ICE-PHASE PRECIPITATION RETRIEVALS OVER LAND USING COMBINED RADAR / RADIOMETER SATELLITE OBSERVATIONS

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1. ABSTRACT INTRODUCTION

Passive microwave (PMW) measurements of ice-phase precipitation, such as snowfall and graupel, provide a physically direct basis for inferring the integrated amount of precipitation within a given field-of-view (FOV), assuming that other sources of noise can be adequately accounted for. However, the vertical distribution of precipitation within the FOV is generally unknown. By combining passive observations with co-located satellite-based radar observations, then we can begin to estimate the vertical distribution of precipitation and simultaneously improve the retrieval uncertainty compared to passive microwave alone. The present research describes the development of a retrieval algorithm for use with the upcoming Global Precipitation Measurement (GPM) mission, which will have co-located dual wavelength radar and radiometer observations available for nearly global precipitation observations.

There are two major requirements for such sensors to detect ice-phase precipitation: (1) channel selection, that is, it is necessary to select microwave channels having frequencies which are sensitive to scattering by ice particles; and (2) accurate knowledge of the relationships between the physical properties of the materials in the observed scene and the radiative properties observed by the satellite.

PMW observations over land surfaces are characterized by radiometrically warm, unpolarized surface emission. The emissivity of land surfaces is also highly variable, both spatially and temporally, at frequencies sensitive to ice-phase precipitation (generally 89 GHz and higher). Typical emissivity values range from 0.6 to 0.98, the variance of which depends primarily on three factors: (1) temperature of the soil and vegetation, (2) moisture content of the soil and vegetation, and (3) snow cover depth and frozen ground. A fourth factor, variable terrain altitude and variances within the field of view are also issue, but their influence on precipitation retrievals is not presently well understood.

Fortunately, satellite-based radar observations are not influenced by the surface properties (except in the case where attenuation estimates are necessary), instead radar reflectivities provide a physically direct measure of the vertical distribution of precipitation, constrained by the vertical resolution and sensitivity of the radar. At present, however, only single-frequency satellite-based radars are being used for precipitation research. In order to perform an accurate retrieval, fairly subjective assumptions of the distribution of particle sizes, shapes, etc. are required. Therefore, it appears that a combination of these two observation types is complementary for the purposes of providing a reasonably well constrained retrieval.

The present research employs observations from the NOAA POES AMSU-B sensor operating at 89, 150, 183.31+/-1, 3, and 7 GHz; and from co-located CloudSat cloud profiling radar observations at 94 GHz. Co-location is defined as coincident overpasses within 30 minutes and 0.25 degrees of each other. We further restrict our retrievals to land and cases where ice-phase precipitation is expected to be the dominant phase of precipitation. The latter restriction requires knowledge of the temperature profiles for the cases being observed. For dealing with PMW surface emissivity, two methods are compared (1) a simple forward model based method, and (2) a statistically-based retrieval of nearby clear-sky emissivities.

A forward model, described by [1], is used to create a database used in the retrieval. The database, described in section 3, consists of scenes of precipitating and non-precipitation scenes with associated profiles of radar reflectivity and top-of-the atmosphere PMW brightness temperatures (TBs) at frequencies consistent with AMSU-B and CloudSat CPR observations.

For the particle size distribution (PSD) a negative exponential PSD is assumed, although the true distribution is generally unknown. Particle shapes, also highly variable and unknown, combined with the above PSD, strongly influence the present retrieval methodology – therefore the retrieval database is designed to be reasonably robust by allowing for a variety of combinations of PSD and particle shape combinations (see [2]).

Nevertheless, we do not expect that these assumptions completely describe all possible variations that might be present in a given precipitating cloud. Our goal, rather, is to achieve a three-way consistency between the observed PMW TBs, observed radar reflectivities, and the forward-model simulated TBs and reflectivities. Presumably, the combined retrieval will provide a reasonable estimate of precipitation, at least within the regions where both observations are co-located, possibly extending outside of this region. We also provide basic uncertainty estimates, which also serve to determine the quality of the retrieval.

2. RETRIEVAL METHODOLOGY

The present retrieval is similar to what is often referred to as a Bayesian retrieval algorithm. This algorithm requires a database consisting of profiles of precipitating clouds and clear-sky cases. The precipitation cases will have a variety of distributions of snowfall shape, size, and vertical extents. For each profile, the vertical radar reflectivities and top-of-the atmosphere PMW TBs are simulated using the forward model. Observed TBs and co-located reflectivities are subsequently differenced with the database-simulated reflectivities and observed TBs. Those profiles minimizing the absolute difference between simulation and observation are selected weighted according to their differences. Profiles perfectly minimizing the difference are assigned a weight of unity, whereas profiles having simulated observations which are extremely different from observations are assigned very small weights. The final retrieval is, therefore, the weighted average of all of the profiles within the database. Similarly, the standard deviation of these weighted profiles provides an estimate of the retrieval uncertainty (with certain statistical conditions implied).

For passive microwave sensors, it is likely that more than one channel will be sensitive to similar physical properties of the atmosphere. Therefore, a covariance matrix is determined for all 5 AMSU-B channels with respect to their sensitivity to ice water path (IWP) – i.e., the variable of interest in the combined retrieval algorithm. Future work will involve specific testing as to the retrieval sensitivity to the covariance matrix.

A quality flag is also assigned to the retrievals according to the uncertainty estimate. If the uncertainty of the retrieval is greater than the retrieved quantity, then the retrieval is presumed to be insensitive to any precipitation present, and a quality flag is set indicating this.

3. DATABASE AND OBSERVATIONS

The accuracy of the present retrieval method requires that the database of observations be relatively robust with respect to the range of surface emissivity, particle sizes, and particle shapes in providing forward modeled TBs and reflectivities consistent with the range in the observations.

For particle size, a negative-exponential particle size distribution (PSD) is assumed of the form $N(D) = N_0 \exp(-\Lambda D)$, where D is the particle diameter, N(D) is the number concentration at diameters from D to $D + \delta D$, Λ is the "slope" of the distribution in log-log space, and N_0 is the intercept number density.

The present form of the database is derived from WRF profiles of precipitating clouds. WRF provides IWP estimates, and using a hydrometeor model we convert these to PSDs and associated radiometric properties using the forward model described in [1]. However, there are significant uncertainties when relying only on a cloud resolving model to generate a robust set of realistic precipitation features. There is ongoing research into incorporating dual-wavelength radar retrievals from field experiments (e.g., 2003 Wakasa Bay field experiment) into the database to expand the range of applicability.

4. REVIEW

This paper describes an ongoing research task with the general goal of improving precipitation retrievals by improving the various elements of the physically-derived forward model and associated retrieval algorithms. While many aspects of the research have been completed, there are a few outstanding elements that require careful research. Specifically, we are actively involved in exploring how the passive microwave portion of the retrieval responds to changes in the land surface emissivity, and how these changes can be better understood and incorporated into the retrieval framework [3]. We are also actively exploring how the combined retrieval is sensitive to variations in particle shape and size [2]. All of the physical properties which substantially contribute to the observed radiances and reflectivities are being revisited and updated as we proceed toward a final algorithm product. This paper highlights the specific efforts with regard to land emissivity and particle size/shape, database development, and specific retrieval algorithm elements.

5. SELECTED REFERENCES

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