Year 3 (July 1, 2009 – June 1, 2010) Progress Report:

Improved Microwave Precipitation Retrieval over Land from TRMM through GPM Era

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Project Summary and Objectives

If the Global Precipitation Measurement Mission (GPM) is to meet its requirement of global 3-hourly precipitation, the use of sounders such as AMSU will likely be needed. This project utilizes the "traditional" imager channels in conjunction with high frequency observations from AMSU and SSMIS, cloud resolving models and advanced radiative transfer models to:

(1) Study the effects of hydrometeors on the 10-183 GHz radiances and utilize them to improve the current Bayesian precipitation retrieval scheme (e.g., GPROF). Focus will be on cold season precipitation systems (e.g., stratiform rain and snowfall) since the present scheme has focused only on tropical rainfall systems.

(2) Investigate the potential of incorporating microwave sounding channels (50-60 GHz and 183 GHz) to the hydrometeor profile retrieval.

(3) Improve the current GPROF "surface screening" to remove ambiguity between precipitation and other surface signatures that resemble precipitation through the use of innovative methods such as dynamic land surface data sets available from ancillary data sets (i.e., NWP assimilation fields, emerging emissivity products, etc.).

Year 3 Progress

Some of the key scientific questions addressed during the third year and final year of this project include:

- Is there a way to improve upon the warm season bias in the current TRMM 2A12 rainfall over land product?

- Are there ways to better characterize the land surface within the satellite FOV?

- Can we detect light rain and snowfall signals over land from satellite measurements?

- If so, what are the characteristics of these precipitation systems and what will we be able to measure with PMM/GPM from space?

Fundamental to these questions are some other key issues to consider:

- What are the deficiencies in the current 2A12 rain over land algorithm?

- What are the microphysical properties of snow (size, density, shape, and number) to radiative properties (scattering and absorption)?

- What is the best method to obtain information on the highly variable land surface emissivity under precipitating situations?

Three main focus areas were addressed over the past year and are summarized below.

Improved TRMM 2A12 Rain Over Land

TRMM products are currently in the sixth version (V6); a release of V7 products is now scheduled for sometime in 2011 (this is nearly a year delay from the original plan, mostly due to repeated issues with convergence on the PR set of algorithms). We are the focal points for the TMI rain over land product, part of the "2A12" level 2 products. We have essentially completed an upgrade to V7 2A12 by reducing a warm season bias in the rain over land part of the product.

It was discovered that one of the main culprits in this bias is in the convective-stratiform (CSI) separation. Additionally, the TB to rain rate relationships were not robust. The new algorithm, created from nearly 10-years of TMI and PR matchups, abandons the cloud resolving model data base and simply uses an improved CSI and TB to RR relationship. It has been delivered to

NASA where it is undergoing testing. The figure below summarizes the TMI – PR biases (current – top; new- bottom) based on the entire TRMM record. As can be seen, the warm season bias has been substantially reduced. Remaining biases are partially attributed to inadequate land surface screening which we are starting to address (next section). The results have been summarized in a paper by Gopolan et al. (2010).

TMI v6 - PR bias (mm/month)

TMI regression - PR bias (mm/month)
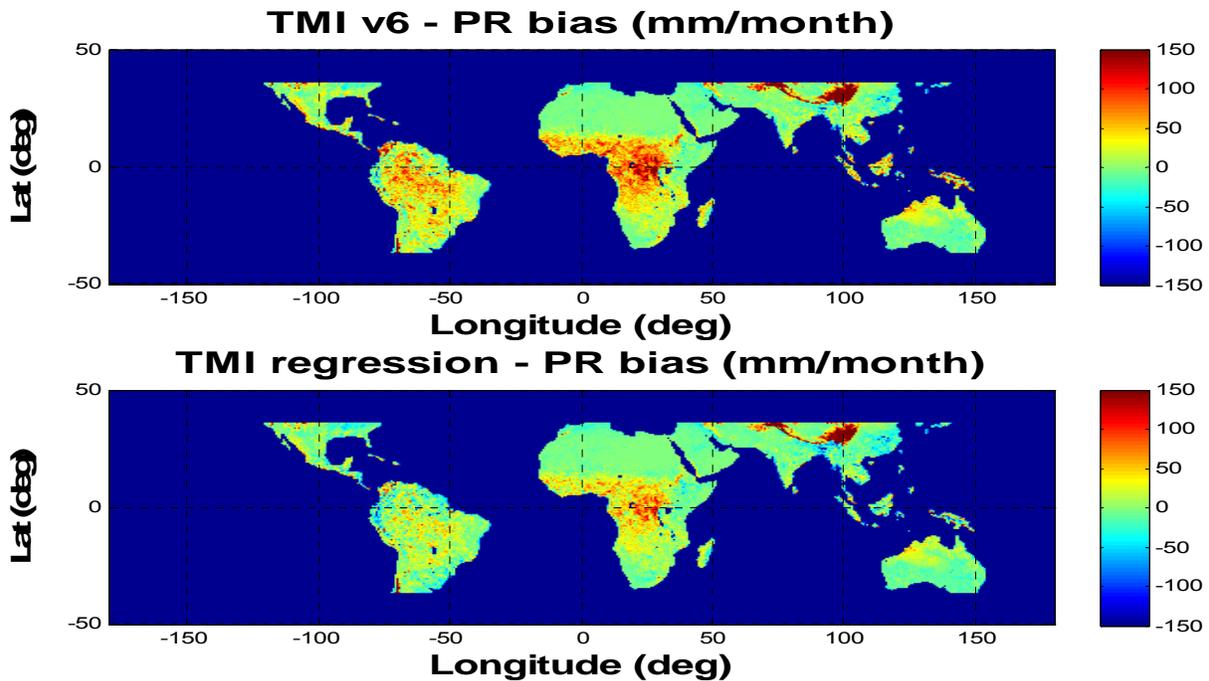
One remaining caveat: the new algorithm was tuned with the V6 PR product; the V7 PR product potentially will be different, thus, we will likely perform a final retuning of our V7 when the V7 PR product is finalized in late 2010. We do not anticipate a very large change in the retuned product, but we are obligated to perform this additionally effort to ensure that the entire TRMM V7 product suite is indeed an improvement over V6.

Surface Characterization

The PMM Science Team has several working groups that support the algorithm teams. We continue to co-lead "The Land Surface Characterization Working Group" (LSWG). The LSWG meets quarterly over the phone and also in person at the PMM annual meetings (most recently in October 2009 in Salt Lake City, UT). We are making excellent progress on an emissivity

intercomparison effort that is now involving nearly 20 participants. Radiances from TMI, AMSU, SSMI, SSMIS and AMSR-E were extracted for 10 target areas across the globe (of varying surface characteristics, e.g., snow, desert, rain forest, etc.). Additionally, cloud mask data, NWP model fields, and land surface model parameters have also been extracted for these targets. Each participant with emissivity techniques has provided estimates for these targets and a thorough evaluation is well underway. A web set is maintained that provides both the input and output data sets (http://cics.umd.edu/~rferraro/LSWG/LSWGnew2.html). We are presently focusing on evaluating the data for three sites – Southern Great Plains (SGP); Hydrometeorology Testbed Southeast (HMT-SE) and the Cloudsat Validation Site (C3VP) in southern Canada. The figure below presents a sample of some of the results at SGP for 37 GHz over the study period and for the various emissivity data sets; a presentation will be given at the 2011 AMS Annual Meeting/Conference on Hydrology and a journal paper is being developed.
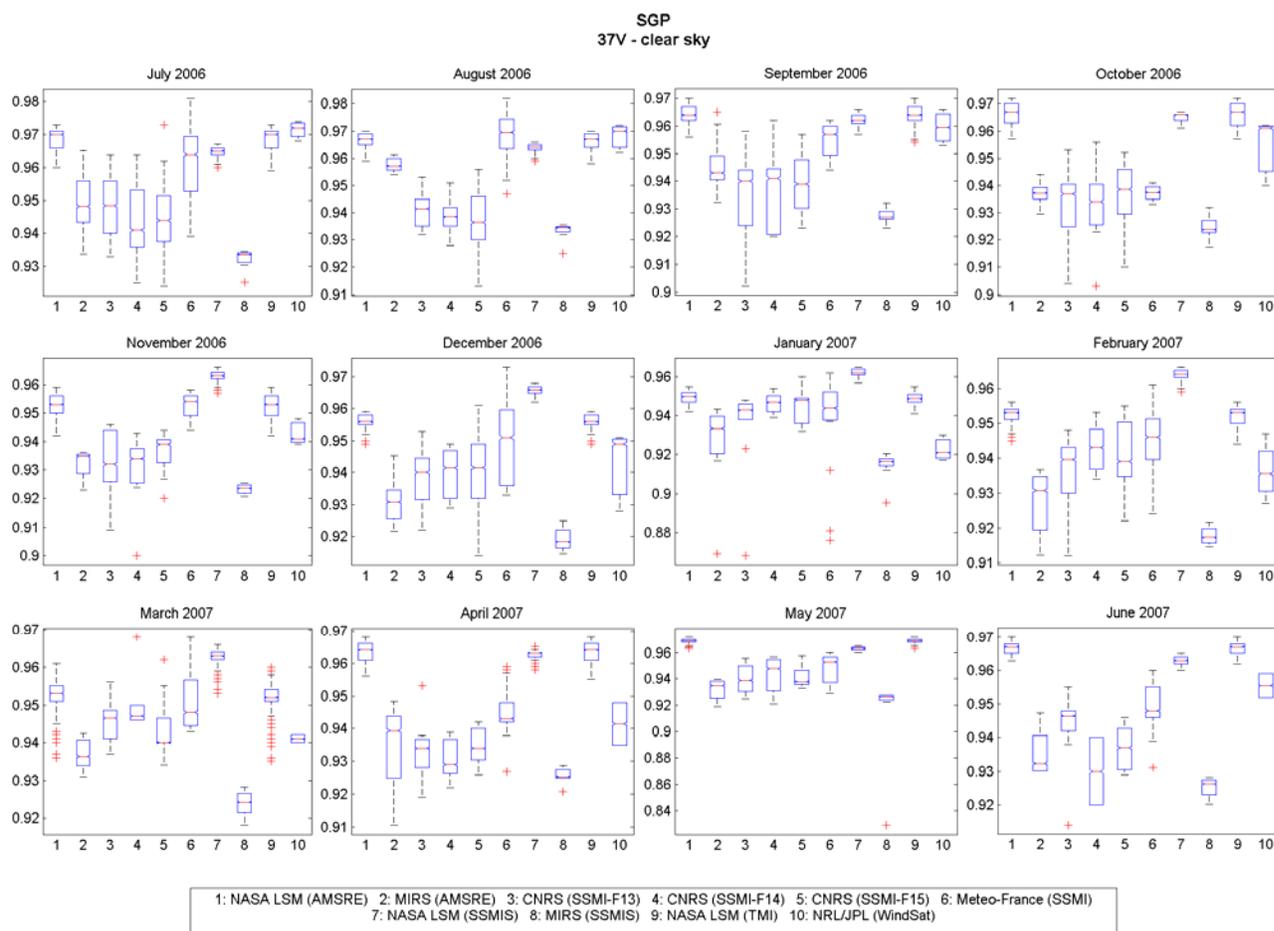
Radiative Transfer in Snowing Atmospheres

Extensive work continues on using the C3VP field campaign data to extract precipitation related parameters in snowing atmospheres that are critical to radiative transfer modeling, in particular, to frequencies at and above 85 GHz. The figures below illustrate some of these parameters and summarize how this data is being used.
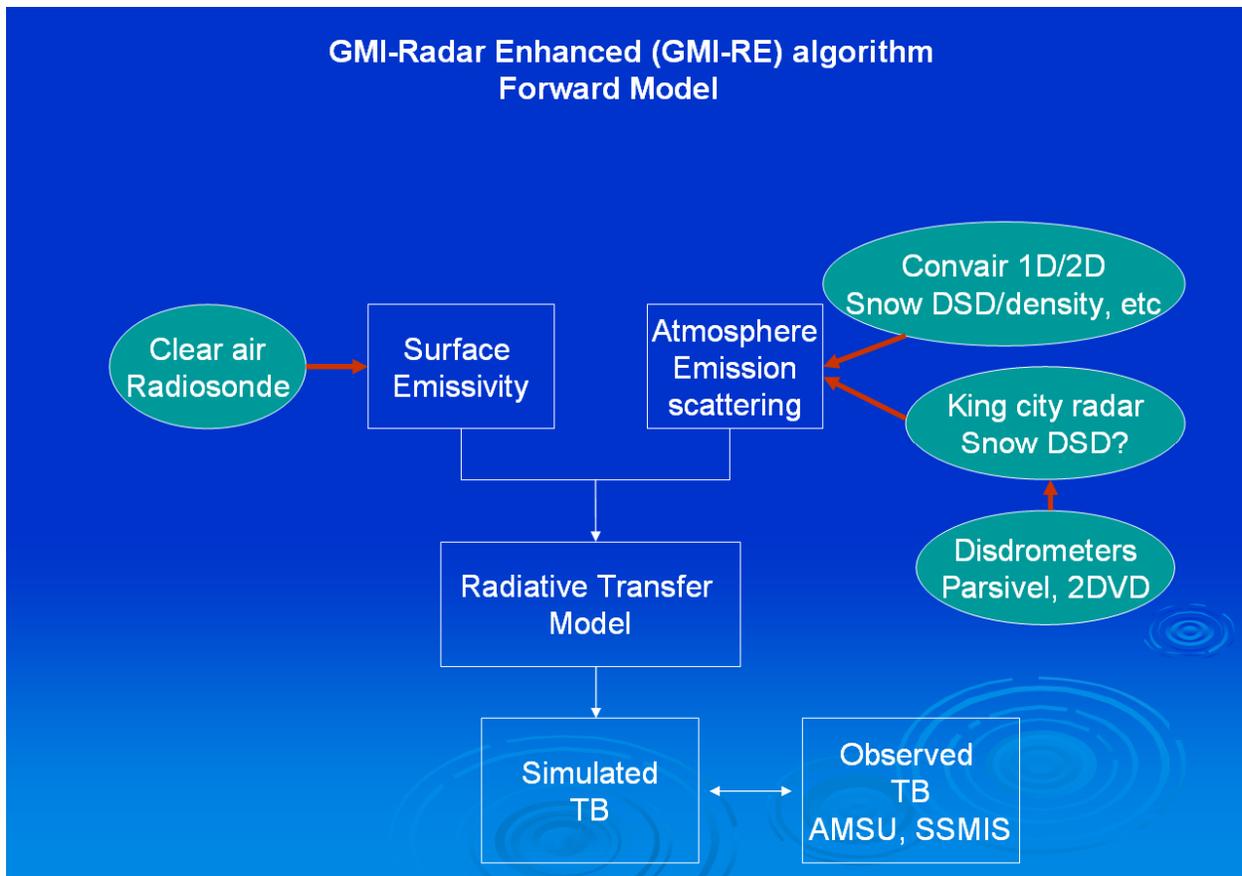
By using the GPM ground validation field campaign data in conjunction with satellite radar snowfall observation and cloud resolving model simulations, radiative transfer model simulations of AMSUB/MHS high frequency brightness temperatures (at and above 89 GHz) are performed with the assumption of spherical and non-spherical snow particles. These satellite simulations are validated with real AMSUB/MHS observations.
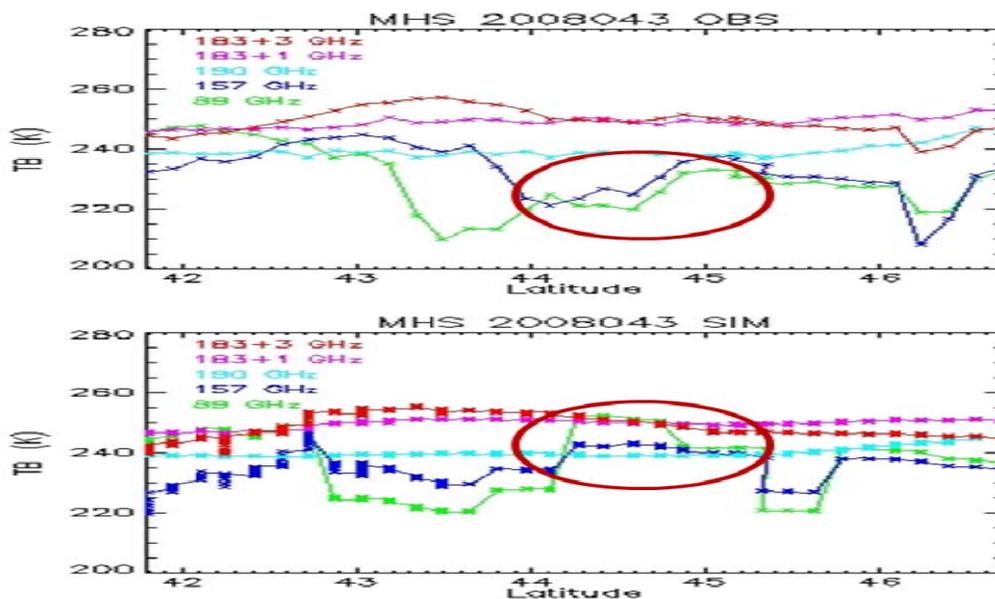
The latest radiative transfer simulations can be explained with a two-step process. The first step is to find the best matched reflectivity profile with CloudSat reflectivity observations using a non-spherical snow particles scattering model developed by Liu (2004). The next figure shows the CloudSat reflectivity observations of a snowfall event on January 12, 2008 and the retrieved reflectivity profiles. These reflectivity profiles are retrieved by using a non-spherical snow scattering model for 10 different snow particle habits (Liu, 2004) and assuming the snow particle size distribution follows a Gamma distribution $N(D) = N_0 D^m exp(- D)$. The computed reflectivity that best matches the CloudSat observed reflectivity (after attenuation correction) is selected and their shape factor (m) and snow particle habit are saved for the radiometer brightness temperature simulations. The reflectivity vertical profiles and their associated particle shape factor and particle habit are served as the basis for the near-coincident passive radiometer high frequency radiative transfer simulations.
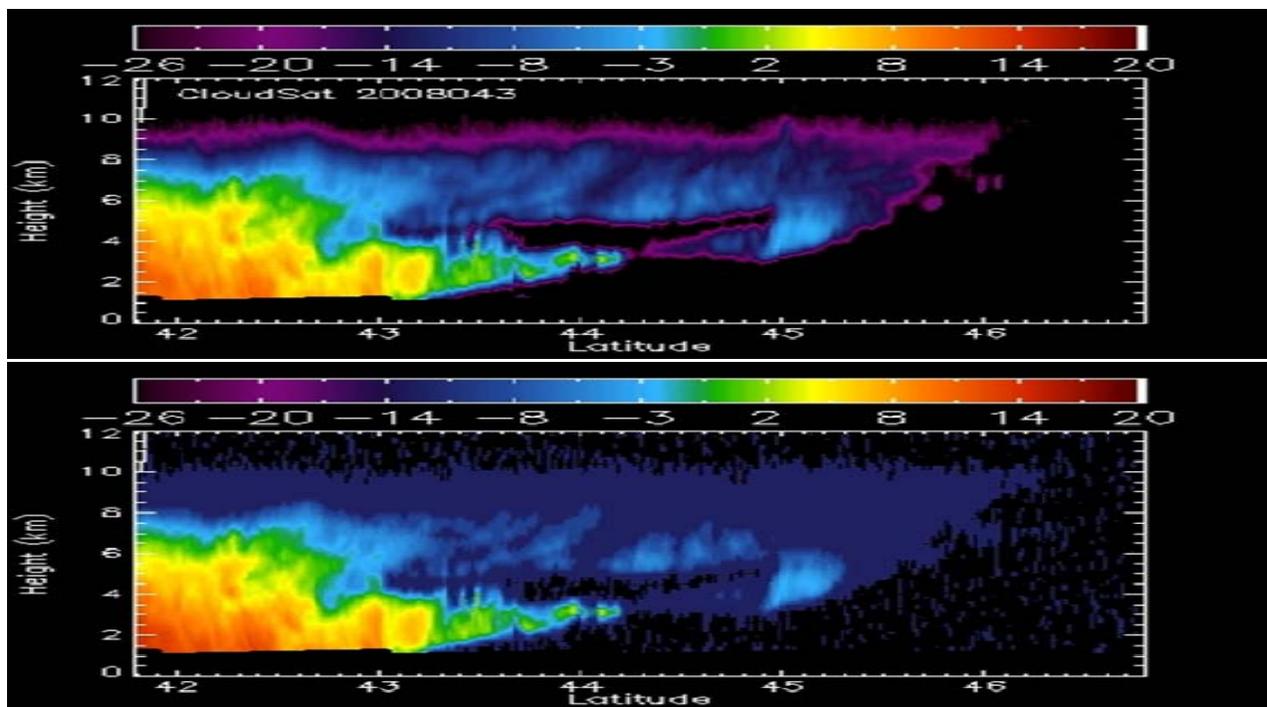
The upper panel shows the CloudSat observations of a snow storm on Febuary 12, 2008, and the lower panel shows the retrived reflectivity profiles.

Next, a passive microwave radiative transfer solver SOI is used in conjunction with the CloudSat retrieved vertical profiles of snow hydrometeor size distribution and shape, ECMWF water vapor and temperature profiles, and the passive microwave brightness temperatures derived

surface emissivity, to simulate the AMSUB/MHS brightness temperatures during snowing condition. The next figure shows the observed (top) and simulated (bottom) MHS brightness temperatures for 89, 157, 183 +-1, 183+-3, and 183+-8 GHz on February 12, 2008. The water vapor sounding channels of 183+-1, 183+-3, and 190 GHz are mostly sensitive to the atmosphere effect and are all within 10 degrees Kelvin (the majority are within 5 degrees Kelvin) of discrepancy between observed and simulated brightness temperatures. The window channels of 89 and 157 GHz are very sensitive to both the surface and atmosphere, particularly the 89 GHz. The differences between the observed and simulated brightness temperatures for these window channels are generally within 15 Kelvin.   The differences are particularly significant at the pixels where part of the field of view is over small lakes and water body where the satellite land/sea tag fails to identify water within the land pixel, as is circled by the red circle in the plot. The emissivity for the water/land mixed pixel is highly sensitive to the freeze/thaw/dry/wet condition and the portion of water body within the FOV for the emissivity estimate and the simulation pixel might be different.   Future activity to incorporate high resolution land/water map will be helpful to screen out this problem.

The upper panel shows the MHS observations at the almost co-incident (within 15 minutes and 25 KM) CloudSat observation at the previous plot. The lower panel is the radiative transfer model simulations of the MHS measurements using CloudSat derived snow size distribution and shape, ECMWF water vapor/temperature profiles and MHS derived emissivity.

This tedious effort is finally starting to pay dividends, as our simulations are starting to get closer to the actual satellite measurements. The residual differences are being investigated but are most likely attributed to errors in the water vapor profiles and surface emissivity used. Once we are confident in the model is working properly, a larger set of simulations can be generated using other input such as NWP model fields.

Relevant Meetings Attended

- 8th International GPM Planning Workshop (Paris, France; June 2009)
- 2nd Workshop on Land Surface Modeling and Remote Sensing (Toulouse, France; June 2009)
- GPCP Working Group on Data Management (College Park, MD; September 2009)
- 2009 PMM Science Team Meeting (Salt Lake City, UT; October 2009)
- 3rd CEOS Precipitation Constellation Meeting (Salt Lake City, UT; October 2009)
- AGU Annual Fall Meeting (San Francisco, CA; December 2010)
- 17th International TOVS Science Conference (Monterey, CA; April 2010)

Collaborations

We continue to collaborate with our NOAA colleagues on the PMM Science team. This includes the production, delivery and evaluation of NOAA POES AMSU/MHS based L2 precipitation estimates to P. Xie and R. Joyce, who use such data as input to CMORPH. Additionally, C. Williams has been extremely helpful in providing insight to the use and interpretation of the C3VP and HMT specialized radar and profiler data sets which is vital to our understanding of winter season cloud microphysical processes. We also offer guidance and interpretation of TRMM L2 rainfall over land data sets to R. Kuligowski who is using such data to help calibrate his SCAMPR technique. We also work closely with new NOAA PI's on the PMM Science Team – F. Weng and S. Boukabara, in particular, on the emissivity intercomparisons study.

Our collaborations also extend out to several other members of the PMM Science Team. Rather than list individuals, participation on the following PMM working groups is noted:

- Canadian CloudSat and Calypso Validation Project (C3VP) working group

- Land surface characterization working group

- L2 algorithm working group

- Drop size distribution working group

Finally, we also participate with NASA on several extramural activities related to PMM, including various advisory panels and planning committees.

Responses to Comments from the 2010 NOAA Review Panel

1. **Make available to the other NOAA PI's the improved surface classification map/scheme**
We are working closely with Chris Kummerow's team at Colorado State Univ. and Christa-Peters Lidard's team at NASA/GSFC on developing a final scheme; once this is completed later in 2011, we will make this information available to the entire PMM Science Team.

2. **For future algorithm upgrades, the improved radar products need to be developed PRIOR TO the improved passive MW algorithms**
We totally agree! Subsequent to this review, we learned at the 2010 PMM Science Team Meeting (October 2010) that JAXA continues to "tinker" with the V7 PR algorithm. Several other PI's on the team urged that the PR upgrades need to be done PRIOR TO the TMI upgrades in the future.

3. **What is needed to better validate the snowfall retrievals?**
We need information on both the cloud microphysical information and atmospheric profiles to validate the radiative transfer simulations. We also need ground information on the the snowfall rates and the snowfall shapes/distributions to test the sensitivity to the model to these parameters.

4. **What can be done to help validate the land surface type information?**
We are working more closely with new members of the PMM Science Team who focus on particular surface types; we expect through the PMM LSWG that a highly accurate method to characterize the land surface information for GPM-era algorithms will be ready for GPM core satellite launch (2013).

5. **Closer synergy with Boukabara, Williams, Weng and Xie is encouraged.**
We agree and we are already moving in this area.

Upcoming Plans

As we use up the remaining funds from the initial 3-year project, we will begin to focus on activities from the newly awarded 3-year project "Land Surface Characterization for GPM-era Algorithms". This is essentially a continuity project, but with more emphasis on regime based database development for the GPM radiometer constellation over land. Over the upcoming year, we plan to:

- Complete the development of the radiative transfer model under snowing conditions through the continued use of SSMIS, AMSU, CV3P and HMT-West data and publish the results in a journal article.
- Continue to co-lead the activities of the Land Surface Working Group:
  - Organize and hold quarterly meetings
  - Complete the initial emissivity study and publish results in a journal quality paper
  - Coordinate the delivery of emissivity databases and access routines to PMM algorithm teams
  - Perform sensitivity studies with various treatment of emissivity information for various TMI, AMSR-E and AMSU case studies through collaboration with T. Matsui (GSFC) who is the lead for the GPM Satellite Simulator.
- Develop and test "self similar" surface data sets within the Bayesian retrieval framework
- Participate on the various PMM working groups, special PMM meetings, etc.
- Attend various GPM and TRMM related meetings (e.g., GPM PPS Design Reviews; PMM Science Team Meeting 2010; 17th AMS Satellite Meteorology Conference; AGU 2010; AMS 2011; 9th International GPM Planning Workshop 2011).

Publications and Presentations

Ferraro, R.R. and co-authors, 2009: Land surface emissivity for precipitation retrieval in the GPM-era, *2nd Workshop on Remote Sensing and Modeling of Surface Properties, Toulouse, France, June 2009.*

Ferraro, R.R., N-Y. Wang, K. Gopalan and A. Sudradjat, 2009: Progress towards improved precipitation retrieval over land in TRMM and GPM era. *2009 PMM Science Team Meeting, Salt Lake City, UT; October 2009.*

Ferraro, R.R., S. Boukabara, F. Weng and N-Y. Wang, 2010: Utilization of land surface emissivity for precipitation retrieval – an obvious linkage between ITWG and IPWG – an implications for GPM-era algorithms. *17th ITSC, Pacific Grove, CA, April 2010.*

Gopolan, K., N-Y. Wang, R. Ferraro and C. Liu, 2009: Status of the TRMM 2A12 Land Precipitation Algorithm. *J. Atmos. Ocean. Tech*., **27**, 1343 – 1354.

Wang, N-Y., R. Ferraro, C. Liu, D. Wolff, E. Zipser and C. Kummerow, 2009: The TRMM 2A12 land precipitation product – status and future plans. *Journal of the Meteorological Society of Japan,* **87***,* 237-253.

Wang, N-Y., K. Gopalan and R. Ferraro, 2009: Improvement of cold season land precipitation retrievals through the use of WRF simulation and high frequency microwave radiative transfer. *2010 AGU Annual Meeting, San Francisco, CA, December 2010.*

BUDGET SUMMARY (all numbers presented are in K)

Improved Microwave Precipitation over Land from TRMM through GPM Era

R. Ferraro and N. Wang

For period from July 1, 2007 – June 30, 2010

	Year 1	Year 2	Year 3[1]
Direct Labor	0	0	0
Grant to CICS/Univ. MD[2]	135	139	140
NOAA Equipment & Supplies	0	0	0
NOAA Travel[3]	2.7	5.4	9.1
STAR Tax (5%)	7.3	7.6	7.9
Total Costs	**145**	**152**	**157**

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[1] Remaining Year 3 support will expire at the end of 2010
[2] Funding supports Co-PI Nai-Yu Wang in Year 1, Nai-Yu Wang and Kaushik Gopolan beginning in Year 2.
[3] Supports Co-PI Ferraro for travel to PMM Science Team meeting and other relevant GPM/TRMM meetings