Modeling L-band brightness temperature at Dome C, Antarctica and comparison with SMOS observations

M. Leduc-Leballeur\textsuperscript{1}, G. Picard\textsuperscript{1}, A. Mialon\textsuperscript{2}, L. Arnaud\textsuperscript{1}, E. Lefebvre\textsuperscript{1}, P. Possenti\textsuperscript{1}, Y. Kerr\textsuperscript{2}

\textsuperscript{1}LGGE (CNRS, Univ. Grenoble Alpes), F-38041 Grenoble, France
\textsuperscript{2}CESBIO (CNES, CNRS, IRD, UPS), F-31401 Toulouse, France
Context

Study of Antarctic climate

- In situ data particularly sparse due to extreme climatic conditions

=> Remote sensing useful means for continuous observations
Context

SMOS satellite

- Launch in 2009
- Microwave radiometer: 1.4 GHz
- Dedicated to Soil Moisture and Ocean Salinity

Interest of SMOS data for Antarctica

- Continuous observations even in cloudy conditions
- Penetration depth in the snow of several hundred meters

=> Strong complementarity with other microwave radiometers (e.g. SSMIS, AMSR-E) which penetrate in dry snow from 5 cm to 20 m
What does SMOS “see” in Antarctica?

How to exploit SMOS data for climate and glaciological applications?

**Prerequisite**

Need to understand the L-band signal over ice-sheets

=> by physical modeling approach
To test this hypothesis, a new simulation was performed with a snow density profile with noise added.

=> Better agreement between simulated and observed $T_B$”
Objective

Two main improvements:

- Use more realistic density profile
- Evaluate wave theory approach instead of radiative transfer theory

Development of a new model dedicated to work at low frequencies
Outline

1. New snow measurements at Dome C
2. New model development: WALOMIS
3. Sensitivity of L-band $T_B$ to snow properties
4. Conclusion
1. New snow measurements at Dome C

BIPOL campaign
summer 2012-2013
(IPEV)

2 profiles:
✓ density and grain size
✓ down to 80 m
✓ every 5 cm
1. New snow measurements at Dome C

The Dense Media Radiative Transfer - Multi Layers model (DMRT-ML, Picard et al., 2013 GMD)

- developed for high frequencies investigations
- based on Dense Media Radiative Transfer Theory (Tsang, 1992; Tsang and Kong 2001)

- with each layer defined by:
  - temperature (T)
  - grain size (r)
  - density (ρ)
  - stickiness parameter (τ)
  - liquid water content (LWC)

Not considered here

Picard et al., 2013 GMD
1. New snow measurements at Dome C

- $T_B$ is over-estimated at both polarisations
- The difference between H and V polarisations is underestimated

$=>$ The measured density profiles clearly improve the simulation

but

- $T_B$ is over-estimated at both polarisations
- The difference between H and V polarisations is underestimated
1. New snow measurements at Dome C

Grain size profiles

Measured grain size

Grain size increased by a factor 5 (unrealistic for Dome C!)

Differences < 0.7 K

DMRT-ML simulations

=> Grain size variations in a realistic range do not affect significantly L-band emission
1. New snow measurements at Dome C

Summary

- The measured density profiles clearly improve the simulation
- Grain size no effect

=> no sufficient for a good agreement with SMOS observations
2. New model development: WALOMIS

At L-band, due to the large wavelength compared to the layer thickness, need to take into account interferences between the layer interfaces.

WALOMIS
Wave approach for low-frequency microwave emission in snow

✓ based on wave approach, i.e. Maxwell’s equation (West et al., 1996; Tsang, 2000)

✓ with each layer defined by:
  - temperature (T)
  - density (ρ)

Note that scattering is not included in this theory
=> acceptable hypothesis for L-band
2. New model development: WALOMIS

Application at Dome C

In the snow, since the model is based on wave theory, it is required to average many different simulations.

Steps

1. measured density profiles

2. stochastic model of $\rho(z)$

3. generate 10 000 profiles

4. run WALOMIS for each profiles

5. Averaging

6. $T_B$
2. New model development: WALOMIS

Step 2: Development of stochastic model

\[ D(z) = \text{Measured density} \]

\[ F(z) = \text{Deterministic part} \]

\[ X(z) = \text{Random part} \]

\[ D(z) \]

\[ F(z) \]

\[ X(z) \]
2. New model development: WALOMIS

Step 2: Development of stochastic model

- variability no stationary throughout the 80 m long profile
  => assumed stationary in 2-m thick layer

- correlation between successive measurements
  => Random part generated by auto-regressive process:

\[ X(z) = \alpha X(z-1) + \epsilon(0,\sigma(z)) \]

where

\( \alpha \) autocorrelation coefficient
\( \epsilon(0,\sigma(z)) \) a Gaussian noise with zero mean and \( \sigma(z) \) standard deviation
2. New model development: WALOMIS

Step 3: Generated density profiles

- **Measured**
- **Simulated**

Step 4
run WALOMIS
for each profile

Step 5
Averaging to obtain final $T_B$
2. New model development: WALOMIS

Results

- For incidence angle lower 60°:
  -> WALOMIS is ok!

- For incidence angle higher 60°:
  -> models and SMOS observations disagree (SMOS accuracy? model surface roughness?).

=> WALOMIS is adapted to the L-band frequencies
Outline

1. New snow measurements at Dome C
2. New model development: WALOMIS
3. Sensitivity of L-band $T_B$ to snow properties
4. Conclusion
3.1. Penetration depth

![Graph showing contribution of each layers to signal emanation depth.](image)

Not exponential because the snowpack is not homogeneous

=> Difficult to define e-folding depth

- 67% of signal emanates from 0-250 m
- 99% of signal emanates from 0-900 m
3.2. Seasonal temperature sensitivity

Temperature between surface and 80 m

Δ ≈ 35°C
Δ ≈ 30°C

℃
-80 -70 -60 -50 -40 -30 -20

Depth (m)
-80 -70 -60 -50 -40 -30 -20

℃
-65°C -30°C

Winter Summer

Differences < 0.2 K

Incidence angles (°)

T_B (K)

0 10 20 30 40 50 60

Summer Winter

SMOS

=> No sensitivity to the surface temperature variations
3.3. Density sensitivity

\[ D(z) = F(z) + X(z) \]

Influence of the deterministic part

\[ F(z) = 400 \text{ kg m}^{-3} \]

\[ F(z) = 700 \text{ kg m}^{-3} \]

On average, for a large difference in \( F(z) \) (300 kg m\(^{-3}\)) => difference less than 5 K

Influence of the random part

\[ X(z) \div 2 \]

\[ X(z) \times 2 \]

Changes in the amplitude of \( X(z) \) => strong impact on simulation
Improvements of the simulation at L-band thanks to:

- high resolution density profiles down to 80 m from BIPOL campaign
- WALOMIS model based on wave theory

3 characteristics of L-band signal at Dome C:

- 99 % of signal emanate from 0-900 m => high penetration depth
- $T_B$ is not sensitive to the seasonal variations of surface temperature
- Strong sensitivity to the snow density, in particular to variability

Perspectives:

- exploit WALOMIS to retrieve glaciological and climate information
Thank you

Acknowledgements: French polar institute (IPEV) and French space agency (CNES)