Analysis Winds Data from ASCAT and SAR Backscatter using Statistical and Modeling Methods during Tropical Cyclone Anggrek (2024) in Indian Ocean

Annisa Amabel Amedea Santoso[1], *Ashari* Wicaksono[2*]

[1]Department of Marine Science, University of Trunojoyo Madura, Jl. Raya Telang PO BOX 2 Kamal-Bangkalan, East Java, Indonesia
[2] Laboratory of Oceanography, University of Trunojoyo Madura, Jl. Raya Telang PO BOX 2 Kamal-Bangkalan, East Java, Indonesia

Abstract. Tropical cyclones are extreme weather phenomena characterized by strong winds that can cause damage to coastal areas, so accurate measurement of wind speed during tropical cyclones is very important. This study aims to measure the intensity of wind speed during the occurrence of Tropical Cyclone Anggrek in 2024 using microwave data from Synthetic Aperture Radar (SAR) and Advanced Scatterometer (ASCAT), both of which have different wind speeds in each measurement product. The methods used in this study include statistical analysis of wind speed data obtained from both sources, and data adjustment using the CMOD7D-v2 model to achieve consistency between SAR and ASCAT wind speed estimates. The results of the analysis show that this adjustment can reduce the SAR and ASCAT wind errors and show lower bias values. This research is expected to help the use of CMOD7D adjustment for wind speed analysis during tropical cyclones. CMOD7 GMF adjustment can help eliminate wind speed differences between SAR and ASCAT data, the analysis results show that the wind speed bias is reduced by 25.07% on January 27, while on January 29 it is reduced by 4.39%.

1 Introduction

Tropical cyclones are among the most devastating meteorological occurrences, with strong swirling winds, heavy rainfall, and storm surges [1]. These events have a profound impact on coastal infrastructure and marine habitats. Accurate wind speed observations in such harsh conditions are critical for catastrophe prevention and understanding atmospheric-ocean interactions. Advances in remote sensing technologies, such as Synthetic Aperture Radar (SAR) and Advanced Scatterometer (ASCAT), have enabled high-resolution measurements of surface wind speeds, providing vital data for meteorological and oceanographic investigations [2, 3].

* Corresponding author: ashari.wicaksono@trunojoyo.ac.id.

SAR technology provides detailed imagery of the Earth's surface regardless of weather conditions, making it particularly effective in observing wind dynamics during cyclones[4]. Meanwhile, ASCAT estimates wind speed by analyzing the roughness of the ocean's surface [5]. However, differences in wind speed estimates between these two technologies often arise due to varying data processing methods and physical measurement principles. For instance, SAR tends to overestimate wind speeds compared to ASCAT [6], necessitating calibration to align their outputs. The CMOD7D model serves as a vital geophysical model function for addressing these discrepancies, enabling more accurate wind speed estimations by calibrating radar backscatter data against reference measurements [2].

The purpose of this study is to assess the accuracy of SAR and ASCAT wind speed data collected during Tropical Cyclone Anggrek 2024. Using the CMOD7D technique and statistical analysis [7], the study will analyze the consistency and differences between the datasets. The error characteristics of the CMOD7D-v2 adjustment for Tropical Cyclone winds can be examined using the Triple Collocation analysis technique; thus, adjustment with this model is expected to determine the correctness of wind speed between SAR and ASCAT data [8]. The results are expected to lead to enhanced monitoring and prediction of extreme weather occurrences, which are critical for disaster risk reduction [2].

A better understanding of wind speed measurement accuracy using remote sensing technologies will aid in developing early warning systems for tropical cyclones. Consequently, the findings of this study can be utilized to enhance disaster preparedness efforts, safeguard human lives and protect ecosystems and infrastructure in vulnerable regions.

2 Materials and Method

2.1 Study Area

Anggrek Tropical Cyclone 2024 lasted for 17 days following the trajectory of Tropical Cyclone which occurred from January 16 to February 01, 2024. Anggrek Tropical Cyclone occurred in Indian Ocean which has coordinates 24.73°S - 20.09°S and 69.78°E - 74.65°E. SAR data availability on January 27 and 29, 2024, while ASCAT data from January 16 to February 01, 2024.

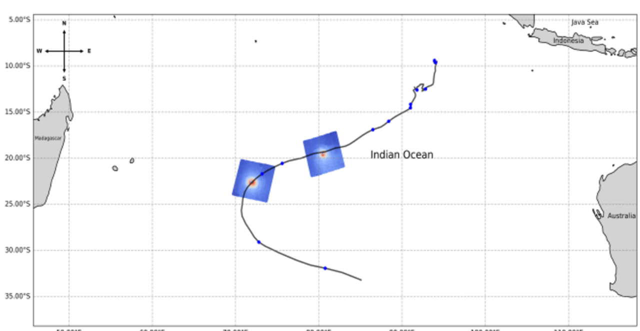

Figure 1. Study area, the track of TC Anggrek 2024.

2.2 Sentinel 1-A

Sentinel-1A is an Earth observation satellite launched by the European Space Agency (ESA) on April 3, 2014, as part of the Copernicus programme. The Copernicus program seeks to offer Earth observation data for environmental, climate change monitoring, disaster management, and other applications (https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-1). This study makes use of wind data from the Synthetic Aperture Radar (SAR) site (https://www.star.nesdis.noaa.gov/socd/mecb/sar/sarwinds_tropical.php). The data were gathered using the Sentinel-1A satellite, which operates in the C-band frequency range, which is particularly useful for detecting ocean surface conditions due to its sensitivity to wind-induced surface roughness and ability to pierce cloud cover. The VH (Vertical-Horizontal) polarization mode improves wind measurement accuracy, making it ideal for identifying surface differences produced by high wind speeds during extreme weather events [9].The SAR data were downloaded as geolocated wind fields, including speed, direction, and metadata such as acquisition time and radar parameters. In this study, GMFs are used to retrieve SAR winds: the MS1AHW GMF for SAR VH signals.

2.3 ASCAT Data

ASCAT (Advanced SCATterometer) is an instrument used to measure wind speed and direction at sea level using radar scatteromete technology [10]. A scatterometer is an active radar device that emits microwaves to the ocean surface and analyzes the backscatter patterns produced by the interaction of the radar waves with small ocean waves [11]. This study utilizes Advanced Scatterometer (ASCAT) wind data sourced from the NASA Earthdata Search Platform (https://search.earthdata.nasa.gov/). The ASCAT data provides near-surface ocean wind speed and direction observations, which are derived from microwave radar backscatter measurements [12]. These measurements are critical for understanding oceanic wind fields and their interaction with atmospheric processes [13]. Data from ASCAT are accessible through the platform and are provided in NetCDF format, containing geolocated wind vectors and relevant metadata. The downloaded data underwent preprocessing steps, including spatial and temporal filtering based on specific geographical coordinates (latitude and longitude) and time ranges of interest. Additional quality control was performed by removing low-quality wind measurements, such as those impacted by rain contamination or sea ice [14], using quality flags embedded in the data. In this research, the CMOD7 GMF is used in the inversion of the wind retrieval.

2.4 Data Analysist

The collection of wind speed data from SAR and ASCAT aims to identify the exact differences between the two data. Next, a statistical comparison of the wind speeds measured by SAR and ASCAT was conducted. The three error metrics used in this analysis include bias, Root Mean Square Difference (RMSD), and Pearson correlation coefficient (CC).

2.4.1 Bias

Bias measures the average difference between observed data (yi) and model data (xi). The formula is:

$$\text{Bias} = \frac{1}{n}\sum(yi - xi) \quad (1)$$

2.4.2 Root Mean Square Difference

RMSD quantifies the deviation between predictions and observations. The formula is:

$$\text{RMSD} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(yi - xi)^2} \tag{2}$$

2.4.3 Pearson Correlation Coefficient (CC)

The correlation coefficient (CC) measures the linear relationship between model results and observations. The formula is:

$$\text{CC}= \frac{\sum_{i=1}^{n}(yi-\bar{y})\,(xi-\bar{x})}{\sqrt{\sum_{i=1}^{n}(yi-\bar{y})^2\sum_{i=1}^{n}(xi-\bar{x})^2}} \tag{3}$$

3 Result and Discussion

3.1 The Distribution VH NRCS, Incident Angle and Wind Speed SAR and ASCAT

The figure presents the distribution of VH NRCS, incident angle, and wind speed from SAR and ASCAT data. The data for panels (a) and (b) represent SAR measurements on January 27 and 29, respectively. This SAR data shows wind speed results in the range of 25–65 m/s when the VH NRCS is in the range of -17–23 dB and has an incident angle in the range of 30°–40°. Meanwhile, the ASCAT data shows wind speed results of 2.5–25 m/s, with VH NRCS values of -5–15 dB and incident angle values of 20°–45°.

Figures (a) and (b) show SAR measurements, which have a higher spatial resolution compared to ASCAT [15]. In these distributions, NRCS values exhibit greater sensitivity to changes in the incident angle, displaying a more detailed and consistent pattern across various wind speeds. SAR provides high-detail data regarding wind structure variations on small spatial scales [16], enabling the observation of localized phenomena that cannot be captured by ASCAT.

In contrast, Figures (c) and (d) present ASCAT data, which have a coarser spatial resolution. The distribution appears more scattered and less sensitive to incident angle variations, as ASCAT is designed to measure wind speeds on a global and regional scale [17]. ASCAT data are effective in providing accurate average wind speed estimates [18], but lack the detailed resolution required to observe small-scale changes, which are clearly visible in SAR measurements.

In accordance with the research of [19], VH NRCS increases when the wind speed strengthens. The dependence of the VH NRCS value on the incident angle can be observed under mild wind speed conditions, ranging from 0 to 30 m/s.

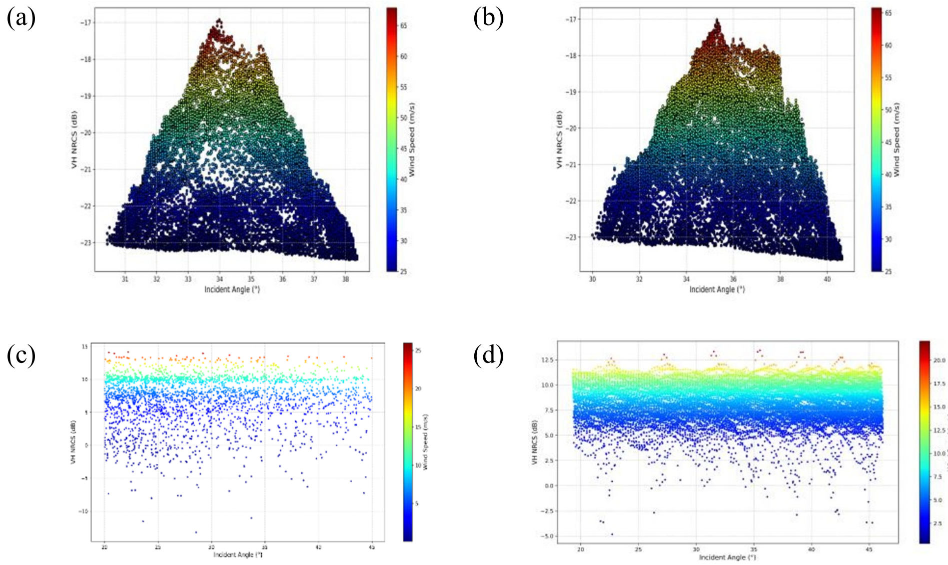

Figure 2. Scatter plots of the distribution VH NRCS, Incident angle and wind speed SAR and ASCAT

3.2 ScatterPlot ASCAT Winds and SAR Winds

The figure shows four scatter plots comparing the wind speed data measured by ASCAT (Advanced Scatterometer) and SAR (Synthetic Aperture Radar), both for the raw data and the data adjusted using the CMOD7 model. This graph aims to evaluate the agreement between the wind speeds produced by these two measurement methods on two different dates, January 27 and January 29. Plots (a) and (b) show the raw data comparison between ASCAT and SAR, while plots (c) and (d) show the comparison of ASCAT data with SAR that has been adjusted using the CMOD7 model. The X-axis shows the wind speed from SAR, while the Y-axis shows the wind speed from ASCAT, with colors representing the density of the data (blue for low density and red for high density). The black diagonal line indicates a perfect match between the two datasets.

The raw data (plots a and b) show a bigger spread, particularly at high wind speeds (>20 m/s). The correlation coefficient (CC) for the raw data from January 27 (panel a) is 0.484, with an RMSD of 3.643 and a bias of 0.456. On January 29 (panel b), the CC is higher at 0.914, with an RMSD of 3.436 and a bias of -0.108. This demonstrates that, while there is a moderate linear relationship between raw ASCAT and SAR data, significant deviations could be attributed to differences in the measurement characteristics of the two instruments, as well as the influence of atmospheric conditions like turbulence or humidity.

After the SAR data is adjusted using the CMOD7 model (plots c and d), the spread of the data becomes more concentrated around the line. On January 27 (plot c), the CC increases significantly to 0.846, with a smaller RMSD of 0.405 and a bias of only 0.042, indicating an improved fit between ASCAT and SAR. Meanwhile, on January 29 (plot d), the CC reaches 0.838, with an RMSD of 7.556 and a bias of 0.109. The improvement in accuracy after adjustment with CMOD7 shows the effectiveness of the model in correcting the systematic differences between the two tools and removing most of the irregularities present in the raw data. The CMOD7 model significantly improves the agreement between ASCAT and SAR wind speed data. The adjusted data show a strong linear relationship and much smaller deviations than the raw data, especially at high wind speeds [2]. Using CMOD7 is effective for calculating wind reconciliation when tropical cyclones occur throughout the region.

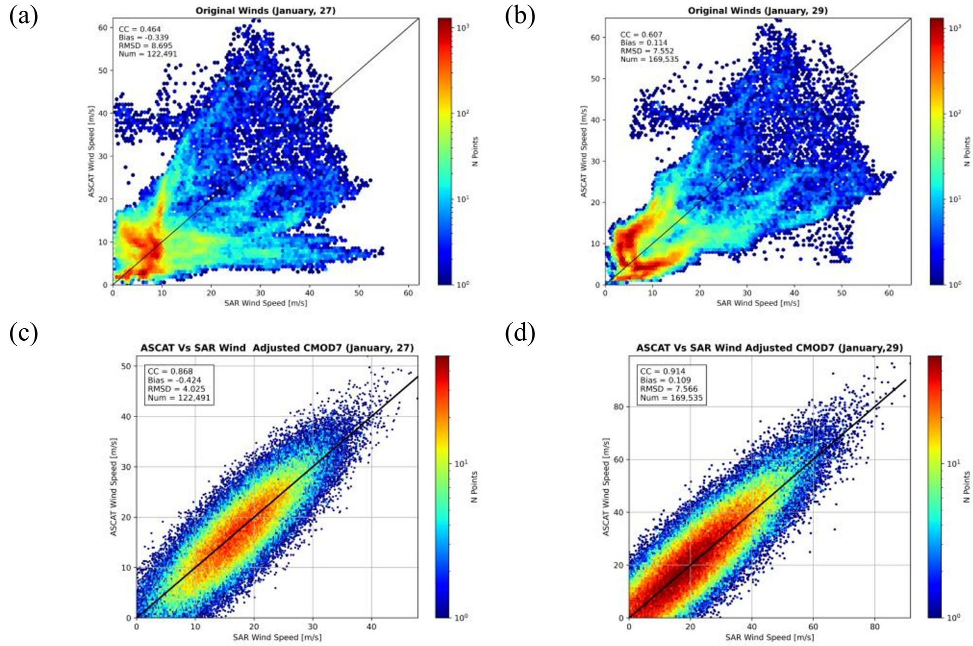

Figure 3. **(Upper panels a-b)** Wind-speed original from ASCAT and SAR. (**Below panels c-d)** Wind-speed adjust by CMOD7 from ASCAT and SAR.

4. Conclusion

Since the advent of active microwave sensors, various GMFs have been designed to detect sea surface winds with better precision. Nonetheless, wind references are limited, necessitating one-second wind changes during extreme conditions. As a result, it is necessary to investigate the retrieval of various GMFs in order to construct a more accurate wind reference.

This study employs the CMOD7 adjustment for SAR and ASCAT wind data. The results suggest that this correction, utilizing GMF, is more effective, resulting in a good reconciliation of wind speed from various wind sources. The CMOD7 GMF modification helps reduce disparities in wind speed between SAR and ASCAT data. The analysis results show that the wind speed bias is reduced by 25.07% on January 27, while on January 29, it is reduced by 4.39%.

References

1 Z. Liu, H. Yang, W. Ai, K. Ren, S. Hu, and L. Wang, Tropical Cyclone Wind Direction Retrieval Based on Wind Streaks and Rain Bands in SAR Images. *Remote Sens.* **16**, 3837 (2024).

[2] W. Ni, A. Stoffelen, K. Ren, X. Yang, and J. Vogelzang, SAR and ASCAT Tropical Cyclone Wind Speed Reconciliation. *Remote Sens.* **14**, 5535, (2022).
[3] W. Ni, A. Stoffelen, K. Ren, and X. Yang, Tropical Cyclone Intensity Estimation From Spaceborne Microwave Scatterometry and Parametric Wind Models,*IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **15**, 4719–4729 (2022).
[4] R. M. Asiyabi, A. Ghorbanian, S. N. Tameh, M. Amani, S. Jin, and A. Mohammadzadeh, Synthetic Aperture Radar (SAR) for Ocean: A Review, *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **16**, 9106–9138 (2023).
[5] T. Cheng, Z. Chen, J. Li, Q. Xu, and H. Yang, Characterizing the Effect of Ocean Surface Currents on Advanced Scatterometer (ASCAT) Winds Using Open Ocean Moored Buoy Data, *Remote Sens.* **15,** 4630 (2023).
[6] E. E. Wright, M. A. Bourassa, A. Stoffelen, and J.-R. Bidlot, Characterizing Buoy Wind Speed Error in High Winds and Varying Sea State with ASCAT and ERA5, *Remote Sens.* **13**, 4558 (2021).
[7] W. Ni, A. Stoffelen, K. Ren, and X. Yang, Tropical Cyclone Intensity Estimation From Spaceborne Microwave Scatterometry and Parametric Wind Models, *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **15**, 4719–4729 (2022).
[8] D. Sergeev, O. Ermakova, N. Rusakov, E. Poplavsky, and D. Gladskikh, Verification of C-Band Geophysical Model Function for Wind Speed Retrieval in the Open Ocean and Inland Water Conditions, *Geosciences*, **13**, 361 (2023).
[9] W. Shao, Z. Lai, F. Nunziata, A. Buono, X. Jiang, and J. Zuo, Wind Field Retrieval with Rain Correction from Dual-Polarized Sentinel-1 SAR Imagery Collected during Tropical Cyclones, *Remote Sens.* **14,** 5006 (2022).
[10] H. Wang *et al.*, Estimation of Significant Wave Heights from ASCAT Scatterometer Data via Deep Learning Network, *Remote Sens.* **13**, 195 (2021).
[11] M. Amani *et al.*, Remote Sensing Systems for Ocean: A Review (Part 2: Active Systems), *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **15**, 1421–1453 (2022).
[12] L. Ricciardulli and A. Manaster, Intercalibration of ASCAT Scatterometer Winds from MetOp-A, -B, and -C, for a Stable Climate Data Record, *Remote Sens.***13**, 3678, (2021).
[13] J. Röhrs *et al.*, Surface currents in operational oceanography: Key applications, mechanisms, and methods, *J. Oper. Oceanogr.* **16**, 60–88 (2023)
[14] X. Mou and W. Lin, An improved wind quality control for the China-France Oceanography Satellite (CFOSAT) scatterometer. *Acta Oceanol. Sin.* **43**, 100–109 (2024).
[15] S. Frolking, T. Milliman, R. Mahtta, A. Paget, D. G. Long, and K. C. Seto, A global urban microwave backscatter time series data set for 1993–2020 using ERS, QuikSCAT, and ASCAT data. **9**, 88 (2022).
[16] Y. He, L. Xu, J. Huo, H. Zhou, and X. Shi, A Synthetic Aperture Radar Imaging Simulation Method for Sea Surface Scenes Combined with Electromagnetic Scattering Characteristics. *Remote Sens.* **16**, 3335 (2024).
[17] W. Lin and M. Portabella, Characterizing Global Sea Surface Local Wind Variability From ASCAT Data, *IEEE Trans. Geosci. Remote Sens.*, vol. 60, pp. 1–10, 2022,
[18] F. Polverari *et al.*, On High and Extreme Wind Calibration Using ASCAT," *IEEE Trans. Geosci. Remote Sens.* **60**, 1–10 (2022).
[19] C. Guo, W. Ai, S. Hu, X. Du, and N. Chen, Effect of precipitation on synthetic aperture radar hurricane wind field retrieval, *Front. Environ. Sci*. **10**, 1034045, (2022).