Progress Report – Year 2 Progress Report (July 2013-June 2014)

NASA Reference #: NNX12AQ76G

Project Title: SNOWFALL FROM SPACE: A SYNERGISTIC MULTI-SENSOR STRATEGY TO IMPROVE SPACEBORNE SNOWFALL ESTIMATES USING NASA MICROWAVE SENSORS AND GROUND-BASED INSTRUMENTS

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Project Objectives

The following four primary objectives of the proposed research are outlined below:

1. **Ground-based radar and microphysical observations of snowfall.**
   A low-cost ground-based observing system comprised of a Micro Rain Radar (MRR), Snowflake Video Imager (SVI) will be deployed to increase our knowledge of near-surface radar reflectivity profiles associated with different modes of snowfall. The coincident SVI data will provide valuable sustained observations of snowflake morphology and particle size distributions (PSD) that will constrain radiative transfer modeling calculations, improve surface snowfall retrievals, and enable MRR reflectivity observations to be translated to proxy Global Precipitation Mission (GPM) Dual-frequency Precipitation Radar reflectivities for validation.

2. **Multi-frequency radar and microphysical observations of snowfall.**
   Multi-frequency radar observations will be used to study the microphysical details of snowfall events. Recent triple-frequency radar modeling results will be tested using Ku-/Ka-/W-band radar observations to determine the efficacy of idealized aggregate particle models versus simpler particle models.

3. **Microwave satellite-based snowfall studies.**
   The microwave signatures of snowfall will be studied within an active/passive modeling and observational framework. Regional snowfall distribution and accumulation studies will be undertaken using CloudSat/AMSR-E/AMSU-B/MHS datasets to demonstrate the utility and associated uncertainties of spaceborne snowfall retrievals. Special attention will be devoted to study any notable differences in the microwave signatures between dominant snowfall modes.

4. **Education/Public Outreach.**
   A comprehensive Educational/Public Outreach (E/PO) plan will be developed and implemented, including multi-year outreach efforts that expose high school students to remote sensing techniques for spaceborne snowfall estimation using NASA satellite platforms.

Year 2 Progress Report (July 2013-June 2014):

1. Research Progress

In support of this project's primary goal (ground-based radar and microphysical observations of snowfall), a Micro Rain Radar (MRR) and Precipitation Imaging Package (PIP) – an updated version of the Snowflake Video Imager – were successfully deployed at the Marquette, MI National Weather Service (NWS) Forecast Office over a two day period in January 2014. Both instruments were procured and/or developed, tested, and sent by collaborators Walt Petersen and Larry Bliven at NASA Wallops Flight Facility. Fig. 1 shows both instruments fully deployed at the Marquette, MI NWS. The deployment was preceded by a three-week testing period at the University of Wisconsin-Madison. Notable achievements during the test period were the construction of a custom-made PIP support/frame system that elevated the PIP equipment above the significant snowpack at Marquette, MI (Fig. 1). This deployment coincided with one of the coldest, snowiest winters in the past two decades, so valuable snowfall data was collected from mid-January through May. Due to valuable support from the Marquette, MI NWS staff - especially Science and Operations Officer Michael Dutter - no major technical difficulties were encountered during the data collection period. The MRR operated without any notable interruptions, while the PIP required only minor camera alignment adjustments during the end of the winter season.

The dataset has been continually transferred to a University of Wisconsin-Madison archive throughout the winter season and is available for distribution to interested investigators. The data will also be transferred to a NASA archive facility in the coming months. Preliminary data analyses will commence within our research group by late summer and will focus on microphysical differences (e.g., particle size distribution) between synoptic (deeper snow-producing clouds) and lake-effect (shallower, convective snow-producing clouds) snow cases that are indicated by both the MRR and NWS operational radar. Follow-on studies will highlight combined observational-modeling studies using the dataset, as well as case studies of Global Precipitation Measurement (GPM) satellite overpasses near the site.

FIG 1: Micro Rain Radar (left and center) and Precipitation Imaging Package (right) deployment at the Marquette, MI National Weather Service Forecast Office during January 2014.

Sample PIP data from a snowfall event on 8 March, 2014 are shown in Fig. 2. This schematic illustrates valuable microphysical information (e.g., particle size distribution evolution throughout the day, precipitation rate, daily averaged particle size distribution, and daily averaged particle fall velocity) that will be used in both observational and modeling studies.

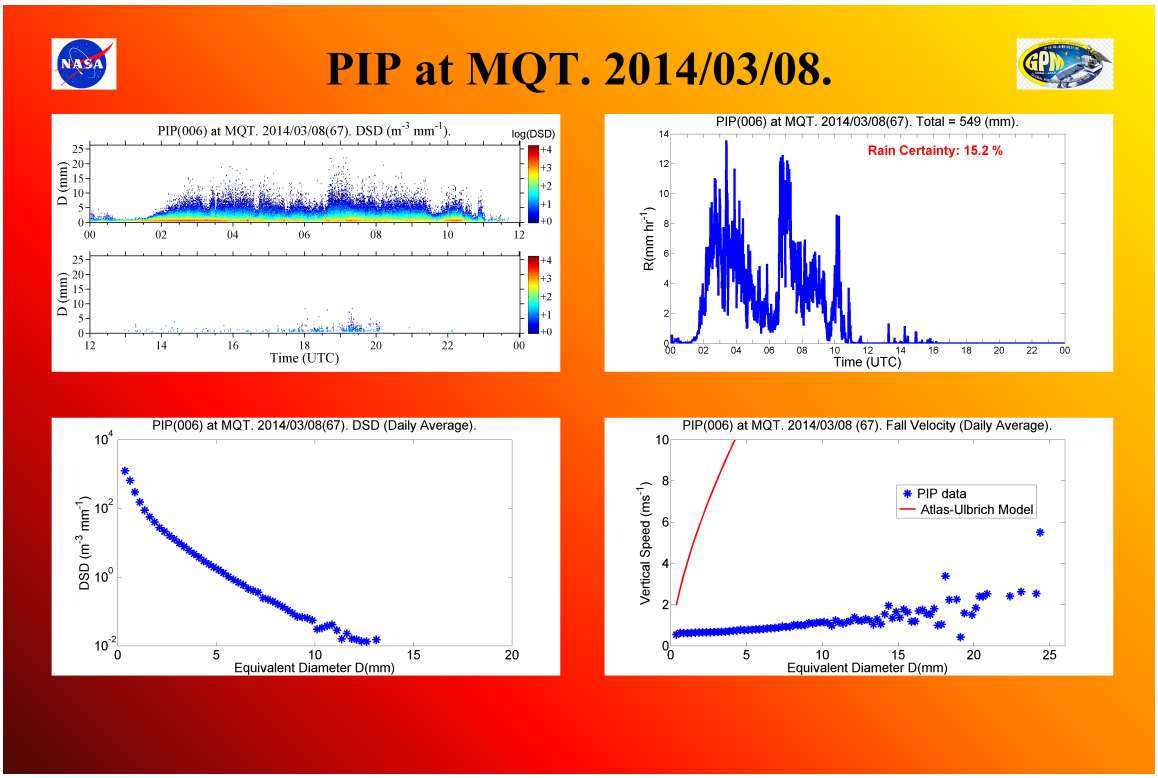

FIG 2: Snow microphysical information derived from the Precipitation Imaging Package for a snowfall event on 8 March, 2014. Fields shown are particle size distribution throughout the day (upper left), precipitation rate (upper right), daily averaged particle size distribution (lower left), and daily averaged particle fall velocity (lower right). Image courtesy of Larry Bliven.

In addition to the instrument deployment, the following progress has been made on project-related research tasks:

- Per objective #2 outlined in the previous section, a multi-frequency radar analysis has been finalized using an airborne dataset from the NASA-sponsored Wakasa Bay field campaign to assess the *Kneifel et al. (2011)* modeling results and highlight similar distinctive features between radar modeling and observational results. Results from this analysis were accepted for publication as *Kulie at el. (2014)* to the Journal of Applied Meteorology and Climatology.

- Per objective #2 outlined in the previous section, combined active/passive simulations were performed by a graduate student (Claire Pettersen) through NIP funding using surface data from Summit Station at Greenland. These simulations are an important analog to similar spaceborne studies and will further clarify what

non-spherical ice models produce realistic signatures from a combined radar/radiometer perspective. These results are especially important to improve microwave snowfall retrievals over remote regions like the Greenland Ice Sheet. Preliminary results from this study were presented at the upcoming American Geophysical Union Fall Meeting in December 2013. Final results from this study were compiled in C. Pettersen's Master's Thesis (Pettersen 2014) and will be submitted for peer-reviewed publication in the near future.

- Per objective #3 outline above, improvements to a combined active and passive microwave dataset containing CloudSat, AMSR-E, and MHS observations continue to be actively incorporated for Global Precipitation Measurement (GPM) Radiometer Algorithm Team purposes. End-to-end code to bin these combined radar-radiometer observations by skin temperature, precipitable water vapor amount, and surface emissivity class to conform to the Goddard Profiling (GPROF) algorithm environment was also developed. Furthermore, all profiles in this 5-year database were matched with numerical model-generated profiles based on a unique set of observational-modeling matching criteria that considered both radiometer and radar properties in the matching procedure. This updated higher latitude dataset was integrated into the GPM the Day 1 passive microwave precipitation algorithm. A newly enrolled graduate student (Marian Mateling) is currently utilizing this dataset to explore passive microwave signatures of different snowfall events.

- Per objective #3 outlined above, global snowfall partitioning studies between different snowfall modes from a microwave remote sensing standpoint studies were undertaken with the aforementioned 5-year combined CloudSat/AMSR-E/MHS dataset. These results will help improve our understanding of regional differences in snowfall modes (e.g., shallow versus deeper, synoptically driven snow) and will help hone microwave-based snowfall retrievals for these distinctive snowfall types. Results from this study are currently being incorporated into a manuscript and were presented by the PI at the American Meteorological Society's 36th Conference on Radar Meteorology. Sample slides from this presentation are shown below.

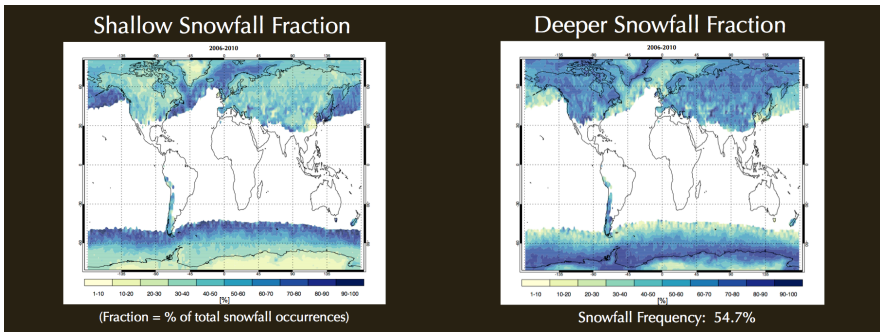

Fig. 1: CloudSat-derived snowfall fraction for shallow versus deeper snowfall modes for the 2006-2010 time period.

- Per objective #3 outlined above, collaborative work with the University of Illinois was undertaken to assess satellite-based microwave snowfall retrievals in complex terrain. Initial results from this collaborative project will be presented at the upcoming AGU Fall Meeting.

2. Education/Public Outreach Activities

Education/public outreach at Westwood High School (a rural Michigan high school located near the Marquette, MI NWS Forecast Office). The PI visited Westwood High School in May 2014 and was a guest lecturer in Ms. Julie Luehmann's Earth Science and Advanced Chemistry classes. Topics covered included the role of NASA missions (e.g., GPM and CloudSat) to measure global precipitation, the key role of snowfall in the global hydrological cycle, and the role that Westwood High School students will play during the 2014-2015 academic year. A year-long outreach project will commence in September, 2014 with Westwood High School. This project will employ Earth Science students to make snowfall accumulation measurements for the entire winter. Students will also log weather conditions and take pictures of the weather/sky cover during GPM overpasses in close proximity to the school. Links to the NASA Global Precipitation Measurement (GPM) will be highlighted during in-class visits by the project PI during early winter of 2014. We are also actively recruiting more schools to join the snowfall measurement activities in the hopes of developing a larger network of active high school participants.

The PI also participated in the UW-Madison Cooperative Institute for Meteorological Satellite Studies (CIMSS) Student Workshop in late June 2014 (http://cimss.ssec.wisc.edu/studentworkshop). The PI led a session on precipitation remote sensing and forecasting that highlighted numerous NASA missions (e.g., TRMM, GPM, CloudSat). This workshop immerses high school students in a week-long learning journey in topics related to meteorology, astronomy, land remote sensing and geology. The PI will actively recruit students from our outreach high schools to participate in this workshop during the summer of 2015. "Scholarships" to defray the cost of attending the workshop will also be offered to two students.

The PI also held an outreach session at Glacier Creek Middle School in Middleton, WI as part of a career-oriented series of guest lectures for 8th graders. The PI presented NASA-related material related to satellite-based snowfall estimates over Greenland.

3. Project-related Presentations and Posters

Kulie, M. S., N. B. Wood, T. S. L'Ecuyer, and R. Bennartz, 2013: Global snowfall partitioning studies using CloudSat observations. AMS 36th Conf. on Radar Meteorology. Breckenridge, CO, 16-20 September 2013.

Nesbitt, S. W., G. Duffy, G. McFarquhar, M. Kulie, C. V. Chandra, P. Kollias, S. Tanelli, W. A. Petersen, and A. Tokay, 2013: Quantifying snowfall scattering and microphysical properties from the Global Precipitation Mission Cold season Precipitation Experiment (GCPEx). AMS 36th Conf. on Radar Meteorology. Breckenridge, CO, 16-20 September 2013.

Pettersen, C., R. Bennartz, M. Kulie, M. Shupe, D. Turner, and V. Walden, 2013: Case study of mixed-phase to ice precipitation in the Arctic. AGU Fall Meeting. San Francisco, CA, 9-13 December 2013.

Reed, K., S. Nesbitt, M. Kulie, T. L'Ecuyer, and N. Wood, 2013: An evaluation of satellite retrievals of snowfall in region of complex terrain. AGU Fall Meeting. San Francisco, CA, 9-13 December 2013.

4. Project-related Peer-Reviewed Publications

Kulie, M. S., M. J. Hiley, S. Kneifel, R. Bennartz, S. Tanelli, 2014: Triple frequency radar reflectivity signatures of snow: Observations and comparisons to theoretical ice particle scattering models. *J. Appl. Meteor. Clim*. **53**, 1080-1098.

Kulie, M. S., N. B. Wood, T. S. L'Ecuyer, and R. Bennartz, 2013: Global snowfall partitioning studies using CloudSat observations. *In preparation*.

Pettersen, C., 2014: Identifying ice hydrometeor signatures above Summit, Greenland using a multi-instrument approach. University of Wisconsin-Madison, Madison, WI. 56 pp.

5. Project-related Graduate Education

Master's Degree Conferred (May 2014): C. Pettersen
Master's Student Enrolled (June 2014): Marian Mateling

6. References

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.

Kulie, M. S., R. Bennartz, T. Greenwald, Y. Chen, and F. Weng, 2010: Uncertainties in microwave optical properties of frozen precipitation: Implications for remote sensing and data assimilation. *J. Atmos. Sci.* **67**, 3471-3487.