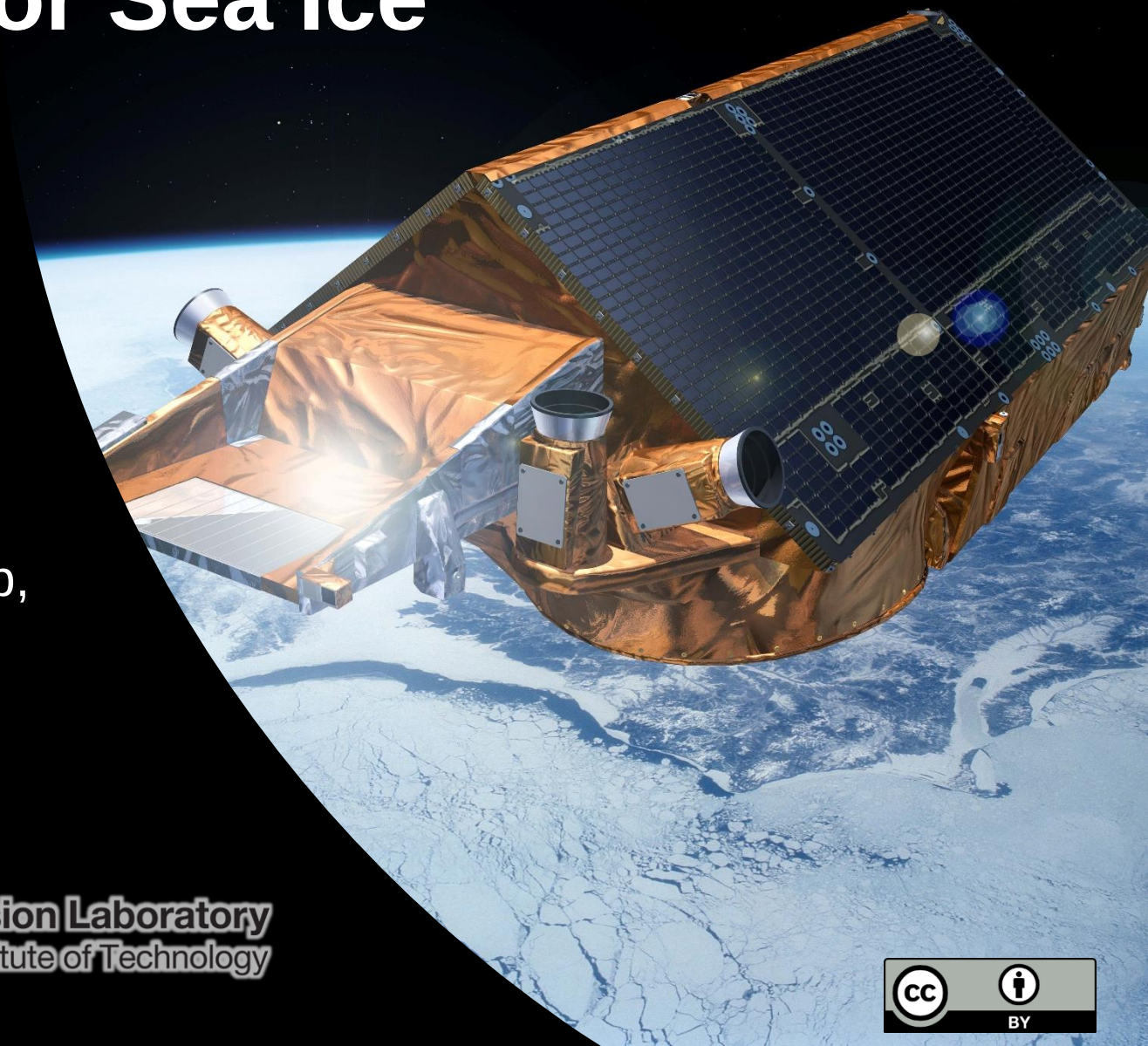
Multi-Peak Retracking of CryoSat-2 SARIn Waveforms: Potential for Sea Ice Applications



A. Di Bella, R. Kwok, T. Armitage, H. Skourup, R. Forsberg

DTU Space
National Space Institute

Jet Propulsion Laboratory
California Institute of Technology

Sea ice thickness from altimetry

$$T = \left(\frac{\rho_w}{\rho_w - \rho_i}\right) F + \left(\frac{\rho_s}{\rho_w - \rho_i}\right) h_s$$

s: snow
i: ice
w: water

$$T \approx F \cdot 10$$
$$\sigma_T \approx \sigma_F \cdot 10$$

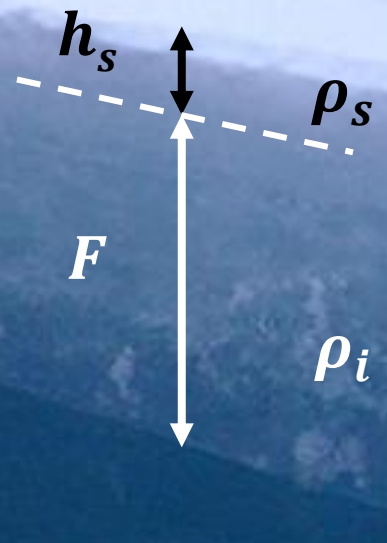
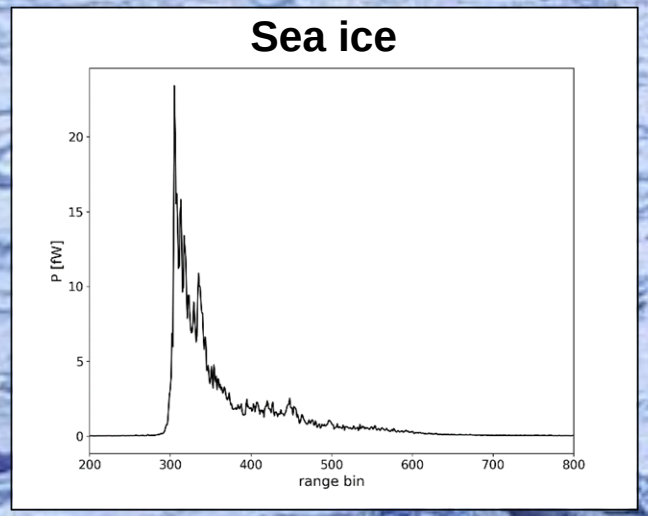
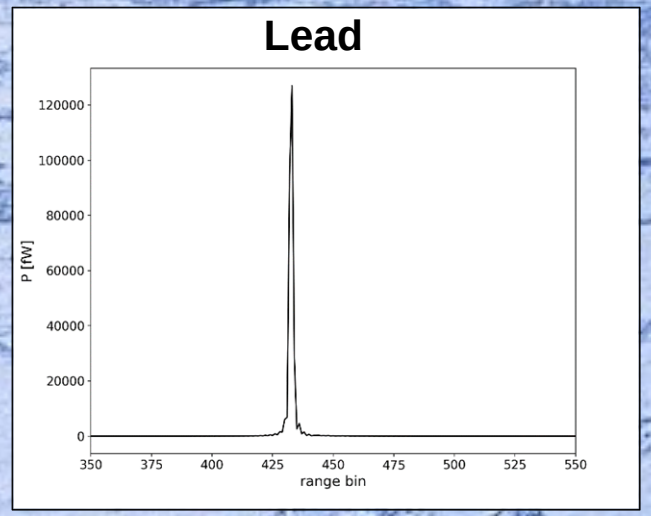
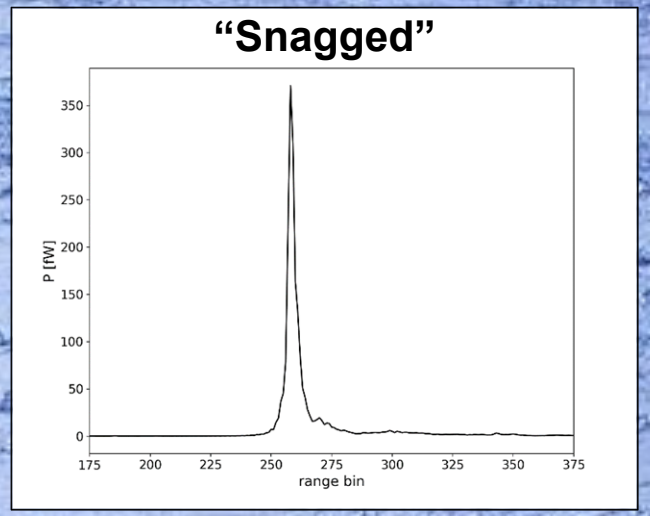


Image: Arctic Response Technology

Waveform classification and snagging



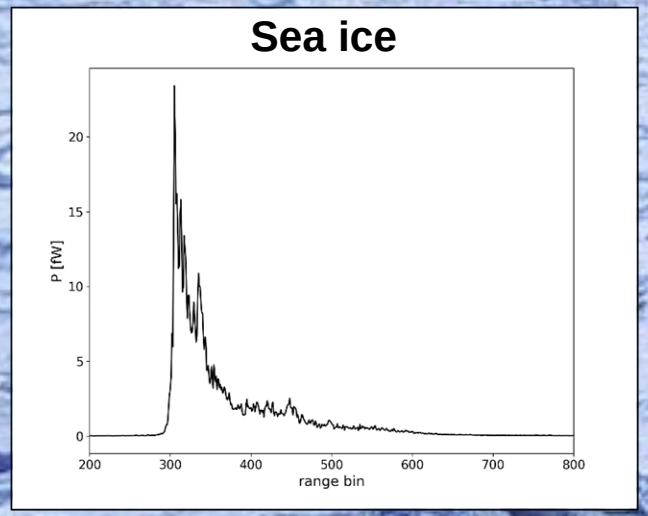


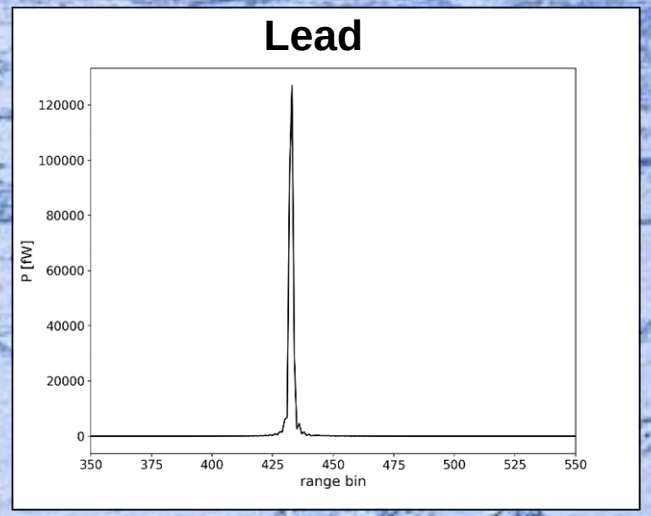


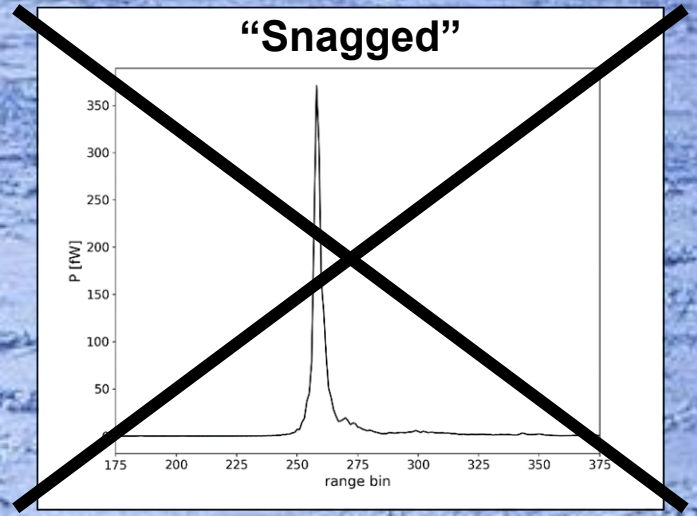
Satellite footprint

Image: James Hannigan/UCAR

Waveform classification and snagging





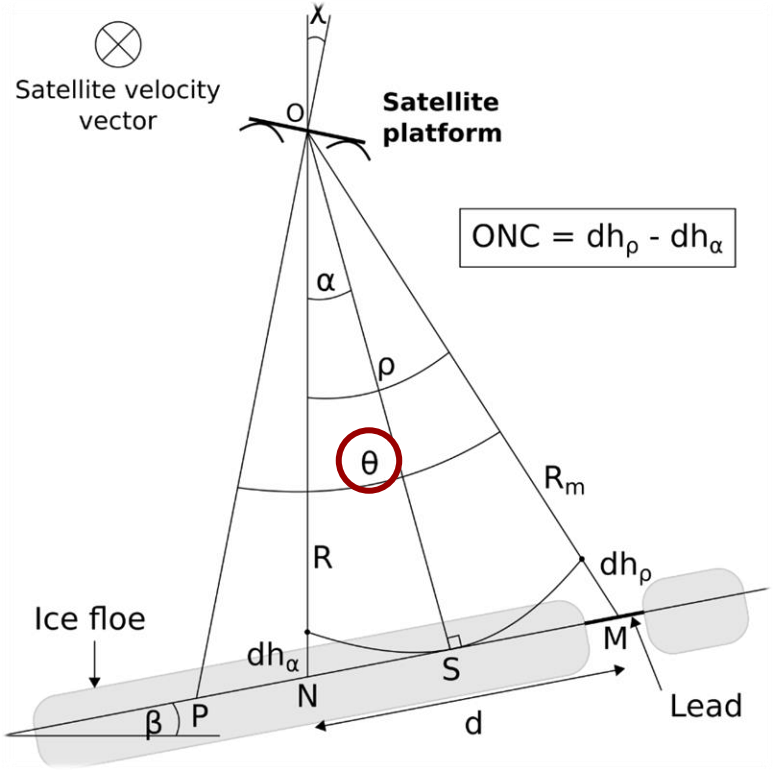


Large range error in regular altimetry!

← **Satellite footprint**

Image: James Hannigan/UCAR

CryoSat-2 SARIn mode



Armitage & Davidson, 2014 (modified)

$\theta, \chi \rightarrow$ measured by satellite

$$dh_\rho \simeq \eta R_m \frac{(\rho-\alpha)^2}{2}$$

$$dh_\alpha \simeq \eta R_m \frac{\alpha^2}{2}$$

$$ONC \simeq \frac{\eta R_m}{2}(\rho^2 - 2\rho\alpha)$$

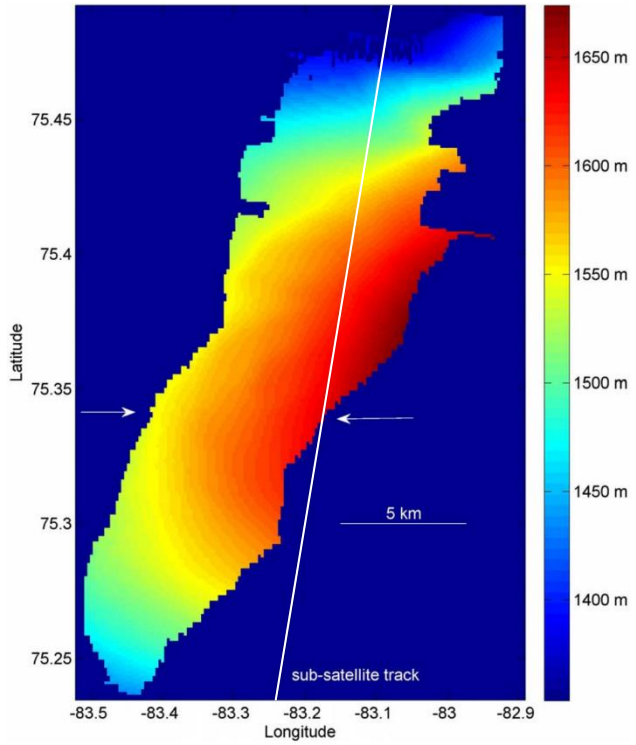
Off-nadir range correction (ONC) can be used to correct for the range overestimation caused by the strong reflection from off-nadir leads

↑ **lead waveforms (snagged)**

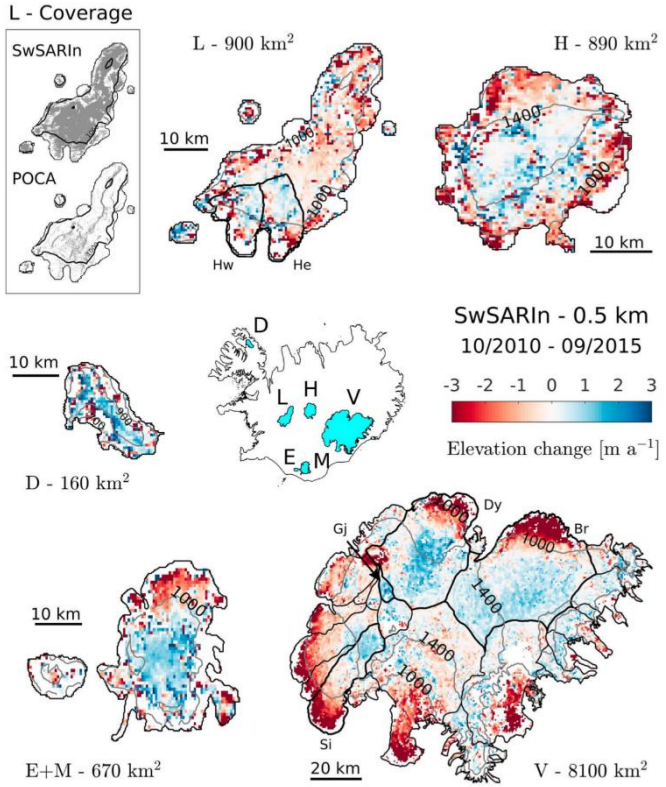
↓ **SSH uncertainty** (Armitage & Davidson, 2014)

↓ **F uncertainty** (Di Bella et al., 2018)

Can we do more with SARIn on sea ice?



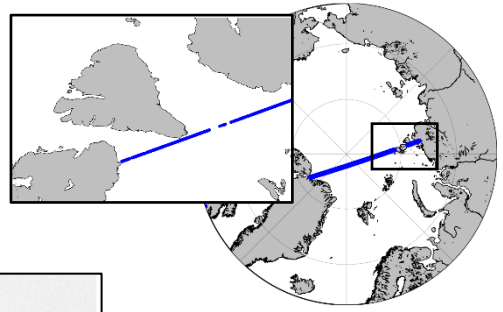
Gray et al., 2013

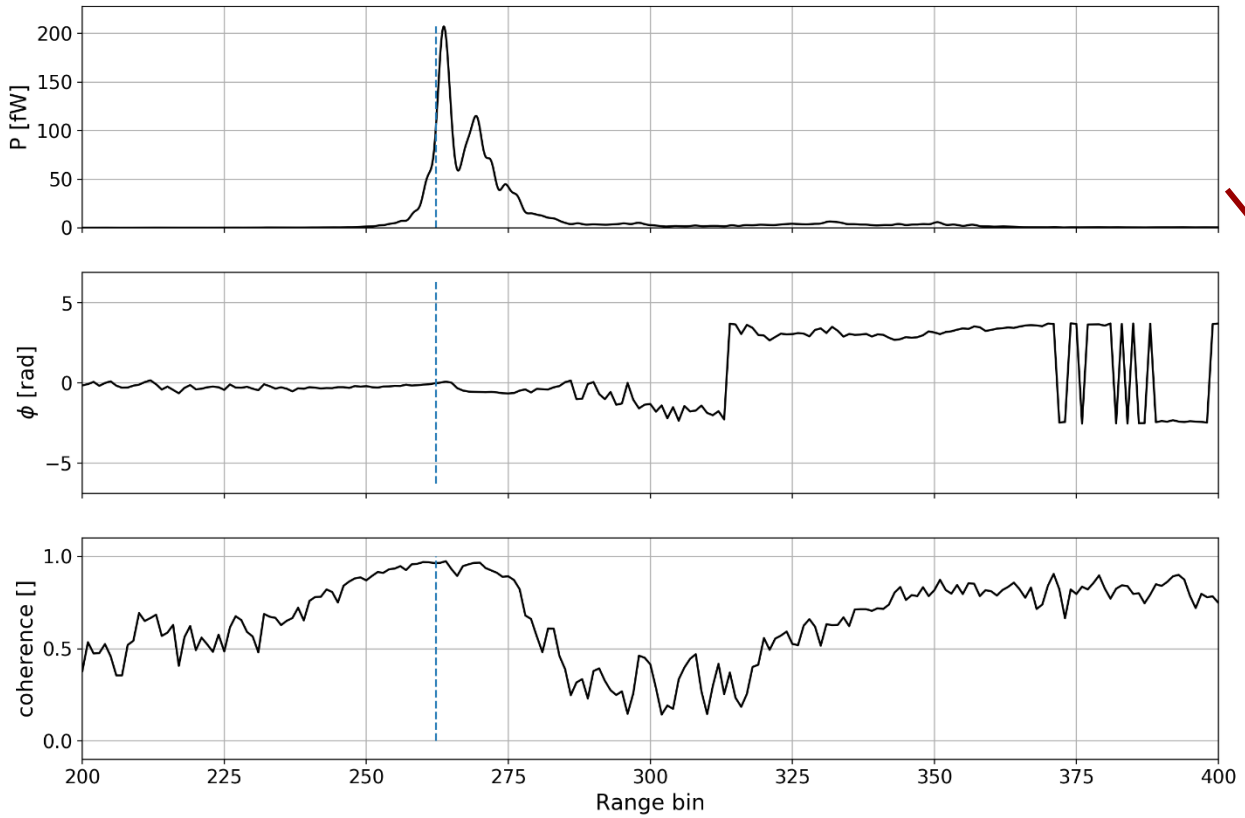


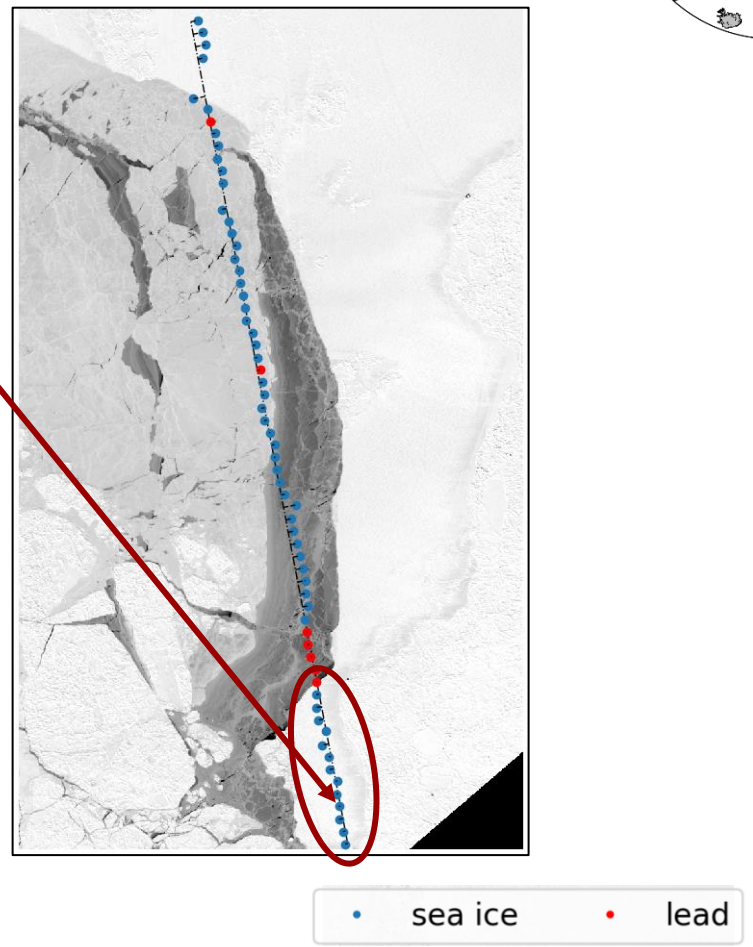
Foresta et al., 2016

Examples of SARIn swath processing over sloped land ice

Can we do more with SARIn on sea ice?

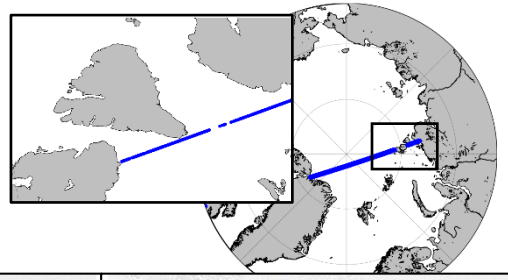


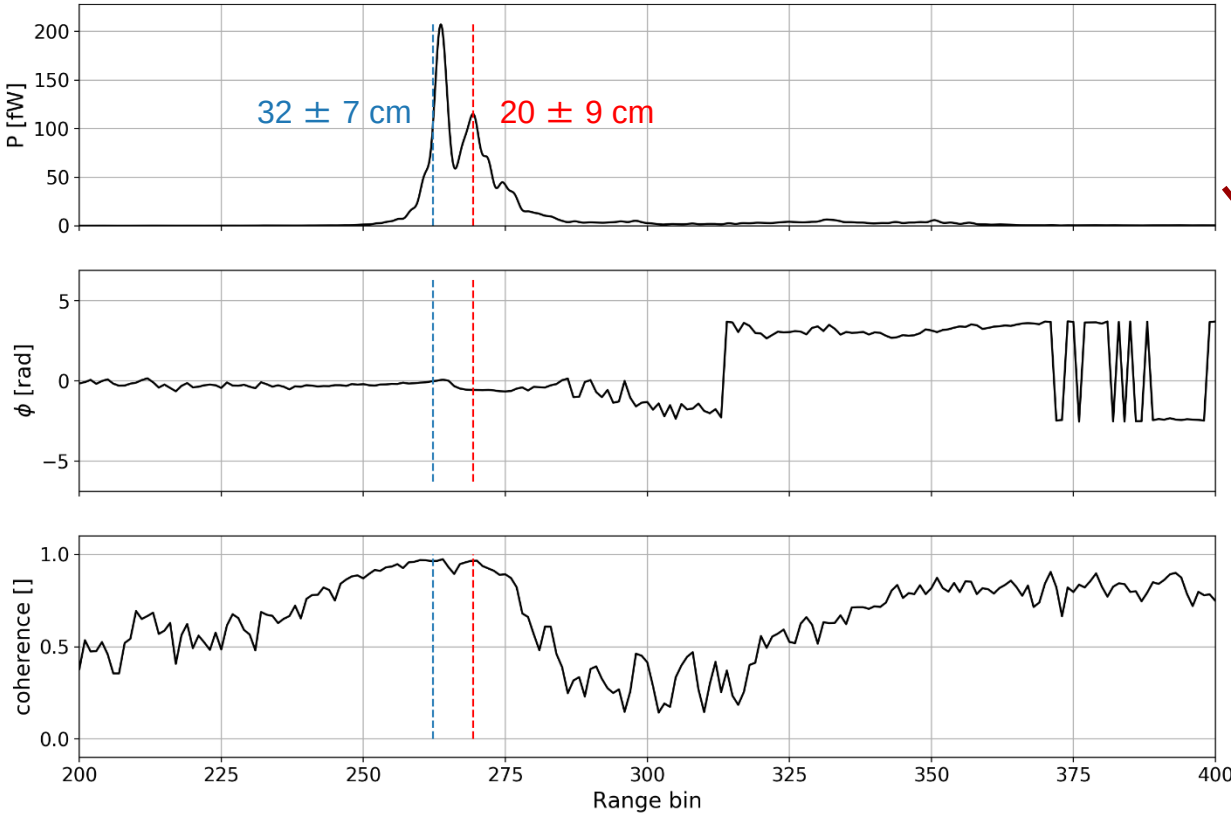


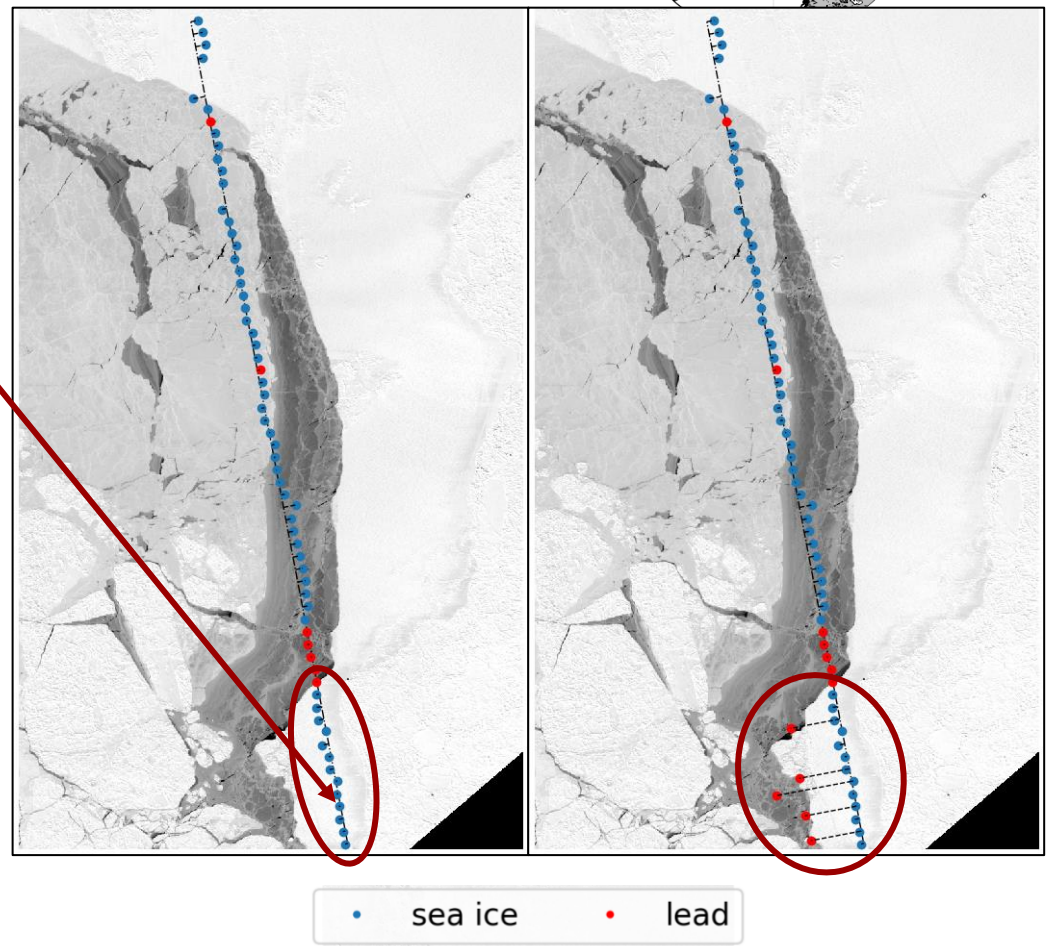


Di Bella et al., submitted

Can we do more with SARIn on sea ice?



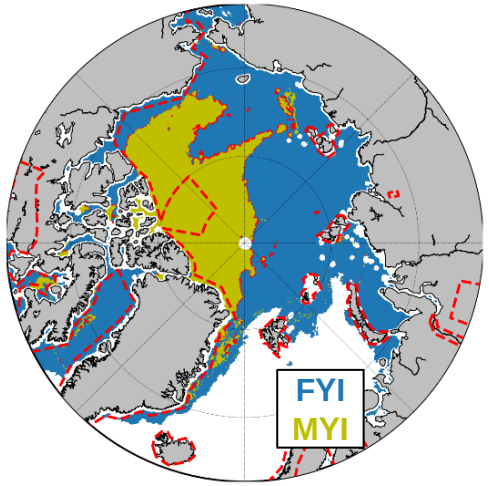




Di Bella et al., submitted

Multi-peaked waveforms in the SARIn Arctic

OSISAF ICE TYPE
15/03/2014



DTU + JPL Jet Propulsion Laboratory

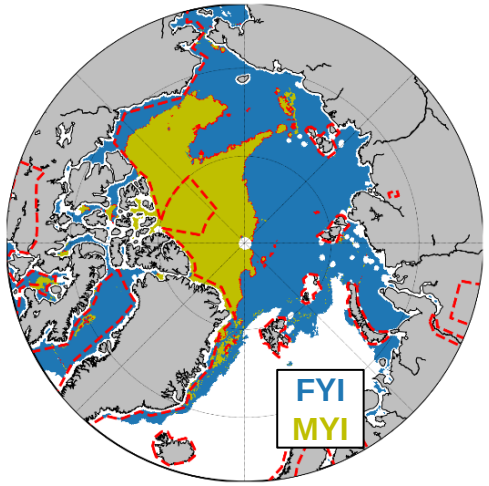
Multi-Peak Arctic
Sea Ice Processor
(**MPASIP**)

	$N_{MP\text{-}WF}$ / N_{WF}
FYI + MYI	14480 / 727357 (2%)
FYI	7542 / 356063 (2.1%)
MYI	6938 / 371294 (1.9%)

Number of multi-peaked waveforms

Multi-peaked waveforms in the SARIn Arctic (validation)

OSISAF ICE TYPE
15/03/2014



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Number of multi-peaked waveforms

DTU + JPL Jet Propulsion Laboratory

Multi-Peak Arctic Sea Ice Processor (**MPASIP**)

AWI

AWI CryoSat-2 sea ice product v2.1 (**AWI**)*

JPL Jet Propulsion Laboratory

R. Kwok (**JPL**)*

DTU

Arctic Sea Ice Processor (**ASIP**)*

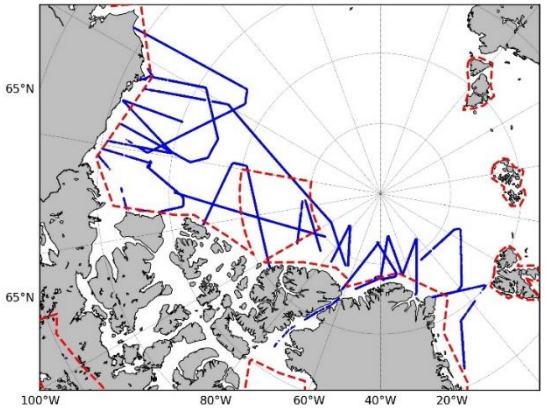
Operation IceBridge NASA

NASA Operation IceBridge IDCSI4 Quick Look (**OIB**)

* No phase information

Radar freeboard comparison

NASA OIB IDCSI4 QL **03/2014**



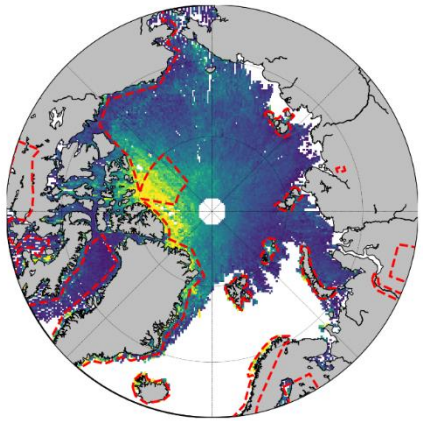
		MPASIP	AWI	JPL
All	r_{Fr}	0.62	0.65	0.59
	ΔF_r	0.08 ± 0.11	0.07 ± 0.10	-0.02 ± 0.07
	N_c	639	632	388
SARIn	r_{Fr}	0.35	0.32	0.41
	ΔF_r	0.15 ± 0.14	0.15 ± 0.12	-0.03 ± 0.07
	N_c	**148**	120	**29**

r_{Fr}: correlation CS2-OIB freeboard

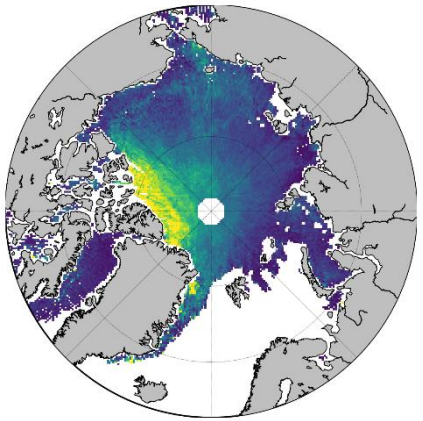
ΔF_r: deviation of CS2 freeboard from OIB

N_c: number of grid cells with valid freeboard used in the comparison

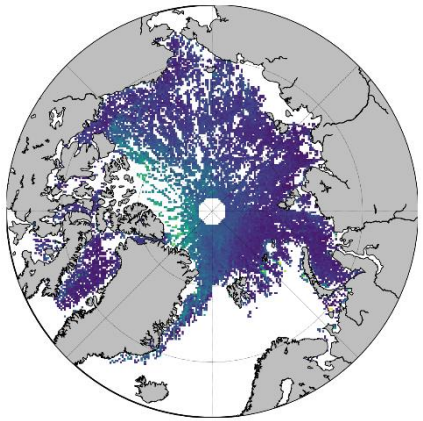
MPASIP

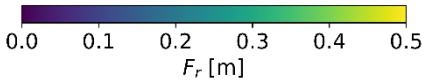


AWI



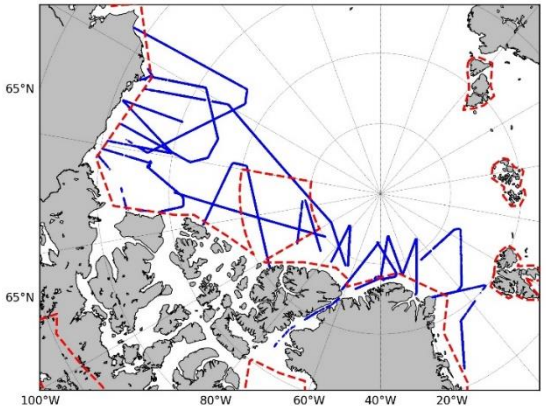
JPL





Radar freeboard comparison

NASA OIB IDCSI4 QL **03/2014**



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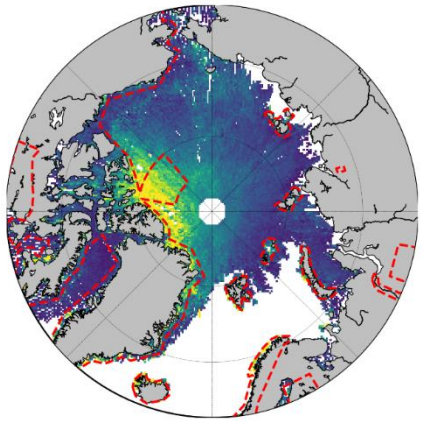
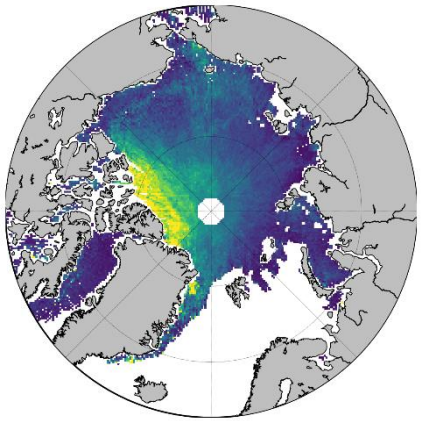
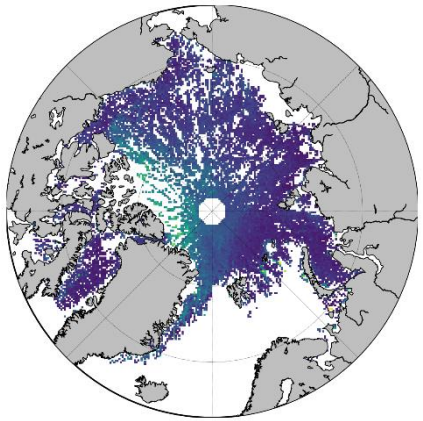
MPASIP

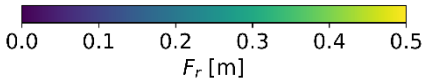


AWI



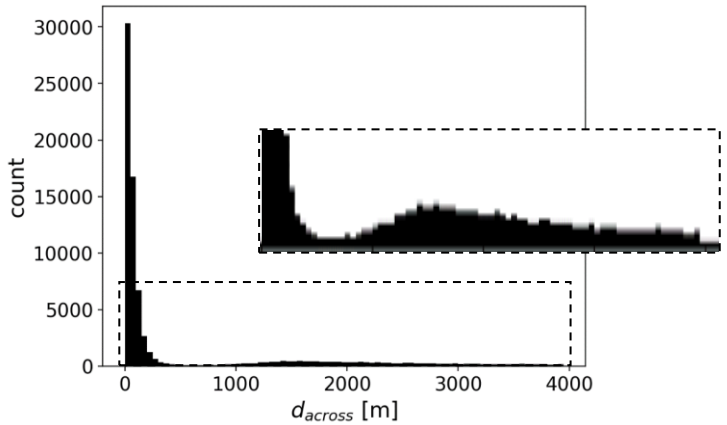
JPL



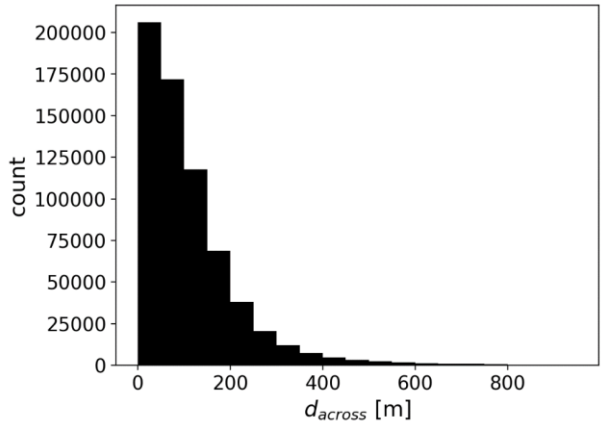


Across-track distance of returns

Leads



Sea ice

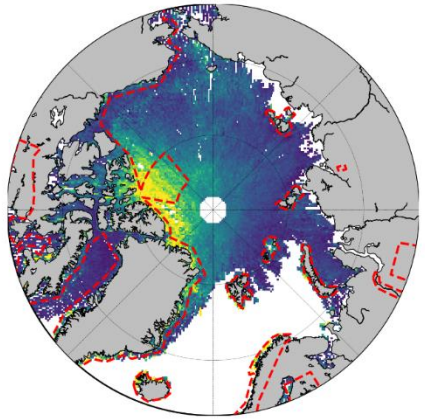


$\overline{d}_{across} \approx 110$ m

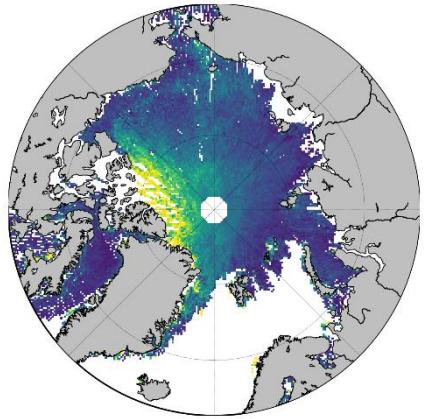
$\overline{ONC} \approx 2$ cm → Average sea ice elevation bias

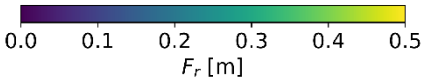
Radar freeboard uncertainty

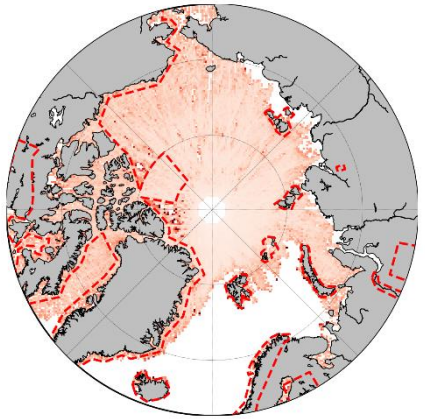
MPASIP

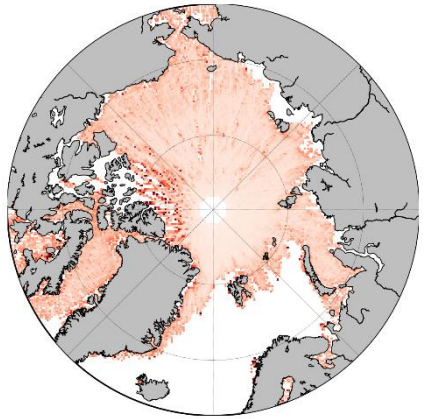


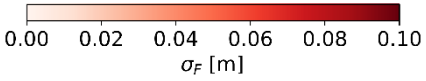
ASIP



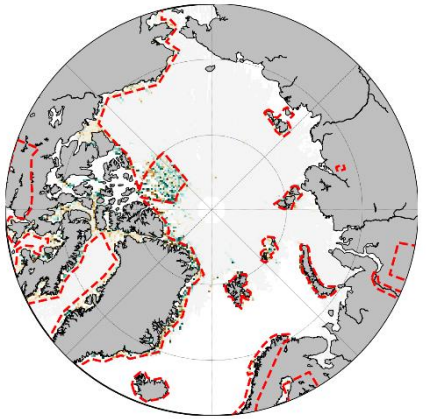


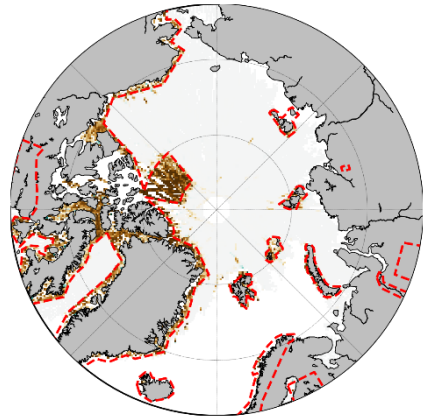


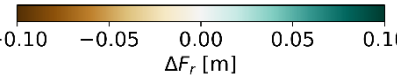


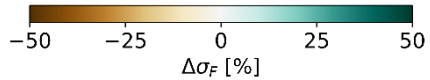


MPASIP - ASIP









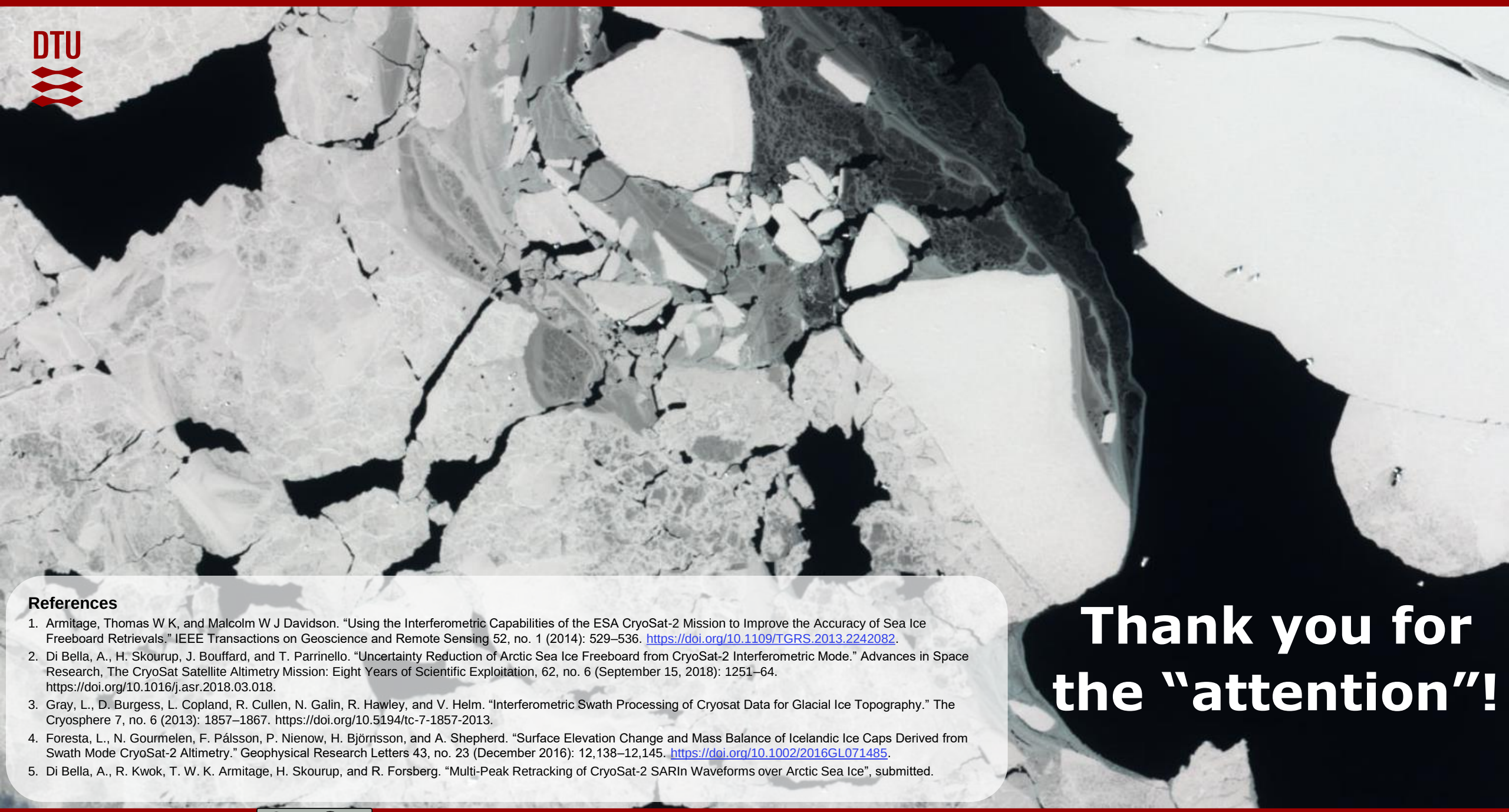
SARIn areas		MPASIP	ASIP	Variation
cm	$\overline{F_r}$	22.8	23.4	0.6
cm	$\overline{\sigma_F}$	2.3	3.6	**−36%**
	N_{lead}	80917	49602	**163%**
	N_F	507678	155989	**325%**

No average bias introduced by multi-peak retracking!

−20% Total SIT

Summary and conclusions

- It is possible to retrieve **more than one valid height measurement for some SARIn waveforms** over Arctic sea ice
- Multi-peak retracking delivers more lead measurements → **more freeboard estimates per grid cell**
- Including several peaks in the processing **doesn't affect mean freeboard** but it strongly **reduces the random uncertainty and increases spatial coverage**
- Good SARIn coverage of coastal areas (**improvement of tide models, MSS, geoid…**)
- The 2% of multi-peaked waveforms in the Arctic…is actually **~15%!** Work is in progress to include even more
- Potential for **Antarctic sea ice estimation** (fragmented sea ice cover favour off-nadir scattering)
- Design of future polar radar altimetry candidate missions should strongly consider SARIn acquisitions over entire polar regions (CRISTAL, …)



Thank you for the “attention”!

References

1. Armitage, Thomas W K, and Malcolm W J Davidson. “Using the Interferometric Capabilities of the ESA CryoSat-2 Mission to Improve the Accuracy of Sea Ice Freeboard Retrievals.” IEEE Transactions on Geoscience and Remote Sensing 52, no. 1 (2014): 529–536. https://doi.org/10.1109/TGRS.2013.2242082.
2. Di Bella, A., H. Skourup, J. Bouffard, and T. Parrinello. “Uncertainty Reduction of Arctic Sea Ice Freeboard from CryoSat-2 Interferometric Mode.” Advances in Space Research, The CryoSat Satellite Altimetry Mission: Eight Years of Scientific Exploitation, 62, no. 6 (September 15, 2018): 1251–64. https://doi.org/10.1016/j.asr.2018.03.018.
3. Gray, L., D. Burgess, L. Copland, R. Cullen, N. Galin, R. Hawley, and V. Helm. “Interferometric Swath Processing of Cryosat Data for Glacial Ice Topography.” The Cryosphere 7, no. 6 (2013): 1857–1867. https://doi.org/10.5194/tc-7-1857-2013.
4. Foresta, L., N. Gourmelen, F. Pálsson, P. Nienow, H. Björnsson, and A. Shepherd. “Surface Elevation Change and Mass Balance of Icelandic Ice Caps Derived from Swath Mode CryoSat-2 Altimetry.” Geophysical Research Letters 43, no. 23 (December 2016): 12,138–12,145. https://doi.org/10.1002/2016GL071485.
5. Di Bella, A., R. Kwok, T. W. K. Armitage, H. Skourup, and R. Forsberg. “Multi-Peak Retracking of CryoSat-2 SARIn Waveforms over Arctic Sea Ice”, submitted.