GLOBAL OBSERVATIONS OF PRECIPITATION USING SATELLITE PASSIVE MILLIMETER-WAVE SENSORS

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ABSTRACT

This paper reviews main results from recently published papers \cite{1}-\cite{5} and recent research being presented at IGARSS 2008 \cite{6,7}. This work starts with developing and validating a global model, MM5/TBSCAT/F(\lambda), that simulates ground-truth and predicts millimeter-wave radiances consistent with those coincidentally observed by AMSU aboard NOAA satellites. Sensitivity studies of the assumptions in the model further encourage its use as ground truth for development of global millimeter-wave precipitation retrieval methods. MM5/TBSCAT/F(\lambda) was then used to 1) study appropriate specifications for geostationary microwave sounders and their retrieval accuracies, 2) evaluate the ability of ATMS to retrieve precipitation, and 3) develop a series of precipitation retrieval algorithms, AMSU/MM5, where the latest version is able to estimate surface precipitation rates over snow-covered land and sea ice consistent with CLOUDSAT observed radar reflectivity profiles, provided that the atmosphere is not too cold to permit retrievals.

Index Terms—AMSU, ATMS, CLOUDSAT, geostationary microwave imagers, GMI, microwave precipitation estimation, microwave radiative transfer, precipitation.

1. INTRODUCTION

Lack of reliable global ground truth has impeded accurate global observations of precipitation using satellites. Rain gauges, ground-based and satellite-borne radars, visible and infrared sensors, and various passive microwave sensors all have deficiencies. For example, rain inhomogeneities, wind, and the lack of good global coverage significantly degrade rain gauge measurements. Infrared satellite observations see only the tops of clouds and most other remote sensors respond to precipitation aloft, not that reaching the ground. Radar is expensive, its global coverage is sparse, and it relies on size-dependent backscattering. For these reasons models combining cloud-resolving forecasts with accurate radiative transfer expressions such as those used in \cite{1,7} could improve the reliability of global ground truth and the performance of retrievals derived from it.

2. MODEL GLOBAL GROUND-TRUEH VALIDATION

To overcome the lack of reliable global ground truth, the MM5/TBSCAT/F(\lambda) model - composed of a Numerical Weather Prediction (NWP) Model, MM5 \cite{8}, a two-stream radiative transfer model, TBSCAT \cite{9}, and electromagnetic scattering models (F(\lambda)) for icy hydrometeors aloft - was developed to provide global ground truth for millimeter-wave precipitation retrieval development \cite{1}. Icy hydrometeors were modeled as homogeneous spheres having wavelength-dependent densities F(\lambda) deduced from electromagnetic computations for various ice shapes. The densities F(\lambda) were chosen so as to yield total Mie scattering cross-sections identical to those computed for equal-mass hexagonal plates (snow), 6-point bullet rosettes (graupel), and spheres (cloud ice) using a discrete-dipole approximation method. The hydrometeors studied were defined as having observed ice habit dimensions and densities. Comparisons of millimeter-wave radiances predicted by MM5/TBSCAT/F(\lambda) with those coincidentally observed by the Advanced Microwave Sounding Unit (AMSU) aboard the operational satellites NOAA-15, -16, and -17 showed reasonable agreement over 122 global storms spanning a year and including different types of precipitation \cite{1}, as illustrated in Figs. 1 and 2. Fig. 2c shows that simulated radiances appear to be colder than observed for a satellite zenith angle (\theta) greater than or equal to 40\degree. This could be due to the planar atmosphere assumption used in the radiative transfer model and is left for future studies.

Sensitivity of predicted radiances to assumptions in MM5/TBSCAT/F(\lambda), and the robustness of predicted retrieval accuracies of millimeter-wave instruments were studied to ensure the utility of the ground-truth model \cite{2}.
Fig. 1. Comparisons of MM5 and AMSU brightness temperatures at 183±7 GHz: (a) AMSU observations at 2344 UTC 31 December 2002, (b) MM5/RTM simulations of (a), (c) AMSU observations at 1003 UTC 2 January 2003, (d) MM5/RTM simulations of (c). Fig. is from [2].

Fig. 2. Brightness temperature histograms (pixels per degree K) for channels near 50.3, 89, 150, 183±7, 183±3, and 183±1 GHz, in order of increasing opacity from left to right, for 122 storms using F(\lambda) from [1] for (a) all, (b) \theta < 40^\circ, and (c) \theta \geq 40^\circ. Only T_A's below 250 K are plotted. For clarity, the absolute T_B's were shifted to the right by 0, 140, 260, 330, 390, and 450 K, respectively. The vertical bar for each histogram represents 230K.

It was found that, whereas predicted radiances are fairly sensitive to assumptions in MM5 and the radiative transfer model, the predicted accuracies of millimeter-wave retrievals are robust to these assumptions assuming the physics is known [2]. To summarize, results from [1] and [2] validate the use of MM5/TBSCAT/F(\lambda) as global ground-truth.

3. PRECIPITATION OBSERVATIONS FROM GEOSTATIONARY MICROWAVE SATELLITES

Current geostationary (GEO) satellites permit better than 15-minute and 10-km resolution at infrared wavelengths, but cannot penetrate overlying clouds, while the more accurate low-earth-orbit (LEO) satellites with cloud-penetrating ~15-km microwave resolution generally repeat their observations only at intervals of hours or more. Although dense radar and rain gauge networks provide good local coverage, they are too costly and land-bound to cover most nations and their surrounding waters. Even the NEXRAD 158-radar system covers only ~20 percent of the continental United States within its best-performance 110-km range, and less than 60 percent within 220-km range.

Geo-microwave systems that resolve important storms in both time and space have been proposed for many years, but generally without analysis of their precipitation and hydrometeor retrieval performance. [3] compares the abilities of eleven alternative passive microwave sensors to retrieve surface precipitation rates and hydrometeor water paths: five instruments observe selected frequencies from 116 GHz to 429 GHz with a filled-aperture antenna, and six observe from 52 to 191 GHz with a U-shaped aperture synthesis array. The analysis was based on neural network retrieval methods trained using 122 global storms simulated by MM5/TBSCAT/F(\lambda). The results showed that a 1.2-m micro-scanned filled-aperture antenna operating at 118/166/183/380/425 GHz (which is relatively inexpensive, technologically mature, simple to build, and readily installed on a geostationary satellite) provides useful observations of important global precipitation with 20-km resolution every 15 minutes. Such a system could not only provide better nowcasting, but may also permit cloud-scale assimilation of precipitation into numerical weather prediction (NWP) models so as to improve both precipitation retrievals and weather forecasts. It was also found that an image sharpening technique can improve spatial resolution by 1.3 times. The benefits of image sharpening are restricted primarily to isolated storms, as illustrated in Fig. 3.

4. AMSU/MM5 PRECIPITATION RETRIEVAL ALGORITHM

The global precipitation retrieval algorithm, AMSU/MM5, was developed for AMSU based on neural networks trained using MM5/TBSCAT/F(\lambda) [4]-[5]. An improved AMSU/MM5 algorithm has recently been developed [6] and results show its improved sensitivity to
Fig. 3. Top to bottom: MM5-simulated surface precipitation rates (RR) of size 5552 km², and RR retrieved by a 1.2-m micro-scanned filled-aperture antenna operating at 118/166/183/380/425 GHz with and without image sharpening, respectively. Left to right: an oceanic typhoon (12/8/02; ~15N/145E), stratiform rain (12/14/02; ~40N/125W), a strong front over France (1/2/03; ~50N/5E), and oceanic warm rain (11/16/02; ~50N/35W); the units are mm/h.

Fig. 4. Global precipitation retrievals at ~15-km resolution for July 15, 2007 (mm/h). White indicates missing pixels, extreme cold, or extreme high altitude.

Stratiform precipitation and its ability to work over most snow and sea ice. These improvements came from the choice of frequencies and principal components feeding the final neural network estimators. They were chosen and filtered such that they have almost no surface effects. The retrievals perform well in terms of simulated rms retrieval errors, plausible global precipitation maps, global precipitation frequency statistics in terms of latitude and precipitation rate, and in comparisons with other sensors and algorithms, including nearly coincident CLOUDSAT data. Fig. 4 shows a global map for retrieved surface precipitation (mm/h). Fig. 5 shows comparisons of AMSU/MM5 and AMSU/NOAA [10]-[11] surface precipitation rate retrievals, and CLOUDSAT reflectivity profiles for: (a) land, (b) sea, (c) snow-covered land, (d) sea ice, and (e) North Pole. Green and red arrows bound the CLOUDSAT image. Darker pink, green, and lighter pink indicate extreme high altitude, extreme cold, and ice or snow, respectively.

Fig. 5. Left to right: AMSU/MM5 and AMSU/NOAA surface precipitation rate retrievals, and CLOUDSAT reflectivity profiles for: (a) land, (b) sea, (c) snow-covered land, (d) sea ice, and (e) North Pole. Green and red arrows bound the CLOUDSAT image. Darker pink, green, and lighter pink indicate extreme high altitude, extreme cold, and ice or snow, respectively.

5. PRECIPITATION RETRIEVAL ACCURACIES FOR ATMS

The United States National Polar Orbiting Environmental Sensor System (NPOESS) Advanced Technology Microwave Sounder (ATMS) on the NPOESS Preparatory Program (NPP) satellite and subsequent NPOESS satellites is a new generation microwave sounder. ATMS differs from its predecessor, AMSU, in several respects that should generally enhance its utility for precipitation sounding. [7] evaluates its ability to retrieve surface precipitation rates

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which significantly improves its performance at high latitudes. The new generation microwave sounder, ATMS, will generally retrieve and image precipitation better than AMSU, and further improvements are expected.

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8. REFERENCES


6. SUMMARY AND CONCLUSIONS

The global ground truth model, MM5/TBSCAT/F(λ), has been shown to be a powerful tool for developing millimeter-wave precipitation retrieval methods. Geostationary satellites with a simple 1.2-2 m micro-scanned filled-aperture antenna operating at 118/166/183/380/425 GHz could provide useful observations of important global precipitation with 20-km resolution every 15 minutes. An improved AMSU/MM5 algorithm employing surface-insensitive signals is more sensitive to stratiform precipitation and operates over most snow and sea ice,