About three principal uncertainty sources in gridded sea-ice concentration products from satellite microwave radiometry

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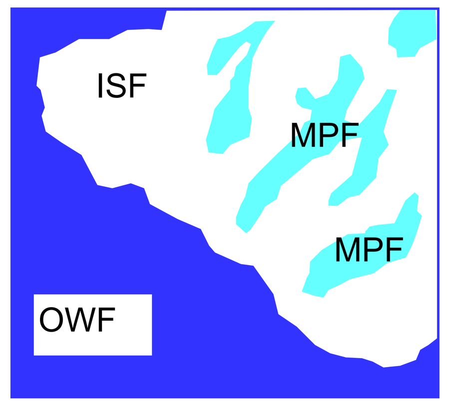
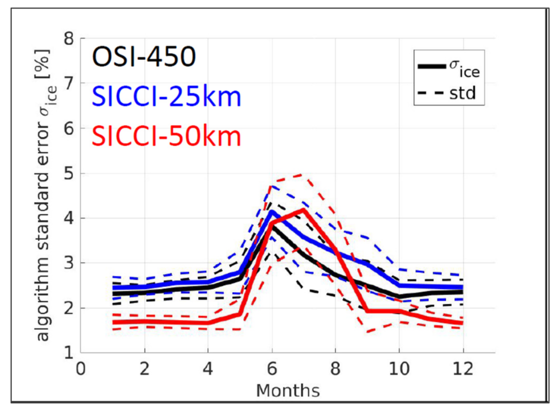
Summer-time bias in sea-ice concentration (SIC) estimates from satellite microwave radiometry

Optical satellite observations permit to distinguish between open water (OWF), melt ponds on top of sea ice (melt-pond fraction, MPF) and sea ice (ice surface fraction, ISF).



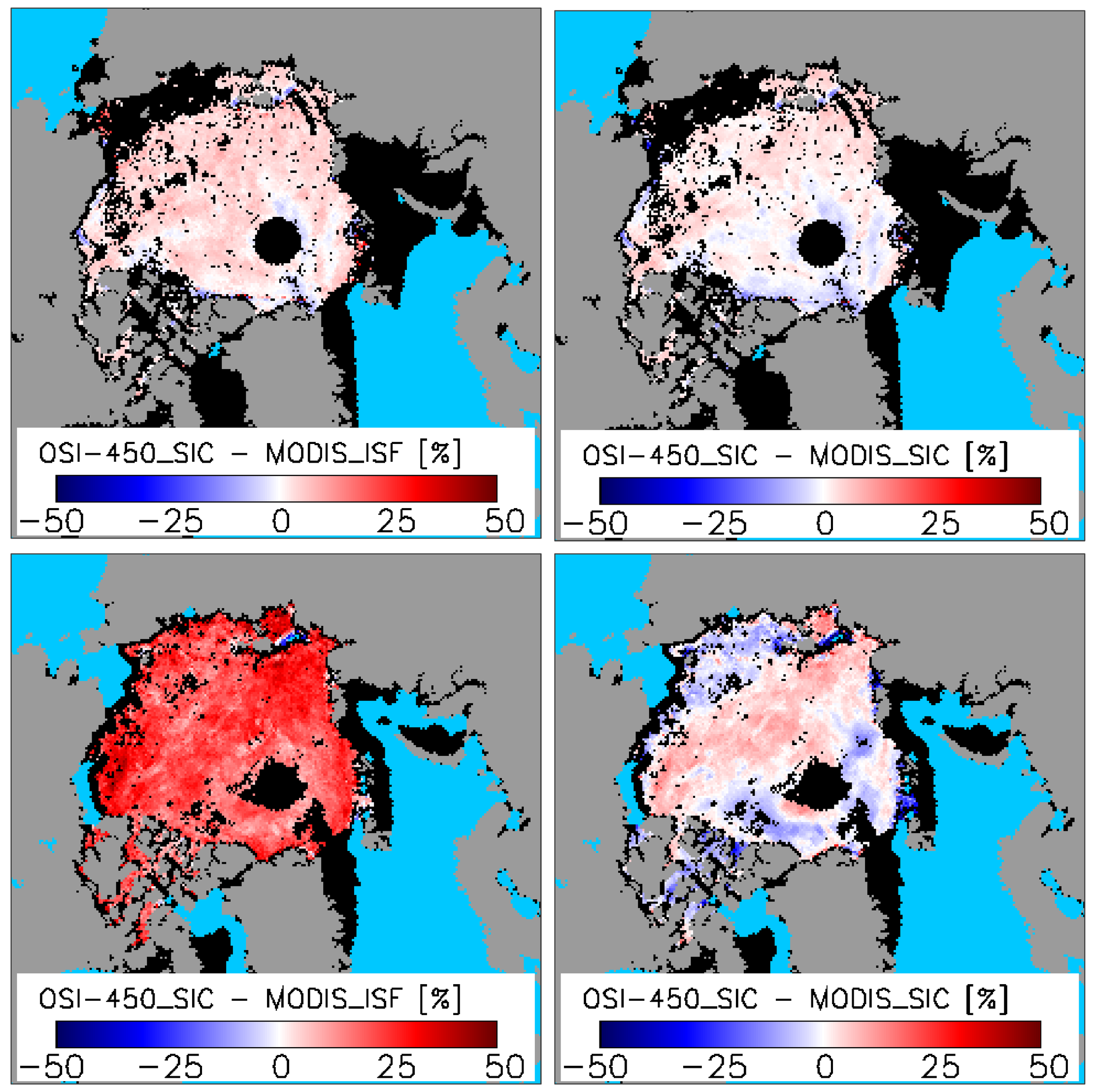


Microwave satellite obervations cannot distinguish between OWF and MPF. In addition, these observations are sensitive to melt-freeze induced changes in sea ice and snow properties.

→ Biases in SIC estimates (see right)
→ Elevated SIC retrieval errors (see above).

Especially, positive SIC biases at a time of more open water (either OWF or MPF) are not well understood.

Reducing SIC bias – particularly in summer – is needed to also use sea-ice area as recommended metric for long-term sea-ice cover observations. In summer, using microwave observations the way forward is switching from SIC to ISF. Alternative solutions such as SIC based on optical observations need more evaluation.



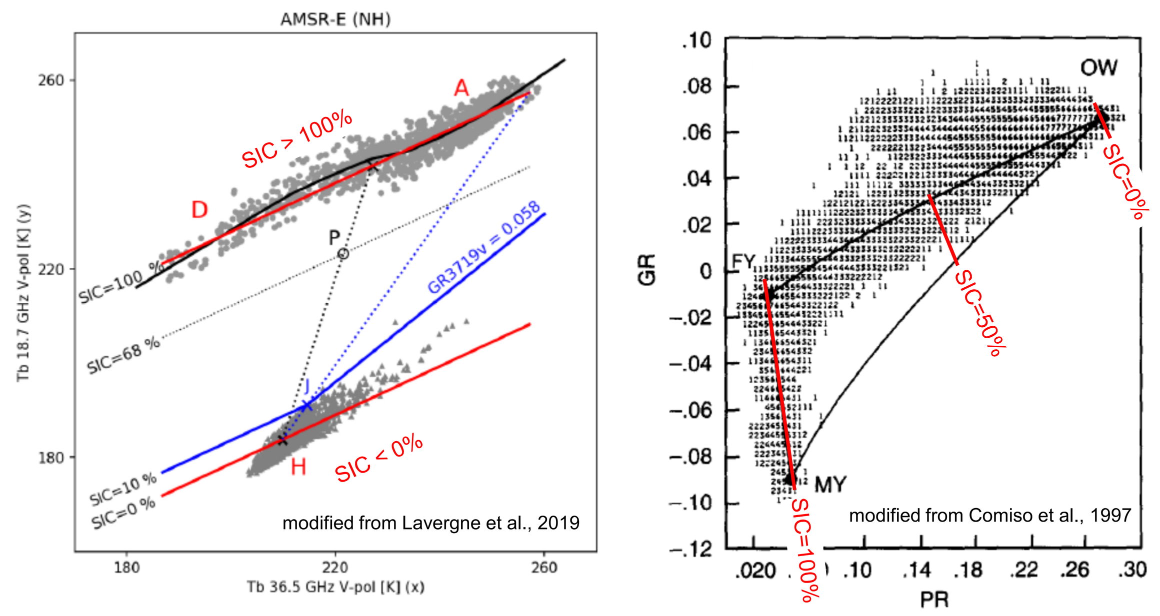
Difference between OSI-450 SIC retrievals and Moderate Resolution Imaging Spectroradiometer (MODIS) estimates of ISF (left) and SIC = 1–OWF = ISF + MPF (right) for May 10 (top) and July 10 (bottom) 2004.

Truncation of SIC at 0% and 100%

Many SIC retrieval algorithms use so-called tie points – aka typical brightness temperatures of pure surface types, e.g. open water (OW), first-year sea ice (FY) or multiyear sea ice (MY), to derive SIC. These define the value range 0% to 100% SIC.

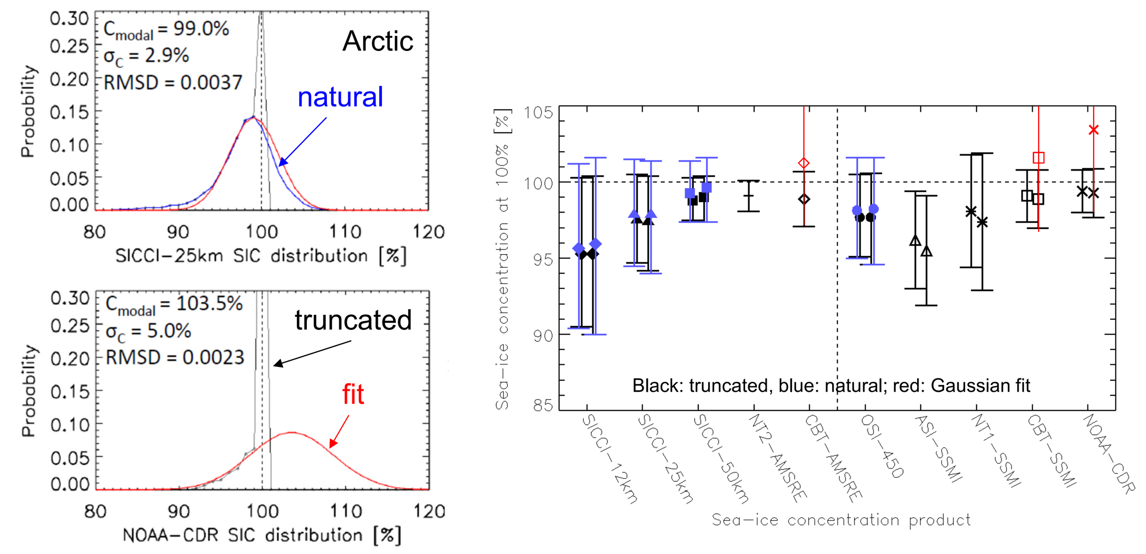
Actual brightness temperatures may vary around these tie points (right), resulting in retrieved SIC < 0% and > 100%.

Commonly, these SIC values are truncated, i.e. SIC < 0% is set to 0% and SIC > 100% is set to 100%, deteriorating the naturally retrieved SIC distribution at the two end-members (below for SIC = 100%).



Left panel) Grey symbols: actual Advanced Microwave Scanning Radiometer on EOS-Aqua brightness temperature observations over SIC = 0% (triangles) and SIC = 100% (disks) conditions. Red: H = open water tie point, red line intersecting H = open water line, A and D = sea-ice tie points, red line = line of 100% SIC (ice line). Retrieved SIC falls into range 0% to 100% between these lines (e.g. at point P) but is < 0% below the line through H and > 100% above the ice line.

Right panel) 2-D histogram of gradient ratio (GR) and polarization ratio (PR) observations in relation to the NASA-Team algorithm tie points (OW, FY and MY ←→ points H, A, and D in left panel) together with indications of SIC = 0% (at OW) and the ice line (connecting FY and MY) in red. Observations left of the ice line result in retrieved SIC > 100%.



Left two panels) SIC distribution at locations with ~100% SIC for two SIC products (ESA-CCI-25km, NOAA-CDR). Black: SIC truncated at 100%; blue: (SICCI-25km only): naturally retrieved SIC; red: Gaussian fit to SIC ≤ 99% (with given RMSD), extended to > 99% SIC. C_{modal}: modal SIC (=centre of Gaussian fit), σ_C: one standard deviation of the fit at C_{modal}. Right panel) Corresponding results summary for winters 2007-2015.

Not taking the SIC distribution around the end members 0% and 100% into account during product evaluation can result in under-estimation of product bias and standard deviation (left).

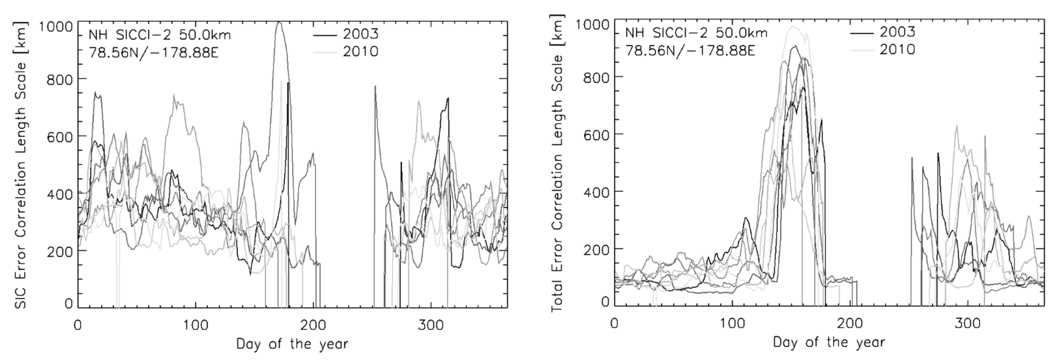
Error correlation length scales

Only few existing SIC products include per-grid cell retrieval uncertainty estimates based on physical principles and error propagation.

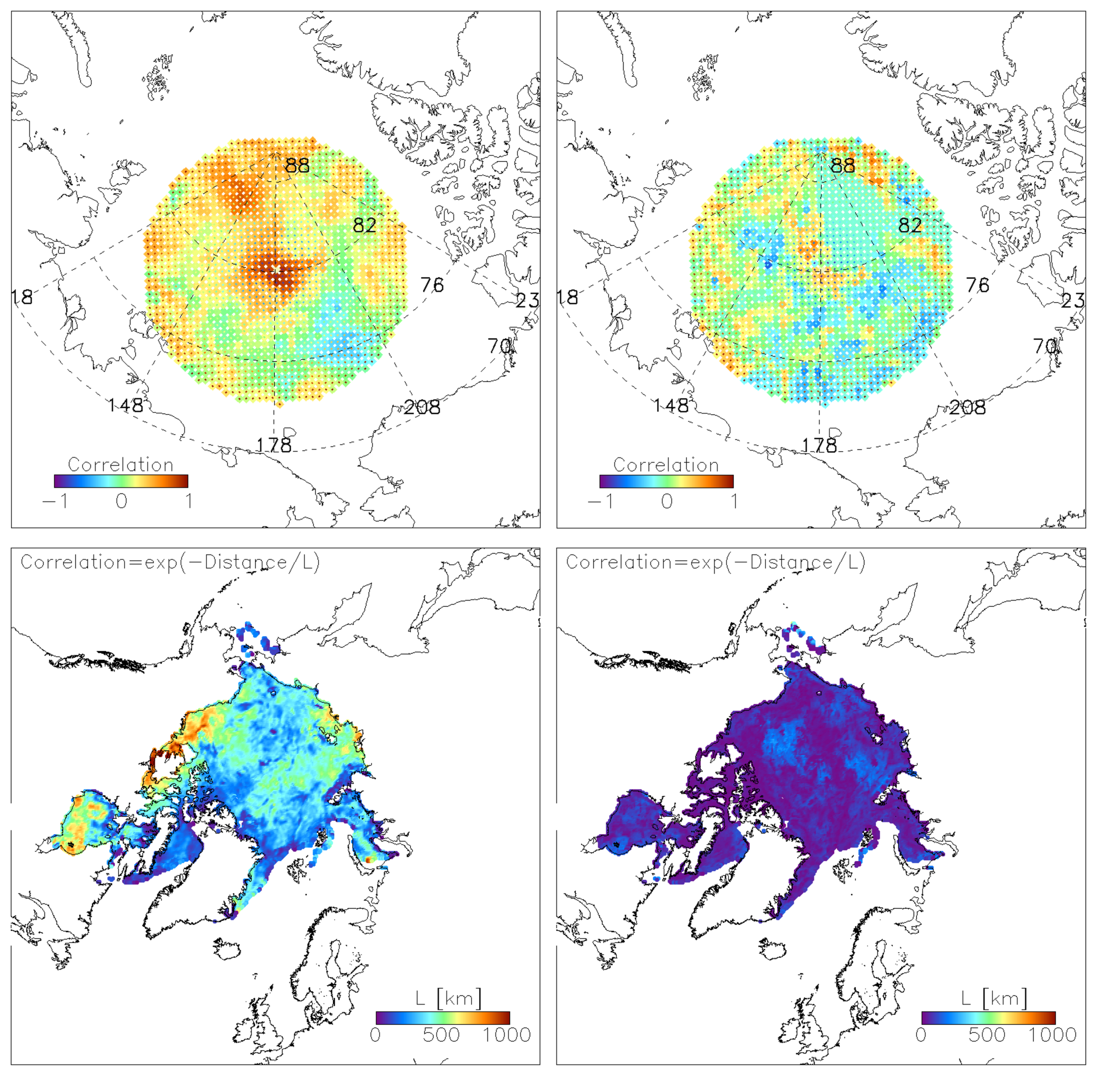
Such uncertainty estimates (named *total retrieval error*) contain sensor noise, tie point uncertainty, and gridding uncertainties but typically cannot quantify biases (named *SIC error*) due to, e.g., uncorrected weather influence or snow/ice property variations other than those represented by the tie points.

None of the SIC products includes information about spatiotemporal error correlations and correlation length scales.

Post-processing allows us to approximate these parameters (right) for SIC error (approximated from the SIC product) and total retrieval error (in the product), showing substantial inter-annual and seasonal variability (below).



Mitigating this knowledge gap in spatiotemporal error correlation in SIC – but also other products such as sea-ice thickness, snow thickness on sea ice, or sea-ice motion – is highly needed to compute reliable long-term trends of parameters describing the polar sea ice cover such as sea-ice area and volume including a credible uncertainty estimate.



Top: Correlation of 31-days stacks of the SIC error (left) and the total retrieval error (right) across a 1000 km radius disc around one grid cell in Jan. 26, 2010 for the Eumetsat OSI SAF OSI-450 SIC product.
Bottom: Resulting error correlation length scale maps for SIC error (left) and total retrieval error (right) for the same date and product.
Time series to the left are for the ESA-CCI 50 km SIC product for years 2003 to 2011 at the location shown in the top panels' centers.

Needs & Questions

- *Better understand summer-time SIC biases*. What are the primary sources of the biases? How can the biases be reduced or mitigated? Do we need to develop alternative retrieval methods, e.g. based on optical observations, and how do we evaluate these? How feasible is a switch from SIC to ISF during summer and how would this be perceived by the SIC product user community?
- *Complement SIC uncertainty information*. How can we represent environmental factors (snow / ice dynamic / thermodynamic metamorphism; weather effects) in the total retrieval error better? How are these environmental factors correlated? How do error correlations and their length scales differ between different SIC products? How can their routine processing be implemented into existing production chains?
- *Enhance quality of SIC uncertainty information*. What are the assumptions used in current SIC products? What is the quantitative impact of these assumptions on the SIC distribution and, especially, evaluation of SIC products at the end members of the natural SIC range?

Recommendations

- Enhance communication. Foster a dialogue about community needs for SIC product quality with special emphasis on a) summer-time biases and a switch to ISF, and b) SIC uncertainties and their spatiotemporal scales and correlations.
- Enhance development of alternative SIC products based on optical or active microwave satellite observations. Develop a strategy to quantitatively evaluate these with fiducial reference measurements.
- Improve representation of scale-dependency in SIC (and other sea ice parameters) evaluation efforts. Provide guidance on how different scales of influencing factors (e.g. local-scale deformation vs. large-scale melting) can be taken into account quantitatively.
- Increase number, accuracy, and representativeness of in situ observations of sea ice/snow surface type and status, ground- and air-borne microwave emissivity observations, as well as meteorological observations.
- Review and communicate current assumptions and their quantitative impact on SIC products and their quality assessment.
- Move away from generally truncated SIC distributions (to the range 0% to 100%) to improve the quality of uncertainty information provided for SIC products.

Useful links: https://nsidc.org ; http://osisaf.met.no/ ; http://esa-cci.nersc.no ; http://www.cen.uni-hamburg.de/en/icdc/
Data sources: SICCI-25km SIC: https://doi.org/10.5285/f17f146a31b14dfd960cde0874236ee5; SICCI-50km SIC: https://doi.org/10.5285/5f75fcb0c58740d99b07953797bc041e; OSI-450 SIC: https://doi.org/10.15770/EUM_SAF_OSI_0008 ;
NOAA-CDR SIC: https://nsidc.org/data/g02202/versions/4/ ; MODIS data: https://doi.org/10.1594/WDCC/MODIS_Arctic_MPF_V02 ; SIC correlation length scales: https://doi.org/10.25592/uhhfdm.10409 ; https://doi.org/10.25592/uhhfdm.10413 ; https://doi.org/10.25592/uhhfdm.10415