The numerical grid construction problem in topographically constrained flows: The Denmark Strait Overflow case

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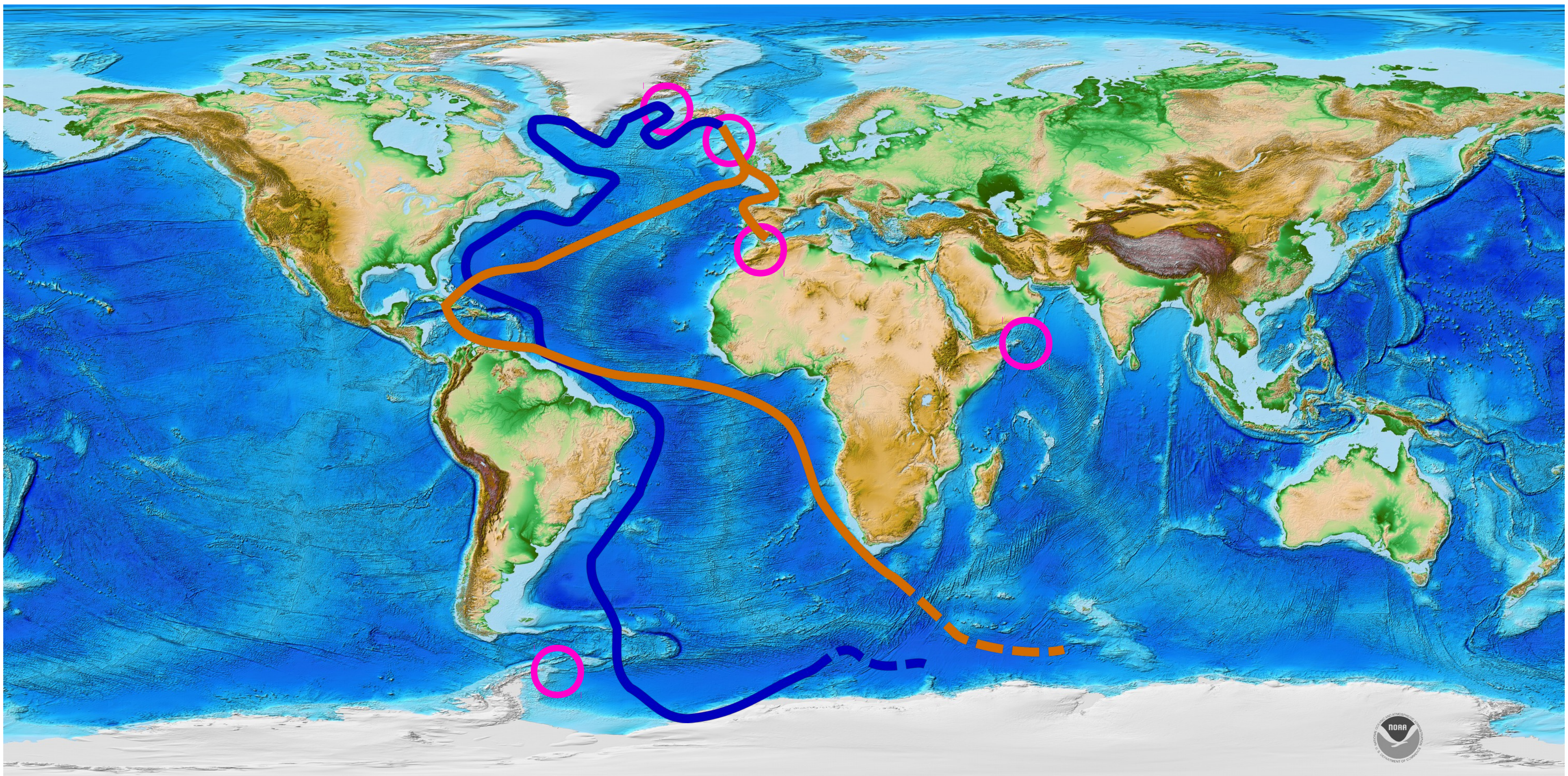
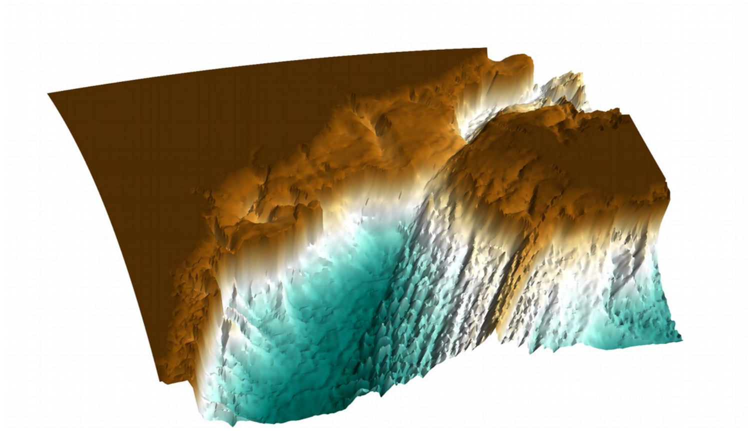
Context

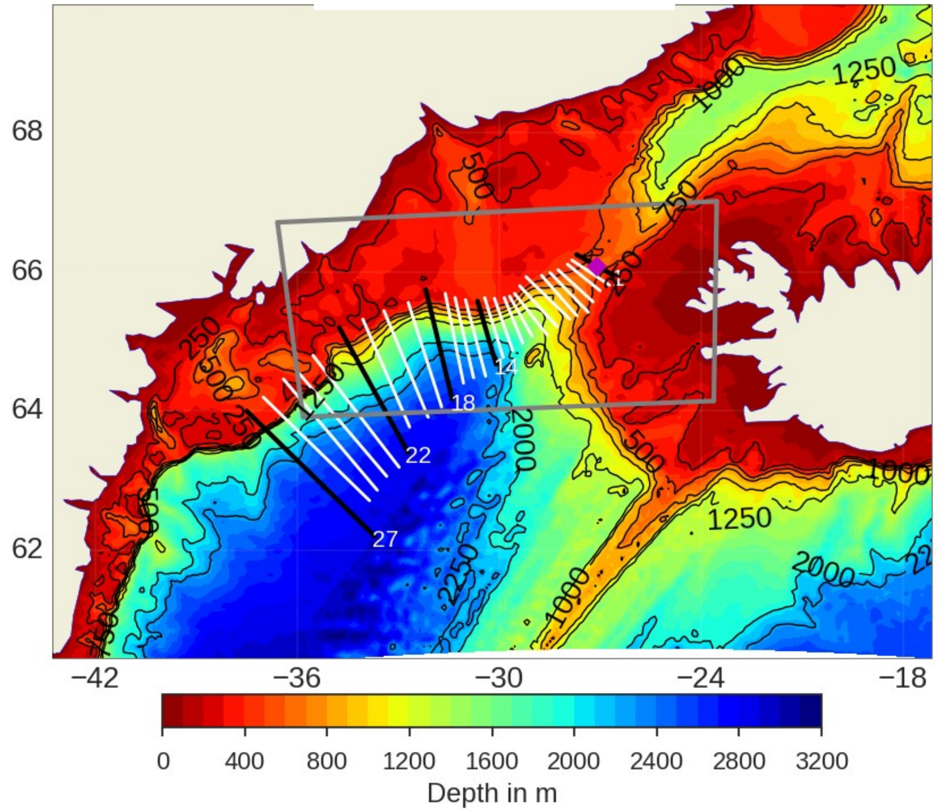
- **Drakkar consortium objective**: Realistic representation of Global ocean eddying circulation study with a numerical modelling approach (mainly with NEMO)
- **Thermohaline circulation** is an important component of the global circulation, forced in part by overflows
- **Overflows** are dense waters formed in marginal seas or continental shelves, flowing over topographic barriers (local phenomena) to join the open ocean



Model configuration



Model domain



- NEMO v3.6: **hydrostatic** OGCM used in z-coordinates at **1/12°**

- Partial Step

- Momentum: EEN advection scheme, bilaplacian isolevel diffusion

- Tracers: TVD advection scheme, laplacian **isoneutral diffusion**

- TKE vertical mixing scheme with Enhanced Vertical Diffusion (EVD)

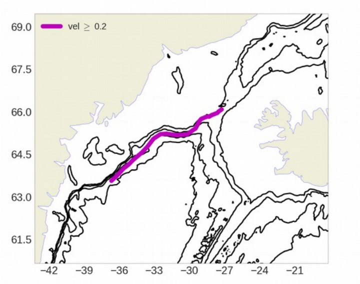
- Possibility of local refinement (AGRIF)

Initial and boundary conditions

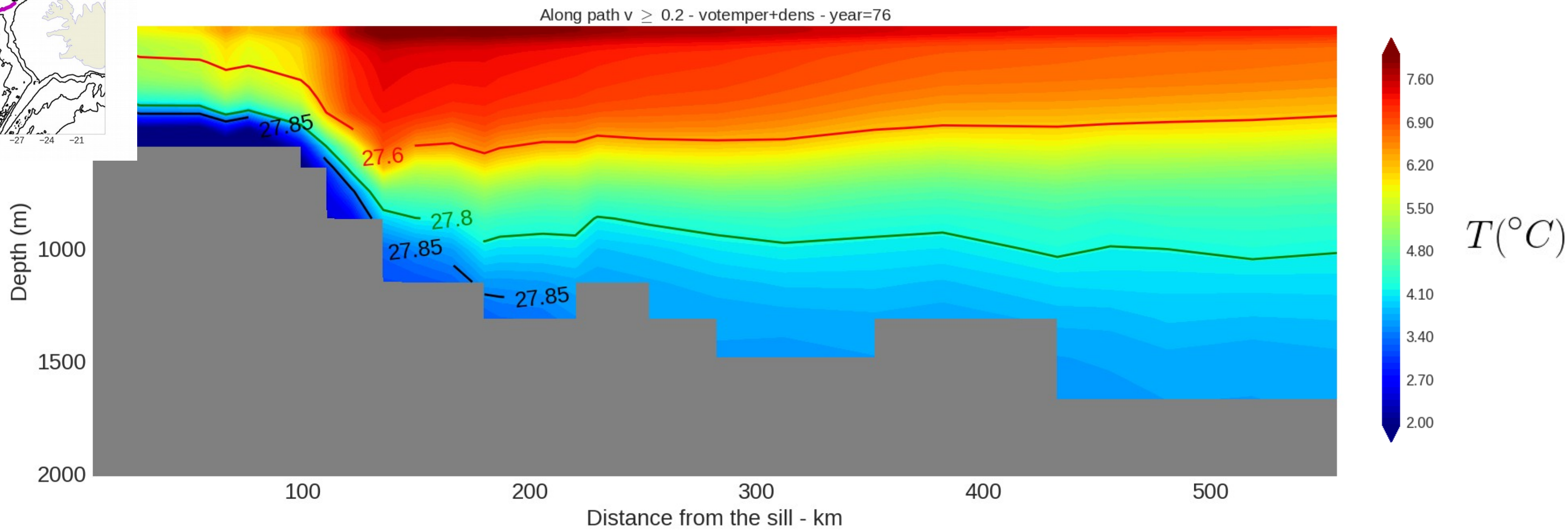
- ORCA12 46L z-partial step simulation (with a ~70 years spin-up)

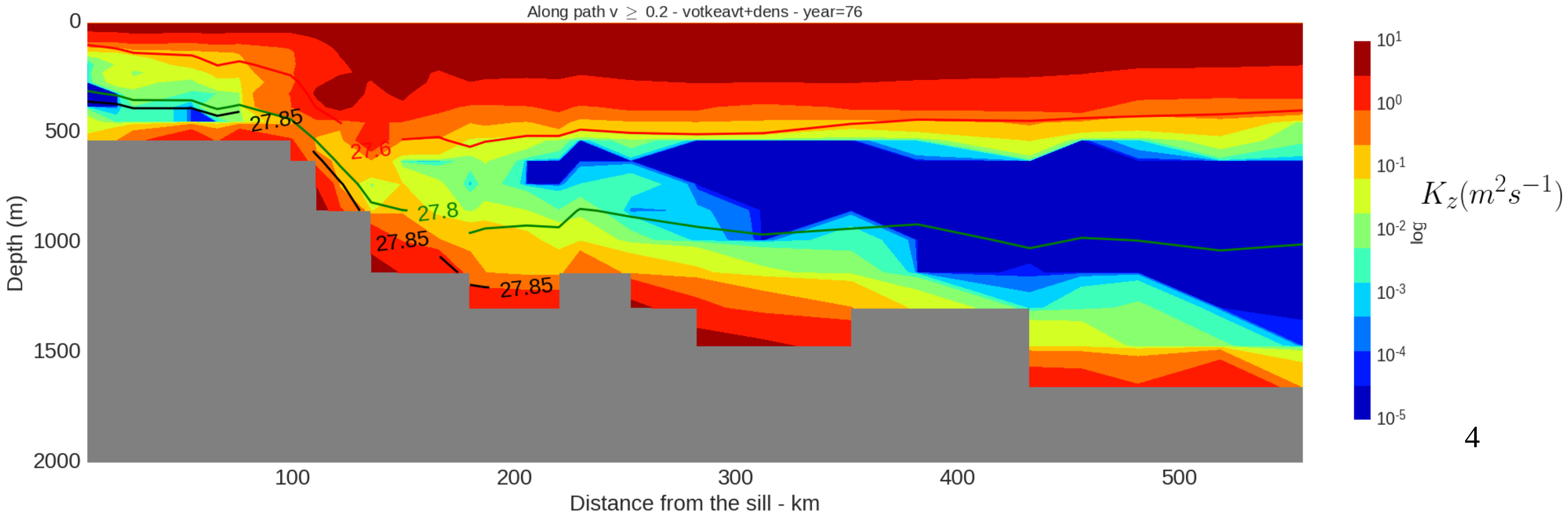
- DFS4 Seasonal climatological forcing

Motivation



Annual mean along path temperature and vertical diffusivity





Sensitivity tests

Sensitivity tests

DENST12 **realistic** configuration fed by global 1/12° 46L model solution

z-coordinate
partial-step

- **Horizontal resolution**

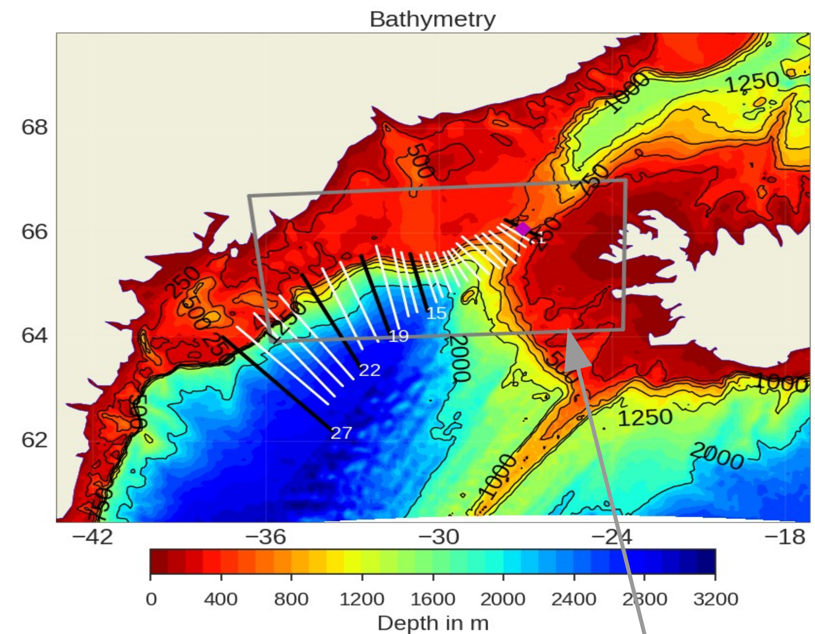
- **Vertical resolution**
- **Lateral boundary condition**

- **Time step**
- **Vertical mixing scheme**

- **EVD impact**

- **Momentum advection scheme**

- **BBL parametrization**



Local horizontal refinement AGRIF (Debreu 2005)

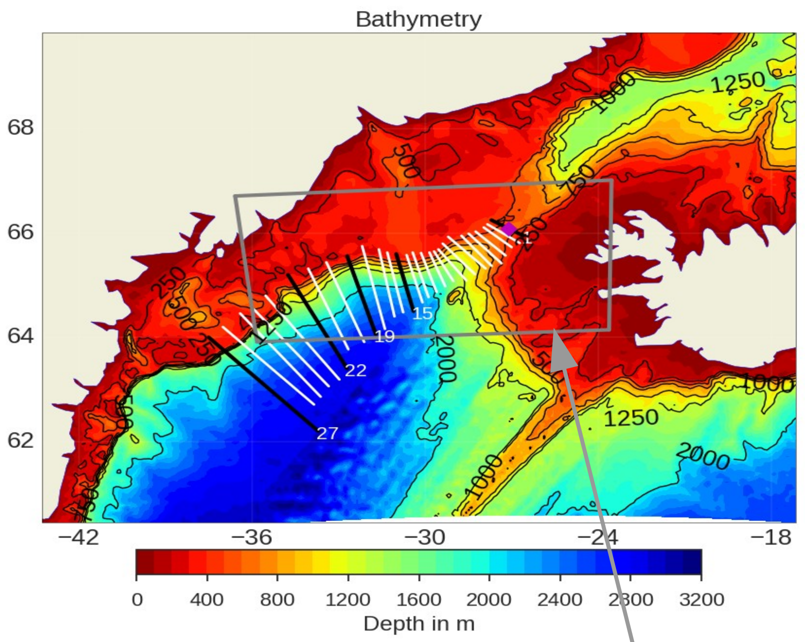
Sensitivity tests

Sensitivity tests

DENST12 **realistic** configuration fed by global 1/12° 46L model solution

Considerable impact

- **Horizontal resolution:** 1/12°, 1/36° and 1/60° (AGRIF)
- **Vertical resolution:** 46, 75, 150 and 300L
- **Lateral boundary condition:** free slip / no-slip
- **Time step:** dt / 5
- **Vertical mixing scheme impact:** constant Kz, TKE, GLS
- **EVD impact:** adaptable to the cell thickness, on tracers and tracers and momentum
- **Momentum advection scheme:** vector formulation / UBS
- **BBL parametrization impact**



Local horizontal refinement AGRIF (Debreu 2005)

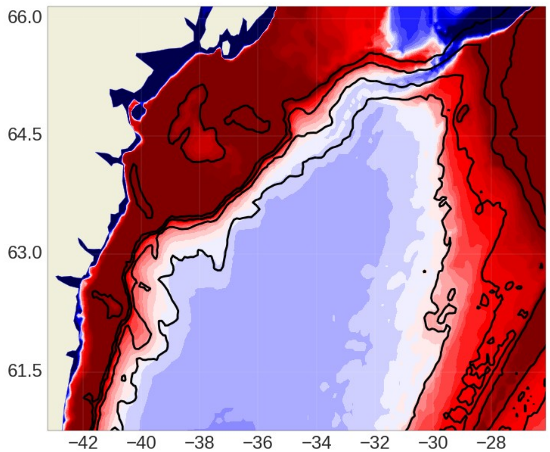
Marginal impact

Around **50 different simulations**

Vertical resolution at **1/12°**

Annual mean bottom temperature of the last year of a **5 years** simulation

46



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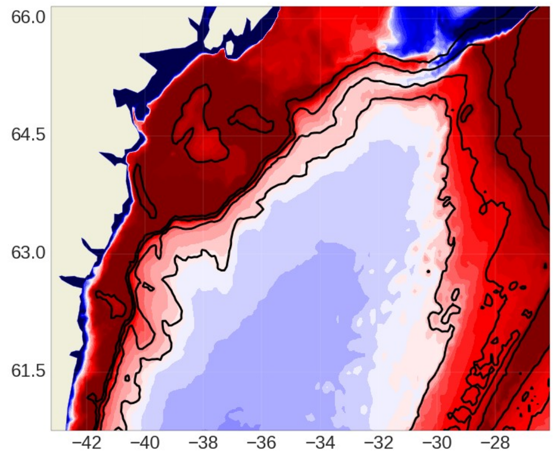
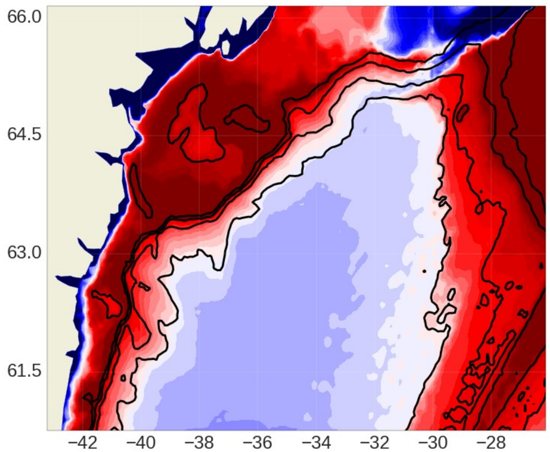
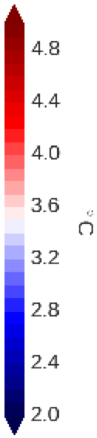
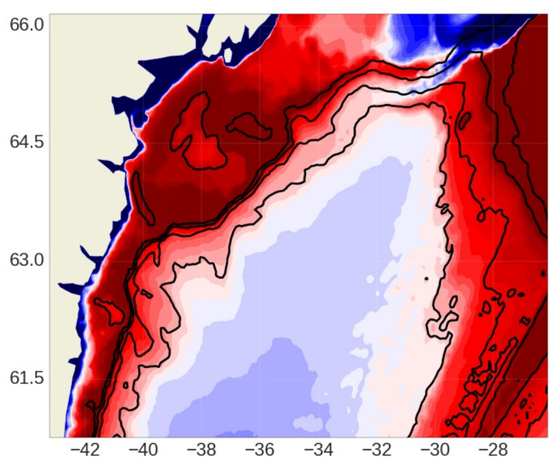


150





300



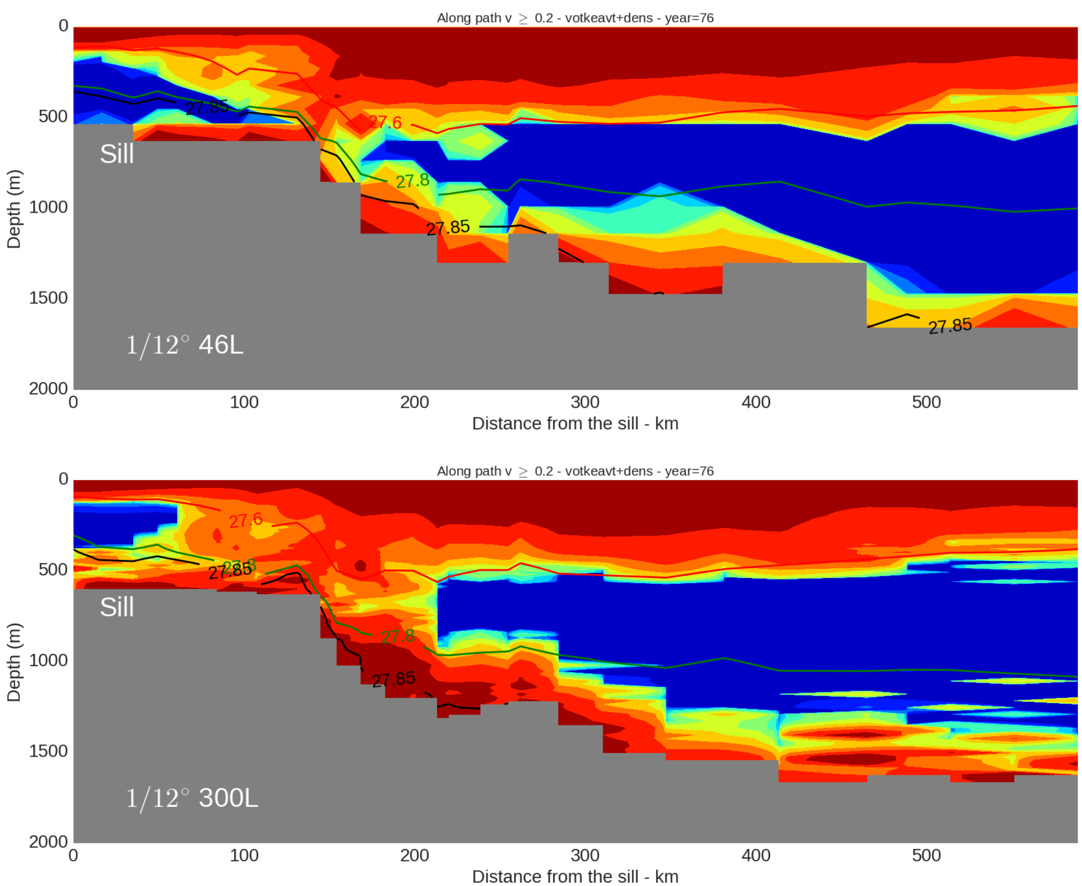
Why at 1/12° there is no improvement at 150 or 300 levels although the **Ekman Boundary Layer is resolved**?

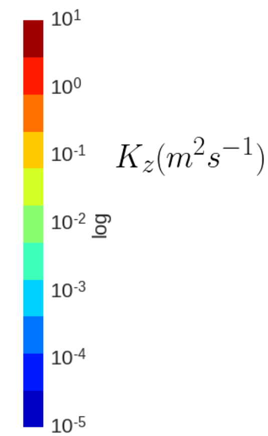
Understanding

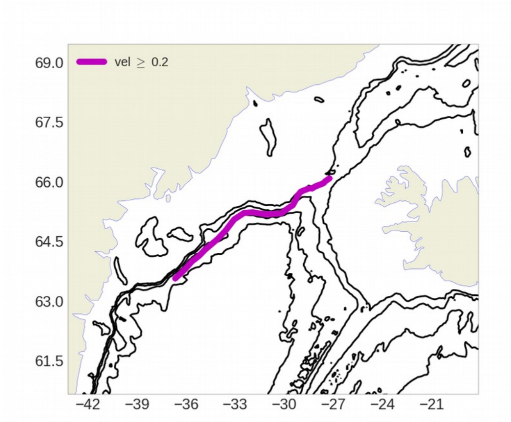
Hydrostatic model: vertical acceleration not present, therefore parametrized using enhanced vertical diffusivity (EVD)

1/12°
46L

1/12°
300L



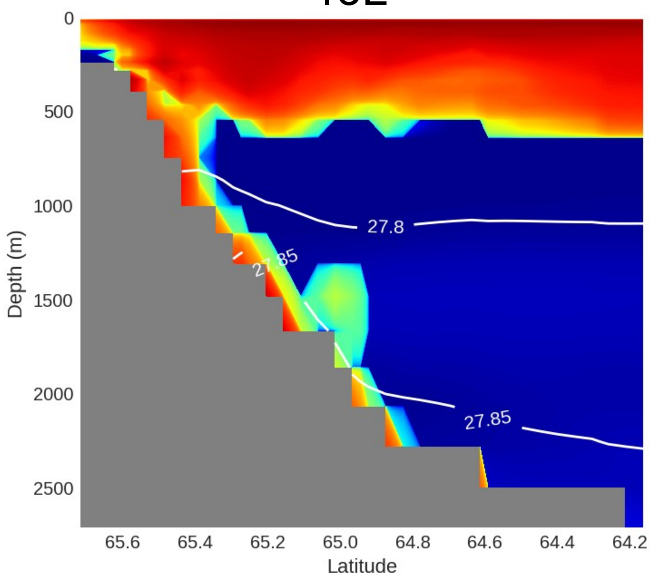




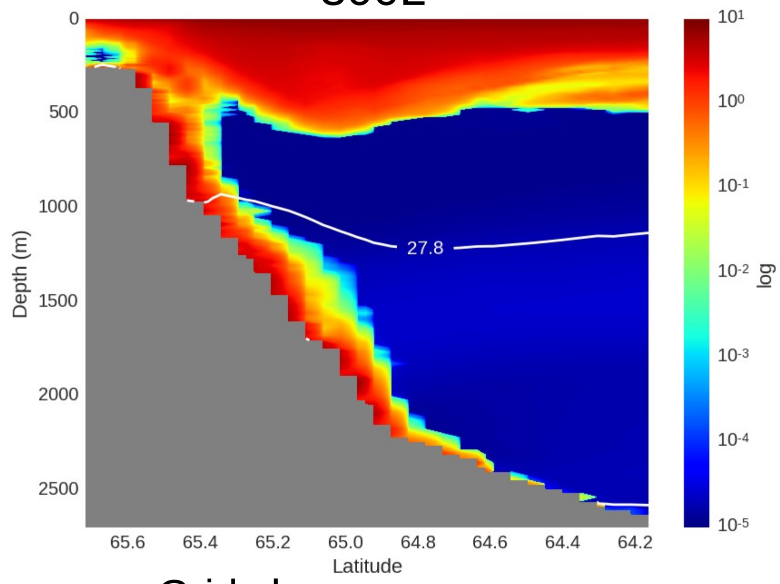
Understanding

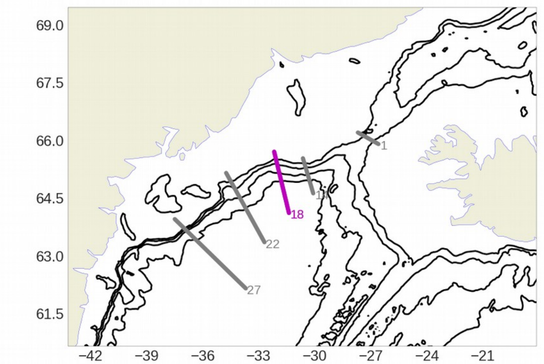
Hydrostatic model: vertical acceleration not present, therefore parametrized

1/12°
46L

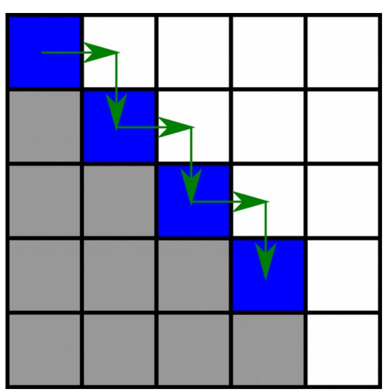


1/12°
300L

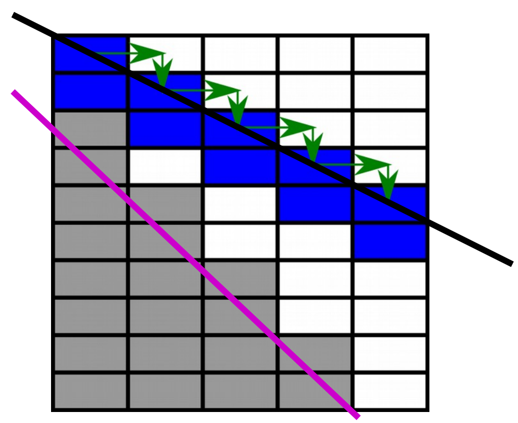




Grid slope



Topographic slope



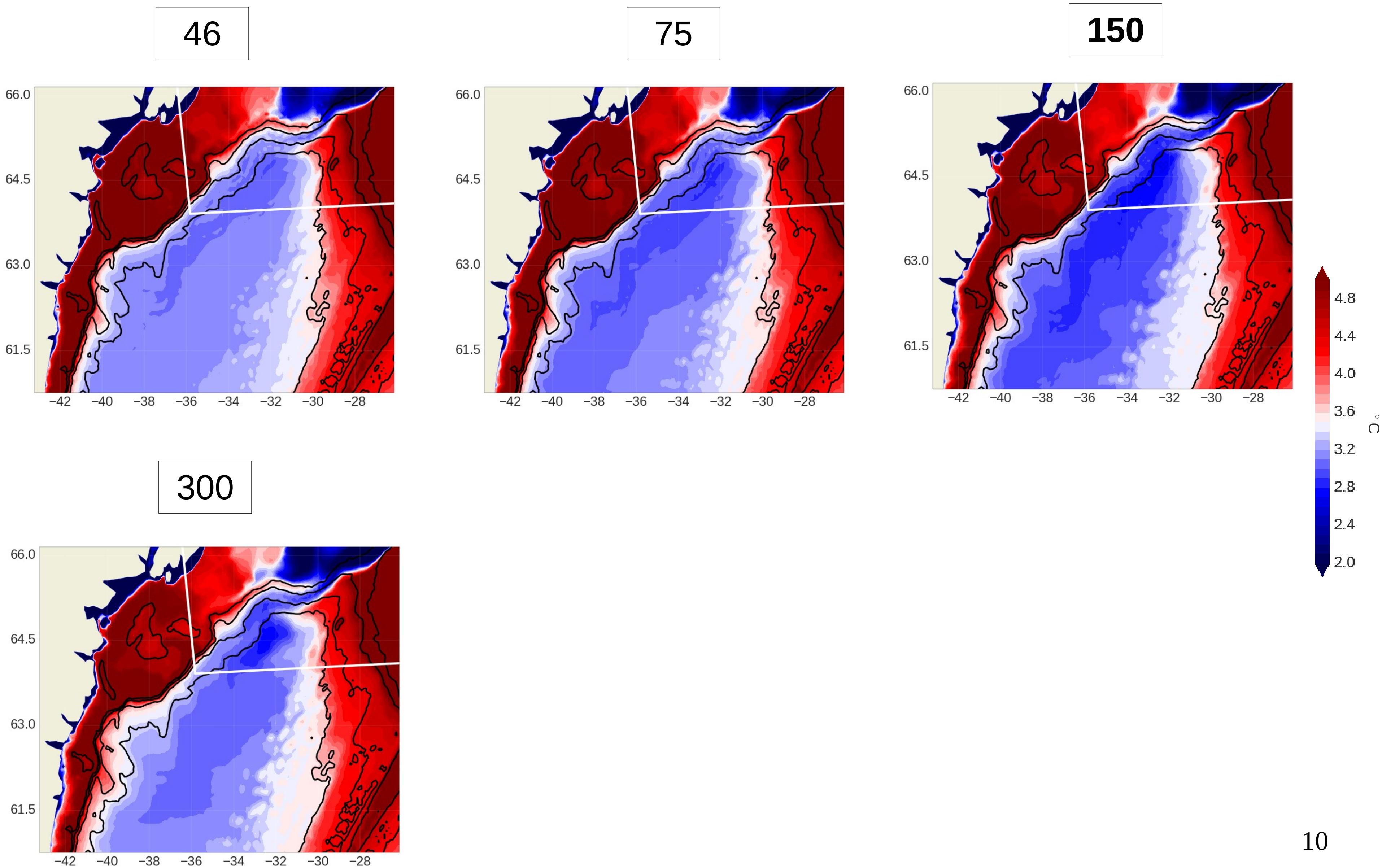
- The occurrence of neutrals instabilities (density inversion) dominates

- Having a more coherent grid confines the convective adjustment to a thin layer

Not only that, the **grid construction** aspect plays an important role

Vertical resolution at **1/36°**

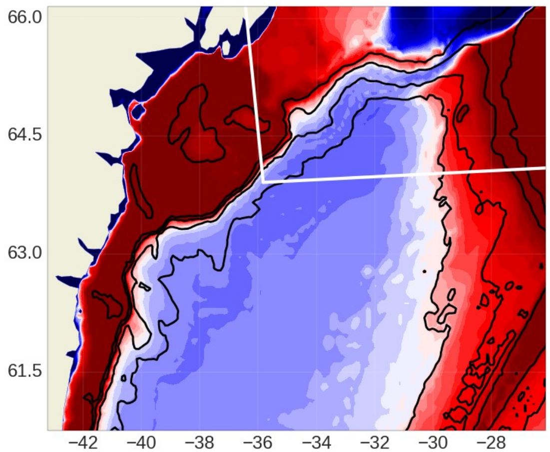
Annual mean bottom temperature of the last year of a **5 years** simulation



Vertical resolution at **1/60°**

Annual mean bottom temperature of the last year of a **5 years** simulation

46



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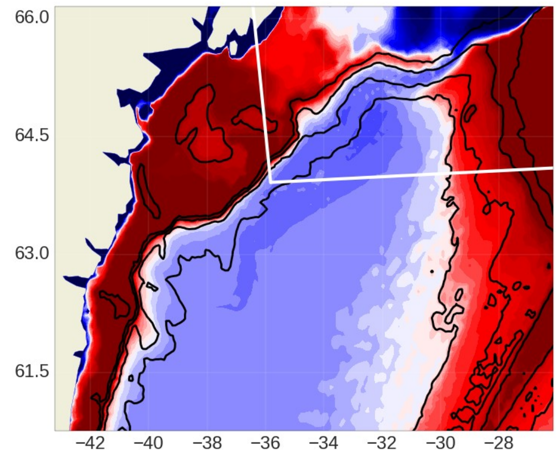
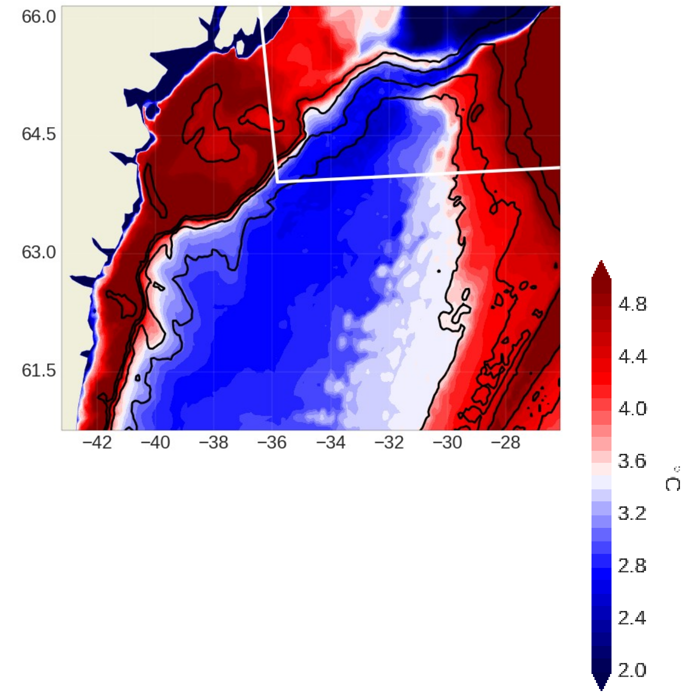
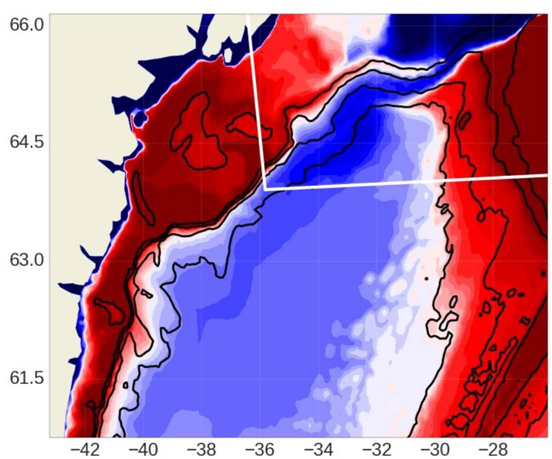


150



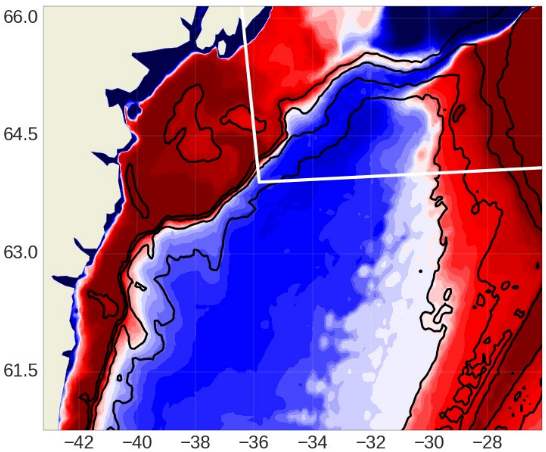
300

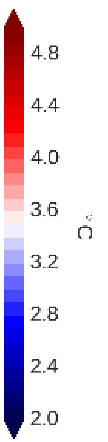


Most performant simulations

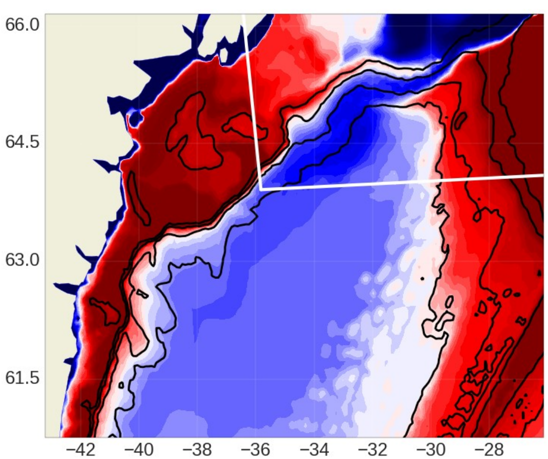
Annual mean bottom temperature of the last year of a **5 years** simulation

1/60° 150

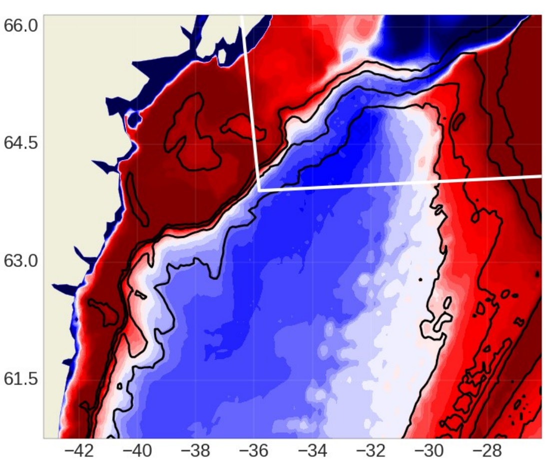




1/60° 300



1/36° 150

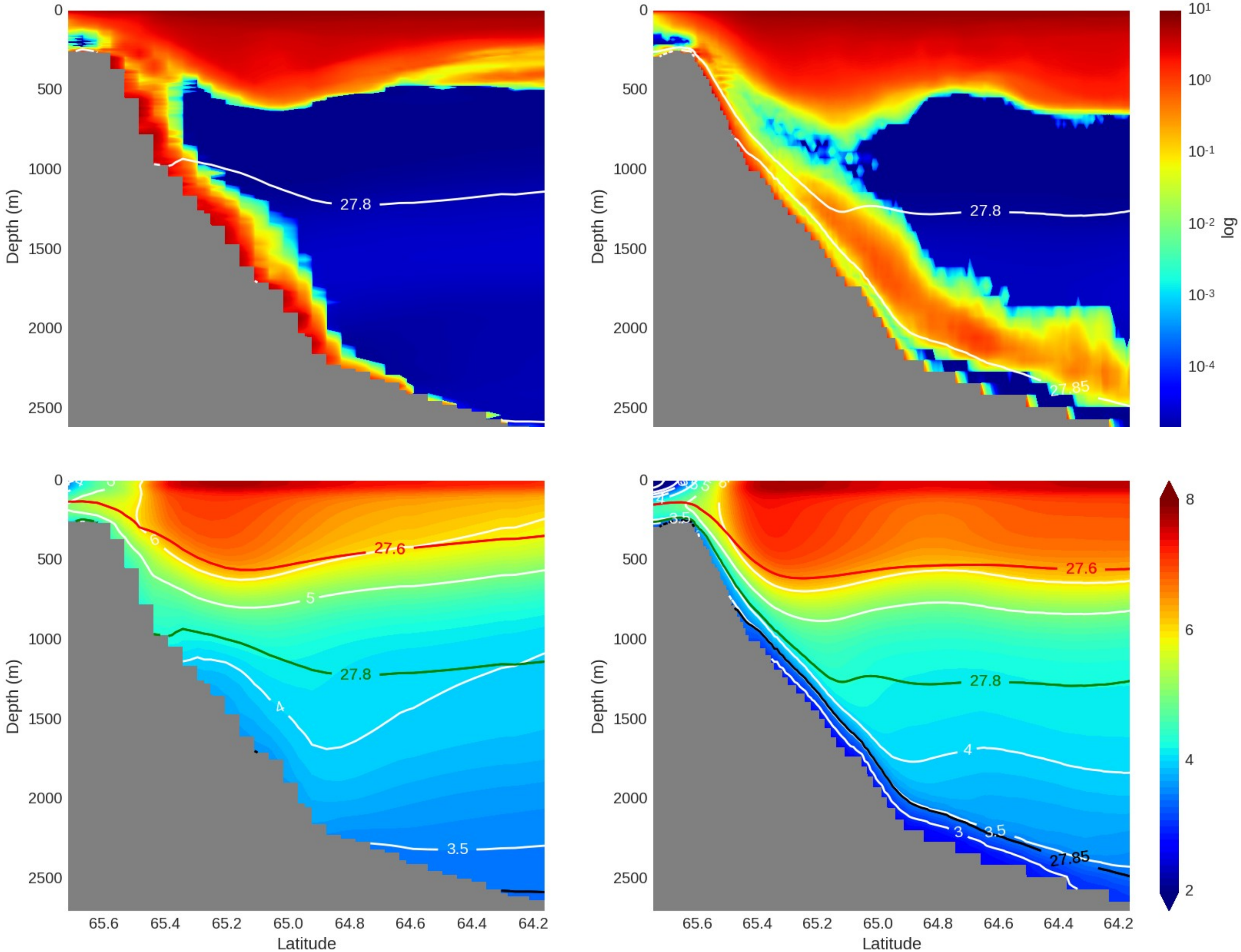


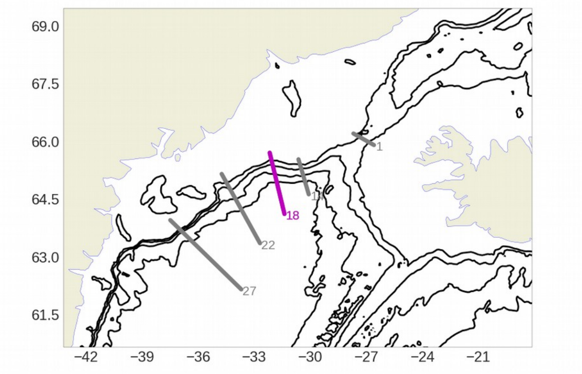
Understanding

Hydrostatic model: vertical acceleration not present, therefore parametrized

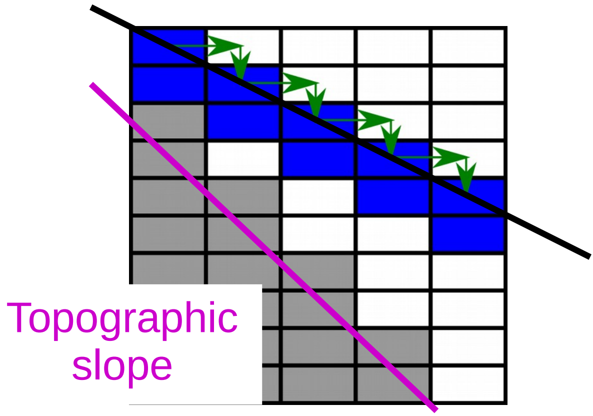
1/12° 300L

1/60° 150L





Grid slope



Not only that, the **grid construction** aspect plays an important role

Preliminary conclusion

- **z-co** : Locally increasing horizontal / vertical resolution at 1/60° 150L bring improvements but at very **high computational costs (x30)**

- Confining the **convective adjustment**, due to the step-like representation of the topography, to a **thin layer**.
This confinement is possible thanks to a better agreement between the grid-slope and the topographic-slope.

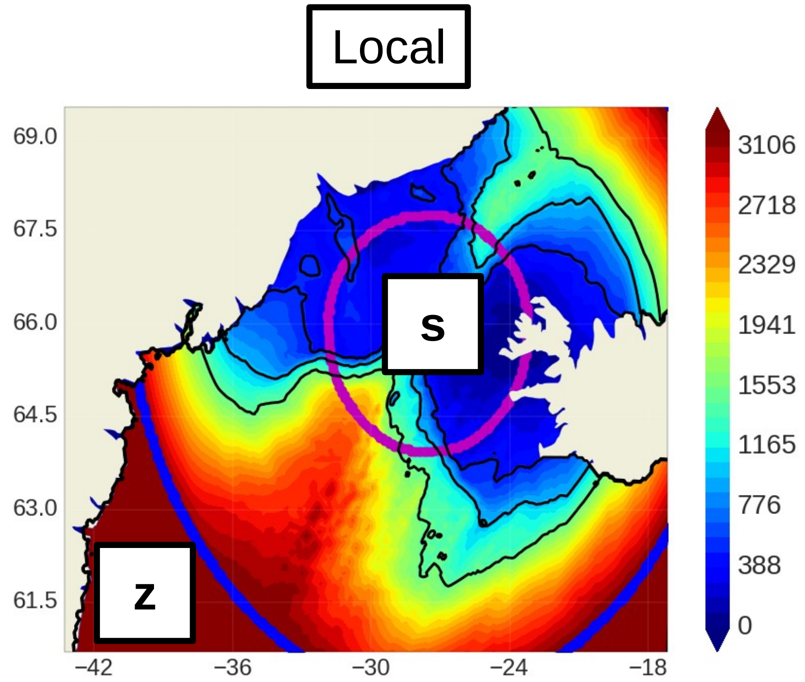
- Resolving the **bottom boundary layer** seems to play an important play in the sink of the DSO

- No satisfactory solution at 1/12°

If it is a grid construction problem, **what if we change the vertical grid where needed**?

Terrain-following coordinates for 1/12°

Our answer: local implementation of s-coord in a global z-model

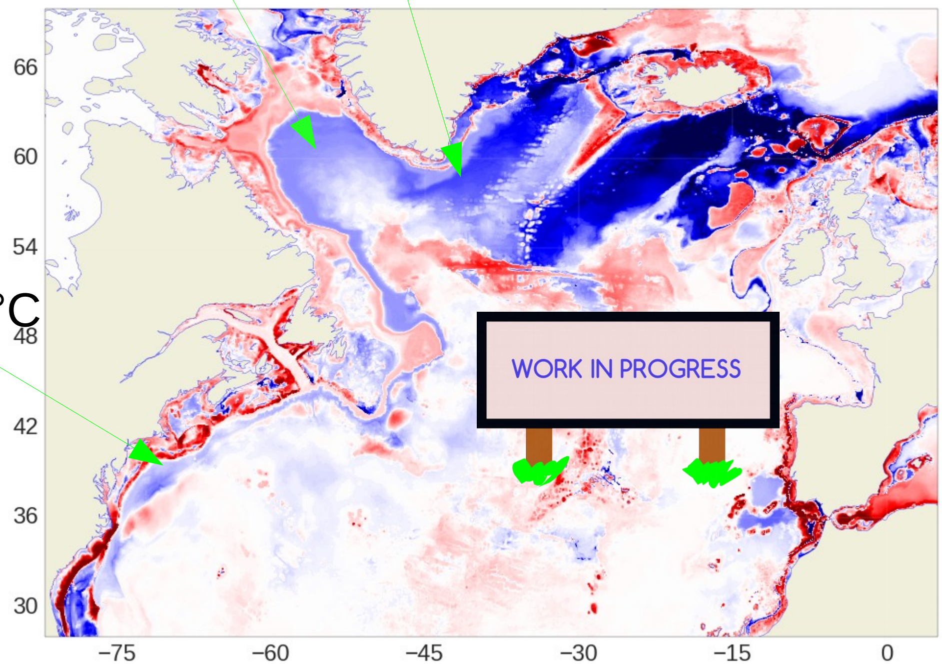


NATL12 comparison

“**Local-s**” minus “z”

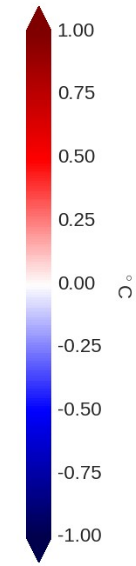
0.25°C 0.35°C

0.15°C



Annual mean bottom temperature of the last year of a **7 years** simulation

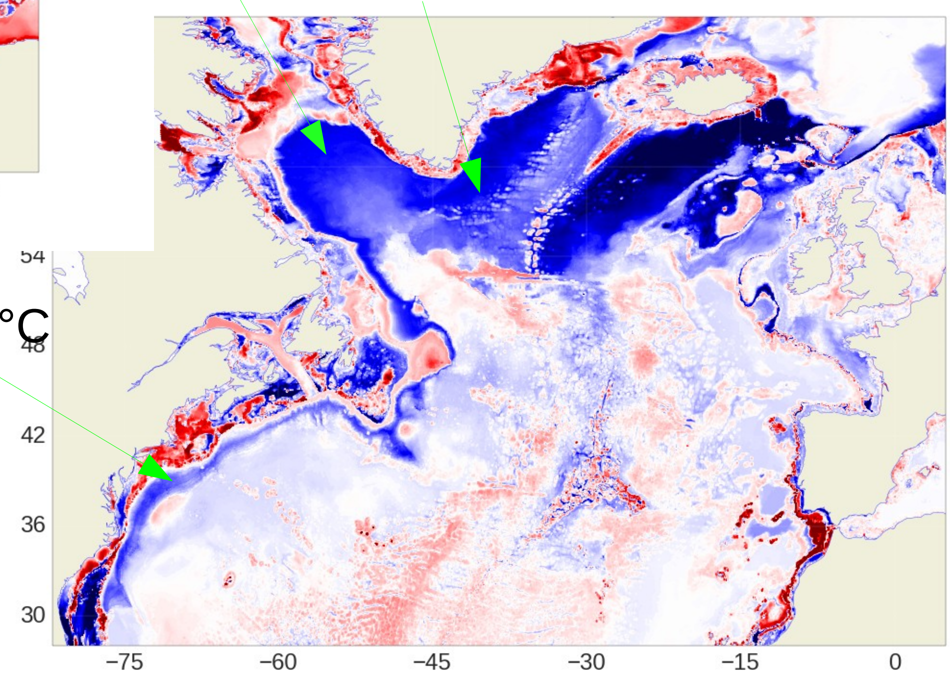
7th year



“**Full domain s-co**” minus “z”

0.50°C 0.65°C

0.35°C



Local-s

- Clear improvement compared to z
- Does not match yet full domain s-co

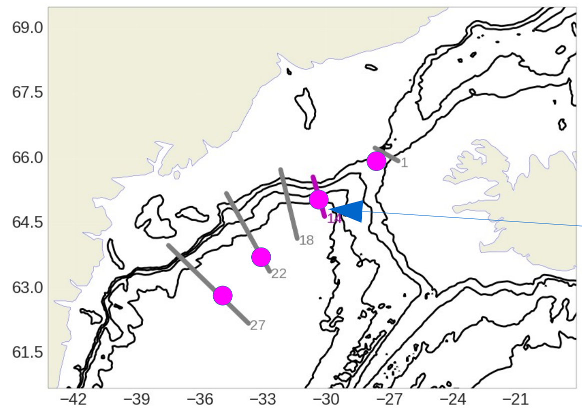
Conclusion

- **z-co** : Locally Increasing horizontal / vertical resolution at 1/60° 150L bring improvements at very **high computational costs (x30)**

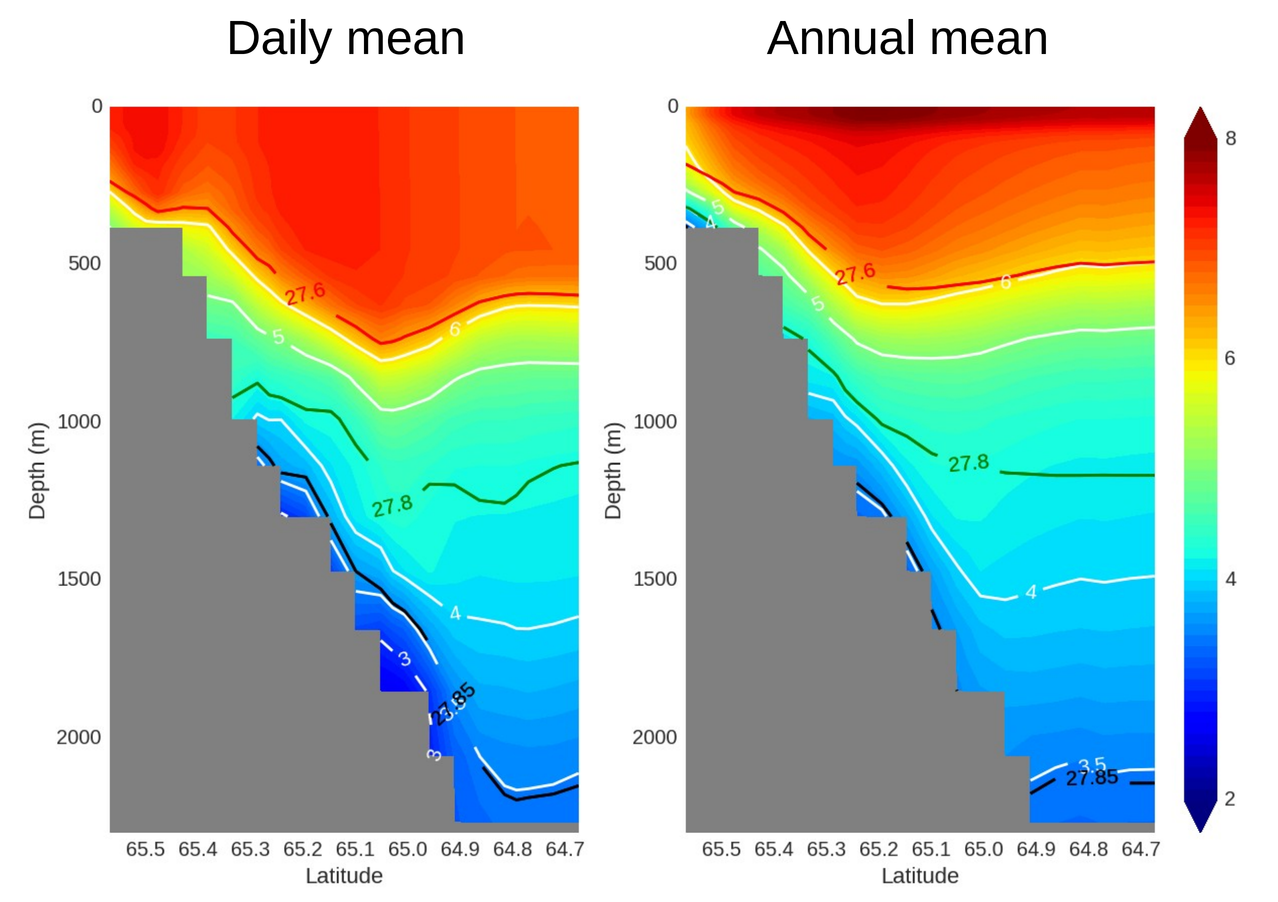
- **Local-s** : Substantial improvements at very small computational costs **Flexible solution for global modeling** (generic implementation)

Thanks!

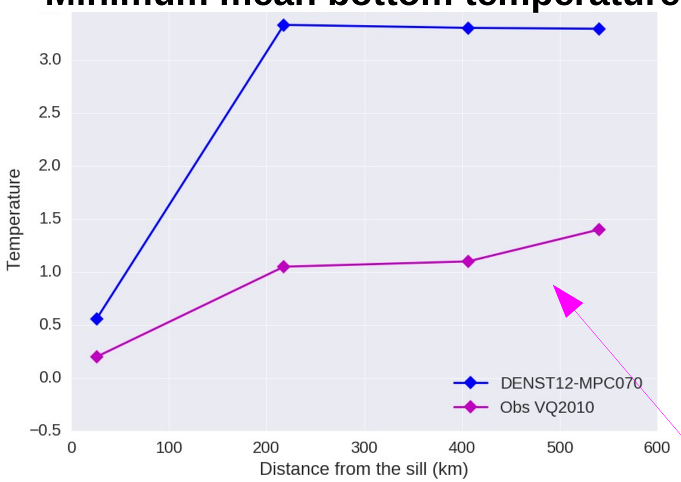
Motivation



Temperature section with density contours



Annual mean
Minimum mean bottom temperature



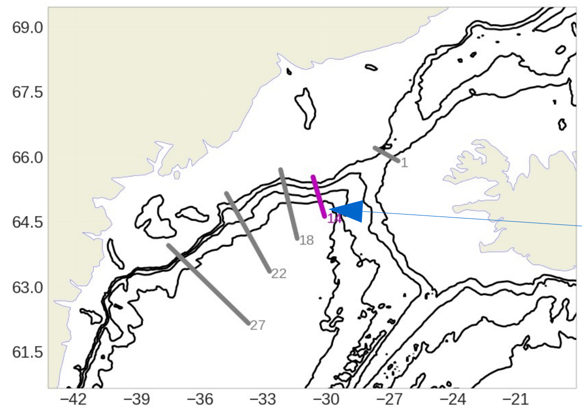
2°C warmer

All runs are 5 year long:
Analysis of the last year

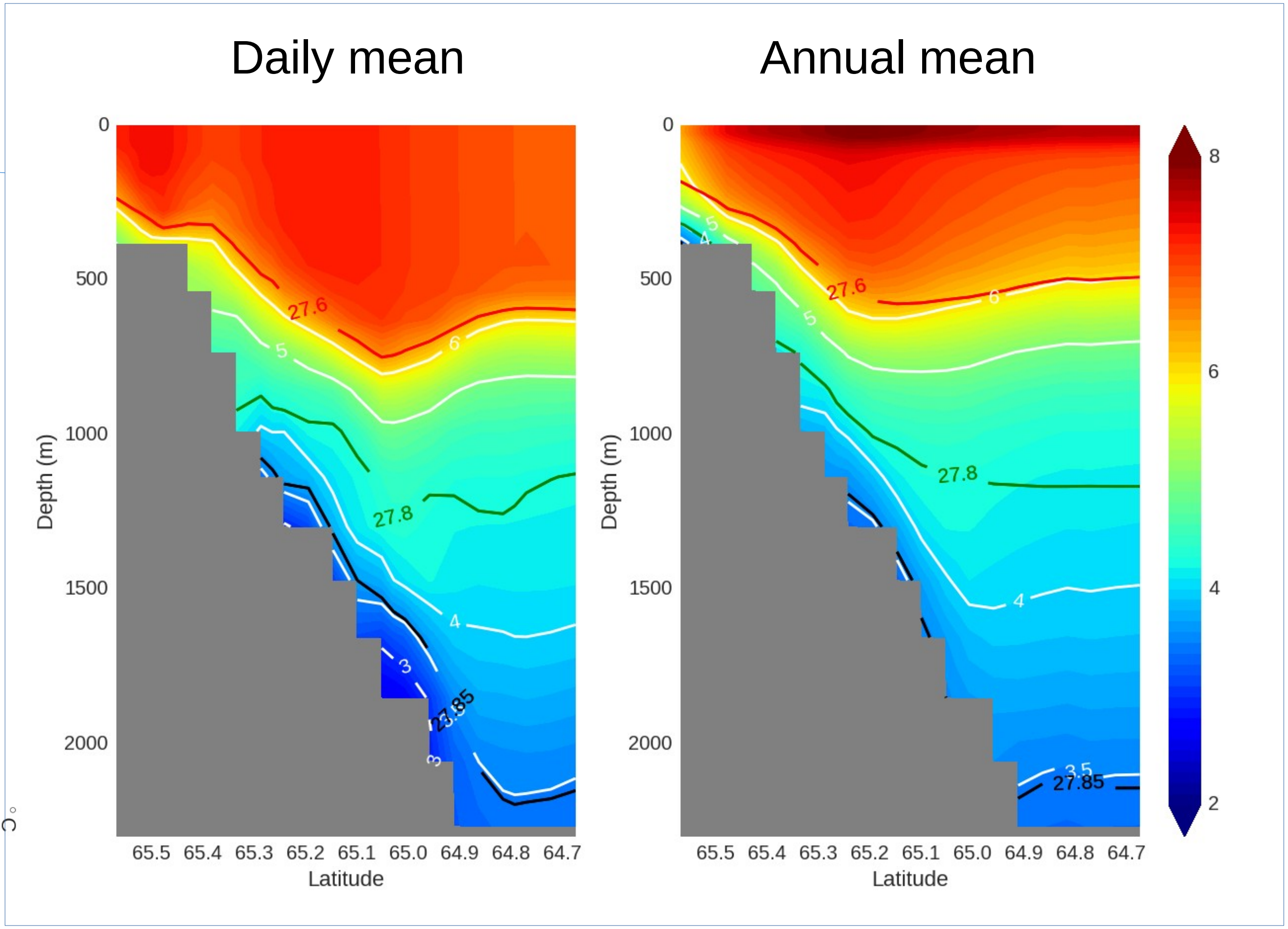
Observations from long-term moorings

Unrealistic overflows at 1/12°

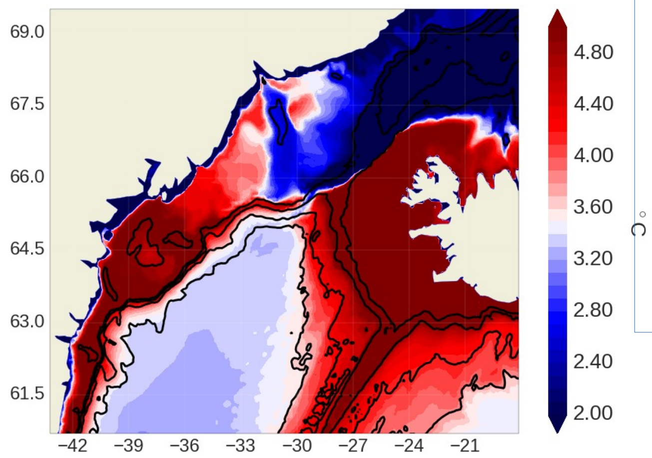
Motivation



Temperature section with density contours

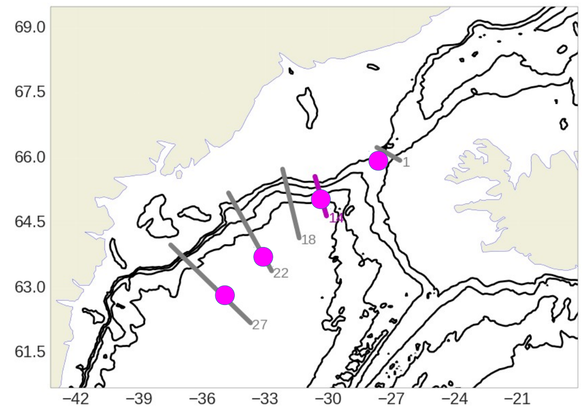


Annual mean bottom temperature

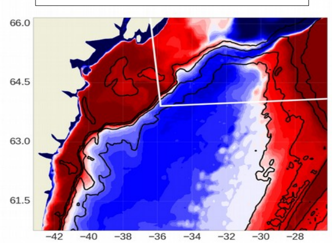


All runs are 5 year long:
Analysis of the last year

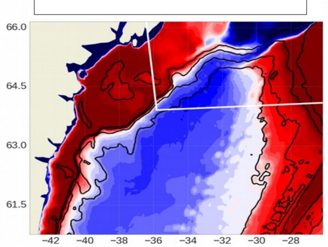
Long-term comparison



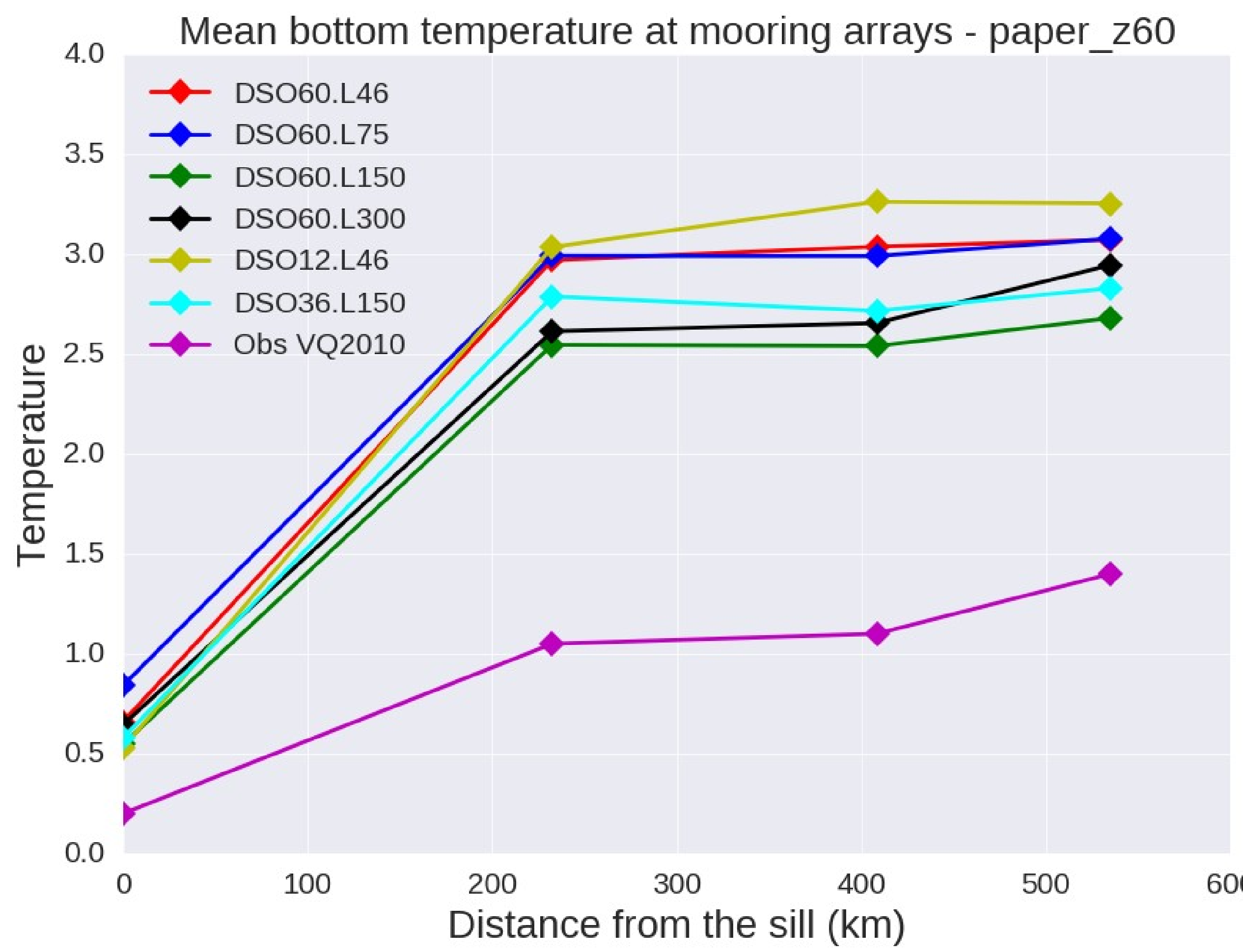
1/60° 150L



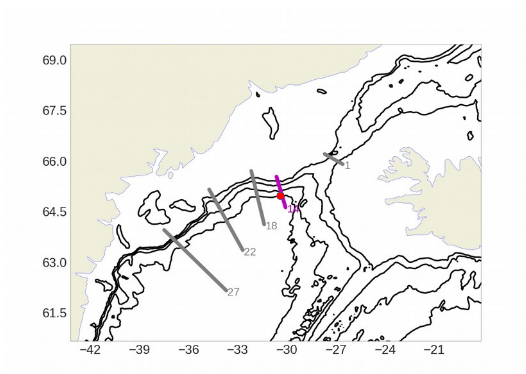
1/36° 150L



Minimum mean bottom temperature at mooring arrays

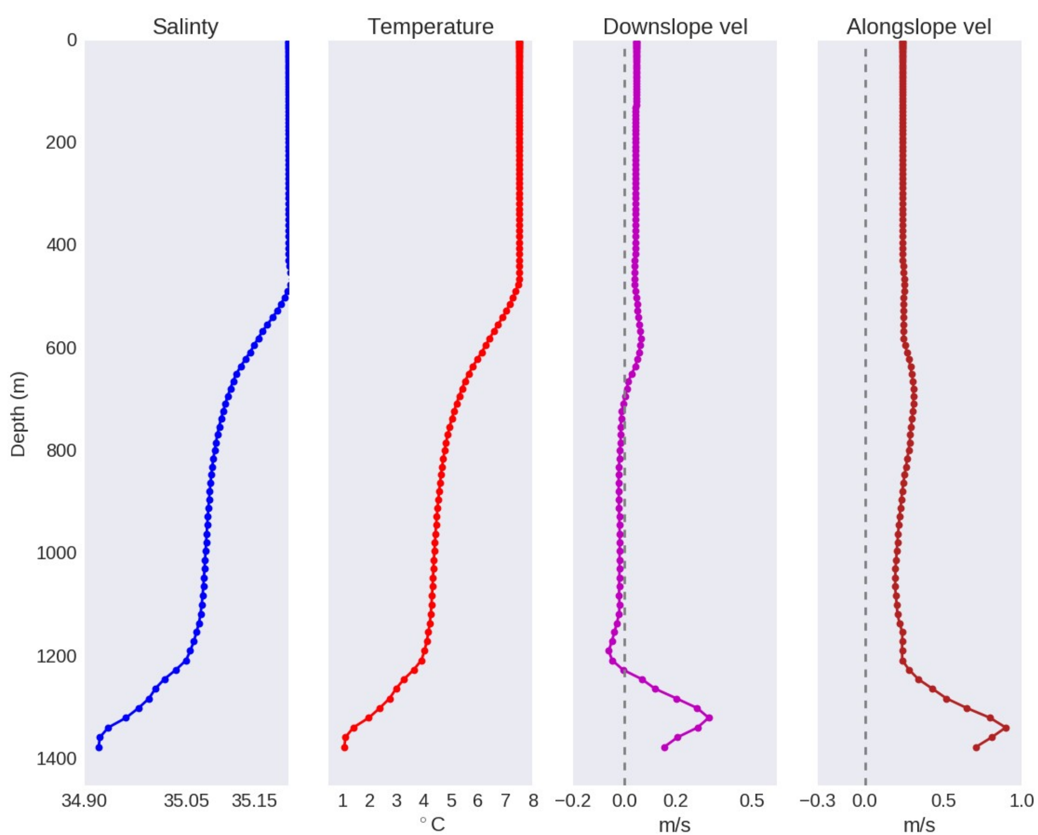


Bottom layer

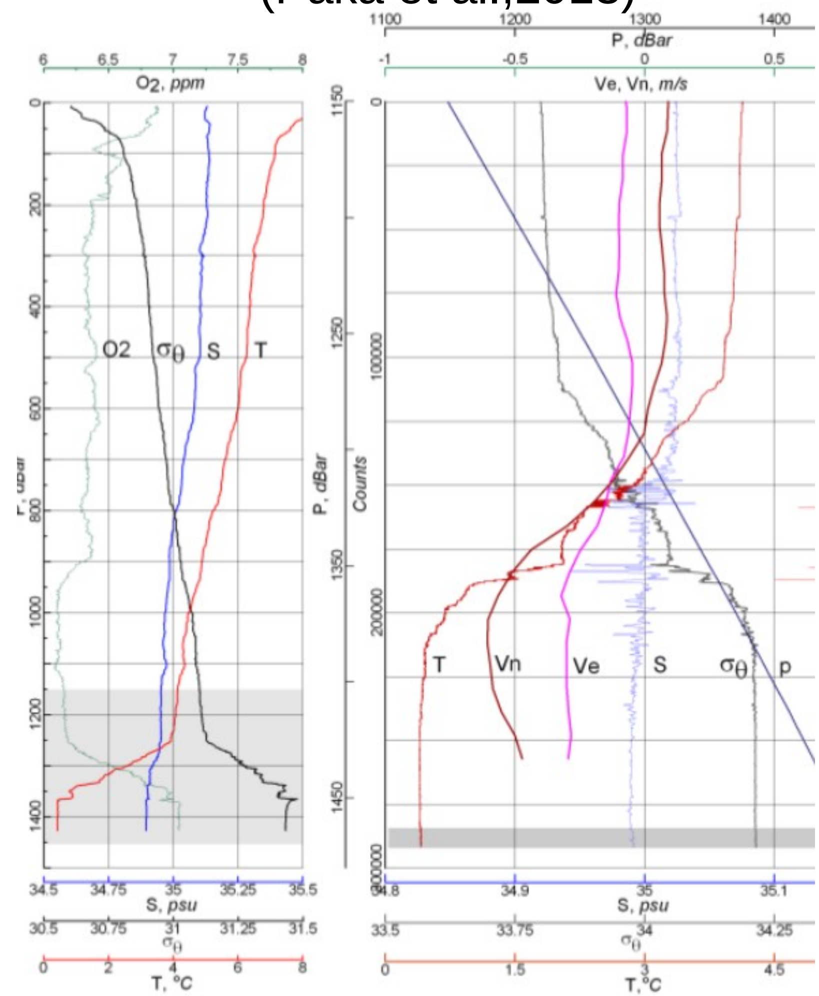


Vertical profiles of salinity, temperature, normal velocity and tangential velocity during the descent

Model (1/60° 300L)



Observations
(Paka et al.,2013)

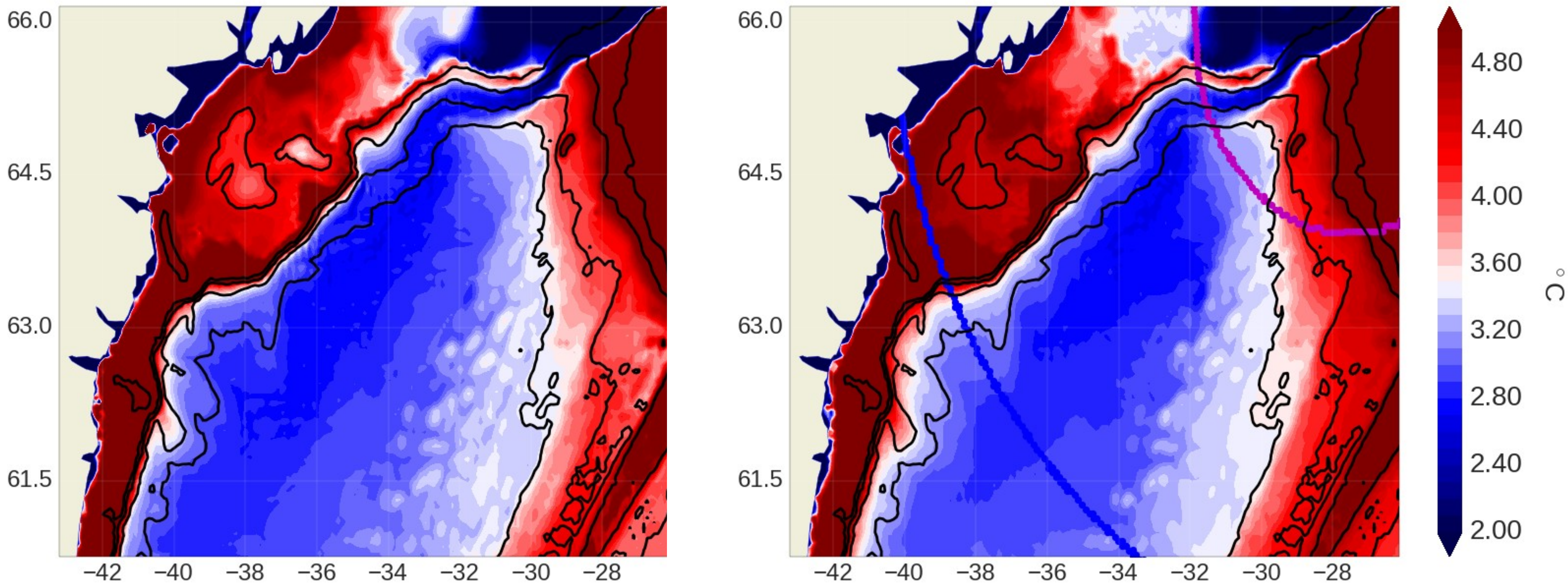


Some results

Annual mean bottom temperature of the last year of a **5 years** simulation

Full domain

Local



Benefits remain clear
with local-s