Validation and Enhancement of AMSR-E Cloud and Precipitation Products

2004 Progress and Planned Research

Our research project on AMSR-E cloud and precipitation products has been progressing in both cloud and precipitation areas. Last year, our list of planned research activities included five elements:

1. Submit ACR data from Wakasa Bay to the DAAC
2. Perform cloud liquid and ice water content retrievals (where the retrieval algorithms are valid), either from radar alone or in combination with Aqua-MODIS overpasses. Compare results to AMSR retrievals.
3. Perform retrievals of light (liquid) precipitation, either from radar alone or in combination with PSR data or Aqua overpasses. Compare results to AMSR retrievals.
4. Study the transition from ice to mixed phase to liquid and from liquid cloud to drizzle to light precipitation, and the consequent ranges of validity of the various cloud and precipitation retrievals
5. Perform preliminary retrievals on snow

We have accomplished or made progress in four of these areas (1, 2, 3, and 5). Current progress in these areas is described in the following sections.

1. Significance of Research to EOS Validation

We have identified a significant bias in the TRMM TMI liquid water path product (refer to discussion below) and expect this bias to extend to the AMSR-E LWP product. We propose to quantify these biases in AMSR-E more fully and to begin a collaboration with the algorithm developer to address these problems.

The Wakasa Bay experiment was directed at validating the AMSR-E precipitation algorithm, with emphasis on cold precipitation processes. We have not yet finalized comparison procedures utilizing Airborne Cloud Radar data but expect to do so within the coming months. This will facilitate validation of (1) light liquid precipitation rates and microphysics, and (2) snowfall products. Specifically, we plan to investigate sources of bias in the AMSR-E rainfall algorithm though physical validation of implicit assumptions such as freezing level, sub-pixel variability, and hydrometeor profiles.

2. Airborne Cloud Radar data from the Wakasa Bay Experiment

The Wakasa Bay experiment was conducted over the Sea of Japan, the Japanese Islands, and the Western Pacific Ocean from 6 January to 14 February 2003. The experiment featured flights by the NASA P-3 Orion aircraft carrying several remote sensing instruments. Our participation in the experiment was chiefly tied to data collected by the UMass/JPL Airborne Cloud Radar (ACR), which operates at 94 GHz (the frequency used by the CloudSat Profiling Radar). Coordinating validation activities between CloudSat and AMSR-E is one of the goals of our project, for reasons of cost savings and exploring the synergies made possible by combining data from CloudSat and AMSR-E.

Over the course of the 12 Wakasa Bay science flights, the ACR collected over 45 hours of radar data—over 55,000 radar profiles—of targets including rain and snow, as well as liquid, ice, and mixed cloud systems. Radar reflectivity data from the first six flights are summarized in time-height plots in Figure 1, which shows a variety of cloud types, ranging from a very thin, scattered layer over Honshu (2003-01-26) to vigorous precipitation with a clearly visible radar bright band over the Western Pacific

(2003-01-23). Version 2 co-polarized and cross-polarized equivalent radar reflectivity factor data have been submitted to the NSIDC DAAC in netCDF format and are available to the public at the AMSR-E Rainfall Validation page (http://nsidc.org/data/amsr_validation/rainfall/). The Version 2 data have been height-corrected using the ACR surface reflectivity peak to correct the altitude coordinate, a correction made necessary due to the imprecise nature of the altitude data obtained from the aircraft navigation system. There was considerable delay in performing this altitude correction due to a discrepancy between the altitude sensed by the ACR and that sensed by the JPL APR-2 radar, which operates at 14 and 35 GHz. While a number of possible causes were investigated by both the JPL APR-2 and the CSU/UMass ACR teams, the altitude discrepancy was never completely resolved; however, the altitude difference is minor (generally one or two ACR range bins) and will be of little consequence for most uses. Analysis based on the ACR data is still in its early stages; early results and plans for further analysis are given in the following sections.

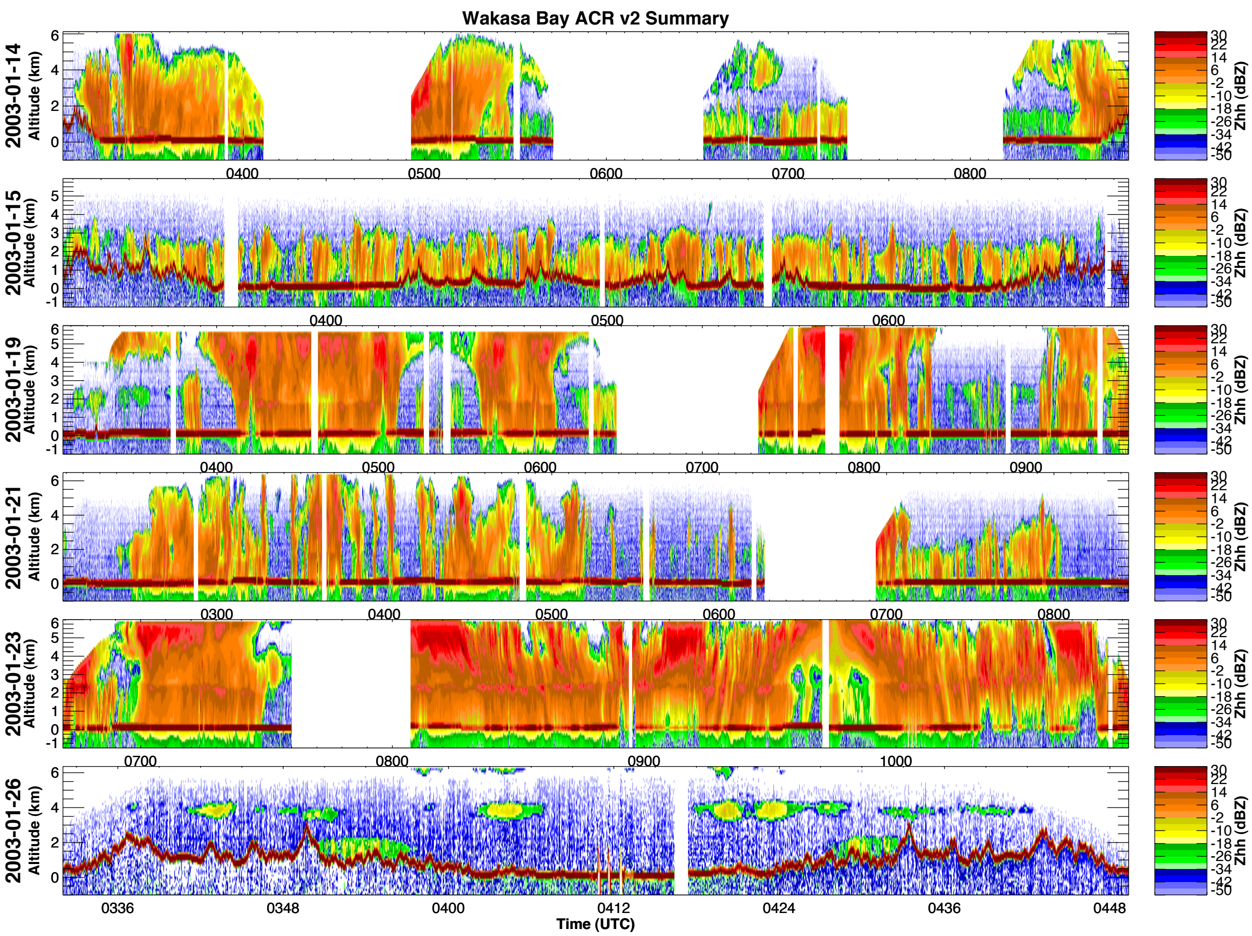

Figure 1: Time-height diagrams of co-polarized 94 GHz equivalent radar reflectivity factor for the first six Wakasa Bay flights.

3. Retrievals of Cloud Properties

3.1 Comparison of Microwave and Visible/Infrared Estimates of Cloud LWP

Liquid clouds play an integral role in the Earth's radiation budget, enhancing reflection of solar radiation to space and thermal emission from the atmosphere to the surface as well as providing a mechanism for the direct transfer of energy to the atmosphere through the release of latent heat. Central to our proposed research was determination of the extent to which the assumptions in different algorithms lead to biases in cloud liquid water path (LWP) estimates. Through this "physical validation", we hope to isolate areas where the AMSR algorithm is in need of improvement and potentially offer suggestions as to how such improvements might be made.

Since liquid cloud products from AMSR have only recently become available, initially LWP retrievals from the Visible and Infrared Scanning Radiometer (VIRS) were compared to collocated estimates from the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI). Considerable care was taken to precisely match VIRS and TMI pixels to remove any potential biases due to spatial mismatches in the data. An initial experiment calculated statistics of TMI LWP for regions determined to be cloud-free based on 0.6 μm channel radiances from VIRS. It was determined that monthly-mean daytime TMI clear-sky biases exceed 0.05 kg m^{-2} in some areas.

Figure 2 shows results from a separate experiment in which LWP estimates from distinct TMI and VIRS-based retrievals are compared for overcast pixels. The two-dimensional histogram (for overcast low cloud-only pixels from July 1998) show significant differences between the two algorithms. On average, TMI LWP estimates are approximately 30% larger than those from VIRS on the monthly mean.

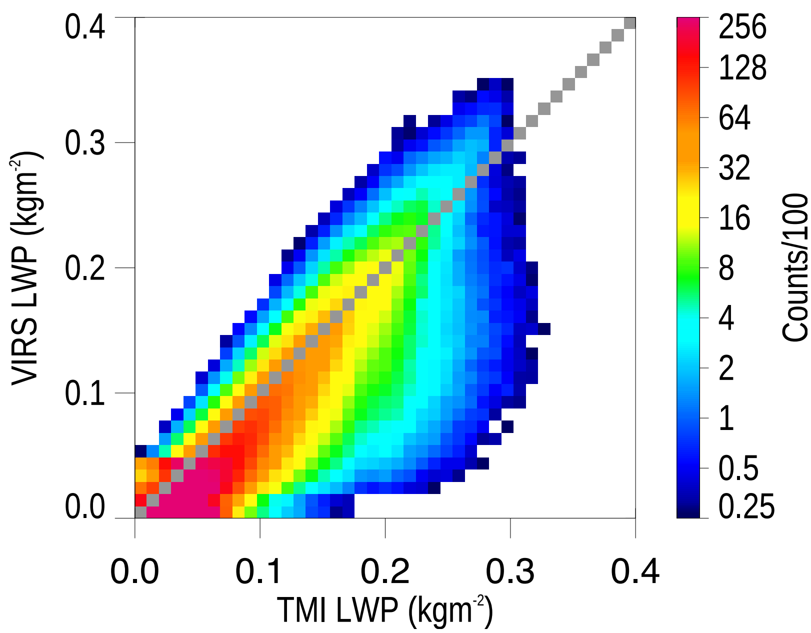

Figure 2: Comparison of TMI and VIRS LWP estimates for overcast low cloud-only pixels for the month of July 1998. Note: only daytime pixels are displayed as the detection of cloud-free pixels is made based on visible radiances. (Data courtesy of T. Greenwald and S. Christopher.)

Since the algorithms employed by the MODIS and AMSR sensors differ only slightly from those used by the TMI and VIRS, we anticipate similar biases to those presented above. At present we are analyzing the recently available Aqua liquid cloud products to verify this. Concurrently, we are seeking Aqua observations that coincide with Wakasa Bay flight legs in which liquid clouds were observed. We plan to use a combination of radar and radiometer data from this field campaign in an effort to study potential sources of these biases that may arise from the algorithms' assumptions.

3.2 Improved Retrieval Algorithms

A primary use of the ACR data collected during the Wakasa Bay Experiment will be as inputs to radar retrievals of cloud and precipitation properties. Retrievals of liquid and ice cloud properties from millimeter-wave radar alone or in combination with measurements of visible optical depth have been developed in the principal investigator's research group (Austin and Stephens 2001, *JGR* [AS2001]; Benedetti, Stephens, and Haynes 2003, *JGR*). The retrievals use an estimation theory framework (Rodgers 2000) and assume a particular form of the cloud particle size distribution. The algorithm finds a combination of distribution parameters that minimize a cost function, obtaining a state vector that is consistent with measurement data and with a priori information about the cloud in proportion to the relative uncertainties in each.

Part of the current year's research efforts have been directed towards improvement of the AS2001 algorithm. The former algorithm (for liquid clouds) assumed a fixed, assigned value of the distribution width parameter. This assumption was problematic in several ways: (1) the uncertainty associated with the fixed width parameter dominated the uncertainty of the retrieval as a whole, (2) determination of the retrieval uncertainty was difficult due to unavailability of covariance terms involving the width parameter, and (3) the retrieval was unable to find distribution parameters that fit the measurements well using the fixed width parameter for some data sets (likely those having a width parameter that differed from the assumed value). An improved algorithm has been developed that retrieves the distribution width parameter in addition to the droplet number concentration and the profile of particle geometric mean radius. Figure 3 shows the performance of the radar-only version of the improved algorithm for ensembles of synthetic clouds whose cloud properties were converted into simulated measurements that were corrupted by simulated measurement noise. The improved algorithm shows marked improvement over the AS2001 version and has been documented in a manuscript soon to be submitted to *JGR*. A parallel improvement will be applied to the ice cloud retrieval in the near future.

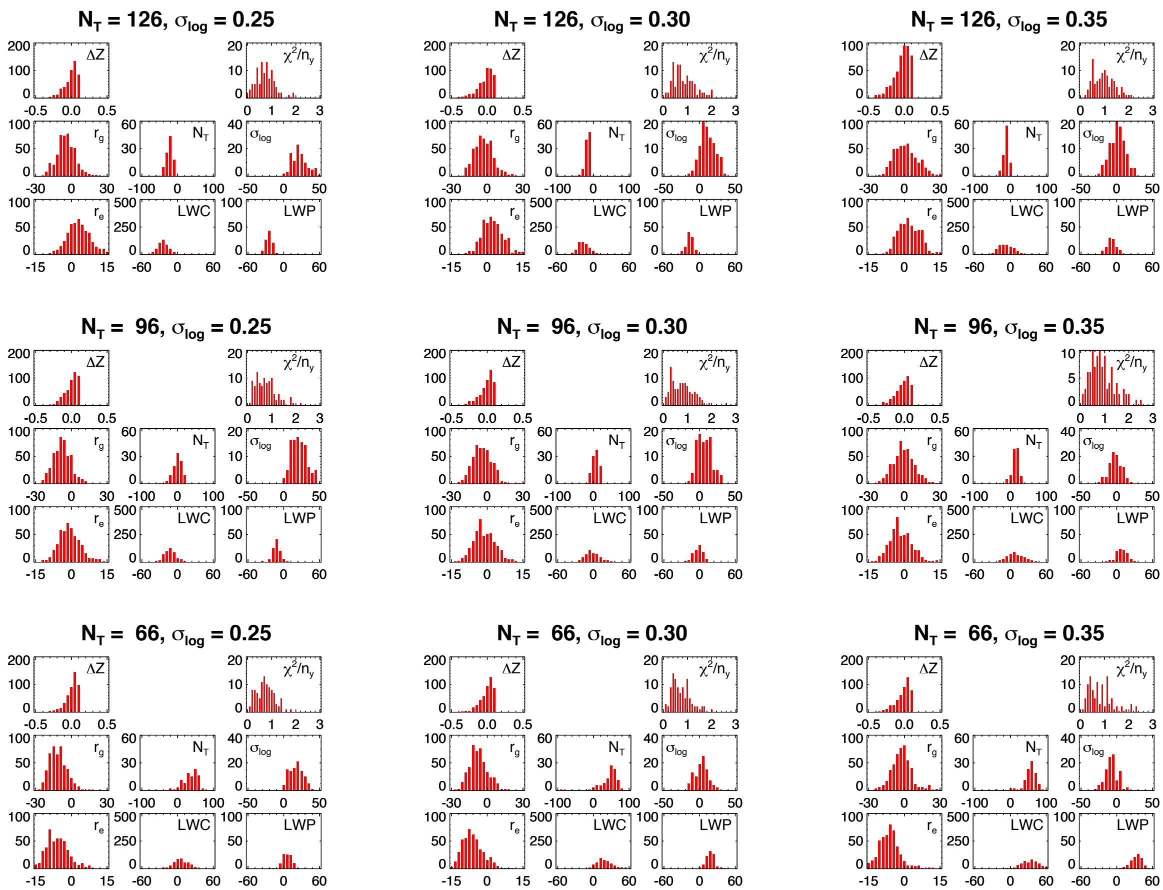

Figure 3: Histogram summary of errors in radar-only retrieval using nine sets of 100 5-bin synthetic cloud profiles with added noise. The top row of each 3 x 3 set of plots contains histograms of $\Delta Z'$ (dBZ) and $\Delta\tau$ (unitless), together with a histogram of χ^2/m (normalized goodness-of-fit parameter) for the 100 profiles in that group. The remaining six plots are histograms of fractional error (in percent) for the retrieved parameters r_g (μm), N_T (cm^{-3}), σ_{log} (unitless) and for the derived quantities r_e (μm), LWC (g m^{-3}), and LWP (kg m^{-2}).

Radar-only versions of the liquid and ice cloud retrievals will next be applied to selected segments of ACR data from Wakasa Bay (now that final versions of these data are available). Results will be compared to selected products from AMSR-E and MODIS overpasses of Wakasa Bay flights.

4. Precipitation Retrievals

4.1 Liquid Precipitation Retrievals from the ACR at Wakasa Bay

The other key component to our AMSR validation effort has been directed toward retrieving precipitation from the ACR data from appropriate Wakasa Bay flights with the aim of assessing the performance of AMSR retrievals in mid-latitude wintertime precipitation. To this end a light rainfall algorithm has been developed for use with millimeter-wavelength radar observations and adapted for use with the ACR observations. The algorithm is built in the optimal estimation framework and special attention has been given to accurately representing all sources of uncertainty in the retrieval so that realistic error estimates can be assigned to retrieved LWC/IWC profiles and surface rainfall rate. Attenuation due to gases, liquid, and ice particles are all accounted for and the algorithm operates at the full 120m vertical resolution of the ACR. Path-integrated attenuation is computed by taking the difference between the maximum observed surface return and an estimate of the clear-sky surface return obtained by averaging all clear-sky pixels from all flight legs. The bright-band (BB) height is estimated from a combination of vertical reflectivity gradients and the maximum reflectivity near the height of the environmental 0°C isotherm. All particles below the BB are taken to be spherical raindrops obeying a Marshall-Palmer drop size distribution (DSD) while those above the BB are assumed to be ice spheres obeying the same DSD. Mie theory is used to establish the scattering and extinction properties of all hydrometeors; the resulting inversion is anticipated to provide accurate retrievals up to ~10 mm h^{-1}.

An example of the application of this algorithm to a single flight leg of Wakasa Bay ACR data is presented in Figure 4. The reflectivities in the upper-left panel exhibit a clear bright band, indicative of a freezing level and liquid precipitation below about 1.5-2 km. For the most part, the path-integrated attenuation is less than 20 dB, suggesting that all but a small portion of the flight leg consisted of light rainfall within the expected range of applicability of the algorithm. The right-hand panels present the results of the retrieval. The majority of the flight leg is characterized by light rainfall between 0.1 and 5.0 mm h^{-1}, and the associated uncertainties fall between 30 and 60%. The high spatial variability in the rainfall field is clearly evident in the high-resolution ACR data.

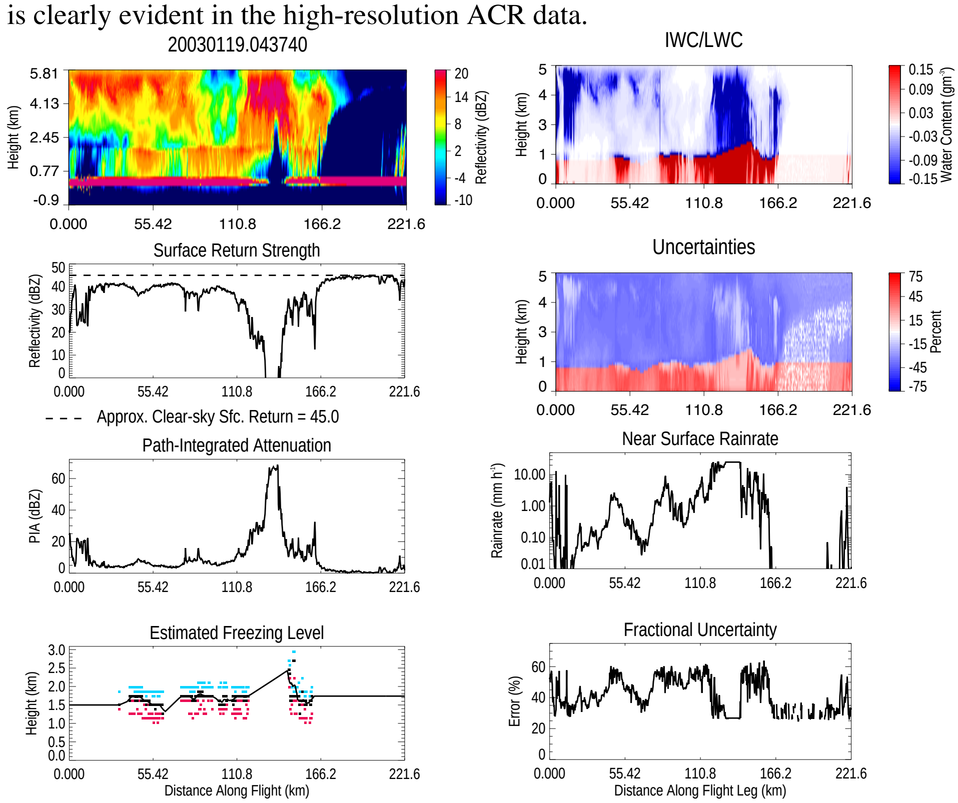

Figure 4: Retrieved IWC/LWC and surface rainfall rate for one flight leg from the AMSR validation field experiment at Wakasa Bay, Japan on 19 January 2003. The panels on the left highlight the input data including (from top to bottom) reflectivity observations, surface return, inferred path-integrated attenuation, and estimated freezing level. The right-hand panels summarize the retrieved liquid and ice water contents, their uncertainties, retrieved surface rain rate, and its uncertainty. Note that the retrieved ice water contents are plotted as negative to facilitate distinction with liquid water content.

In the coming months we will make direct comparisons with AMSR-E overpass data to mutually assess the products. The first element of these comparisons consists of performing correlative analysis of the results from the two algorithms to assess random and systematic differences in their rainfall estimates as well as to evaluate AMSR-E's light rainfall detection capabilities. In addition, we plan to carry out physical validation of the assumptions implicit in the AMSR-E rainfall algorithm, such as freezing level, sub-pixel variability or beamfilling, and the impact of the shape of the liquid and ice water content profiles. It is hoped that such comparisons will illustrate the complementary nature of active and passive measurements for rainfall retrievals and, as a result, provide a consistency check on the assumptions employed in each algorithm.

4.2 Preliminary Retrievals on Snow

A primitive version of a combined active/passive retrieval of snowfall was developed as an initial exploration into the application of the estimation theory framework to frozen precipitation. This first effort was primitive in that the forward model for the millimeter-wave brightness temperature was overly simplistic. These efforts will be extended to more sophisticated schemes in the near future.

5. Publications and Presentations

Austin, Richard T. and Graeme L. Stephens, "Retrieval of stratus cloud microphysical parameters using millimeter-wave radar and visible optical depth, 2. Improved algorithm", to be submitted to *J. Geophys. Res*.

Austin, Richard T., Tristan S. L'Ecuyer, and Graeme L. Stephens, 2003: "Validation and Development of GPM Algorithms using the A-Train Suite of Instruments", poster presentation at 3rd GPM Workshop, Noordwijk, Netherlands, 24-26 June 2003.

6. Plans for the coming year

We have a number of activities planned for the remainder of the project:

1. Examine AMSR-E and MODIS LWP estimates for biases similar to TMI/VIRS.
2. Implement cloud radar algorithm improvement in ice cloud algorithm.
3. Compare Aqua observations to LWP estimated from ACR on Wakasa Bay flights.
4. Compare AMSR-E precipitation product to ACR precipitation retrievals at Wakasa Bay.
5. Continue development of radar snowfall algorithm and apply to Wakasa Bay data.

7. Proposed activities for project extension

Because the LWP bias is serious, we request extended funding to conduct more extensive correlative analysis using data from other sensors and other sources to confirm its existence and magnitude. One key correlative study we propose to conduct in this extended period involves the use of CERES albedo data, both from TRMM and from Aqua. The approach will be to use both sources of LWP data in a CERES simulator and compare the results with measured CERES albedos. The low uncertainty in CERES albedo should provide an independent indicator of LWP bias. Once we have confirmed a bias in the AMSR-E product, we plan to work closely with the algorithm developer to address the error.