The DMRT-ML model: numerical simulations of the microwave emission of snowpacks based on the Dense Media Radiative Transfer theory

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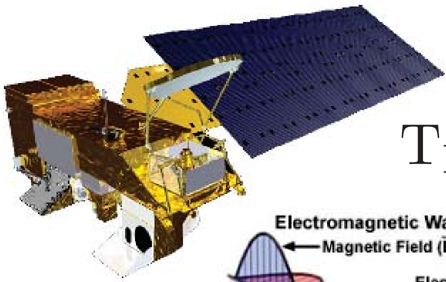
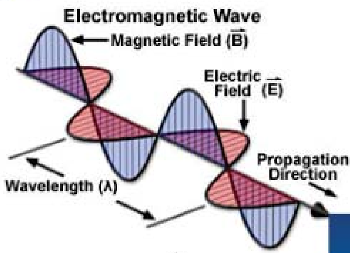
[3] Uni. Grenoble Alpes/CNRS, Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France
[4] Centre d'Applications et Recherches en Télédétection Université de Sherbrooke, Québec, Canada

Sophistication of microwave radiative transfer models



$$\mathrm{T_B}_{\ \nu,\ p} = f(\text{radiative transfer interactions in the snowpack})$$



RT models relate snow and radiation properties

Models can be:

Theoretical

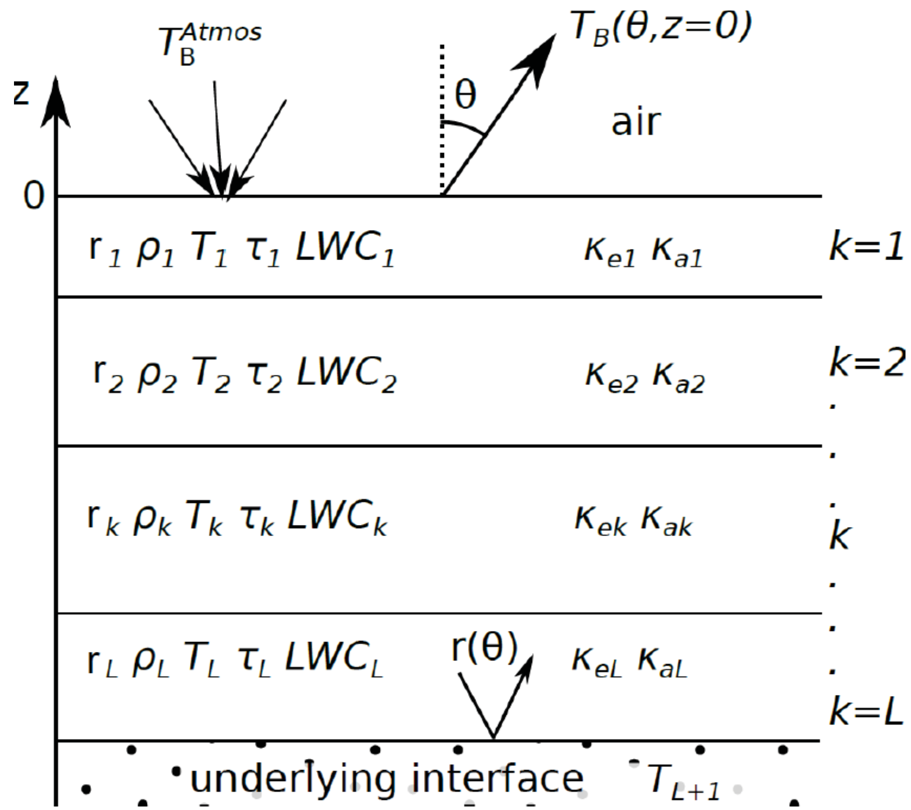
Semi empirical

Empirical

Outline

DMRT-ML – Snowpack and Soil Configurations

(Dense Media Radiative Transfer Multi-Layer model)



Every **layer** is defined by:

- Grain size (sphere radius r)
- Density (ρ)
- Temperature (T)
- Stickiness parameter (τ)
- Liquid water content (LWC)

It can be layers of snow or ice

DMRT-ML – Snowpack and Soil Configurations

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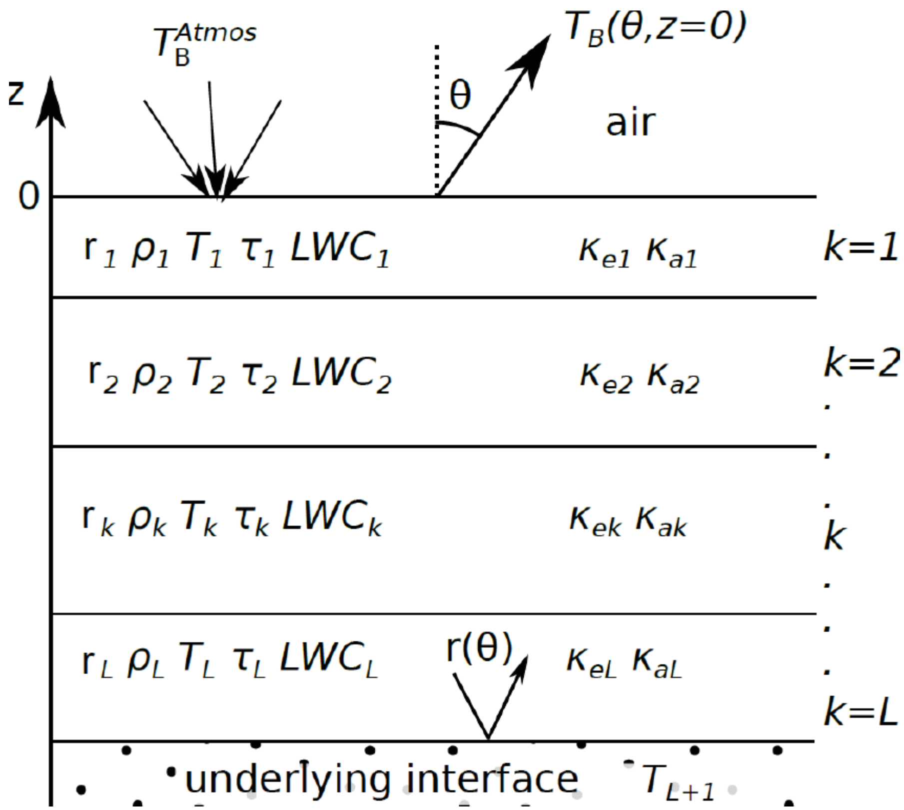

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It can be layers of snow or ice

Underneath interface can be:
Snow, Ice, Soil (smooth or rough), Fresh water

DMRT-ML – Snowpack and Soil Configurations

(Dense Media Radiative Transfer Multi-Layer model)

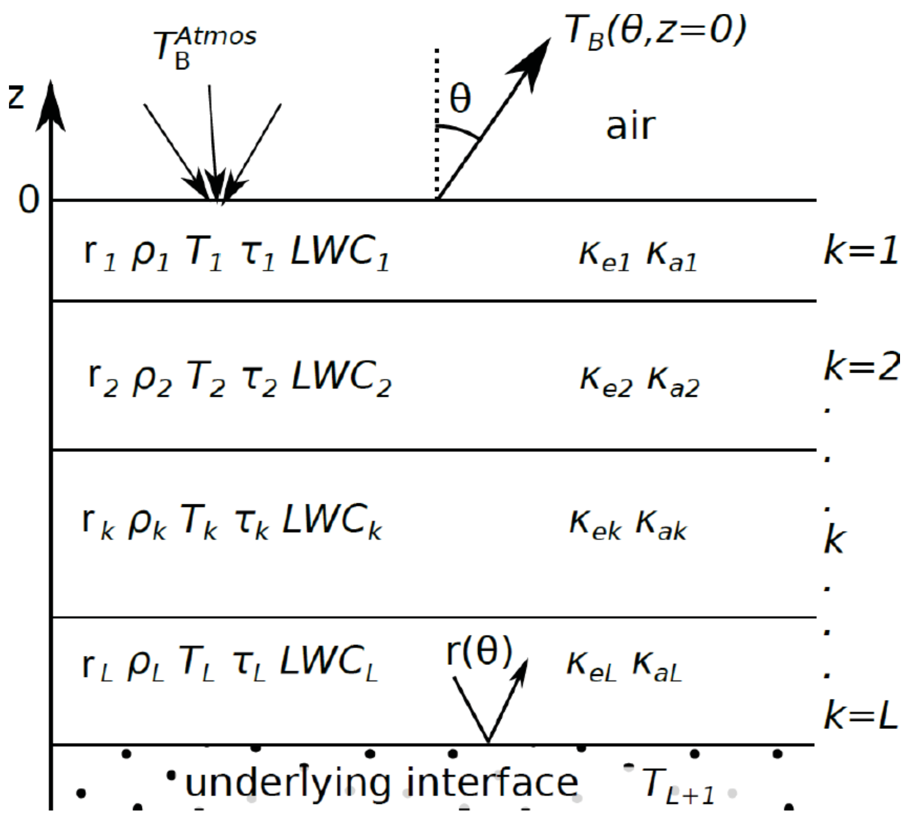
Interface model	Material	Dielectric constant	ID	Variables and parameters
No interface	None		0	
Flat surface, Fresnel	Any	prescribed	1	ε
Flat surface, Fresnel	Soil	from P99	2	SM, f_{clay}, f_{sand}, ρ_{orga}, T
Flat surface, Fresnel	Soil	from D85	3	SM, T
Rough surface WM99	Any	prescribed	101	σ,ε
Rough surface WM99	Soil	from P99	102	σ, SM, f_{clay}, f_{sand}, ρ_{orga}, T
Rough surface WM99	Soil	from D85	103	σ, SM, T
Flat surface, Fresnel	Ice	from M87, M06	202	T
QH model W83	Any	prescribed	301	σ, Q, H, ε
QH model W83	Soil	from P99	302	σ, Q, H, SM, f_{clay}, f_{sand}, ρ_{orga}, T
QH model W83	Soil	from D85	303	σ, Q, H, SM, T
Flat surface, Fresnel	Fresh water	from M87	402	T

SM: soil moisture (volume fraction)
ϵ: dielectric constant
σ: surface RMS height (m)
$f_{\rm clay}$, and $f_{\rm sand}$: fractions of clay and sand
$\rho_{\rm orga}$: density of dry organic matter (kg m^{-3})
T: soil temperature (K)
Q, and H: dimensionless parameters

P99 = Pulliainen et al. (1999)
D85 = Dobson et al. (1985)
M87 = Mätzler (1987)
M06 =Mätzler et al. (2006)

DMRT-ML – Snowpack and Soil Configurations

(Dense Media Radiative Transfer Multi-Layer model)



Every **snow layer** is defined by:

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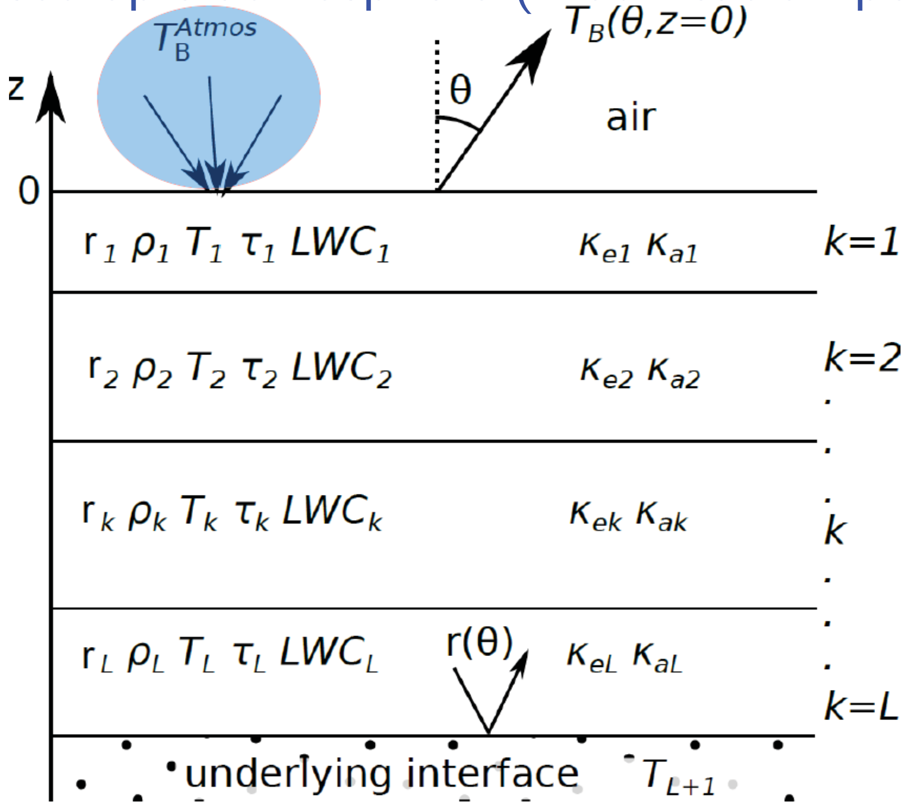
DMRT-ML – Snowpack and Soil Configurations

(Dense Media Radiative Transfer Multi-Layer model)

isotropic atmosphere (modification possible to account for the angular dependency)



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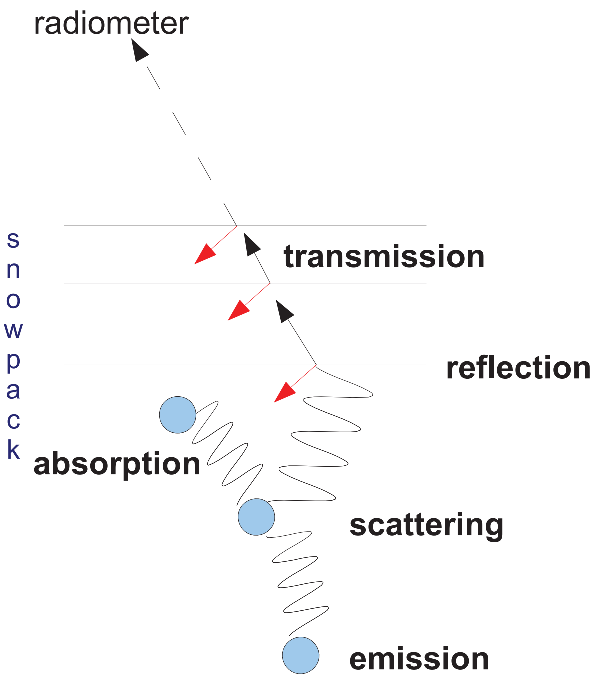
DMRT-ML – Elements



DMRT-ML computes:

. emission
. scattering
. absorption

} **using the DMRT theory**

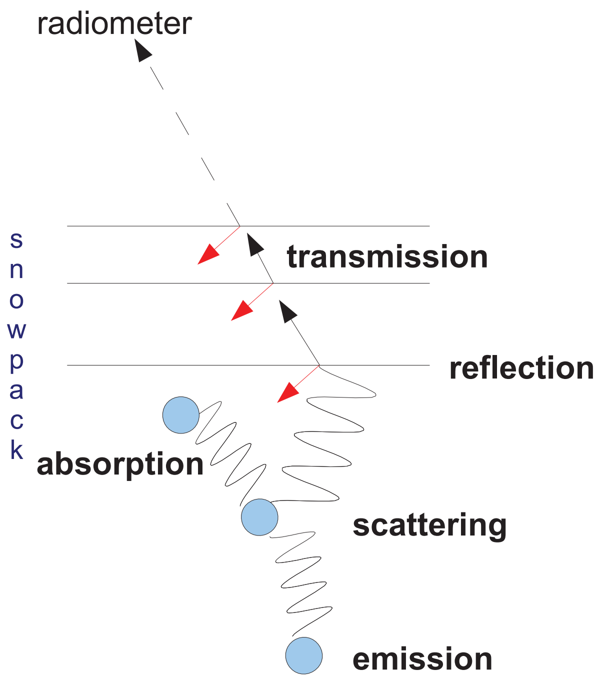
DMRT-ML computes the reflection coefficients at:

. snow/snow interfaces
. snow/atmosphere interface

} **using Fresnel**

DMRT-ML solves the radiative transfer equation
using the DISORT method
(64 or 128 streams are adequate)

DMRT-ML – Elements



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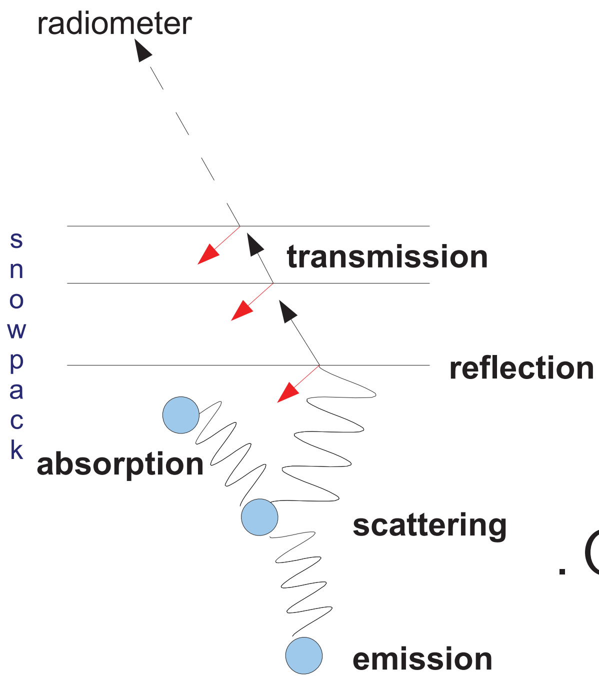
Two DMRT flavors were implemented:

DMRT-ML – Elements



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. QCA-CP

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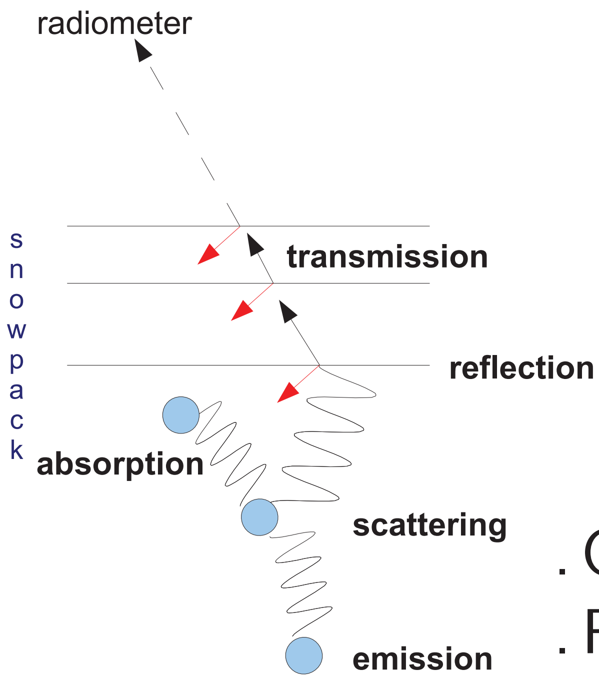
DMRT-ML – Elements



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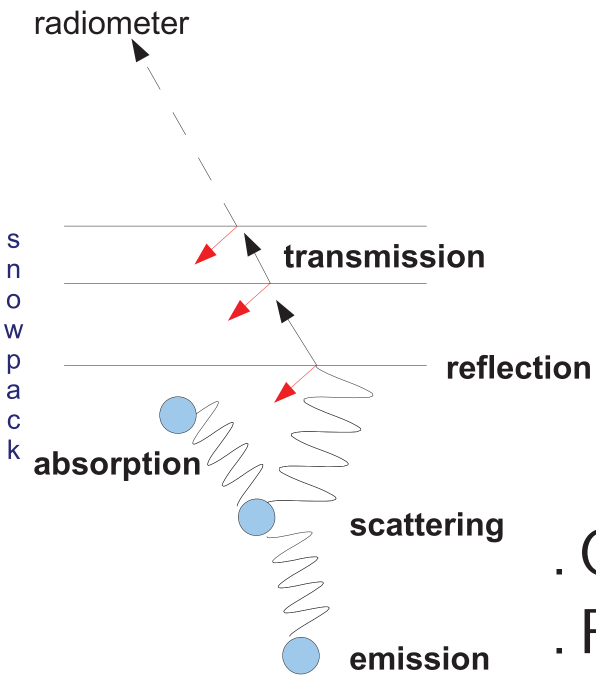

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Two DMRT flavors were implemented:

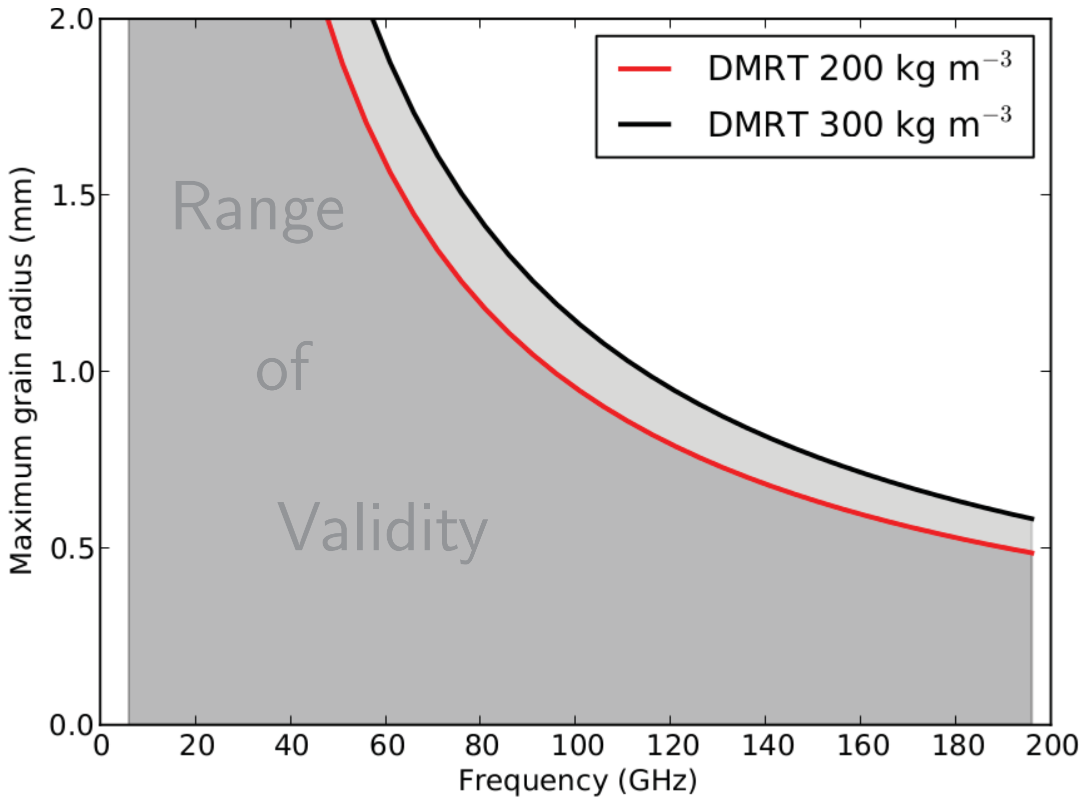
. QCA-CP	. QCA-CP
. Rayleigh assumption	. Rayleigh assumption
. Optional correction for large particles *(Grody, 2008)*	. No large particles

DMRT-ML – Elements

Optional correction for large particles *(modified from Grody, 2008)*:

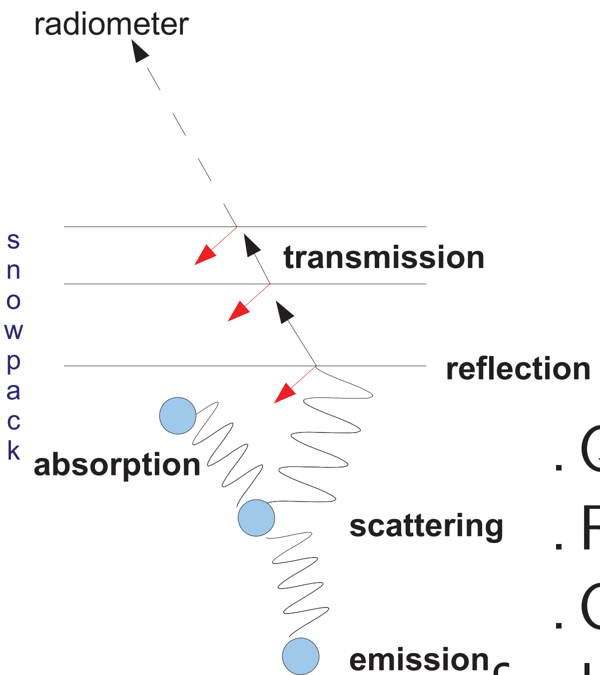
the scattering efficiency coefficient $Q_s^{\max}$ cannot exceed 2

($Q_s^{\max}$=2, theoretical asymptotic value for very large particles)



It is not recommended to consider a many and thick layers of large grains

DMRT-ML – Elements



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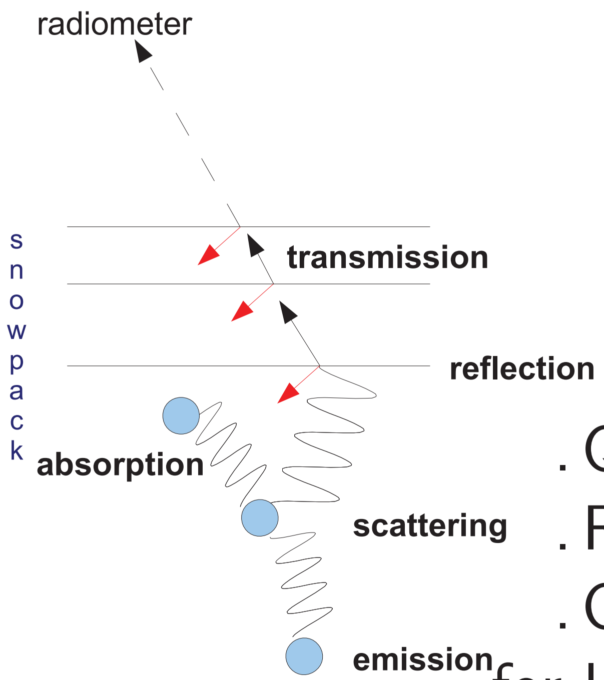

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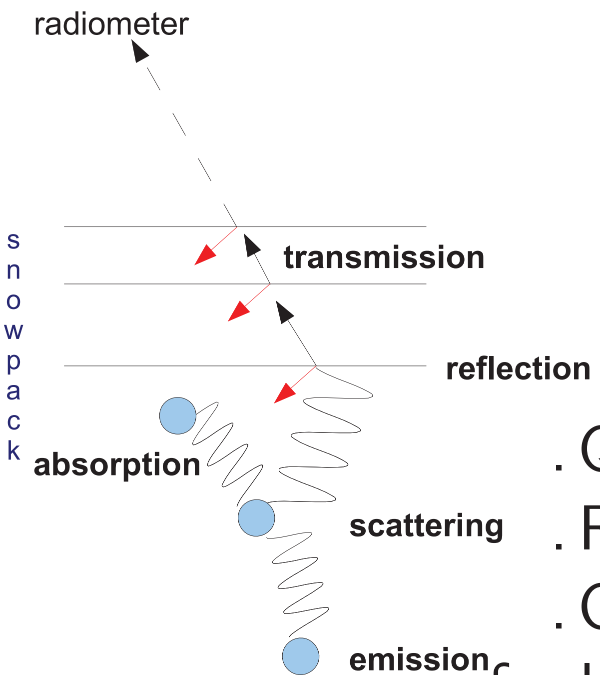
. Mono-disperse	. Poly-disperse (i.e. Rayleigh distribution)

DMRT-ML – Elements



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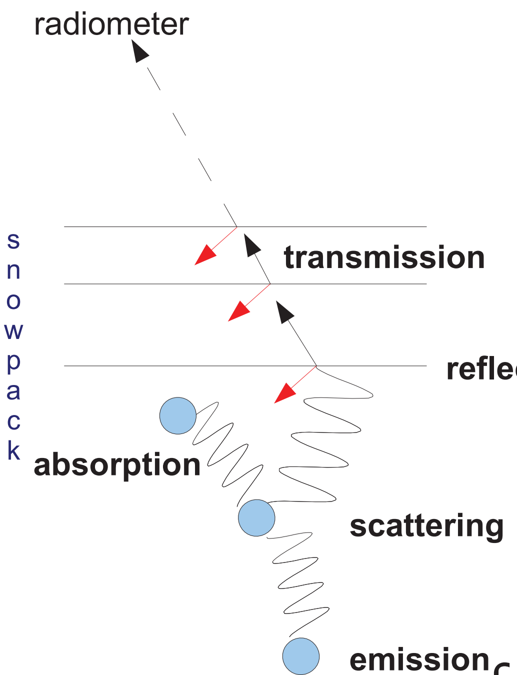
DMRT-ML – Elements



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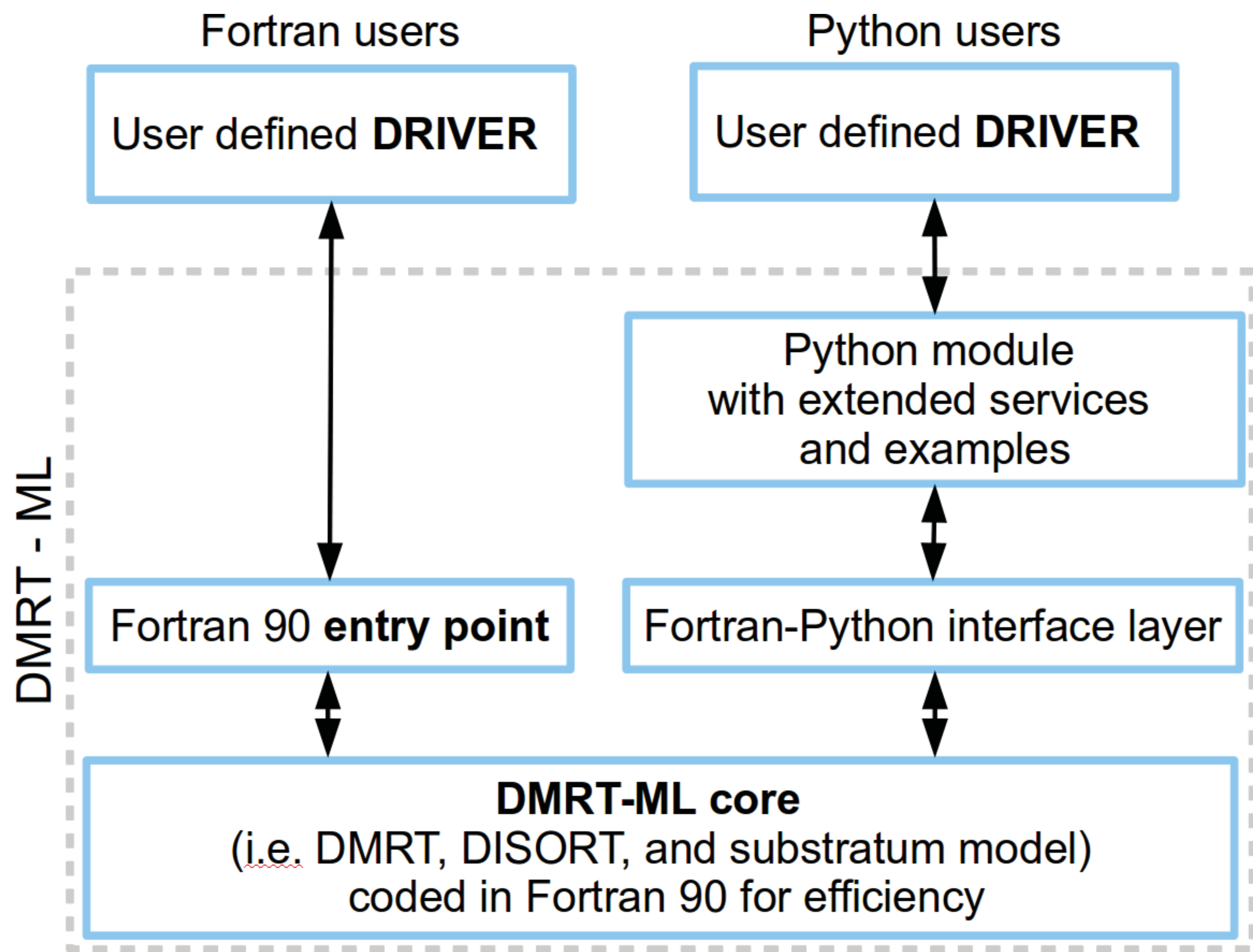
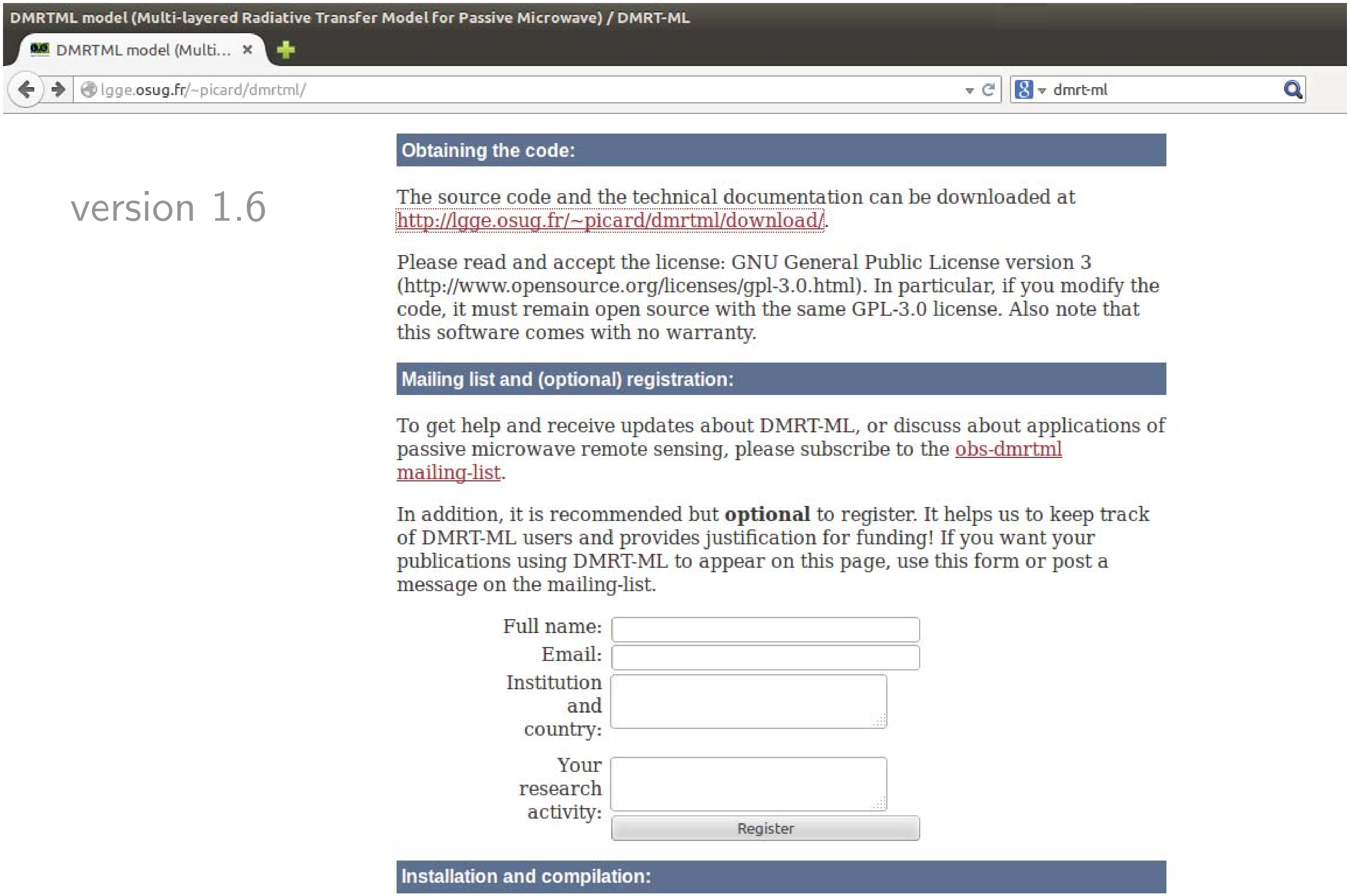
. Mono-disperse	. Poly-disperse (i.e. Rayleigh distribution)
. Optional "short range" stickiness	. No stickiness
Recommended	

DMRT-ML – Implementation



DMRT-ML – Open source model

version 1.6


DMRTML model (Multi-layered Radiative Transfer Model for Passive Microwave) / DMRT-ML

DMRTML model (Multi... ×

lgge.osug.fr/~picard/dmrtml/

dmrt-ml

Obtaining the code:

The source code and the technical documentation can be downloaded at http://lgge.osug.fr/~picard/dmrtml/download/.

Please read and accept the license: GNU General Public License version 3 (http://www.opensource.org/licenses/gpl-3.0.html). In particular, if you modify the code, it must remain open source with the same GPL-3.0 license. Also note that this software comes with no warranty.

Mailing list and (optional) registration:

To get help and receive updates about DMRT-ML, or discuss about applications of passive microwave remote sensing, please subscribe to the obs-dmrtml mailing-list.

In addition, it is recommended but **optional** to register. It helps us to keep track of DMRT-ML users and provides justification for funding! If you want your publications using DMRT-ML to appear on this page, use this form or post a message on the mailing-list.

Full name:

Email:

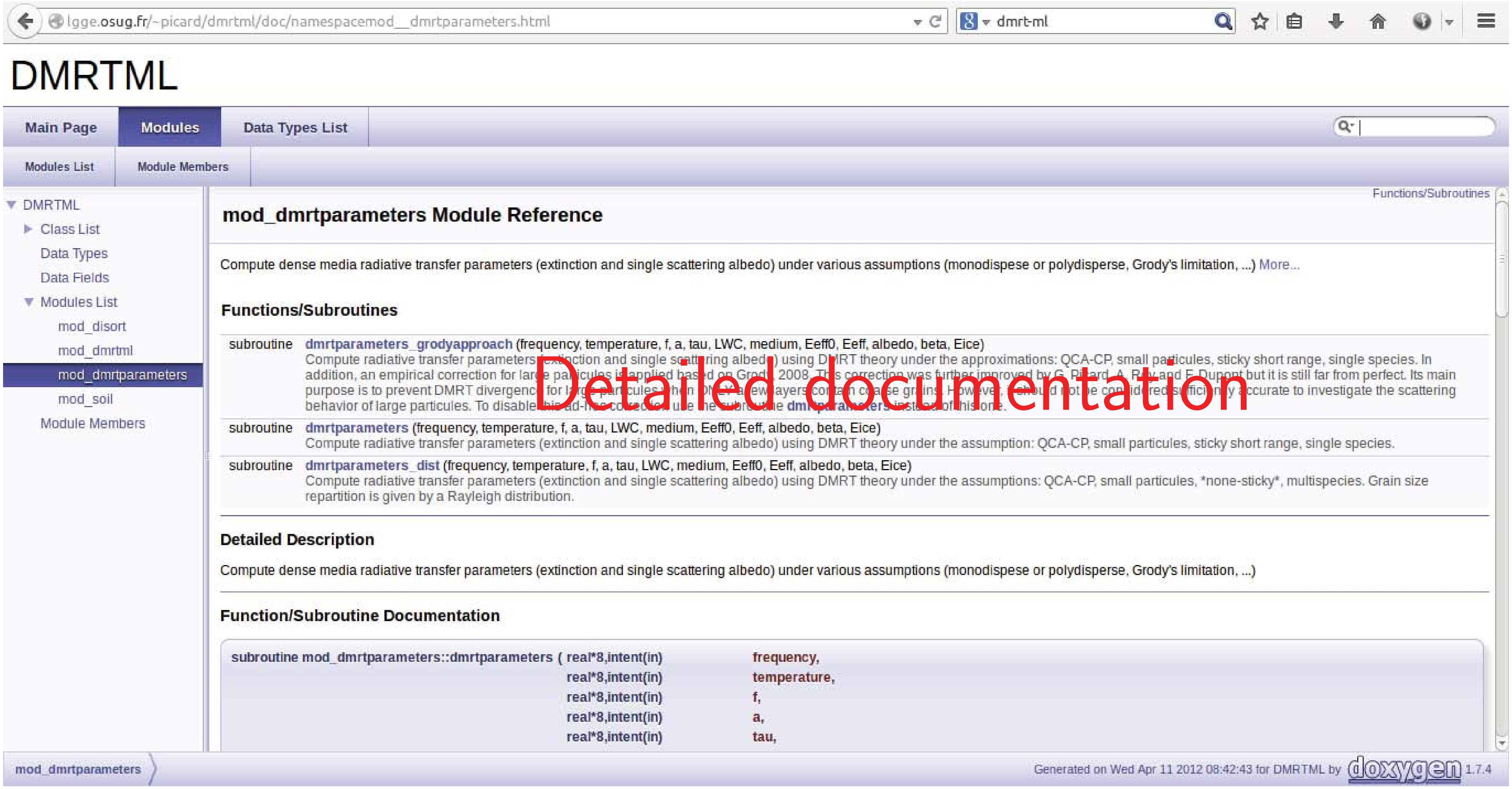
Institution and country:

Your research activity:

Register

Installation and compilation:

DMRT-ML – Open source model



Detailed documentation

The one-line Python code:

dmrtml.dmrtml(frequency,128,height,density,radius,temp,
tau=dmrtml.NONSTICKY,dist=False,soilp=None)

Outline

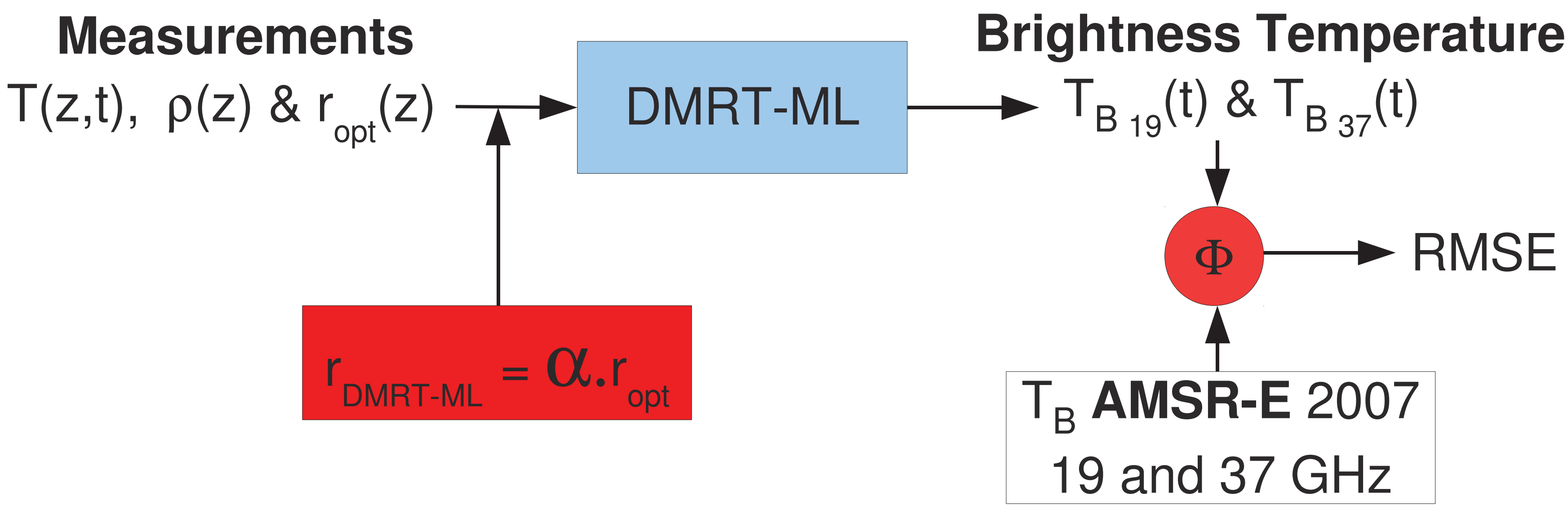
Methodology

Measurements $\qquad$ **Brightness Temperature**

$T(z,t)$, $\rho(z)$ & $r_{opt}(z)$ $\longrightarrow$ DMRT-ML $\longrightarrow$ $T_{B\,19}(t)$ & $T_{B\,37}(t)$

r_{opt} may be measured using near infrared sensors (camera, integrating sphere, profiler, etc.)

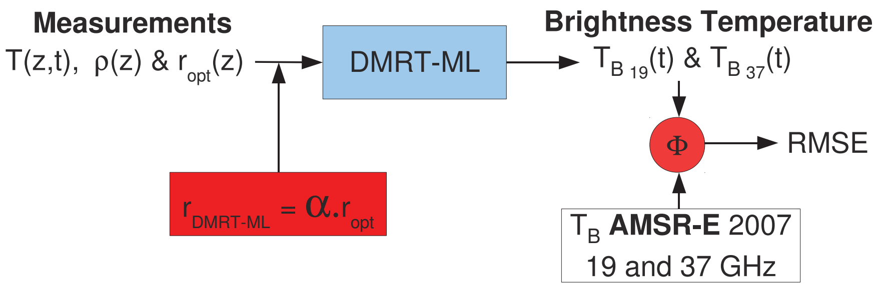
Methodology



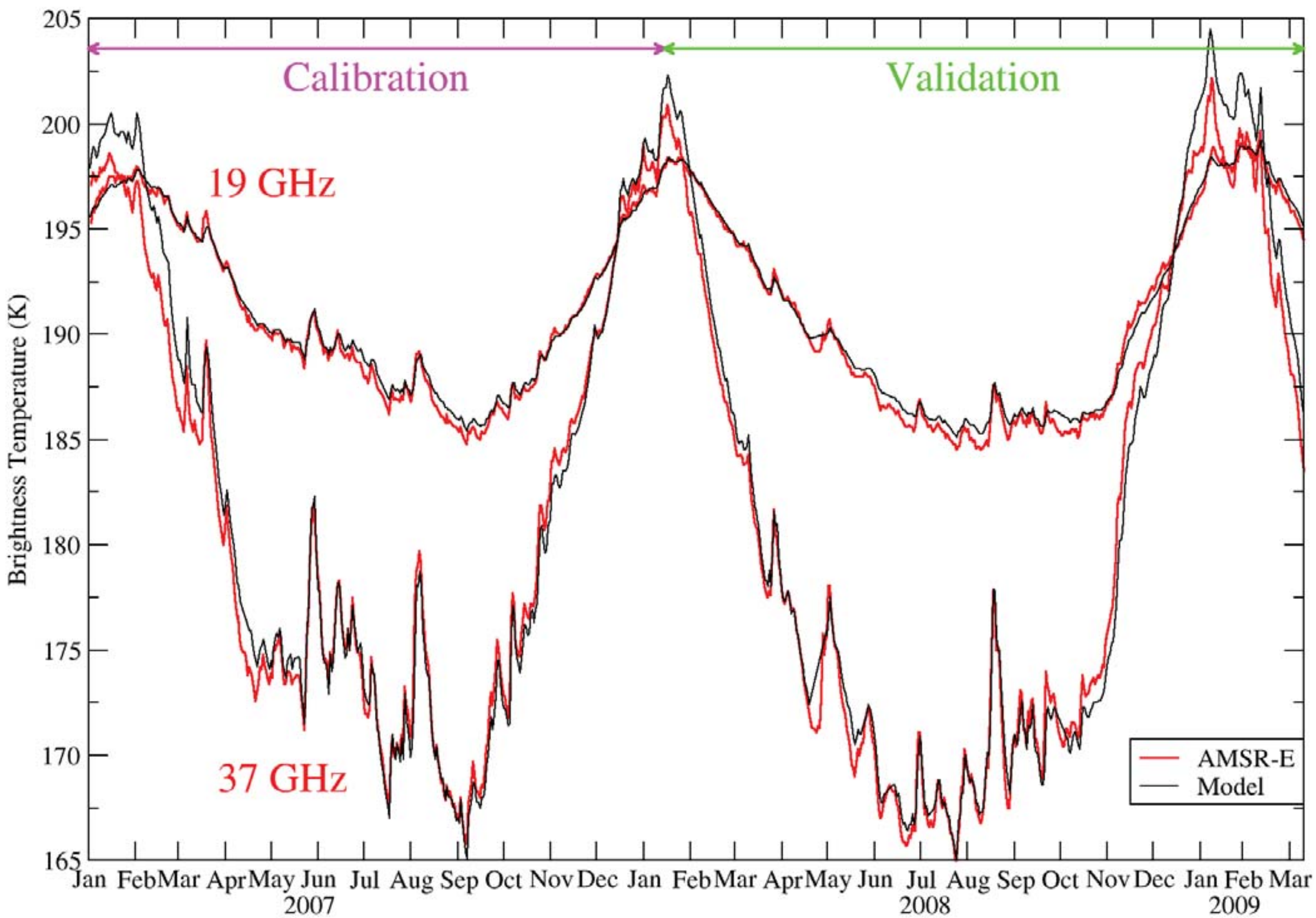
α is a calibrated parameter identical at both frequencies.

(Brucker et al., 2011 JoG)

Dome C, Antarctica



Calibration result: α**=2.8**



V pol.

$RMSE_{19} \simeq 0.4K$

$RMSE_{37} \simeq 1K$

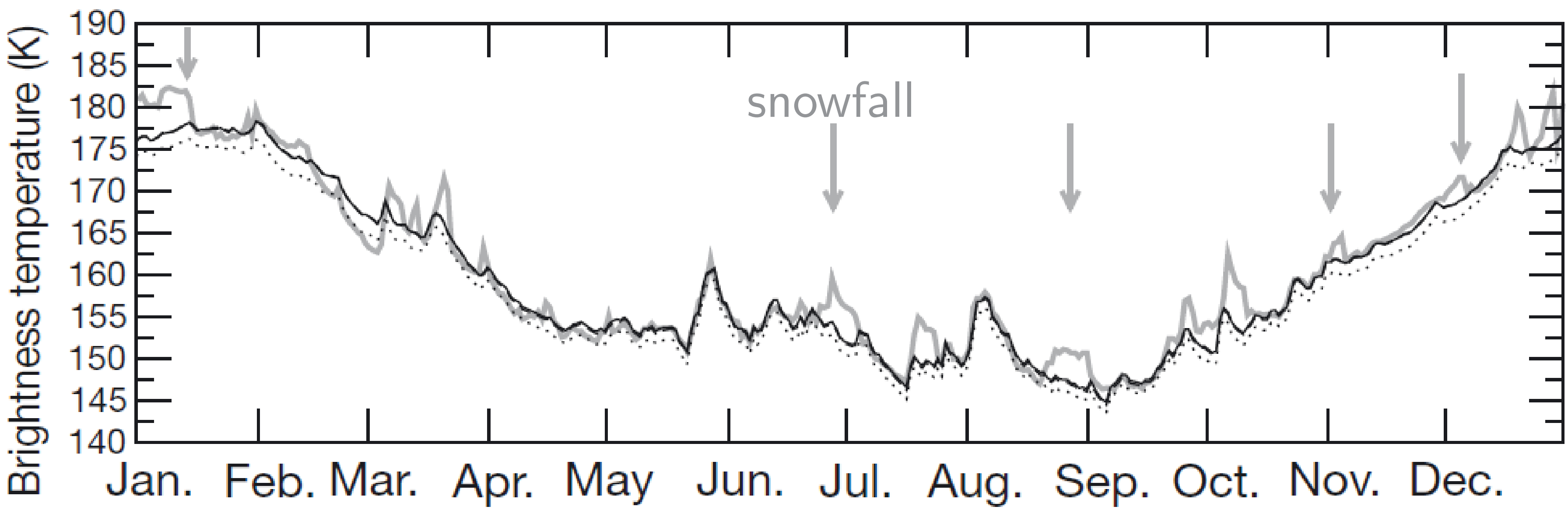
$\overline{RMSE} \simeq 0.8K$

(Brucker et al., 2011)

Good calculation of the extinction coefficient

Dome C, Antarctica

Simulated and observed T_B at 37 GHz, **H pol.**

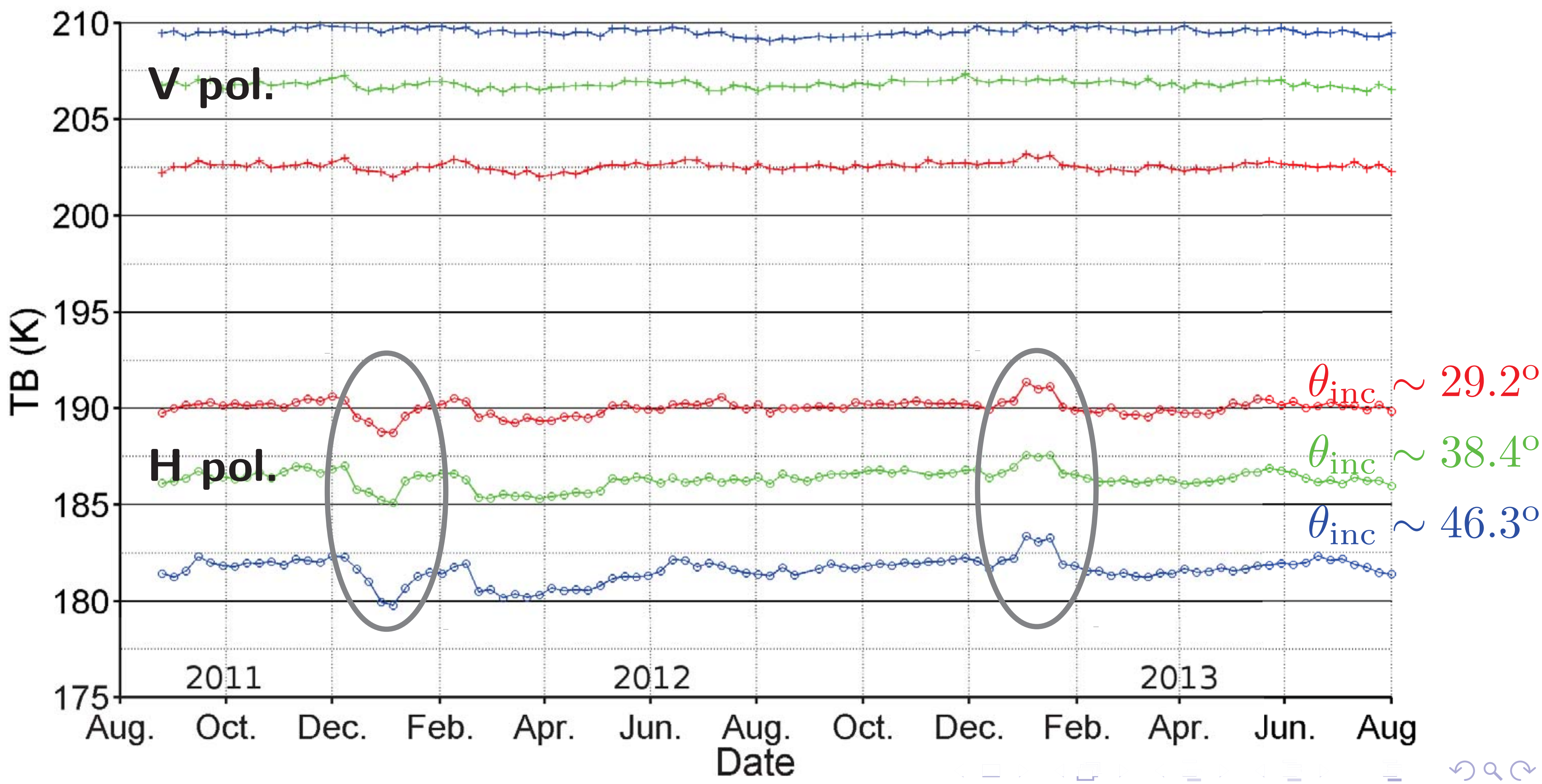


Rapid variations are not reproduced (constant surface properties)

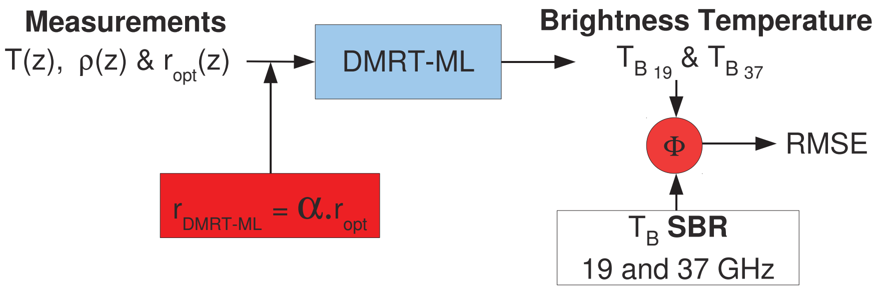
(Brucker et al., 2011 JoG)

Dome C, Antarctica

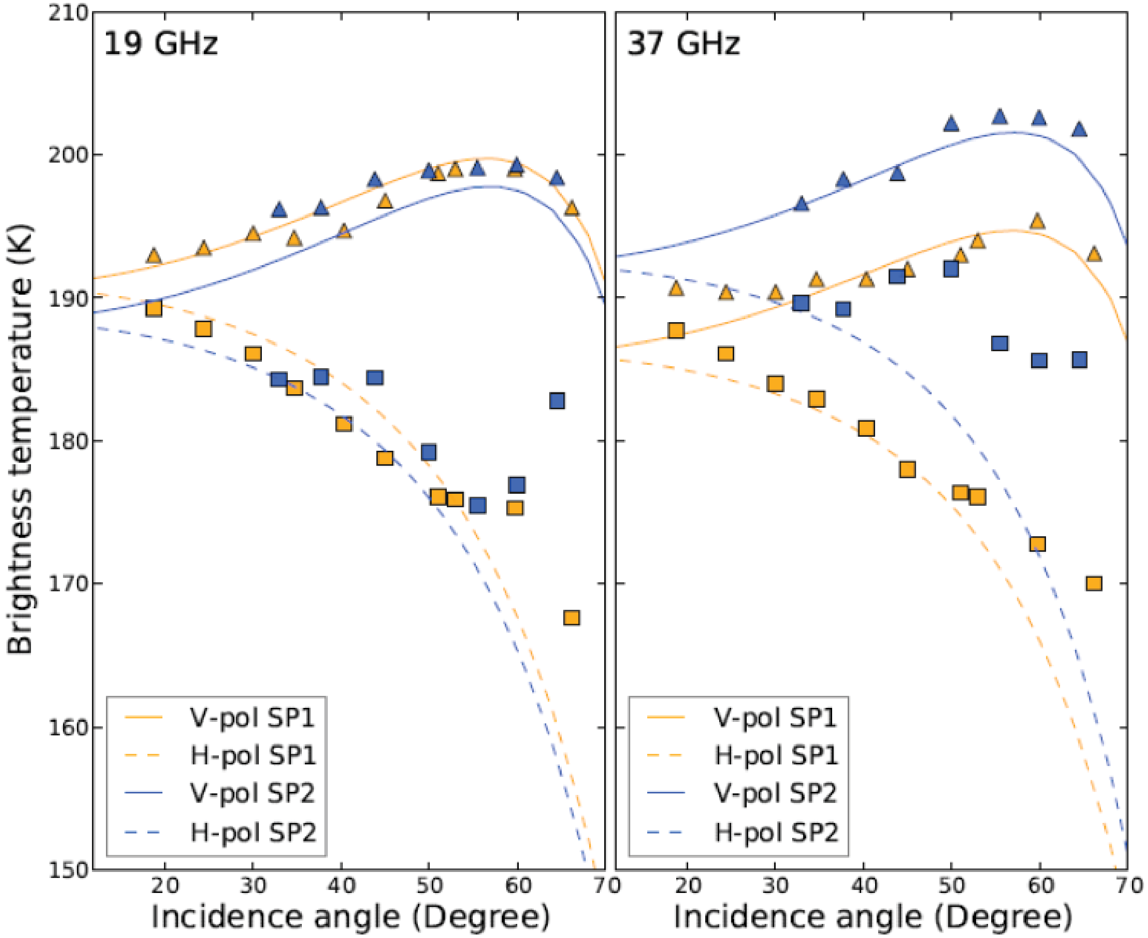
Aquarius (1.4 GHz) TB observations
show rapid variations at H pol.



Dome C, Antarctica



Calibration result: α=**2.3**



Reasonable simulations at both <u>Vertical</u> & Horizontal pol.

Reproduce smooth and chaotic surfaces

Issues at high incidence angles $(> 60^o)$

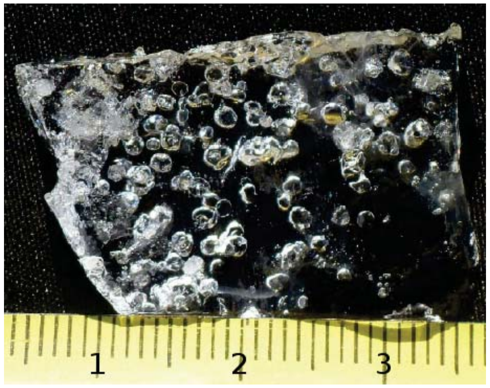
(Picard et al., 2014 TC)

Ablation Zone, Antarctica

Cap Prud'Homme

(Dupont et al., 2014 TGRS)

Bubbly Ice



Importance of bubble size & ρ_{ice}

Ablation Zone, Antarctica

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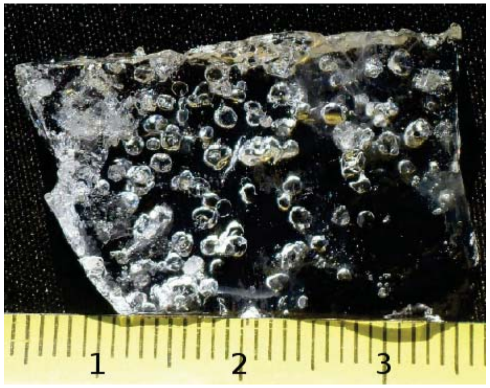
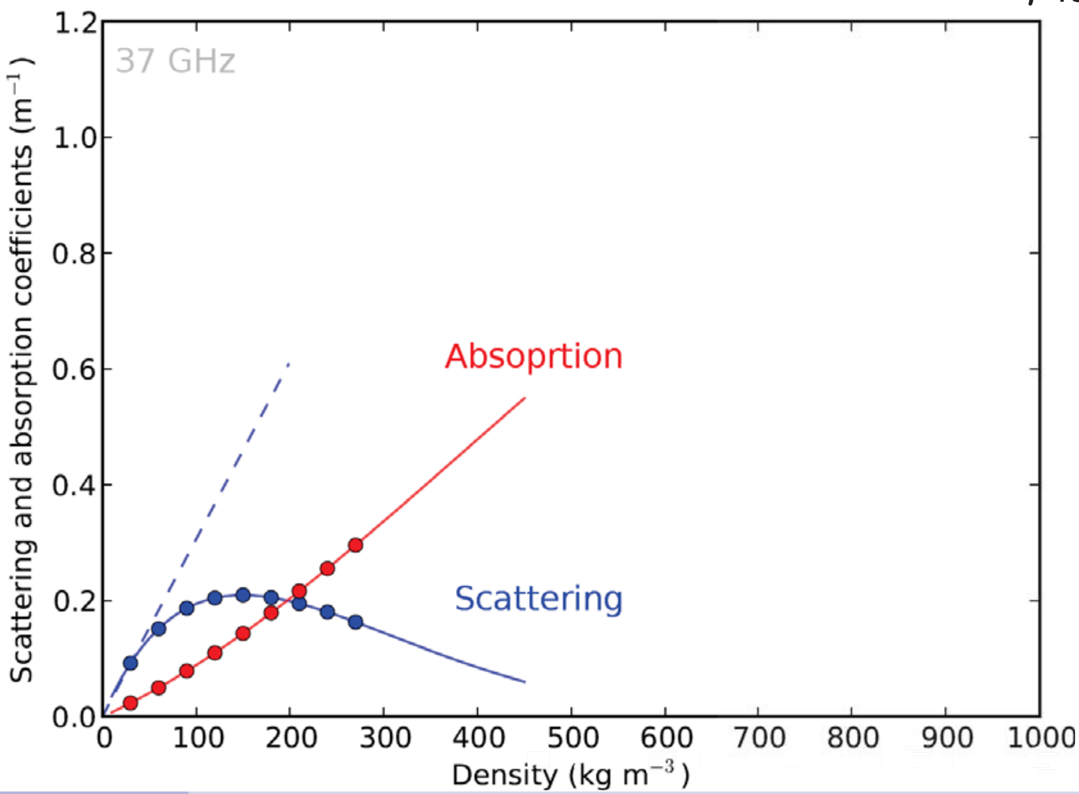


Importance of bubble size & ρ_{ice}

The DMRT theory is valid up to fractional volume of 30%.



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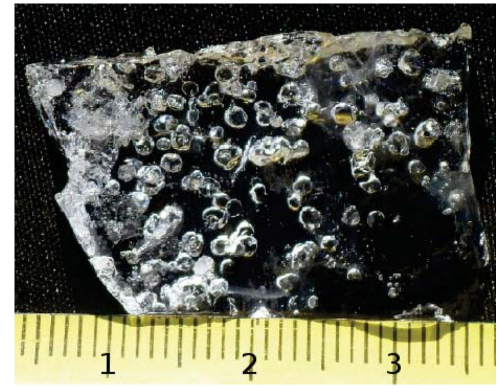
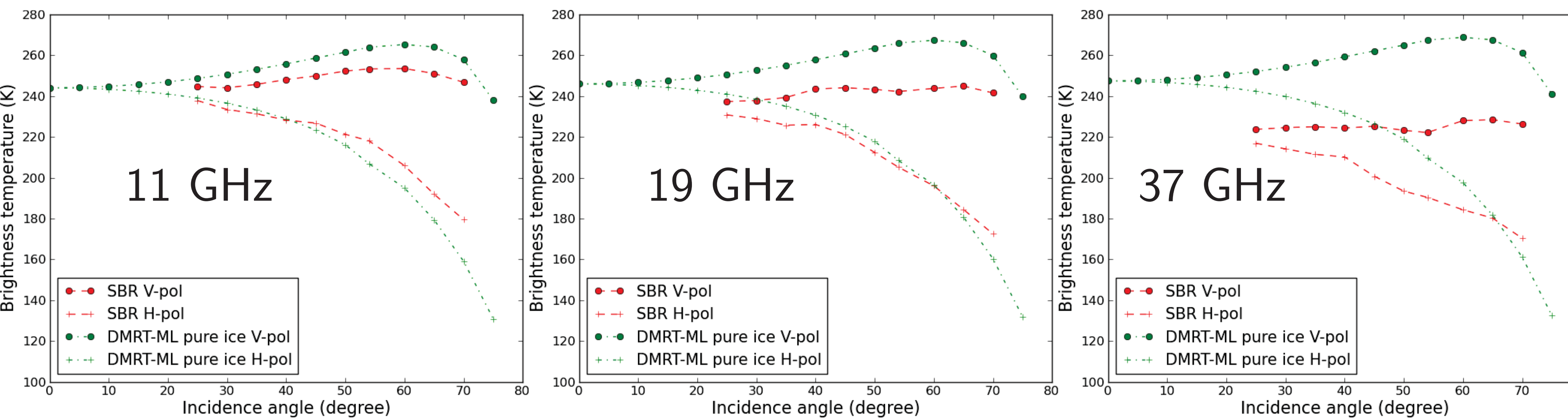


Importance of bubble size & ρ_{ice}

Observations Simulations



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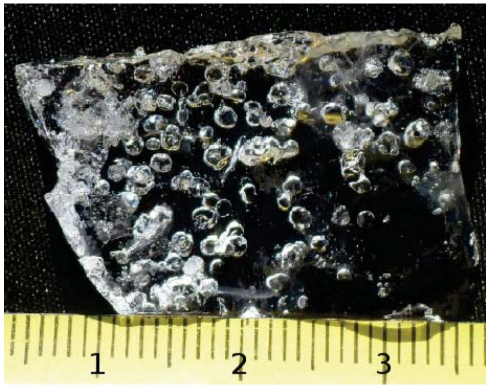

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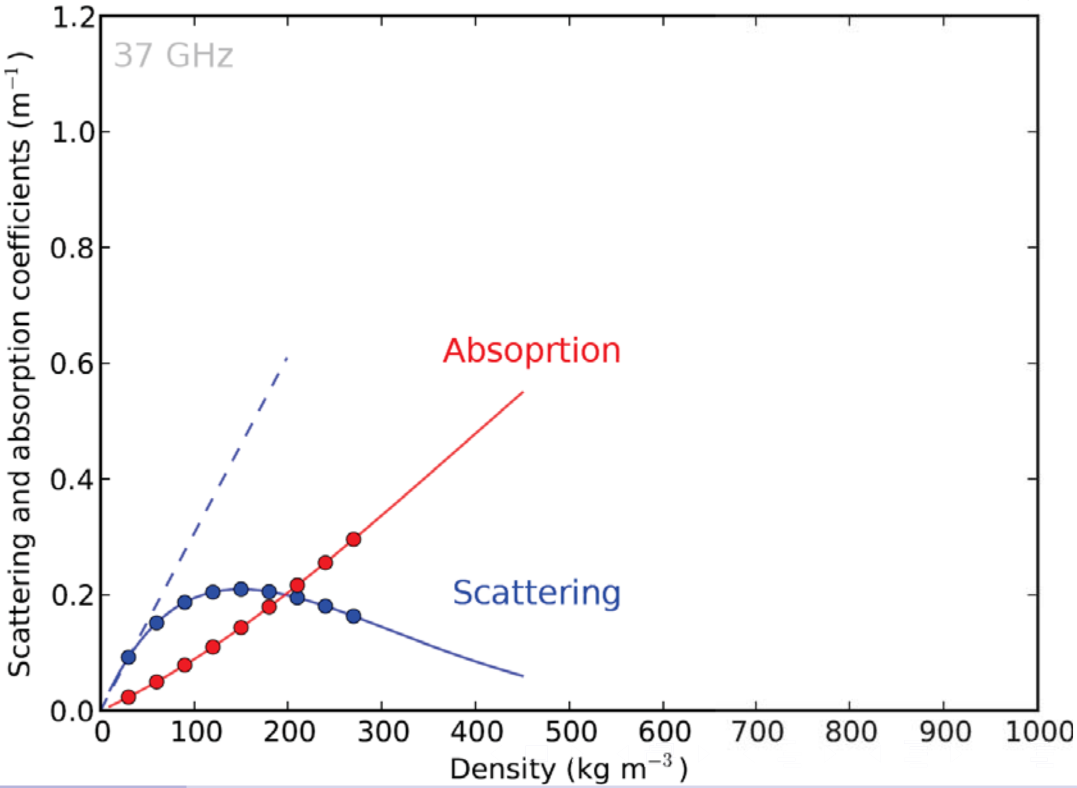

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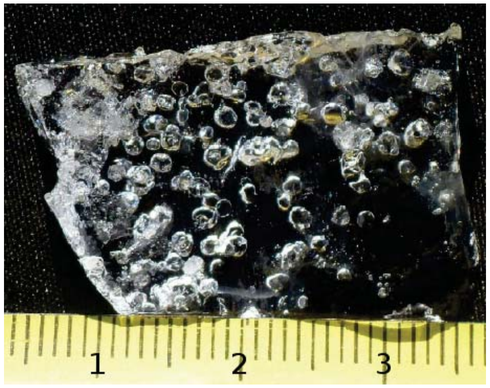

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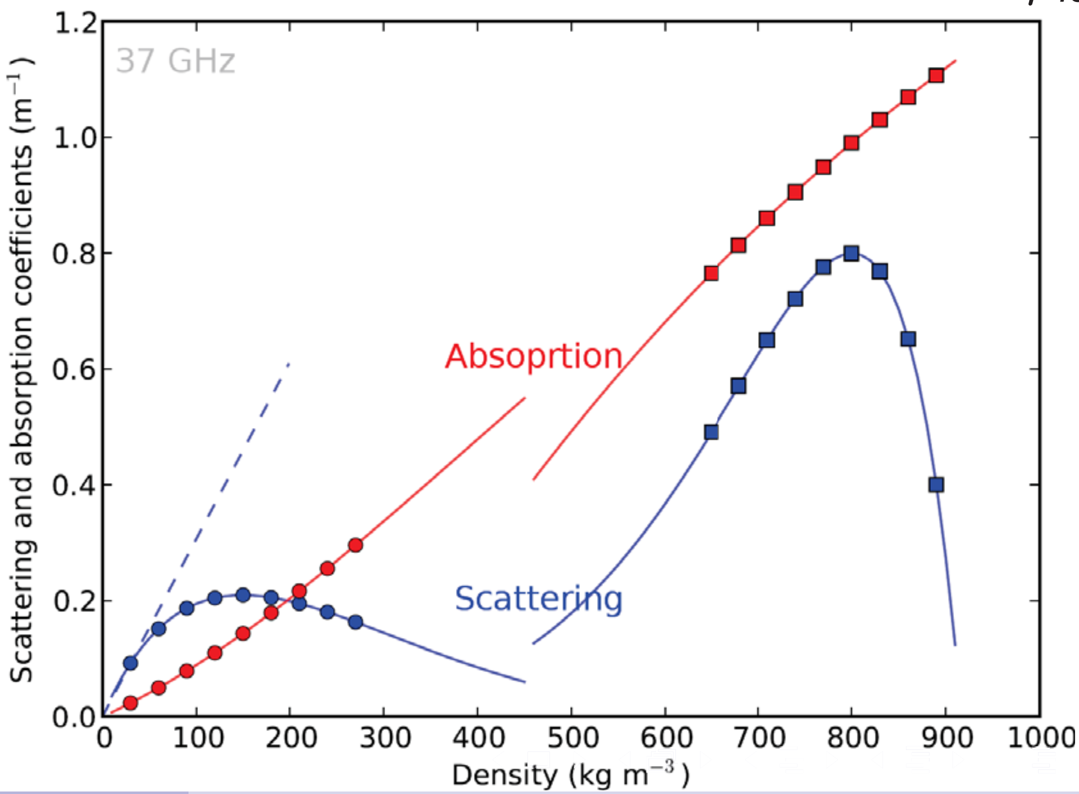

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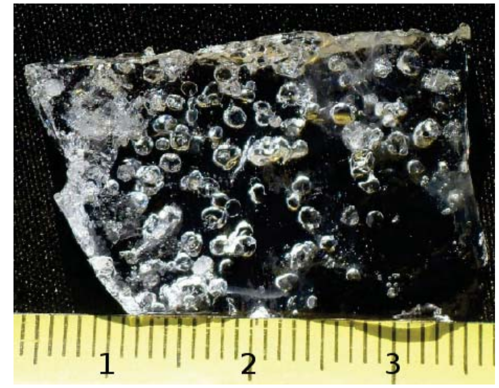
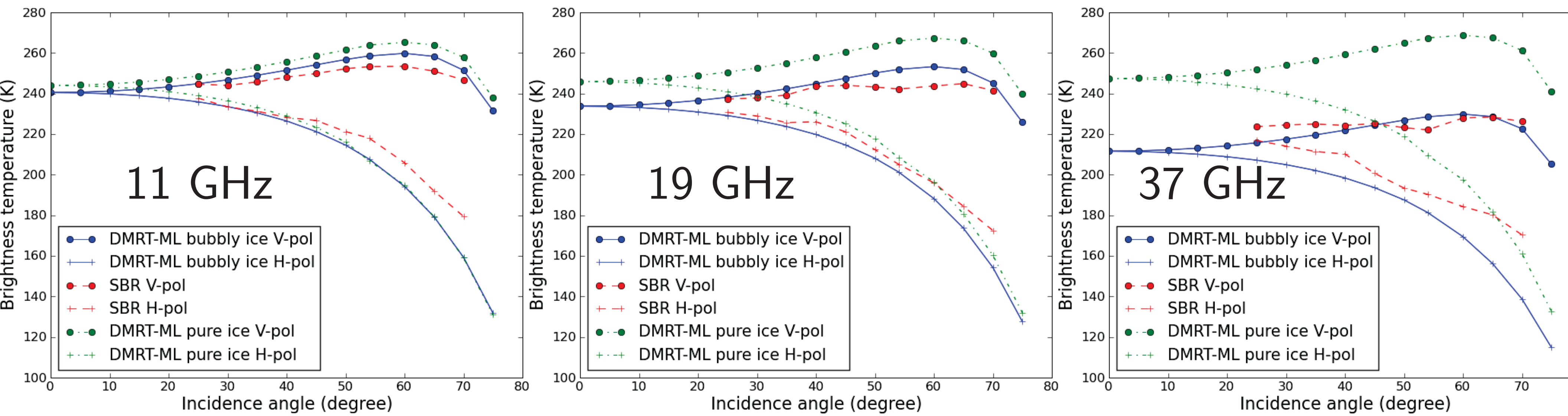
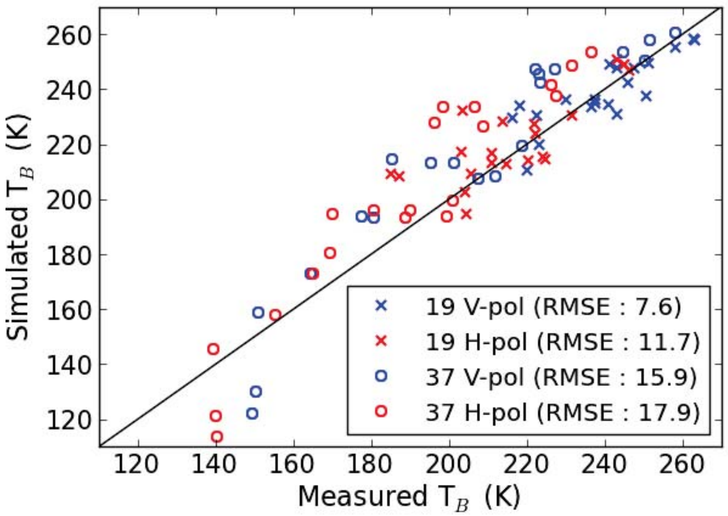


Importance of bubble size & ρ_{ice}

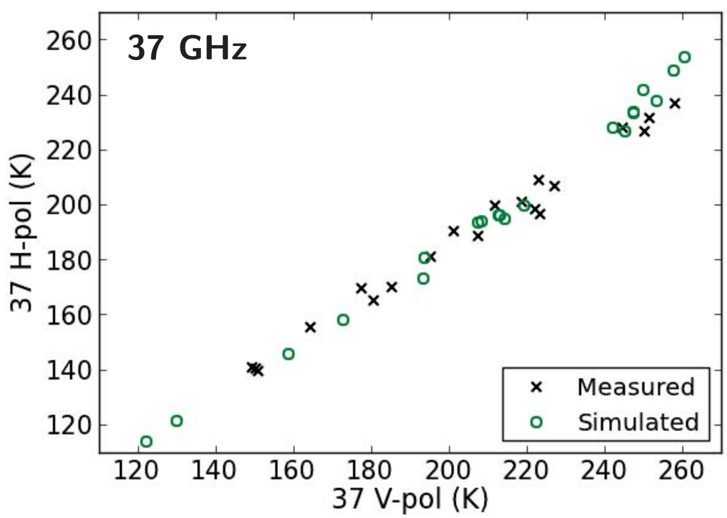
Observations New simulations

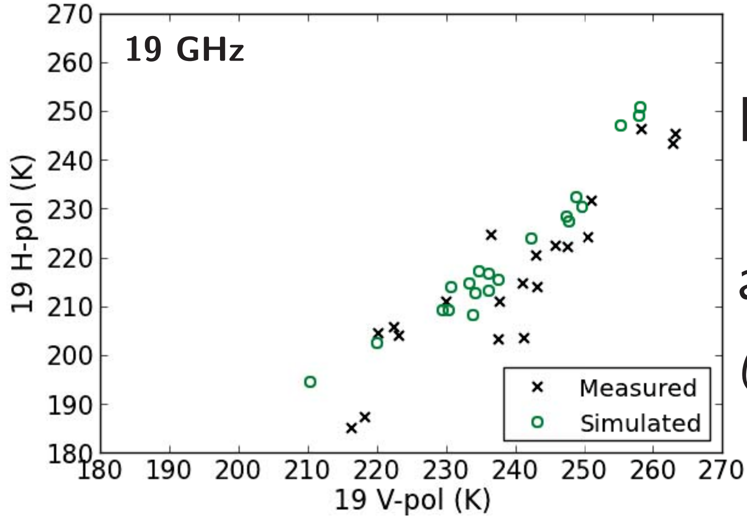


Seasonal Arctic/sub-Arctic Snowpacks: Manitoba & Québec



Calibration result: α=**3.3**





Reasonable results at both V & H, and at 19 & 37 GHz

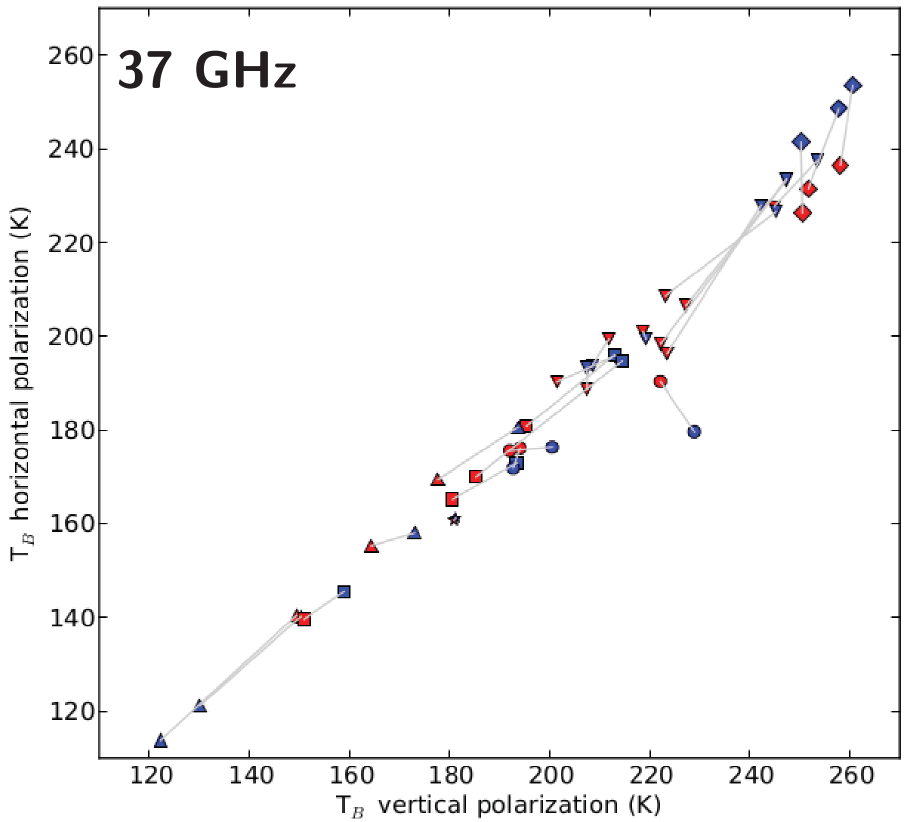
(Roy et al. 2013 TGRS)

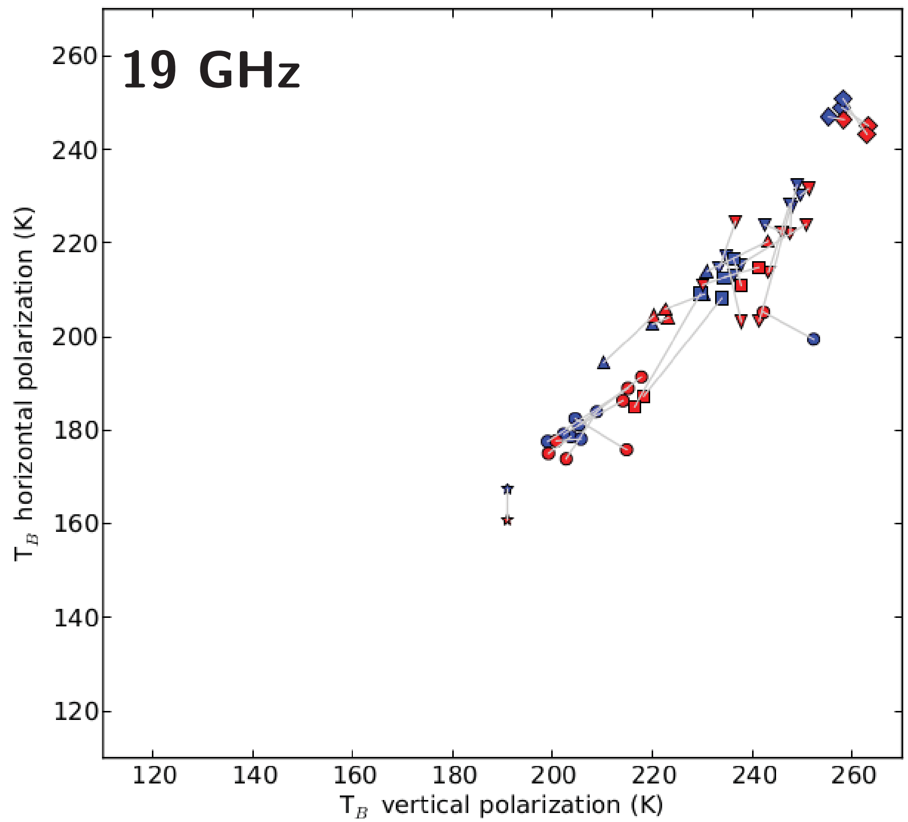
Soil model: Wegmüller & Mätzler (1999)

Dependence between H & V pol.

Observed and simulated TB

over Dome C (⋆), ice-sheet ablation or percolation areas (○),
tundra (△), windy tundra (▽), fen (□), grassland (◇)





DMRT-ML predicts reliable dependence between H & V pol. near 50-55^o

Validations & Applications

DMRT-ML has been validated, in very different environments, on

- deep firn on ice sheet
- shallow snow covers overlying soil (Arctic and Alpine regions) or ice

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DMRT-ML is now used in applications for:

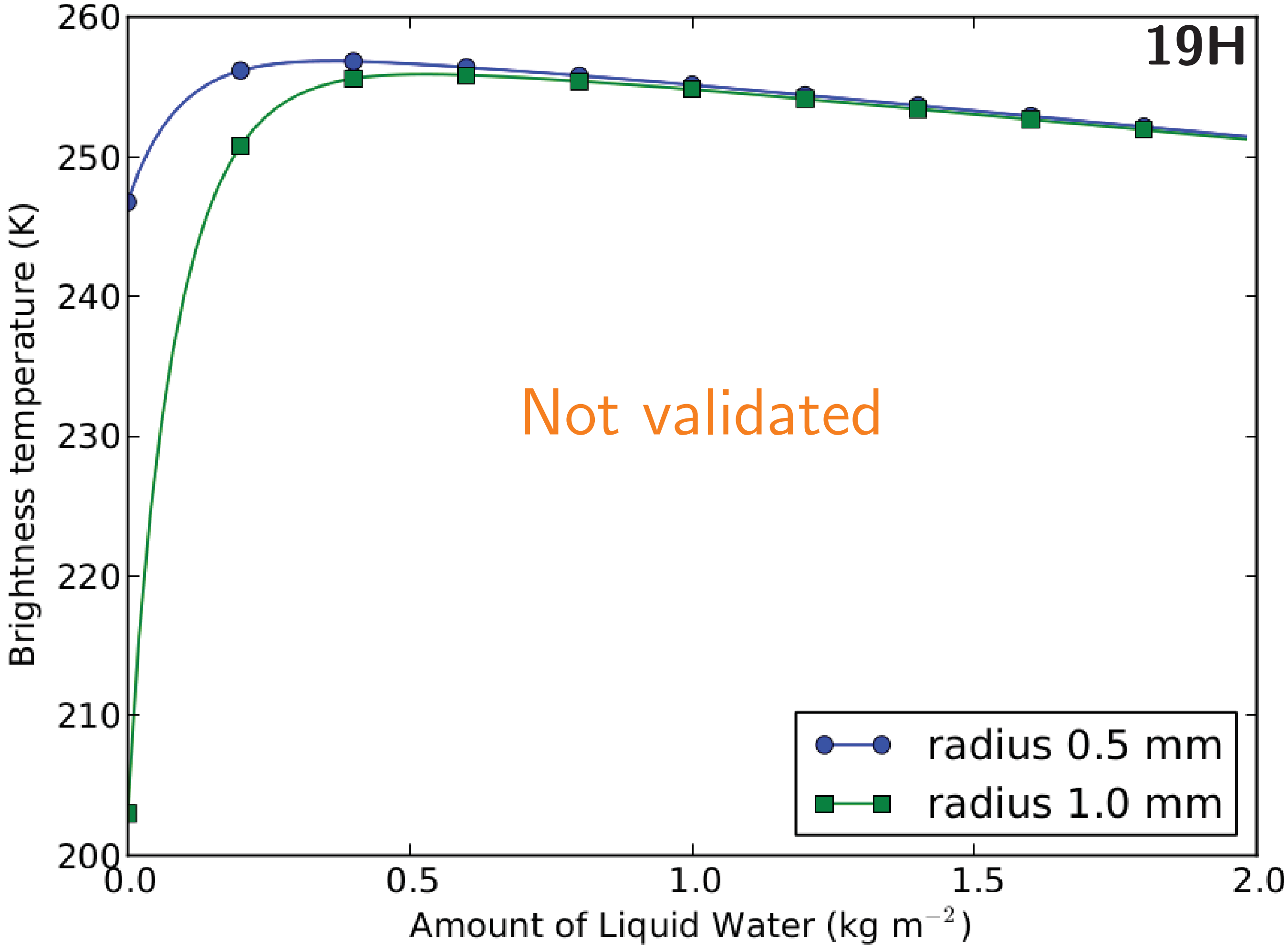
- hemispheric SWE retrievals
- sensor developments
- snow property retrievals with inverse methods
- coupling with snow evolution models
- data assimilation

Outline

1. Descriptions of the DMRT-ML Model
2. Validations Experiments
3. Current Limitations & Challenges
4. Conclusion

Current Limitations & Challenges

Liquid water content



T_{snow}=273 K, ρ=300 kg m^3

Water is in the top 10 cm

Current Limitations & Challenges

Grain Size Factor (α)

Density

Roughness

Large Particles

Current Limitations & Challenges

Grain Size Factor (α)

Model	Location	α
DMRT-ML	Antarctica	2.8
	Antarctica	2.3
	Barnes Ice Cap	3.5
	Sub-Arctic	3.3

- α, factor between $r_{opt}^{measured}$ & $r_{sphere}^{DMRT-ML}$ is likely due to microstructure.
- Stickiness and grain size distribution may contribute to α.

Density

Roughness

Large Particles

Current Limitations & Challenges

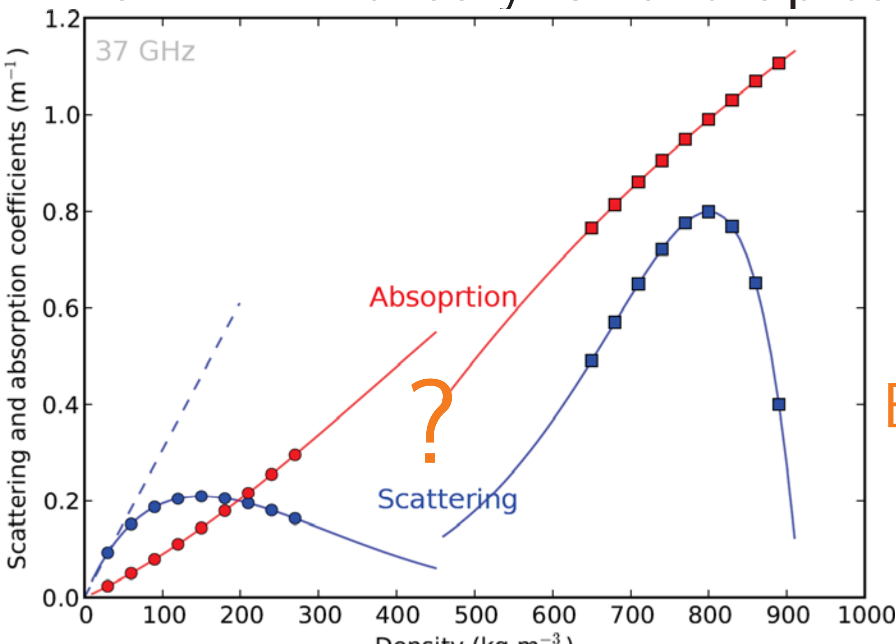
Grain Size Factor (α)

Model	Location	α
DMRT-ML	Antarctica	2.8
	Antarctica	2.3
	Barnes Ice Cap	3.5
	Sub-Arctic	3.3

- α, factor between $r_{opt}^{measured}$ & $r_{sphere}^{DMRT-ML}$ is likely due to microstructure.
- Stickiness and grain size distribution may contribute to α.

Density

- The DMRT theory is valid up to fractional volume of 30%.



i.e. $0 - 275\ \mathrm{kg\,m^{-3}}$,
and $642 - 917\ \mathrm{kg\,m^{-3}}$.

Bridging = Combination of the two valid domains *(Dierking et al., 2012)*

Current Limitations & Challenges

Grain Size Factor (α)

Model	Location	α
DMRT-ML	Antarctica	2.8
	Antarctica	2.3
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. α, factor between $r_{opt}^{measured}$ & $r_{sphere}^{DMRT-ML}$ is likely due to microstructure.

. Stickiness and grain size distribution may contribute to α.

Density

. The DMRT theory is valid up to fractional volume of 30%.

Roughness

. Surface roughness, and layer interface roughness are not considered.

Large Particles

Current Limitations & Challenges

Grain Size Factor (α)

Model	Location	α
DMRT-ML	Antarctica	2.8
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- α, factor between $r_{opt}^{measured}$ & $r_{sphere}^{DMRT-ML}$ is likely due to microstructure.
- Stickiness and grain size distribution may contribute to α.

Density

- The DMRT theory is valid up to fractional volume of 30%.

Roughness

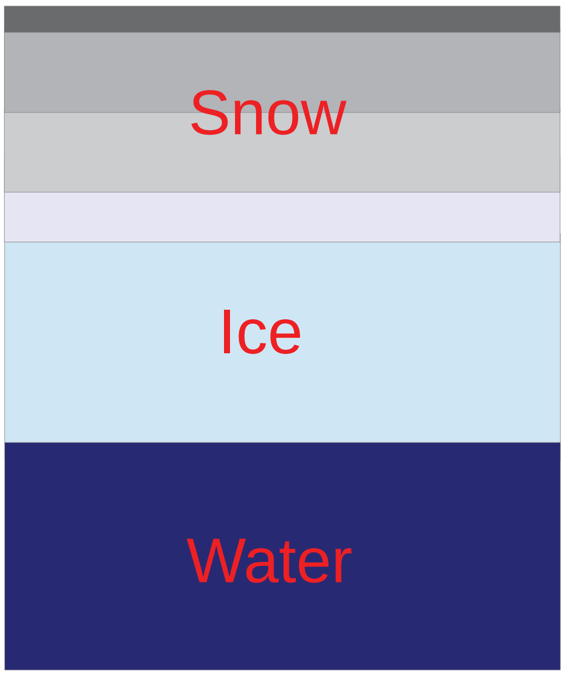
- Surface roughness, and layer interface roughness are not considered.

Large Particles

- The DMRT-Mie theory is only available under the QCA
  is time consuming

Current Limitations & Challenges

Brine in snow and ice



Configuration already possible with DMRT-ML

DMRT-ML does not include dielectric constant parameterizations for brine content (yet)

Outline

1. Descriptions of the DMRT-ML Model
2. Validations Experiments
3. Current Limitations & Challenges
4. Conclusion

Conclusion

DMRT-ML is validated and operational for both seasonal snow & perennial snow

DMRT-ML is a published open source model available at:
http://lgge.osug.fr/~picard/dmrtml/

Email distribution list **obs-dmrtml@ujf-grenoble.fr**

$\boxed{\text{DMRT-ML} \rightsquigarrow \text{Community Model}}$

Contributions for model developments are welcome

DMRT-ML description

- G. Picard, L. Brucker, A. Roy, F. Dupont, M. Fily, and A. Royer, Simulation of the microwave emission of multi-layered snowpacks using the dense media radiative transfer theory: the DMRT-ML model, Geosci. Model Dev., 6, 10611078, 2013

Validations

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- A. Roy, G. Picard, A. Royer, B. Montpetit, F. Dupont, A. Langlois, C. Derksen and N. Champollion, Brightness temperature simulations of the Canadian seasonal snowpack driven by measurements of the snow specific surface area, IEEE TGRS, vol.51, no.9, pp.4692–4704, 2013.
- F. Dupont, G. Picard, A. Royer, M. Fily, A. Langlois, A. Roy, and N. Champollion, Modeling the microwave emission of bubbly ice; Applications to blue ice and superimposed ice in the Antarctic and Arctic, IEEE TGRS vol.52, no.10, pp.6639–6651, 2014
- G. Picard, A. Royer, L. Arnaud, and M. Fily, Influence of snow dunes on the microwave brightness temperature: investigation with ground-based radiometers at Dome C in Antarctica, The Cryosphere, vol.8, doi:10.5194/tc-8-1-2014

Applications

- L. Brucker, G. Picard, and M. Fily. Snow grain size profiles deduced from microwave snow emissivities in Antarctica. J. of Glaciol., 56(197), 2010.
- Picard, G., Domine, F., Krinner, G., Arnaud, L., and Lefebvre, E. Inhibition of the positive snow-albedo feedback by precipitation in interior Antarctica, Nature Climate Change, 2, 795–798, doi:10.1038/nclimate1590, 2012.
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