

THE FEASIBILITY OF DETECTING SUPERCOOLED LIQUID WITH A FORWARD-LOOKING RADIOMETER

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ABSTRACT

A three-dimensional radiative transfer model is utilized to determine the feasibility of a forward-viewing passive sensor for remotely detecting hazardous icing conditions. W-band ground-based radar simulations show no obvious ability to discriminate a cloud-top supercooled layer; however, the spectra for a forward-viewing passive sensor show a strong signal at two stand-off distances when compared with the clear sky spectrum. Such an instrument would be critical for manned and unmanned aircraft, particularly when size, weight, and power requirements restrict the installation of de-icing equipment.

Index Terms— Radiometer, radar, clouds, supercooled liquid

1. INTRODUCTION

Supercooled liquid clouds constitute an appreciable climate feedback effect, and, as the climate warms, the presence of supercooled liquid is expected to increase. Such changes will alter the albedo of clouds; however, the partitioning of liquid and ice in mixed-phase clouds is poorly represented in global climate models. Beyond climate applications, supercooled liquid presents a hazard to aviation through airframe icing. To address both of these areas, improvements in the ability to detect and measure supercooled layers in mixed-phase clouds are necessary, and simulation tools are required to interpret remote sensing observations of clouds. Radiative transfer modeling demonstrates a strong radiometric response to supercooled liquid layers that are not visible to ground-based W-band radar.

2. RADIATIVE TRANSFER MODEL DESCRIPTION

To perform radiative transfer simulations, we used the Atmospheric Radiative Transfer Simulator (ARTS), version 2.3 [1]. For passive simulations, we simulated spectra from 30 GHz to 200 GHz using Monte Carlo integration, which accounts

for scattering effects [2]. To simulate dual-polarization radar with finite antenna beams, we extended ARTS to calculate radar reflectivity using Monte Carlo sampling of a Gaussian antenna pattern to produce a finite beam response.

Hydrometeor scattering properties for ice particles are calculated using the T-Matrix method for fixed orientation [3] with a temperature-dependent complex permittivity for ice [4]. While T-Matrix calculations are not as representative as the higher-fidelity discrete dipole approximation (DDA) for frozen hydrometeors with irregular shape, a comprehensive database of DDA-computed particles is not available for horizontally-aligned snow particles. Although the size of water droplets are outside of the scattering regime for this study, spherical supercooled cloud liquid droplets are modeled as a scattering species using the T-Matrix for random orientations [5] with complex permittivity prescribed by Turner et al. [6] to produce the phase matrices necessary for radar reflectivity calculations. Gas absorption is calculated using the complete Rosenkranz absorption model [7, 8, 9], with improvements to oxygen absorption [10].

3. CLOUD MODEL DESCRIPTION

The cloud profile model is a simplistic expression of a mixed-phase cloud observations [11]. The profile of liquid, pristine ice, and aggregated snow is shown in Fig. 1. All hydrometeor species are represented by a gamma distribution with shape parameter $\mu = 3$. The effective radii for liquid cloud, pristine ice, and aggregated snow are 10 μm , 20 μm , and 100 μm respectively. The size of supercooled liquid droplets suggest spherical geometries. Pristine ice particles are modeled as cylindrical plates with a four-to-one aspect ratio, and aggregates are oblate spheroids with a 1.33-to-one aspect ratio. The von Mises distribution, which is a good directional statistics approximation of a Gaussian distribution, is used to prescribe particle flutter, with a Gaussian-equivalent standard deviation of 10° . As shown in the cloud profile, the vertical extent of the cloud is 1.5 km. The three-dimensional nature of the radiative transfer model allows finite horizontal dimensions. The cloud extends 500 km in the north-south direction to approximate

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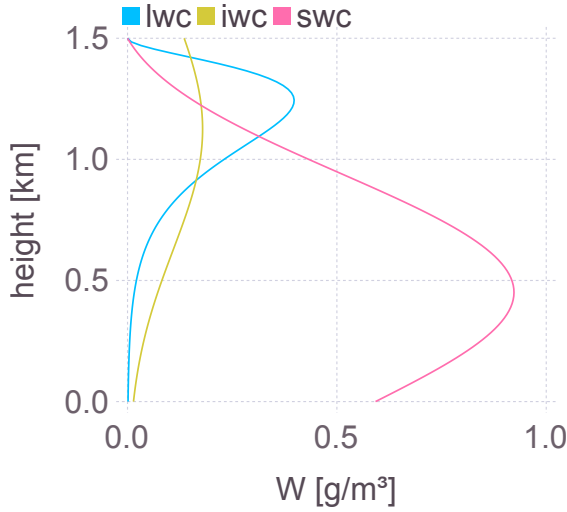


Fig. 1. Liquid, ice, and snow model profiles.

an infinitely long cloud, while the cloud is limited to 100 km in the east-west dimension.

4. SIMULATION RESULTS

The simulation results show unique responses for both active and passive sensors, suggesting that synergistic observations can capture overarching features of subarctic mixed-phase clouds. Moreover, the three-dimensional domain geometry facilitates simulating the response of a forward-viewing radiometer designed to detect and quantify flight-path icing conditions for an aircraft approaching a mixed-phase cloud.

Radar reflectivities at 90 GHz respond primarily to the larger aggregated snow as shown in Fig. 2; however, there is not an obvious response to the supercooled liquid or the pristine ice particles. By simulating a forward-viewing passive sensor at the level of the supercooled layer, we demonstrate a strong response at distances of 15 km and 30 km from the cloud edge, when compared to clear sky simulations (Fig. 3). The response to an ice-only cloud (not shown) deviated by only 1 K from the clear sky simulations.

5. CONCLUSIONS

The simulation results presented in this work demonstrate the feasibility of a forward-viewing passive sensor for avoiding hazardous flight conditions. Additionally, such measurements could be used for monitoring supercooled liquid layers that present an appreciable climate feedback mechanism. Of course, more comprehensive simulations over a wide range of conditions are necessary for determining the information

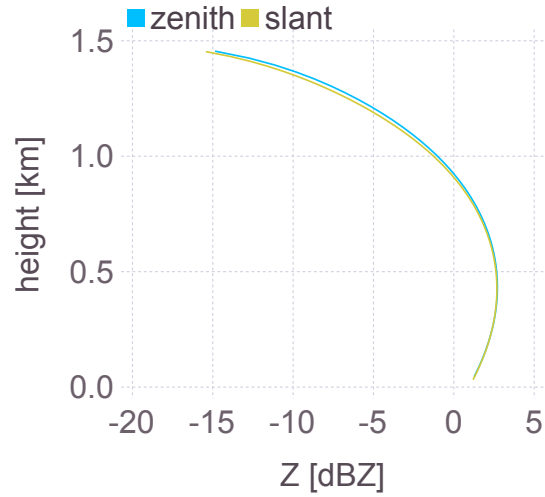


Fig. 2. Reflectivities for zenith and 45° slant-path views.

content in the passive brightness temperature spectra for varying liquid and ice water contents and for precipitating supercooled conditions.

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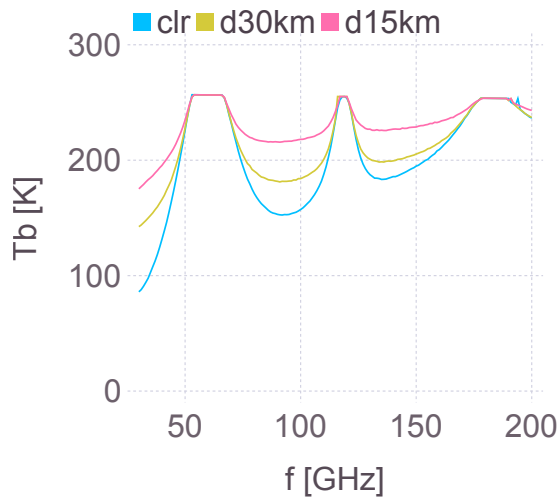


Fig. 3. Passive microwave T_b spectra for a forward-viewing sensor.

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