Estimating the Atmospheric Backscatter

I. MODULE OVERVIEW

The power that is backscattered by the wind−roughened sea surface and is measured by the scatterometer instrument at 13.4 GHz can be significantly altered by the presence of liquid and frozen hydrometeors in the atmosphere. Near−surface wind speed and direction are routinely retrieved based on the surface return measured by the scatterometer. Hence, the presence of precipitation that obscures the surface signal will lead to erroneous estimates of the near−surface wind. Furthermore, the impact that the precipitating hydrometeors have on the scatterometer measurements depends strongly upon both the intensity and the phase of the precipitation (liquid versus frozen).

In the absence of rain, the scatterometer signal is attenuated by the water vapor and the cloud liquid water in the atmosphere. The attenuation increases significantly when rain and frozen hydrometeors are present in the atmospheric column. However, the precipitating hydrometeors also scatter back a significant portion of the scatterometer signal. The precipitation−related backscattered power adds up to the power scattered by the wind−roughened sea surface, thus counteracting the attenuating effect of the water vapor and the precipitating liquid (and less importantly, frozen) water particles that exist in the atmosphere. In general:

$$P_{measured} = P_{surface} * A_{AtmosphericAttenuation} + P_{Backscattered}(Rain, Graupel, Snow) \quad (1)$$

As the rain intensity increases, the power that is backscattered by the precipitating hydrometeors increases in importance. Under such conditions, correction for atmospheric attenuation only is inappropriate. In case of heavy rain, the backscattered power may overpower the effect that the atmospheric attenuation has on the power scattered by the sea surface.

All this emphasizes the importance of obtaining an estimate of the precipitation−related backscatter power and correcting the scatterometer signal for the two counteracting effects of the precipitation − attenuation of the surface signal that is coupled with additional precipitation backscatter.

II. PURPOSE

The algorithm in this module uses AMSR−based retrievals of columnar liquid in light−to−moderate rainy conditions to provide an estimate of the precipitation−related volumetric backscatter. This atmospheric backscatter estimate is computed along the scatterometer line−of−sight and has been attenuated by the precipitation in the intervening layers. The volumetric backscatter is given in equivalent sigma0 dB.

III. BACKGROUND

There are four important steps in estimating the line−of−sight volumetric precipitation backscatter that has also been attenuated by the intervening rainy layers.

1. Estimating the column height.

In light to moderate rainy conditions, the AMSR algorithms for retrieval of geophysical parameters provide estimate of the vertically integrated liquid. However, to compute the rain−related attenuation and backscatter we need the mass of the rain per unit volume − M_R. This rain mass can be obtained by the dividing the columnar liquid by the column height H. Hence, an estimate of the column height is needed. Following approaches cited in the literature, we estimate the column height as a function of the AMSR−retrieved sea surface temperature. In particular, we use the approach of Wentz and Spencer (1998) and compute the column height [km] in the following manner:

$$H = 1 + 0.14 T_{Sea\ Surface} - 0.0025 T^{2.}_{Sea\ Surface} \quad \text{for} \quad T_{Sea\ Surface} < 27.85 \quad (2)$$

$$H = 3\,km \quad \text{for} \quad T_{Sea\ Surface} \geq 27.85$$

where $T_{Sea\ Surface}$ is the temperature in degrees Centigrade.

2. Partitioning between cloud and rain

As already mentioned, in light to moderate rainy conditions, the AMSR algorithms for retrieval of geophysical parameters provide estimate of the vertically integrated liquid. This liquid includes both cloud liquid water and rain. The cloud liquid water contributes only to the atmospheric attenuation but plays no role in generating atmospheric backscatter at the frequency of the scatterometer instrument due to the very small size of the cloud droplets. Therefore, the estimation of the atmospheric backscatter requires that we first partition the columnar liquid to cloud and rain and consider only the rain amount when estimating the backscatter. Such partitioning is not necessary when columnar attenuation is estimated. Hence, the second step in the current algorithm is to provide that partitioning. To do that we start with the fact that

the columnar liquid L is equal to the sum of the columnar cloud liquid C and the columnar rain R:

$$L = C + R \quad (3)$$

We then make the assumption that the columnar liquid attenuation A_{tot} is equal to the sum of the columnar cloud attenuation A_{totC} and the columnar rain attenuation A_{totR}.

$$A_{tot} = A_{totC} + A_{totR} \quad (4)$$

In developing the AMSR algorithms we have established relations that allow us to compute the columnar attenuation (in nepers) by cloud and that by total liquid as functions of the estimated cloud and total liquid. These relationships are of the form:

$$A_{tot} = a_{1L} L + a_{2L} L^2 \quad (5)$$

and $A_{totC} = a_{1C}[1 - a_{2C}(T_C - 283)]C = a_{0C} C$ where T_C is the representative cloud temperature which is taken to be the mean temperature between the surface and the freezing level. The last relationship can be written out as:

$$A_{totC} = a_{0C}(L - R) \quad (6)$$

The coefficients a_{1C} and a_{2C} that make up the a_{0C} in equation 6, where developed by studying the relationship between the columnar cloud C that was derived from atmospheric soundings and the total attenuation by that columnar cloud that was computed with the aid of a radiative transfer model. The specification of the atmospheric scenes came from approximately 20 000 radiosonde flights launched from small islands over a three−year period. The radiosondes provide atmospheric profiles of temperature, pressure and dew point depression. Vapor density and vertically integrated vapor content were computed based on these observations. The cloud layers contained in the soundings were analyzed following Keihm et al, 1995. Cloud liquid density and vertically integrated cloud liquid were estimated.

The coefficients a_{1L} and a_{2L} that relate the columnar total liquid (cloud plus rain) to the attenuation associated with it (equation 5) were developed in a similar manner

with the only difference that the database was constructed in a different manner even though the atmospheric scenes were specified from the same set of 20 000 soundings used before. The difference is that, in the first case, soundings with diagnosed columnar liquid > 0.34 mm were considered to contain rain and, thus, excluded from consideration, while in this case they were retained. Next, sets of soundings were used to develop "observational" scenes that have horizontal inhomogeneity in them. For each "observation" 9 different atmospheric scenes were considered. The "observation" was constructed by linearly averaging the columnar total liquid and the atmospheric transmittance over the 9 points. Once the database relating the columnar total liquid and the associated atmospheric attenuation was constructed, regression was used to compute the coefficients a_{1L} and a_{2L} .

To estimate the columnar attenuation by rain we use a relationship between the density of rain [g/m^3] and the associated attenuation at 13.4 GHz. This relationship was developed by Jonathan Meagher (private communications) using Drop Size Distribution (DSDs) that were observed during the TOGA−COARE experiment. The relationship is of the form $A_R = a_R M_R^{b_R}$ where $M_R = \frac{R}{H}$ is the density of rain and A_R is given in dB/km. The vertically integrated nadir rain attenuation (in nepers) is then given by:

$$A_{totR} = \frac{a_R H^{1-b_R} R^{b_R}}{10 \log e} \quad (7)$$

where H is the column height estimated in step 1.

After substituting (5)−(7) in (4) and re−arranging the terms we obtain the following:

$$a_{1L} L + a_{2L} L^2 - a_{0C} L = -a_{0C} R + \frac{a_R H^{1-b_R} R^{b_R}}{10 \log e} \quad (8) \text{ or}$$

$$R = \frac{a_{1L} L + a_{2L} L^2 - a_{0C} L}{-a_{0C} + \frac{a_R H^{1-b_R} R^{b_R - 1}}{10 \log e}} \quad (9)$$

We solve the equation iteratively in two steps. Since b_R is very close to 1, during the first step we assume that $R^{b_R-1}=1.$ After obtaining the first estimate of R we compute R^{b_R-1} and use this new value in the second iteration.

Two additional constraints are put on the estimated rain R:

$$if\ L<0.1\ then\ R=0.$$

$$if\ L>3.5\ then\ R=L-(1.75-0.023(14.5-L))$$

The second constraint assures that: i) the cloud liquid water will not start decreasing for higher values of R after a max of $C=1.5\,mm$ at $L\simeq 3.5\,mm$ (L of 3.5 mm falls in the category of moderate−to−heavy rain and roughly corresponds to rain rates in excess of 15 mm/h); ii) the estimated cloud liquid will not exceed 1.75 mm.

Once R is estimated, the cloud−rain partitioning is done. The performance of the cloud−rain partitioning has been evaluated and the following has been found: i) rain begins when the total liquid L > 0.1 mm; ii) the cloud liquid C increases with rain; iii) the cloud versus rain relationship levels off at high rain with C reaching a maximum value between 1 and 2 mm. These three characteristics were found to be true for 38 northeast Pacific extratropical cyclones (Wentz, 1990) with the exception that the onset of rain was associated with L > 0.18 mm. Indeed, Wentz and Spencer (1998) developed a cloud−rain rate parameterization based on the above study.

3. Estimating the equivalent radar reflectivity at each level in the vertical

The equivalent radar reflectivity per unit volume ($\frac{mm^6}{m^3}$) is computed in linear units using the relationship

$$Z=c_R M_R^{d_R}=c_R\left(\frac{R}{H}\right)^{d_R} \quad (10)$$

The parameters c_R and d_R were determined by Jonathan Meagher (private communications) using observational data collected during the TOGA−COARE experiment.

4. Computing the line−of−sight attenuated volumetric backscatter

The final step in estimating the line−of−sight volumetric atmospheric backscatter involves integration of Z (the equivalent radar reflectivity factor per unit volume) along the slant path. During this integration the point estimates of Z from equation (10) are first attenuated by the intervening rainy layers and then summed up. Finally, the volumetric atmospheric equivalent radar reflectivity factor Z_{tot} ($\frac{mm^6}{m^2}$) is converted to equivalent sigma0 linear units using

$$\eta = \frac{\pi^5}{\lambda^4} K_W^2 \, Z_{tot} \frac{1}{10^{6*3}} \qquad (11)$$

where K_w^2 is the dielectric constant for water and λ is the wavelength of the scatterometer in m.

To produce an estimate of the wind−related surface sigma0 in the L2B processor, the line−of−sight attenuated volumetric precipitation backscatter η is first subtracted (in linear units) from the measured sigma0 and, then, the atmospheric attenuation correction (including rain) is applied to the result.

<u>NOTES</u>:

1. It should be noted that the underlying assumption in all of the above computations is the assumption that the cloud and the rain are uniformly distributed with height. This is certainly only an approximation. However, employing such an approximation is justified by the results of a study by Kyle Hilburn and Frank Wentz reported at the

2003 SeaWinds Cal/Val meeting. In their study they looked at the relative importance (negative impact) of assumptions about vertical homogeneity, horizontal homogeneity and Drop Size Distributions (DSDs). They found that: i) assumptions of vertical homogeneity appear to have no impact on attenuation estimates while horizontal homogeneity (beamfilling) assumptions can modulate the attenuation estimates by 3 to 5 dB for rain rates of 25 mm/h; ii) vertical homogeneity assumptions have an impact of backscatter estimations but only for higher rain rates (> ~4 mm/h). For these higher rain rates, the vertical profile assumptions were as important as the DSD assumptions.

Based on their results we conclude that vertical homogeneity assumptions have a smaller negative impact on estimations of attenuation and backscatter in *light rain conditions (rain rate < 5 mm/h)* than the assumptions of horizontal homogeneity. While we assume vertical homogeneity, we have taken care to properly resolve the horizontal inhomogeneity in the observations. We accomplish that by using a number of different (in homogeneity and rain−intensity) retrieval databases and selecting a particular retrieval datatabase for each retrieval data point based on the observed horizontal variability of the AMSR−based rain indicator.

2. This algorithm is very new and its performance is currently under investigation by the JPL team. The performance evaluation might lead to changes in parameters and increase in complexity of the approach (e.g. inclusion of geographically specific Z−M relationships that would account for the likely geographical variability of the DSD distributions).

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