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Operational ice modelling and forecasting, sea ice data assimilation, impact of satellite observations

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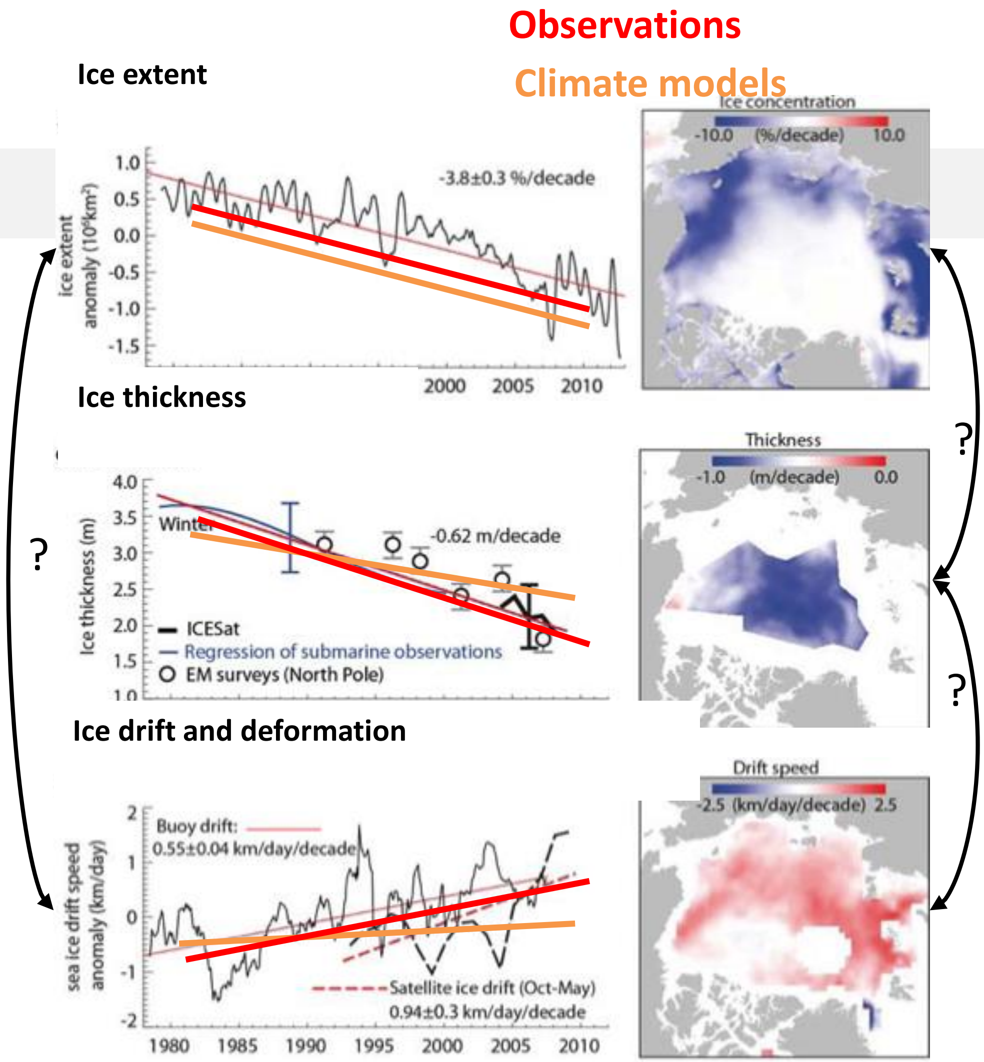
COPERNICUS • MARINE ENVIRONMENT MONITORING SERVICE •
CMEMS ARCTIC OCEAN MFC
Contract ARCTIC - MFC
Until April 30 2018

Known trends in the Arctic sea ice

Smaller

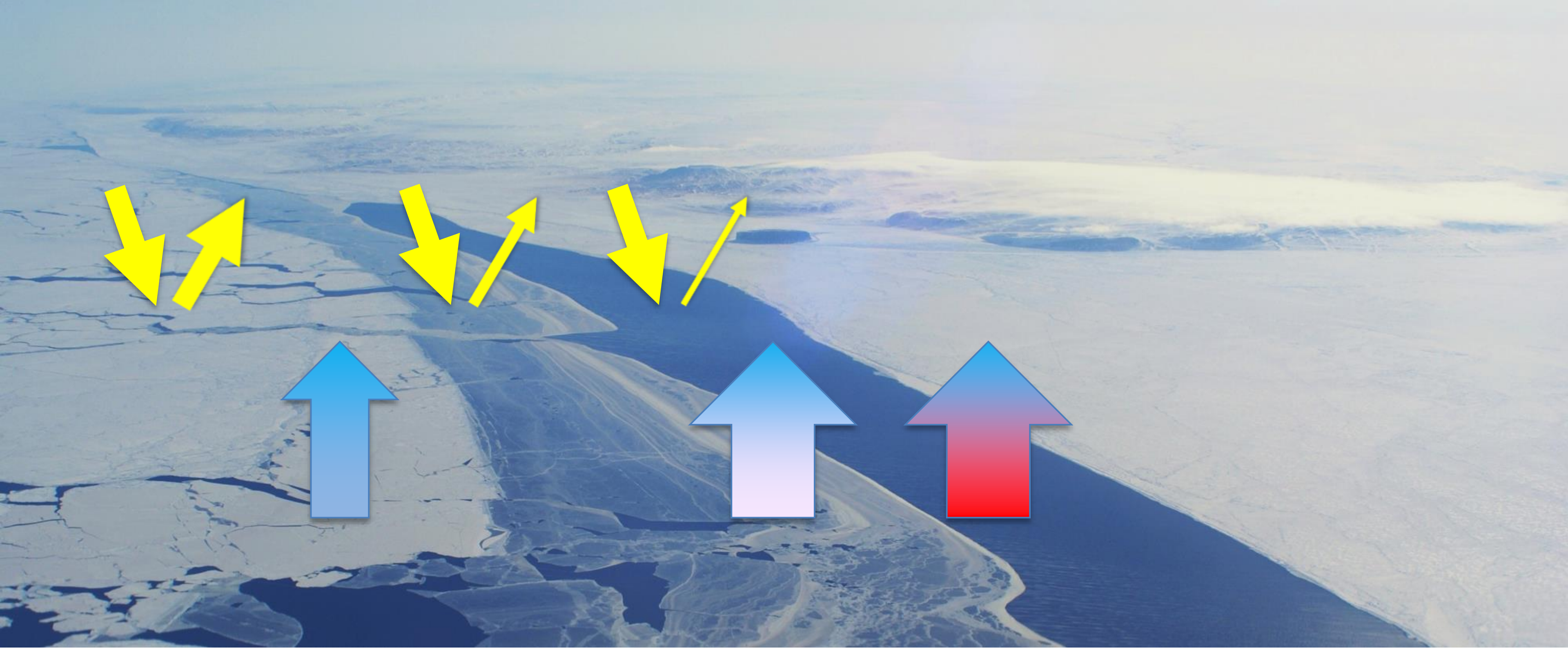
<u>Thinner</u>

Faster



From IPCC report, 2013

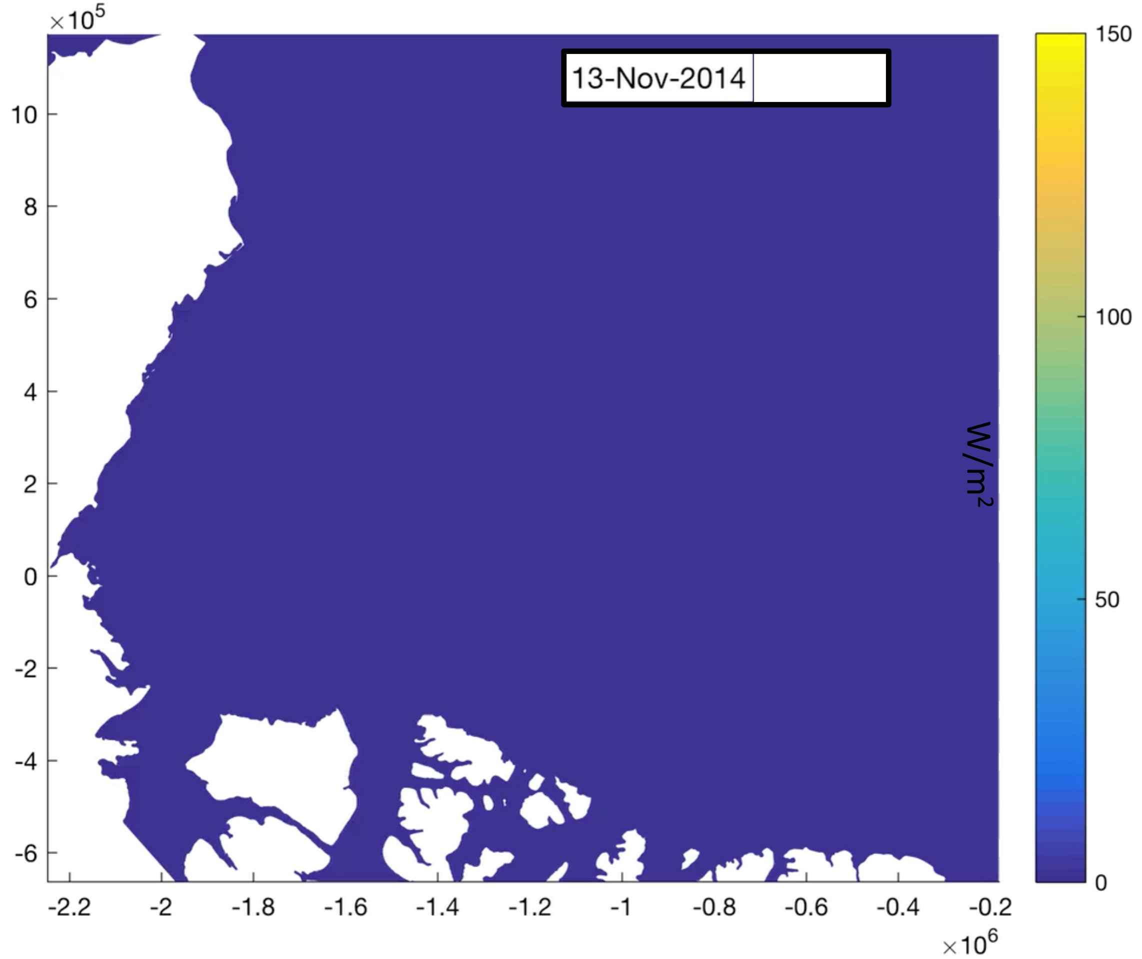
The presence of sea ice largely affects **ocean-atmosphere interactions**.



Sea ice acts on:

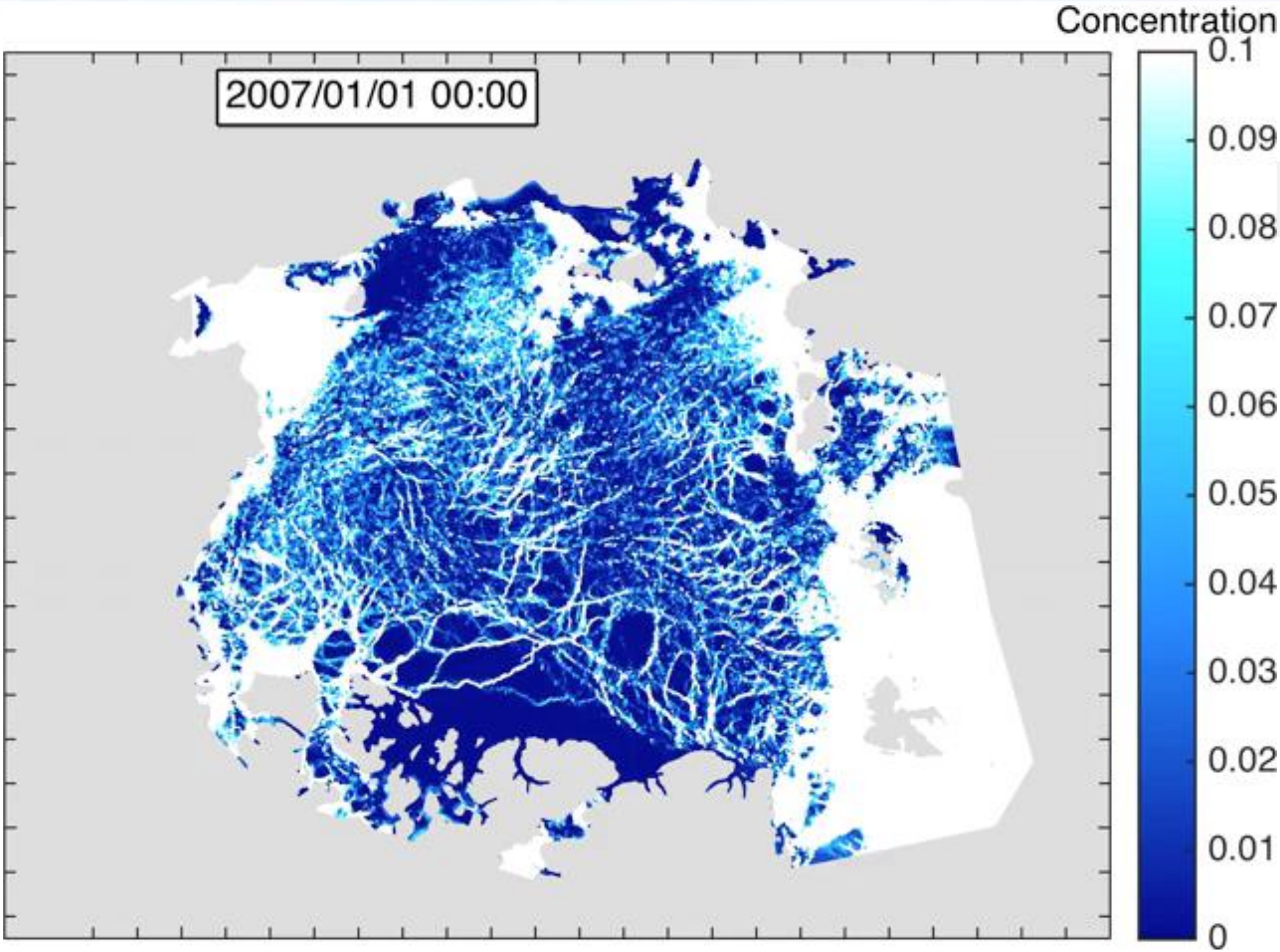
- surface albedo,
- heat fluxes,
- momentum fluxes,
- salt rejection,
- …

Heat flux through leads, from neXtSIM model



Olason et al., in prep.

Lead fraction from the neXtSIM model, defined as the fraction of open water and thin ice.

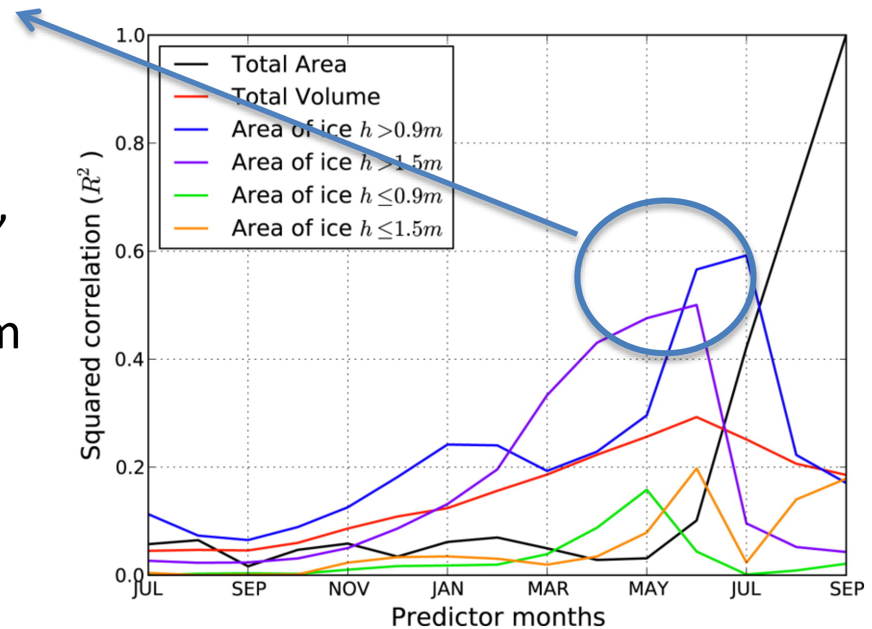


Users needs: climate

When is the best time to assimilate Sea ice thickness?

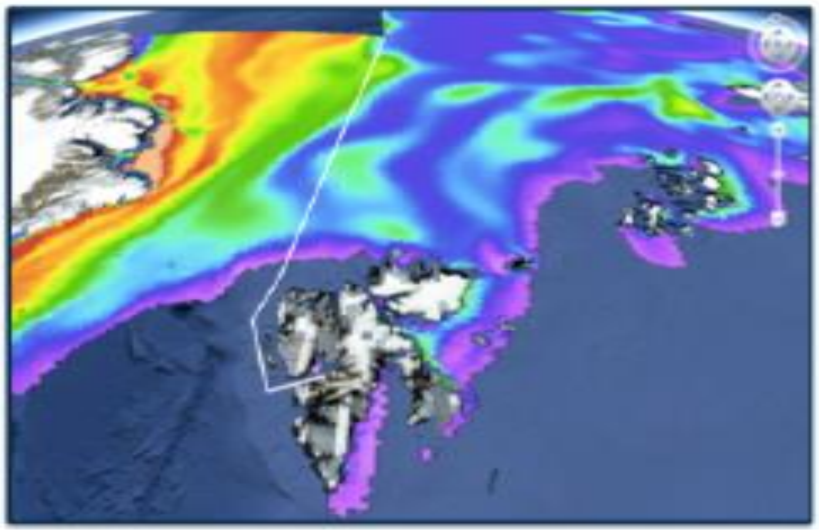
Thick ice observations in June is a good predictor of the minimum ice area in September.
(Chevallier et al. 2012)

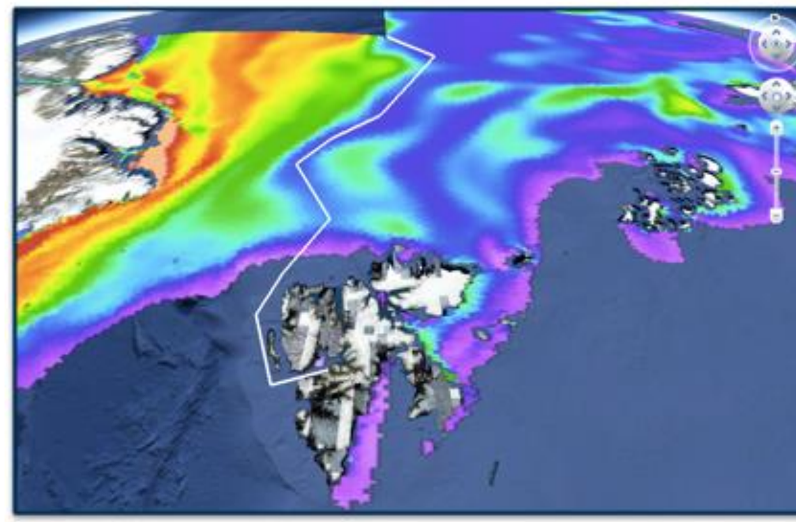
… Unfortunately for the sea ice minimum, ice thickness measurements are only available from October to April (both from SMOS and CryoSAT2).



Users needs: detailed maps

Tourism on an icebreaker to the North Pole?

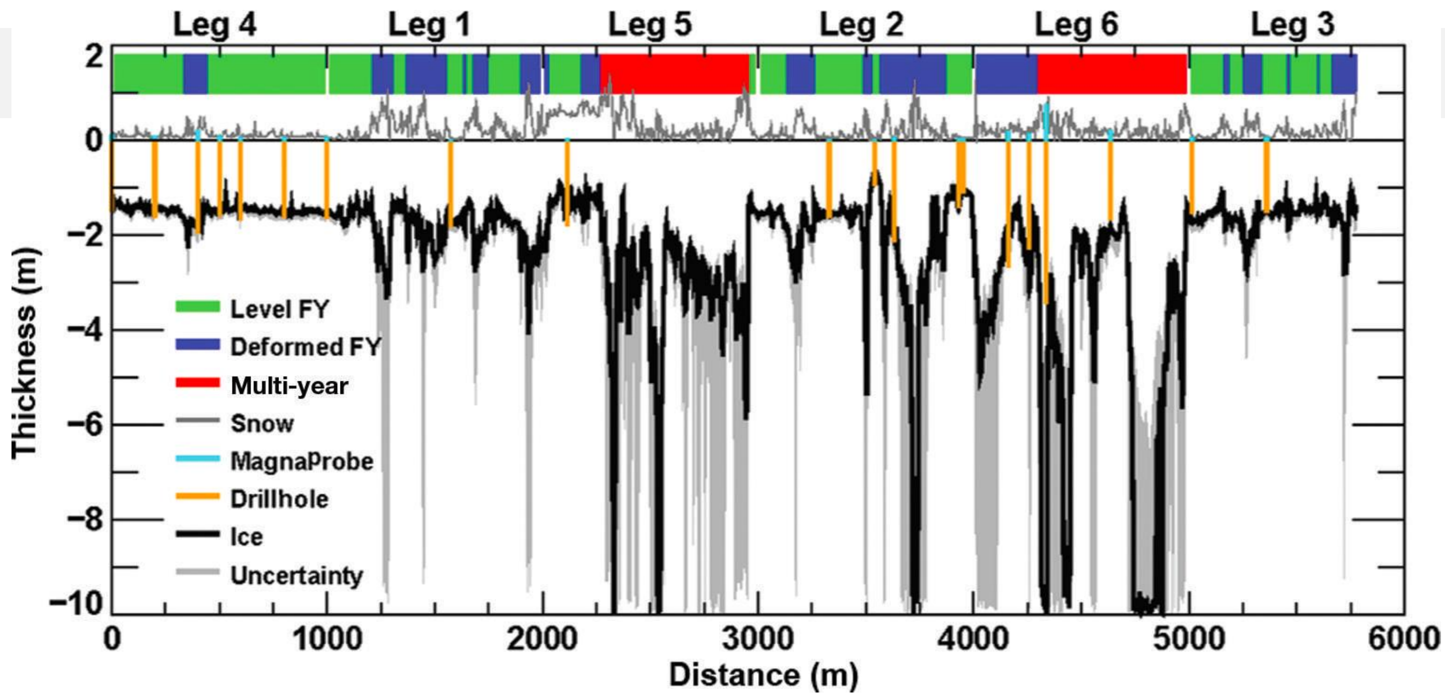




(image courtesy of N. Dubreuil, Ponant Cruises)

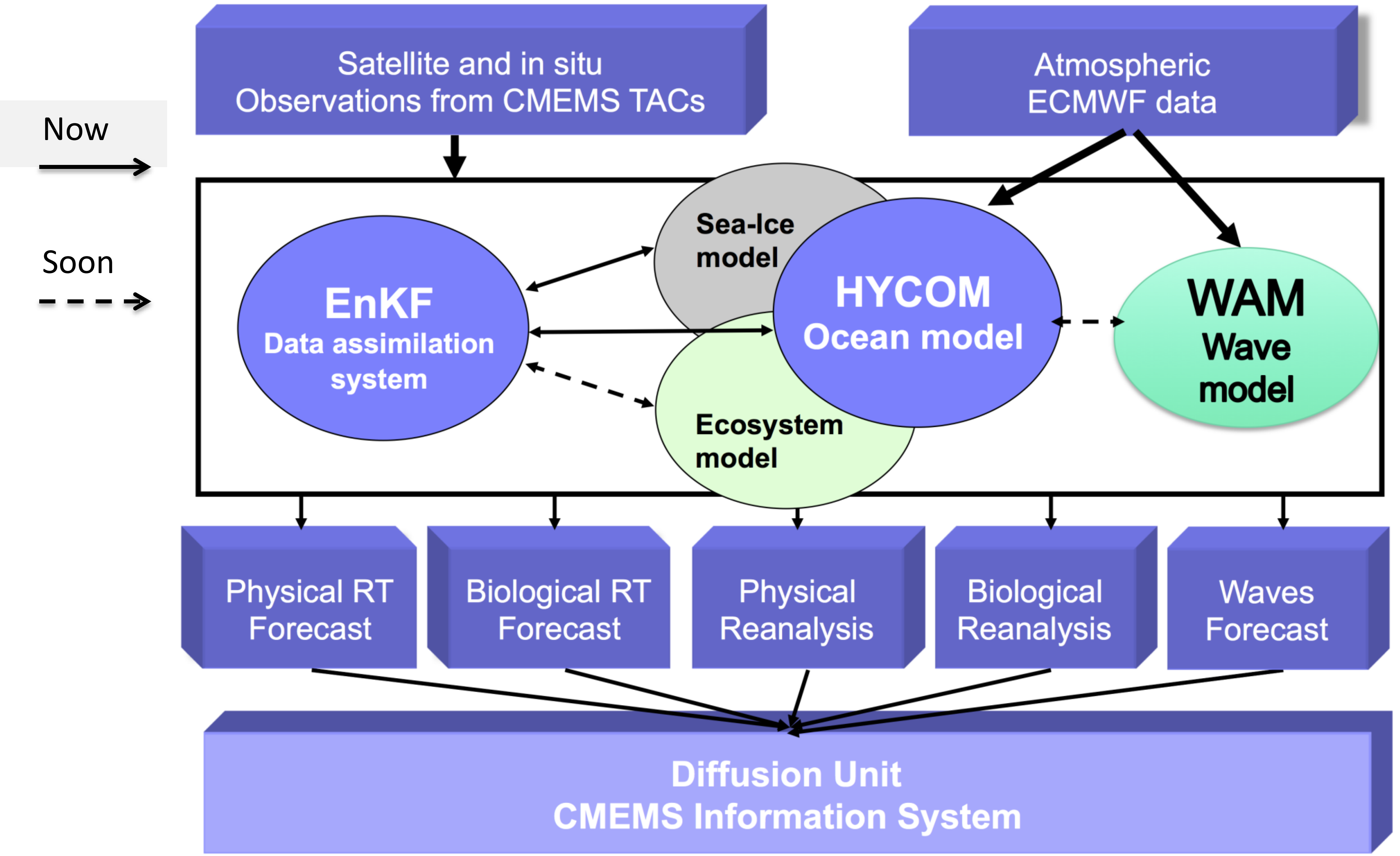
The left route consumes **much** more fuel than the one to the right (~exponential of the ice thickness). Fuel costs of the whole expedition? Background colour: ice thickness from ARC MFC reanalysis. Uncertainties?

Spatial scales in sea ice?



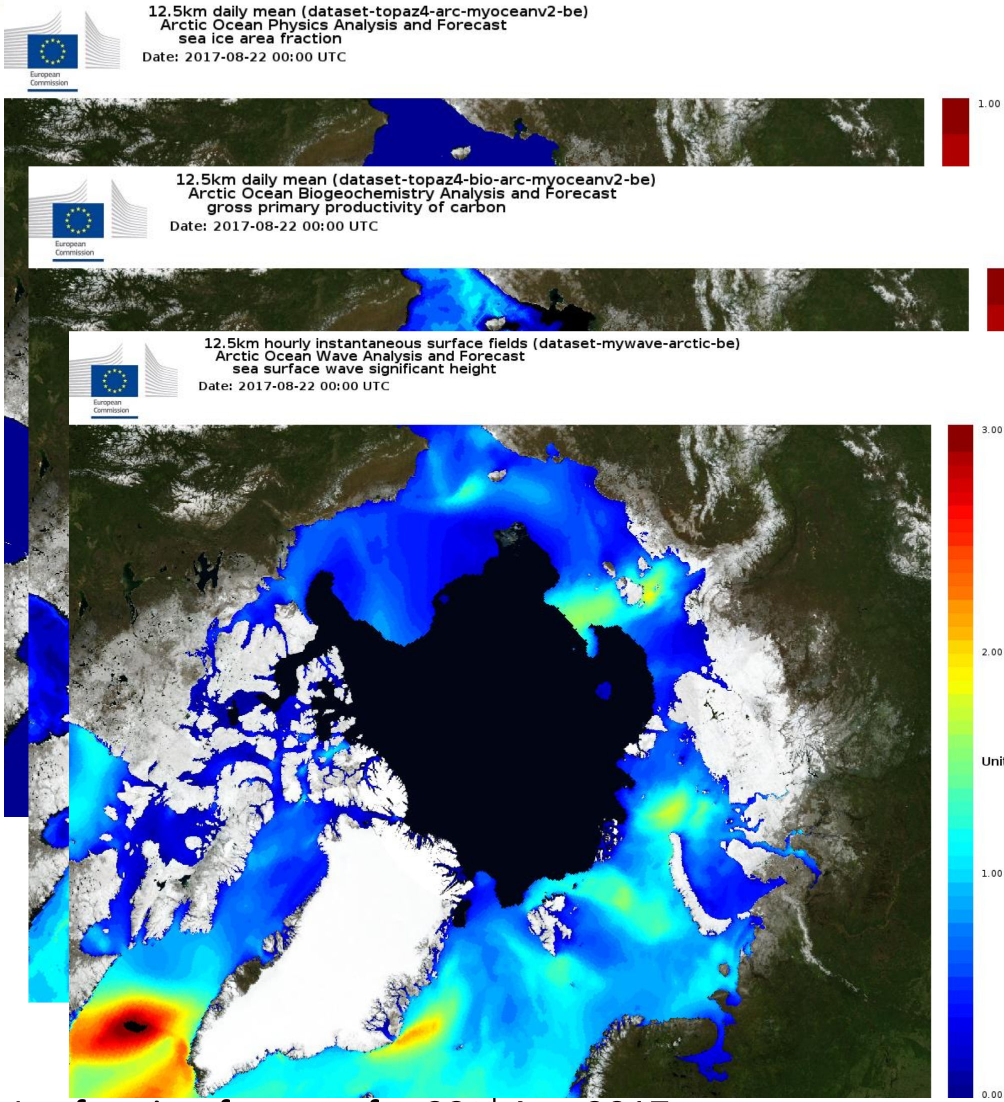
Survey lines sampled at 5m intervals for ice thickness (using EM-31) and snow depth (using MagnaProbe). Geiger et al., Impact of Spatial Aliasing on Sea Ice Thickness. Annals of Glaciology 56(69) 2015

The ARC MFC (TOPAZ system + WAM)



The TOPAZ system

- Exploited operationally at MET Norway
  - Since 2008
  - Ecosystem coupled online in Jan. 2012
  - Monitored 24/7
- Waves forecast since April 2017
  - From MET Norway's WAM model
- 24 years reanalysis at NERSC
  - Assimilation of satellite and in situ data
  - Updated every year until Y-2
- 3-years ecosystem reanalysis
  - Assimilation of ocean colour data and in situ profiles
  - Update ongoing 2007-2012
- Copernicus service
  - Free distribution of data
  - Dynamical viewing (Godiva2)



Ice fraction forecast for 22nd Aug 2017
And associated primary production
And significant wave heights

Sea ice thickness: TOPAZ vs SMOS

Validation results for TOPAZ when not assimillating sea ice thickness observations

Let

H: SMOS sea ice thickness

dH: uncertainty

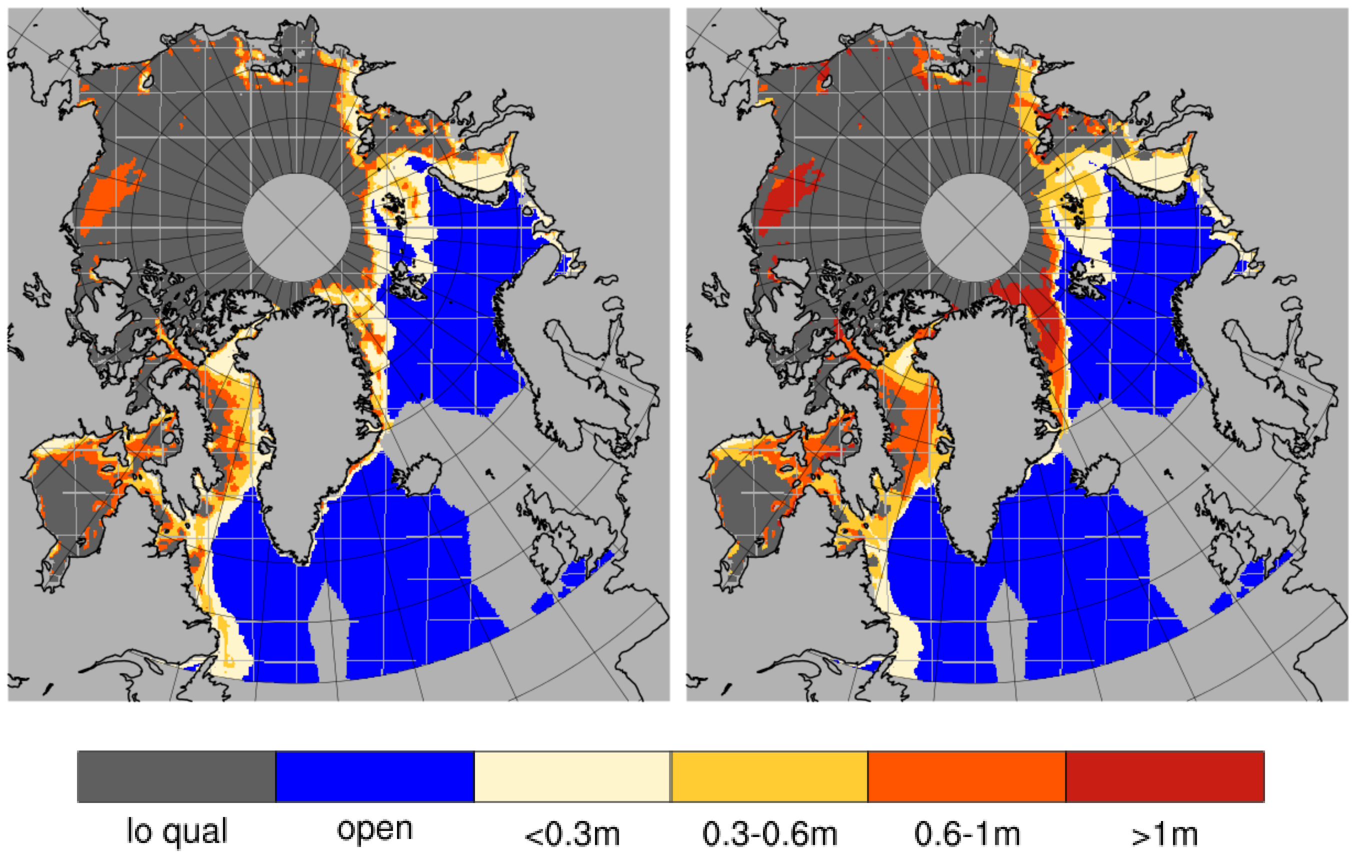
Criteria applied for observations to be used:

dH < 1m

dH/H < 0.75

SMOS, 2017-02-08

TOPAZ 7-day f.c., valid 2017-02-08



Ice thickness validation

TOPAZ reanalysis

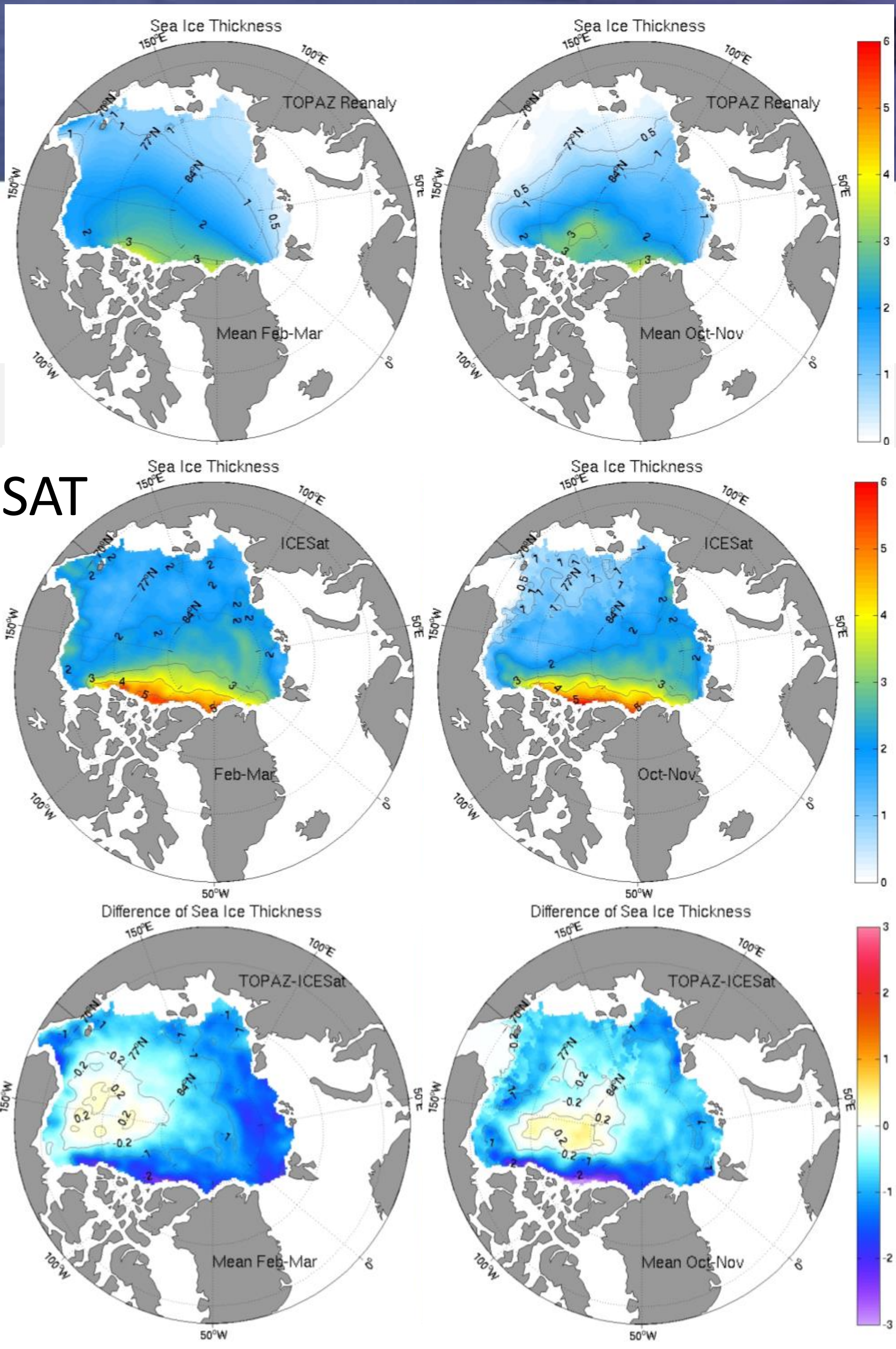
Independent satellite IceSAT (Kwok, JPL)

TOPAZ

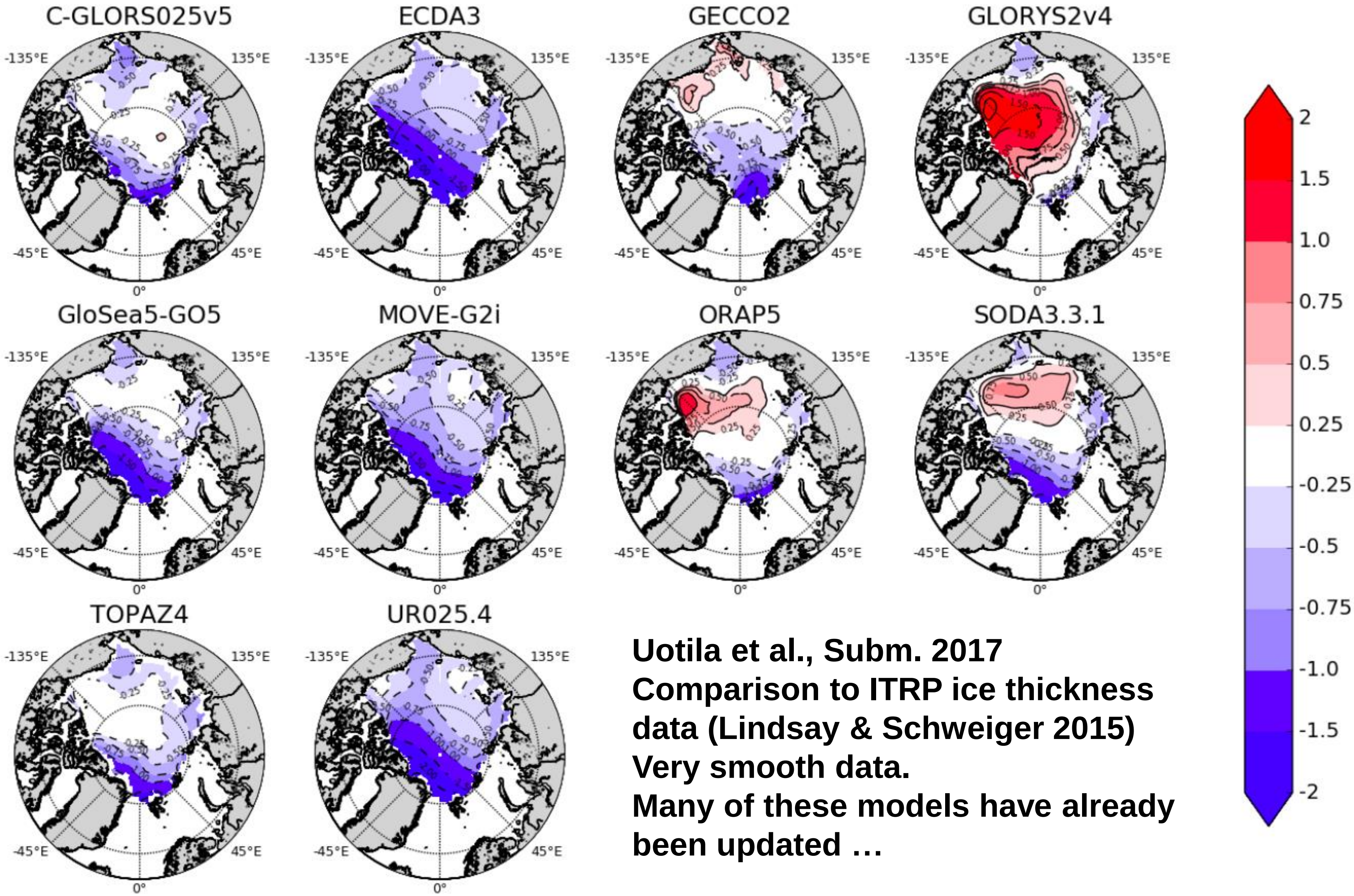
Underestimates thick ice

Overestimates thin ice

Common feature of other models (Johnson et al. JGR 2012, See also PORA-IP, Uotila et al.)



PORA-IP intercomparison



Uotila et al., Subm. 2017
Comparison to ITRP ice thickness data (Lindsay & Schweiger 2015)
Very smooth data.
Many of these models have already been updated …

Why should the sea ice thickness be wrong?

Thermodynamics

- Errors in snow depths,
- Melt ponds
- Brine channels
- Lateral melt / freezing
- Early phases of ice formation
- Ocean temperature
- Air temperature

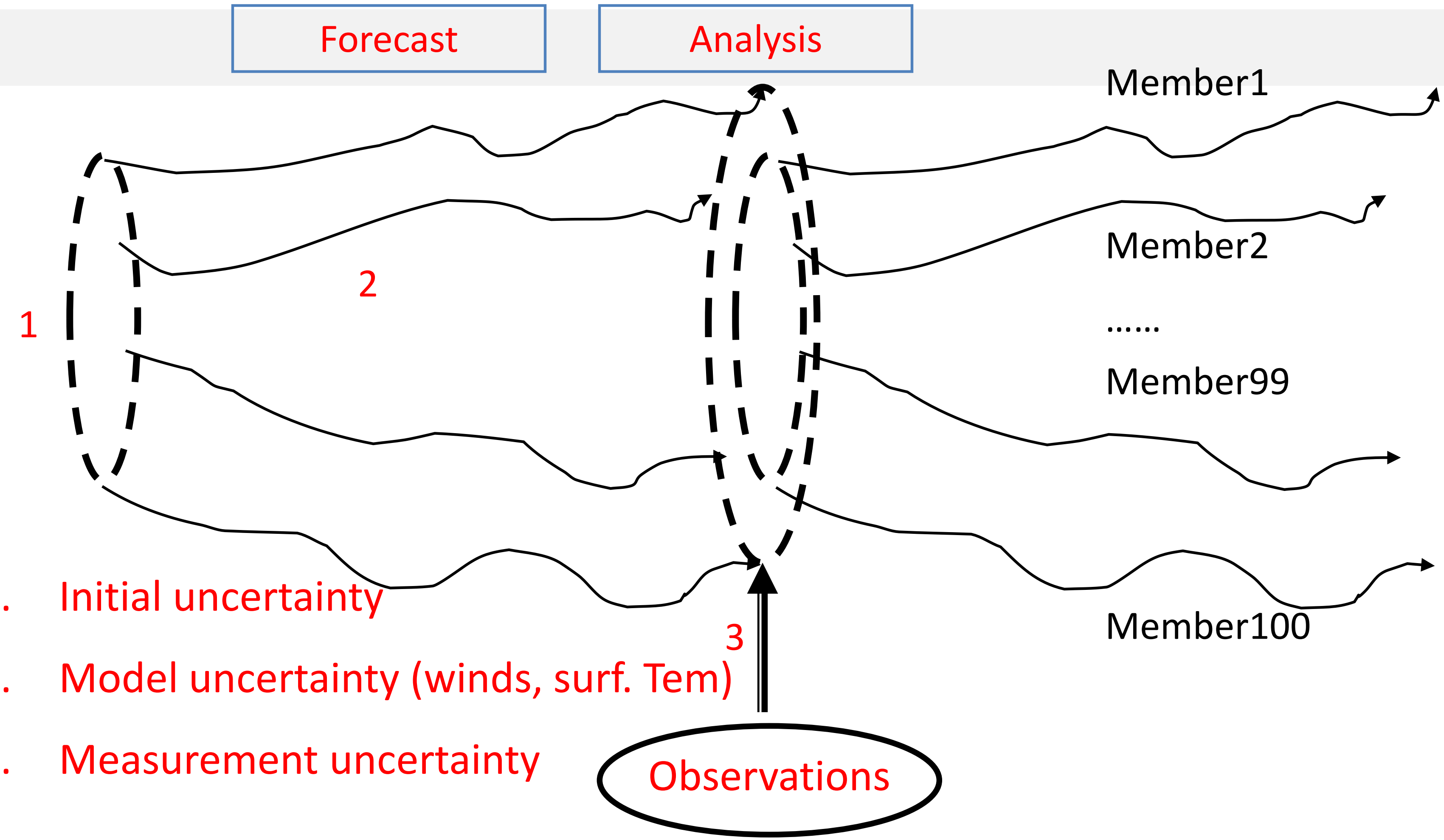
Dynamics

- Deformations
- Ice drift
  - Thick ice drifts off too fast
- Numerical mixing of thin and thick ice
- Ocean currents
- Surface winds

Feedbacks!

Ice thickness accumulates ALL the errors

Ensemble Kalman filtering

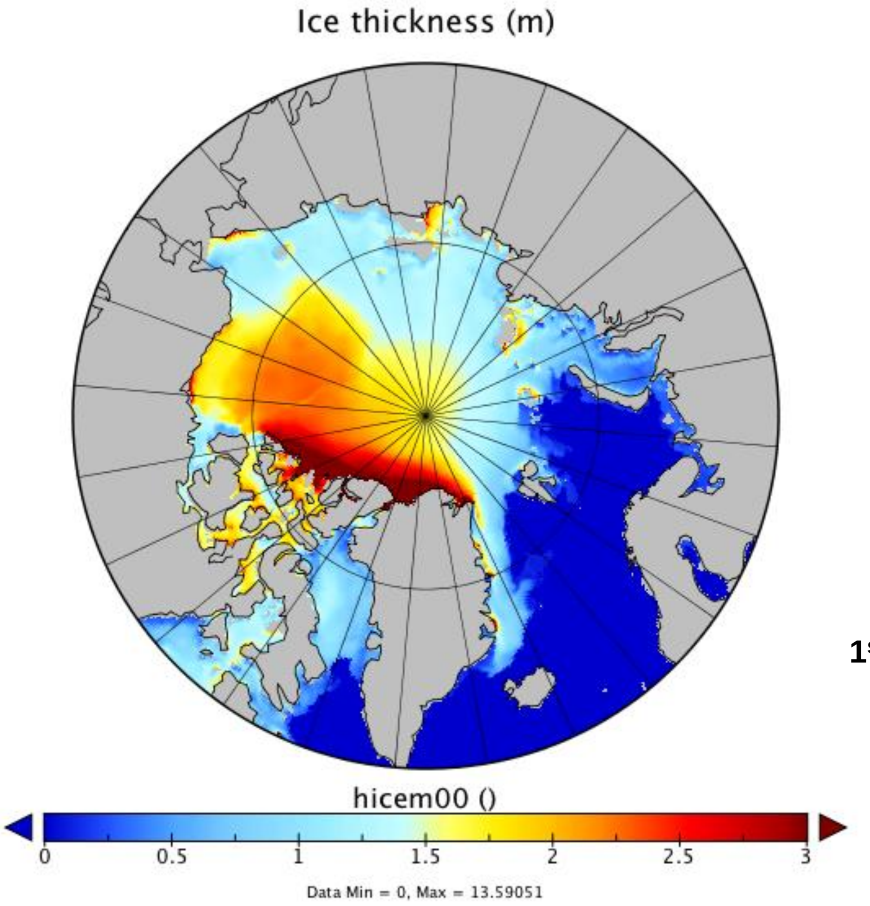


1. Initial uncertainty
2. Model uncertainty (winds, surf. Tem)
3. Measurement uncertainty

Present probabilistic forecast in ARC MFC

Different members on the same date (ice thickness not assimilated)

How good is it for ensemble (EnKF) assimilation?



1st March 2008

Assimilation

DEnKF, asynchronous

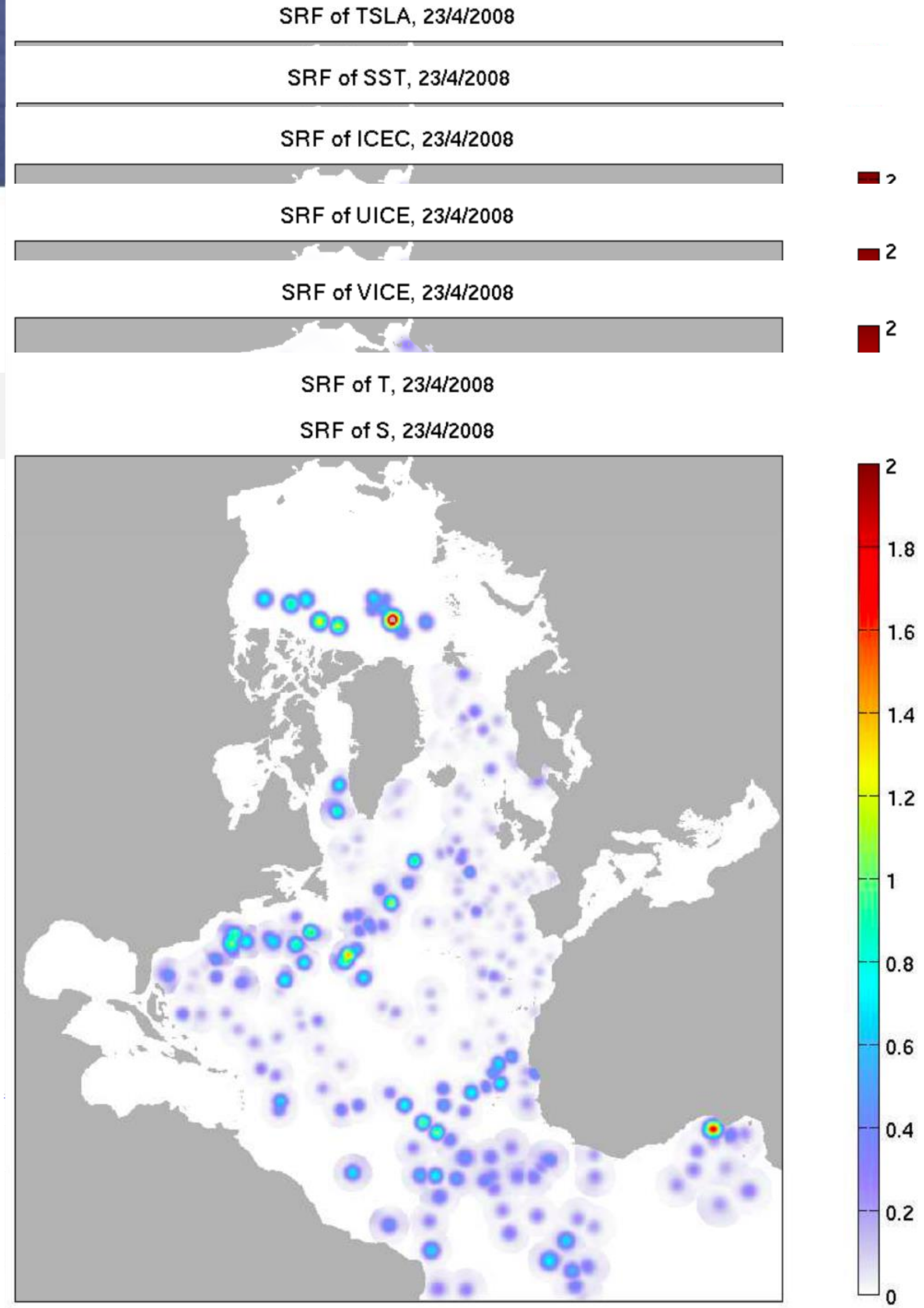
- **100 members**
- **Local analysis (~90 km radius)**

Observations (400.000):

- **Sea Level Anomalies (SL TAC)**
- **SST (OSI TAC)**
- **Sea Ice Concentr. (OSI TAC)**
- **Sea ice drift (OSI TAC)**
- **T/S profiles (INS TAC, IPY)**
- ***New since Oct 17:* Sea ice thickness (SMOS, UHam)**

SRF: local spread reduction factor

$$\mathrm{SRF} = \sqrt{\frac{\mathrm{tr}(\mathbf{H}\mathbf{P}^f\mathbf{H}^\mathrm{T}\mathbf{R}^{-1})}{\mathrm{tr}(\mathbf{H}\mathbf{P}^a\mathbf{H}^\mathrm{T}\mathbf{R}^{-1})}} - 1$$



TWO Ice thickness satellites:

<u>CryoSat2:</u>

Pro:

- Thick ice
- High resolution along track 300m.

Contra:

- Low coverage
- Requires long processing windows
- High latency
- Imprecise in thin ice (small freeboard)
- Uncertainty with snow
- Not available in summer

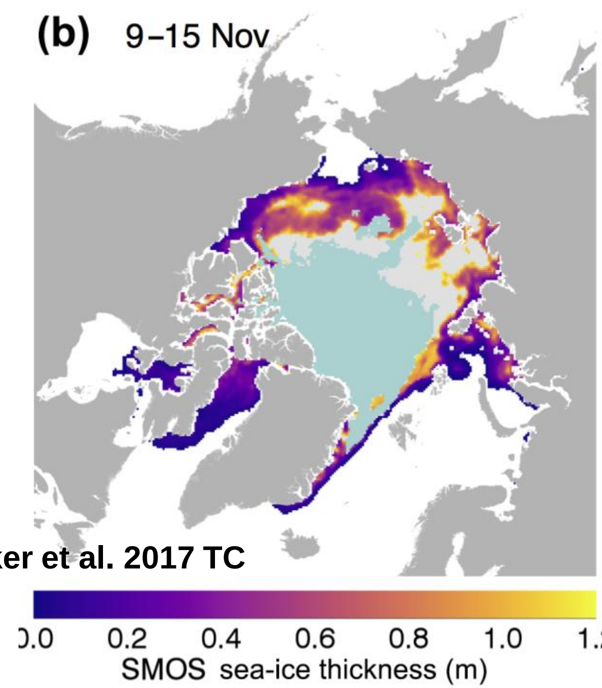
<u>SMOS:</u>

Pro:

- Daily full coverage, October – March
- Better for NRT operations

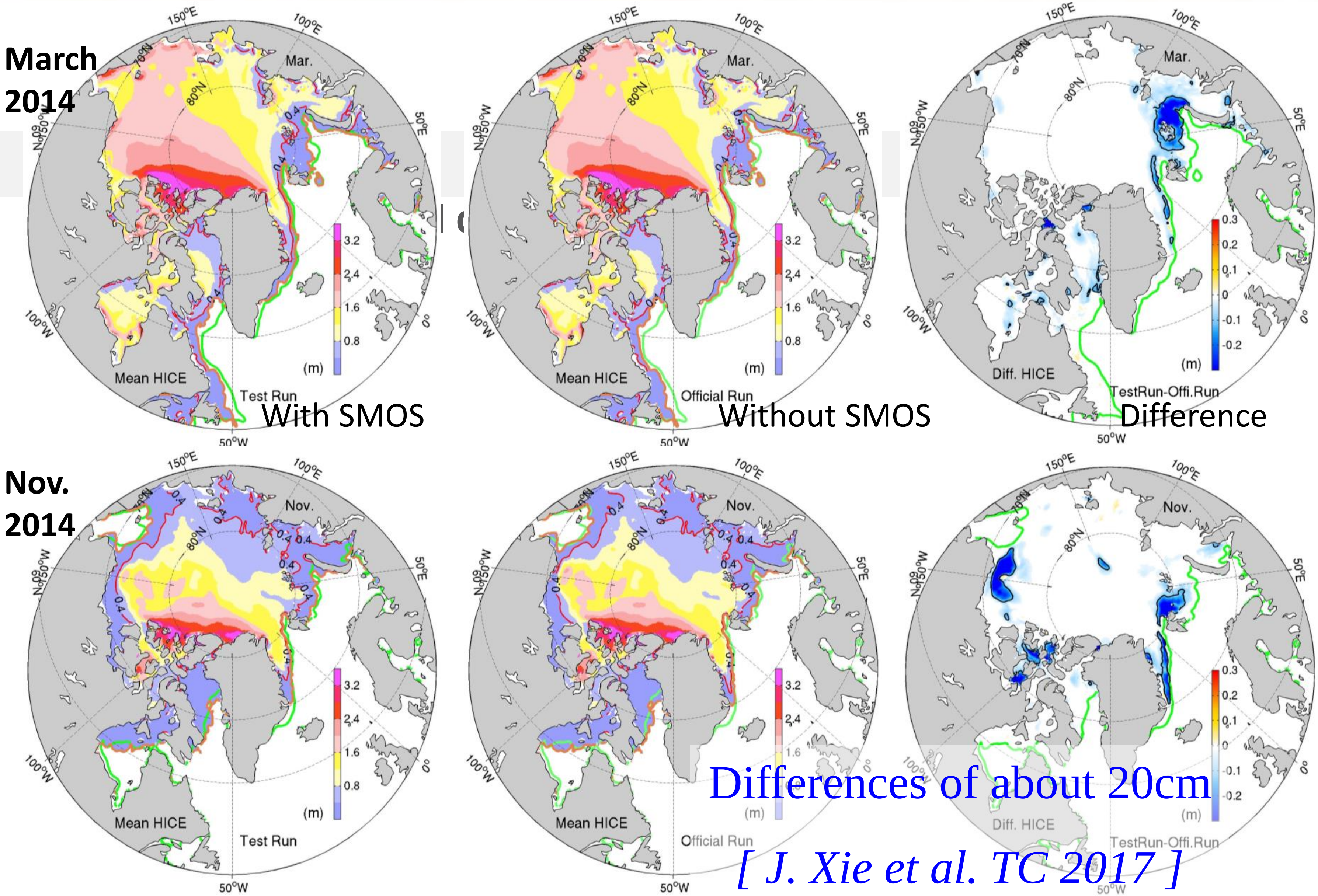
Contra:

- Coarse resolution ~35 km.
- Only 0 to 0.5m in level ice
- Until 1.5 m in deformed ice
- Not available in Summer



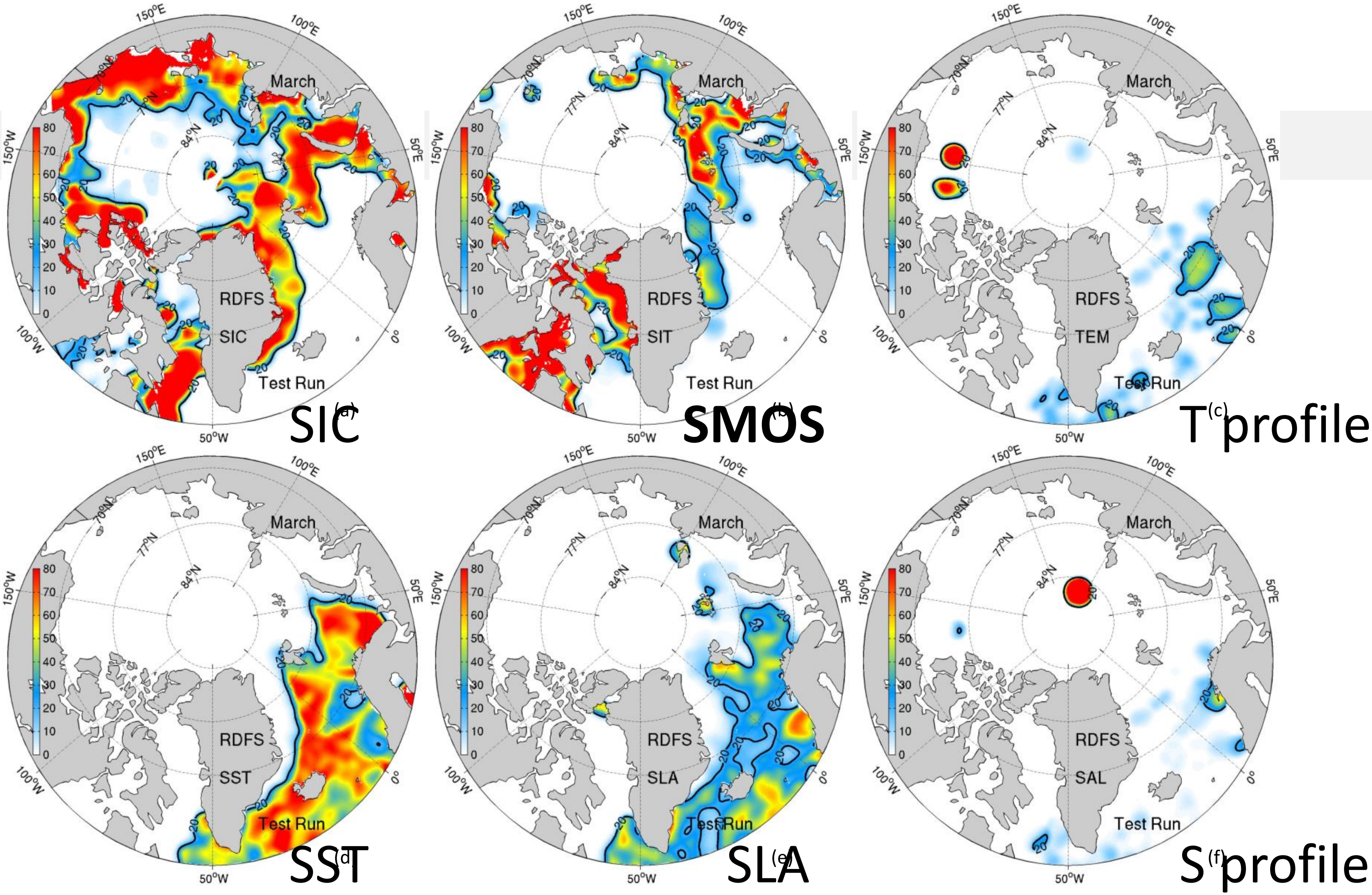
Ricker et al. 2017 TC

Impact of assimilating SMOS
thin ice only (<40 cm)

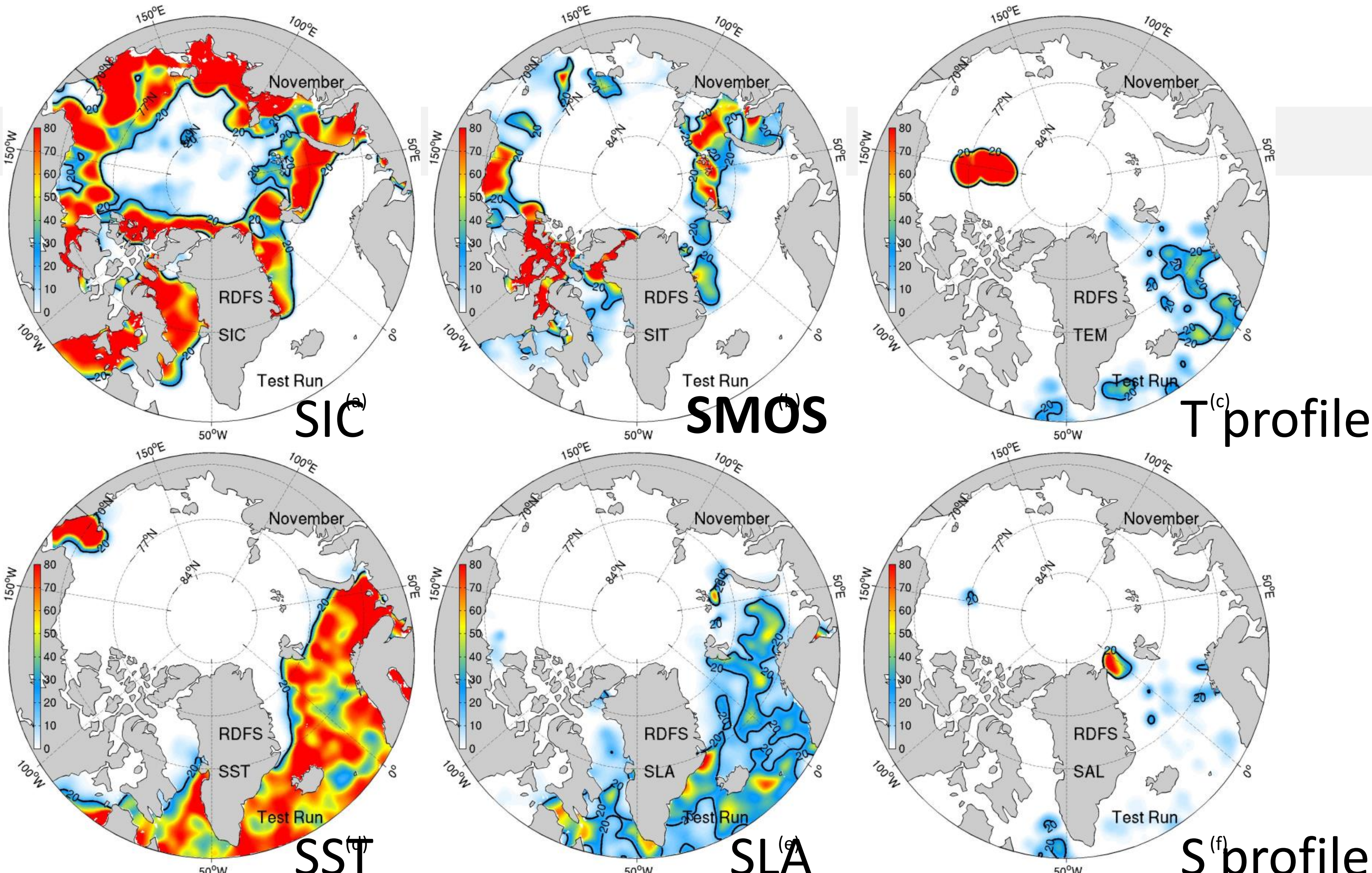


[J. Xie et al. TC 2017]

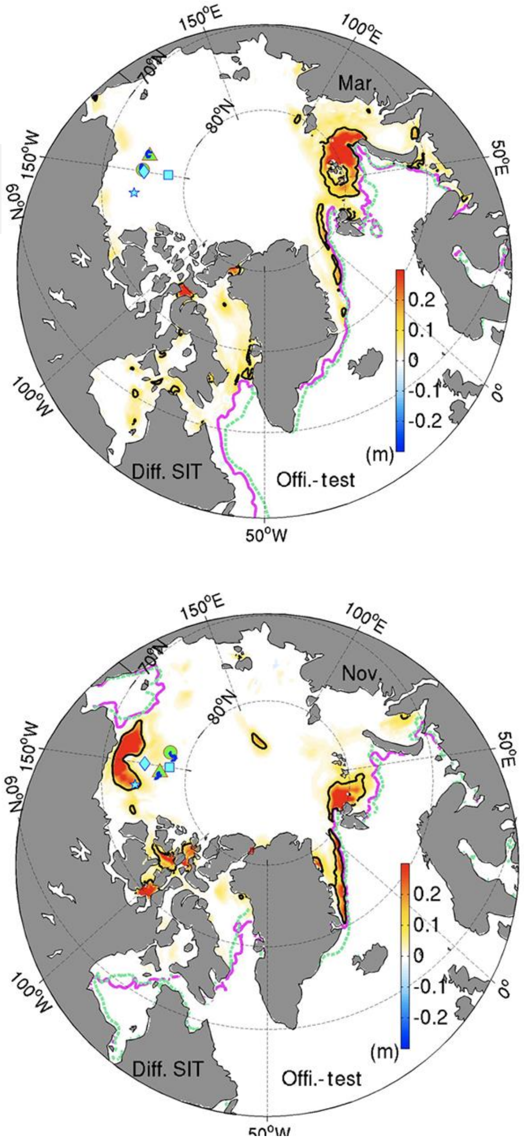
Relative impact of observations in March 2014

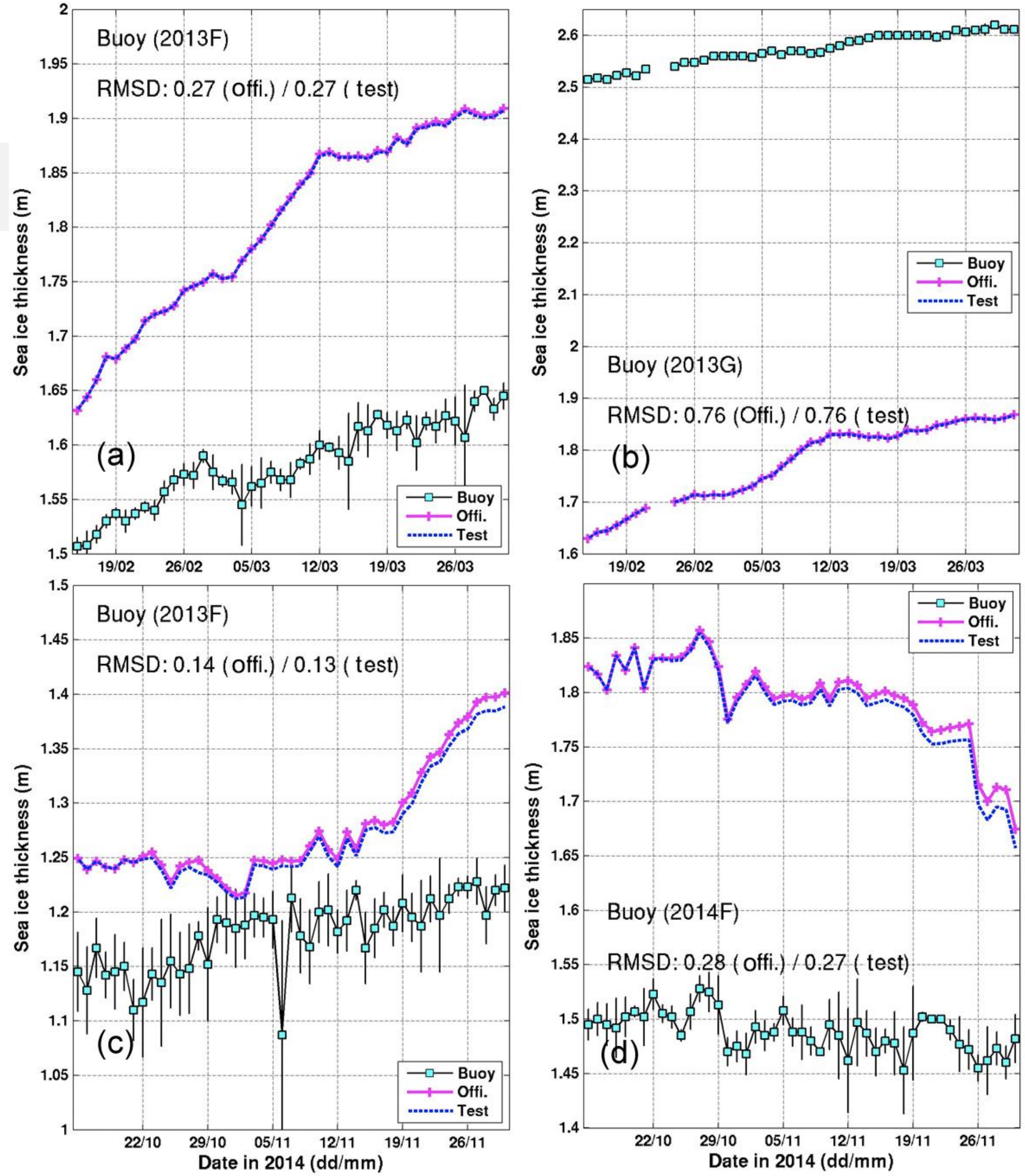


Relative impact of observations in Nov. 2014



Comparison to independent IMB data





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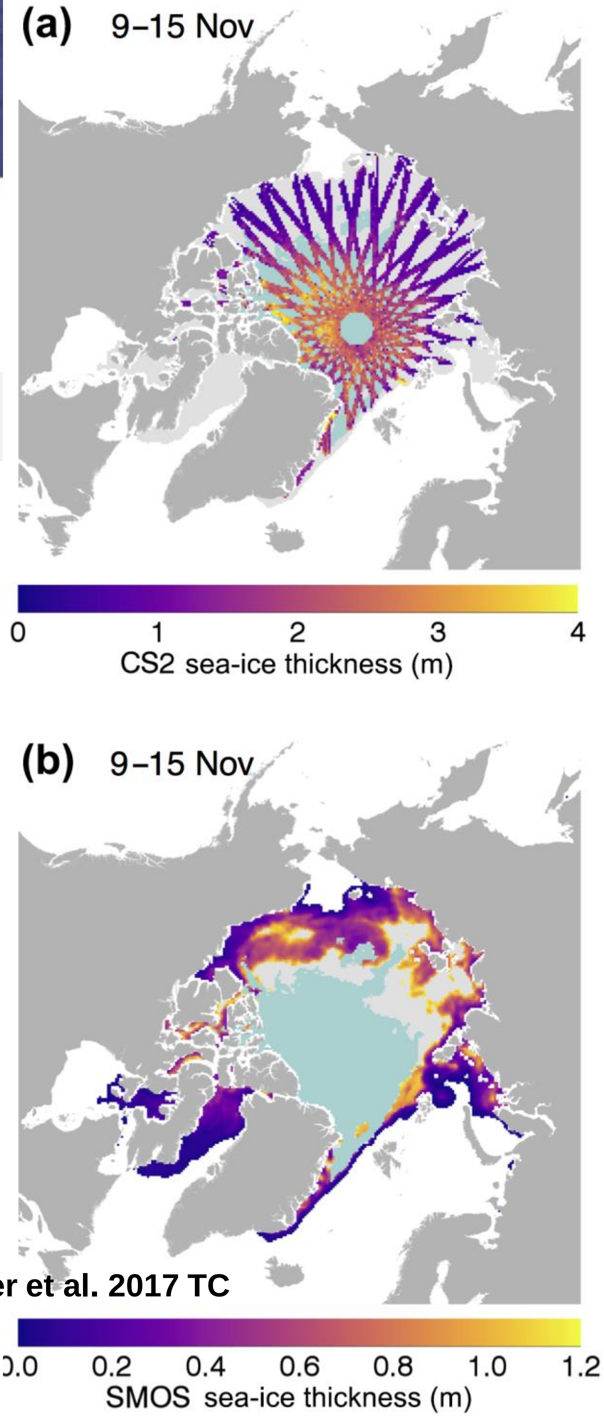
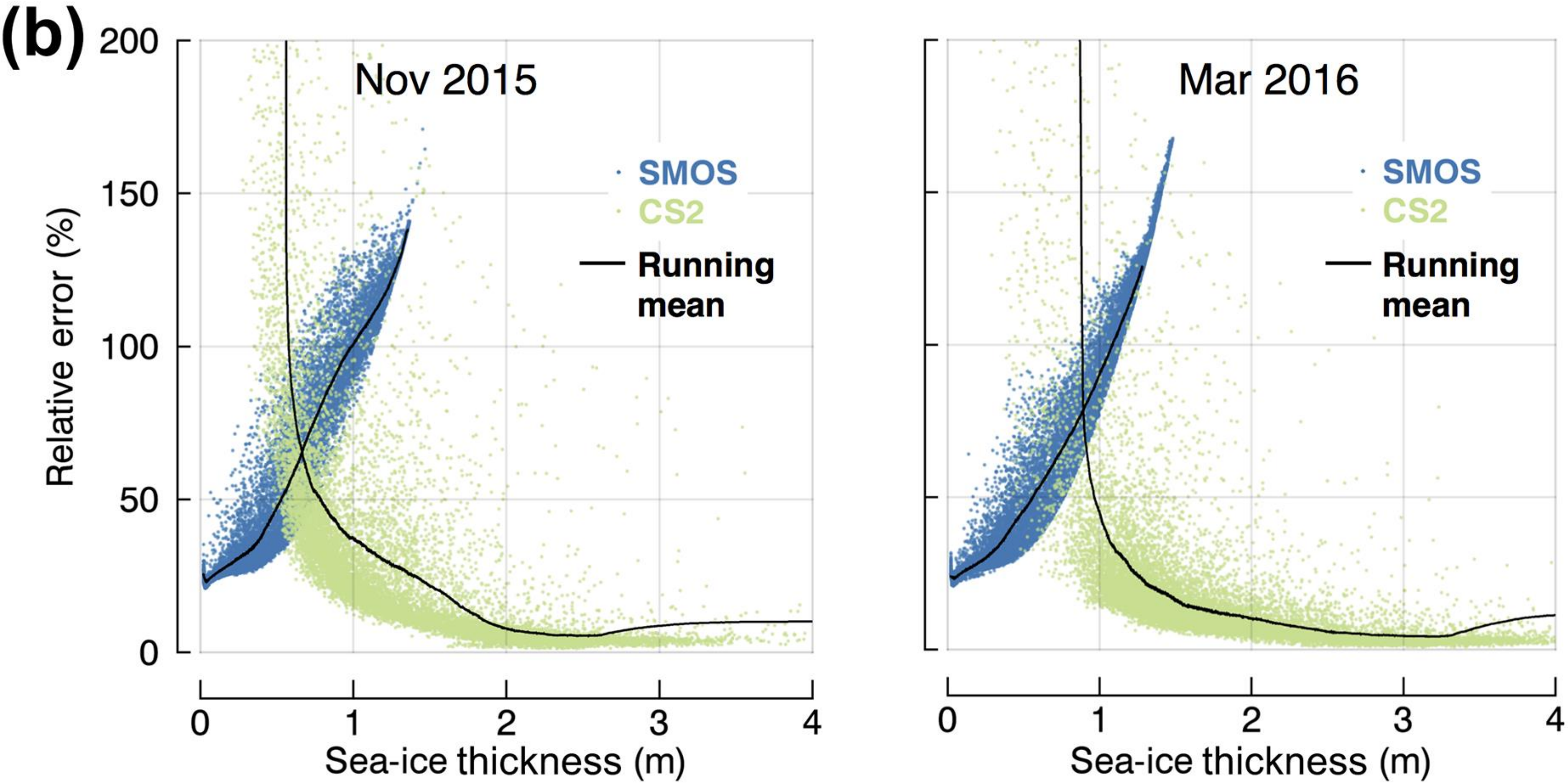


Ricker et al. 2017 TC

Observations errors: relative uncertainties



What about biases? …

Ricker et al. 2017 TC

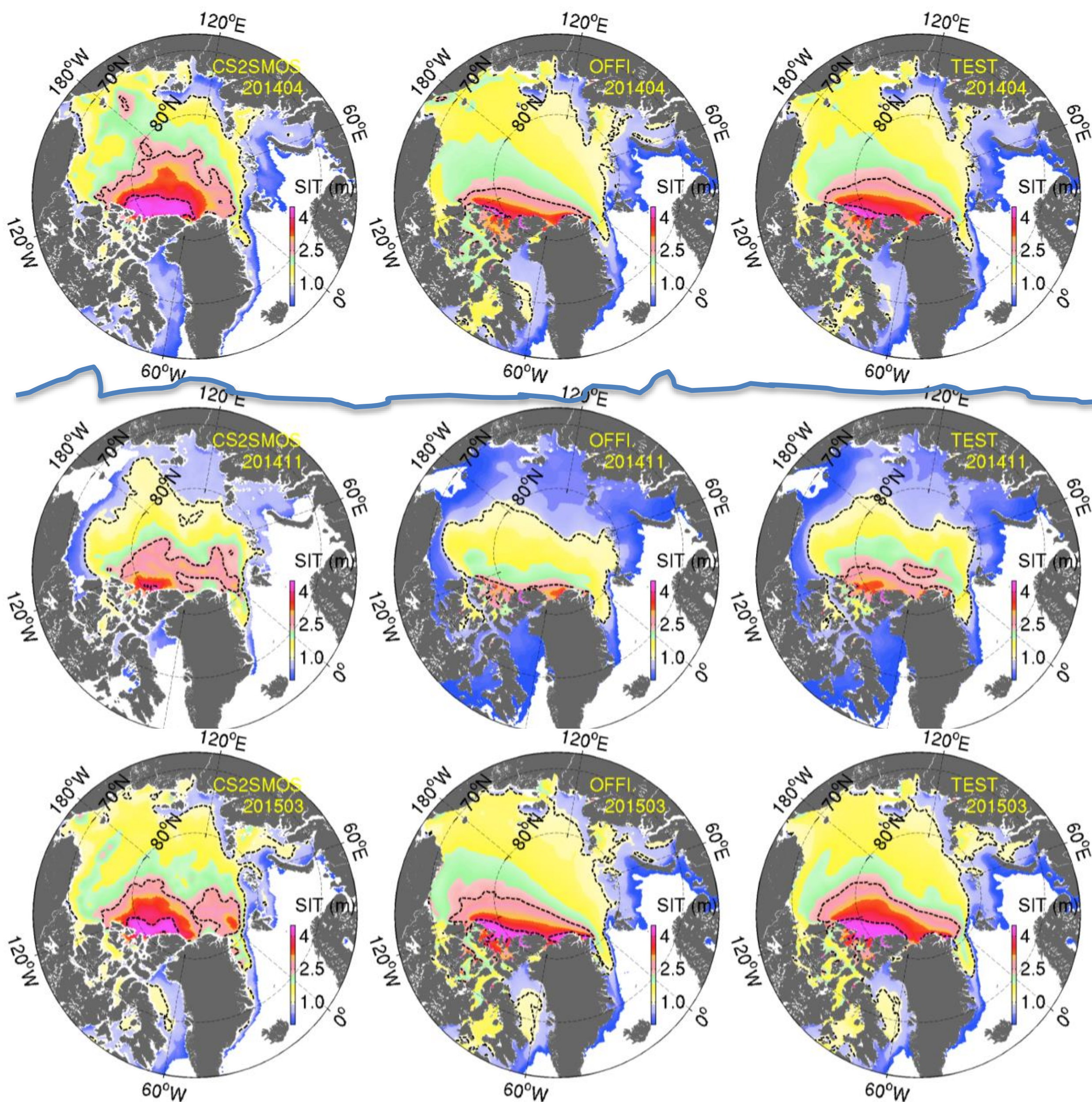
Assimilating combined CS2SMOS

April 2014

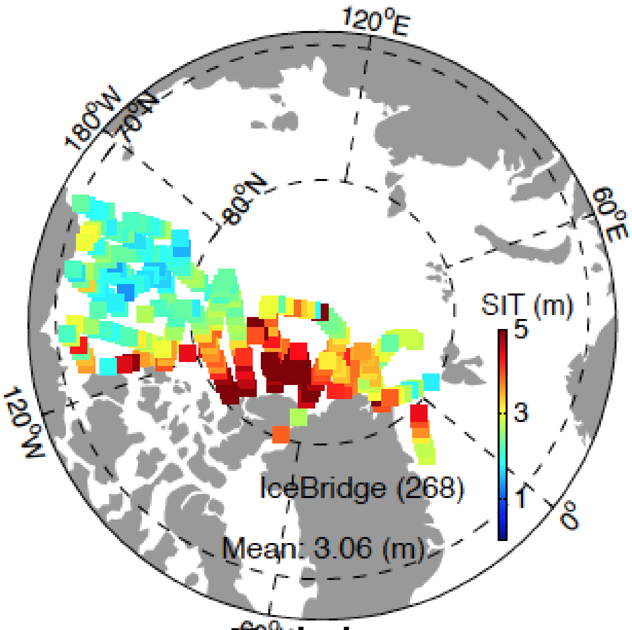
May – Oct Summer Break

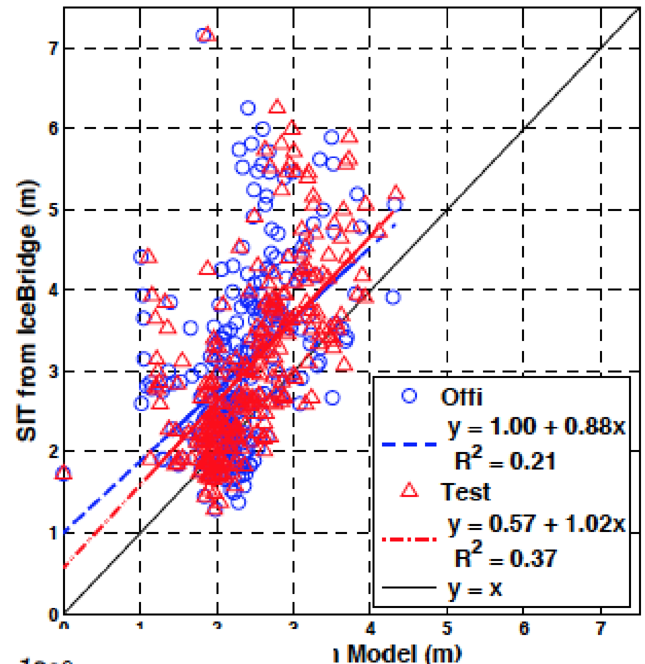
Nov 2014

Mar 2015

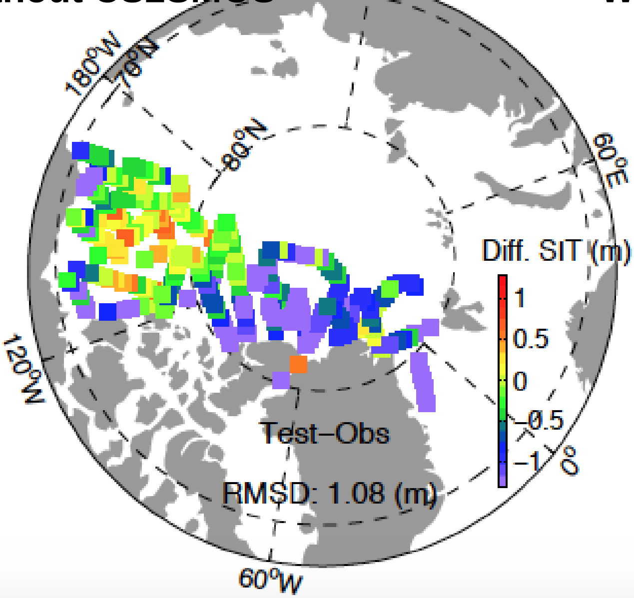


Validation against operation IceBridge data

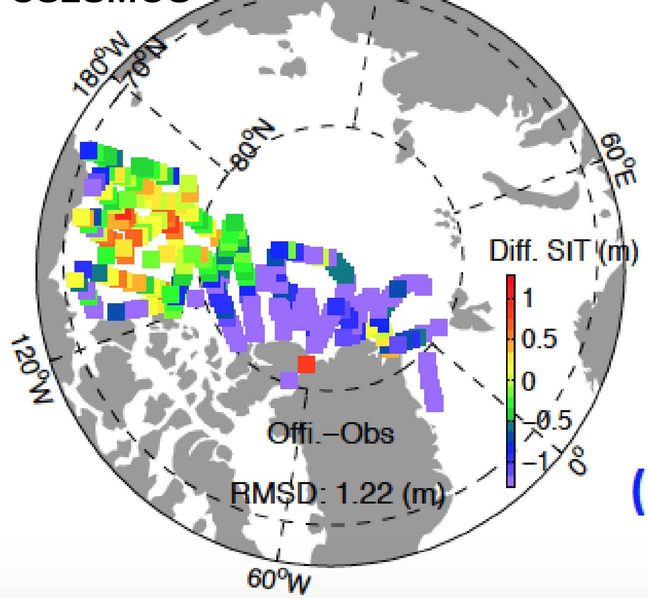




Mod-obs
Without CS2SMOS



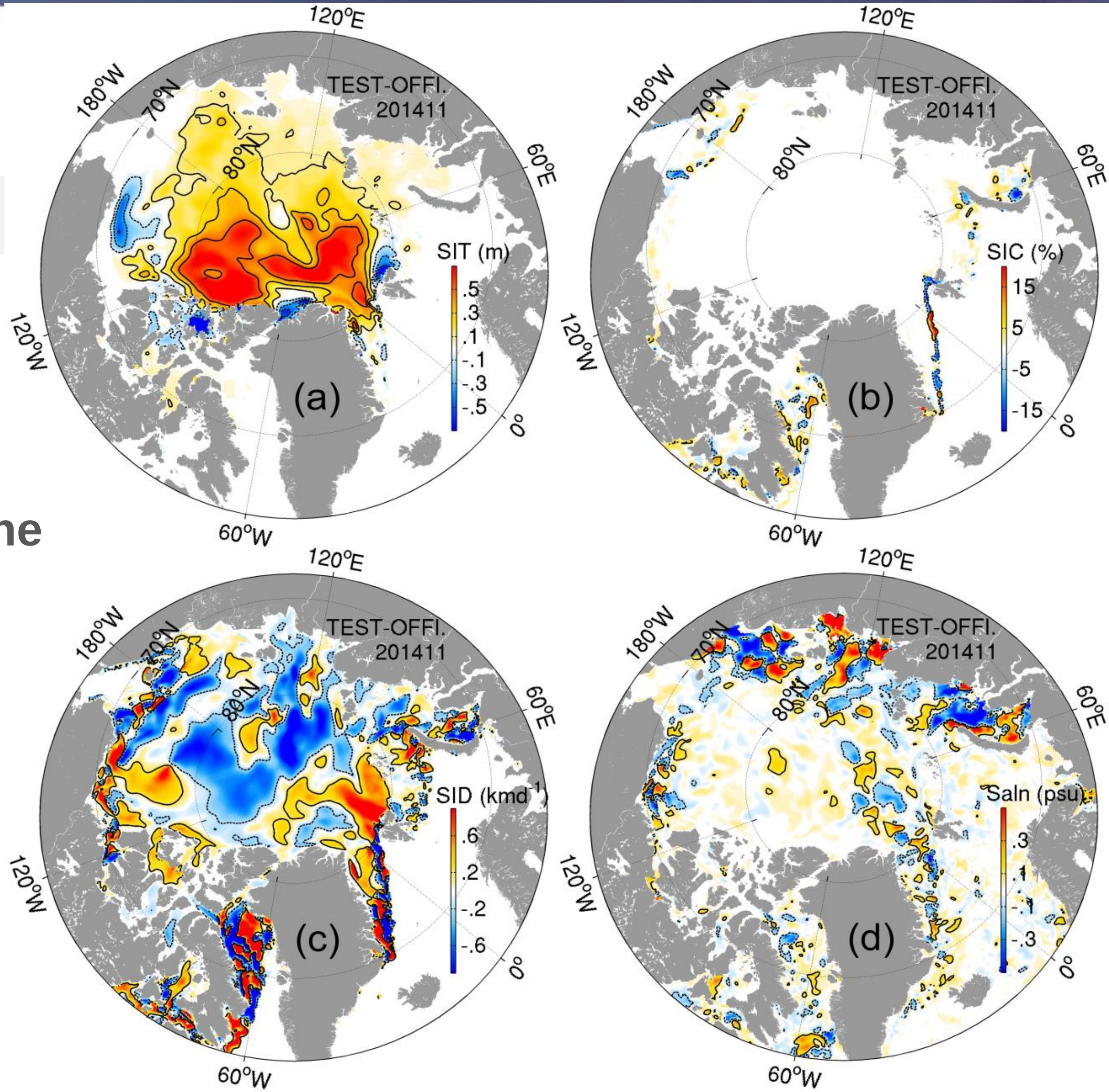
Mod-obs
With CS2SMOS



(March and April of 2014 and 2015)

Multivariate EnKF assimilation updates

- **Thicker ice**
  - **> 50 cm updates**
- **Slower ice drift**
  - **- 0.5 km/d**
- **Same ice edge**
- **Slightly more saline surface waters**

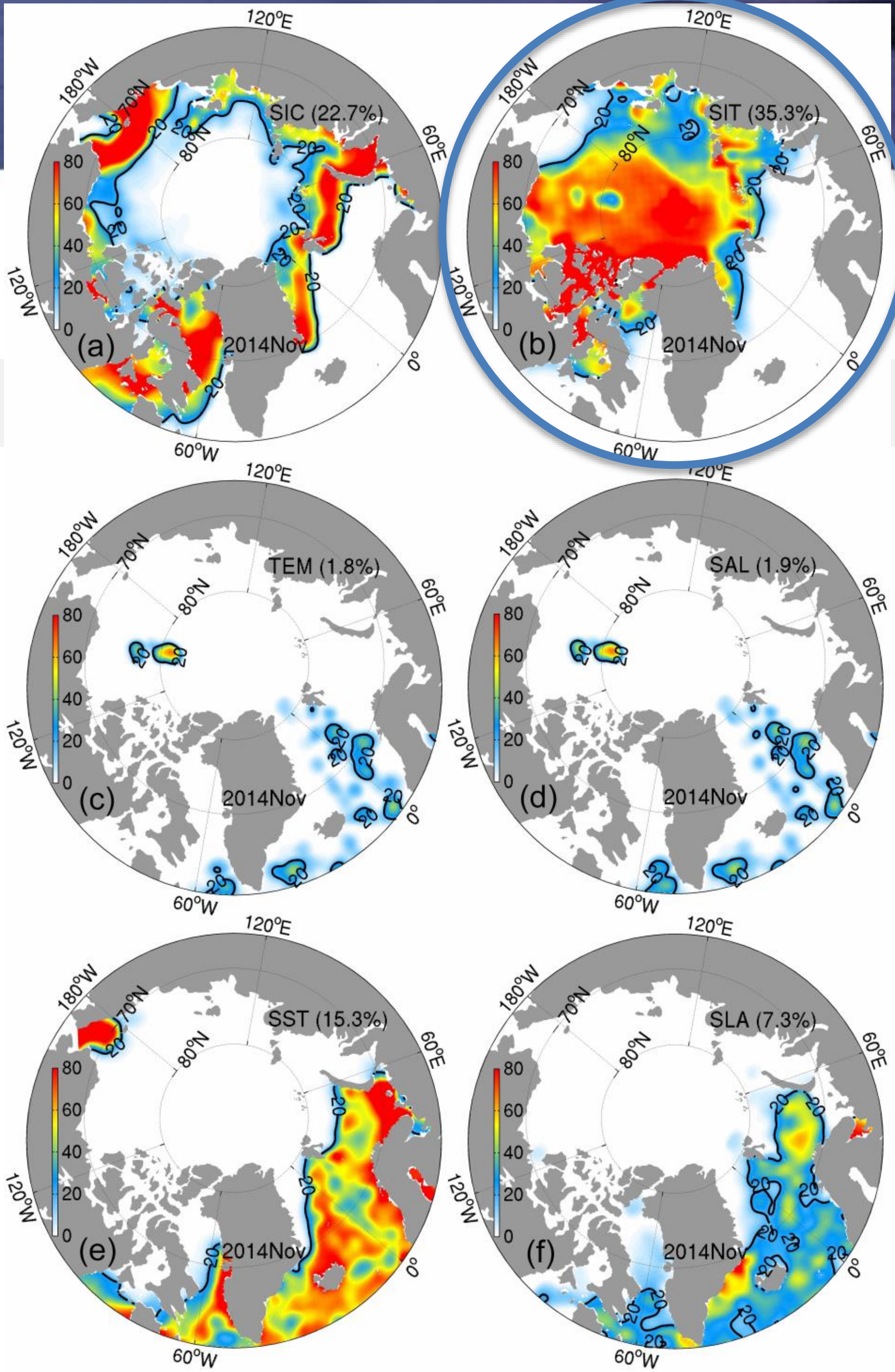


Complementarity of Observing systems

Relative share of Degrees of Freedom for Signal (DFS)

Ice concentrations most useful near the ice edge

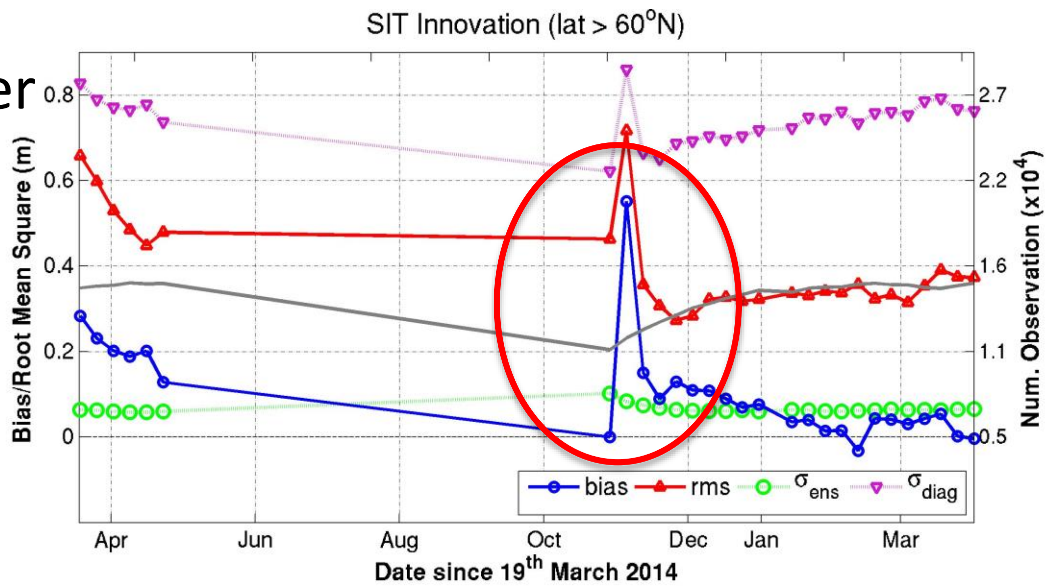
Ice thickness most useful inside the pack.

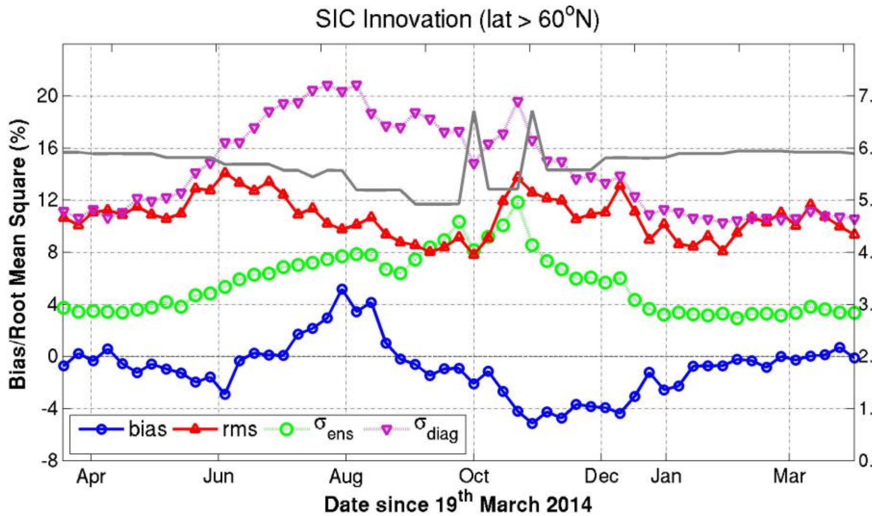


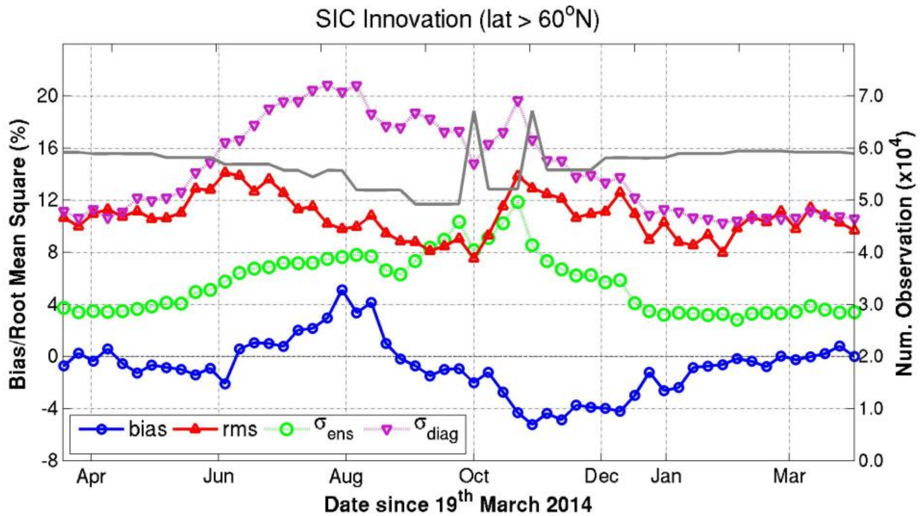
EnKF: Data assimilation diagnostics

- Bias spike in early November
- Coincident with thickening (SMOS to CS2 transition)
- SST, TSLA, SIC not affected
- Ice volume? …

$$\sigma_{diag}^2 = BIAS^2 + \sigma_{en}^2 + \sigma_o^2$$



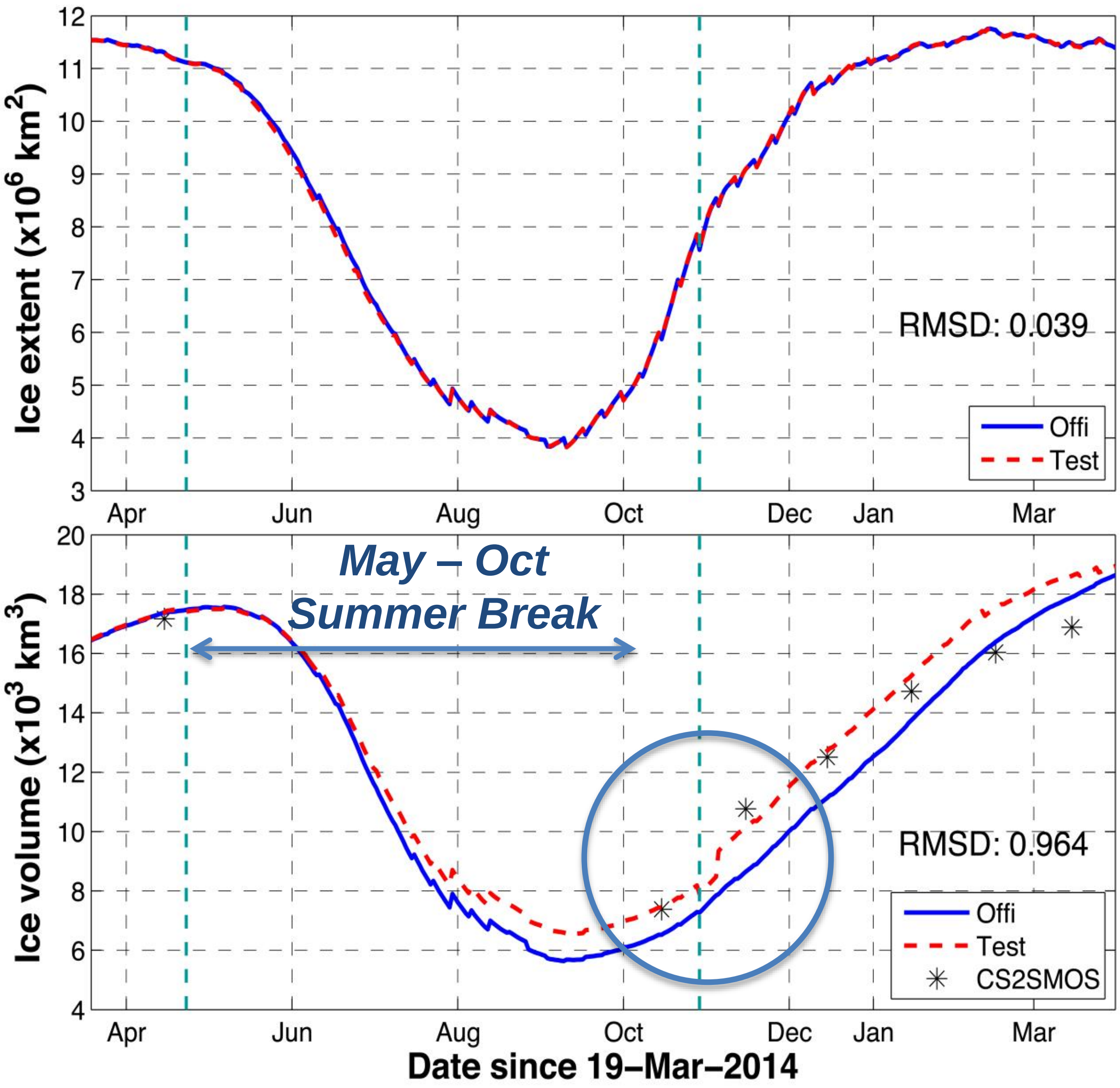




Ice volume in V3 and V4 Arctic reanalysis

Ice area remains the same

Sudden increase of ice volume



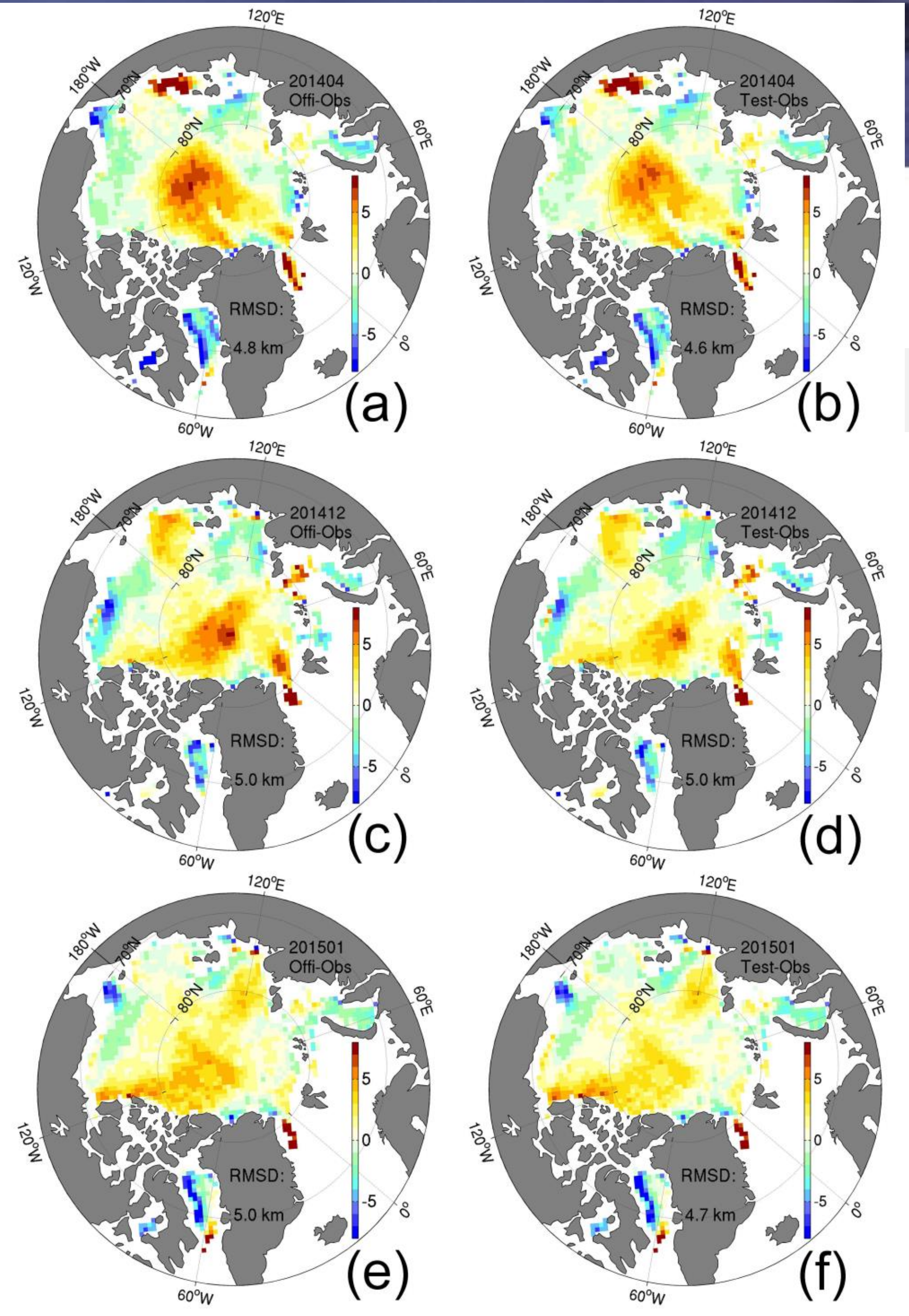
Impact on ice drift

Comparison to OSI-SAF ice drift (coarse resolution)

Thicker ice -> slower drift

Improvement by less than 5% (disappointing?)

Maybe time to try an alternative rheological model?



neXtSIM developments

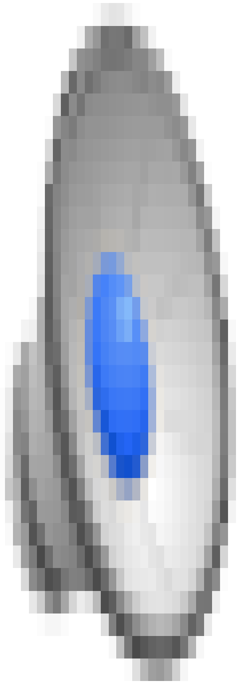
Maxwell-Elastic-Brittle rheology

- Improved representation of scaling laws of deformation
  - Localization of deformation
  - Intermittency of deformation
  - Coupling of localization and intermittency

3 classes of ice thickness

- Following Winton 2000

Implemented in Greenland Sea at 2 km resolution in NRT.



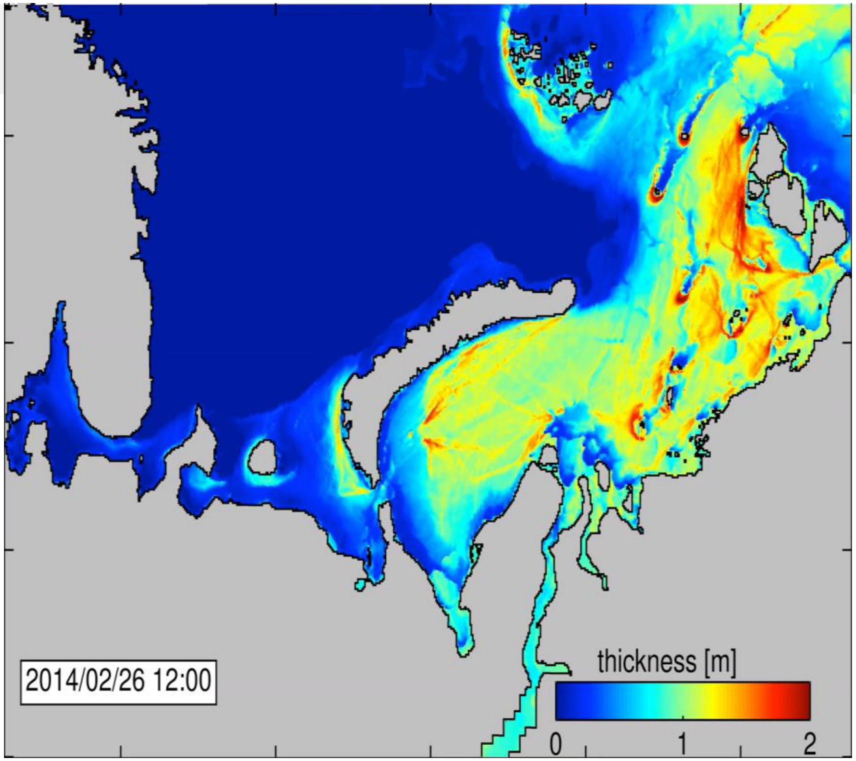
neXtSIM developments

Implementation in NRT for Kara Sea and Barents Sea at 2 km

- **Atm. Forcing from ECMWF**
- **Ocean forcing from TOPAZ**
- **Direct insertion of AMSRE sic.**
- **Direct insertion of SMOS sit.**
- **https://www.nersc.no/data/nextsim-f**

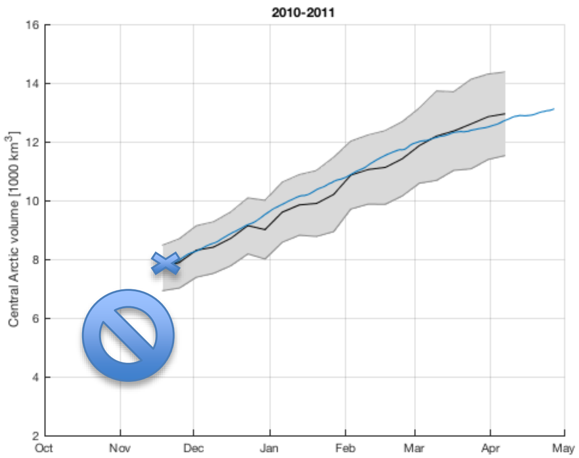
Plan:

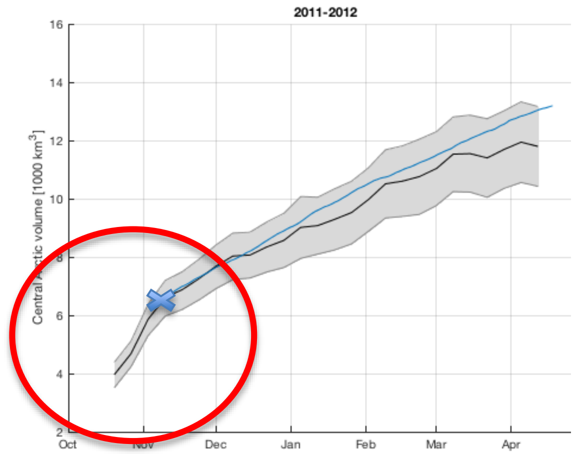
Pan-Arctic configuration in NRT in ARC MFC in 2019.

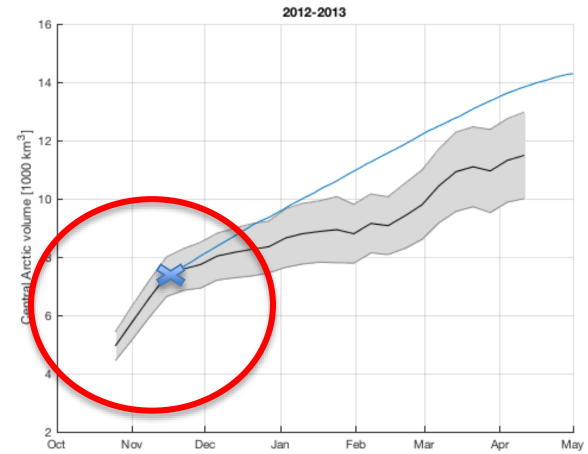


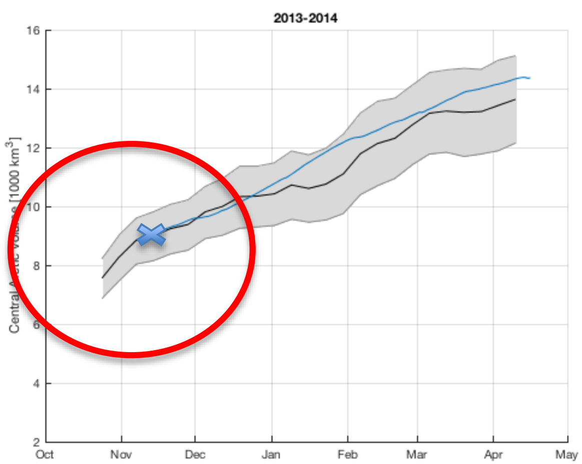
Merged CS2SMOS: compared to neXtSIM

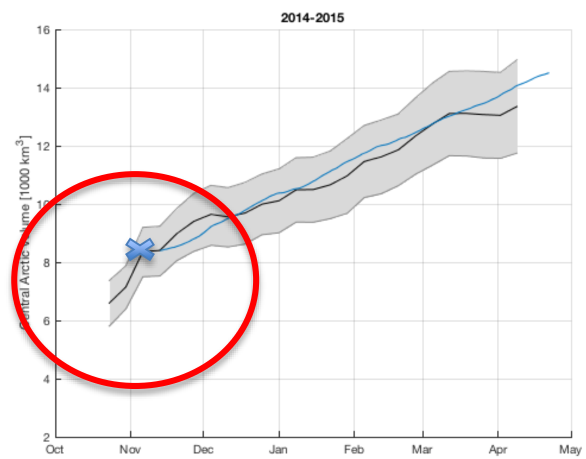
Ice volume jumps (weekly averages)











- CS2SMOS
- (+/- interpolation errors)
- Model (neXtSIM)

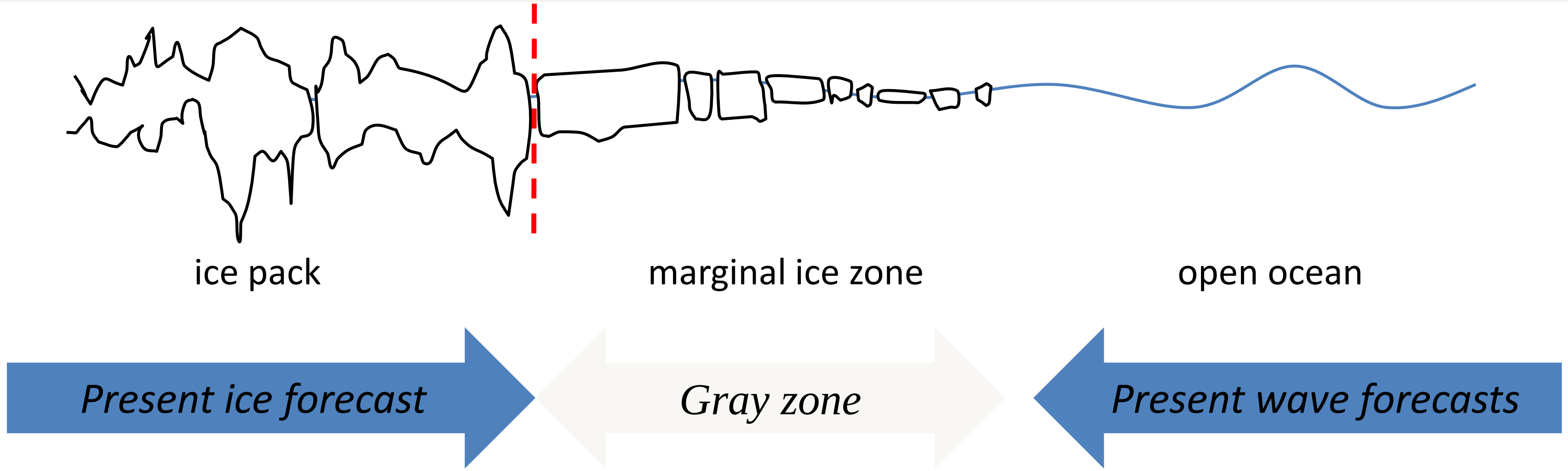
From E. Oláson

Unrealistic jump from Oct. to Nov.: apparent relation to SMOS -> CS2 differences

Model initialised in November for that reason. Use the same snow thickness (reconstructed)

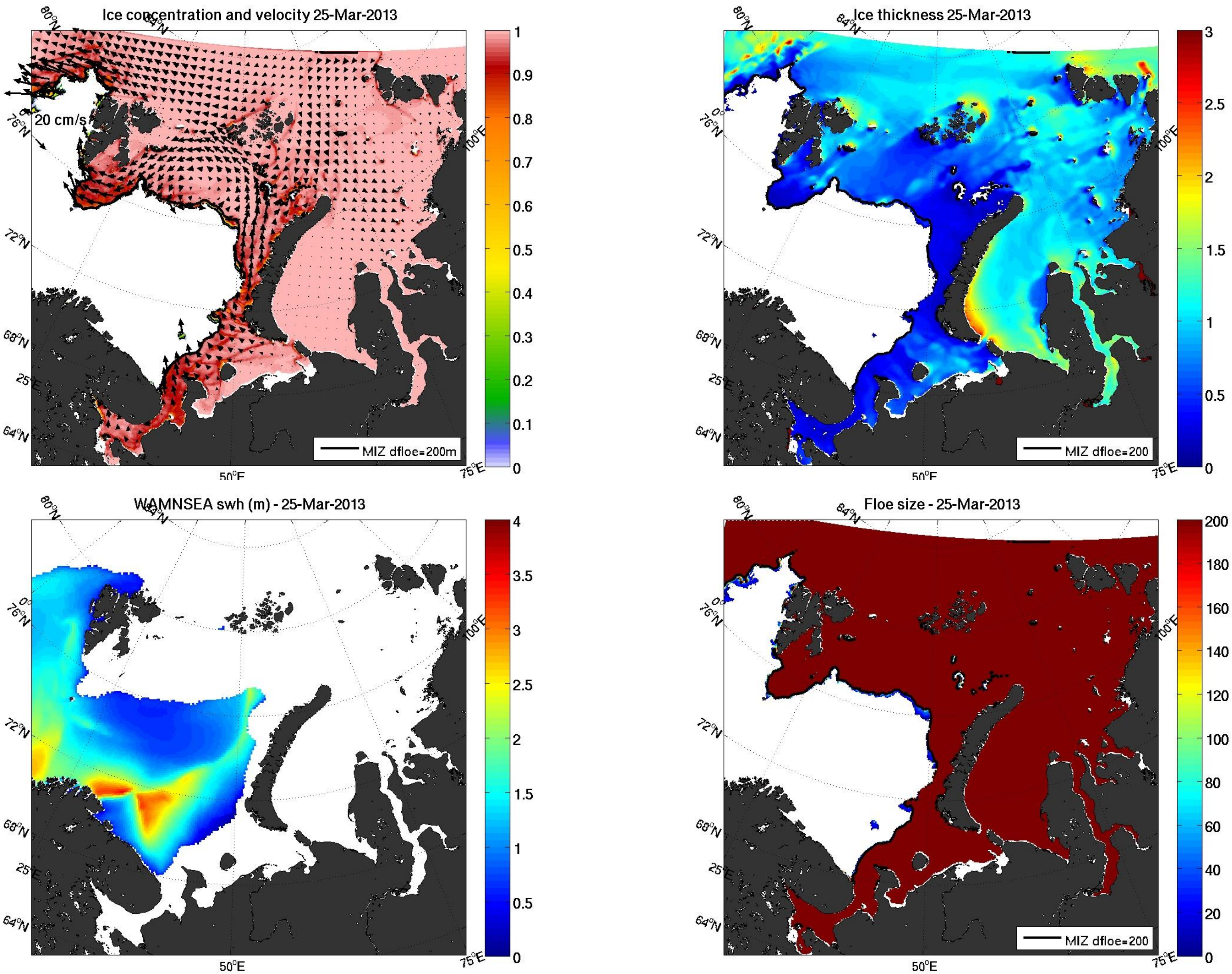
Waves-in-Ice coupling

- Sea ice floe size defined by a wave-in-ice module (WIM)

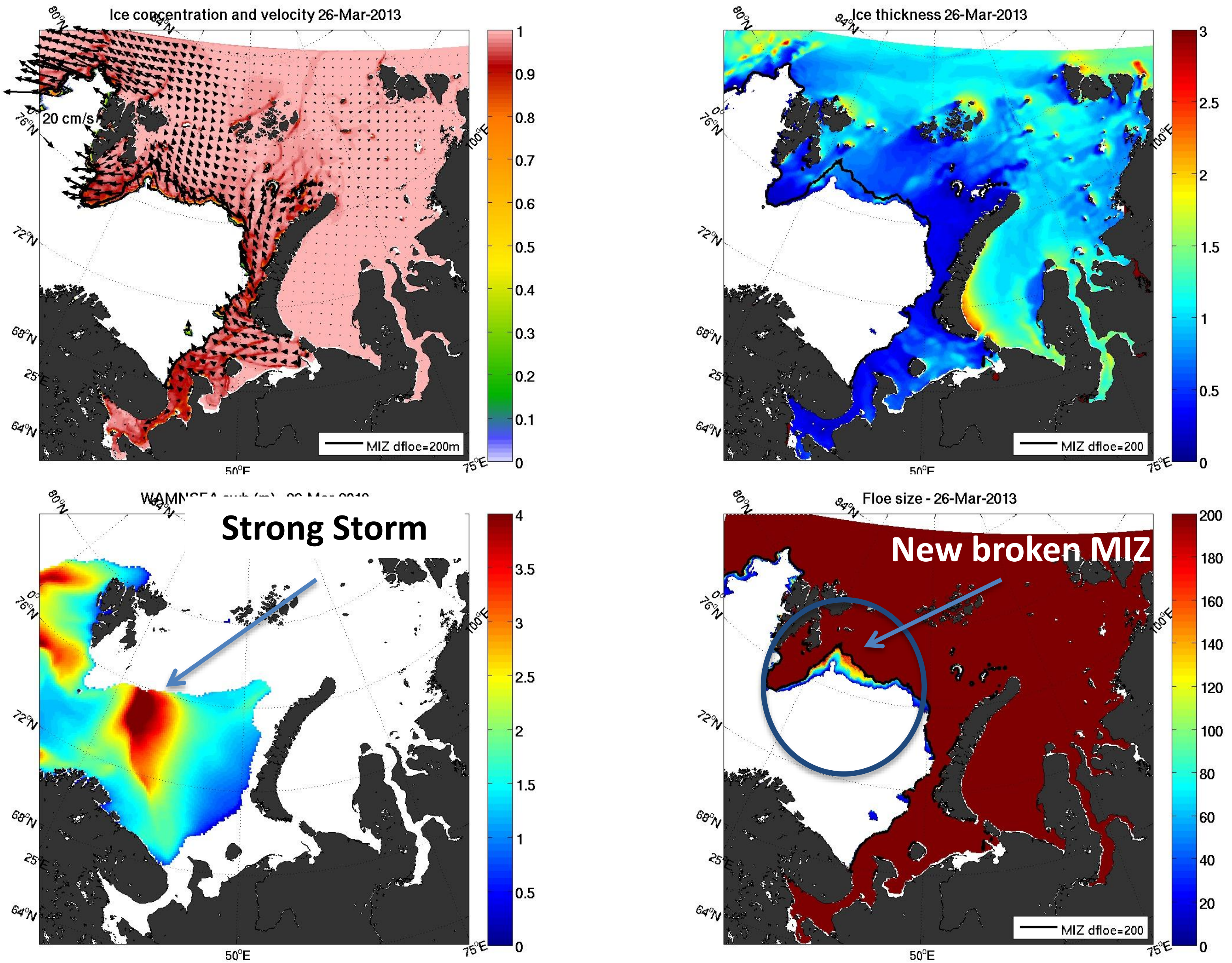


SWARP EU project (FP7, 2014-2017)
http://swarp.nersc.no

TOPAZ+WIM 25-Mar-2013

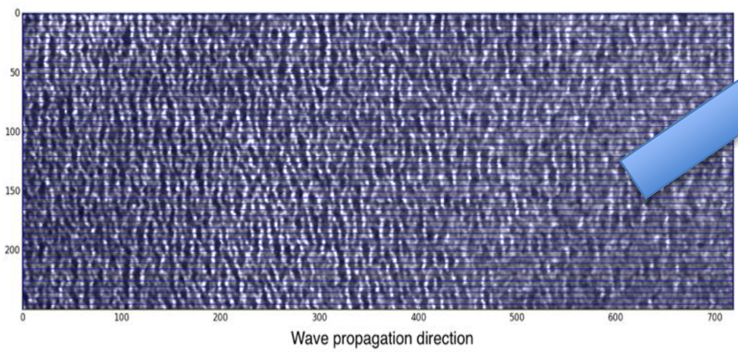


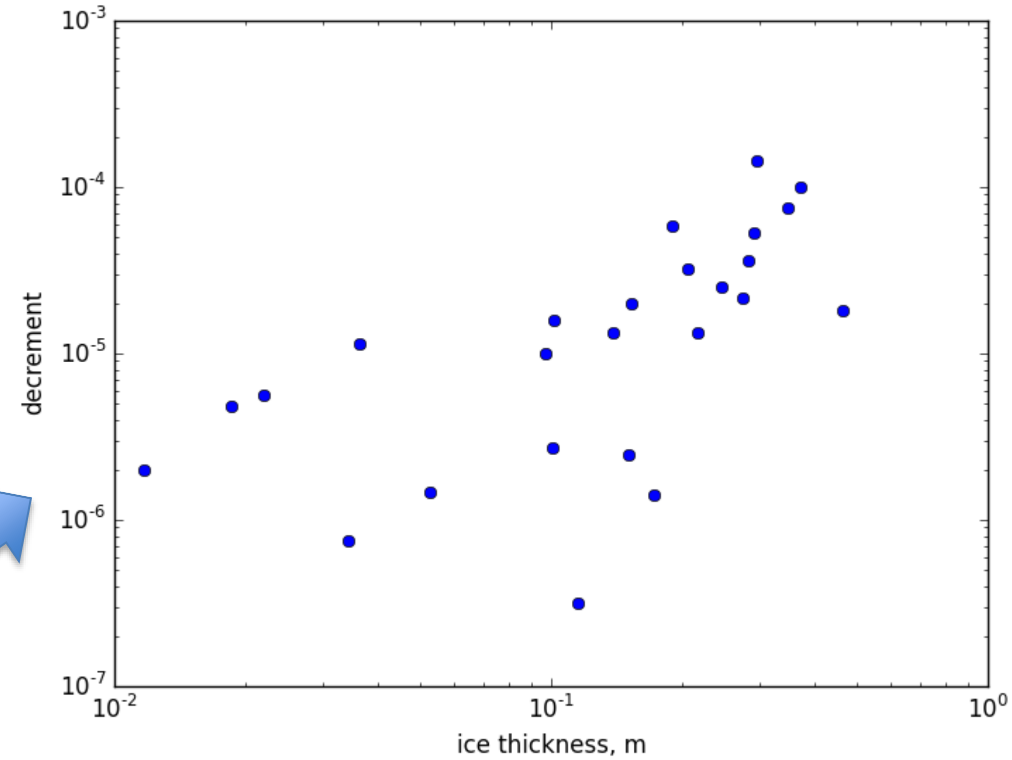
TOPAZ+WIM 26-Mar-2013



Waves in ice

Wave amplitude attenuation from SAR (Sentinel-1) **in ice**





Ice thickness from SMOS

From F. Collard, OceanDataLab

Conclusions

Assimilation of SMOS and CS2 is deemed useful

- Better fit to independent IMB and IceBridge data (20% RMSE)
- Minor improvement of ice drift (5%)
- No degradation of ice edge, SST, SSS nor Sea Level.
- Works with EnKF thanks to thickness sensitivity to air temperature and winds

Uptake in Arctic MFC

- CS2SMOS assimilated in V4 update of Arctic Reanalysis
- SMOS only for operational NRT forecasts 19th October 2017
- Thin is ice useful
  - for example for fluxes and waves-in-ice attenuation

Remaining issues

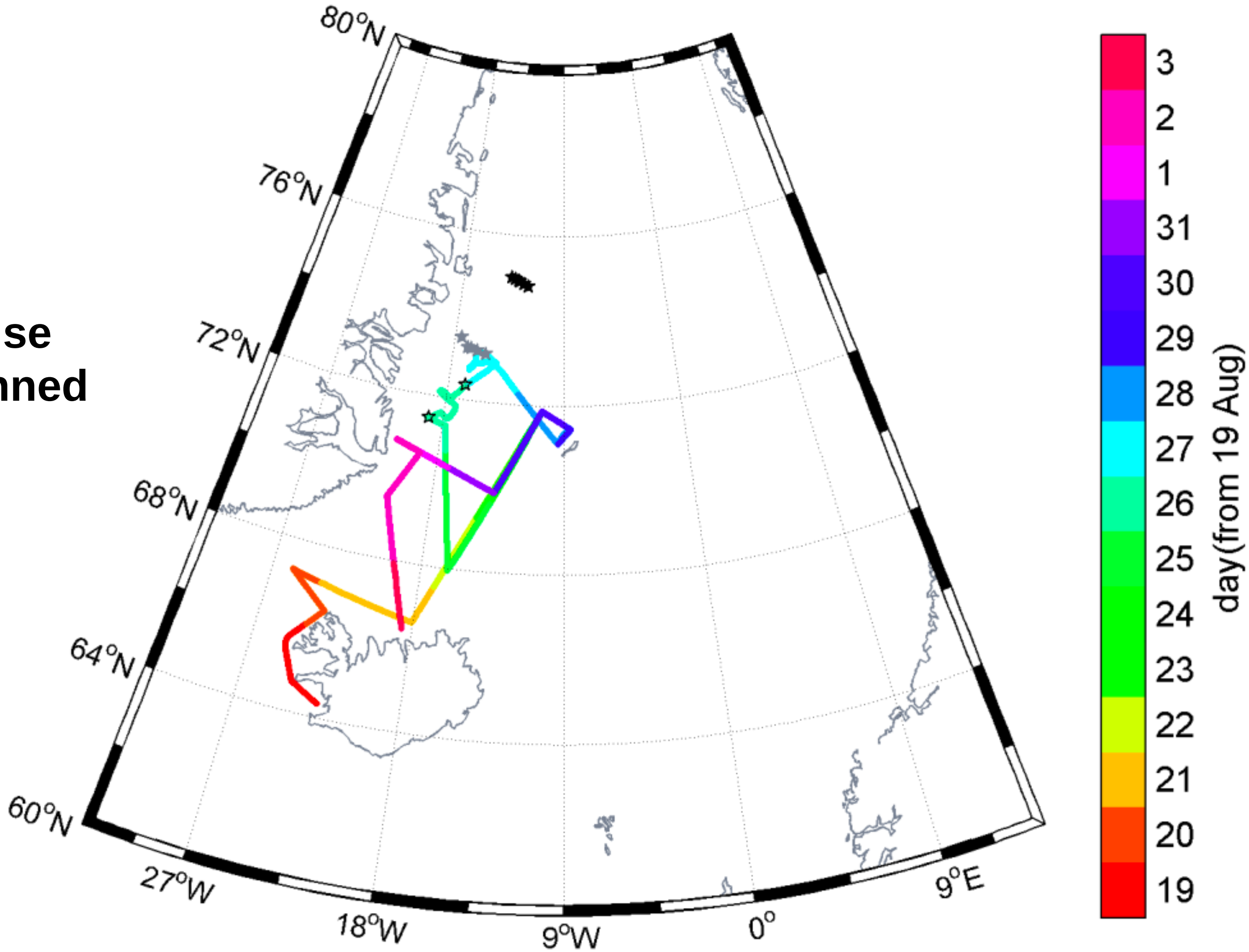
- Offset CS2 – SMOS is problematic.
- CS2SMOS “uncertainty estimates” are only interpolation errors.
  - Should include uncertainty propagation as well.
  - We added an arbitrary background error between 0.1 m and 0.5 m.
- Impact still limited before significant model improvements
  - Dynamics (new rheology Maxwell-EB in neXtSIM)
  - Thermodynamics (melt ponds, brines, lateral melt…)

Requirements

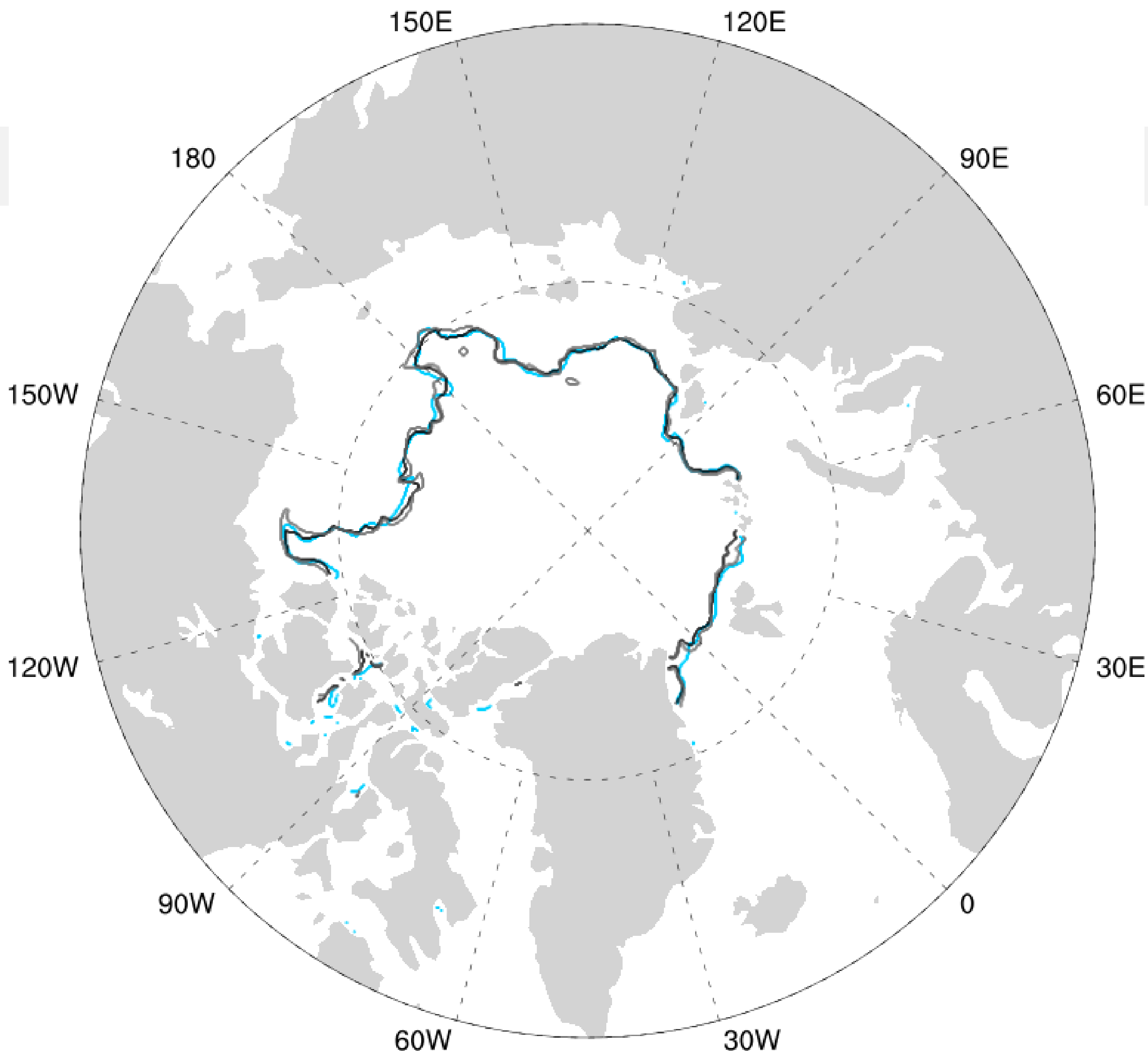
1. No gap in the SMOS ice thickness series, please.
2. Better understanding of the nature of the signal:
   - Multiple classes of ice at subgrid scale:
   - Does SMOS measure the average or the thinnest ice class?
3. Higher resolution
   - Down to 10 km would be excellent
   - Better synergy with C-band PMW (AMSR2 etc)
4. Less sensitivity to wet surface if possible

Extra slides on the August 2017 problem

Research cruise originally planned by SHOM.



Ice edge on 30th Aug 2017 (reasonable?)



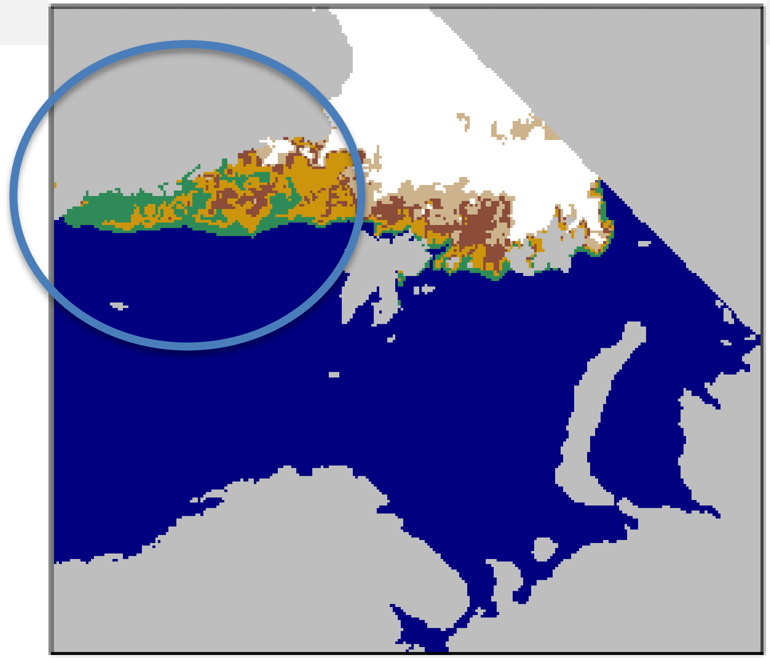
Obs (OSI SAF, PMW)
Best estimate
Forecast

… Or not? Problems with PMW in Summer

Week of the 30th Aug. 2017

Forecast

Analysis



Assimilation analysis (PMW assimilated)

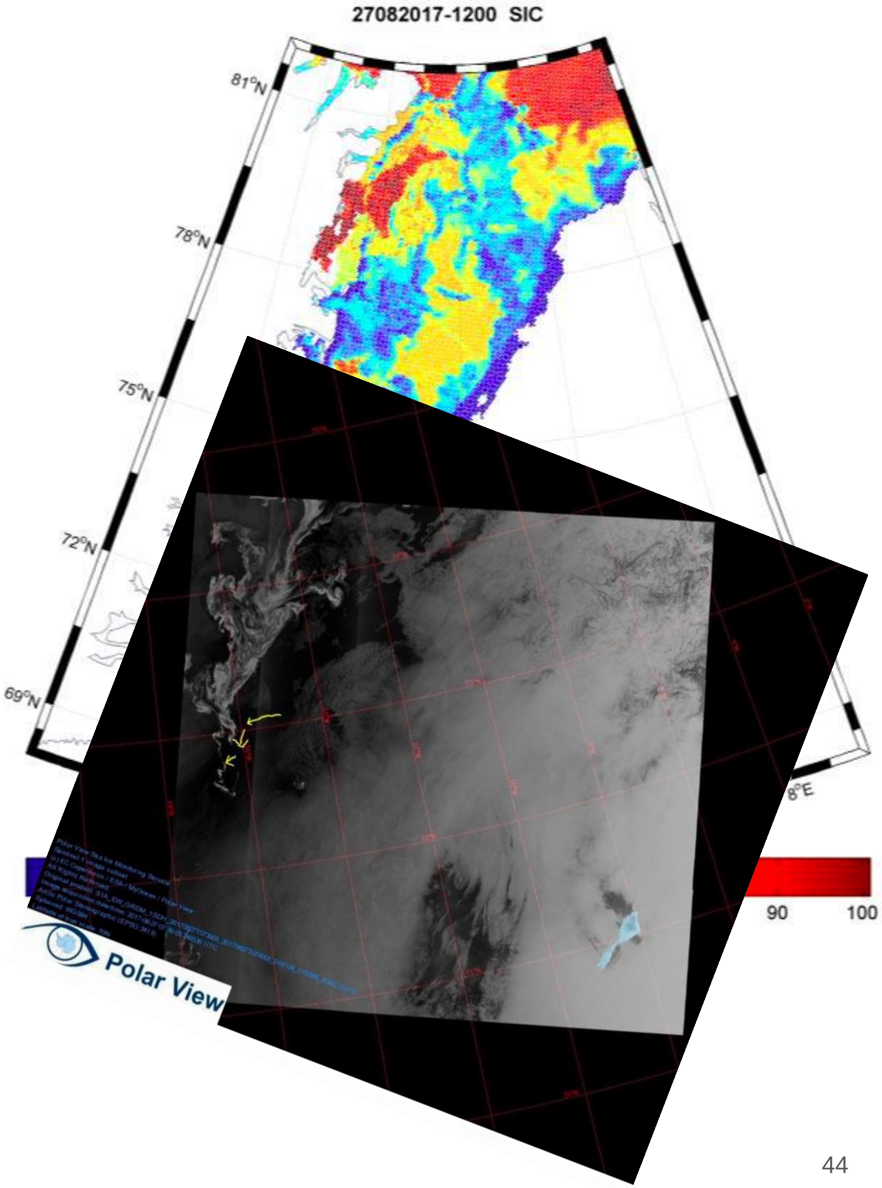
Manual ice charts MET Norway

At least 3 weeks of large discrepancies

Support for SHOM Greenland Sea cruise

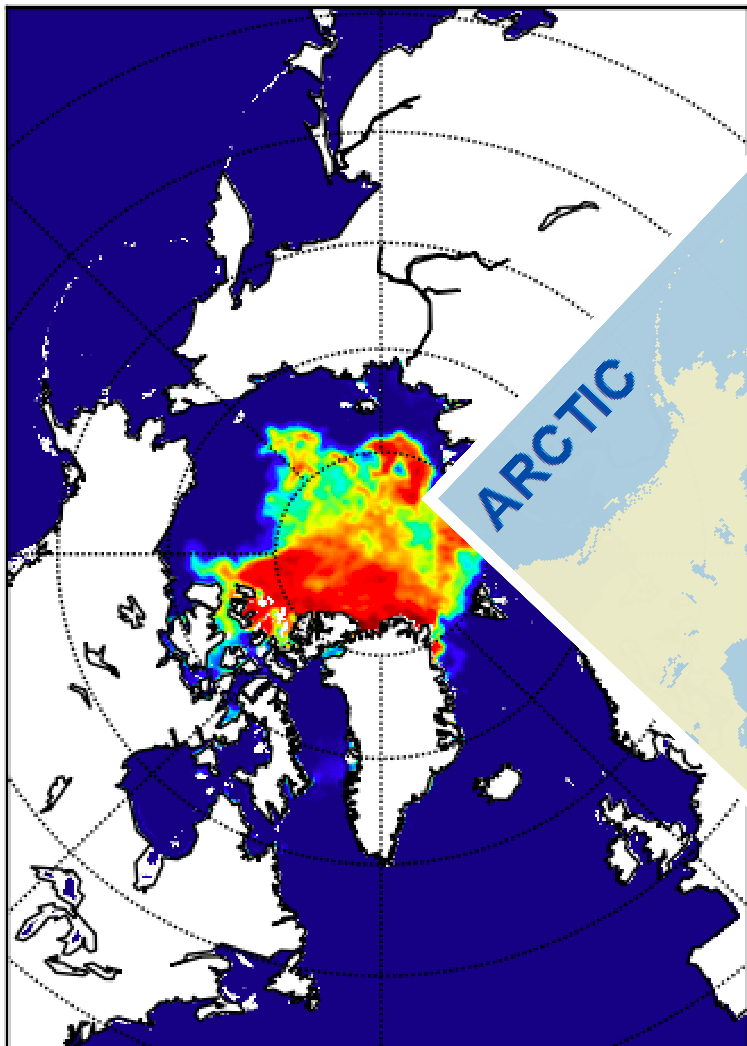
NeXtSIM forecasts of the Greenland Sea

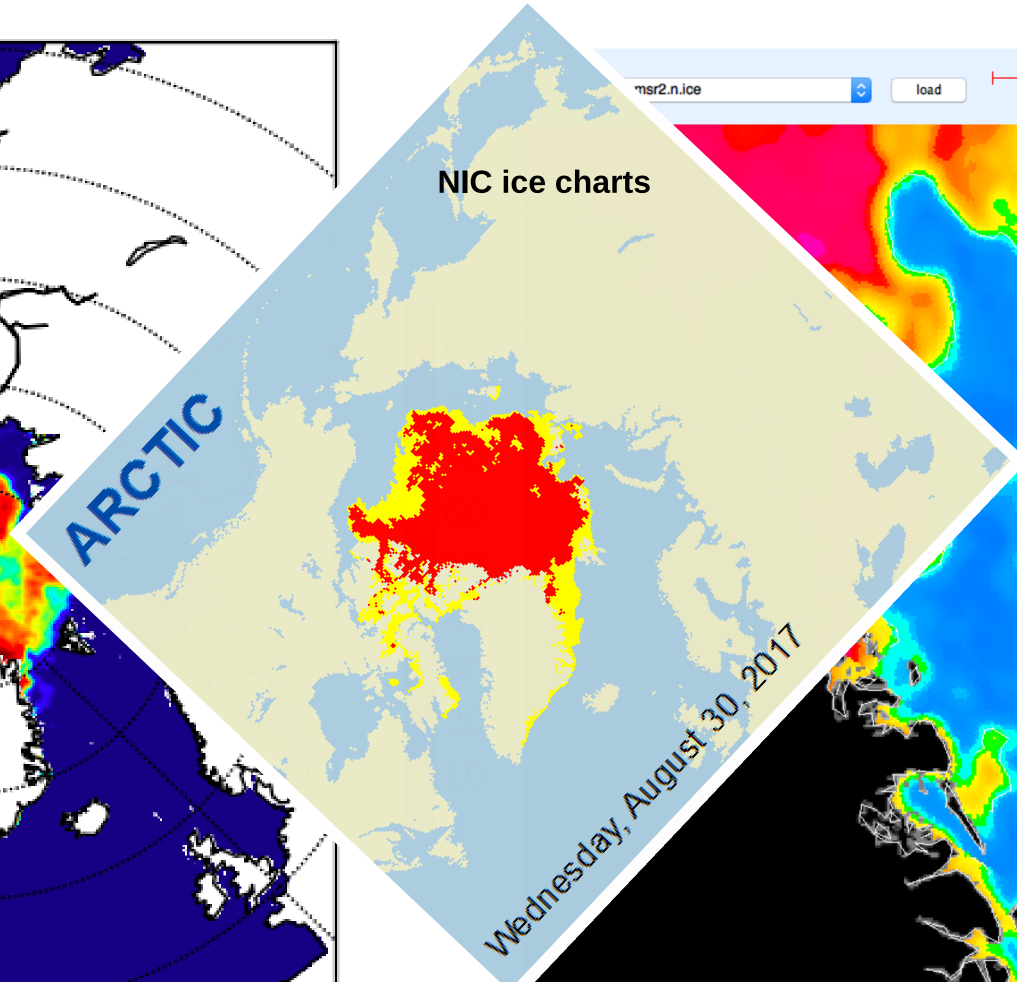
- 2 km resolution
- Bc from CMEMS (TOPAZ)
- Atm. Forecasts from ECMWF
    - Bias correction:
    - Had to offset T2m colder by 10 deg!!
- Assimilation of US ice charts
- SHOM found it useful for planning the cruise
    - deployment of moorings



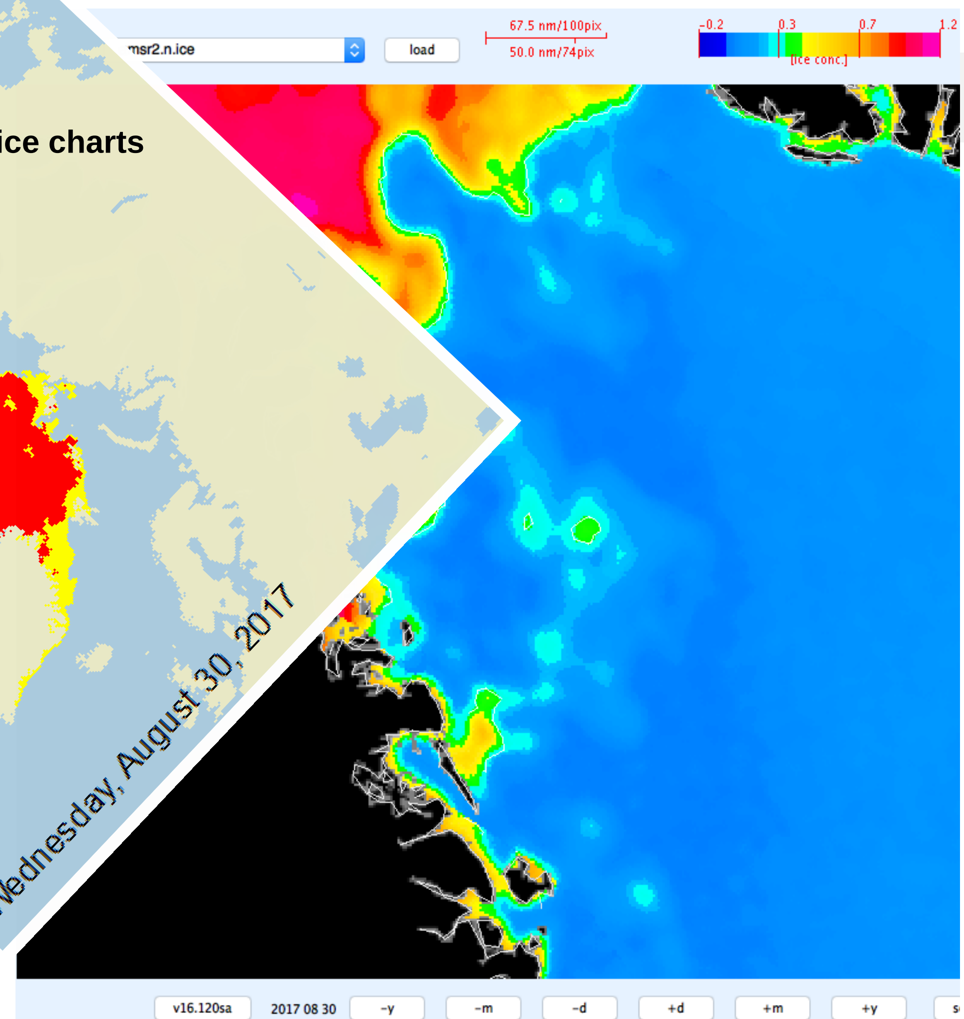
PMW data on 30th Aug 2017

Display OSI SAF Sea Ice Concentration for 20170830 (1200 UTC).





AMSR2 data from DTU, Dk



Summary of the August 2017 issue

C-band PMW (SSMI and AMSR2) show correctly low ice concentrations

- **If the right algorithms are used**
- **Better in AMSR2 than SSM/I due to smaller footprint**
- **In agreement with 2 ice charts (Eur and US).**

To forecast ice in the Greenland Sea, we had to remove 10 deg to the ECMWF 2m air temperature over the whole Greenland Sea.

What is ECMWF doing with the sea ice?