Altimetry mission performances over lake Vostok Antarctica: Cryosat-2, AltiKa and Sentinel-3A

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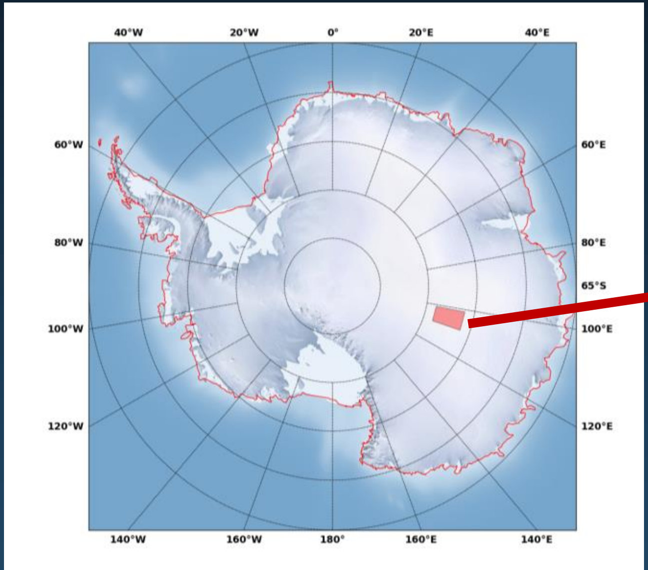
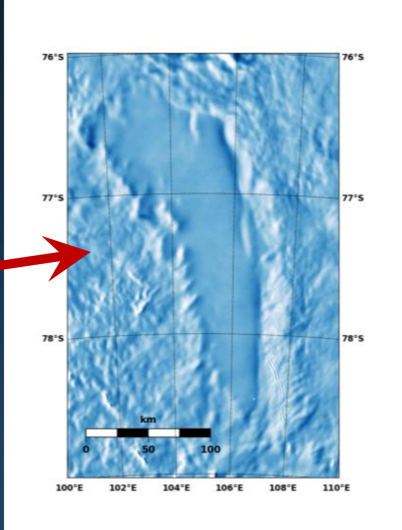
Introduction - Context

- Several altimetry missions are currently observing polar ice sheets with different modes and frequency bands: **CryoSat-2 LRM & SARIn Ku** / **AltiKa LRM Ka** / **Sentinel-3AB SAR Ku**

- This presentation briefly shows results from a 2017 study: a performance assessment of radar altimetry over Antarctica, with acquisitions made in **LRM Ku** / **LRM KA** / **SAR Ku** over lake Vostok by comparison to GNSS & ICESat (to be updated with ICESat-2)

Lake Vostok calibration site





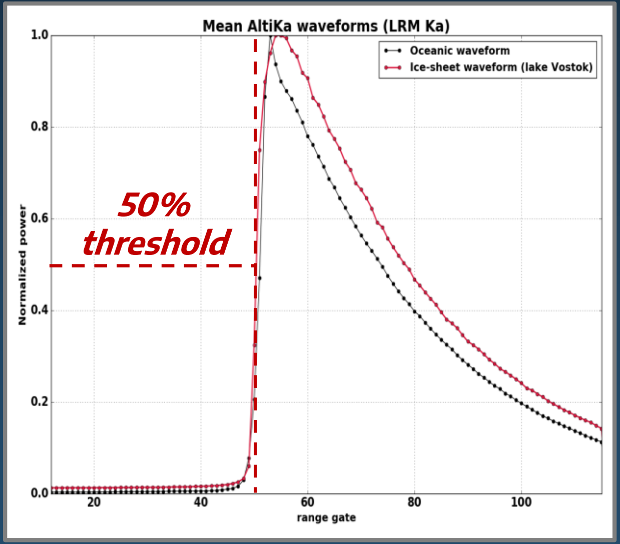
MODIS image of the lake Vostok

Flat surface (0.025% slope => ~2cm slope induced error), surface stable over time:
Lake Vostok is an excellent calibration site for radar altimetry.

Waveform retracking

- In this study A **Threshold Peak Retracker (TPR)** is chosen to estimate the altimeter range (similar approach than Helm et al. [2014]). In summary, retracking epoch is estimated at "*WF max * Threshold*".

- Retracking threshold are chosen to attempt an estimation of surface elevation at snow/air interface:



AltiKa LRM Ka: Volume scattering has no "visible" impact on the leading edge. Retracking point is positioned at mid-power (**50%**, same as ocean)

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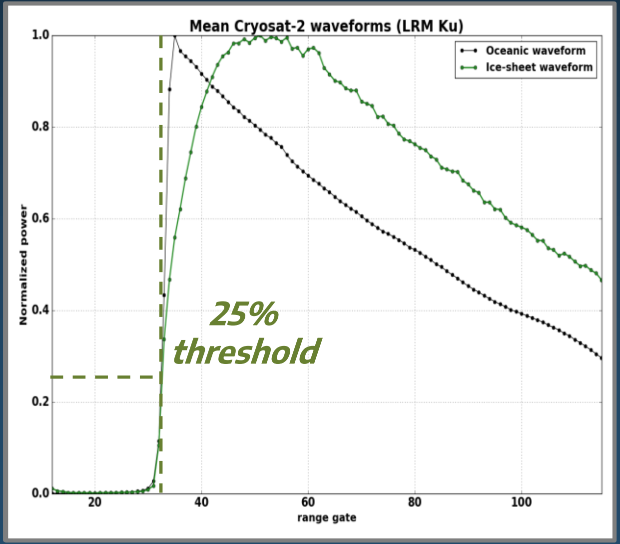

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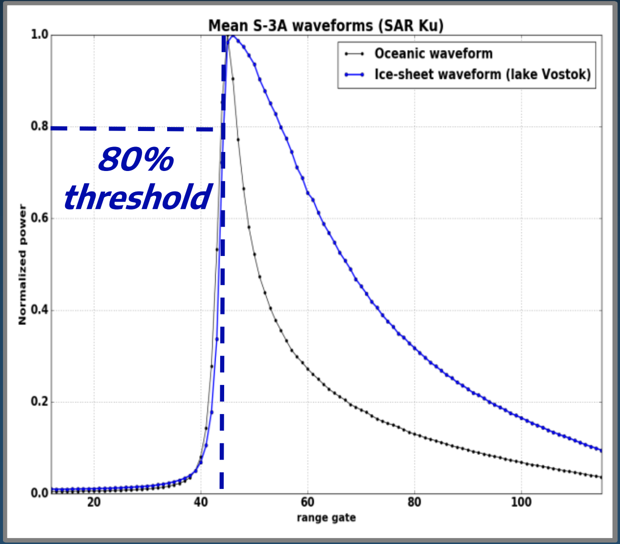

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Sentinel-3A SAR Ku: Leading edge looks non-sensitive to volume scattering, we choose **80%**, same threshold as Ocean. *We also estimate surface elevation from PLRM acquisitions with a* ***25%*** *threshold.*

Median bias and STD between altimetry and GNSS/ICESat at crossovers

		Altika LRM Ka (50% threshold)	Cryosat-2 LRM Ku (25% threshold)	Sentinel-3A PLRM Ku (25% threshold)	Sentinel-3A SAR Ku (80% threshold)
GNSS (~200 Xovers)	Median bias (cm)	-22.6	-27.6	-22.2	-21.1
	STD (cm)	*13.2*	*16.3*	*17.3*	*22.6*
ICESat (~400 Xovers)	Median bias (cm)	-25.2	-24.7	-20.8	-18.9
	STD (cm)	*8.4*	*14.3*	*15.2*	*19.9*

Altimetry data acquired from May 2016 to April 2017.

- The retracking thresholds chosen provide a vertical alignment within ~5cm between the 3 missions
- **With these retracking thresholds** altimetry underestimates surface elevation from 20cm to 25cm compared to GNSS and ICESat estimations. ***=> Signal penetration into the snowpack (volume scattering)***
- Sentinel-3A SAR mode has the lowest precision due to the high retracking threshold position on the leading edge: 80% (more sensitive to speckle noise and volume scattering)
- **AltiKa is the most precise,** even if retracking threshold (50%) is higher compare to (P)LRM Ku (25%)
- **Seasonal surface elevation variations have been noticed** over lake Vostok (**artificial** variations due to surface/snow change, investigated in Lacroix et al. [2009]). Even with the 25% low retracking threshold in (P)LRM. More important variations in Ku compared to Ka.

Comments / open questions

- **Similar analyses to be performed outside lake Vostok using ICESat-2 acquisitions**. But slope induced error adds up (uncertainty in the relocation)

- **How to efficiently use dual CRISTAL Ku/Ka measurements over ice sheets ?** *=> Potential to discriminate and estimate snow parameters from the waveforms (see G.Picard presentation)*

- What is the best approach to remove impact of volume scattering in the radar altimetry elevations ? During the L2 retracking processing ? And/or with an additional correction after retracking ?

- **Recent high resolutions DEMs from stereographic images must improve the measurement retracking & relocation algorithms** (REMA, ArcticDEM). *Future studies planned by CLS/CNES*

- **Continuity between LRM (historical) & SAR/SARIn (future?) to be ensured !** + consistency in the dual-band Ku/Ka estimations**.** Retracking solutions must account for these requirements

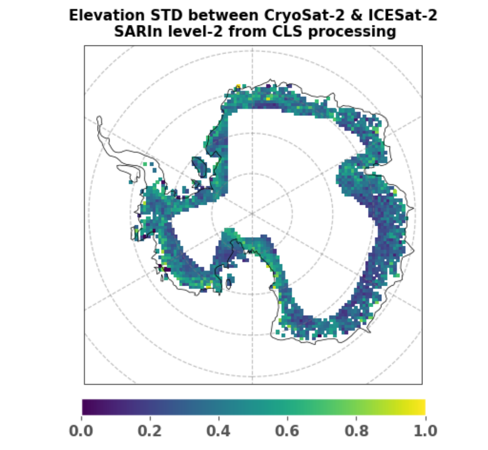
- Radar wave polarization impact to be analyzed in more details in LRM/SAR & Ku/Ka

Last results: CryoSat-2 SARIn investigations

<u>On going work at CLS:</u> Analysis of CroySat-2 SARIn elevations over Antarctica by comparison to ICESat-2 ATL06 at crossovers (from CS-2 Baseline-D)

- Development of a dedicated L2 processing for SARIn data (POCA retracking)
- CryoSat-2/ICESat-2 statistics after a 3δ editing over whole Antarctica:
  - median bias ~ -10cm
  - STD ~ 50cm
  - Without editing, rare large outliers >20m (only 0.25% of data)
- Performances get better over linear surfaces exhibiting clear leading edge waveforms (more Antarctica's interior)

  <u>=> in such situations snow/air interface corresponds in average to a 60-65% threshold</u> => consistent with Sentinel-3A SAR mode analyses. TO BE CONFIRMED.



STD of CS-2/IS-2 elevation biases at Xover (m)

Polar Monitoring project overview

Project dedicated to CRISTAL mission definition, involving CLS, Lancaster University, FMI, IGE & LEGOS. Objectives:

- **Review of the state of the art and analysis of user requirements** in the context of the Earth Observing System at the date of the mission 2025-2030
- **Assessment and consolidation of the CRISTAL mission requirements & observation system**, allowing to reach user requirements
- **Altimetry simulations over snow surface** to analyse the potential of the CRISTAL dual-band mission. In particular, simulations will focus on coupling a snow model with an altimetry simulator to analyse Ku/Ka bands observations
- **CRISTAL orbit definition & evaluation**

Deliverables available in https://www.polarmonitoringproject.org/

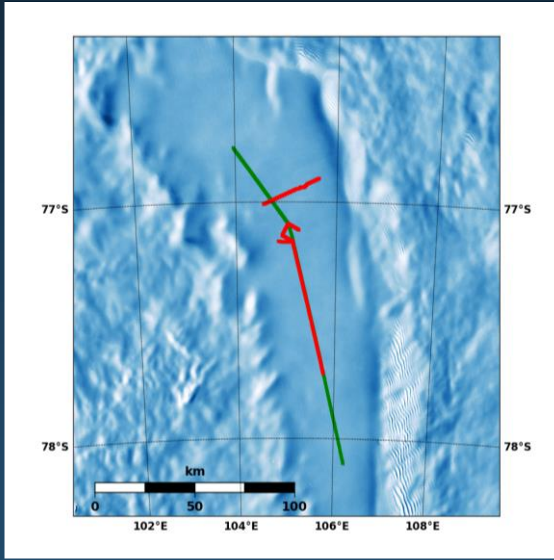
Back-up

Comparison to GNSS acquisitions

Between 2001 and 2015 several kinematic GNSS profiles have been measured in the area of lake Vostok. GNSS data have been processed by the Technische Universität Dresden and are available for download. Courtesy to Schröder et al., [2017].

Two GNSS profiles have been measured in January 2011 & 2013:

- **2011 GNSS data:** **3374** measurements over the study area
- **2013 GNSS data:** **6880** measurements over the study area



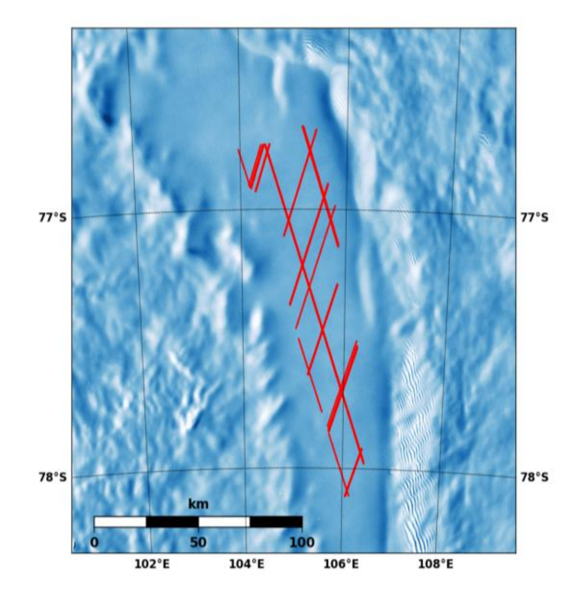
Location of the GNSS acquisitions.
2011 (green) ; 2013 (red)

Comparison to ICESat acquisitions

- **Comparison with ICESat elevations (GLAH12 v34)** at crossovers (ICESat acquisitions between 2003 and 2009)
- ICESat brings two major advantages:
  1) No signal penetration into the snowpack. Surface elevation is estimated at snow/air interface.

  2) Footprint is 35 meters radius. No slope-induced error. *POCA = nadir.*
- Precision of several cm over lake Vostok [Ewert et al., 2012]

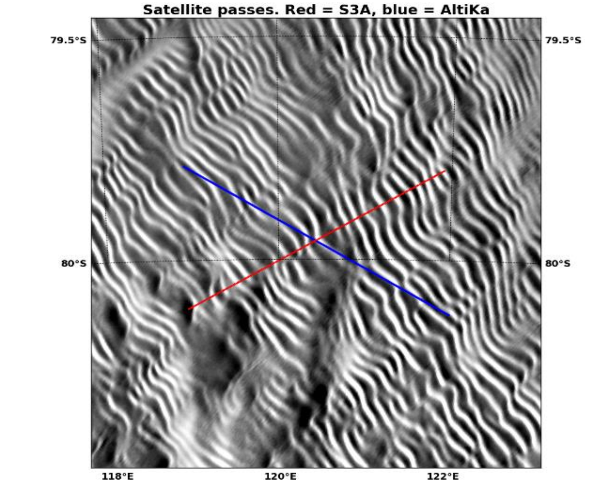
Study performed in 2017 with ICESat => to be updated with ICESat-2 !



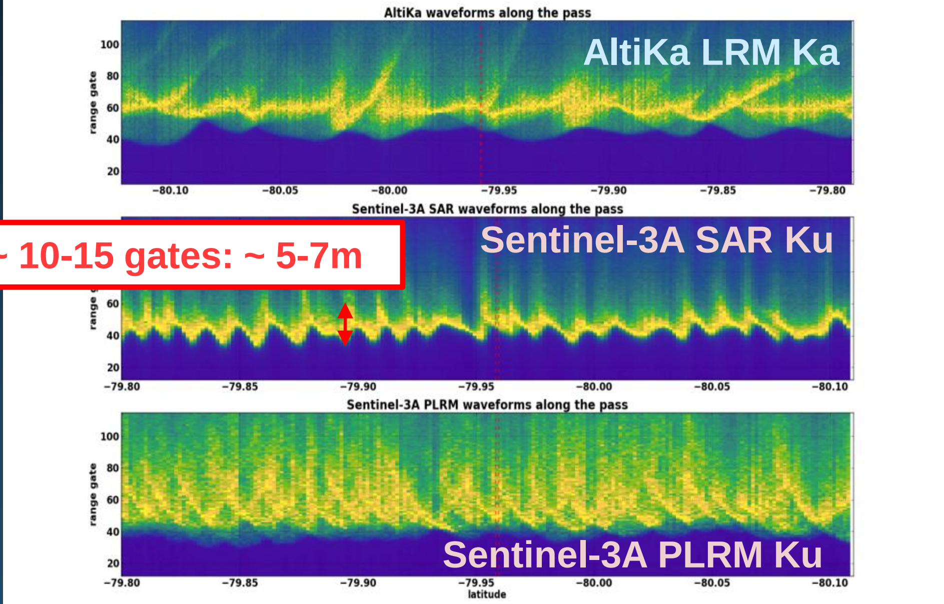
Location of the ICESat tracks on the study area (red)

Observations of megadunes by Sentinel-3A

meagadunes are surface oscillations *from 2 to 8 meters in amplitude and 2 to 5 kilometers in wavelength [Ekaykin et al., 2016]*



Sentinel-3A track (red) / AltiKa track (blue)



Nice demonstration of the along-track footprint reduction provided by SAR altimetry

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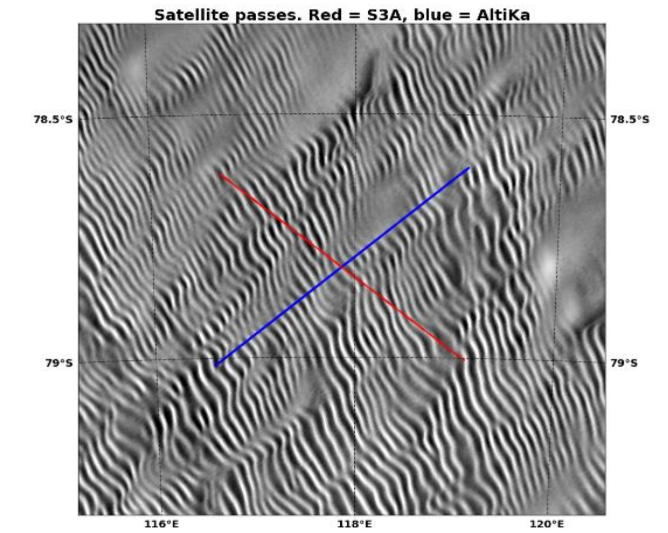

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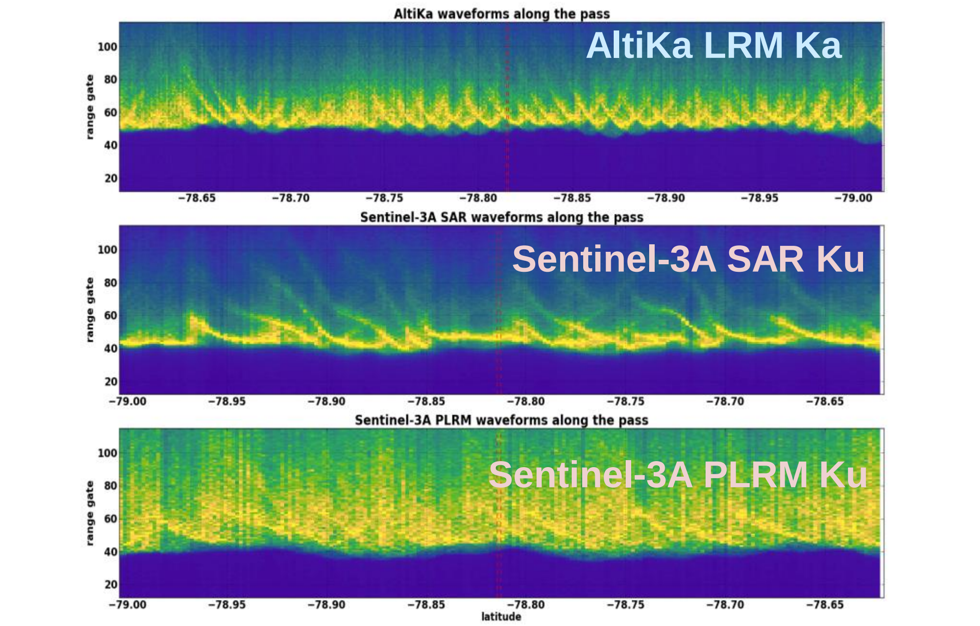


Not possible to see megadunes topography in SAR mode if sateliite track is ~co-linear to megadune field (across-track footprint remains same as LRM)

Lake Vostok calibration site

- **<u>Extremely flat</u>**

North-south slope tilting 60 m over ~250 km. Average slope is 0,025%. *[Siegert, 2005] ; [Ewert, 2012]*

- **<u>Equilibrated local ice-mass balance</u>**

Mean snow accumulation: **6.24 cm/yr** *[Ekaykin et al., 2004].*
Mean vertical velocity of snow particle: -**6.17 cm/yr** *[Richter et al., 2014].*

- **<u>Consequently, surface elevation is stable over time from GNSS studies</u>**

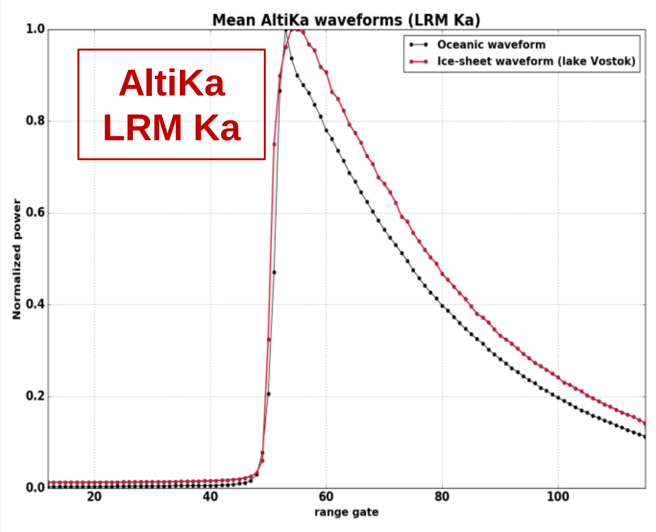
From 2001 to 2013: +1mm/yr *[Richter, 2014]*
From 2001 to 2015: 0 mm/yr *[Schröder, 2017]*

Flat surface, surface stable over time:
Lake Vostok is an excellent calibration site for radar altimetry.

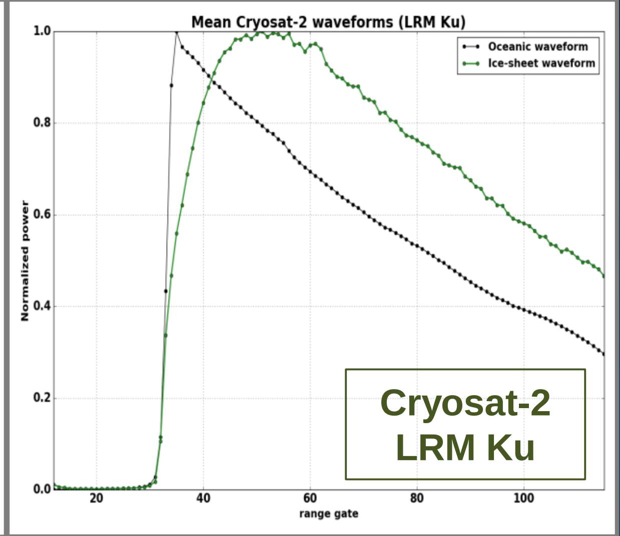
Comparison of mean Oceanic and LandIce waveforms (lake Vostok)

Methodology: Individual waveforms with a same epoch estimation are normalized and aggregated. For oceanic mean WFs, SWH estimation is 1 meter (+/- 20cm).

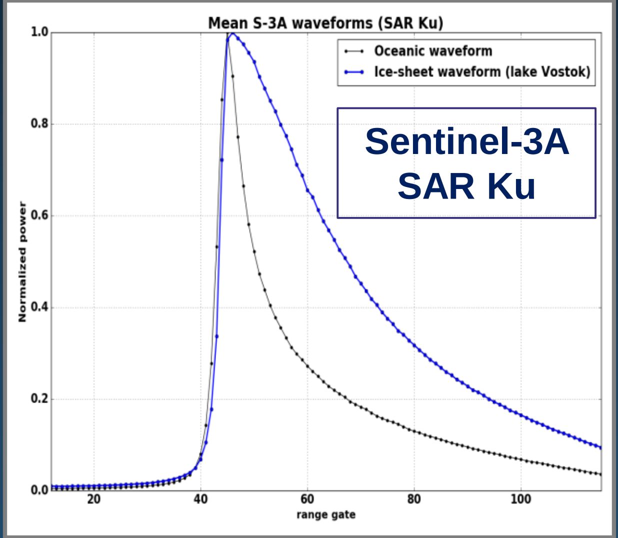
Oceanic and landice leading edge have been aligned on the window analysis.



518 WFs aggregated over LandIce



264 WFs aggregated over LandIce



874 WFs aggregated over LandIce