

# Influence of Sea Surface Backscattering on the Spaceborne Radar Measurements of Rainfall

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## ABSTRACT

A critical issue for TRMM Precipitation Radar (PR) is to estimate path integrated attenuation using Surface Reference Technique (RST), which assumes uniform ocean surface backscattering background at precipitation scale, and attributes the difference in measured surface backscattering cross sections inside and outside of storms to path-integrated attenuation. Since ocean surface winds are the major force that controls the strength of the backscattering signals, it is very desirable to examine or "explain" the measured ocean backscattering using ocean surface wind fields. To this end, we examined the feasibility of retrieving ocean surface winds from TRMM PR data for the benefit of surface reference technique. A geophysical model function, a forward model, is developed based on ocean surface wind speed retrieved from TRMM Microwave Imager data. A field-wise wind retrieval procedure, an inverse model, is formulated using maximum likelihood estimation. TRMM PR data are analyzed to demonstrate that the PR derived ocean wind speed can explain the ocean backscattering successfully. Possible improvements on the existing surface reference technique are also discussed.

## INTRODUCTION

A major challenge for the TRMM (Tropical Rainfall Measuring Mission) Precipitation Radar (PR) [1] is to improve the existing method for the estimation of Path Integrated Attenuation (PIA), which is needed by the TRMM rain profiling algorithm for computing attenuation corrected radar reflectivity factor. Currently the PR standard algorithm uses the surface reference techniques (SRTs) to perform such a PIA estimation [2]. One version of the SRTs measure normalized radar cross section (NRCS) of the sea surface inside and outside the rainy area, and attribute the difference in the measured NRCSs to the PIA. The underlying assumption of this method is that the ocean surface backscattering background is quite uniform at the precipitation scale. The surface NRCS inside the precipitating storm can thus be estimated by taking mean and standard deviation of NRCS over a small area just outside the storm. This is a rather efficient way to estimate the surface reference and its bulk uncertainty. It can provide relatively reliable attenuation estimation when PIA is much larger

than the uncertainty on surface NRCS, mostly under the condition of heavy precipitations. However, the assumption of uniform ocean background has not been examined in any way, quantitatively or qualitatively. In reality, the surface scattering is likely to be different inside and outside rainy cells due to spatial variation of sea surface roughness and wave damping effects by precipitation. In addition, the standard SRTs also require convergence of NRCS statistics over the sampling scale. The questions are: how many samples does one need, and how close should those samples be to the storm. The answer is by no means obvious and is case dependent. If the surface condition changes quickly going into the precipitation region, at no scale can the standard SRTs achieve reliable estimation of surface reference. Furthermore, without any physical modeling of NRCS, it is difficult to combine measurement statistics taken in along-track and cross-track directions because of the nonlinear dependence of NRCS on incidence angle and surface roughness. When statistics are taken along just one direction, inconsistency is usually evident in the other dimension. To address these aforementioned issues, we will analyze surface NRCS observed by TRMM Precipitation Radar using a Geophysical Model Function (GMF) which relates the radar observation to geophysical parameters. By doing so, we should be able to provide some physical understanding or physical justification on the existing SRTs. Possible algorithm improvements will also be discussed.

## METHODOLOGY

Ocean NRCS measurement can be basically explained by near surface wind field [3], however it's also a function of many secondary environmental variables, such as wind field variation within a single radar footprint, fluctuation in foam coverage, as well as spatial variation of sea surface temperature (SST) and salinity (SSS). Therefore sea NRCS is noisy in nature even with all the instrument noise removed. When we select rain-free NRCS as our scattering background in the SRTs, we face two fundamental questions. First, how do we characterize such a noisy background, and more importantly how do we extract such a characteristic? Second, for any given method of characteristics extracting, what are the associated uncertainties in estimated NRCS?

The answer to the first question seems to be quite

obvious: we want to extract mean NRCS field with all the noise reduced to minimal. But how to achieve this goal is less obvious and not necessarily straightforward. The standard SRTs approach is to sample NRCS measurement over a small area outside the storm. In this study, we will characterize the NRCS background using ocean surface wind field, and associate this wind field with mean NRCS field. In other words, we will estimate surface wind field from noisy NRCS measurement and use the estimated wind field to explain the mean NRCS field within the uncertainty of NRCS measurements. This new approach is also based on the observation that wind field is more coherent and relatively smoother than the corresponding NRCS field. Therefore, by prescribing certain wind model in our wind retrieval, we can infer wind field inside the storm from NRCS measurements outside the storm. In this way, we removed the basic assumption of uniform backscattering background and invariant of NRCS inside and outside rainy region. Of course, this method still assumes that the geophysical model function is invariant under both rain and rain-free conditions. No effect of wave damping by rain is considered in this paper.

The answer to the second question follows naturally the first question. Past experience in ocean scatterometry has demonstrated that the NRCS noise depends on wind speed. For a fixed incidence angle, the noise is less at higher wind speed and much larger at low wind speed. Once the wind field is estimated, the associated uncertainty in NRCS can be determined through prior constructed statistics that relate NRCS noise to wind speed. These statistics are built upon large global data sets. Therefore, the NRCS uncertainty estimate in this way should be more robust than any specific area sample.

Although studies in scatterometry have demonstrated that ocean NRCS is mostly influenced by surface wind field, it is not necessarily clear if such a wind field can be extracted from PR measurements of NRCS field. If the answer is yes, we also need to know how close this extracted winds are to the truth or in-situ measurements. For this study we will focus on the wind retrieval for the benefit of surface reference techniques, and leave the calibration/validation of wind algorithm to future work. To implement this new approach, we first examined the consistency between PR NRCS data and SASS-2 model function by co-locating PR NRCS measurements and TMI brightness temperature measurements. It was found that PR NRCS data are in excellent agreements with the SASS-2 geophysical model function. To seek insight into the theoretical basis of the standard surface reference technique, we then derived a field-wise wind retrieval procedure using maximum likelihood estimation. One of the unique advantages of the field-wise approach is its capacity to incorporate

sensitivity and noise information of NRCS data consistently in both along- and cross-track dimensions. Once the wind field is estimated, the NRCS reference for rainy cells can be readily estimated using geophysical model function. Case study is presented in the next section.

## RESULTS AND DISCUSSION

In the PR and TMI match-up data set, we calculated ocean winds using TMI brightness temperatures under rain-free conditions [4]. In Fig. 1, PR NRCS observations are plotted against wind speed retrievals from TMI for several different PR incidence angle bins. The SASS-2 model function for the mean incidence angle of each corresponding angle bin is also plotted for comparison. There is an excellent agreement between model function and the PR data, which indicates that NRCS measurements can be largely explained by ocean wind field.

On August 28, 1998, category one hurricane Bonnie, located just off the Southeast coast of the U.S., was captured by ascending TRMM PR. Fig. 2 plots the inferred rain-free NRCS reference along with the PR measured NRCS at 3.7° incidence angle. Two kind of rain-free NRCS reference are presented in the Figures: the NRCS reference from standard SRT algorithm 2A21 (the solid lines) and that from the estimated surface wind field (the dotted lines). The real PR measurements are plotted as solid lines with "+" signs. In general, Both agreement and difference exist between the two different NRCS surfaces reference estimates. Wind field based surface reference follows quite well the spatial variation of mean NRCS field within the uncertainty of PR measurements. The wind field deduced surface does indicate a systematic spatial variation of NRCS up to 1.5dB. In Fig. 3, Path Integrated Attenuation (PIA) estimated based on wind field retrieval is compared with that from standard algorithm 2A21.

The first image of the Figure is PIA estimates based on surface wind analysis, the second image is PIA from TRMM 2A21 products, and the third image is rain flag. As pointed out in TRMM document [5], PIA images of 2A21 sometimes show a striated or streaky pattern where PIA jumps up and down from angle bin to angle bin as show in Fig. 3. We believe that this "streaky" pattern has two causes. First, the NRCS noise is always significant and increase with incidence angle quickly. Also, the noise is much larger at low wind conditions than at high wind conditions. When different incidence angle bins are delt independently in the standard SRTs, noise level fluctuation can be mistakenly interpreted as variations in mean NRCS field. Second, the incidence angle dependence of NRCS is not considered correctly in the standard SRTS algorithm. However, these two issues are addressed automatically in the field-wise wind retrieval algorithm. There is no "streaky pattern" in the wind field based PIA image.

The PIA estimates using both 2A21 and method in this paper are compared in Fig. 4 for the three storms examined above. There is a good correlation between two different PIA estimates. The overall mean difference is about 0.7 dB with rms difference about 1 dB. However these differences are, in general, case dependent. For instance, the rms difference is about 2.6 dB for a low wind case we examined but not shown here.

### CONCLUSIONS

Applications of this method to PR data in hurricane regions indicate that the retrieved ocean surface wind speed can adequately explain the PR NRCS observations within the measurement uncertainty. The NRCS reference and the path integrated attenuation derived from wind field analysis have a good correlation with those from the TRMM 2A21 algorithm. Nevertheless, significant differences exist between the wind-based method and the standard surface reference technique.

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### REFERENCES

- [1] C. Kummerow, W. Barnes, T. Kouz, J. Shiue, and J. Simpson, "The Tropical Rainfall Measuring Mission (TRMM) sensor package," *J. Atmos. Oceanic Tech.*, vol. 15, pp. 809–817, 1998.
- [2] R. Meneghini, T. Kozu, J. A. Jones, T. Iguchi, and K. Okamoto, "Estimates of path attenuation for the TRMM radar," *Proc. IEEE Geosci. Remote Sensing Symposium (IGARSS'98)*, Seattle, WA, 1998.
- [3] F. Wentz, S. Peteherych, and L. A. Thmas, "A model function for ocean radar cross section at 14.6 GHz," *J. Geophys. Res.*, vol. 89, pp.3689–3704, 1984.
- [4] L. Connor, and P. Chang, "Ocean surface wind retrievals using the TRMM Microwave Imager," *IEEE Trans. Geosci. Remote Sensing*, in press.
- [5] R. Meneghini, "TRMM 2A21 User's Guide," <http://trmm.gsfc.nasa.gov>, 1998b.

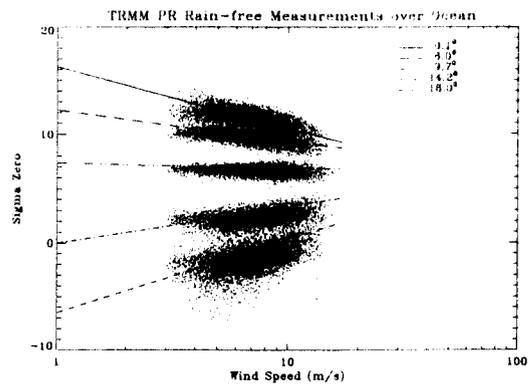


Figure 1. PR NRCS observations and TMI wind speed.

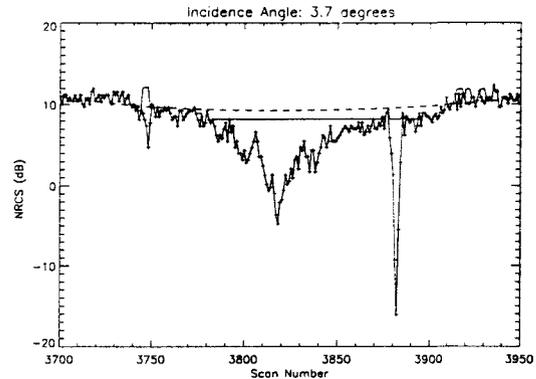


Figure 2. NRCS measurements and estimated reference.



Figure 3. Estimated PIA for hurricane Bonnie.

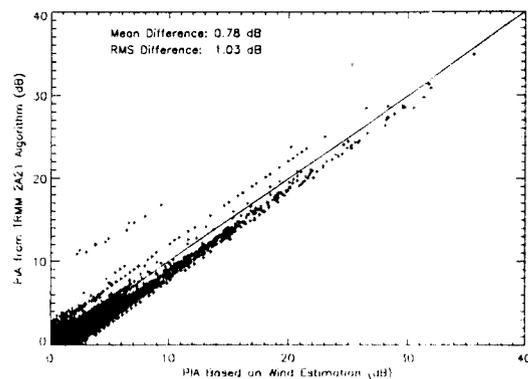


Figure 4. Comparison of PIA estimates.