Second Year Progress Report

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

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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

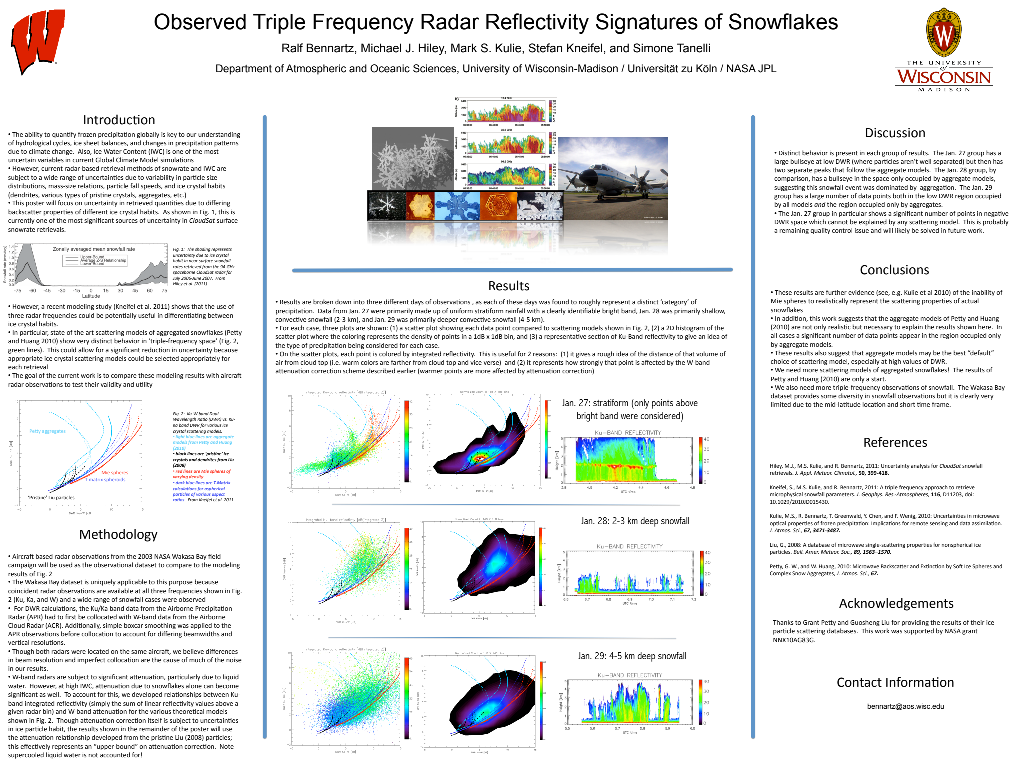
We continue to work closely with the GPM Passive Radiometer Algorithm Team to assist with Day 1 algorithm development activities. Our initial limited CloudSat/AMSR-E observational and empirical cloud property profile dataset (~30 A-Train orbits) was delivered to Dr. Chris Kummerow's research group at 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)



5. Presentations and Posters

Kulie, M. S., S. Kneifel, M. J. Hiley, R. Bennartz, 2011: Snowfall properties observed by ground-based cloud radars. AMS 35th Conference on Radar Meteorology, Pittsburgh, PA, 26-30 September 2011.

Hiley, M. J., M. S. Kulie, R. Bennartz, S. Kneifel, and S. Tanelli, 2011: A multi-frequency approach to retrieve microphysical snowfall parameters for current and future NASA observation systems. AMS 35th Conference on Radar Meteorology, Pittsburgh, PA, 26-30 September 2011.

Kulie, M. S., M. J. Hiley, and R. Bennartz, 2011: The sensitivity of combined multi-frequency radar and passive microwave signatures to snow microphysical modeling assumptions and implications for spaceborne snowfall retrievals. AMS 35th Conference on Radar Meteorology, Pittsburgh, PA, 26-30 September 2011.

S. Tanelli, W.- K. Tao, T. Matsui, C. Hostetler, K. S. Kuo, J. W. Hair, C. Butler, N. Niamsuwan, M. P. Johnson, J. Jacob, A. Battaglia, S. L. Durden, D. Diner, J. Martonchick, O. Kalashnikova, F. J. Turk, T. Y. Nakajima, T. S. L'Ecuyer, S. M.

Kreidenweis, G. L. Stephens, A. J. Heymsfield, D. P. Donovan, G. J. van Zadelhoff, J. T. Johnson, N. Majurec, A. Parodi, L. Liao, S. Kneifel, R. Bennartz, M. S. Kulie, G. J. Tripoli, T. Hashino, P. Kollias, W. Szyrmer, G. de Boer, S. J. Ghan, A. M. Fridlind, A. S. Ackerman, and G. Liu 2011: NASA's integrated Instrument Simulator Suite for Atmospheric Remote Sensing from spaceborne platform (ISSARS) and its role for the ACE and GPM missions. AMS 35th Conference on Radar Meteorology, Pittsburgh, PA, 26-30 September 2011.

Bennartz, R., M. J. Hiley, M. S. Kulie, S. Kneifel, and S. Tanelli, 2011: Observed triple frequency radar reflectivity signatures of snowflakes. PMM Science Team Meeting. Denver, CO, 7-11 November 2011.

Kulie, M. S., S. Kneifel, M. J. Hiley, and R. Bennartz, 2011: The sensitivity of combined passive microwave and multi-frequency radar signatures to microphysical assumptions. American Geophysical Union Fall 2011 Meeting. San Francisco, CA, 5-9 December 2011.

6. Peer-Reviewed Publications

Kneifel, S., M. S. Kulie, and R. Bennartz, 2011: A triple-frequency approach to retrieve microphysical snowfall parameters. *J. Geophys. Res.*, **116**, D11203, doi:10.1029/2010JD015430.

Hiley, M. J., M. S. Kulie, and R. Bennartz, 2011: Uncertainties in CloudSat snowfall retrievals. *J. Appl. Meteor. Clim.* **50**, 399-418.

S. DiMichele, M. Ahlgrimm, R. Forbes, M. Kulie, R. Bennartz, M. Janiskova, & P. Bauer, 2012: Interpreting an evaluation of the ECMWF global model with CloudSat observations: Ambiguities due to radar reflectivity forward operator uncertainties. *Q. J. Royal Meteor. Soc.,* In revision.

M. J. Weber, B. B. Yang, M. S. Kulie, R. Bennartz, and J. H. Booske, 2012: Atmospheric attenuation of 400 GHz radiation due to water vapor. *IEEE Trans. on Terahertz Sci. and Tech*. In revision.

Hiley, M. J., M.S. Kulie, S. Kneifel, R. Bennartz, S. Tanelli, 2012: Triple frequency radar reflectivity signatures of snow: Observations and comparisons to theoretical ice particle scattering models. In preparation.