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Saint Petersburg, Russia

Spin-up technique for long-term Arctic ice simulation

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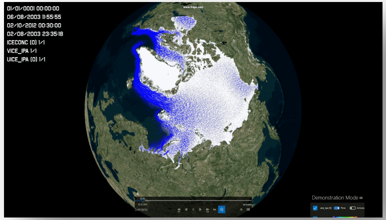
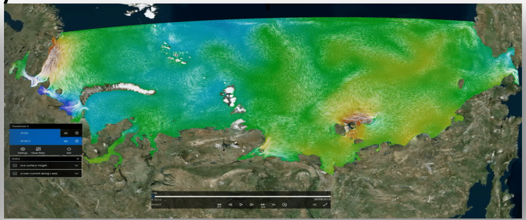
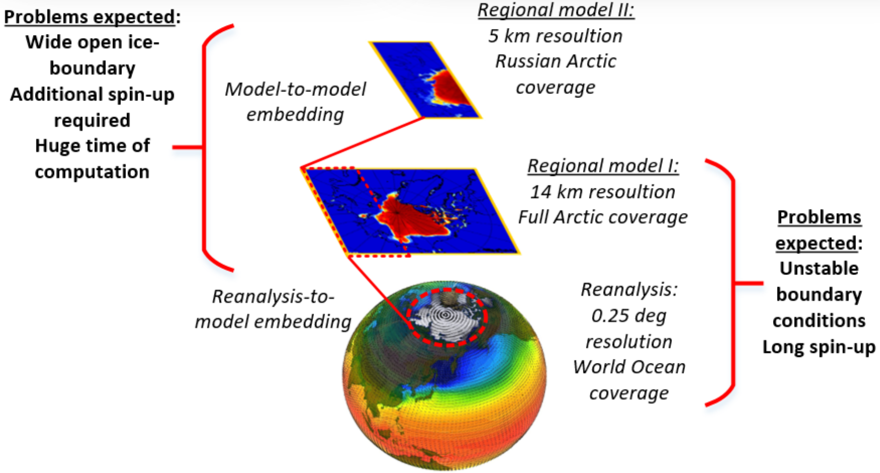
NEMO Users Meeting, 2018, Toulouse, France

Task overview and problem statement

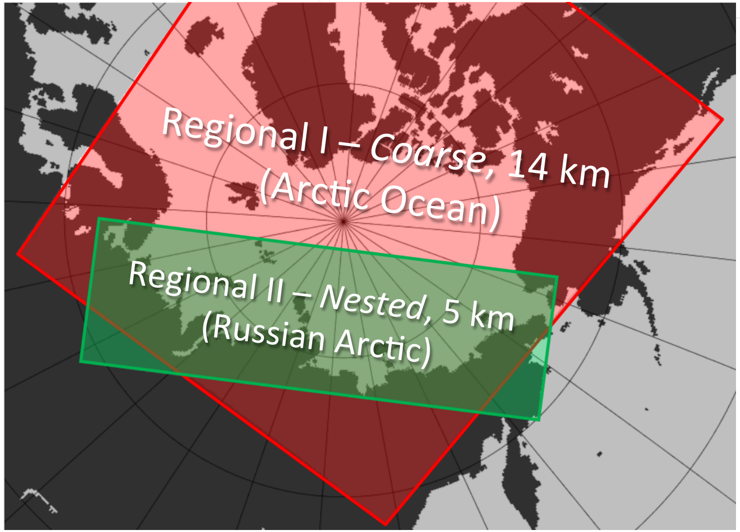
The aim: 1965-2017 hourly dataset with 12 variables*







The modelling strategy for 2-stage NEMO/LIM3 model used in long-term Arctic simulation



Target areas spatial location

Models: NEMO 3.6 + LIM3

Expected simulation time with 80-cores HPC:

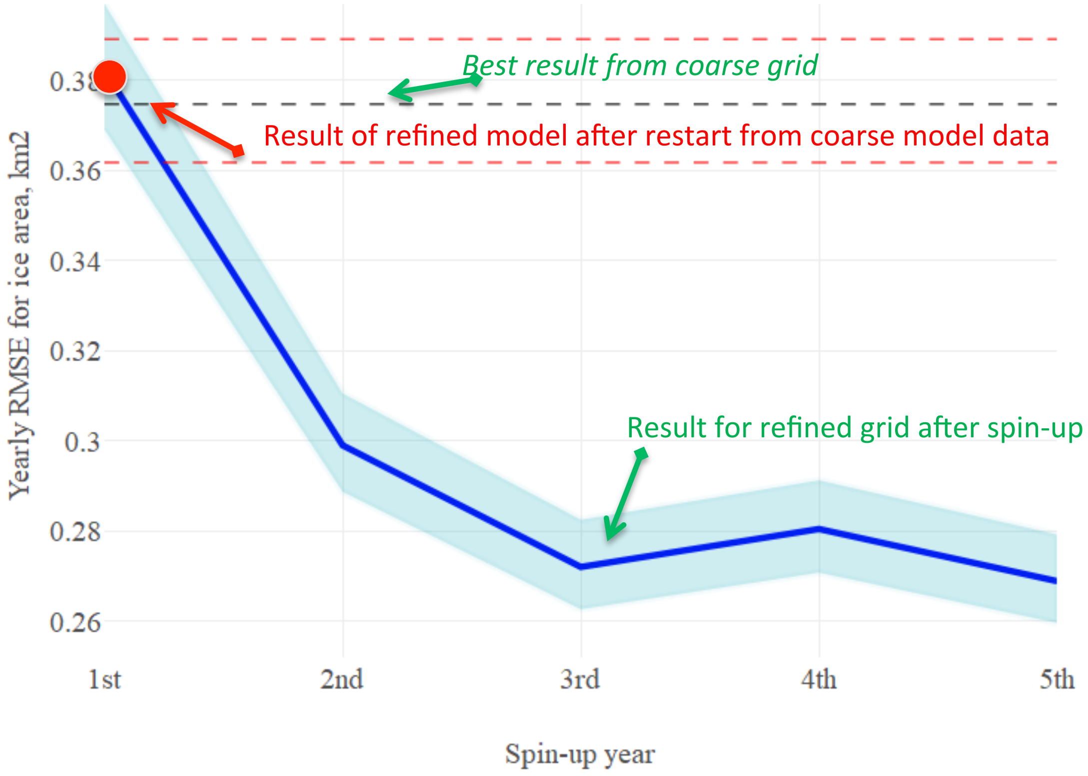
48 days (*coarse*) + 140 days (*refined*)

Total time before deadline: 1 year

The volume of datasets: 50Tb

*Self-developed TerraXT GIS is used to visualize the ice concentration, drift, sea currents and surface height (as an example)

“Offline” grid-to-grid transfer issue



Secondary spin-up for nested grid model

Main issues and constraints:

- We need to run coarse and nested NEMO configurations separately (due to the computational limitations)
- Spin up of coarse model takes about 10 model years
- One of the main problems is stable ice annual dynamics
- Interpolation of restart files causes problems and requires additional spin-up for refined grid
- We want to provide many experiments “from scratch” to calibrate parameters and increase the quality of final dataset

The motivation of the ice restoration idea

Foundation		Pro and contra		Conclusion
Code	*Data*	*Possible benefits*	*Possible problems*	*Research question*
sbc_ssr restoration subroutine already exists in NEMO and can be used as base for modification	The satellite observations are available for the most part of the simulation period	Accelerated spin-up of model Better quality of results	Instability of model (no convergence) – additional experiments required	The research question is «Can specific ice state restoration methods help us to intensify the initial spin-up of complex 2-stage model?»

sbcssr_ice: heat flux based ice restoration method

Baseline: surface temparature/salinity restoring implemented in NEMO (sbc_ssr)

$$Q_{ns} = Q^o_{ns} + \frac{dQ}{dT}\left(T|_{k=1} - SST_{Obs}\right)$$

where SST is a sea surface temperature field (observed or climatological), T is the model surface layer temperature and dQ/dT is a negative feedback coefficient usually taken equal to −40 W/m2/K.

*(from **NEMO ocean engine** (G. Madec), Note du Pôle de modélisation, Institut Pierre-Simon Laplace (IPSL), France, No 27, 2008)*

Alternative solution: the under-ice temperature correction (experiment was conducted, but the model become **unstable**)

From concept to implementation

I. Explore data (coverage, uncertainty, artefacts)

II. Implement a more robust approach

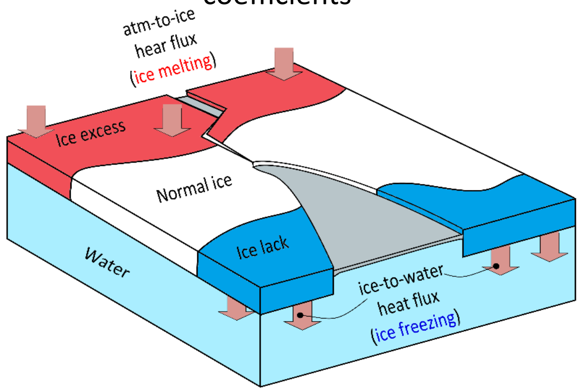
III. Calibrate melt/freeze coefficients

IV. Validate the developed methods

Proposed flux-based ice restoration concept:

$$Q = \begin{cases} Q + C_{melt} \cdot \widetilde{Q}, & \text{if there is too much ice} \\ Q - C_{freez} \cdot \widetilde{Q}, & \text{if there is not enough ice.} \end{cases}$$

Q – heat flux, $\widetilde{Q}$ – damping term, C_{melt} и C_{freez} - coefficients

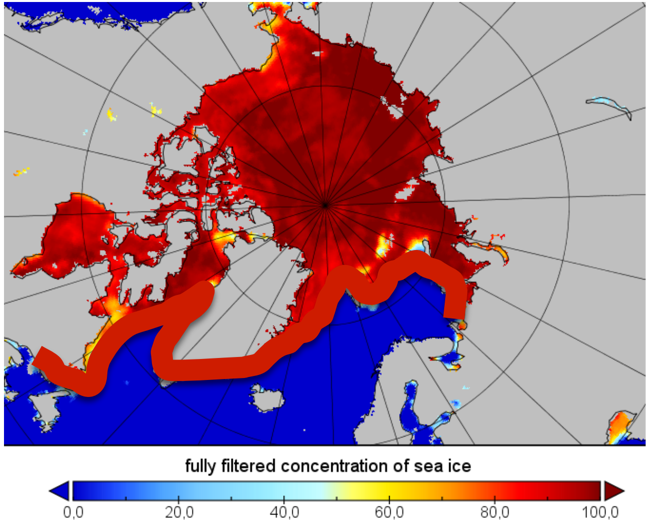


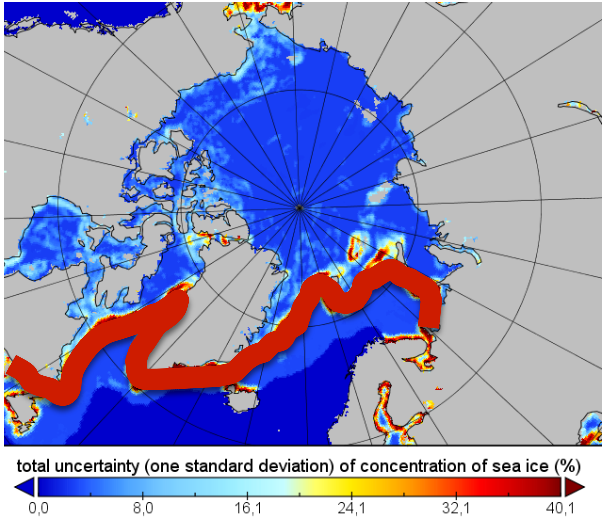
Visual representation of flux-based restoration

Heat fluxes to correct:
qsr_ice (*solar heat flux over ice* , increase to melt),
qsr_oce (*non solar heat flux over ocean* , increase to freeze)

Datasets and observations: Concentration

Dataset: **OSISAF v2.0***
Time coverage: daily, 1979-2015





<u>Details</u>:

- Daily OSI-SAF data interpolated to grid
- NEMO in-fly time interpolation enabled

<u>Possible issues</u>:

- High uncertainty near the edge
- Strange values near the coast (concentration too high for summer)

**Eastwood S. et al. Global sea ice concentration reprocessing: product user manual //Product OSI-409, Version. – 2010. – T. 1.*

We can try to pre-process the data and catch the artifacts but may be it's better to adapt the algorithm to it?

Weighted restoration approach

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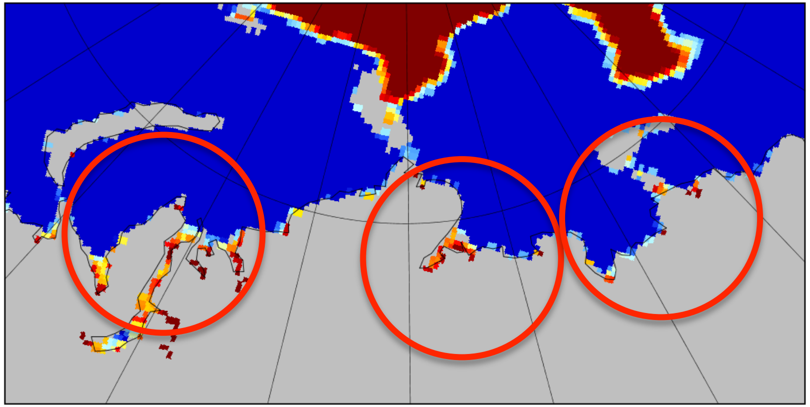
OSISAF concentration data for 2015.09.26

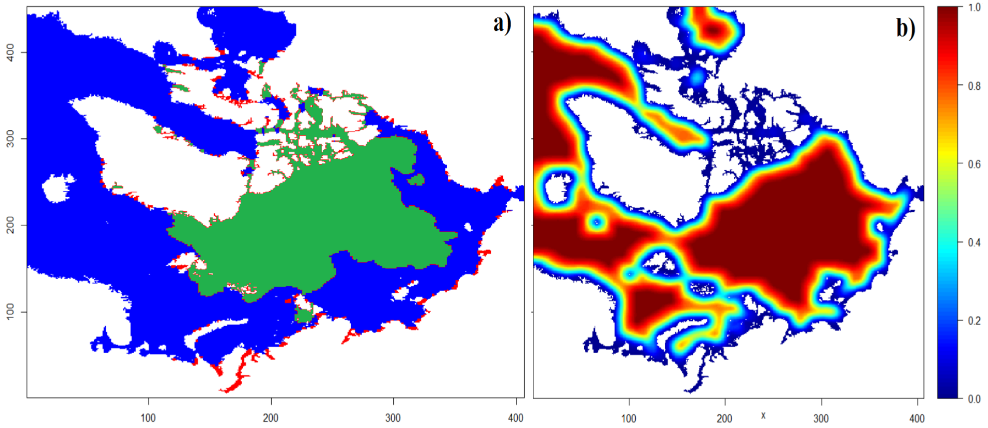


fully filtered concentration of sea ice using atmospheric correction of brightness temperatures and open water filters (%)

0,0 10,0 20,0 30,0 40,0 50,0

Coastal artifacts[2]

Restoration mask



2. Compared with AARI ice charts (http://www.aari.ru/odata/_d0015.php?lang=1)

Wrong values (induced by anomalies in brightness temperature[1]) can decrease the quality of model data with applied restoration

1. Maslanik J. A., Serreze M. C., Barry R. G. Recent decreases in Arctic summer ice cover and linkages to atmospheric circulation anomalies // Geophysical Research Letters. – 1996. – T. 23. – №. 13. – C. 1677-1680.

Restoration weights mask generated based at coastal proximity and saved in *restoration_mask.nc* file

The new term w in restoration equation:

$$Q_{i,j} = \begin{cases} Q_{i,j} + (n_{i,j}^{sat} - n_{i,j}^{mod}) \cdot w_{i,j}^{rest} \cdot C_{rest}^{(freez)} \\ Q_{i,j} + (h_{i,j}^{sat} - h_{i,j}^{mod}) \cdot w_{i,j}^{rest} \cdot C_{rest}^{(freez)} \end{cases}$$

Datasets and observations: Thickness

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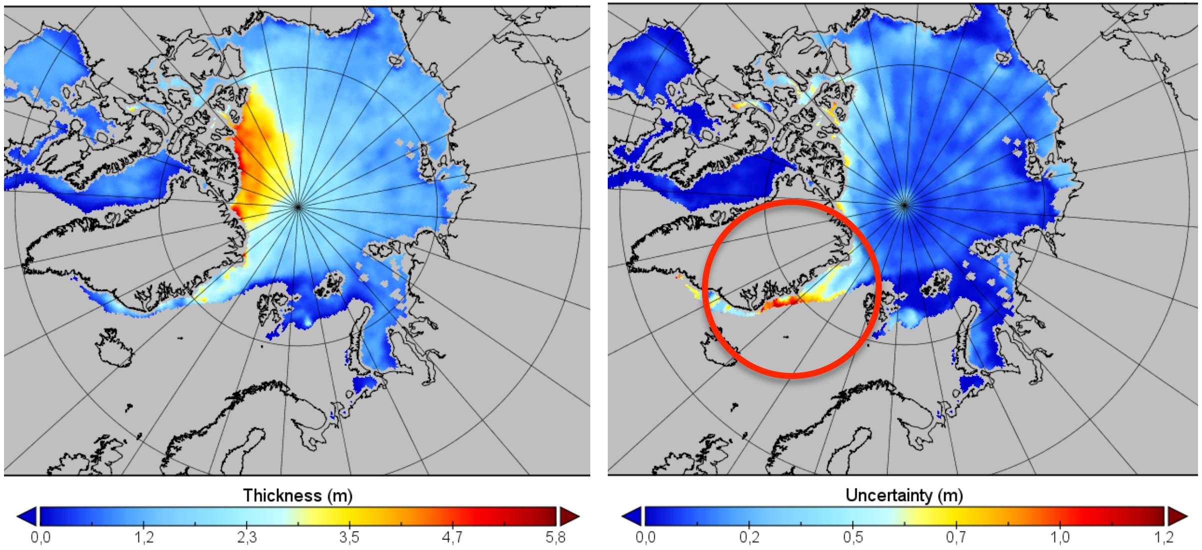
Dataset: **CryoSat 2** + **SMOS***
Time coverage: weekly, 2010-2016 (no data between March and October)



Details:

- Weekly CR2SMOS data interpolated to daily grid
- No-data summer range set to 0
- NEMO in-fly time interpolation disabled

Possible issues:

- High uncertainty near the edge
- No values in cells near the coast
- Only cell averaged values are available (instead ice categories of LIM3)

*Ricker R. et al. *A weekly Arctic sea-ice thickness data record from merged CryoSat-2 and SMOS satellite data //Cryosphere. – 2017. – T. 11. – №. 4. – C. 1607-1623.*

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The knowledge about uncertainty of observations can be used too

The final version of ice restoration algorithm

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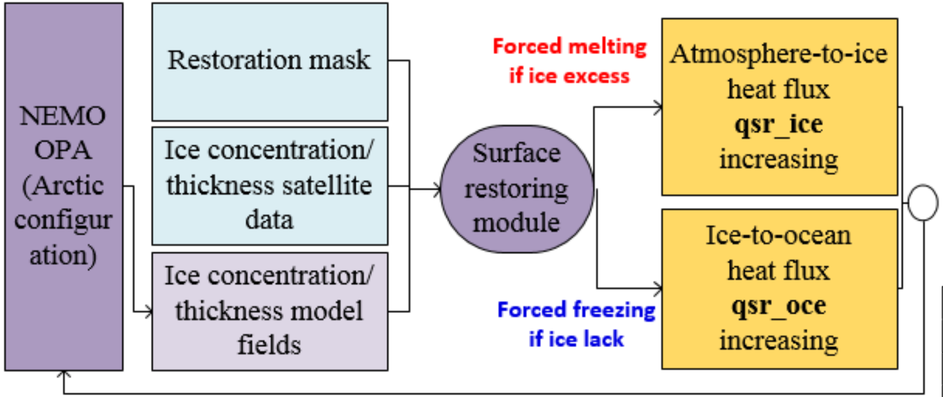

Ice restoration workflow

<u>Balance of fluxes:</u>

If ice should be significantly decreased – more heat to **qsr_ice** (*solar heat flux over ice)*

If ice should be significantly increased – more heat to **qsr_oce (**non solar heat flux over ocean**)**

Error metrics for model runs with different ice restoration types

Type	RMSE (th. of km^2)	MAE (th. of km^2)
No restoration	511	416
Concentration rest.	275	223
Concentration+Thickness rest.	**261**	**208**

$$Q_{i,j} = \begin{cases} Q_{i,j} + (n^{sat}_{i,j} - n^{mod}_{i,j}) \cdot w^{rest}_{i,j} \cdot C^{(melt)}_{rest}, & \text{if } (n^{sat}_{i,j} - n^{mod}_{i,j}) < 0 \text{ and } \text{abs}(n^{sat}_{i,j} - n^{mod}_{i,j}) > \sigma \\ Q_{i,j} + (h^{sat}_{i,j} - h^{mod}_{i,j}) \cdot w^{rest}_{i,j} \cdot C^{(melt)}_{rest}, & \text{if } (h^{sat}_{i,j} - h^{mod}_{i,j}) < 0 \text{ and } \text{abs}(h^{sat}_{i,j} - h^{mod}_{i,j}) > \sigma \text{ and } h^{sat}_{i,j} \neq 0. \\ Q_{i,j} + (n^{sat}_{i,j} - n^{mod}_{i,j}) \cdot w^{rest}_{i,j} \cdot C^{(freez)}_{rest}, & \text{if } (n^{sat}_{i,j} - n^{mod}_{i,j}) > 0 \text{ and } \text{abs}(n^{sat}_{i,j} - n^{mod}_{i,j}) > \sigma \\ Q_{i,j} + (h^{sat}_{i,j} - h^{mod}_{i,j}) \cdot w^{rest}_{i,j} \cdot C^{(freez)}_{rest}, & \text{if } (h^{sat}_{i,j} - h^{mod}_{i,j}) > 0 \text{ and } \text{abs}(h^{sat}_{i,j} - h^{mod}_{i,j}) > \sigma \text{ and } h^{sat}_{i,j} \neq 0. \end{cases}$$

*For the ice melting case, Q is **qsr_oce** , for ice freezing - **qsr _ice**. In the equation, n^{sat} and n^{mod} represent the ice concentration in satellite data and in the model respectively, σ is the confidence interval, taken from satellite total error and dispersion, h^{sat} and h^{mod} are the corresponding ice thicknesses and $w^{rest}_{i,j}$ is the restoration correction weighted mask.*

The new *namelist* parameters and its calibration

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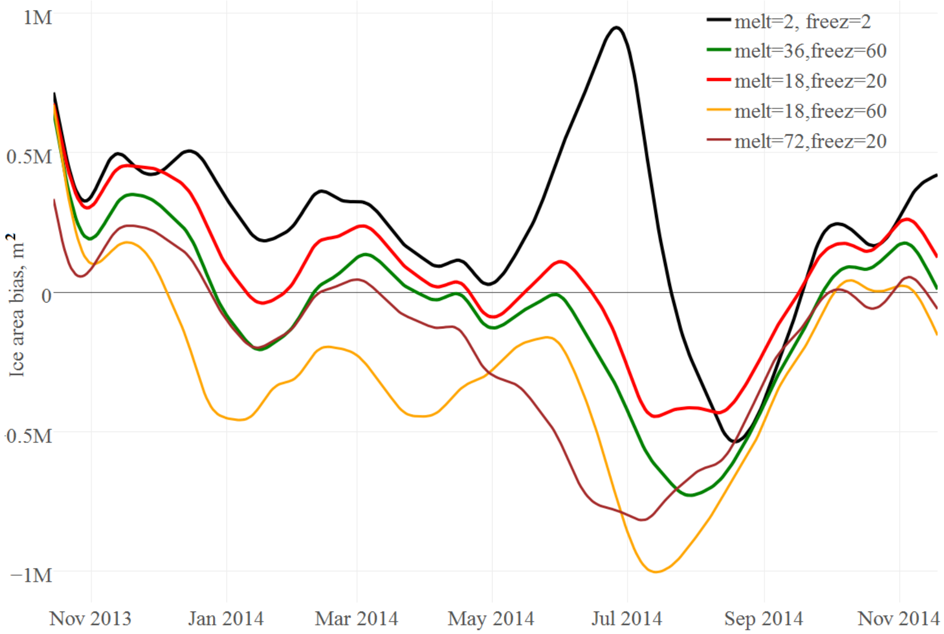

Restoration error for different restoration weights set

```
!-----------------------------------------------------------------------
&namsbc_ssr    !   surface boundary condition : sea surface restoring
!-----------------------------------------------------------------------
!              !  file name  ! frequency (hours) ! variable  ! time interp. !  clim  ! 'yearly'/
!              !             !  (if <0  months)  !   name    !  (logical)   !  (T/F) ! 'monthly'
...
sn_ssi       = 'conc'  ,        24         ,  'ice_conc'    ,    .true.    , .false. , 'yearly'
sn_ssit      = 'cr2smos_th'  ,       24          ,  'Thickness'   ,    .true.    , .false. , '
sn_ssit_error     = 'cr2smos_th'  ,       24          ,  'Uncertainty'  ,    .true.    , .fa
sn_resto     = 'restoring_mask'  ,      -1          ,  'rratio'    ,    .true.    , .true. , '

cn_dir       = './restoring/'      !  root directory for the location of the runoff files
...
nn_ssir      =     1      !  add a retroaction term in the surface ice conc (=1) or not (=0)
rn_dqdi_melt      =   18     !  magnitude of the retroaction on ice conc     [W/m2/K]
rn_dqdi_freez     = 20     !  magnitude of the retroaction on ice conc     [W/m2/K]
rn_dqdi_thick_melt      =   18     !  magnitude of the retroaction on ice thickness     [W/m2/K]
rn_dqdi_thick_freez     = 36     !  magnitude of the retroaction on ice thickness     [W/m2/K]
...
```

Id	Freez. coeff. (W/m²/%)	Melt. coeff. (W/m²/%)	Bias (10^3 km²)	RMSE (10^3 km²)	MAE (10^3 km²)
1	2	2	239	400	338
2	36	60	-73	306	230
3	**18**	**20**	**58**	**265**	**213**
4	18	60	-290	438	348
5	72	20	–195	368	267

Error metrics for different restoration weights rn_ddqi_melt and rn_ddqi_freez

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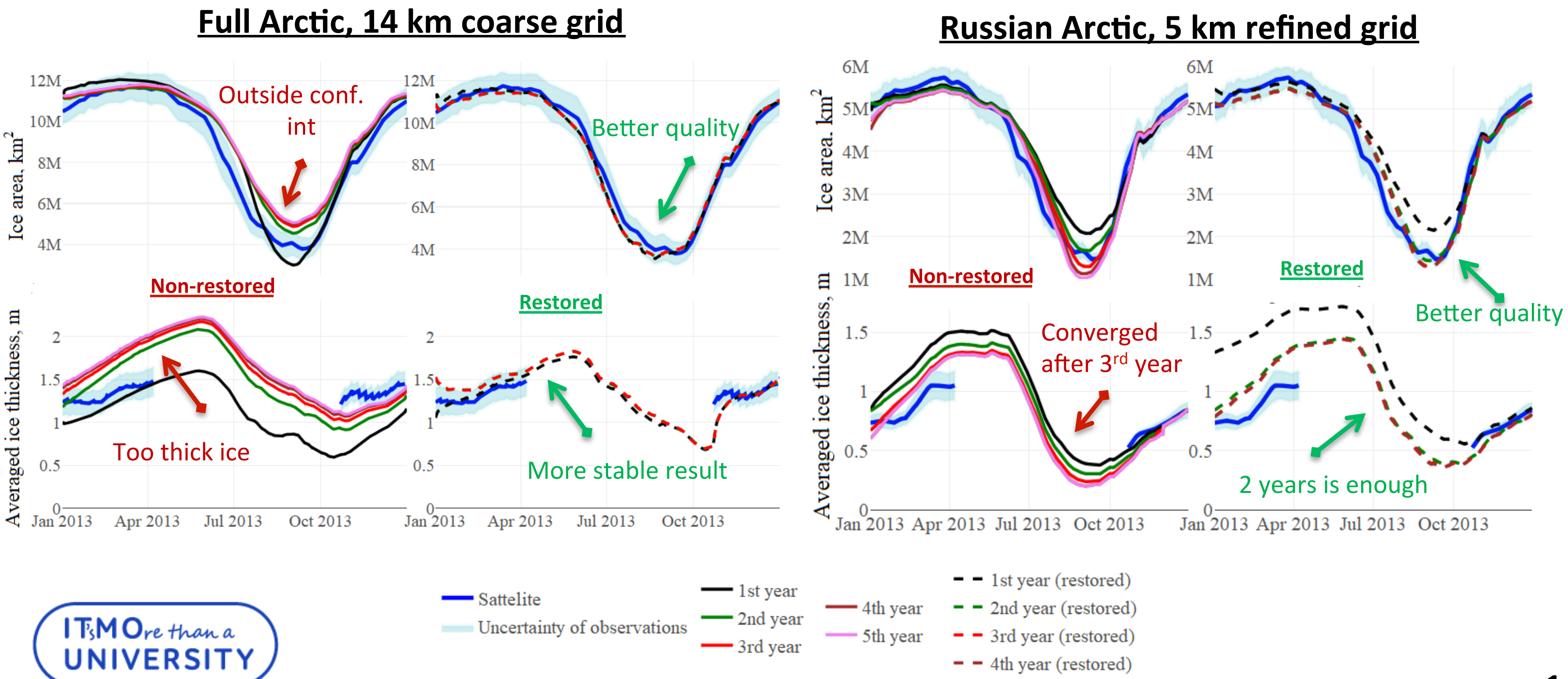
The validation of the restoration technique



The results of validation

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Year	Non-restored model				Restored model			
	*Area RMSE, km²*10⁶*	*Thickness RMSE*, m*	*Area MAE, km²*10⁶*	*Thickness MAE*, m*	*Area RMSE, km²*10⁶*	*Thickness RMSE*, m*	*Area MAE, km²*10⁶*	*Thickness MAE*, m*
Coarse (14km) grid								
1	0.69	0.34	0.57	0.28	0.34	0.09	0.27	0.06
2	0.76	0.28	0.59	0.26	**0.33**	**0.13**	**0.27**	**0.11**
3	0.89	0.31	0.70	0.29	0.33	0.13	0.28	0.11
4	0.94	0.33	0.76	0.30	0.33	0.13	0.28	0.11
Nested (5km) grid								
1	0.38	0.26	0.28	0.20	0.43	0.48	0.30	0.37
2	0.29	0.19	0.23	0.16	0.26	0.19	0.20	0.16
3	0.27	0.13	0.23	0.11	0.25	0.17	0.20	0.14
4	0.28	0.12	0.24	0.10	0.25	0.17	0.20	0.14

**Only for time range with observations available*

The nested model still requires additional calibration of thickness restoration coefficients

Conclusions and details

Conclusions:

- The transition from a coarse grid to refined requires a secondary spin-up for ice state.
- The developed algorithm can be applied even for non-ideal real-world datasets with missing values and artifacts.
- The methods for "soft" assimilation of ice observations allows to accelerate the convergence of the model and increase the quality.
- The positive effect of restoration is higher for coarse grid model .

The details of research:

- The additional details of the project's technical part is discussed in paper "Adaptation of NEMO-LIM3 model for multigrid high resolution Arctic simulation" (pre-print in available in *https://arxiv.org/abs/1810.03657*) [Alexander Hvatov will present details in next section].
- The project's results overview, analysis and validation of 50-years simulation results of Arctic Seas will be presented in separate paper (work in progress).

Modified source codes:

Available in *https://github.com/nicl-nno/nemo-multigrid-adaptation* under CeCILL license

Thank you!

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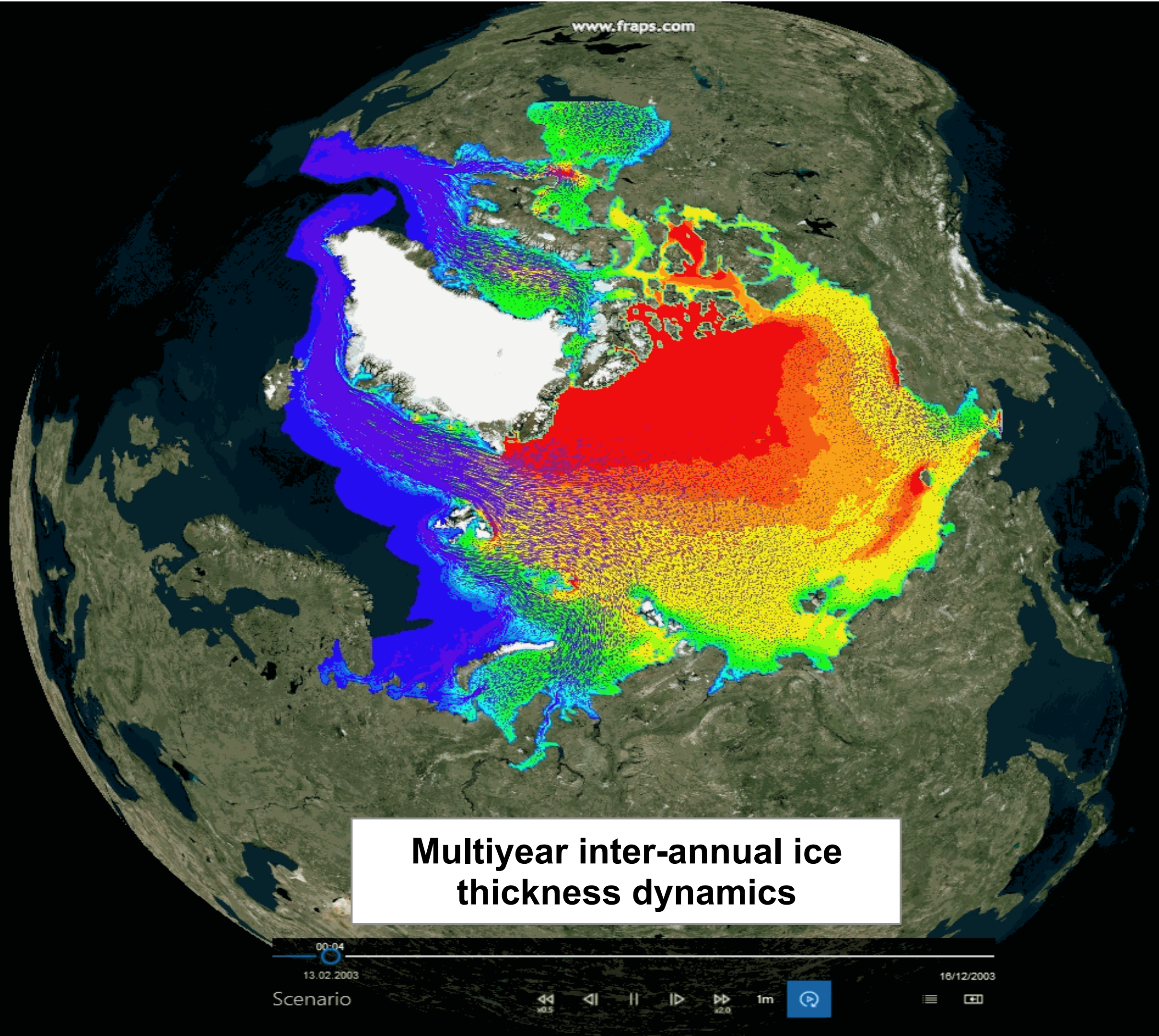
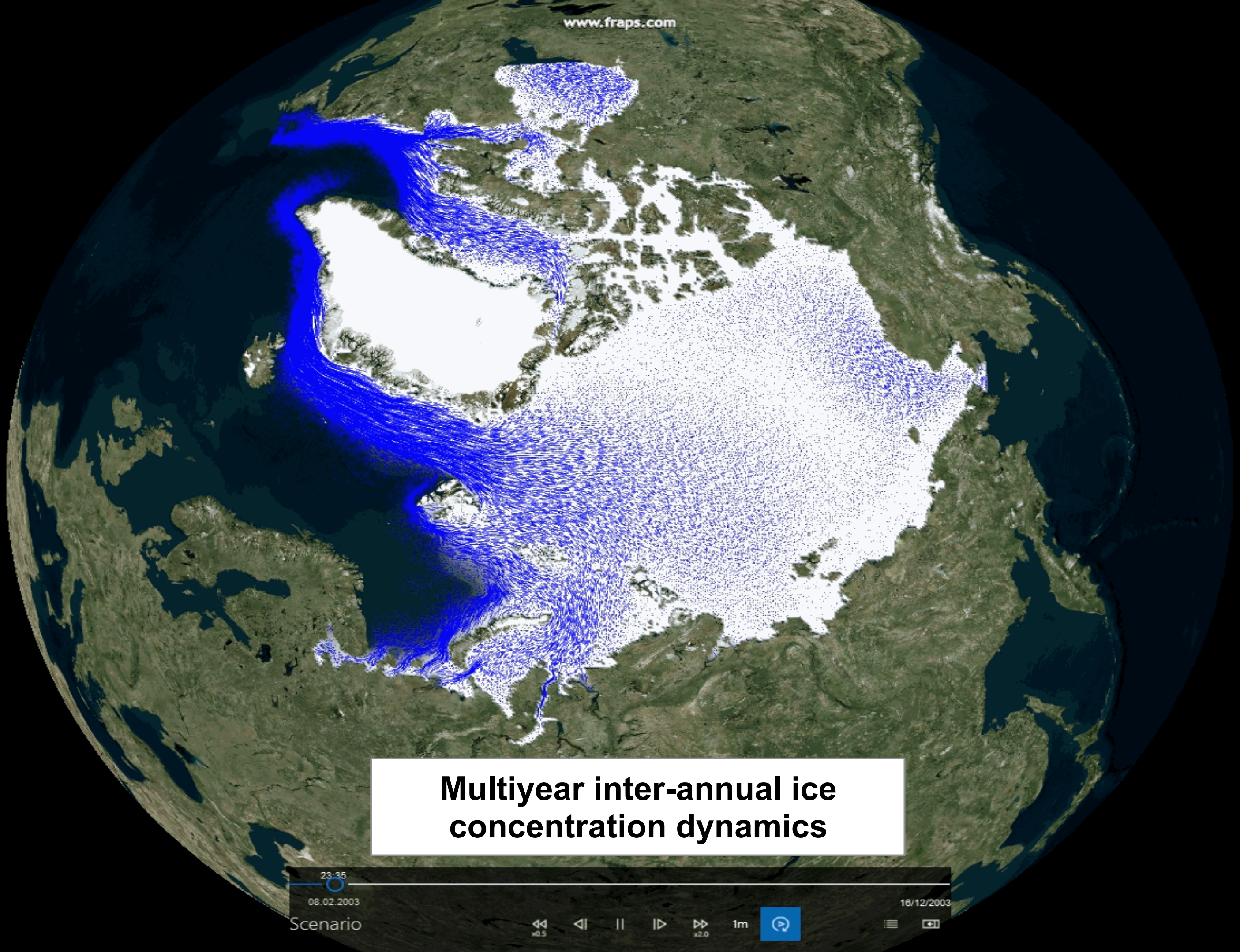
Additional slides

(animations generated with self-developed *TerraXT GIS* software)



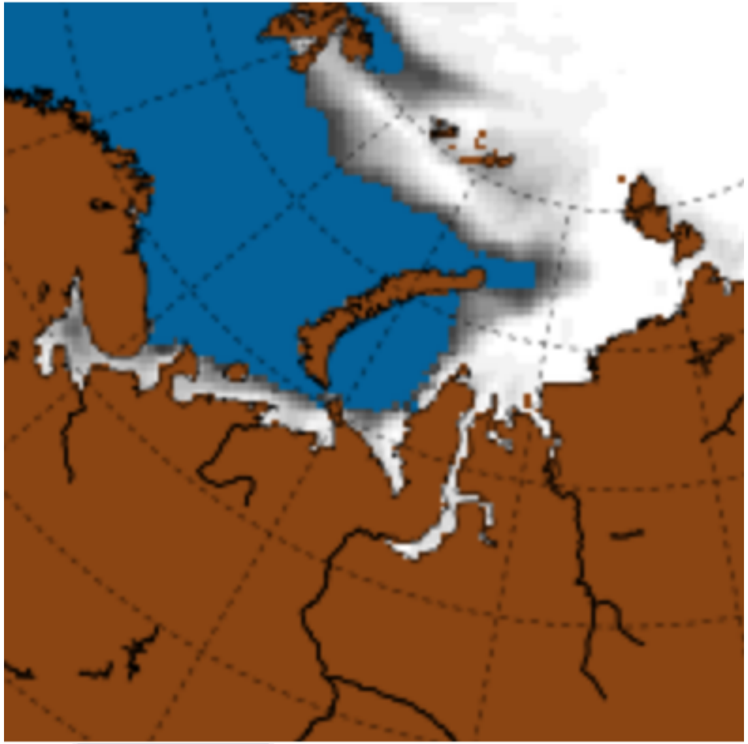
Multiyear inter-annual ice thickness dynamics



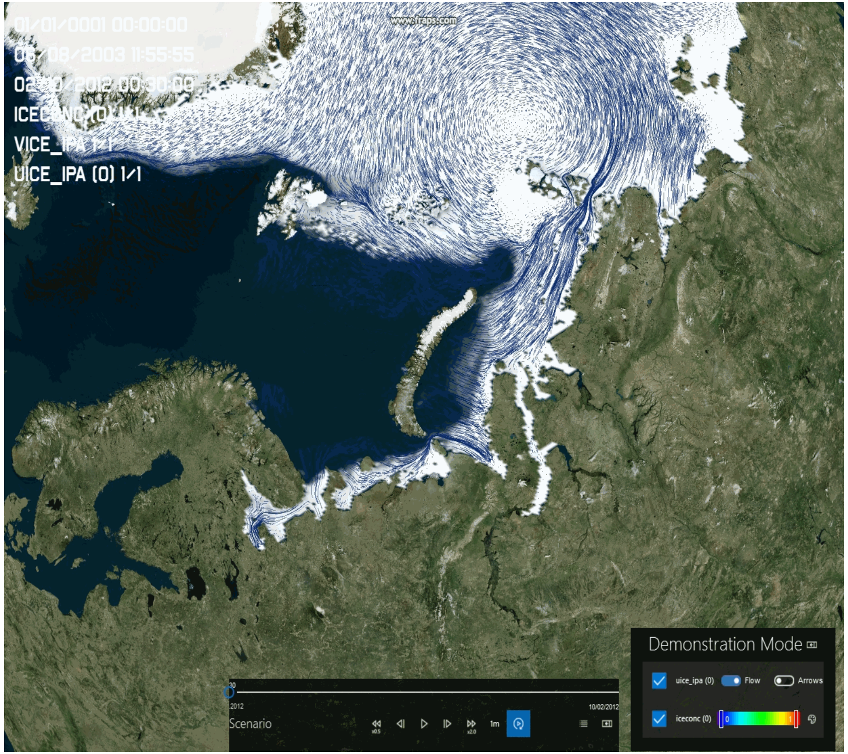
Multiyear inter-annual ice concentration dynamics

The results of validation

Kara Sea in Feb. 2012 by satellite observations

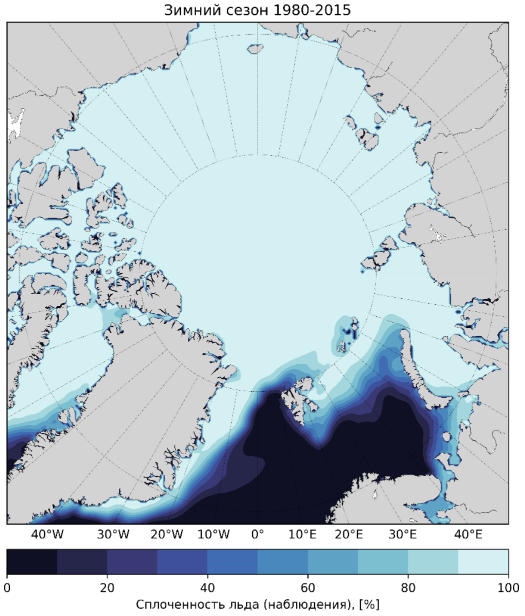


Kara Sea in Feb. 2012 by NEMO results with restoration enabled

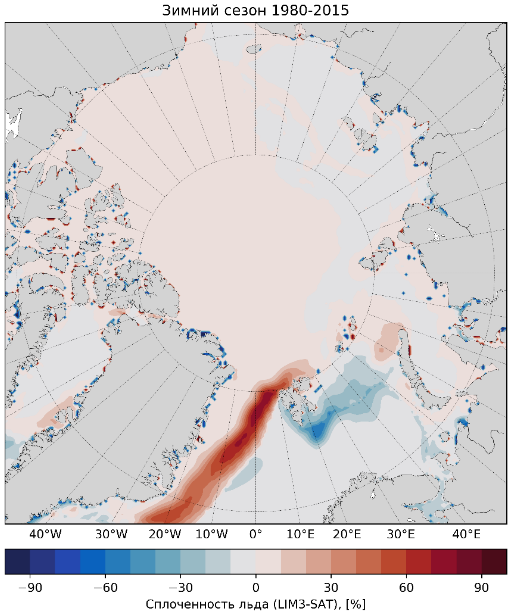


The results of validation - winter

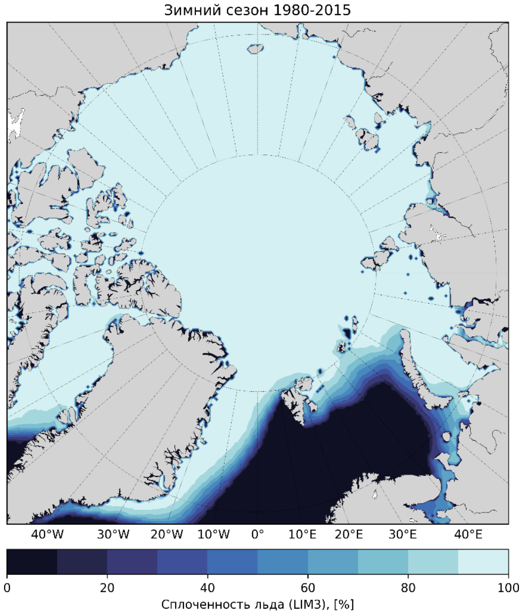
Satellite



LIM3-Sattelite

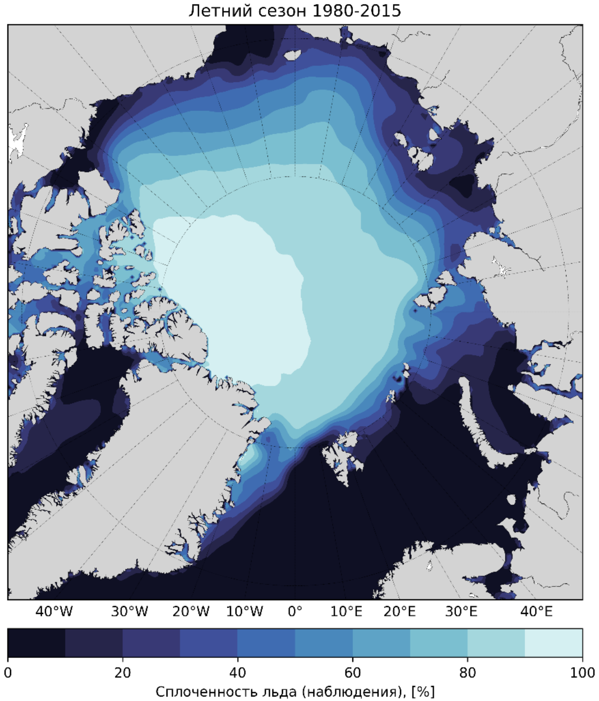


LIM3

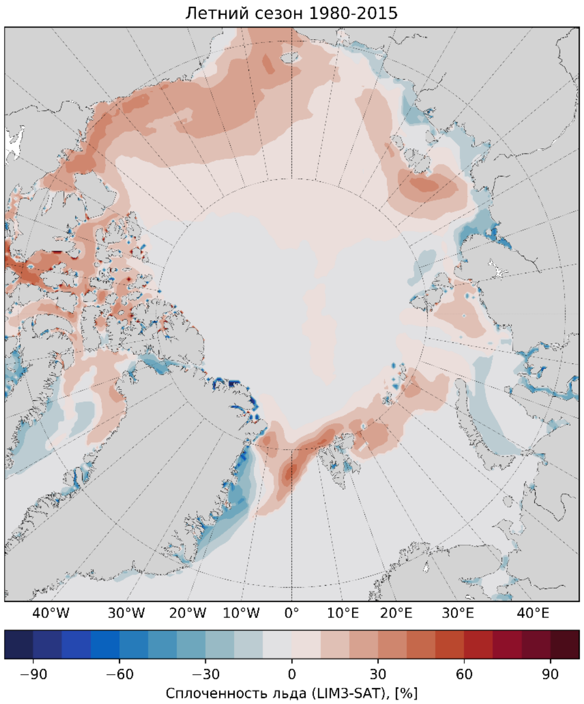


The results of validation - summer

Satellite



LIM3-Sattelite



LIM3