Comparative Analysis of Wind Speed And Direction Measurements From Sentinel- 1 SAR And Sentinel - 3 Satellites

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ABSTRACT

This study focuses on the comparison of wind direction and speed between two satellites, Sentinel -1 SAR and Sentinel-3, using satellite data with a study area Southwest of Cyprus. While Sentinel 3 relies on sea surface anemometers, Sentinel 1 SAR uses radar for its measurements. The differences in results between the two satellites offer important insight into measurement methods and the use of satellite data in meteorology. The direction and speed of the wind is vital for marine safety and the prevention of hazards during navigation and marine surveys. Satellite observations provide important information, making this study critical for predicting and responding to marine hazards. Thus, understanding the differences between the wind measurements from Sentinel - 1 SAR and Sentinel - 3 is crucial to developing effective forecast models and achieving improved marine safety.

Keywords: Sentinel-1 SAR, Sentinel-3, wind speed direction, Cyprus

1. INTRODUCTION

Maritime surveillance is a cornerstone in ensuring the safety and efficient management of maritime activities. In the exploration of wind measurements in the southwest of Cyprus, two key satellites, Sentinel-1 SAR and Sentinel-3, are compared to understand their differences and implications for marine safety and hazard prevention.

Sentinel-1 SAR, equipped with Synthetic Aperture Radar (SAR), operates reliably day and night, unaffected by cloud cover or lack of illumination. Its C-SAR instrument facilitates wide-area monitoring with dual polarization capabilities, enhancing its ability to detect and track various phenomena. Offering multiple acquisition modes, including Stripmap and Interferometric Wide Swath, Sentinel-1 SAR provides crucial data for monitoring maritime activities [7]

On the other hand, Sentinel-3 primarily focuses on measuring sea surface topography, temperature, and color. Its key instruments, such as the Ocean and Land Colour Instrument (OLCI) and Sea and Land Surface Temperature Radiometer (SLSTR), contribute to environmental monitoring and data collection. Additionally, the SAR Radar Altimeter (SRAL) and Microwave Radiometer (MWR) on Sentinel-3 support ocean forecasting systems, providing valuable insights into marine conditions [6]

When it comes to measuring wind conditions, Sentinel-1 SAR employs the Ocean Wind Field (OWI) component to estimate surface wind speed and direction. With a spatial resolution of 1 kilometer, it provides valuable data on wind patterns and behavior. In contrast, Sentinel-3 relies on sea surface anemometers and instruments like SLSTR and SRAL to gather wind information.

The accurate measurement of wind is crucial for ensuring marine safety and preventing hazards at sea. Understanding the differences between Sentinel-1 SAR and Sentinel-3 measurements is essential for developing effective forecast models and response strategies. By bridging measurement gaps and leveraging the strengths of both satellites, marine safety and resource management in the Cyprus region can be significantly improved.

Extensive studies of different methodologies are used to calculate wind speed direction. The research assesses the correlation between vertical emission-horizontal reception (VH) polarization signals from Sentinel-1 Interferometric

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Wide Swath (IW) imagery and extreme ocean surface wind speeds during strong tropical cyclone conditions. It introduces a new geophysical model mode (GMF) called S1IW.NR, which accurately covers wind speeds up to 74 m/s. Through validation against SFMR measurements with clustered SAR and scaled frequency, the study demonstrates the accurate retrieval of wind extremes, thereby enhancing our understanding of wind extremes and improving wind speed estimation using SAR data [1]. Another study reveals that both satellites are suitable for wind field inversion applications. It highlights the slight advantage of Sentinel-1 over GF-3 in terms of root mean square error (RMSE), providing information on the data quality of different SAR satellites for wind field inversion purposes. This information helps researchers and practitioners select appropriate satellite data for specific research or operational needs [4]. Additionally, another study investigates wind speed estimation using Sentinel-1 EW and IW modes, focusing on convective systems. Although the authors are not identified, the research examines factors that affect SAR-based wind speed retrieval, such as wind direction uncertainty, image quality (e.g., speckle noise, thermal noise), and precipitation. This contributes to understanding the challenges and potential improvements in SAR-based wind speed estimation, particularly in the context of weather transport systems [3]. Also, another involves the assimilation of wind speed and direction data from various sources, including Sentinel-1, Sentinel-3, and Global Navigation Satellite Systems (GNSS), in Weather Research and Forecasting (WRF) model simulations. The study demonstrates that Sentinel-1 wind data make a significant contribution to data assimilation for short-term wind forecasts, thereby enhancing the accuracy of weather forecasts. This highlights the importance of incorporating SAR-derived wind data into numerical weather prediction models to improve short-term forecasting capabilities [5]. Finally, the study examines the quality of data from the Sentinel-1 and GF-3 SAR satellites for wind field inversion. The purpose of the study is to evaluate the quality of SAR satellite data for wind field inversion. The methodology used involves using the CMOD5.N C-band model to invert the data from the Army areas [2].

The remainder of this paper is structured as follows. Section 2 discusses the methodology followed, including data collection for the analysis of wind speed and direction measurements from Sentinel-1 SAR and Sentinel - 3 satellites. Section 3 compares the results of the two methodologies, using map algebra to compare wind speed data. Sections 4 and 5 conclude this paper with future work, directions, and conclusion.

2. METHODOLOGY

2.1 Study Area

The study area encompasses the Southwest Region of Cyprus, including the cities of Paphos and Limassol, as well as the Akamas Peninsula and Coral Bay beach.

Figure 1. The Southwest Region of Cyprus as a study area.

The data utilized comes from the Sentinel-3 and Sentinel-1 satellites, specifically the S3B_SL_2_WST and S1A_IW_GRDH_1SDV products, for a specific date during the winter period of 2024 when strong winds were observed. The Sentinel-3B SLSTR (Sea and Land Surface Temperature Radiometer) data provides information on sea surface temperature, while the Sentinel-1A IW (Interferometric Wide Swath mode) GRDH (Ground Range Detected High resolution) data offers high-resolution synthetic aperture radar images. The combination of these data sets allows for the analysis of the impacts of strong winds on the sea surface.

2.2 Methods

The methodology for extracting wind speed and direction from Sentinel-1 and Sentinel-3 satellite data emerges as a significant process in the fields of meteorology and climate research. After thermal noise removal to enhance data quality, the use of trajectory files ensures satellite positioning accuracy. Subsequent processing stages include boundary noise removal and the application of a land-sea mask to distinguish between terrestrial and maritime areas. Calibration corrections address systematic errors, while wind field estimation techniques are utilized to accurately compute wind speed and direction. Finally, terrain correction compensates for elevation differences, ensuring the accuracy and reliability of the derived data. For wind speed calculation, the CMOD5 model for NRCS is employed, with corresponding transformations applied for ENVISAT HH polarized products before CMOD5 model application, as described in detail in the literature [8].

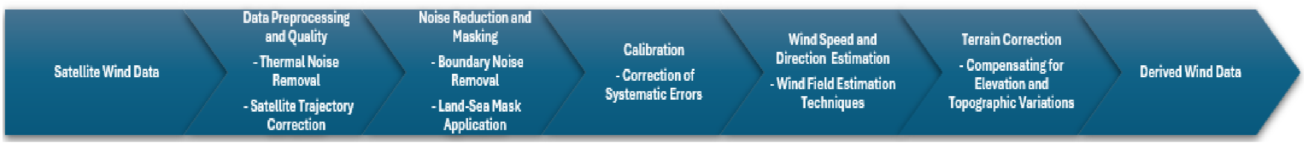

Figure 2. Logic Diagram of methodology.

3. RESULTS

3.1 Results from Satellite Sentinel-1:

Wind speed measurements obtained from Satellite Sentinel-1 exhibit a wide range, varying between -12.75 to 7.22 meters per second (m/s). The average wind speed recorded is -2.87 meters per second (m/s), with a standard deviation of 3.84 meters per second (m/s). The data demonstrates significant fluctuations in wind speeds, spanning from values near zero to a maximum of 7.22 meters per second (m/s).

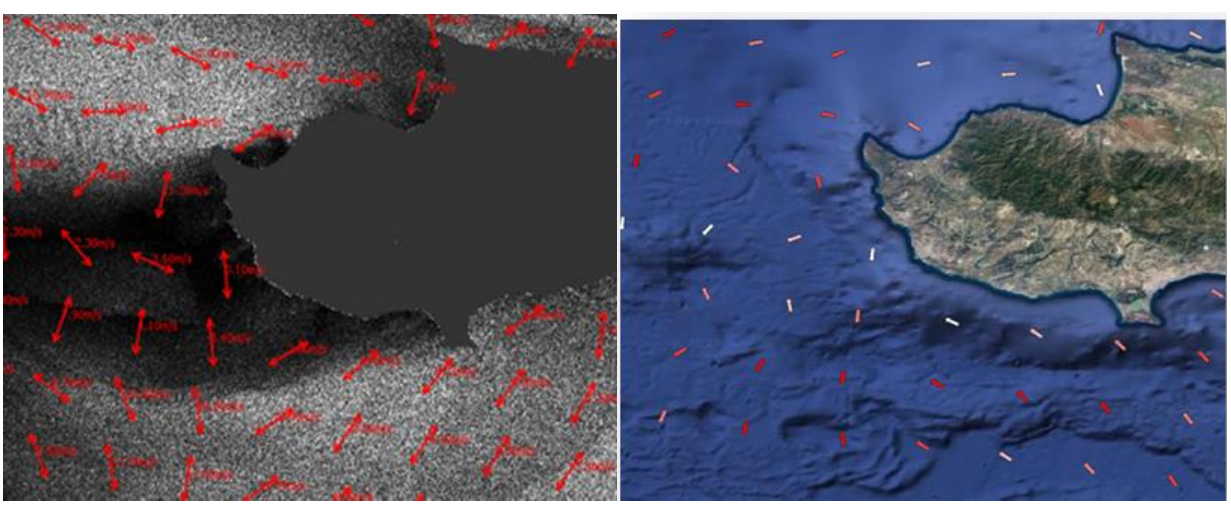

Figure 3. Wind speed and direction calculation from Sentinel-1.

3.2 Results from Satellite Sentinel-3:

For Satellite Sentinel-3, wind speed ranges from 0 to 9.80, with an average of 4.70 and a standard deviation of 2.40. The data from Sentinel-3 shows less variability compared to Sentinel-1, with more consistent values and a broader range from 0 to 9.80.

Figure 4. Wind speed from Sentinel-3.

3.3 Comparison using Map Algebra:

Map algebra was employed to compare wind speed data obtained from Sentinel-1 Synthetic Aperture Radar (SAR) and Sentinel-3 satellites. The analysis revealed intriguing insights: the minimum wind speed recorded was -3.59, while the maximum reached 8.42. The mean wind speed calculated was 2.42, with a standard deviation of 2.06. These findings underscore the variability and characteristics of wind speed measurements derived from different satellite sources, enhancing our understanding of atmospheric dynamics and the reliability of satellite data for environmental monitoring and research.

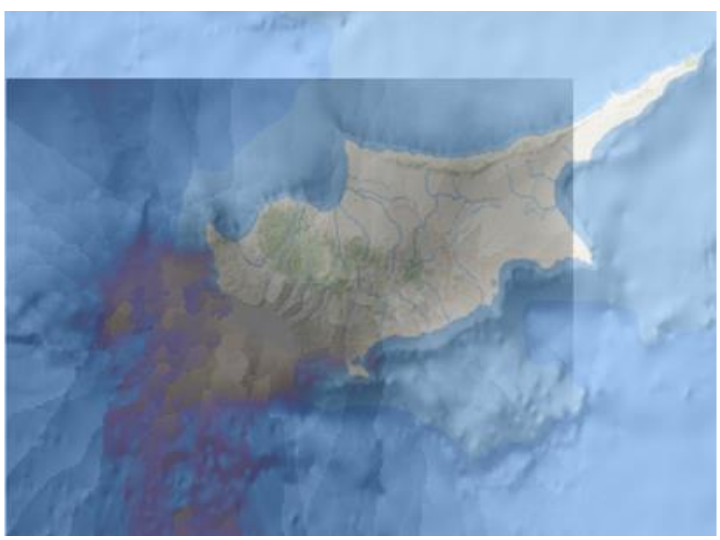

Figure 5. Comparative Analysis of Sentinel-1 and Sentinel-3 Data

4. CONCLUSIONS

In this study, wind direction and speed data from the Sentinel-1 SAR and Sentinel-3 satellites were compared over the Southwest Region of Cyprus, highlighting the differences in the results. While Sentinel-3 relies on sea surface anemometers, Sentinel-1 SAR uses radar technology. The analysis, conducted using map algebra, revealed significant variability in wind speed measurements between the two satellites, with Sentinel-1 showing greater variability compared to Sentinel-3. Additionally, comparison of wind direction and speed data from the Sentinel-1 SAR and Sentinel-3 satellites revealed significant differences in measurement methods, with Sentinel-3 providing greater spatial coverage and greater data density. This expanded coverage enhances the spatial resolution and efficiency of overall data collection, enabling a more comprehensive monitoring of wind patterns and environmental conditions. The study contributes to the improvement of forecast models and enhances safety at sea through improved accuracy in wind speed and direction forecasts.

5. FUTURE WORKS

In future work, extending the analysis to encompass long-term data trends would offer valuable insights into the temporal variations of wind patterns and their implications for climate change impacts in the Southwest Region of Cyprus. Integrating additional data sources, such as ground-based measurements or data from other satellite missions, could enhance the accuracy and reliability of wind speed and direction estimates. Employing advanced statistical techniques and localized studies within specific regions could further elucidate microclimatic variations and refine predictive models. Moreover, the application of validated and calibrated wind data from Sentinel-1 SAR and Sentinel-3 satellites to other regions with similar environmental characteristics could broaden the generalizability of findings and their utility in broader geographical contexts, ultimately advancing our understanding of wind dynamics and bolstering applications in environmental monitoring and marine safety.

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