Towards 30 years of Arctic sea ice thickness

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Introduction

Sea ice is a key witness and driver of climate change. Sea ice extent evolution is widely studied and well identified contrary to its thickness. Nevertheless the thickness is a mandatory variable to fully understand the evolution of sea ice. Thin ice would be more sensitive to storms and will melt faster during spring time than thick ice. Sea ice area or extent products start in the 70's for both polar oceans, whereas no thickness product has been available before winter 2002/2003 for the Arctic [1,2,3] and 2010 for the Antarctic. The objective of this study was to retrieve sea ice thickness from the very beginning of the altimetry era : 1991 for both hemisphere and reach a 30 years record of sea ice thickness.

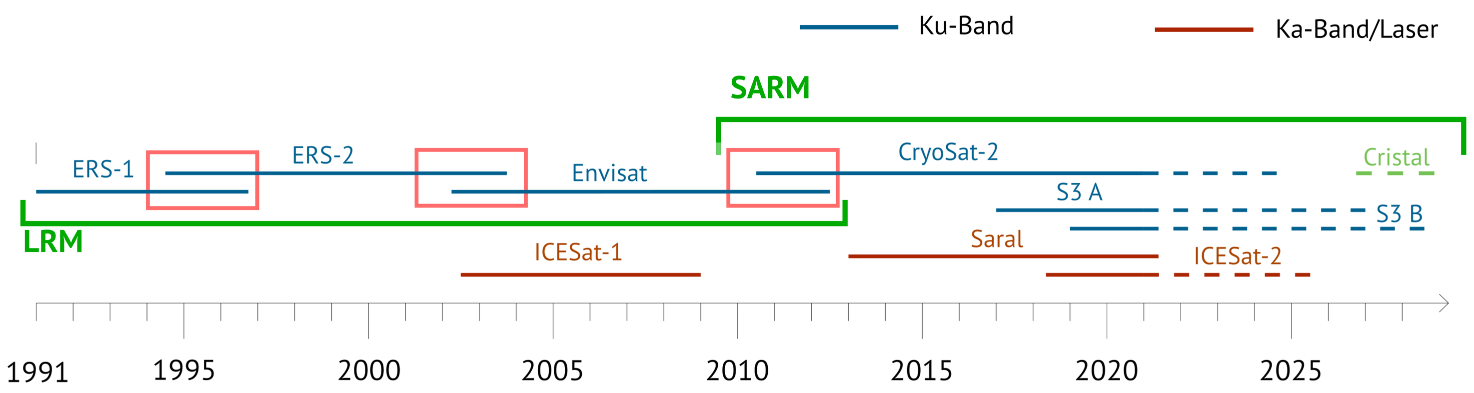

Figure 1 : Overview of Altimetry missions for sea ice observation

Methods

Sea ice thickness (SIT) can be retrieved using altimetry by making the difference between the height measured over the ice floes and over the leads (water) : the radar freeboard. The sea ice thickness can be deduced assuming hydrostatic equilibrium and by correcting the radar freeboard of the signal propagation slowdown within the snow pack.

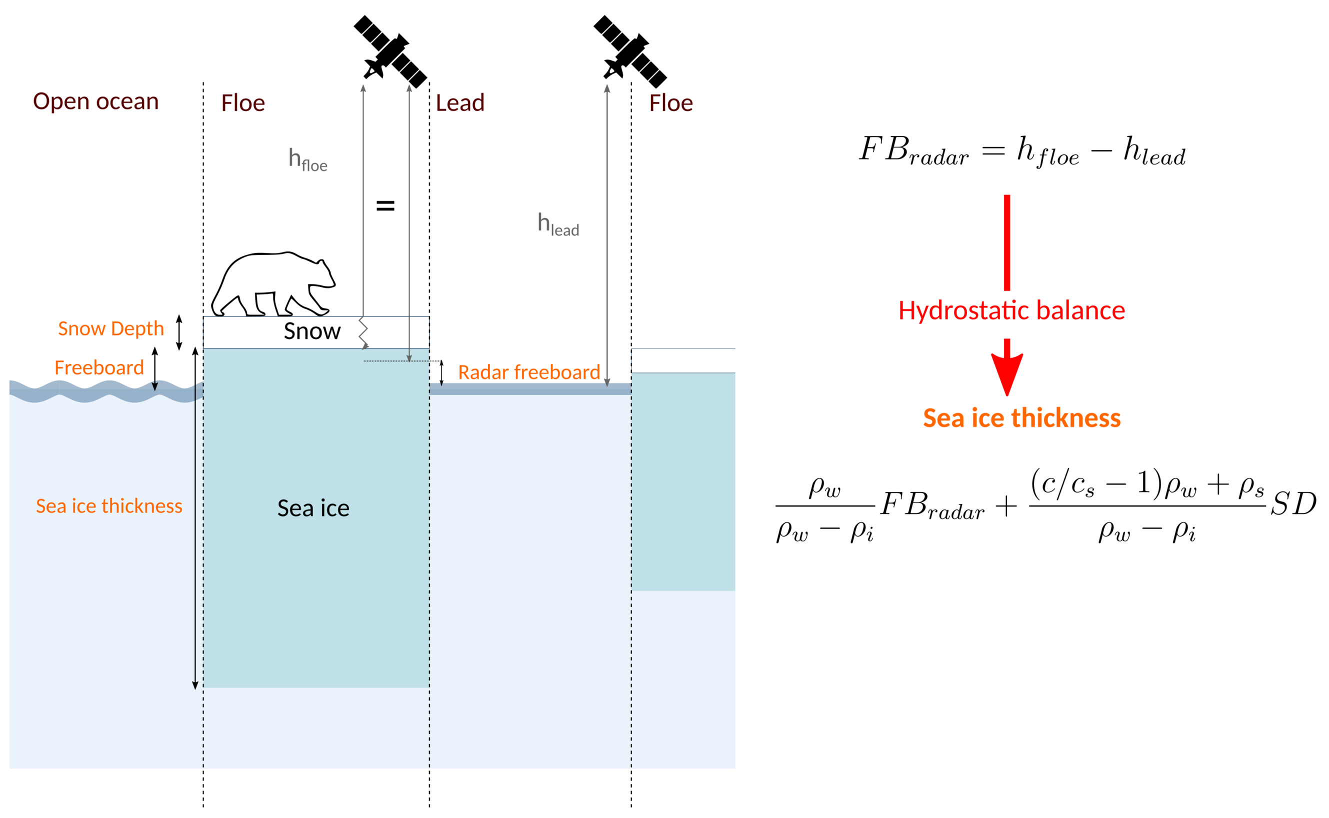

Figure 2 : Sea ice thickness retrieval from altimetry, freeboard methodology.

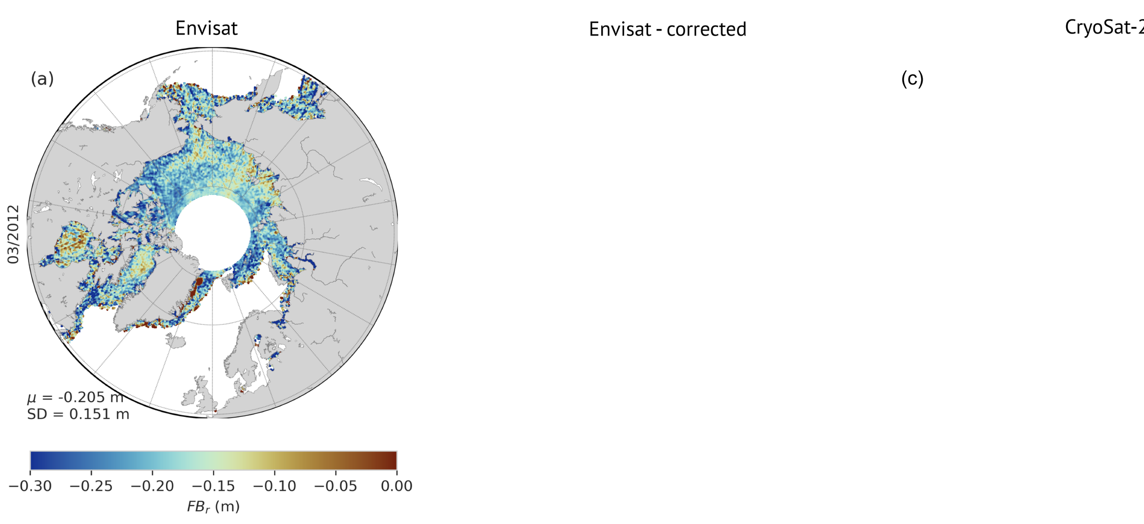

Figure 4 : Radar freeboard from (a) Envisat, (b) Envisat corrected and (c) CryoSat-2 for April 2012

Pulse Blurring issue :

The instabilities of the height anomalies (mainly over sea ice) are known as "pulse blurring" and are a consequence of the on-board tracker settings. This phenomenon occurs for both ERS-1 and ERS-2 missions [6]. The height tracking loop that aims at maintaining the individual echos in the acquisition window was unadapted for sea ice surface. This results in a changing tracker height during the consitution of the average echo and leads to blurred averaged waveforms.

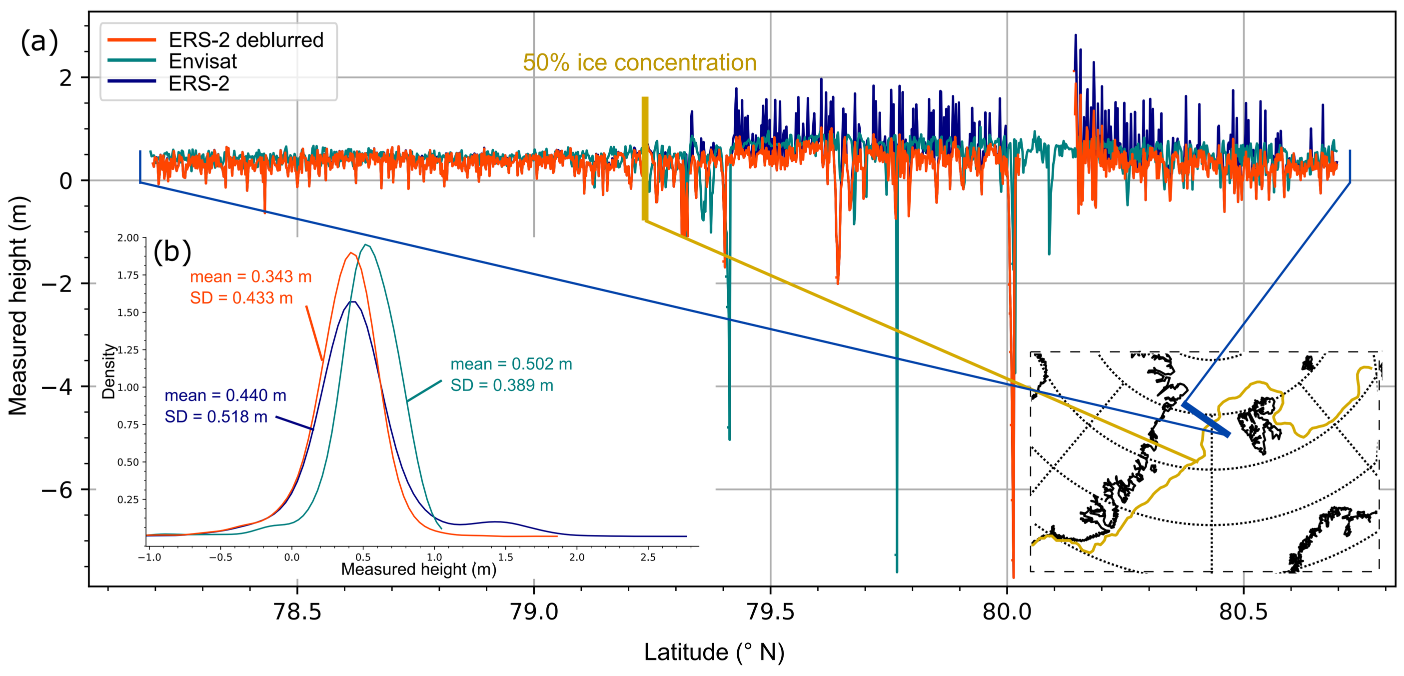

Figure 3 : Profiles of surface height anomaly over sea ice and ocean for pass 25 between 78° N and 81° N for Envisat in blue-green (cycle12), ERS-2 in blue and ERS-2 deblurred in orange (cycle 80). The red line represents the limit of 50 % concentration of sea ice, so as the limit between open ocean and an ice-covered area. The dark blue line shows the location of the pass between Svalbard Island and Greenland.

Impact of LRM on freeboard measurments :

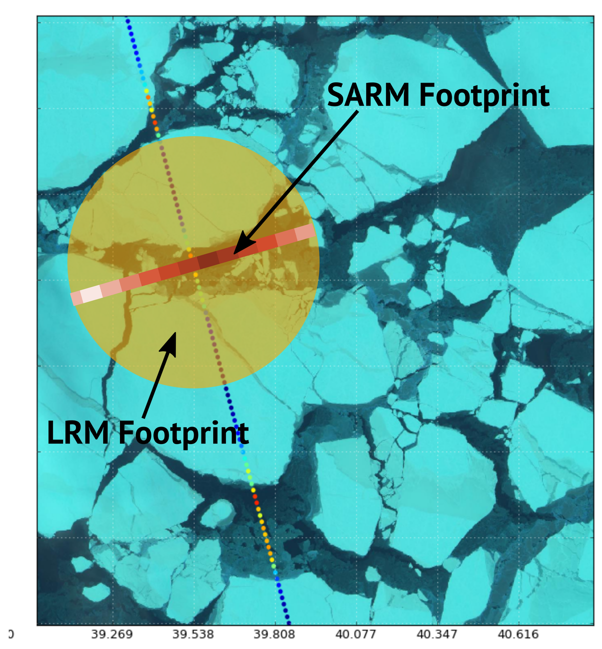

Figure 5 : Footprint size differences between SARM and LRM

The chosen calibration method is based on a neural network. It allows to manage nonlinearities and to correct the freeboard by taking into account parameters characterizing the state of sea ice (roughness, age etc.).

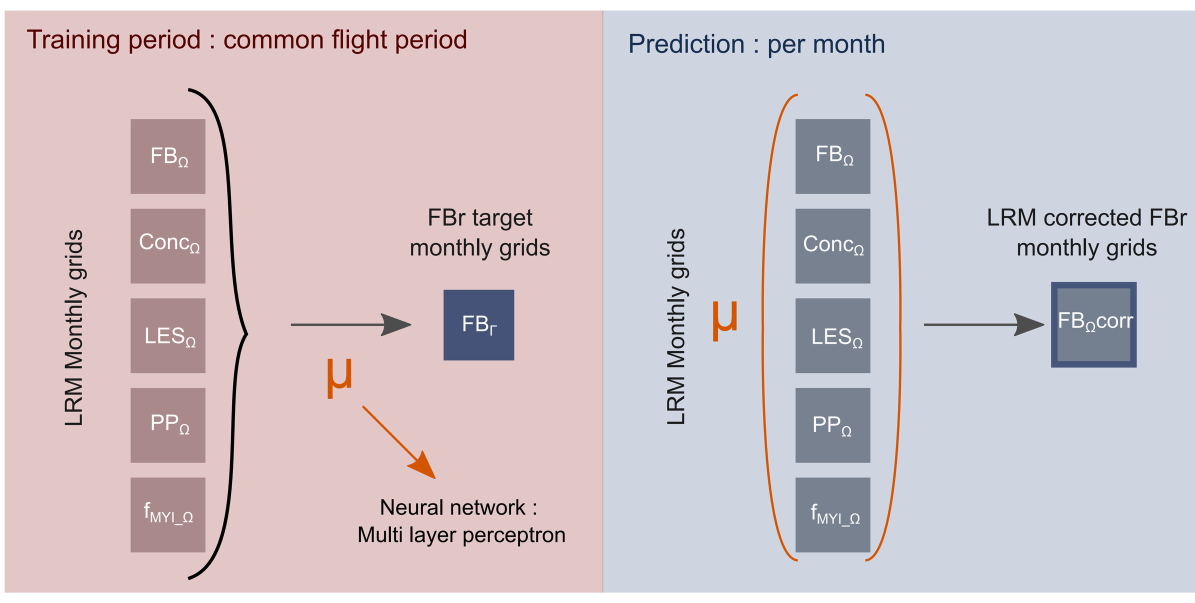

Figure 6 : Methodology of the LRM radar freeboard calibration

Sea ice thickness estimations became exploitable thanks to CryoSat-2 (2010) and ICESats missions and their reduced footprint size. Former altimeters with large footprint size such as Envisat, ERS-1/2 are more impacted by the surface roughness and measurements need to be corrected. The correction developed takes advantage of the mission-overlap periods between missions to calibrate past missions over recent ones using a neural network.

Uncertainties were computed using Monte Carlo methodology from the very begining of the processing chain until the basin-scale volume computation.

Results

Monthly radar freeboard from ERS-2 and Envisat have been corrected between 1995 and 2012 New arctic radar freeboards were validated using a dozen of independent datasets (Airborne data, ULS, Satellites, ...). Methodologies and validations are presented in [4]. To convert this monthly radar freeboard into a volume time series, the radar freeboard has been converted to sea ice thickness using snow depth from [5]. Monthly sea ice volume are obtained by multiplying the radar freeboard by the sea ice area into each grid cells and sum up over the whole grid for each month.

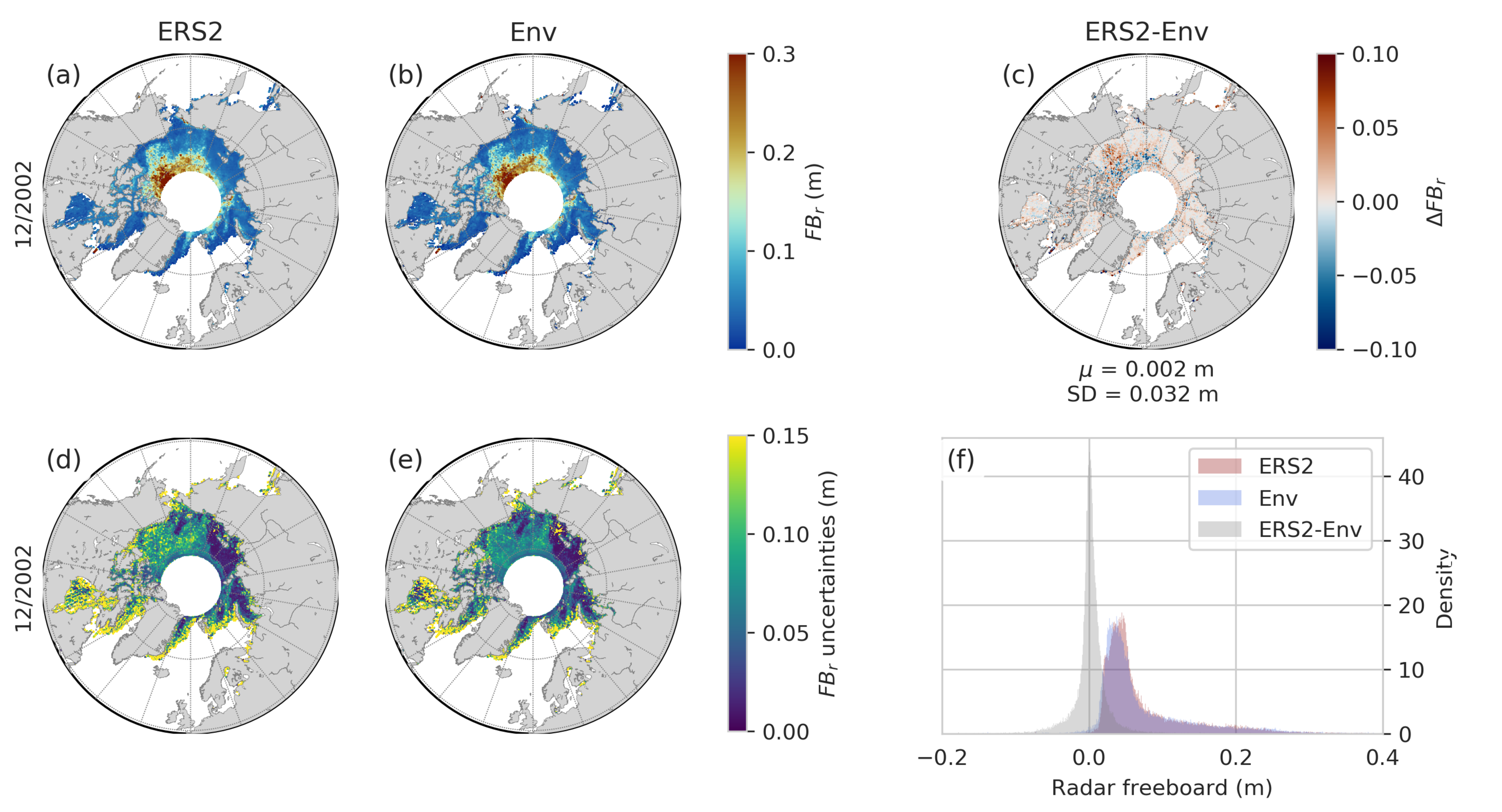

Figure 7 : Comparison of ERS-2 calibrated radar freeboard against Envisat reference for December 2002. The map (a) refers to ERS-2 aside with corresponding Envisat radar freeboard (b). Maps bellow (d), (e) are the related uncertainties. The right column presents differences freeboard maps (ERS-2 - Env), (c) and (f) is the distribution of ERS-2 FBr in red, Envisat FBr in blue and ΔFBr in grey

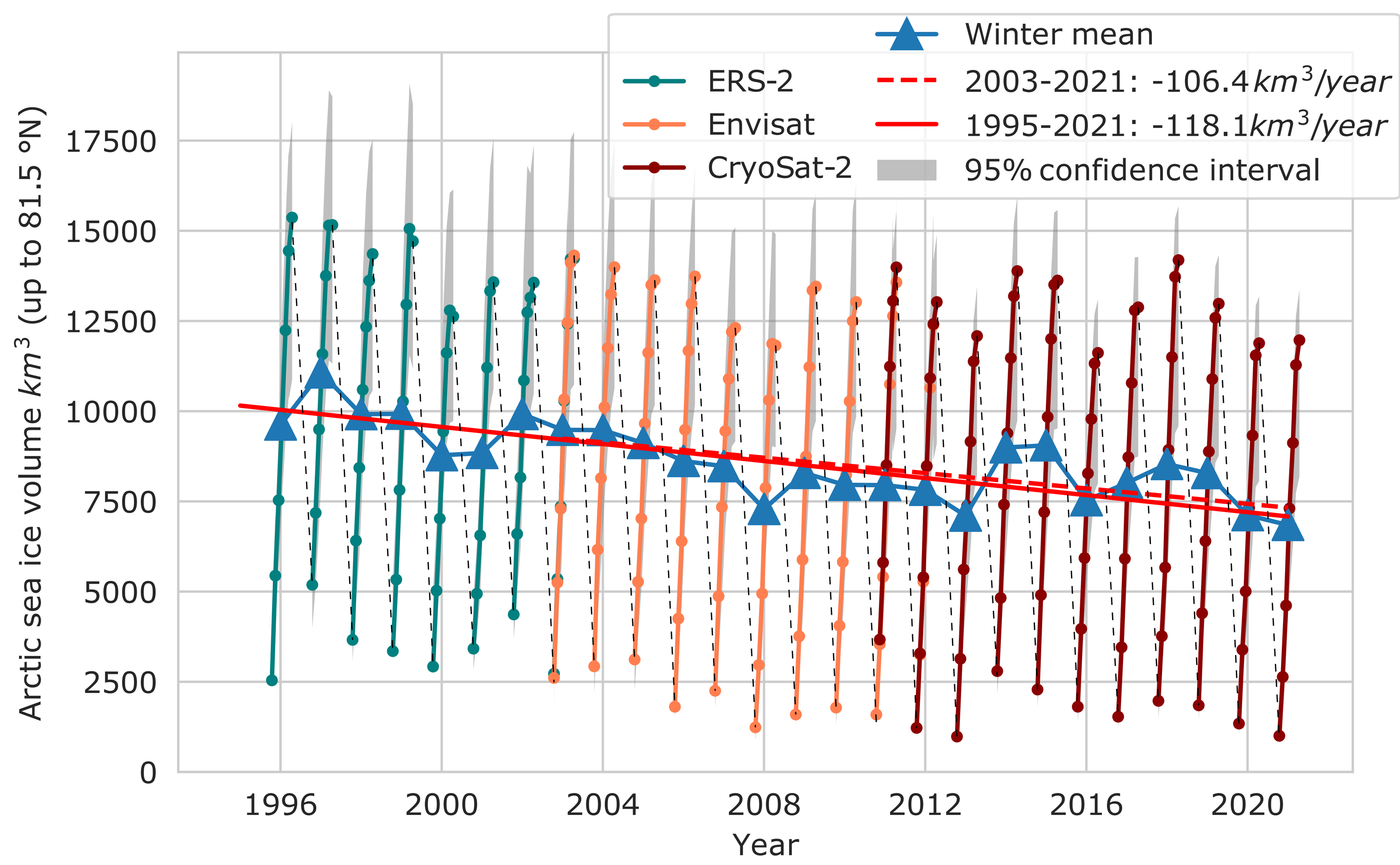

Figure 8 : Arctic sea ice volume between 1995 and 2021 during winter time. Dots represent monthly sea ice volume and triangles winter average sea ice volume. No data of thickness are available during summer time. Limitation at 81.5° N.

References

[1] Laxon, S. et al 2003 : High interannual variability of sea ice thickness in the Arctic region, 2003.
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[3] Paul, S. et al 2018: Empirical parametrization of Envisat freeboard retrieval of Arctic and Antarctic sea ice based on CryoSat-2: progress in the ESA Climate Change Initiative, The Cryosphere
[4] Bocquet et al 2022 : Arctic sea ice radar freeboard retreival from ERS-2 using altimetry : Toward sea ice ithickness observation from 1995 to 2021, The Cryosphere Discussion
[5] Stroeve et al 2020 : A Lagrangian snow evolution system for sea ice applications (SnowModel-LG): Part II—Analyses,
[6] Peacock & Laxon 2004 : Sea surface height determination in the Arctic Ocean from ERS altimetry

Conclusion

Link to the paper Bocquet et al 2022 (TC discussion) for more information

This work provides the very first long time series of sea ice thickness and volume for both polar oceans (see poster SC42022_003 : Sea ice thickness and volume from altimetry in the Antarctic for southern hemisphere). Measurements are provided with their uncertainties estimates following a Monte Carlo methodology. Uncertainty quantification is quite new for this kind of measurements. Future work will consist in studying sea ice changes of the past 30 years.

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This study was funded by a PhD CNES-CLS grant and in the framework of the FDR4ALT ESA project