TOWARDS AN IMPROVED WIND AND RAIN BACKSCATTER MODEL FOR ASCAT

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ABSTRACT

The ASCAT scatterometer measures the backscatter from the ocean surface with which it infers the near-surface wind vector. When rain is present in the observation area the wind-induced backscatter is modified by the rain. This paper uses co-located observations from TRMM PR to model the effects of rain on the ASCAT observed backscatter. Two model types are considered, a phenomenological rain model and a lumped effect rain model which are comparable for most rain rates. For low rain events the ASCAT observed backscatter due to rain is not substantial, however for moderate to high rains the rain-induced backscatter from the ocean surface can be significant, and for extreme rain rates the atmospheric scattering and attenuation are dominant.

***Index Terms*—** ASCAT, backscatter, wind, rain

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 ASCAT is also subject to rain contamination [1]. Although rain contamination is mitigated 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 considers general models for the combined wind and rain effects on the observed backscatter.

2. BACKSCATTER MODEL

The ASCAT observed backscatter over the ocean surface is a function of the wind vector, which makes wind estimation possible [2]. 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 [3]. 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, and 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. As 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 both 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 180000 such co-located measurements from February of 2007 to June of 2009.

2.1. Atmospheric and surface scattering

The total atmospheric rain 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, λ_0 is the ASCAT wavelength, and $Z_m(r)$ is the TRMM PR observed reflectivity at the range r [4]. Although TRMM PR has a significantly different observation geometry from ASCAT, the rain profiles can be related to C-band observations by adjusting each of the TRMM PR observed terms for the changes in incident angle

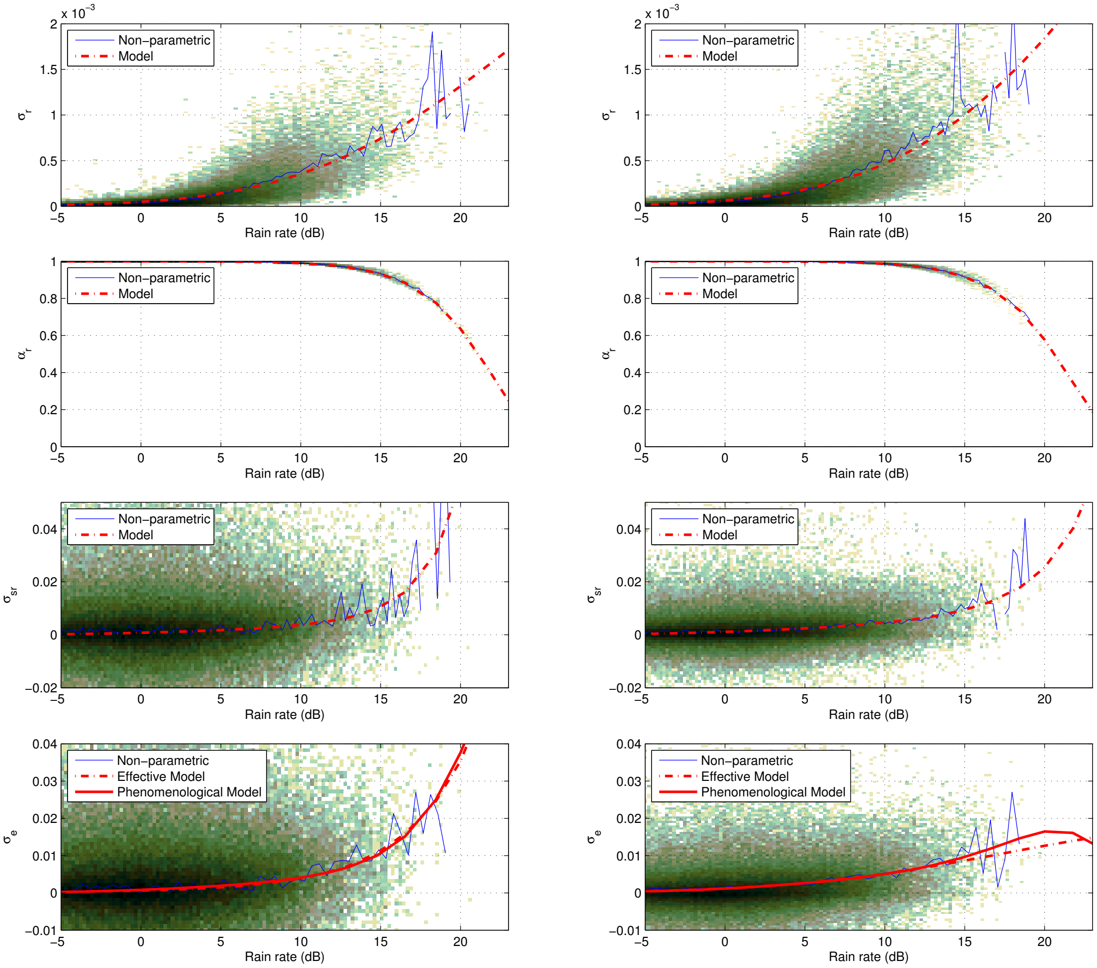

Fig. 1. Top images: σ_r as a function of surface rain rate in dB (km-mm/hr). Upper-middle images: Two-way atmospheric attenuation α_r as a function of rain rate. Lower-middle images: Rain induced surface backscatter σ_{sr} estimates as a function of rain rate in dB. Bottom images: σ_e estimates, σ_e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

from TRMM PR to ASCAT.

Since the characteristics of rain attenuation are very different at Ku-band (TRMM) and C-band (ASCAT), the TRMM measurements of the path-integrated attenuation are not applicable to ASCAT. The rain attenuation can instead be approximated using the International Telecommunications Union (ITU) rain attenuation model [5], using the surface rain rates measured by TRMM PR. 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 6 hour availability and global coverage. These ECMWF wind fields can be used in conjunction with the geophysical model function, CMOD5 [6], to compute 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, enables the estimation of the surface backscatter 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 ef-

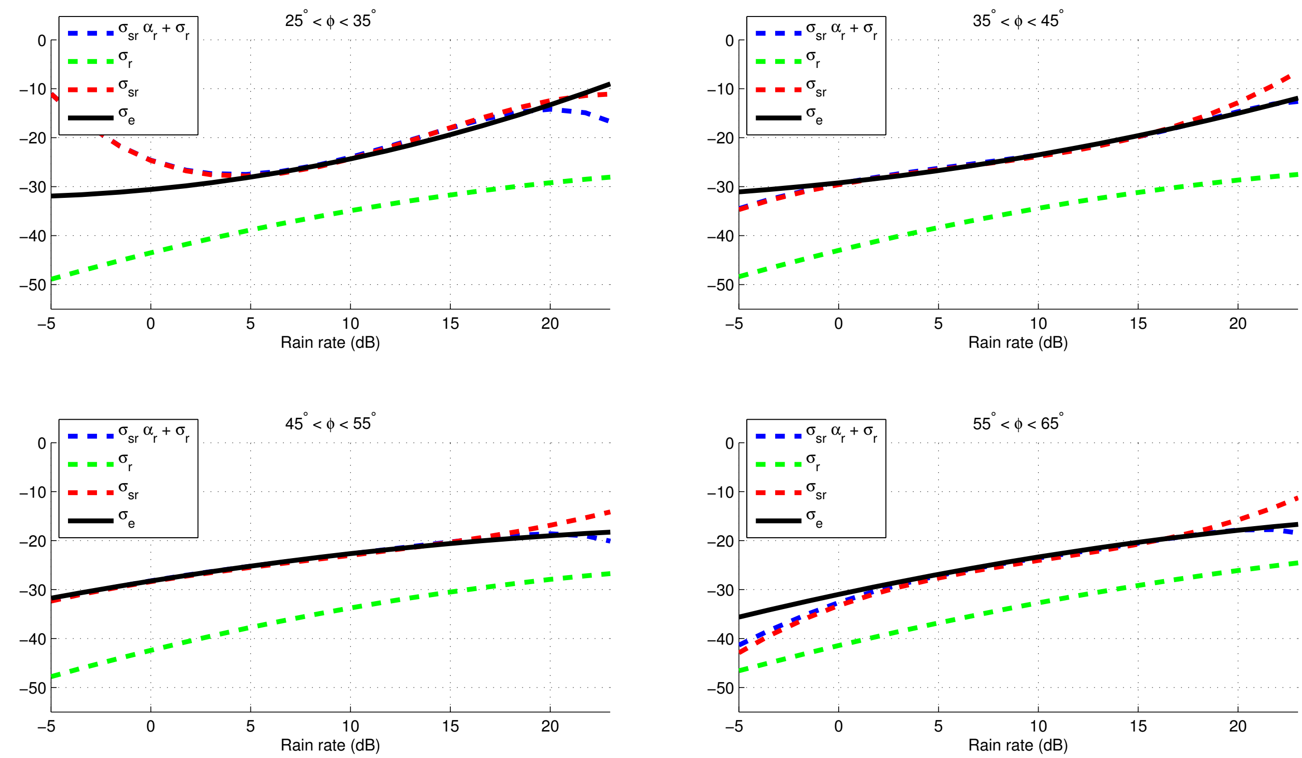

Fig. 2. Model comparisons as a function of incidence angle. Below rain rates of 0 dB and above 18 dB the data to determine each of the models is too noisy to be accurate. However the increase in attenuation as a function of rain rate appears to be a natural consequence. Above a rain rate of 20dB the σ_e model appears to increase, this is not a realistic effect and is instead an artifact of the model choice.

fects, 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 [7]. 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 in the previous section, past efforts at rain modeling for scatterometers have used an effective rain backscatter model, e.g. [1]. 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. The effective rain model fits the data quite well for low to moderate rain rates. However for intense rain rates, the scattering effects due to rain may not be modeled well.

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 18 dB there is insufficient data to substantiate the model accuracy and below 0 dB the backscatter noise is too high to discern the rain signal. 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.

3. MODEL COMPARISONS

To compare the phenomenological and effective rain 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 backscatter 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 dominated by the surface scatter σ_{sr}. Although there is insufficient extreme rain data, the rain attenuation model implies that as the rain rate increases past 20 dB the phenomenological model transitions to be dominated by the atmospheric backscatter σ_r as rain attenuation increases. Although attenuation is not shown in the figure, this transition is due to the atmospheric attenuation of the surface backscatter for moderate to high rain rates. Thus for low to high rain rates the rain backscatter is dominated by the surface scatter but for intense and extreme 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. The effective rain model parametrization essentially assumes that rain backscatter always increases with increasing rain rate. As there are relatively few of the highest rain rate cases in the co-located dataset 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 are few high rain data points to indicate how the surface backscatter behaves for high rain rates, the effects of atmospheric attenuation are well understood 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 to high rain rates, it does not accurately portray the effects of rain on the backscatter for extreme rain rates. For this the phenomenological rain model should be used.

4. CONCLUSIONS

Although this paper neglects some important aspects of the rain backscatter model such as irregular beam-filling and wind speed dependence, the model discussed herein reflects the general characteristics of rain induced backscatter at C-band as observed by ASCAT. 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 remain the same. The general characteristics of rain backscatter can be summarized for C-band as: for most rain rates the surface backscatter is dominant, however for high to extreme 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. Finally, these results also show that rain contamination is important to consider at C-band.

5. REFERENCES

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