Simulation of seasonal snow microwave TB using coupled multi-layered snow evolution and microwave emission models

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Objective

To evaluate the accuracy the coupled Crocus-MEMLS snow evolution-emission model, and to leverage the simulated snow properties to interpret the observed time series of brightness temperatures (TB).

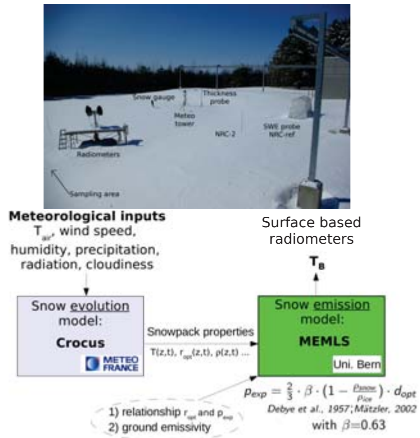
Context

The accurate quantification of SWE has important societal benefits, including improving domestic and agricultural water planning, flood forecasting and electric power generation. However, passive-microwave SWE algorithms suffer from variations in TB due to snow metamorphism, difficult to distinguish from those due to SWE variations. Coupled snow evolution-emission models are able to predict snow metamorphism, allowing us to account for emissivity changes. They can also be used to identify weaknesses in the snow evolution model.

Moreover, thoroughly evaluating coupled models is a contribution toward the assimilation of TB, which leads to a significant increase in the accuracy of SWE estimates.

Method

- Location: SIRENE station (45.37N, 71.92W, 250 m, Quebec, Canada)
  Maritime seasonal snow
  Winter with several warm periods, melting snow, and rain-on-snow events
- Coupled model: Crocus-MEMLS
- Radiometers: Surface based, operating at 19 & 37 GHz

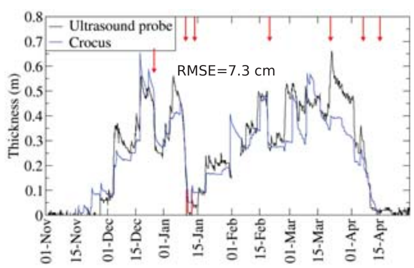


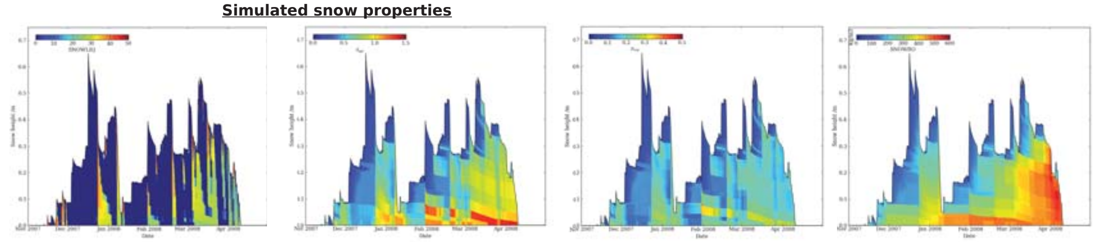
Crocus (Brun et al., 1989, 1992)
- Validated in alpine conditions
- Driven hourly by meteorological data
- Here, the precipitation phase was estimated based on a function of Tair:
  Tair<2°C → dry snowfall
  Tair>2°C → rainfall (i.e. there was no wet snowfall)

Crocus computes surface energy balance, mass & energy exchanges between snow layers. It includes physical processes for: solar radiation absorption, heat diffusion, surface fluxe exchange, dry/wet metamorphism, mechanical snow settlement, internal melting, percolation, and refreezing.

MEMLS (Wiesmann and Mätzler 1999, Mätzler and Wiesmann 1999)
- Based on a radiative transfer scheme using the six-flux theory
- Computes absorption
  & multiple-volume scattering (here, improved Born approx.)
- MEMLS inputs are of two kinds, to characterize:
  - the snowpack (a stack of horizontal smooth layers as in Crocus)
  - the underlying ground

Simulated snow properties



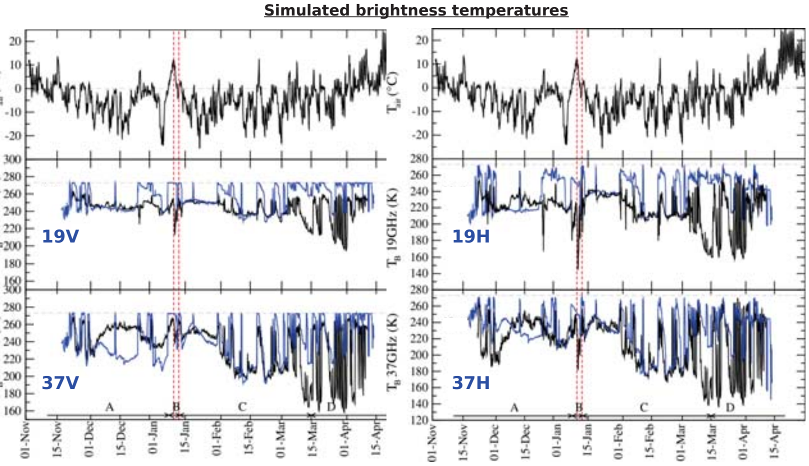


Snow depth was correctly simulated compared to the ultrasound probe. SWE was well simulated too (RMSE of 22.9 mm) compared to the cosmic particle counter measurements, but SWE was underestimated at the end of the season. Of note, the snowpack disappearance was correctly predicted, which is important for a good prediction of TB.

Grain optical diameter was converted into exponential correlation length. The resulting values range between 0.034 mm and 0.396 mm, within the range of MEMLS validity.

The predicted density shows smooth vertical variations, and no presence of an ice crusts or ice layers, contrary to in situ observations. This affects the TB simulations (esp. at H pol.).

Simulated brightness temperatures

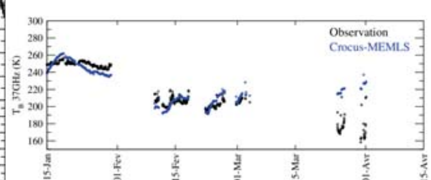


Observations
Crocus-MEMLS

Channel	RMSE (K) January 15th–March 31st	RMSE (K) January 15th–March 3rd
19V	10.2	2.8
37V	14.7	6.5
19H	14.0	3.6
37H	13.8	6.9

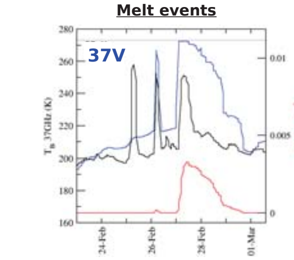
Most of the errors comes from the overestimated TB at the end of the season.

Dry snow only



The trend in decreasing TB during the season results from an increase in scattering.

Melt events



Simulated TB remains due to Crocus too low percolation and runoff rates.

Conclusion (Brucker et al., 2011)

The Crocus-MEMLS coupled model was able to accurately predict melt events (success rate: 86%). The residual error was due to an overestimation of the duration of several melt events simulated by Crocus.

When the snowpack was completely dry, Crocus-MEMLS correctly simulated the evolution of TB resulting from temperature gradient metamorphism. RMSE ranged between 2.8 K at 19V to 6.9 K at 37H, despite the lack of ice layers in the simulated snowpack.

During dry periods near the end of the season, simulated TB were overestimated, due to a limitation of the growth of large snow grains.

Refs: * Brucker, Langlois, Royer, Picard, & Fily (2011), Hourly simulations of the microwave TB of seasonal snow in Quebec, using a coupled snow evolution-emission model. RSE.
* Brun, Martin, Simon, & Coleou (1989). An energy and mass model of snow cover suitable for operational avalanche forcasting. J. of Glaciology.
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