Sea-ice thickness and volume from altimetry in the Antarctic over 2003-2020

F. Garnier, M. Bocquet, S. Fleury,
J. Bouffard, C. Boulard and F. Rémy

Email : florent.garnier@legos.obs-mip.fr

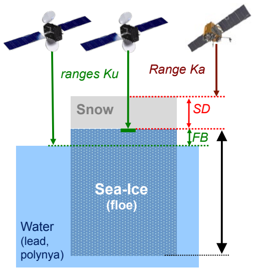
LIVING PLANET FELLOWSHIP
CRYOSPHERE

Introduction and Objectives:

Sea-ice plays a crucial role on processes such as the oceanic circulation and salinity or the ocean-atmosphere exchanges and is a key witness of the on-going climate change. The undergoing rapidly changing sea ice in response to global warming leads to significant changes in the polar regions that can feed back on the climate system both regionally and globally. Unlike for the northern hemisphere, sea ice **observations remain widely under-exploited in Antarctic**. The main reason is the **strong lack of in-situ data**, making satellite observations very difficult to validate. Then, except for a few studies such as *Zwally et al, 2008, Kurtz et al, 2012* or more recently *Paul et al, 2018,* sea ice thickness estimations in the Antarctic are nearly nonexistent and no valid sea ice volume estimations have yet been drawn. Using a comparable methodology as for the Artic, **we present in this poster new Sea Ice Thickness and Volume estimations in the Antarctic. Our results show that the strong sea ice extent decrease in 2016 was associated with an important thinning that continue thereafter.**
All the results presented here are published in Garnier et al, 2022: Latest Altimetry-Based Sea Ice Freeboard and Volume Inter-Annual Variability in the Antarctic over 2003–2020

1- Altimetric FB/SIT measurements

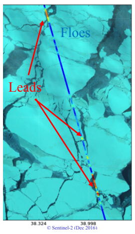
Sea ice thickness (SIT) measurement relies on the freeboard methodology (laxon et al,2003). The heights are calculated as the difference between the **floes** and the **leads** (SLA in sea ice fractures). The same methodology is used to derive snow depth Cryosat-2 Ku and Saral/Altika Ka radar frequencies *(see 3-)*.



4 steps:

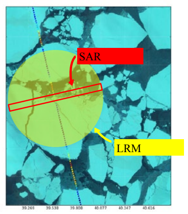
1. Leads/floes identification from pulse peakiness waveform classification.
2. 50% **TFMRA** retracking on leads and floes.
3. Freeboard and/or snow depth computation.
4. Conversion to SIT with the hydrostatic equilibrium (*equation below*).

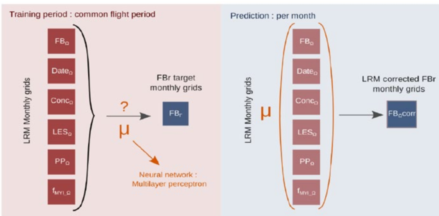
$$SIT = \frac{\rho_w}{\rho_w - \rho_i} FB + \frac{(1\text{-}c_s/c)\rho_w + \rho_s}{\rho_w - \rho_i} SD$$

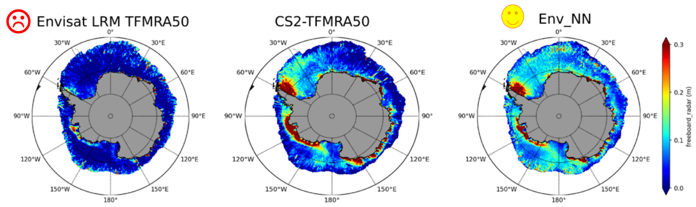


2- Envisat/Cryosat-2 radar freeboard in Antarctica

One of the most impacting **inter-mission bias** is the transition from Low Resolution Mode (LRM) to Synthetic Aperture Radar (SAR) altimetry (cf. figure below). To ensure the **Envisat/Cryosat-2** continuity, Envisat freeboards are **re-calibrated** on Cryosat-2 using a multi-layer perceptron neural network methodology (cf. figure below) developed by *Bocquet et al, 2022*. Using the data of the common winter 2011 (the training period), the calibration function characterizes, at each grid cell, the state of the sea ice from the Envisat inputs: LRM radar freeboard, date (month), sea ice concentration (SIC), leading-edge slope, pulse peakiness, and sea ice type.



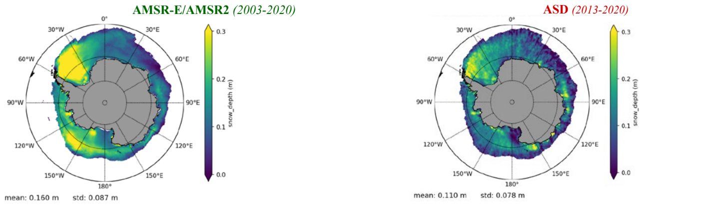




Maps of annual mean radar freeboard of Envisat LRM TFMRA-50 (left), CS2-TFMRA50 (middle) and the Envisat LRM data calibrated on CS2-TFMRA50 using the neuronal network approach (Env-NN, right), for the 2011 common flight period.

3 - Snow depth

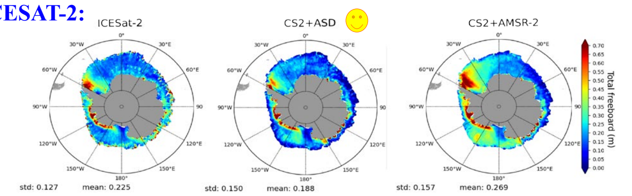
AMSR-E/AMSR2 *(2003-2020)* **ASD** *(2013-2020)*



Maps of the 2015 annual mean snow depth of: ***(Left)*** *the AMSR-E/AMSR-2 unified L3 daily data from the NSIDC (https://nsidc.org/data/AU_SI12/versions/1) and* ***(Right)*** *the Ka/Ku ASD product developed at the LEGOS (Garnier et al, 2021). In addition, an AMSR-E/AMSR-2 snow depth climatology developed at the University of Bremen (UB) and the Institute of Environmental Physics (IUP) in the context of the CCI, is used for 2003-2020 time series (cf. section 5)*

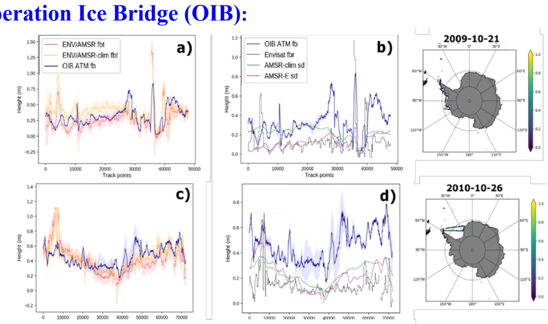
4 - Comparisons of total freeboard

ICESAT-2:



Maps of the annual mean total freeboards of ICESat-2, compared with CryoSat-2 estimations computed using ASD and AMSR-2 snow depth data, in average over 2019.

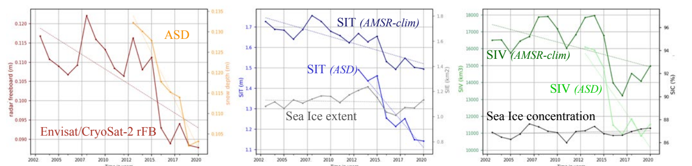
Operation Ice Bridge (OIB):



*Along-track comparison with the OIB ATM total freeboards of the 21 October 2009 (first line) and 30 October 2009 (second line) missions. The figures (**a**,**c**) compare with the calibrated Envisat total freeboards computed from AMSR-E (ENV-AMSRE) and AMSR-clim (ENV-AMSRclim). The figures (**b**,**d**) compare with the 2 AMSR snow depth solutions and the calibrated Envisat radar freeboards. The shaded zone refers to the uncertainty of the products.*

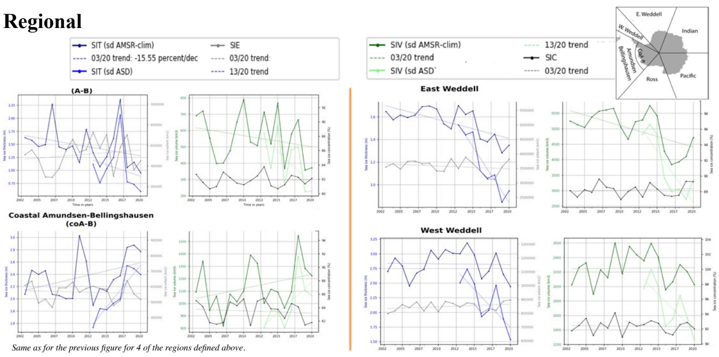
5 - Sea ice freeboard, snow depth, sea ice thickness and sea ice volume time series over 2003-2020

Global Antarctic



2003–2020 time series of radar freeboard (in red), snow depth (in orange), sea ice thickness (in blue) and volume (in green) for sea ice concentration higher than 75%. The NSIDC sea ice extent (in grey) and concentrations (in black) are also represented. The radar freeboards are those of the CS2-TFMRA50 dataset. All 2013–2020 series are computed using the ASD snow depth while the 2003–2020 series use the AMSR-clim. Trends are also indicated in dotted lines.

Regional



Same as for the previous figure for 4 of the regions defined above.

Main references:

-Bocquet., M et al, (2022). Arctic sea ice radar freeboard retrieval from ERS-2 using altimetry: Toward sea ice thickness observation from 1995 to 2021. *EGUsphere*, 1-33.
-Garnier, F., Fleury, S., et al, (2021). Advances in altimetric snow depth estimate using bi-frequency SARAL/CryoSat-2 Ka/Ku measurements. The Cryosphere, 1-40
-Guerreiro, K., Fleury, S.,et l (2017). Comparison of CryoSat-2 and ENVISAT radar freeboard over Arctic sea ice: toward an improved Envisat freeboard retrieval. *The Cryosphere*, *11*(5), 2059-2073.
-Kurtz, N. T., & Markus, T. (2012). Satellite observations of Antarctic sea ice thickness and volume. *Journal of Geophysical Research: Oceans*, *117*(C8).
-Paul, S., Hendricks, 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, 12(7), 2437-2460
-Petty, A. A., R. Kwok, M. Bagnardi et al, 2021.ATLAS/ICESat-2 L3B Daily and Monthly Gridded Sea Ice Freeboard, Version 2.
-Kwok, R., Kacimi, S., et al (2019). ICESat−2 surface height and sea ice freeboard assessed with ATM lidar acquisitions from Operation IceBridge. Geophysical Research Letters, 46(20), 11228-11236.
Turner, J. et al, (2017). Unprecedented springtime retreat of Antarctic sea ice in 2016. Geophysical Research Letters, 44(13), 6868-6875.

Acknowledgments:

We thank the **ESA living planet fellowship program**, the CNES TOSCA project and the ESA CSAO+ and Polar+ projects for their support.

6 - Conclusion

- **First nearly 20 years of sea ice thickness and volume dataset in the Antarctic.**
- **Over 2013–2020 period, radar freeboards and SIT decreased by about 40% per decade. The SIV decreased by about 60% per decade considering the whole Antarctic.**
- **The abrupt thinning from 2016 occurs in all regions except the Amundsen-Bellingshausen sea sector.**
- **Need for more validation data.**