→ EARTH OBSERVATION SUMMER SCHOOL

Earth System Monitoring & Modelling

30 July–10 August 2018 | ESA–ESRIN | Frascati (Rome) Italy

Sea ice concentration – retrieval and assimilation

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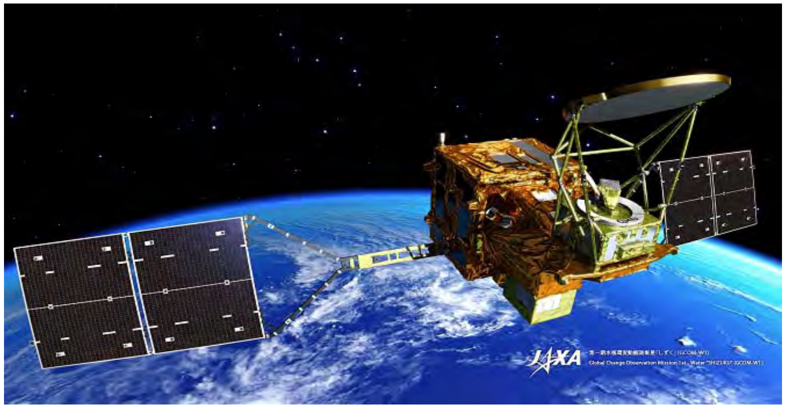
Technical University of Denmark DTU

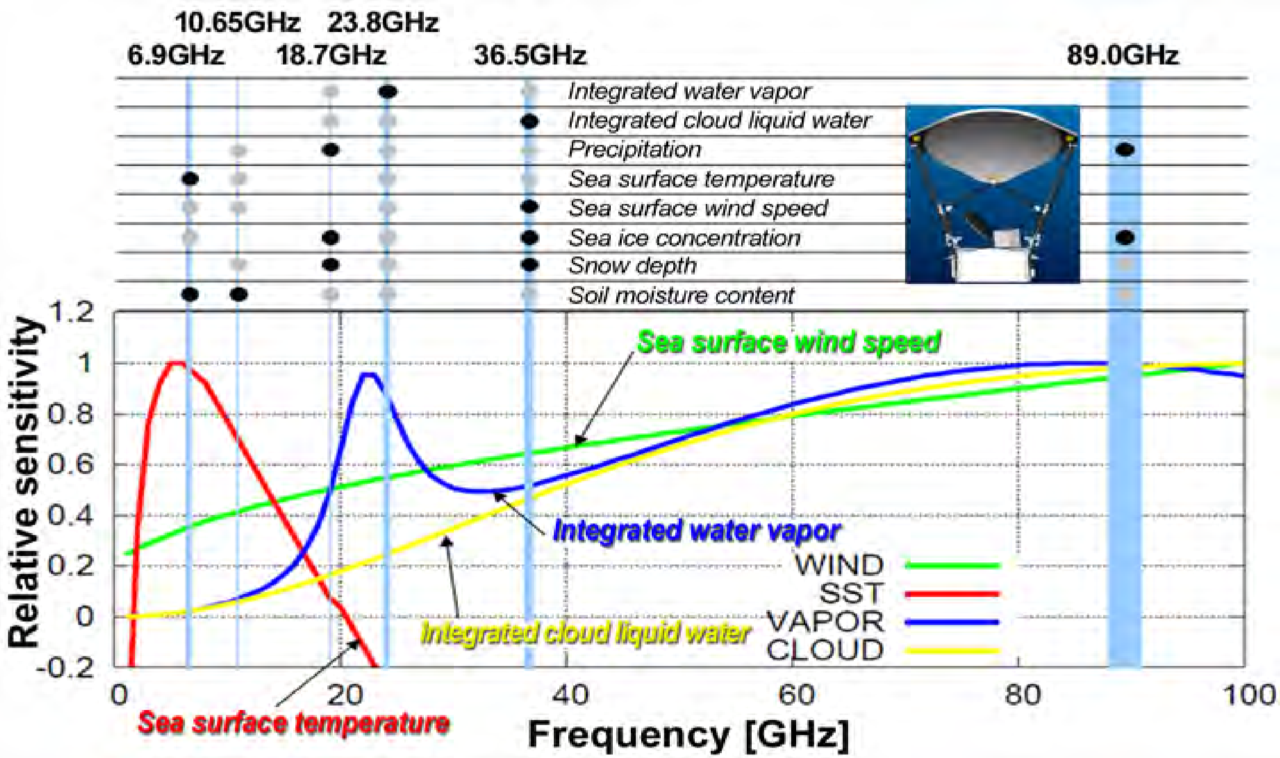
esa

European Space Agency

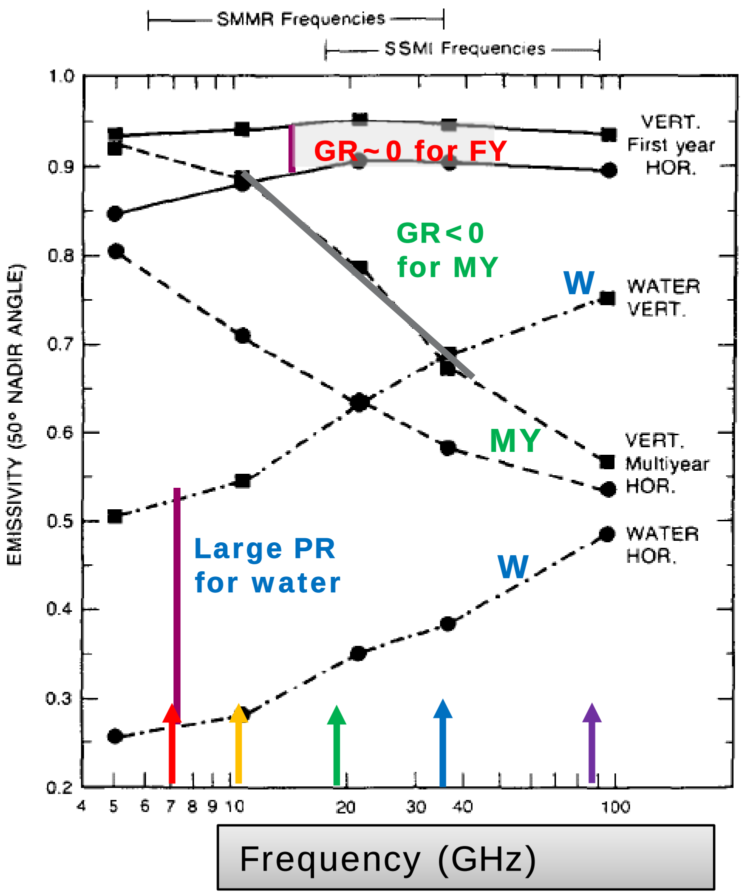
AMSR2 on JAXA's GCOM-W



AMSR2 Channel Set					
Center Freq.	**Band width**	**Pol.**	**Beam width**	**Ground res.**	**Sampling interval**
GHz	**MHz**		**degree**	**km**	**km**
6.925/7.3	350	V/H	1.8	35 x 62	10
10.65	100		1.2	24 x 42	
18.7	200		0.65	14 x 22	
23.8	400		0.75	15 x 26	
36.5	1000		0.35	7 x 12	
89.0	3000		0.15	3 x 5	5



Signature - Summary



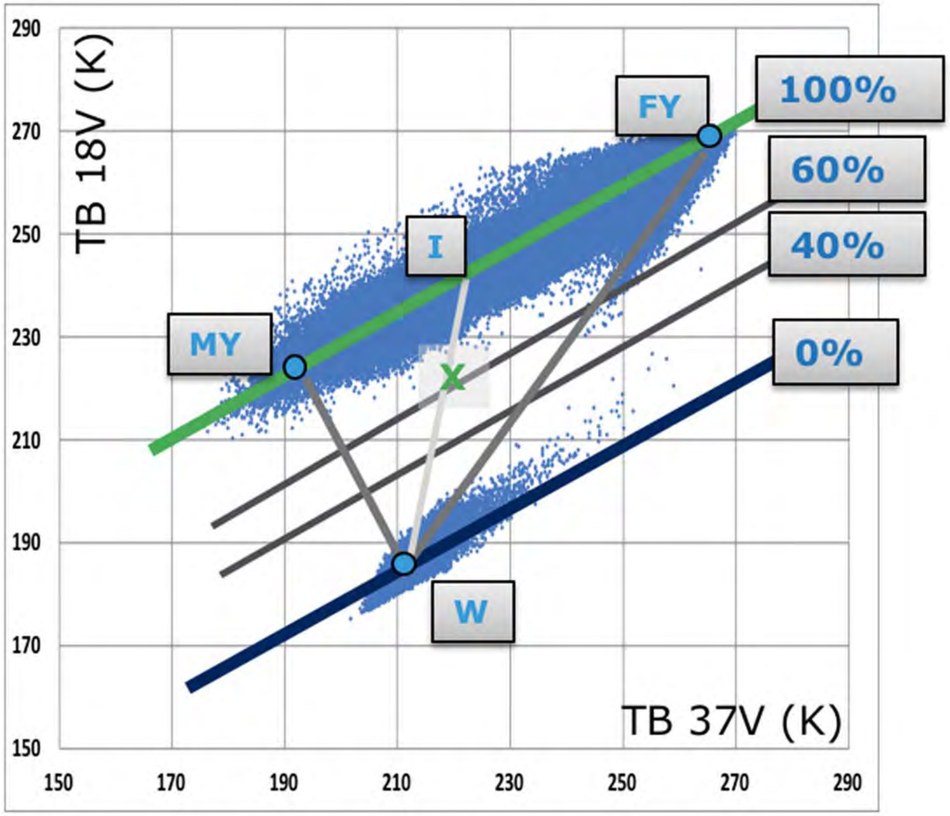
- FY-ice emits almost like a black body
- MY-ice volume scattering reduce emissivity for shorter wavelengths
- Large polaristion difference for water surface

Example of algorithm principle - Tie-points

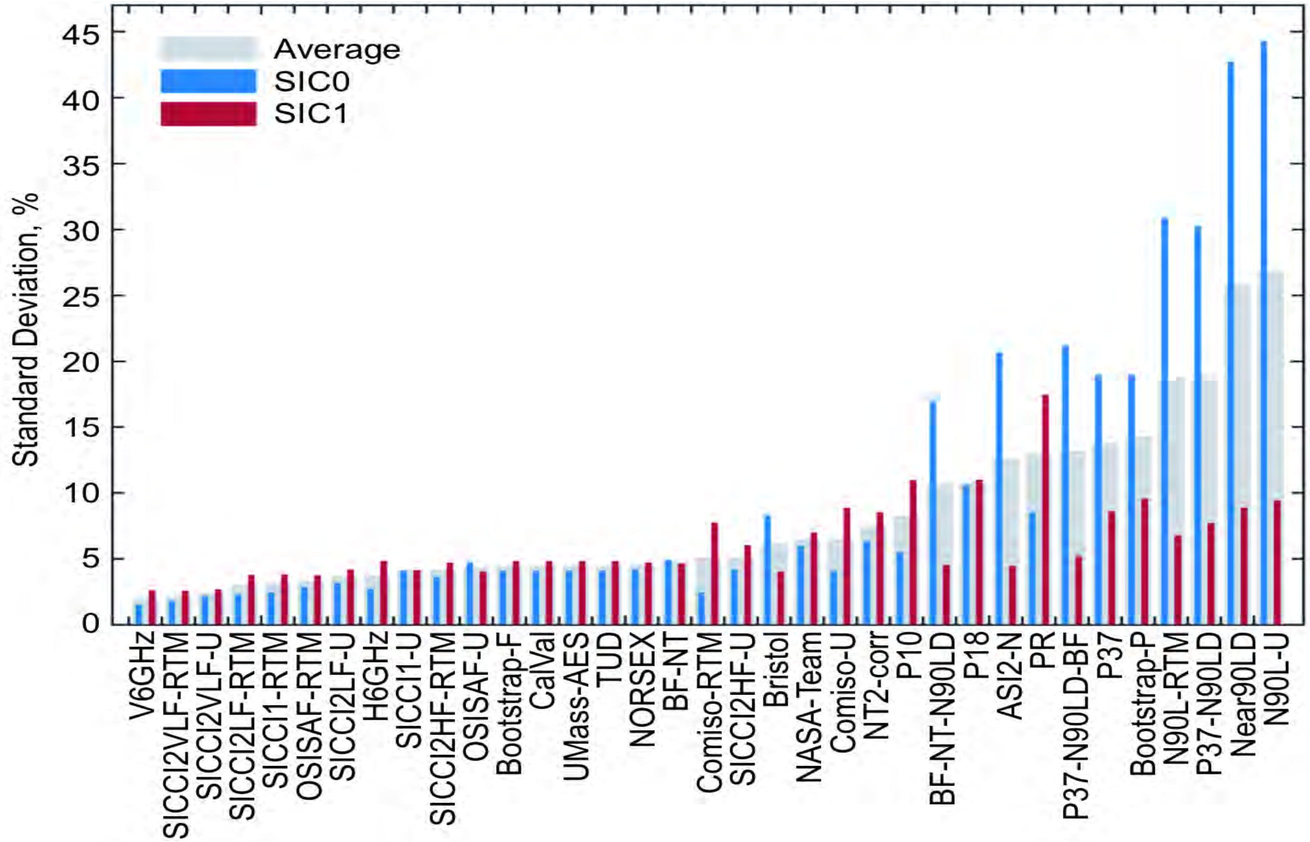
$$C_T = \frac{T_B - T_B^W}{T_B^I + T_B^W}$$

where **X** is the new observation, **W** is the water signature and **I** is a point on the **FY** to **MY** line (the 100 % line)

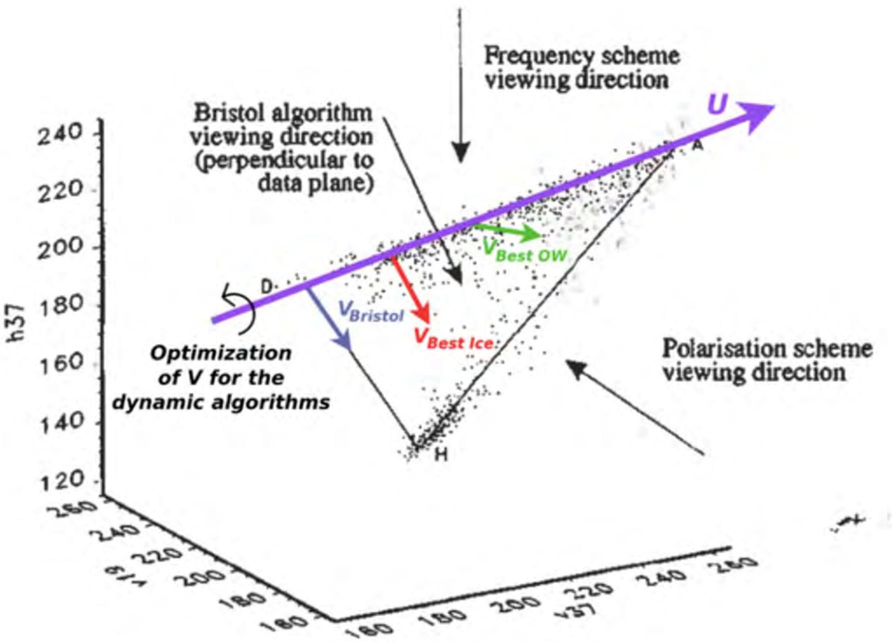
W, **FY** and **MY** are called **tie-points**

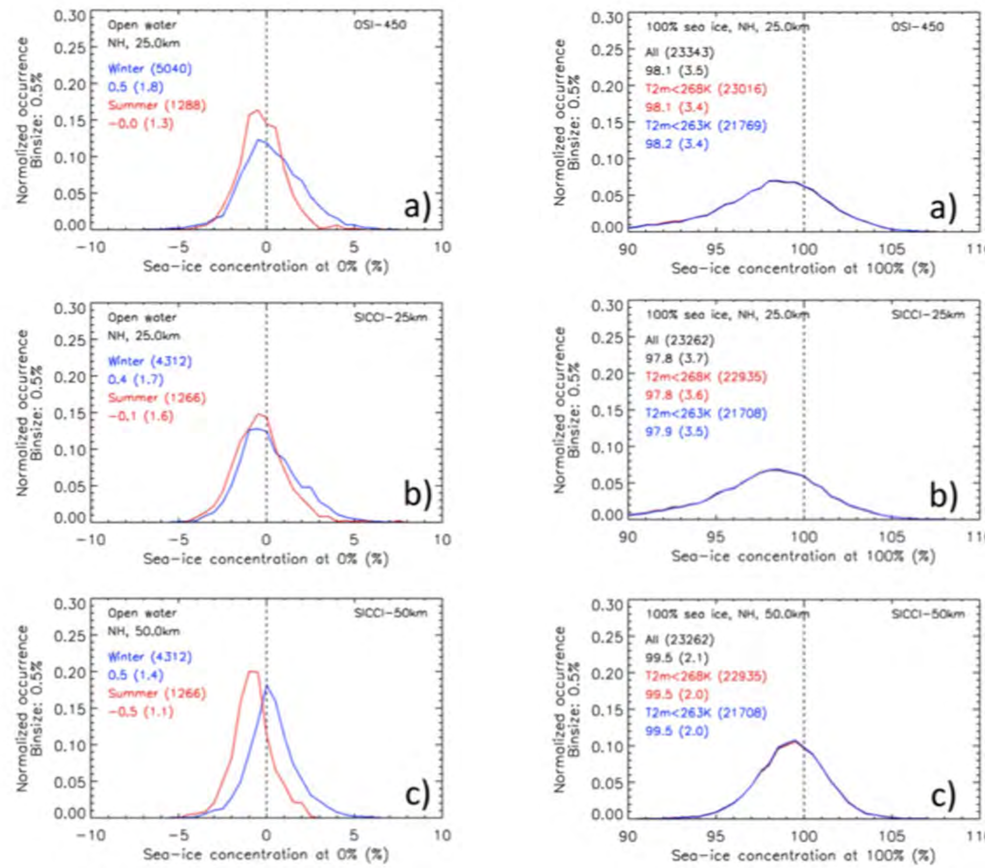


Algorithm selection

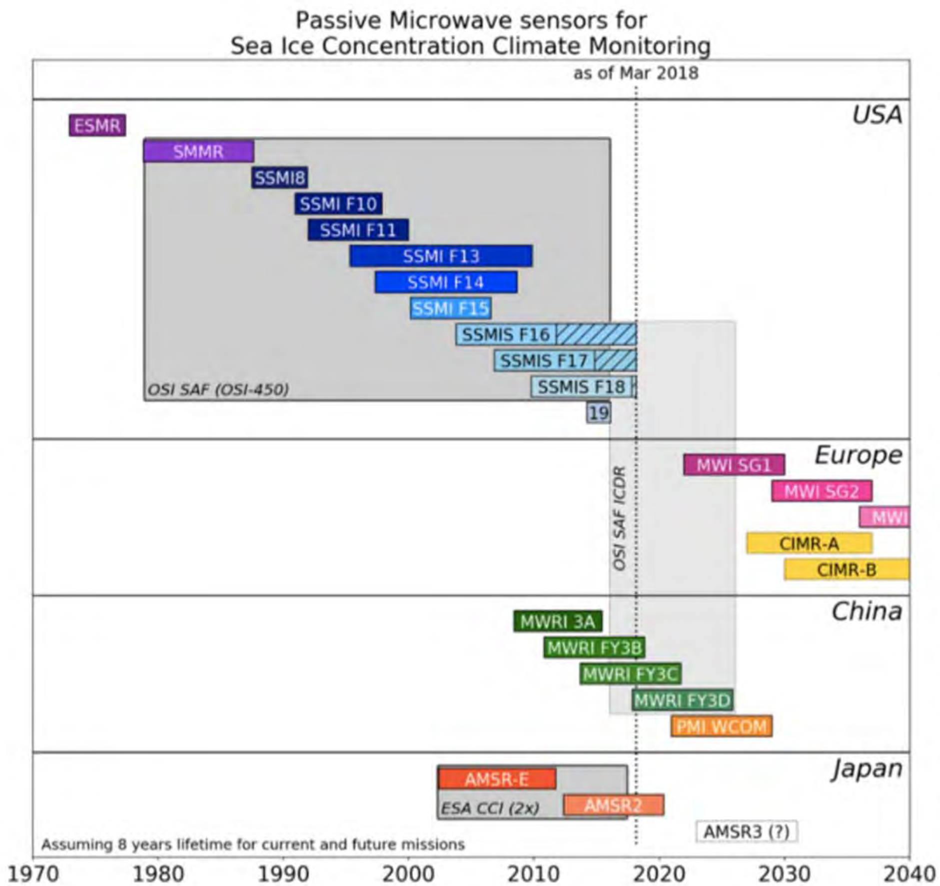


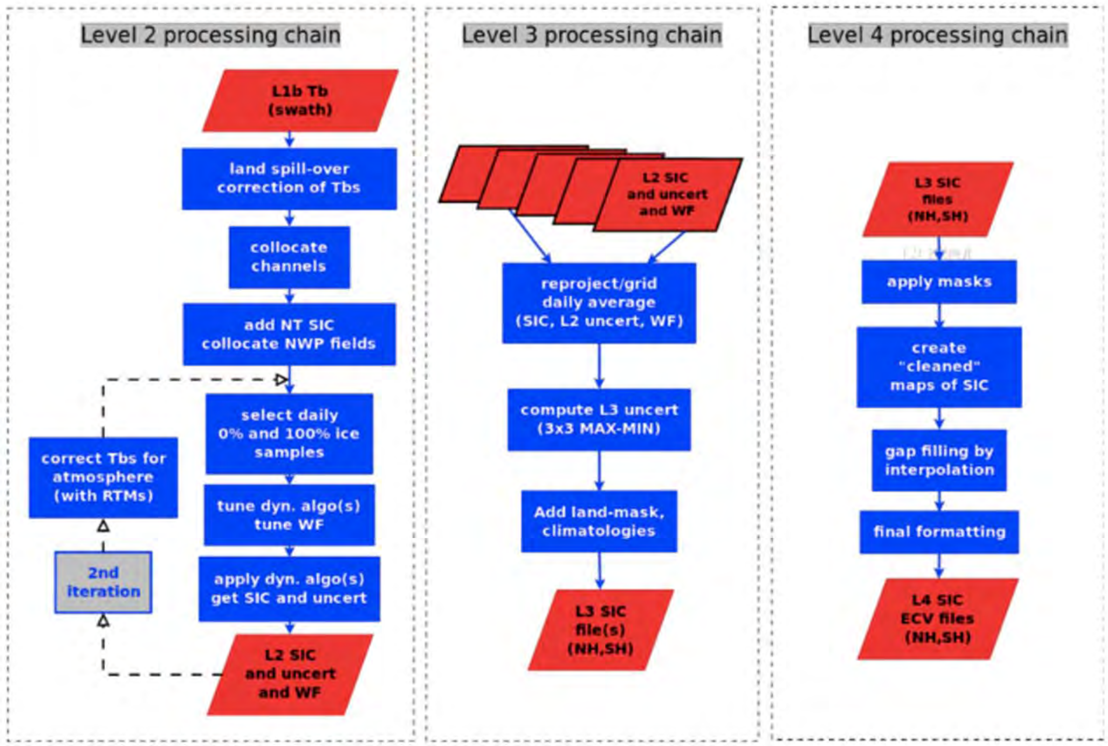
OSISAF/SICCI algorithm





Available PMR data and necessary processing steps





Figures from Lavergne et al, 2018

CDR	Algorithm / Channels	Instruments	Period	Grid resolution	Project
OSI-450	(19v,37v,37h)	SMMR SSM/I SSMIS	1979-2015	25x25 km	OSI SAF
SICCI2 25.0km	(18v,36v,36h)	AMSR-E AMSR2	2002-2011 2012-**2017**	25x25 km	sea ice cci
SICCI2 50.0km	(06v,36v,36h)	AMSR-E AMSR2	2002-2011 2012-**2017**	50x50 km	sea ice cci

Status October 2017:

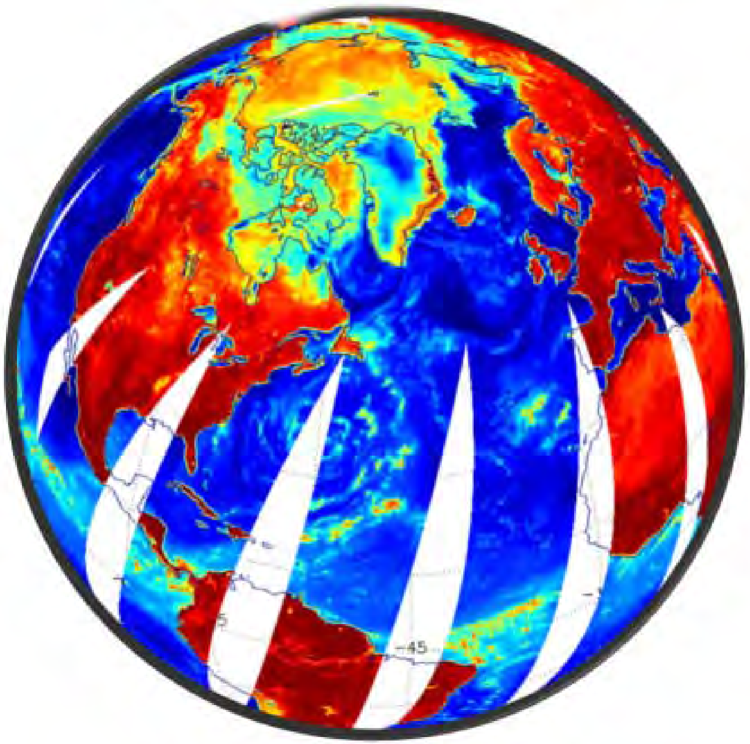
The OSISAF CDR was **released** in May 2017: http://osisaf.met.no;

The ESA CCI CDRs are **released**: (http://cci.esa.int/data);
March 2017, v2.0, 2002-2015;
October 2017, v2.1, extended to 15th May 2017.

Polar orbiting satellite – SSMIS & SSM/I daily coverage

esa

SSMIS



SSM/I

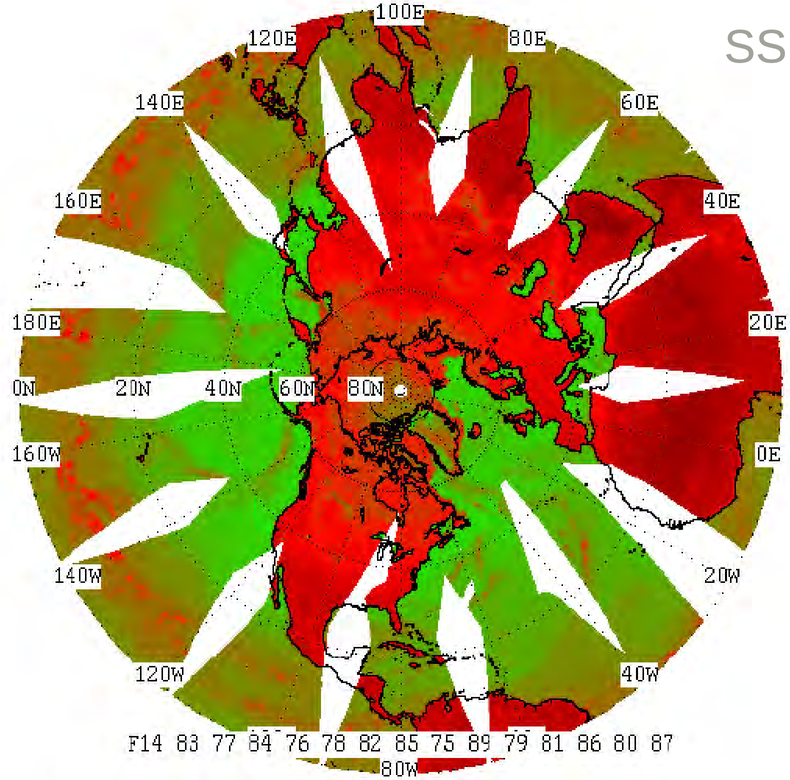
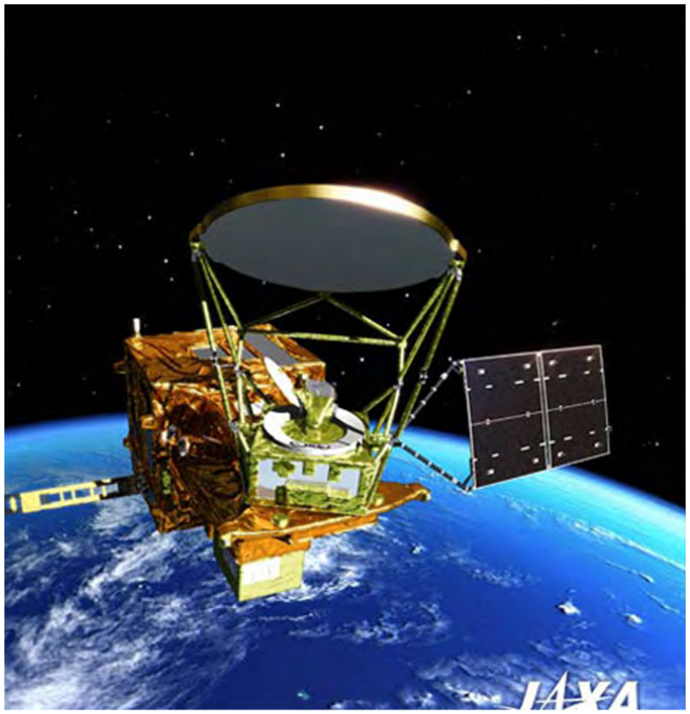


Figure 3.4-3. Example showing swath coverage and gaps at low latitudes. This represents one day of coverage by one satellite.

Resolution

Radiometric resolution

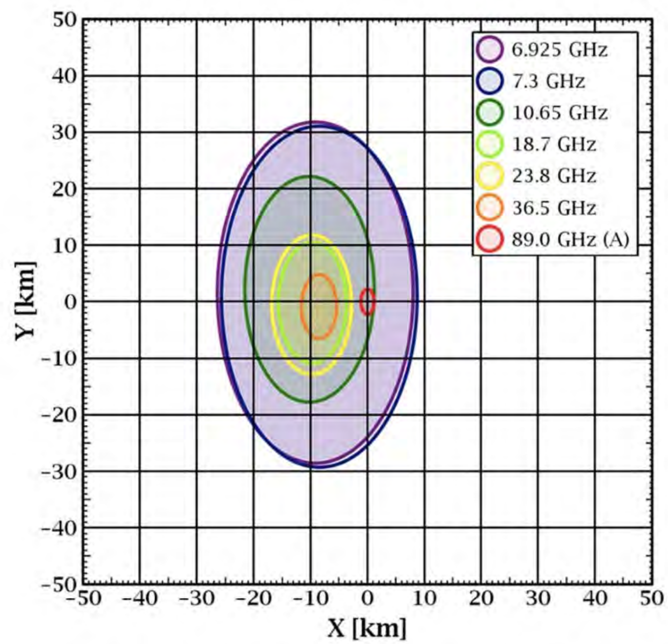
$$\Delta T = \frac{T_A + T_N}{\sqrt{B\tau}}$$



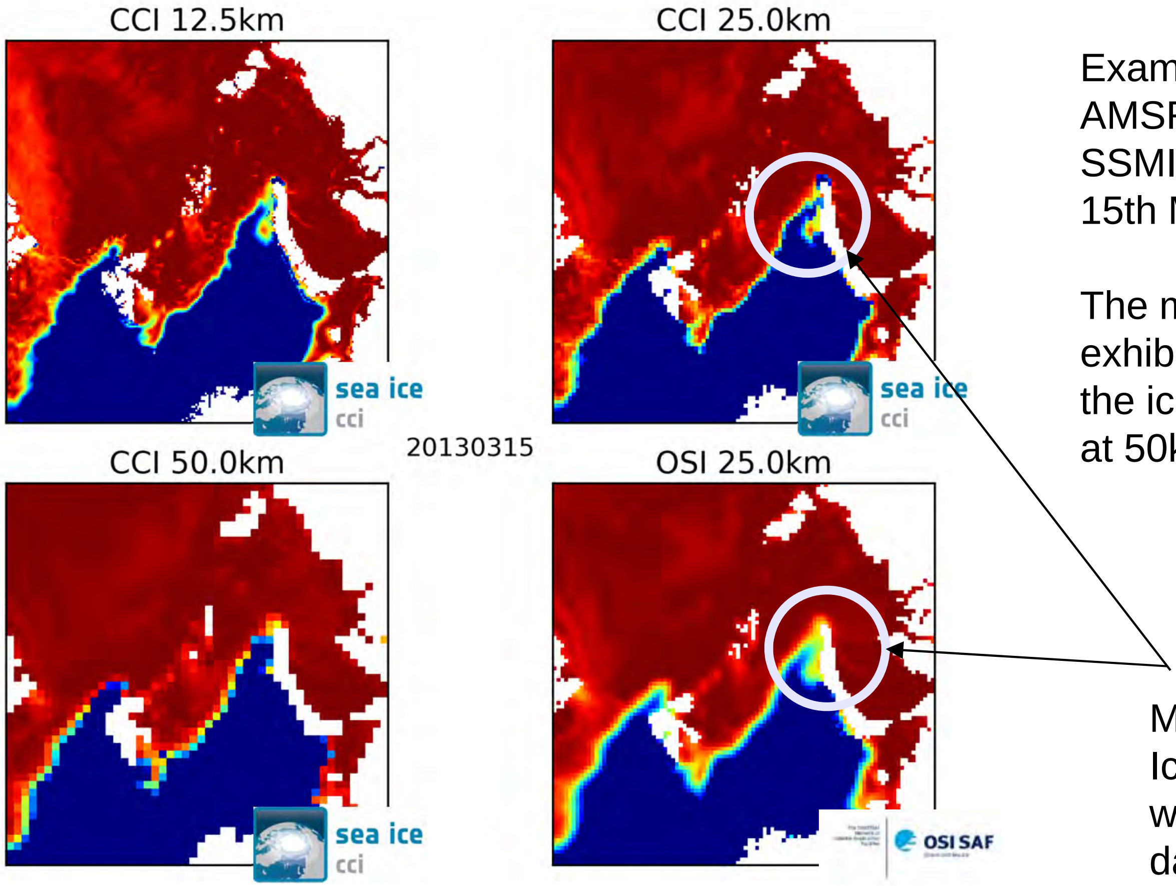
Spatial resolution

Antenna beamwidth

$\theta_{3dB} \sim 1.2\lambda/D$



Product comparison - 20130315

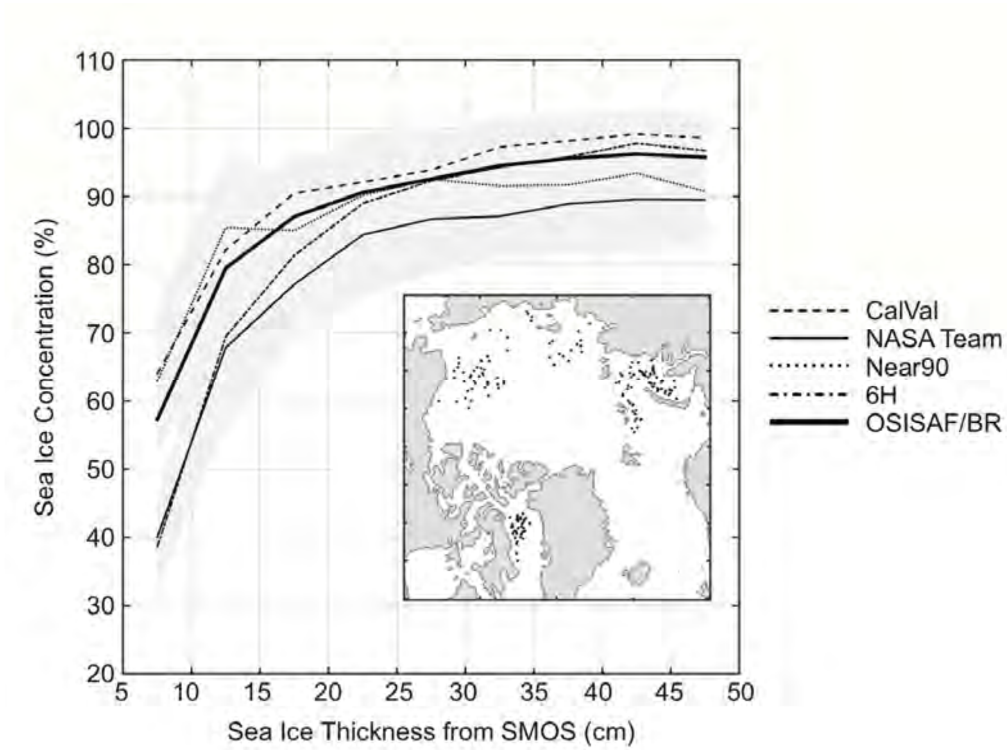


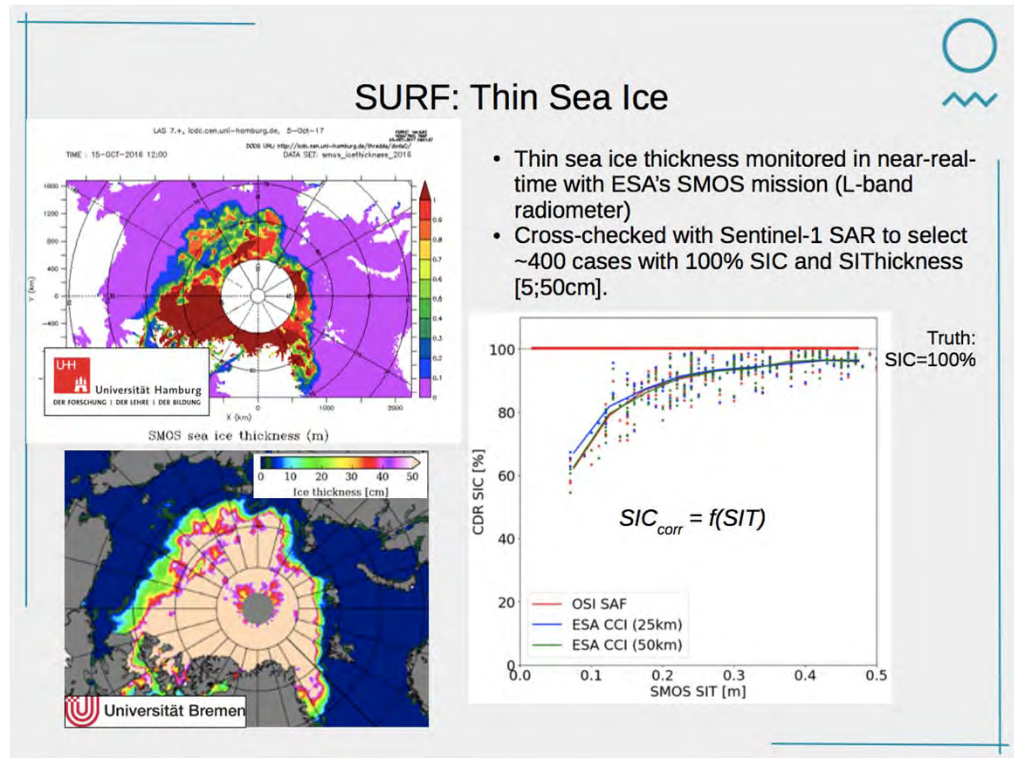
Example maps from the 3 AMSR2 (CCI) and the SSMIS (OSI) CDRs on 15th March 2013.

The maps from AMSR2 exhibit more details along the ice edge, except that at 50km using 6 GHz.

Much finer Marginal Ice Zone details with CCI/AMSR data.

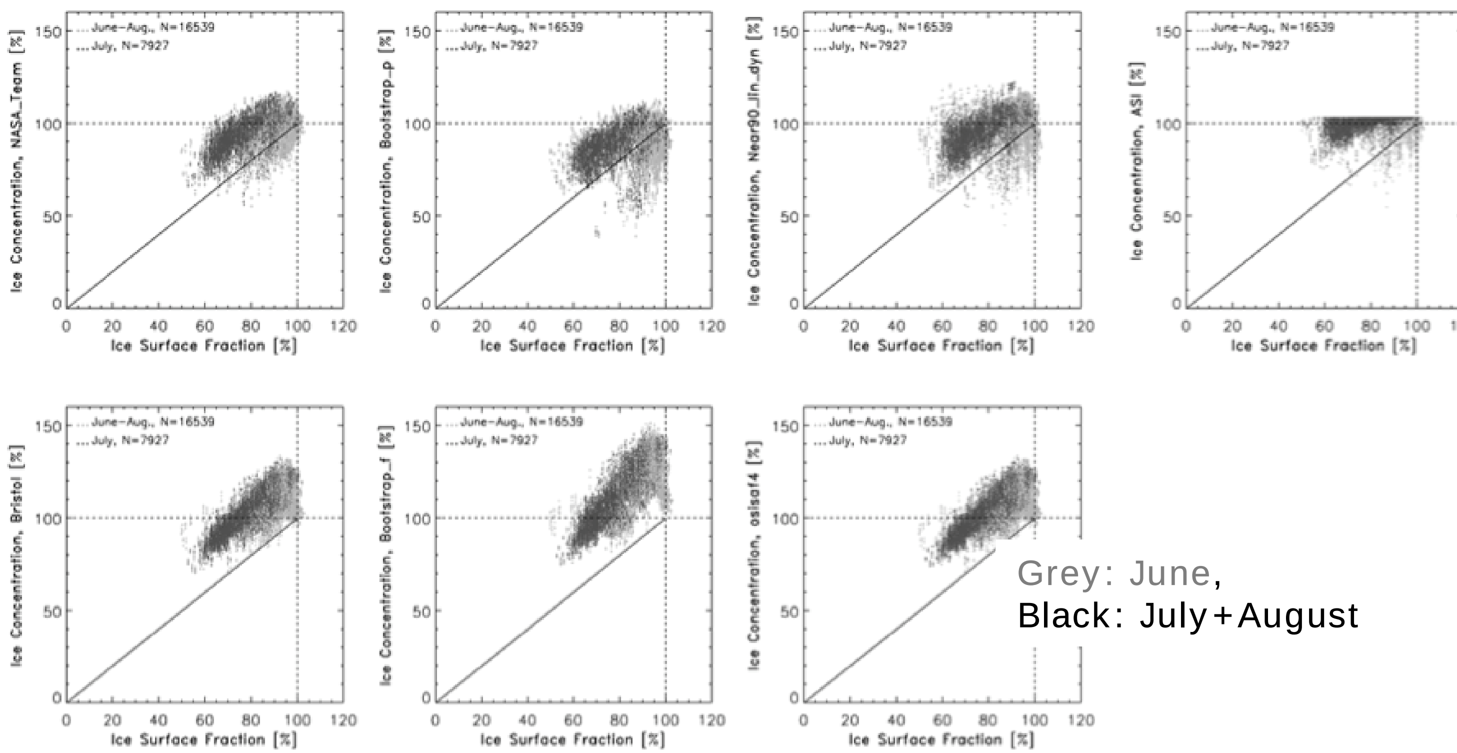
Apparent concentration of thin ice





Sea ice concentration and melt ponds

Ice surface fraction is the fraction of the surface which is ice
(NOT melt-pond and NOT lead/open water)

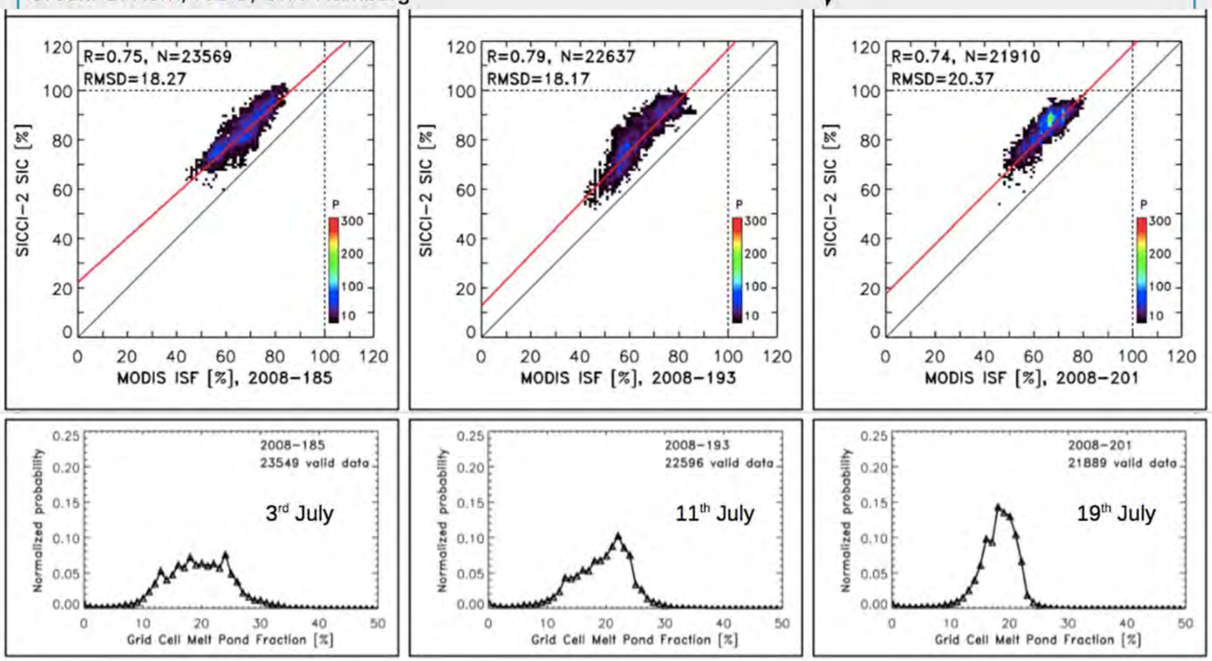


Grey: June,
Black: July+August

SURF: Melt-pond water

What modelers get today

Credit: S. Kern, ICDC, Univ Hamburg



Melt ponds & thin ice - summary

At the PMW channels we use for SIC retrievals, there is no difference between the emission of sea water (leads) and melt water (ponds). PMR SIC = ISF = 1 – (LeadFraction + MeltPondFraction) and all SIC algorithms underestimate the concentration of thin ice

- Melt ponds will be seen as open water, and cannot be distinguished from leads and other openings
- 100%, thin (<20cm) sea ice will be systematically retrieved as lower concentration of sea ice.
- 100%, thin (>20cm, <50cm) can also be biased low because it is typically more saline, smooth, snow-free.
- EO community cannot “fix” this consistently unless we bring external SIT information, e.g. from models.
- EO community provides operators f(SIC,SIT) to modelers for translating model (SIC,SIT,MPF) to PMR SIC

Sea ice concentration, area and extent

- What the satellites measure is more or less the fraction of the resolution cell covered by ice at the surface.
- Often data are provided on a finer grid than the resolution!

- It is the misinterpretation of melt ponds that has led to the invention of the concept of sea ice extent (all grid cells with a concentration above 15%)
- The 15% threshold was introduced since most sea ice concentration algorithms deploy a so-called weather filter to remove spurious weather induced ice but which on average also removes ice up to 15% (sometimes more).
- Note that sea ice extent calculation will depend on resolution – finer resolution will lead to smaller extent – be sure to use the same resolution when comparing extents (Notz, 2014)

Observation operator(s)

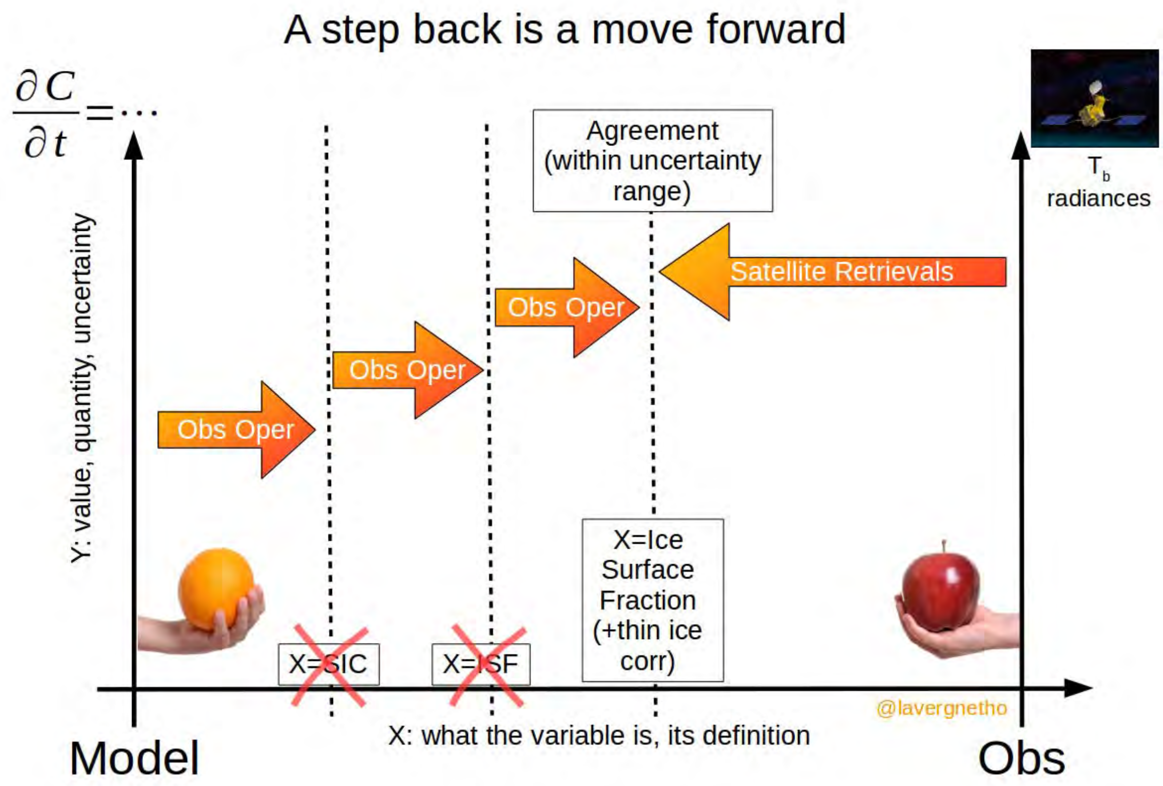
Translate model state to observation space using simple models such as

- Melt-pond correction
- Thin ice correction

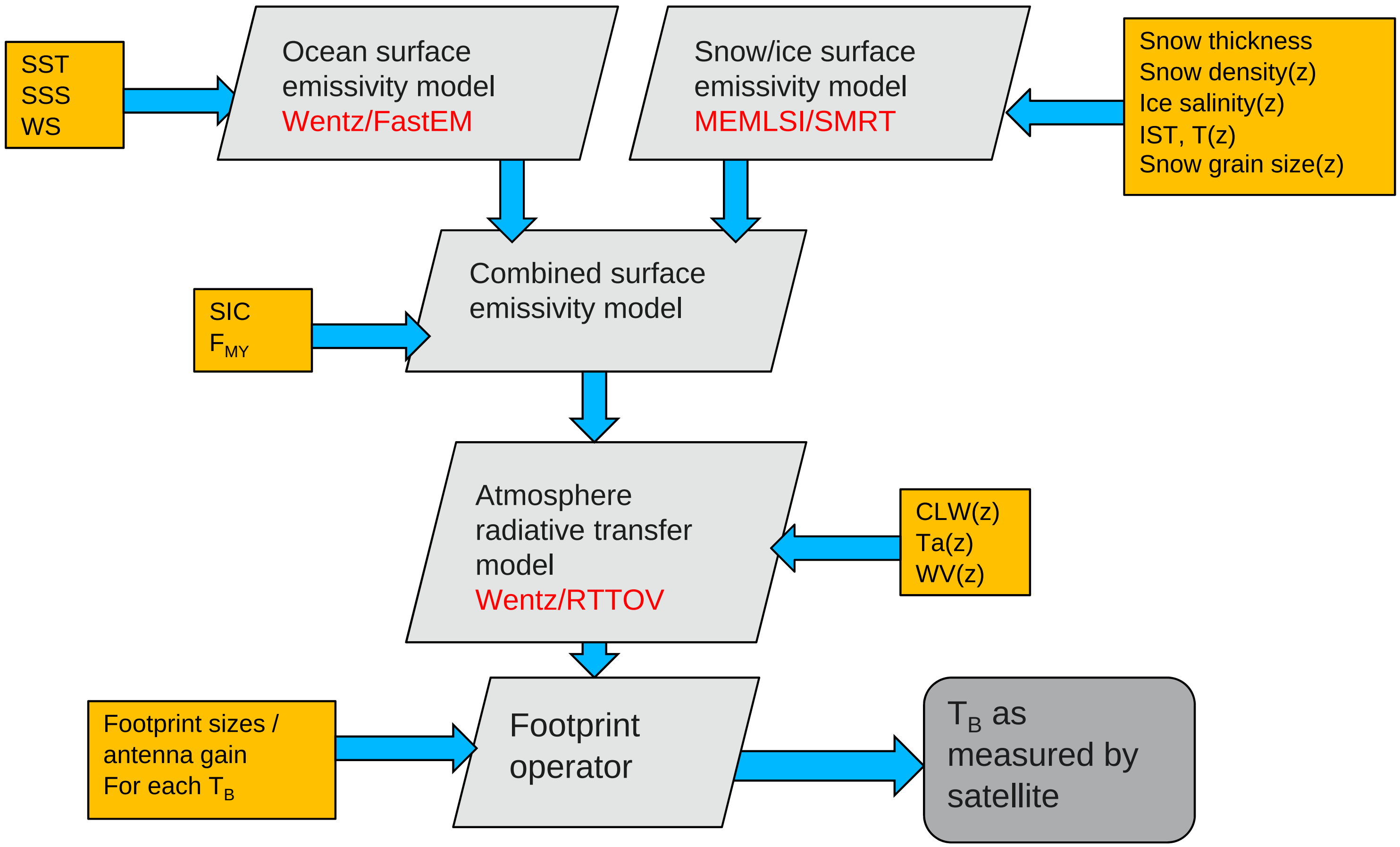
Using model ice concentration, thickness distribution and melt pond fraction

Curtesy Thomas Lavergne, MET, Norway

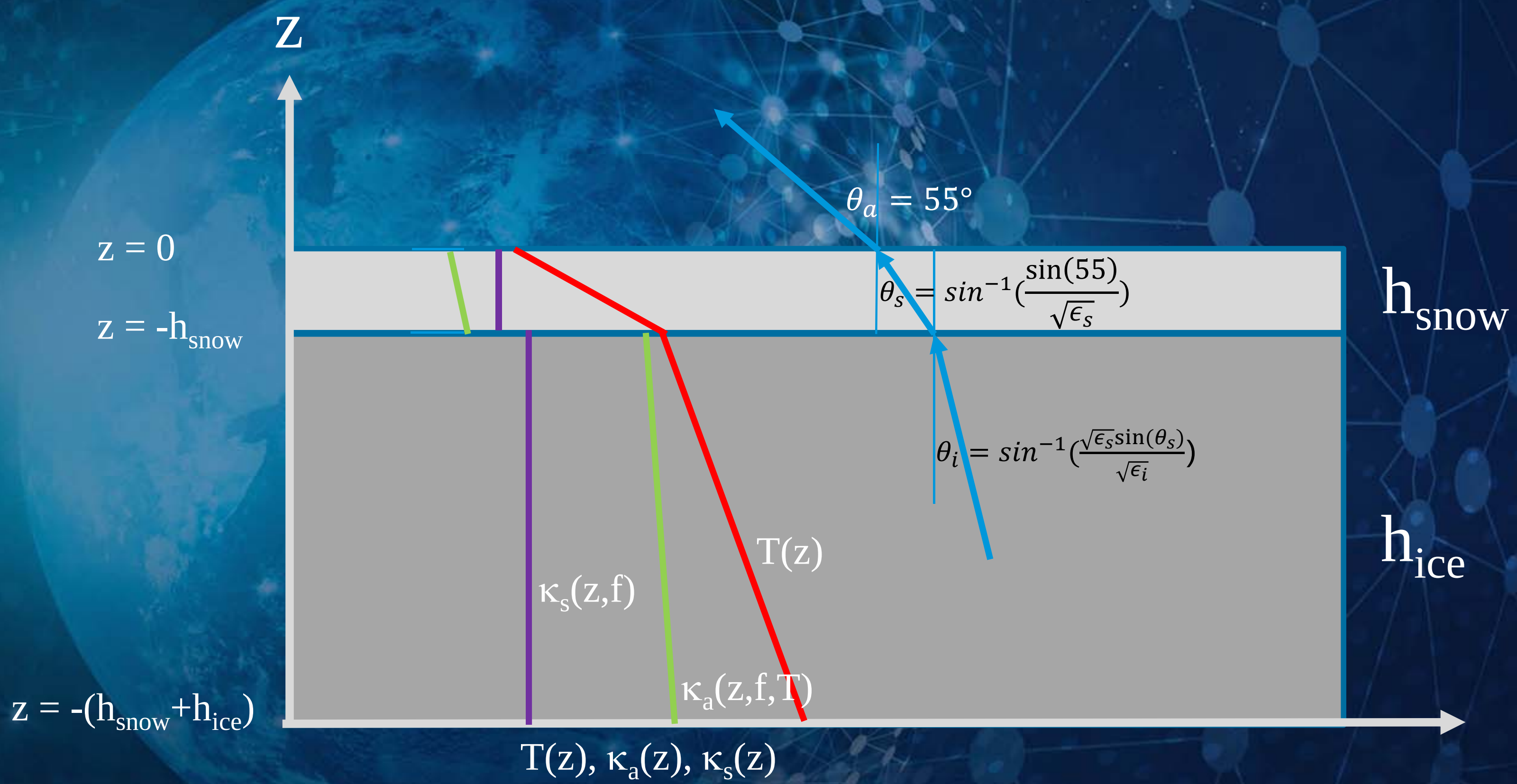
https://figshare.com/articles/A_step_back_is_a_move_forward/5501536/1



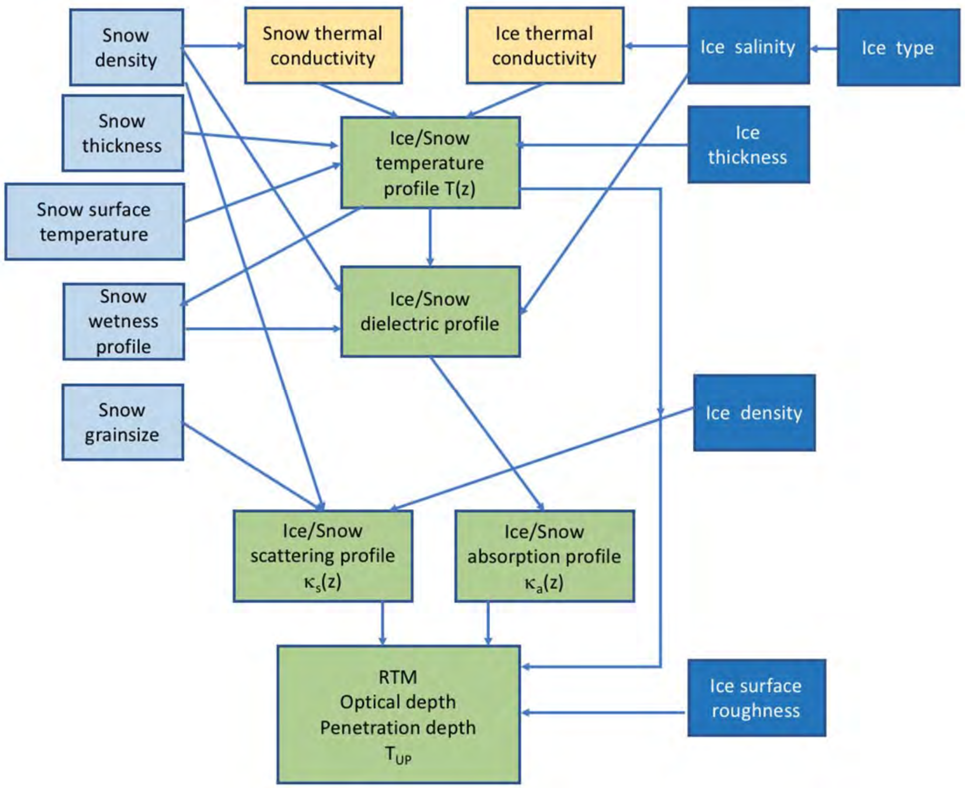
Observation operator(s)



Ice/snow Emissivity model



Simple ice/snow emissivity/TB model



TB as a function of

- f_{MY} Multi-year ice fraction
- T_{ice} (snow surface temperature)
- h_{snow}(snow thickness)
- h_{ice} (ice thickness)
- T_{DN} Downwelling TB (known from atmosphere RTM)

T_{ice},h_{ice},h_{snow} -> T(z) using fixed thermal conductivities for snow, FY and MY respectively
Salinity + T(z) -> brine volume, $V_b(z)$ -> dielectric profile ($\varepsilon(z)$) -> $\kappa_a(z)$ -> penetration depth (D_p).
Dielectric profile ($\varepsilon(z)$) -> $\kappa_a(z)$ and later a simple $\kappa_s(z)$ profile.
Reflections only at air/snow and snow/ice interface – Include scattering from surface roughness.

Ice emissivity – Simple radiative transfer model

- Perform radiative transfer using standard formulation.
- Incidence angle variation in snow and ice (Snell's law). $n_1 * \sin(\theta_1) = n_2 * \sin(\theta_2)$, where n_1 and n_2 are the refractive indices in medium 1 and 2 respectively. This needs to be done for both air/snow and snow/ice.
- Assume no reflection at other layer boundaries.

$$T_B = \sec\theta \int_{-(h_{ice}+h_{snow})}^{0} T(z)\kappa_a(z)e^{-\tau(z,0)}dz \text{ (+scattering contribution)}$$

$$\tau(z_1, z_2) = \sec\theta \int_{z_1}^{z_2} (\kappa_a(z) + \kappa_s(z))dz$$

Simple optimal estimation – definitions

p is a vector of

- Total ice concentration,
- MY-fraction,
- Ice temperature,
- Sea Surface Temperature (SST)
- Wind speed,
- Column water vapour
- Cloud liquid water

$$\mathbf{T_A} = \mathbf{Mp} + \mathbf{e}$$

Measurement (radiometer sensitivity) and model error characterized by covariance $\boldsymbol{S_e}$

And we have additional information from Climatology (typical values for the state variables (mean $\boldsymbol{p_o}$ and covariance $\boldsymbol{S_p}$)

Due to the non-linearities in the model, we need to iterate:

$$\mathbf{p}_{n+1} = \mathbf{p}_n + \left(\mathbf{S}_p^{-1} + \mathbf{M}_n^T \mathbf{S}_e^{-1} \mathbf{M}_n\right)^{-1} \left(\mathbf{M}_n^T \mathbf{S}_e^{-1} \left(\mathbf{T}_A - \mathbf{T}_{A,n}\right) + \mathbf{S}_p^{-1} \left(\mathbf{p}_0 - \mathbf{p}_n\right)\right)$$

Estimation theory – Measurement noise

$$T_A = Mp + e$$

$$\hat{p} = (M^t M)^{-1} M^t T_{ap} \qquad (7.6)$$

$$T_A = Mp + e \qquad (7.7)$$

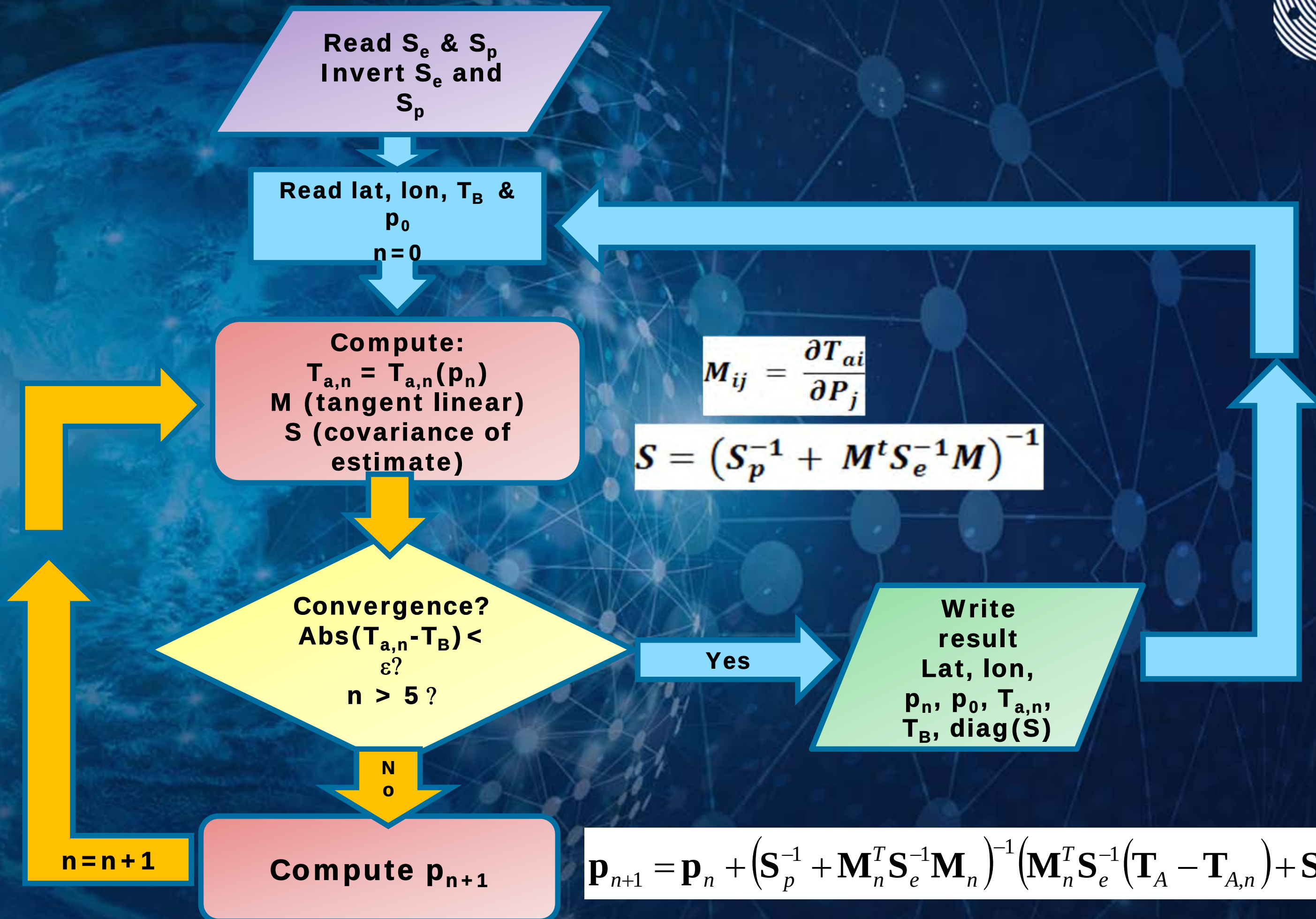
$$\hat{p} = (M^t S_e^{-1} M)^{-1} M^t S_e^{-1} T_A \qquad (7.8)$$

$$\hat{S} = (M^t S_e^{-1} M)^{-1} \qquad (7.9)$$

$$\hat{p} = \hat{S}(S_p^{-1} p_0 + M^t S_e^{-1} T_A) \qquad (7.13)$$

$$\hat{S} = (S_p^{-1} + M^t S_e^{-1} M)^{-1} \qquad (7.11)$$

Optimal estimation processor

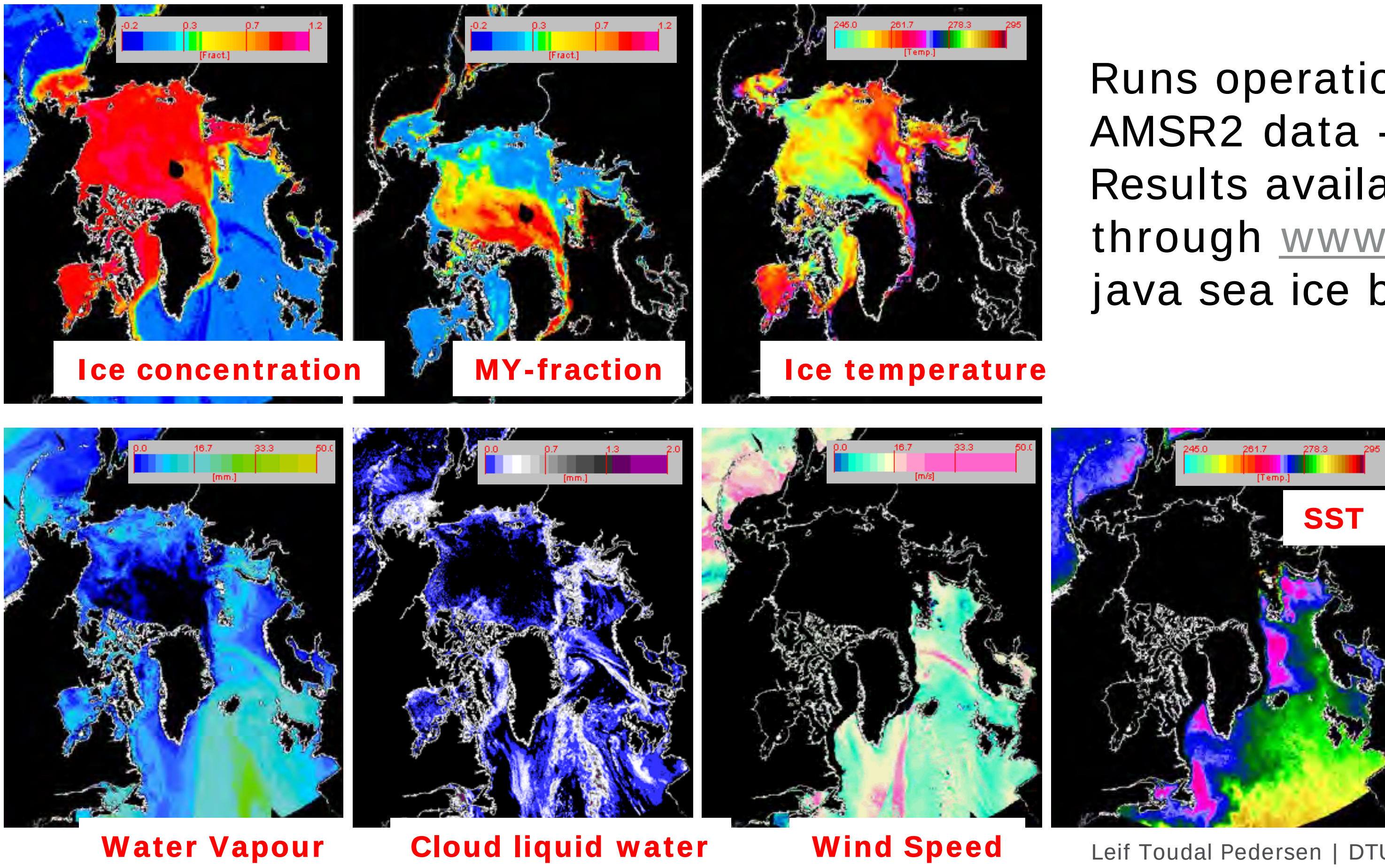


$$M_{ij} = \frac{\partial T_{ai}}{\partial P_j}$$

$$S = \left(S_p^{-1} + M^t S_e^{-1} M\right)^{-1}$$

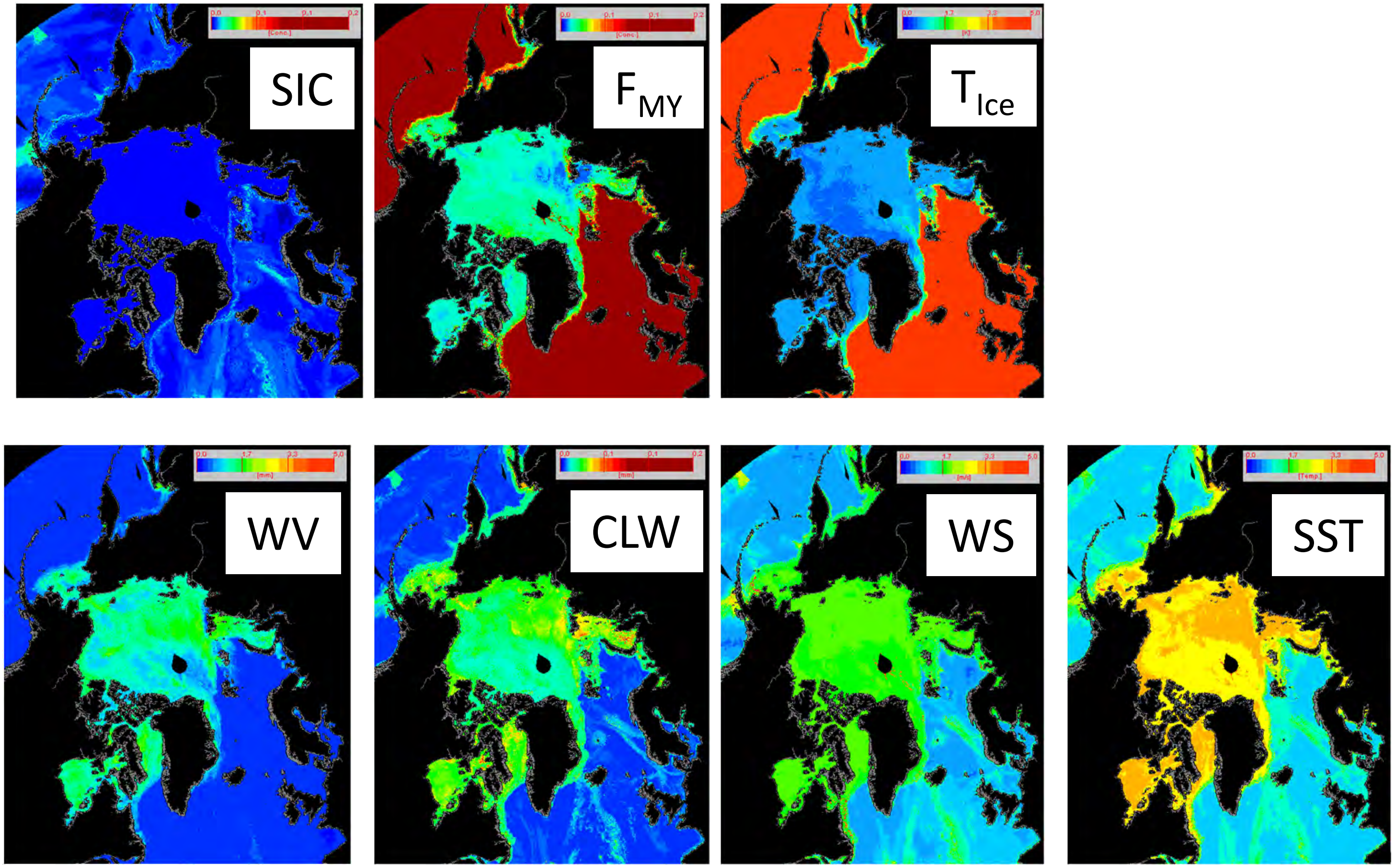
$$\mathbf{p}_{n+1} = \mathbf{p}_n + \left(\mathbf{S}_p^{-1} + \mathbf{M}_n^T \mathbf{S}_e^{-1} \mathbf{M}_n\right)^{-1} \left(\mathbf{M}_n^T \mathbf{S}_e^{-1} \left(\mathbf{T}_A - \mathbf{T}_{A,n}\right) + \mathbf{S}_p^{-1} \left(\mathbf{p}_0 - \mathbf{p}_n\right)\right)$$

OE AMSR-E retrieval - February 4, 2006

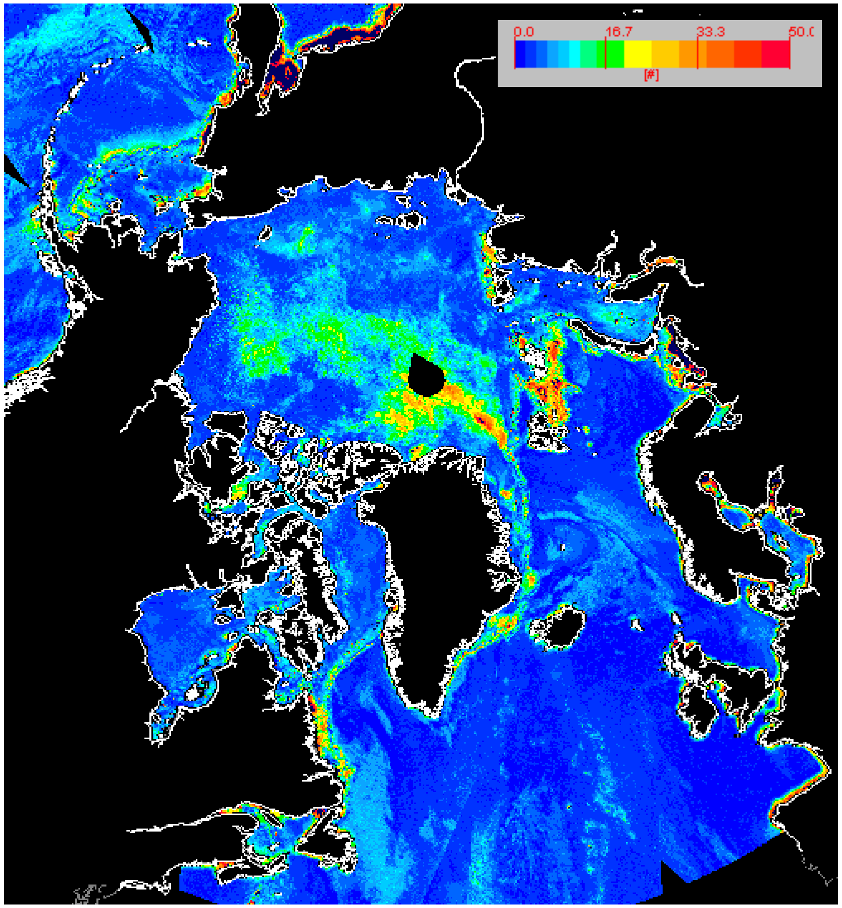


Runs operationally with AMSR2 data - Results available through www.seaice.dk java sea ice browser

Diagonal elements of S matrix – estimated uncertainty



Cost function ($T_B(p)-T_Bobs$)



Discrepancies along strong gradients due to mismatching footprints

Discrepancies inside Arctic Ocean due to too simple ice forward model

Conclusions

Satellite data products are NOT the truth

All SIC algorithms underestimate thin ice

All SIC algorithms see melt-ponds as 0% ice

Algorithms overestimate SIC in Summer due to difficulty in tie-point definition

Icecharts are NOT the truth either

They typically overestimate intermediate ice concentrations

They are not necessarily consistent from day to day

4 reasons why icechart and PMR SIC products differ

1. Thin ice is underestimated in PMR SIC
2. Melt ponds are seen as open water in PMR SIC (PMR SIC = ISF)
3. Wet snow on ice may lead to regional overestimation – tie-points are hemispheric
4. Ice charts often overestimate intermediate concentrations

However, when used with caution, satellite data (and icecharts) provide a wealth of useful information about sea ice and it's snow cover

Data providers should provide quantitative estimates of known issues – ask them for specifications for observation operators!!

Ressources

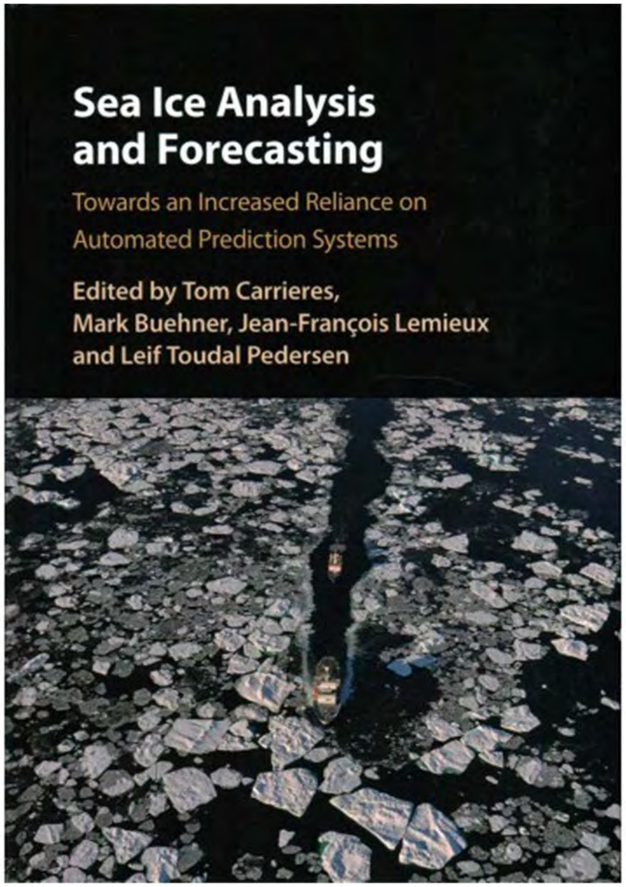
OSISAF operational and arctived Sea Ice products (netCDF & quicklooks)
http://osisaf.met.no/p/ice/index.html

ESA CCI Sea Ice CDR (netCDF) (AMSR-E/AMSR2)
https://icdc.cen.uni-hamburg.de/1/projekte/esa-cci-sea-ice-ecv0.html

ESA CCI and H2020 SPICES projects Round Robin Data Package
https://figshare.com/articles/Reference_dataset_for_sea_ice_concentration/6626549

Lavergne, T., Sørensen, A. M., Kern, S., Tonboe, R., Notz, D., Aaboe, S., Bell, L., Dybkjær, G., Eastwood, S., Gabarro, C., Heygster, G., Killie, M. A., Kreiner, M. B., Lavelle, J., Saldo, R., Sandven, S., and Pedersen, L. T.: Version 2 of the EUMETSAT OSI SAF and ESA CCI Sea Ice Concentration Climate Data Records, The Cryosphere Discuss., https://doi.org/10.5194/tc-2018-127, in review, 2018.

Ivanova, N., Pedersen, L. T., Tonboe, R. T., Kern, S., Heygster, G., Lavergne, T., Sørensen, A., Saldo, R., Dybkjær, G., Brucker, L., and Shokr, M.: Inter-comparison and evaluation of sea ice algorithms: towards further identification of challenges and optimal approach using passive microwave observations, The Cryosphere, 9, 1797-1817, https://doi.org/10.5194/tc-9-1797-2015, 2015.



Sea Ice Analysis and Forecasting (Book)

Towards an Increased Reliance on Automated Prediction Systems

Edited by Tom Carrieres, Mark Buehner, Jean-François Lemieux, Leif Toudal Pedersen

This book provides an advanced introduction to the science behind automated prediction systems, focusing on sea ice analysis and forecasting. Starting from basic principles, fundamental concepts in sea ice physics, remote sensing, numerical methods, and statistics are explained at an accessible level. Existing operational automated prediction systems are described and their impacts on information providers and end clients are discussed. The book also provides insight into the likely future development of sea ice services and how they will evolve from mainly manual processes to increasing automation, with a consequent increase in the diversity and information content of new ice products. With contributions from world-leading experts in the fields of sea ice remote sensing, data assimilation, numerical modelling, and verification and operational prediction, this comprehensive reference is ideal for students, sea ice analysts, and researchers, as well as decision-makers and professionals working in the ice service industry.

Cambridge University Press, Fall 2017

End of part 2

Thank you ☺

European Space Agency

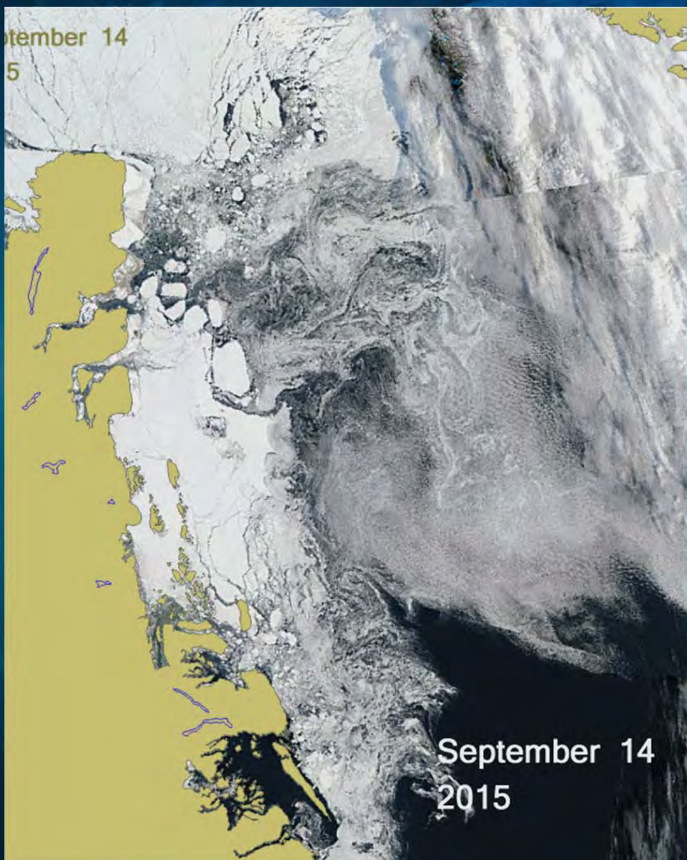
Include volume scattering

$$T_B = \frac{1}{\cos(\theta)} \int_{-(hice+hsnow)}^{0} T(z)\kappa_a(z)e^{-\tau(z,hsnow)}dz + \frac{1}{\cos(\theta)} \int_{-(hice+hsnow)}^{0} T_{DN}(z)\kappa_s(z)dz$$

$$\tau(z_1, z_2) = \frac{1}{\cos(\theta)} \int_{z_1}^{z_2} (\kappa_a(z) + \kappa_s(z))dz$$

$$T_{DN}(z) = T_{DN}(0)e^{-\tau(0,z)} + \frac{1}{\cos(\theta)} \int_{z}^{0} T(z)\kappa_a(z)e^{-\tau(z,hsnow)}dz$$

Icecharts


tember 14
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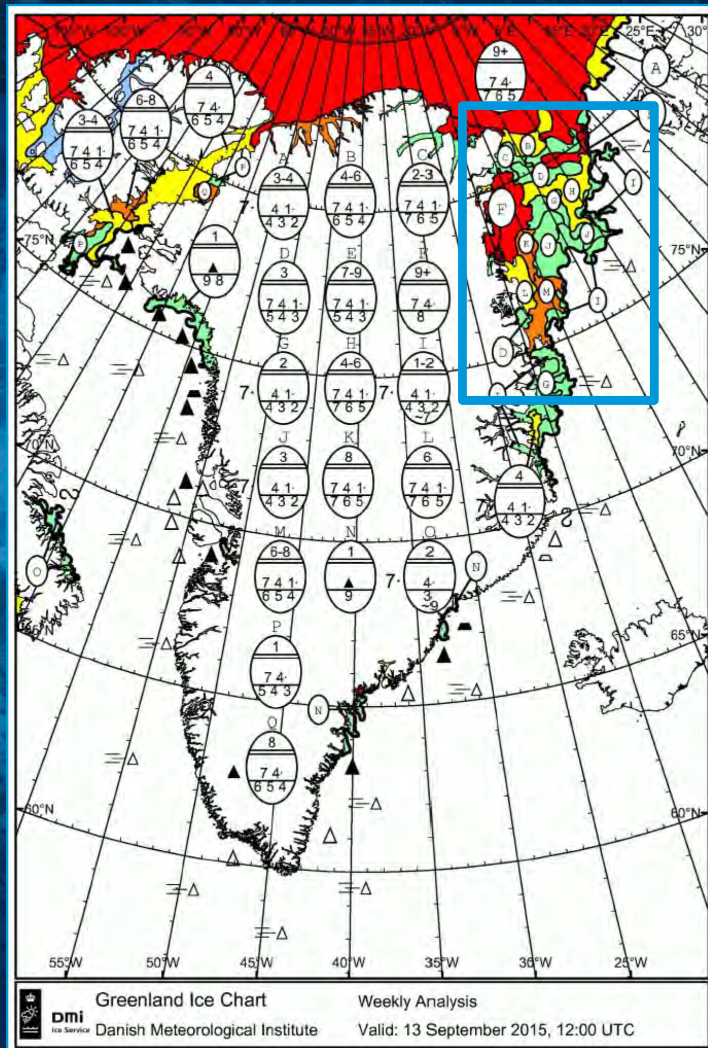
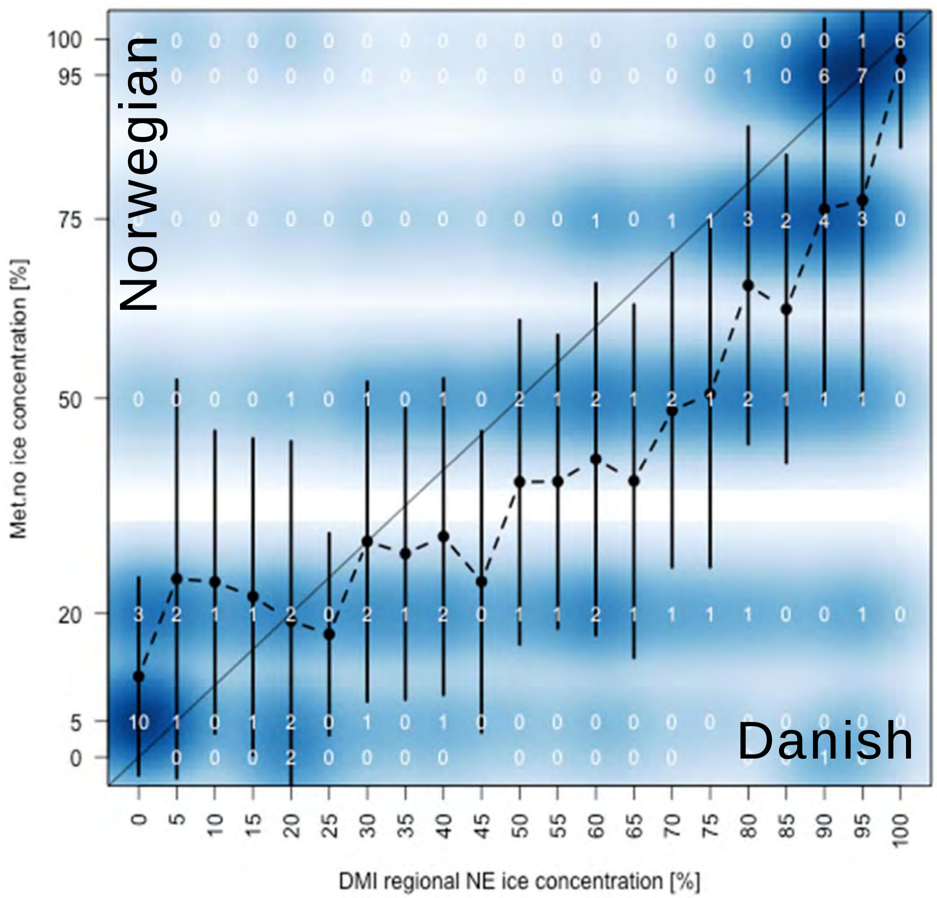
September 14
2015

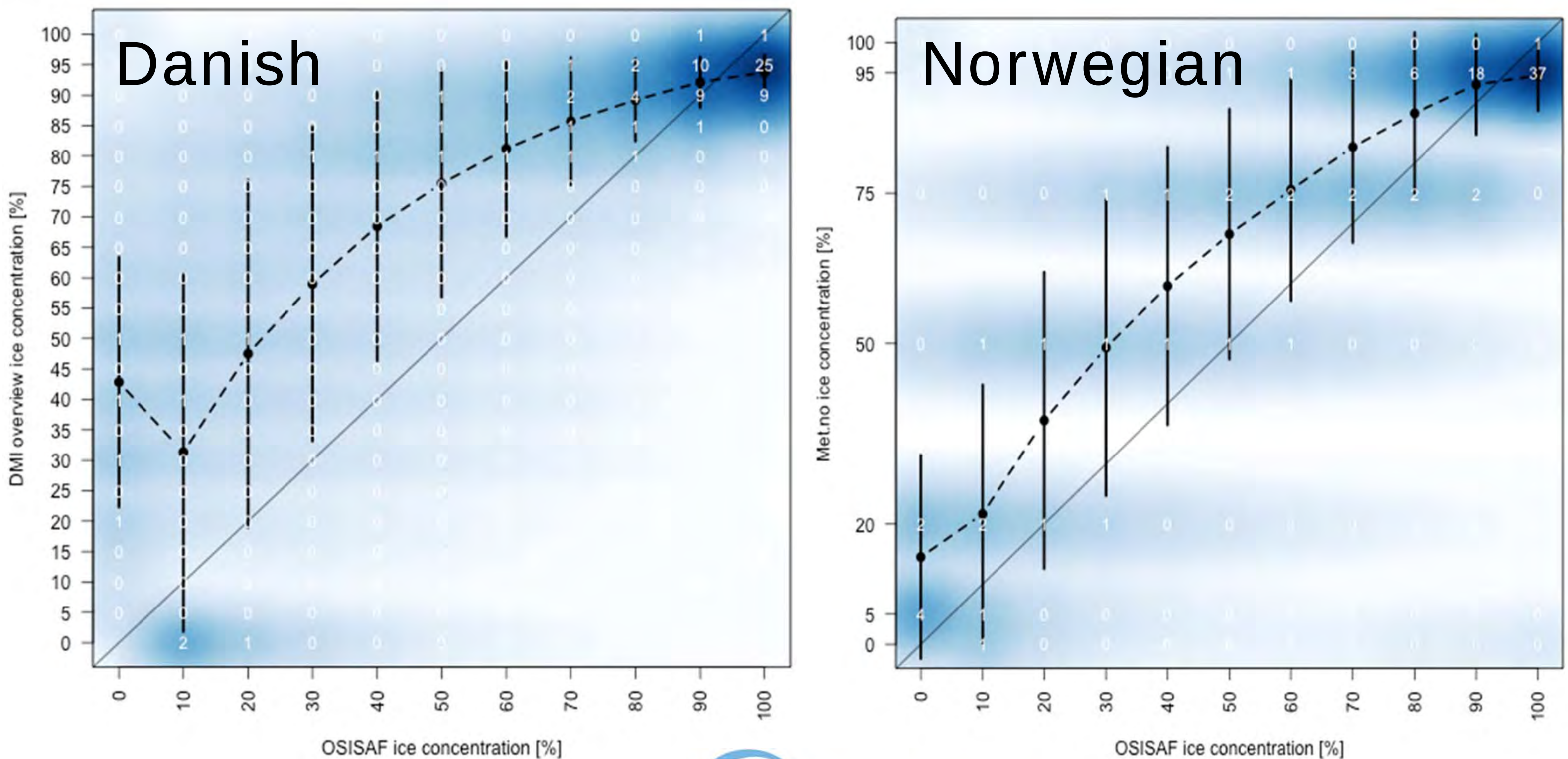

75°N
70°N
65°N
60°N
55°W
50°W
45°W
40°W
35°W
30°W
25°W
Greenland Ice Chart
Weekly Analysis
DMI
Danish Meteorological Institute
Valid: 13 September 2015, 12:00 UTC

Icechart to OSISAF SIC intercomparison

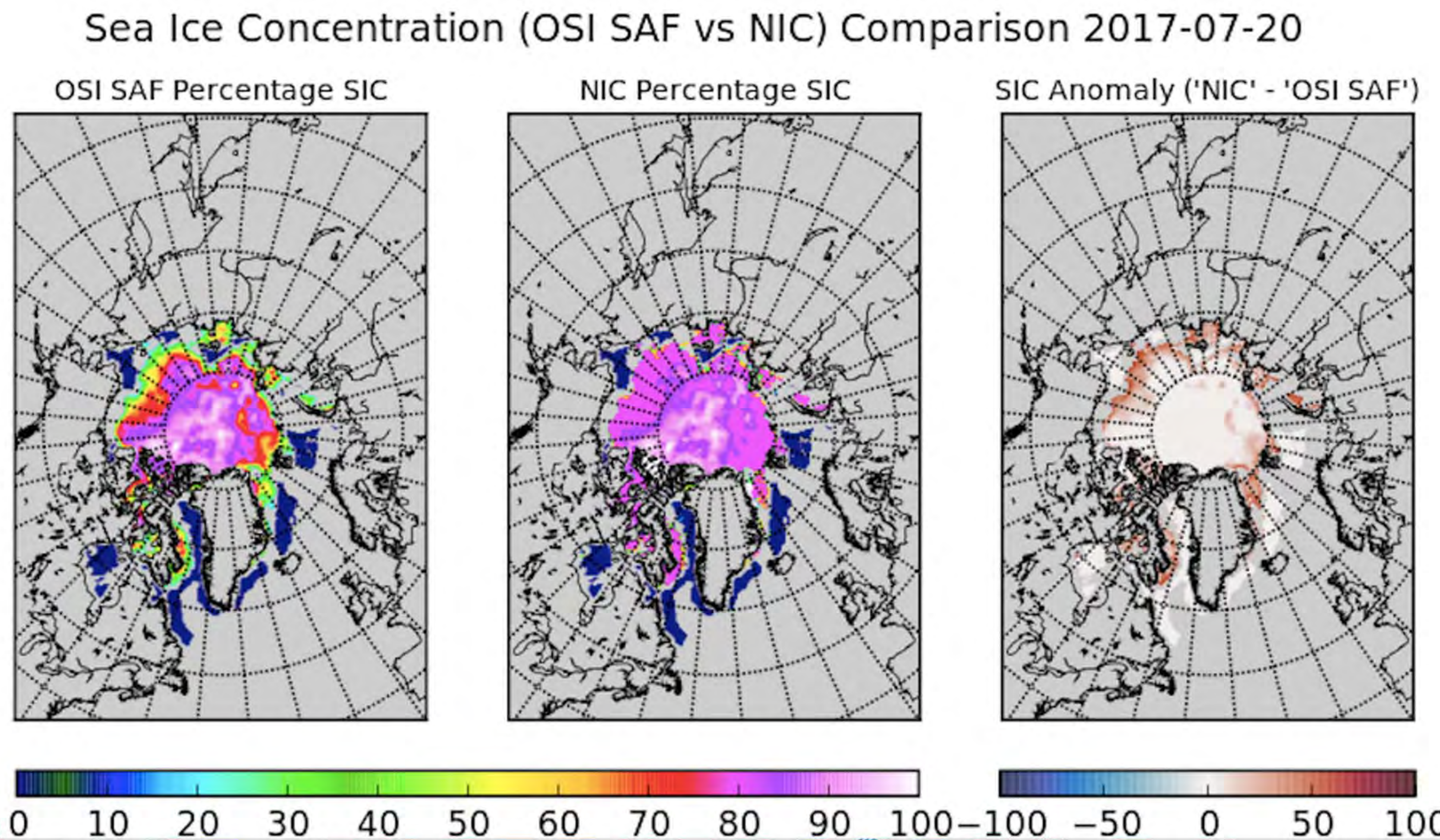


East Greenland Area

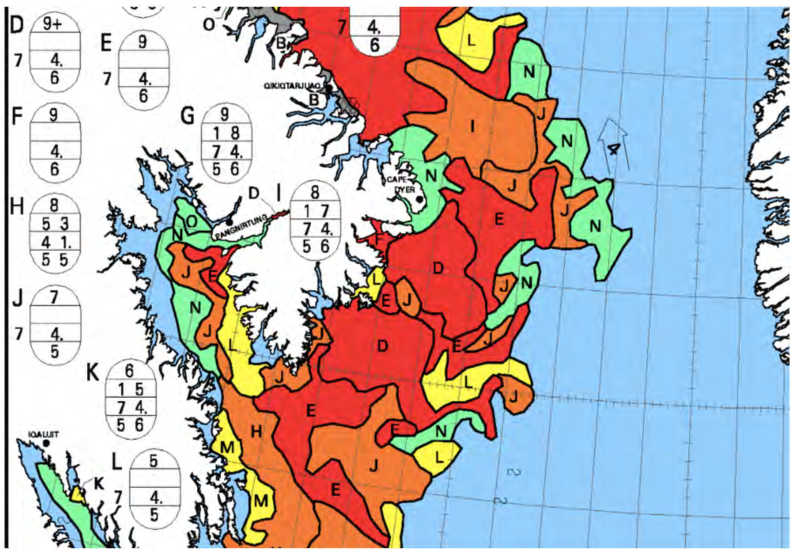
See also:
Karvonen, Juha, Jouni Vainio, Marika Marnela, Patrick Eriksson, and Tuomas Niskanen, *A Comparison Between High-Resolution EO-Based and Ice Analyst-Assigned Sea Ice Concentrations,* IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING, VOL. 8, NO. 4, APRIL 2015


Danish
DMI overview ice concentration [%]
OSISAF ice concentration [%]
Norwegian
Met.no ice concentration [%]
OSISAF ice concentration [%]

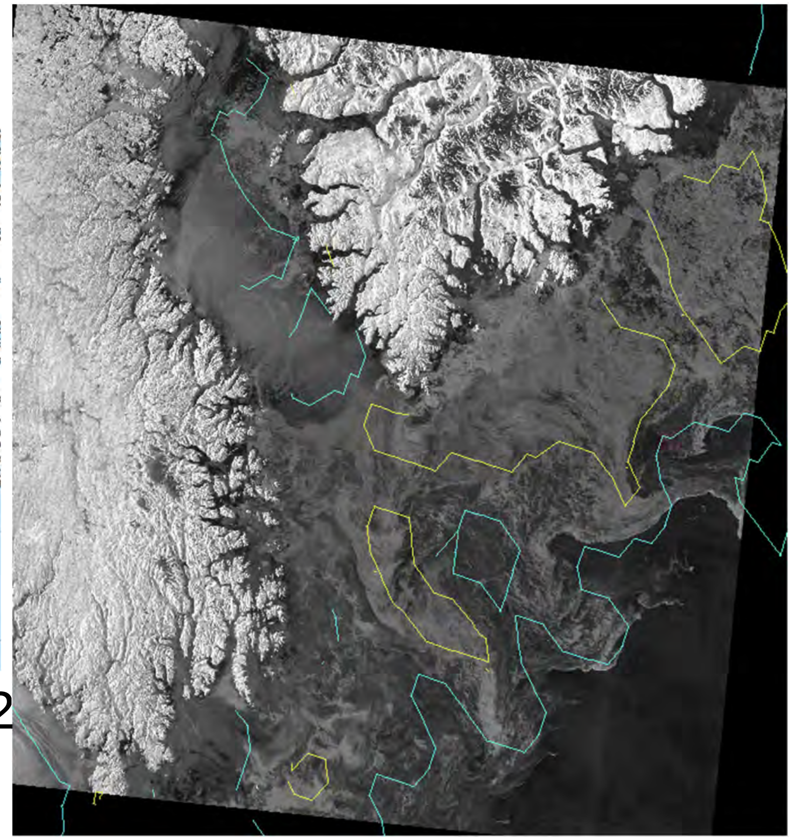
Icechart vs OSI-SAF ice concentration



CIS Icechart vs Sentinel-1 SAR



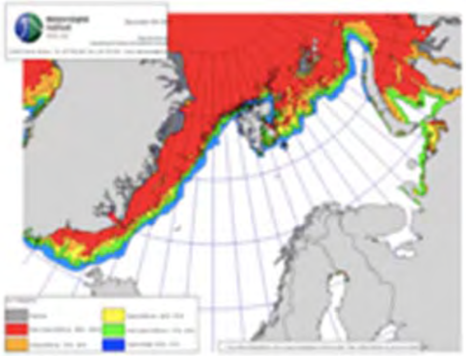
CIS daily ice chart on July 2



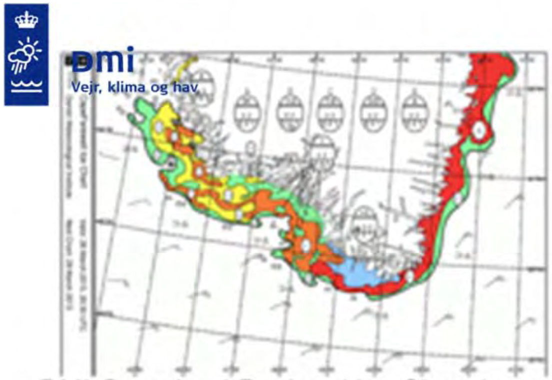
Sentinel-1 SAR on July 20, 2017

Icechart to OSISAF SIC intercomparison

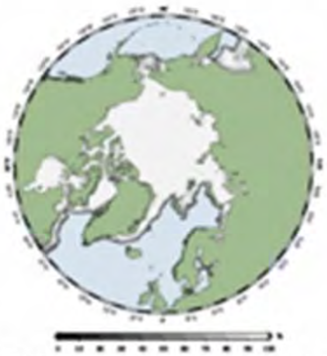
DMI Greenland Overview Ice Chart



Met.no Svalbard Ice Chart

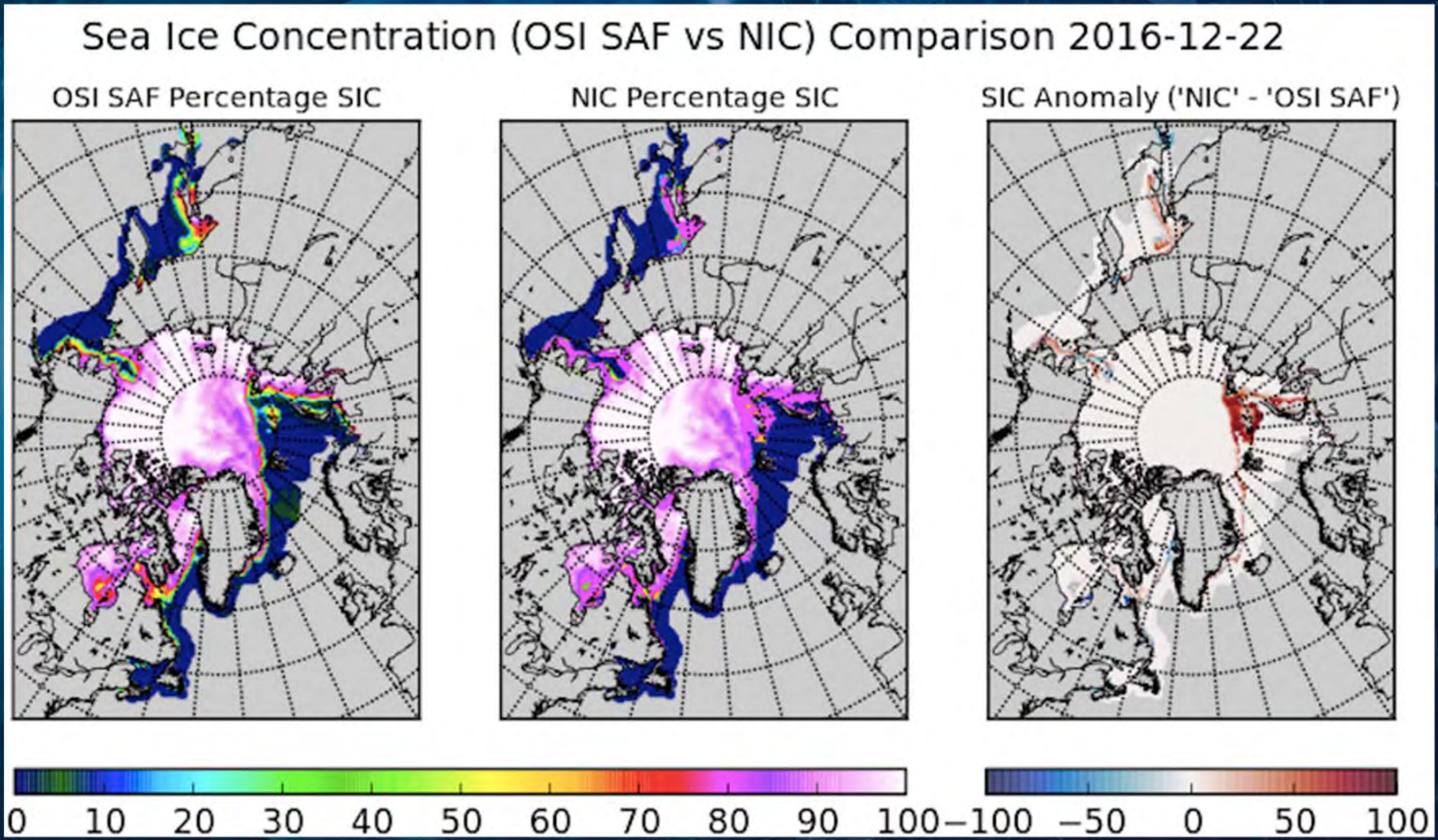


DMI Greenland Regional Ice Chart (example)



OSISAF Ice Concentration data

Icechart to OSISAF SIC intercomparison



Danmarks Meteorologiske Institut

Sentinel-1 SAR and MET Icechart 2016-12-22