

The NeXtSIM-F sea ice forecasting system

Timothy Williams, Anton Korosov, Pierre Rampal, Einar Olason

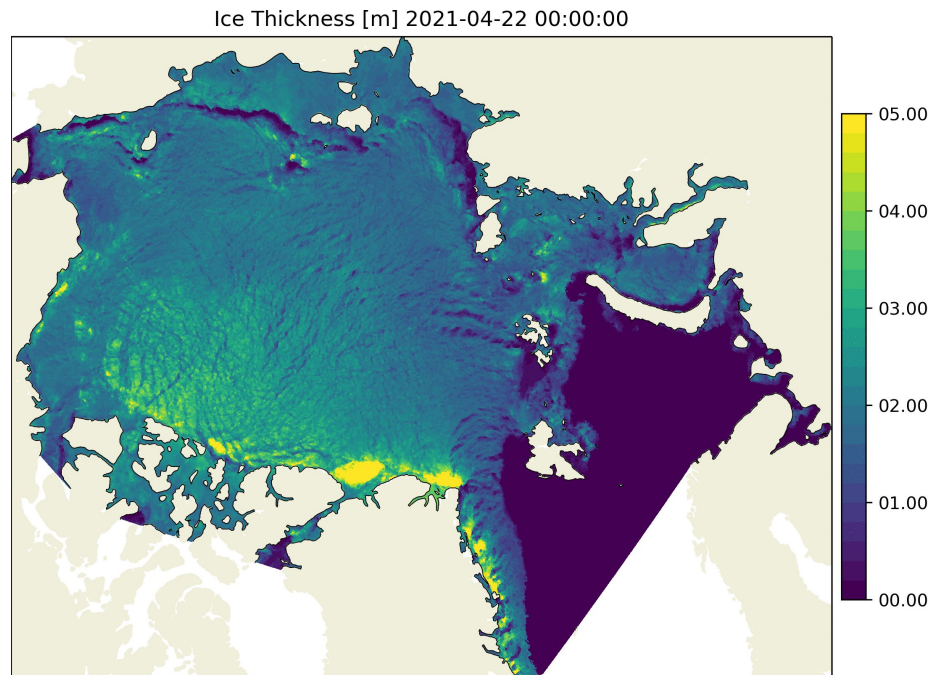
Sea ice modeling group, NERSC

Laurent Bertino
ARC MFC leader, NERSC



neXtSIM-F sea ice forecasting platform

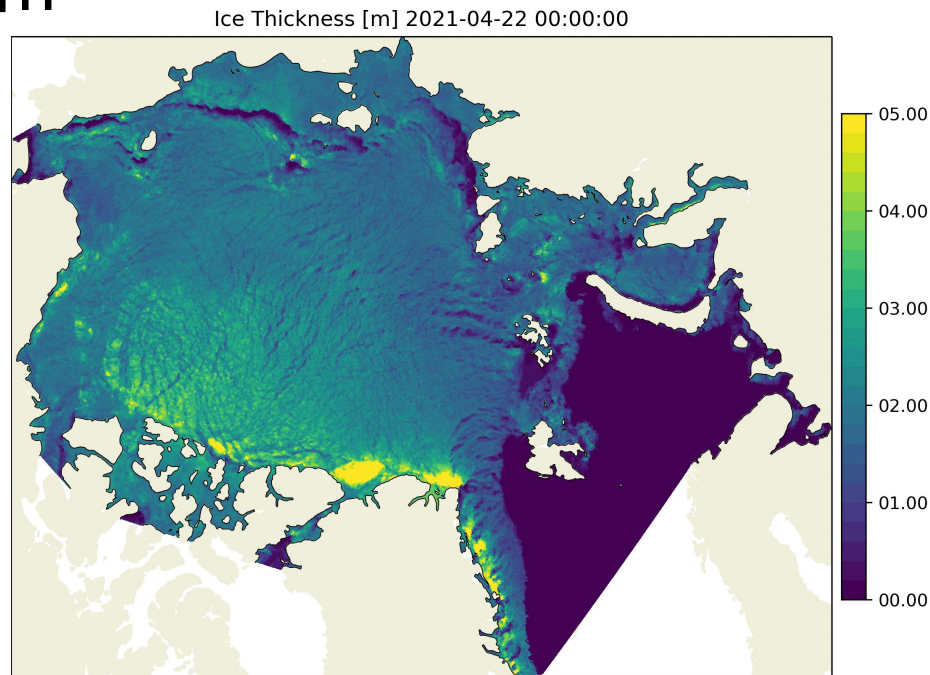
- Running operationally
- Was included as part of CMEMS ARC-MFC portfolio in July 2020
 - MEB+ rheology
 - Spring + dashpot
 - Ice pressure + damage clipping
- Was upgraded in December 2020
 - BBM rheology
 - Spring + dashpot
 - Bingham friction element
- To be upgraded in December 2021
 - Improvements to BBM
 - Better tuned fast ice



Recent forecast of sea ice thickness
- run on 2021-04-23

neXtSIM-F forecast platform

- Currently running a 10-km Arctic domain
- Daily:
 - 1-day hindcast
 - 7-day forecast
 - Stand-alone model, forced by TOPAZ4 (ocean) and ECMWF IFS (atmosphere)
 - Takes 25-30 mins with 16 CPU on a local server
 - Was 2.5h with MEB+ (required an implicit solution method)

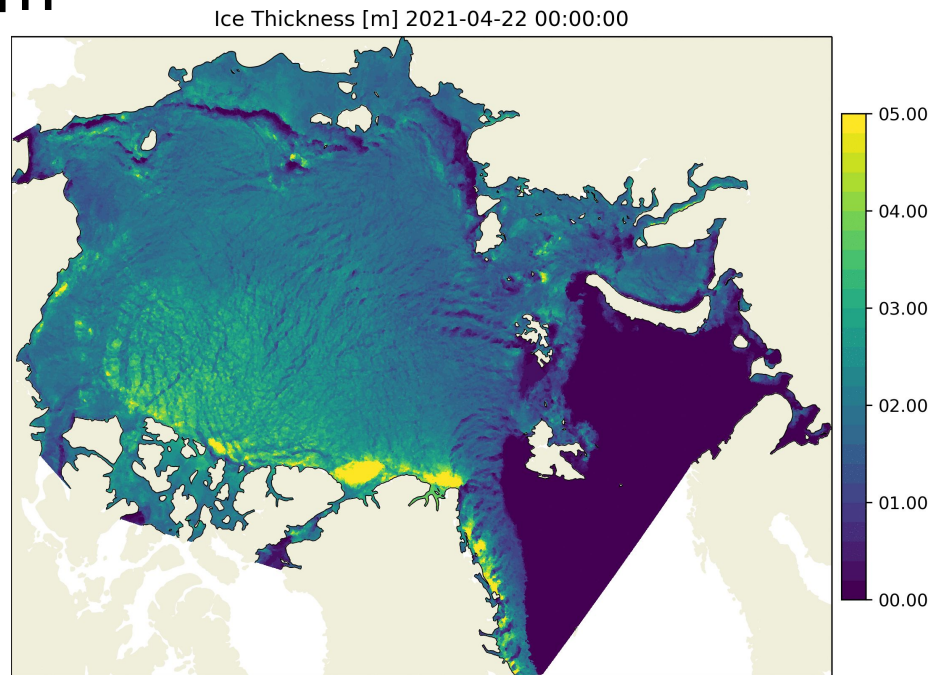


*Recent forecast of sea ice thickness
- run on 2020-04-23*

neXtSIM-F forecast platform

- Assimilation

- Blend of OSISAF SSMI and AMSR2 concentration
 - Use AMSR2 to give sharper ice edge
 - Only change concentration if ice masks disagree
 - Changing ice conc led to terrible drift/thickness fields
- Compensating heat flux if ice removed
 - To stop regrowth
- SST lowered to freezing point if ice added
 - To stop melting

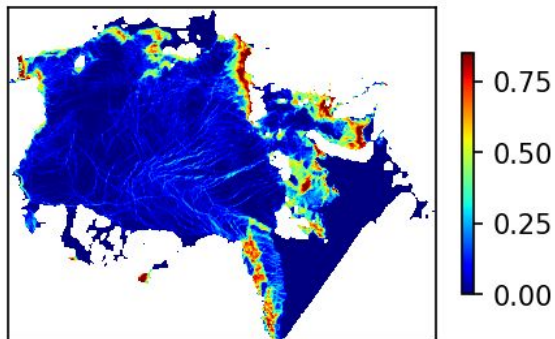


Recent forecast of sea ice thickness
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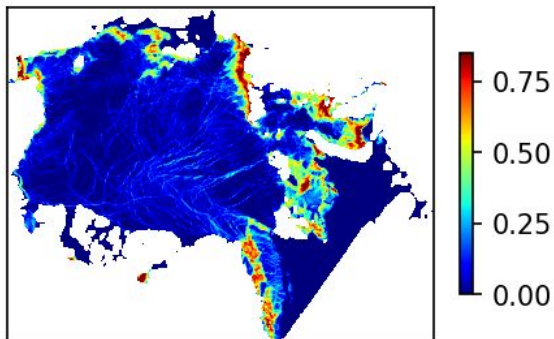
neXtSIM-F forecast platform

Correction to concentration - more a correction of extent

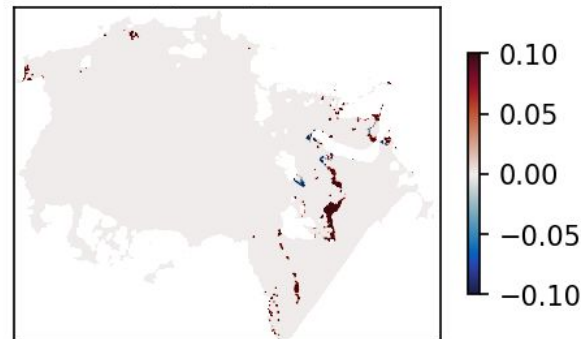
*Thin ice concentration
- prior to assimilation*



*Thin ice concentration
- after assimilation*



*Thin ice concentration
- innovation*



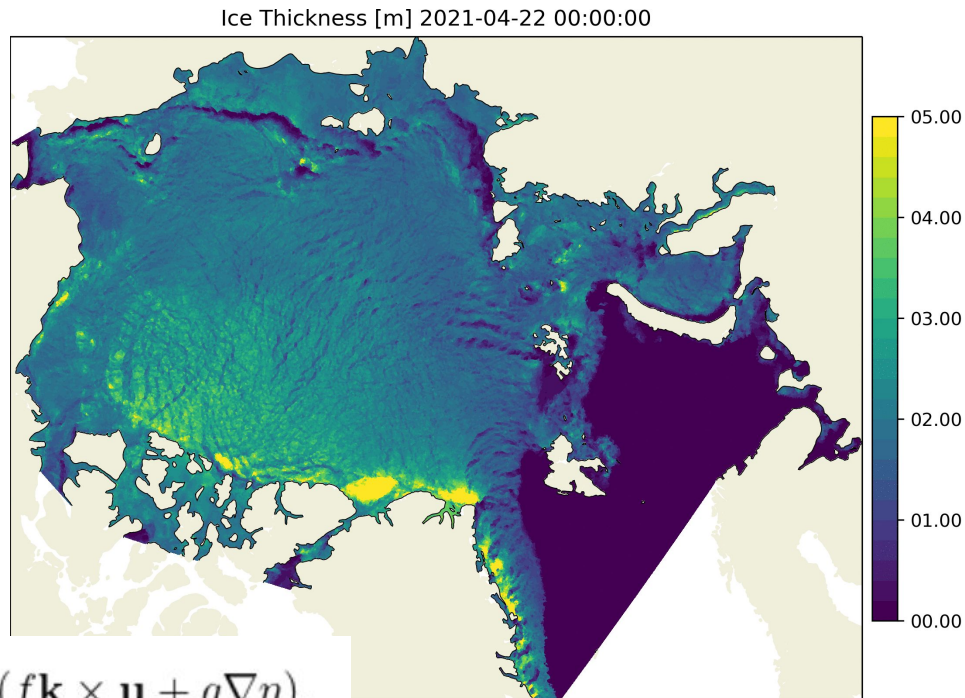
From forecast run on 2020-05-04

neXtSIM sea ice model

- Lagrangian FEM model
 - Triangular moving mesh
- Latest version uses the Brittle-Bingham-Maxwell (BBM) rheology
- Reproduces spatial and temporal statistics of sea ice deformation
 - Localisation (LKFs)
 - Intermittency
- Two ice categories: “young” and “old”

Momentum equation:

$$\rho_i(h + h_y) \frac{D\mathbf{u}}{Dt} = \nabla \cdot (h\boldsymbol{\sigma}) + \tau - \rho_i(h + h_y)(f\mathbf{k} \times \mathbf{u} + g\nabla\eta),$$

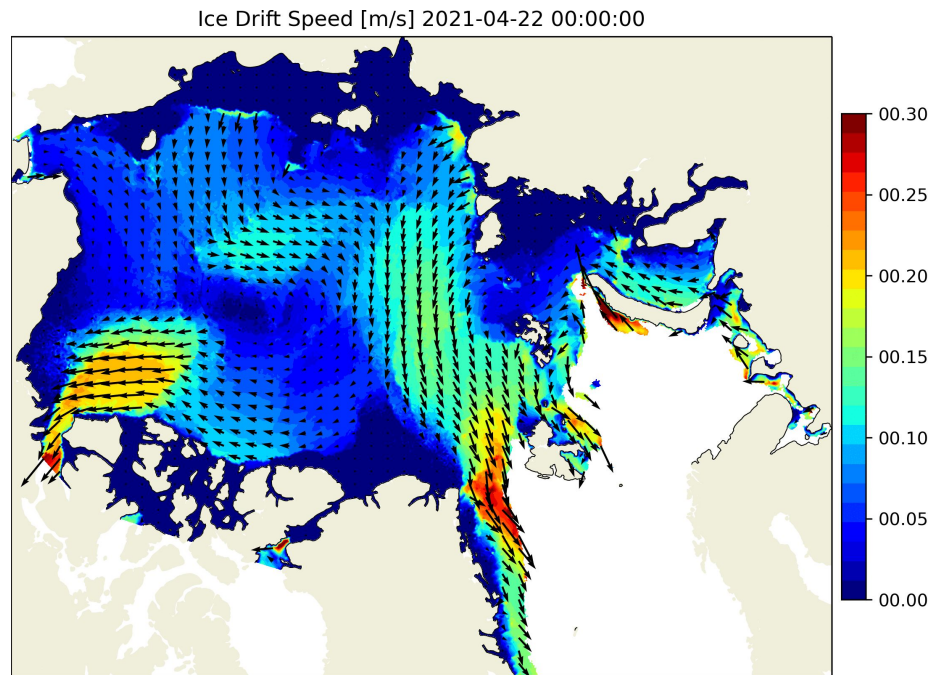


neXtSIM Sea Ice Model

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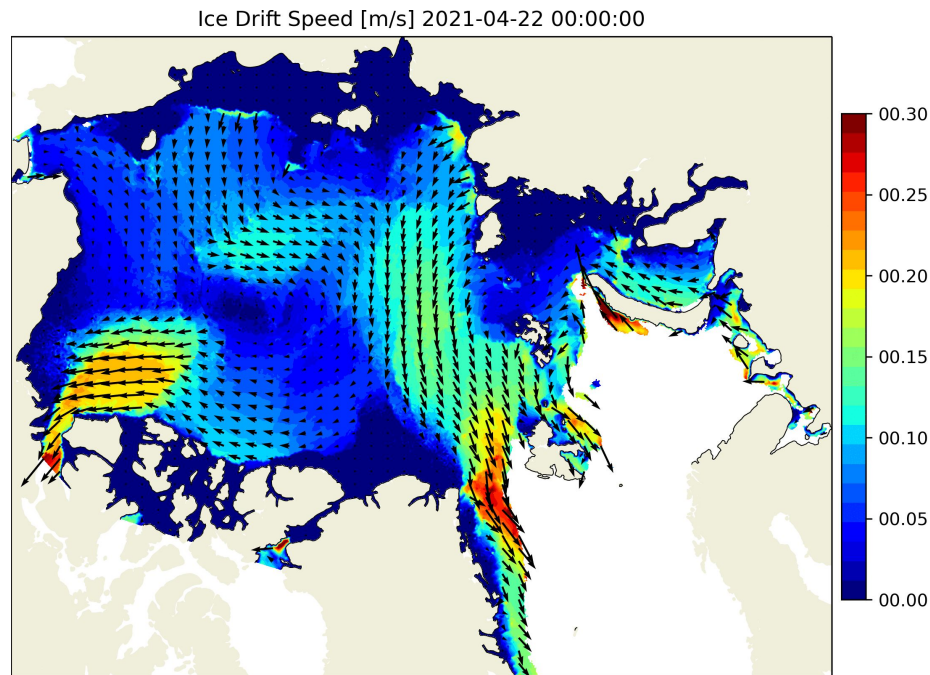
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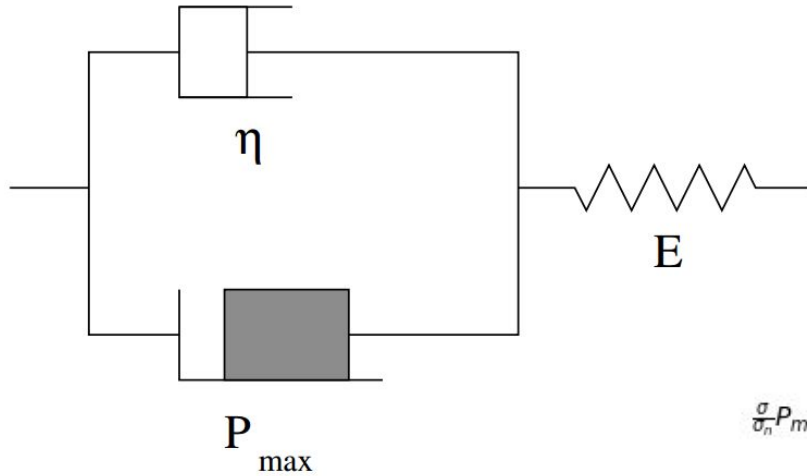
BBM rheology

- **OPERATIONAL VERSION!**
 - Latest version coming in Olason et al (in prep)
- Brittle Bingham-Maxwell rheology
 - Brittle (cumulative damage)
 - Maxwell viscoelasticity
 - Bingham friction element to reduce convergence of damaged ice
 - Developed to improve thickness in multi-decadal simulations



Recent forecast of sea ice drift
- run on 2020-04-23

BBM rheology



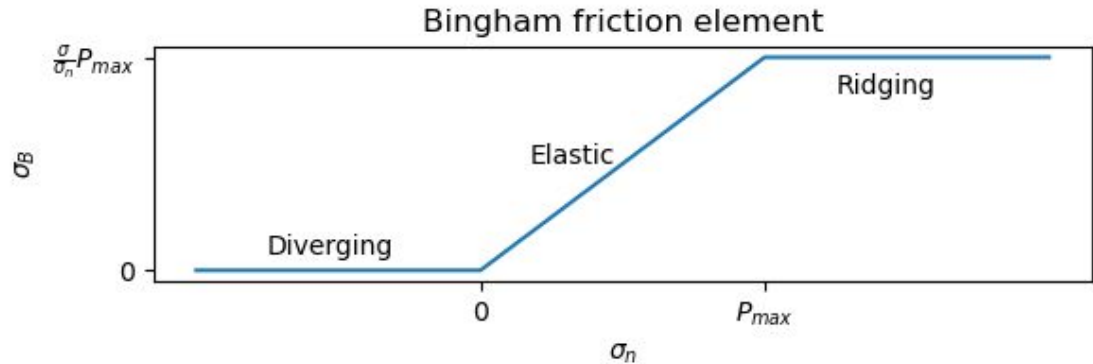
Bingham element gives resistance to compression while damaged

Damage (d) used to lower stiffness and viscosity and thus stresses where applied stress is high

- Applied stress passed onto neighbours
- Propagation of damage (cracks/LKFs)

$$E = E_0(1 - d)e^{-C(1-A)}$$

$$\eta = \eta_0(1 - d)^\alpha e^{-C(1-A)}$$



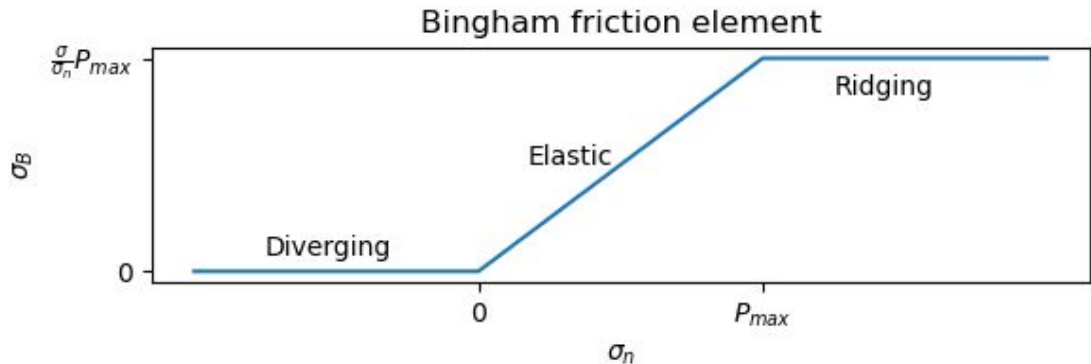
BBM rheology

$$\dot{\boldsymbol{\sigma}} + \frac{\boldsymbol{\sigma}}{\lambda} \left(\tilde{P} + \frac{\lambda \dot{d}}{1-d} \right) = E \mathbf{K} : \dot{\boldsymbol{\varepsilon}}, \quad \tilde{P} = \begin{cases} 1 & \text{for } \sigma_n \leq 0 \text{ (diverging),} \\ 0 & \text{for } 0 < \sigma_n < P_{\max} \text{ (elastic),} \\ 1 - \frac{P_{\max}}{\sigma_n} & \text{for } \sigma_n > P_{\max} \text{ (ridging),} \end{cases}$$

Viscous relaxation time

- Drops with more damage
- Doesn't depend on concentration

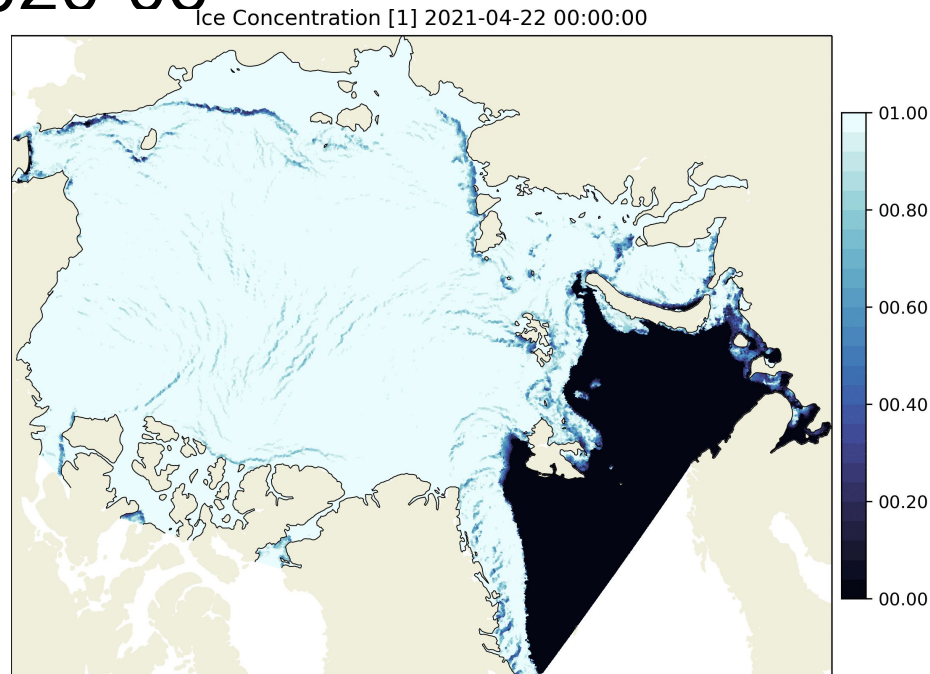
$$\lambda = \frac{\eta}{E} = \frac{\eta_0}{E_0} (1-d)^{\alpha-1}$$



Evaluation for 2018-11 - 2020-06

BBM:

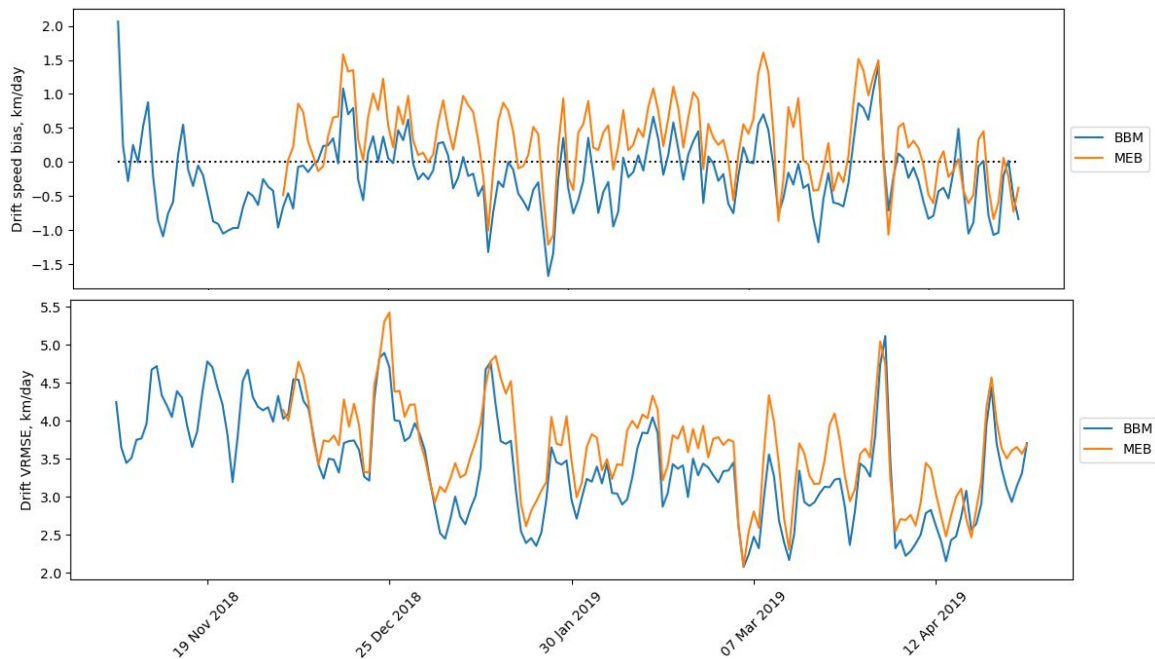
- Drift agrees well with observations
 - Less deterioration with time from initialisation
- Thickness too high off NE Greenland and north of Svalbard
 - Thicker than with MEB+
- Concentration underestimated in Fram Strait
 - Improvement from MEB+
- Problems with fast ice in Laptev Sea



Recent forecast of sea ice concentration

- *run on 2020-04-23*

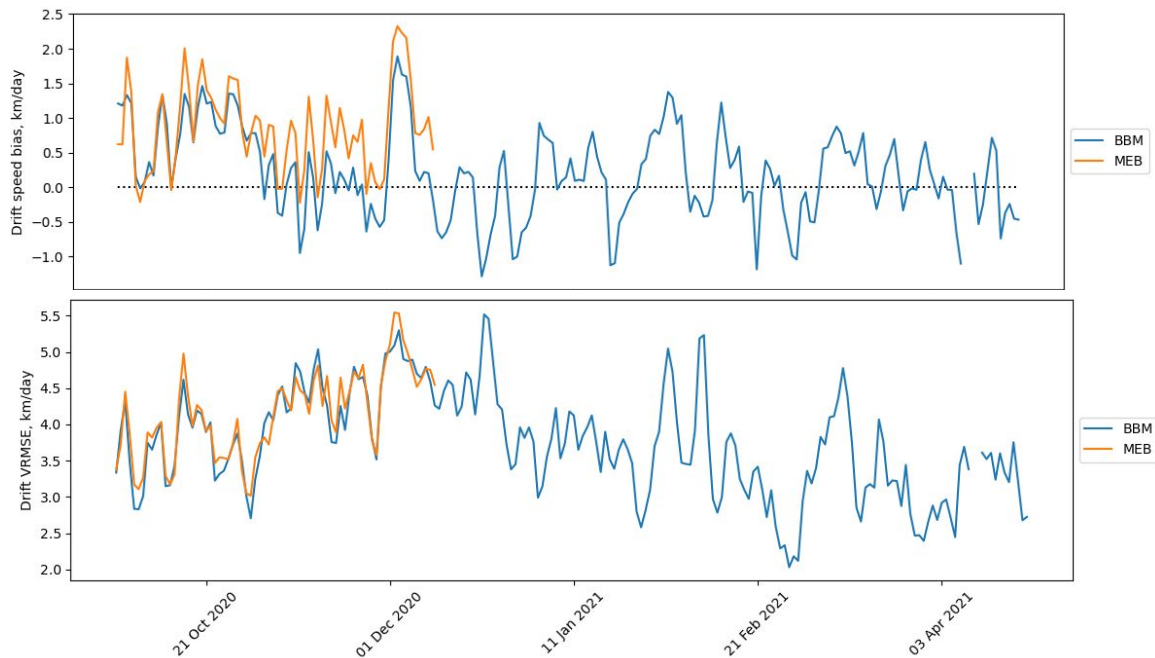
Evaluation of analysis: *Ice drift*



Comparison of analysis to OSI SAF drift (48h, 60km product). Winter 2018-2019.

- **Just after initialisation**
- **RMSE speed mostly 1.5 - 3.5 km/day.**

Evaluation of analysis: *Ice drift*



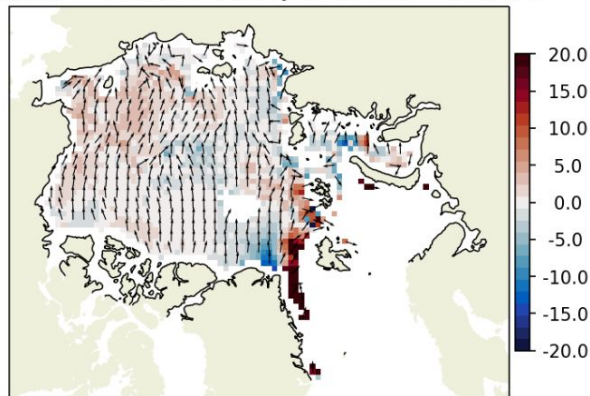
Comparison of analysis to OSI SAF drift (48h, 60km product). Winter 2020-2021.

- **2 years after initialisation**
- **RMSE speed mostly 1.5 - 3.5 km/day.**

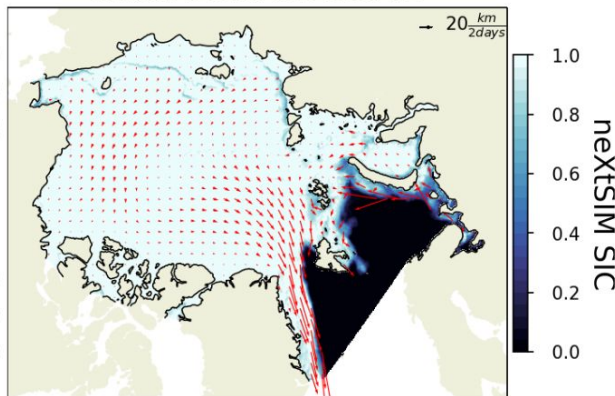
Evaluation of analysis: *Ice drift*

Comparison analysis to OSISAF 48h drift. April 2021 average. BBM rheology

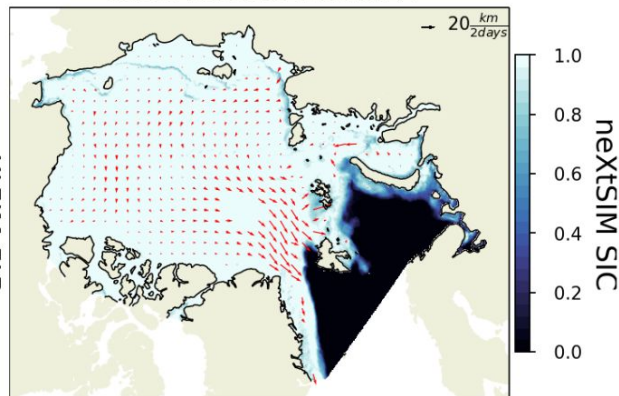
(NEXTSIM - OSISAF) [km/2days] 20210401-20210422



NEXTSIM 20210401-20210422

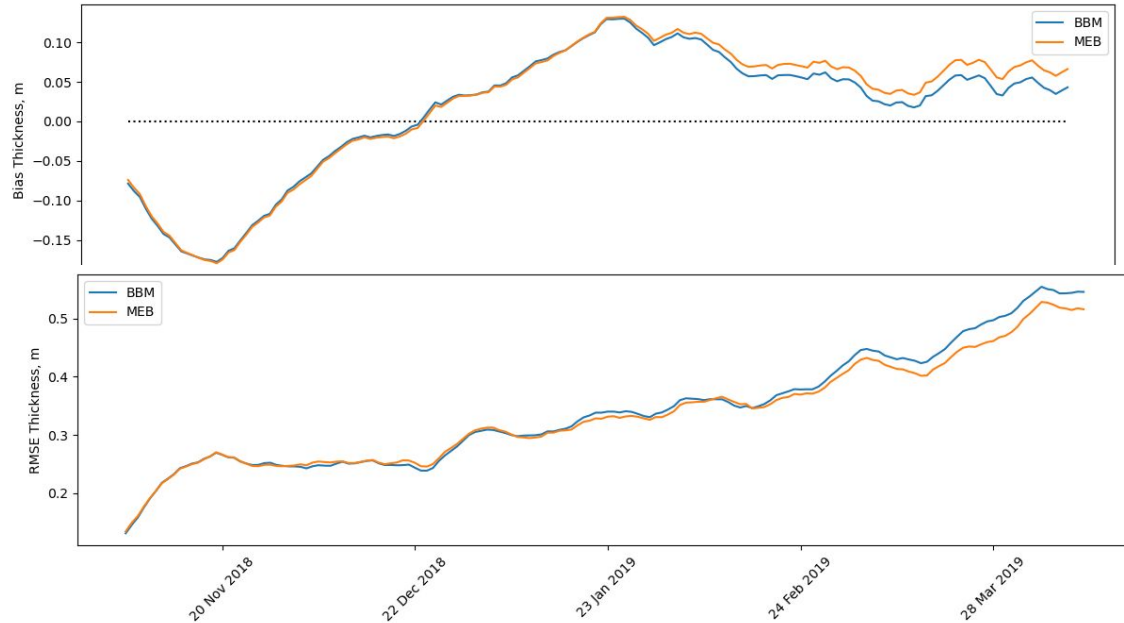


OSISAF 20210401-20210422



- Quite good agreement
 - Main pattern and direction is good
 - Too fast through the centre of the Fram Strait
 - Slightly too slow north of Greenland

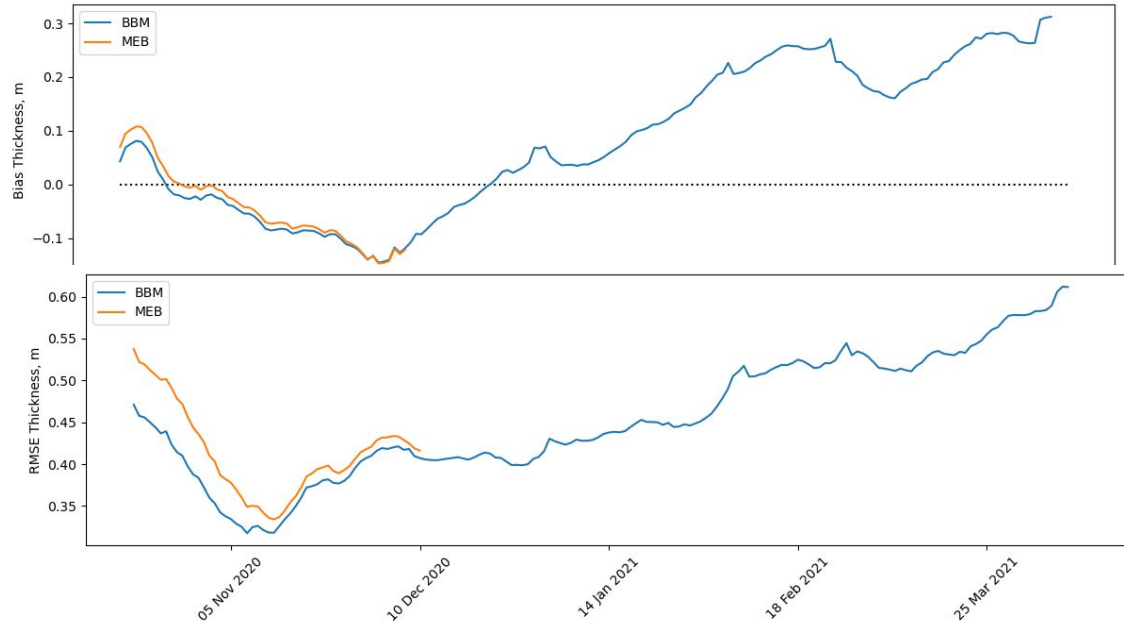
Evaluation of analysis: *Ice thickness*



Comparison of analysis to CS2-SMOS thickness. Winter 2018-2019.

- **Just after initialisation**

Evaluation of analysis: *Ice thickness*



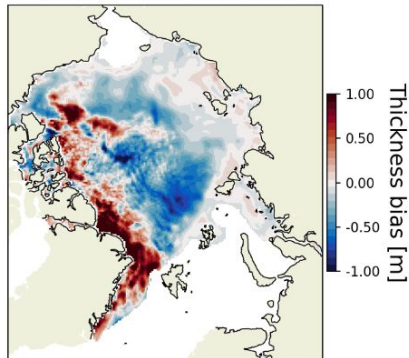
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- **2 years after initialisation**

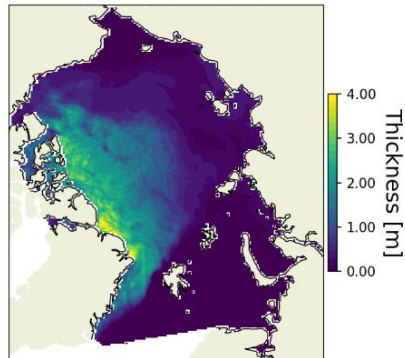
Evaluation: *Ice thickness*

Comparison analysis to CS2-SMOS thickness. Nov 2020 average. MEB rheology

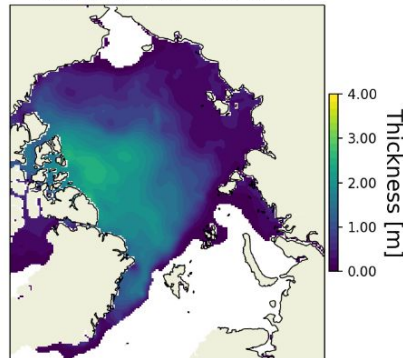
Thickness bias (neXtSIM-F - Cs2SmosThick)
Mean 2020-11-01 - 2020-11-30



neXtSIM-F Thickness (Cs2SmosThick grid)
Mean 2020-11-01 - 2020-11-30



Cs2SmosThick
Mean 2020-11-01 - 2020-11-30

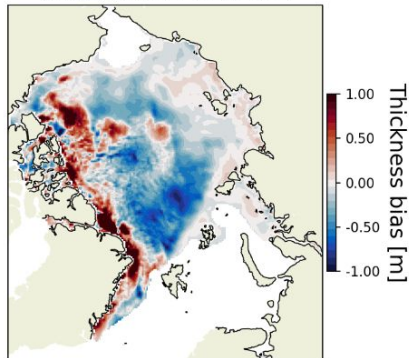


- Too thick north of Greenland and Canada
- Too thin towards center

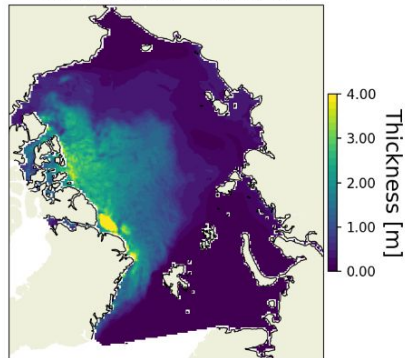
Evaluation: *Ice thickness*

Comparison analysis to CS2-SMOS thickness. Nov 2020 average. BBM rheology.

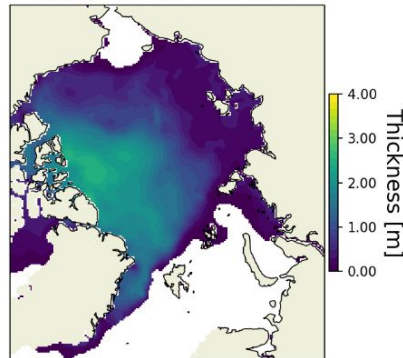
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Cs2SmosThick
Mean 2020-11-01 - 2020-11-30

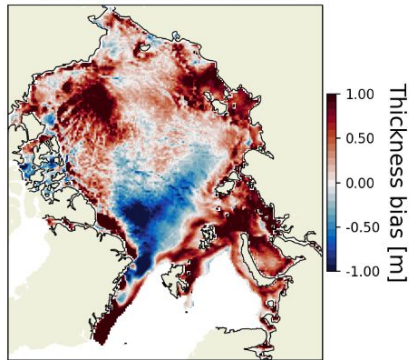


- Too thick north of Greenland and Canada
 - Thicker regions more compressed than MEB
- Too thin towards center

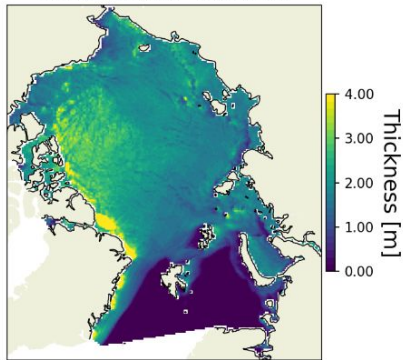
Evaluation: *Ice thickness*

Comparison analysis to CS2-SMOS thickness. April 2021 average. BBM rheology.

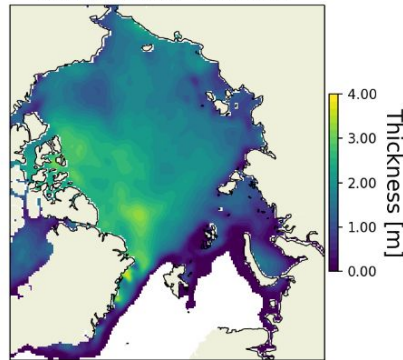
Thickness bias (neXtSIM-F - Cs2SmosThick)
Mean 2021-04-01 - 2021-04-15



neXtSIM-F Thickness (Cs2SmosThick grid)
Mean 2021-04-01 - 2021-04-15

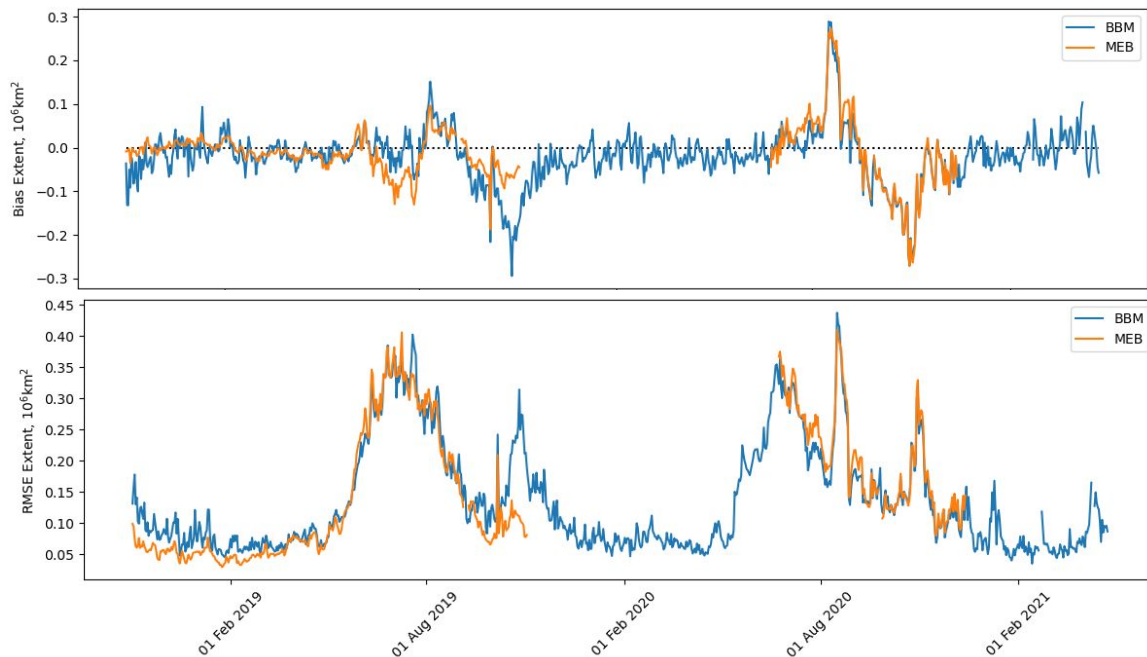


Cs2SmosThick
Mean 2021-04-01 - 2021-04-15



- Overestimation of ice thickness nearly everywhere
 - From new tuning, threshold between thin and thick ice could help this.

Evaluation of analysis: *Ice extent*



IIEE

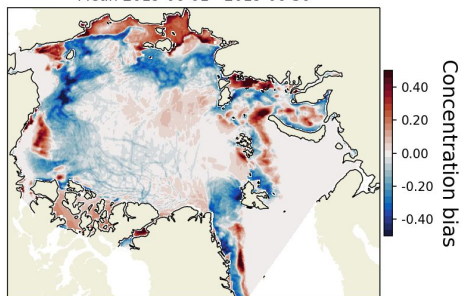
Comparison of analysis to OSI SAF SSMI concentration. Nov 2018 - April 2021.

- **Underestimating extent in summer; some issues in ice advance period**
- **MEB sometimes has lower average errors than BBM, sometimes worse**

Evaluation of analysis: *Ice concentration/extent*

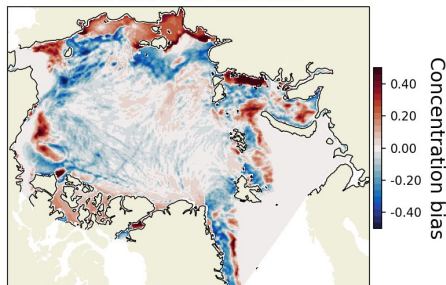
Comparison analysis to OSI SAF ice concentration (SSM/I). June 2019 average.

Concentration bias (neXtSIM-F - OsisafConc)
Mean 2019-06-01 - 2019-06-30



MEB

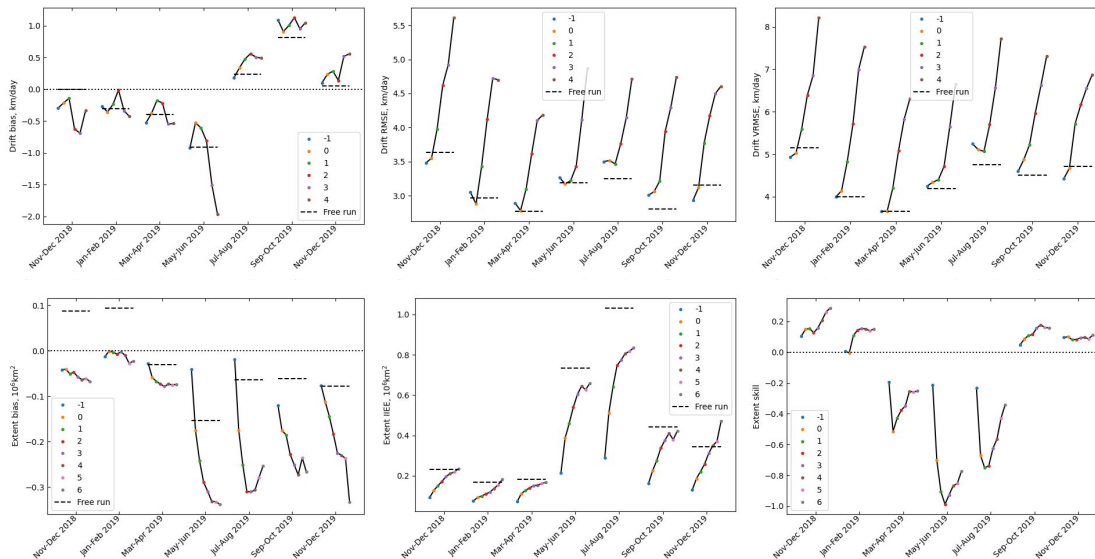
Concentration bias (neXtSIM-F - OsisafConc)
Mean 2019-06-01 - 2019-06-30



BBM

- Underestimation of ice extent in summer in the Fram Strait
 - Caused by too-thick ice north of Svalbard allowing an arch to form
 - Much improved with BBM
- Problems with fast ice in Laptev Sea

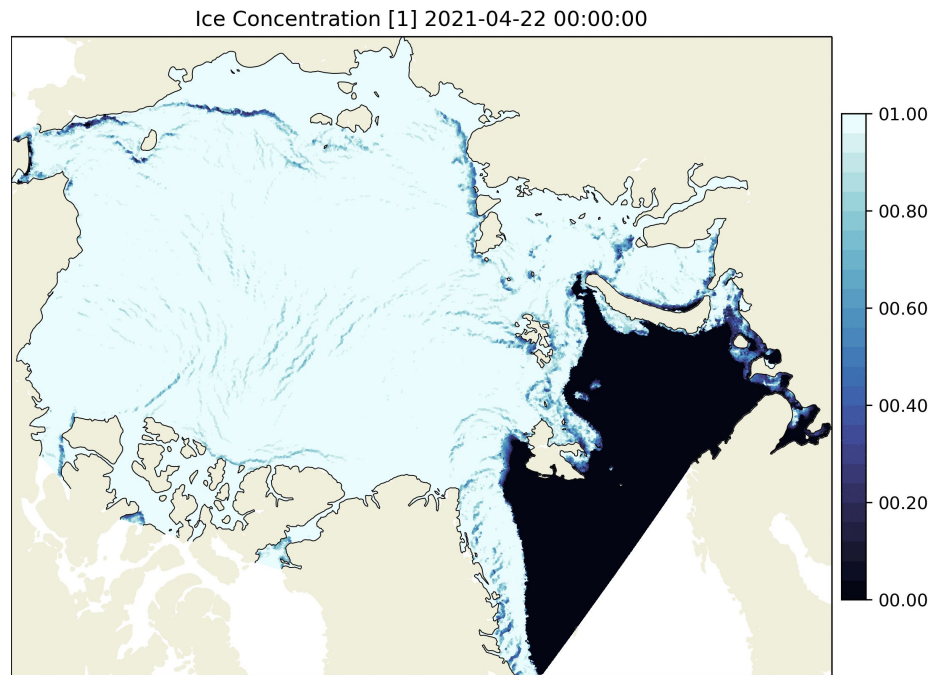
Evaluation of forecast: *Drift/extent*



- Drift errors increase by about 3km/day for lead time 4(-6) days
 - Probably due to errors in winds
- Extent generally underestimated
 - Skill lower in summer; corrections not persisting

Conclusions

- Drift agrees well with observations
 - MEB and BBM
- Thickness slightly better with BBM
- Thick ice by North Greenland still causes some problems
 - Arching reduces export through Fram Strait
 - Improved with BBM



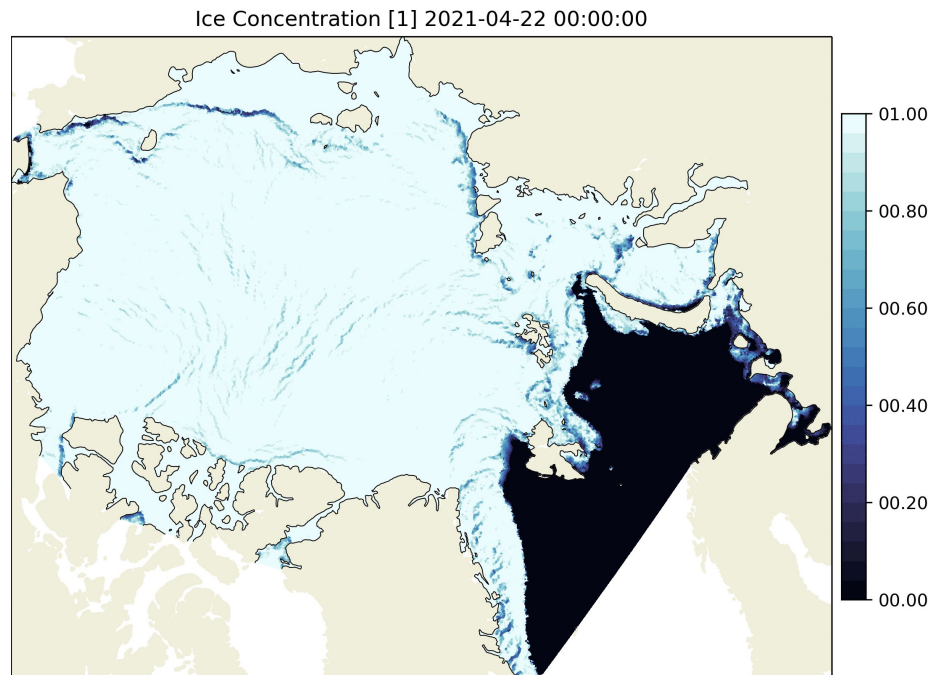
Recent forecast of sea ice concentration

- *run on 2020-04-23*

Outlook

Ongoing developments for neXtSIM:

- Dynamical improvements and tuning
 - eg concentration-dependent viscous relaxation time
 - Publication being finalised (Olason et al, *in prep*)
 - Most developments will be included in the December 2021 CMEMS update
- Coupling
 - Waves (WW3)
 - Ocean (NEMO, HYCOM)
 - 1D atmospheric boundary layer



Recent forecast of sea ice concentration
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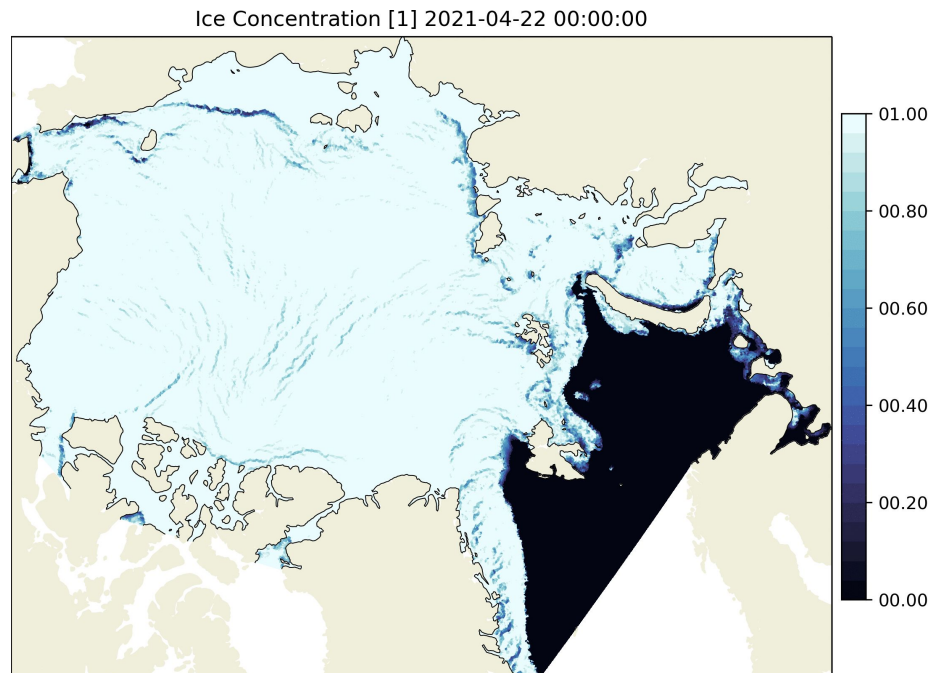
Outlook

Ongoing developments for neXtSIM:

- Advanced assimilation
 - ENKF
 - Challenging for a Lagrangian model
- Assimilation of unique data
 - SAR-derived deformation and ice type (Korosov et al, *in prep*)

Other possibilities:

- Assimilation of CS2-SMOS



Recent forecast of sea ice concentration
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