Ku/Ka band observations over Polar Ice sheets

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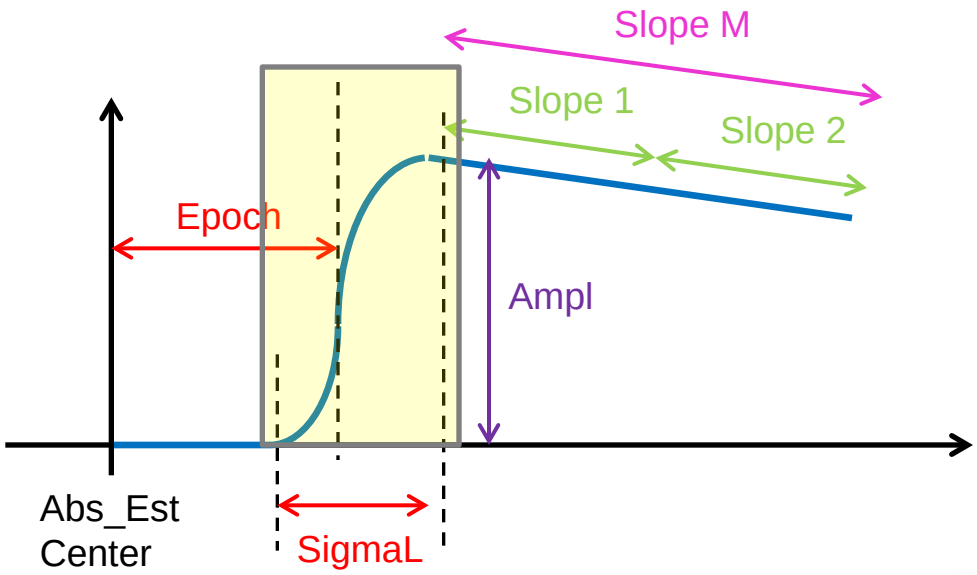
A.Guillot, N.Picot : CNES
F.Remy : LEGOS

Context

- The idea is to compare Ku and Ka measurements over ice sheets (Saral, RA-2 & CS-2 LRM) in order to better understand the ones historically done in Ku band (link with R&T Ka Snow/Ice measurements) and to improve the retracking algorithms
- In the frame of the CNES SARAL PEACHI project, we have analyzed the output of the **ice-2 retracker** designed by LEGOS (FRANCE) for ice sheets (first for ERS and RA-2)
- Some evolutions have been introduced in the algorithm mainly to account for the **antenna gain pattern** and **for the PTR**
- The ice-2 algorithm is implemented in the Saral ground segment but also used for RA-2 and ERS ½. The same evolutions have to be done for all missions in order to compare the geophysical output

Principle of the ice-2 algorithm (LEGOS)



Ice-2 model

Epoch and SigmaL are computed by fitting **a simplified Brown model** on the leading edge of the waveforms.
(Double loop exploring all potential epoch/sigmaL pairs)
Power is computed after this loop.

Slope 1, Slope 2 and Slope M are computed in a second step with regressions on the trailing edge of the waveform

Principle of the ice-2 algorithm

– General expression of the return power as a function of time :

$$V_m(t) = \frac{P_u}{2}\exp\left(s_t(t-\tau)\right)\left\{\left[1+erf\left(\frac{t-\tau}{\sigma_L}\right)\right]\right\} + P_n$$

– where :

- S_t = Slope of the logarithm of the trailing edge
- σ_L = width of the leading edge

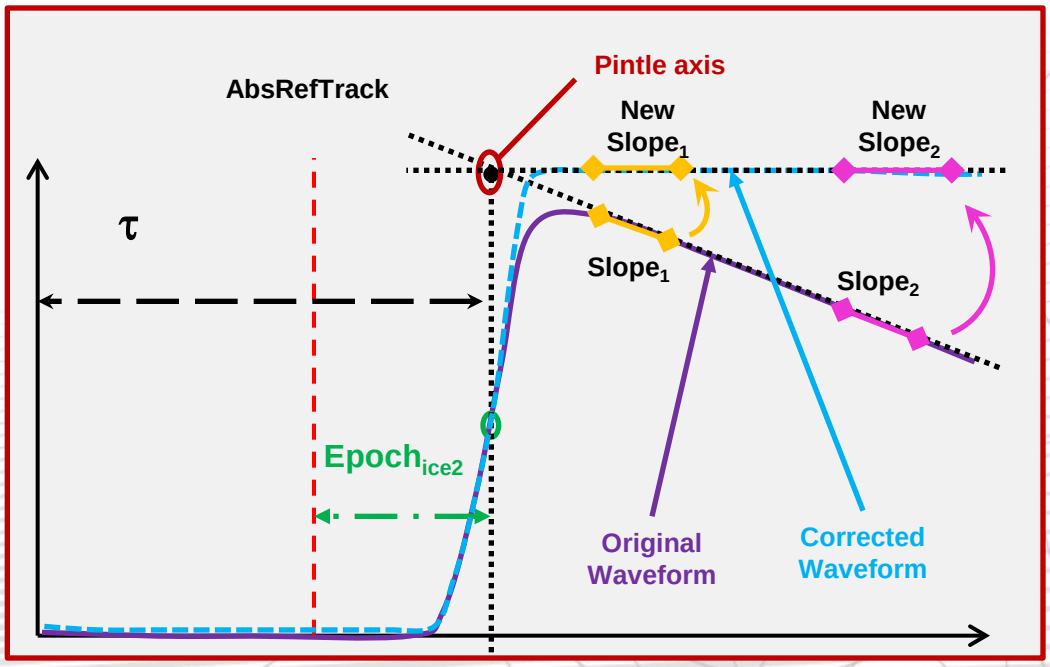
Introduction of this exponential term in the model

– Identifying each term, it comes:

$$s_t = -\frac{4c}{\gamma h\left(1+\frac{h}{R_e}\right)}$$

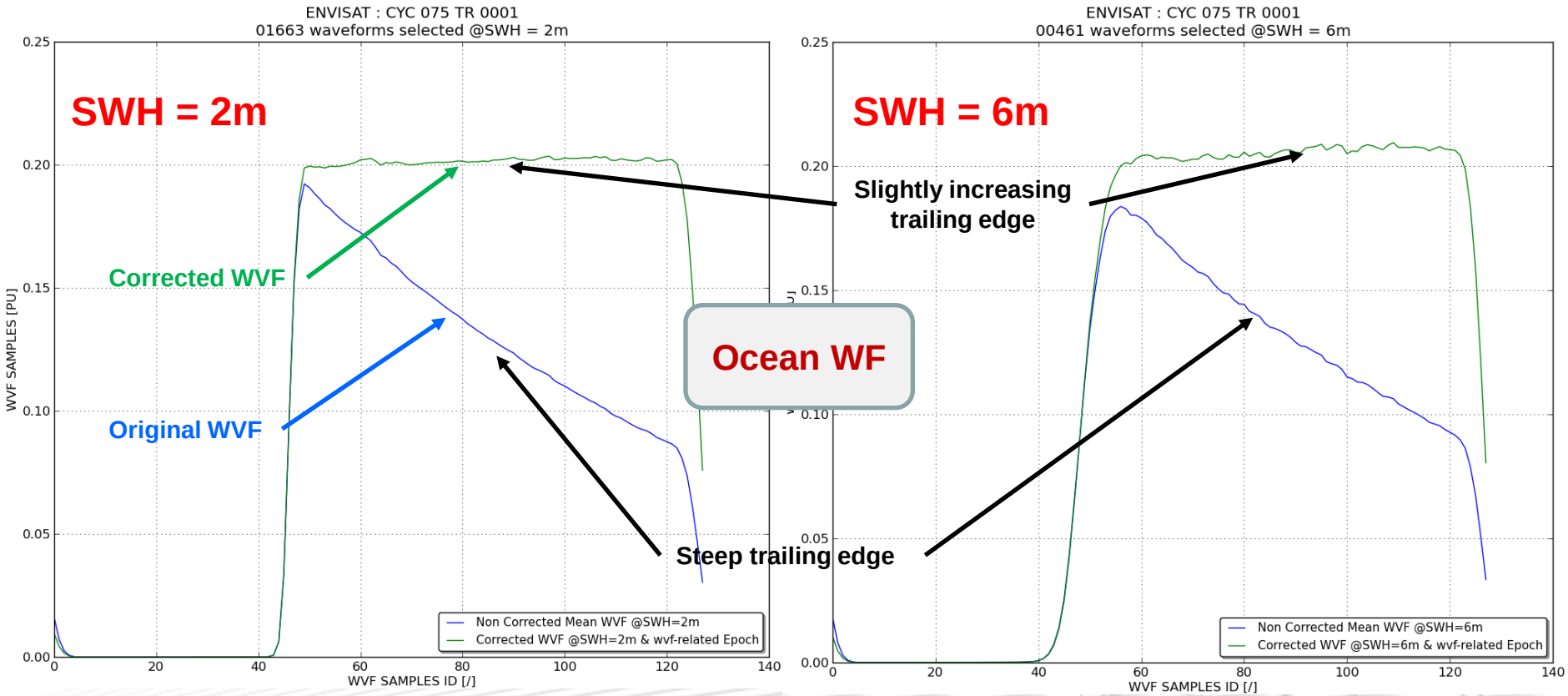
with

$$\gamma = \frac{2}{Log_e(2)}\sin^2\left(\frac{\theta_0}{2}\right)$$



ENVISAT/RA-2 echos corrected for the AGP

ENVISAT/RA-2: CYC 75 – Tr1 → 1002 (Dec 2008 - Jan 2009) Ku band



Filter correction included in the RA-2 waveforms

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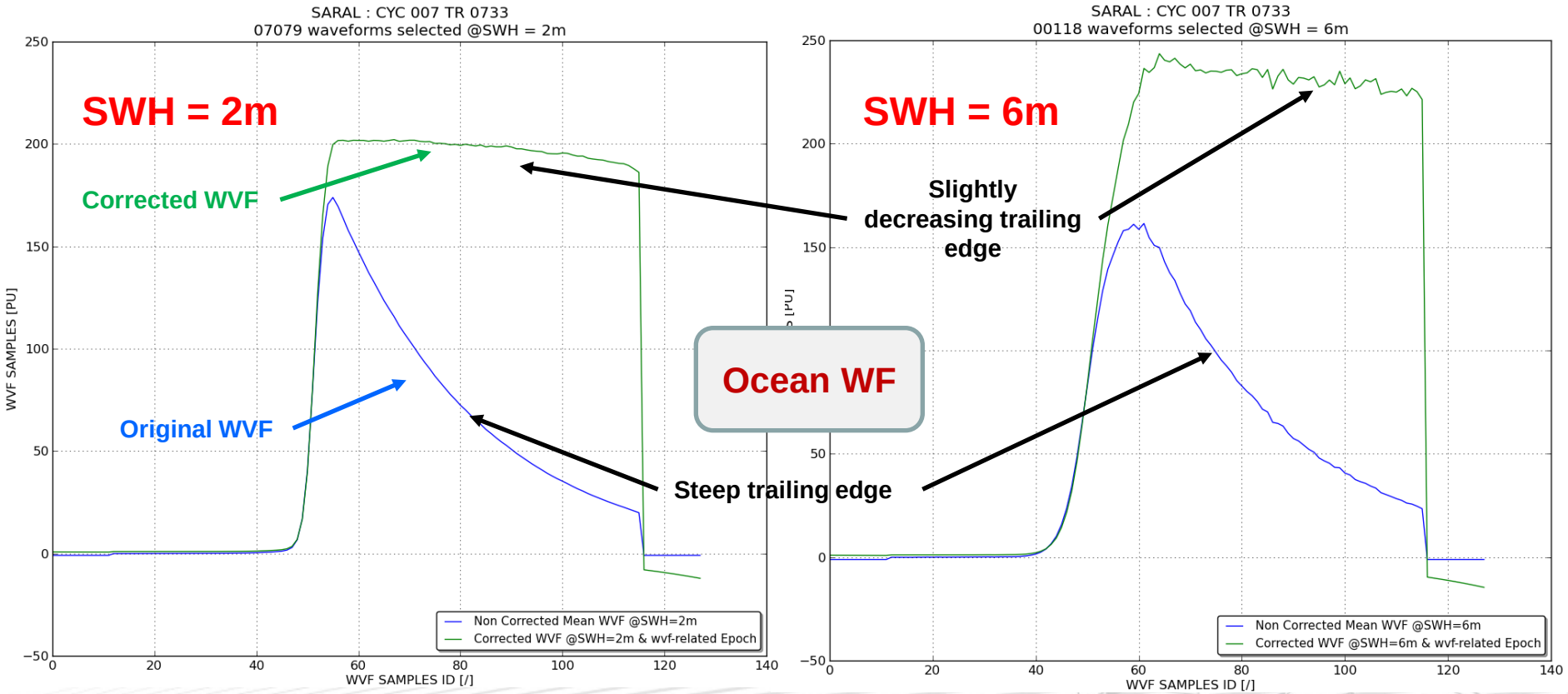
SARAL echos corrected for the AGP

SARAL/ALTIKA: CYC 7 – Tr 1 → 1002 (Oct-Nov 2013)

Ka band



Filter correction applied (CAL LTM 2014/02/03)

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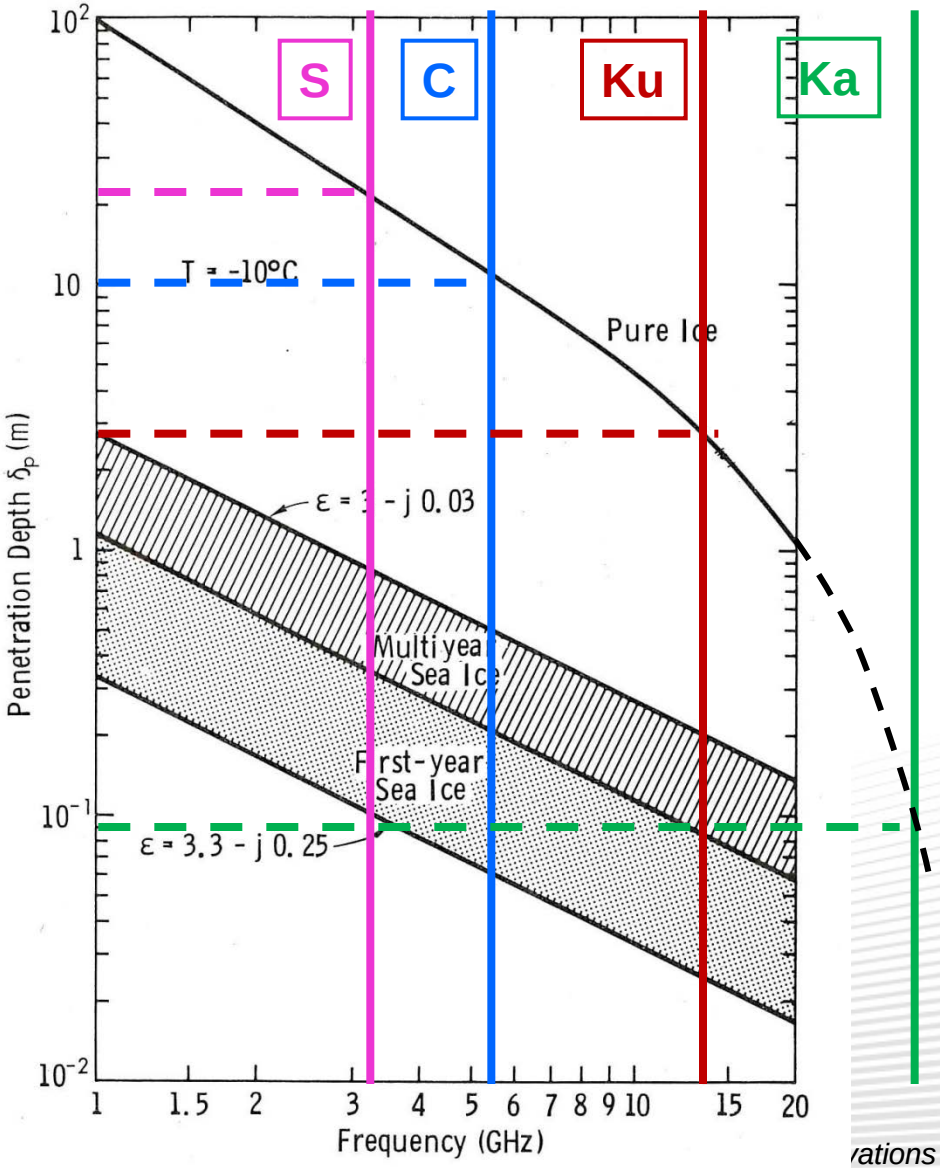
Radar wave penetration (Ulaby, 1986)



Pure ice : *(values given at -10°C)*

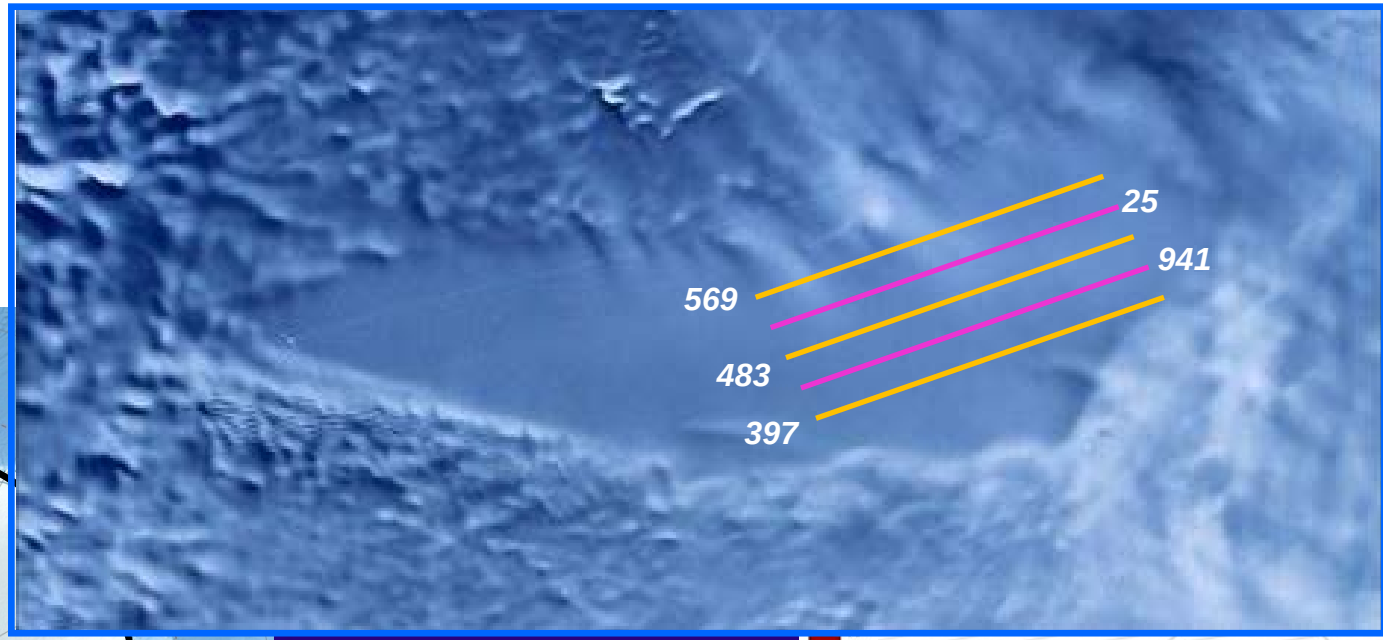
- ✓ S band penetration : 20 m
- ✓ C band penetration : 10 m
- ✓ Ku band penetration : 3 m
- ✓ Ka band penetration : < 10 cm

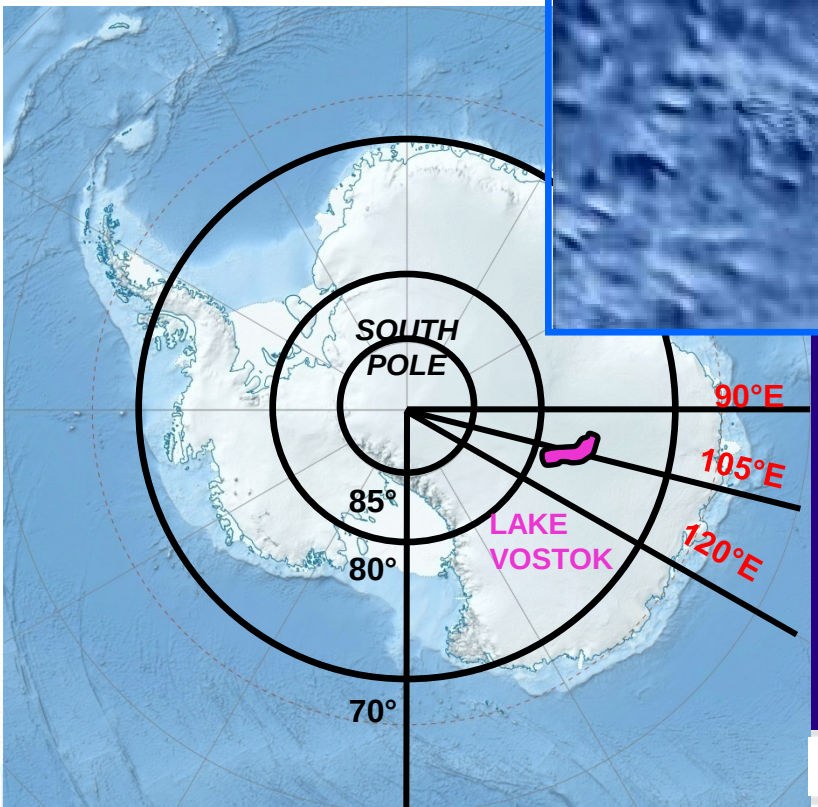
(For lower temperatures)

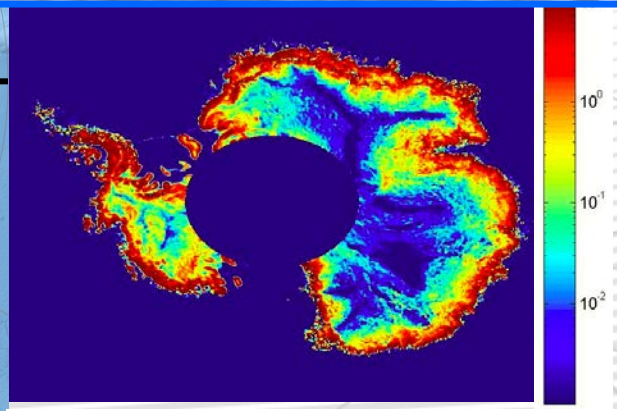
- ✓ Ku band penetration : 5-12 m
- ✓ Ka band penetration : < 1 m

Application on real echos over Antarctica

- **Case of the subglacial VOSTOK lake chosen because very flat**







RADARSAT SENSOR IMAGE

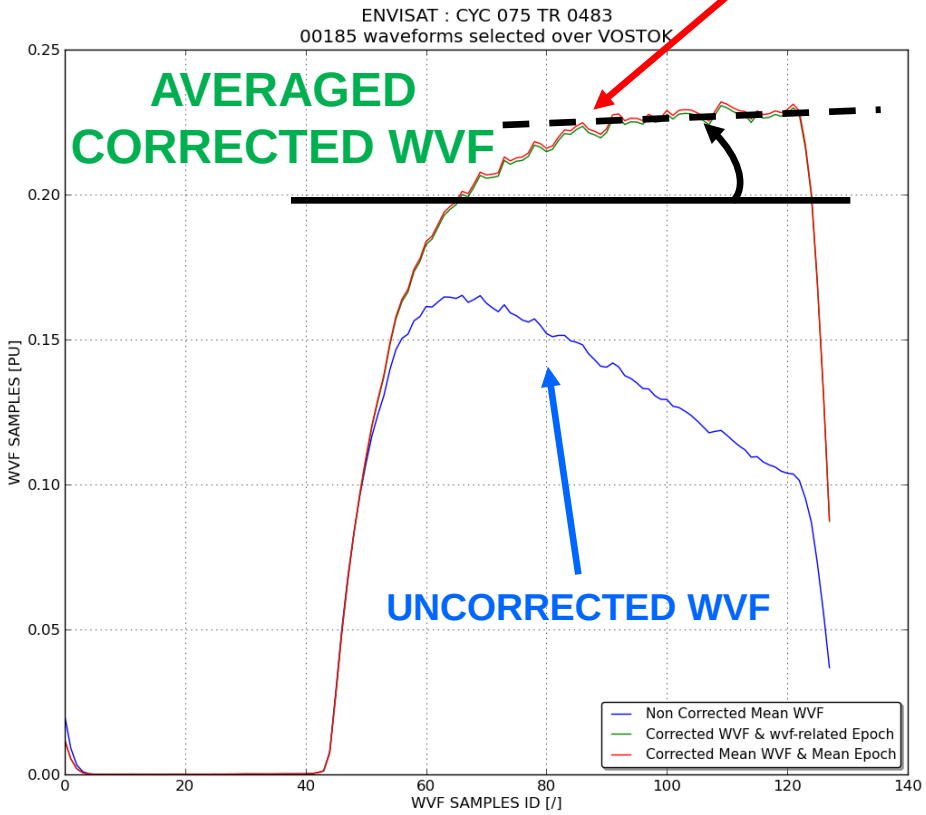
Slopes of the surface, F.Remy, LEGOS

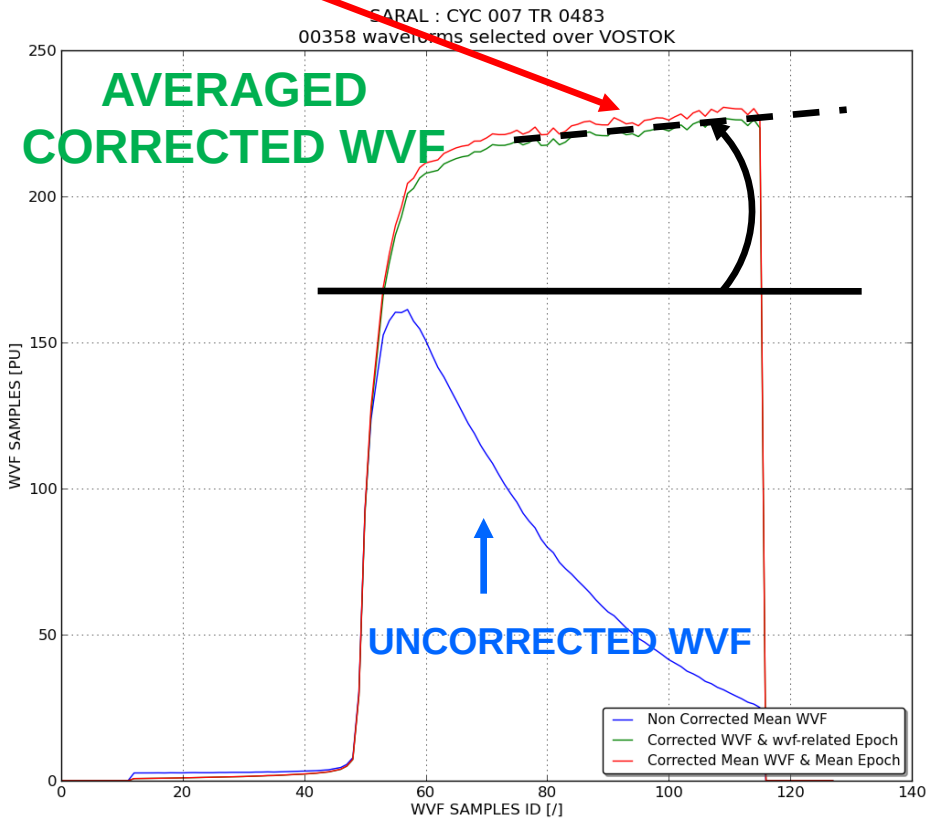
Ku/Ka Waveforms on subglacial Vostok lake pass 483 (lat -76.8 et -76.2 deg)

ENVISAT
CYC 75 TR 483

Ice body physical properties effect (predominance of surface scatterring for Ka, surface slopes)

SARAL
CYC 7 TR 483





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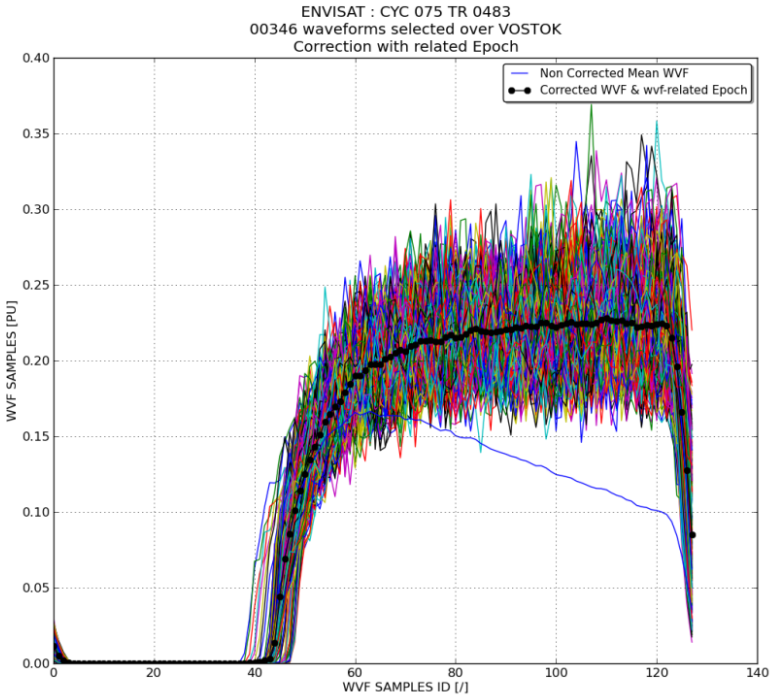
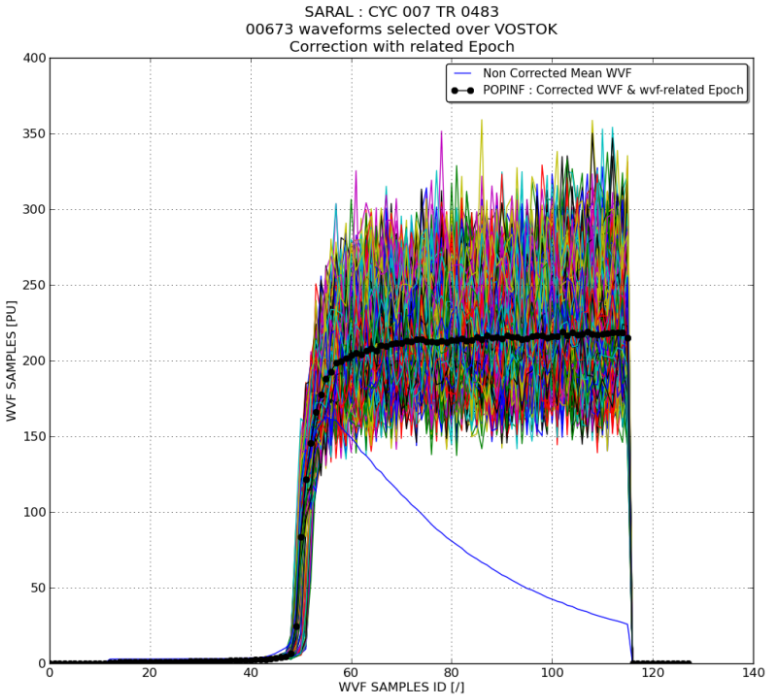
Ku/Ka Waveforms on subglacial Vostok lake pass 483 (lat -76.8 et -76.2 deg)

ENVISAT
CYC 75 TR 483



SARAL
CYC 7 TR 483



➔ Clear effect of volume scattering in the Ku waveforms
➔ Much less in Ka

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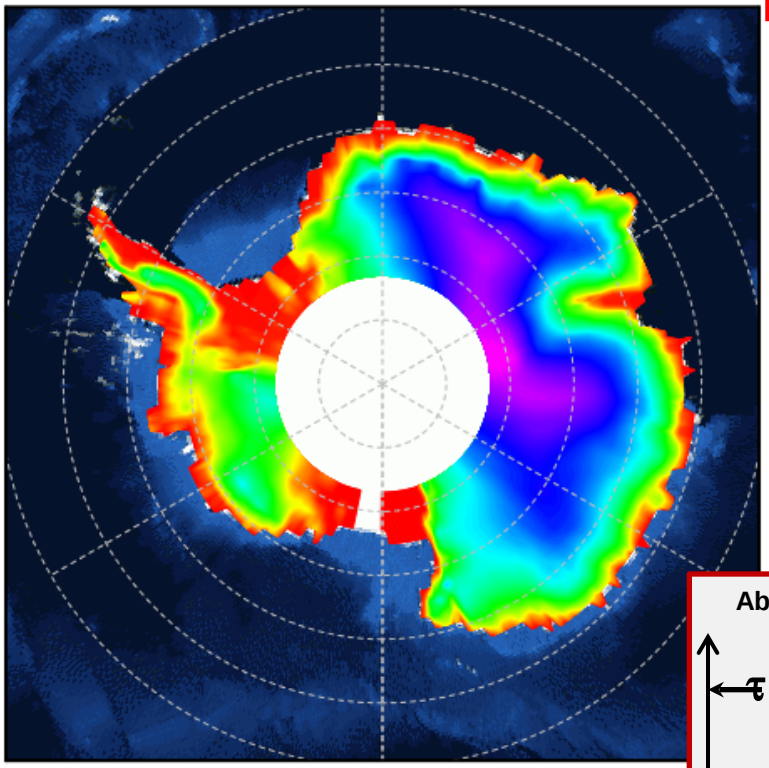
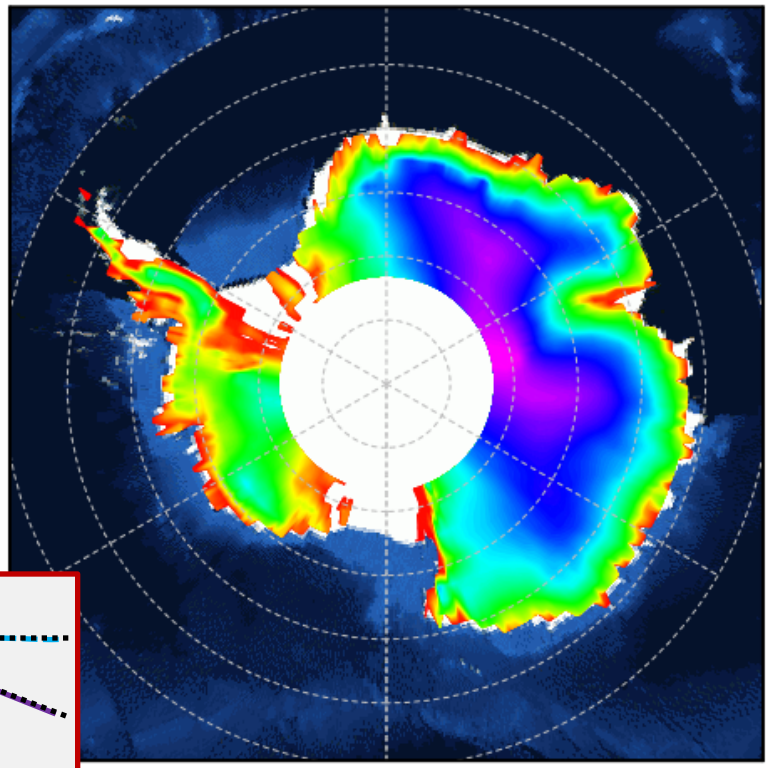
Application on real echos over Antarctica

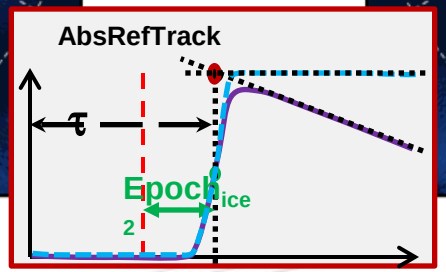
ENVISAT - CYC 075

HEIGHT

SARAL - CYC 007







CORRECTED HEIGHT [m]

0 1000 2000 3000 4000

CORRECTED HEIGHT [m]

0 1000 2000 3000 4000

The heights should be the same but :

- Saral is much more impacted by the slopes of the surface
- The penetration depth is much higher on Ku band (not visible with this scale)

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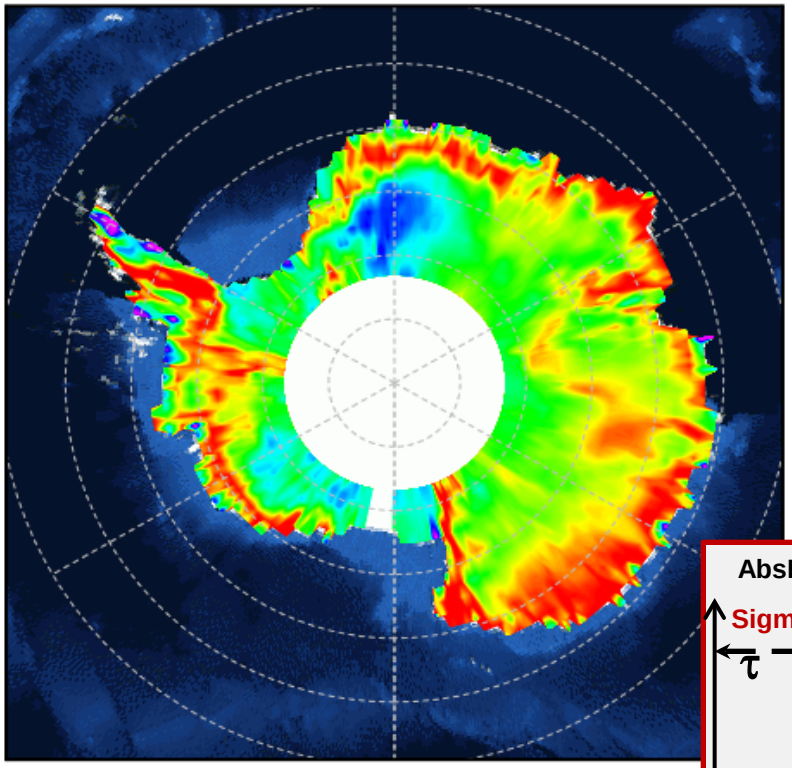
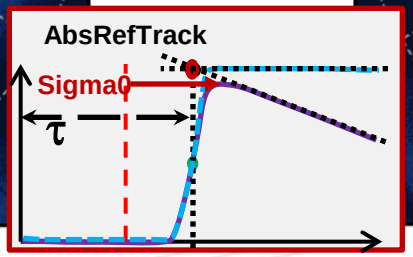
Application on real echos over Antarctica

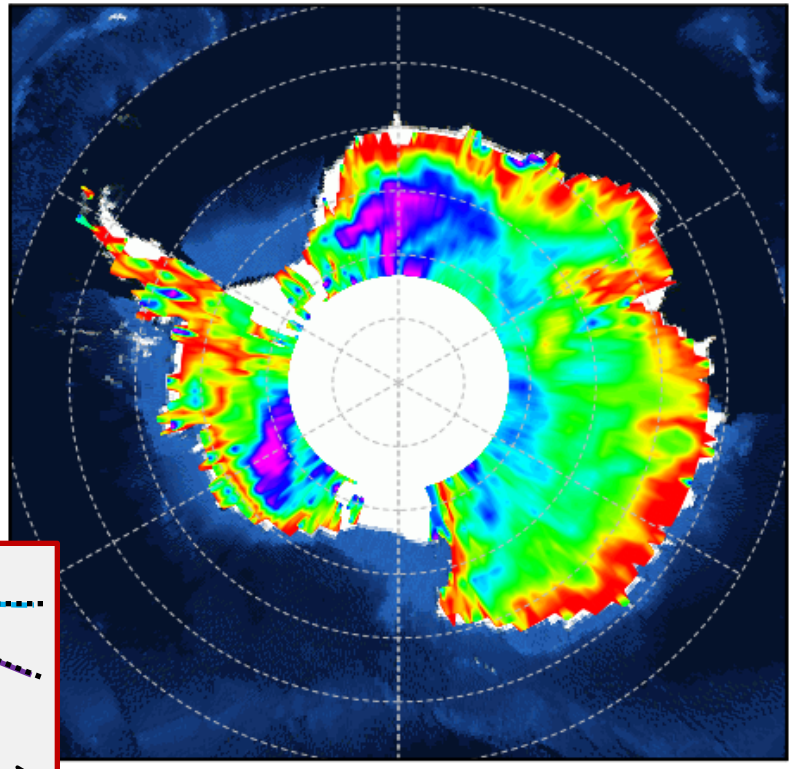
ENVISAT - CYC 075

Sigma0

SARAL - CYC 007







CORRECTED SIG0 [dB]

0 5 10 15

CORRECTED SIG0 [dB]

-2 0 2 4 6 8 10 12

Some patterns are different. Non linear relationship between Ku/Ka sigma0.

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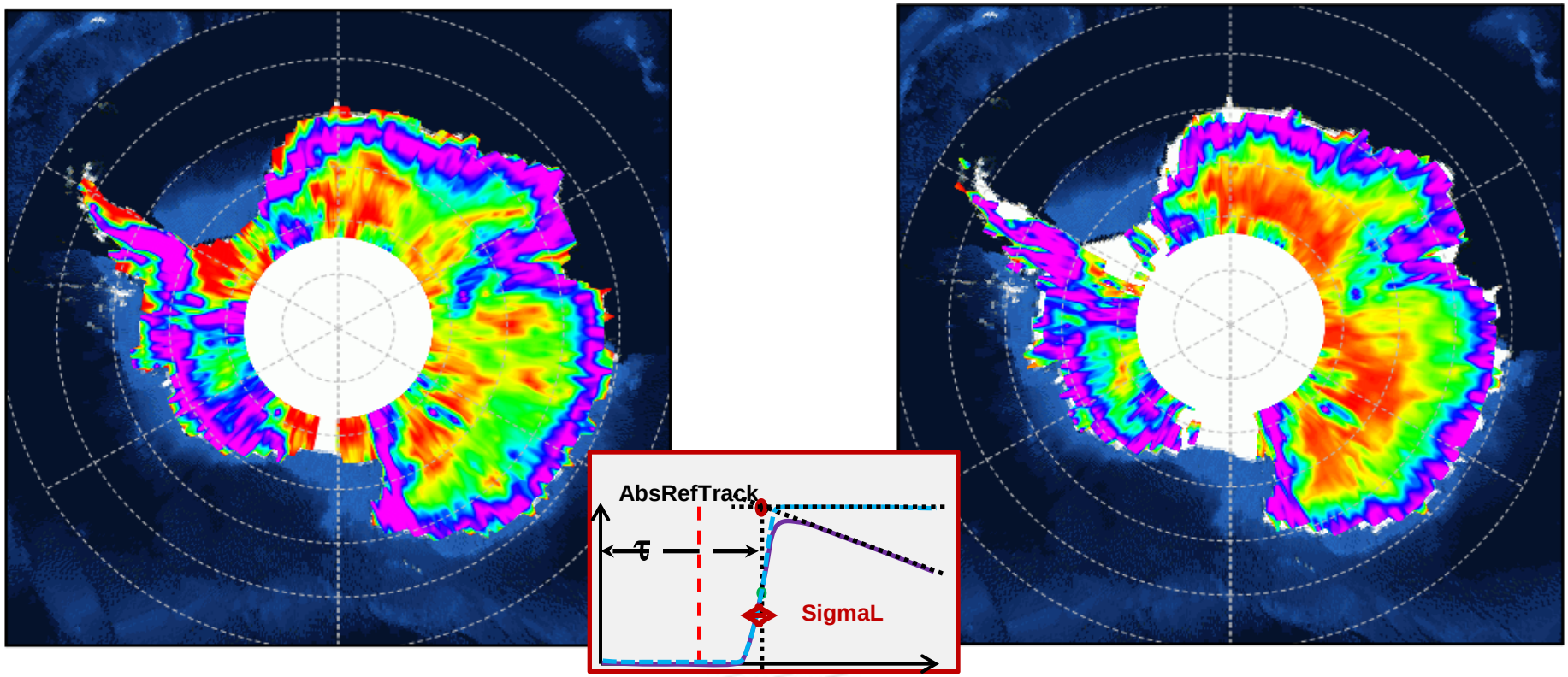
Application on real echos over Antarctica

SigmaL

ENVISAT - CYC 075

SARAL - CYC 007



Patterns obviously different. Clearly linked to the volume scattering smaller for Saral

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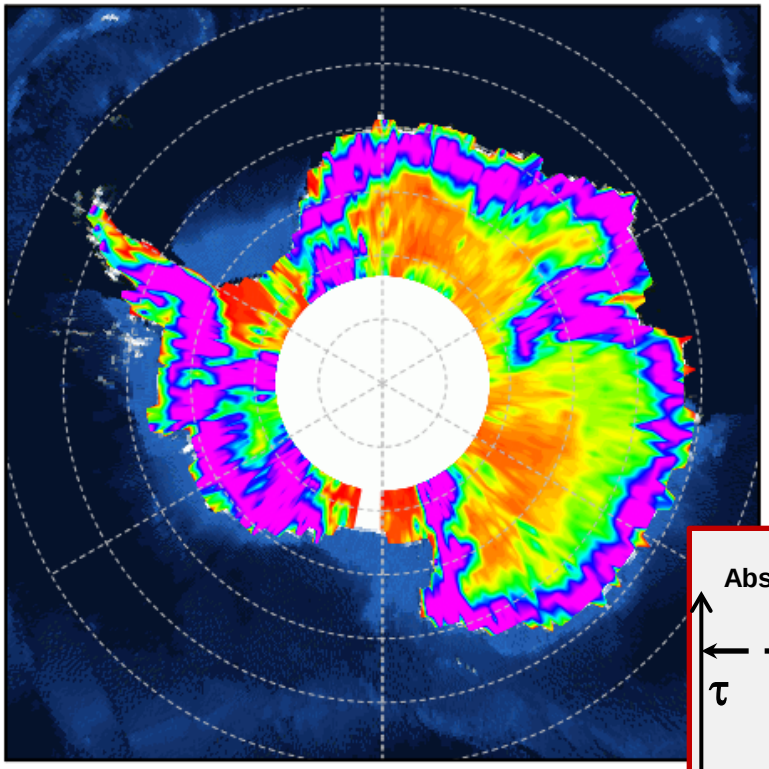
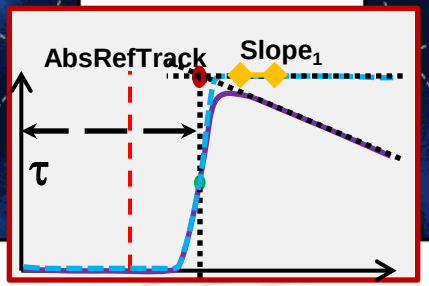
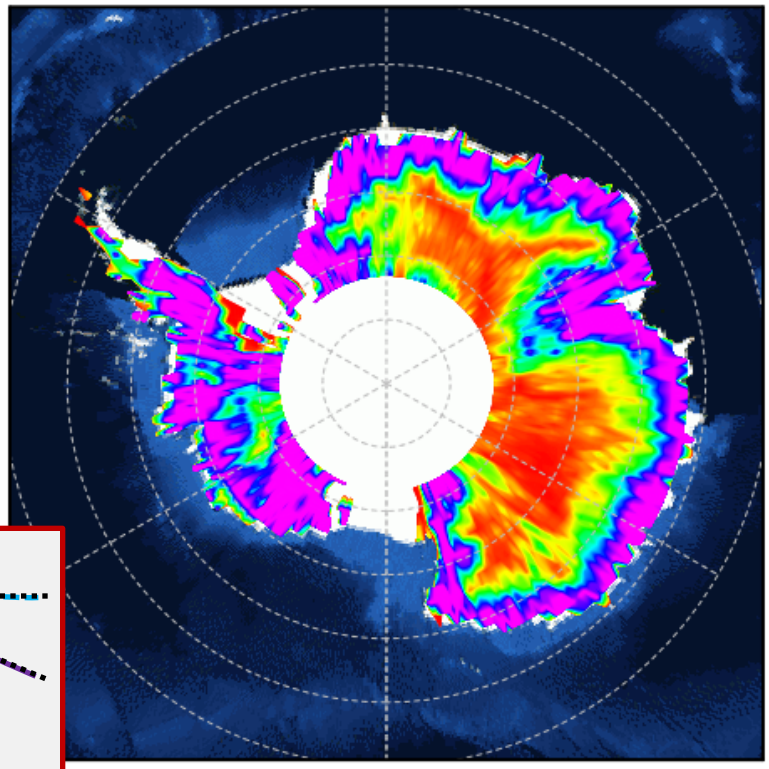
ENVISAT - CYC 075

SLOPE1

SARAL - CYC 007







CORRECTED ICE-2 SLOPE1 [Ms-1]

0 2 4 6 8 10 12 14

CORRECTED ICE-2 SLOPE1 [Ms-1]

0 10 20 30 40 50

SARAL much more impacted than Envisat/RA-2 by surface slopes

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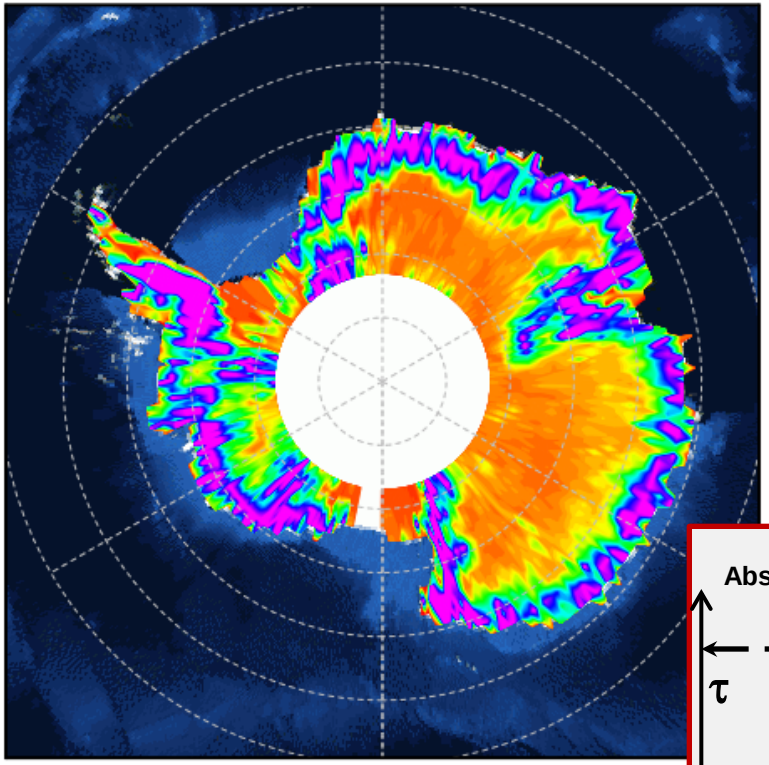
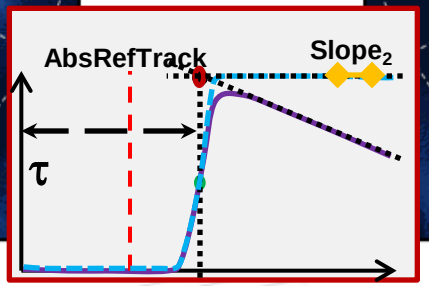
Application on real echos over Antarctica

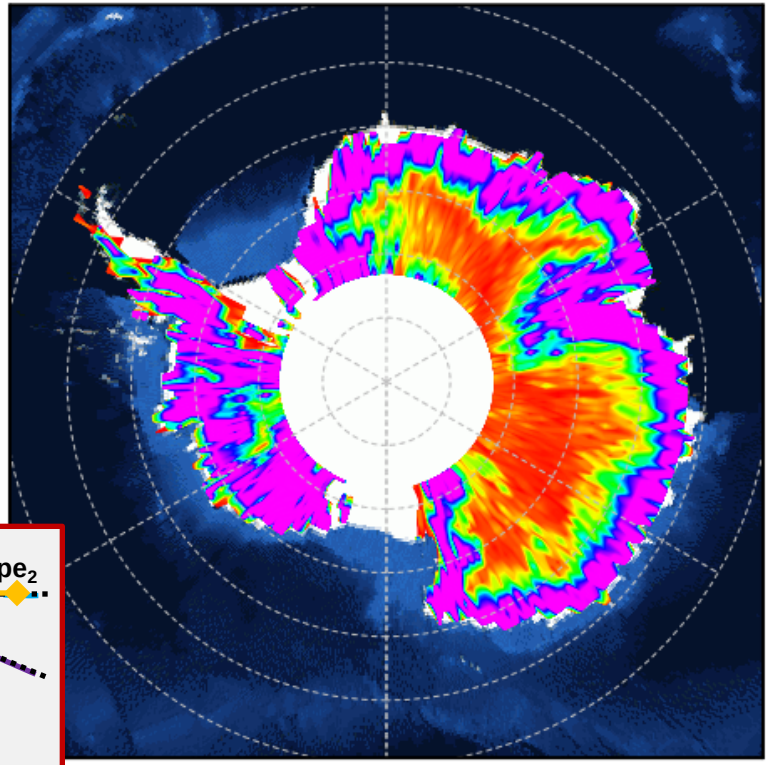
ENVISAT - CYC 075

SLOPE2

SARAL - CYC 007







CORRECTED ICE-2 SLOPE2 [Ms-1]

0 2 4 6 8 10 12

CORRECTED ICE-2 SLOPE2 [Ms-1]

0 10 20 30 40 50

SARAL much more impacted than Envisat/RA-2 by surface slopes

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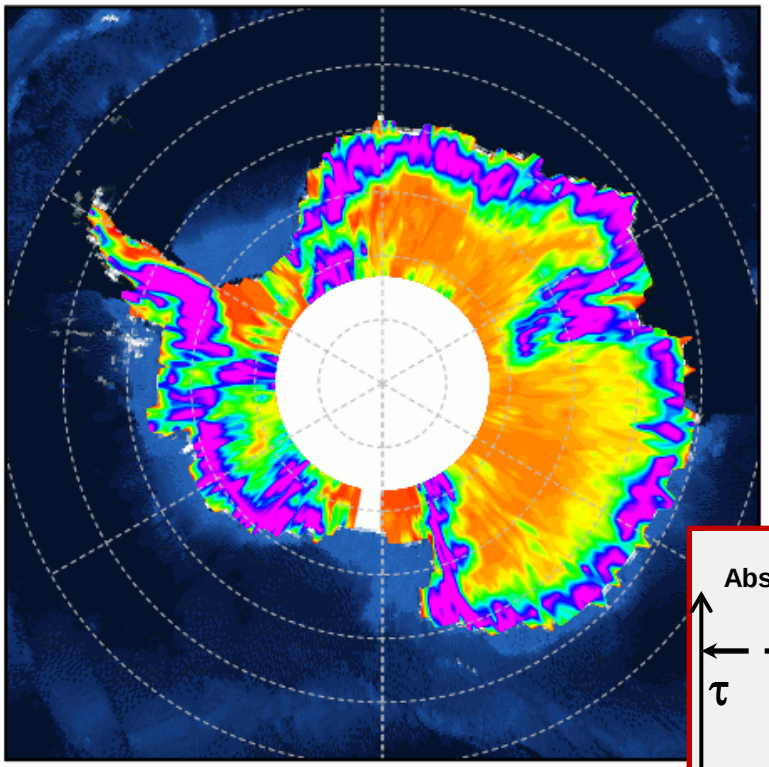
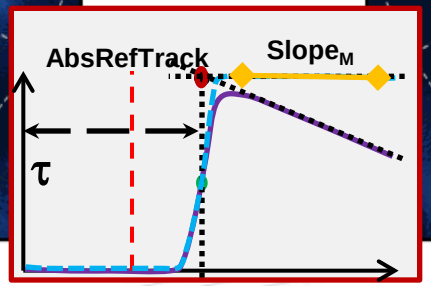
Application on real echos over Antarctica

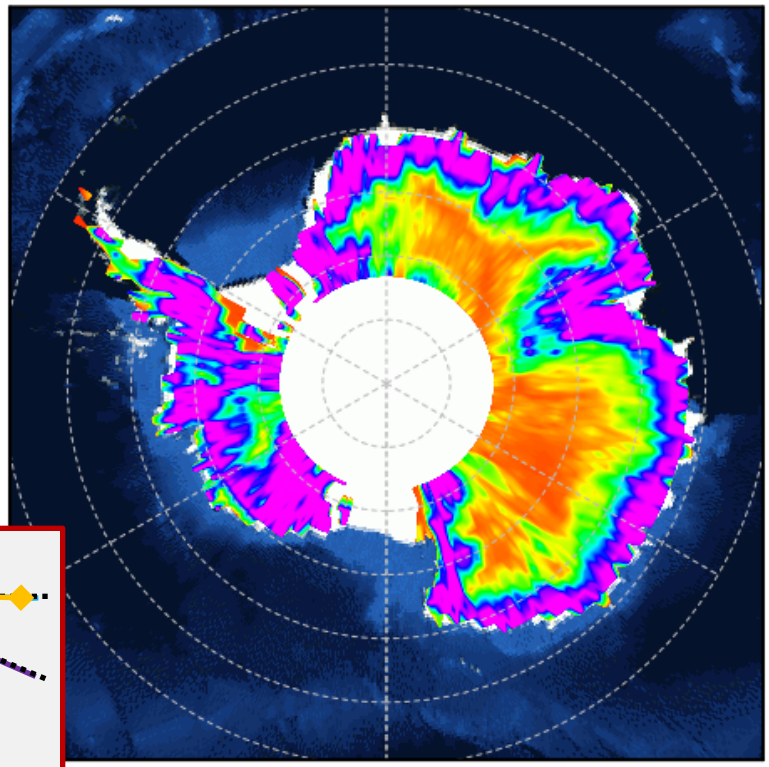
ENVISAT - CYC 075

SLOPEM

SARAL - CYC 007







CORRECTED ICE-2 SLOPEM [Ms-1]

0 2 4 6 8 10 12

CORRECTED ICE-2 SLOPEM [Ms-1]

0 20 40 60

SARAL much more impacted than Envisat/RA-2 by surface slopes

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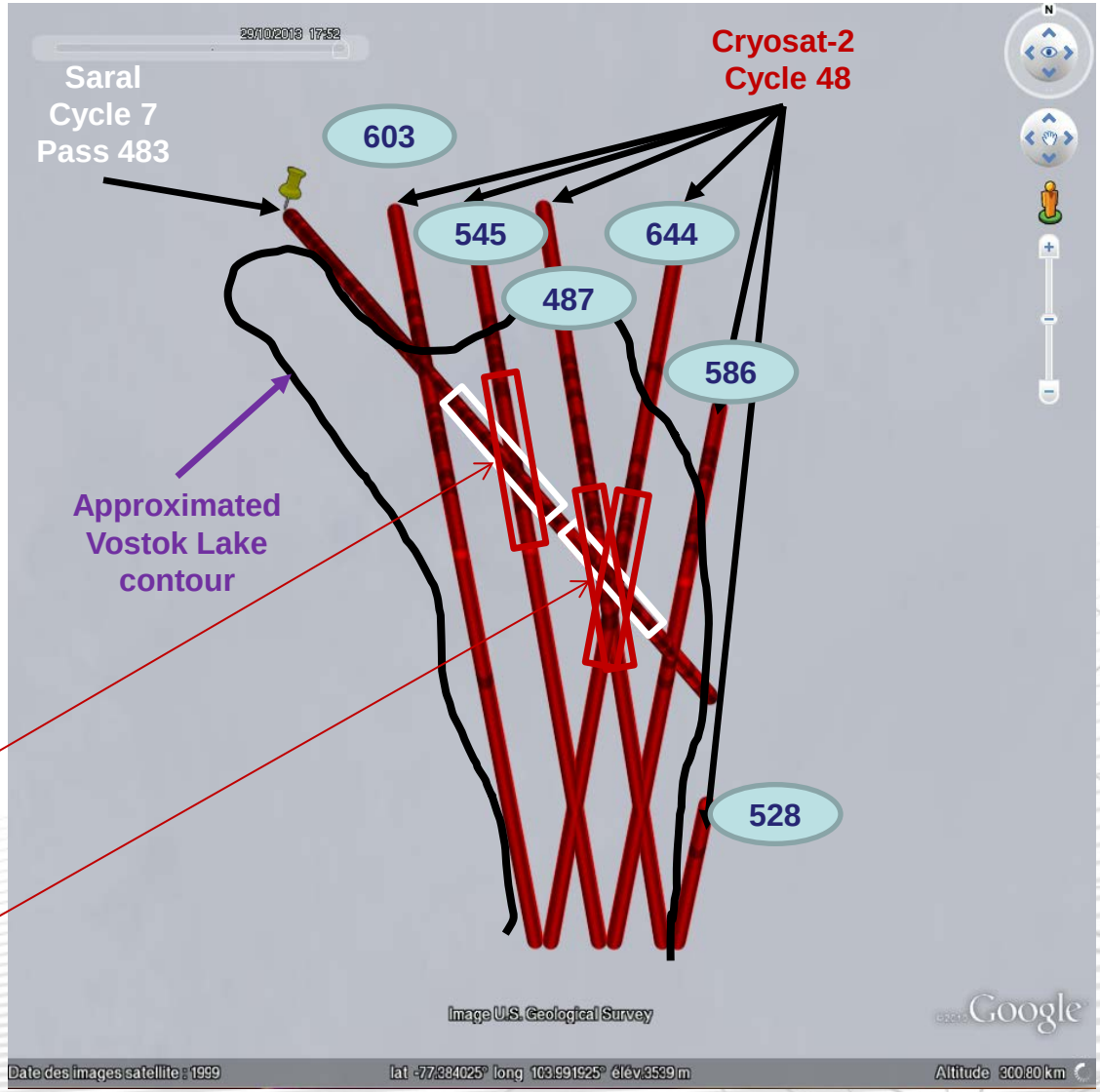
Analyses at Ku/Ka X-overs (Vostok lake)

Cryosat-2 - Cycle 48

Saral - Cycle 7

X-over < 3 days

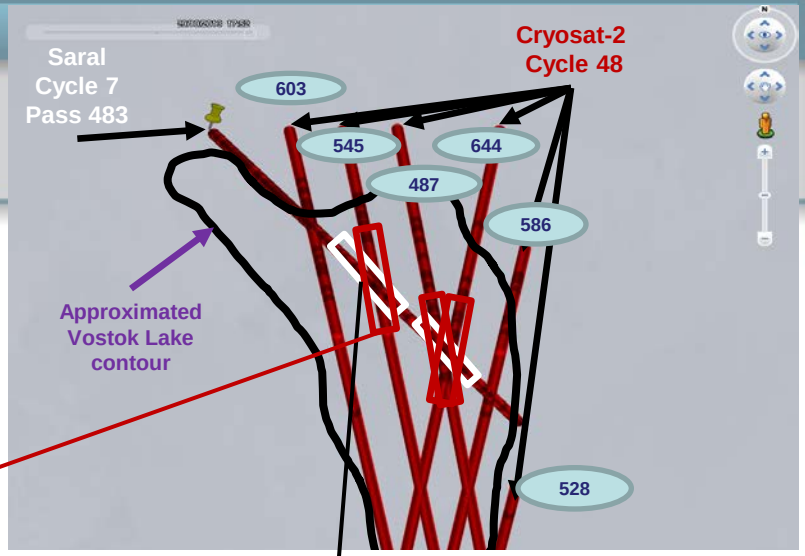


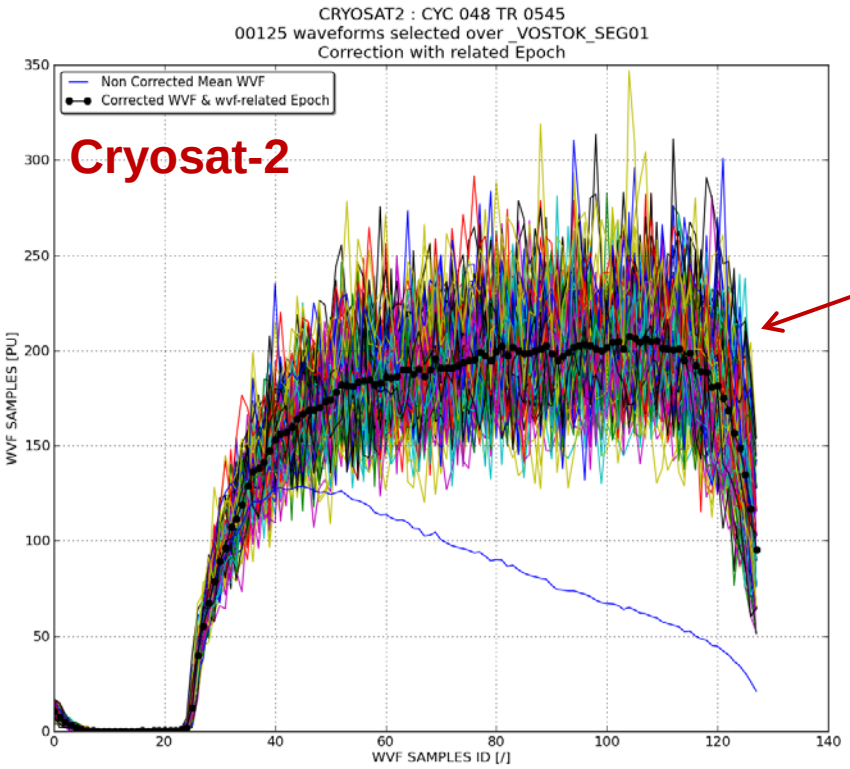
Delta time : 17 hours

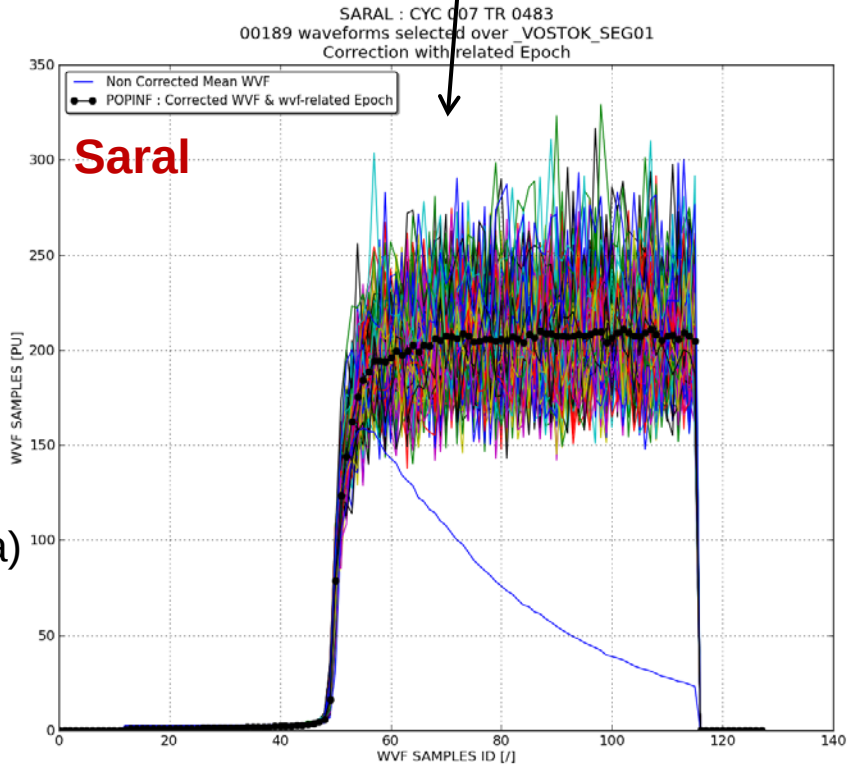
Delta time P487 : -3 days

Delta time P644 : +2 days

Waveforms at X-overs



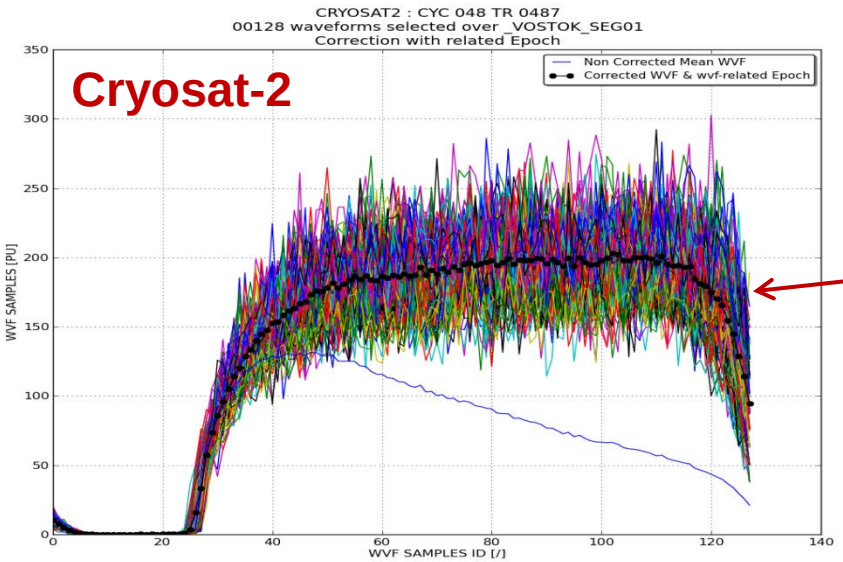


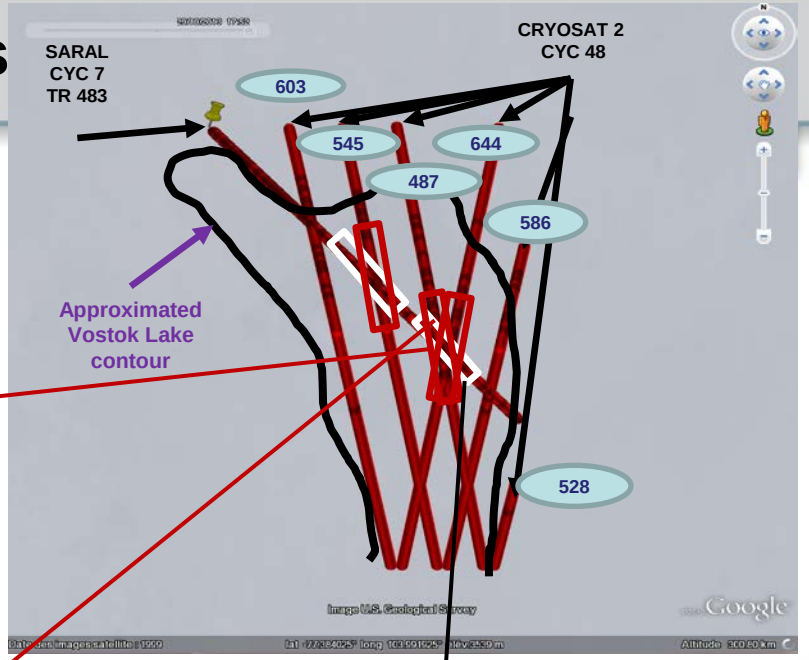


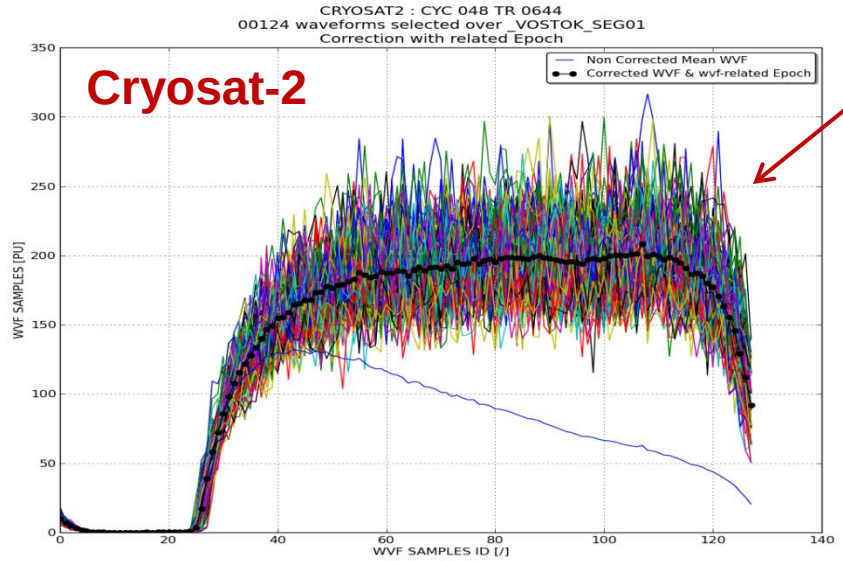
- Homogeneous data segments
- Penetration effects on Ku data (much less on Ka)
- !! 47 cm gates in Ku while 32 cm in Ka !!
- Smaller gates in snow/ice layers
- Very coherent with the multi-layer theory

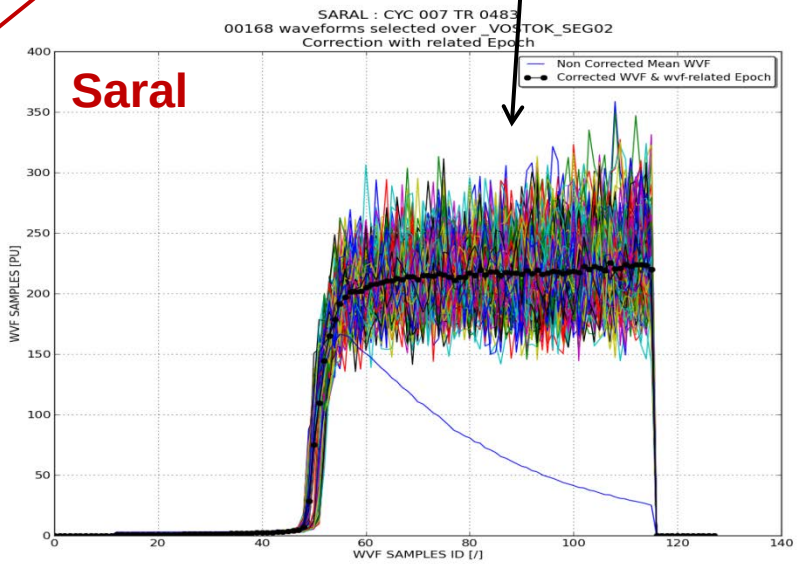
(see D.Blumstein/F.Mercier presentation)

Waveforms at X-overs



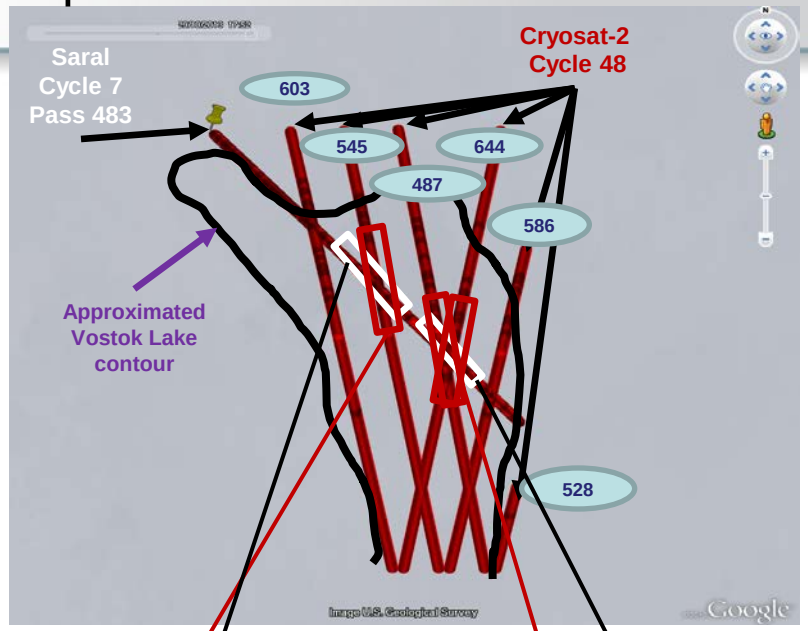


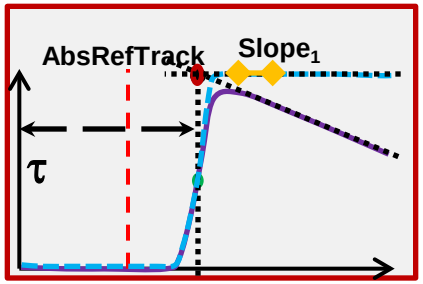




Analyses at Ku/Ka cross-overs

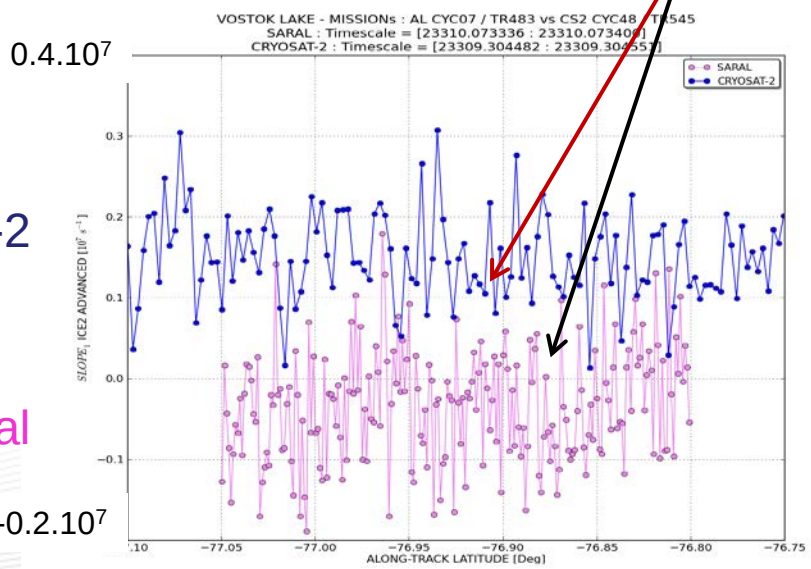
➔ Slope 1

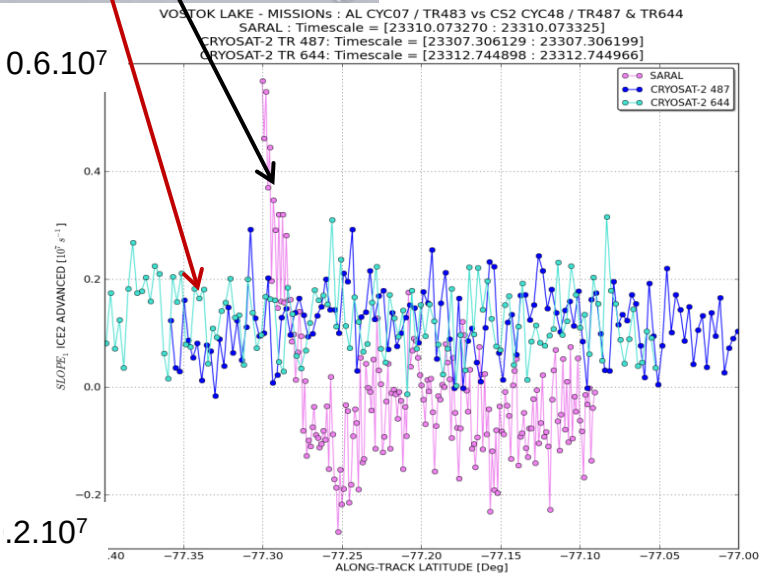




CS-2

Saral

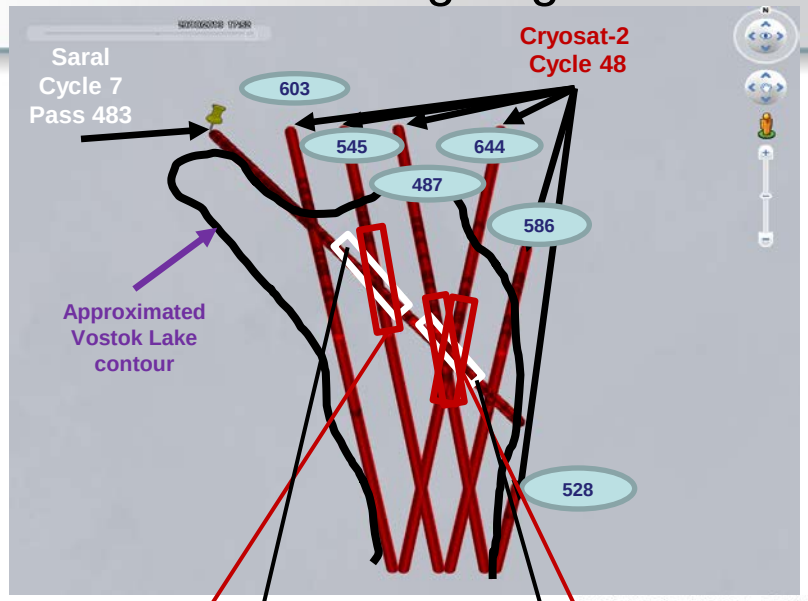


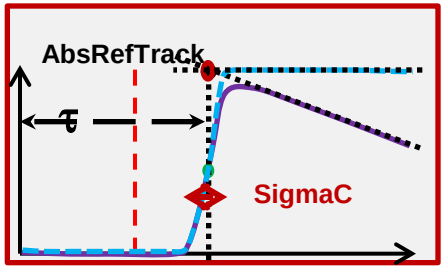


Analyses at Ku/Ka cross-overs

➔ Width of the leading edge : σ_C

σ_C corrected for the PTR width and for the $\sqrt{2}$ coefficient

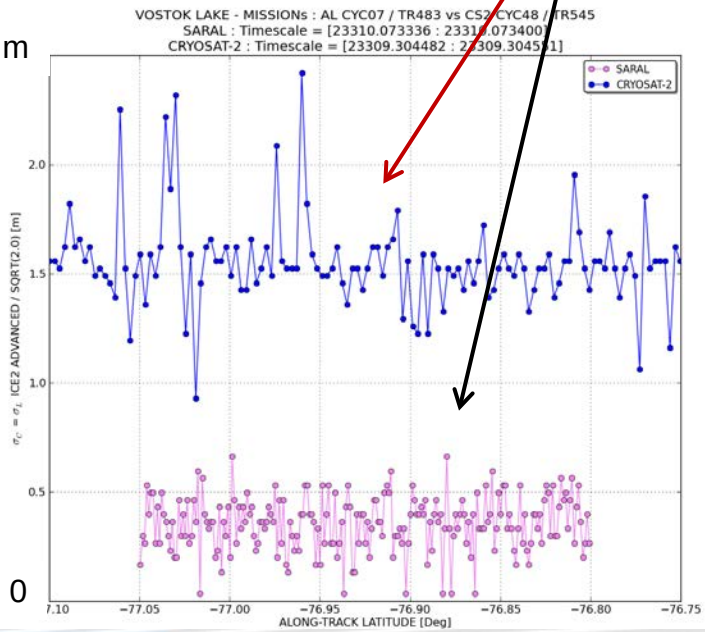




Cryosat-2

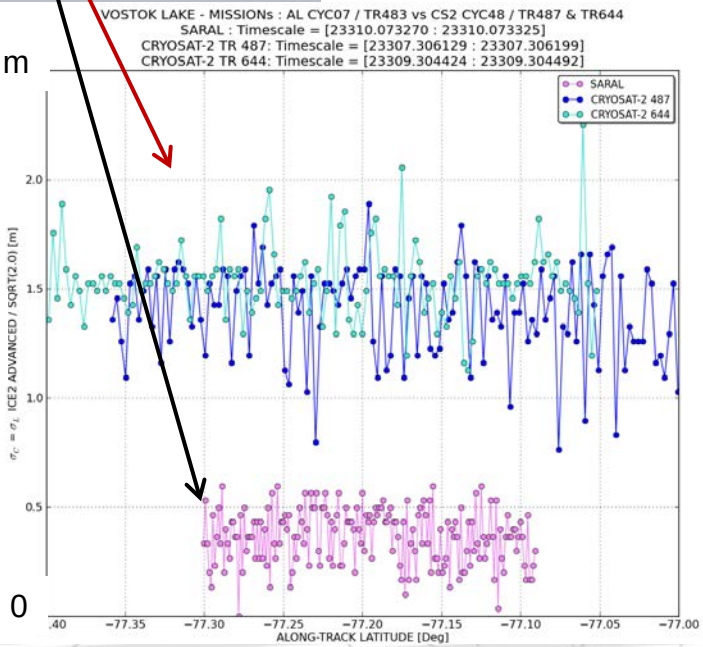
Saral

2,5 m



σ_C

2,5 m



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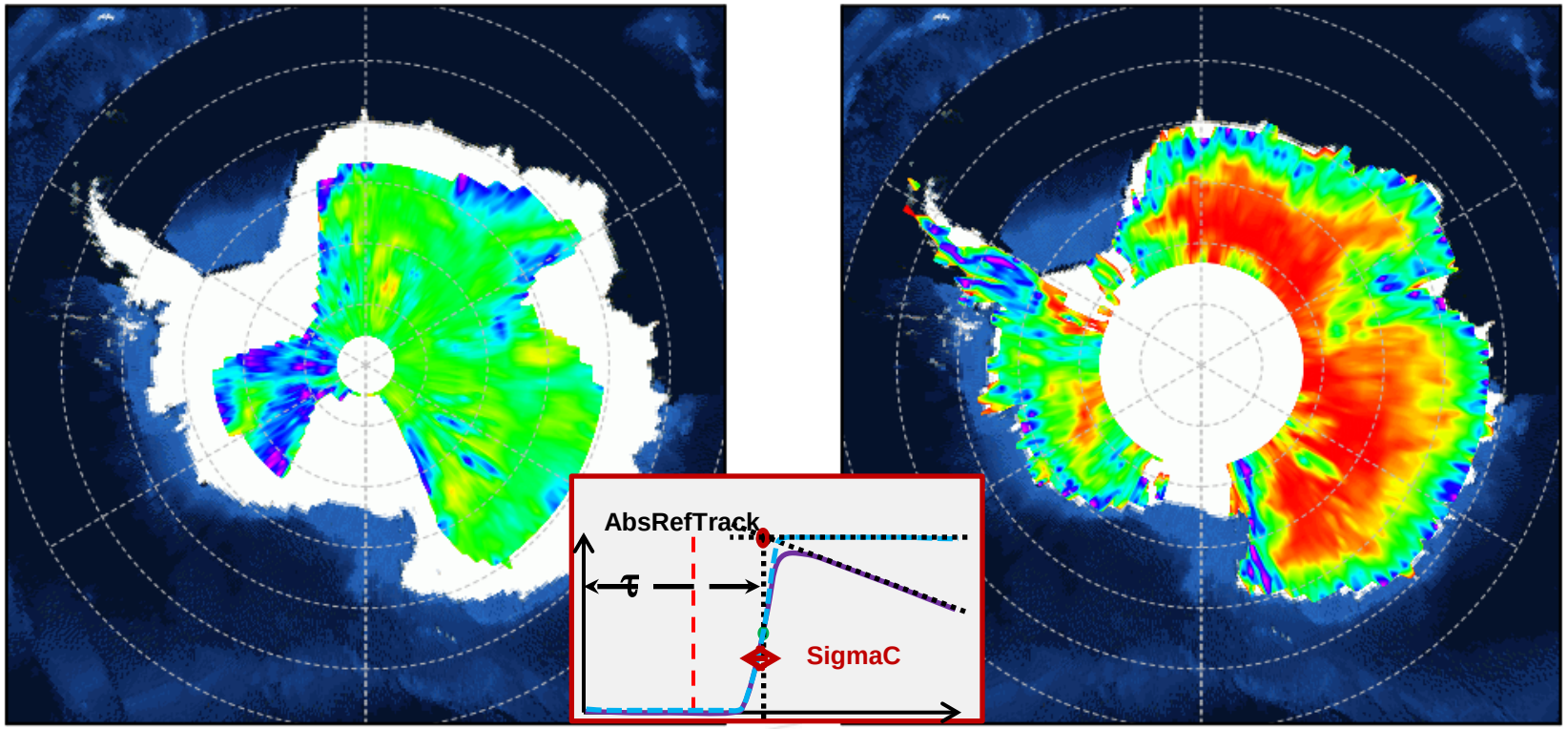
Collocated CS-2 / Saral measurements

SigmaC

CRYOSAT2 - CYC 048 & 049

SARAL - CYC 007



SIG_C = CORRECTED SIGL / SQRT(2.0) [m]

0.5 1.0 1.5 2.0 2.5

SIG_C = CORRECTED SIGL / SQRT(2.0) [m]

0.5 1.0 1.5 2.0 2.5

P.Thibaut, «Ku/Ka band observations over Polar Ice Sheets», CCT Glaciologie CNES 2014

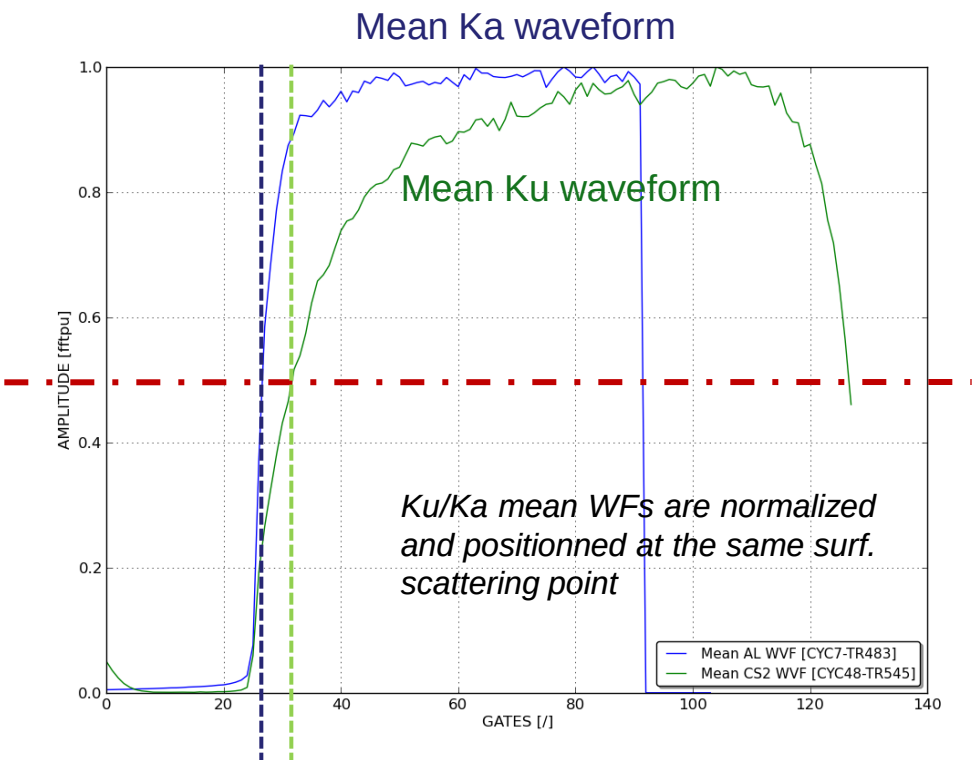
Ice-2 topography errors in Ku band

- In Ku band, a range bias is introduced by the ice-2 rtk which doesn't account for the volume scattering (around 2.5 m in our example)

- The antenna pattern correction is not done at the pintle axis position corresponding to the surface reflexion point (all individual echoes coming from the different layers are corrected by the same AGP)

- We should retrack the point corresponding to the surface reflexion

- Surface slopes impact a lot the shape of the WF (equivalent to mispointing angle) mainly in Ka band (reduced AGP)



5 Ku gates = 2.5 m

P.Thibaut, «Ku/Ka band observations over Polar Ice Sheets», CCT Glaciologie CNES 2014

Conclusions (1/3)

- Ku/Ka have different signatures on the echos (on τ, σ_L,S1, S2, SM) linked to their penetration properties in the water/snow/ice surface
- Accounting for the antenna gain pattern **is mandatory** for inter-comparison between missions (ERS/Envisat/Saral/Cryosat-2)
- LEGOS (F.Remy) is defining corrections (Echo and Geo) to account for the penetration of the wave in the layer and cross-track surface slopes. The validity of these corrections has to be checked (and potentially updated) considering the output of this work (for all missions but in particular for RA-2)

Conclusions (2/3)

- Same orbit than ERS-1, ERS-2 and RA-2
  - ➔ **20 years of continuous observation**
- Excellent behavior of the Saral tracker over ice sheet and sea ice
  - ➔ **very few loss of data**
- Narrower beamwidth for Saral than for Envisat
  - ➔ **echos less impacted by off-nadir returns (but more impacted by slope effects)**
- Penetration depth much smaller in Ka (divided by 30 wrt to Ku)
  - ➔ **Better estimation of the surface height**
- Smaller range resolution (32 cm in Ka wrt 47 cm in Ku)
  - ➔ **increased accuracy of the height estimation**
- Increased Pulse Repetition Frequency (PRF : 4KHz wrt 2KHz)
  - ➔ **increased spatial sampling of the surface**
- First simultaneous active and passive measurements in Ka band

➔ **Great performances of SARAL/AltiKa !!**

Conclusions (3/3)

Many studies can be done on the subject (on topography but also on surface slopes and penetration depth).

- A monitoring of the ice sheets can be performed using the full reprocessed data set (and merging all missions) (20 years of data)
- Height trends and Mass balance of the continental ice caps
- Characterisations of the errrors ?
- Polarisation effects at cross-overs
- Validity of the Bamber model to be checked ? (Bamber = ERS data set + icesat). Validation of Bamber with Saral data. Comparison of slopes.
- What about SAR mode over ice sheet (CS-2 in LRM but S3 …) ? Which algorithm, on stacked data, on bursts, on individual echo ?
- Greenland ? Covered by SAR CS-2 data. Good testing area for S3.
- Etc … etc … A lot to do !!!