13A.6 POTENTIAL APPLICATION OF THE SURFACE REFERENCE TECHNIQUE OVER LAND AT LARGE INCIDENCE ANGLE

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1. INTRODUCTION

Airborne meteorological radars typically operate at attenuating wavelengths. Correction for attenuation along the propagation path, therefore, is required to retrieve reflectivity factor for accurate estimation of the rainfall rate. The surface reference technique (SRT) to correct the observed reflectivity for the effects of attenuation has been developed for down-looking radars (Meneghini et al.,1983). The SRT algorithm uses the radar cross section of the ocean surface as a means of estimating the path integrated attenuation. In the SRT an initial value is determined for the radar cross section of a rain-free area in relatively close proximity to the rain cloud. During subsequent observations of precipitation any decrease in the observed surface cross section from the reference value is assumed to be a result of the two-way attenuation along the propagation path (PIA). The PIA for each beam is then used as a limiting condition in an attenuation correction algorithm (Iguchi and Meneghini, 1994).

A number of studies have evaluated the SRT with airborne radar observations (Meneghini et. al, 1992). In these studies, the SRT has been used on observations at a variety of incidence angles acquired during flights over the ocean. Development of the SRT has focused on cases over water because the ocean surface presents a well known, and relatively constant, microwave reflection. In addition to airborne applications, the SRT is used for processing the reflectivity profiles from the spaceborne precipitation radar launched in 1998 on the Tropical Rainfall Measuring Mission (TRMM).

Limited studies employing the SRT over land have been reported to date. In general this is because the radar cross-section of land surfaces can be highly variable particularly at near-nadir incidence angles. A second concern centers around the question of variations in surface cross-section under raining conditions.

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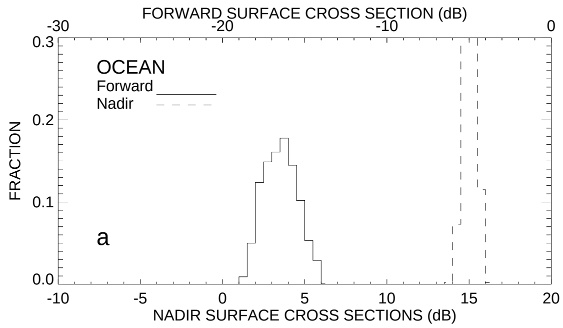
This paper will present the statistics of the surface echo from the airborne radar observations at both nadir and 33 degree incidence angle in the cloud free-region for cases over land and ocean. The paper will also present an example of the observed surface echo along a flight track over land in the rain area. The data was collected by NASA ER-2 airborne Doppler radar during field campaigns conducted for TRMM validation in Texas, Florida (1998) and Brazil (1999).

2. OBSERVATIONS

The following observations were obtained with the NASA ER-2 Doppler radar (EDOP). The EDOP radar is an X-band radar with two fixed antennas, one pointing at nadir and the second pointing approximately 33° ahead of nadir. The beam width of the antennas is 3° in the vertical and horizontal directions which, for a 20 km altitude, yields a nadir footprint at the surface of 1 km. The ER-2 ground speed is nominally 210 m s^{-1} and the integration period used by the data system is 0.5 s. These two values imply that an estimate of the surface cross-section is obtained every 100 m along the flight track and that 10 samples are obtained during the time it takes the aircraft to travel one beam width. The transmit pulse is 0.5 μs and the gate spacing is over sampled at 37.5 m intervals. Additional details of the radar and processing are described by Heymsfield et al. (1996).

The surface reference procedure has been applied to cases over ocean at nadir incidence (Caylor , et. al, 1997). Therefore, as a starting point it is instructive to briefly examine the statistics of the ocean surface echo for comparison to those found for rain-free land. Figure 1a shows histograms of the surface echo observed with EDOP from the nadir and forward antennas for a cloud-free region of ocean off the Gulf coast of Florida. The data are typical in that the surface echo at nadir incidence has rather small fluctuations of ± 1 dB while the echo at 33 degrees incidence is more variable having a standard deviation of ± 2 dB. The situation is very different over land (Figure 1b) in that the nadir echo becomes highly variable with a standard



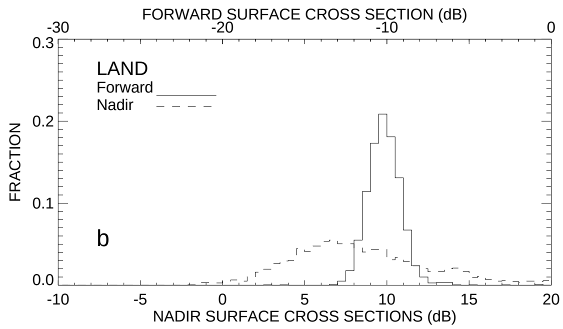


FIGURE 1. Nadir and forward surface echo for cloud-free ocean (a), and similar observations for cloud-free land (b).

deviation of ± 4 dB. However, it is clear that the surface echo over land for the forward beam shows a very similar distribution to that over open ocean with a standard deviation of ± 2 dB.

The importance of distributions such as these to the surface reference technique is that variability of the surface echo along the flight track limits the minimum PIA that can be observed. And while the observations in the nadir direction have large variability over land, there is the potential that non-nadir incidence angles may provide as good an estimate of PIA over land as they do over the ocean. The surface echo statistics from the forward and nadir antennas in a variety of geographic area show results similar to those of Figure 1b. The data are from along the eastern coast of the United States, the west U.S. and the Amazon rain forest in Brazil to provide some observations with different agricultural surface characteristics. The results indicate that the variability of the surface return at an incidence angle of 33° is relatively small.

It should be emphasized that the absolute value of the surface echo is not critical for the SRT since it is a differential technique. What is important, however, is that the magnitude of the surface echo does not change as a consequence of becoming wet from the rain since any changes in the surface cross-section are assumed to be a result of attenuation along the propagation path. In the cases studied so far with the EDOP radar, no significant change in the cross-section has been observed at the transition between rainy and clear conditions for non-nadir incidence. An example of surface echo is shown in Figure 2 from a flight track 8 km long near Ji Parana, Brazil on 12 February, 1999. The flight track covers a thunderstorm embedded in a clear region. The large 15 dB dip around beam number 300 is due to the attenuation by a thunderstorm. In this cell, radar cloud top reach up to 15 km and peak reflectivity of 56 dBZ was observed.

3. DISCUSSION

The primary measurements required by the surface reference technique (SRT) are a reference estimate of the normalized surface cross-section in a rain free region and a measurement of the surface cross-section for each beam containing rain. The difference between the reference and the rain cross-sections provides an estimate of the path integrated attenuation.

Successful application of the SRT requires several assumptions to hold. Foremost among these is that any observed changes in the surface cross-section are a result only of the propagation medium. Thus for ocean observations, the wind induced surface roughening must be identical for all observations and there must be no change in surface roughness as a consequence of the action of the rain such as splash products or wave damping. Deviations from these assumptions will introduce errors in the estimated PIA and hence in the attenuation corrected reflectivity profile. For land observations the same assumptions are required although surface roughening as a consequence of wind action is not a factor in this case. What is important is any change in the magnitude of the cross-section between raining and rain-free regions. In addition, changes in the cross-section as a function of vegetation or geographic features must be considered for land observations. Figure 2 demonstrates that there appears to be rather small differences in the surface cross-section between adjacent areas in clear and raining conditions.

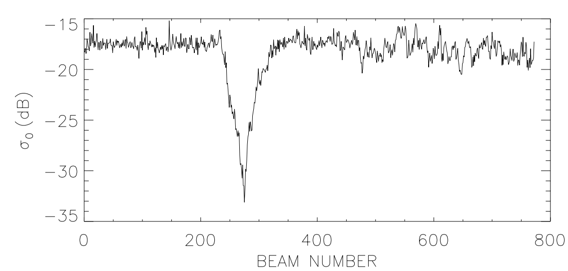


FIGURE 2. Forward surface cross section σ_0 along a track from clear to rain area.

4. SUMMARY

The surface observations from the TRMM field campaign are examined. Under the rain-free conditions, the statistics of the ocean surface echo were compared to those of land. The results show that while the observations in the nadir direction are highly variable over land, at 33° incidence angle, the variability in the surface return decreased significantly. The situation is reversed over ocean where the surface return at nadir incidence is more stable than that at 33° incidence. This findings suggest that a combination of nadir and off-nadir observation should be used to obtain the accurate estimate of the PIA. The results also suggest that values of PIA larger than 2 dB at 3 cm can be accurately estimated over land and ocean surface.

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