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Saint Petersburg, Russia

Adaptation of NEMO-LIM3 model for multigrid high resolution Arctic simulation

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Our project description

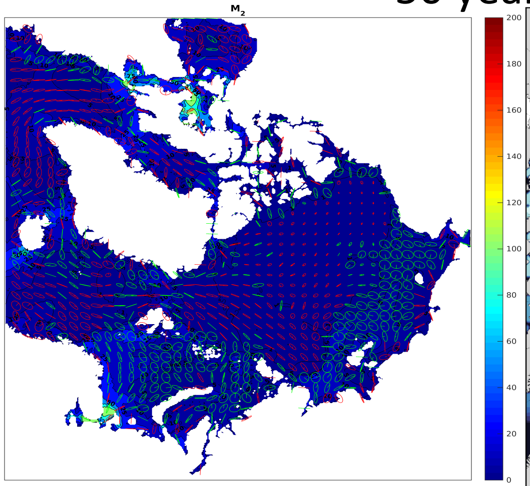
Initial setup:

- Mid-res to hi-res model of Russian Arctic
- Several models (Atmospheric, Spectral Wave, Ocean)
- 50 model years (1965-2015)
- Short time (initially, 1 year for entire project)

Goals:

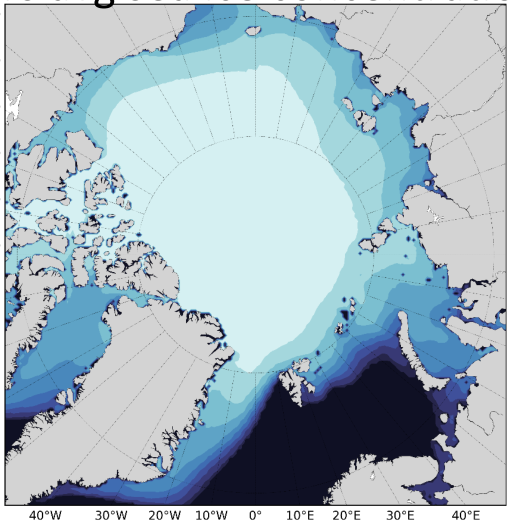
- 50 year time series
- Detailed ice field
- Results then are used in statistical forecasting system

Our team: http://en.escience.ifmo.ru



Tides amplitudes and ellipses

50 years avg sea ice concentration



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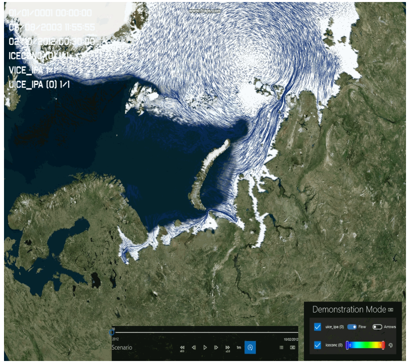


- WRF(15km scale, regular)
- NEMO(14km and 5km scale)
- WaveWatchIII (NEMO 14 km grid)
- Reanalyses\Datasets (various scales)

} All have different grids, coordinate systems and resolutions

Our model:

- NEMO 3.6+LIM3
- Curvilinear grid
- Two regional grids (mid-res for Arctic and hi-res for Russian seas of Arctic)
- Results from other models as forcing

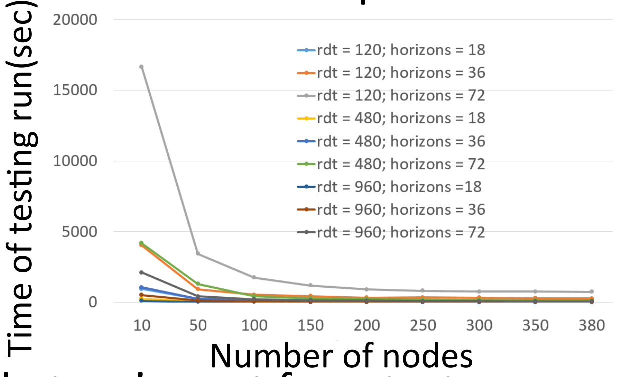
Problems:

- Regional configuration vs Global with nesting
- Grid area size vs computation time
- Vertical grid chaging vs stability
- Coupling of mid-res and hi-res
- Boundary data and conditions type

Time and stability tests and resulting pipeline

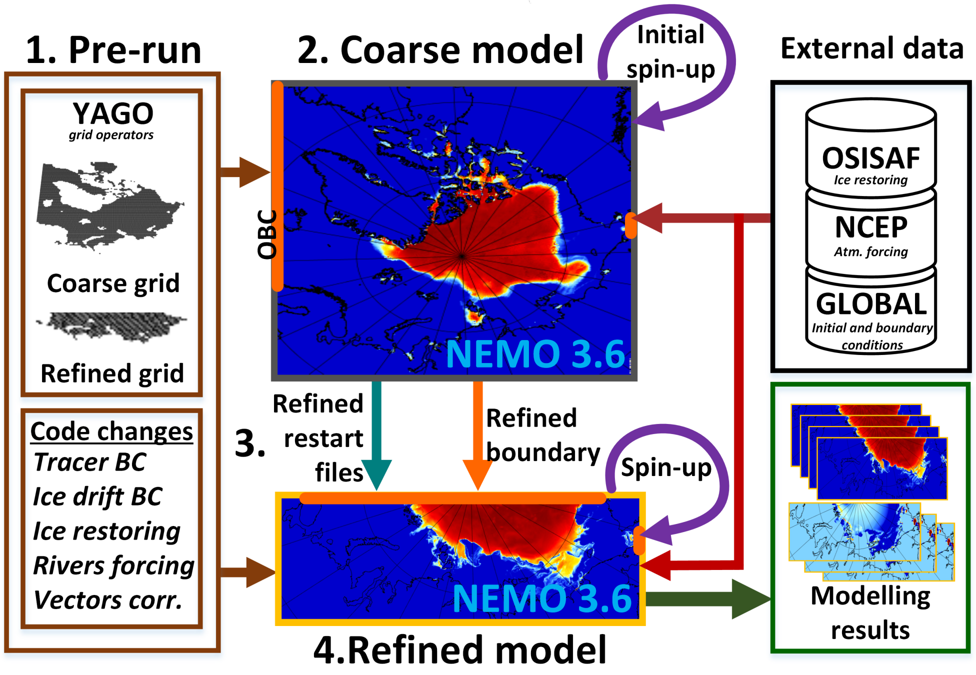
Performance tests (200 test runs):

- Time step (for 14km)
- Vertical grid
- Horizontal grid
- Number of computational nodes



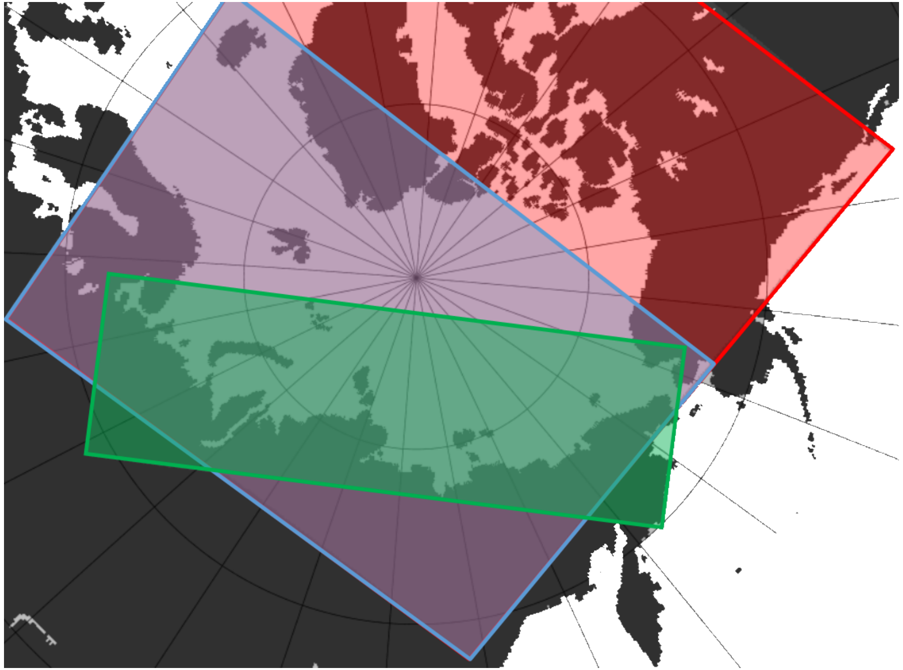
What we've got from tests:

- Horizontal grid
- Stable vertical grid
- Optimal timestep
- Optimal number of nodes



Our NEMO pipeline

NEMO-LIM3 grids coupling



Grids:

- NEMO large-scale (452x406, 14 km avg)
- Possible AGRIF grid (that contains region of interest)
- NEMO small-scale (1100x400, 5km avg)

Online:

+ No problems with data transfer
- Increased integration time
- Restart problems

Offline:

+ Fast and fast restarts
- Boundary coupling problems
- Additional tuning of hi-res model
- Double data amount

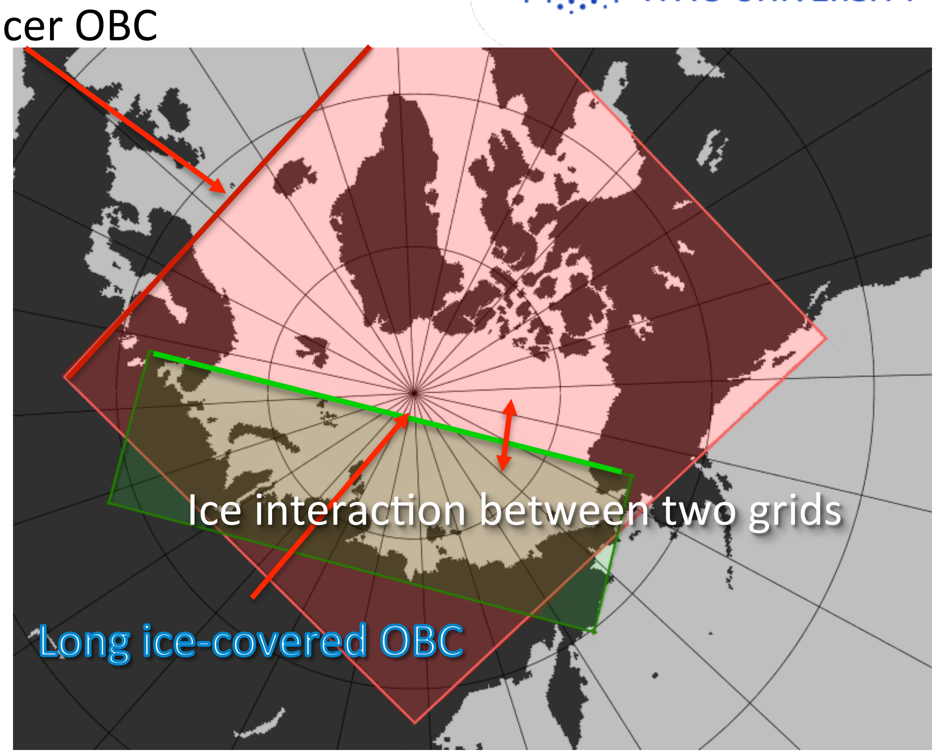
Challenges within our setup

Expected:

- Due to coupling with other models – different coordinate systems and grids
- Long open boundaries
- Long ice-covered open boundaries
- Data transfer mid-res -> hi-res

Unexpected:

- Ice model instability at the long boundary



Grid Solution:
YAGO[2]: yet another grid operator (author S.Kosukhin):

- WRF (regular, auto generated) -> NEMO (curvilinear)
- Minimal distortion (as close to regular grid as possible)

[2]Yago: Yet another gridded data operator (2018). doi:10.5281/zenodo.1217892. URL https://github.com/skosukhin/yago

Different coordinate systems and grids

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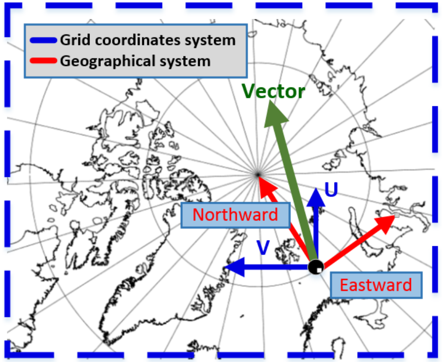
YAGO: yet another grid operator (author S.Kosukhin):

- WRF (regular, autogenerated) -> NEMO (curvilinear)
- Minimal distortion (used to be as close to regular grid as possible)

Rotation from E-N to the used in NEMO grid and vice versa to keep everything in one notation:

- Use ocean reanalyses and ice satellite databases as a boundary and initial conditions
- Rotate model data back from NEMO to E-N to compare with reanalyses



Eastward-northward -> NEMO rotation

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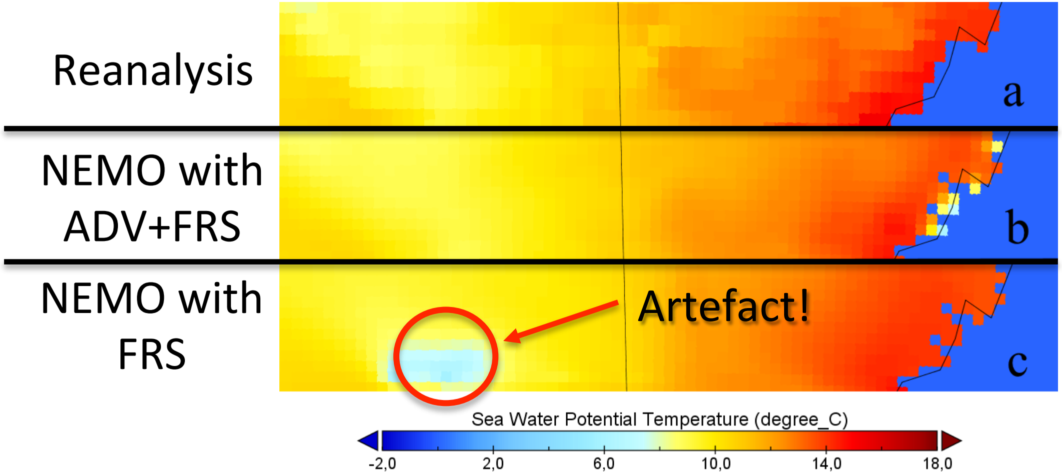
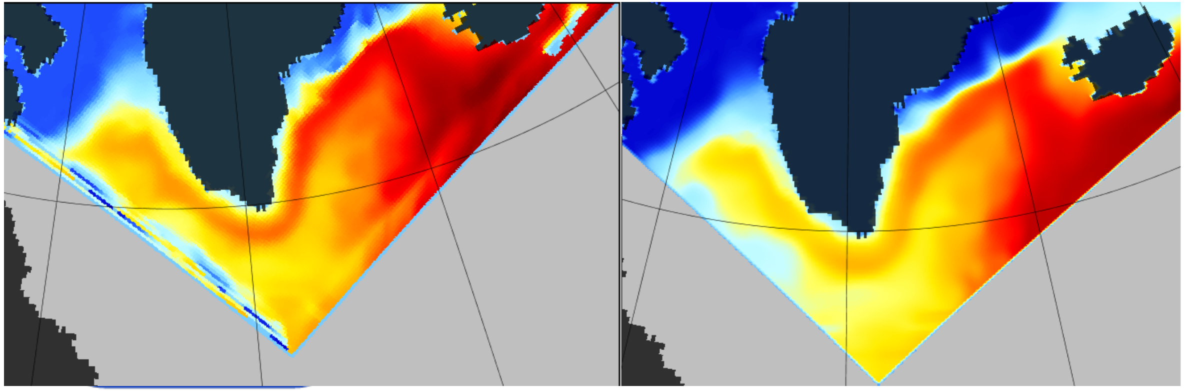
Long open boundaries: tracers I





Long tracer open boundary:

- Inflow and outflow changes
- Reducing computation time and make grid as small as possible
- How to threat low-res boundary data for mid-res grid
- Artefacts
- Every long open boundary modelling case is unique?

- Corner with Flather (from test runs)

Long open boundaries: tracers II

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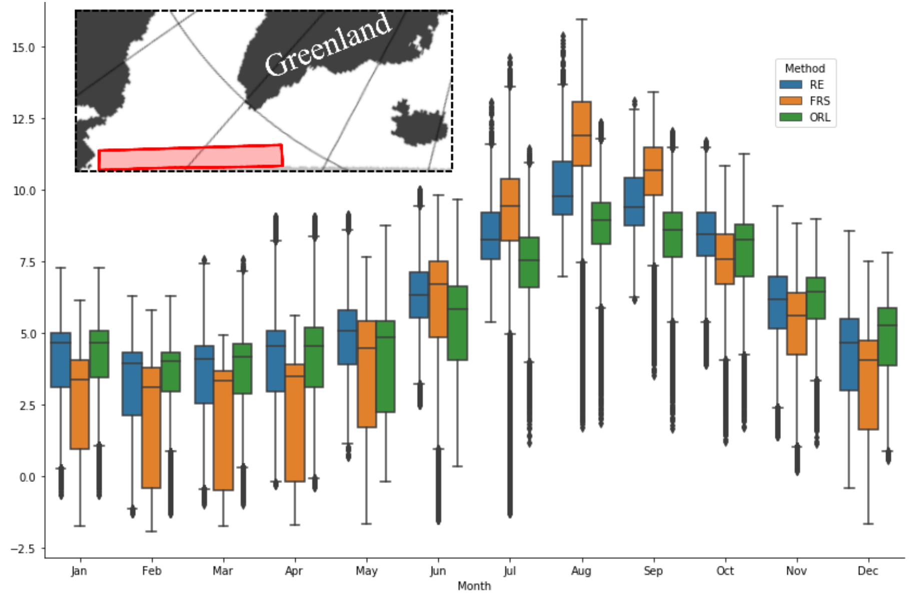


Long tracer open boundary:

- Inflow and outflow changes
- Artefacts
- Every long open boundary modelling case is unique?

This trick is used to compensate low-res boundary data with more physically correct boundary conditions

$$\varphi(x,t_{n+1}) = \begin{cases} \varphi(x,t_n)+FRS, & \varphi \text{ inflow at } x \\ \varphi(x,t_n)+ADV, & \varphi \text{ outflow at } x \end{cases}$$

FRS – from NEMO

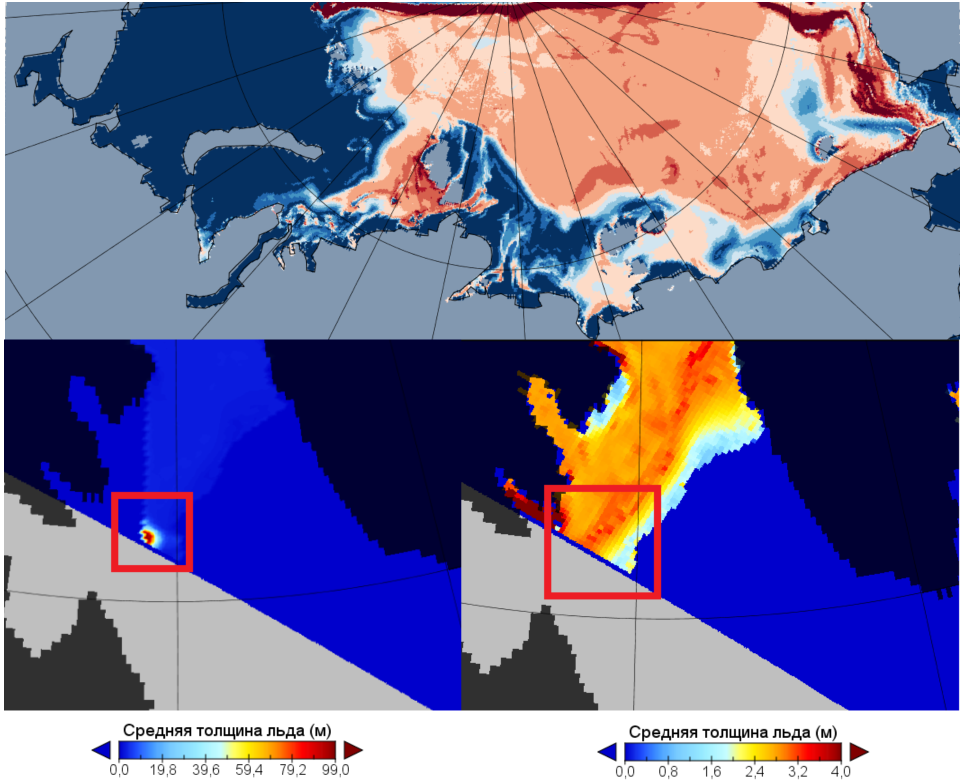
ADV[1]: $\partial\varphi/\partial t = (u+c_T)\,\partial\varphi/\partial n$, c_T − phase velocity (from ORL)

[1]Palma, E. D., & Matano, R. P. (2000). On the implementation of open boundary conditions for a general circulation model: The three-dimensional case. *Journal of Geophysical Research: Oceans*, *105*(C4), 8605-8627.

For the wide open boundaries it is useful to separate inflow and outflow

Long open boundaries: ice

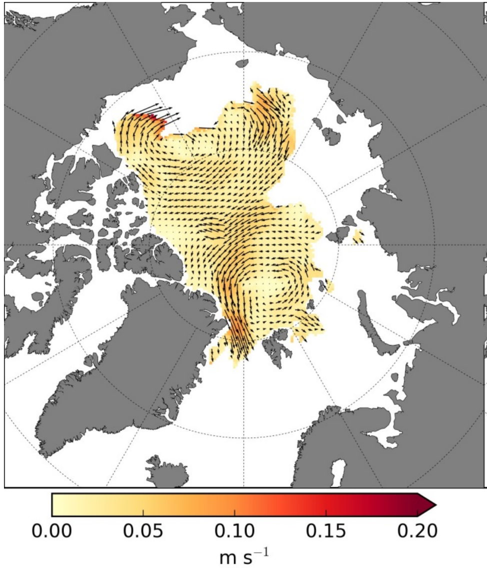
Ice tend to 'stack' at the boundary and show invalid behavior within the area



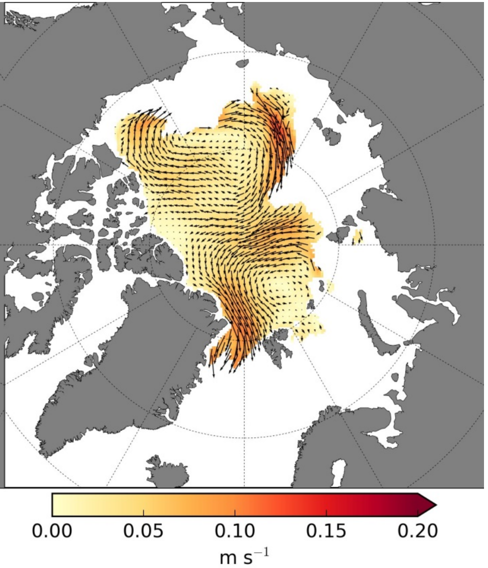
Why ice can 'stack':

- LIM2 type boundary conditions
- Existing ice drift scheme is not full
- 'Non-classical' grid

Long open boundaries: ice

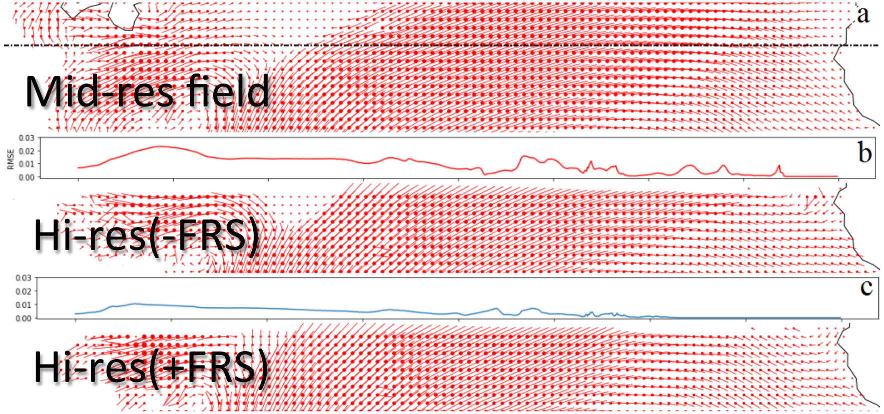


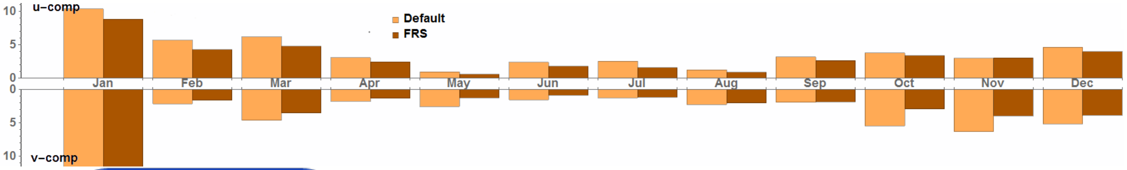
Satellite



NEMO+LIM3

Ice tend to show invalid drift behavior at the boundary





Additional FRS conditions on the drift help ice to move out of the boundary and make ice drift field closer to real

Ice interaction between two grids

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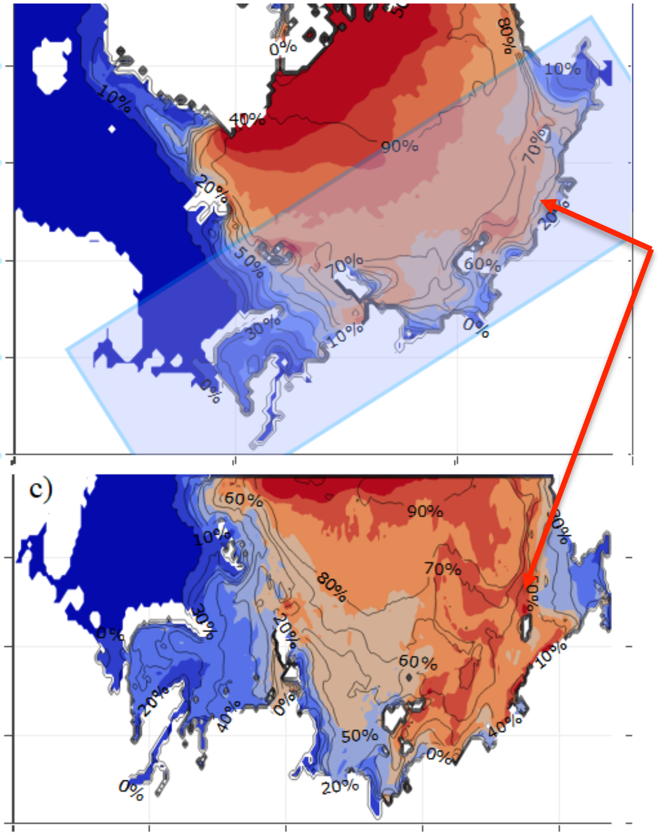
Is the interpolated termohaline field from the large scale is valid for the small scale?

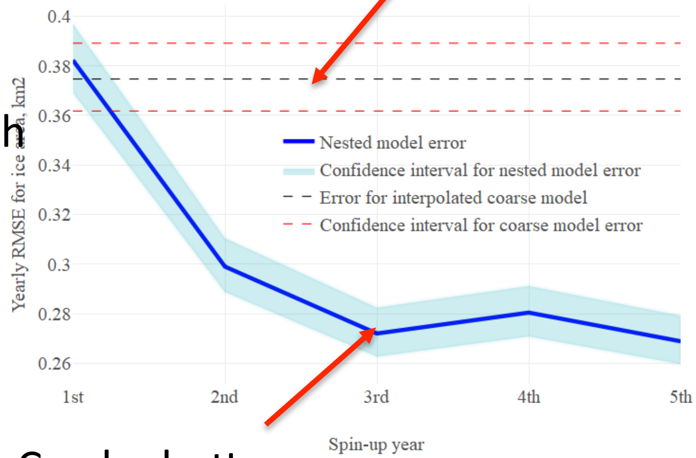


Full spin-up time is different for different time-scales

5 year spin-up from scratch

There is no way to use data from external source (satellite, mid-res), so we introduce ice data assimilation

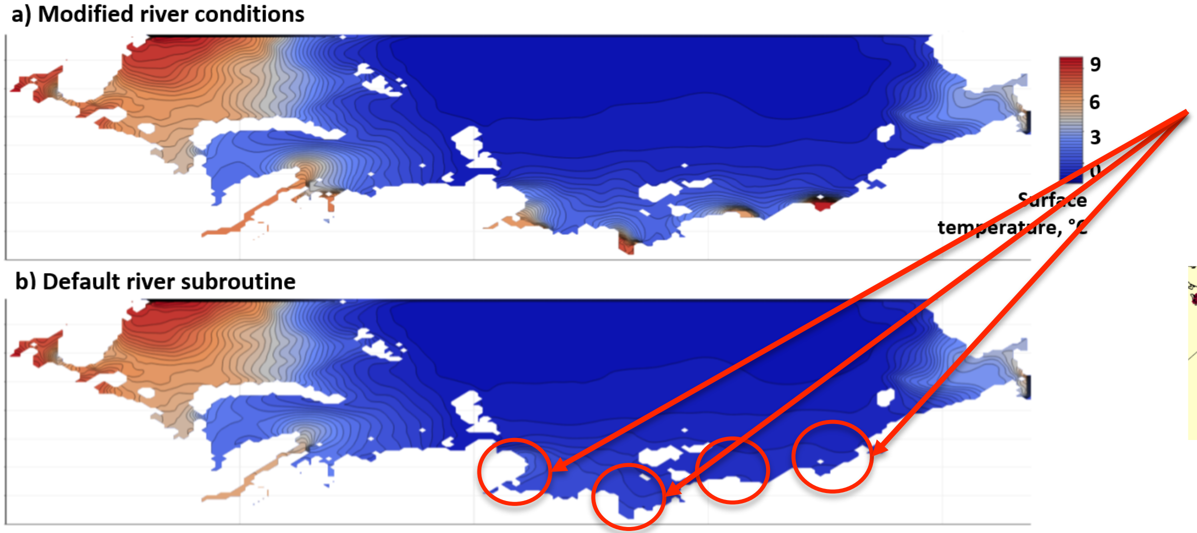
10 year mid-res spin-up RMSE



Can be better

After mid-res spin-up, additional hi-res spin-up is required

Rivers



Summer averaged surface temperature

- Small rivers tend to freeze even with the introduced in NEMO fix

- River mask is required for the temperature fix in the river mouth

Conclusions and future plans

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Conclusions:

- Two grids can be 'offline' coupled
- 'Offline' coupling allows one to select nested grid in a more flexible way, but flexibility introduces some challenges
- One could live with long open boundaries, without cutting them off, but special approach is required for every case
- Additional spin-up required when initial field is transferred between mid-res and hi-res

Future plans:

- Make NEMO4-based model
- Results discussion article
- Ice restoration article

Preprint: https://arxiv.org/abs/1810.03657

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Thank you!

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