PolarMonitoring project WP3: Simulation & performance analysis

WP31: New implementations in SMRT for altimetry applications

Progress meeting 2 - ESTEC – 4/10/2019

WP 3.1 Objectives

"To build a snow radiative transfer model to be integrated in the CLS altimeter simulation tool Altidop"

1) Adapt SMRT to provide not only the total backscatter from the surface but also the time travel of the individual echo required by the simulator to re-construct the radar waveform

2) Definition of two study cases with different snow parameters

Coupling of a snow model with an altimetric model

1) Simulate **the total backscattering** with a Snow Radiative Transfer model: $\sigma_{TOT}(f,\theta_i) = \sigma_{surf}(f,\theta_i) + \sigma_{vol}(f,\theta_i)$

2) Estimate **the propagation speed in each layer** to introduce the time-dependency and rebuild the total echo

Snowpack properties

R_{opt}, ρ_{snow}, T°, thickness,

SMRT: Snow Microwave Radiative Model

EM model+surf. model: Estimate scattering parameters for each layer → Solve the time-dependent RT equation (tv(z)) → PFS convolution → Radar waveform

vertical backscattered distribution of σ_{vol} and σ_{surf}

Radar parameters

Scene parameters

AltiDop

1- Generation of the scene → 2- Radar equation for each facets (P_{FS}) → 3- Restitution of the altimetric signal → **Radar waveform**

Theory to estimate the energy backscattered

With P_{layers} : surface echo, P_{grains}: volume echo

$$P_{\mathrm{FV}}(t) = \frac{1}{(4\pi)^3 H^4}\left[P_{\mathrm{layers}} + P_{\mathrm{grains}}\right]$$

$$P_{\mathrm{layers}}(t) = \sum_{n=1} \lambda_n^2 \cdot A(z_n) \cdot \delta(t - t_v(z = z_n)) \otimes \int_S \delta(t - t'(z = 0, \theta))\sigma_1^0(z = z_n, \theta) G^2(\theta) dS$$

$$P_{\mathrm{grains}}(t) = \int_z \lambda^2(z) \cdot A(z) \cdot \delta(t - t_v(z))\gamma_{\mathrm{grains}}(z) dz \otimes \int_S \delta(t - t'(z = 0, \theta)) G^2(\theta) dS$$

Vertical scattering distributions for the layers and the grains: SMRT outputs

P_{FS} : SMRT

P_{FS} : AltiDop

- **SMRT outputs:**

1- $t_v(z)$ with a vertical permittivity profile **=> new rt solver**

2- Scattering of snow grains $\gamma_{grains}(z)$ with any formulation available in SMRT

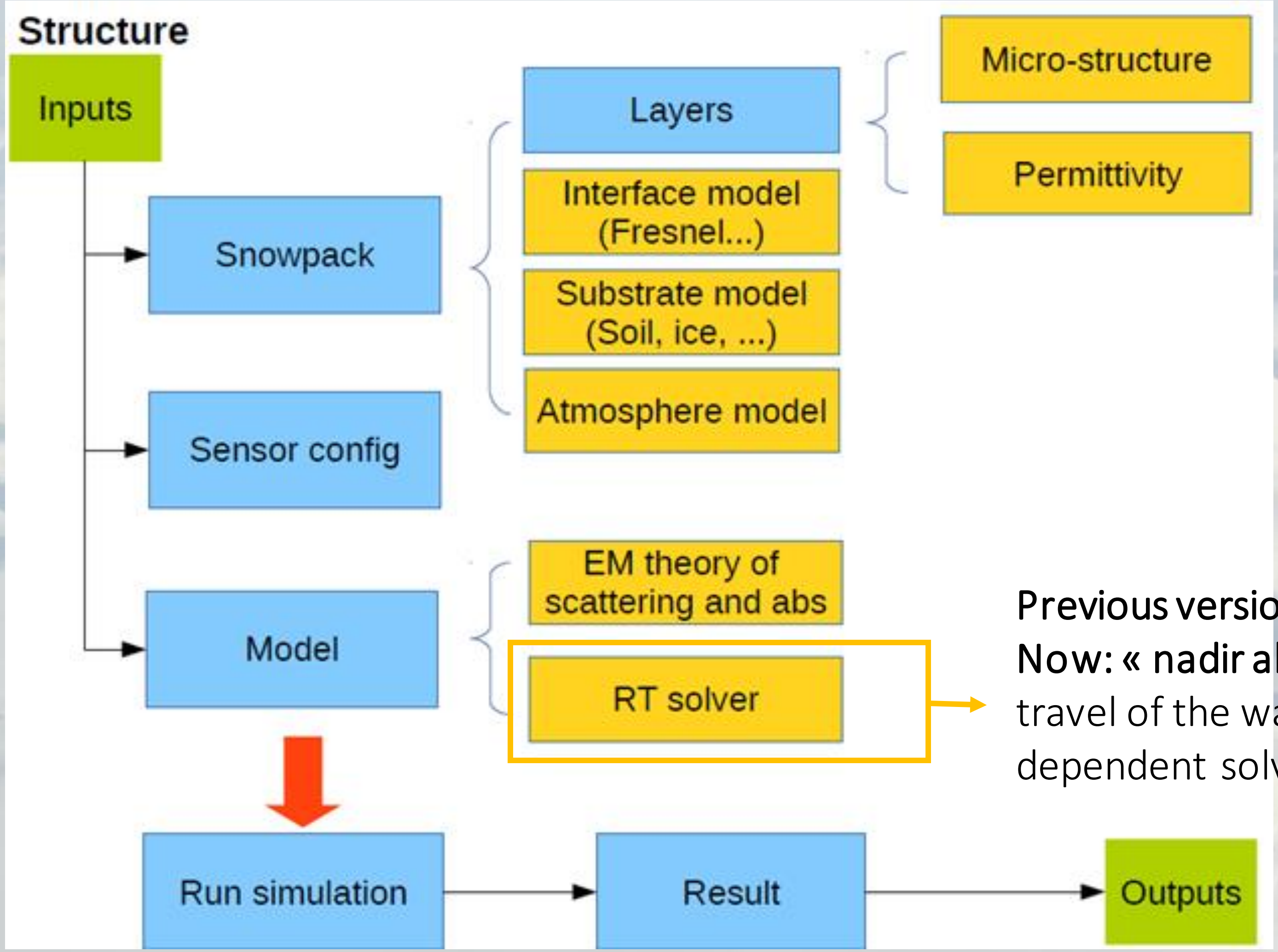
3- A(z) is the power extinction at the depth z

4- Surface backscattering coefficient $\boldsymbol{\sigma_l^0}$ profile given by SMRT

=> with an adapted surface model according to roughness heights.

Adaptation of SMRT for radar altimetry

- **New implementation:** to output Backscatter contributions of every layer
  + **Propagation speed of electromagnetic waves in each layer**

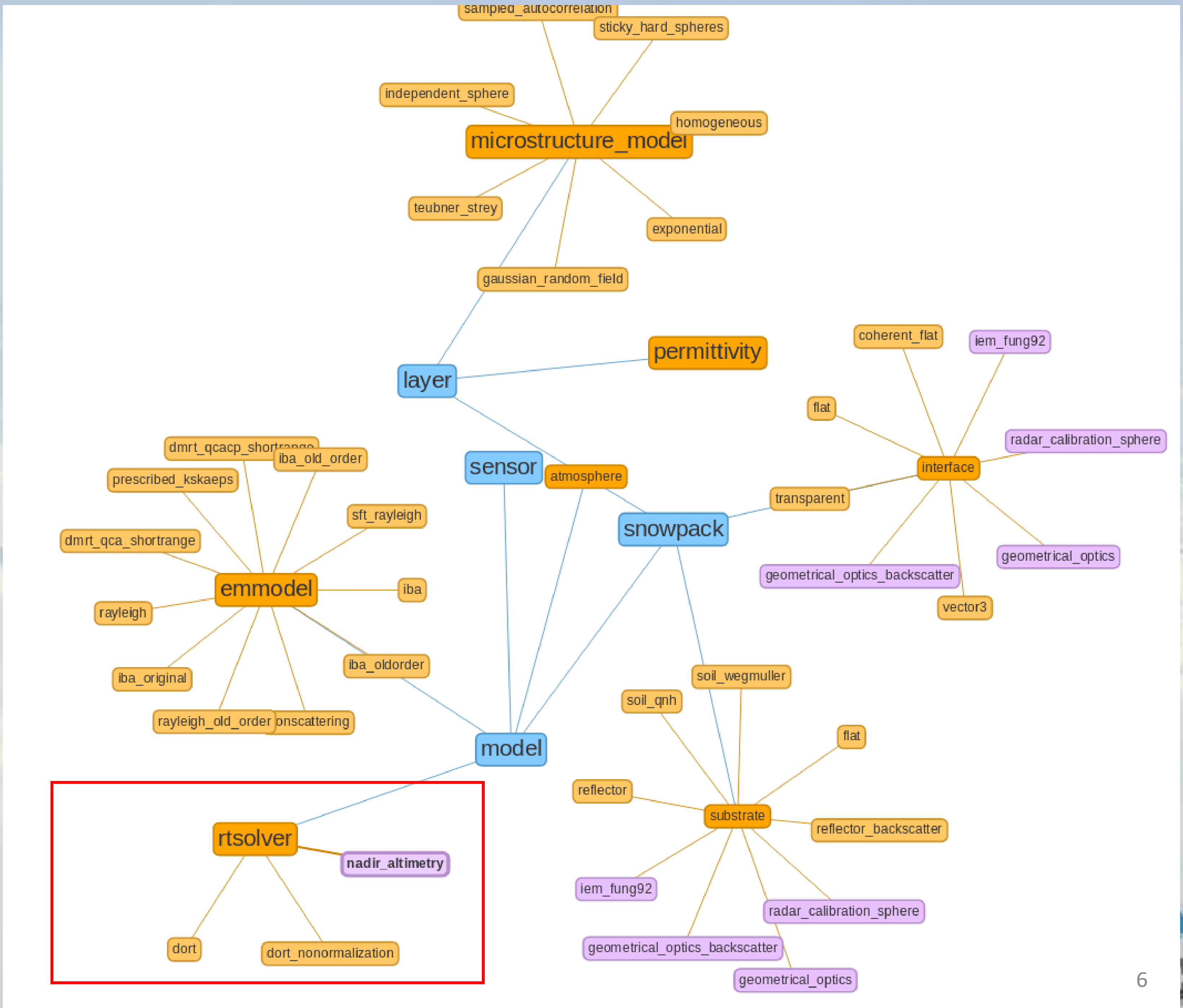


For each box many formulations are available and new ones can be easily developed

Previous version : only "DORT" solver
Now: « nadir altimetry » solver => to have the time-travel of the wave in each layer (1st order time dependent solver)

→ $\sigma_{TOT}(t, f)$

Adaptation of SMRT for radar altimetry

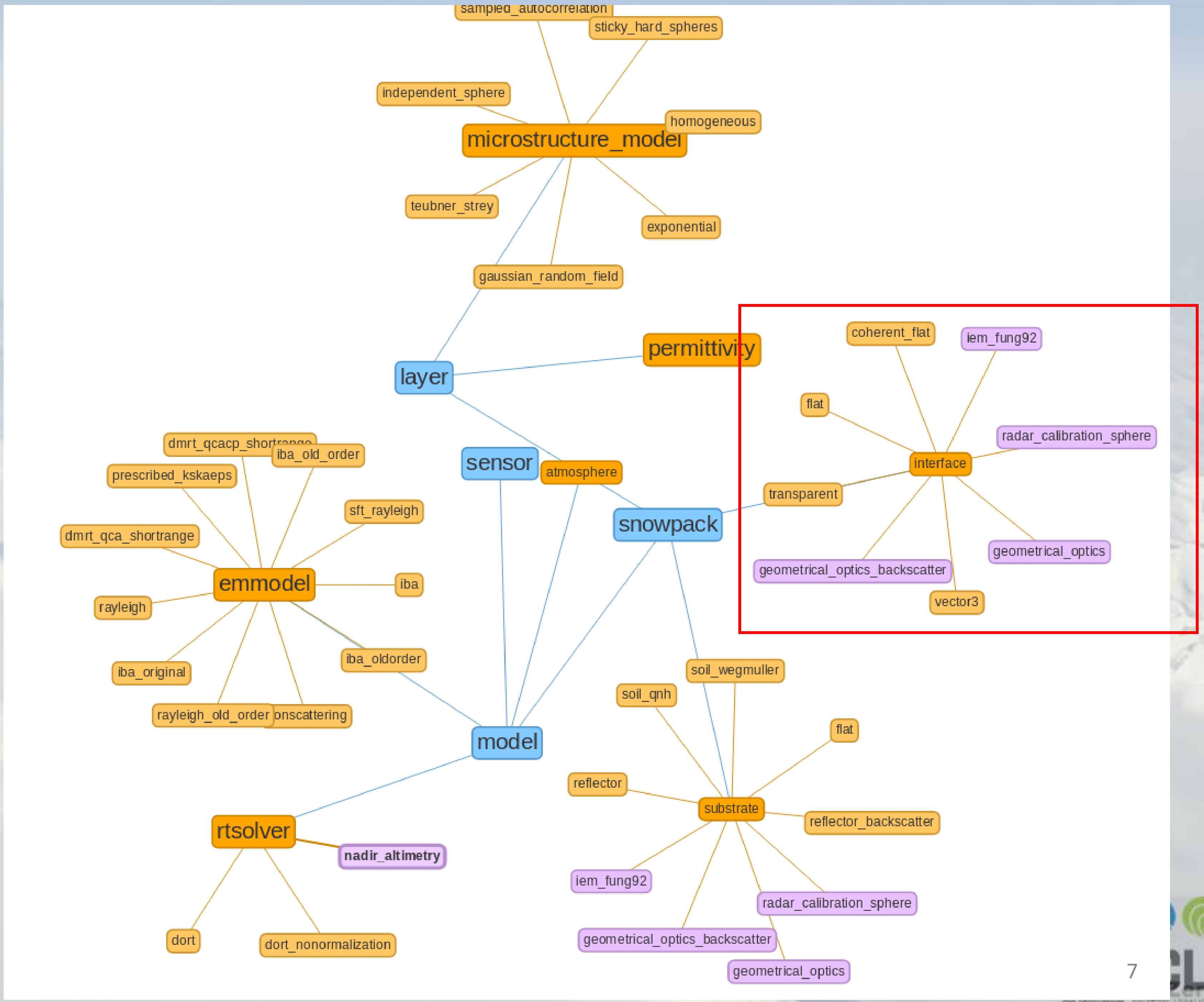


Adaptation of SMRT for radar altimetry

Different surface scattering models working with limited ranges of roughness:

=> **Geometrical optics:** Surface height roughness >> λ (>> 10 cm in S, >> 3 cm in Ku, >> 1cm in Ka)

=> **IEM**: Surface height rms < 10 cm in Ku band, and 5 cm in Ka band



New implementations in SMRT

- Coded in Python
- Very easy to use, open-source and fully documented

Inputs

Snowpack

Sensor config

Choose model

Run

Outputs

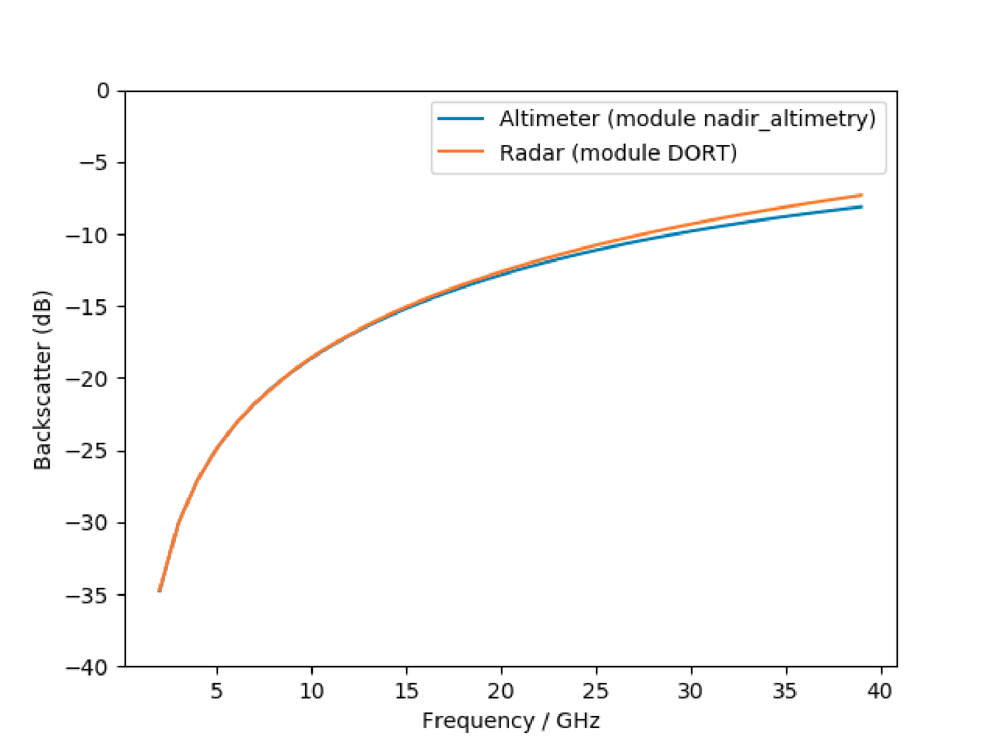
```
## Prepare inputs
thickness = [100.0]
density = 350.
temperature = 225.0
# snow grain size parameter
corr_length = 0.0013
# surface parameter
rough_rms = 0.005
rough_length = 0.04

## Create sublayers interfaces and snowpack
interface = make_interface("iem_fung92", roughness_rms=rough_rms, rough_length=long)
snowpack = make_snowpack(thickness=thickness, microstructure_model="exponential", corr_length=corr_length,
                         density=density, temperature=temperature, interface=interface)

## Create the sensor
sensor = envisat_ra2('Ku')

## Create the model
m = make_model("iba", "nadir_altimetry",
               rtsolver_options=dict(skip_pfs_convolution=False, return_contributions=True))

## run the model SMRT
result = m.run(sensor, snowpack)

## Outputs:
print(result.sigma())
```

=> Radar waveform

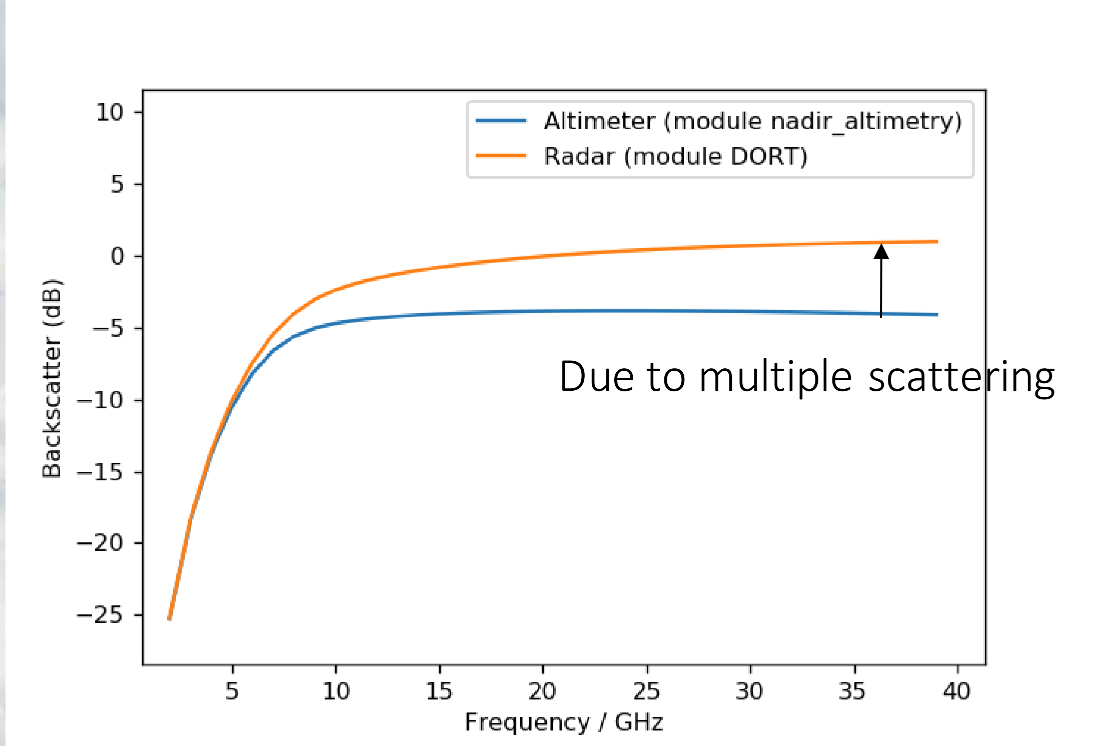
Intrinsic validation of the total backscatter

Comparison between the two solvers: simulations with 2 simple 1-layer snowpack, at the nadir

Small surface height rms



Large surface height rms (more scatterings)



=> Good agreements between the two RT solvers at the nadir at low frequency

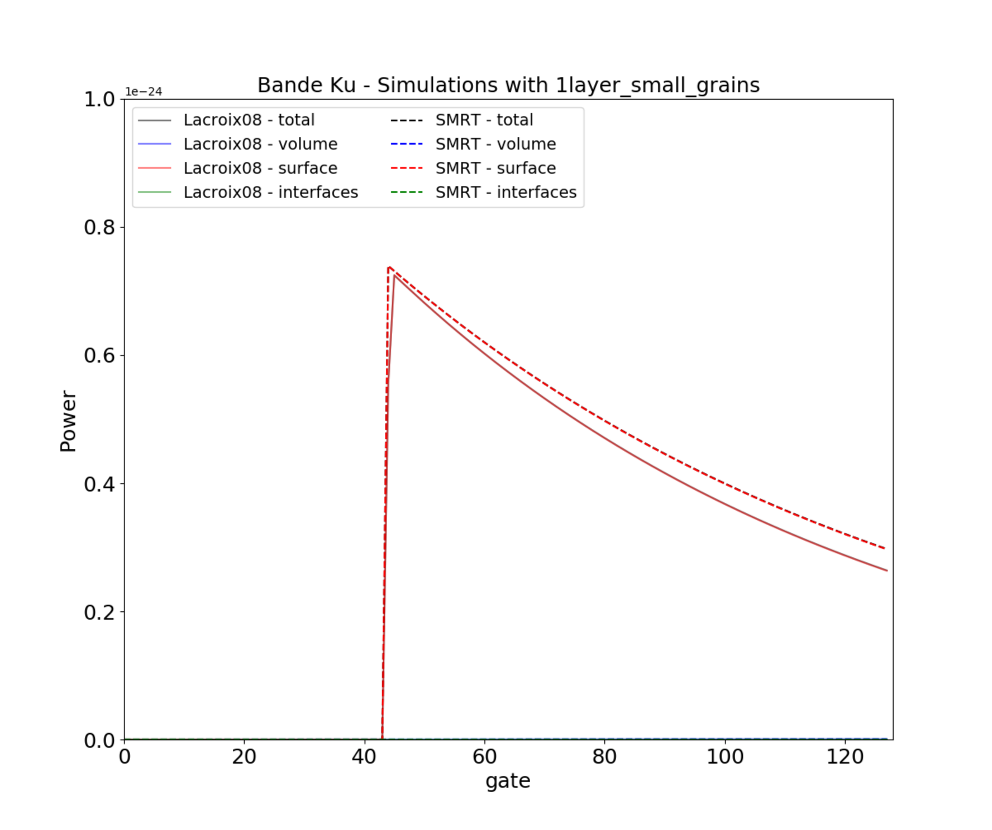
=> Show **the effects of the 2nd order (multiple scattering)** at high frequencies

Validation (Ku band): Comparison with Lacroix et al., 2008

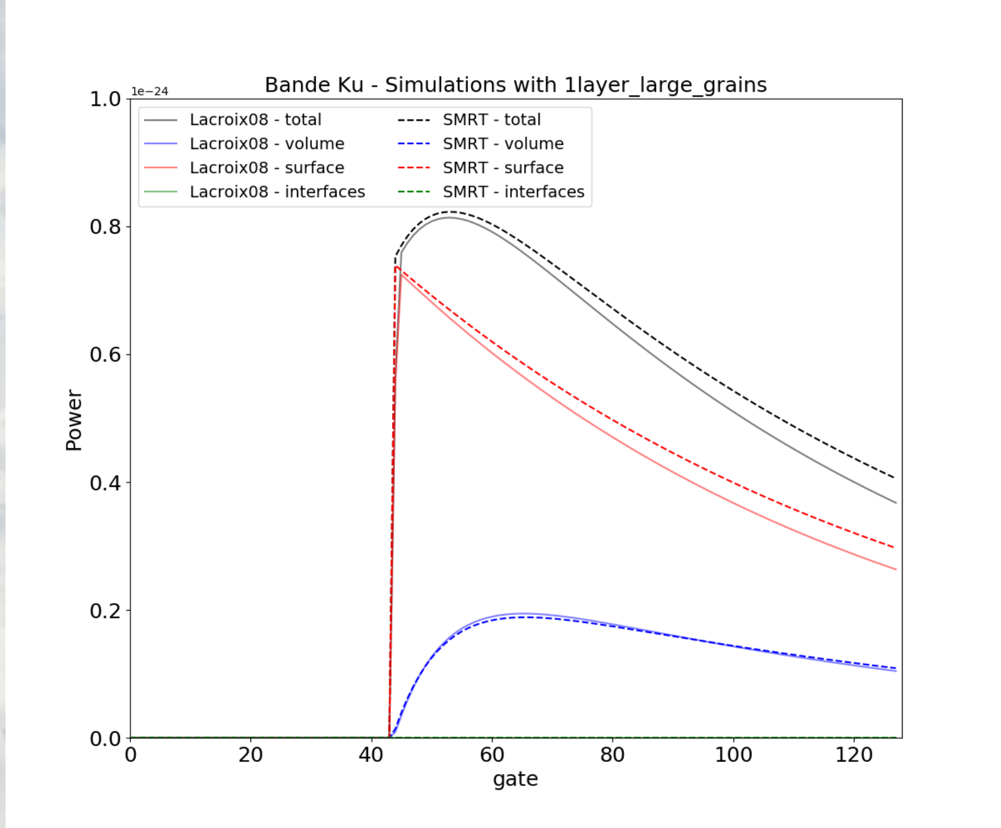
Lacroix et al., 2008: altimeter model adapted for dual-frequecy, accounting for snowpack properties (simple sowpack)

Comparison of waveform simulations with different snow grain sizes

A 1-layer snowpack with small snow grains



A 1-layer snowpack with large snow grains



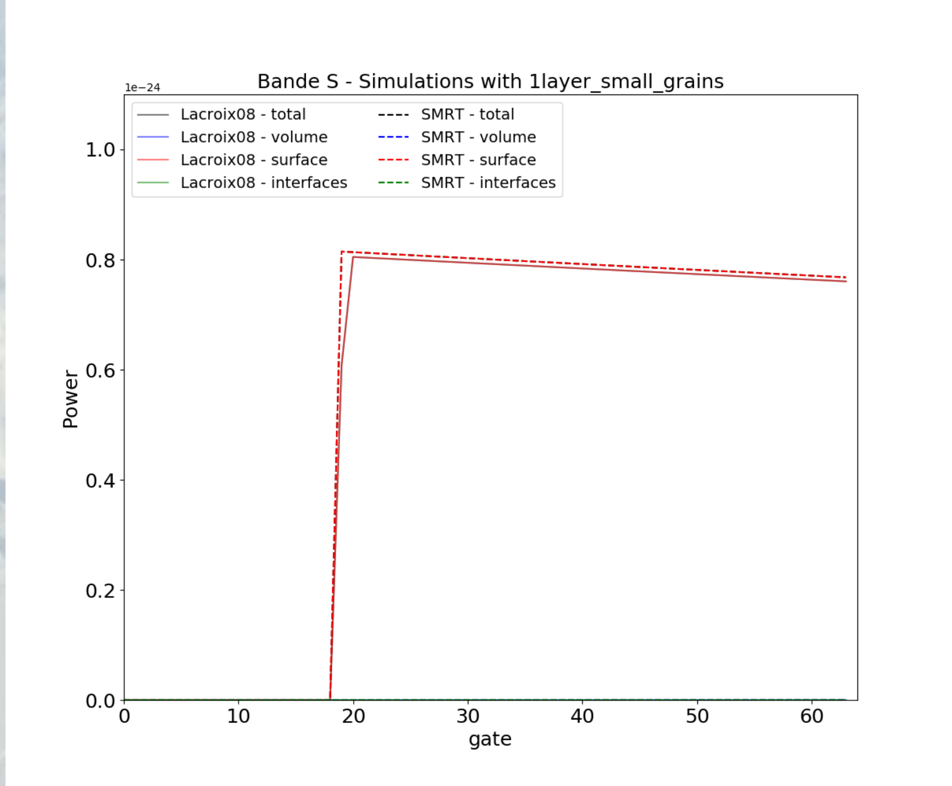
=> Good agreement between volume echos.

=> Small differences between surface echos => work in progress in SMRT

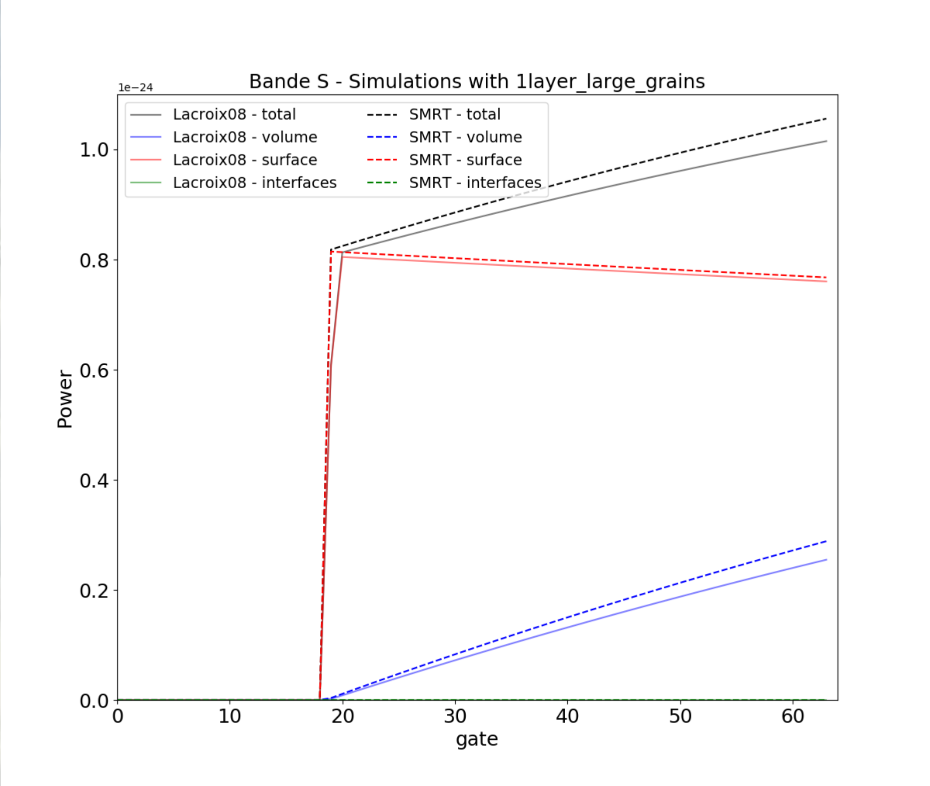
Validation (S band): Comparison with Lacroix et al., 2008

Comparison of waveform simulations with different snow grain sizes

A 1-layer snowpack with small snow grains



A 1-layer snowpack with large snow grains



=> Good agreements between surface echos.

=> Small differences between volume echos for snowpack with large grains (numerical)

Validation: simple modeling of the Antarctic ice sheet

=> 2 realistic synthetic snowpack in Antarctica

Table 3
Snow parameters inversion at 2 locations (Vos = Vostok, Mau = Dronning Maud Land) based on the fit on individual waveforms represented in the Figs. 12 and 13

Location (lon, lat)	ρ_0 (g cm^{-3})	μ (kg/m^2)	Φ_g (mm)	σ_h (mm)	l (cm)
Vos (104.13, −76.57)	0.24±0.03	80±70	0.9±0.07	3.9±0.3	14±3.6
Mau (9.83, −74.96)	0.34±0.05	422±339	0.8±0.17	4.8±0.5	33.5±4.9

The error range is found by considering a signal to noise ratio on the waveforms of 10%.

Lacroix et al., 2008

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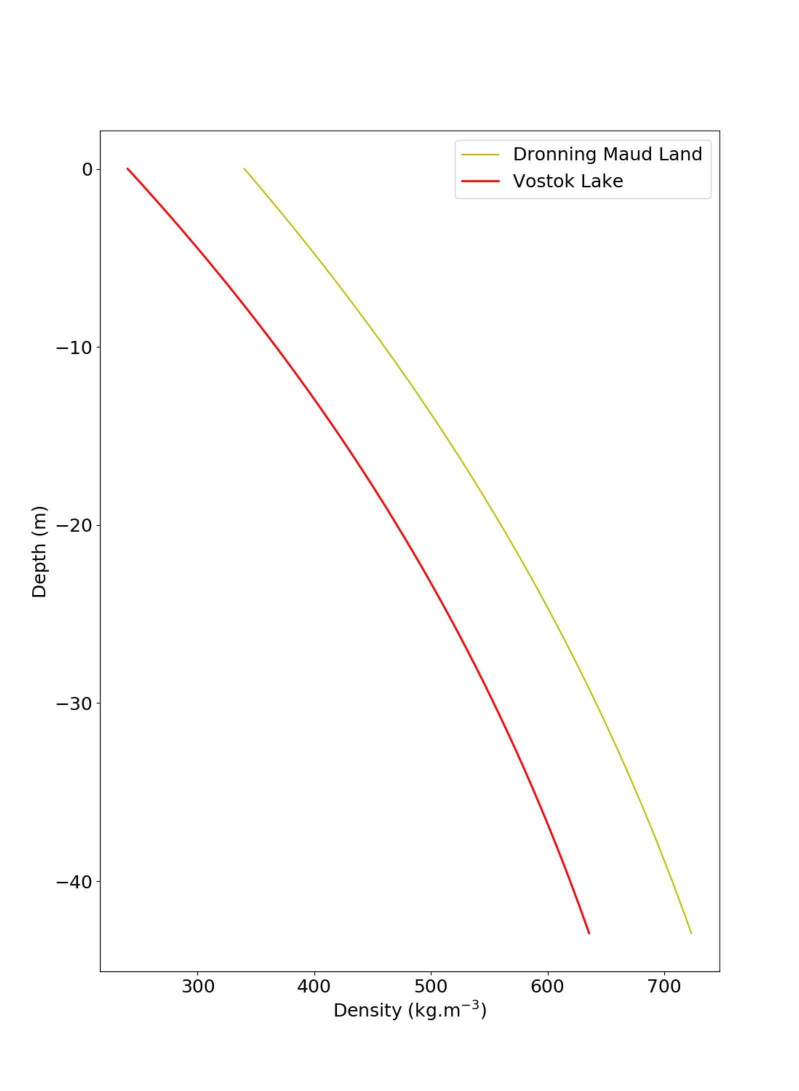
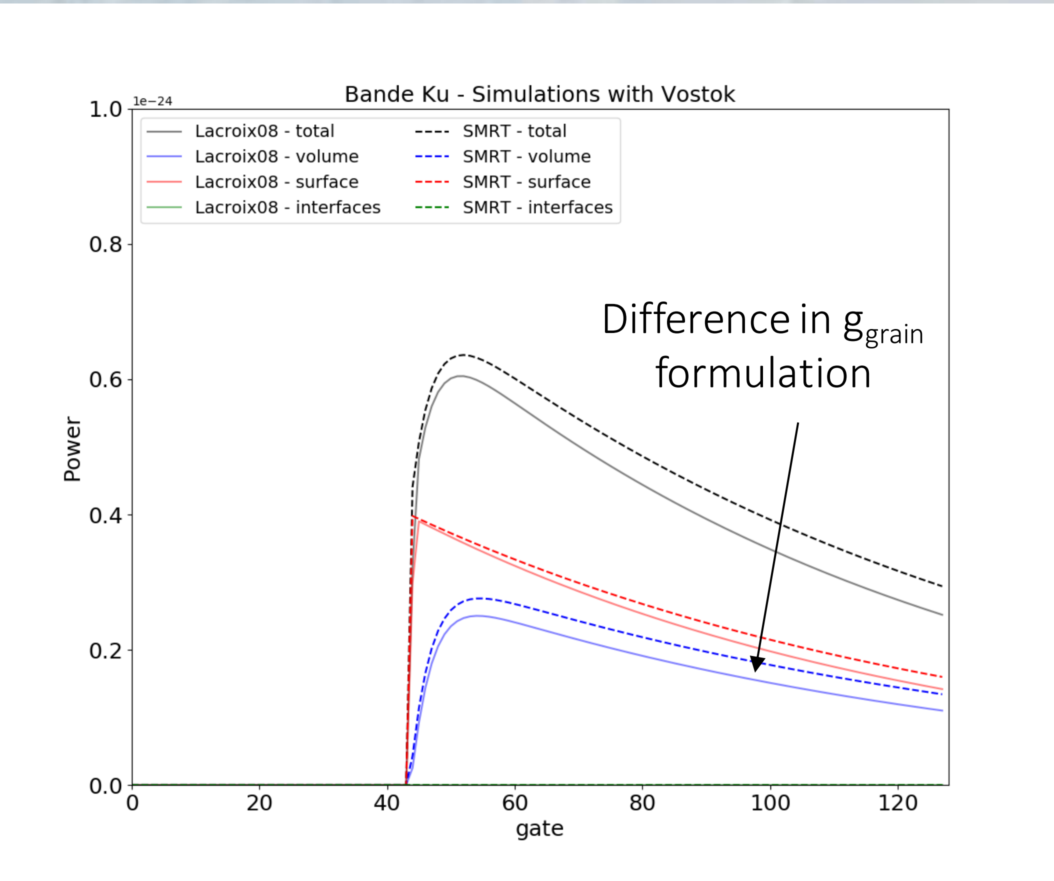


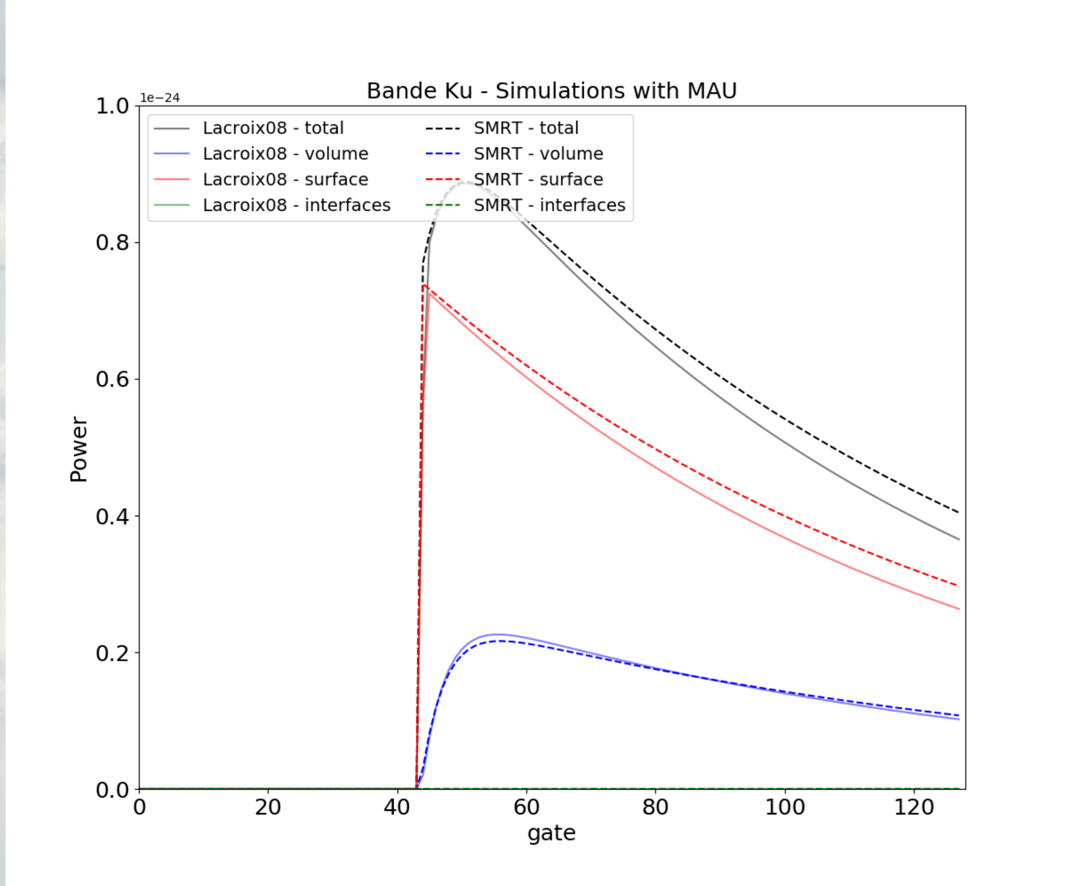
Validation: simple modeling of the Antarctic ice sheet

Ku Band (~ 13 GHz)

Vostok Lake (ρ_0 = 240 kg m^{-3}, **grain radius = 900 nm**)



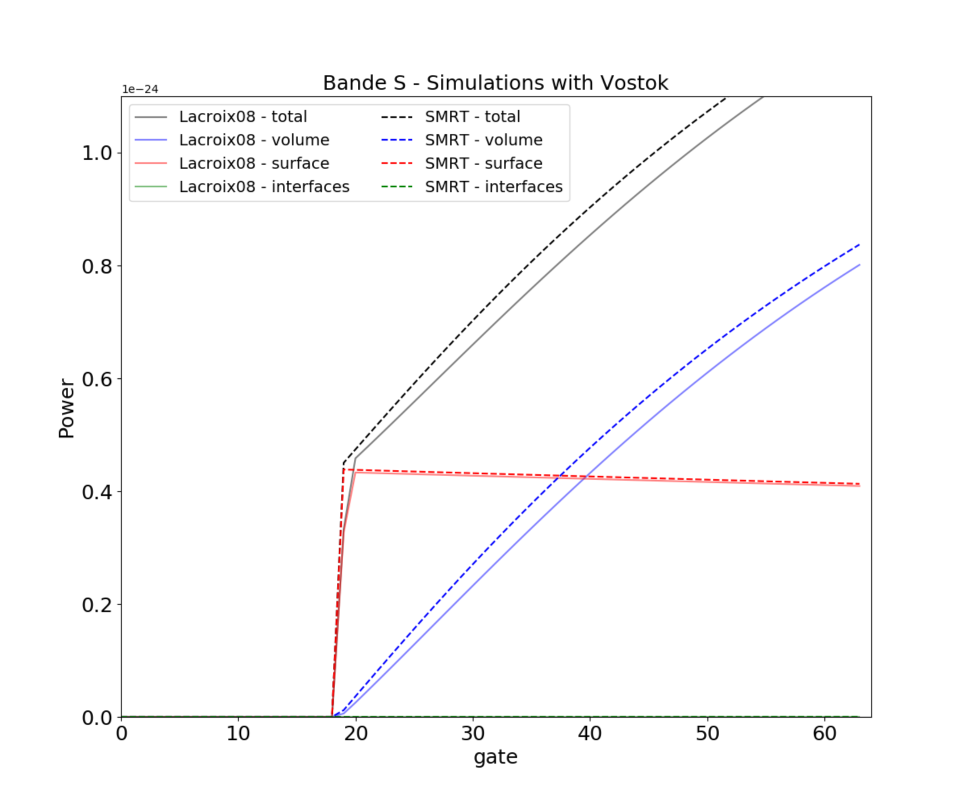
Dronning Maud Land (ρ_0 = 340 kg m^{-3}, grain radius = 800 nm)



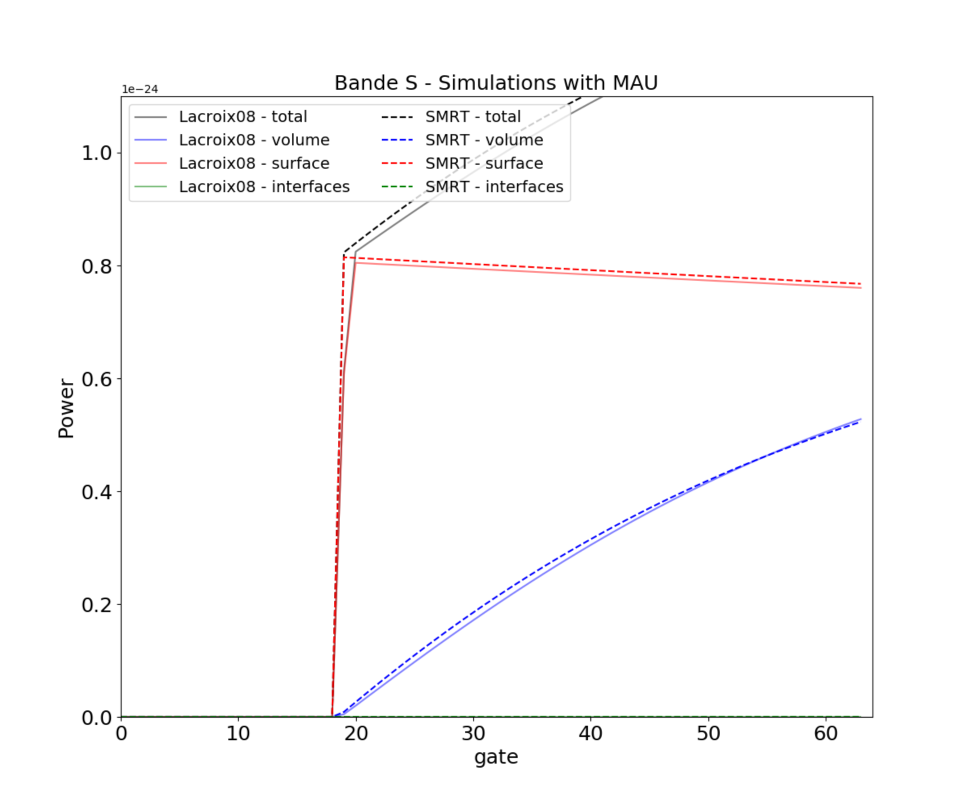
Validation: simple modeling of the Antarctic ice sheet

S Band (~3 GHz)

Vostok Lake
(rms = 3.9 mm, l = 4.8 cm, grain radius = 900 nm)



Dronning Maud Land
(rms = 4.8 mm, l = 33 cm, grain radius = 800 nm)



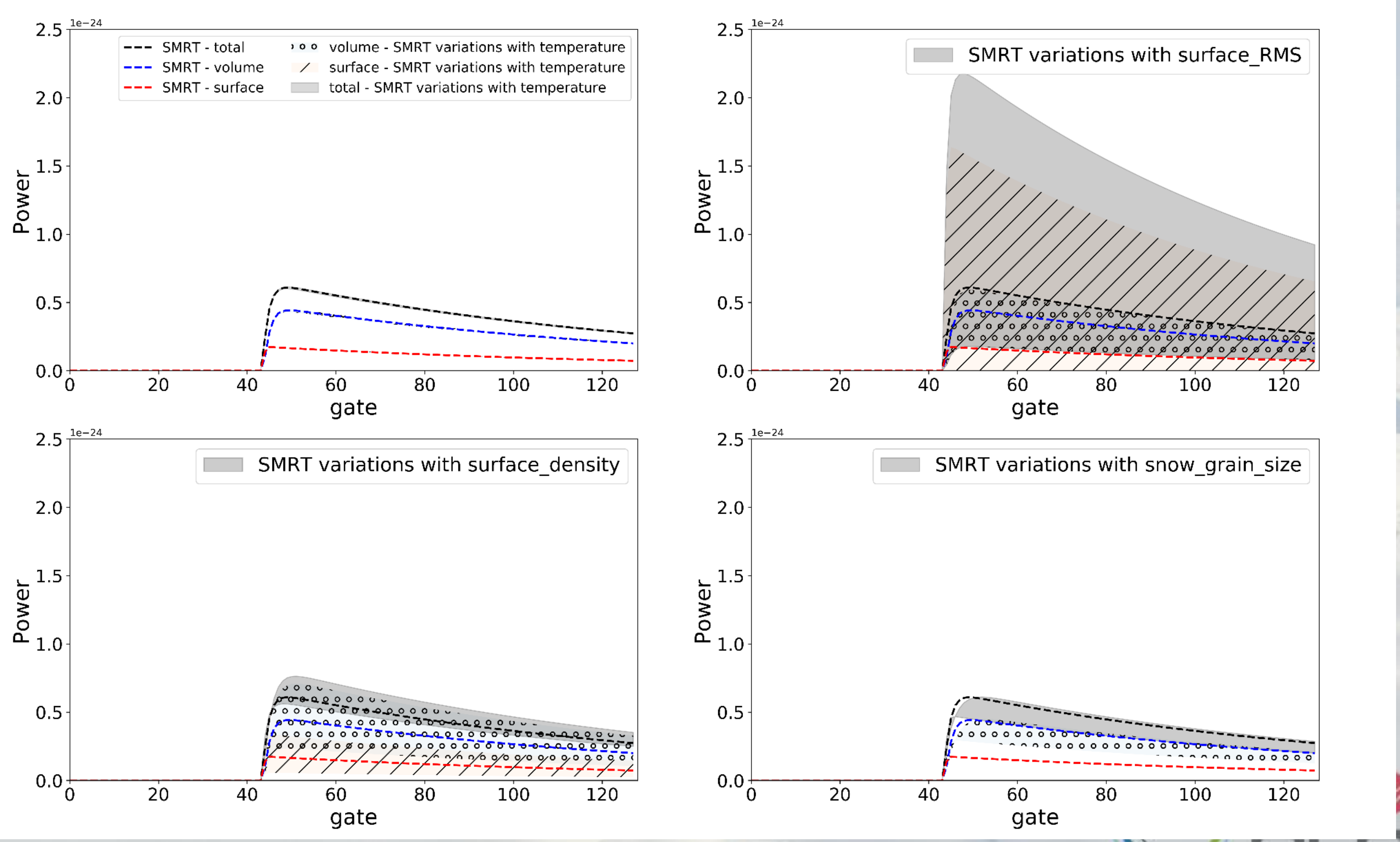
Preliminary sensitivity analysis: Ku band

Table 2
Range of variation of the snow parameters over the Antarctic ice-sheet

Parameter	Notation (units)	Min value	Max value	Step	References
Surface density	ρ_0 (g cm^{-3})	0.2	0.5	0.02	Goodwin et al. (1988)
Accumulation rate	μ (kg m^{-2} y^{-1})	0	2000	$\frac{1}{\mu}$ constant	Vaughan et al. (1999)
Snow grain size	Φ_g (mm)	0.1	1	0.1	Surdyk and Fily (1993)
Surface rms height	σ_h (mm)	1	20	1	Lacroix et al. (submitted for publication)
Correlation length	l (cm)	4	50	2	Lacroix et al. (submitted for publication)
Snow temperature	T (K)	190	260	10	King and Turner (1987)

Lacroix et al., 2008

Snowpack of reference:
ρ_0 = 350kg m^{-3},
grain radius =500 nm
Temperature = 225 K
Thickness = 50 cm
rms = 5 mm, l = 5 cm (IEM)



Preliminary sensitivity analysis: S band

Table 2
Range of variation of the snow parameters over the Antarctic ice-sheet

Parameter	Notation (units)	Min value	Max value	Step	References
Surface density	ρ_0 (g cm^{-3})	0.2	0.5	0.02	Goodwin et al. (1988)
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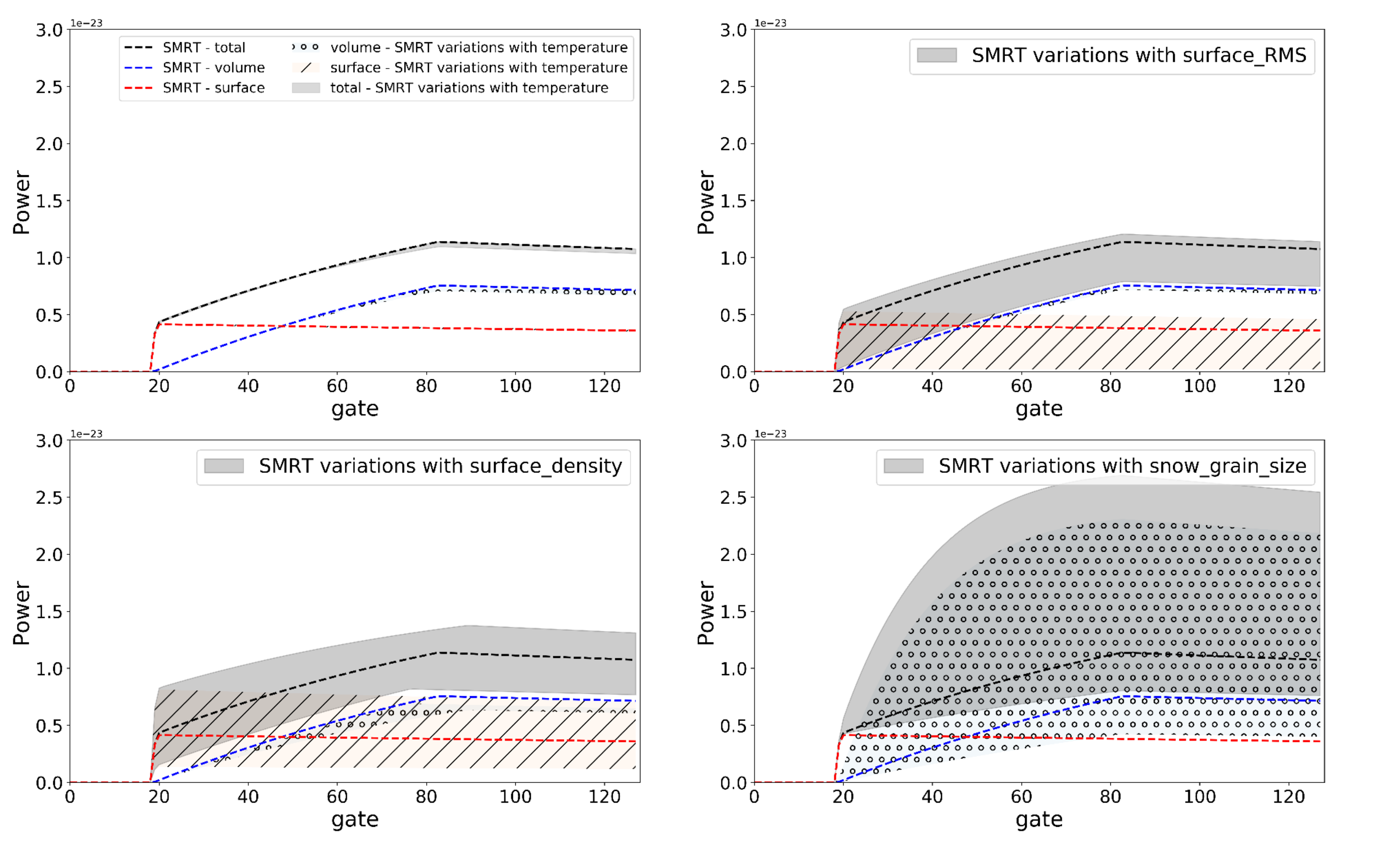

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Conclusion

What has been done?

- New implementations in an existing snow radiative transfer model for altimetric applications,
- Intrinsic validations
- Eexternal validations with an existing altimeter simulator and realistic snowpack
- Preliminary sensitivity analysis with a simple snowpack

Work in progress

- Sensitivity analysis with study cases.
- Performance analysis:

Check the following hypothese => **Backscatter is computed assuming only first order scattering**
OK for Ku-band, but has to be verify for Ka-band (interactions of order 2+ are less negligible…)

Perspective

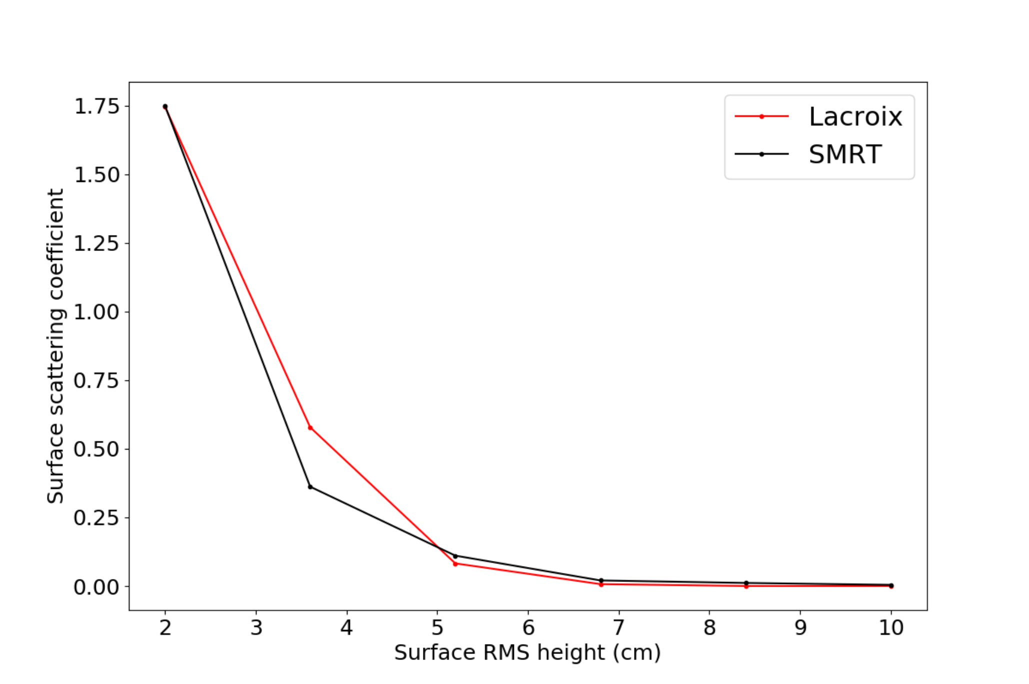
Major difficulties: validation with in situ data. Work in progress at IGE…
=> new concept using passive/active microwave simulations to build a realistic study case.
=> using in-situ measurements of snow properties and surface roughness acquired during the Asuma traverse (2015/2016) in Antarctica
=> Sentinel-3 observations

Thank you for your attention

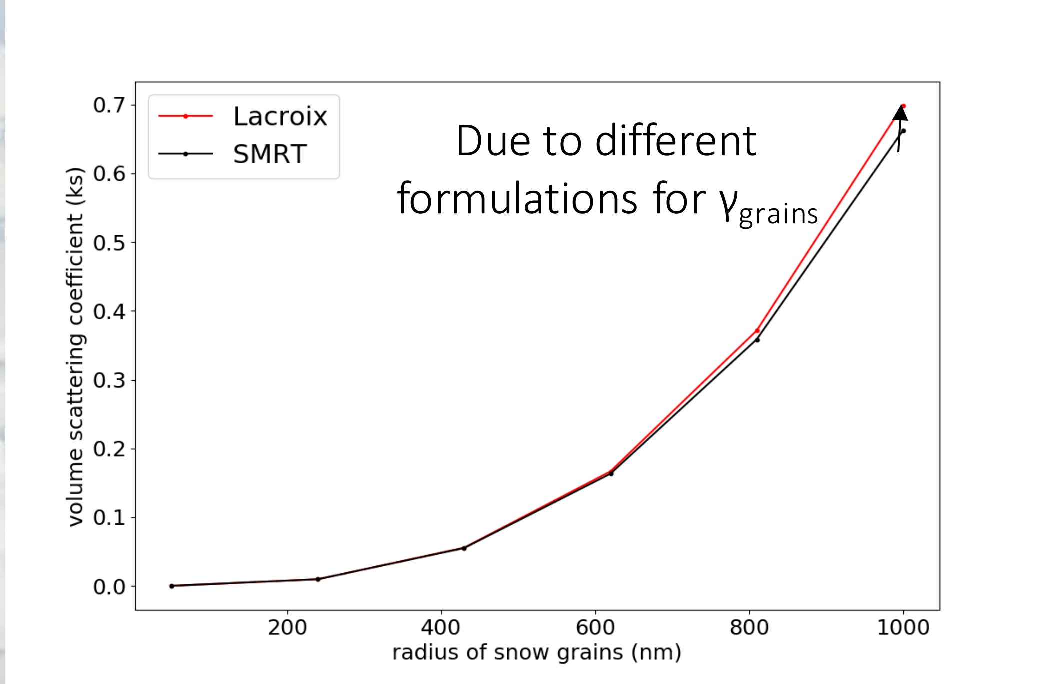
Validation (Ku band): Comparison with Lacroix et al., 2008

Lacroix et al., 2008: altimeter model adapted for dual-frequecy, accounting for snowpack properties (simple sowpack)
Comparison of simulated scattering coefficients: SMRT/Lacroix et al. 2008

- σ_s according to surface height rms (IEM model)



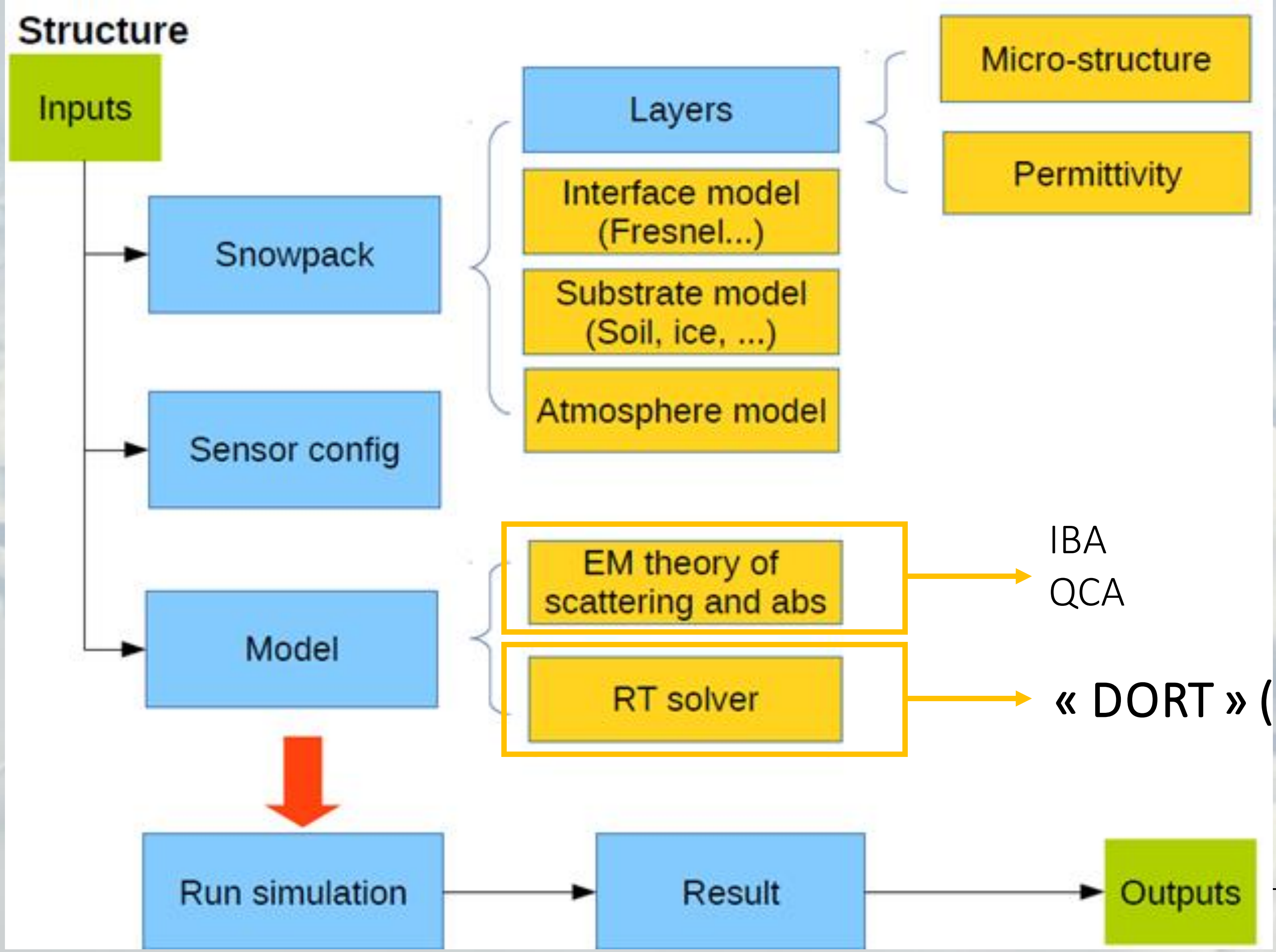
- γ_{grains} according to snow grain size (Iba EM model)



=> Good agreements, differences due to numerical resolutions (especially with large grains)

How does SMRT work ?

- **Existing version:** SMRT is plane-parallel multi-layer radiative transfer model (time independent)



IBA
QCA

« DORT » (Time independent)

T_B or σ_{TOT} at f and theta

For each box many formulations are available and new ones can be easily developed