Microwave radiative transfer in a snow pack: Models and experimental objectives for Cold Land Processes Experiment II

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Outline

- Introduction, motivation, and relevance to JULES
- MEMLS Radiative Transfer
  - Classical RT with Empirical scattering and absorption properties
- Coherent collective scattering
  - Improved Born Approximation (Mätzler, 1998)
  - Dense Medium Radiative Transfer (Tsang & Kong, 2001)
- The second Cold Land Processes Experiment (CLPX-II)
Reflected atmospheric and surface emission

\[ T_n = T_a + \varepsilon_s T_s \exp(-\tau) + (1 - \varepsilon_s) T_d \exp(-\tau) \]

\[ T_d = T_z \exp(-\tau) + T_a \]
Snapshot of Snow and Ice Extent

- Snow cover where population density low
  - Few radiosondes released
  - Sparse data for analysis of temperature and humidity fields for use in NWP model
- Frequent passage of polar orbiting satellites
- However use of this data for retrieval of temperature and humidity requires knowledge of surface component.
Relevance to JULES

- JULES to be land surface scheme for future operational NWP.
- Hope to assimilate microwave sounding radiances over land (AMSU).
- Couple fast regression based microwave radiative transfer model to snow module.
- First need to validate complex snow radiative transfer models in 20 to 200 GHz range.
Microwave Emissivity Model of Layered Snowpacks

- Mult-layer, multiple scattering radiative transfer model with empirically derived scattering coefficients.
  - Evaluated on frequency range: 5 to 100 Ghz.
- Option to use theoretically determined scattering and absorption properties.
MEMLS (cont'd)

- Plane stratified model.
- Input profile: density, temp., correlation length, wetness, layer thicknesses.
- Outputs: dual polarization emissivity
- Aux. Inputs: freq and look angle.
- Scattering and absorption properties need to be determined.

Figure 1. A multilayer system with a wave incident from above at an angle $\theta_n$. 
Models for calculating scattering and absorption properties

- Improved Born Approximation (IBA; Mätzler, 1998)
  - one of the options in MEMLS
  - Parameter describing granular medium
    » Correlation length
- Quasi Crystalline Approximation (QCA; eg. Chapter 6 of Tsang and Kong, 2001)
  - Can handle particles in Mie scattering regime
  - Parameter describing granular medium
    » Particle radius (distribution)
- Evaluation of these models is underway (20-200 GHz)
  - Numerical simulations
  - Upcoming airborne campaign (CLPX-II)
CLPX-II

Snow transects in Brooks Range and on North Slope

Aircraft based in Fairbanks
CLPX-II

- Snow study areas (yellow)
- Snow survey transects
  - Snow depth (very frequent)
  - Snow pit profiles (periodic)
  - FMCW ground based radar
    » Continuous snow depth transects
  - Input profiles for MEMLS
- Flight lines (white)
  - Measurements of $T_B$, $T_{surf}$, altitude
- Atmospheric profile data
  - Sonde dropping runs
  - In situ aircraft instrumentation
  - Water vapor profiling lidar
  - Allow retrieval of emissivities (Harlow, 2007)
- Scatterometer data
  - Active/passive synergy
Demands on JULES snow module

- Profiles of temperature, density, wetness, stratigraphy
- Profiles snow grain size or correlation length.
- CLPX-II focus on arctic dry snow
  - Minimal wetness and stratigraphy (no thaw)
  - Strong temperature gradient
    » Temperature gradient metamorphosis
    » Penetration of microwaves
  - Temperature of emission of microwaves greater than IR surface temperature.
Grain size or Correlation length

- Simulation of grain size depth profiles most difficult demand on snow module.
- Field data will provide pit profiles distributed in time and space.
  - With distributed met data can evaluate snow modules.
  - With observed microwave and IR brightness temperatures can evaluate snow microwave radiative transfer routines.
Conclusions

- Ability to retrieve emissivity with BAe-146 (Harlow, 2007)
- Three models of microwave emission (increasing complexity)
  - Weng and Yan (2003) (~msec/spectrum)
  - MEMLS with IBA (~sec/spectrum)
  - MEMLS with QCA (~10^5 sec/spectrum)
- Need data set to validate these models on the 100-200 GHz frequency range.
  - CLPX-II
- Need to evaluate a snow thermophysical model that provides depth and area distributed profiles of snow grain size, density and temperature.
- Coupling within JULES
  - Future data assimilation of AMSU radiances over land
  - Fast regression based snow rad transfer model
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References

On airborne microwave emissivity retrieval:
Harlow, R.C., 2007: “Airborne Retrievals of Snow Microwave Emissivity at AMSU

On MEMLS, IBA and correlation length of snow:
Mätzler, C., 2002: “Relation between grain-size and correlation length in snow,” J.
Mätzler, C., and A. Wiesmann, 1999: Extension of the Microwave Emission Model of
Layered Snowpacks to Coarse-Grained Snow. Remote Sens. Environ., 70, 317-
325.
Wiesmann, A., and C. Mätzler, 1999: Microwave emission model of layered

On Quasi Crystalline Approximation: