

Coupling of the regional climate model MAR with the ocean model NEMO: difficulties and first results

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2 April 2024 – IMAU Colloquium, Utrecht

Part I :

Making MAR talk to NEMO and vice versa

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Poles are rapidly changing :

- Sea ice decline
- Ocean heat uptake
- Temperature rising

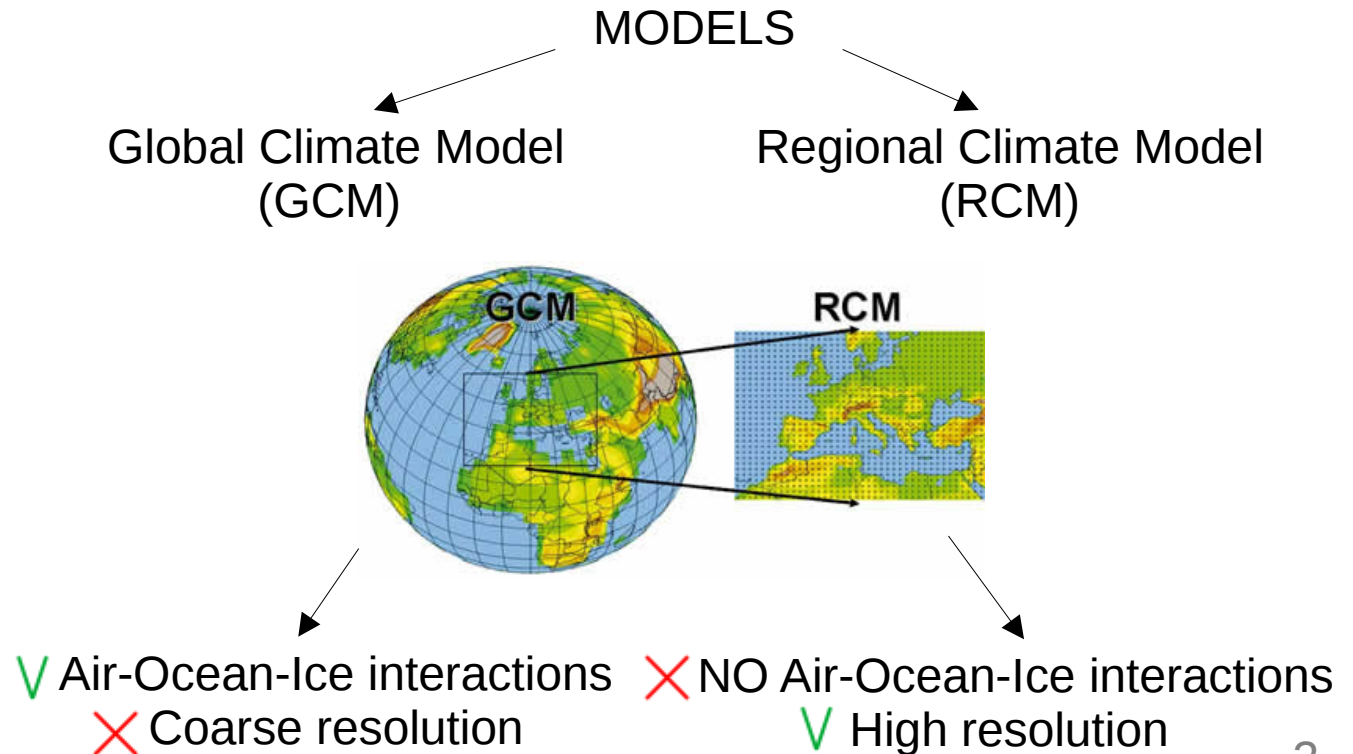
Arctic Amplification : temperature rising 3x faster than the rest of the planet

→ **Interaction processes** at the air-ocean-sea-ice interface at the heart of these temperature rises





How to study air-ocean-ice interaction processes ?





How to study air-ocean-ice interaction processes ?

Coupling RCM with an ocean model



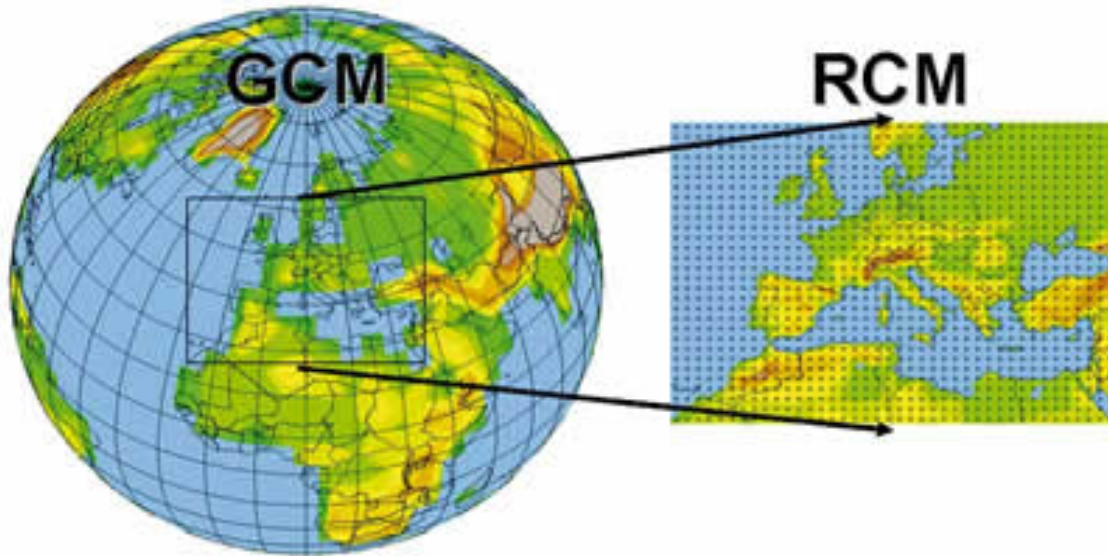
Better representation and understanding of
air-ocean-ice interactions processes



Better climate projections

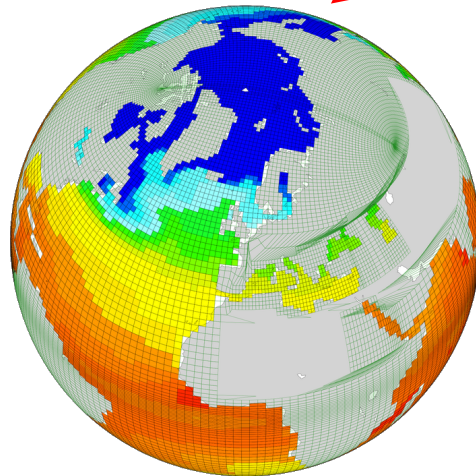


Better anticipation of climate change consequences
on local populations and ecosystems

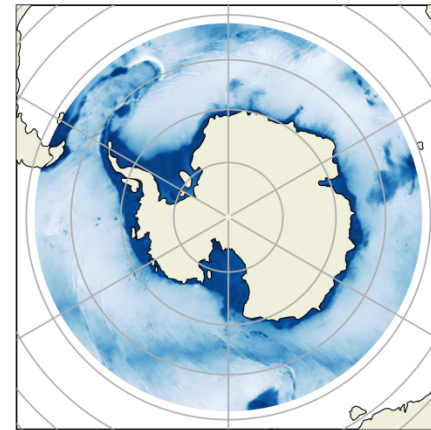


**3D atmosphere and snow
regional climate model**

3D Ocean model
SI³ sea ice model included

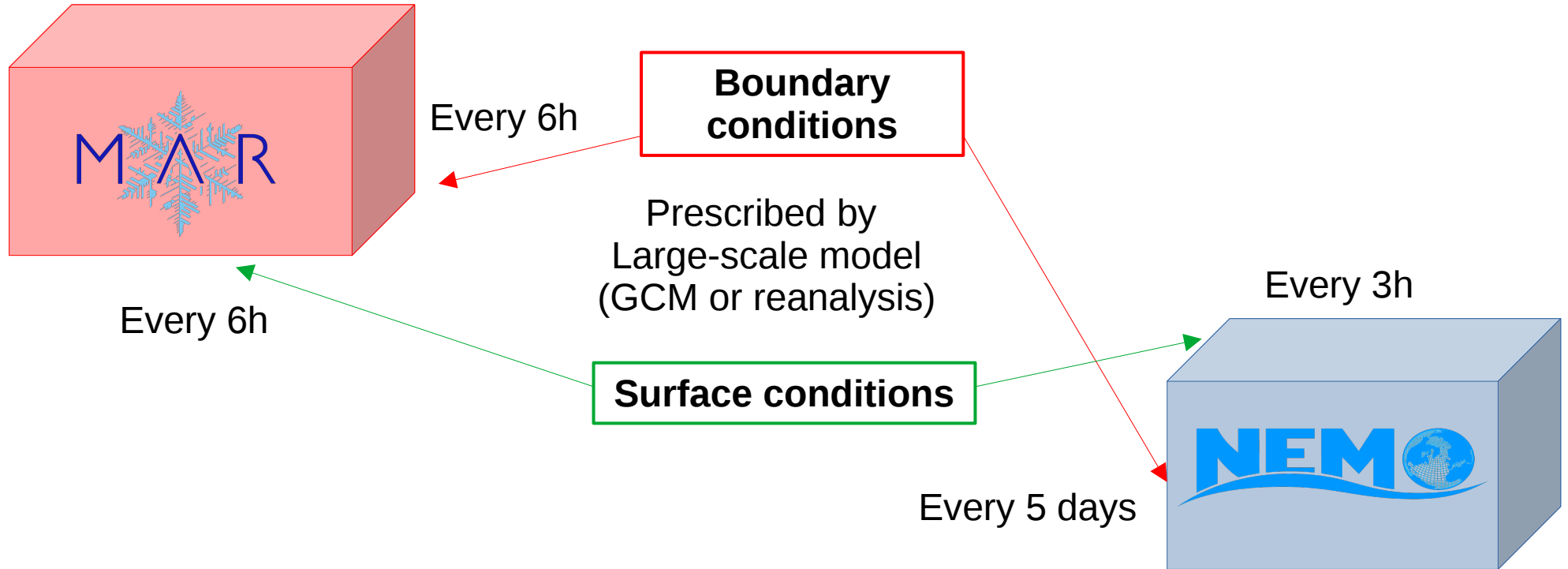


Global configuration

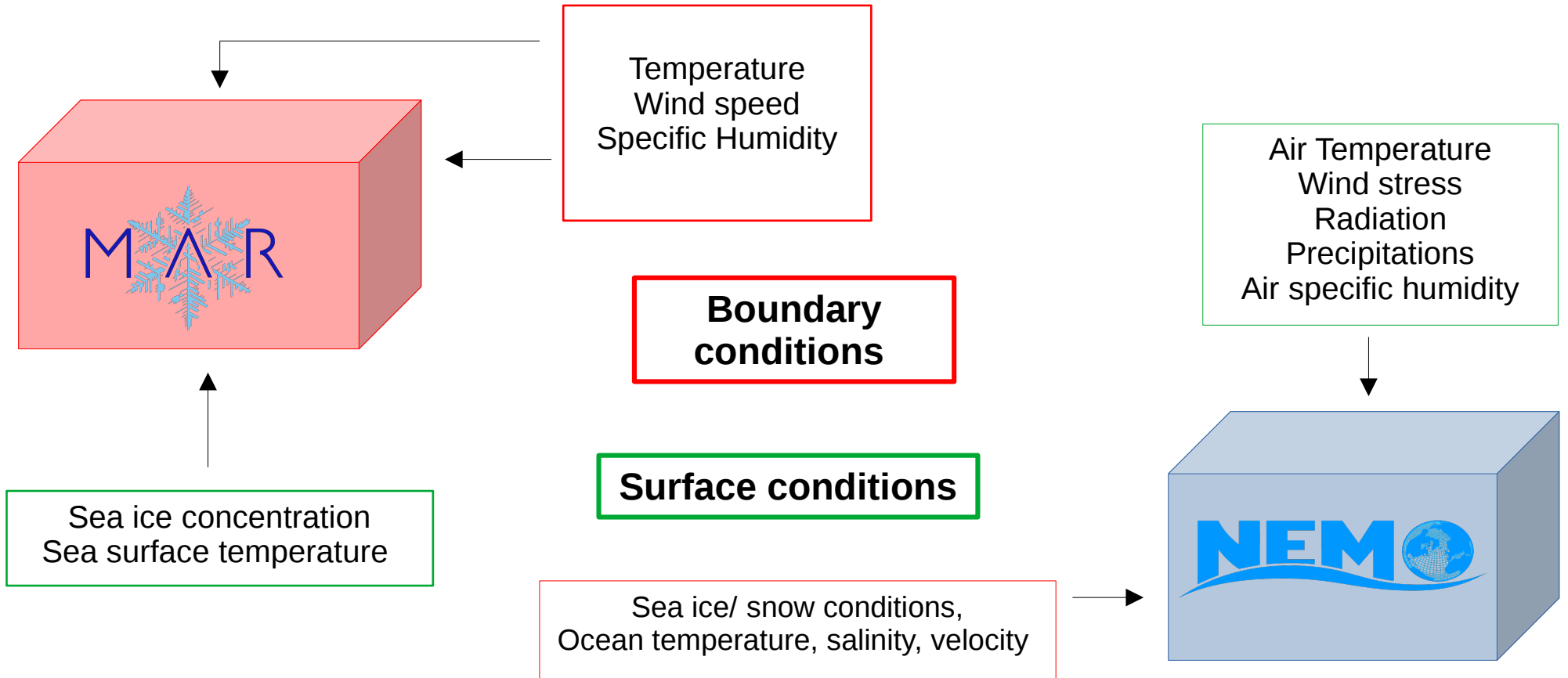


OR Regional configuration

How does it work ?

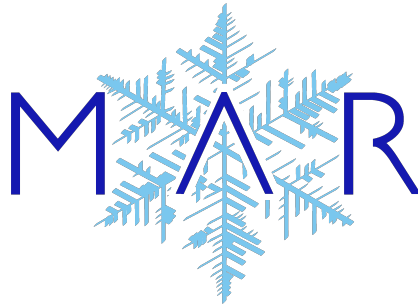


How does it work ?



Strengths

- ✓ Good snow representation
 - Complex snow albedo scheme
 - Densification of snow layers
 - Refreezing
 - Snow – air interactions
- ✓ Good snowpack discretization



Weaknesses

- ✗ No interactions with the ocean surface
- ✗ Sea ice represented like continental ice
- ✗ Sea ice concentration prescribed from forcings
- ✗ Fixed sea ice thickness (50 cm)

Strengths

- ✓ Representation of sea ice processes
 - growth/melt
 - Albedo evolution
 - Snow to ice conversion
 - Ocean-sea ice interactions

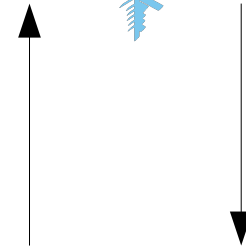
- ✓ Advection of sea ice



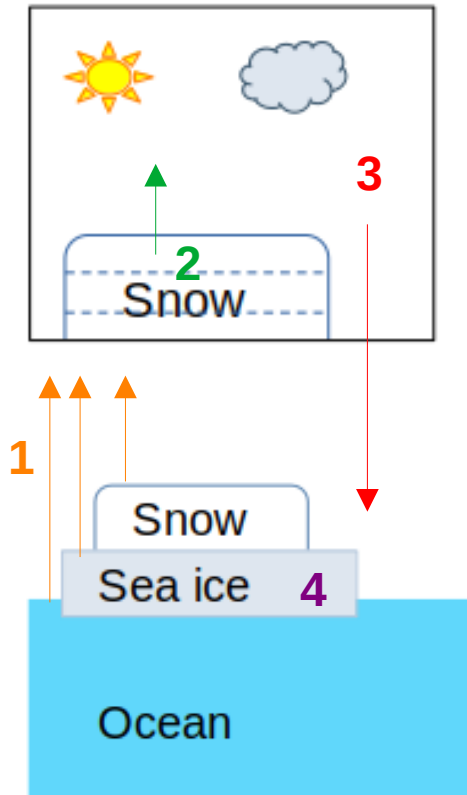
Weaknesses

- x Poor snow representation
 - Constant albedo
 - No rain percolation
 - Constant density

- Make profit of the best of each side concerning ice & snow
- Enabling high temporal/spatial resolution on an atmosphere-ocean-sea ice system
- New exchanged variables (not prescribed anymore)
- Main focus on process studies



Who does what ?

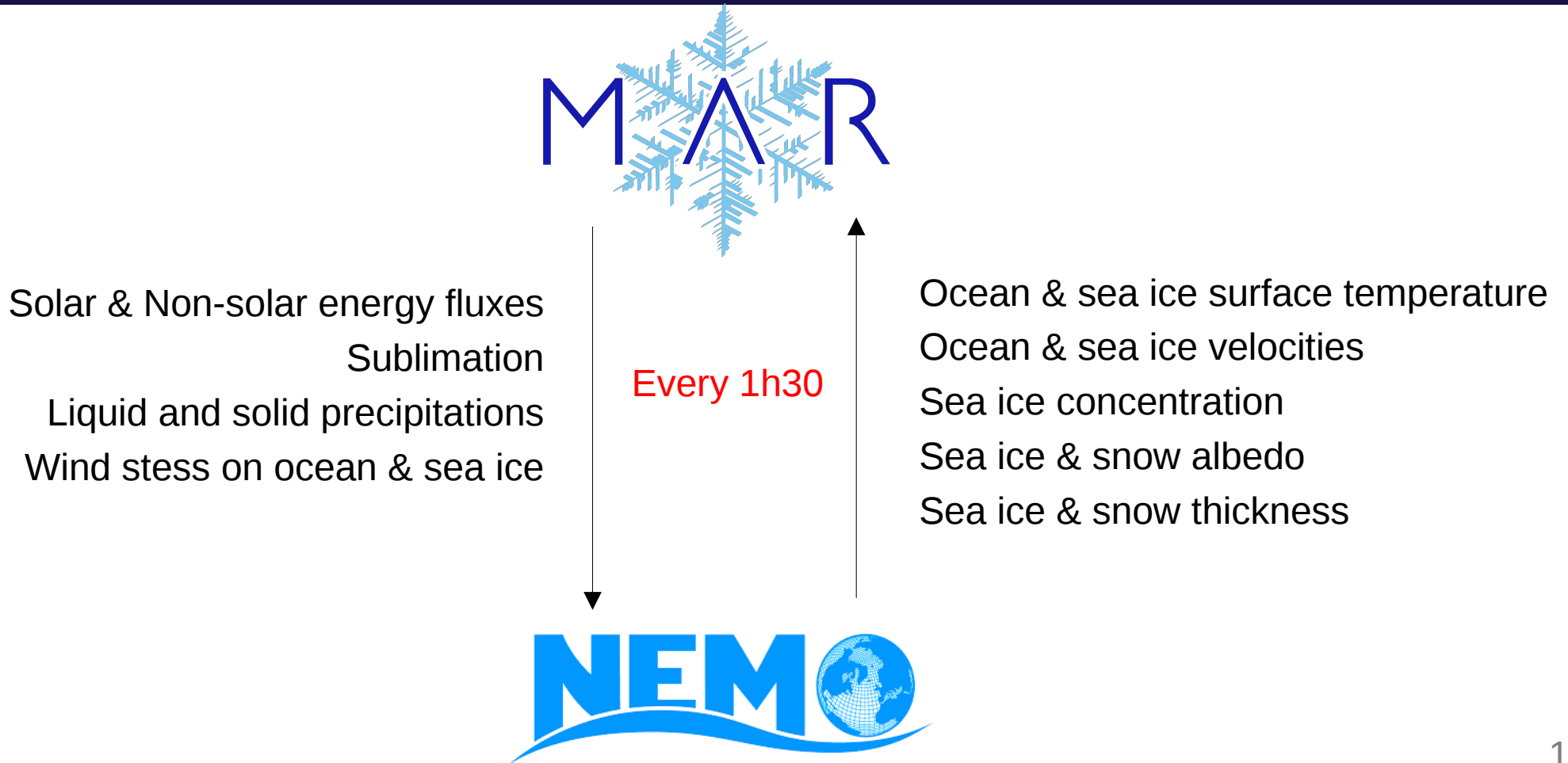


2) Discretize snow and ice layers

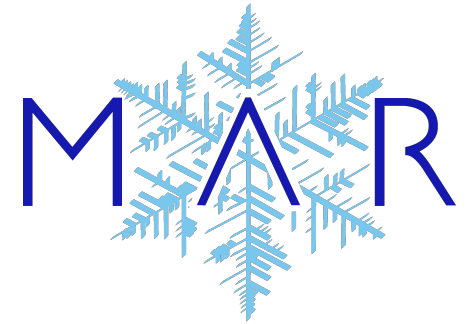
3) Computes surface radiative fluxes, Non-radiative fluxes, Mass fluxes

1) Calculates snow & sea ice properties as it can advect them + ocean surface properties

4) Receives fluxes, Updates sea ice, snow and ocean surface properties



Use of a 3rd party coupler :
OASIS3-MCT



Interpolates exchanged fields
on both model grids

Part II :

The MAR-NEMO coupling journey over Arctic and Antarctic

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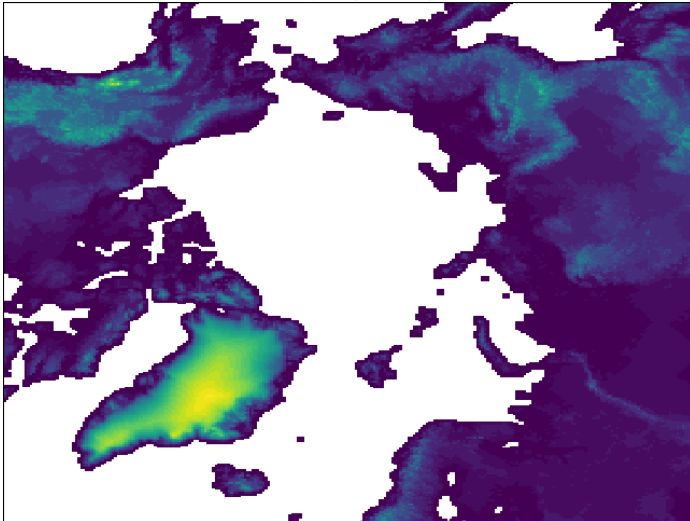


- MAR version 3.13.0
- Easy to set up
- NESTOR tool : downscaling of forcing fields

Pan-Arctic domain

25 km resolution
274x284 grid cells
24 vertical levels

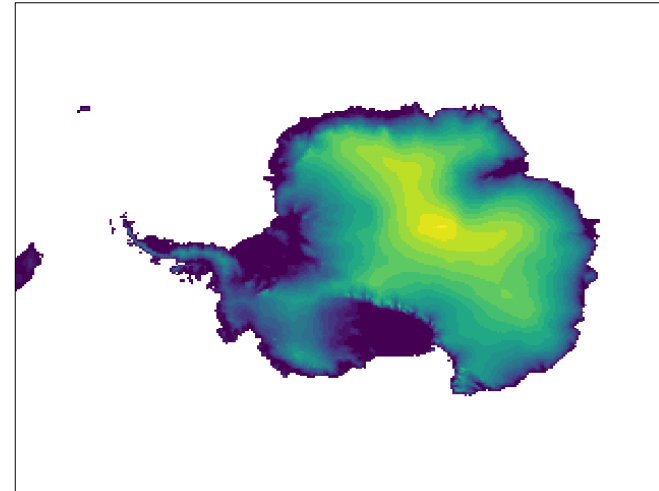
Polar Stereographic projection



Pan-Antarctic domain

25 km resolution
305x272 grid cells
24 vertical levels

Rotated Polar Stereographic projection

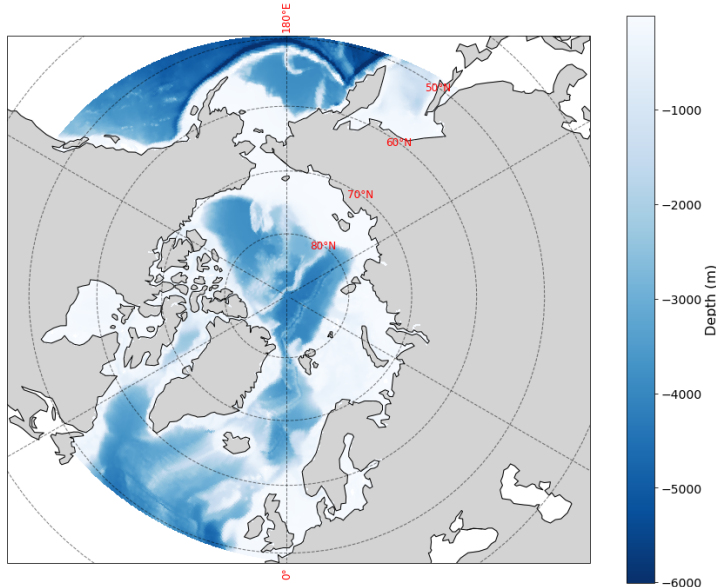




- NEMO version 4.2.0 (coupled with SI³ sea ice model)
- Need to set up a regional configuration to reduce computation costs

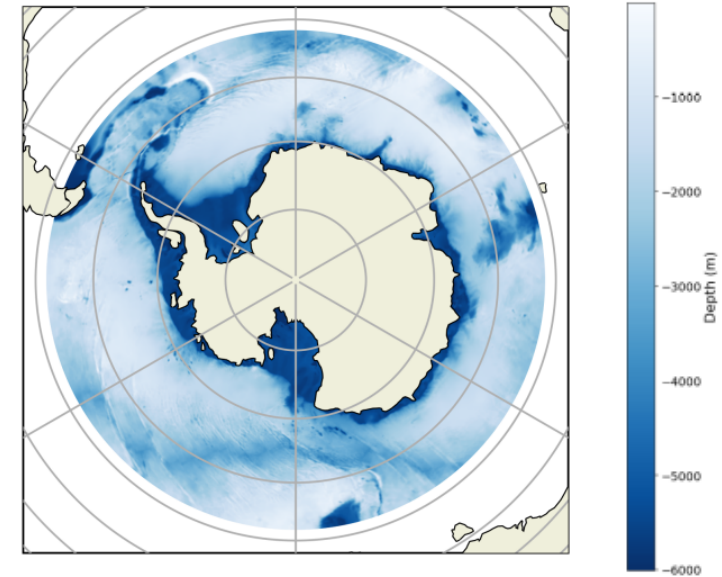
Pan-Arctic domain

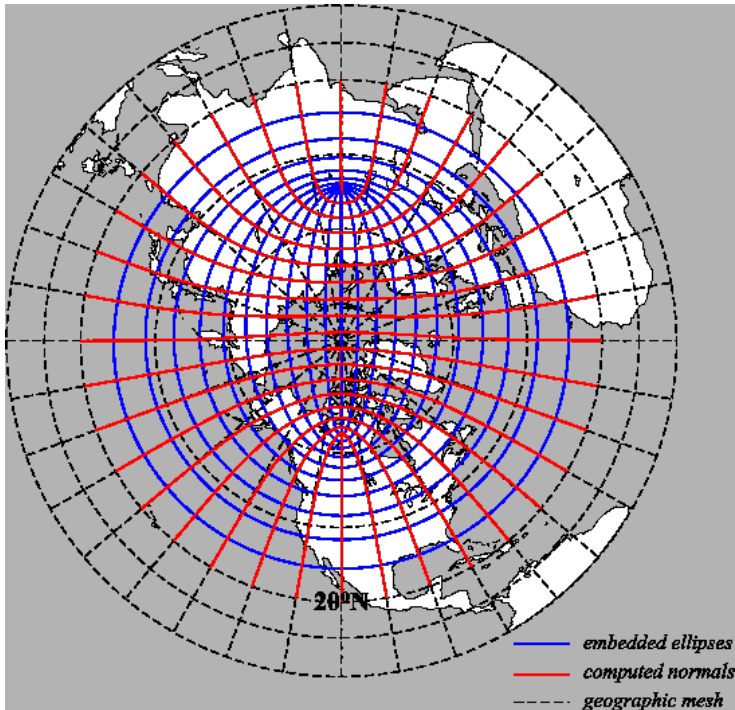
1/4 degree resolution
1440x296 grid cells
121 vertical levels



Pan-Antarctic domain

1/4 degree resolution
1440x439 grid cells
121 vertical levels

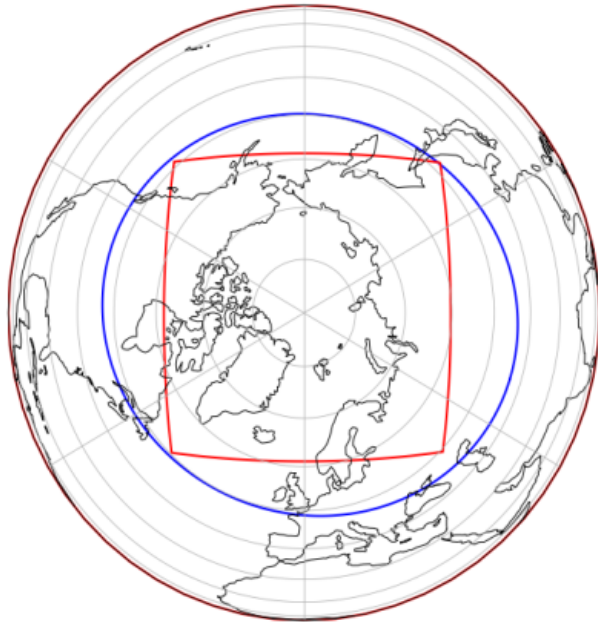




- Regional domains based on the global eORCA025 ocean grid (Mathiot & Jourdain, 2023).
- Tripolar grid with 2 « North Poles » over the continents.
- Extended southward around Antarctica to represent under-ice-shelves sea

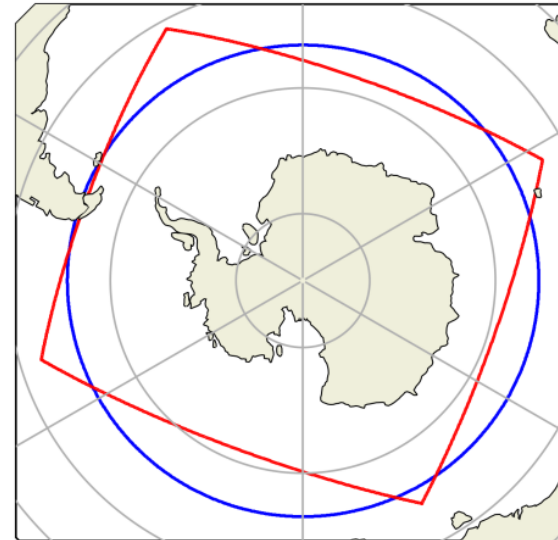


Pan-Arctic domains



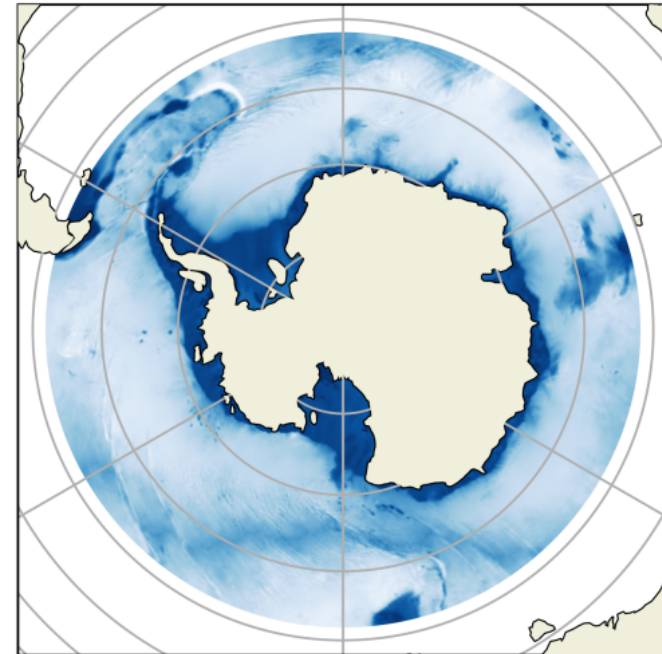
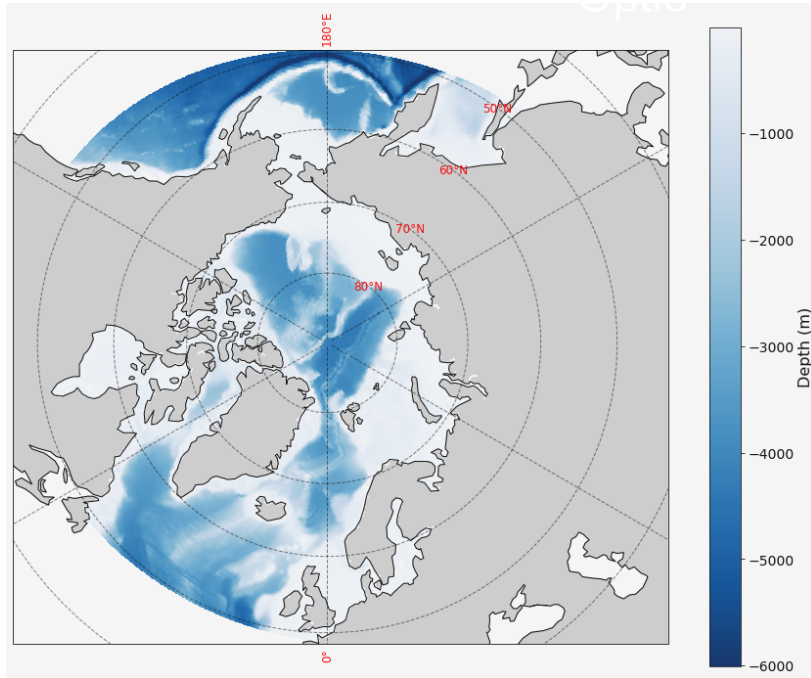
— NEMO
— MAR

Pan-Antarctic domains



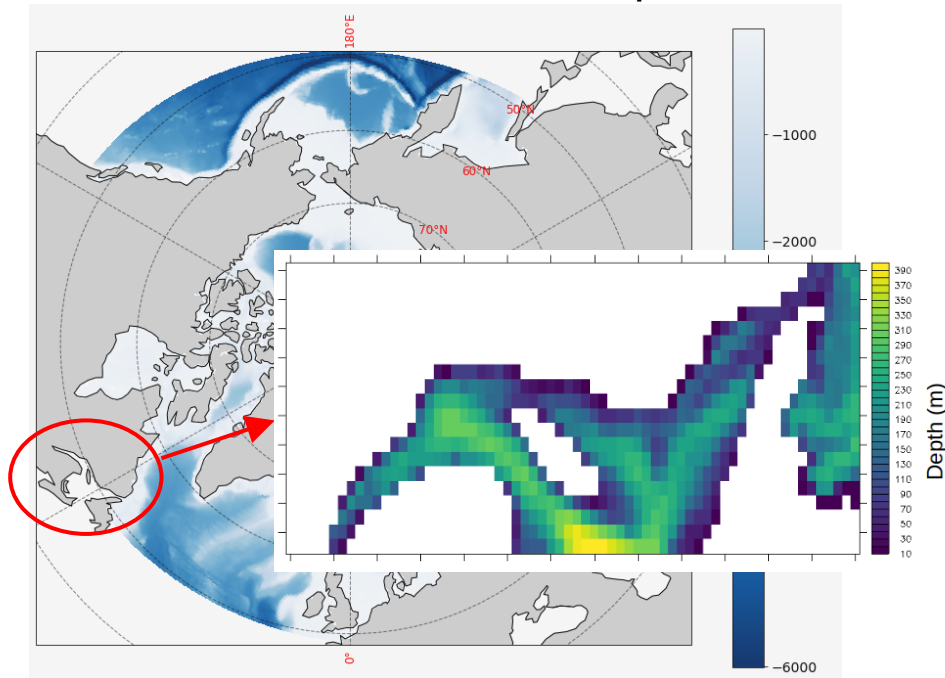


- **Forcing fields at the ocean boundaries.**
 - Antarctic → One big boundary



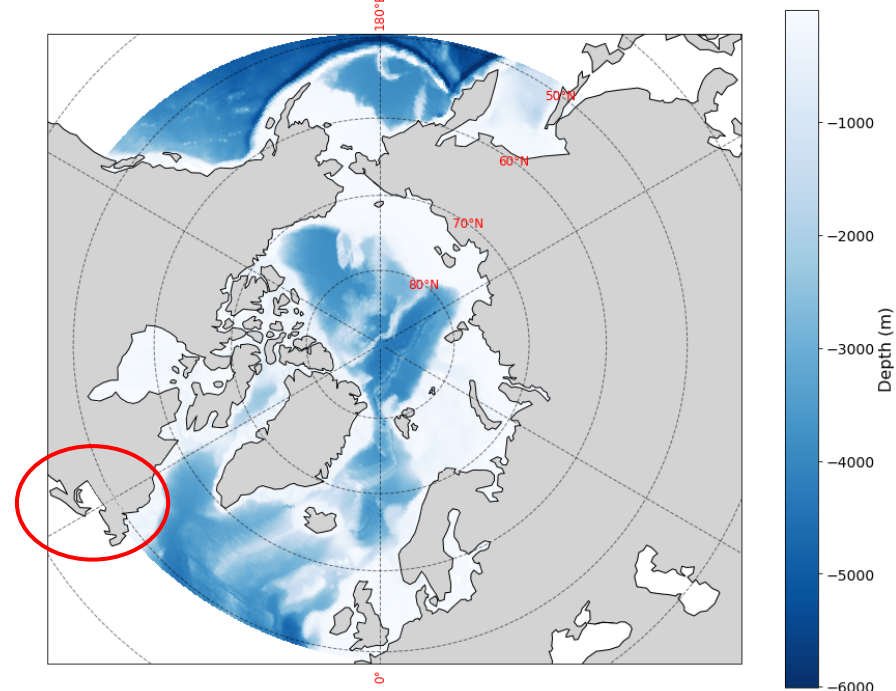
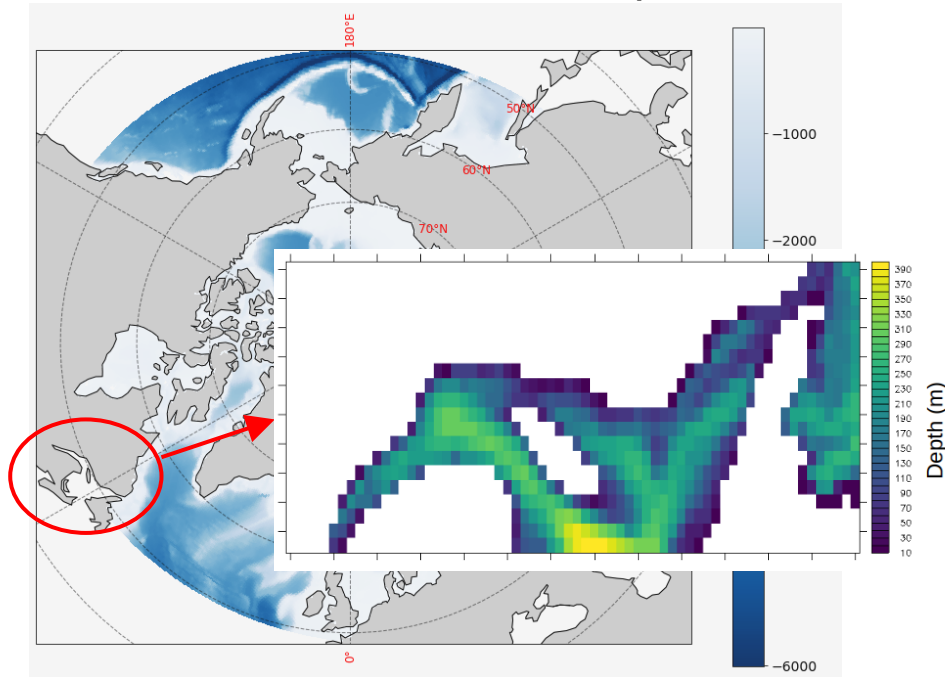


- **Forcing fields at the ocean boundaries.**
 - Antarctic → One big boundary
 - Arctic → mutiple boundaries + closed seas
 - Option in NEMO to remove closed seas

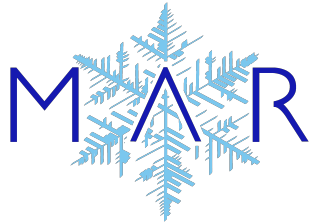




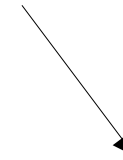
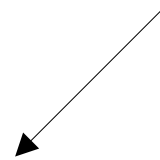
- **Forcing fields at the ocean boundaries.**
 - Antarctic → One big boundary
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 - Option in NEMO to remove closed seas



Standalone runs



Arctic : OK
Antarctic : OK



Arctic :
Start the simulation
from scratch :
MODEL CRASH

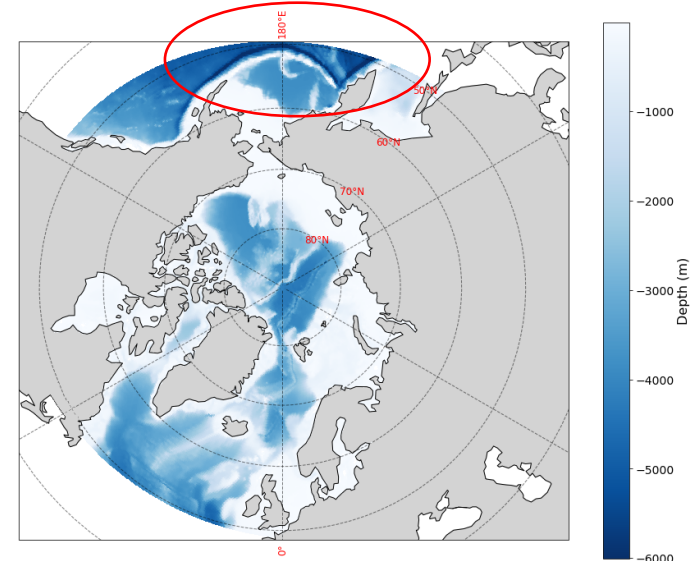
Antarctic :
OK

Standalone runs



Arctic :
One example of
model crash

Deep trenches in near
Aleutian islands with grid
cell thickness > standard
thickness of deepest wet
level (203m)



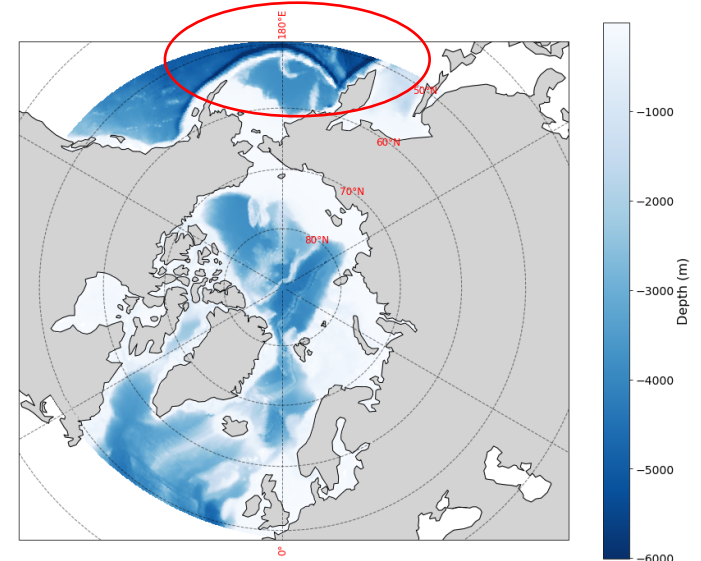
Standalone runs



Arctic :
One example of
model crash

Deep trenches in near
Aleutian islands with grid
cell thickness > standard
thickness of deepest wet
level (203m)

Case not considered by the
initialization subroutine



Standalone runs

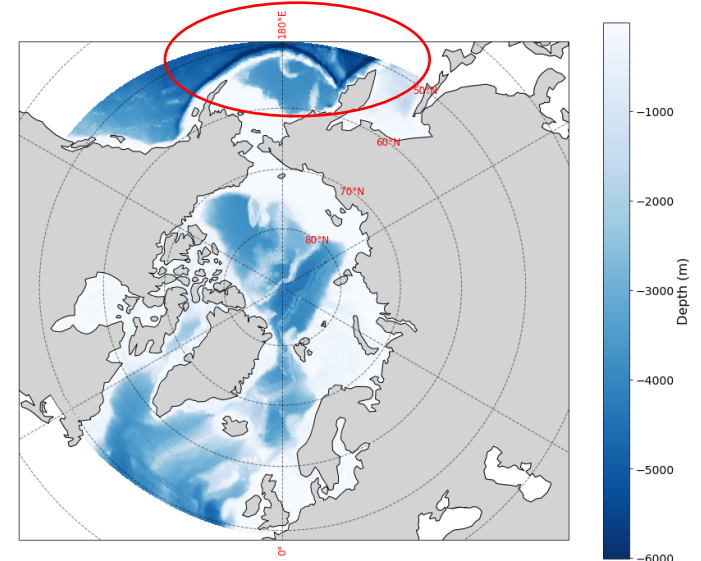


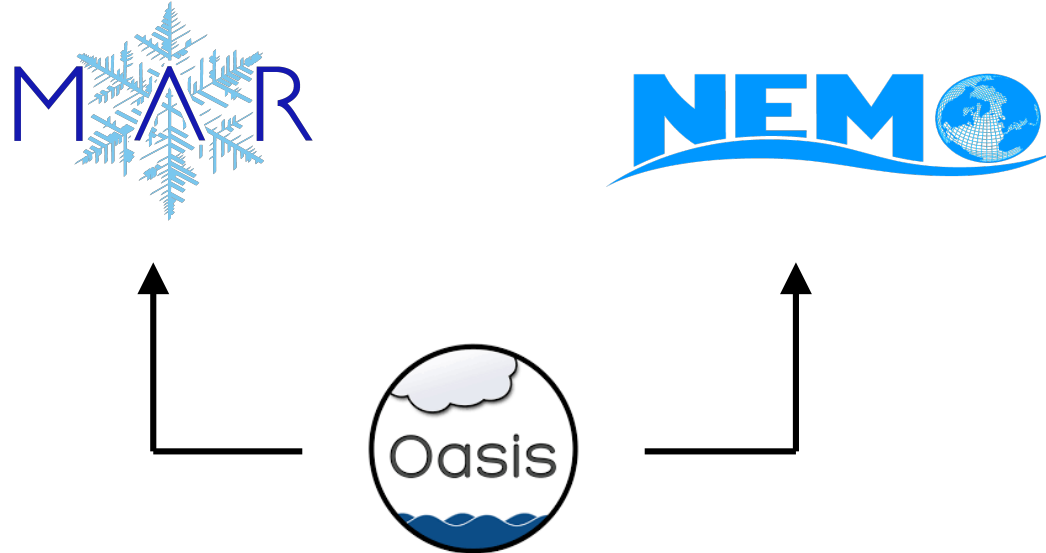
Arctic :
One example of
model crash

Deep trenches in near
Aleutian islands with grid
cell thickness > standard
thickness of deepest wet
level (203m)

 Fresh water
at depth

Case not considered by the
initialization subroutine



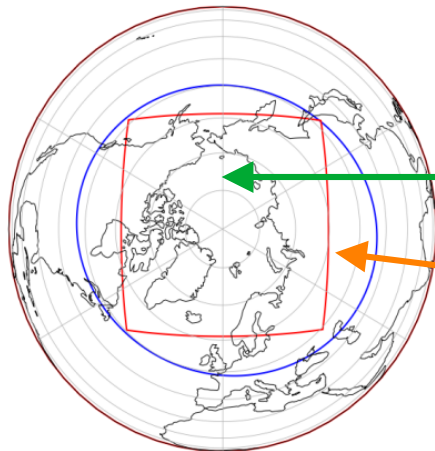


Challenge #1 : Include the OASIS code in the models

→ already done by Christoph Kittel (ULiège) and Pierre-Vincent Huot (UCL)



Challenge #2 : The models do not overlap everywhere.

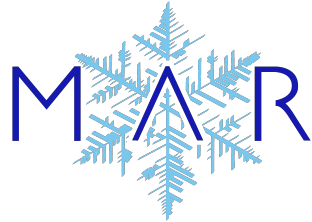


Mixed coupled simulations :

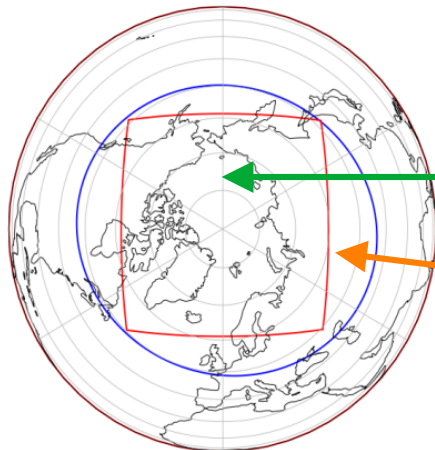
Models exchange fluxes and state variables

Large-scale surface conditions are prescribed

— NEMO-SI³ domain
— MAR domain



Challenge #3 : The models do not overlap everywhere.



— NEMO-SI³ domain
— MAR domain

Mixed coupled simulations :

Models exchange fluxes and state variables

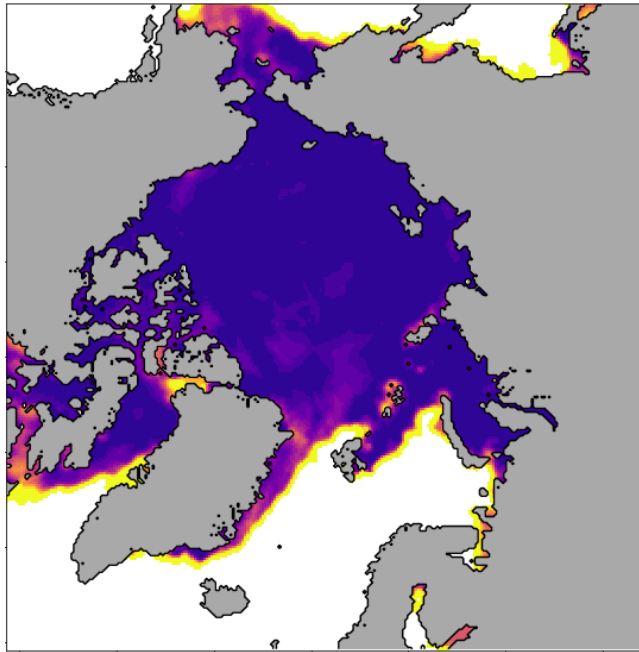
Large-scale surface conditions are prescribed

Need a mask to make the transition between the two type of areas !!

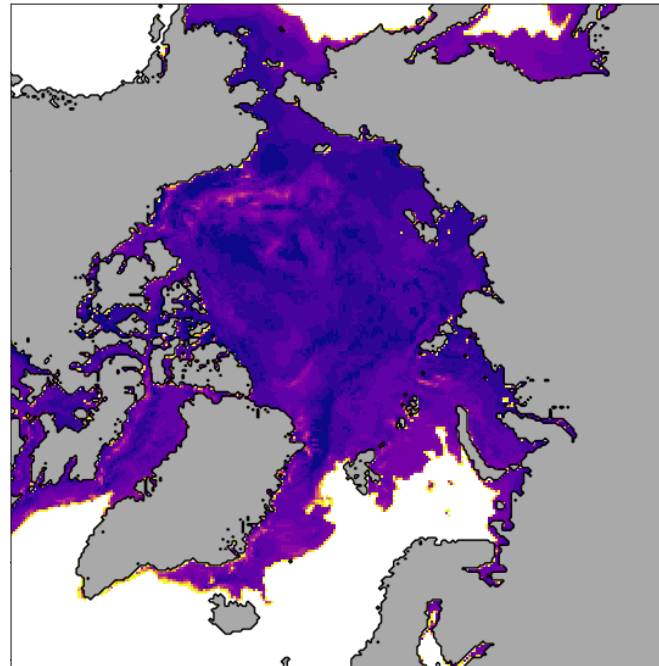
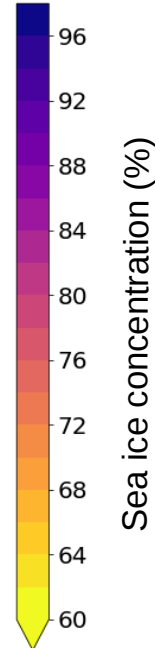
MAR

Arctic sea ice concentration (SIC)

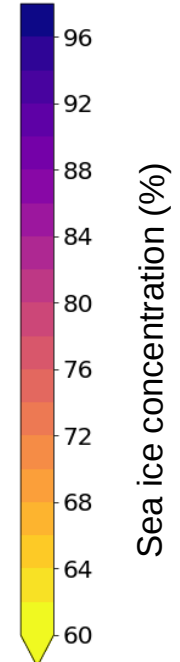
(01-Jan-2000)



SIC in MAR prescribed by ERA5



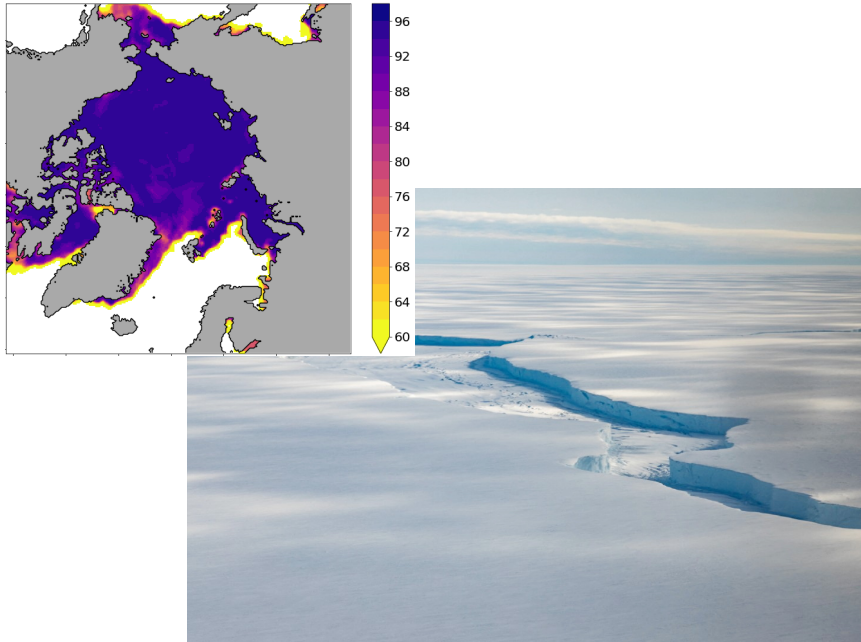
SIC in MAR when coupled to NEMO



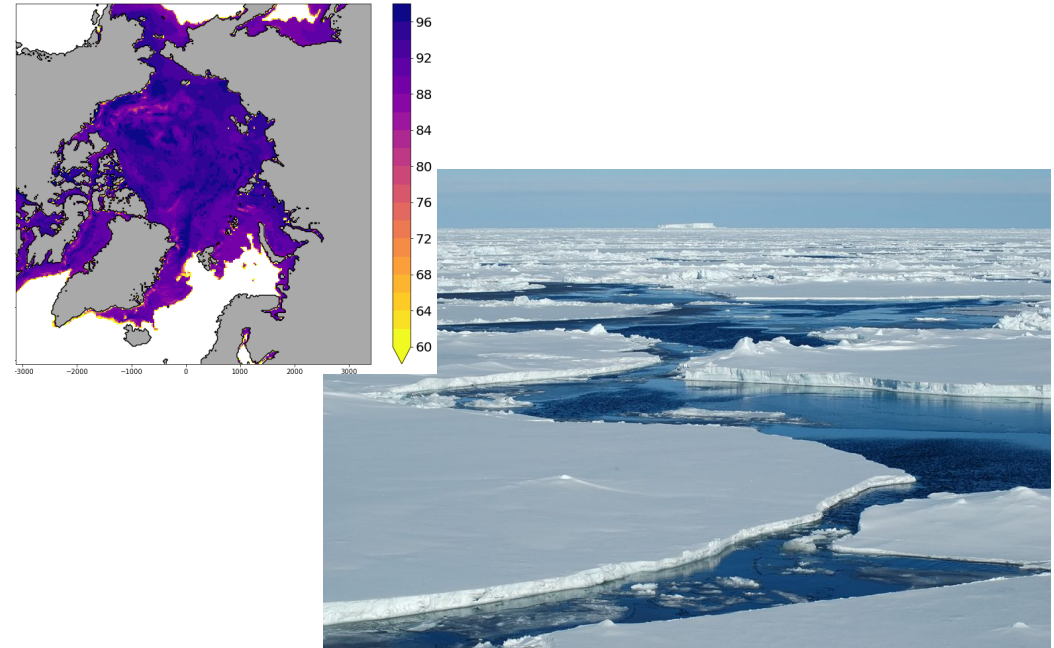
M A R

Arctic sea ice concentration (SIC)

(01-Jan-2000)



SIC in MAR prescribed by ERA5

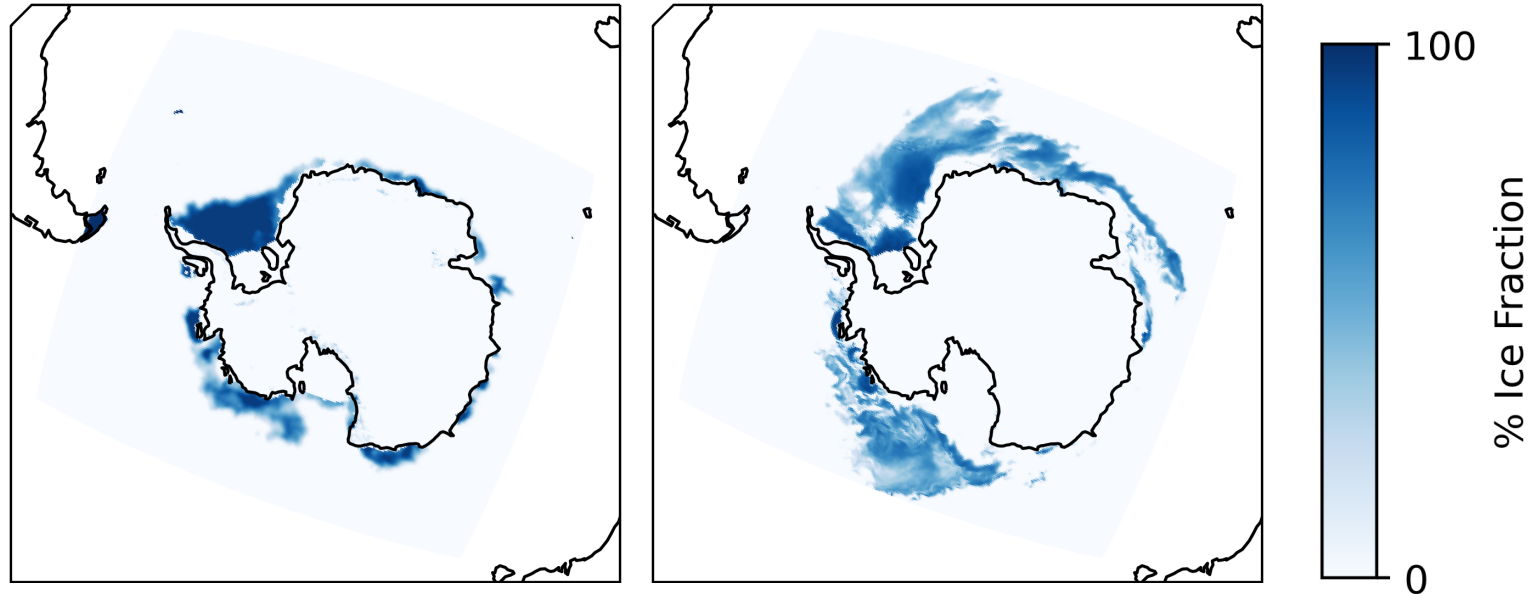


SIC in MAR when coupled to NEMO

MAR

Antarctic sea ice concentration (SIC)

(01-MAR-2000)



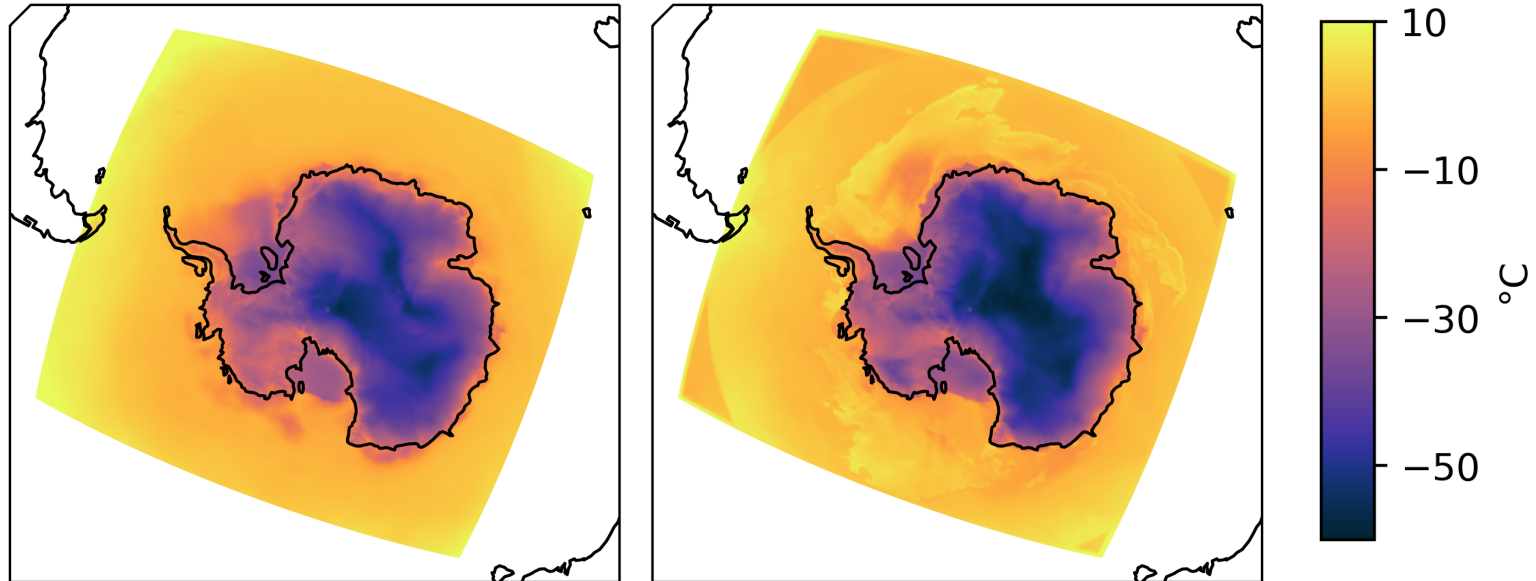
SIC in MAR prescribed by
ERA5

SIC in MAR when coupled
to NEMO

MAR

Antarctic surface temperature

(01-MAR-2000)



Surface T° in MAR
prescribed by ERA5

Surface T° in MAR when
coupled to NEMO

- The coupling of MAR-NEMO is a useful tool to study air-ocean-ice interaction processes
- There is better processes representation but results are not necessarily closer to reality than standalone models forced by ERA5 because they are less constrained by observations
- The coupling is promising for climate projections, notably to estimate Arctic and Antarctic amplifications

- Gurban Madec and the NEMO team (2017). *ORCA family : global ocean with tripolar grid*. Consulted online on March 2024 :
<https://www.nemo-ocean.eu/doc/node108.html#SECTION0019310000000000000000>
- Mathiot, P. & Jourdain, N. C. (2023) Southern Ocean warming and Antarctic ice shelf melting in conditions plausible by late 23rd century in a high-end scenario. *Ocean Science*, 19:6, 1595-1615, doi :<https://doi.org/10.5194/os-19-1595-2023>