A Wind Speed Retrieval Algorithm by Combining 6 and 10 GHz Data from Advanced Microwave Scanning Radiometer: Wind Speed inside Hurricanes

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A wind speed retrieval algorithm was developed using 6 and 10 GHz h-pol (6H and 10H) data of the Advanced Microwave Scanning Radiometer (AMSR) aboard the Advanced Earth Observation Satellite-II (ADEOS-II) and AMSR-E aboard AQUA, for the purpose of retrieving wind speed inside rainstorms, primarily hurricanes and typhoons. The h-pol was used rather than the v-pol, because the brightness temperature sensitivity to the ocean wind at h-pol is larger than v-pol. The microwave emission change of 6H and 10H corresponding to ocean wind was evaluated in no-rain areas by combining AMSR and SeaWinds data aboard the ADEOS-II (SeaWinds was NASA’s scatterometer), and it was found that the ratio of the two 6H to 10H increments due to ocean wind is 0.9. Assuming that this result also holds with higher wind speeds and under rainy conditions, the brightness temperatures at 6H and 10H were simulated using a microwave radiative transfer model. A parameter W6 (unit: Kelvin) was then defined, representing an increment at 6H due to ocean wind. W6 is applicable to rainy areas, and to all ranges of sea surface temperature. W6 was compared with wind speed reported by the National Hurricanes Center for several hurricanes in the Western Atlantic Ocean during three years (2002 to 2004). W6 averaged around centers of hurricanes was found to exhibit a sensitivity to wind speed, such as increasing from 22 K to 65 K as the wind speed rose from 65 to 140 knots (33 to 72 m/s), and an empirical relationship relating the averaged W6 to wind speed in hurricanes was derived.

1. Introduction

In constructing algorithms to retrieve ocean wind speed from satellite-borne passive microwave radiometers, selections of parameters, such as frequencies, polarizations, et al., affect the main framework of the algorithms. As for frequency, it is common to use higher frequencies such as 36 GHz rather than lower frequencies for retrieval of low to moderate winds up to 25 m/s in no-rain areas, since the sensitivity to ocean wind at higher frequencies is better than that at lower frequencies (Wentz, 1983). However, the atmospheric opacity at higher frequencies exceeds that at lower frequencies. Actually, the brightness temperature (Tb) at 36 GHz becomes saturated inside rainstorms such as hurricanes and typhoons, and sometimes decays. In other words, Tb of 36 GHz does not contain information about the ocean surface inside rainstorms. Therefore, it is necessary to develop algorithms that use lower frequencies, even if they do have lower sensitivity to ocean wind.

In 2002, two passive microwave radiometers were successfully launched; one was the Advanced Microwave Scanning Radiometer-E (AMSR-E) aboard AQUA of the National Aeronautics and Space Administration (NASA), launched on May 4. The other was AMSR aboard Advanced Earth Observing Satellite-II (ADEOS-II) of the Japan Aerospace Exploration Agency (JAXA), launched on December 14. AMSR and AMSR-E (hereafter AMSRs) were developed by JAXA and are almost identical. AMSRs use several frequencies at 6, 10, 18, 23, 36, and 89 GHz (Kawanishi et al., 2003). Unfortunately, ADEOS-II stopped functioning on October 25, 2003, due to a failure of a cable from a solar panel.

As for observations by airborne passive microwave radiometers inside rainstorms, observations of hurricanes...
at frequencies from 4.5 to 7.2 GHz were made (Uhlhorn and Black, 2003), in which wind measurements up to 60 m/s were conducted. They inferred that Tb increased due to foam over the ocean. As for observations by satellite-borne passive microwave radiometers, AMSRs enable us to observe rainstorms at 6 and 10 GHz at fine spatial resolution. The first sensor with 6 and 10 GHz was the Scanning Multichannel Microwave Radiometer (SMMR) carried on Nimbus 7 in 1978 (Fu et al., 1988), and the spatial resolution at 6 GHz was 150 km; that of AMSR is 50 km.

In this paper we develop an algorithm to retrieve wind speed inside rainstorms, using the 6 and 10 GHz h-pol (hereafter, 6H and 10H) data of AMSRs. First, we investigate the features of the ocean emission at 6H and 10H concerned with ocean wind. Next, we simulate Tb at 6H and 10H, under extensive atmospheric conditions, and derive a parameter, W6, which represents an increment at 6H due to ocean wind. W6 is applicable to rainy areas, and to all ranges of sea surface temperature. As one feasible application, we derive an empirical equation to relate W6 with wind speed in hurricanes in the Western Atlantic Ocean. Finally, remaining problems in the current algorithm and another applications of W6 are discussed.

2. Sensors and Data

AMSRs are forward-looking, conically scanning radiometers at the constant incidence angle of 55.0 degree (Kawanishi et al., 2003). AMSR uses frequencies of 6.9, 10.7, 18.7, 23.8, 36.5, 50.3, 52.8, and 89.0 GHz. Those for AMSR-E are the same, except for the absence of 50 GHz. There are two polarizations (v-pol and h-pol) at frequencies other than 50 GHz, but only v-pol at 50 GHz. The spatial resolution at the Earth’s surface at 6 GHz is 40 × 70 km for AMSR, and 43 × 75 km for AMSR-E. The spatial resolution at 10 GHz is 27 × 46 km for AMSR, and 29 × 51 km for AMSR-E. The spatial sampling interval on the Earth’s surface is 10 km at all frequencies except for 89 GHz, at which it is 5 km.

SeaWinds, a NASA scatterometer, was installed on ADEOS-II; it operated at 13.4 GHz and was dedicated to measuring the ocean surface wind vectors (Liu, 2002). We used the Level 2B geophysical data of SeaWinds with spatial resolution 25 km. We have combined the SeaWinds data with the AMSR data to evaluate increments of Tbs at 6H and 10H due to ocean wind, as discussed in Section 3.

We also used the wind speed data reported by the National Hurricane Center (NHC) at Miami, Florida, USA. We will compare the NHC wind speed inside hurricanes with a parameter derived from AMSRs in Section 5. NHC analyzed wind speed using all kinds of available data, including those from sondes dropped by aircraft. NHC reports 1-minute averaged wind speed in knots. Multiplying by 0.5148 converts knots to m/s, and the relation of 1-minute to 10-minute averaged wind speed is that the former is 12% greater (http://www.nhc.noaa.gov).

3. Ocean Microwave Emissions at 6 and 10 GHz h-pol

It is necessary to access the wind induced emissivity change at both 6H and 10H, because we retrieve wind speed by combining data from these bands. We use h-pol rather than v-pol, because the sensitivity to the ocean wind at h-pol is larger than v-pol (Shibata, 2003). In this paper, we define two similar parameters: the first one is the difference between the AMSR 6(10)H and calm ocean emission, corrected for the atmospheric effects, which is defined by Eq. (1), and the other is the difference between the AMSR 6(10)H and calm ocean emission, which is explained in Section 4. The former parameter is used to quantify the wind speed dependence at 6H and 10H, and the latter is used to develop the wind speed algorithm under degraded conditions where data are not corrected for atmospheric effects. The former parameters 6(10)H* are defined by Eq. (1), and represent the quantity of ocean microwave emission changed by ocean wind at 6(10)H.

\[
6(10)H^* = \text{AMSR}_{6(10)H} - \text{atmos\_effect}_{6(10)H} - \text{calm\_ocean}_{6(10)H},
\]

where AMSR_{6(10)H} is Tb of AMSRs at 6(10) GHz h-pol, atmos\_effect_{6(10)H} is the atmospheric correction at 6(10) GHz h-pol, and calm\_ocean_{6(10)H} is the ocean microwave emission at 6(10) GHz h-pol under calm ocean conditions. The atmospheric correction was calculated by using data of 23V and 36V (Shibata, 2004). The 23 GHz frequency was used to eliminate the effect of water vapor, and 36 GHz to eliminate the effect of cloud liquid water. In these calculations, we excluded rainy areas by specifying a maximum limit of atmos\_effect_{6H}.

The coefficient of r in calm\_ocean_{6(10)H} is the reflection coefficient given by the Fresnel formula with an incidence angle of 55.0 degrees and a salinity of 35 PSU. The complex dielectric constant of the ocean water was obtained from Klein and Swift (1977). The reflection coefficient is a function of frequency, polarization, incidence angle, SST, and salinity. We used SST from the
Reynolds weekly analysis (Reynolds and Smith, 1994). The weekly SST was interpolated on a corresponding day, and also interpolated spatially into a corresponding point. As for the salinity effect, the sensitivity at 6H is 0.003 K/PSU at 0°C SST, and –0.039 K/PSU at 30°C SST, when the salinity changes from 30 to 35 PSU. The one at 10H is 0.006 K/PSU and –0.012 K/PSU, respectively. Therefore, the salinity effect is negligible in our study.

Figures 1 to 3 were obtained by combining data of the AMSR 6(10)H and SeaWinds in July 2003. Figure 1 illustrates the relations of 6H to the SeaWinds wind speed. Two lines are plotted in this figure: the bold line corresponds to crosswind condition and the thin line to downwind condition. The relative wind direction is defined as the relative angle between the AMSR viewing direction and the SeaWinds wind direction. Figure 1 indicates that 6H increases with wind speed, and this relation is nonlinear. 6H gradually separates between cross and downwind conditions above 5 m/s wind speed. We have limited data above 22 m/s wind speed, but the difference between cross- and downwind conditions gradually seems to become larger.

In Fig. 1, we see that the sensitivity of 6H to wind speed averaged up to 20 m/s is 1 K/(m/s). This value seems to be higher than the one reported earlier. Sasaki et al. (1988) summarized the experimental results from the ocean microwave observations, and inferred that the sensitivity at around 6–7H is about 0.5 K/(m/s), even though their experiments were limited to ground-based observations.

Figure 2 plots the relations between 6H and 10H under crosswind conditions. In Fig. 2, solid circles mark SeaWinds wind speeds in 5 m/s intervals from 5 to 25 m/s. In this figure, the dotted line corresponds to a 45-degree line.
degree tilted line, and we see that the ratio of $6H^*$ to $10H^*$ is 0.90. This ratio is constant at wind speed up to 25 m/s. The ratios of $6H^*$ to $10H^*$ under other relative wind directions are the same. These results are in good agreement with observations reported by Uhlhorn and Black (2003).

Figure 3 plots the relation between $6(10)H^*$ and the relative wind directions. The relative wind directions are plotted with interval 45°, and the SeaWinds wind speed also plotted from 1 to 23 m/s with 2 m/s interval. The relative angle of 0° corresponds to an upwind direction, and angles of 90 and –90° correspond to a crosswind, while the angle of 180° corresponds to a downwind. Figure 3 demonstrates that $6H^*$ and $10H^*$ behave quite similarly. $6H^*$ and $10H^*$ do not vary with the relative wind direction at wind speed below 5 m/s, but they do vary with the relative wind direction above that. They reach maximum values in crosswind conditions, and minima in up- and downwind conditions. The difference of $6H^*$ between cross and down directions is 1.5 K, and the difference between crosswind and upwind conditions is 1.0 K at a wind speed of 21 m/s. Those of $10H^*$ are 1.5 K for both conditions.

4. Definition of W6

In the previous section we saw that the wind dependence ratio between $6H^*$ to $10H^*$ is 0.9 under low and moderate wind speed (up to 25 m/s) when atmospheric effects and no-rain conditions are taken into account. In this section we develop a wind speed retrieval algorithm by assuming that this ratio still holds at higher wind speed and under rainy conditions. The wind speed algorithm will be developed based on simulated Tbs using a microwave radiative transfer model. The microwave radiative transfer model was from (Shibata, 1994, 2004).

In the microwave radiative transfer model, three processes should be taken account of: absorption, emission, and scattering. Molecules of water vapor and oxygen absorb the microwave. Liquid water in clouds and raindrops also absorbs the microwave. These particles emit the microwave corresponding to the ambient temperature. Raindrops scatter the microwave depending on its wavelength. Scattering can be neglected if the microwave wavelength is much larger than the raindrop size. For example, the scattering can be neglected for frequencies below 10 GHz up to 12 mm/hour of rain rate (Ulaby et al., 1986). At this rain rate, it was estimated that the accumulated liquid water might become 5 kg/m² for typical clouds and 12 kg/m² for fully developed clouds (Falcone et al., 1979). In wider areas such as $40 \times 70$ km² of the AMSR spatial resolution, the accumulated liquid water averaged within those areas may become much smaller.

This simulation used one-year Japanese aerological observations. The microwave model consists of 60 levels, each 200 m in depth ranging from the surface to 12 km, followed by 18 levels for each 1 km of depth from 12 to 30 km. Within each level, molecules and liquid water absorb the microwave, and they emit the microwave corresponding to the ambient temperature. In the simulation, the water vapor changes from 0 to 60 kg/m², and the liquid water changes from 0 to 3.75 kg/m².

First, we simulated Tbs under a calm ocean surface condition. The Tbs of group A in Fig. 4(a) are the results with 15°C SST. The Tbs increases from O to P, due to the increment of water vapor and liquid water. We see that Tbs lie on a single line from O to P, and two effects due to water vapor and liquid water are almost the same. The Tb increment due to water vapor is small (such as 9 K for
10H, and much smaller for 6H). Therefore, the Tb increment depicted in Fig. 4(a) is mainly due to liquid water.

Secondly, group B in Fig. 4(a) was obtained by assuming a roughened ocean condition, i.e., increasing the emissivity of the ocean surface by 0.2 for 10H and by 0.18 for 6H. We assumed that the ratio of 6H to 10H is 0.9 for higher wind speed and under rainy conditions. The value of 0.18 for 6H was chosen arbitrary, and it corresponds to the Tb increment of 52 K for 6H. This Tb increment is related to the NHC wind speed in Section 5. The point O under the calm condition shifts to Q under the roughened condition at the lowest atmospheric opacity. Point P shifts to R at higher atmospheric opacity. The slope of the line PR is larger than that of OQ, because of different atmospheric opacity between 6H and 10H.

In Fig. 4(a), Tb of 6H increases by the length of OQ* at the lowest atmospheric opacity. It increases by the length of PR* at higher atmospheric opacity. Those Tb increments represent the ocean wind effect. The lengths of OQ* and PR* are different due to the different atmospheric effects (mainly due to rain) on 6H.

In Fig. 4(a), we set SST = 15°C. For other SSTs, two lines A and B are shifted in parallel. We can eliminate the dependence of Tb on SST by subtracting the calm ocean emission, and we define a parameter \(6(10)H^*\) by Eq. (2).

\[
6(10)H^* = \text{AMSR}_6(10)H - \text{calm ocean}_6(10)H, \quad (2)
\]

where \(\text{AMSR}_6(10)H\) and \(\text{calm ocean}_6(10)H\) are the same as in Eq. (1).

In Fig. 4(a), the relations between 6H and 10H are slightly nonlinear, but we have approximated them as linear for simplicity. By using \(6(10)H^*\), we obtained Fig. 4(b), in which the line A is approximated as a linear line passing the point O(a, b) with the slope c. Now, we have the AMSR observation of \((10H^*, 6H^*)\) at an arbitrary point on the line B in Fig. 4(a), and we set it on the point F in Fig. 4(b). Then, we obtain an intersecting point E(10H^*, 6H^*) made by two lines OP and EF. The slope of the line EF is sl. Finally, we define W6 (unit: Kelvin) by the length of EF* divided by the atmospheric effect (=fac).

\[
W6 = \text{EF}*/\text{fac} = (6H^* - 6H^*_E)/\text{fac}
\]

\[
= (6H^* - c \times 10H^* + a \times c - b) \times \text{sl}/(\text{sl} - c)/\text{fac}, \quad (3)
\]

where \(a = 15, b = 10.5, c = 0.46\)

\[
\text{sl} = 0.90 + 0.40 \times (10H^*_E - a)/80, \quad (4)
\]

\[
\text{fac} = 1 - 0.20 \times (10H^*_E - a)/80. \quad (5)
\]

Constants a, b, and c in Eq. (3) are parameters defining the line OP. Equation (4) gives the slope of the line EF. The minimum value of sl is 0.9 corresponding the lowest atmospheric opacity, and it increases as the length of OE* (= 10H^*_E – a) increases. Constant values of 0.4 and 80 in Eq. (4) are determined from Fig. 4(a). The atmospheric effect given by Eq. (5) is the ratio of two lengths, PR*/OQ*, in Fig. 4(a). Constant values of 0.2 and 80 in Eq. (5) are also determined from Fig. 4(a).

To calculate sl and fac, we need to know the length of OE*. There may be several methods of determining \(10H^*_E\) of the point E*. Here, we used an iterative one, i.e., calculate the first \(10H^*_{(1)}\) by using the observed \(10H^*\), then calculate the second \(10H^*_{(2)}\) by using the first \(10H^*_{(1)}\), .... The convergence to E* is fast, such as n = 4 for the absolute difference of \((10H^*_{(n)} - 10H^*_{(n-1)})\) to become less than 0.1 K. The difference of W6 whether lines A and B are treated as linear or nonlinear is less than 1 K when the length of OE* is 80 K.

As additional information, we compare W6 with \(6H^*\) in Fig. 5, which was obtained from monthly AMSR data in July 2003. Since \(6H^*\) was obtained from no rainy areas, the comparison was made only in no rainy areas. The thin line corresponds to a 45-degree tilted line; the compared data are marked by "∗" with 1 K intervals of \(6H^*\). We see that the differences between W6 and \(6H^*\) are very small. This result assures us that we can convert W6 to the wind speed by using the relation shown in Fig. 1.

5. Conversion of W6 to Wind Speed in Hurricanes

Verifications of the proposed method are done with selected hurricane cases in this section. Figure 6 shows the Tb of \(6H^*\) and \(10H^*\) inside and around hurricanes, where we confined cases to hurricane centers that were fully embedded in AMSRs swaths. We also restricted ourselves to cases that hurricane centers do not contain land areas, because \(6H^*\) and \(10H^*\) cannot be evaluated over land.

Figure 6(a) is made from AMSR-E on Sep. 13, 2003,
for Isabel with 140 knots of wind speed at 1800Z; Fig. 6(b) is from AMSR-E on Sep. 13, 2004, for Ivan with 140 knots at 1800Z; Fig. 6(c) is from AMSR-E on Sep. 15, 2004, for Ivan with 115 knots at 1800Z; and Fig. 6(d) is from AMSR-E on Sep. 23, 2004, for Jeanne with 75 knots at 1800Z. The time difference between AMSR-E’s observation and NHC observation is within one hour. In Fig. 6(a), the data marked by arrow A correspond to the outer area around Isabel, and the data marked by B correspond to the area inside Isabel. The situation is similar for other cases. We see that arrow B moves upward as wind speed increases. This result is in good agreement with the Tb simulation result seen in Fig. 4(a).

We calculated \( W_6 \) by Eq. (3), and show spatial maps of \( W_6 \) in Fig. 7 for four cases, corresponding respectively to the one in Fig. 6. In Fig. 7, solid circles mark the center of each hurricane. We see that \( W_6 \) increases as the NHC wind speed increases. The area with larger values of \( W_6 \) seems to be confined to an area of the order of \( 100 \times 100 \) km\(^2\), except for the case (d). As the hurricane strength, we define Eq. (6), in which \( W_6 \) is averaged for pixels according to \( W_6 \) value from the maximum to smaller until the averaging number reaches \( n \).

\[
W_{\text{ave}} = \frac{1}{n} \sum_{i=1}^{n} W_6(i) \tag{6}
\]

\( W_{\text{ave}} \) is the parameter dependent on the area size averaged. Here, we set \( n = 100 \), corresponding roughly to an area of \( 100 \times 100 \) km\(^2\), because AMSRs spatial sampling is in 10 km intervals.

Figure 8 illustrates the relation between \( W_{\text{ave}} \) (\( n = 100 \)) and NHC wind speed, made from all cases. Figure 8 indicates that \( W_{\text{ave}} \) increased from 22 K to 65 K as the wind speed increased from 65 to 140 knots. We see that the relation between \( W_{\text{ave}} \) and wind speed is nonlinear in the range between 65 and 140 knots. We express this relation as two linear branches shown by dotted line in Fig. 8, and numerically by Eq. (7).

\[
\text{Wind speed (knots)} = \begin{cases} 
2.86 \times W_{\text{ave}} & \text{if } W_{\text{ave}} < 38.5 \text{ K} \\
1.14 \times (W_{\text{ave}} - 38.5) + 110.1 & \text{if } W_{\text{ave}} > 38.5 \text{ K}.
\end{cases} \tag{7}
\]
The wind speed retrieved by Eq. (7) is in knots, in accordance with the data provided by NHC. We believe that the equation obtained is also applicable to typhoons. In case the unit is m/s, it becomes Eq. (8).

\[
\text{Wind\_speed (m/s)} = \begin{cases} 
1.47 \times \text{W6\_ave} & \text{if W6\_ave < 38.5 K} \\
0.59 \times (\text{W6\_ave} - 38.5) + 56.7 & \text{if W6\_ave > 38.5 K.}
\end{cases}
\]  

(8)
Equations (7) or (8) are applicable to hurricanes or typhoons, in particular for very high wind speed. Data of wind speed less than 90 knots in Fig. 8 seem to be scattered, compared with those above that speed.

In Fig. 8, the relation of $W_{6\text{ave}}$ and SeaWinds wind speed from Fig. 1 is overlaid. The scales at which $W_{6\text{ave}}$ and $W_6$ are plotted are the same. The SeaWinds wind speed (m/s) was converted to knots, and multiplied by 1.12 (SeaWinds wind speed is 10-minute average). We see that there is a gap between $W_6$ and $W_{6\text{ave}}$ around 50 knots of NHC wind speed. As explained above, $W_{6\text{ave}}$ is the parameter dependent on the area size averaged. If we were to reduce the area size (i.e., decrease sampling number $n$), $W_{6\text{ave}}$ would increase. The gap might disappear by applying a smaller $n$, i.e., we should apply a variable parameter ($n$) dependent on wind speed. We could redraw a smoother line after we added further data from hurricanes later in 2005, in which a concept of the variable parameter will be taken into account.

To summarize this section, the result obtained above shows that the atmospheric effects are well modeled, and that is why only the wind speed dependence remains.

6. Conclusions and Discussions

A wind speed retrieval algorithm using 6H and 10H of AMSRs has been developed. This study was undertaken to retrieve the wind speed inside rainstorms, primarily hurricanes and typhoons. To see the features of 6H and 10H corresponding to ocean wind, we introduced two quantities, 6H* and 10H*, which are independent of atmospheric effects and SST. These quantities were obtained only in no-rain areas. By comparing 6H* and 10H* of AMSR with SeaWinds data, we obtained the relations of 6H* and 10H* to ocean wind speeds and relative wind directions. The ratio of 6H* to 10H* increments due to ocean wind is 0.9. Incorporating this result in the microwave radiative transfer model, we simulated Tbs of 6H and 10H under conditions of both heavy rain and high wind speed. From this simulation, we defined another two quantities; $6H^-$ and $10H^-$. Finally, we obtained $W_6$ by combining $6H^-$ and $10H^-$. We checked $W_6$ for hurricanes, comparing it with wind speed reported by the NHC for several hurricanes in the Western Atlantic Ocean from 2002 to 2004. We saw that $W_6$ averaged around centers of hurricane increased from 22 K to 65 K as the wind speed increased from 65 to 140 knots (33 to 72 m/s), and the empirical equation relating the averaged $W_6$ to wind speed in hurricanes was derived. We consider that the equation obtained is also applicable to typhoons.

For practical applications of $W_6$ for hurricanes and typhoons, we should consider several points. First, we should modify the current method for storms in which the areas of high wind are not fully observed, i.e., high wind areas are lacking partially due to land areas, or projecting from AMSR swaths. In case that the storm centers remain in the AMSR swath, the current method will be applicable by changing the averaging number for $W_6$, compensated for the lack. In other cases, it should not be applied, since guessing wind speed in the center might be difficult.

Second, we might modify the current method for storms in which wind distribution is asymmetrical with respect to the storm center. We saw an anisotropic feature depending on the relative wind direction in the Tbs of 6H and 10H as shown in Figs. 1 and 3. At high wind speed such as 50–150 knots, we have no observational data on Tb difference due to the anisotropic feature, but it is quite possible that it would reach several Kelvin. In situations where the distribution of winds is symmetrical with respect to the storm center, errors of $W_{6\text{ave}}$ due to anisotropic features might be reduced by averaging $W_6$ around the storm center. In situations where the wind distribution is asymmetrical (i.e., higher winds cluster on one side of the storm), errors might remain. After roughly estimating the order of the anisotropic effect at high wind speed from AMSRs data in hurricanes and typhoons with asymmetrical wind distribution, we should create a table for correcting the asymmetry.

Third, there is radio frequency interference (RFI) at 6 GHz. The RFI at 6 GHz is very severe over continents such as North America. Strong RFI on lands affects the coastal region, and it is found around small islands. There-
fore, we should remove the RFI areas manually from maps of W6.

W6 is useful to retrieve wind speed inside rainstorms in middle and high latitudes, and our next target may be the explosive cyclones in the Northern Atlantic and Northern Pacific Ocean. The explosive cyclone is defined as one where the pressure drops rapidly (24 hPa/1 day). The explosive cyclones develop rapidly, and measurements of ocean wind from satellite-borne sensors like AMSRs should be helpful.

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