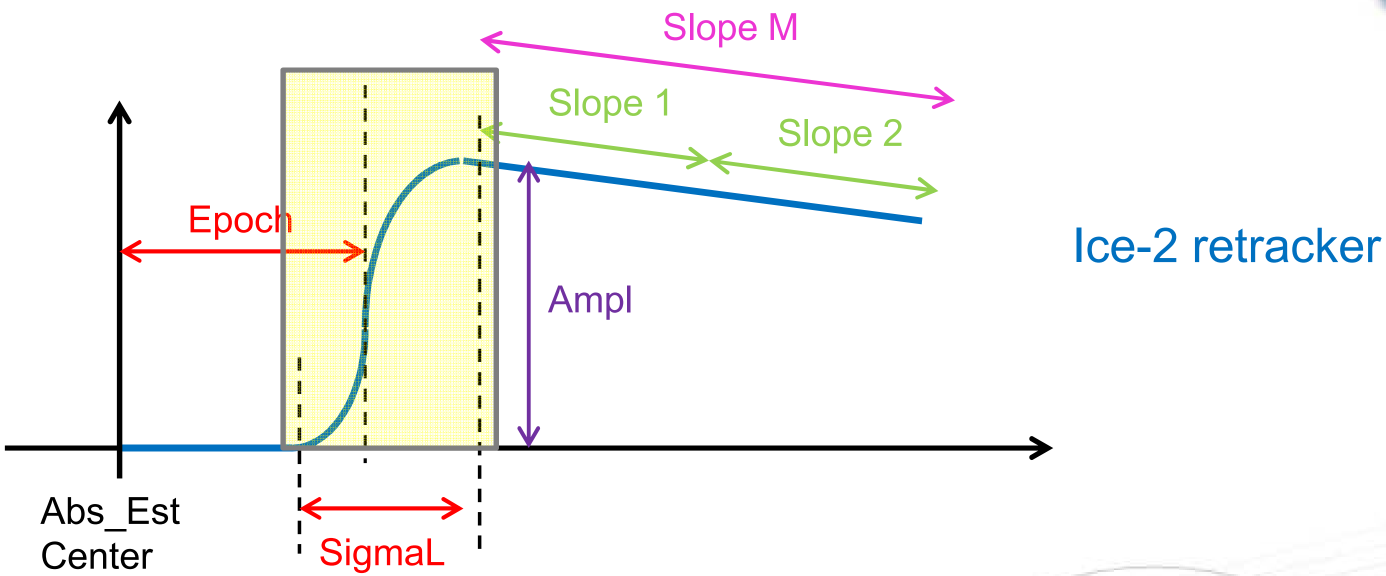
Ku/Ka band observations over Polar Ice sheets

P.Thibaut, Y.Lasne, F.Mercier : CLS
A.Guillot, N.Picot : CNES
F.Remy, D.Blumstein : LEGOS

Context

- First opportunity to compare Ku and Ka measurements over ice sheets (Envisat/RA-2 & CS-2 LRM, SARAL) with the aim to better understand the historical measurements in Ku band (ERS and RA-2) 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 (originally for ERS and RA-2)
- Some evolutions have been introduced in the algorithm mainly to account for the **antenna gain pattern (AGP)** and **for the PTR width**
- The ice-2 algorithm is implemented in the SARAL ground processing but also used for RA-2 and ERS ½ reprocessing and in the next Sentinel-3 ground processing

Principle of the ice-2 retracker (LEGOS)



Epoch and SigmaL are computed by fitting **<u>a simplified Brown model</u>** 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

P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Principle of the ice-2 retracker

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

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

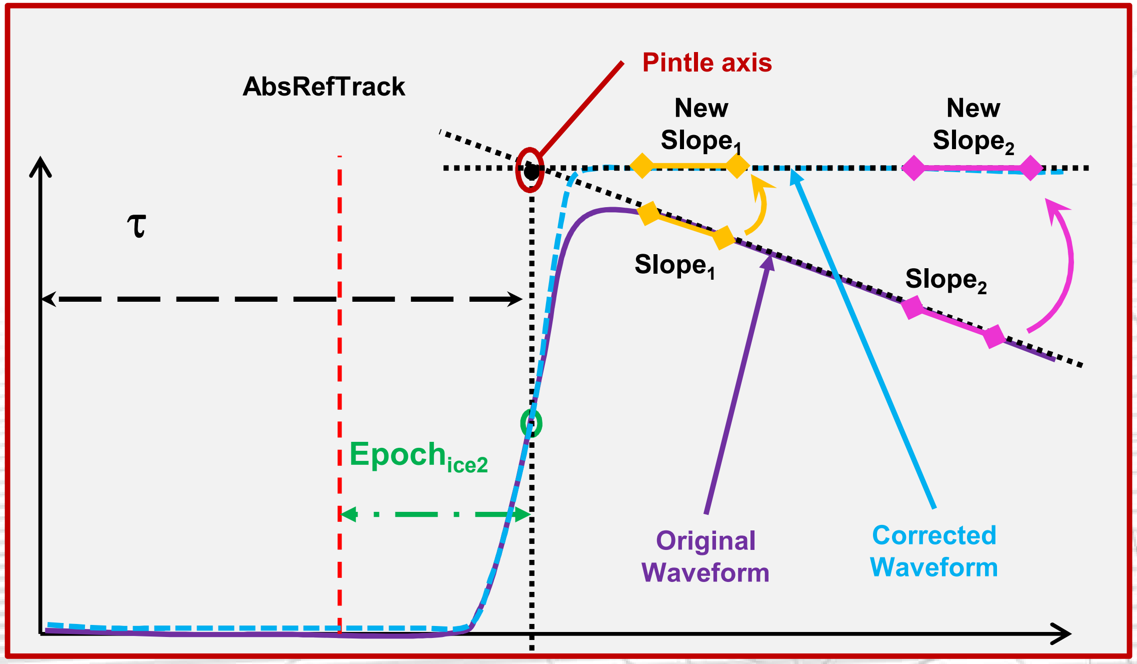
- where :
  - S_t = Slope of the logarithm of the trailing edge
  - σ_L = width of the leading edge

This term is not accounted for in then current processing chains.
For the study, we introduced it in the model

- Identifying each term, it comes:

$$s_t = -\frac{4c}{\gamma h\left(1+\frac{h}{R_e}\right)} \qquad \gamma = \frac{2}{Log_e(2)}\sin^2\left(\frac{\theta_0}{2}\right)$$

- WF must be corrected for the antenna gain pattern before to compute the slopes of the trailing edge

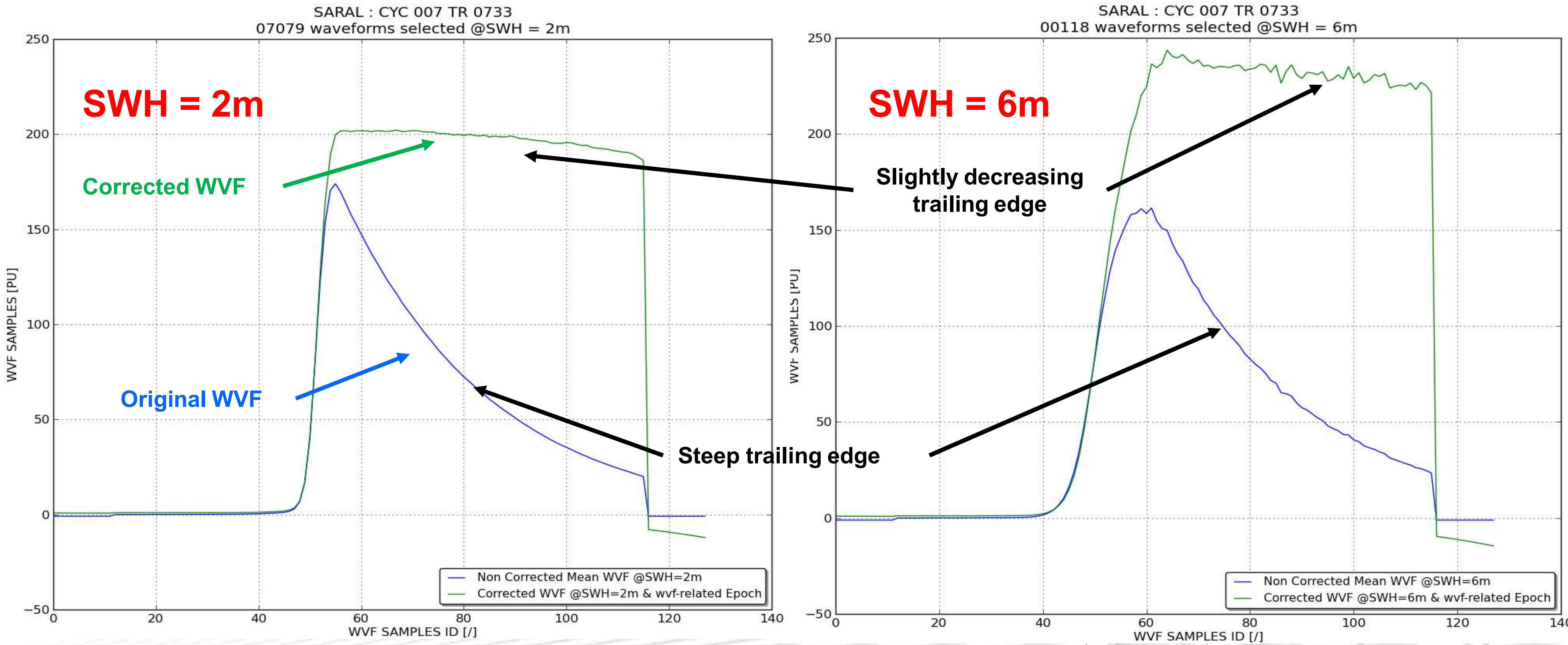


P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

SARAL echos corrected for the AGP (over ocean)

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

Ka band



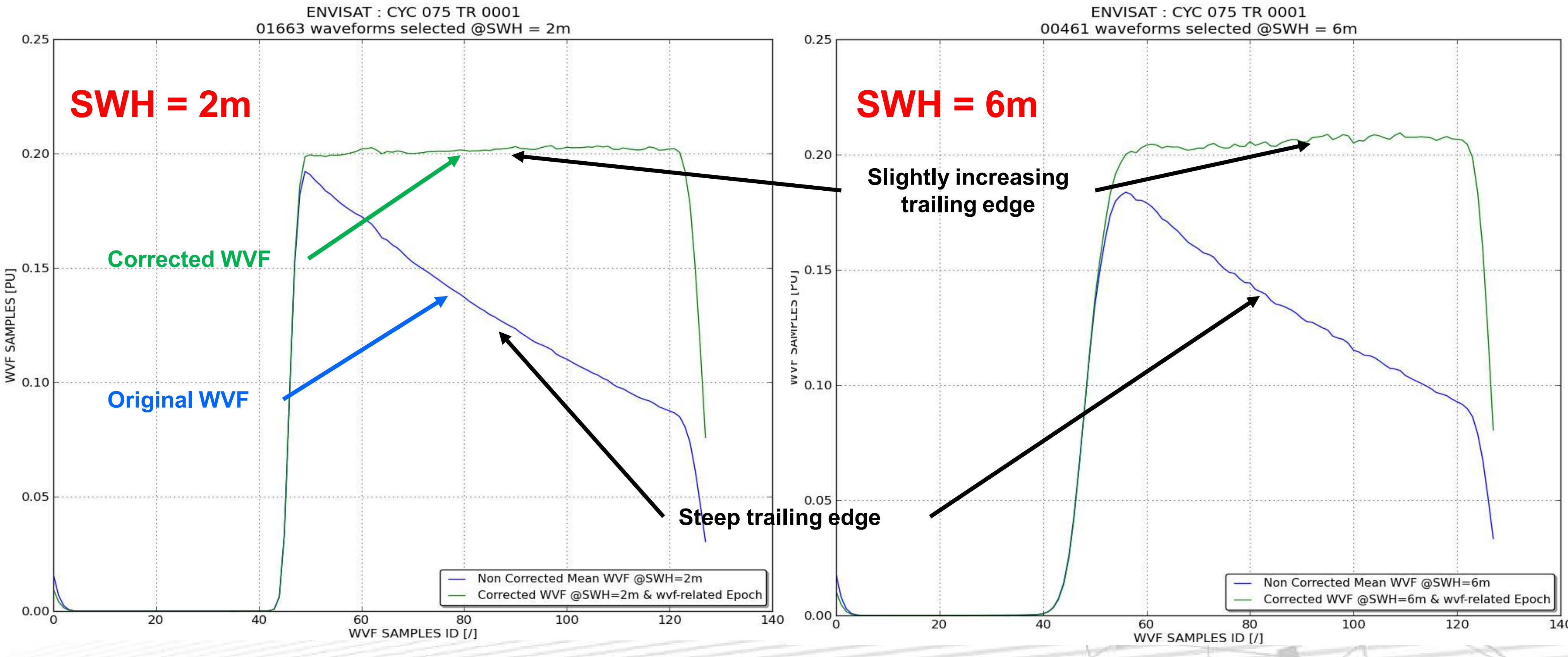
Filter correction applied (CAL LTM 2014/02/03)

P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

ENVISAT/RA-2 echos corrected for the AGP (over ocean)

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

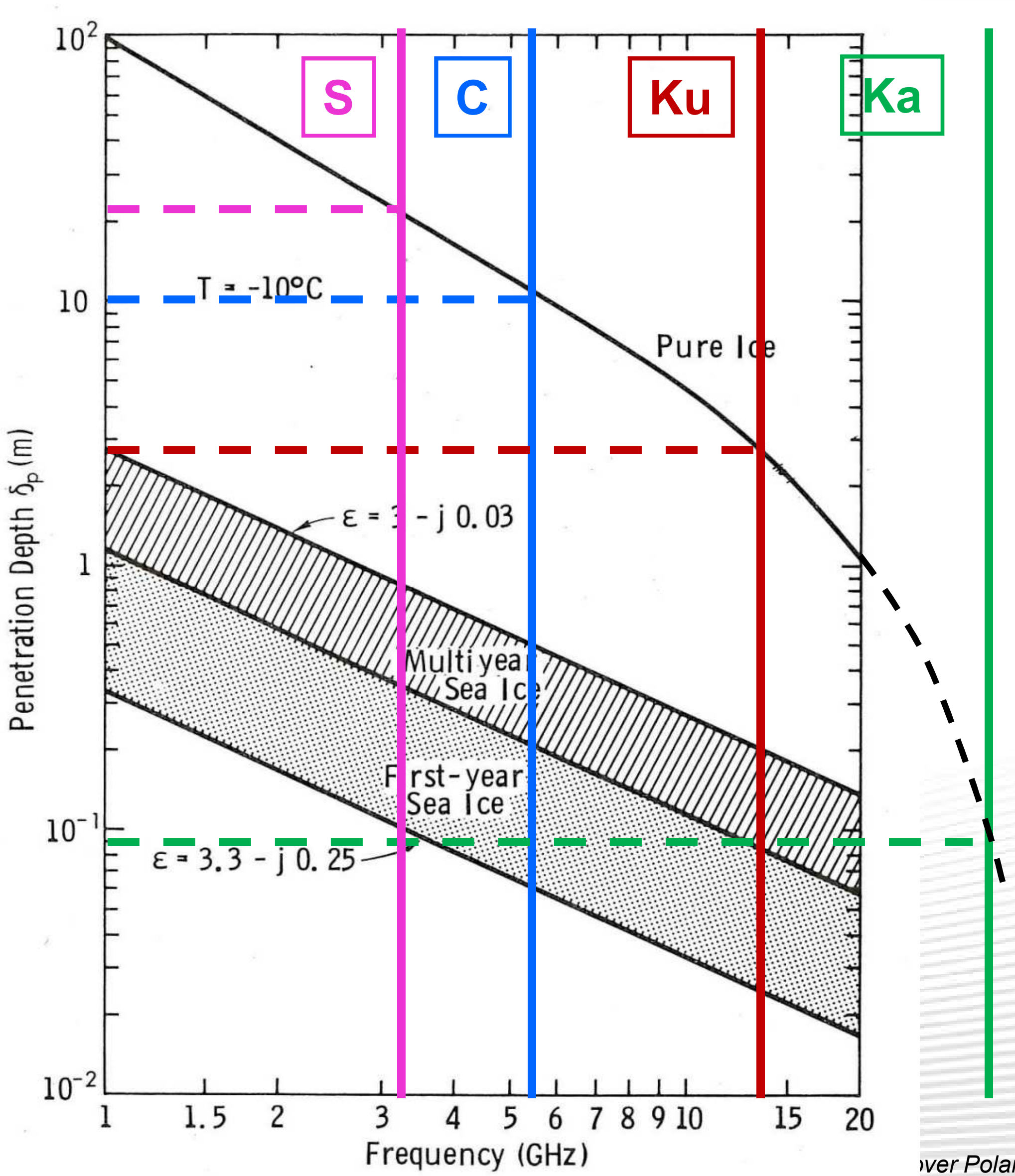
Ku band



Filter correction included in the RA-2 waveforms

P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Radar wave penetration depth (Ulaby, 1986)



Pure ice : *(values given at -10°C)*

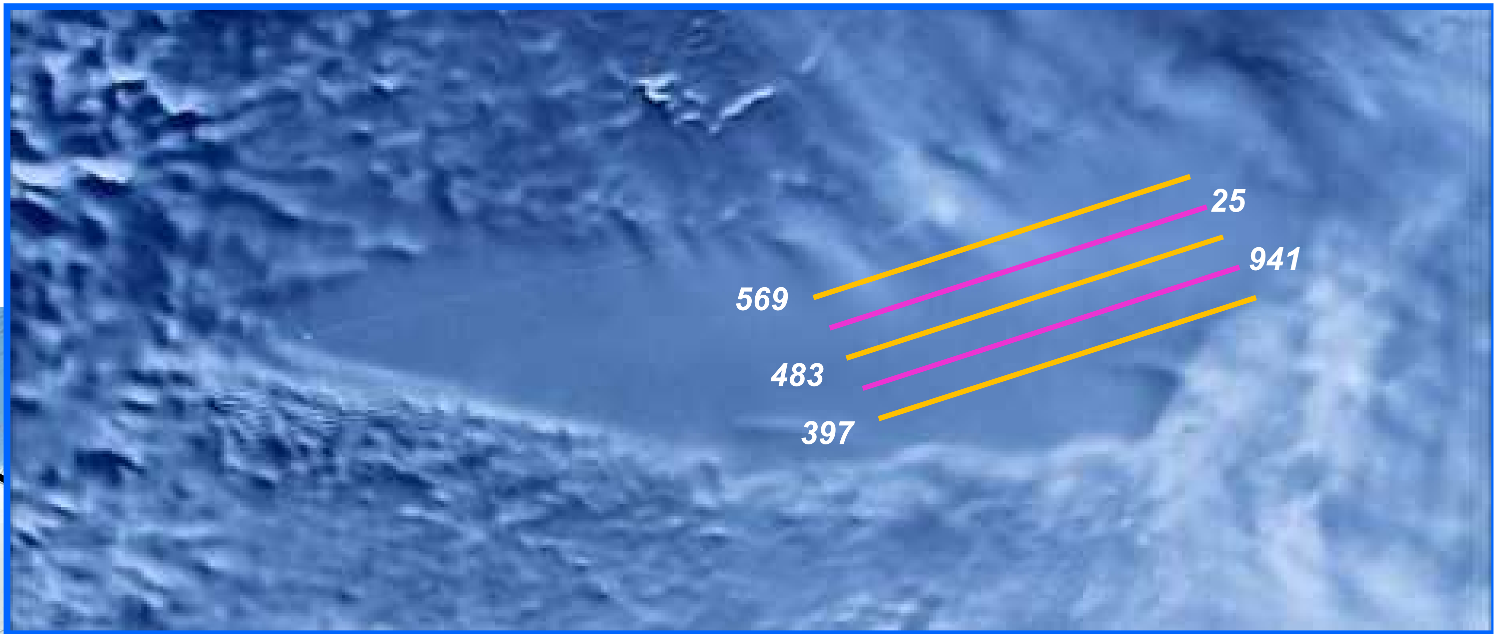
- ✓ S band penetration : 20 m
- ✓ C band penetration : 10 m
- ✓ Ku band penetration : 3 m
- ✓ Ka band penetration : < 10 cm

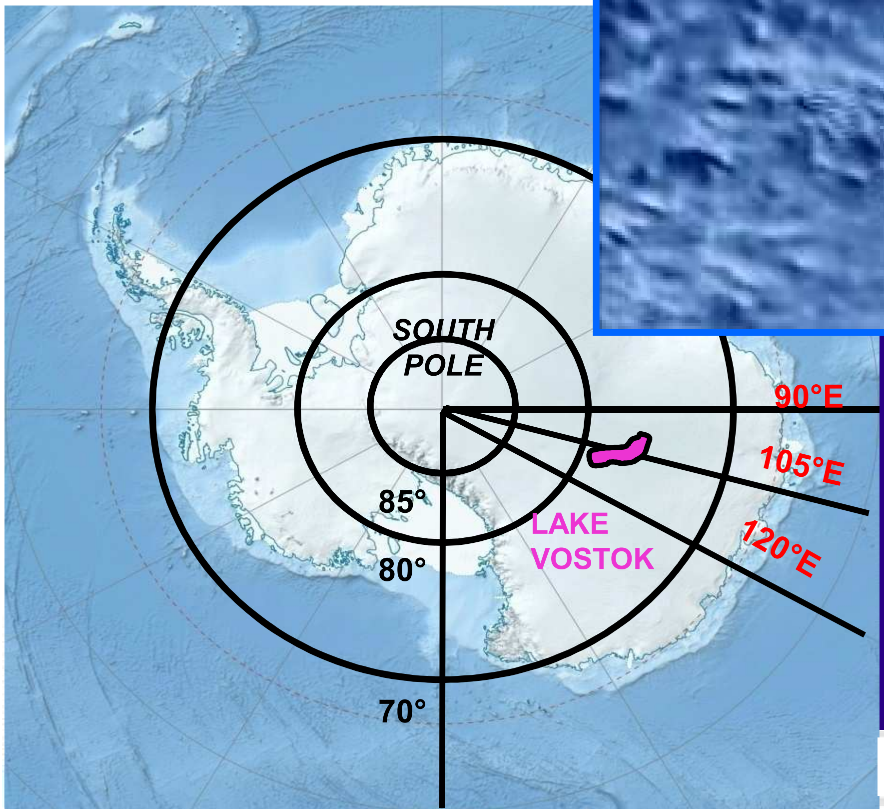
(For lower temperatures)

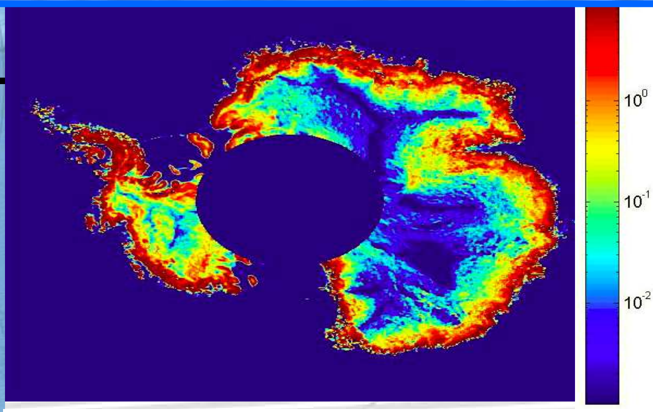
- ✓ Ku band penetration : 5-12 m
- ✓ Ka band penetration : < 1 m

Application on real echos over Antarctica

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







Slopes of the surface, F.Remy, LEGOS

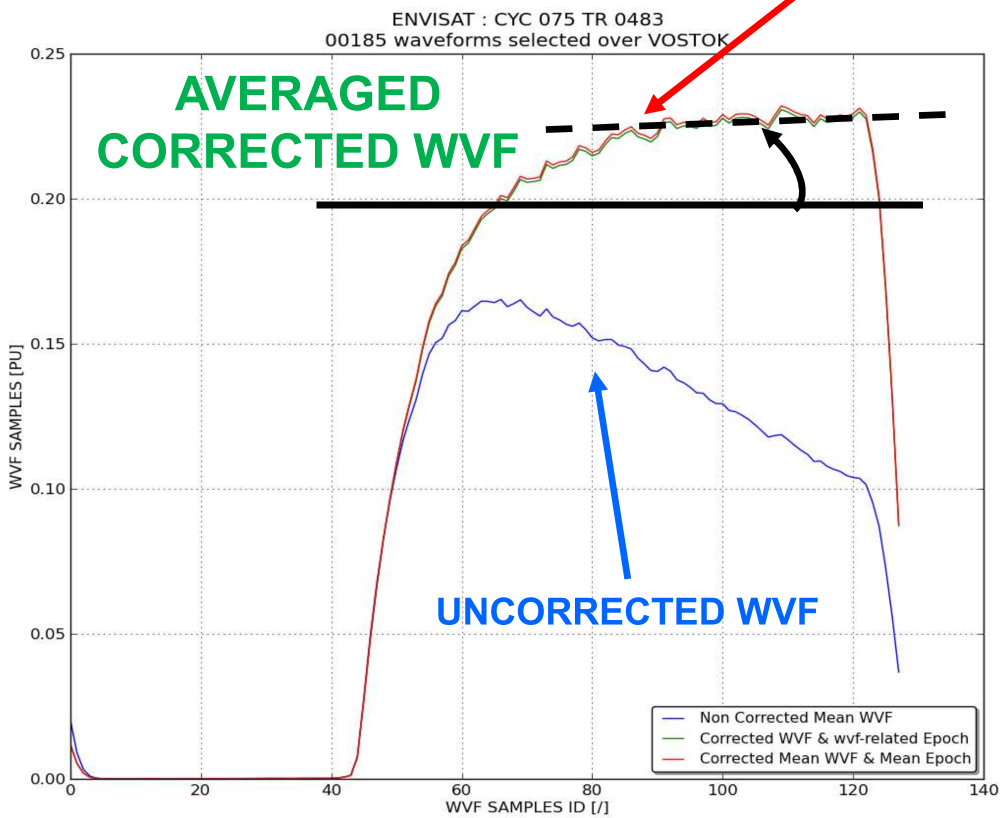
RADARSAT SENSOR IMAGE

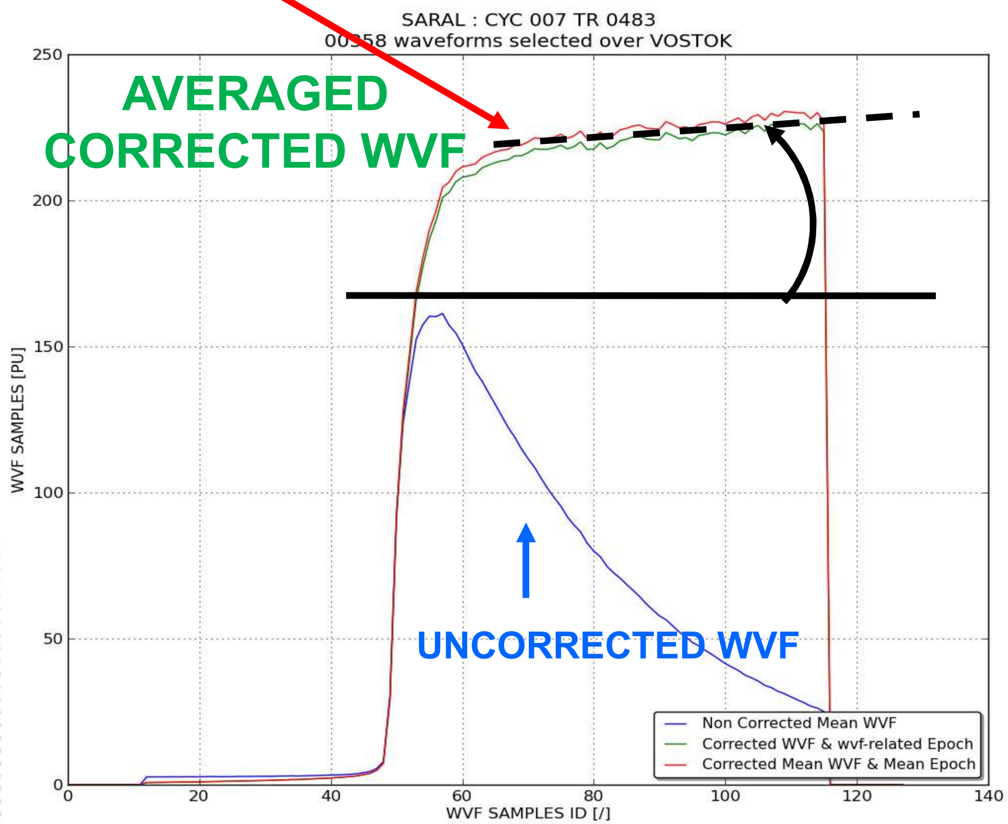
Ku/Ka Waveforms on subglacial Vostok lake pass 483 (lat -76.8 et -76.2 deg)

ENVISAT
CYC 75 TR 483

Ice body physical properties effect (predominance of surface scatterring for Ka, volume scattering for Ku)

SARAL
CYC 7 TR 483



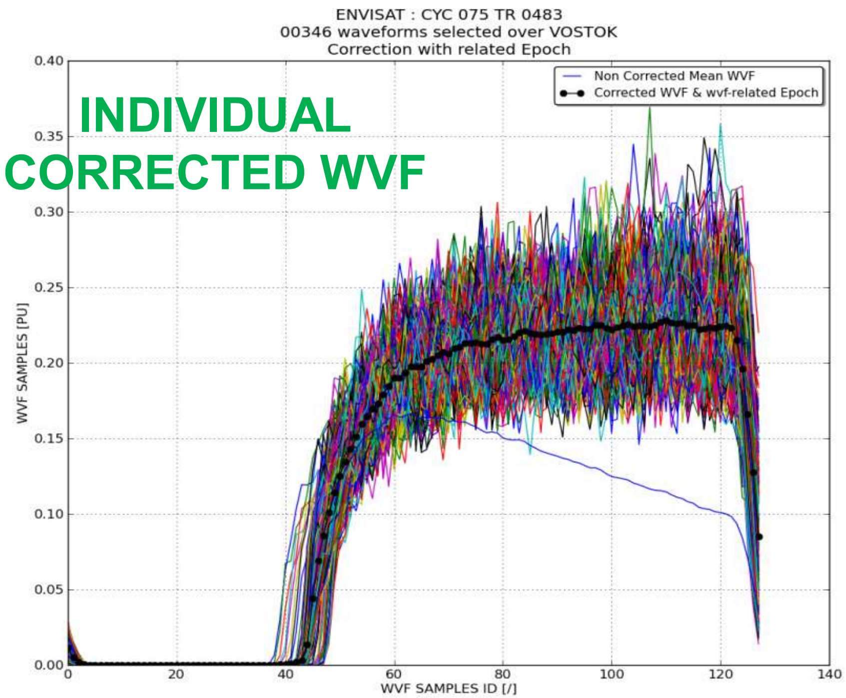


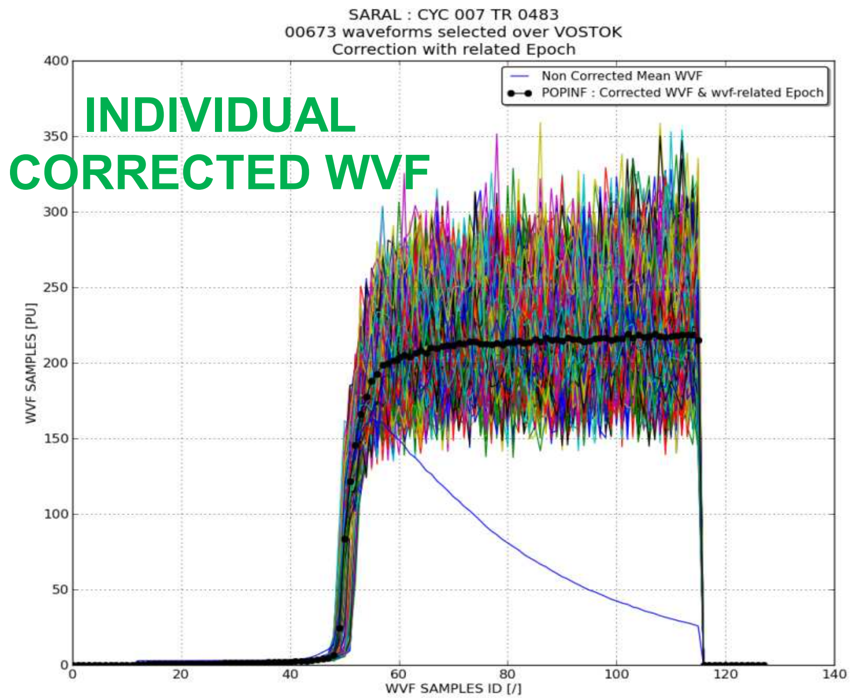
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

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





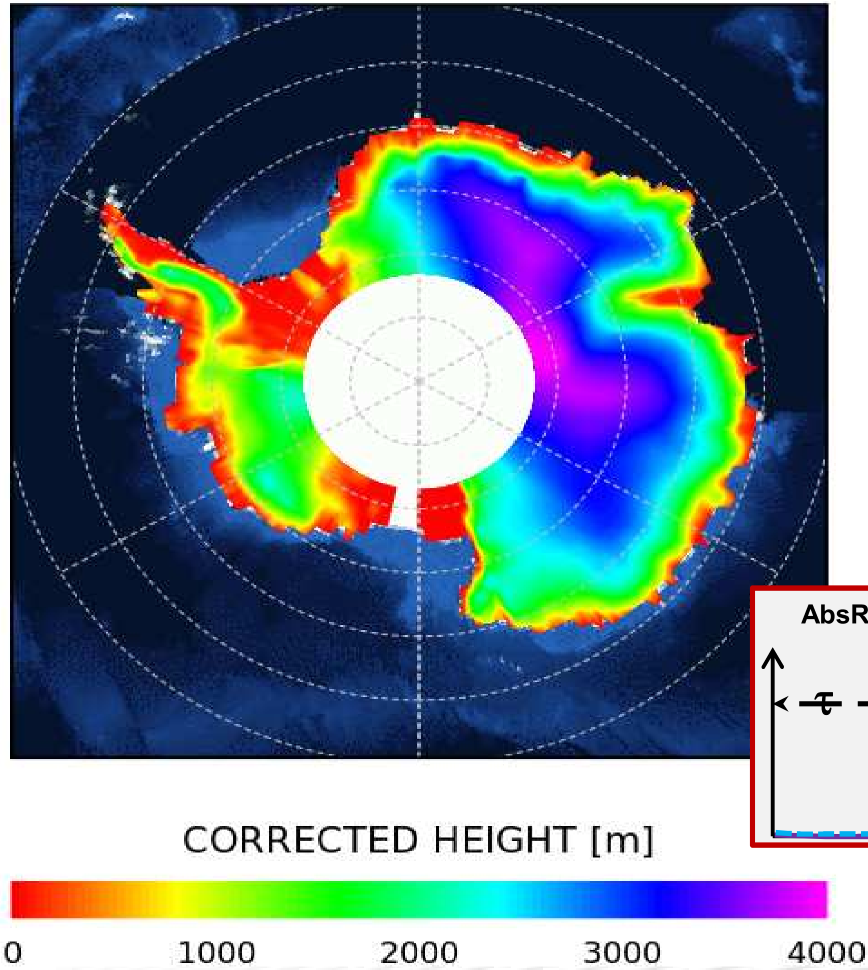
➔ Clear effect of volume scattering in Ku waveforms

➔ Much less in Ka

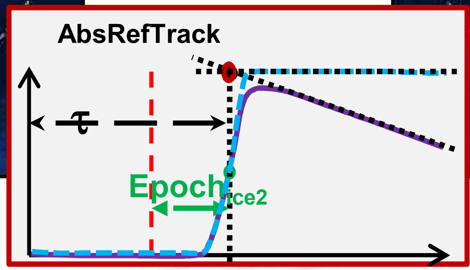
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Application on real echos over Antarctica

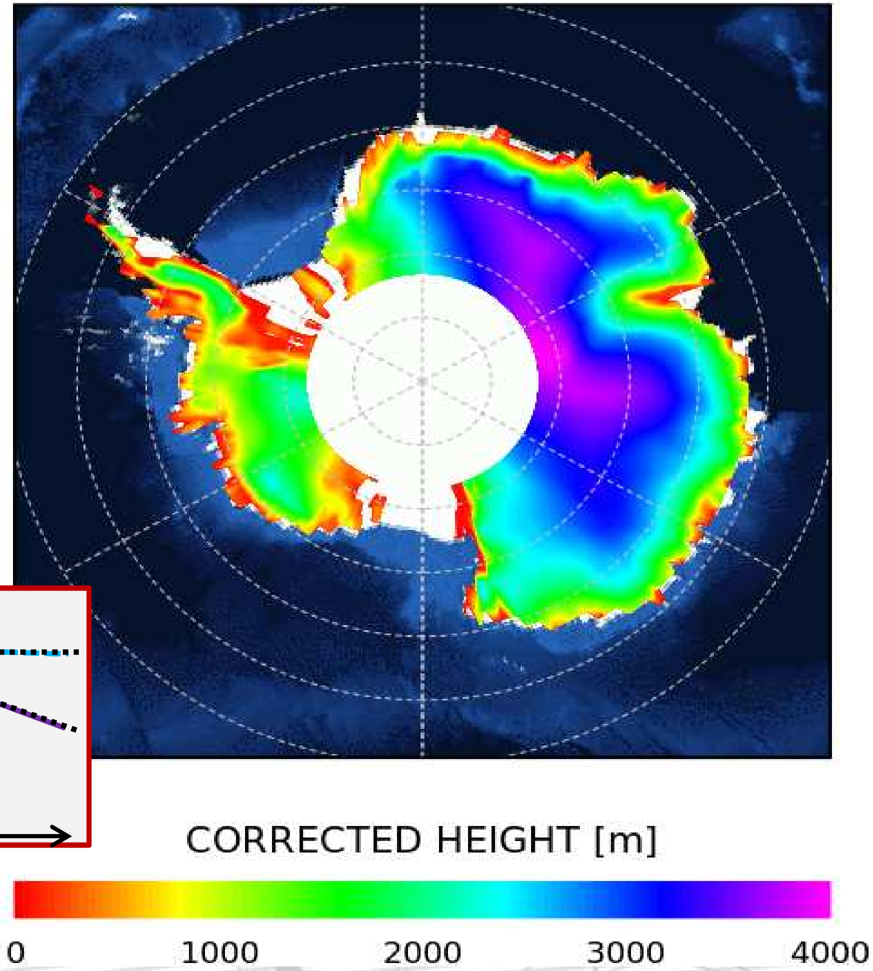
ENVISAT - CYC 075



Height



SARAL - CYC 007



Heights should be the same but :

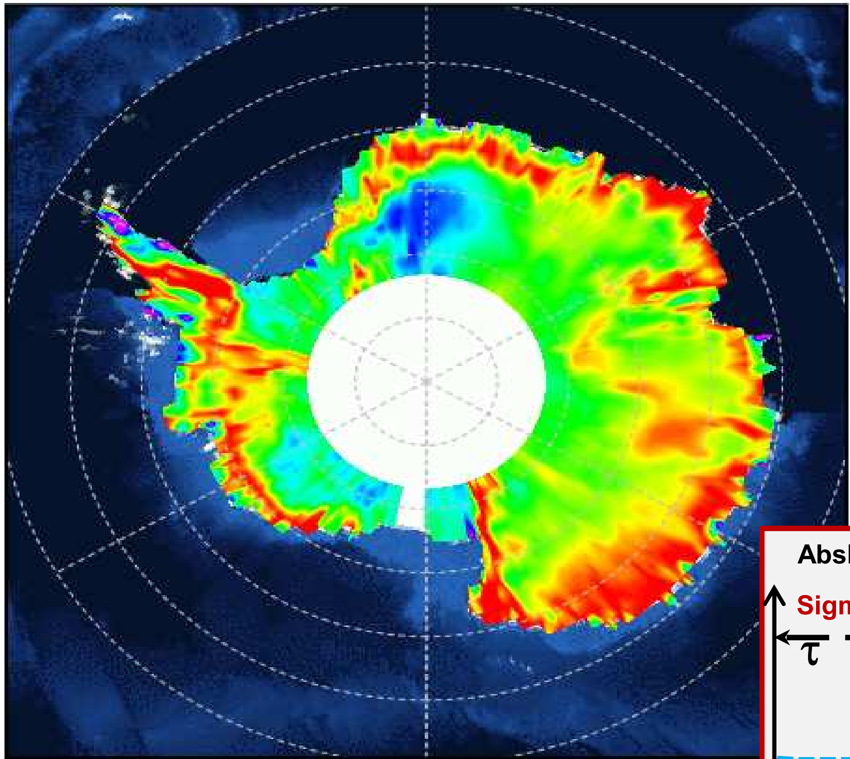
- Saral is much more impacted by surface slopes
- The penetration depth is much higher on Ku band wrt to Ka (not visible with this scale)
- Periods are different .

P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

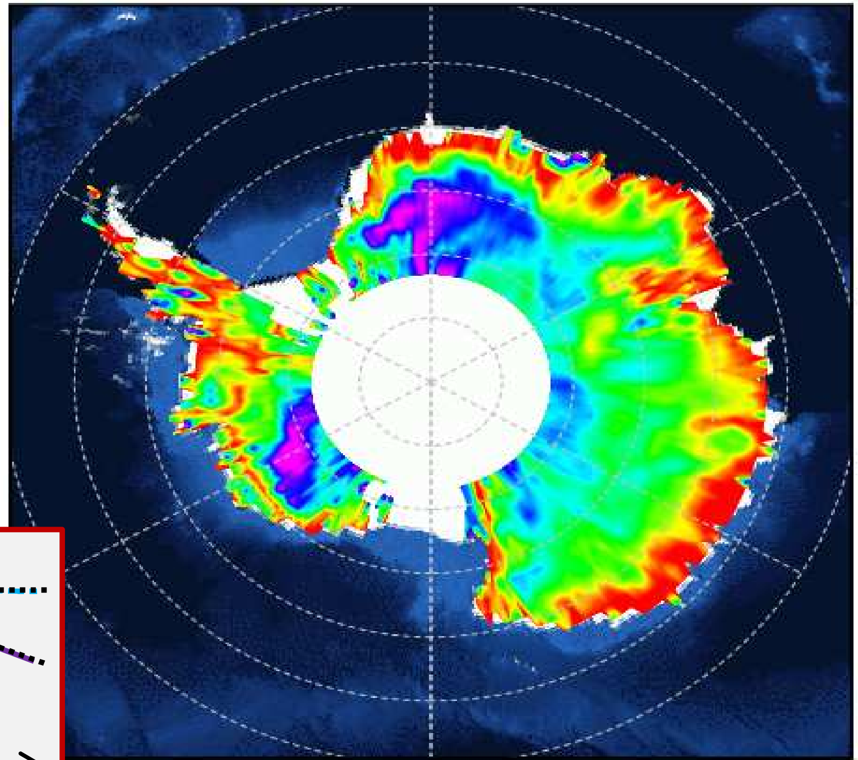
Application on real echos over Antarctica

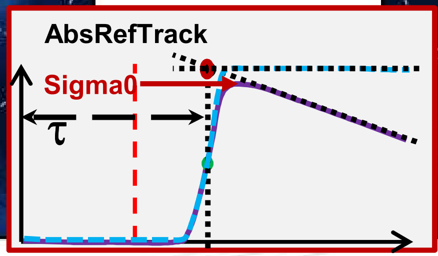
Sigma0

ENVISAT - CYC 075



SARAL - CYC 007





CORRECTED SIG0 [dB]

CORRECTED SIG0 [dB]

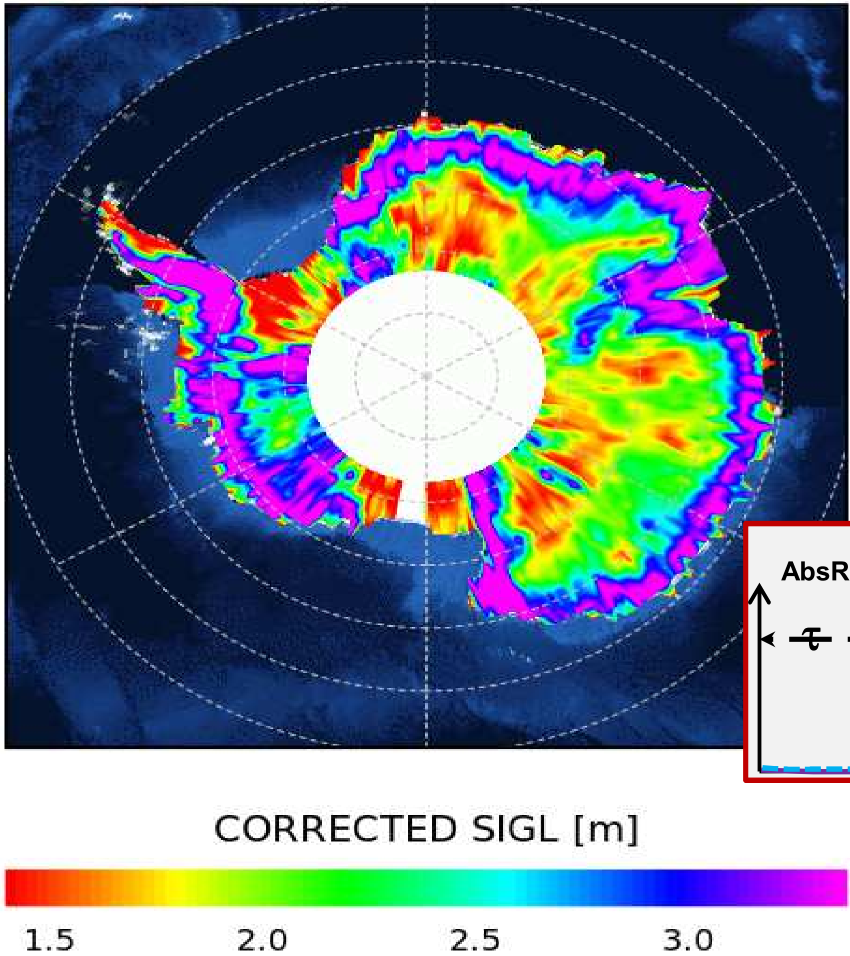
Some patterns are different. Non linear relationship between Ku/Ka sigma0.

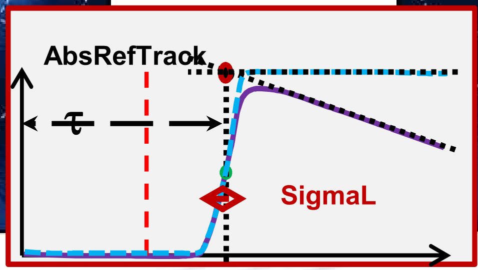
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Application on real echos over Antarctica

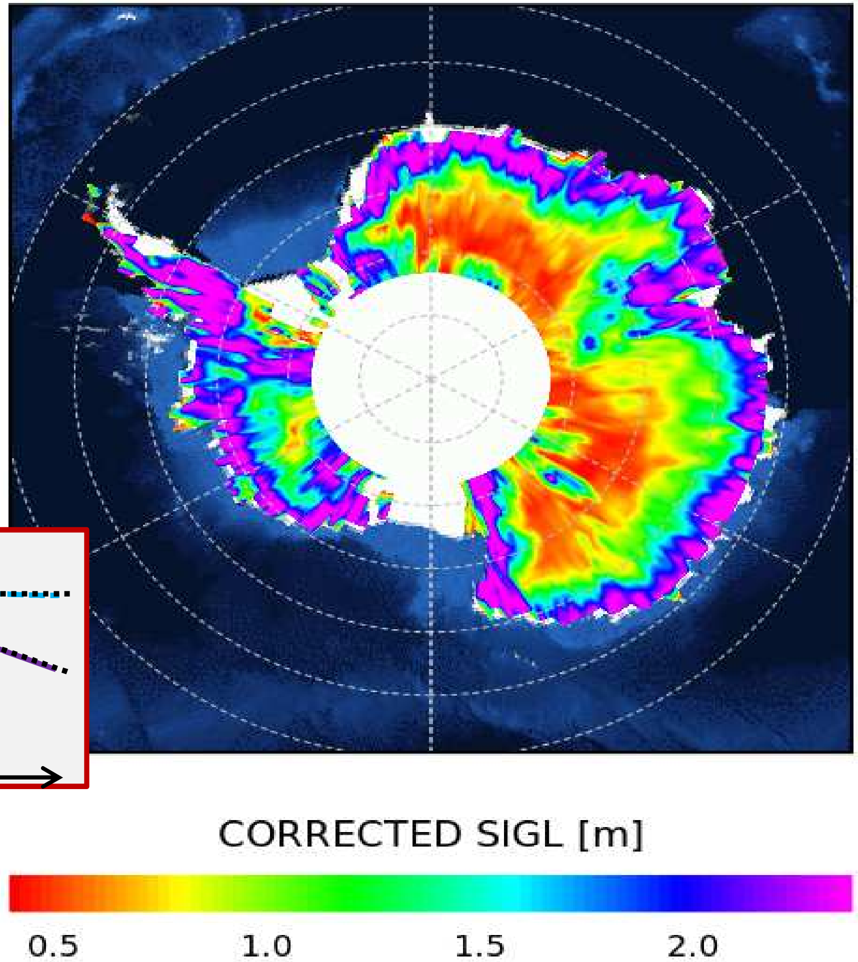
SigmaL

ENVISAT - CYC 075





SARAL - CYC 007

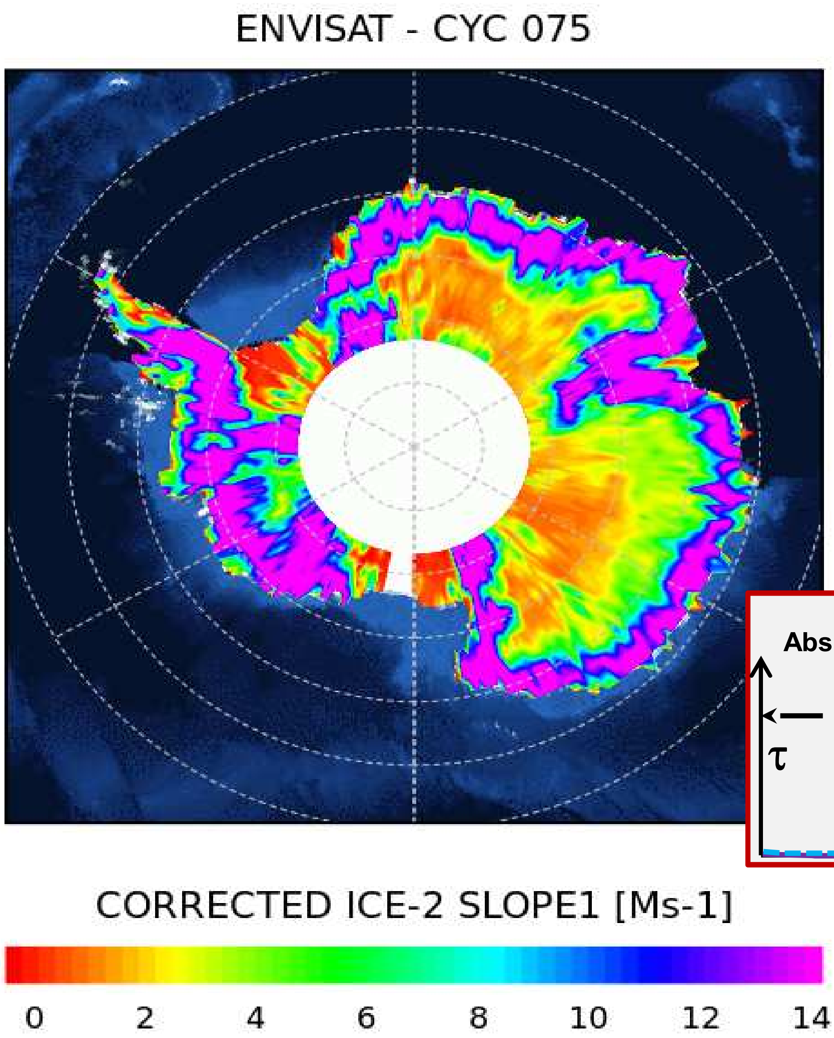


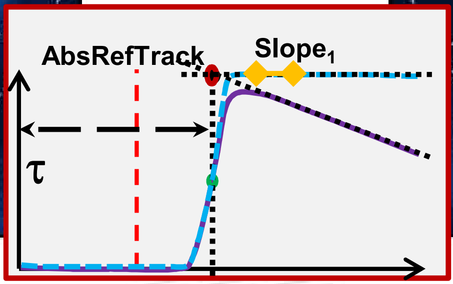
Patterns obviously different. Clearly linked to the penetration depth smaller for Saral

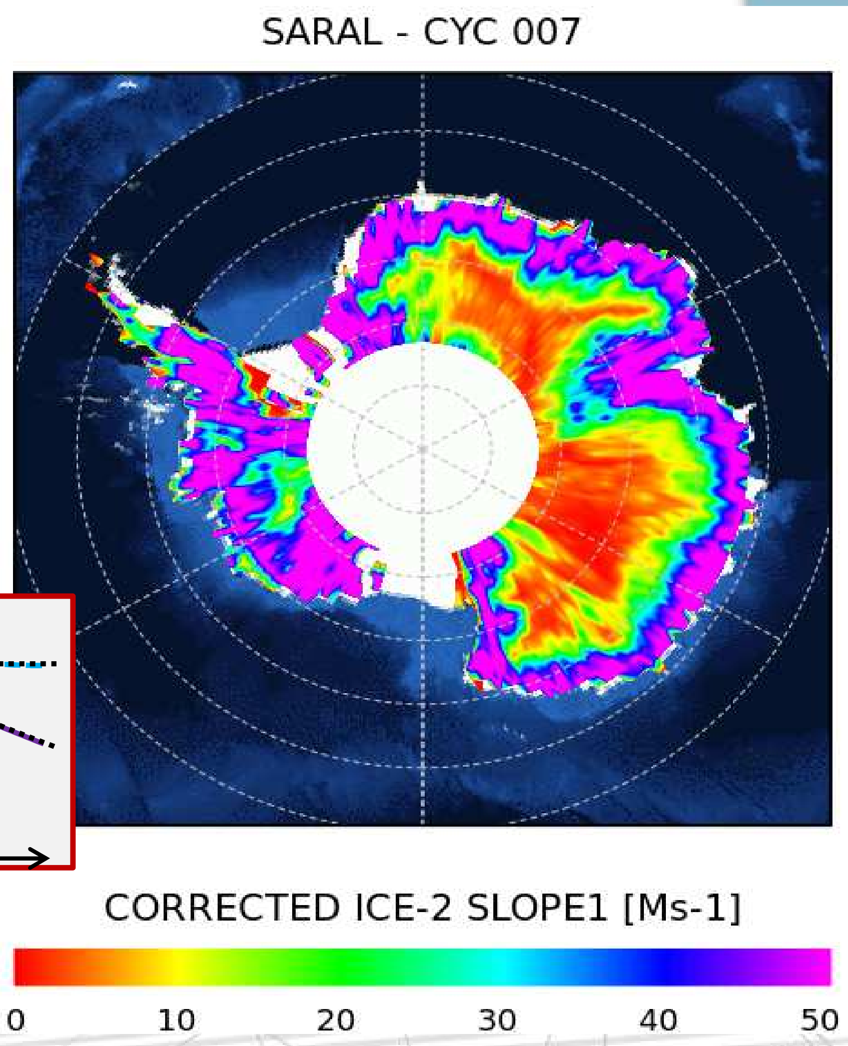
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Application on real echos over Antarctica

Slope1





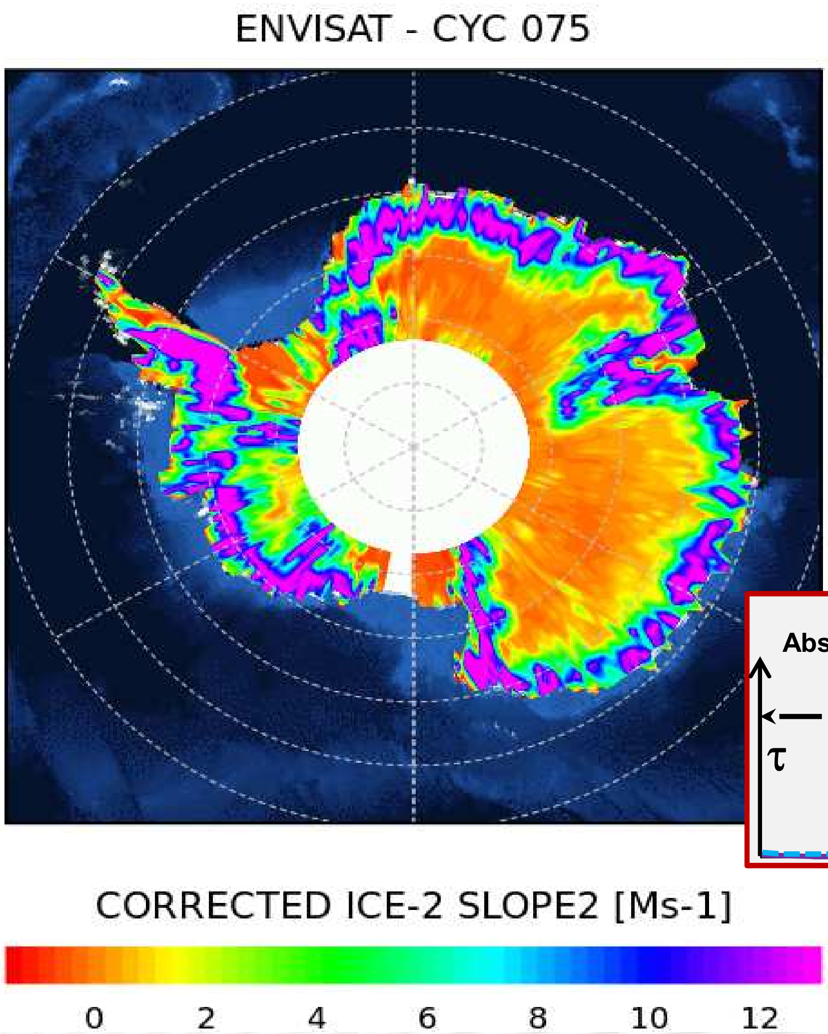


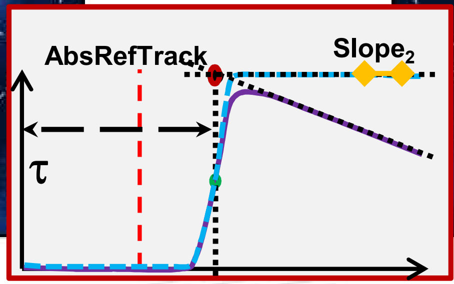
SARAL much more impacted than Envisat/RA-2 by surface slopes (smaller antenna gain pattern)

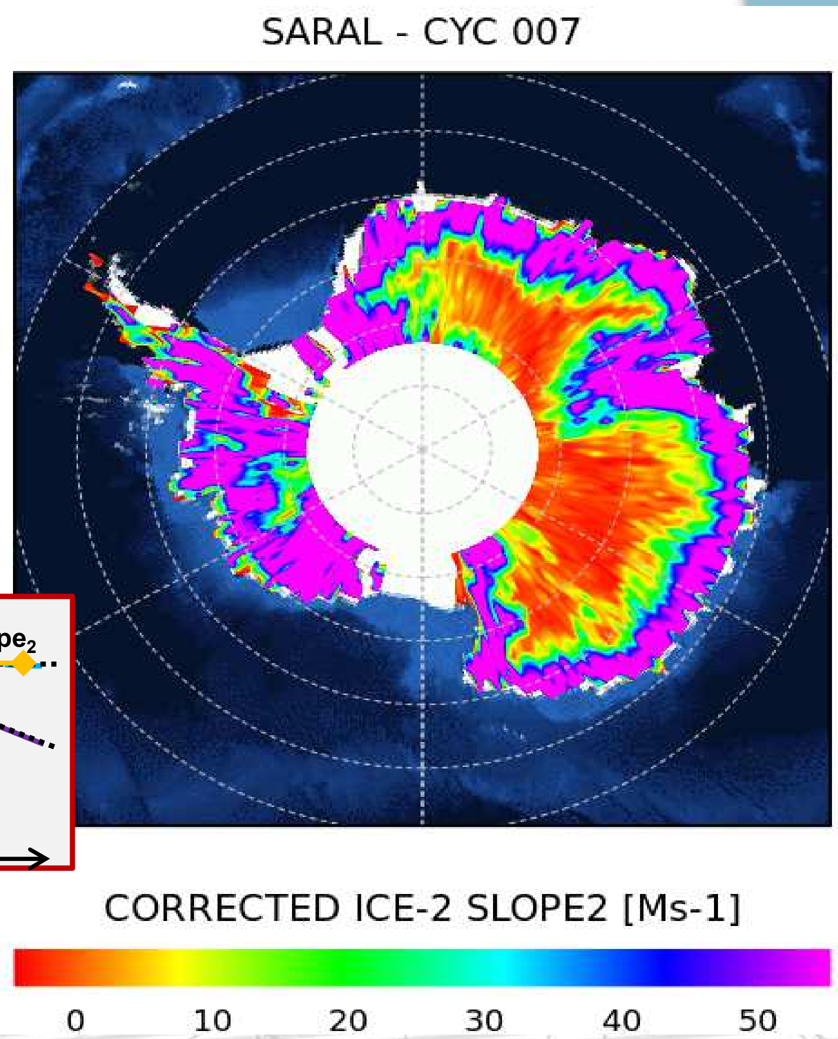
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Application on real echos over Antarctica

Slope2





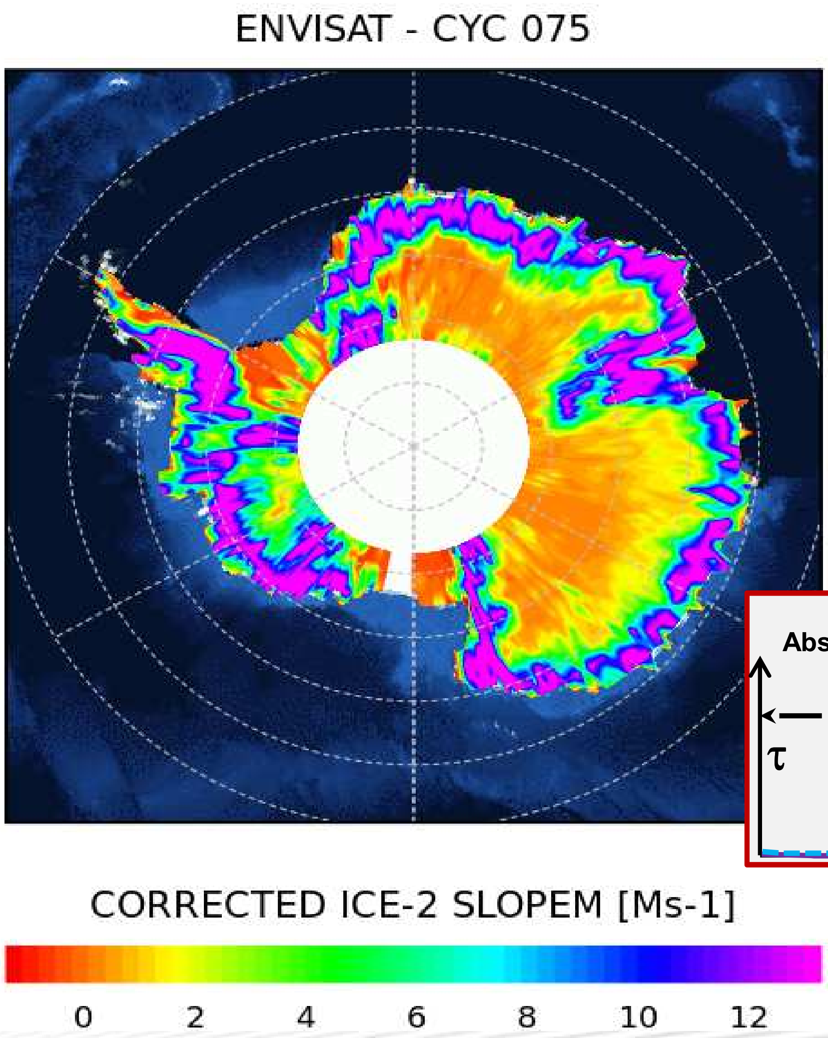


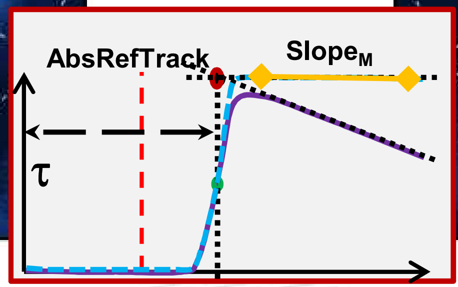
SARAL much more impacted than Envisat/RA-2 by surface slopes (smaller antenna gain pattern)

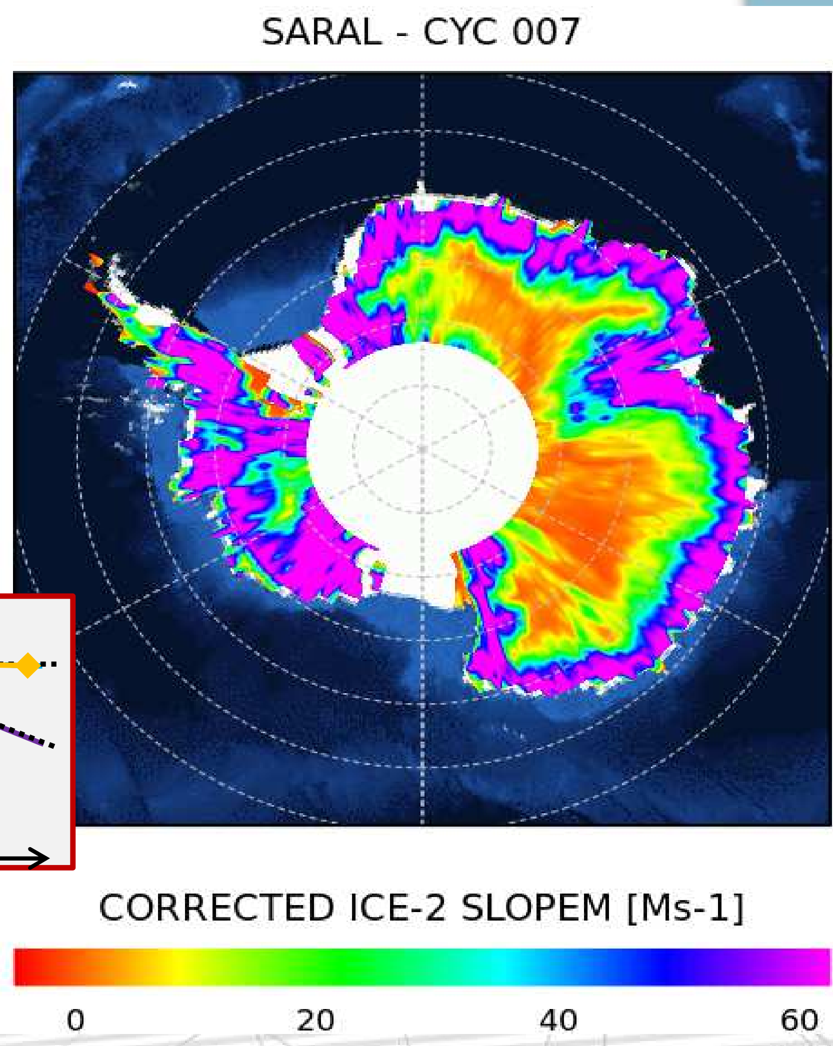
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Application on real echos over Antarctica

SlopeM







SARAL much more impacted than Envisat/RA-2 by surface slopes (smaller antenna gain pattern)

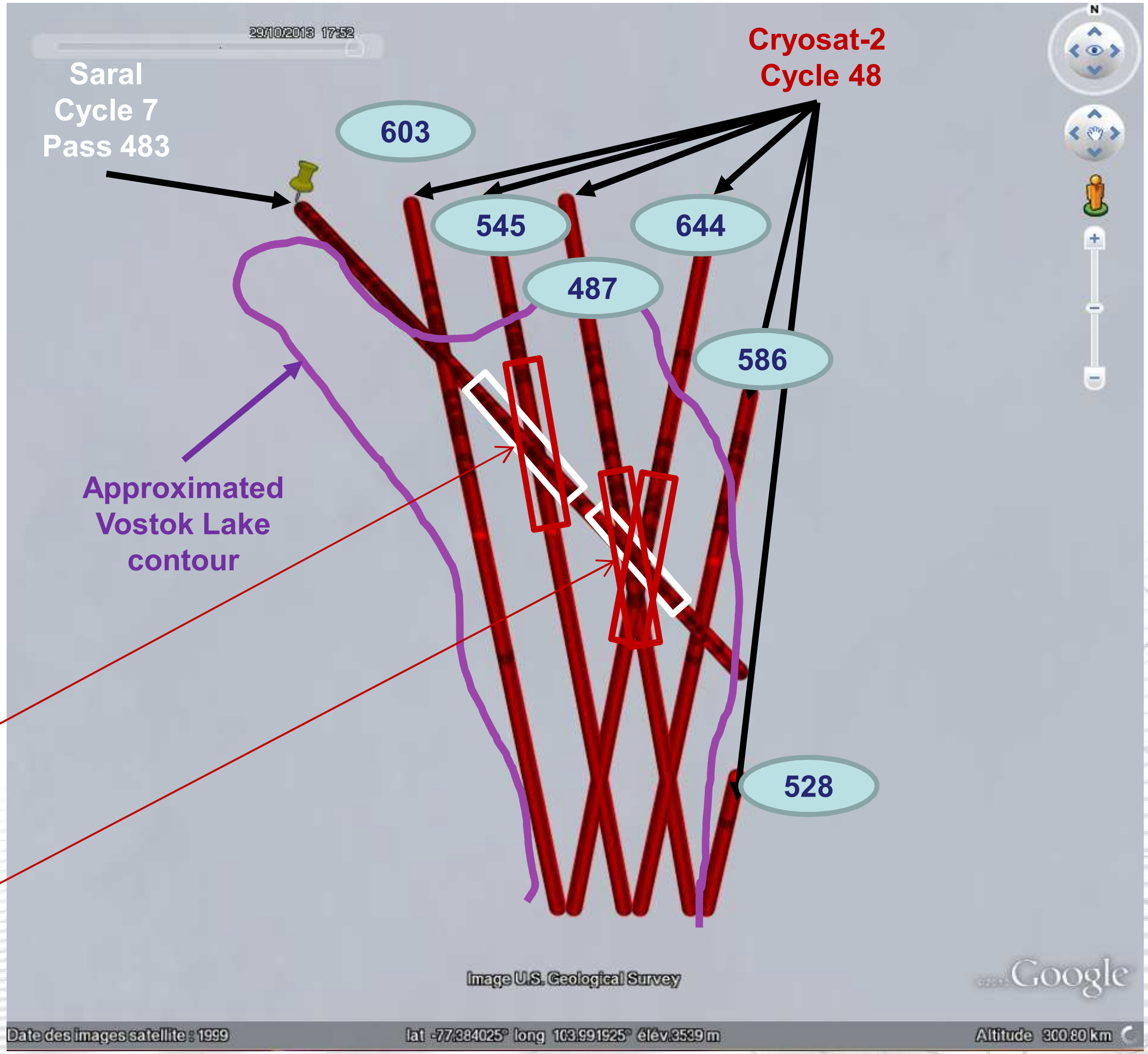
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

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

Cryosat-2 - Cycle 48

Saral - Cycle 7

X-over < 3 days

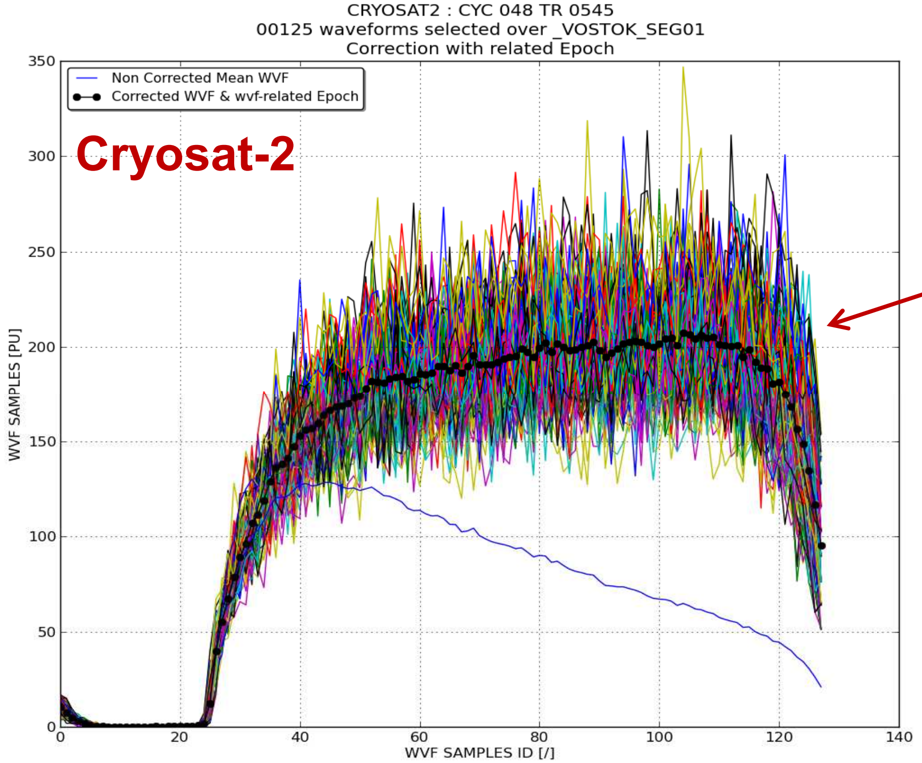


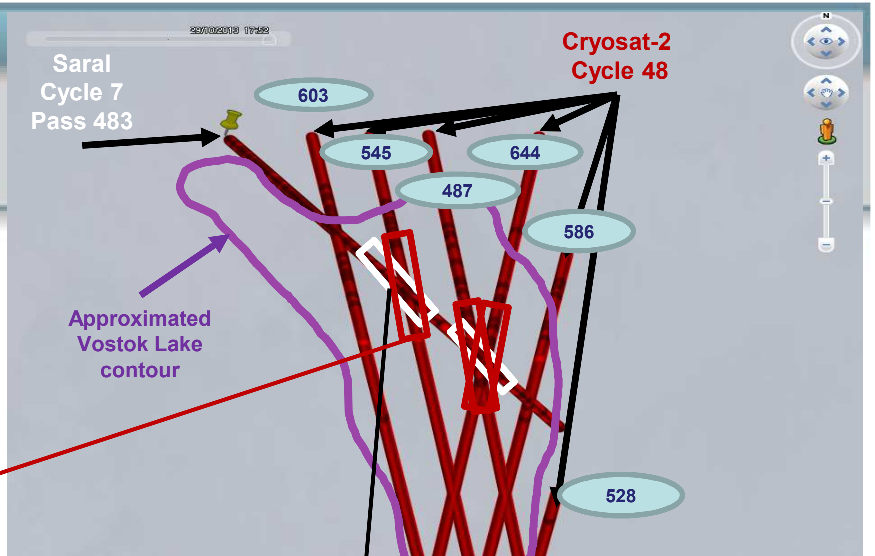
Delta time : 17 hours

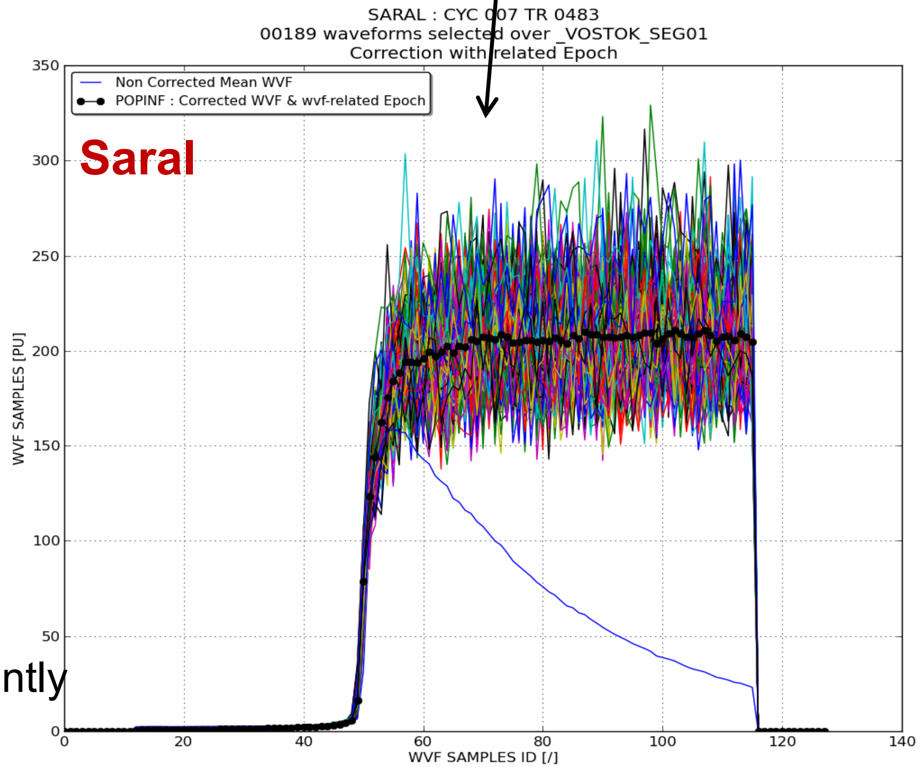
Delta time P487 : -3 days
Delta time P644 : +2 days

P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Waveforms at X-overs



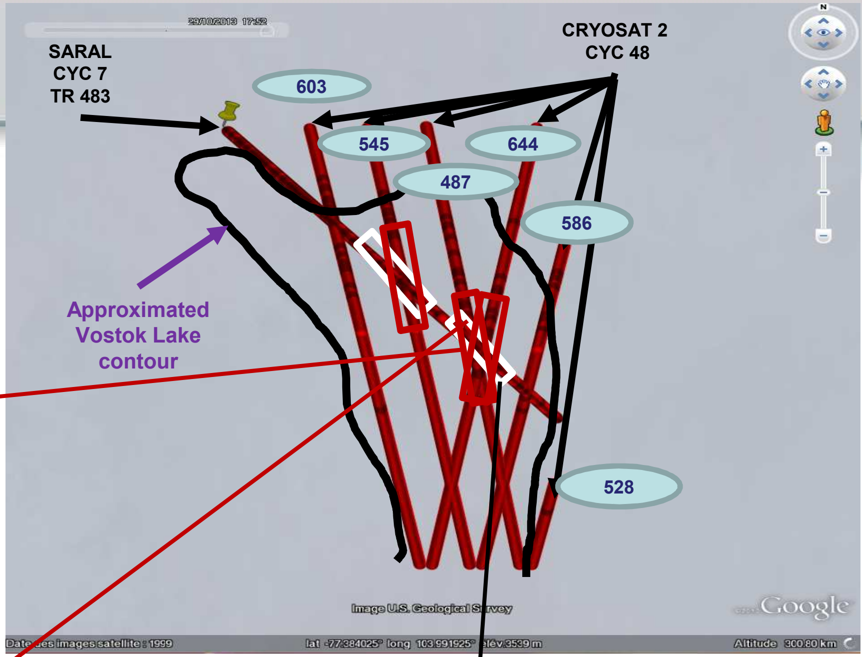


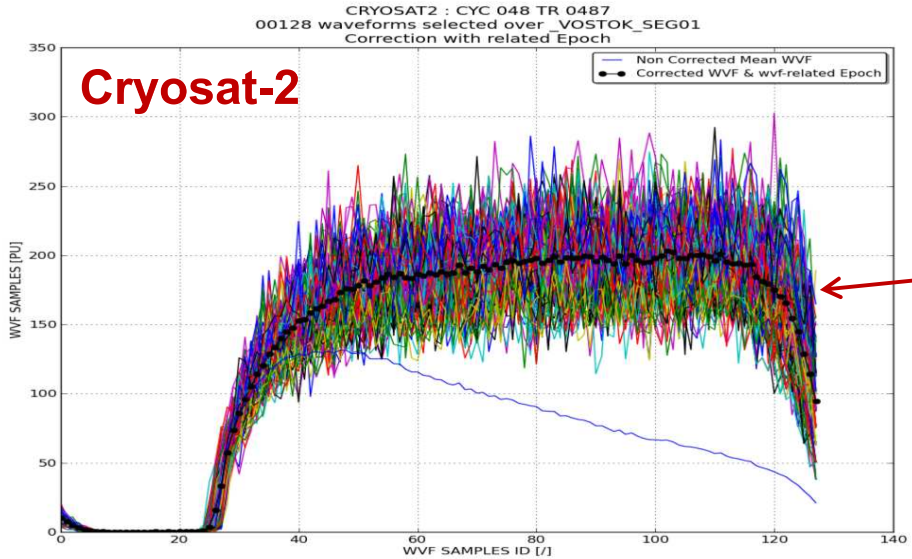


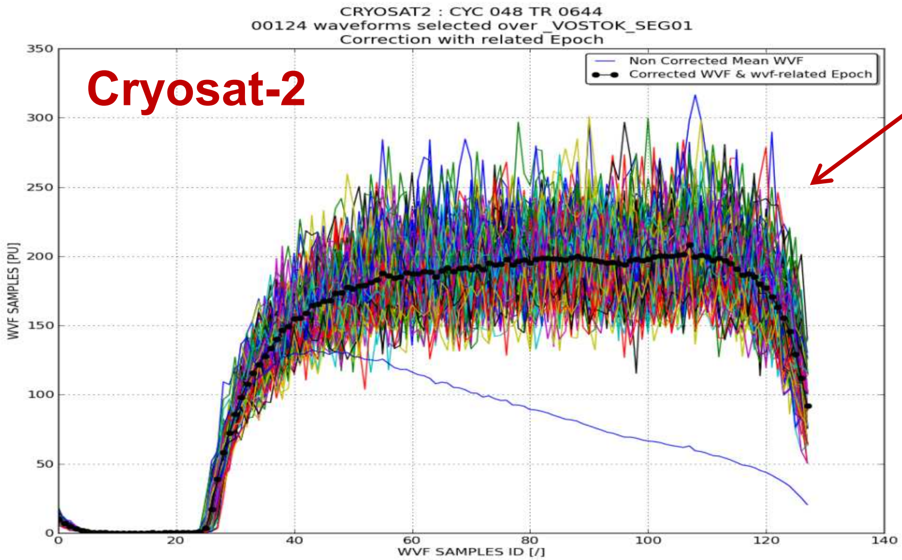
- Homogeneous data segments
- Penetration effects on Ku data (much less on Ka)
- !! 47 cm gates in Ku while 32 cm in Ka !!
- Smaller gates in snow/ice layers
- Coherent with the multi-layer theory developed currently in LEGOS

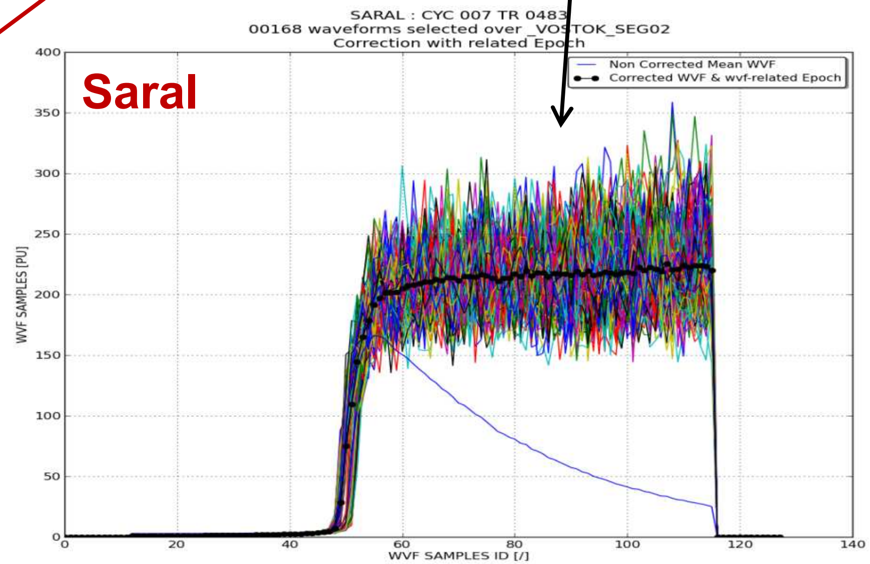
(see D.Blumstein, F.Nino et al poster)

Waveforms at X-overs





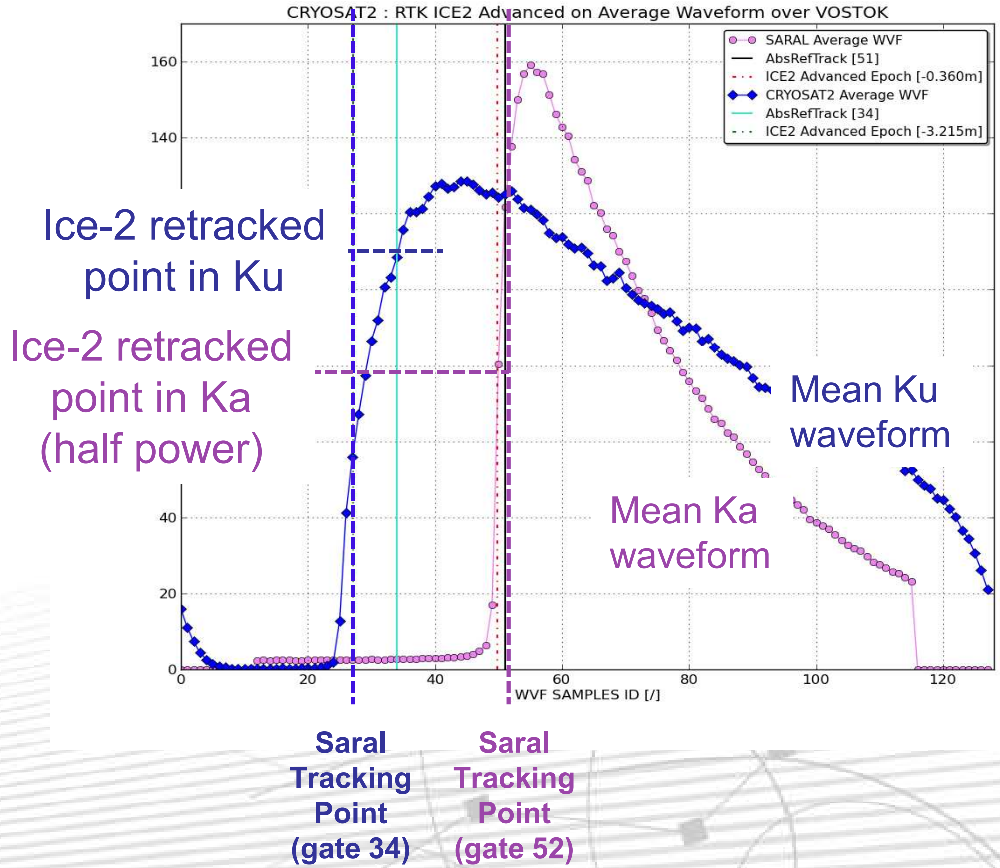




P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Collocated Ku/Ka waveforms over ice sheets

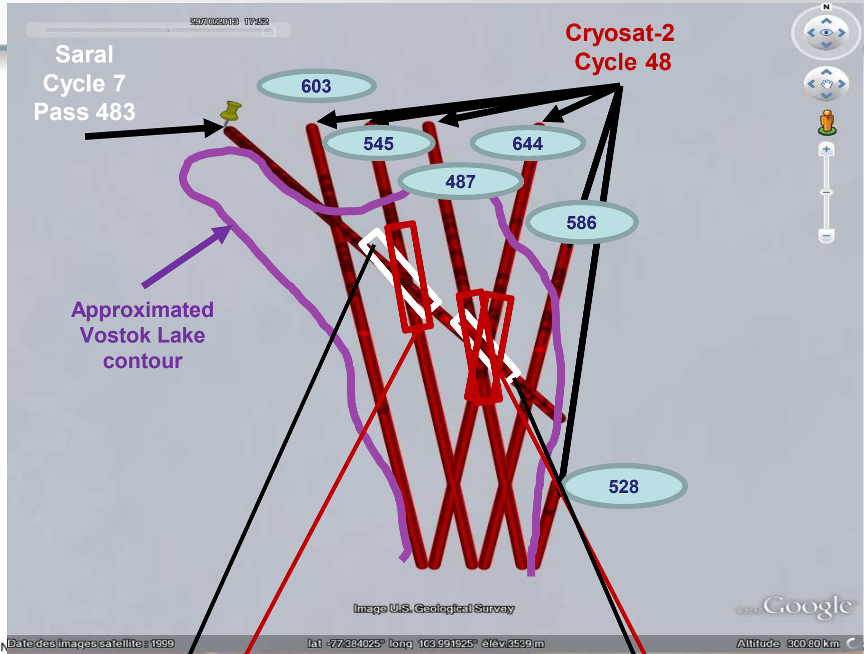
- ❑ In Ka band, the Ice-2 algorithm retracks approximately the half power point of the the leading edge. Not the case in Ku band (much higher)
- ❑ In Ku band, a height bias is introduced by the ice-2 rtk which doesn't account for the volume scattering (around 1 m in our example)
- ❑ Corrections have to be applied on the retracking output to account for penetration depth (in both bands)
- ❑ LEGOS (F.Remy) is defining corrections (Echo and Geo) to account for the penetration 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). Will be done also for Saral measurements

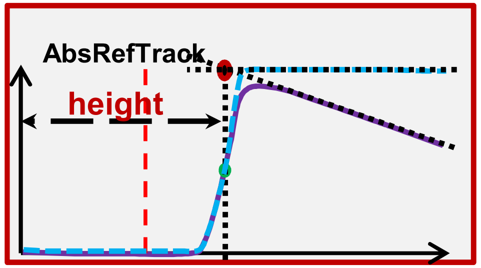


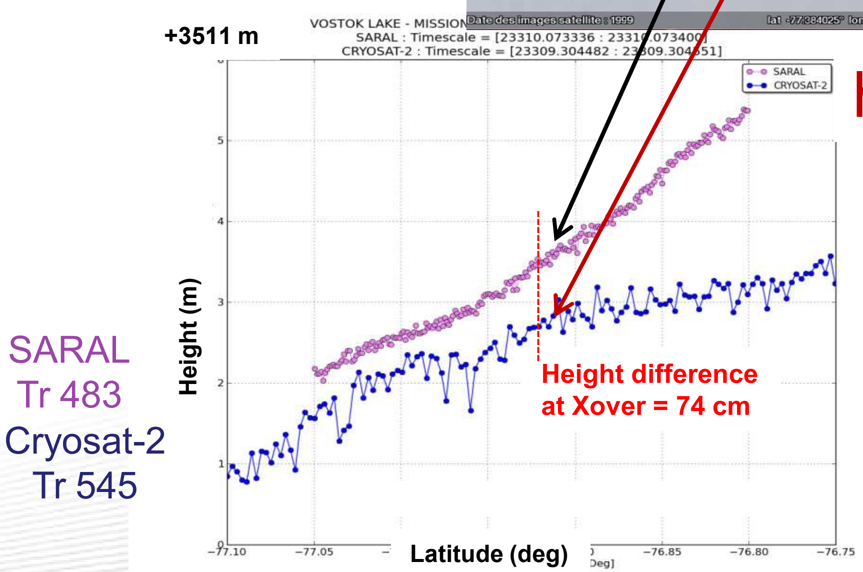
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

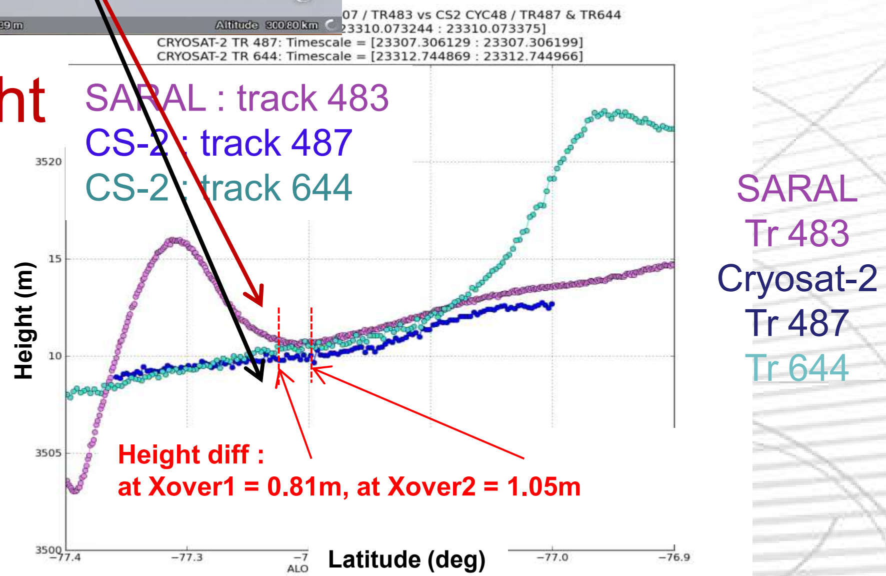
Ku/Ka comparison at Xovers ➔ Height

➔Ku/Ka height bias around 1 m







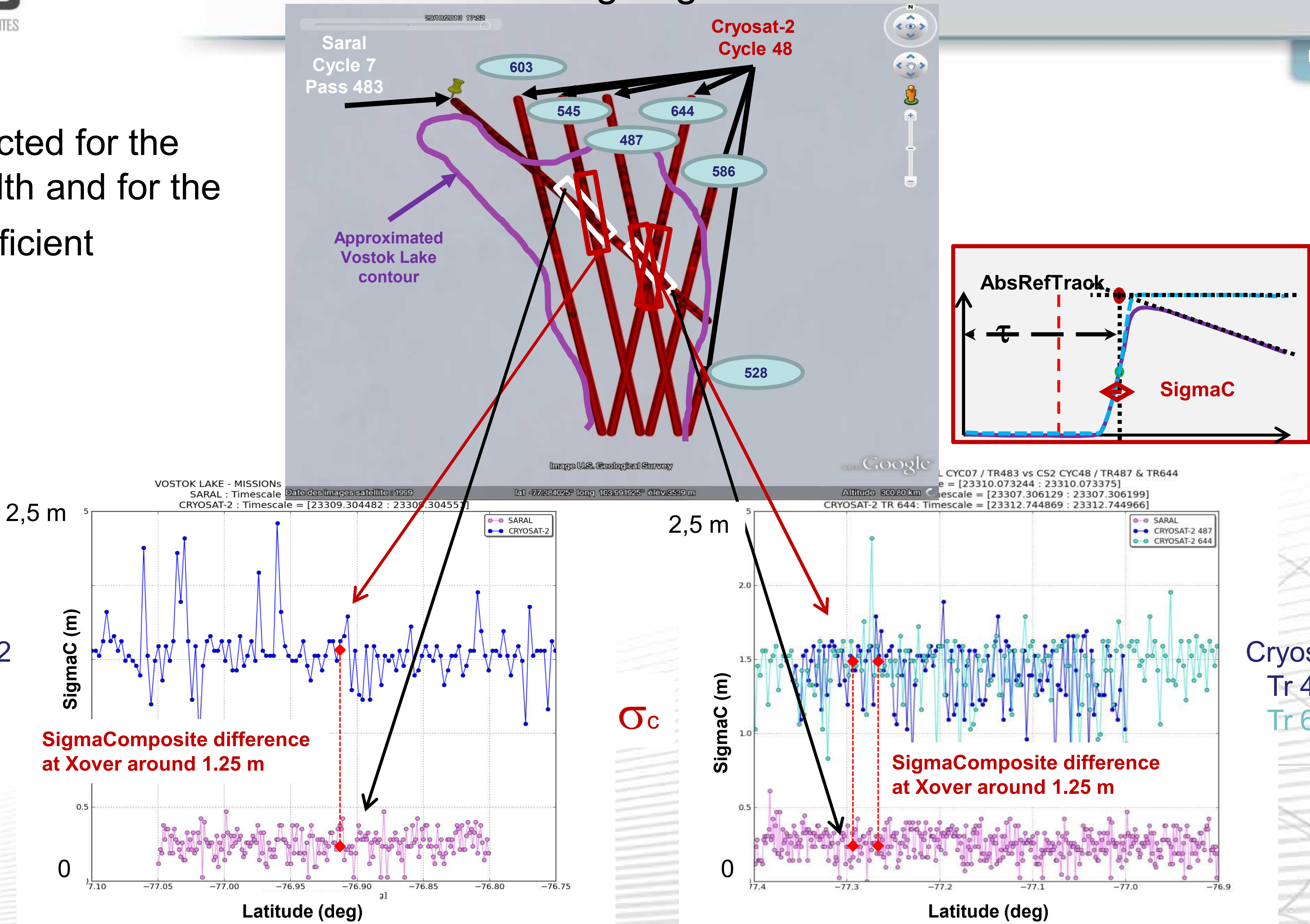


P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Ku/Ka comparison at Xovers

➔ Width of the leading edge : σc

σc corrected for the PTR width and for the V2 coefficient



Cryosat-2
Tr 545

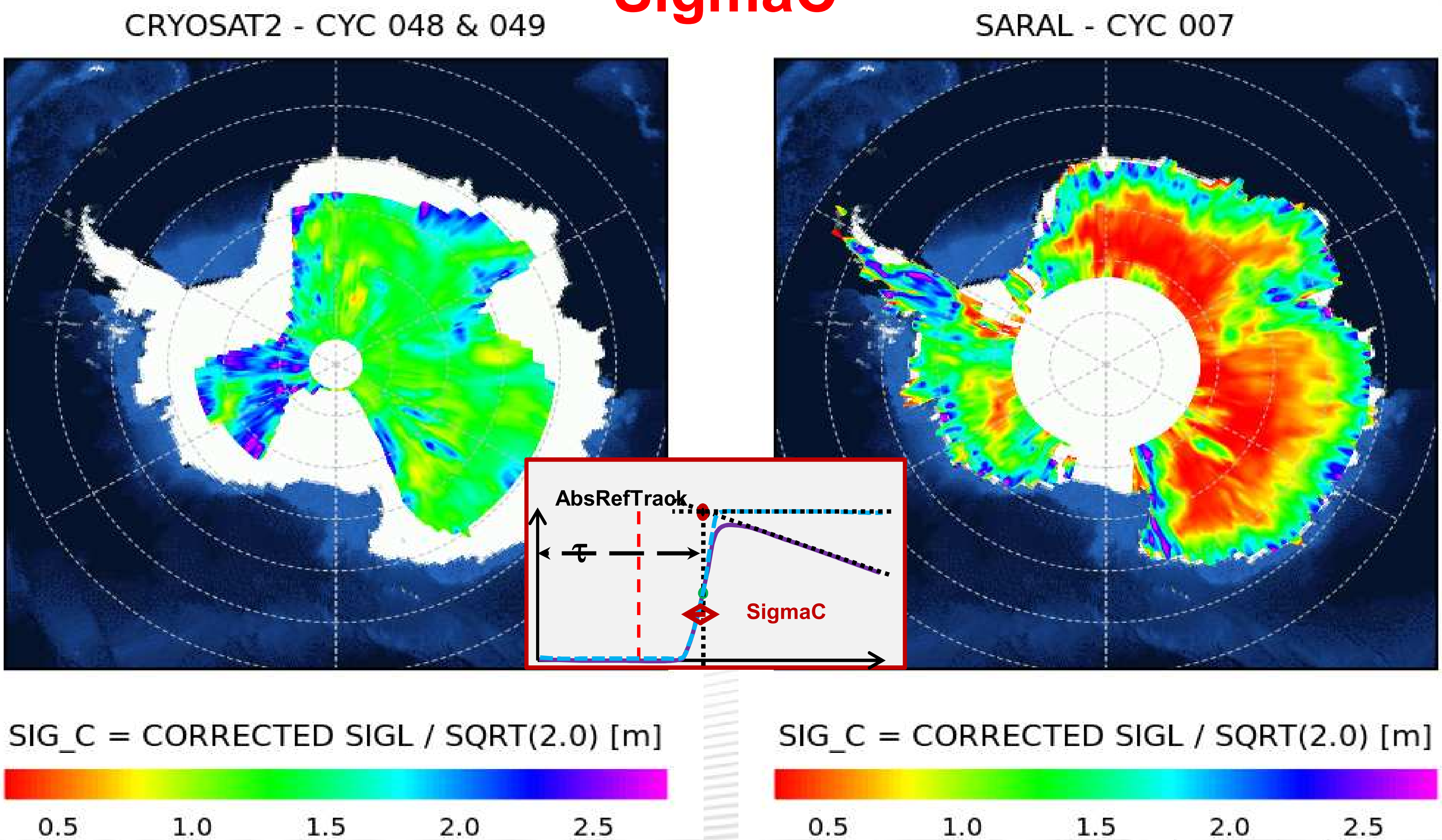
SARAL
Tr 483

Cryosat-2
Tr 487
Tr 644

P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Collocated CS-2 / Saral measurements

SigmaC



P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Conclusions (1/2)

- 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 (<u>but more impacted by slope effects</u>)**
- Penetration depth much smaller in Ka
  - ➔ **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 !!**

P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Conclusions (2/2)

- 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 **(also true over sea ice regions ➔ consequences on freeboard estimations)**
- Accounting for the antenna gain pattern **is mandatory** for inter-comparison between missions (ERS/Envisat/Saral/Cryosat-2) ➔ 20 years of data
- Retrackers have to be adapted/tuned to better account for penetration depth (mainly in Ku band). Corrections have to be computed and provided.
- Many new studies can be performed with Saral data (or revisit of old studies) : mass balance variations, height trends, polarisation effects, characterisation of the errors, comparison with lidar, in situ etc, etc …

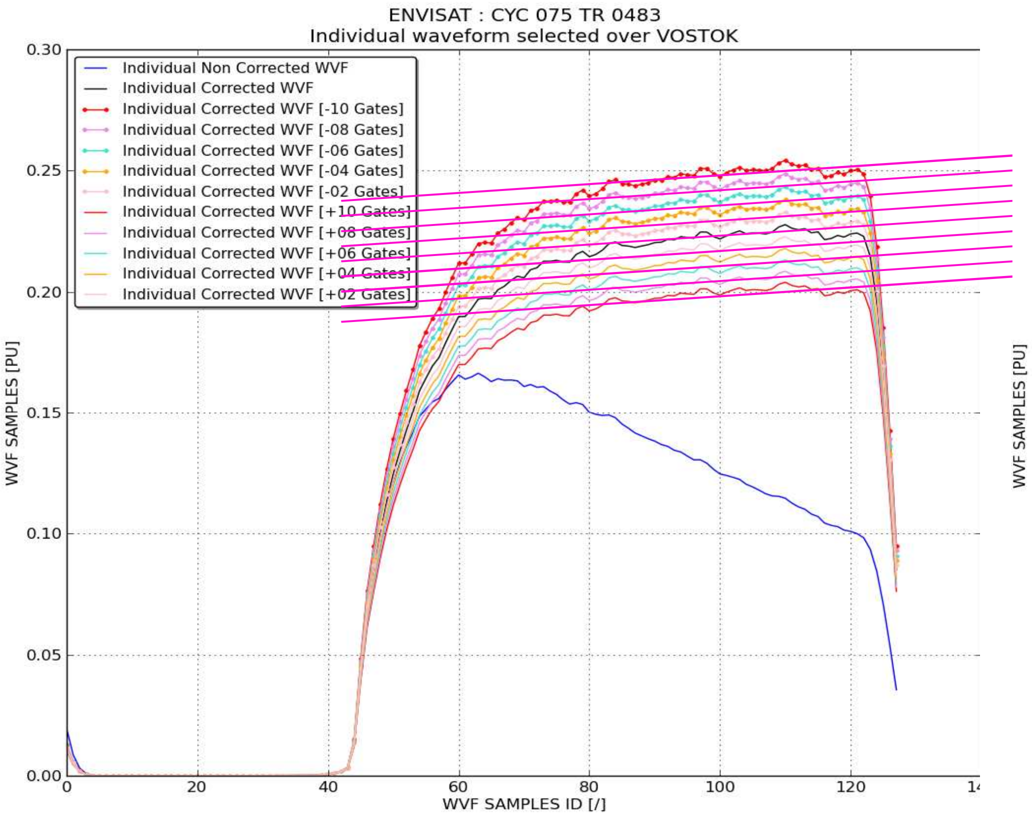
- What about SAR mode over ice sheets (CS-2 in LRM but S3 will be in SAR mode every where…) ? Which algorithm ? on stacked data ? on bursts ? on individual echo ?
- Comparaisons between SAR (with restricted waveform footprint but penetration effects) and Ka measurements will be very informative

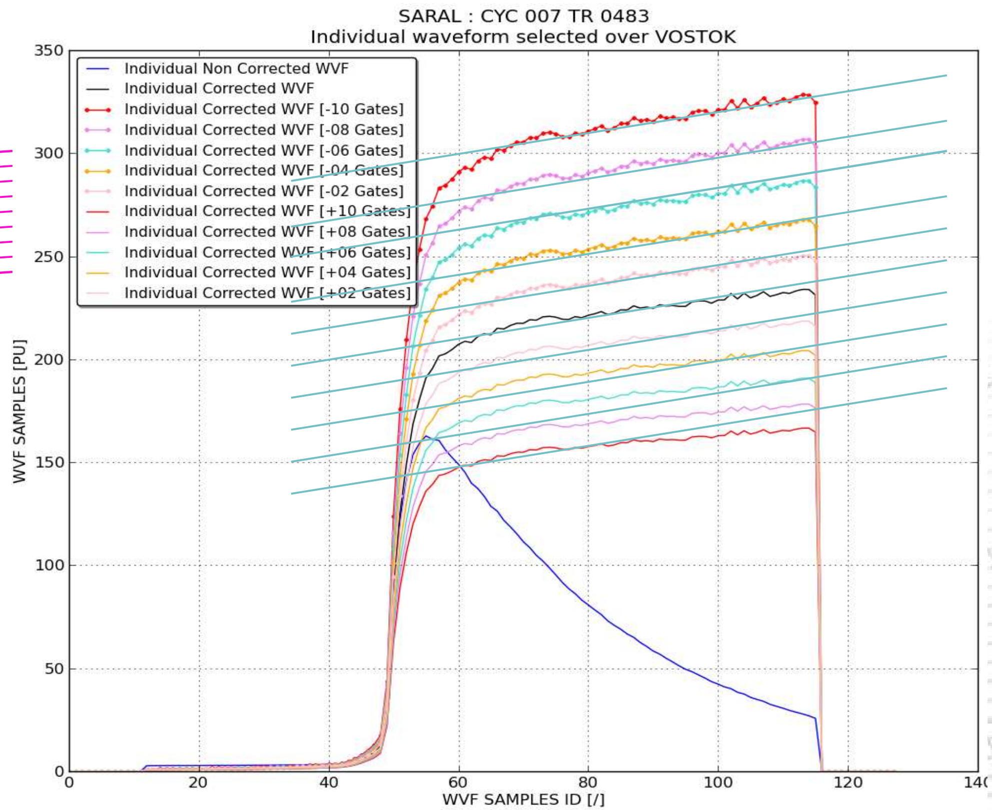
Thank you
for your attention

Impact of an offset on the pintle axis position

ENVISAT CYC 75 TR 483

SARAL CYC 7 TR 483



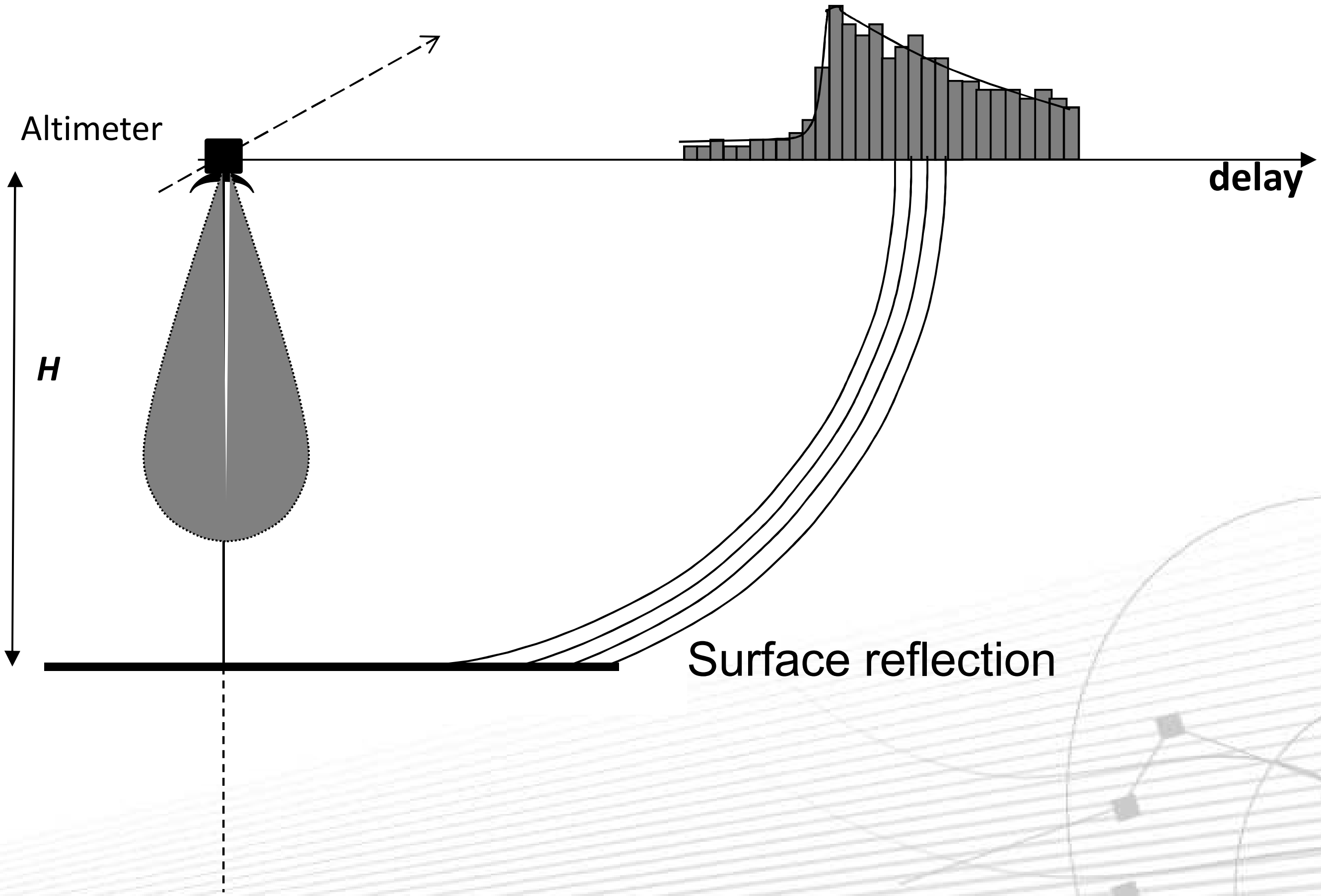


➔ Small impact on slopes for Ku, larger for Ka

➔ Great impact on Pu

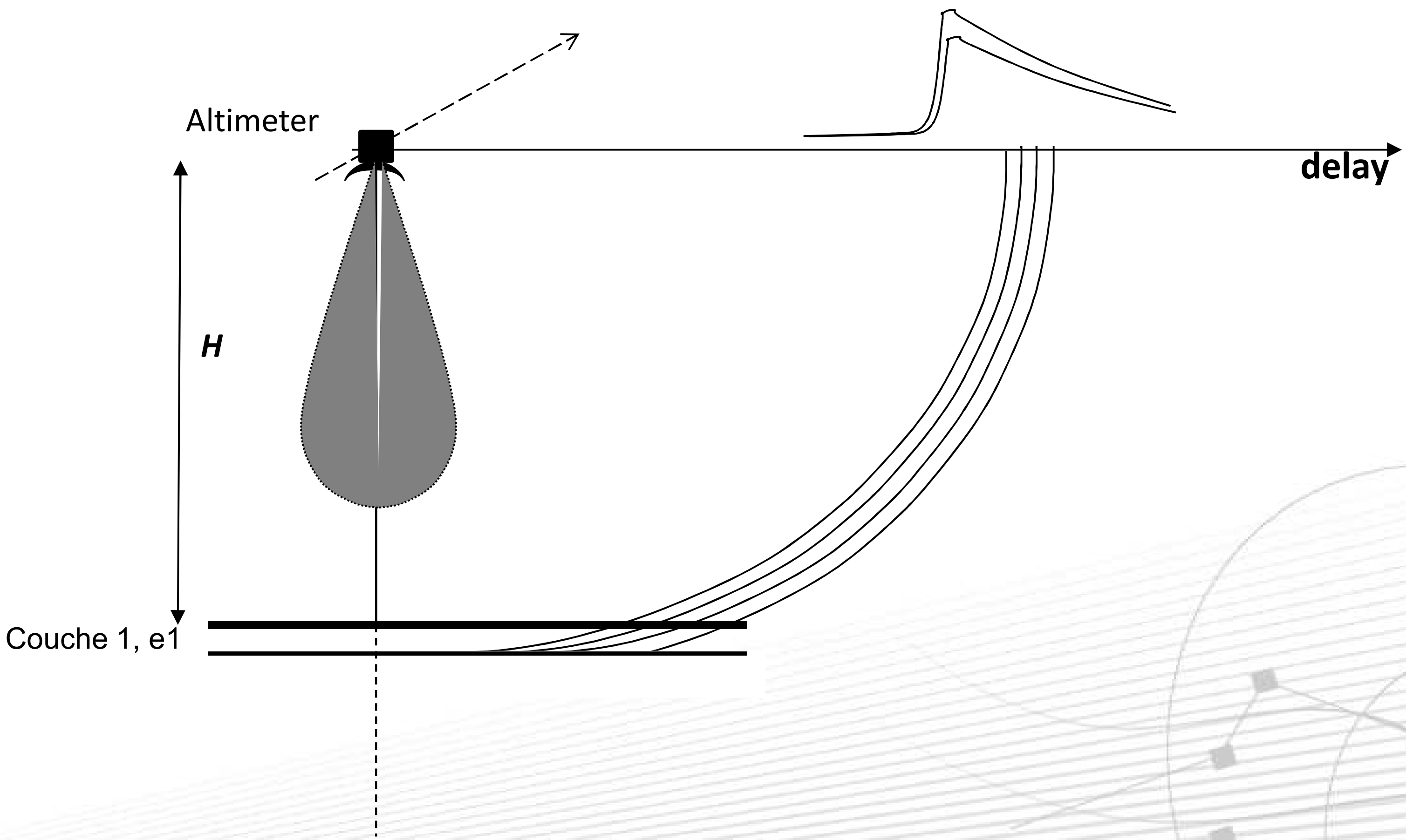
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Muli-layer reflection on ice



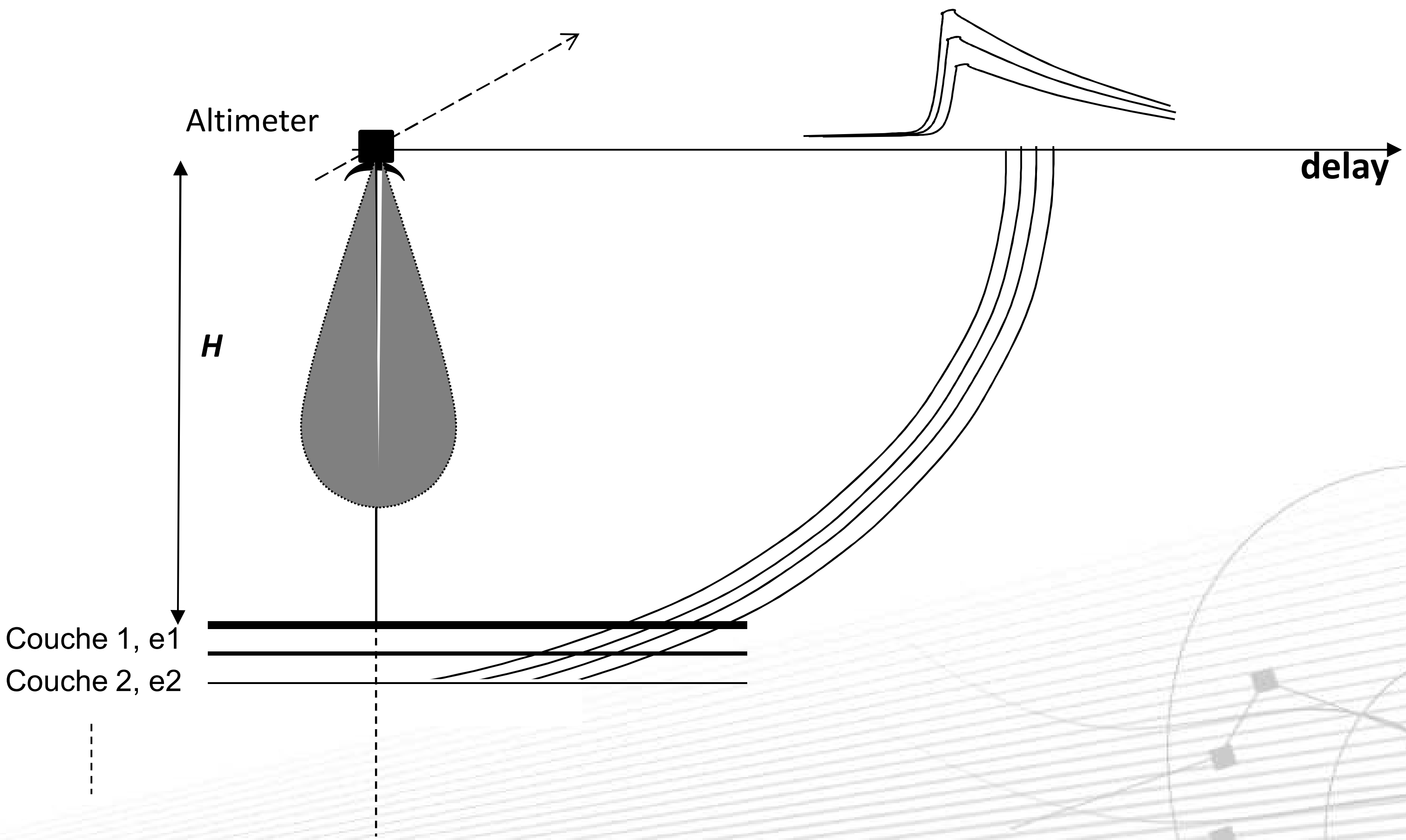
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Muli-layer reflection on ice



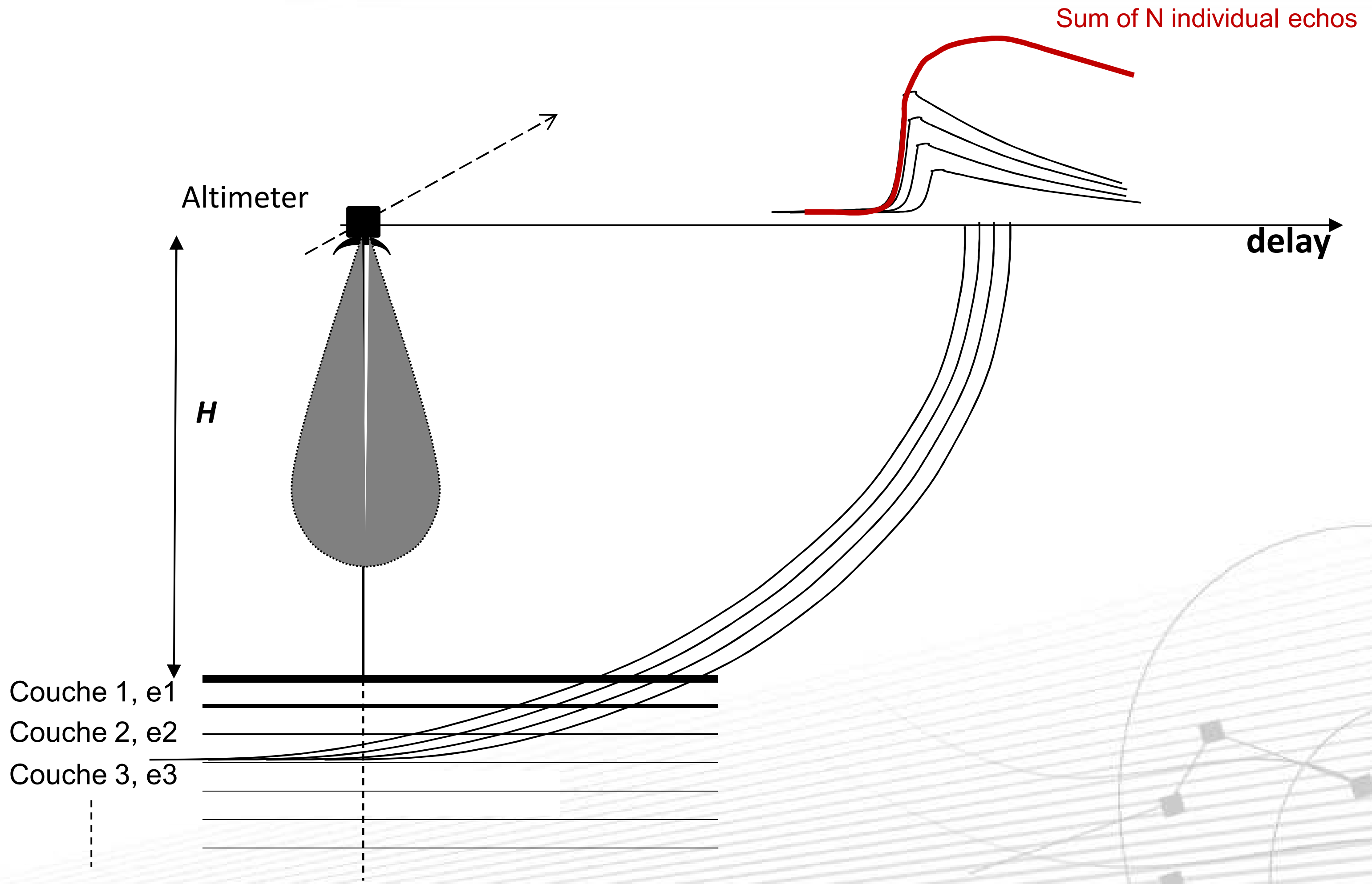
P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Muli-layer reflection on ice



P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.

Muli-layer reflection on ice



P.Thibaut & al «Ku/Ka band observations over Polar Ice Sheets», SARAL Meeting in Constanz, October 2014.