

Second Year Progress Report

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Project Title: High-latitude precipitation studies using combined active and passive microwave satellite observations

Principal Investigator:

Ralf Bennartz

Department of Atmospheric and Oceanic Sciences and Space Science and Engineering Center (SSEC)

University of Wisconsin-Madison

Madison, WI

Co-Investigator:

Mark S. Kulie

Department of Atmospheric and Oceanic Sciences and Space Science and Engineering Center (SSEC)

University of Wisconsin-Madison

Madison, WI

Project Objectives

The following research themes are to be addressed in the project (excerpt from proposal abstract):

- We propose to adapt our combined active/passive modeling framework that was developed using currently available CloudSat, Advanced Microwave Scanning Radiometer (AMSR-E), and Advanced Microwave Sounding Unit-B (AMSU-B)/Microwave Humidity Sounder (MHS) observations to coherently simulate all GPM passive microwave frequencies and radar returns at DPR frequencies. This approach can be applied to mesoscale model output to generate synthetic observations, as well as to actual observations using CloudSat, AMSR-E, and AMSU/MHS as proxies for GPM instruments. This combined modeling platform allows the active and passive response to precipitation to be modeled in a physically consistent framework and also enables uncertainties associated with the simulations to be readily obtained (Kulie and Bennartz 2009, Kulie et al. 2009).
- We plan to continue our current higher latitude precipitation studies with the combination of AMSR-E, AMSU/MHS, and CloudSat as proxies for GPM. Based on our forward model approach we will determine errors and uncertainties associated with snowfall retrievals due to the choice of ice particle model and particle size distribution parameterization. The utility of these errors and uncertainties can be further enhanced by stratifying them regionally or by precipitation category or cloud type.

Second Year Progress:

1. Research Progress

Valuable snowfall-related microwave remote sensing results were obtained and published by our research group in the past year. For instance, Hiley et al. (2011) highlighted uncertainties associated with active microwave spaceborne snowfall retrievals using CloudSat observations. In addition to an exhaustive discussion of the uncertainties associated with important snowfall retrieval assumptions (e.g., microphysics and surface temperature thresholds), a snowfall accumulation validation exercise was performed using independent ground-based measurements from Canada. The potential complicating factor of columnar cloud liquid water coincident with surface snowfall (a very important topic to consider for passive microwave snowfall retrievals) was also discussed using coincident CloudSat reflectivity observations and AMSR-E liquid water path retrievals. This publication heavily utilized the microwave scattering database that is the key component of the combined active/passive modeling system outlined in the project objectives.

Results from a second research project published by Kneifel et al. (2011) will also

benefit the snowfall retrieval community. This manuscript presented triple-frequency (Ku-/Ka-/W-band) modeling results using the different snowflake/ice habits contained in our microwave scattering database. Triple-frequency signatures associated with non-spherical aggregate models were shown to be distinct and unique from commonly used spherical, ellipsoid, and simple non-spherical renditions of frozen hydrometeors. These results provide evidence that the aggregate models could be optimal default models for passive and combined active/passive microwave retrieval schemes.

The following list highlights other relevant research conducted over the past year:

- In an effort to validate the triple-frequency modeling work published by Kneifel et al. (2011), we have analyzed an airborne triple-frequency dataset from the NASA/JAXA-sponsored Wakasa Bay AMSR Precipitation Validation Campaign. The combined dataset comprised of Airborne Precipitation Radar-2 (APR2; Ku-/Ka-band) and Airborne Cloud Radar (ACR; W-band) was provided by Dr. Simone Tanelli at the NASA Jet Propulsion Laboratory. The data from these two sensors were quality-controlled and collocated, and observations from the frozen region of low freezing level stratiform rain events indicate triple-frequency signatures that conform better with the unique aggregate model behavior highlighted in Kneifel et al. (2011). We continue to analyze this dataset and will submit a manuscript summarizing the results in the near future.
- An initial analysis of ground-based 35 GHz radars has been performed to assess typical radar signatures associated with snowfall. This work will continue throughout the next year to produce a dataset that will be useful both scientifically and for GPM snowfall algorithm development purposes.
- We have collaborated with researchers at the University of Wisconsin Department of Electrical and Computer Engineering to compare atmospheric attenuation using millimeter-wave propagation models that are commonly used in microwave retrieval algorithms to high-frequency (400 GHz) laboratory measurements. This work has been submitted as a publication and is currently in revision.

2. GPM Algorithm Development Team Activities

We continue to work closely with the GPM Passive Radiometer Algorithm Team to assist with Day 1 algorithm development activities. Our initial limited CloudSat/AMSR-E observational and empirical cloud property profile dataset (~30 A-Train orbits) was delivered to Dr. Chris Kummerow's research group at Colorado State University and is currently being expanded to include an entire year (~5,500 A-Train orbits) of data. This higher latitude dataset will include microphysical profiles and coincident AMSR-E brightness temperatures observations for inclusion in the GPM the Day 1 passive microwave precipitation algorithm. We will

continue working with Dr. Kummerow's group to deliver the complete updated CloudSat/AMSR-E empirical dataset over the next few months.

We also collaborated with Drs. Gail Skofronick-Jackson, Ben Johnson, and Joe Munchak from NASA Goddard Space Flight Center on mutually interesting research topics related to microwave remote sensing. Dr. Munchak visited UW-Madison for two weeks and performed initial work using coincident CloudSat-TRMM observations. Further collaborative work is planned using the Wakasa Bay triple-frequency dataset for GPM-related combined active/passive snowfall retrieval testing purposes.

3. International Workshop on Space-based Snowfall Measurement

PI R. Bennartz served as the lead program committee member for the 3rd International Workshop on Space-based Snowfall Measurement (IWSSM) held in Grainau, Germany in March 2011. The IWSSM was jointly sponsored by the International Precipitation Working Group (IPWG), the GEWEX Radiation Panel (GRP), NASA's CloudSat Mission, and NASA's Precipitation Measurement Missions (PMM) Program. The IWSSM built upon the success of previous workshops and served as an excellent venue for the snowfall measurement community to discuss both the current state of the science related to space-based snowfall measurements. Over 50 attendees with diverse scientific backgrounds convened to formulate high-level recommendations that will guide future space-based snowfall remote sensing efforts.

4. Overview Poster – PMM Science Team Meeting 2011 (Denver, CO)



Observed Triple Frequency Radar Reflectivity Signatures of Snowflakes

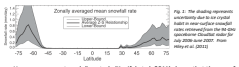
Ralf Bennartz, Michael J. Hiley, Mark S. Kulie, Stefan Kneifel, and Simone Tanelli

Department of Atmospheric and Oceanic Sciences, University of Wisconsin-Madison / Universitat zu Köln / NASA JPL

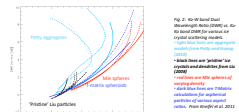


Introduction

- The ability to quantify frozen precipitation globally is key to our understanding of hydrological cycles, ice sheet balances, and changes in precipitation patterns due to climate change. Also, Ice Water Content (IWC) is one of the most uncertain variables in current Global Climate Model simulations.
- However, current radar-based retrieval methods of snowsize and IWC are subject to a wide range of uncertainties due to variability in particle size distributions, mass-size relations, particle fall speeds, and ice crystal habits (identical, various types of protuberant crystals, aggregates, etc.).
- This poster will focus on uncertainty in retrieved quantities due to differing backscatter properties of different ice crystal habits. As shown in Fig. 1, this is currently one of the most significant sources of uncertainty in CloudSat surface snowsize retrievals.

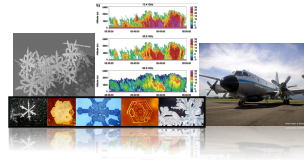


- However, a recent modeling study (Hou et al. 2011) shows that the use of three radar frequencies could be potentially useful in differentiating between ice crystal habits.
- In particular, some of the best scattering models of aggregated snowflakes (Petty and Huang 2012) show very distinct behavior in 'triple-frequency space' (Fig. 2, green lines). This could allow for a significant reduction in uncertainty because appropriate ice crystal scattering models could be selected a priori for each retrieval.
- The goal of the current work is to compare these modeling results with aircraft radar observations to test their validity and utility.



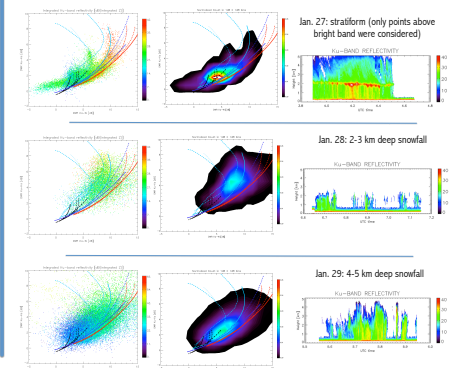
Methodology

- Aircraft based radar observations from the 2003 NASA Wabesa Bay field campaign will be used as the observational dataset to compare to the modeling results of Fig. 2.
- The Wabesa Bay dataset is uniquely applicable to this purpose because coincident radar observations are available at all three frequencies shown in Fig. 2 (Ku, Ka, and W) and a wide range of snowfall cases were observed.
- For DWR calculations, the Ku/Ka band data from the Airborne Precipitation Radar (APR) had to first be collocated with W-band data from the Airborne Cloud Radar (ACR). Additionally, simple linear smoothing was applied to the APR observations before collocation to account for differing beamwidths and vertical resolutions.
- Though both radars were located on the same aircraft, we believe differences in beam resolution and imperfect collocation are the cause of much of the noise in our results.
- W-band radars are subject to significant attenuation, particularly due to liquid water. However, at high IWC, attenuation due to snowflakes alone can become significant as well. To account for this, we developed relationships between Ku-band integrated reflectivity (simply the sum of radar reflectivity values above a given radar bin) and W-band attenuation for the various retrieval models shown in Fig. 2. Though attenuation correction itself is subject to uncertainties in ice particle habit, the results shown in the remainder of the poster will use the attenuation relationships developed from the retrieval in (2008) particles; this effectively represents an 'upper-bound' on attenuation correction. Note supercooled liquid water is not accounted for!



Results

- Results are broken down into three different days of observations, as each of these days was found to roughly represent a distinct 'category' of precipitation. Data from Jan. 27 were primarily made up of uniform stratiform rainfall with a clearly identifiable bright band, Jan. 28 was primarily shallow, convective snowfall (2-3 km), and Jan. 29 was primarily deeper convective snowfall (4-5 km).
- For each case, three plots are shown: (1) a scatter plot showing each data point compared to scattering models shown in Fig. 2, (2) a 2D histogram of the scatter plot where the coloring represents the density of points in a 108 x 108 bin, and (3) a representative section of Ku-band reflectivity to give an idea of the type of precipitation being considered for each case.
- On the scatter plots, each point is colored by integrated reflectivity. This is useful for 2 reasons: (1) it gives a rough idea of the distance of that volume of air from cloud top (i.e. warm colors are further from cloud top and vice versa) and (2) it represents how strongly that point is affected by the W-band attenuation correction scheme described earlier (warmer points are more affected by attenuation correction).



Discussion

- Distinct behavior is present in each group of results. The Jan. 27 group has a large tail/area at low DWR (where particles aren't well separated) but then has two separate peaks that follow the aggregate models. The Jan. 28 group, by comparison, has a tail/area in the space only occupied by aggregate models, suggesting this snowfall event was dominated by aggregates. The Jan. 29 group has a large number of data points both in the low DWR region occupied by all models and the region occupied only by aggregates.
- The Jan. 27 group in particular shows a significant number of points in negative DWR space which cannot be explained by any scattering model. This is probably a remaining quality control issue and will likely be solved in future work.

Conclusions

- These results are further evidence (see, e.g. Kulie et al 2010) of the inability of Mie spheres to realistically represent the scattering properties of actual snowflakes.
- In addition, this work suggests that the aggregate models of Petty and Huang (2012) are not only realistic but necessary to explain the results shown here. In all cases a significant number of data points appear in the region occupied only by aggregate models.
- These results also suggest that aggregate models may be the best 'default' choice of scattering model, especially at high values of DWR.
- We need more scattering models of aggregated snowflakes! The results of Petty and Huang (2012) are only a start.
- We also need more triple-frequency observations of snowfall. The Wabesa Bay dataset provides some diversity in snowfall observations but is clearly very limited due to the mid-latitude location and short time frame.

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Contact Information

bennartz@aos.wisc.edu

5. Presentations and Posters

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