# EVALUATION OF MARINE SURFACE WINDS OBSERVED BY ACTIVE AND PASSIVE MICROWAVE SENSORS ON ADEOS-II

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**ABSTRACT:** Marine surface winds observed by two microwave sensors, SeaWinds and Advanced Microwave Scanning Radiometer (AMSR), on the Advanced Earth Observing Satellite-II (ADEOS-II) are evaluated by comparison with off-shore moored buoy observations. The wind speed and direction observed by SeaWinds are in good agreement with buoy data with root-mean-squared (rms) differences of approximately 1 m $s^{-1}$ and 20°, respectively. No systematic biases depending on wind speed or cross-track wind vector cell location are discernible. The effects of oceanographic and atmospheric environments on the scatterometry are negligible. The wind speed observed by AMSR also exhibited reasonable agreement with the buoy data in general with rms difference of 1.2 m $s^{-1}$. Systematic bias which was observed in earlier versions of the AMSR winds has been removed by algorithm refinements. Intercomparison of wind speeds globally observed by SeaWinds and AMSR on the same orbits also shows good agreements. Global wind speed histograms of the SeaWinds data and European Centre for Medium-range Weather Forecasts (ECMWF) analyses agree precisely with each other, while that of the AMSR wind shows slight deviation from them.

**KEY WORDS:** Marine surface winds, Microwave scatterometer, Microwave radiometer, Air-sea interaction

## 1. INTRODUCTION

The Advanced Earth Observing Satellite-II (ADEOS-II) was launched by the National Space Development Agency of Japan (NASDA) on 14 December 2002, into an 802.9-km, near-polar, sun-synchronous orbit at an inclination angle of 98.7°. The mission carries five sensors including SeaWinds and Advanced Microwave Scanning Radiometer (AMSR), that measure near-surface winds under all weather and cloud conditions over the global oceans.

SeaWinds is a microwave scatterometer that measures wind speed and directions over the ocean surface. It uses a rotating dish antenna with two pencil beams that sweep in a circular pattern at incidence angles of 46° (H-pol) and 52° (V-pol). The antenna radiates microwave pulses at a frequency of 13.4 GHz across broad regions of the Earth's surface. The instrument can measure vector winds over a swath of 1800 km with a nominal spatial resolution of 25 km. Daily coverage is about 92% of the global ice-free oceans. SeaWinds was also carried by the QuikSCAT satellite launched in June 1999. Ebuchi et al. (2002) reported that the wind speed and direction observed by SeaWinds on QuikSCAT are in good agreement with offshore buoy observations, with root-mean-squared (rms) differences of 1 m $s^{-1}$ for wind speed and 23° for wind direction.

AMSR is a multi-frequency, dual-polarized microwave radiometer that measures microwave emissions from the Earth's surface and atmosphere. It measures scalar wind speed over the oceans together with various physical parameters of the ocean surface and atmosphere including sea surface temperature, integrated water vapor, liquid water content, and precipitation. AMSR has eight frequency channels (6.925, 10.65, 18.7, 23.8, 36.5, 50.3, 52.8, and 89.0 GHz) with dual polarization. Conical scanning is employed to observe the Earth's surface with a constant incidence angle of 55°. Multi-frequency measurement is realized by an array of primary horns. The offset-parabolic antenna has a diameter of 2 m and is the largest space-borne microwave radiometer antenna. Typical sampling interval is 10 km and the swath of the observation is approximately 1450 km.

Marine surface winds observed by spaceborne microwave sensors over the global oceans with high spatial resolution and frequent temporal sampling are utilized in various fields of meteorology, oceanography, and climate studies to investigate such topics as ocean surface waves, wind-driven ocean circulations and air-sea fluxes of momentum, heat, water vapor, and gasses (e.g., Liu, 2002). Surface vector wind and wind stress fields derived from scatterometer observations are applied to drive ocean circulation models on various scales and are also assimilated into global numerical weather prediction models. However, microwave scatterometers and radiometers do not directly measure the marine surface wind but instead measure the electromagnetic radiation backscattered or emitted from the sea surface. Surface winds are then estimated through empirical relationships between the backscatter cross sections or brightness temperatures and 10-m neutral equivalent winds (Liu and Tang, 1996). Validation of the observed winds is therefore necessary to evaluate the quality of the wind data and to assess the error structure. Numerous validation studies have been carried out by comparing winds derived from microwave scatterometers and radiometers with in-situ observations by buoys and vessels.

Ebuchi (2005a, 2005b, 2006) evaluated wind vectors observed by SeaWinds and wind speed observed by AMSR by comparison with data from the National Data Buoy Center (NDBC), Tropical Atmosphere Ocean/

Triangle Trans-Ocean Buoy Network (TAO/TRITON) and Pilot Research Moored Array in the Tropical Atlantic (PIRATA) buoys deployed in the Atlantic and Pacific Oceans and Gulf of Mexico. Also wind speeds observed by SeaWinds and AMSR on the same satellite orbits were compared with each other in order to assess the consistency of the measurements. Instantaneous observations of the marine surface winds by the active and passive microwave sensors on the same satellite gave us a unique chance for the intercomparison of the wind data.

Ebuchi (2005a, 2005b, 2006) reported that earlier versions (versions 1 and 3) of AMSR wind speeds are systematically lower than the buoy and SeaWinds data for wind speed lower than 5 m $s^{-1}$, and have a discontinuous trend relative to the buoy and SeaWinds data at wind speed of 5-6 m $s^{-1}$. Reflecting the validation results, the algorithm used to retrieve wind speed from AMSR brightness temperatures has been refined and new wind products has been distributed to scientific users. In the present paper, the same validation techniques utilized by Ebuchi (2005a, 2005b, 2006) is applied to the new AMSR wind products (version 4).

## 2. DATA

### 2.1 Seawinds

The SeaWinds Science Data Product, Level 2B, which was processed and distributed by the National Aeronautics and Space Administration (NASA)/Jet Propulsion Laboratory (JPL) Physical Oceanography Distributed Active Archive Center (PO.DAAC), are utilized in this study. The wind data were produced using a Maximum- Likelihood Estimator (MLE) with the QSCAT-1 geophysical model function and a median filter ambiguity removal algorithm with the Numerical Weather Product (NWP) initialization. The spatial resolution of the wind data is 25 km and the reference level of the wind vectors is 10 m. The Multidimensional Histogram (MUDH) Rain Flag was applied to indicate the presence of rain. All the flagged data, including data with rain flag, were discarded. Data observed in a period from 10 April 2003 to 24 October 2003 were used in the present study.

### 2.2 AMSR

The AMSR Level-2 Standard Product/Sea Surface Wind, which was processed and distributed by the Japan Aerospace Exploration Agency (JAXA), are utilized in this study. The AMSR standard algorithm developed by Shibata (2002) is used to derive the wind speed from the brightness temperatures. The first version (version 1) was released to the users in December 2003. Base on evaluations of the data product, the wind retrieval algorithm was refined and the entire data product was reprocessed using the new algorithm. The version 4 data product is now available to users. The version 4 wind data over the period from 10 April 2003 to 24 October 2003 are analyzed in this study.

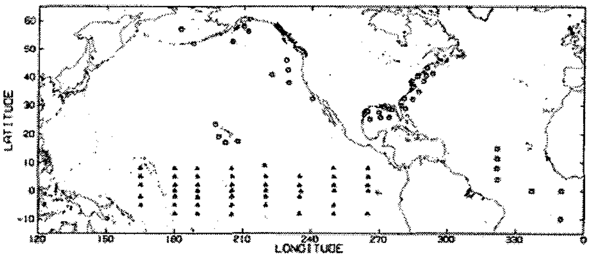

Figure 1. Locations of the NDBC (circles), TAO/TRITON (triangles), and PIRATA (squares) buoys used in this study.

### 2.3 Buoys

In order to compare with the SeaWinds and AMSR wind data, buoy observations from 34 NDBC, 48 TAO/TRITON, and 7 PIRATA buoys were collected. Only those buoys located offshore and in deep water were selected. Locations of the buoys are shown in Figure 1. Details of the NDBC and TAO buoys, instruments, and stations were described by Meindl, and Hamilton (1992) and McPhaden (1995), respectively. The PIRATA buoys are identical to the TAO buoys. High temporal sampling data with an interval of 10 min. are utilized. The wind speed measured by the buoys at various heights above the sea surface was converted to equivalent neutral wind speed at a height of 10 m using the method proposed by Liu and Tang (1996).

The SeaWinds and AMSR wind data and buoy observations were collocated in time and space. SeaWinds/AMSR wind observation cells closest to the buoy locations in space and the buoy data closest to the SeaWinds/AMSR observations in time were chosen. Temporal difference and spatial separation between the SeaWinds/AMSR and buoy observations were restricted to less than 10 min. and 12.5 km, respectively.

## 3. COMPARISON OF WIND SPEED AND DIRECTION OBSERVED BY SEAWINDS WITH BUOY DATA

Figure 2 shows a comparison of wind speed and direction observed by SeaWinds with the buoy data. Statistical values of the comparison are summarized in Table 1. In general, both the wind speed and direction derived by SeaWinds on ADEOS-II are in good agreement with buoy observations. No systematic biases in the wind speed and direction are discernible.

In the comparison of wind speed, the bias is negligible, and the rms difference is approximately 1 m $s^{-1}$, which is much smaller than the mission requirement of 2 m $s^{-1}$. In terms of wind direction, the rms difference is greater than 25°. Taking data of buoy wind speed higher than 3 m $s^{-1}$, the rms difference is considerably reduced to about 20°,indicating that the accuracy of the SeaWinds-derived wind direction at low wind speed range is worse than that at moderate to high wind ranges. This result also indicates that the mission requirement for the wind direction measurement, which is less than 20° in the wind speed

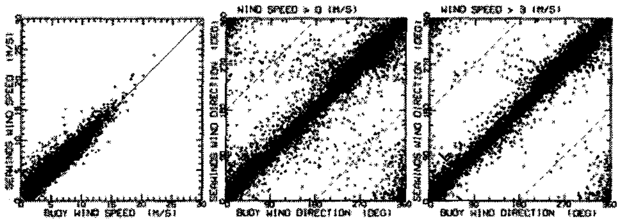

Figure 2. Comparison of wind speed (left) and direction (middle for data of all the wind speed ranges, and right for data of wind speed greater than 3 m $s^{-1}$) observed by SeaWinds with buoy data.

Table 1. Statistical values of the comparison of wind speed and direction observed by SeaWinds and buoy data.

| | Number of data | Bias | RMS difference |
|---|---|---|---|
| Wind Speed (m/s) | 10754 | -0.04 | 0.93 |
| Wind Direction (deg.) | | | |
| (Buoy Wind Speed > 0 m/s) | 10670 | 3.3 | 29.2 |
| (Buoy Wind Speed > 3 m/s) | 9301 | 3.0 | 20.7 |
| (Buoy Wind Speed > 5 m/s) | 6938 | 2.7 | 15.3 |

range from 3 to 20 m $s^{-1}$, is almost satisfied. These results are similar to comparisons of wind vectors observed by SeaWinds on QuikSCAT with buoy data reported by Ebuchi et al. (2002).

Residuals of the wind speed and direction are investigated to examine the dependences on wind speed and cross track cell location (results are not shown here). The wind speed residual is close to zero and shows no systematic dependence on the buoy wind speed over the whole wind ranges. In terms of the residual of wind direction, the standard deviation increases at low wind range, corresponding to the result in Table I and indicating that wind directions at low winds are less accurate. The standard deviations of the wind speed and direction residuals slightly increase towards the nadir and outer cells.

Correlations between the wind speed residual with various atmospheric and oceanic parameters observed by the buoys are calculated in order to assess the influence of atmospheric and oceanic conditions on the scatterometry. It is confirmed that the influence of the thermal condition of the sea surface and the sea state have negligible influences on the Ku-band radar backscattering. This conclusion is consistent with results from the NSCAT Ku-band scatterometer on ADEOS (Ebuchi et al., 1998) and SeaWinds on QuikSCAT (Ebuchi et al., 2002).

## 4. COMPARISON OF WIND SPEED OBSERVED BY AMSR WITH BUOY DATA

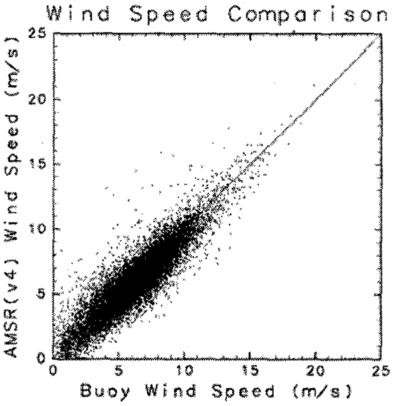

Figure 3. Comparison of wind speed observed by AMSR with buoy data.

Figure 3 shows a comparison of AMSR wind speed (version 4) with buoy observations. In general, the AMSR wind speed agrees with the buoy observations with a bias of -0.24 m $s^{-1}$ (AMSR-buoy) and rms difference of 1.17 m $s^{-1}$. These values are comparable to or slightly larger than the results for SeaWinds (Table 1). No systematic bias in the wind speed is discernible The systematic bias in the wind speed reported for the previous versions (versions 1 and 3) of the AMSR product by Ebuchi (2005a, 2005b, 2006) has been removed by the algorithm improvement.

## 5. INTERCOMPARISON OF WIND SPEED OBSERVED BY SEAWINDS AND AMSR

Wind data globally observed by SeaWinds and AMSR along identical satellite orbits were collocated by wind cell to cell. All the flagged data, including rain flagged data, were discarded. Only data observed in latitudes between 65°S and 65°N are used to avoid contamination by sea ice, which was not detected by AMSR and SeaWinds. The number of collocated data points is approximately 63 million.

Figure 4 shows the comparison of wind speeds observed by AMSR (version 4) and SeaWinds. Number density of the data points in bins of 0.1 x 0.1 m $s^{-1}$ is shown by contours. The bias (AMSR-SeaWinds) and rms difference are -0.08 m $s^{-1}$ and 1.17 m $s^{-1}$, respectively, indicating that wind speeds observed by the two sensors are generally in good agreement.

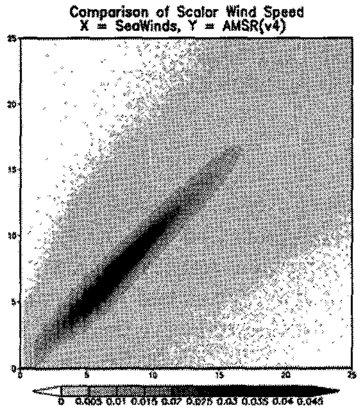

Figure 4. Comparison of wind speeds observed by AMSR (version 4) and SeaWinds. Horizontal and vertical axes are the SeaWinds and AMSR wind speeds in m $s^{-1}$. Number density of data points in % is shown by contours.

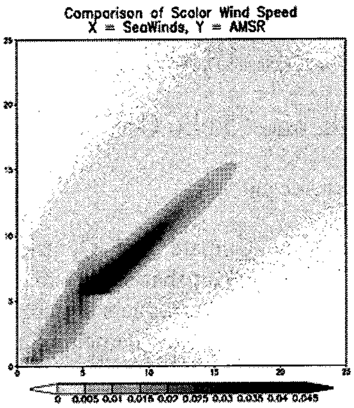

Figure 5. Same as Fig. 4 except for the version 1 AMSR wind data.

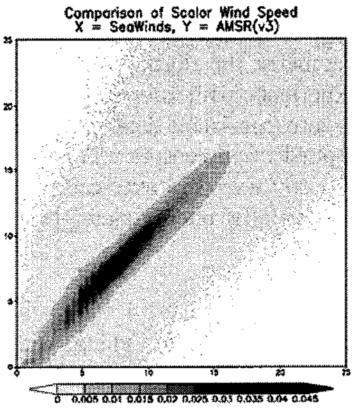

Figure 6. Same as Fig. 4 except for the version 3 AMSR wind data.

Figures 5 and 6 show the same plots as in Fig. 4 except for the versions 1 and 3 of the AMSR products, respectively. It is clearly shown that the version 1 and 3 winds exhibit discontinuous trend at around 5-6 m $s^{-1}$. In the wind speed range lower than 5 m $s^{-1}$, the wind speed derived from AMSR is systematically lower than that from SeaWinds. The large number of the AMSR-SeaWinds collocated data set clearly shows that the discontinuous trend in wind speeds of versions 1 and 3 has been eliminated in version 4.

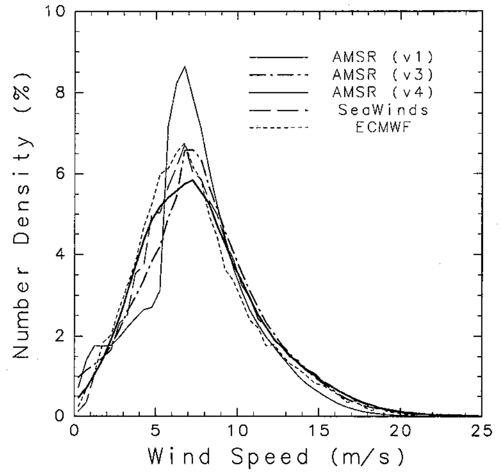

Figure 7. Comparison of global wind speed histograms.

## 6. COMPARISON OF GLOBAL WIND SPEED HISTOGRAM

Histograms of wind speed over the global oceans are calculated from all the wind speed data in latitudes from 65°S to 65°N and for the period of 7 months from April to October 2003. Comparison of the global wind speed histograms calculated from three versions of the AMSR wind products and SeaWinds wind speed is shown in Fig. 7. For reference, the histogram calculated from the European Centre for Medium-range Weather Forecasts (ECMWF) analysis (2.5° x 2.5°, 12-hour intervals) in the same period is also shown in the figure. The histograms of SeaWinds and ECMWF are in good agreement. The histogram of AMSR wind speed shows different features from them. However, the histogram for the version 4 AMSR winds is closer to those of SeaWinds and ECMWF wind over the whole wind speed range than those of the earlier versions.

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