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The influence of non-spherical particles and land surface emissivity on combined radar / radiometer precipitation retrievals

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1. Introduction

One of the newer atmospheric research areas is remote sensing of falling snow. Falling snow retrieval algorithms typically rely on radar signatures or passive high frequency channels ($>= 90$ GHz) that relate scattering by ice to the falling snow. In physically-based retrievals of falling snow, algorithms necessarily employ a number of subjective assumptions regarding the relationship between precipitation particles and the observed microwave radiances and radar reflectivities. One common and persistent assumption is that frozen precipitation-sized particles may be treated as spherical particles, which may or may not be reasonable, depending on the precipitation type. Another standard assumption is that the surface emissivity of land surface at passive microwave frequencies is "constant", and is often based on a pre-existing categorization of surface type.

This research seeks to explore the forward modeled brightness temperature and radar reflectivity sensitivity to continuous variations in particle shape from a sphere to an idealized aggregate and/or pristine dendrite. We also examine the sensitivity of snowfall detection to land surface emissivity against forested and snow covered backgrounds.

2. Particle Properties

Recent research has shown that the scattering and absorption properties of non-spherical particles can vary significantly from spherical particles [Kim, M.-J., et al., 2008]. However, the true particle shapes (and spatial distributions thereof) within a precipitating cloud remain unknown without in-situ observations. The choice of using spherical particles to simulate realistic frozen precipitation particles (e.g., needles, dendrites, graupel, etc.) is often motivated by computational convenience, through the use of well-tested Mie-theory based codes, and by the lack of practical alternatives. For small size parameters ($x << 1 : x = 2\pi r/\lambda$, where r is the particle radius and λ is wavelength), the spherical assumption appears to be reasonably valid. Precipitation sized frozen particles often have physical dimensions on the order of high frequency wavelengths, or have structures that are on the order of these wavelengths which are individually spatially distributed much differently than spheres of equivalent mass.

In the present research, we employ the discrete dipole approximation through the code entitled "DDSCAT" to compute the scattering and absorption properties of individual particles. This information is subsequently used in the forward model and retrieval.

3. Models and Retrievals

The forward model for computing passive microwave brightness temperatures used in the present research incorporates full Stokes polarization. Vertical profiles of radar reflectivities at 13.4 and 35.6 GHz (consistent with the case study) are computed using the full radar reflectivity equation, accounting for non-Rayleigh effects and path-integrated attenuation throughout the vertical column.

For the studies of particle shape, the retrieval method described in [Johnson, B.T., 2007], employs the dual-wavelength ratio method (e.g., Meneghini, R., 1997) for retrieving a solution space consisting of vertical profiles of particle size distributions having forward modeled dual-wavelength ratios consistent with the observed ratios. For this set of "candidate solutions" the top-of-the-atmosphere brightness temperatures are computed and compared to observations, further constraining the radar-based retrieval. The retrieval sensitivity to particle shape through a continuous change from non-spherical to spherical particles are examined using simulated retrievals and a few selected case studies.

For studies of falling snow detection, it is important to identify which retrieval methodology works best over snow covered land surfaces and in regions of highly variable land cover. The high variability (urban, to snow covered, to forest, to lakes) impacts land surface emissivity and hence the observed brightness temperatures, generating challenges for retrieval algorithms because snow covered surfaces under clear air conditions can have similar TB as precipitating snow cases.

4. Case Studies

The case studies for the falling snow detection over land come from the Canadian CloudSat Calipso Validation Programme (C3VP) held during the winter of 2006-2007 near the Great Lakes region, 70 km north of Toronto. The C3VP data set provides a rich data set for briefly addressing some of the approaches we are examining for snowfall retrievals over highly variable backgrounds.

For retrieval of snowfall and sensitivity to particle shape, we primarily focus on radiometer and radar data obtained over precipitating snow clouds during the 2003 Wakasa Bay field Experiment, which consisted of a dual wavelength radar (13.4 and 35.6 GHz) co-located with a high frequency radiometer operating at 89, 150, 183.31, 220, and 340 GHz. Observations in this study were made over ocean.