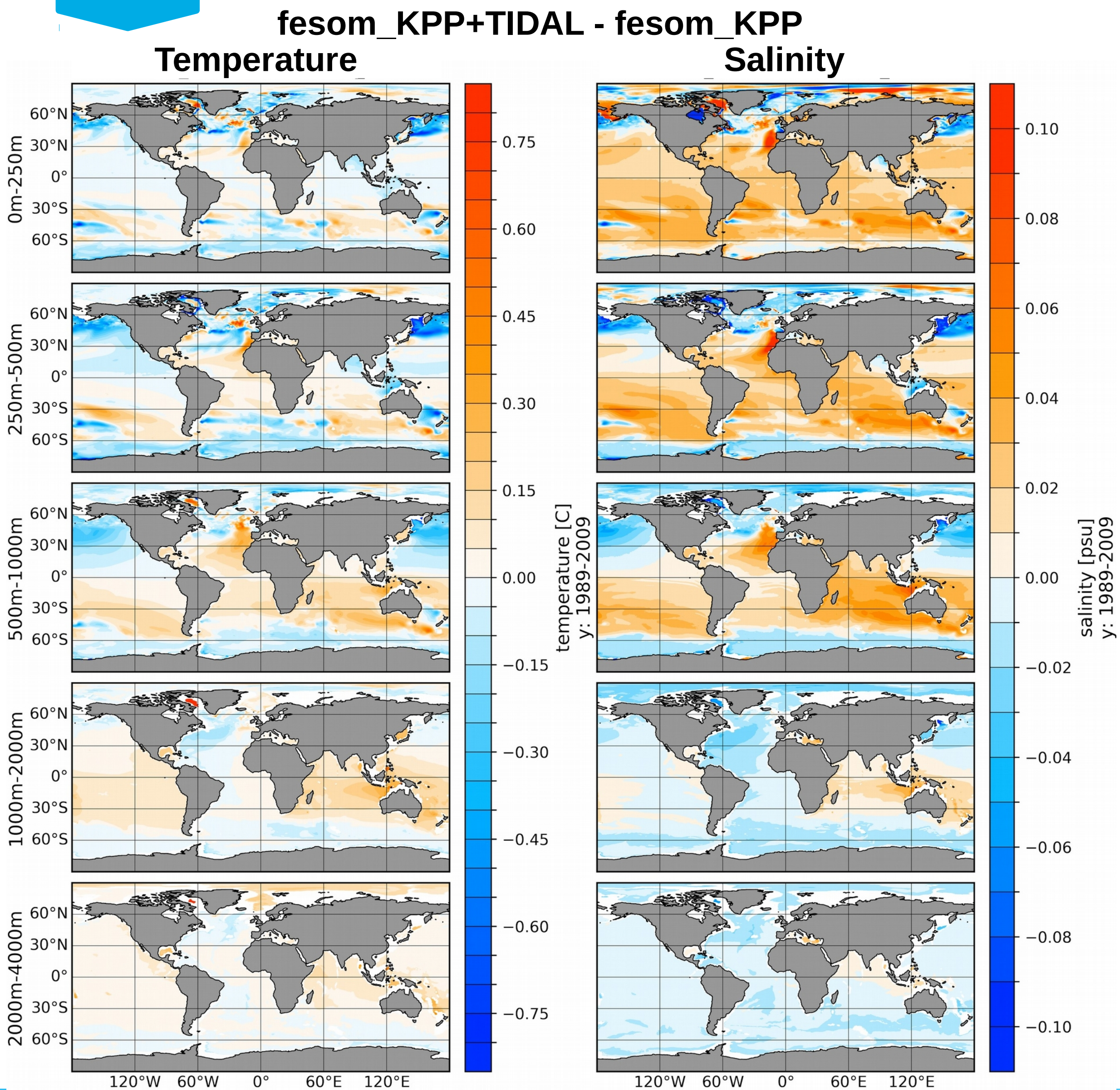
# Implementation of CVMIX vertical mixing library

- Temp. biases between fesom_KPP, cvmix_KPP, fesom_PP and cvmix_PP and WOA18

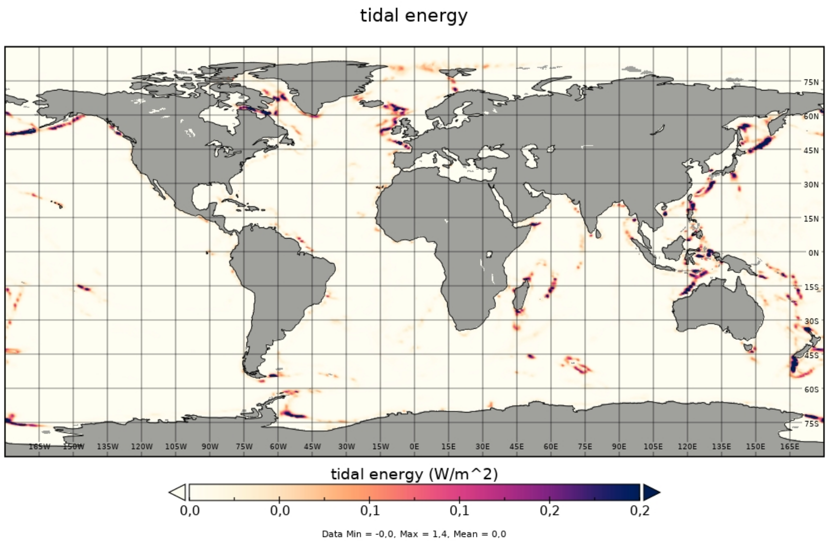


# Implementation of CVMIX vertical mixing library

## ■ Effect of cvmix_TIDAL mixing parameterisation




- cvmix_TIDAL computes tidal induces vertical mixing after Simmons et al. 2004
- reads near bottom tidal forcing climatological field for tidal induced wave dissipation

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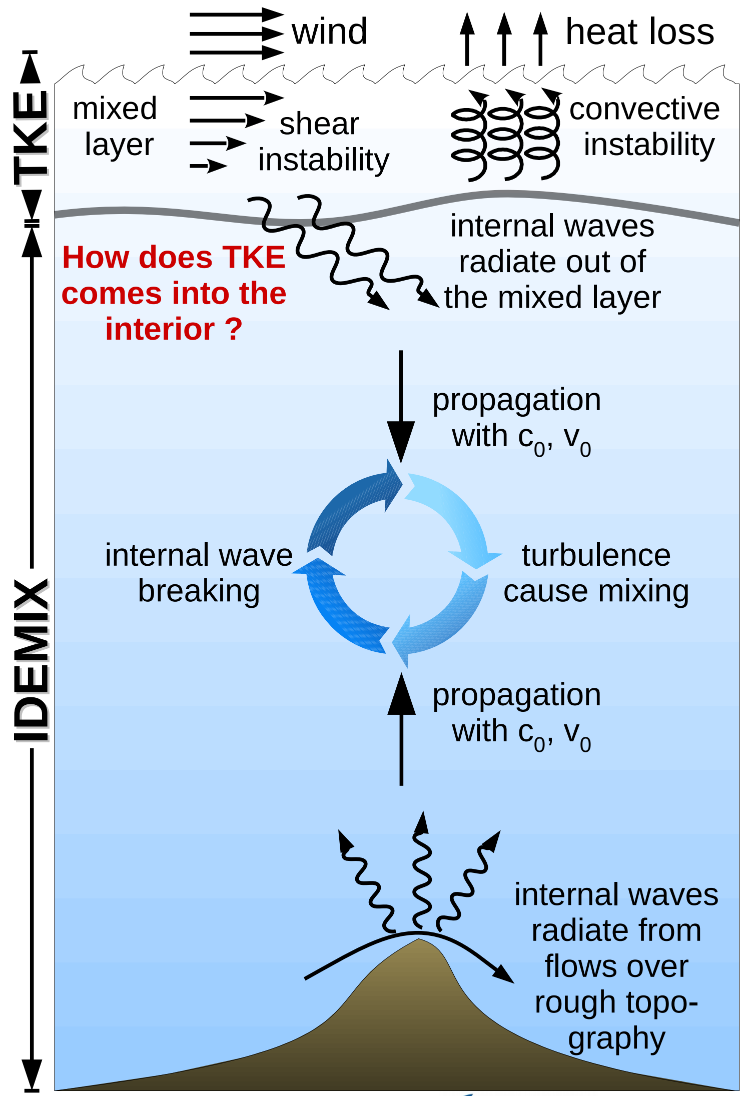
# Implementation of CVMIX vertical mixing library

TRR181

## Other via CVMIX implemented mixing schemes

- **Turbulent-Kinetic-Energy (TKE)** closure vertical mixing of Gaspar et al. (1990) + **closure of internal wave energy (IDEMIX)** of Olbers and Eden (2013) and Eden et al. (2014)
- TKE+IDEMIX is devolped by Eden and Olbers as part of the TRR181 Project - “Energy Transfer in Atmosphere and Ocean“
- Idea of TKE+IDEMIX: is to provide an energy consistent way to link diapycnal mixing with the internal wave field
- TKE+IDEMIX is yet not part of the CVMIX library but uses its infrastrucutre




→ from Nils Brüggeman

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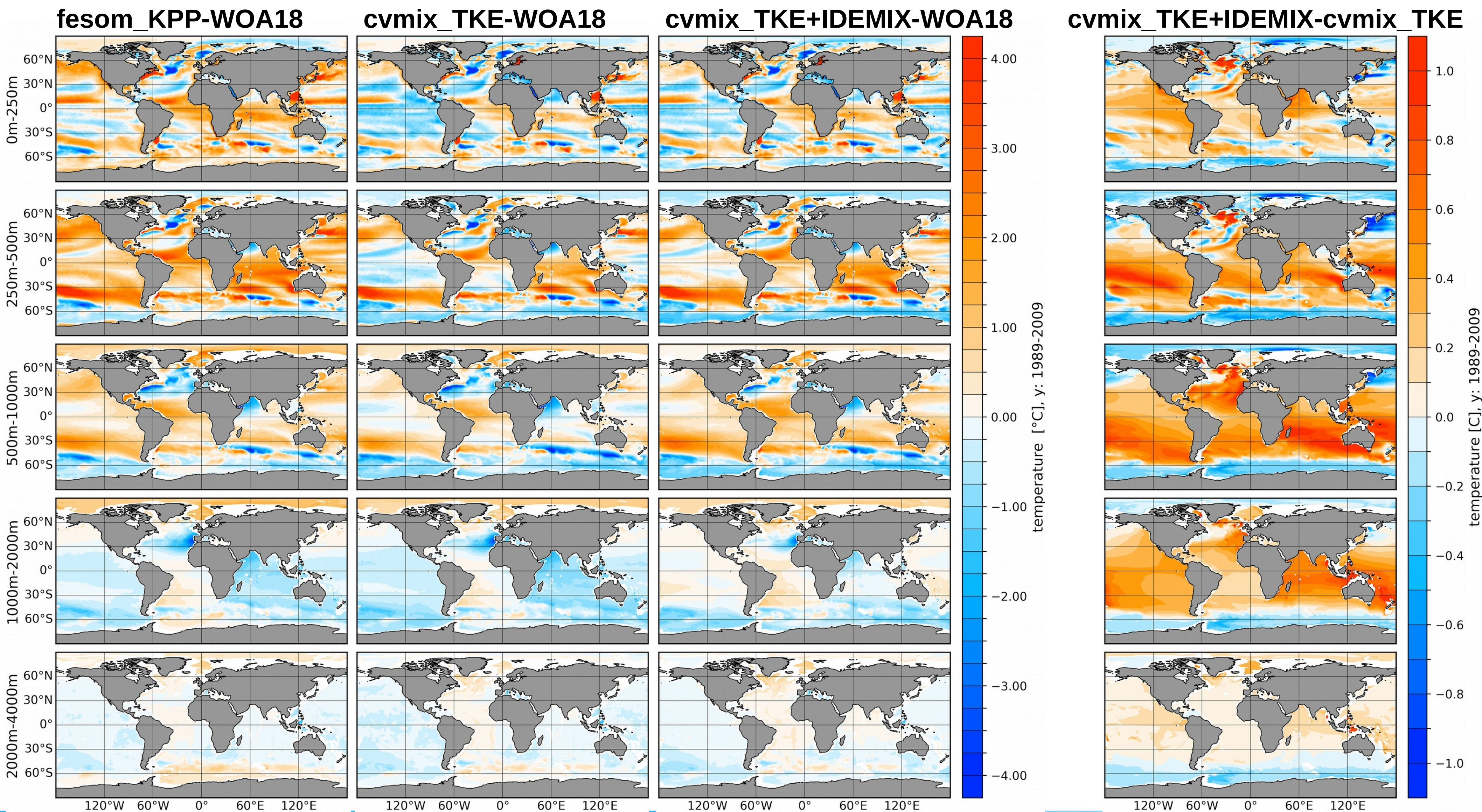
# Implementation of CVMIX vertical mixing library

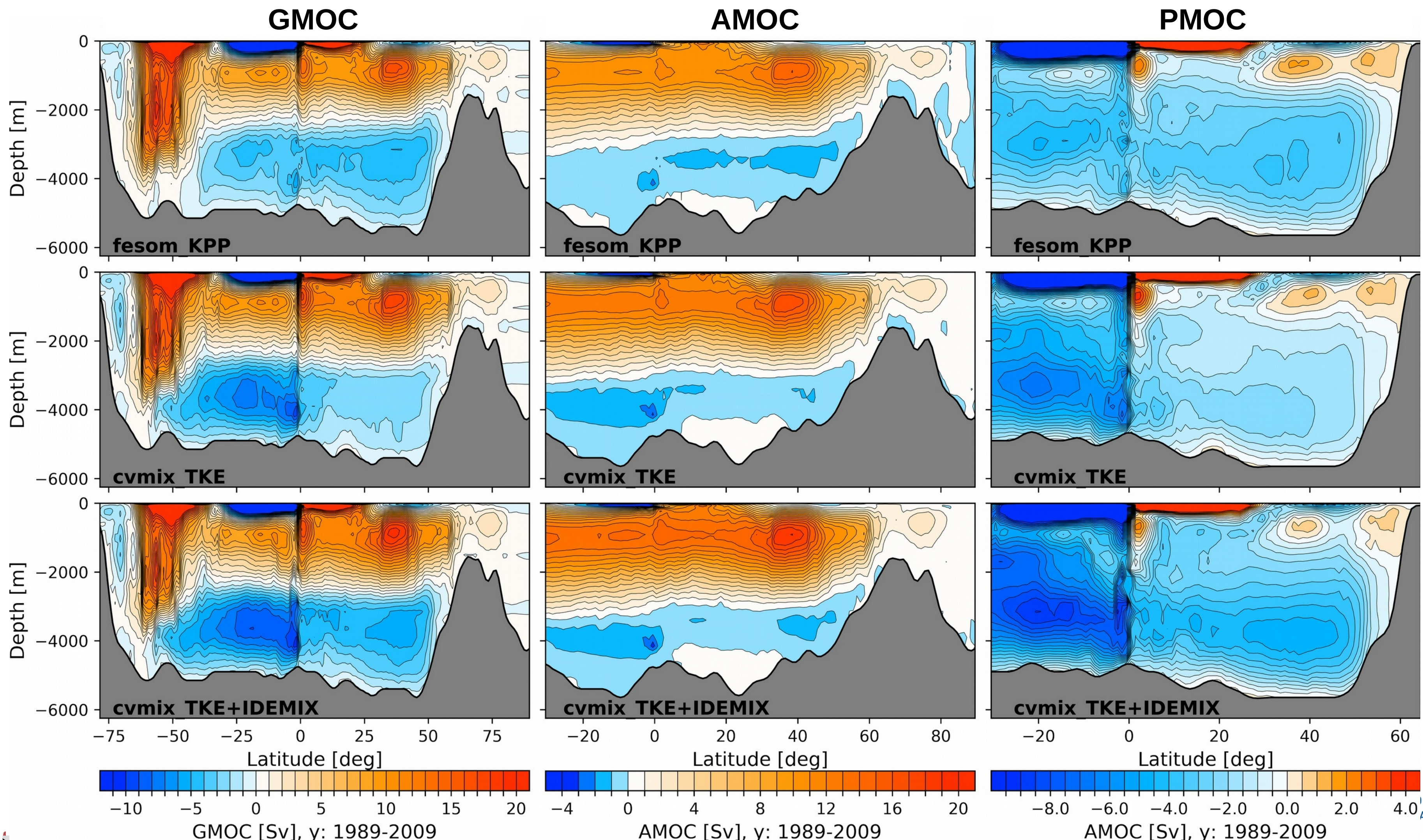
## TKE and IDEMIX



# Implementation of CVMIX vertical mixing library

## TKE and IDEMIX

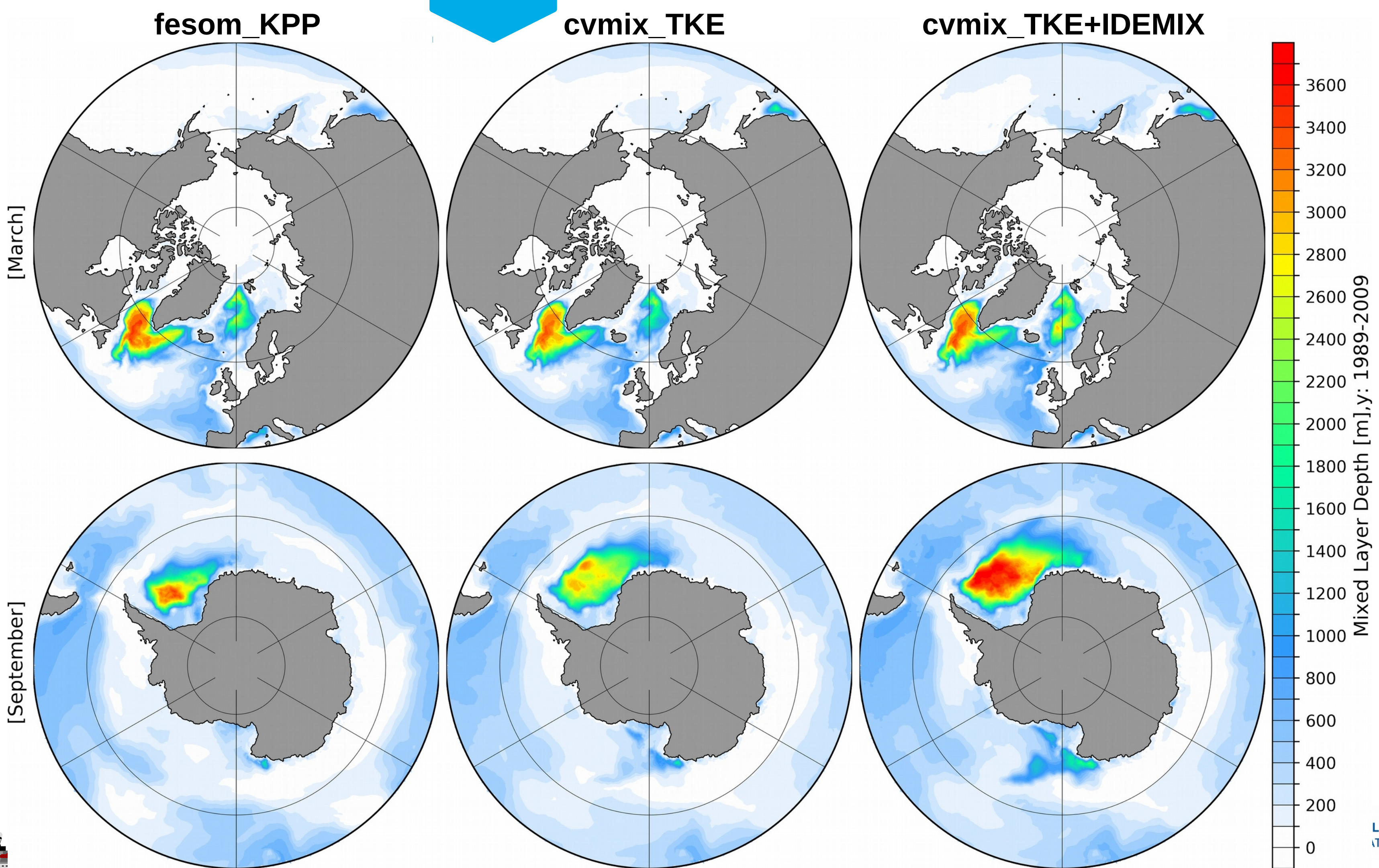
- Global, Atlantic and Pacific MOC for fesom_KPP, cvmix_TKE and cvmix_TKE+IDEMIX



# Implementation of CVMIX vertical mixing library

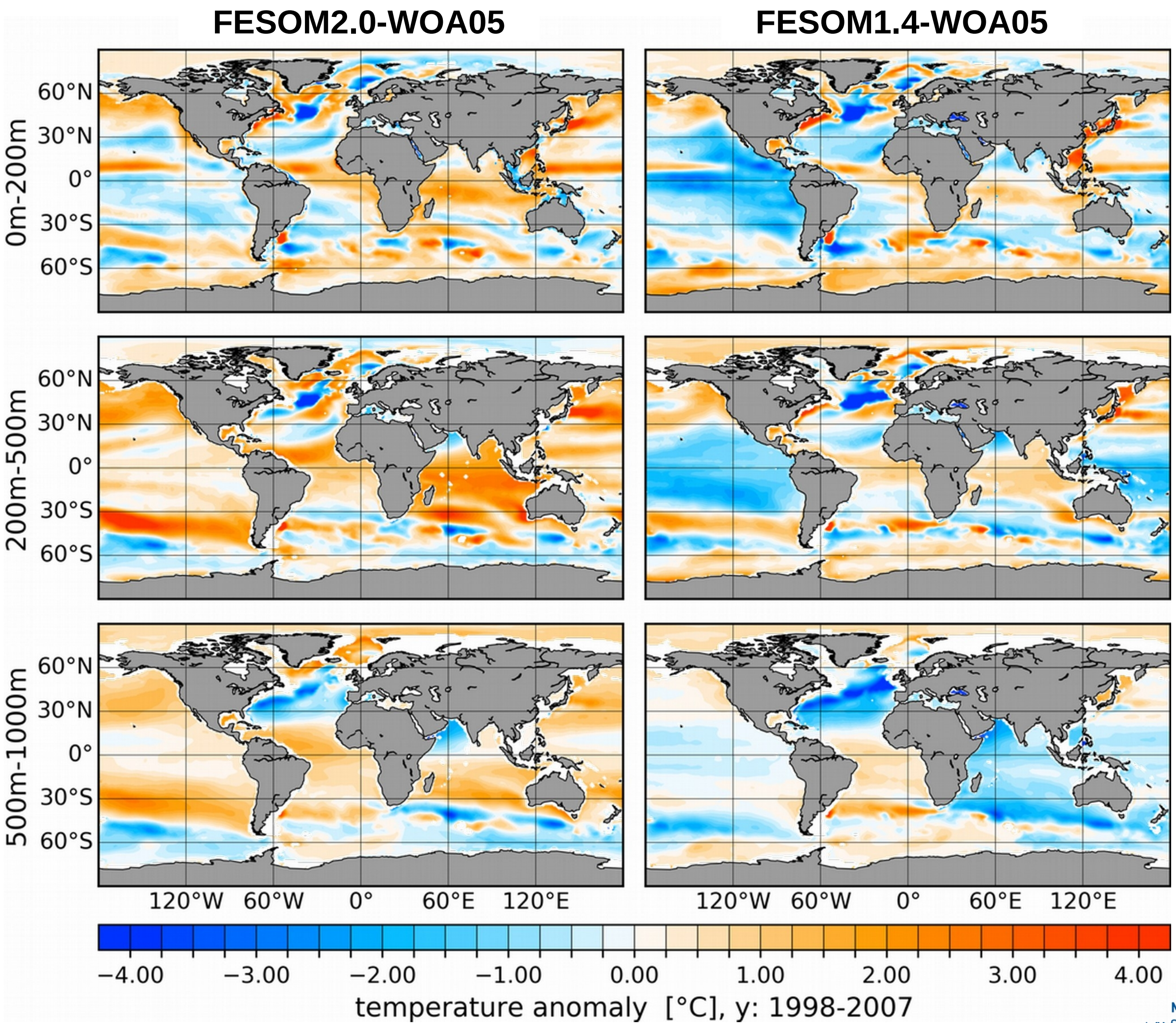
## TKE and IDEMIX

- Maximum March/September mixed layer depth (MLD) for fesom_KPP, cvmix_TKE and cvmix_TKE+IDEMIX



# Comparison between FESOM2.0 and FESOM1.4

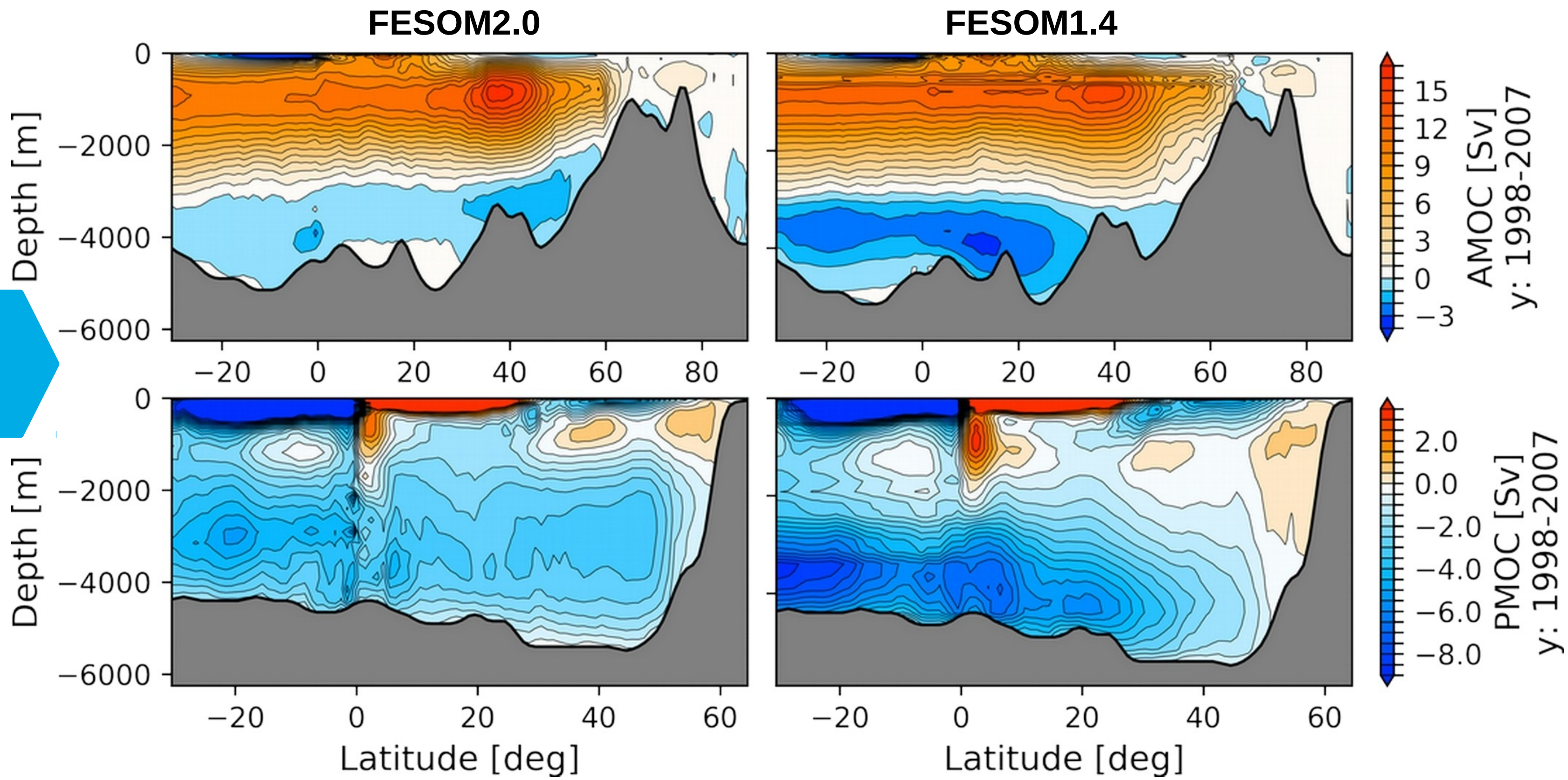
## Hydrographic Biases




- Temp. biases bet- ween FESOM 2.0 and 1.4 with respect to WOA05

# Comparison between FESOM2.0 and FESOM1.4

## Meridional Overturning Circulation




- Atlantic and Pacific MOC for FESOM 2.0 and 1.4

# Comparison between FESOM2.0 and FESOM1.4

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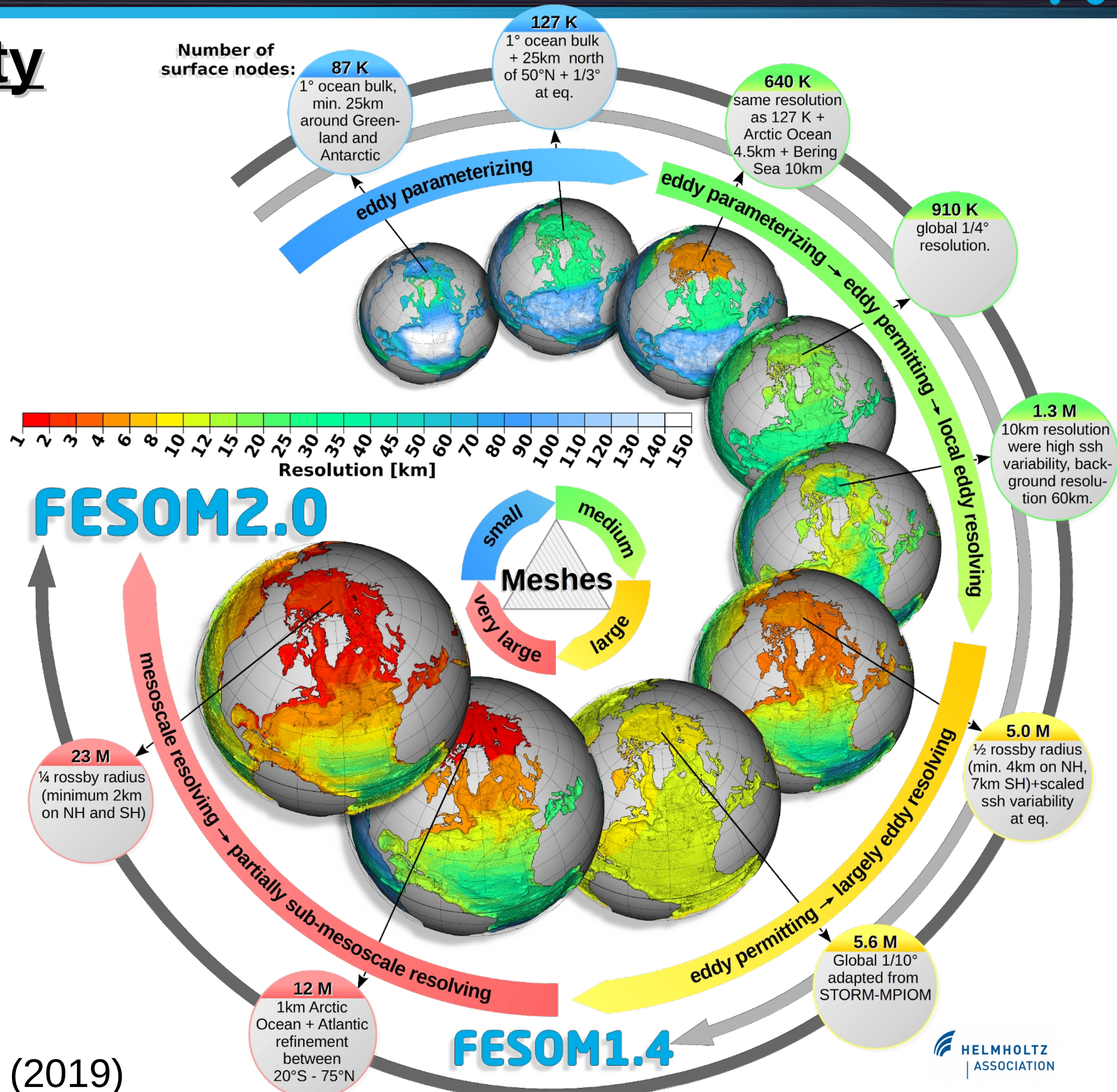
## Mesh applicability




Scholz et al. (2019)

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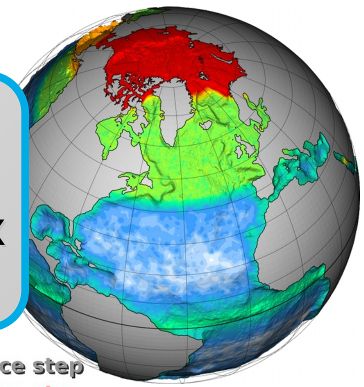
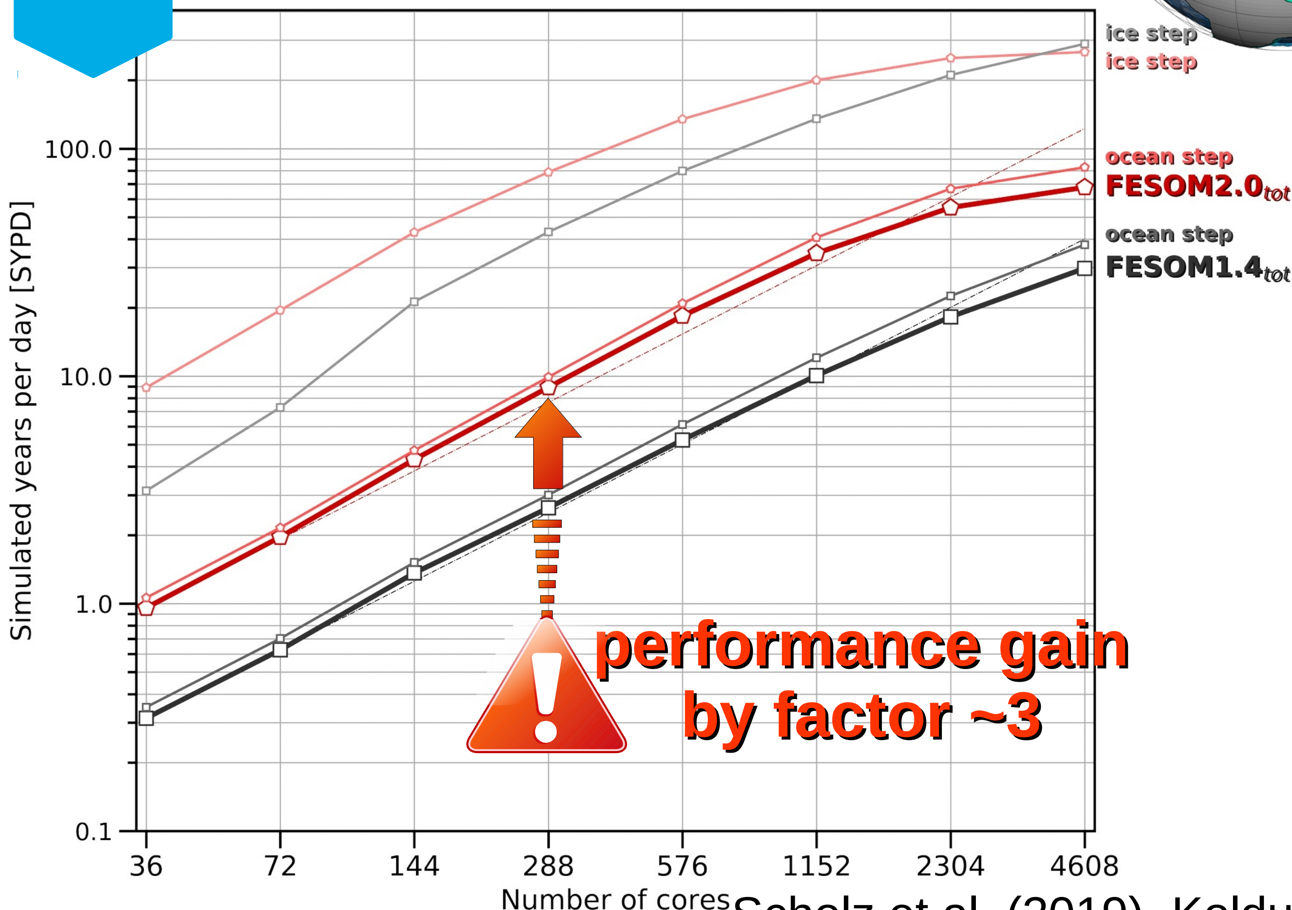
# Comparison between FESOM2.0 and FESOM1.4

## Performance and Scalabilty

- Mesh minimum resolution 4.5 km in the Arctics (#surface vertices: ~640 000, #layers: 48)
- 432 CPUs, Cray CS400, 308 compute nodes, 2x Intel Xeon Broadwell 18-Core CPUs, 64GB RAM





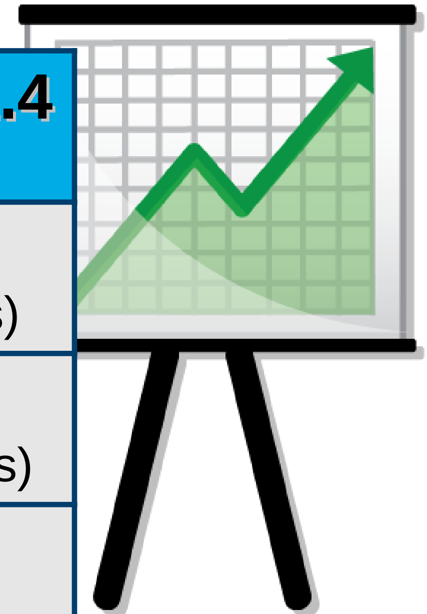

Scholz et al. (2019), Koldunov et al. (2019)

# Comparison between FESOM2.0 and FESOM1.4

TRR181

## Throughput in simulated years per day (SYPD)

| Mesh | FESOM2.0 | FESOM1.4 |
|---|---|---|
| CORE2 ~1° resolution (~127K) | **191** (432 CPUs) | **62** (432 CPUs) |
| Arctic 4.5km (~640K) | **59** (2304 CPUs) | **20** (2304 CPUs) |
| ¼ Rossby Radius with 2km cutoff (~22M) | **1** (14K CPUs) | |



| Mesh | FESOM2.0 | NEMO Prims et al. (2018) |
|---|---|---|
| Global ¼° resolution (~910K) | **~5** (512 CPUs) | **~3** (512CPUs) |

**FESOM2.0 is able to compete with state of the art regular grided models!**

Scholz et al. (2019), Koldunov et al. (2019)

# Outlook

## Things to come

- Terrain following coordinates, vanishing quasi sigma (VQS) hybrid coordinates
- Higher order advection schemes for tracer
- Ocean kinetic energy backscatter parametrization
- Relaxation of layer thicknesses towards isopycnal layers
- Compute parts in single precission

## Summary

- ✔ ALE components in FESOM2.0 are fully usable
- ✔ CVMIX is implemented into FESOM2.0
- ✔ FESOM2.0 and FESOM1.4 shows a comparable magnitude in biases
- ✔ FESOM2.0 is around 3 times faster than its predecessor and we are able to compete with state of the art regular gridded models

# Finish !