

# LONG TERM TREND OF OCEAN SURFACE NORMALIZED RADAR CROSS SECTION OBSERVED BY TRMM PRECIPITATION RADAR

Ken'ichi Okamoto<sup>(1),(2)</sup>, Tsuyoshi Kubokawa<sup>(3)</sup>, Akio Tamura<sup>(4)</sup> and Tomoo Ushio<sup>(5)</sup>

(1) *Osaka Prefecture University, 1-1, Gakuen-Cho, Sakai, 599-8531, Osaka, Japan,*

*E-mail:okamoto@aero.osakafu-u.ac.jp*

(2) *Earth Observation Research Center, NASDA, Office Tower X, 23 F, Triton Square, 1-8-10, Harumi, Chuo-ku, Tokyo, 104-6023, Japan*

(3) *As (1) above, but E-mail: kubokawa@aero.osakafu-u.ac.jp*

(4) *As (1) above, but E-mail: tamura@aero.osakafu-u.ac.jp*

(5) *As (1) above, but E-mail: ushio@aero.osakafu-u.ac.jp*

## ABSTRACT

We analyzed monthly averages and standard deviations of NRCS observed by the TRMM PR over three years from January 1998 to December 2000. It is found out that the standard deviation of NRCS takes the minimum values of about 1.3 dB for incidence angles about 5°. Scatter plots of the wind speed observed by TMI versus NRCS by PR were calculated for various incidence angles. Positive and negative correlations between wind speeds observed by TMI and NRCS by PR were found clearly for larger (more than 15°) and smaller (less than 3°) incidence angles, respectively.

## INTRODUCTION

Tropical Rainfall Measuring Mission (TRMM) is the joint U.S.-Japan space mission dedicated to observe tropical and subtropical rainfalls that play a key role in the global hydrologic cycle and in the global energy cycle. The orbit of TRMM takes the altitude of 350 km and is inclined 35 degrees. TRMM has three sensors to observe precipitation. They are the precipitation radar (PR), multi-channel dual polarized microwave radiometer (TMI), and visible and infrared cross-track scanning radiometer (VIRS). TRMM PR is the first spaceborne precipitation radar to observe the three dimensional structure of rain. The PR operates at 13.8 GHz with the horizontal polarization. In addition to the precipitation, it can observe the back scattering properties of the Earth's surface. These data also may be used for the remote sensing of the ocean surface wind and so on. We analyzed the incidence angle dependence of the ocean surface NRCS (Normalized Radar Cross Section) observed by the TRMM PR over the three years from January 1998 to December 2000. The NRCS data are provided by the TRMM PR standard algorithm 2A21[1]. Monthly averages and standard deviations of NRCS of the ocean under the conditions of no rain were calculated over the area of latitude within +/- 35 degrees for three years. One of the targets of this research is to find the incidence angle which is the most insensible to the ocean surface conditions produced mainly by the wind over the ocean surface. This incidence angle will be useful for the calibration of TRMM PR and future spaceborne precipitation radars by using the ocean surface as the natural calibrator. The other target of this research is to find incidence angles which are sensible to the ocean surface condition produced by the winds and to study the dependence of NRCS on the surface wind speed for these incidence angles. As the reference data of the surface wind speed, the ocean surface wind speed data produced by the TMI were used.

## INCIDENCE ANGLE DEPENDENCE OF OCEAN SURFACE NRCS

The cross track scan angles (off-nadir angles) of the TRMM PR, which are almost equal to the incidence angles to the Earth's surface, are limited to +/-17.04 degrees with step of 0.71° from the nadir. Although the cross track scan consists of 49 angle bins or beam positions, there are only 25 distinct off-nadir angles by considering symmetrical configuration of beam positions around the nadir direction. Fig. 1 shows the incidence angle dependence of the

ocean surface NRCS in January 2000 in dB unit. Both the average and standard deviation of NRCS are shown for each incidence angle. The theoretical curve shows the best fit result by using the quasi-specular scattering formula of NRCS by Valenzuela[2],

$$\sigma^0 = \frac{R^2}{s^2} \frac{1}{\cos^4 \theta} \exp\left(-\frac{\tan^2 \theta}{s^2}\right) \quad (1)$$

where  $R$  is the Fresnel's reflection coefficient for normal incidence, and  $s^2$  is the mean square surface slope contributed by ocean wave whose lengths are greater than the wavelength of the microwave.  $R^2$  takes 0.481996 and  $s^2$  takes 0.02668 in Fig. 1. Standard deviation takes minimum value about 1.3 dB around incidence angle of 5°. All analyzed NRCS data for 36 months show the similar incidence angle dependence and standard deviations take minimum value around incidence angle of 4-5°. Fig. 2 shows variation of NRCS for 36 months (Jan. 1998 - Dec. 2000) at incidence angles of 4.45°, 10.45° and 16.45°. Averages of NRCS of three incidence angles are very stable. Averages of NRCS at all remaining 22 incidence angles also take very stable value.

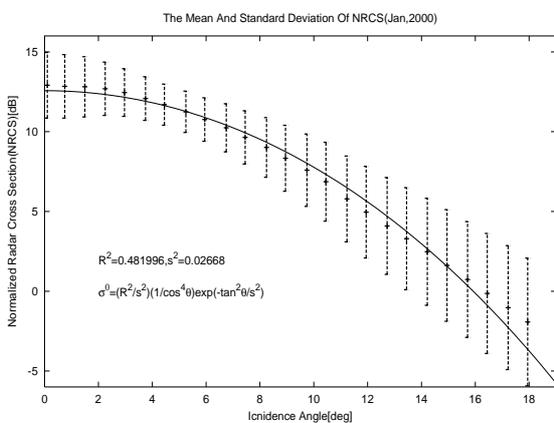


Fig. 1 Incidence angle vs. NRCS (Jan. 2000)

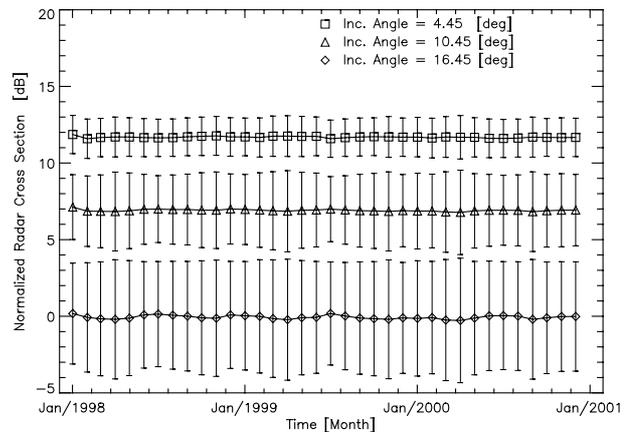


Fig. 2 Variation of NRCS at 4.45°, 10.45° and 16.45°

Fig. 3 shows standard deviations of monthly averages of NRCS of all incidence angles for 36 months. Standard deviations are less than 0.13 dB for all incidence angles and monthly averages of NRCS are very stable. Standard deviation of the monthly averages of NRCS takes minimum values of about 0.05 dB around incidence angles of 5-8°. This results shows that NRCS values for incidence angles about 5° can be used for calibration of the TRMM PR and the next generation's spaceborne radars.

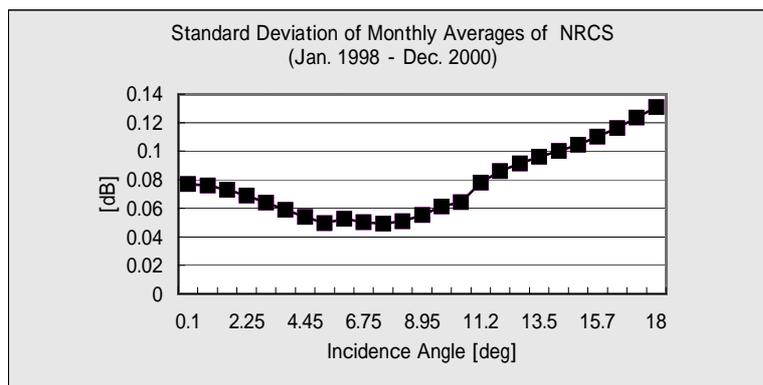


Fig. 3 Standard deviation of monthly averages of NRCS

## RELATION BETWEEN OCEAN SURFACE NRCS AND WIND SPEED OVER THE OCEAN

Average values of NRCS ( $\sigma^0$ ) are calculated for each  $1^\circ \times 1^\circ$  grid box within the longitude of  $0^\circ$ - $360^\circ$  and the latitude of  $\pm 35^\circ$ . Yearly average values of NRCS for all off-nadir angles (as the difference of the off-nadir angles and incidence angles are less than  $1^\circ$  at the most, we call it incidence angle hereinafter) are calculated in 1998, 1999 and 2000. The ocean surface wind speed data retrieved from the TMI 37 GHz brightness temperature data by Wentz were used. The data shows monthly averaged wind speeds of 10m above the sea surface which are calculated for each  $0.25^\circ \times 0.25^\circ$  grid box. These data are averaged to produce yearly averaged wind speeds for each  $1^\circ \times 1^\circ$  grid box within the longitude of  $0^\circ$ - $360^\circ$  and the latitude of  $\pm 35^\circ$ . When the wind speed over the ocean surface is weak, ocean surface is smooth and behaves like a mirror to result the steep decrease of reflected power as the incidence angle increases. On the other hand, when the wind speed is strong, ocean surface becomes rough and backscattered power decreases gently as the incidence angle increases. Therefore it is expected that NRCS decreases as wind speed increases for small incidence angle and NRCS increases as wind speed increases for large incidence angle. Fig. 4, 5, and 6 show the scatter plots between the logarithm of ocean surface wind speed and NRCS (dB) when the incidence angles are  $0^\circ$ ,  $7.81^\circ$  and  $17.04^\circ$ , respectively in 2000. Contours show the data sample number and linear lines in the figures are determined by the least square method.

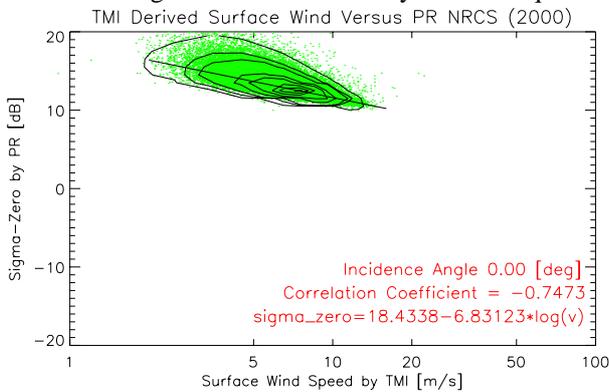


Fig. 4 Relation between NRCS and ocean surface wind speed in 2000 (incidence angle =  $0^\circ$ )

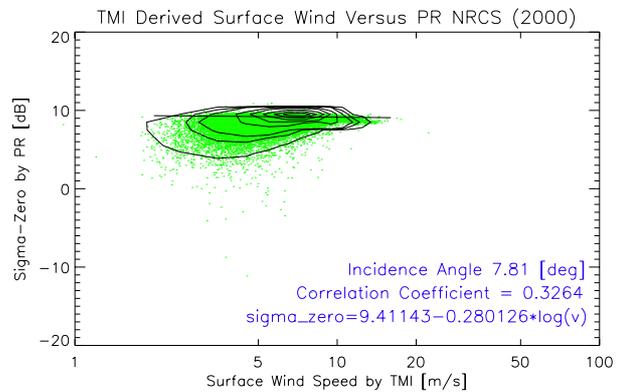


Fig. 5 Relation between NRCS and ocean surface wind speed in 2000 (incidence angle =  $7.81^\circ$ )

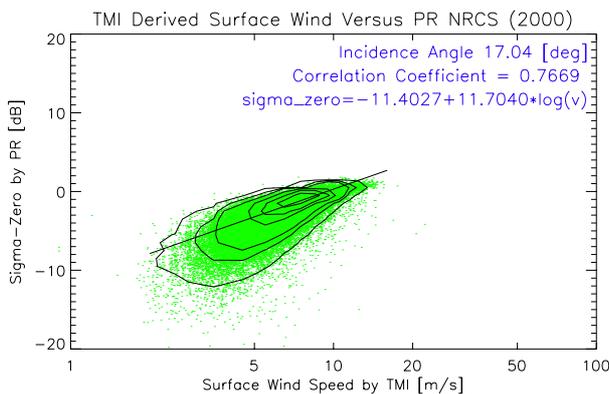


Fig. 6 Relation between NRCS and ocean surface wind speed in 2000 (incidence angle =  $17.04^\circ$ )

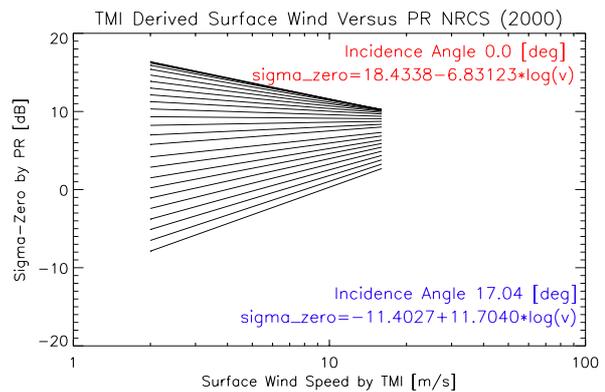


Fig. 7 Linear lines which approximate relation between NRCS and ocean surface wind speed for each incidence angle.

In Fig. 4 (incidence angle =  $0^\circ$ ), NRCS decreases as the ocean surface wind speed increases. The negative correlation between NRCS and the ocean surface wind speed is observed and the correlation coefficient is  $-0.7473$ . In Fig. 5 (incidence angle =  $7.81^\circ$ ), NRCS does not depend on the ocean surface wind speed. No correlation is observed

between NRCS and the ocean surface wind speed and the correlation coefficient is 0.3263. In Fig. 6 (incidence angle =17.04°), NRCS increases as the ocean surface wind speed increases. The positive correlation between NRCS and the surface wind speed is observed and the correlation coefficient is 0.7669. Fig. 7 shows the group of linear lines which approximate relations between ocean surface wind speed and NRCS for 25 incidence angles. The uppermost line shows approximate relation for the incidence angle of 0° and the bottommost line shows approximate relation for the incidence angle of 17.04°. The incidence angle increases by 0.71°. Table 1 shows coefficient  $a$  and  $b$  when the relation between  $\sigma^0$ (dB) and  $v$ (m/s) is approximated as

$$\sigma^0 (dB) = a \log(v) + b \quad (2)$$

Table 1. Values of  $a, b$  in  $\sigma^0(dB) = a \log(v) + b$  (2000)

Incidence Angle (°)	$a$	$b$	Incidence Angle (°)	$a$	$b$
0	-6.83	18.43	9.23	1.50	6.55
0.71	-6.80	18.36	9.94	2.48	5.03
1.42	-6.60	18.18	10.65	3.47	3.14
2.13	-6.26	17.80	11.36	4.43	1.53
2.84	-5.69	17.11	12.07	5.36	-0.109
3.55	-4.95	16.15	12.78	6.28	-1.66
4.26	-4.12	15.10	13.49	7.20	-3.24
4.97	-3.28	13.98	14.20	8.11	-4.85
5.68	-2.50	12.88	14.91	9.02	-6.50
6.39	-1.75	11.79	15.62	9.87	-8.07
7.10	-1.04	10.63	16.33	10.89	-9.77
7.81	-0.28	9.41	17.04	11.70	-11.40
8.52	0.57	8.05			

## CONCLUSIONS

The incidence angle dependence of the ocean surface NRCS show that standard deviation of NRCS takes minimum value about 1.3 dB around incidence angle of 5°. Standard deviations of the monthly averages of NRCS take minimum values of about 0.05 dB around incidence angles of 5-8°. This results shows that NRCS values for incidence angles about 5° can be used for calibration of the TRMM PR and future spaceborne radar. The positive correlations between ocean surface wind speed by TMI versus NRCS by PR were found clearly for larger incidence angles (especially for more than 15°) and negative correlations between ocean surface wind speed by TMI versus NRCS by PR were found clearly for smaller incidence angles (especially for less than 3°), respectively. These results suggest that the TRMM PR can be used to retrieve the ocean surface wind speeds. The incidence angle which is the most insensible to the ocean surface wind speed is found to be about 8°. This value of incidence angle is a little larger than the incidence angle of 5° which is recommended for the calibration of TRMM PR and future spaceborne radar.

## ACKNOWLEDGEMENTS

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## REFERENCES

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