Deriving convective structure from microwave sounder observations

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Microwave sounders have been used for many years to measure the thermodynamic state of the atmosphere, i.e. the three-dimensional distribution of temperature, water vapor and liquid water, both from space, from aircraft and from the ground. Currently, the most advanced satellite based microwave sounding system is the Advanced Microwave Sounding Unit (AMSU-A and -B) operating on a number of weather satellites, and the current state of the art in "retrieval" systems is represented by the Microwave Integrated Retrieval System (MIRS) [Boukabara, 2007]. Data from these systems are routinely used in numerical weather prediction to great effect. Microwave sounders have been particularly effective because the observations are only minimally affected by clouds. In contrast, infrared sounders, which are otherwise both more accurate and have higher resolution are only able to penetrate very thin clouds.

Atmospheric sounding [Janssen, 1993] is based on the fact that the thermal radiation received by a radiometer originates at wavelength-dependent depths in the atmosphere. This is caused by a non-uniform absorption spectrum, particularly by molecular absorption lines. At wavelengths near the peak of such a line, absorption may be so strong that most of the underlying atmosphere is opaque, and only the top of the atmosphere is "seen". Conversely, at wavelengths far away from the lines, often called a "window" region, the atmosphere may be nearly transparent, and the surface or the bottom of the atmosphere is seen instead. Through spectral sampling, i.e. by measuring narrow spectral bands, or "channels", it is then possible to probe into different depths of the atmosphere. A "weighting function" describes which portion of a channel's signal strength originates from different depths. For a radiometer looking down into the atmosphere from a high-flying aircraft or a satellite, a typical weighting function reaches a peak at a certain depth, which is characteristic for that channel. A set of channels is selected so that the respective weighting functions are evenly distributed through the atmosphere. Fig. 1 shows the MW absorption spectrum in the sounding region (left) and the nominal AMSU-A temperature weighting functions in the 50-GHz band (right).

Liquid droplets and ice particles make most clouds completely opaque in the infrared band, but in the microwave region they are partially transparent. The microwave spectral absorption features of liquid water therefore make it possible to determine the vertical distribution of the liquid water in clouds from microwave sounder measurements [Rosenkranz, 2006]. Scattering caused by the larger ice particles, such as those created through deep convection, is also easily measured by MW sounders, and that makes it possible to infer precipitation rate and convective intensity [Bauer, 2003].

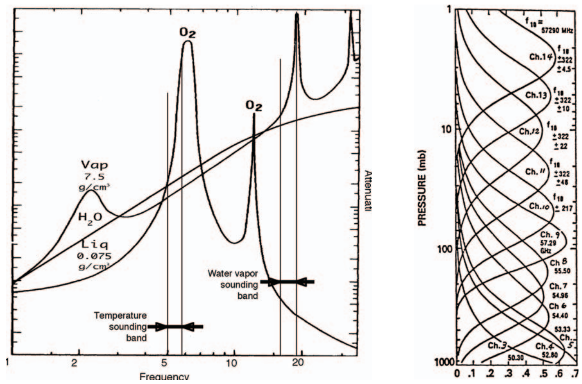

Fig. 1. Absorption spectrum (l), weighting functions (r)

Here we report on a new method that makes it possible to derive the three-dimensional structure of convection and precipitation, i.e. where the sounder is used as a “scattering profiler” rather than as an “absorption profiler”. This is possible because the various channels’ vertical sensitivity to scattering is analogous to that for absorption. Consider a scattering layer at a certain altitude. Radiation from below the layer will be severely scattered away from the radiometer, and the observed brightness temperature of a channel with a weighting function peaking below the layer will be significantly depressed. A channel with a weighting function peaking above the layer will be only minimally affected. It is thus possible to spectrally “slice” the vertical distribution of scattering in the same way as is normally done with absorption.

Using aircraft observations of tropical convection systems obtained in a recent NASA hurricane field experiment (the Tropical Cloud Systems and Processes, TCSP, in 2005) we have developed an empirical algorithm to derive vertical profiles of reflectivity from microwave sounder observations. In TCSP a microwave sounder, the High Altitude MMIC Sounding Radiometer (HAMSR) operated along with a radar system, the ER-2 Doppler Radar (EDOP) on the same aircraft platform, and we have used those simultaneous observations to develop the algorithm and test it. Our analysis reveals correlations between the observations from the radiometer and the radar ranging well above 90% at altitudes between 2 and 14 km, i.e. it is possible to derive reflectivity profiles from 2 km above the surface to the top of the convective cells. Accuracy ranges from 2 dBZ at the highest altitudes to 6-8 dBZ near the surface. Our current algorithm does not account for the normal atmospheric absorption signal, which is therefore equivalent to a noise source. In the next phase of development we will account for this signal, and we expect the retrieval accuracy to reach 2-3 dBZ at all altitudes.

Fig. 2 shows an example from TCSP. In this case the aircraft flew directly over the eye of Hurricane Emily (then a strong category 4 storm). The upper panel shows the EDOP reflectivity profile along the flight track (EDOP observes in the nadir direction only), and the lower panel shows the reflectivity derived from HAMSR. We note that all major features are captured by HAMSR. Since the sounder is a scanning instrument, it is possible to apply the retrieval algorithm in three dimensions, and Fig. 3 shows a stack of horizontal slices at altitudes from 2 km to 15 km. From that it is possible to get a 3-dimenional picture of the convective structure.

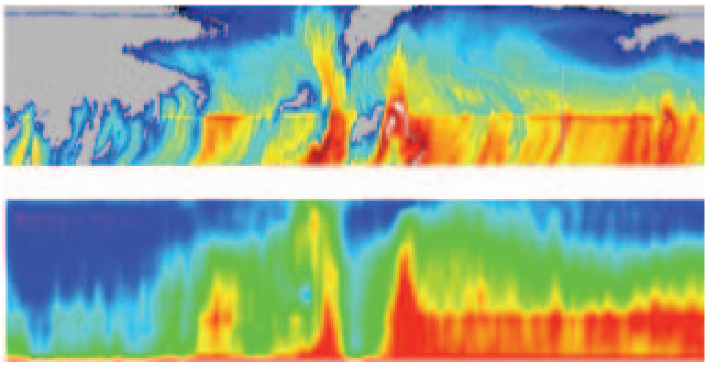

Fig. 2. Radar reflectivity, nadir plane: High-resolution observations with EDOP (upper panel) and low-resolution inferred from HAMSR (lower panel). Hurricane Emily, July 17, 2005

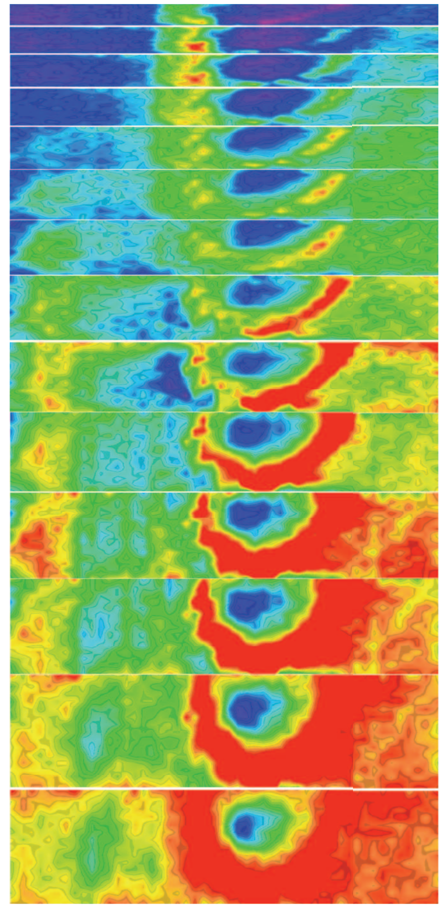

Fig. 3. 2D plots of radar reflectivity inferred from HAMSR at altitudes from 2 km to 15 km above the surface (every km). Hurricane Emily, July 17, 2005

This methodology can also be applied to satellite soundings. Fig. 4 shows an example using data from the AMSU-A/HSB sounders flying on the NASA Aqua satellite. There is of course a significant difference in horizontal spatial resolution, and the algorithm needs to be properly tuned. The preliminary results in Fig. 4 are based on the untuned algorithm. Nevertheless, significant structural details are revealed.

The "ultimate" application of this method is obtained with a geostationary microwave sounder. Such a sensor does not yet exist, but one is under development at the Jet Propulsion Laboratory. Called the Geostationary Synthetic Thinned Aperture Radiometer (GeoSTAR) [Lambrigtsen, 2004], it is the planned payload for the Precipitation and All-weather Temperature and Humidity (PATH) mission recommended by the NRC in its "decadal survey" of earth science [Anthes, 2007]. With this system it will be possible to monitor the three-dimensional structure of hurricanes and other severe storms every 15-20 minutes through their life cycles.

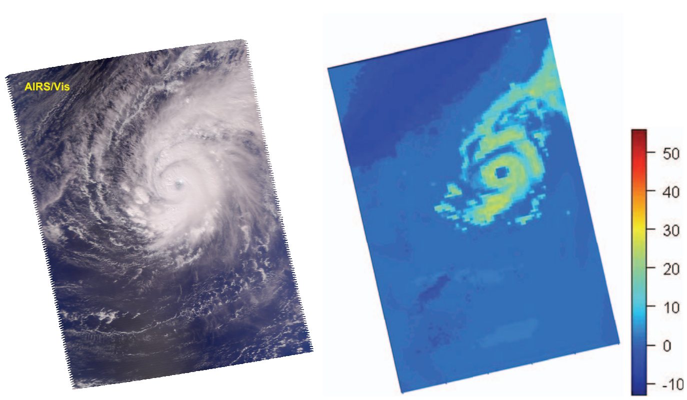

Fig. 4. Reflectivity at 9 km derived from NASA Aqua AMSU-A/HSB (right). Supertyphoon Pongsona, 2002

In summary, the new method described here will enable a number of new analyses of convection that were previously only possible in a narrow range of cases where radar observations are available. With this method, it will soon become feasible to derive radar-like information from the considerable number of microwave sounders that have been in operation since 1998, with a large expansion in global coverage.

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ACKNOWLEDGMENTS

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.