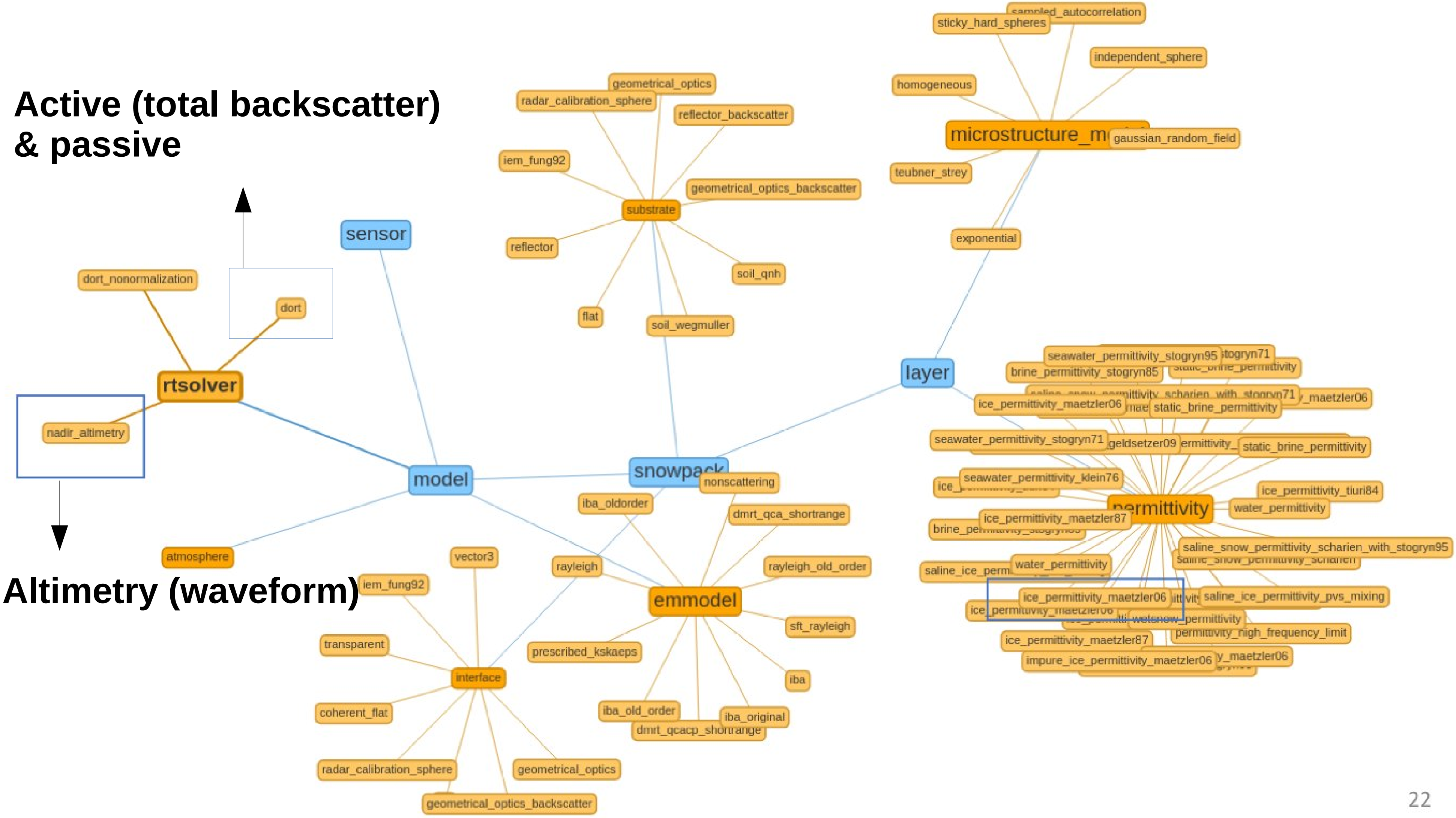
Simulating altimetric data with SMRT

Sponsored by :

Altimetric RT solver

Need a specific RT solver for the altimetry because the equation to be solved is different.

The altimetric solver fits well in the overall SMRT structure, despite its specificities.



Active (total backscatter) & passive

Altimetry (waveform)

Altimetric RT solver

The solver is: nadir_lrm_altimetry

Based on Brown, 1977 (surface only) and Adams and Brown, 1998 (surface+volume)

Limitations:

- nadir altimetry	satellite ok. airborne=~~
- First order scattering. No multiple scattering.	bands S, C, Ku ok. Ka ~~
- Low Resolution Mode (LRM). No SAR InSAR processing yet.	Sentinel 3 is some places only.
- Gaussian surface = no complex surface topography, no POCA.	sea-ice ok, ice-sheet ~~

Altimetric RT solver

SMRT's nadir altimetry model computes the waveforms in two steps:

1- compute the **vertical** profile of backscatter

Sigma = f(z)

- backscatter from the surface
- backscatter from the volume (scattering)
- backscatter from the inter-layer interfaces
- backscatter from the substrate (bottom interface)

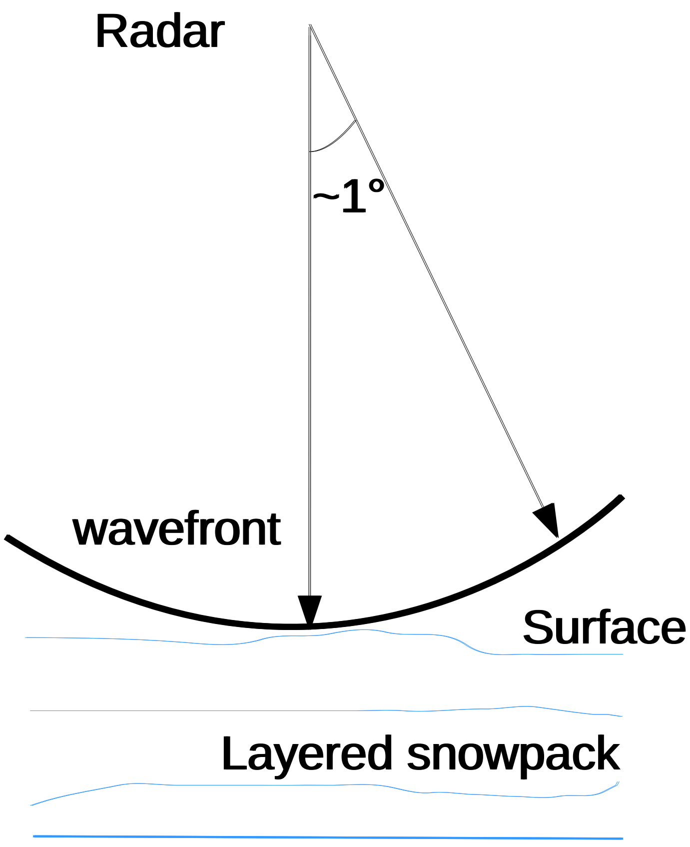
Main approx: 1^{st} order backscatter only

2- distribute in time accounting for the **horizontal** spread/delay of the wavefront

- Brown 1977's model → flat or tilted surface.
- « convolution with the pulse surface response »

Main approx: **LRM model**, no complex topography

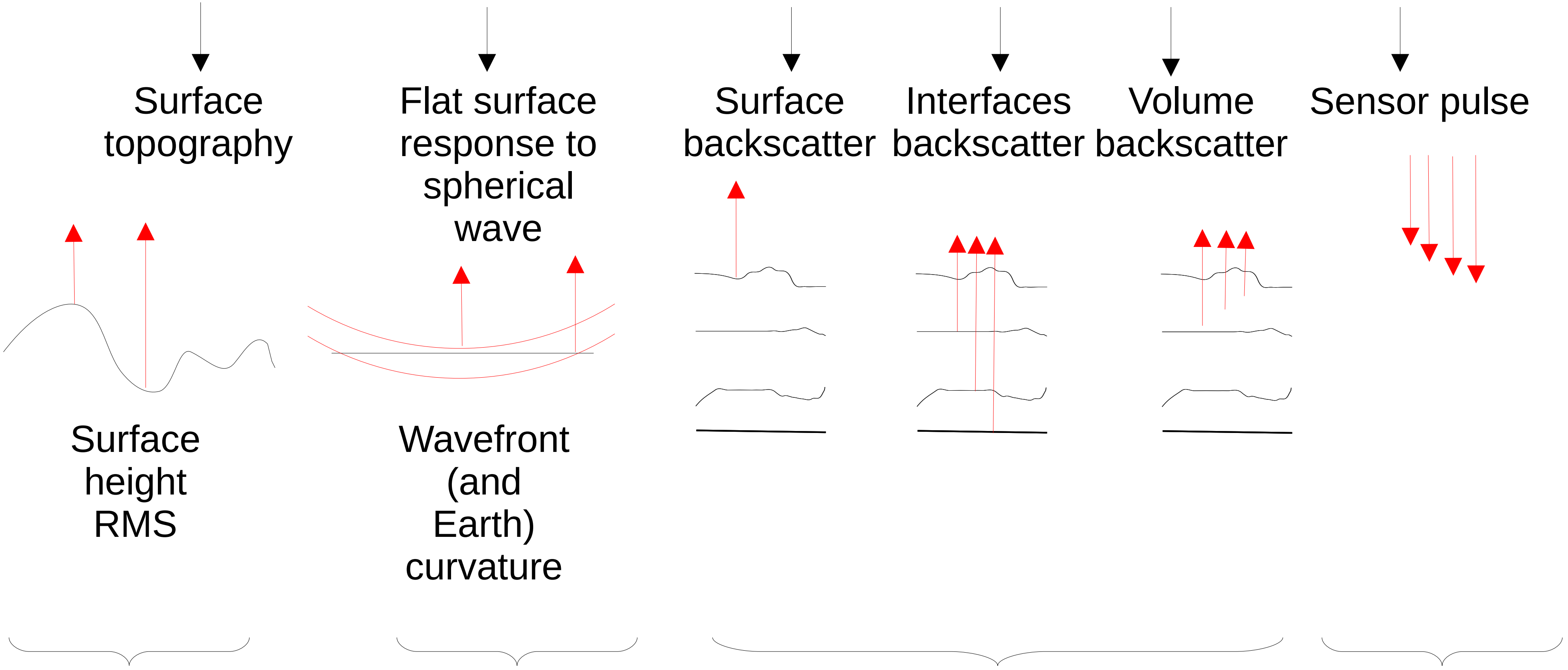
Sigma = f(t)



Altimetric RT solver

More details in Larue et al. 2021

$$P_r(t) = pdf(t) \otimes P_{\mathrm{FIR}}(t) \otimes \left[\sigma_s^0 \delta(t) + I_{\mathrm{int}}(t) + I_{\mathrm{vol}}(t)\right] \otimes P_t(t)$$



Surface topography

Surface height RMS

Flat surface response to spherical wave

Wavefront (and Earth) curvature

Surface backscatter

Interfaces backscatter

Volume backscatter

Sensor pulse

Gaussian surface assumption → analytical eq

Brown model

Solved with the time-dependent radiative transfer equation

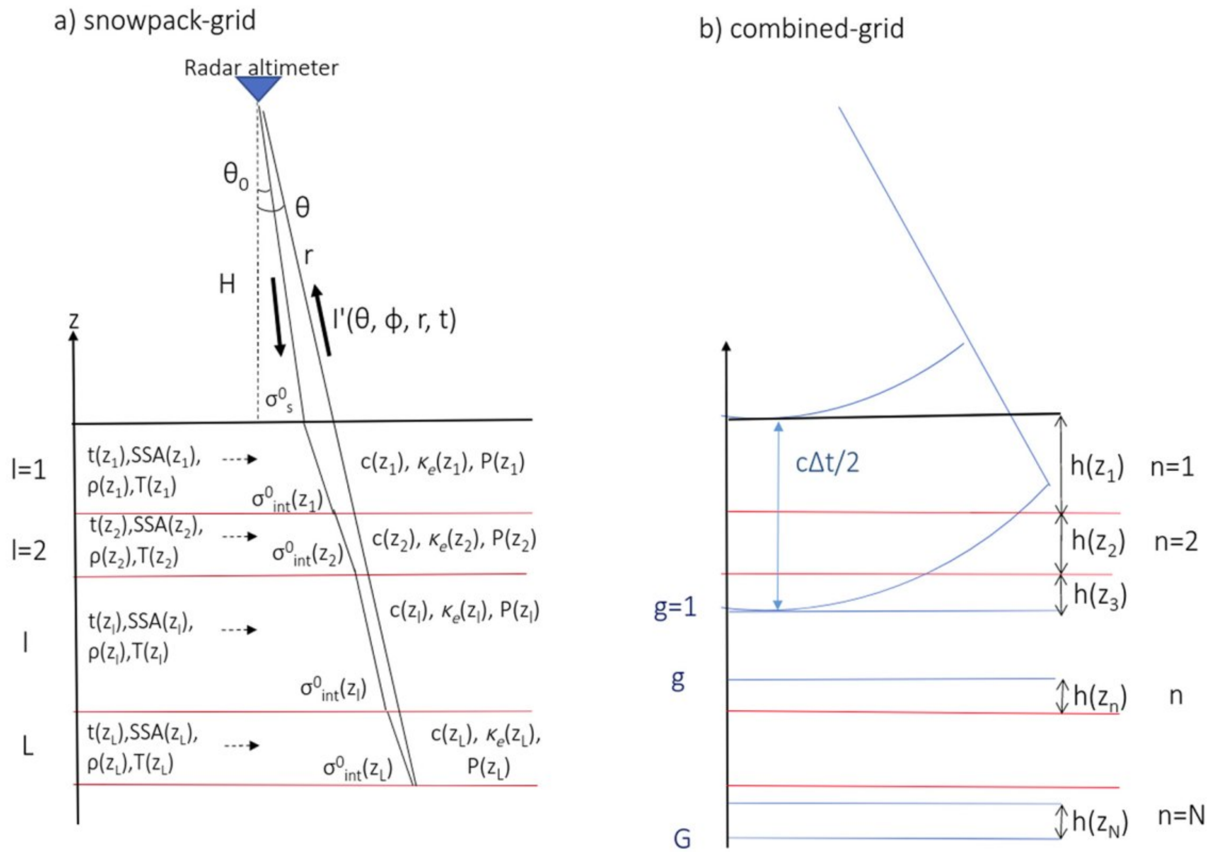
Gaussian pulse → analytical eq

Altimetric RT solver

Need to solve the time-dependent RT equation

$$\frac{1}{c(\mathbf{r})}\frac{\partial}{\partial t}I'(\theta,\phi,\mathbf{r},t)+\frac{\partial}{\partial s}I'(\theta,\phi,\mathbf{r},t)=-\kappa_e(\mathbf{r})I'(\theta,\phi,\mathbf{r},t)$$
$$+\frac{1}{4\pi}\int_{4\pi}P(\theta,\theta',\phi-\phi',\mathbf{r})I'(\theta',\phi',\mathbf{r},t)d\Omega'$$

First, need to define a vertical grid of equal time. Depends on the speed of wave → depends on refractive index.



Altimetric RT solver

Then compute the backscatter from the volume
e.g. for layer n

$$I^{1^{\mathrm{st}}}_{\mathrm{n,vol}}(z=0,t) = E_0\left(t-2\sum_{n'=1}^{n-1}\frac{h(z_{n'})}{c(z_{n'})}\right)\frac{1}{n(z_n)}\frac{P(0,0,\pi,z_n)}{4\pi}$$

$$\frac{1-exp(-2\kappa_{\mathrm{e}}(z_n)h(z_n))}{\kappa_{\mathrm{e}}(z_n)}exp\left(-2\sum_{n'=1}^{n-1}\kappa_{\mathrm{e}}(z_{n'})h(z_{n'})\right)\prod_{i=1}^{N}T(z_i)^2.$$

Backscatter by the actual layer

Attenuation by upper volume

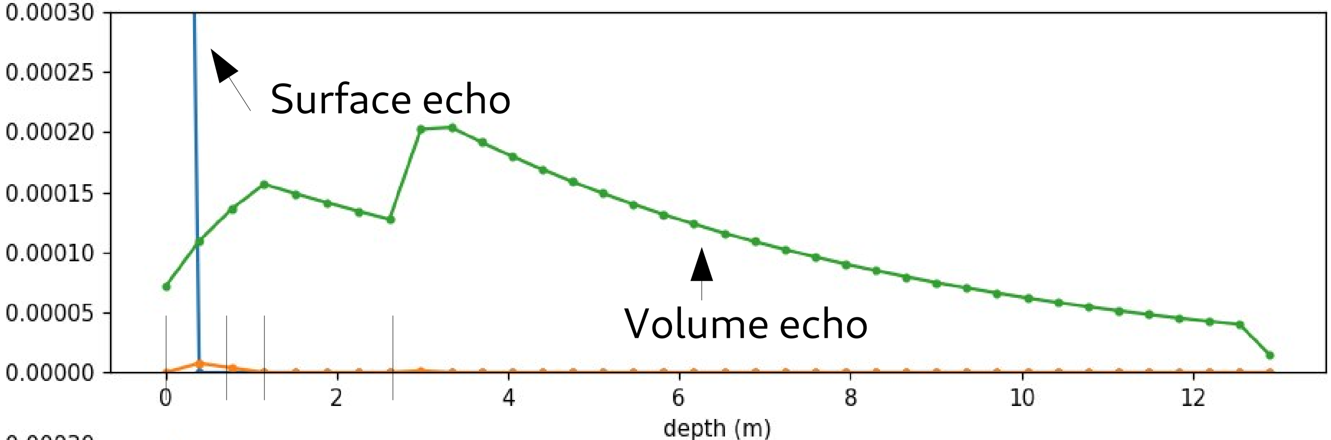
Attenuation by upper interfaces

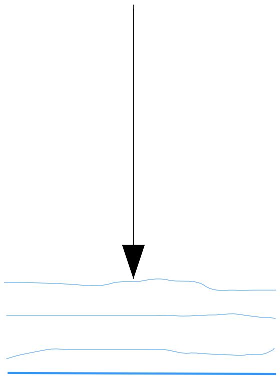
Similar for internal interfaces and the surface: see Larue et al. 2021

Applications & validation

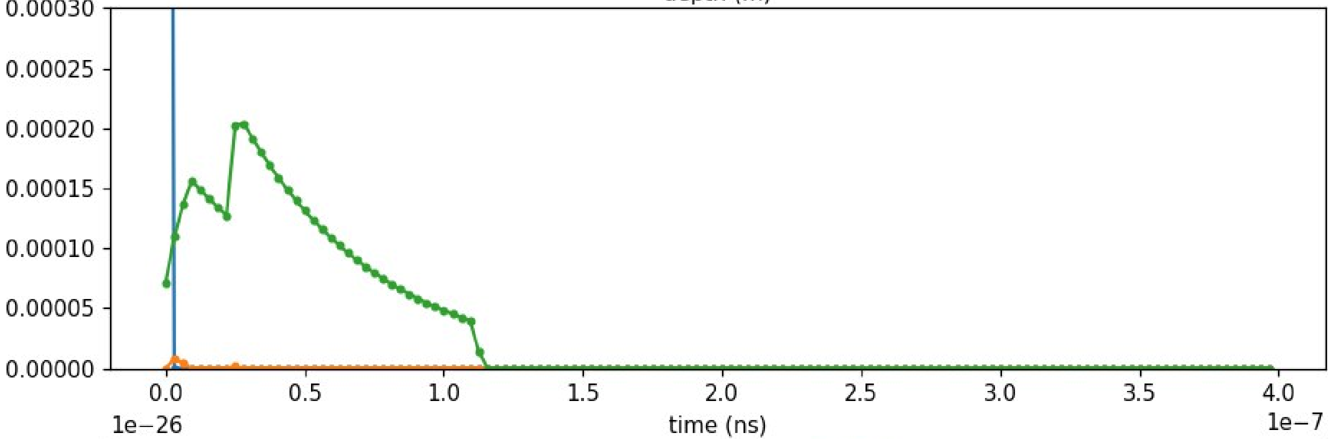
Illustrations: a snowpack with 4 layers with increasing scattering strength

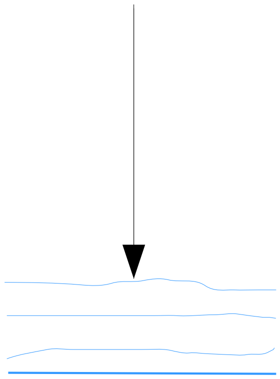
Sigma = f(z)
(vertical)



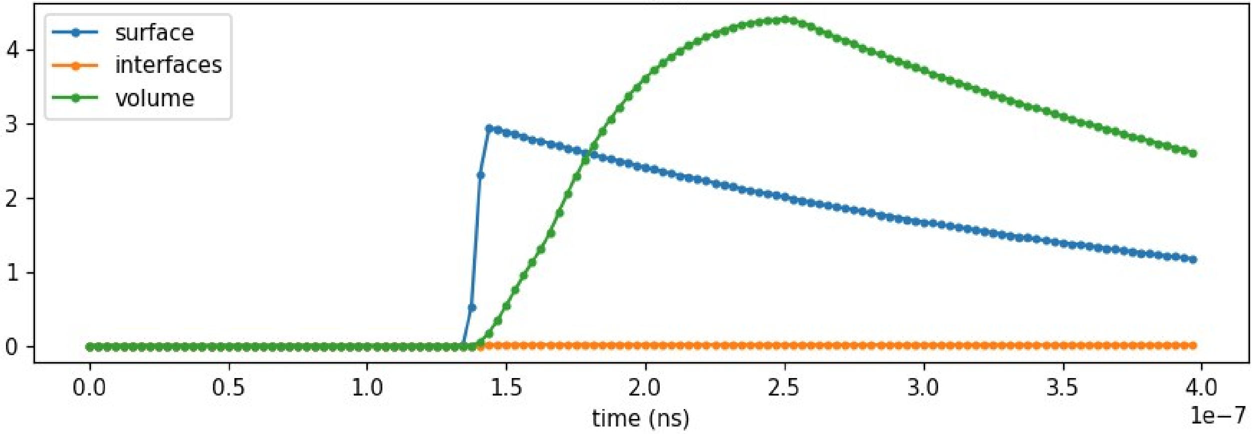


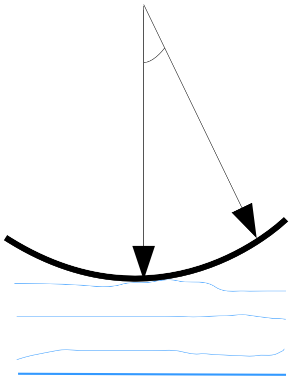
Sigma = f(t)
(vertical)





Sigma = f(t)
(vertical+
horizontal)



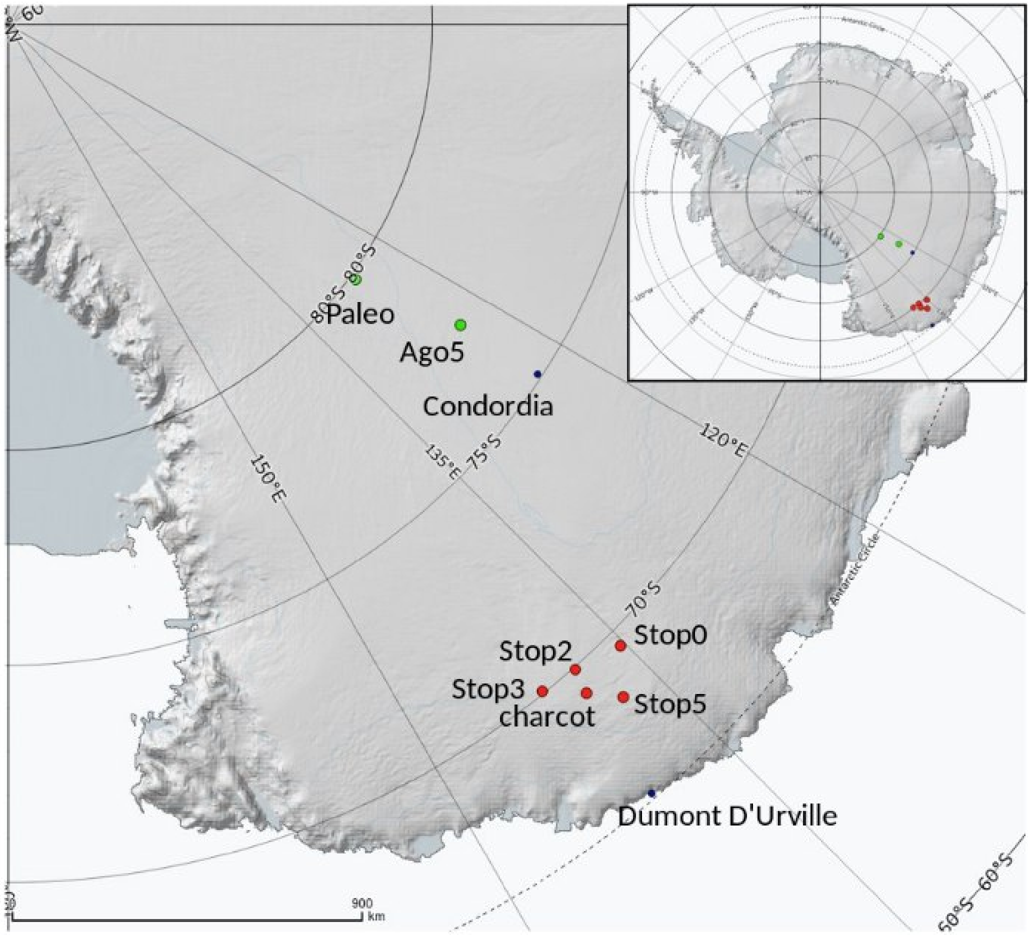


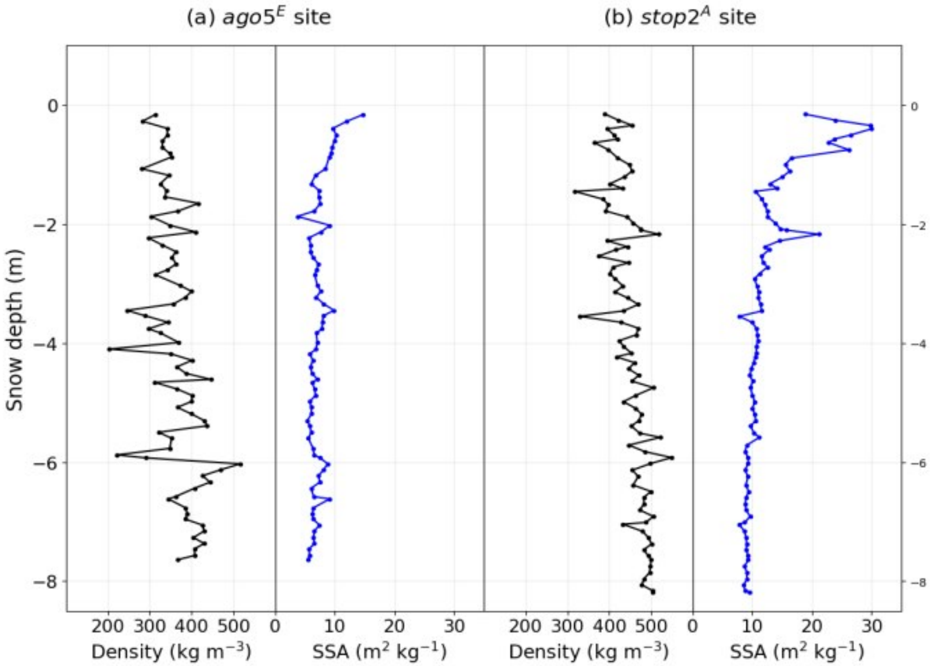
Applications & validation

Larue et al. 2012

Acquisition of in-situ data during two traverses in East Antarctica (2016 and 2019) and at Concordia station

Name	Latitude	Longitude	Slope	σ_{surf}	T	MSS	SSA	ρ
stop5^A	-68.75	137.44	0.02	0.31	-37.2	0.03	11.6	448
charcot^A	-69.38	139.02	0.13	0.33	-37.9	0.02	12.0	433
stop0^A	-69.64	135.28	0.01	0.18	-41.1	0.02	12.4	437
stop2^A	-69.95	138.55	0.05	0.34	-40.4	0.03	12.4	449
stop3^A	-70.06	141.20	0.21	0.45	-38.9	0.05	11.5	446
ago5^E	-77.24	123.48	0.09	0.32	-54.4	0.01	7.4	361
paleo^E	-79.85	126.20	0.08	0.30	-50.5	0.01	7.7	392

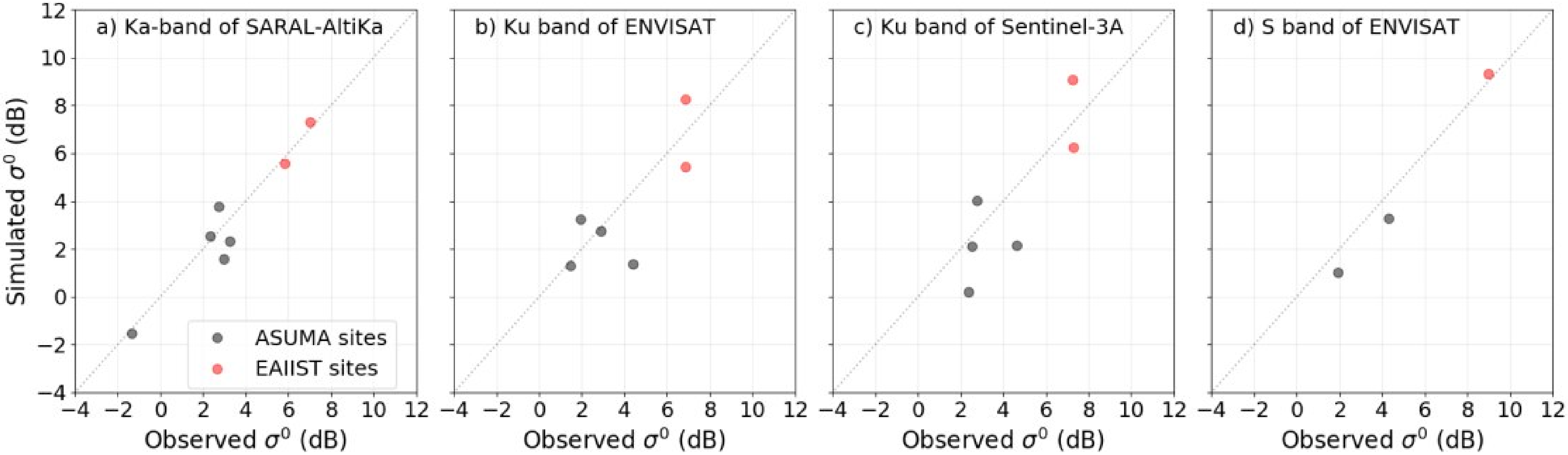




Applications & validation

Results for AltiKa, ENVISAT and Sentinel 3A (LRM mode)

Total backscatter:



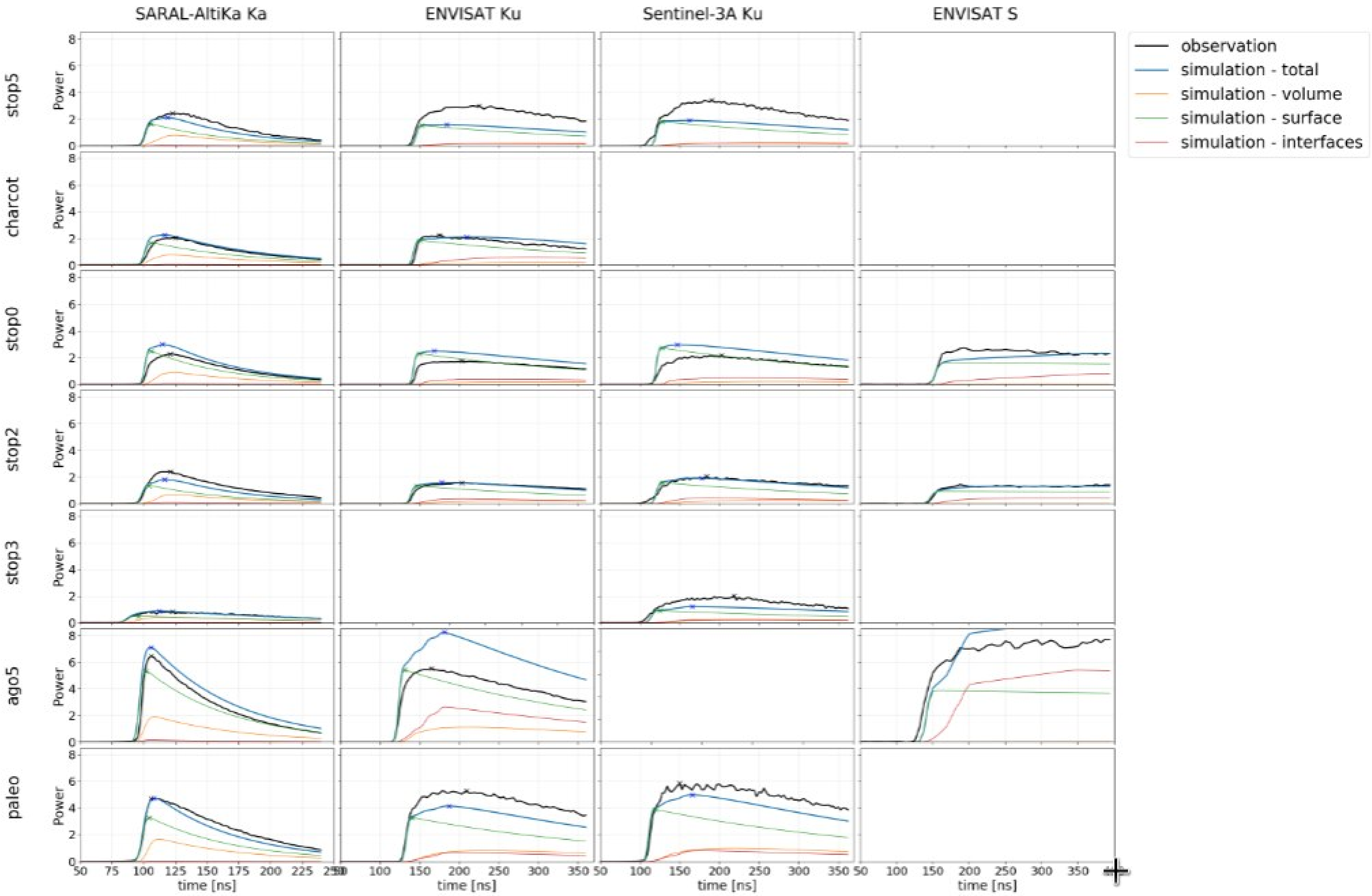
Clear increasing trend for the coastal regions to the interior

The model says:
- surface roughness is the main factor (smoother in the interior)
- grain size, density and temperature are also significant factors

Difficulties: Altimeters are not radiometrically calibrated sensors. Must scale the results

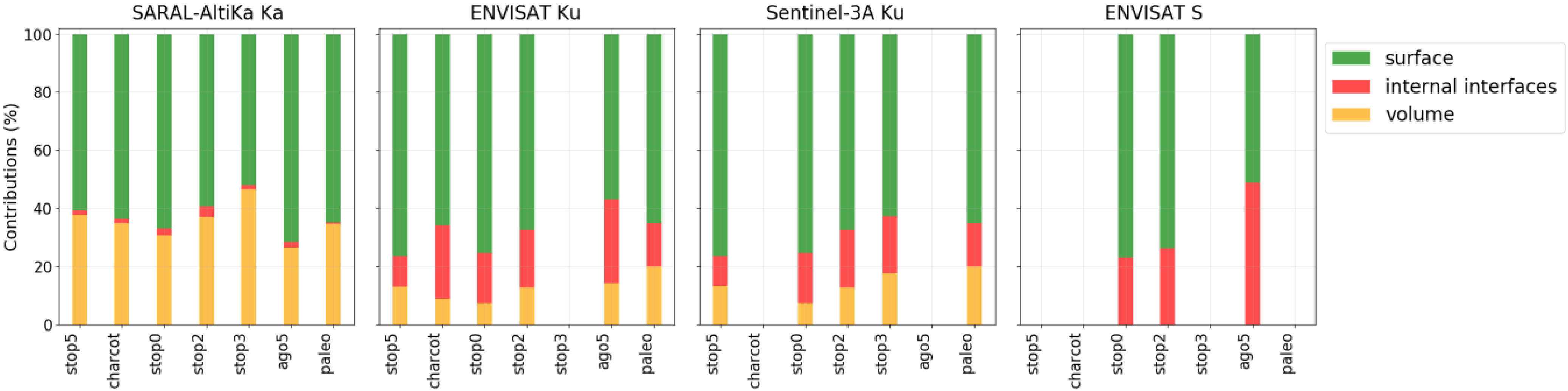
Applications & validation

Waveforms:



Applications & validation

Contributions of the surface, volume, inter-layer interfaces:



- The surface backscatter dominates at all the frequencies

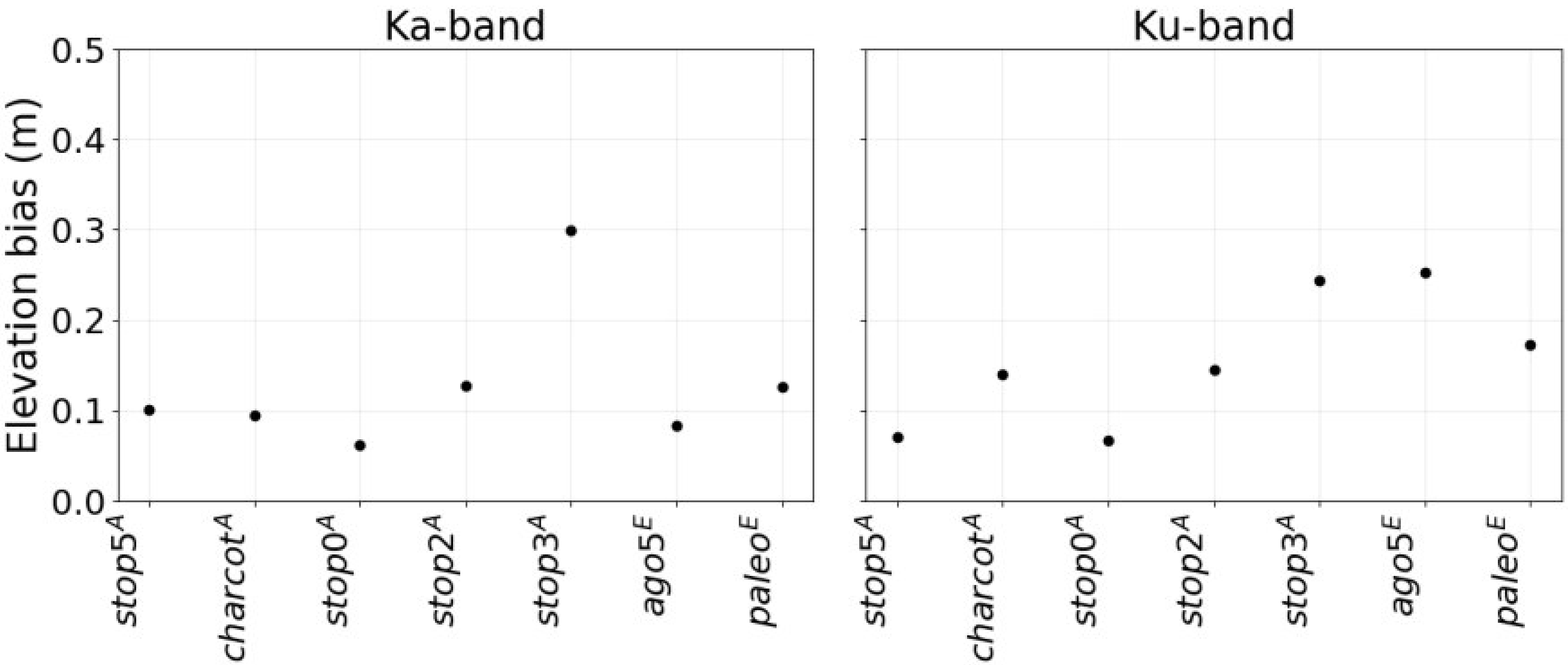
- Volume scattering is larger at Ka-band … but penetration depth is much less than at the lower frequencies . With pd ~0.5 m, the volume echo comes very closely after the surface echo.

  - in Ku band, a *large* penetration depth but a *small* volume contribution
  - in Ka band, a *small* penetrationdepth but a *large* volume contributuon

→ Uncertain consequences for the elevation bias.

Applications & validation

Elevation bias simulations:



- same order of magnitude at Ku and Ka bands

- the bias does not depend on the same factors at both bands (roughness, grains, ...)

Conclusion & perspectives

Current applications:

- validation in Antarctica, published.

- validation on frozen lakes

- validation on sea-ice

Next step, it is possible to implement:

- SAR / InSAR simulator. Important for S3 and Cristal.

- Account fro real topography (DEM based). Important for the ice-sheets

- Multiple scattering through Monte-Carlo RT simulation. May be important for Ka altimetry