

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

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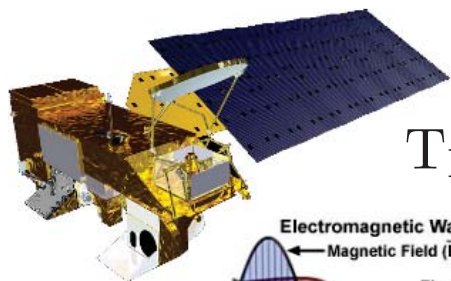
² Universities Space Research Association – GESTAR, Columbia, MD, USA

³ Uni. Grenoble Alpes/CNRS, Laboratoire de Glaciologie et Géophysique de
l'Environnement, Grenoble, France

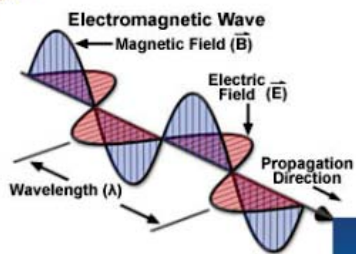
⁴ Centre d'Applications et Recherches en Télédétection
Université de Sherbrooke, Québec, Canada



Sophistication of microwave radiative transfer models



$$T_{B \nu, \rho} = f(\text{radiative transfer interactions in the snowpack})$$



RT models relate snow and radiation properties



Models can be:

Theoretical

Semi empirical

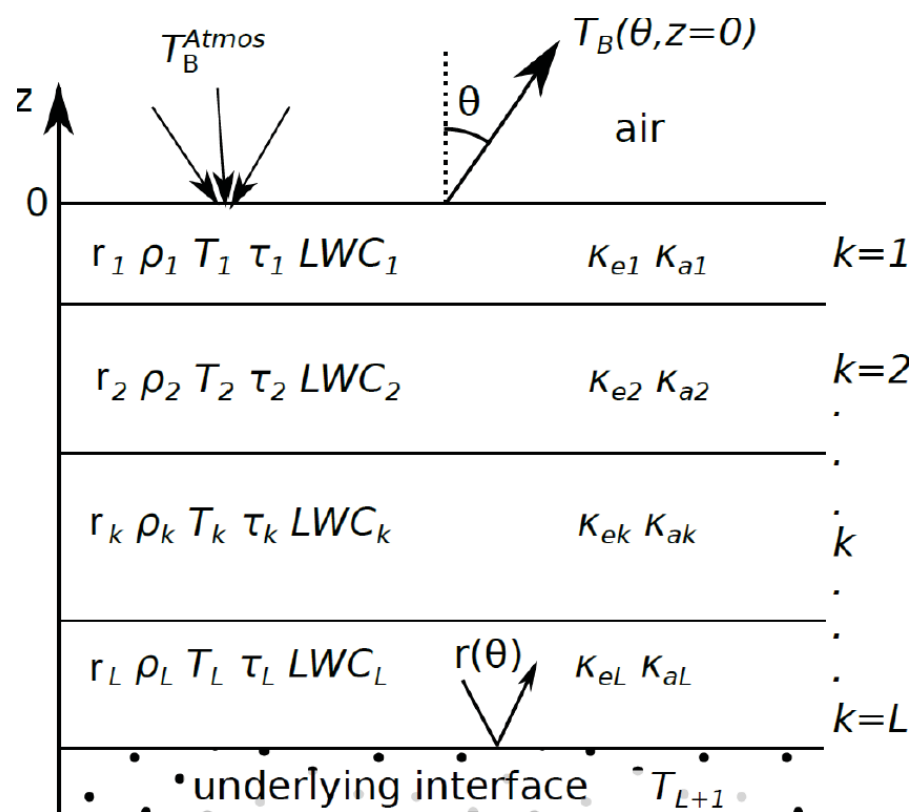
Empirical

Outline

1. Descriptions of the DMRT-ML Model
2. Validations Experiments
 - 2.1 Antarctic Accumulation Zone
 - 2.2 Ablation & Superimposed-Ice Zones on Ice Caps
 - 2.3 Arctic Seasonal Snow Cover
- 3 Current Limitations & Challenges
- 4 Conclusion

DMRT-ML – Snowpack and Soil Configurations

(Dense Media Radiative Transfer Multi-Layer model)



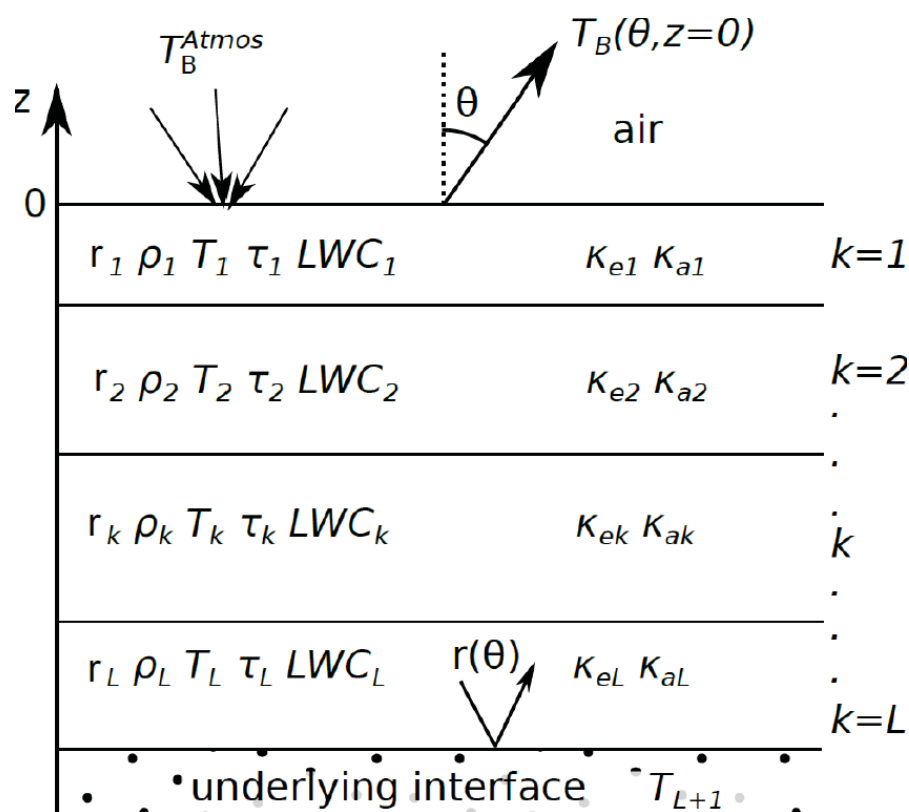
Every **layer** is defined by:

- 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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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	$SM, f_{\text{clay}}, f_{\text{sand}}, \rho_{\text{orga}}, T$
Flat surface, Fresnel	Soil	from D85	3	SM, T
Rough surface WM99	Any	prescribed	101	σ, ϵ
Rough surface WM99	Soil	from P99	102	$\sigma, SM, f_{\text{clay}}, f_{\text{sand}}, \rho_{\text{orga}}, T$
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	$\sigma, Q, H, SM, f_{\text{clay}}, f_{\text{sand}}, \rho_{\text{orga}}, T$
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_{clay} , and f_{sand} : fractions of clay and sand

ρ_{orga} : density of dry organic matter (kg m^{-3})

T: soil temperature (K)

Q, and H: dimensionless parameters

P99 = Pulliainen et al. (1999)

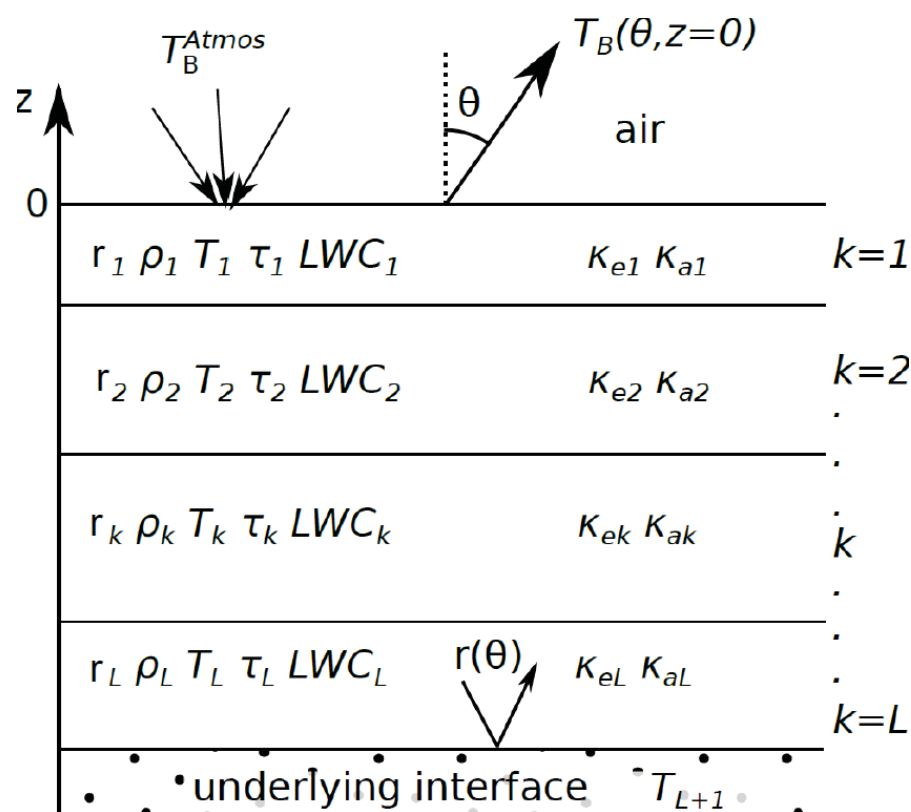
D85 = Dobson et al. (1985)

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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- Density (ρ)
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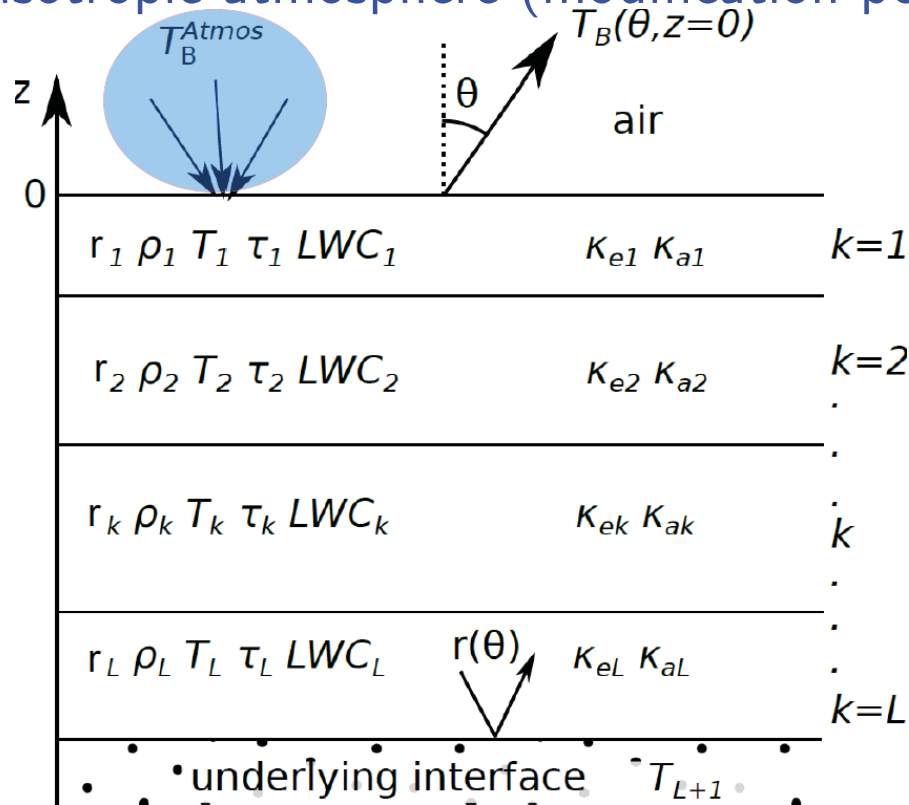
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DMRT-ML – Snowpack and Soil Configurations

(Dense Media Radiative Transfer Multi-Layer model)

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



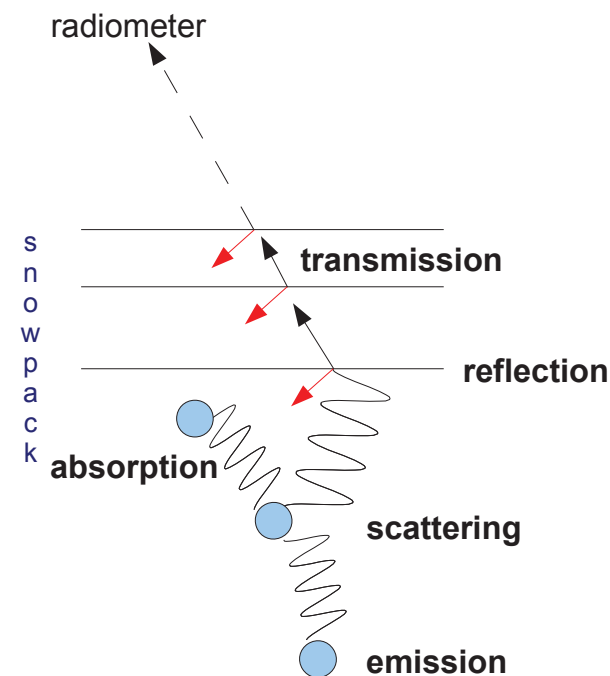
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DMRT-ML – Elements



DMRT-ML computes:

- . emission
 - . scattering
 - . absorption
- } **using the DMRT theory**

DMRT-ML computes the reflection coefficients at:

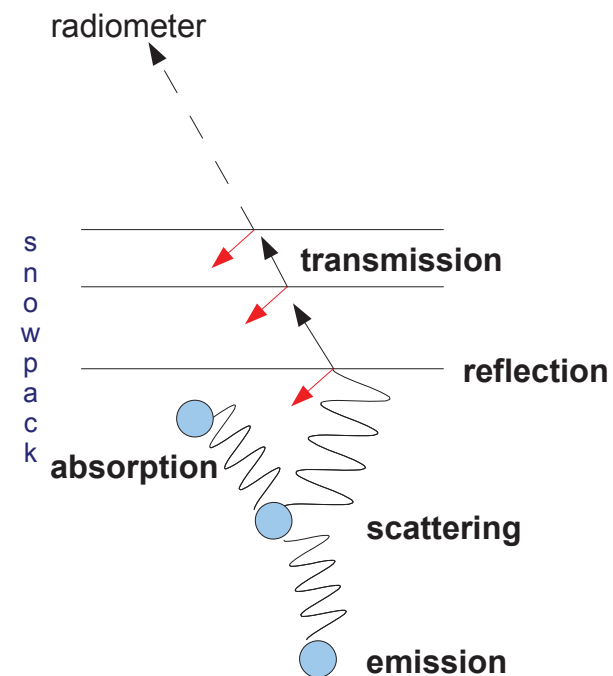
- . snow/snow interfaces
 - . snow/atmosphere interface
- } **using Fresnel**

DMRT-ML solves the radiative transfer equation

using the DISORT method

(64 or 128 streams are adequate)

DMRT-ML – Elements

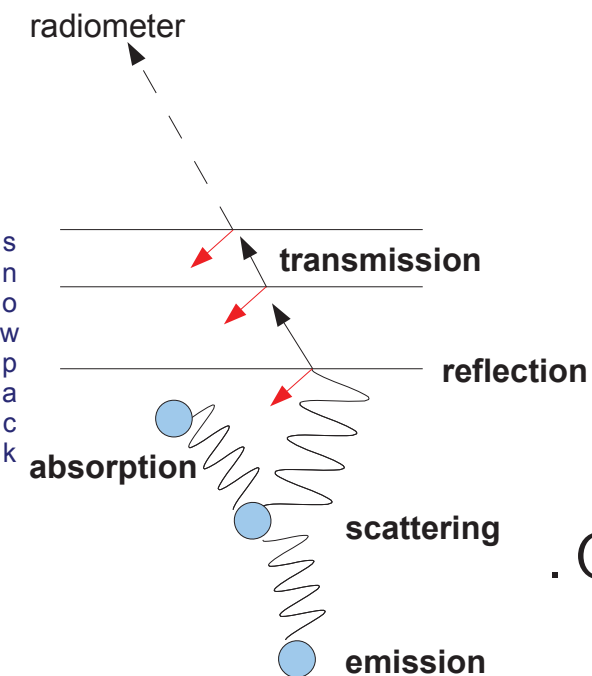


DMRT-ML computes:

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Two DMRT flavors were implemented:

DMRT-ML – Elements



DMRT-ML computes:

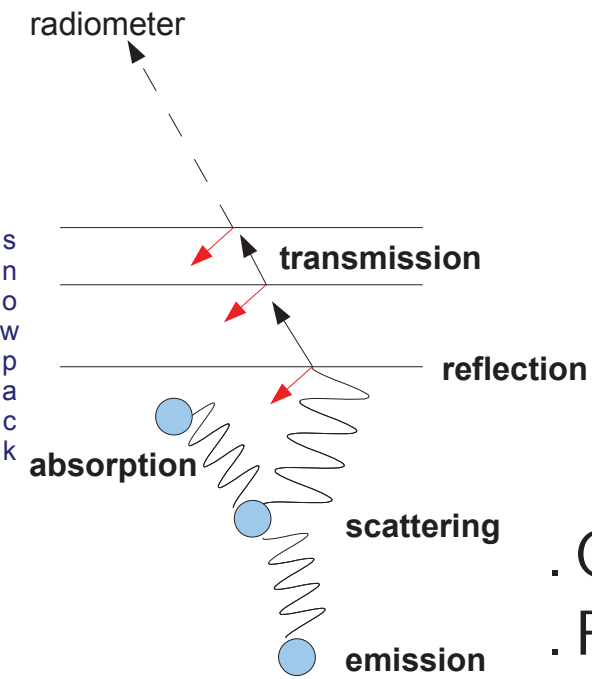
- . emission
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 - . absorption
- } using the DMRT theory

Two DMRT flavors were implemented:

. QCA-CP

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DMRT-ML – Elements



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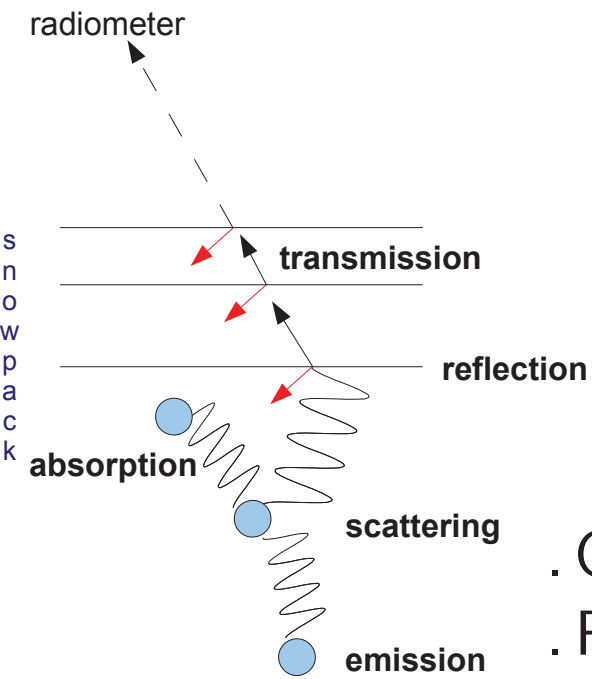
} using the **DMRT theory**

Two DMRT flavors were implemented:

- . QCA-CP
- . Rayleigh assumption

- . QCA-CP
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DMRT-ML – Elements



DMRT-ML computes:

- . emission
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- } **using the DMRT theory**

Two DMRT flavors were implemented:

- | | |
|--|---|
| <ul style="list-style-type: none"> . QCA-CP . Rayleigh assumption . Optional correction | <ul style="list-style-type: none"> . QCA-CP . Rayleigh assumption . No large particles |
|--|---|

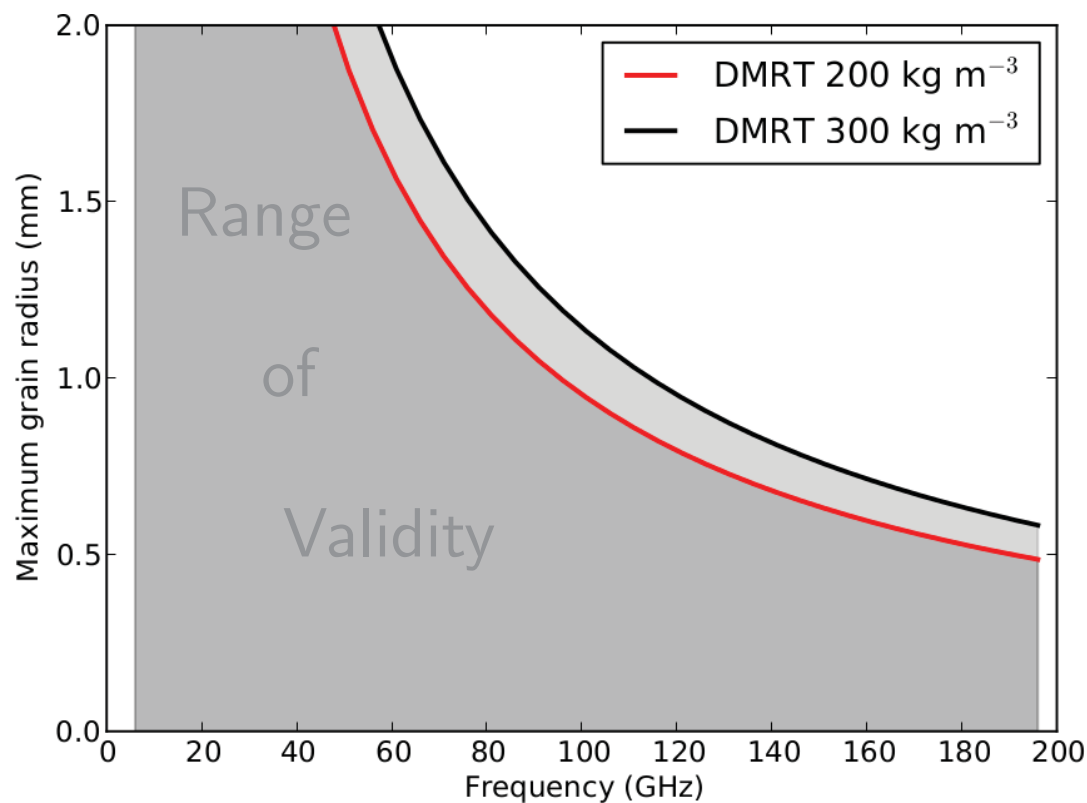
for large particles (*Grody, 2008*)

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)

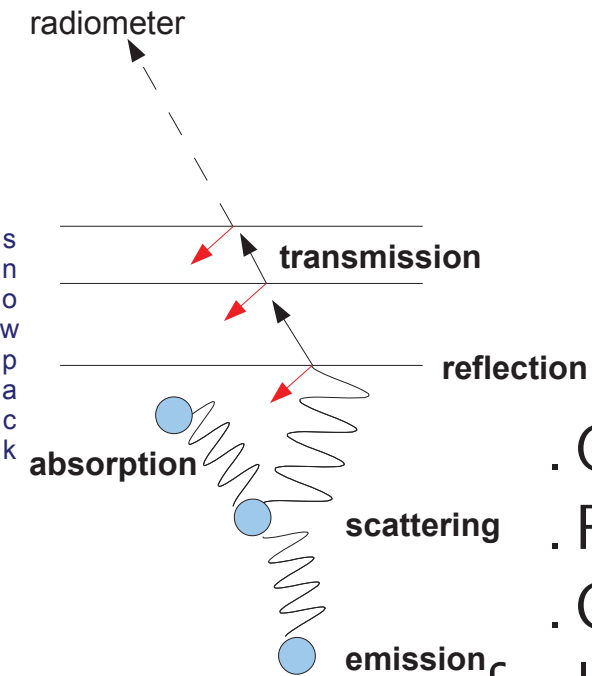


It is not recommended to consider a many and thick layers of large grains

DMRT-ML – Elements

DMRT-ML computes:

- . emission
 - . scattering
 - . absorption
- } **using the DMRT theory**



Two DMRT flavors were implemented:

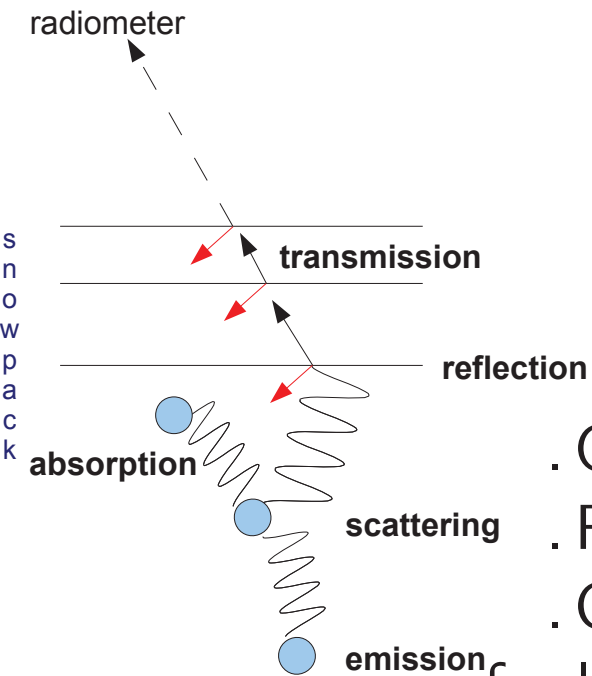
- | | |
|-----------------------|-----------------------|
| . QCA-CP | . QCA-CP |
| . Rayleigh assumption | . Rayleigh assumption |
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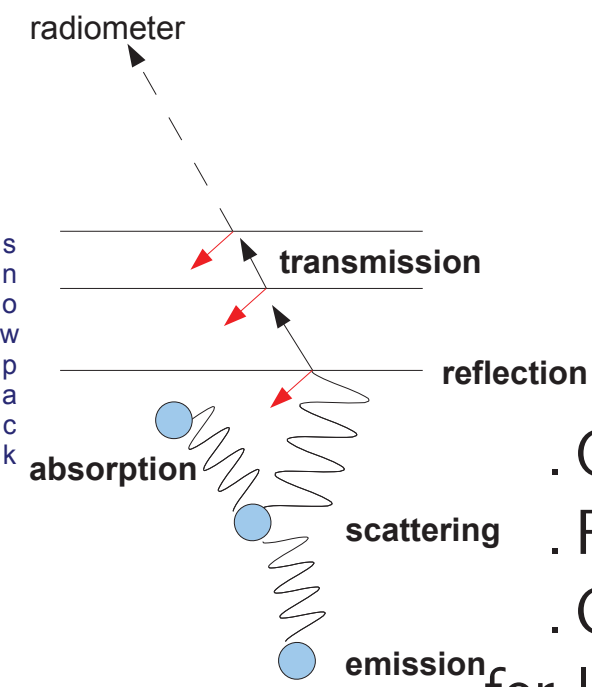
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- | | |
|--|------------------------------|
| . QCA-CP | . QCA-CP |
| . Rayleigh assumption | . Rayleigh assumption |
| . Optional correction | . No large particles |
| for large particles (<i>Grody, 2008</i>) | |
| . Mono-disperse | . Poly-disperse |
| | (i.e. Rayleigh distribution) |

DMRT-ML – Elements

DMRT-ML computes:

- . emission
 - . scattering
 - . absorption
- } **using the DMRT theory**



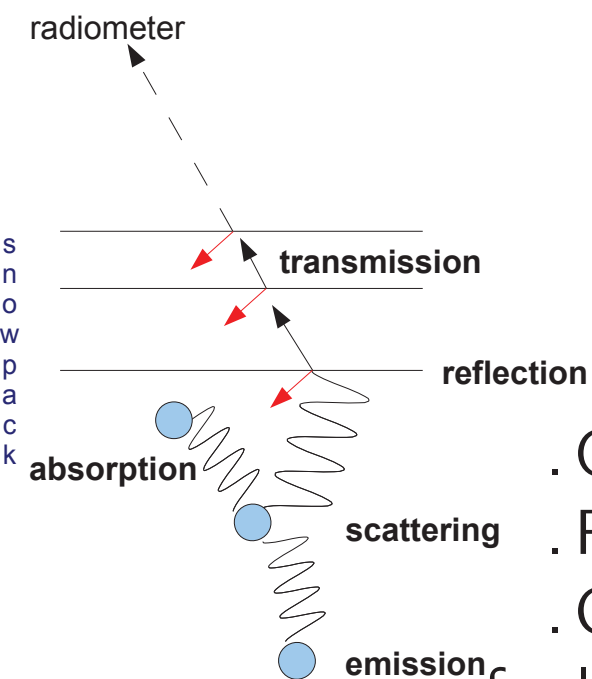
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- | | |
|--|---|
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|--|---|
- for large particles (*Grody, 2008*)
- | | |
|--|---|
| <ul style="list-style-type: none"> . Mono-disperse . Optional “short range” stickiness | <ul style="list-style-type: none"> . Poly-disperse (i.e. Rayleigh distribution) . No stickiness |
|--|---|

DMRT-ML – Elements

DMRT-ML computes:

- . emission
 - . scattering
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- } **using the DMRT theory**

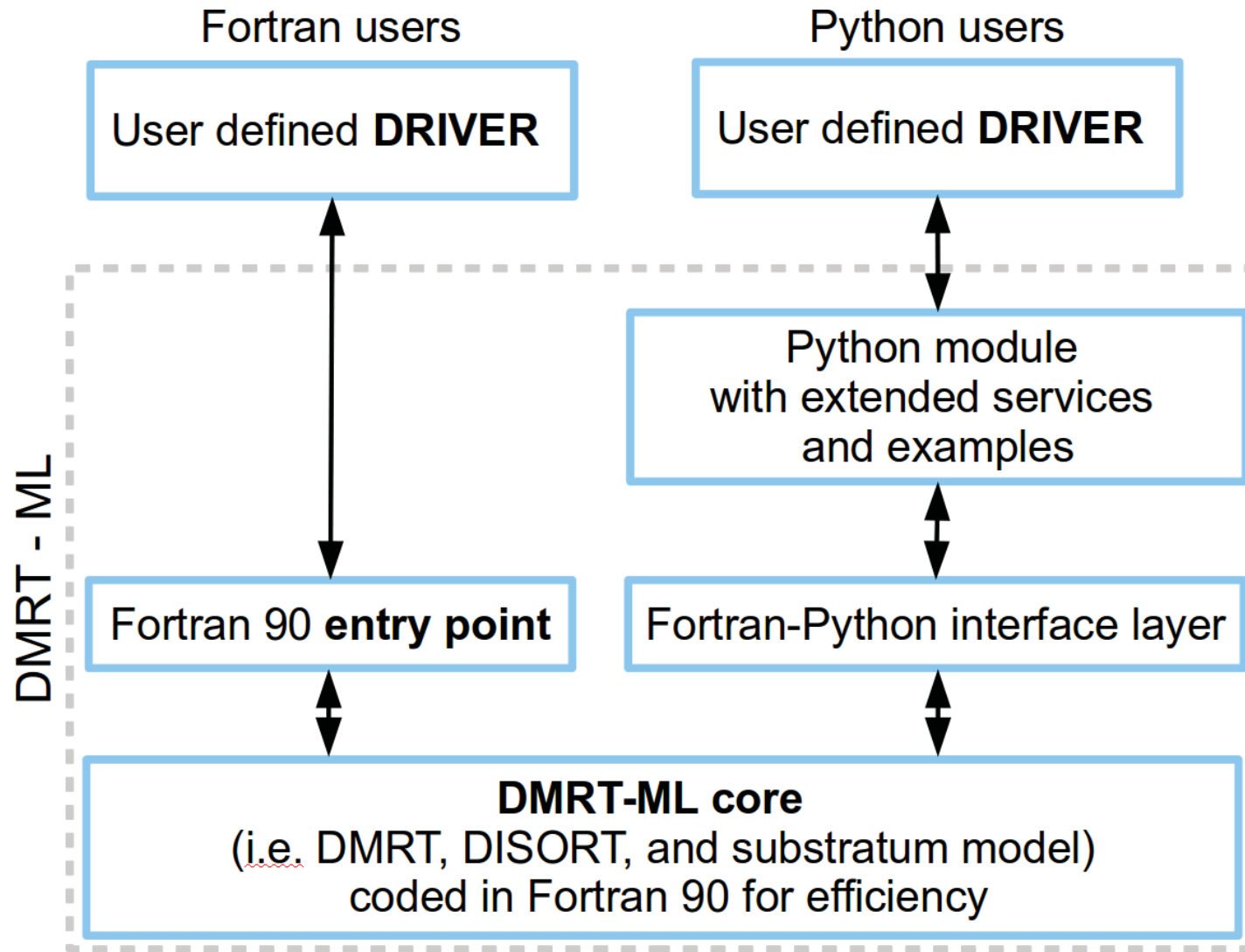


Two DMRT flavors were implemented:

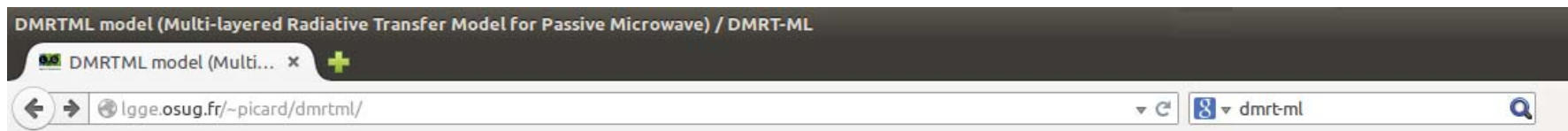
- | | |
|---|--|
| <ul style="list-style-type: none"> . QCA-CP . Rayleigh assumption . Optional correction for large particles (<i>Grody, 2008</i>) . Mono-disperse . Optional “short range” stickiness | <ul style="list-style-type: none"> . QCA-CP . Rayleigh assumption . No large particles . Poly-disperse (i.e. Rayleigh distribution) . No stickiness |
|---|--|

Recommended

DMRT-ML – Implementation



DMRT-ML – Open source model



version 1.6

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:

Installation and compilation:



DMRT-ML – Open source model

lgge.osug.fr/~picard/dmrtml/doc/namespacemod__dmrtparameters.html

dmrt-ml

DMRTML

Main Page **Modules** Data Types List

Modules List Module Members

DMRTML

- Class List
- Data Types
- Data Fields
- Modules List
 - mod_disort
 - mod_dmrtml
 - mod_dmrtparameters**
 - mod_soil
- Module Members

mod_dmrtparameters Module Reference

Compute dense media radiative transfer parameters (extinction and single scattering albedo) under various assumptions (monodispese or polydisperse, Grody's limitation, ...) More...

Functions/Subroutines

subroutine **dmrtparameters_grodyapproach** (frequency, temperature, f, a, tau, LWC, medium, Eeff0, Eeff, albedo, beta, Eice)
 Compute radiative transfer parameters (extinction and single scattering albedo) using DMRT theory under the approximations: QCA-CP, small particules, sticky short range, single species. In addition, an empirical correction for large particules is applied based on Grody (2008). This correction was further improved by G. Picard, A. Riv and F. Dupont but it is still far from perfect. Its main purpose is to prevent DMRT divergency for large particules when DMRT is used in a few layers contain coarse grains. However, it should not be considered sufficiently accurate to investigate the scattering behavior of large particules. To disable this ad-hoc correction, use the subroutine **dmrtparameters** instead of this one.

subroutine **dmrtparameters** (frequency, temperature, f, a, tau, LWC, medium, Eeff0, Eeff, albedo, beta, Eice)
 Compute radiative transfer parameters (extinction and single scattering albedo) using DMRT theory under the assumption: QCA-CP, small particules, sticky short range, single species.

subroutine **dmrtparameters_dist** (frequency, temperature, f, a, tau, LWC, medium, Eeff0, Eeff, albedo, beta, Eice)
 Compute radiative transfer parameters (extinction and single scattering albedo) using DMRT theory under the assumptions: QCA-CP, small particules, *none-sticky*, multispecies. Grain size repartition is given by a Rayleigh distribution.

Detailed Description

Compute dense media radiative transfer parameters (extinction and single scattering albedo) under various assumptions (monodispese or polydisperse, Grody's limitation, ...)

Function/Subroutine Documentation

```

subroutine mod_dmrtparameters::dmrtparameters ( real*8,intent(in)      frequency,
real*8,intent(in)      temperature,
real*8,intent(in)      f,
real*8,intent(in)      a,
real*8,intent(in)      tau,

```

mod_dmrtparameters

Generated on Wed Apr 11 2012 08:42:43 for DMRTML by [doxygen](#) 1.7.4

The one-line Python code:

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

Outline

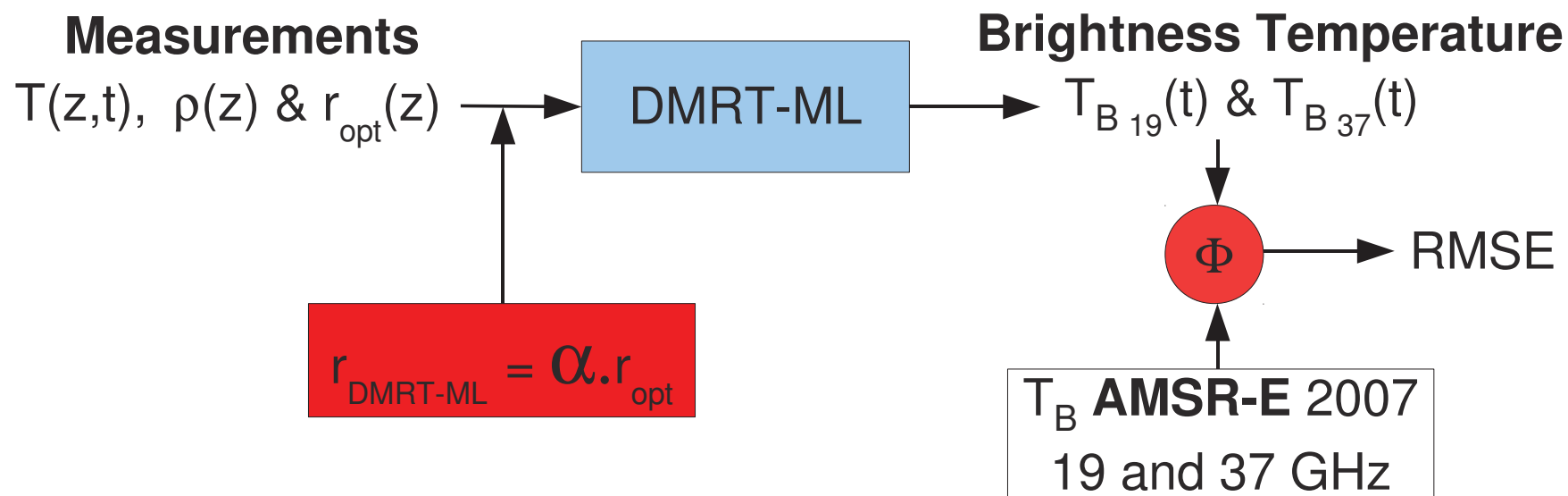
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Methodology



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

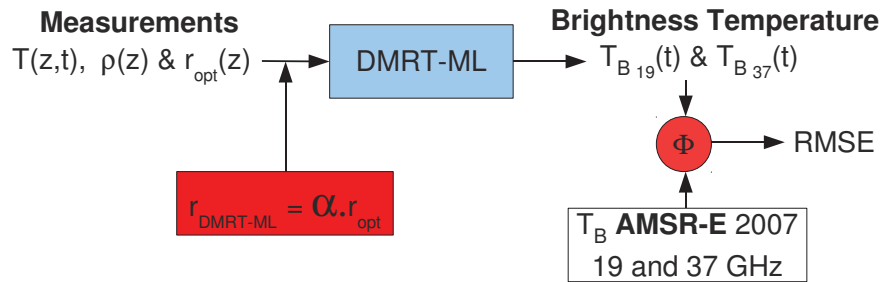
Methodology



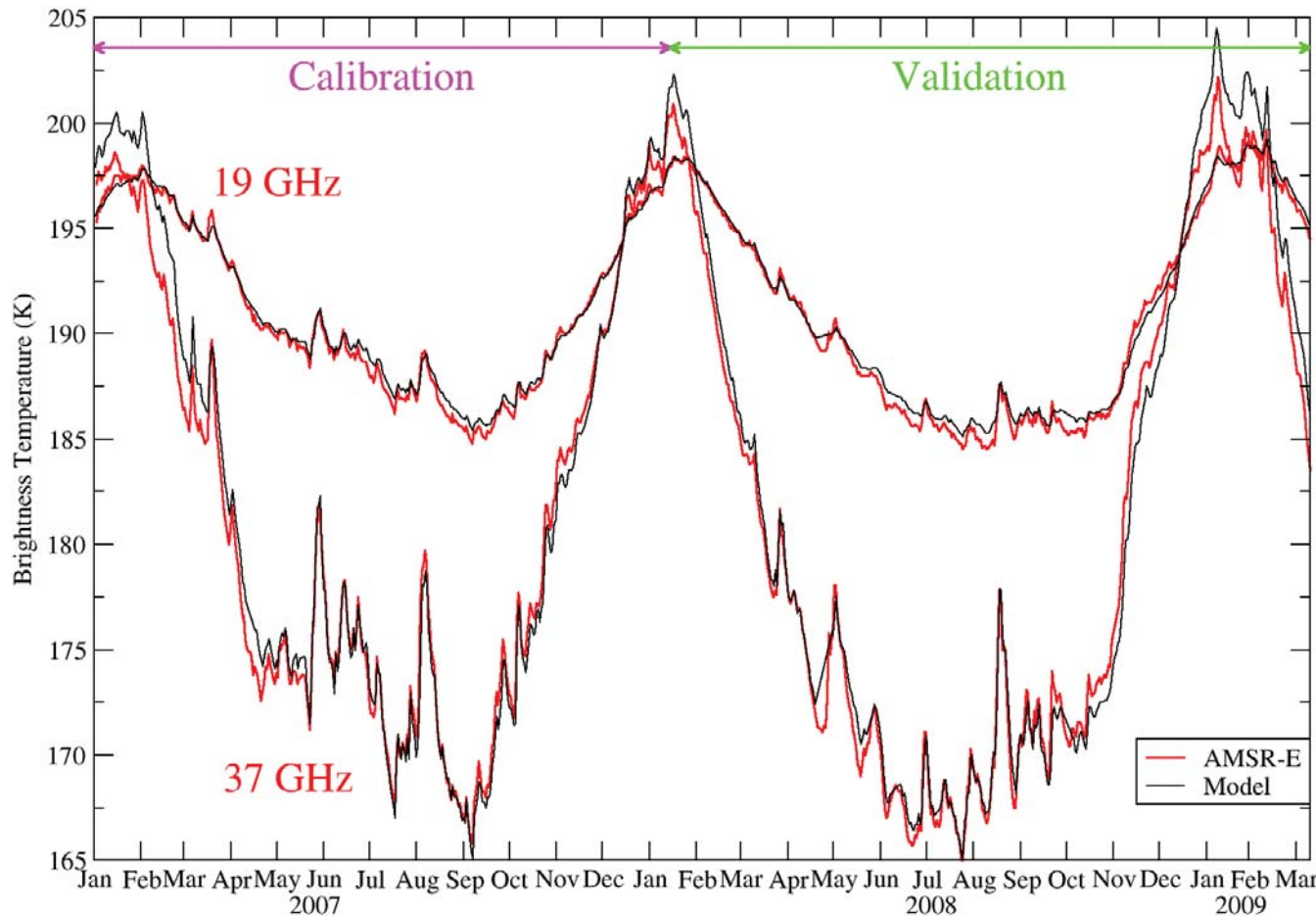
α is a calibrated parameter identical at both frequencies.

(Brucker et al., 2011 JoG)

Dome C, Antarctica



Calibration result: $\alpha=2.8$



V pol.

$RMSE_{19} \simeq 0.4K$

$RMSE_{37} \simeq 1K$

$\overline{RMSE} \simeq 0.8K$

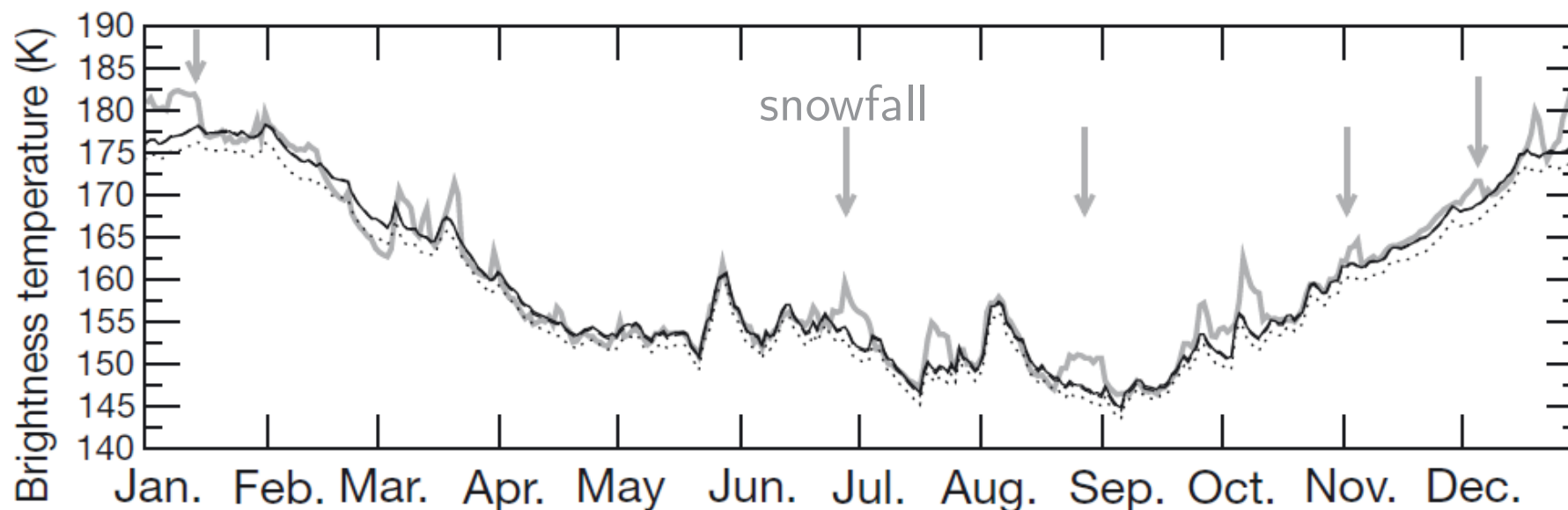
(Brucker et al., 2011)

Good calculation of the extinction coefficient



Dome C, Antarctica

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

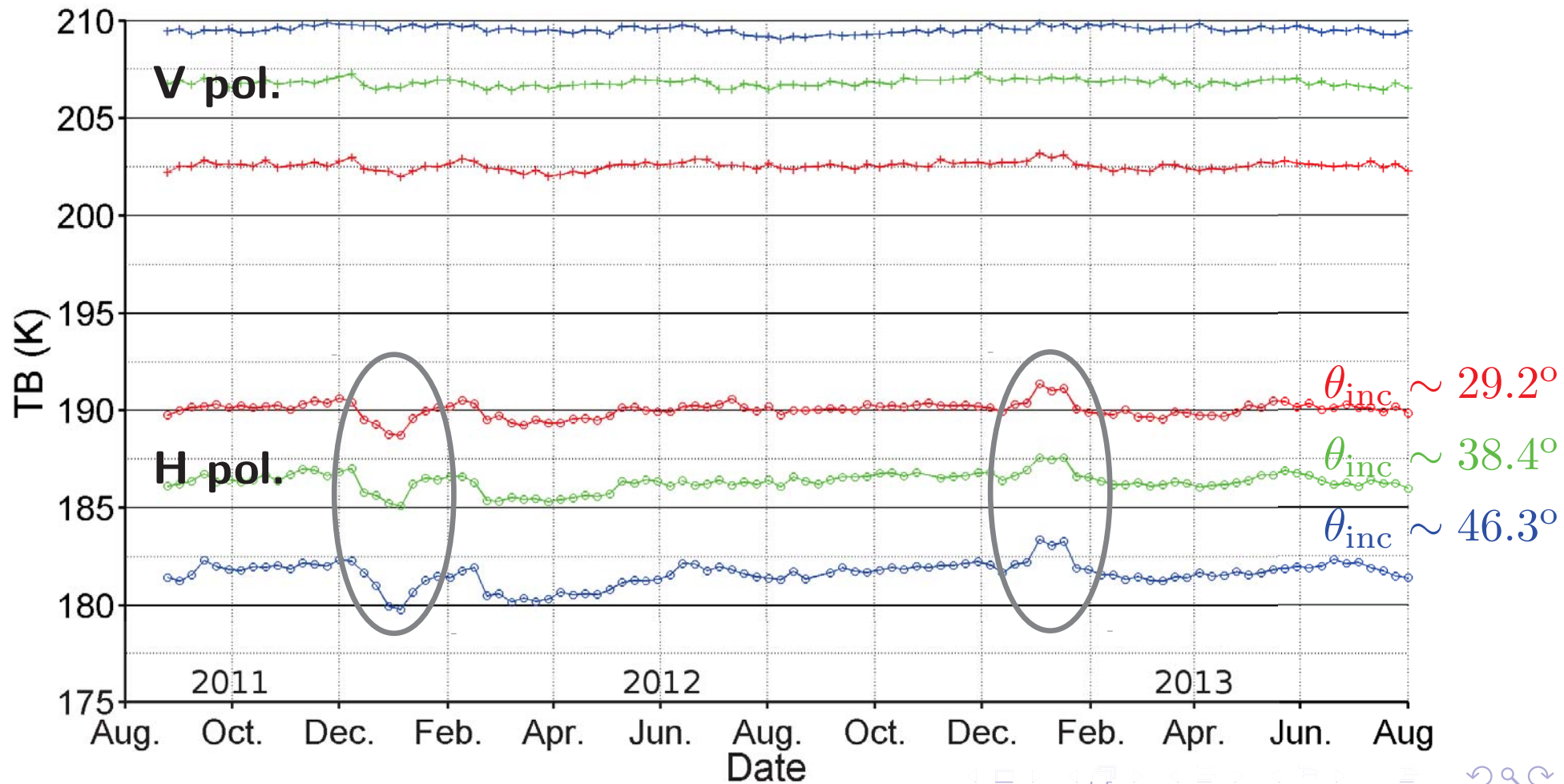


Rapid variations are not reproduced (constant surface properties)

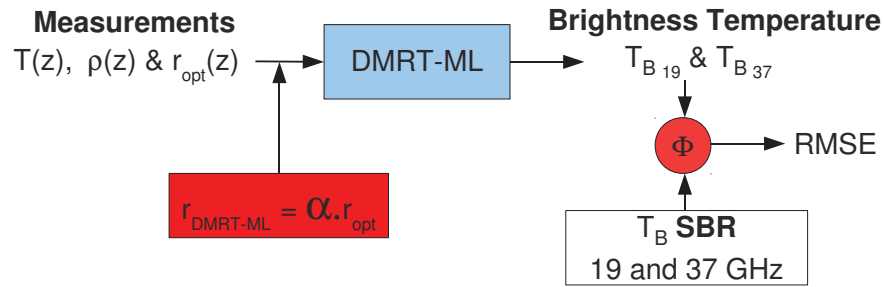
(Brucker et al., 2011 JoG)

Dome C, Antarctica

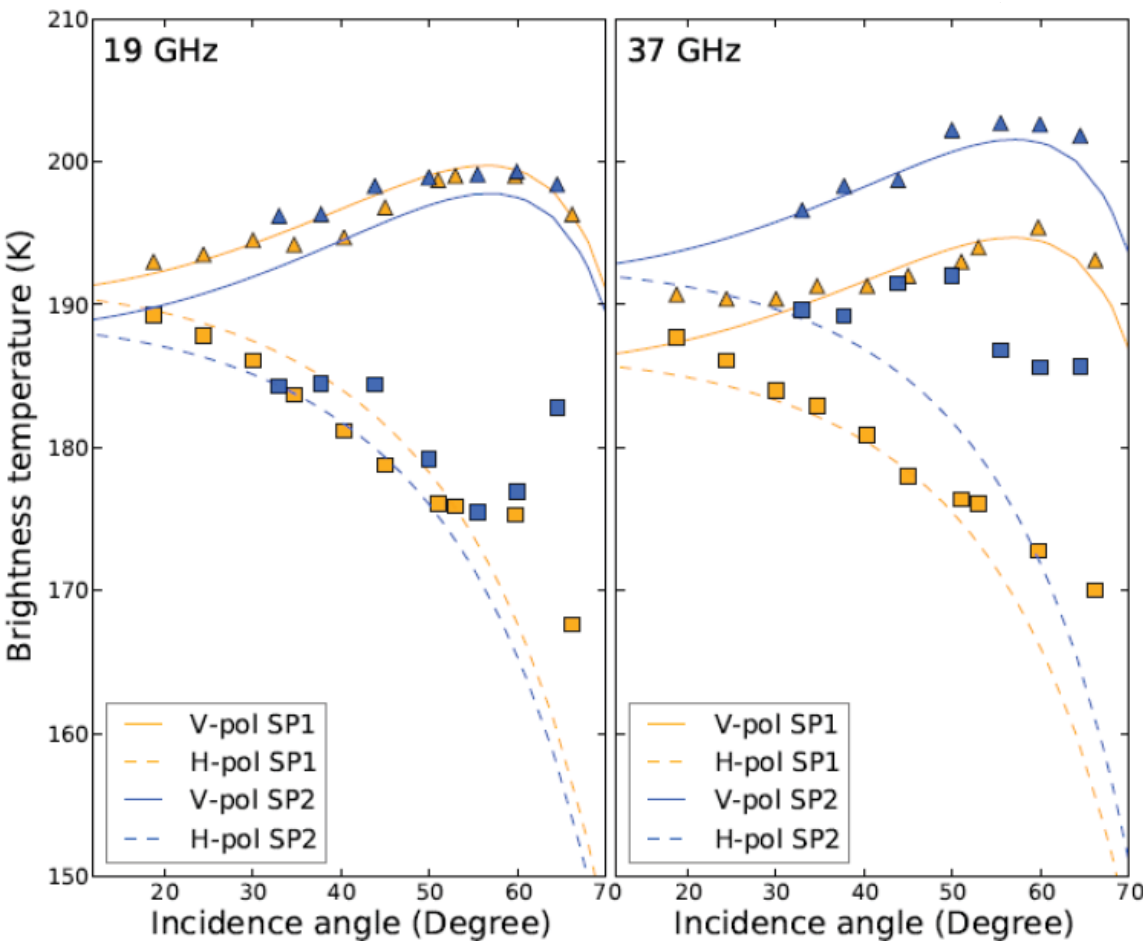
Aquarius (1.4 GHz) TB observations show rapid variations at H pol.



Dome C, Antarctica



Calibration result: $\alpha=2.3$



Reasonable simulations at both Vertical & Horizontal pol.

Reproduce **smooth** and **chaotic** surfaces

Issues at high incidence angles ($> 60^\circ$)

(Picard et al., 2014 TC)

Ablation Zone, Antarctica

Cap Prud'Homme

(Dupont et al., 2014 TGRS)



Bubbly Ice



Importance of
bubble size & ρ_{ice}

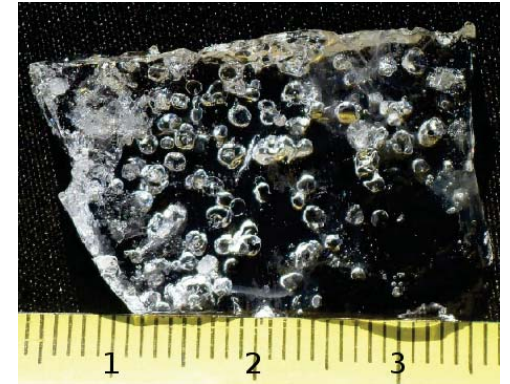
Ablation Zone, Antarctica

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(Dupont et al., 2014 TGRS)

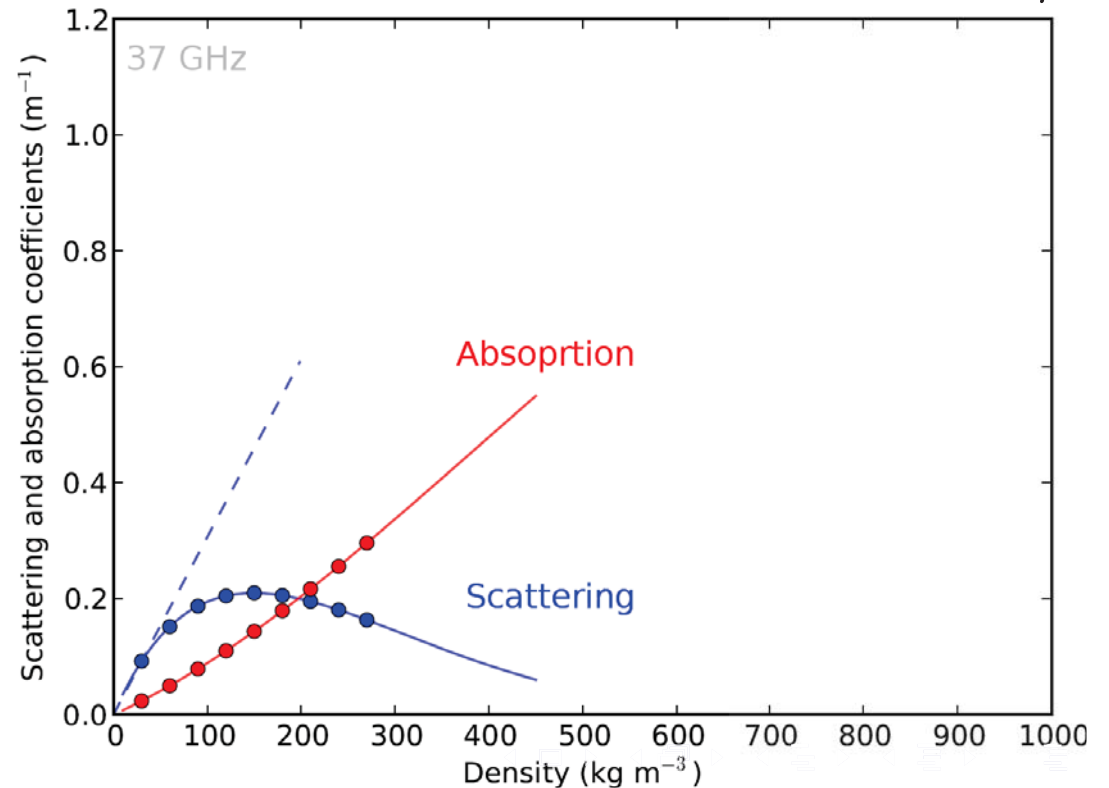


Bubbly Ice



Importance of
bubble size & ρ_{ice}

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



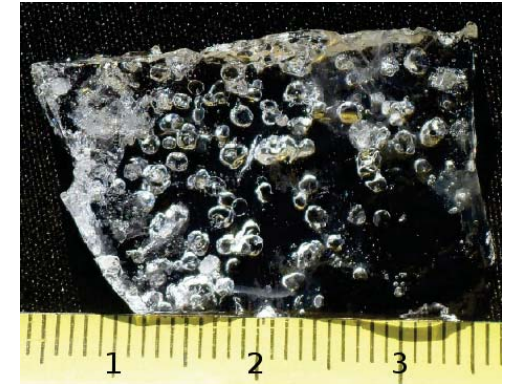
Ablation Zone, Antarctica

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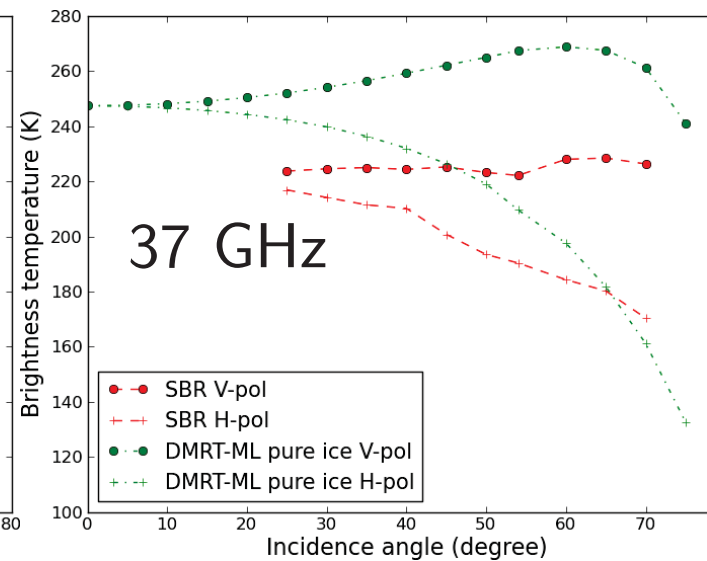
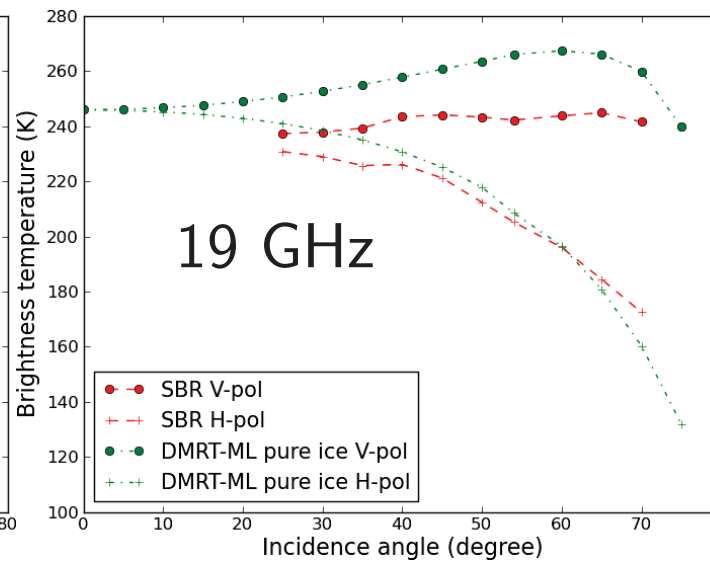
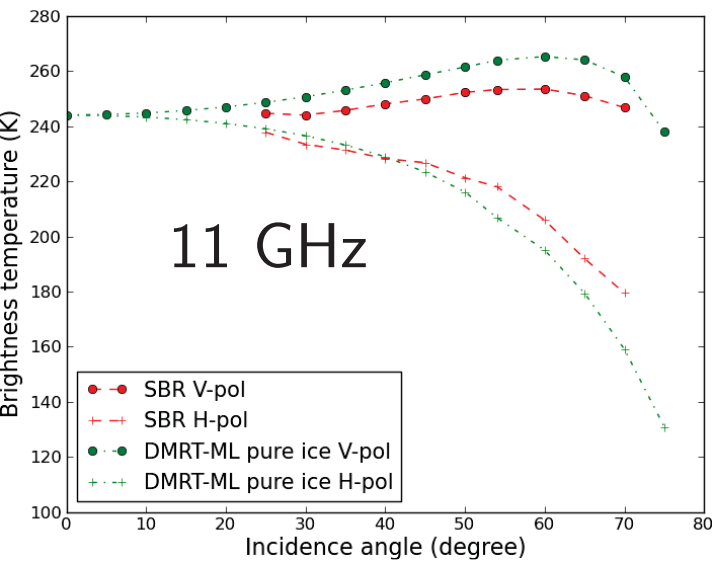
Bubbly Ice



Importance of bubble size & ρ_{ice}

Observations

Simulations



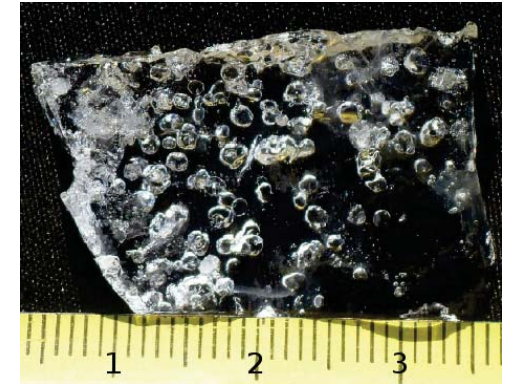
Ablation Zone, Antarctica

Cap Prud'Homme

(Dupont et al., 2014 TGRS)

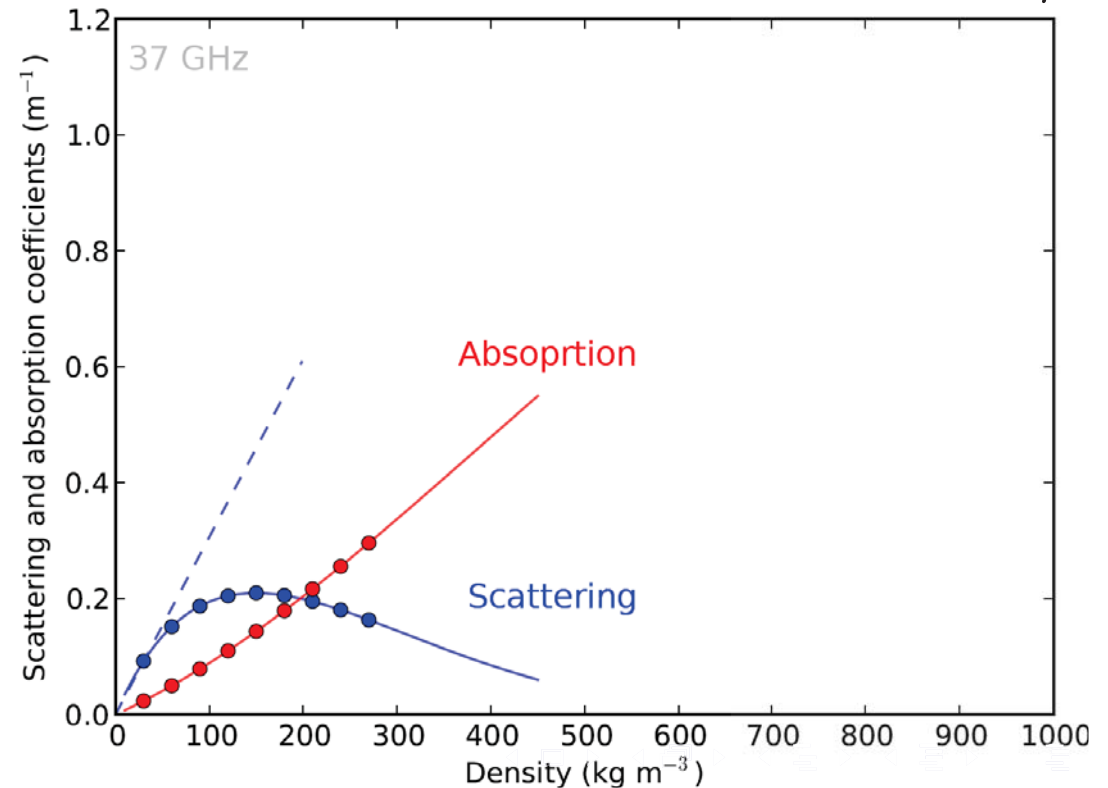


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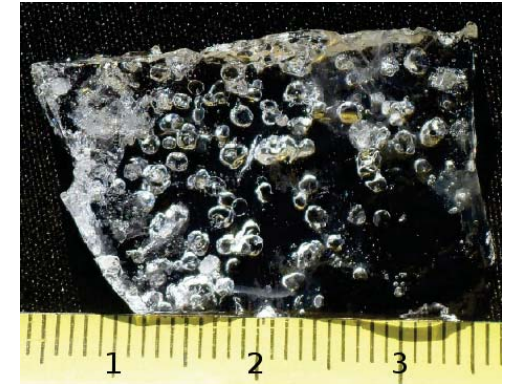
Ablation Zone, Antarctica

Cap Prud'Homme

(Dupont et al., 2014 TGRS)

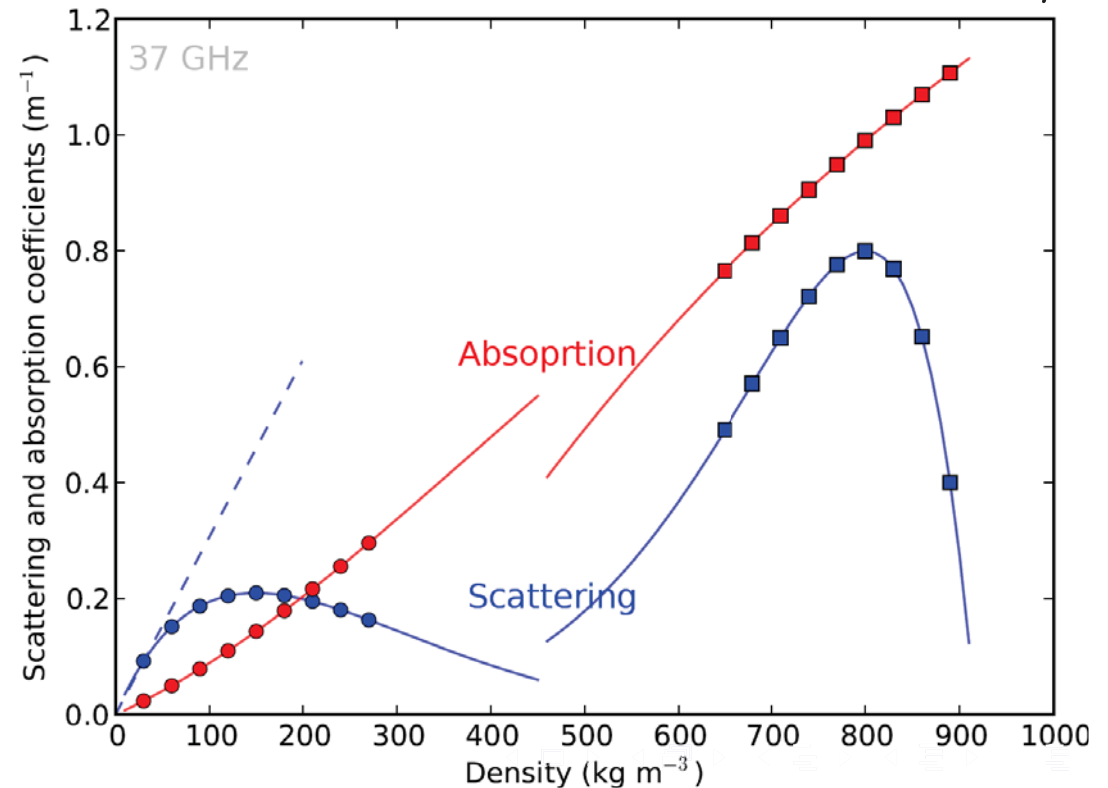


Bubbly Ice



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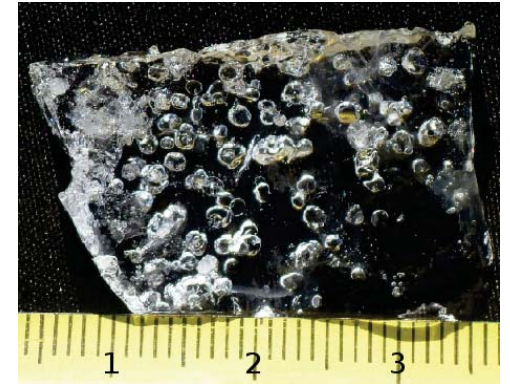
Ablation Zone, Antarctica

Cap Prud'Homme

(Dupont et al., 2014 TGRS)



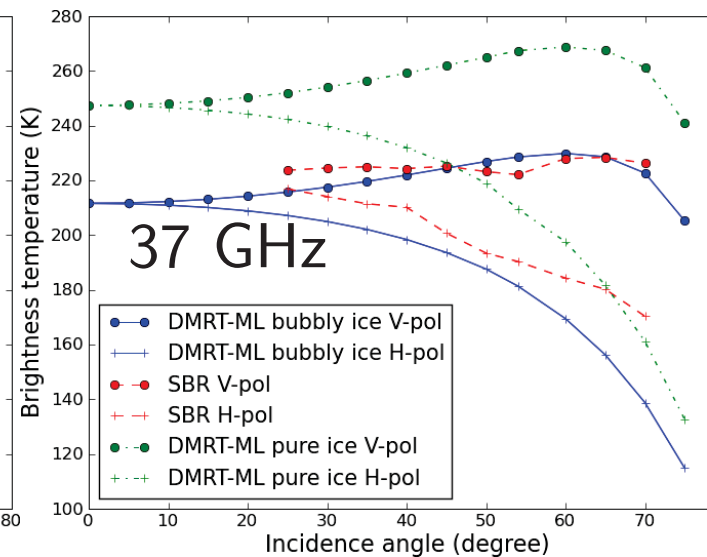
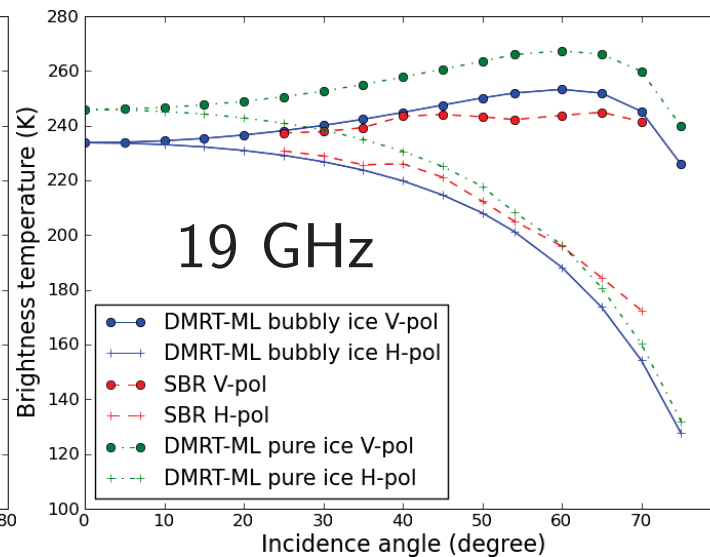
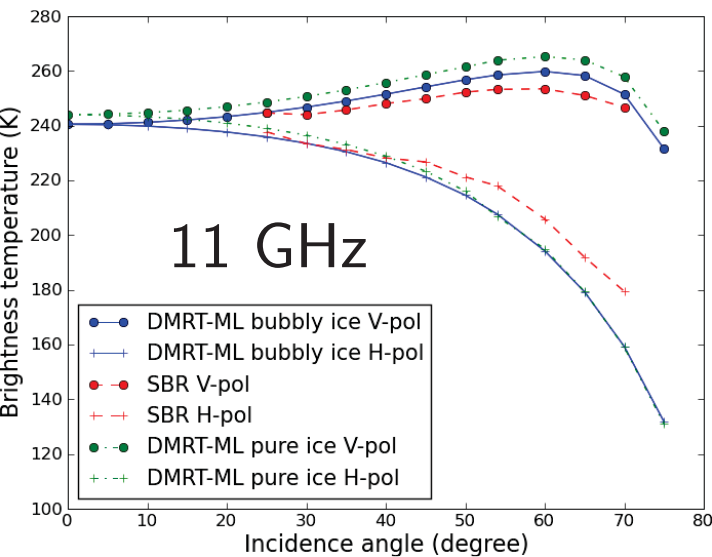
Bubbly Ice



Importance of bubble size & ρ_{ice}

Observations

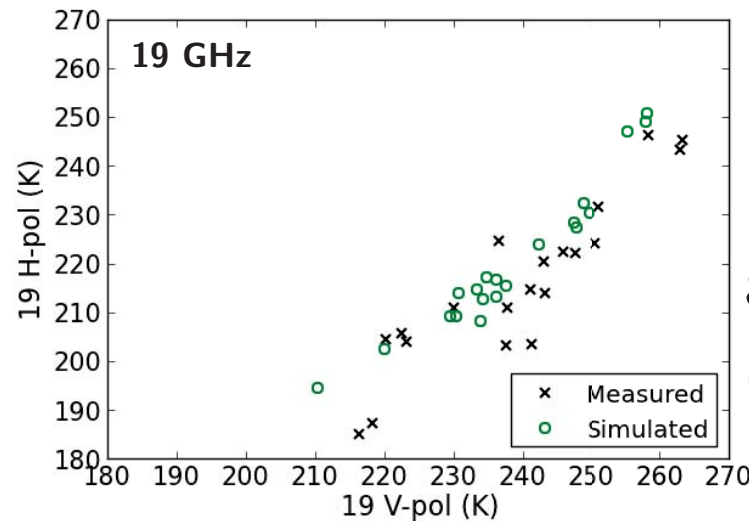
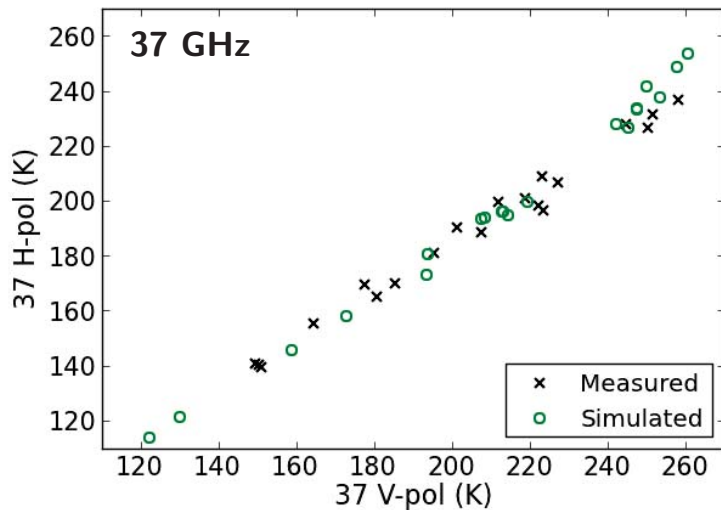
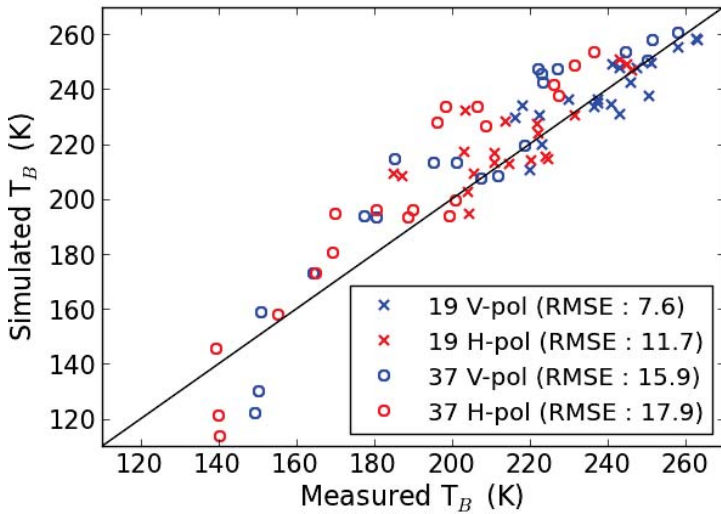
New simulations



Seasonal Arctic/sub-Arctic Snowpacks: Manitoba & Québec



Calibration result: $\alpha=3.3$

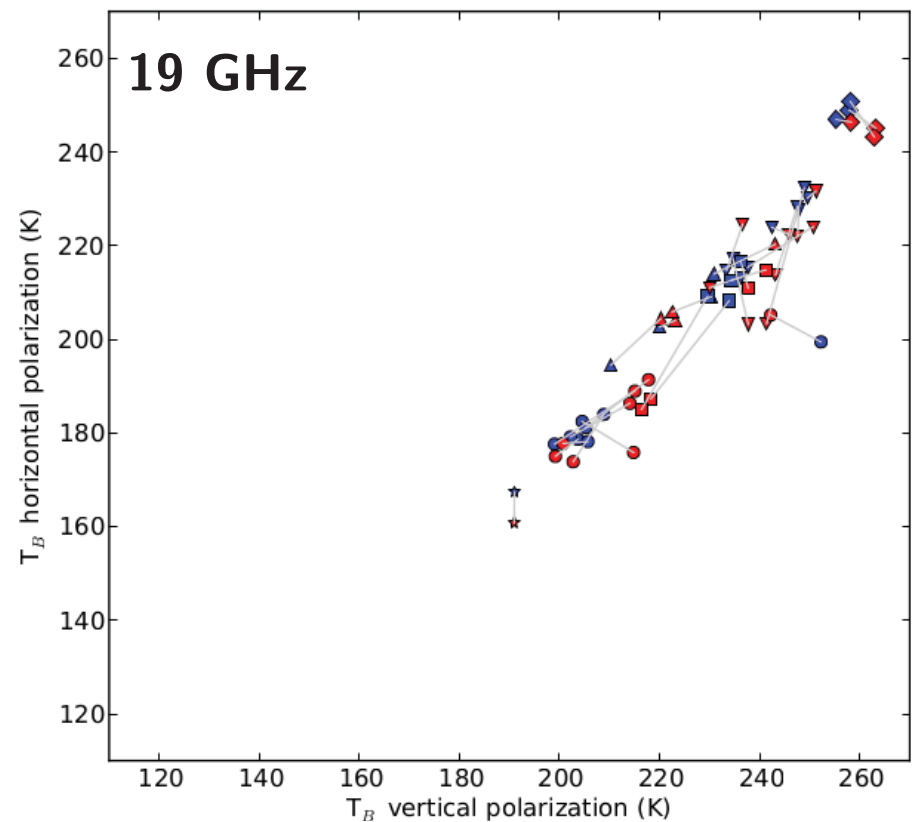
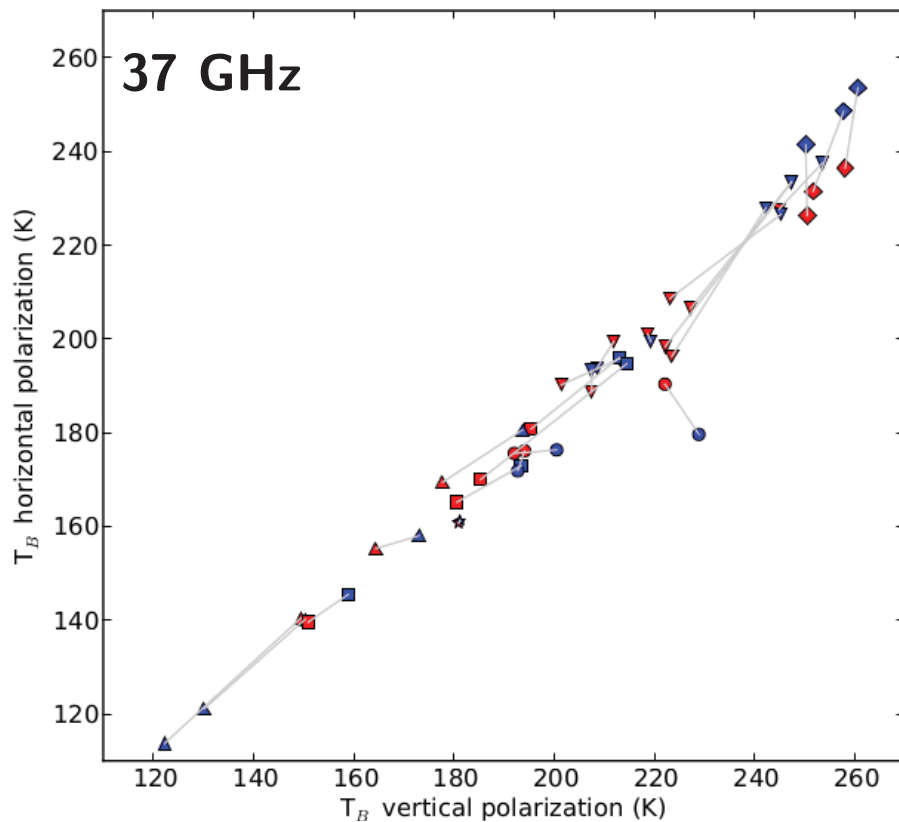


Reasonable results
at both V & H,
and at 19 & 37 GHz
(Roy et al. 2013 TGRS)

Soil model: Wegmüller & Mätzler (1999)

Dependence between H & V pol.

Observed and **simulated** TB
 over Dome C (\star), ice-sheet ablation or percolation areas (\circ),
 tundra (\triangle), windy tundra (∇), fen (\square), grassland (\diamond)



DMRT-ML predicts reliable dependence between H & V pol. near $50\text{-}55^\circ$

Validations & Applications

- DMRT-ML has been validated, in very different environments, on
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DMRT-ML is now used in applications for:

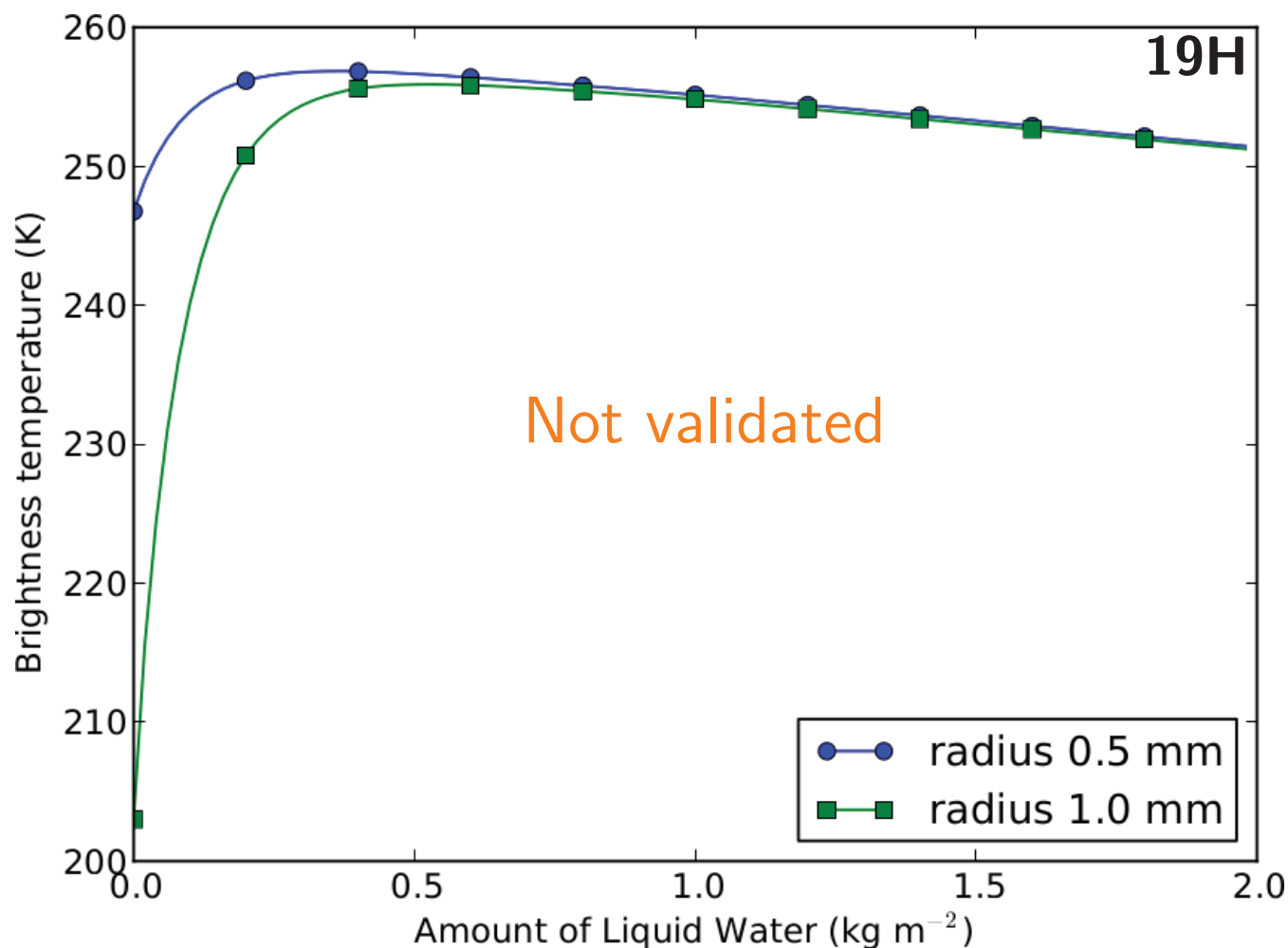
- hemispheric SWE retrievals
- sensor developments
- snow property retrievals with inverse methods
- coupling with snow evolution models
- data assimilation

Outline

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

Current Limitations & Challenges

Liquid water content



$$T_{\text{snow}} = 273 \text{ K}, \rho = 300 \text{ kg m}^3$$

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 .

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Current Limitations & Challenges

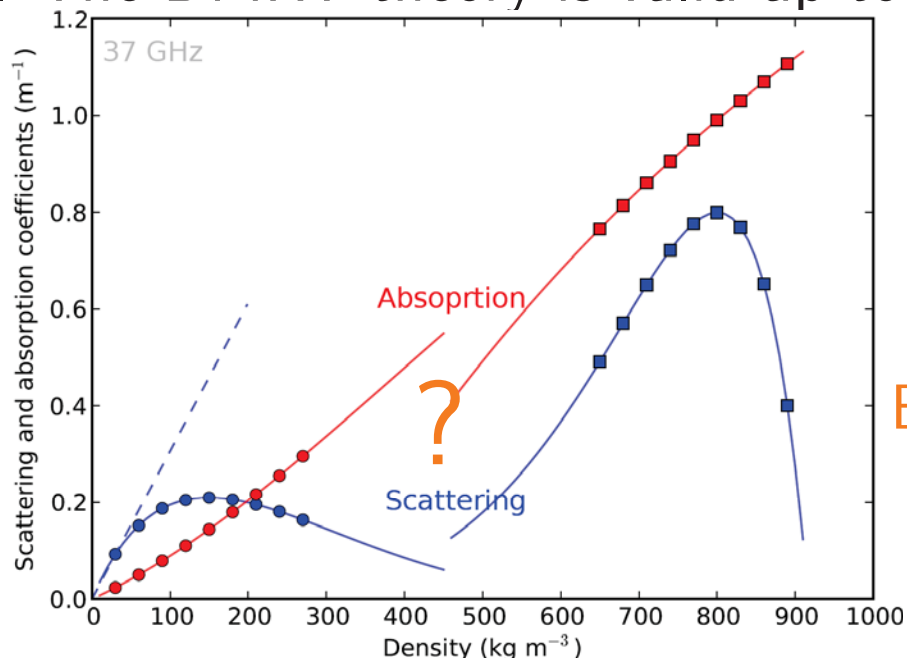
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Density

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



i.e. 0 – 275 kg m⁻³,
and 642 – 917 kg m⁻³.

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

Current Limitations & Challenges

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

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Current Limitations & Challenges

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- . 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

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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**

DMRT-ML \rightsquigarrow 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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- 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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