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CHANGE OF THE BRIGHTNESS TEMPERATURE IN THE MICROWAVE REGION DUE TO THE RELATIVE WIND DIRECTION

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1. ABSTRACT

The dependence of the brightness temperature of the spaceborne microwave radiometer on the relative wind direction to the sensor direction is evaluated using the match-up data between the SSM/I brightness temperature and QuikSCAT wind vector cell from 1999 August to December. The number of the match-up data is 2011056 with cut-off criteria is 5 minutes in time and 25km in distance. We try the preliminary approach by using the match-up data. The change of 37GHz horizontal polarization caused by wind is extracted as the shift from the relationship between horizontal and the vertical polarization without surface wind. Significant changes of both the brightness temperature itself and the shift of the horizontal polarization due to wind are found depending on the relative wind direction. The impact of the apparent change according to the relative wind direction can become up to about 5K, which might correspond to 20% to 40% of the retrieved wind speed.

2. INTRODUCTION

The ocean surface wind speed can be estimated by using the dependence of the brightness temperature of the airborne microwave radiometer on the polarization and the frequency, using the knowledge of the statistical distribution of the facets of the ocean surface according to the surface stress. Cox and Munk (1954a 1954b) carried out a frontier work that pointed out the different distribution of the facets of the ocean surface between the cross-wind and the along-wind direction. Recently, Ebuchi and Kizu (2002) investigated the difference of the distribution with numerous sun glitter data derived by the satellite observation. They concluded that the result of Cox and Munk was likely to overestimate the skewness of the distribution of the ocean surface under the cross-wind condition. However, there is still significant difference between the cross-wind and along-wind condition. Therefore, the brightness temperature of the microwave observation may shift according to the direction of the surface wind relative to the direction at which the sensor is looking. Wentz (1992), from the brightness temperature observed by Special Sensor Microwave/ Imager (SSM/I) collocated with the buoy-based vector winds, carefully evaluated the dependence on the relative wind. Although their result showed the apparent shift of the brightness temperature due to the wind direction relative to the sensor, their result may have problems due to the small number of the collocated data and the limited condition. Advanced Earth Observation Satellite II (ADEOS-II) installs the micro wave scatterometer in addition to micro wave radiometer Advanced Microwave Scanning Radiometer(AMSR). It is forecast that a large amount of collocated observations of the brightness temperature and the

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wind vector is obtained. This study will present the preliminary analysis of the dependence of the brightness temperature on the relative wind direction based on the collocated data in order to improve the presumption accuracy of the sea winds without knowing the in situ wind direction, by quantitatively evaluating the shift of the brightness temperature due to the surface meteorological and oceanographic conditions, because the microwave radiometer is not necessarily installed with scatterometer.

The brightness temperature of the SSM/I and the wind vector, which are obtained by the microwave scatterometer, are compared as a preliminary experiment, and the dependence of the brightness temperature is examined.

3. DATA AND METHOD

The match-up data set is made from the brightness temperature of SSM/I and the vector winds at level 2B of the SeaWinds installed on QuikSCAT from August 1999 to December. The cut-off criteria of the difference of the each observation cells are 25km in the distance of the center of the observation cells and 5minutes in the observation time. The sea surface temperature (SST) in the observation cell of SSM/I used the weekly mean temperature of the objective analysis, which had been made by the method of Reynolds and Smith (1994). The precipitable water and the liquid water of the column are presumed from the brightness temperature of SSM/I.

The data exists in the limited area in the south Indian Ocean due to the relation of the orbit of both satellites, though the number of match-up data was 2011056 in total. The geographical distribution of them is limited within high latitudes. The azimuth angle of the direction at which SSM/I is looking and the meteorological and oceanic condition such as SST or wind speed may be partial in range as shown in Figure 1. Many of the relative wind directions to the sensor exist on the left-hand side possibly because of the tendency of the persistent wind direction in the high latitude. This problem about the

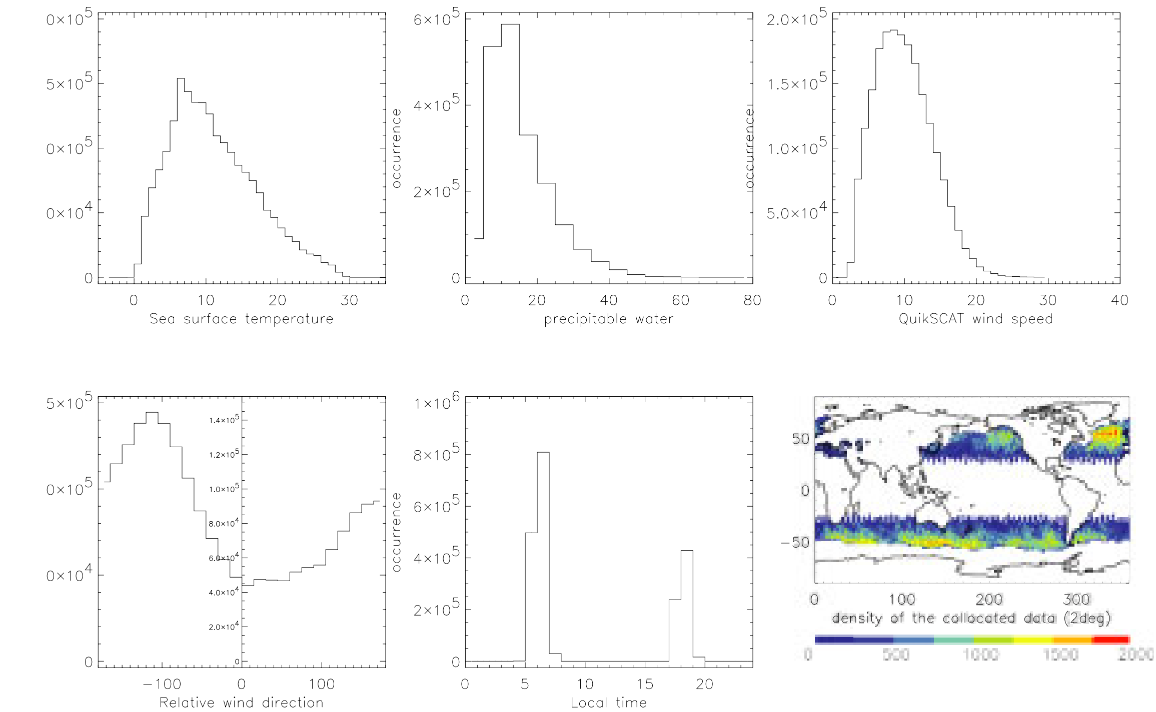

Figure 1: The distribution of the meteorological and oceanic conditions of the match-up data. The histograms of the occurrence of SST (top left), precipitable water (top center), wind speed (top right), wind direction relative to the sensor direction (bottom left), local time (bottom center), and the spatial distribution of the match-up data (bottom right) from August 1999 to December 1999 are shown.

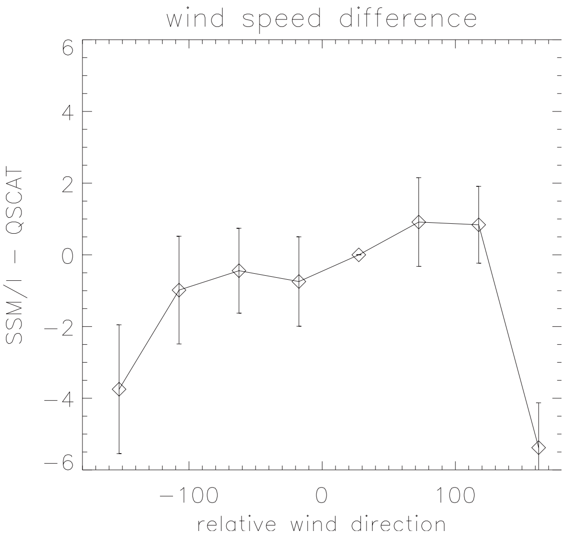

Figure 2: The mean (diamond) and the standard deviation (vertical bar) of the differences between the SSM/I wind speed and QuikSCAT wind speed at each category of the relative wind direction.

limited area and the partial distribution of the meteorological condition cannot be avoided until the simultaneous observation of scatterometer and the radiometer becomes possible.

Although the match-up data is in the limited meteorological condition, the preliminary analysis can be made in ranges where a large number of observations exist. A comparison between the raw SSM/I wind and the QuikSCAT wind at selected ranges of the relative wind direction reveals the significant effect on the retrieved wind speed by the shift of the brightness temperature due to the relative wind direction as shown in Figure 2. Figure 2 also shows the asymmetry between the upwind and the downwind cases. The means and the standard deviations at each relative wind direction are tabulated in Table 1.

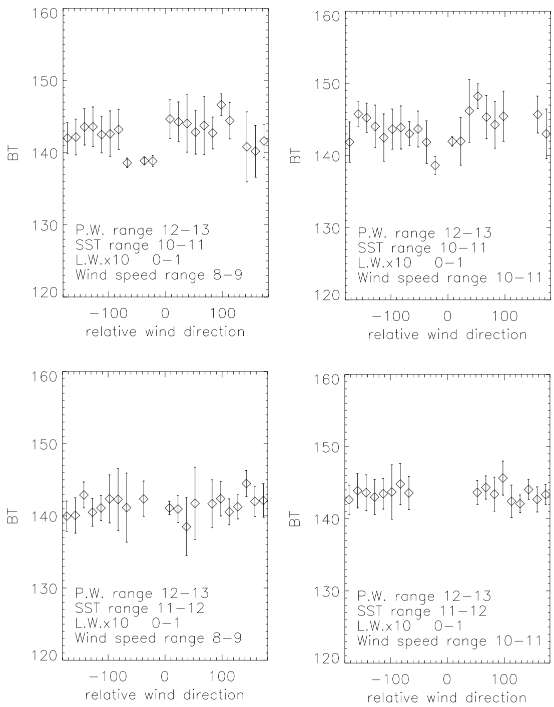

Figure 3: The change of the brightness temperature of 37GHz horizontal polarization due to the azimuth angle of the wind relative to the sensor direction. The ranges of the SST(°C), precipitable water(mm), liquid water (Kg/m^2) wind speed are displayed on the top of each column.

4. RESULTS

We attempt to extract the dependence of the brightness temperature of the horizontal polarization of 37GHz, which is most sensitive to the change of the wind speed and used for obtaining it. First, we categorize all of the match-up data into groups every 5°C for SST, 4m/s for wind speed, 4mm for precipitable water, and 0.1 Kg/m^2 for liquid water. Because of the limited condition of the observation, most of the data exist below 10 °C for SST, and 15mm for precipitable water.

Table 1: The mean and standard deviation of the differences between SSM/I wind and QuikSCAT wind at each category. (m/s)

Relative wind direction	[-180,-135]	[-135,-90]	[-90,-45]	[-45,0]	[0,45]	[45,90]	[90,135]	[135,180]	Total
SSM/I-QSCAT	-3.8±1.8	-1.0±1.5	-0.4±1.2	-0.7±1.2	N/A	0.9±1.2	0.8±1.1	-5.4±1.2	-1.1±1.4

Figures 3 and 4 respectively show the average brightness temperatures of the horizontal and vertical polarization of 37GHz plotted against the relative wind direction to the SSM/I. The most prominent feature should be the apparent shift of the brightness temperature due to the relative wind direction. The brightness temperature becomes maximum value in the nearly cross-wind condition. Although peaks appear in 10 or 20 degrees shifted from 90°, it should be natural because the wind direction derived by QuikSCAT has the rms error about 13° in comparison with the in situ observation (Wentz et al. 2001, Kubota et al. 2002). The difference between the cross-wind and the along-wind direction is about 2 to 5K, which is larger than the result of Wentz (1992). On the other hand, a comparison between the different categories reveals that the dependence of the brightness temperature on the relative wind direction changes with the range of physical parameters. The rate of change increases in proportion to the larger wind speed. The dependence seems to change largely between the different ranges of the liquid water.

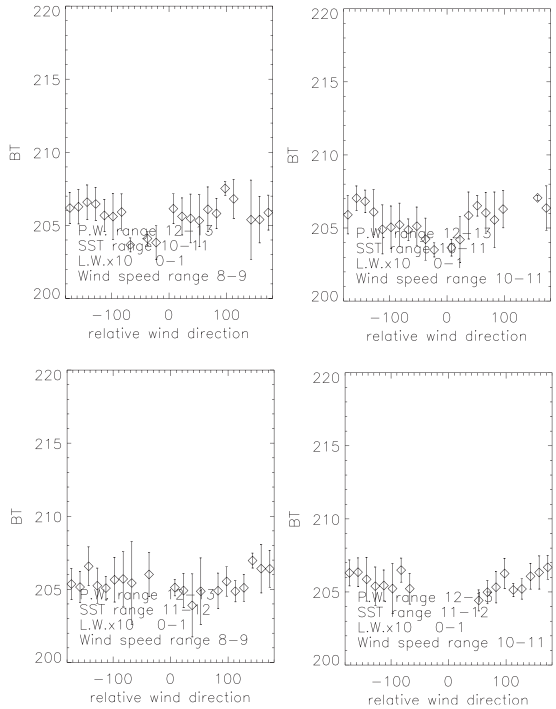

Figure 4: same as Figure 3 except for the vertical polarization.

Moreover, a comparison between Figures 3 and 4 indicates the trends of the brightness temperature in each category differ between the horizontal and the vertical polarization. The change in the vertical polarization is not so clear as in the horizontal

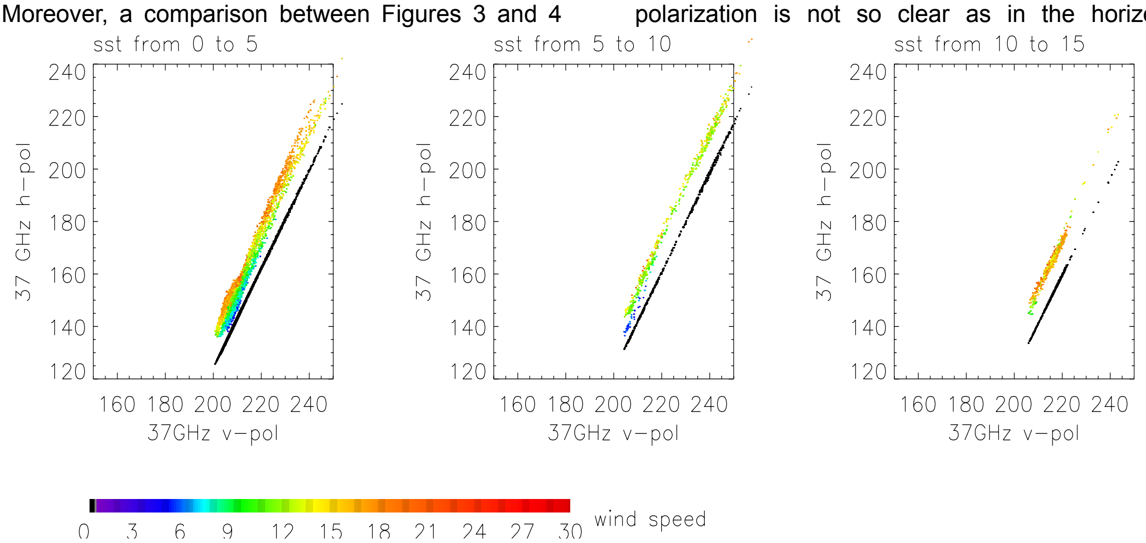

Figure 5: Shaded points show the relationship between the horizontal and the vertical polarization of the brightness temperature of 37GHz of the match-up data in the range of SST between (left) 0 and 5°C, (center) 5 and 10°C, (right) 10 and 15°C. The shades indicate the wind speed at the match-up data. The black points at the bottom of the plotted data show the relationship between the horizontal and the vertical polarization without the surface wind, which was computed from the atmospheric profile observed near Japan. The relationship without the surface wind is almost linear and unique to SSTs. The difference of the brightness temperature between the black dot and the observed data at each vertical polarization indicates the change of the brightness temperature caused by the wind.

polarization. As the surface wind speed is estimated using the difference of the sensitivity between the horizontal and the vertical polarization, the impact of the brightness temperature itself may be reduced.

Therefore, evaluating the difference of the sensitivity between the vertical and the horizontal polarization should have more impact to the accuracy of the wind speed derivation. Figure 5 indicates the relationship between the horizontal and the vertical polarization of 37GHz in the range with various wind speed in the match-up data. The black dots at the lowest value of plotted data are computed by the atmospheric radiation transfer model with the atmospheric profile observed by the rawin sonde near Japan. They indicate the condition with wind speed of 0m/s. The relation between these polarizations without surface wind is unique to SSTs. Therefore, the deviation of the horizontal polarization from the bottom of the plotted dots in the respective SST ranges in Figure 5 can be considered as the shift of the horizontal polarization due to the wind.

Figure 6 shows the shift of the horizontal polarization temperature of 37GHz caused by wind speed plotted to the azimuth angle of the vector wind relative to the SSM/I direction. The shift according to the relative wind direction is evident. Because the shift of the brightness temperature in 37GHz horizontal polarization corresponds to the wind speed, the dependence on the relative wind direction should indicate that the wind speed derived by the brightness temperature is also significantly affected by the relative angle between the surface wind and the sensor direction. Figure 5 and Figure 6 show that the impact of it is about 2K to 5K and that it corresponds about 20% to 40% of the wind speed from 5m/s to 10m/s. The dependence is likely to become stronger in the larger wind speed.

5. DISCUSSION AND CONCLUSIONS

This study provides the preliminary analysis about the dependence of the brightness temperature of the microwave radiometer on the relative wind direction between the surface wind and the sensor direction. The significant dependence of both the brightness

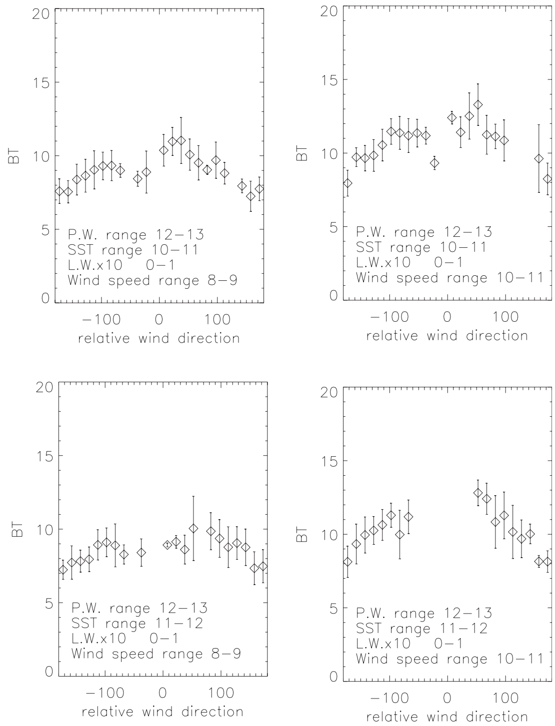

Figure 6: Same as Figure 2 except for the shift of the brightness temperature of the 37GHz horizontal polarization caused by the wind.

temperature itself and the shift of the horizontal polarization due to wind should show that the correction for the relative wind direction should be needed for estimating the wind speed. The brightness temperature according to the wind speed can change about 20% to 40% due to the relative wind direction.

The dependence is likely to be large under the high wind speed. Tendency of the dependence does not largely change with the precipitable water in this analysis.

The change due to the relative wind direction may be retrieved without knowing the information of the wind direction, judging from the statistical relationship between the physical parameters to affect brightness temperature. The brightness temperature can be explained by a function of the physical parameters, such as

$$BT = F(T, PW, LW, W, \eta), \qquad (1)$$

where T, PW, LW, W, and η indicate the SST, precipitable water, liquid water, wind speed, and relative wind direction, respectively. When the deviation from a typical condition,

$$BT_0 = F(T_0, PW_0, LW_0, W_0, \eta_0), \quad (2)$$

is showed by preceding Δ, ΔBT can be approximated by a linear relationship such as,

$$\Delta BT = \frac{\partial F}{\partial T}\Delta T + \frac{\partial F}{\partial PW}\Delta PW + \frac{\partial F}{\partial LW}\Delta LW + \frac{\partial F}{\partial W}\Delta W + \frac{\partial F}{\partial \eta}\Delta\eta. \quad (3)$$

When we observe the brightness temperature and retrieve the physical parameters by the microwave imager except for the relative wind direction η, we get the value in the left-hand side of eq.(3) and terms except for the last one in the right-hand side. Because we do not know the η, every Δη should be possible. As the relative wind direction is grouped into 8 categories in this approach, we can obtain 8 possible values of the right-hand side of eq.(3). The η and Δη which to produce the closest value of the right-hand side of eq.(3) to the left-hand side should be determined as the correct value. Figure 7 shows an example of the selecting of η from the other possibilities, using the Indian Ocean data. As the number of the data in the category is not enough to obtain the stable solution of the SVD, range of the data used in Fig.7 is expanded. Although the amount of the data which to establish the statistically stable relationship is not enough, the approach seems to be good in general. This approach should be worth evaluating in the various conditions.

After the successful launch of ADEOS-II, we will obtain the large amount of the collocated data of wind vectors observed by the scatterometer and the brightness temperatures by microwave radiometer under the various climate conditions. The large amount of data should enable us to establish the statistical relationship of the brightness temperature and the physical parameters.

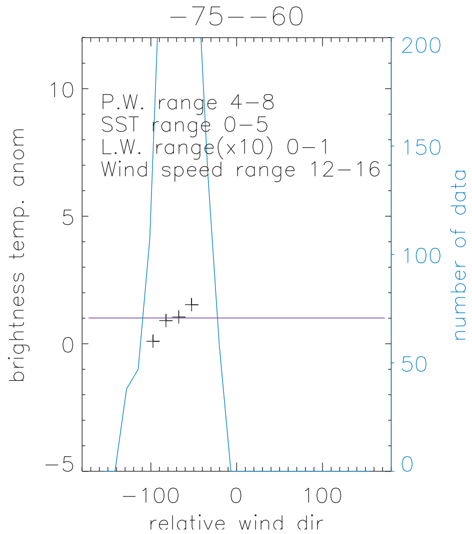

Figure 7: The selection of the correct η from the possible values. The crosses are the possible value of the right-hand side of eq.(3) which can be obtained when the number of data at each category is over 100. The thin blue line indicates the number of data at each category. The purple line shows the value of the left-hand side of eq.(3).

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