Sea Winds AMSR Rain Indicator Algorithm

I. MODULE OVERVIEW

The power that is backscattered by the wind−roughened sea surface and is measured by the scatterometer instrument at 13.8 GHz is 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 particular, light to moderate rain primarily attenuates the measured by the scatterometer signal. Not accounting for the presence of such rain would, thus, result in an underestimation of the near−surface wind speed and in a possibly wrong wind direction estimation.

On the other hand, when moderate to heavy rain and frozen hydrometeors are present in the atmospheric column, they 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:

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

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.

Failure to properly account for the two counteracting effects that precipitation has on the scatterometer measurements would result in erroneous wind speed and direction estimates that are based on these measurements. This clearly illustrates the need of using reliable methods for: i) identifying the rainy situations and separating them from the non−rainy ones; ii) estimating the intensity of the rain with the purpose of determining which one of the two regimes is present.

Microwave observations of the top of the atmosphere (TOA) radiation have been proven to provide very valuable information about the presence and the amounts of precipitating hydrometeors with which the earth−emitted radiation interacts as it propagates through the atmosphere. The AMSR instrument that flies on board the ADEOS−II spacecraft provides such information and carries the significant benefit of providing observations that are collocated and contemporaneous with the scatterometer data.

SWS Algorithm Specification −− AMSR Rain Indicator

Purpose

The algorithm in this module uses AMSR measurements of brightness temperatures at both vertical and horizontal polarization and at different frequencies to compute the Rain Indicator. The Rain Indicator can be then used to identify the presence of rain and to define which regime (attenuation−dominated or precipitation−backscatter dominated) is prevalent. It should be noted that the algorithm uses AMSR actual observations (with frequency−dependent spatial resolution) as opposed to using the "constructed" AMSR measurements (the resampled to common spatial resolution observations).

Background

Microwave signals at the top of the atmosphere (TOA) can be classified into two categories depending on how the microwave field interacts with the hydrometeors:

− emission signal − dominant at lower frequencies; warming signature

− scattering signal −dominant at higher frequencies; cooling signature

Emission and scattering based algorithms work favorably in different rainfall regimes:

− emission signal − better for light rain

− scattering signal −better for heavy rain

Hence, both emission and scattering signals have to be incorporated in the algorithms in order to cover the entire rainfall spectrum.

<u>Emission signal</u>

Strong emission in the atmosphere reduces the polarization difference (PD) of the radiation emitted from the highly polarized ocean surface. The polarization difference is representative of the atmospheric emission itself. The advantage of using the PD (or Polarization Index − PI) over Tbs is that PD is largely independent of the physical atmospheric temperature.

$$PD=\frac{TB_V-TB_H}{TB_{VBackGround}-TB_{HBackGround}} \quad (2)$$

$$RI_{emission} = 1 - \frac{1}{\sum a_i} \sum a_i * PD_i \quad (3)$$

where i=1,N is the number of channels that are used

Scattering signal

$$RI_{scattering} = 1 - \frac{(1+0.818)*TB_{V89} - 0.818*TB_{H89}}{(1+0.818)*TB_{V89BackGround} - 0.818*TB_{H89BackGround}} \quad (4)$$

Rain Indicator

$$Rain\,Indicator = a_o * RI_{emission} + a_1 * RI_{scattering} + a_2 * RI^2_{scattering} \quad \mathbf{(5)}$$

The Rain Indicator has been found to vary between roughly −4 and +6 (currently, values in the range −6 to +9 are accepted as valid). A value of $RI < 0.5$ indicates non−raining conditions. A value of $0.5 < RI < 4.2$ has been found to indicate the presence of light to moderate rainy conditions, while a value of $RI > 4.2$ is indicative of the presence of moderate to heavy rainy conditions.

To evaluate the performance of the Rain Indicator as a rain flag, we used TMI data and computed the Rain Indicator for a number of TRMM orbits. Comparison of the rain−no−rain classification made by the current Rain Indicator to the classification made by the TMI−based rain indicator that is used by the TRMM mission shows 86.5 % success rate in agreement in identifying rainy conditions and 99.3 % success rate in agreement in identifying non−rainy conditions, thus bring the success rate of having the two independent indices in agreement to 98.8%. Instead, if a value of $RI < 0.4$ is used to indicate non−rainy conditions then the success rate of agreement between the current Rain Indicator and the TMI−based one becomes the following: 93.1% success rate in identifying rainy conditions; 98.8% success rate in identifying non−rainy conditions; and 98.6% success rate of having the two independent indices in agreement.

At low RI values (low intensity rain) the attenuation of the surface signal by the precipitating hydrometeors is the dominant source of error. In this case

$$\frac{P_{surface} * A_{VaporAttenuation}}{(P_{surface} * A_{Vapor\ Cloud\ Rain\ Attenuation} + P_{Backscattered}(Rain, Graupel, Snow))} > 1.$$

which indicates that the power that is backscattered by the precipitating hydrometeors is not sufficient to compensate for the precipitation−related loss of surface−scattered power.

As the Rain Indicator value increases above the 0.5 threshold for the onset of light precipitation, the power that is backscattered by the precipitating hydrometeors increases in importance. Under such conditions, correction for atmospheric attenuation only is inappropriate.

As the value of the Rain Indicator increases above the 4.2 threshold, the power that is backscattered by the hydrometeors in the atmosphere dominates the surface echo signal and the following relationship becomes true:

$$\frac{P_{surface} * A_{Vapor\ Cloud\ Rain\ Attenuation}}{(P_{surface} * A_{Vapor\ Cloud\ Rain\ Attenuation} + P_{Backscattered}(Rain, Graupel, Snow))} \ll 1.$$

<u>Determining the background conditions</u>

The above−defined Rain Indicator has the potential not only to separate rainy from non−rainy conditions but also to identify the dominant mode of the effect that precipitation has on the surface signal measured by the scatterometer. However, the Rain Indicator is dependent upon a good knowledge of the background brightness temperatures.

To provide this knowledge we originally used the NOAA/NESDIS algorithm to estimate the Liquid Water Path (LWP) in the atmospheric column:

$$LWP_{19} = -2.7(\ln(290 - TB_{19V}) - 2.84 - 0.40 \ln(290 - TB_{22V})) \quad \textbf{(6)}$$

or

$$LWP_{37} = -1.15(\ln(290 - TB_{37V}) - 2.99 - 0.32\ln(290 - TB_{22V})) \quad \textbf{(7)}$$

The likelihood of drizzle or rain is high when $LWP_{19} > 0.6\,mm$ or $LWP_{37} > 0.2\,mm$. Because of that $LWP_{37} < 0.075\,mm$ was used as an indicator of clear or cloudy but non−raining conditions. The brightness temperatures observed at each channel under non−raining conditions were then used to define the background conditions that are needed in order to compute the Polarization Differences.

In an effort to improve the definition of the background, a new formula for the LWP estimation was later developed based on our database. Formula (8) is currently used to provide the initial estimate of the LWP. Areas with LWP< 0.075 mm are considered to be cloud−free and their brightness temperatures are used to define the background conditions.

$$LWP = 0.0350 + 1.328 * (-\ln(290. - TB_{36v}) + 4.211) - 0.472 * (-\ln(290 - TB_{23V}) + 4.047) \quad (8)$$

INPUT

The algorithm needs the following AMSR brightness temperatures that are generated by Level 1A processor:

tb_18v	18.7 GHz vertical polarization
tb_18h	18.7 GHz horizontal polarization
tb_23v	23.8 GHz vertical polarization
tb_23h	23.8 GHz horizontal polarization
tb_36v	36.5 GHz vertical polarization
tb_36h	36.5 GHz horizontal polarization
tb_89v	89.0 GHz vertical polarization
tb_89h	89.0 GHz horizontal polarization

Furthermore needed are:

scan_quality_flag	bit flags that indicate the character and the quality of the data observed within a particular radiometer scan
tb_surface flag	surface flag for brightness temperature measurements that carries information about land and/or sea ice contamination
tb_quality_flag	bit flags that indicate the quality of each AMSR observation for each instrument channel.

OUTPUT

tb_rain_indicator — a non−dimensional parameter that reflects the ambient atmospheric conditions

amsr_param_qual_flag — bit flags that indicate the quality of the geophysical parameters that are retrieved based on the AMSR observations

PROCESSING

Step 1: For each scan, check the scan_quality_flag to determine whether the scan has good quality data for the channels 18.7 V, 18.7 H, 23.8 V, 23.8 H, 36.5 V, 36.5 H, 89.0 V and 89.0 H. If not, skip the computation of the Rain Indicator for that scan.

Step 2: For each location, use tb_surface flag to determine whether land is present in the Field of View (FOV) of any of the above channels. Determine whether sea ice is detected in the FOV. If land or sea ice are detected, skip the computation of the Rain Indicator for this location.

Step 3: For each location, use tb_qual_flag to determine whether there are good quality data for the channels 18.7 V, 18.7 H, 23.8 V, 23.8 H, 36.5 V, 36.5 H, 89.0 V and 89.0 H. If not, skip the computation of the Rain Indicator for that location.

Step 4: In each rev, use the first good AMSR measurement over open water to define the background (BG) brightness temperatures for each channel. The background brightness temperatures are defined as these observed in clear air or cloudy but non−precipitating conditions. Since the first good open water AMSR measurements in each rev will be found over the Antarctic waters, the likelihood of observing rain there is very low. Hence, the observations should be representative of the BG conditions. Confirm the absence of rain by computing the Liquid Water Path (LWP) following our new approach (equation 8). If LWP < 0.075 mm, then no rain or significant cloud is present and BG brightness temperatures are set to be equal to the observed at this location. If LWP > 0.075 mm, skip the BG Tb definition and proceed to the next good AMSR observation to repeat the process of BG definition. *The Rain Indicator is not computed at the location(s) used to define the background conditions for the southern−most good AMSR observations*.

Step 5: Compute the tb_rain_indicator. This is a three−step processes: first, the Polarization Differences for each of the participating frequencies are computed by making use of the actual observations and the BG brightness temperatures corresponding to the particular frequencies (equation 2); next, computed are the emission and scattering indices (equations 3 and 4); finally, the emission and scattering indices are combined to produce the Rain Indicator (equation 5).

Step 6: Compute the LWP using the new algorithm (equation 8). If LWP < 0.075 mm, update the BG brightness temperatures to the ones observed at the current location. If LWP > 0.075 mm, then proceed without updating the BG temperatures.

Step 7: If the computed Rain Indicator falls in the range −6 to +9 (−6 < RI < +9), then set bit 20 of the amsr_param_qual_flag to 0 (meaning that the Rain Indicator based on AMSR is usable).

Repeat steps 2,3,5,6 and 7 for each observation in the scan. For each new scan, start with step 1. Step 4 is executed only once per rev.

References:

Wentz, F. J., and T. Meissner, 2000: Algorithm theoretical basis document (ATBD) AMSR Ocean Algorithm, RSS Tech Proposal 121599A−1