An innovative Sea Ice Concentration algorithm for the Copernicus Imaging Microwave Radiometer (CIMR) mission

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- **The Copernicus Imaging Microwave Radiometer (CIMR)** is a High Priority Candidate Mission for **Copernicus** expansion, designed to respond directly to the Integrated **EU Arctic Policy**.

- **CIMR** will provide :

  First priority

  - **Sea Ice Concentration (SIC)**
  - **Sea Surface Temperature (SST)**

  Second priority

  - **Sea Surface Salinity (SSS)**
  - **Ocean Wind Speed (OWS)**
  - **High Ocean Wind Speed (HOWS)**
  - **Sea Ice Thickness (SIT), below 0.8 m**

  And many other parameters…

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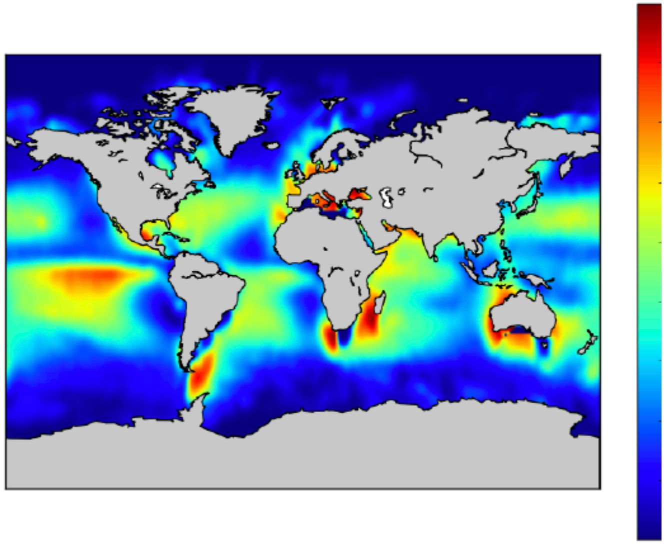
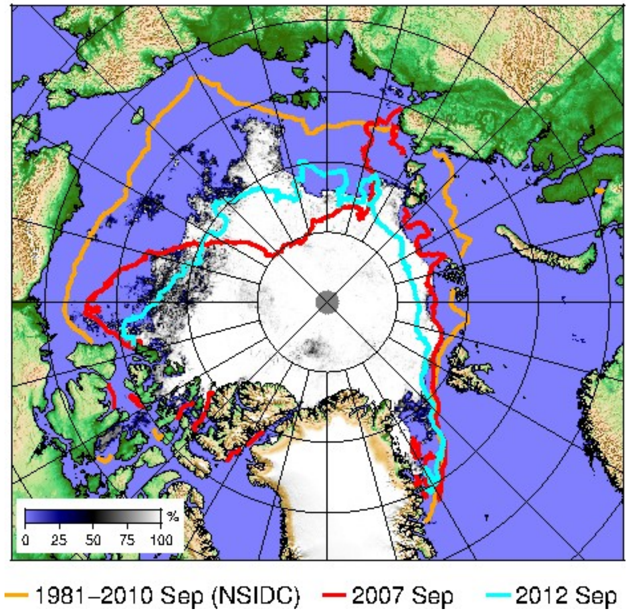


Mean clear sky probability (from ATSR)



Sea Ice extent in Septembre for different years

The situation today

- SST is derived from IR under clear sky (<40% globally)
- SST and SIC are derived from microwave sensors even under cloudy conditions (e.g., AMSR2)
- Microwave SST is derived with low spatial resolution because of the use of the 6 GHz (~50 km with AMSR2)
- SIC is contaminated by the atmosphere when using high frequencies (36 GHz or above) and is estimated with low spatial resolution when using the low frequencies (6 GHz)
- SSS is derived from SMOS and SMAP
- There is no guarantee of continuation of the measurements of these products, with 6 and 1.4GHz, with AMSR2, SMOS and SMAP.

CIMR: an innovative instrument concept

- Sun synchronous polar orbit with full coverage of the poles (6pm / 6am)
- Passive microwave conically scanning imager (55°)
- Swath > 1900 km
- 5 frequencies with at least dual vertical polarizations

Frequency (GHz)	1.4	6.9	10.65	18.7	36.5
Footprint (km)	<60	15	15	5	<5
NeDT (K)	0.3	0.2	0.3	0.4	0.7

- Low noise receivers with RFI mitigation
- ~7 m mesh Large Deployable Reflector rotating at ~7 RPM

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Footprint (km)	<60 40	15 48	15 33	5 18	<5 9
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SMAP (1.4) — AMSR2 (6.9–36.5)

- Low noise receivers with RFI mitigation
- ~7 m mesh Large Deployable Reflector rotating at ~7 RPM

CIMR: optimized retrieval concepts

- **Over ice-free ocean**, optimal estimation method to simultaneously and consistently retrieve SST, SSS, OWS, HOWS (along with IWV and ILW), using all CIMR channels, thanks to a sea surface emissivity model carefully evaluated over the full frequency range

- **Over sea ice**, development of an optimal estimation scheme for the SIC, using all the CIMR channels in a consistent way. It is based on the Round Robin datasets to derive a simplified but robust radiative transfer model for sea ice.
  => combines the advantage of the low frequency sensitivity and the spatial resolution from the high frequencies

Kilic et al., JGR, 2018

CIMR: optimized retrieval concepts

Optimal estimation method: general framework (Rodgers, 2002)

Estimate:

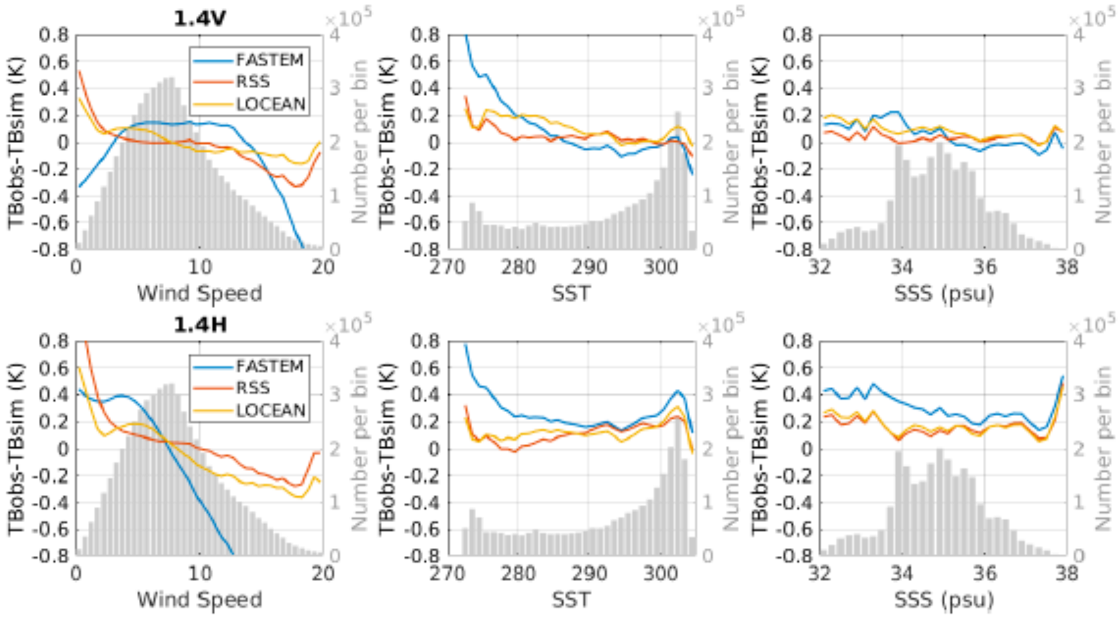
$$\hat{x}_{i+1} = x_i + Q(K^t S_e^{-1}(y - F(x_i)) + S_a^{-1}(x_i - x_a))$$

With the estimate error covariance:

$$Q = (K^t S_e^{-1} K + S_a^{-1})^{-1}$$

Over ice-free ocean, classic method. The Jacobians K are provided by the radiative transfer model. The method uses all CIMR channels in a simultaneous and consistent retrieval of all quantities.

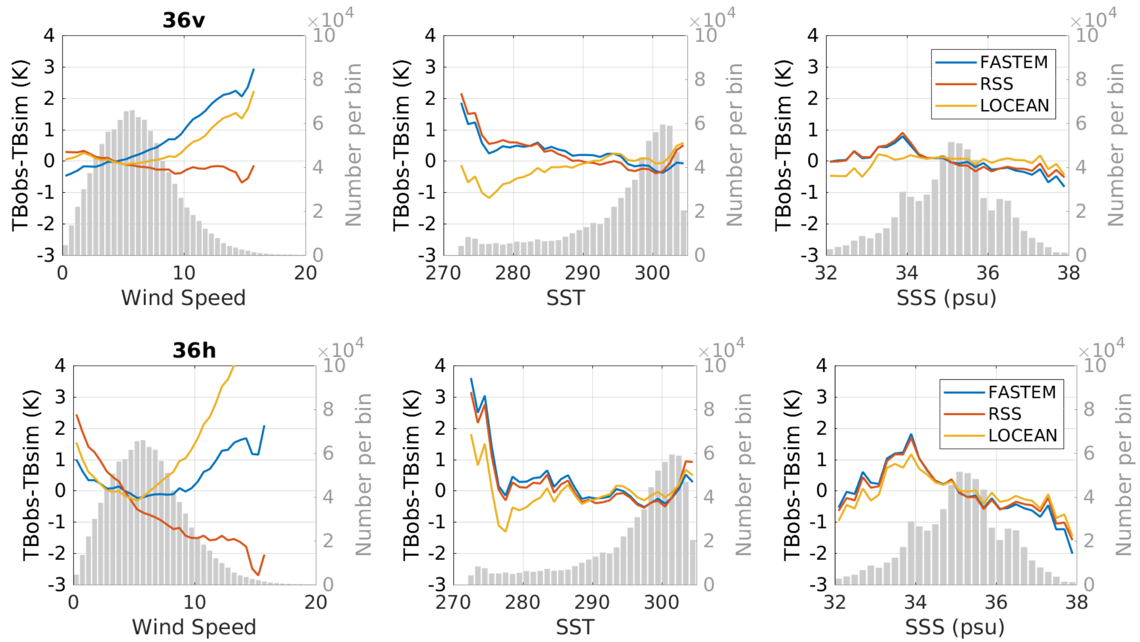
CIMR: optimized retrieval concepts



-Systematic evaluation of radiative transfer models, globally, from 1.4 to 36GHz, with SMAP and AMSR2 (Kilic et al., to be submitted)

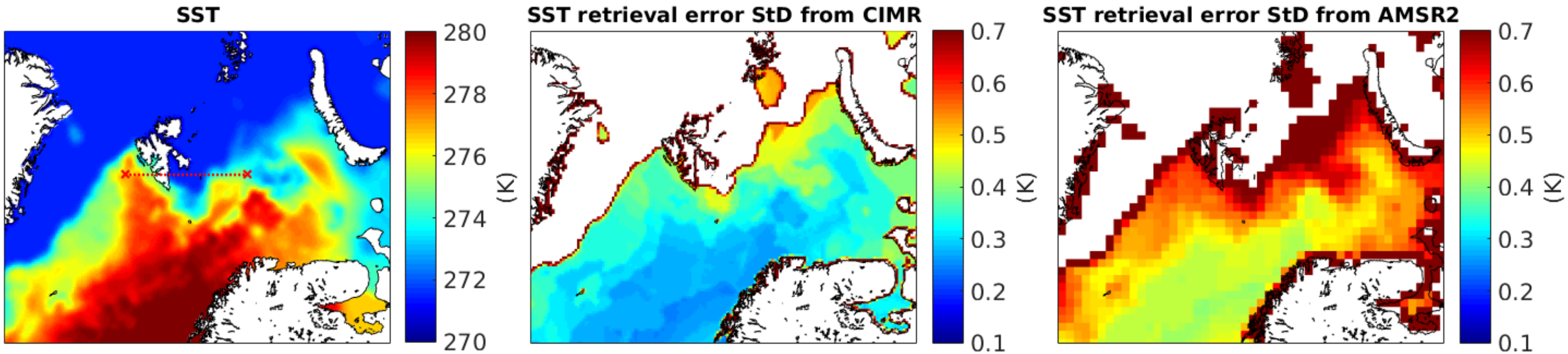
-Optimization of a physically-based model underway to cover the full frequency range.

Over ice-free ocean

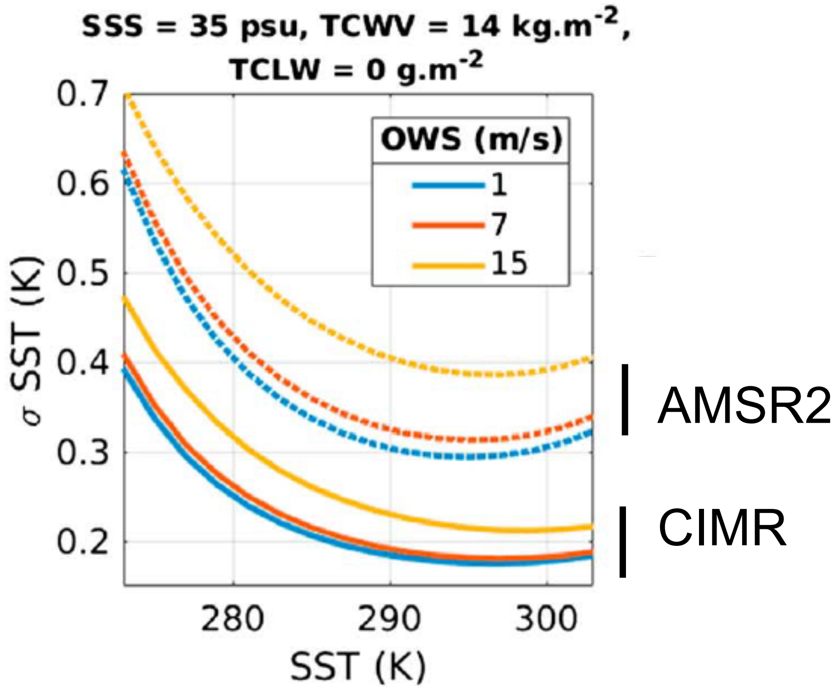


CIMR: optimized retrieval concepts

Over ice-free ocean: comparison with AMSR2 results



SST retrieval precision is improved compared to AMSR2, even for cold water where the retrieval is difficult.



CIMR: optimized retrieval concepts

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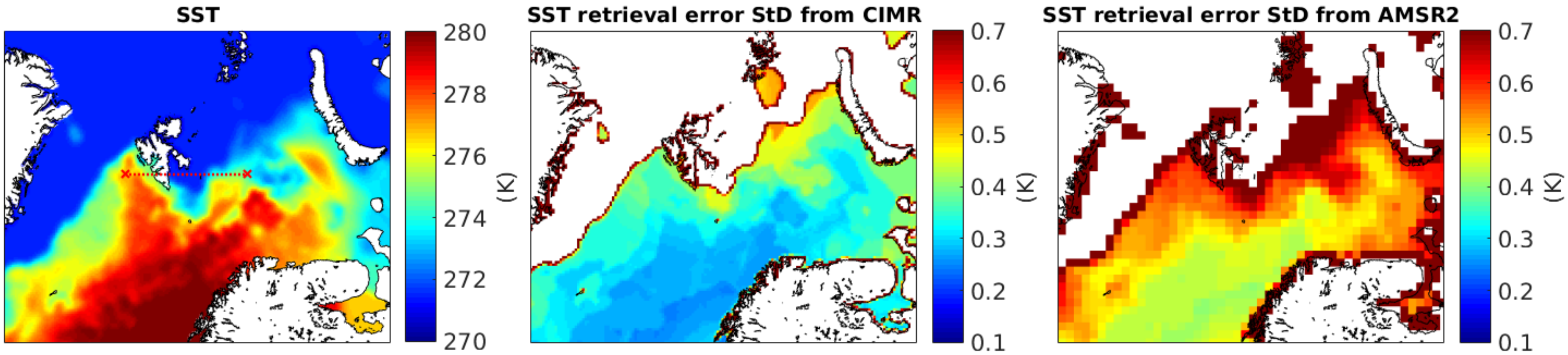
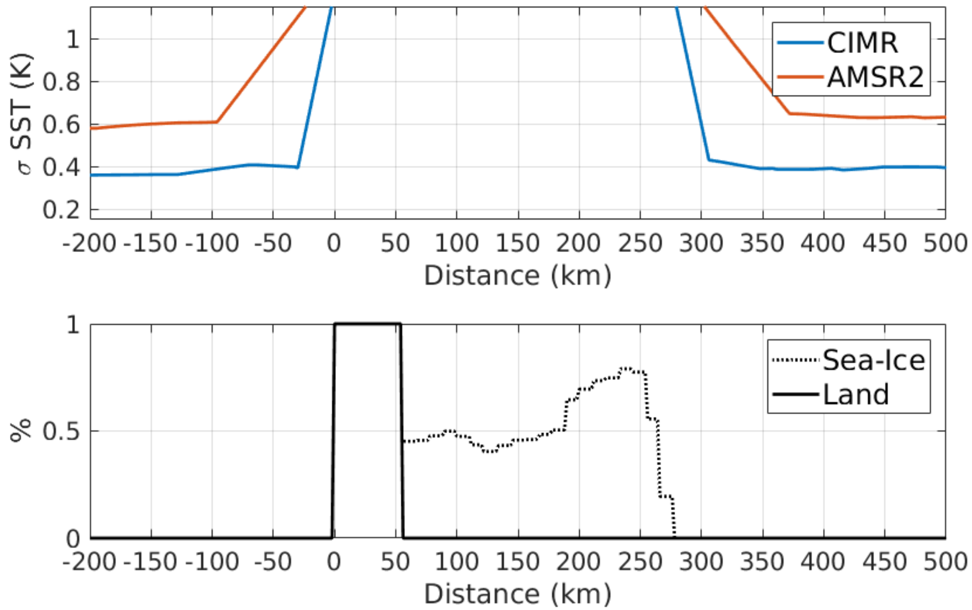


Improvement close to the coasts and sea ice margins.



CIMR: optimized retrieval concepts

Over ice-free ocean

Sea Surface Temperature

- Better spatial resolution (from 60 to 15 km)
- Better cover of coastal areas (down to 20 km)
- Higher retrieval precision (~ 0.2 K)

Sea Surface Salinity

- High radiometric sensitivity to provide a precision of ~0.3 psu instantaneously
- Coincident analysis of SSS, SST, and OWS

High Sea Surface Wind Speed

- Unique estimation of the high surface wind speed with the 1.4GHz (Reul et al., 2012)

CIMR: optimized retrieval concepts

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With the estimate error covariance:

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Over sea ice, no radiative transfer model suitable over the full frequency range.

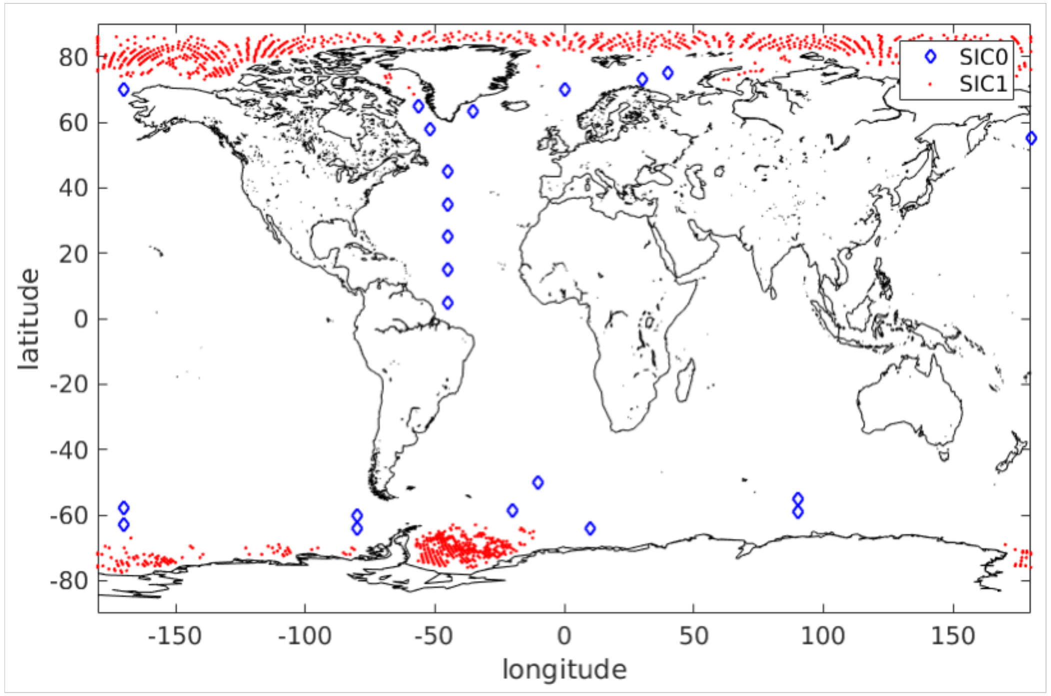
=> Use of the Round Robin dataset (ESA CCI project, Pedersen and Saldo, 2016) to derive one, along with the necessary statistics.

CIMR: optimized retrieval concepts

Over sea ice

The Round Robin Data Package

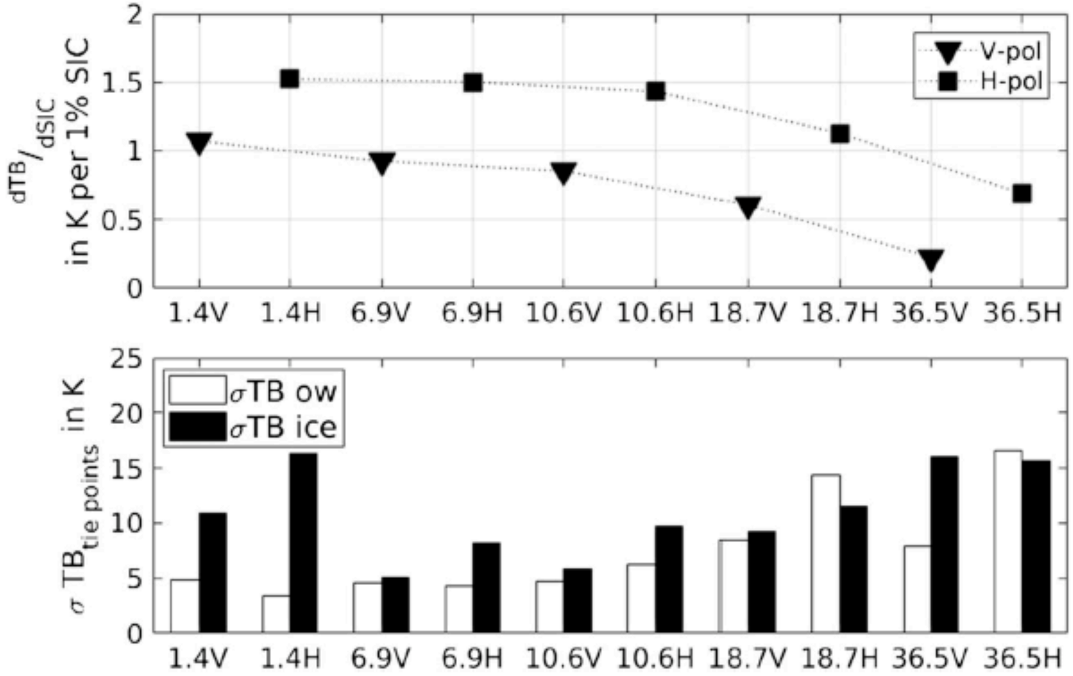
- Developed for ESA Sea ice CCI project (Pedersen et al., 2018)
- Observed TBs for 0% and 100% SIC and for many situations
- AMSR2 (from 6.9 to 89 GHz) and SMOS (at 1.4 GHz)

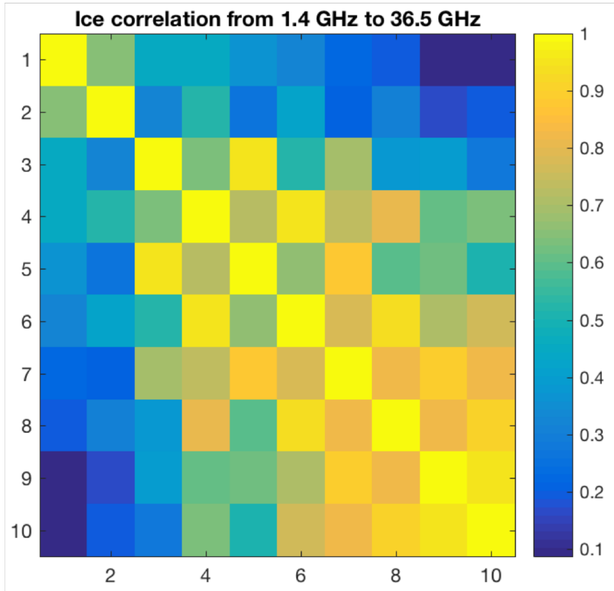


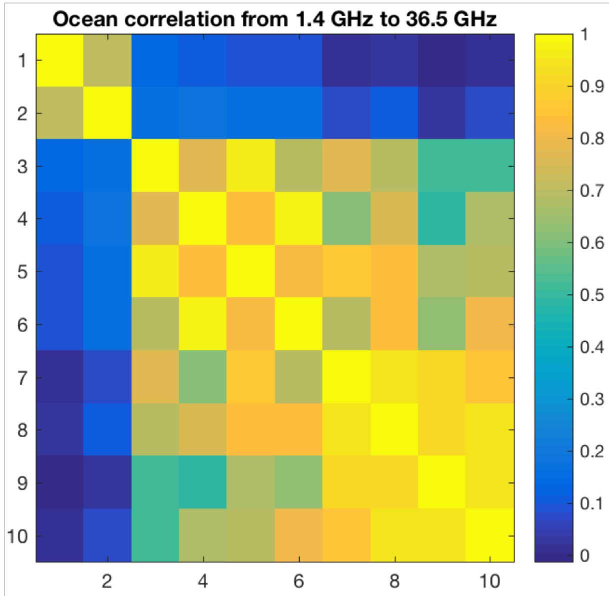
CIMR: optimized retrieval concepts

Over sea ice

Jacobians provided by the **Round Robin dataset**







Covariances provided by the **Round Robin dataset**

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Over sea ice

Forward radiative transfert model

$$TB = F(SIC) = SIC \cdot TB_{ice} + (1 - SIC) \cdot TB_{ocean}$$

Jacobian:

$$K = \frac{dTB}{dSIC} = TB_{ice} - TB_{ocean}$$

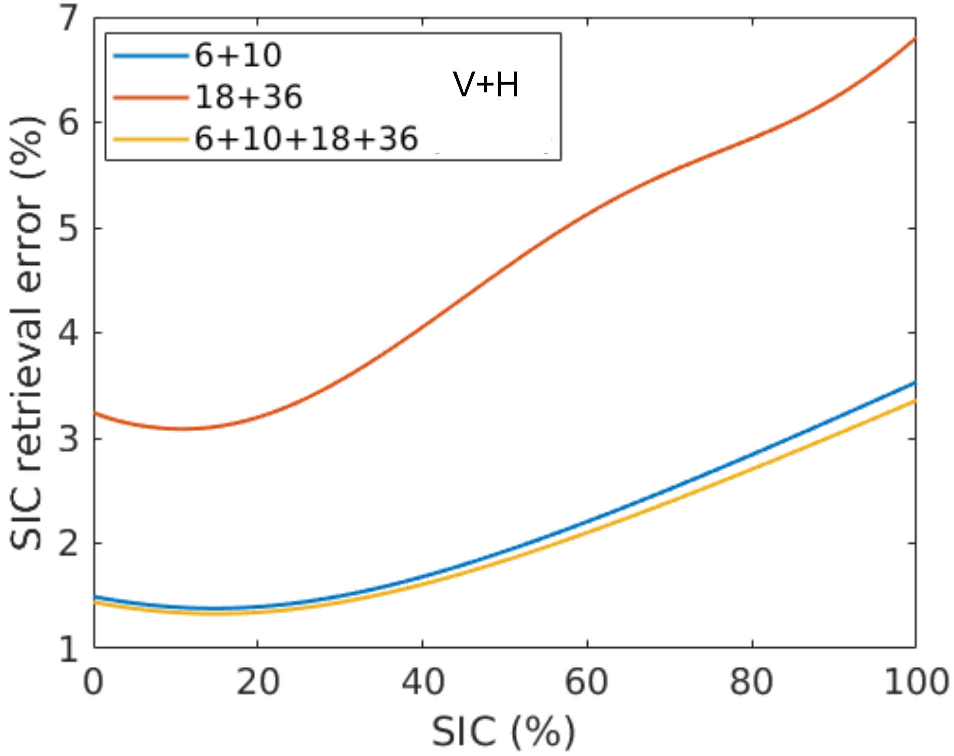
Observation error covariance (neglecting instrument)

$$S_e = SIC^2 \cdot COV_{TB_{ice}} + (1 - SIC)^2 \cdot COV_{TB_{ocean}},$$

A priori SIC: x_a=50%
A priori error S_a=50%

CIMR: optimized retrieval concepts

Over sea ice



Within the optimal estimation framework, possibility to easily combine channels and test their contributions

CIMR: optimized retrieval concepts

Over sea ice

How to exploit the high spatial resolution of the high frequencies while benefiting from the accuracy of the lower frequency ?

A downscaling methodology, compatible with the optimal estimation framework.

- ***A posteriori*** **combination of the SIC estimations at high resolution (with large retrieval errors) with the SIC estimation at low resolution (with small retrieval error)**
- **The high resolution estimation for each pixel is constrained and re-computed to fit the SIC estimation obtained at low resolution (taking into account the respective retrieval errors).**

CIMR: optimized retrieval concepts

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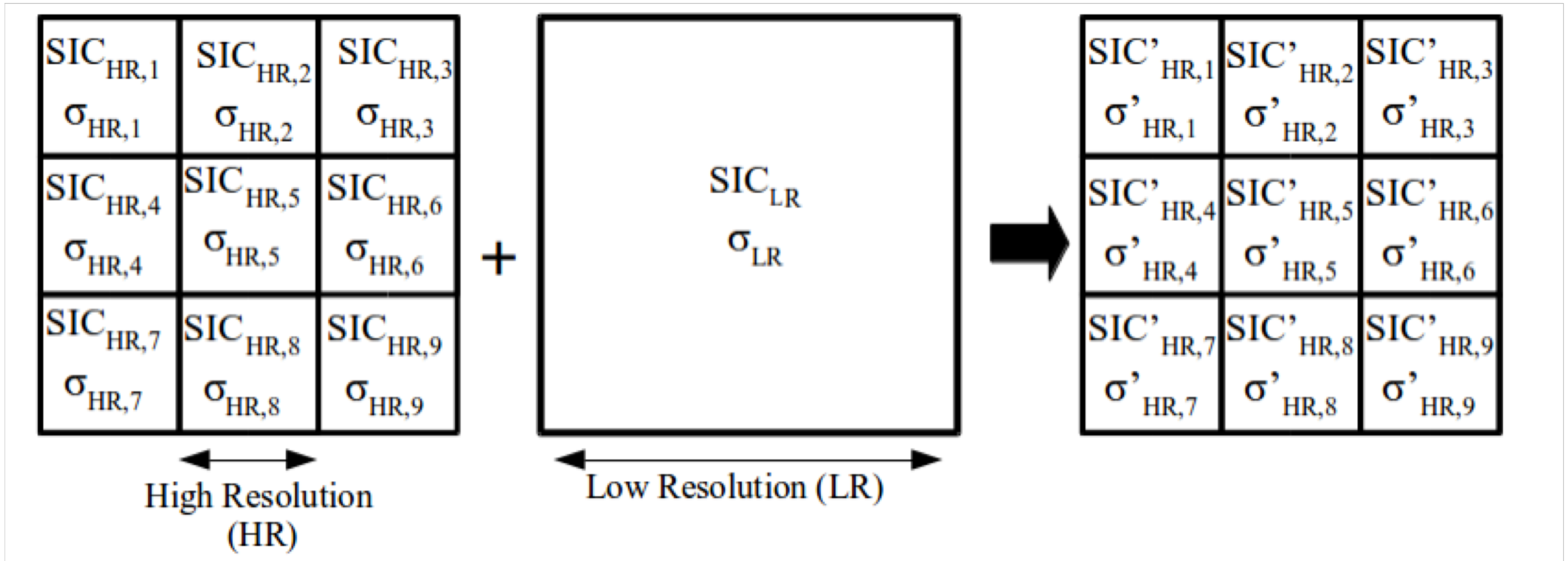

CIMR: optimized retrieval concepts

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Example with the CIMR configuration

SIC estimation using 18 + 36 GHz TBs at 5km

100 % ± 6.5 %	90 % ± 6 %	60 % ± 5.5 %
90 % ± 6 %	50 % ± 5 %	30 % ± 3.5 %
50 % ± 5 %	20 % ± 3.5 %	0 % ± 3.2 %

\+

SIC estimation using 6+10 GHz TBs at 15km

50 % ± 2 %

➡

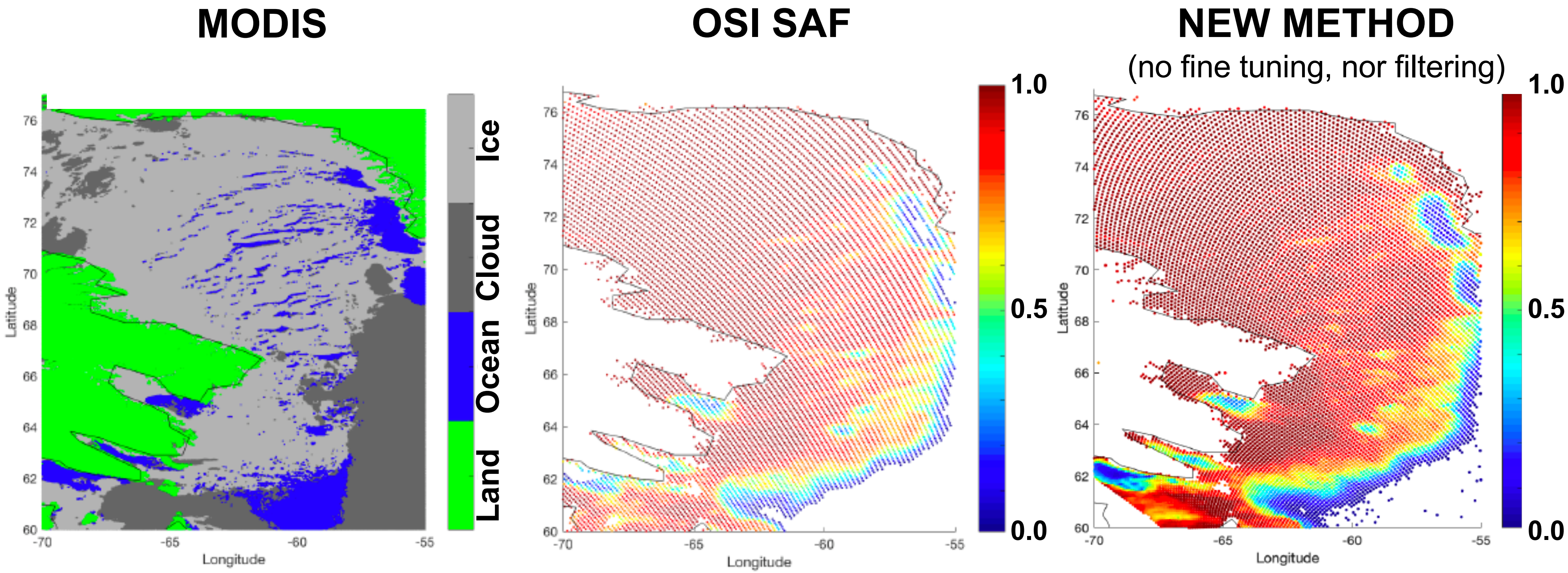
New SIC estimation

94.1 % ± 5.9 %	84.6 % ±5.5 %	55 % ± 5.1%
84.6 % ± 5.5 %	45.5 % ±4.7 %	26.8 % ±3.4 %
45.5 % ±4.7 %	16.8 % ±3.4 %	-2.9 % ±3.1 %

CIMR: optimized retrieval concepts

Over sea ice

Test of the methodology using AMSR2 data



A clear sky situation close to Greenland 20/04/2018 **(other situations tested)**

CIMR: optimized retrieval concepts

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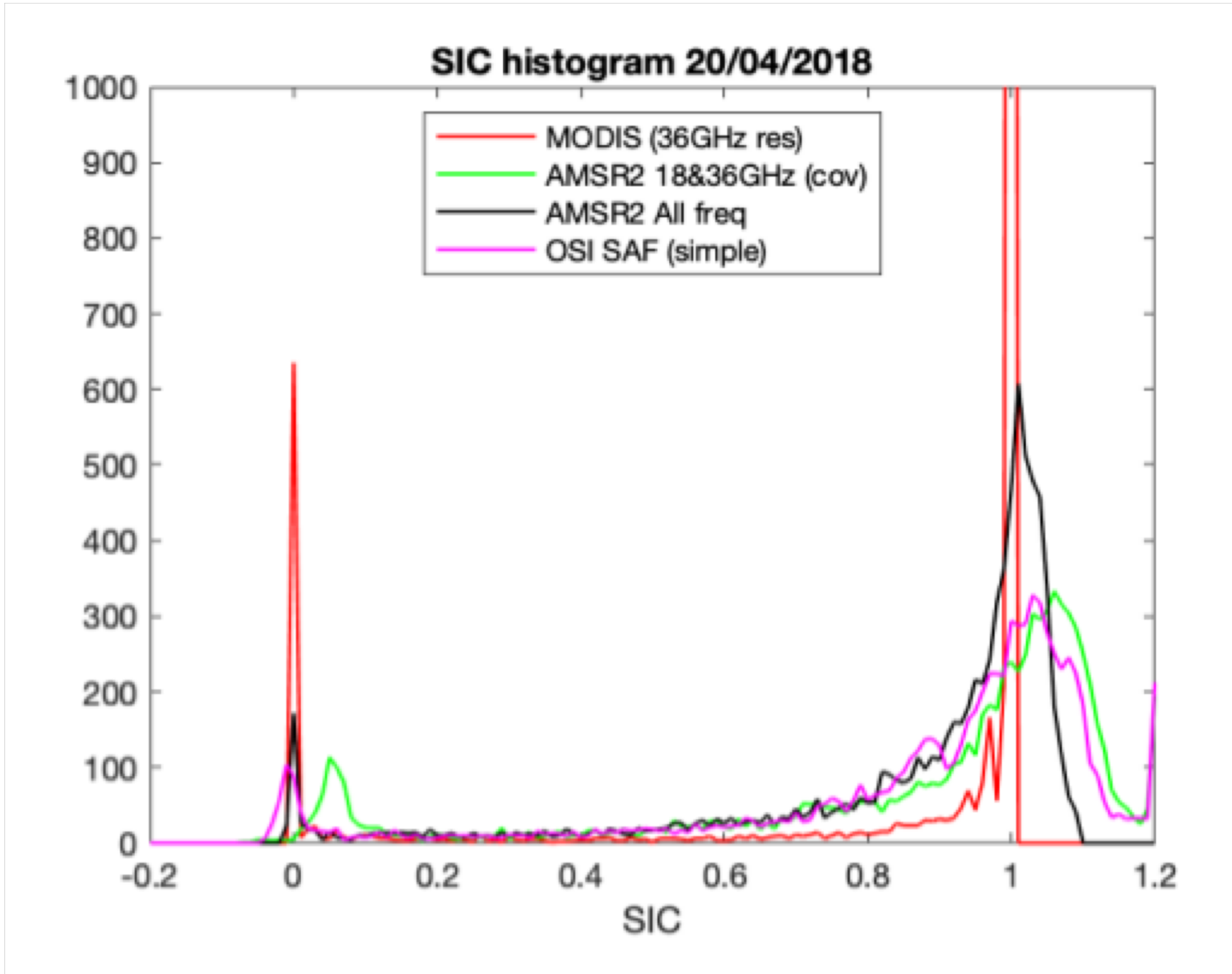

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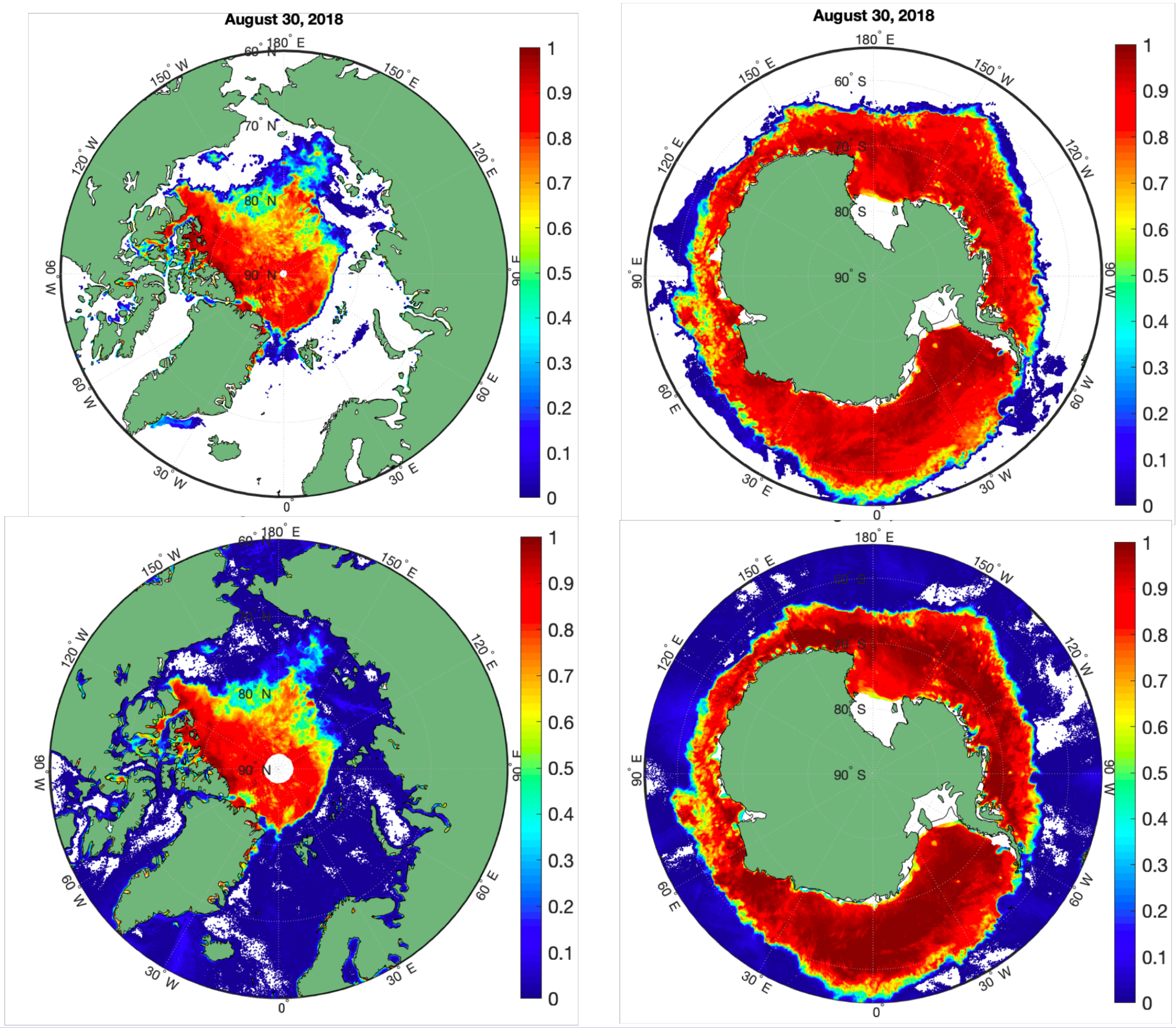

OSI SAF

NEW METHOD

(no fine tuning, nor filtering)

CIMR: optimized retrieval concepts

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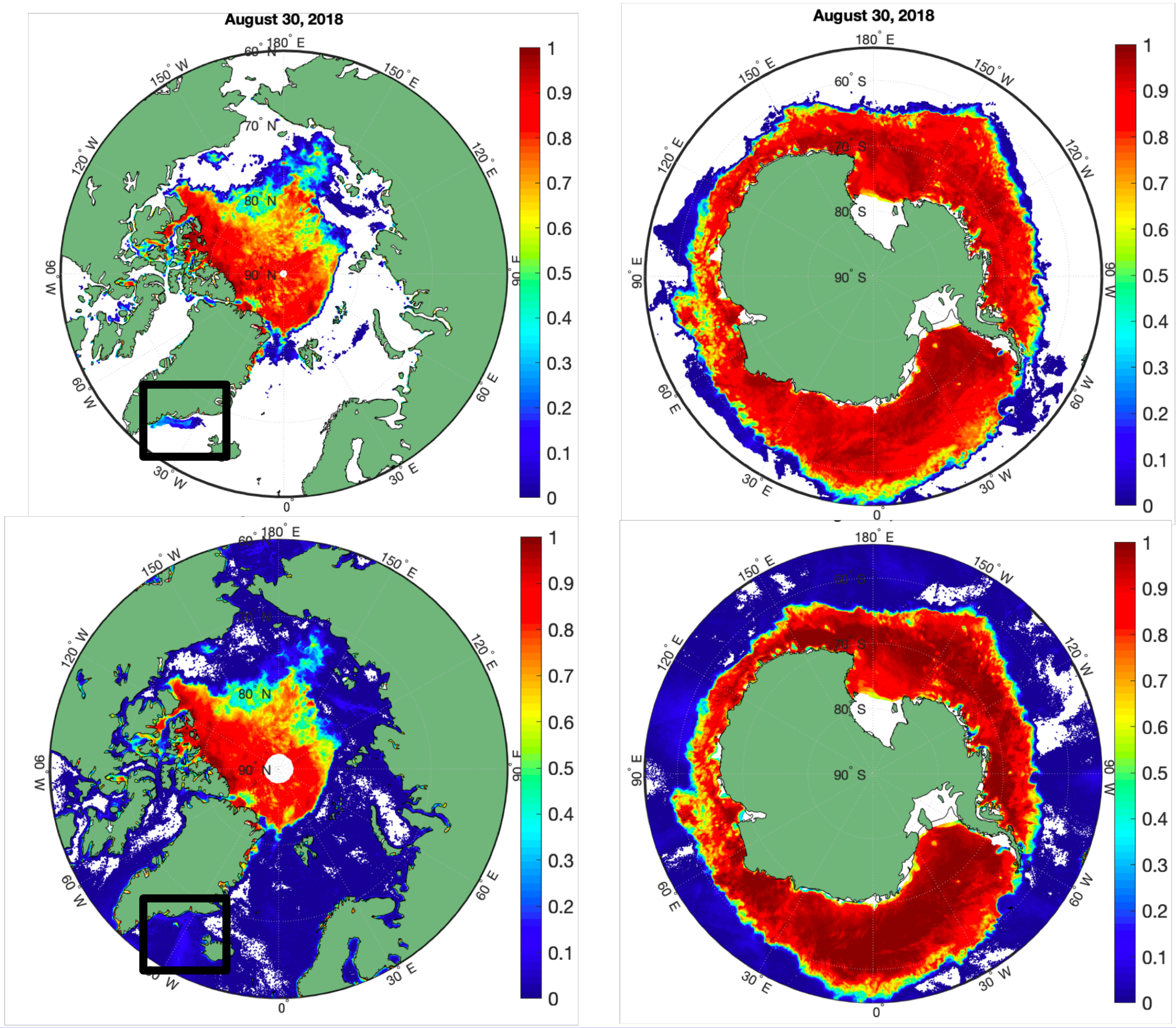

OSI SAF

NEW METHOD

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CIMR products

Coincident and consistent SST, OWS, SSS, and HOWS over ocean and SIC, Sea Ice Type, and Thin Sea Ice Thickness over sea ice

Variable	Spatial resolution	Precision (instantaneous)	Temporal sampling
All-weather sea surface temperature (SST)	15 km	~0.2 K	Twice daily
Sea Surface Salinity (SSS)	< 60 km	~0.3 psu	Twice daily
High Ocean Wind Speed (HOWS)	< 60 km	<5 m/s	Twice daily
All-weather Sea Ice Concentration (SIC)	< 5 km	<5%	Twice daily
Sea Ice Type	15 km		Twice daily
Thin Sea Ice Thickness (SIT)	< 60 km	<10%	Twice daily

CIMR: Conclusion

- **A new passive microwave mission concept for Copernicus expansion, optimized for the observation of polar regions, with low noise receivers at 1.4, 6.9, 10.65, 18.7, 36.5 GHz and a large deployable antenna.**
- **Measurements of key oceanic variables for meteorology, oceanography, and climate analysis, with unique synergies.**
- **All weather products, with better quality and / or spatial resolution, and available close to the coasts**
- **With no guarantee of continuation of low frequency measurements (after AMSR2, SMOS, and SMAP), it will insure continuity, with improved products**
- **Needless to say, it will also benefit the land surface community (soil moisture, surface skin temperature, surface water extent and dynamics, vegetation characterization…)**