TOWARDS AN IMPROVED WIND AND RAIN BACKSCATTER MODEL FOR ASCAT

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1. INTRODUCTION

The value of scatterometers in understanding the global wind field has been demonstrated over the last 3 decades. The ASCAT scatterometer, recently launched by the European Space Agency, builds on previous scatterometer knowledge to produce an accurate and reliable product. However, like previous C-band scatterometers [3] ASCAT is also subject to rain contamination. Although rain contamination is mitigated somewhat by operating at C-band (5.255 GHz), rain can still have substantial effects on the wind estimates if unaccounted for. In an effort to produce more reliable wind estimates under raining conditions this paper attempts to model the combined wind and rain effects on the observed backscatter.

2. BACKSCATTER MODEL

The ASCAT observed backscatter over the ocean the surface backscatter is a function of the wind vector, which makes wind estimation possible [1]. However, the backscatter signal is sensitive to rain. In raining conditions, the wind backscatter is modified in several ways. Rain drops striking the surface of the ocean cause increased surface roughness due additional waves in the form of stalks, rings and crowns [2]. Falling hydrometeors cause two effects on the observed backscatter. First, the backscatter from the surface of the ocean is attenuated due to the atmospheric rain. Second, the atmospheric rain causes additional scattering of the radar signal. Although there are other factors which effect the backscatter theses terms dominate the overall backscatter. Thus, we limit the backscatter model to account for each of these phenomenological terms.

The observed backscatter σ^o can be modeled as

$$\sigma^o = (\sigma_w + \sigma_{sr})\alpha_r + \sigma_r \tag{1}$$

where σ_w is the wind induced surface backscatter, σ_{sr} is the rain induced surface backscatter, α_r is the attenuation factor of the surface backscatter due to atmospheric rain and σ_r is the additional volume scattering due to atmospheric rain. To model the atmospheric effects of rain requires measurements of the atmospheric parameters. ASCAT is not capable of resolving the atmospheric effects of rain, since it lacks appropriate range resolution, we turn to another instrument.

The Tropical Rain Measuring Mission Precipitation Radar (TRMM PR) uses a 13.8 GHz radar to make atmospheric rain observations. It measures the columnar rain profile and atmospheric attenuation. Here we use TRMM PR data from observations that are spatially and temporally co-located with ASCAT. The co-located data sets consist of ASCAT backscatter observations together with TRMM PR rain profile data co-located spatially and within 10 minutes temporally. TRMM PR data for each co-location is spatially averaged to have the same resolution as ASCAT. In this paper we utilize data from 80000 such co-located measurements over the course of 2007 and 2008.

Although TRMM PR uses a significantly different frequency from ASCAT, the rain profiles and attenuation measurements can be related to C-band observations. In this short paper however, we have not fully compensated for the change in frequency.

TRMM PR also has an extremely different viewing geometry from ASCAT so we adjust each of the TRMM PR observed terms for the changes in incident angle from TRMM PR to ASCAT.

2.1. Atmospheric and surface scattering

The total atmospheric backscatter term σ_r can be estimated from TRMM PR observations of atmospheric reflectivity Z_m as

$$\sigma_r = \int_0^{r_{nc}} 10^{-10} \frac{\pi^5}{\lambda_0^4} |K_w|^2 Z_m(r) dr \tag{2}$$

where r_{nc} is the lowest no clutter range, $|K_w|^2$ is a coefficient related to the absorption properties of water and $Z_m(r)$ is the TRMM PR observed reflectivity at the range r. TRMM PR also observes the path integrated attenuation (PIA) due to atmospheric rain. The rain attenuation term α_r is calculated from PIA observations by $\alpha_r = 10^{-PIA/10}$. As noted we do not yet explicitly compensate for the change in frequency although we have compensated for the change in incidence angle. Figure 1 shows the atmospheric backscatter and attenuation models, in addition to the data used to derive the models.

To evaluate the effects of rain on the surface backscatter requires an estimate of the wind backscatter σ_w in addition to the backscatter parameters measured by TRMM PR. Estimates of the wind backscatter can be formed using predictive wind models and the geophysical model function. The European Center for Medium-Range Weather Forecasting (ECMWF) produces a model wind product with a 6hr availability and global coverage. These ECMWF wind fields can be used in conjunction with the geophysical model function, in this case CMOD5, to produce the expected wind backscatter σ_w. The geophysical model function is empirically derived to return the expected value of the backscatter given the wind vector and measurement geometry.

Combining the estimated σ_w, the TRMM PR measurements of α_r and σ_r together with the ASCAT observed backscatter σ_m allows for the estimation of the surface scatter due to rain. The estimates of the surface backscatter σ_{sr} are shown in Fig. 1 for both high and low incidence angles.

Rain drops striking the ocean surface can have several effects, not all of which are modeled here. Rain striking the ocean causes additional surface roughness in the form of ring, stalk and crown waves. These waves can increase the surface backscatter causing roughness in addition to that caused by the wind. For intense rain rates, this effect is particularly dependent upon wind speed [4]. However, above a certain rain rate this relationship breaks down as the rain-induced surface-turbulence begins to attenuate all surface waves.

2.2. Combined scattering effects

Instead of adopting the phenomenological model discussed previously, past efforts at rain modeling for scatterometers have focused on an effective rain backscatter model e.g. [3]. The effective rain model assumes that the overall contribution from the surface backscatter and atmospheric backscatter are similar. Based on this assumption the combined wind and rain backscatter model can be written $\sigma^o = \sigma_w \alpha_r + \sigma_e$ where $\sigma_e = \sigma_{sr} \alpha_r + \sigma_r$. The effective rain model has some advantages. Because there are fewer rain dependent terms the model has fewer parameters to estimate. This is advantageous not only in the model estimation but also in usage of the model for wind and rain estimation.

Despite these advantages, the effective rain model has the limitation that a fewer parameter model cannot model much variation. The effective rain model seems to fit the data quite well for low to moderate rain rates. However, for intense rain rates the scattering due to rain can be quite different.

The effective rain model is shown together with the estimates of σ_e in Fig. 1. The data readily indicates that σ_e increases with rain rate for low to moderate rain rates. Above about 15dB there is insufficient data to substantiate the model accuracy. For comparison the phenomenological model is also shown in Fig. 1. Note that although the phenomenological model is derived using estimates of σ_r and σ_{sr} it has generally the same fit to the σ_e data as does the effective rain model below 15dB. Although

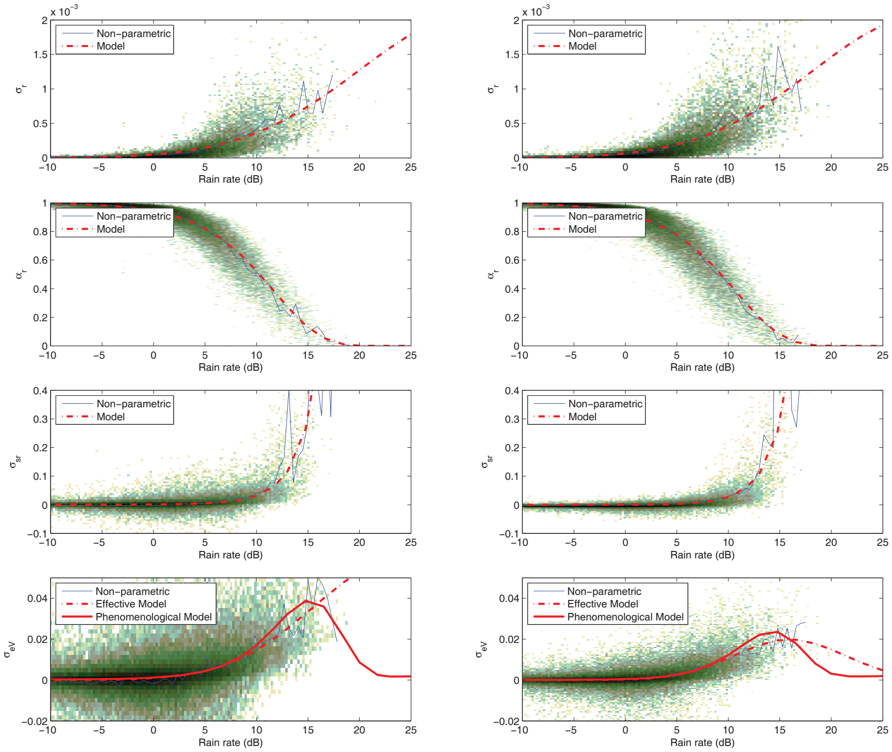

Fig. 1. Top images: σ_r as a function of integrated rain rate in dB (km-mm/hr). Upper-middle images: Two-way atmospheric attenuation α_r as a function of rain rate. Lower-middle images: Rain induced surface backscatter σ_{sr} estimates as a function of rain rate in dB. Bottom images: σ_e estimates, σ_e model and $\sigma_{sr}\alpha_r + \sigma_r$ model. The left figures correspond to incidence angles $> 45°$ and the right to incidence angles $< 45°$. Much of the variability in each image is due to the wide range of incidence angles represented.

there is little data above rain rates of 15dB, this region is of great interest.

3. MODEL COMPARISONS

Both the effective and phenomenological rain models have advantages and limitations. To compare the two models, the most important issue is to determine which model more accurately portrays the effects of rain on the observed backscatter. To illustrate this comparison each of the models is shown in Fig. 2 on a logarithmic scale as a function of rain rate in dB. Note that the models are shown as a function of incidence angle.

In each case, the model for σ_{sr} is 10 to 20dB higher than the model for σ_r. This implies that the phenomenological model is at first dominated by the surface scatter σ_{sr} but as the rain rate increases past 10 dB the phenomenological model transitions slowly to the model for σ_r. Although not shown in the figure, this transition is due to the atmospheric attenuation of the surface scatter for moderate to high rain rates. Thus for low to moderate rain rates the rain backscatter is dominated by the surface scatter but for high rain rates the atmospheric scattering dominates. This is true for all incidence angles although the point at which the transition from σ_{sr} to σ_r dominance occurs is dependent on incidence angle.

This difference between the two model types is fundamental and cannot be understated. The effective rain model parametrization essentially assumes that rain backscatter always increases with increasing rain rate. As there is relatively little data for the highest rain rate cases it is easy to adopt this assumption. However, since the surface backscatter dominates the backscatter for low to moderate rain rates this assumption can be problematic. Although there is relatively little data to

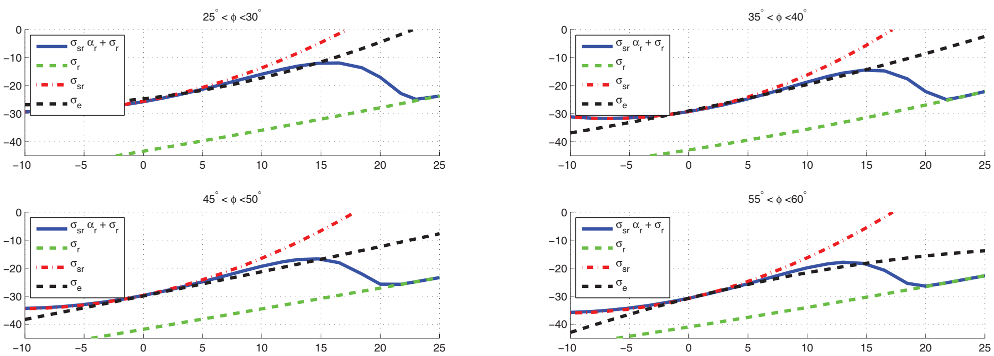

Fig. 2. Model comparisons as a function of incidence angle. Above 15 dB the data to determine each of the models is too noisy to be accurate. However the increase in attenuation as a function of rain rate appears to be a natural consequence. Above a rain rate of 15dB the σ_e model appears to increase, this is not a realistic effect and is only an artifact of the model choice..

indicate how the surface backscatter behaves for high rain rates, the effects of atmospheric attenuation are well understood and are supported by data even for the highest rain rates. Since the attenuation is dominant for moderate to extreme rain rates it is less important how the surface backscatter behaves since it is extremely attenuated. This effect, which is not accounted for in the effective rain model, is the fundamental difference between the two rain models and accounts for the inaccuracy of the effective rain model for high rain rates. Thus while the effective rain model is a reasonable approximation to the backscatter due to rain for moderate rain rates, it does not accurately portray the effects of rain on the backscatter for moderate to high rain rates.

4. CONCLUSIONS

Although this paper neglects some aspects of the rain backscatter model such as observation frequency, irregular beam-filling and a wind speed dependence, the models discussed herein reflect the general characteristics of rain induced backscatter. While the numeric values for the models may change slightly as these aspects are accounted for, it is anticipated that the general trends discussed here will not change. Thus the general characteristics of rain backscatter can be summarized for C-band as: for low to moderate rain rates the surface backscatter is dominant, for moderate to high rain rates the atmospheric attenuation begins to dominate the surface scattering and for intense and extreme rain rates the attenuation is strong enough that the atmospheric scattering is dominant. Since the effective rain model does not account for the changes in high to intense rain rates it is not a good modeling choice for high rain rates.

5. REFERENCES

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