

Comparison of wind data from QuikSCAT and buoys in the Indian Ocean

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Abstract

The performance of QuikSCAT derived wind vectors is evaluated using *in-situ* data obtained with moored buoys over the Indian Ocean. The results show that the mean differences for wind speed and wind direction are 0.37 ms^{-1} and 5.8° , root mean square deviations are 1.57 ms^{-1} and 44.1° and corresponding coefficients of correlation are 0.87 and 0.75 respectively. The matching between *in-situ* and satellite estimates seems to be better in North Arabian Sea than in Equatorial Indian Ocean. The effects of sea surface temperature and air-sea temperature difference on wind residuals were investigated. In general, for unstable atmospheric conditions, the QuikSCAT overestimates the winds. It is speculated that low wind speed during rain free conditions and high wind speed with rain may be the reason for the less accurate retrieval of the wind vector from QuikSCAT over Indian Ocean.

1 Introduction

The space-based scatterometer measurements of wind speed and direction help a wide variety of studies of oceanic processes and improve weather forecast via data assimilation in the operational models (Goswami and Rajagopal, 2003). The idea of remote sensing of ocean surface winds was based on the hypothesis that the backscatter, from the ripples and bubbles, of microwave pulses sent by scatterometer system are in equilibrium with the local wind stress. A model function relating the backscatter with the wind vectors obtained from other sources is used for estimating the wind vectors. The usual sources of wind vectors are *in-situ* observations such as buoys, ships, and reanalysis products, which are limited by a coarse resolution and an incorrect physics in the planetary boundary layer (Brown and Foster, 1994). Wentz et al (2001) gave the details of the Geophysical Model Function (GMF) for the QuikSCAT scatterometer launched by National Aeronautics and Space Administration (NASA).

The surface roughness, from which the wind speed and direction are derived, is also dependent on many other parameters apart from the wind speed and direction, such as SST, atmospheric density stratification (Liu, 1984; Wu, 1991), currents (Kelly et al, 2001), rain (Weissman et al, 2002), etc. Validation of the observed wind vector over different oceans is necessary to evaluate the quality of the wind data and to assess the error sources since the accuracy of scatterometer-derived winds is shown to vary over different oceans (Bentamy et al, 2002).

Earlier studies by Ebuchi et al, (2002) found that the root mean square difference (RMSD) for wind speed and direction are $\sim 1 \text{ ms}^{-1}$ and 23° , respectively. Over the Indian Ocean, Goswami and Sengupta (2003) carried out a comparison of 3-day running mean winds from QuikSCAT with 2 buoys in Indian Ocean. They found that the RMSD between QuikSCAT and the limited *in-situ*

observations (slightly more than two years) over Bay of Bengal (BoB) and Arabian Sea (AS) were $\sim 1.4 \text{ m s}^{-1}$ for both zonal and meridional components, which is larger than that found over the eastern Pacific indicating the poorer wind retrievals by QuikSCAT over the Indian Ocean. So far there has been no comparison studies between the QuikSCAT winds and *in-situ* winds over Indian Ocean collocated spatially and temporally. *In-situ* observations of wind vectors were much less in the Indian Ocean compared to those in the Pacific and the Atlantic. In the present study, wind vectors observed by QuikSCAT and buoys over the Indian Ocean are compared to validate the QuikSCAT wind vectors. The role of various air-sea interaction parameters such as SST, air-sea temperature difference on the scatterometer retrieval is also assessed. It is expected that over the Indian Ocean, with seasonally reversing wind directions, comparison of sea surface wind vectors with *in-situ* measurements will throw new light on the performance of pencil beam Scatterometer wind products. The authors believe that this work will provide confidence in analysis and applications with the observations of the forthcoming Indian Scatterometer mission (Sarkar, 2003). The Oceansat – 2 will carry a Ku band pencil beam scatterometer, and is scheduled for launch in 2007.

2 Data

2.1 Satellite data

NASA launched QuikSCAT on 19 June 1999 into a sun-synchronous circular orbit with 98.6° inclination and 803 km altitude. The mission carries a Ku-band scatterometer ‘SeaWinds’. It uses a rotating dish antenna with pencil beams that sweep a circular pattern at incidence angles of 46° (H-Pol) and 54° (V-pol). The instrument is capable of measuring winds over a swath of 1800 kms with a nominal spatial resolution of 25 km. Daily coverage is more than 90% of the global ice-free

oceans. The QuikSCAT swath data mapped to 0.25-degree grid divided into two maps based on ascending and descending passes obtained from the Remote Sensing Systems is used. The swath data that are not averaged in ascending and descending maps is more suitable for validation study and will get more match-up data with the buoys. The QuikSCAT data are calibrated to approximate a wind at 10 m above the ocean surface in a neutrally stratified atmosphere and have a spatial resolution of 25 km. Satellite microwave radiometers Special Sensor for Microwave Imaging (SSM/I) and Tropical rainfall measuring mission Microwave Imager (TMI) are used for rain flagging.

2.2 In-situ data

The data obtained from seven buoys by National Institute of Ocean Technology (NIOT) (Premkumar et al., 2000) and one Triangle Trans-Ocean buoy Network (TRITON) buoy deployed by Japan Marine Science and Technology Center (JAMSTEC) is used. The locations of these buoys and the periods of data available are shown in Figure 1. The stated accuracies for wind speed and direction for NIOT buoys are $\pm 1.5\%$ with resolution of 0.07 ms^{-1} for wind speed and 0.1° for direction (Premkumar et al., 2000). Eight observations are obtained everyday. Post calibration and error flagging of data are carried out by NIOT before the buoy data is released. Nominal accuracies of the TRITON wind speed and direction are 0.3 ms^{-1} and 2° (Kuroda 2002). The wind speed from TRITON and Tropical Atmosphere Ocean (TAO) buoys indicate good agreement from the in situ inter-comparison in the early stage of TRITON deployments; the mean wind speed differences are from -0.34 ms^{-1} to 0.27 ms^{-1} in eleven deployments, but the TRITON wind direction indicated -38° to 24° . This large error of wind direction is found due to the firm error and encoder alignment error, and is reported to be eliminated. After that the residuals of the wind direction sensor are 2° bias of

differences in average with the standard deviation of 6° and the largest one was 10° comparing the pre and post calibration after one-year deployment (Appendix 4 in Kuroda 2002).

3 Methodology

The QuikSCAT vector winds are collocated with the buoy observations in both space and time. The QuikSCAT wind cells closest to the buoy locations within 25 kms and buoy observations closer to the QuikSCAT winds within 30 minutes are chosen. It is found that time lags of up to 1 h in the case of wind speed comparisons do not produce significant changes in the key statistics (Gower 1996, Hwang et al. 1998). Sarkar et al. (2002) showed that the de-correlation time for wind speed over the NIO to be about ~ 1.5 hour. Also taking greater than 25 km search radius for QuikSCAT can lead to additional variability due to the inhomogeneous distributions of geophysical parameters. This could have possibly resulted in incorrect comparison statistics for QuikSCAT. The eventual choice is always a compromise between the window size and the number of data (Chen and Lin, 2001). The authors believe that the choices of temporal window of 30 minutes and 25 km search radius in this study are appropriate. The wind speeds observed by the buoys are at 3 m above the sea surface for the NIOT buoys and it is at 3.5 m above for the TRITON buoy. These winds are first converted to the equivalent neutral wind speed at a height of 10 m using the method of Liu and Tang (1996).

4 Results and discussion

Figures 2 (a-h) illustrate the comparison results for both wind speed and wind direction. The complete statistics of the comparison is given in Table 1. The correlation between the QuikSCAT retrieved winds and buoy measured winds over the entire Indian Ocean is 0.86. It can be seen from Table 1 that there is a small positive bias of 0.37 m s^{-1} for the QuikSCAT. Figure 2e gives the

comparison for the wind direction for the entire Indian Ocean. The wind direction is having a correlation coefficient of 0.75 and a bias of 5.81 deg. The correlation coefficient for winds with speed greater than 4 m s^{-1} varies between 0.79 and 0.82. Coefficient of correlation for wind speeds (Table 1) is found to vary between 0.79 and 0.88, the mean bias vary between 0.34 and 0.44 ms^{-1} and RMSD vary between 1.56 and 1.58 ms^{-1} for the Equatorial Indian Ocean (EIO) and Northern Indian Ocean (NIO) respectively. The QuikSCAT is found to overestimate the winds (especially for low wind speeds). This could be due to expected underperformance of scatterometer wind retrievals at wind speeds below 4 ms^{-1} . The mission requirement for the QuikSCAT specifies the error figures in the derived wind speed to be less than 2 m s^{-1} and less than 20° in direction within the range $3\text{--}30 \text{ m s}^{-1}$. Wind speeds stronger than 20 m s^{-1} are rarely seen in our data. Comparison of QuikSCAT derived wind direction (right panel of Figure 2) shows a larger scatter, the coefficient of correlation varying over wider range. It is 0.69 and 0.84 for the EIO and NIO respectively. The EIO being the doldrums region explains a larger scatter in the wind directions.

Figures 2b and 2f give the comparison of QuikSCAT with buoy over the EIO. The correlation for the wind speed is 0.79 and for the direction is 0.69. The bias for wind speed from QuikSCAT is 0.44 m s^{-1} and that for direction is 5.56 deg . Figures 2c and 2g show the comparison over the AS and Figures 2d and 2h over the BoB. The numbers of collocated points are very few over the AS. This is due to the fact that the buoys in the AS are unfavourably located with respect to QuikSCAT passes. The QuikSCAT is showing similar behaviour over both the basins of the NIO as can be seen from these Figures. The bias for the combined wind speed over NIO is 0.34 m s^{-1} , which is low compared to the EIO, and that for direction is 6.0° , which is almost equal to that over EIO. The correlation coefficient of 0.88 for wind speed and 0.84 for the direction over NIO is higher than that for EIO.

Thus QuikSCAT derived winds over NIO matches better with *in-situ* compared to those derived over the EIO.

Earlier studies by Thompson et al., (1983) and Keller et al., (1985) have reported a dependence of backscatter cross section in L and X-bands on the environmental parameters namely wind, air and sea temperature etc. Their study also revealed that decrease in the air-sea temperature difference increases the backscatter power for constant winds. In this study, an analysis of the residuals of wind speed (QuikSCAT-Buoy, ΔW) along with other meteorological and oceanographic parameters is carried out. Figure 3 shows the dependence of the ΔW and wind direction residual (ΔD) on the wind speed measured by the buoy. No significant differences are seen in the nature of dependence of ΔW and ΔD on wind speed for EIO and NIO regions. So consolidated results for the entire Indian Ocean, consisting of 1968 data points are shown here (Figure 3). It can be seen that for low wind conditions, ΔW is positive indicating that QuikSCAT is overestimating, while it is underestimated for high wind speed cases (Figure 3a). The mean and standard deviation (SD) indicate that the residuals for winds in the range of 4 – 10 ms^{-1} are minimal, while for lower and higher ends, they are larger. The SDs (Figure 3c) (shown as vertical lines) too is large at the lower and higher extremes. The histogram, representing sixty-six months' wind observations over the Indian Ocean (shown in the bottom panels in Figure 3(c)) indicate that more than 80% of data are within 4 – 10 m s^{-1} . The right panels (Figures 3b and 3d) show the dependence of ΔD on buoy wind speed. The QuikSCAT estimated wind direction for low wind speeds is showing higher variations from *in-situ* than for those with higher wind speed.

Figures 4a and 4c show the dependence of the wind speed residual on the air-sea temperature difference (ΔT). This exercise reveals that as air-sea temperature difference decreases scatter for wind residual increases. Similar results reported by Keller et al., (1985) for X band scatterometer.

They found that with decrease in air-sea temperature difference, power increases. Figure 4d and 4e shows the dependence of ΔW on SST over the Indian Ocean. SST in EIO is found to be always higher than marine atmospheric boundary layer temperature (ΔT always negative) and is greater than 28°C (Figures 4c & 4f). Figure 4b and 4e shows the bin average behaviour of residual wind with air-sea temperature and SST respectively. The EIO has distinct characteristics. Unlike in the NIO, where SST range is almost 8°C (between 24°C and 32°C), the SST in EIO is restricted between 28°C and 31°C . In the NIO, ΔT ranges between -5 and 2 , implying that the air can be either warmer or colder than the sea surface (Sengupta et al, 2001). We could not, however, decipher any pattern from the scatters between winds residual with SST. This result is similar to those reported for the Pacific and Atlantic (Ebuchi et al, 2002).

No seasonal dependence was observed for the winds retrieved by QuikSCAT. Figure 5 gives the monthly average values of wind residuals and wind speed in different months over the Indian region. The Indian Ocean is having two periods of wind reversal (transition periods between the two monsoon seasons) during which the winds are low. It is observed that the average ΔW is high ($> 0.4 \text{ ms}^{-1}$) during the periods of last week of July to second week of October and during December to January. These are the periods when winds are in the falling phase and are high during the monsoon periods, while average wind speed is low during non-monsoon periods and high during the monsoon periods. In view of the limitations of reanalysis data (Goswami and Sengupta, 2003) the space-based observations over EIO assume added importance.

5 Conclusions

The wind speed and direction obtained from the QuikSCAT is compared with the *in-situ* buoys over the Indian Ocean. This is for the first time such comparison of QuikSCAT derived wind speed and

wind direction with a large sample of buoy measurements were carried out. The wind speeds show a correlation coefficient of 0.86, a bias of 0.37 m s^{-1} and a RMSD of 1.57 m s^{-1} . The directions show a correlation coefficient of 0.75, a bias of 5.81° and RMSD of 44.1° . The performance of QuikSCAT over the NIO is better compared to its performance over the EIO. This may be due to the fact that the equator is usually very calm with predominantly low wind speeds, for which QuikSCAT derived winds are known to be less accurate. Another reason may be that the spatial size and distribution of the wind structures varies with the wind speed. At low wind speed there can be structures smaller than the scatterometer cell with high variability both in terms of wind speed and wind direction. The comparison of buoys time series with scatterometer spatial averages is difficult to interpret if these kinds of structures exist. The over estimation of the QuikSCAT at low wind speed may be due to this type of problem. The analyses with the meteorological and oceanographic parameters show that scatter increases with decreasing air-sea temperature difference. Our study reveals that the QuikSCAT retrieval algorithm does not perform well over the Indian Ocean as well as it does over the Pacific and the Atlantic Oceans reported by Ebuchi et al, 2002. Perhaps Geophysical Model Function for QuikSCAT, used for wind retrieval did not adequately represent Indian Ocean conditions. Therefore, there is a need for developing/fine tuning a model function suitable for retrievals for the Indian Ocean as well. The wind retrieval from the proposed Scatterometer onboard Oceansat-2 by India is expected to address the issue of a suitable model function for the global Oceans.

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TABLE 1: The statistics of the comparison between QuikSCAT and buoy measured wind vectors

		R		Bias		RMSE		N	
		> 4 ms ⁻¹	All	> 4 ms ⁻¹	All	> 4 ms ⁻¹	All	> 4 ms ⁻¹	All
<i>Buoy</i>									
EIO	Speed	0.79	0.79	0.26	0.44	1.37	1.56	427	854
	Direction	0.81	0.69	2.87	5.56	29.70	49.00	427	854
NIO	Speed	0.82	0.88	0.12	0.34	1.45	1.58	821	1114
	Direction	0.88	0.84	3.25	6.00	33.90	39.00	773	1028
All Buoys	Speed	0.82	0.86	0.17	0.37	1.42	1.57	1248	1968
	Direction	0.85	0.75	3.35	5.81	31.80	44.10	1200	1882

Figures

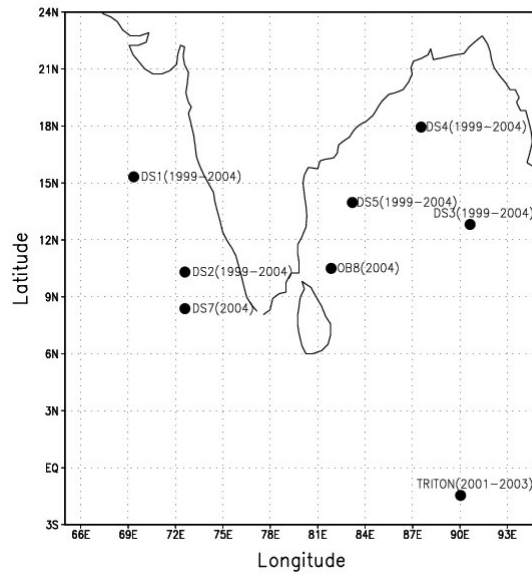


Figure 1. Locations of Indian Ocean Buoys operated by NIOT and the TRITON buoy. The periods of data availability are written in the brackets.

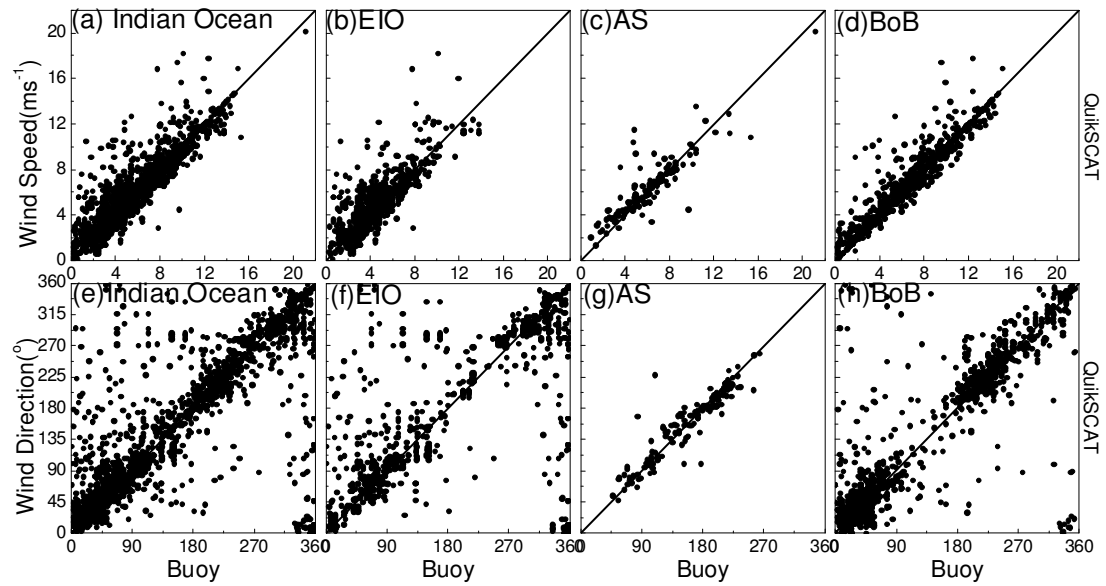


Figure 2. Comparison of QuikSCAT wind speed (ms^{-1}) (top panels) and direction (Degree) (bottom panels) with *in-situ* data, (a) and (e) for entire Indian Ocean, (b) and (f) for EIO, (c and g) for AS and (d and h) for BoB.

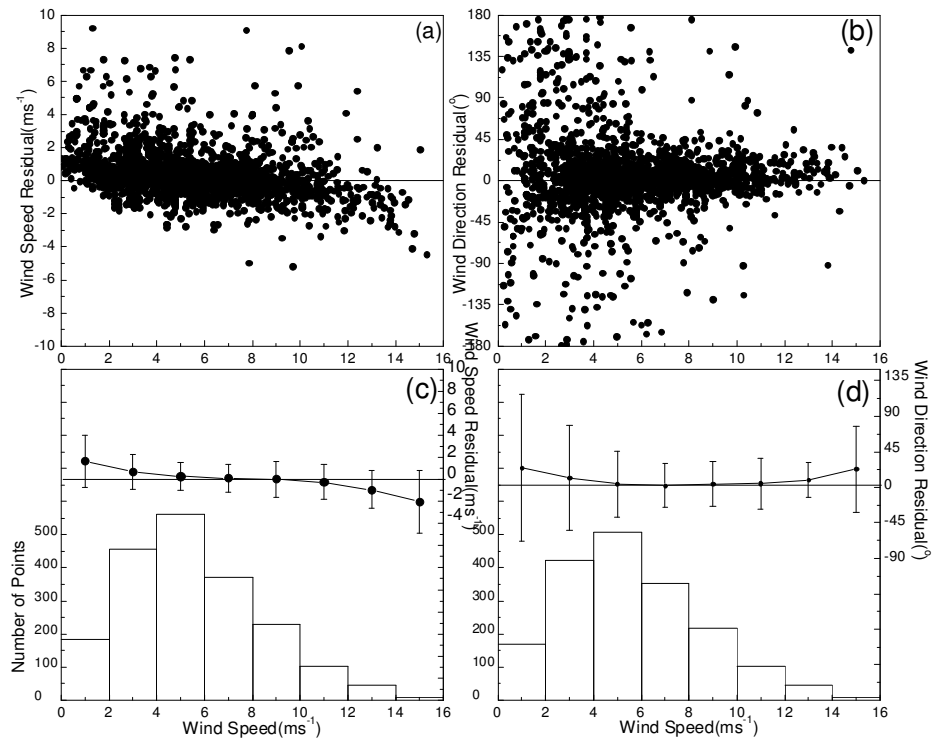


Figure 3. (a) and (b) shows the dependences of wind speed residual and direction residual (QuikSCAT-Buoy) on buoy wind speed, while (c) and (d) shows the number of data points and bin averages of residual wind with respect to particular wind speed bin and the standard deviations are shown by the bar. The axes on the left side of (c) and (d) are the numbers of data points while the right side are the residual wind.

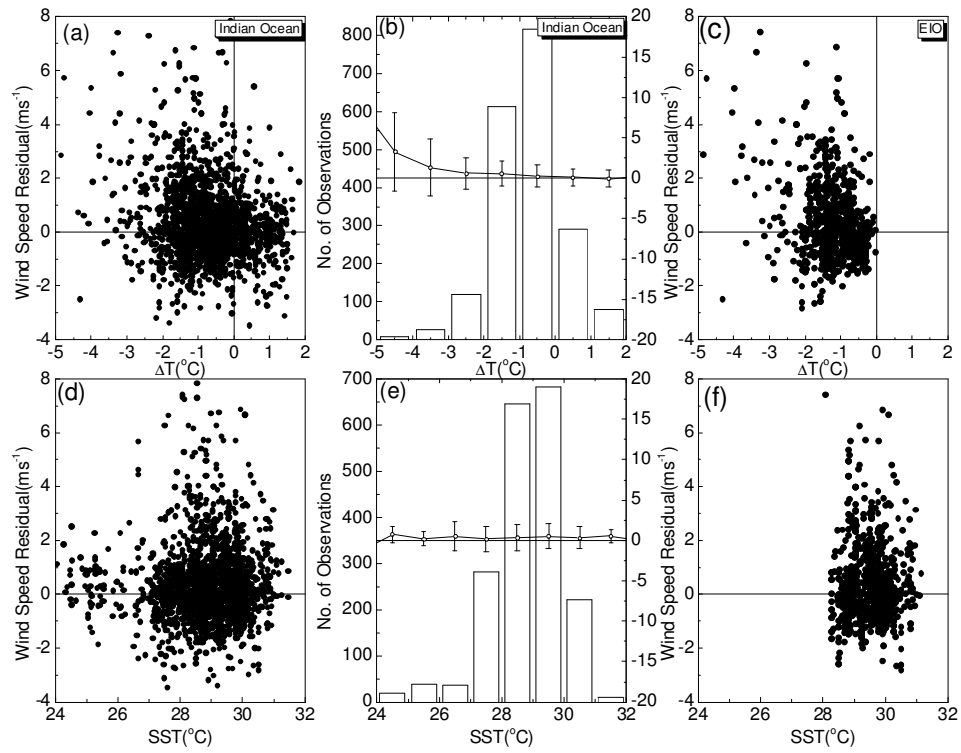


Figure 4. (a) and (c) are scatter plot of wind speed residual (QuikSCAT-Buoy) Vs. Air-Sea temperature difference over the Indian Ocean and EIO respectively and (d) and (f) are scatter plot of wind speed residual Vs SST over the same regions, while (b) and (e) represents bin average behavior of residual wind with air-sea temperature difference and SST respectively. Histograms show the numbers of collocations in that bin.

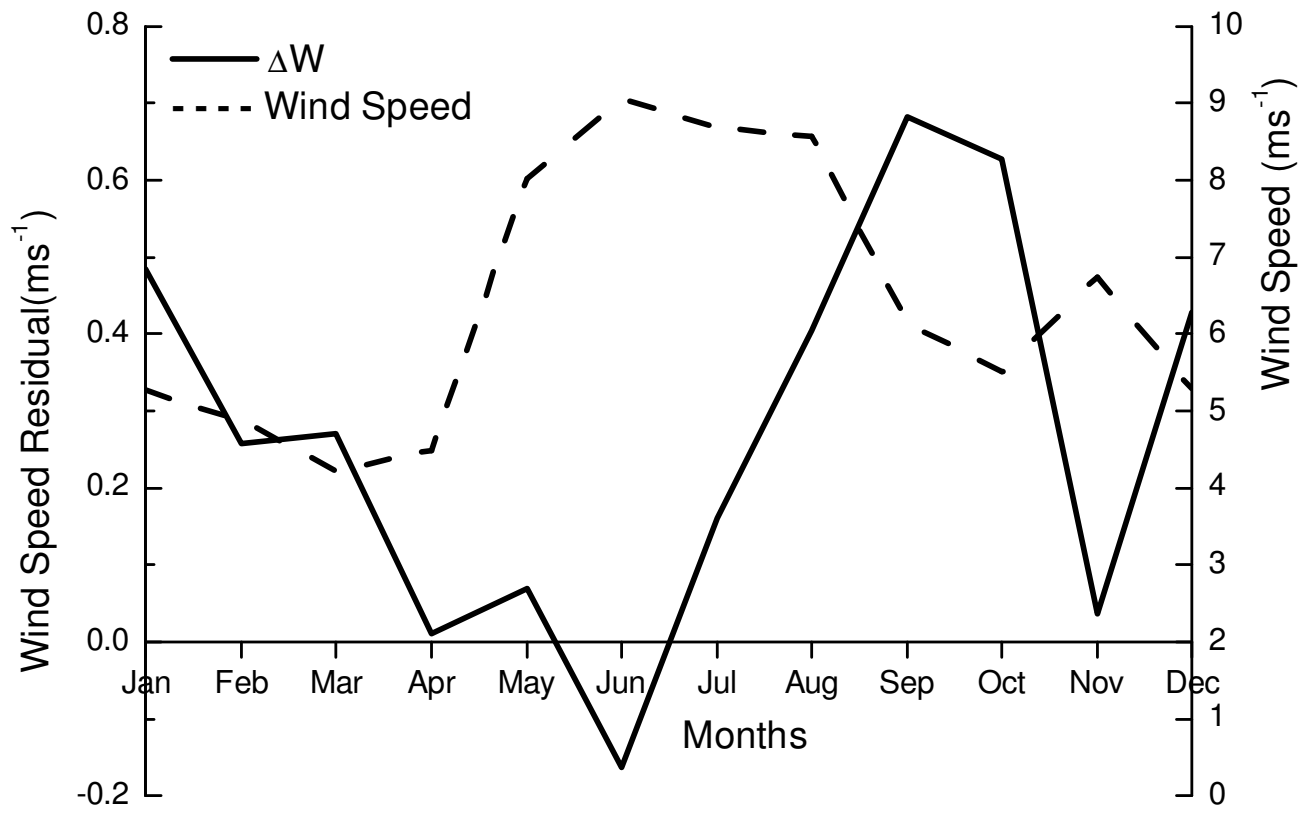


Figure 5. The seasonal variation of wind speed residual and wind speed averaged for 2000-2003.