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High-wind-speed evaluation in the Southern Ocean

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[1] Space-based scatterometer instruments provide crucial surface wind measurements with high resolution over global oceans. Midlatitude regions in the Southern Ocean are unique places to evaluate scatterometer winds at high-wind bands because these regions host the strongest wind fields at the ocean surface. The objective of this study is to evaluate high wind speeds observed by Quick Scatterometer (QuikSCAT) wind measurements and produced by simulation models and compare them with weather station data in the Southern Ocean. The occurrence and intensity of high-wind events in scatterometer measurements are compared with that of reanalysis winds, and the spatial and seasonal variability of high-wind characteristics is examined. The results show that the speeds of scatterometer winds are similar to model simulations in the monthly mean field but consistently stronger than both European Centre for Medium-Range Weather Forecasts and National Centers for Environmental Prediction/National Center for Atmospheric Research winds in high-wind bands. When scatterometer winds are compared with the weather station observations at Macquarie Island, the present study finds no systematic bias at high-wind bands across all months. However, both weather station and QuikSCAT winds are higher than the model simulations in high-wind bands most of the time. This suggests that model simulations may underestimate surface wind strength in high-wind bands. Such underestimation would lead to up to an 80% reduction in energy flux between the atmosphere and ocean. Even though high winds occur only sporadically and the reanalysis underestimation in high wind speed is not in itself of great magnitude, they have a significant impact on global climate. *INDEX TERMS:* 3329 Meteorology and Atmospheric Dynamics: Mesoscale meteorology; 3337 Meteorology and Atmospheric Dynamics: Numerical modeling and data assimilation; 3339 Meteorology and Atmospheric Dynamics: Ocean/atmosphere interactions (0312, 4504); 3360 Meteorology and Atmospheric Dynamics: Remote sensing; 3394 Meteorology and Atmospheric Dynamics: Instruments and techniques; *KEYWORDS:* QuikSCAT winds, Southern Ocean, wind evaluation

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1. Introduction

[2] The Southern Ocean is a vital element in the global climate. Its circumpolar current plays a crucial role in the global transport of mass, heat, momentum, and climate signals from one ocean basin to another. Moreover, the Southern Ocean hosts the strongest surface winds of any open ocean area, fostering strong heat, moisture, and momentum exchanges between the ocean and atmosphere. However, the Southern Ocean is tremendously undersurveyed by traditional observation methods because of the remoteness of the area and rough environment, causing the largest data gap of global oceans. The data gap introduces large uncertainties into data simulation of the region, both in global climate modeling and in estimating the global energy budget. In the last two decades, satellite technologies have greatly enhanced our ability to monitor climate variables in this remote region, such as cloud, sea surface temperature, sea ice, surface height, surface wind, and precipitation. These satellite observations play critical roles in modern climate studies.

[3] Surface winds are crucial to determining many climate variables, such as heat, moisture, and momentum flux between the atmosphere and ocean, mixed layer depth, and Ekman transports, etc. Surface winds directly influence ocean circulation, water mass formations, and energy transports between ocean basins. For more than a decade, space-based scatterometers have provided measurements of surface winds over global oceans with high spatial and temporal resolution (ERS-1/2, NASA Scatterometer (NSCAT), and Quick Scatterometer (QuikSCAT)). In particular, QuikSCAT, a Ku-band scatterometer with a new design providing continuous 1800-km swath, has been covering 93% of the global ocean daily with a within-swath spatial resolution of 25 × 25 km since September 1999 [*Liu*, 2002]. The root-mean-square (RMS) differences between collocated QuikSCAT and buoy measurements are 0.7 m/s for the speed and 13° for the direction under moderate conditions [*Wentz et al.*, 2001]. Validated by high-quality

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wind observations from research vessels, *Bourassa et al.* [2003] showed that the uncertainties of QuikSCAT winds are 0.45 m/s and 5° for QSCAT-1 model function and 0.3 m/s and 3° for Ku-2000 model function. On the other hand, these validation studies were limited for winds <20 m/s. Whether these validations are applicable to the areas where winds could exceed 20 m/s because of strong westerly and frequent cyclone activities remains unclear.

[4] Historically, scatterometer measurements were subject to limitations on wind retrieval from backscatter under high-wind conditions. High-wind saturation was predicted by a theoretical study [e.g., *Donelan and Pierson*, 1987]. Such limitations were observed by NSCAT measuring tropical cyclones [*Jones et al.*, 1999] and by scatterometers on aircraft for measuring wind speeds higher than 20 m/s [*Donnelly et al.*, 1999]. QuikSCAT measurements also show considerable variation as a function of wind speed at speeds higher than 35 m/s [*Yueh et al.*, 2000]. However, recent studies show that backscatter measured by QuikSCAT is sensitive to wind variation at wind speeds as high as 50 m/s under clear-sky conditions [*Wentz et al.*, 2001] and during tropical cyclones at various rain rates [*Yueh et al.*, 2001]. For modern scatterometer instruments the high-wind saturation likely comes from wind retrievals because of shortcomings of model functions.

[5] The objectives of this study are to cross-examine QuikSCAT winds against other wind products in the Southern Ocean from 30°S to ice edge, where the strong westerly prevails, and to evaluate the impact of scatterometer winds on the estimation of cyclone activities and surface momentum flux. Because of the remoteness and rough environment the region lacks ground truth data, such as buoy and ship measurements, presenting a tremendous challenge to wind evaluation. In cross-examining QuikSCAT winds against National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis and European Centre for Medium-Range Weather Forecasts (ECMWF) operational archive surface winds over the open Southern Ocean, this study finds discrepancies between the simulated winds and satellite observations in wind speeds. Wind observations from the Macquarie Island Weather Station are then used as ground truth measurements to evaluate both scatterometer winds and simulated winds.

2. Data and Processes

2.1. Scatterometer Winds

[6] In this study, I use two QuikSCAT products that provide surface wind adjusted to 10-m equivalent neutral winds [*Ross et al.*, 1985]: level 2 swath data by QSCAT-1 model function available from the Physical Oceanography Distributed Active Archive Center at the Jet Propulsion Laboratory and swath data produced by the Ku-2001 geophysical model function [*Wentz et al.*, 2001] from the Remote Sensing System. QSCAT-1 scatterometer winds (hereinafter referred to as QSCAT-JPL) are research-quality data. I choose to use selected ambiguity in retrieving QSCAT-JPL winds. The Ku-2001 model function (hereinafter referred to as QSCAT-RSS) is an improved version of Ku-2000 model function, with better accuracy in retrieving winds higher than 20 m/s. On the basis of ship observations the uncertainties of QuikSCAT wind speed and wind direction are 0.45 m/s and 5° for QSCAT-JPL products and 0.3 m/s and 3° for QSCAT-RSS products [*Bourassa et al.*, 2003], respectively. QuikSCAT contains up to 76 cells across the satellite swath. Because of larger uncertainties in the inner swath (<200 km from nadir) and outer swath (>700 km from nadir) [*Bourassa et al.*, 2003], 8 outer cells at each side of the swath and 18 cells in the inner swath are excluded. One challenge for QuikSCAT wind retrieval is the rain contamination [*Sharp et al.*, 2002]. To avoid the rain contamination, wind cells with any rain flag are excluded.

[7] Selected QuikSCAT swath winds from September 1999 to December 2000 are averaged into a 1° × 1° grid at 12-hour temporal intervals. A three-dimensional interpolator [*Zeng and Levy*, 1995] is then applied to fill spatial/temporal gaps. To fill a missing data point, the three-dimensional interpolator uses data within a circle of 450-km radius weighted by the distance to the missing data point. It also considers data within three time intervals centered at the time when the missing data occur. Such interpolated 12-hourly wind fields are then averaged to yield daily 1° × 1° gridded data, which are cross-examined with simulated daily winds.

2.2. Simulated Winds

[8] I use 10-m winds from both the ECMWF operational archive surface analysis data [*Trenberth*, 1992; *Trenberth et al.*, 1993] and NCEP/NCAR reanalysis products [*Kalnay et al.*, 1996; *Kistler et al.*, 2001] from 1999 to 2000 in this study. Both simulated data sets are independent of scatterometer observations for the study period. The NCEP/NCAR reanalysis model runs on a Gaussian grid with a horizontal resolution of 1.875° (approximately 210 km). Its daily 10-m winds are outputted at the model grid. The winds are then linearly interpolated into a 1° × 1° grid for the comparison. The ECMWF analysis runs with a model horizontal resolution of ~1.125°, which provides six-hourly 10-m winds at the model grid. This wind product is also linearly interpolated into the 1° × 1° grid. Then winds at 0000, 0600, 1200, and 1800 geomagnetic time (GMT) are averaged into a daily temporal resolution to be consistent with NCEP/NCAR and QuikSCAT winds.

2.3. Weather Station Data

[9] The data from the Macquarie Island Weather Station (54°30′S, 158°57′E) are chosen as ground truth in this study for the following reasons: The size of the island (34-km long and 5-km wide at its widest point) is rather small compared to the satellite footprint, so its existence is unlikely to influence surface winds in the surrounding waters. Also, this hilly, long, and narrow-shaped island has an approximate north-south orientation, is located in the mean westerly zone where strong winds prevail, and is covered by grass without trees, shrubs, or other woody plants. In addition, the Australia Antarctic Station, where the weather station is located, is at a relatively flat area on the island's northern tip, surrounded by a marine environment. The hills in most parts of the island may not have strong impact on the local surface winds at the station. The elevation of the station is 6 m, close to sea level. A few weather observers and a meteorological technician maintain the weather station. It provided high-quality meteorological observations from surface to upper atmosphere all year

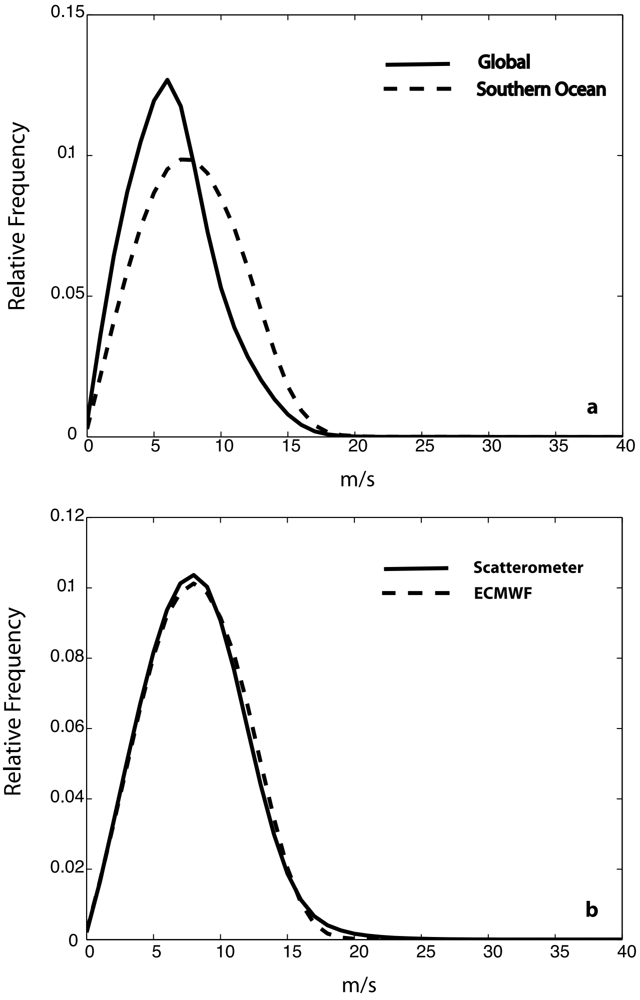

Figure 1. (a) Wind speed histogram for the global and Southern Ocean (30°S to ice edge) ECMWF surface winds and (b) wind speed histogram for the Southern Ocean observed by QuikSCAT and simulated by ECMWF.

round for forecasting and research purposes. The Australia Antarctic Service provided three-hourly surface winds recorded at the 10-m height at this weather station for this study.

3. Comparison With Simulated Wind Products

[10] Earlier studies [*Atlas et al.*, 1999; *Ebuchi*, 1999] have shown that NSCAT winds are in good agreement with ECMWF and NCEP/NCAAR reanalysis winds in terms of a global average. Moreover, the NSCAT provides more spatial structures than the model simulations because of its higher spatial resolution [*Liu et al.*, 1998]. Since the NSCAT era, the accuracy of strong winds has improved because of improved scatterometer geophysical model functions in QuikSCAT wind retrievals [*Yueh et al.*, 2001, 2003]. However, a unique characteristic of the Southern Ocean is its strong and persistent wind field and rich storm activities, and scatterometer winds have not been fully validated in this area. QuikSCAT wind distributions clearly show that the winds in middle-high latitudes of the Southern Ocean (south of 30°S) significantly shifted to high-wind band compared to the global wind distribution (Figure 1a). Currently, model calibration is based on buoy data, in which high winds were usually collected during hurricanes accompanied by rains. Rain contamination imposes uncertainties on hurricane high-wind observations [*Stiles and Yueh*, 2002]. Therefore only very limited high winds in rain-free conditions contribute to the model calibration. QuikSCAT winds were also validated by high-quality wind measurements from research vessels in both hemispheres [*Bourassa et al.*, 2003]. However, ships usually avoid extreme weather, so their measurements have only a limited number of high-wind events. Therefore high-wind situations were not adequately validated in either case. The Southern Ocean makes an ideal place to evaluate scatterometer wind measurements in an environment of consistent strong winds with and without rain. The histograms of ECMWF and QuikSCAT winds in the Southern Ocean visually indicate that satellite observations capture more high winds with speeds stronger than 15 m/s than do ECMWF simulations (Figure 1b). Since these high winds only account for about 5% (4%) of total scatterometer (ECMWF) winds observed during the study period, the monthly mean wind speeds of satellite observations averaged over the Southern Ocean are in good agreement with model simulations, except for the period from May to October, when scatterometer winds are stronger than simulated winds (Figure 2). The greatest difference between monthly mean of QSCAT-JPL and NCEP/NCAR winds reaches 0.5 m/s during austral winter. The differences between the monthly QSCAT-RSS and ECMWF winds are relatively minor, representing a very small bias of 0.02 m/s for the study period. This Southern Ocean bias indicates that QuikSCAT observed stronger wind speeds than did model simulations, in contrast with earlier studies showing a global mean bias between NSCAT and ECMWF (approximately −0.1 to −0.2 m/s) and NCEP/NCAR reanalysis (−0.1 m/s) [*Atlas et al.*, 1999; *Ebuchi*, 1999]. Among different wind products, QSCAT-JPL monthly winds are only slightly higher than

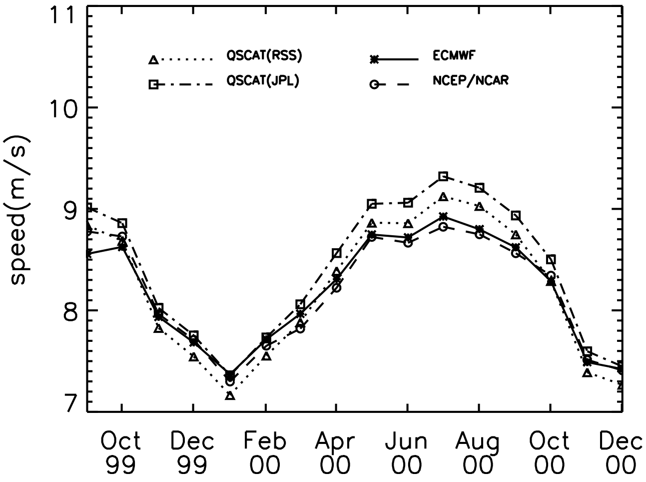

Figure 2. Monthly wind speeds (m/s) averaged over the Southern Ocean from September 1999 to December 2002 from QSCAT-RSS (dotted line) and QSCAT-JPL (dot-dashed line) as well as from NCEP/NCAR reanalysis (dashed line) and ECMWF operational analysis (solid line).

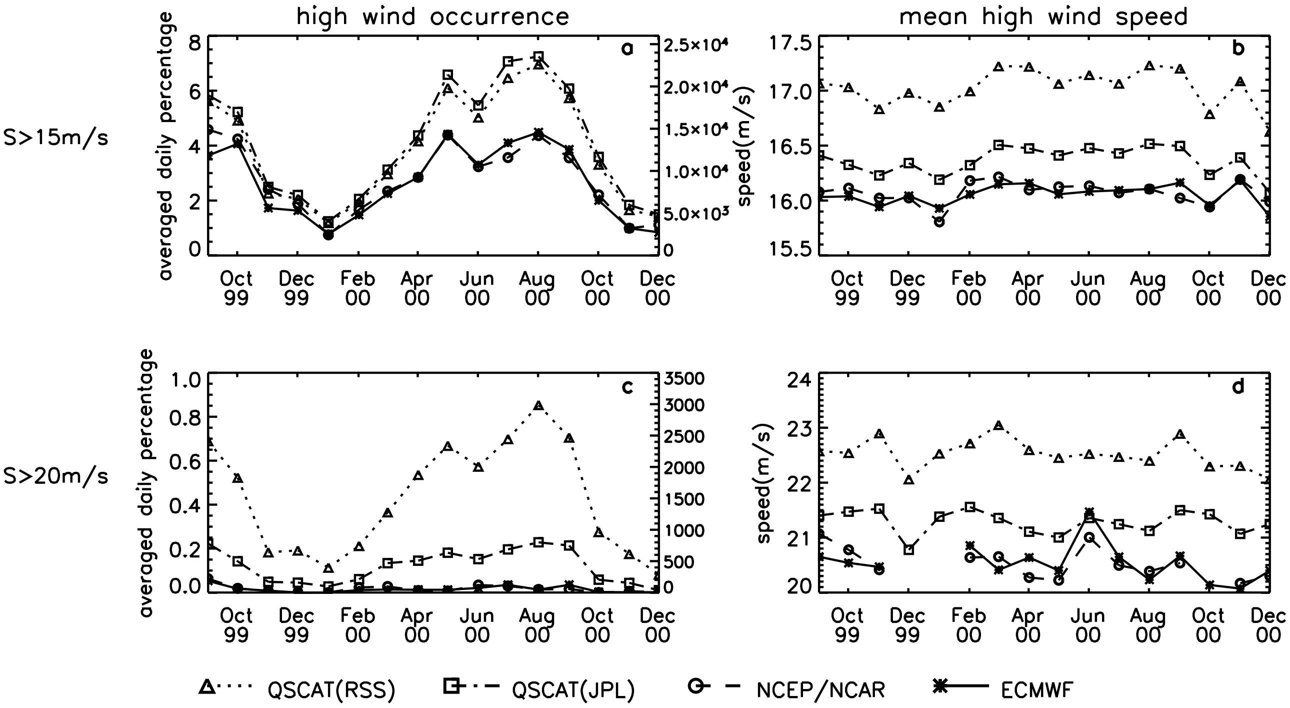

Figure 3. Monthly (a) high-wind (speed >15 m/s) occurrence and (b) mean high wind speed together with (c) extremely strong wind (speed >20 m/s) occurrence and (d) their mean speed, in the Southern Ocean from September 1999 to December 2000 observed by the satellite and simulated by models.

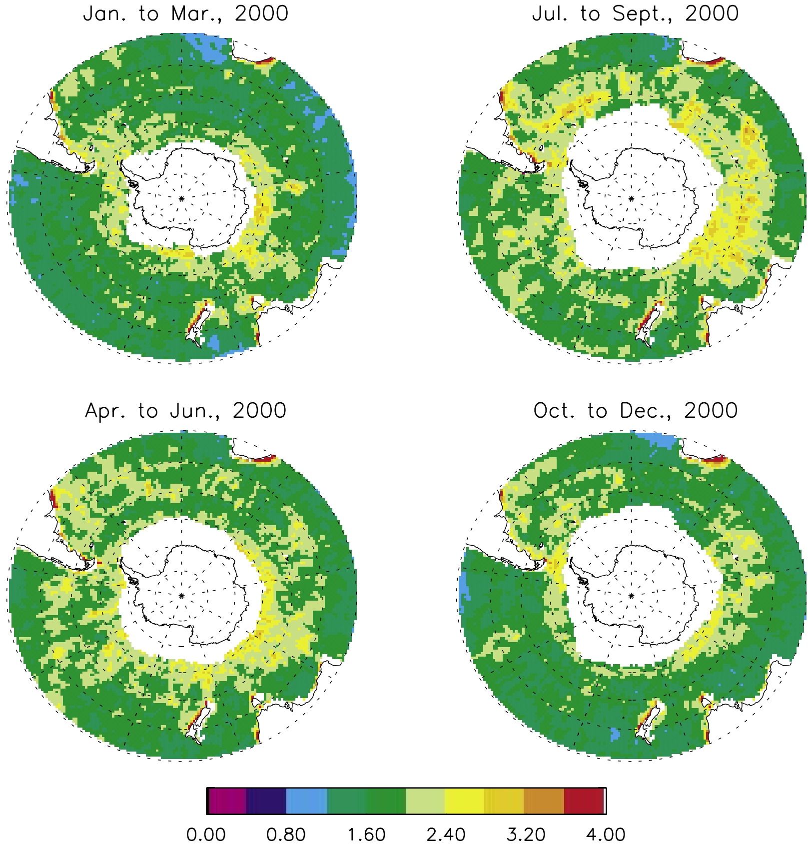

Figure 4. Seasonal RMS wind speed differences between QSCAT-RSS and ECMWF daily winds (m/s).

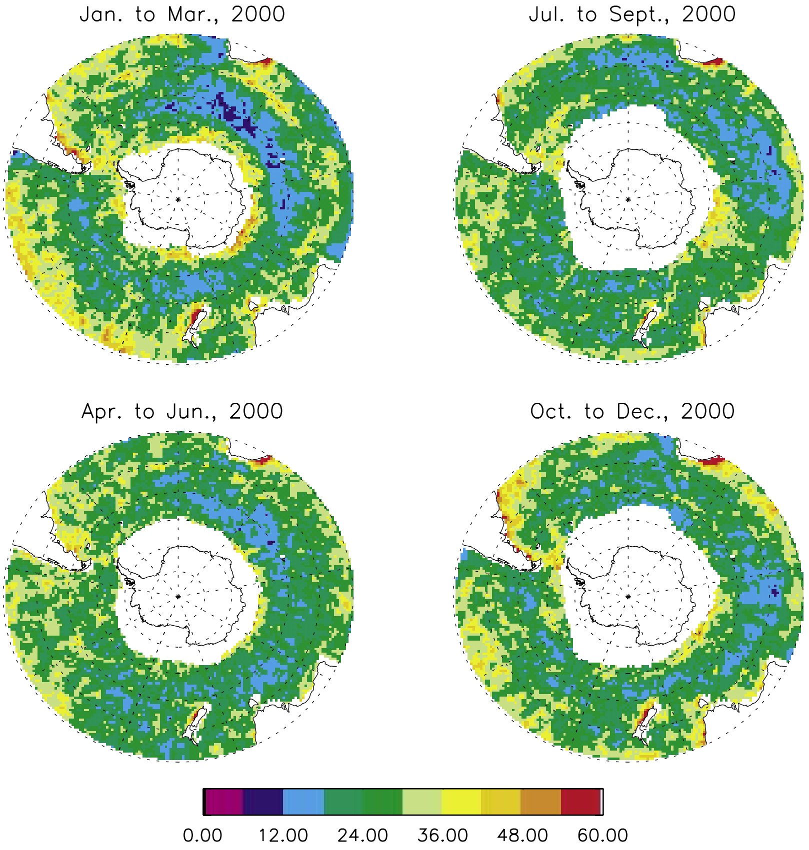

Figure 5. Seasonal RMS wind direction differences between QSCAT-RSS and ECMWF daily winds (degrees).

QSCAT-RSS winds while ECMWF winds are slightly stronger than NCEP/NCAR winds in general.

[11] However, the discrepancy between QuikSCAT and simulated winds becomes more pronounced when we examine high-wind bands. The scatterometer observed more high-wind events, and its wind speeds averaging in the range of 15 m/s and higher are consistently stronger than ECMWF and NCEP/NCAR winds throughout all seasons (Figures 3a and 3b). The mean high wind speeds of QSCAT-RSS are ~1 m/s higher than model-simulated winds, while the mean QSCAT-JPL winds are ~0.4 m/s higher than simulated winds on average. Moreover, QuikSCAT observed many more extremely strong winds (speed >20 m/s) than did model simulations. The differences between scatterometer and simulated wind speeds reach 2 m/s for QSCAT-RSS winds and 1 m/s for QSCAT-JPL winds in this extremely high wind band (Figures 3c and 3d).

[12] Next, we examine the spatial distribution of the discrepancies between QSCAT-RSS and ECMWF wind speeds. Particularly large discrepancies are found in the westerly regions of the South Indian Ocean, south of Australia, and the southwest Atlantic during austral winter. Some significant differences are also found in the westerly region and near ice edge during austral autumn (Figure 4). The mean RMS of wind speed differences (averaged over the Southern Ocean) varies from 1.7 m/s in summer to 2.1 m/s in winter, yielding a total mean of 1.93 m/s over the study period, which is comparable to the global average [*Atlas et al.*, 1999; *Ebuchi*, 1999]. Evaluating wind direction, on the other hand, averaged over the Southern Ocean and throughout all seasons yields a mean RMS difference of 33°. Moreover, the RMS of wind direction differences is minimal in the westerly regions where large RMS wind speed differences occur, suggesting that the ambiguity of

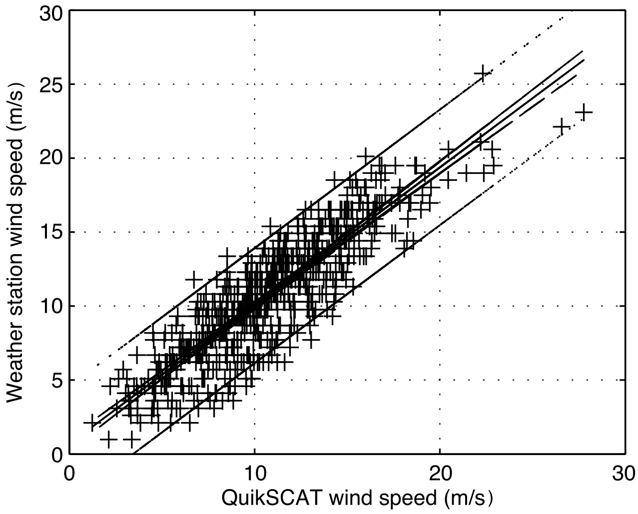

Figure 6. Scatterplot of QSCAT-RSS and weather station observed wind speeds after erroneous data pairs were removed. The centerline is the linear regression. The two lines next to the repression line are the 95% confidence level for the regression line, and the two outer lines are the 95% confidence level for the regression points.

Table 1. Mean High-Wind-Speed Differences Between Different Wind Products

	Bias		Bias Without Erroneous Points	
	QSCAT-RSS	QSCAT-JPL	QSCAT-RSS	QSCAT-JPL
QuikSCAT−weather station	0.62	−0.14	−0.03	−0.31
Weather station−ECMWF	0.86	0.86	0.79	0.79
QuikSCAT−ECMWF (at Macquarie Island)	1.11	0.66	0.44	0.50
QuikSCAT−ECMWF over Southern Ocean	1.11	0.39	0.49	0.29

wind direction from the scatterometer winds is small in the strong wind regions. Large RMS of wind direction differences occurs in the areas where winds are weak, such as north of 40°S, particularly in austral summer and spring. Interestingly enough, in these regions and seasons the wind speed differences are very small. Some extremely large RMS of wind direction differences are found near ice edge and continent coast, likely because of land contamination (Figure 5).

[13] Since the scatterometer measurements were interpolated into the grid points before averaging in time, errors could be introduced during the interpolation process when fast-moving systems are present. To clarify the importance of the errors associated with the interpolation in the wind speed RMS distribution, the wind speed difference RMS is recalculated using 2-day mean wind speed time series from both scatterometer measurements and ECMWF winds. The 2-day mean time series of scatterometer observations were generated by bin averaging all wind cells that fell in a grid during a 2-day period without interpolation. The new seasonal RMS of wind speed differences (not shown here) does not present lower magnitudes than the RMS shown in Figure 4, indicating that the errors introduced by the interpolation are not a major source for the RMS. Furthermore, the mean RMS of wind speed differences (based on interpolated field) averaged over the Southern Ocean is quite close to the RMS between QSCAT-RSS and ECMWF winds collocated near the Macquarie Island (see section 4). Since the collocated QSCAT-RSS winds are from swath data without any interpolation, this again suggests that the errors introduced by the interpolation scheme are not significant in the RMS of wind speed differences.

[14] The discrepancies between QuikSCAT and simulated winds could come from two sources. First, model-simulated winds may underestimate surface wind strength or miss some mesocyclones since the models run on much lower resolutions than the satellite footprint and because in situ observation input to the simulations is very sparse in the Southern Ocean. *Hilburn et al.* [2003] showed such cases where NCEP/NCAR reanalysis missed mesoscale cyclones in the Southern Ocean. Second, scatterometers may overestimate the wind strength in the high-wind band because of imperfection of the model functions. To isolate the error source, the QuikSCAT and ECMWF winds are further compared with the winds recorded at the Macquarie Island Weather Station.

4. Comparison With Winds at the Weather Station

[15] Because the landmass of the island can cause radar echoes and contaminate backscatters for wind retrievals in the surrounding ocean, the wind cells that fell in a circular area of a 25-km radius centered at the station were excluded for the collocation. We collocate the QSCAT-RSS winds and weather station winds by extracting the wind cells from each satellite swath pass that fell in a ring-shaped area bounded by a 25-km and a 50-km radius from the weather station. QuikSCAT usually passes this area in about 10 s

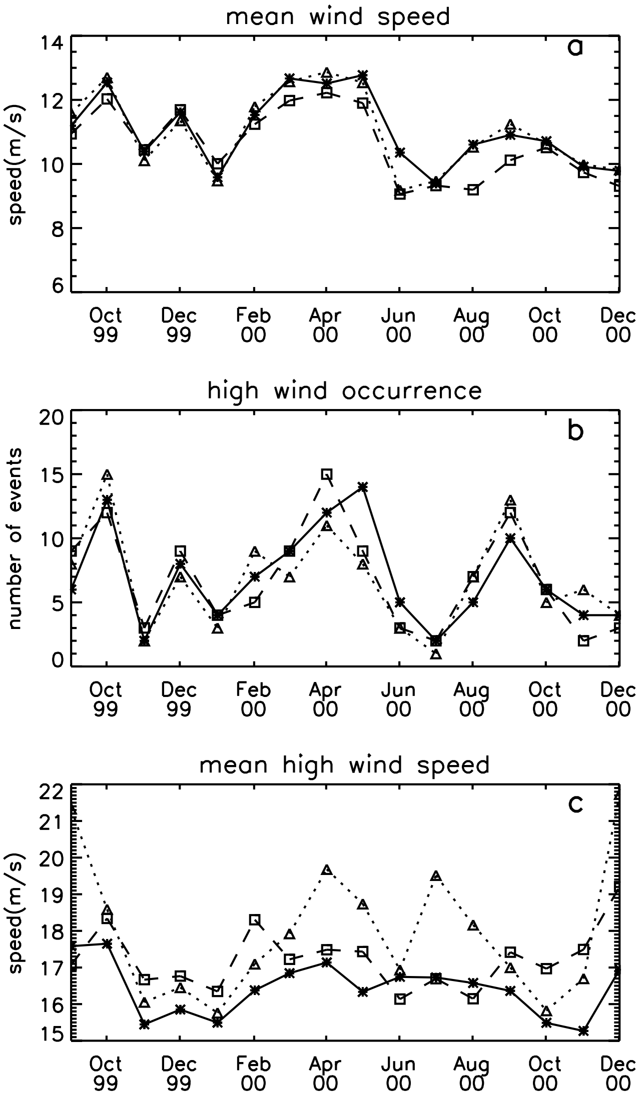

Figure 7. (a) Monthly mean surface wind speeds (m/s) at Macquarie Island observed by the weather station (dashed line) and QSCAT-RSS (dotted line) and simulated by ECMWF (solid line) calculated from collocated data for the period of September 1999 to December 2000. (b) High-wind (speed >15 m/s) occurrence and (c) mean high wind speeds.

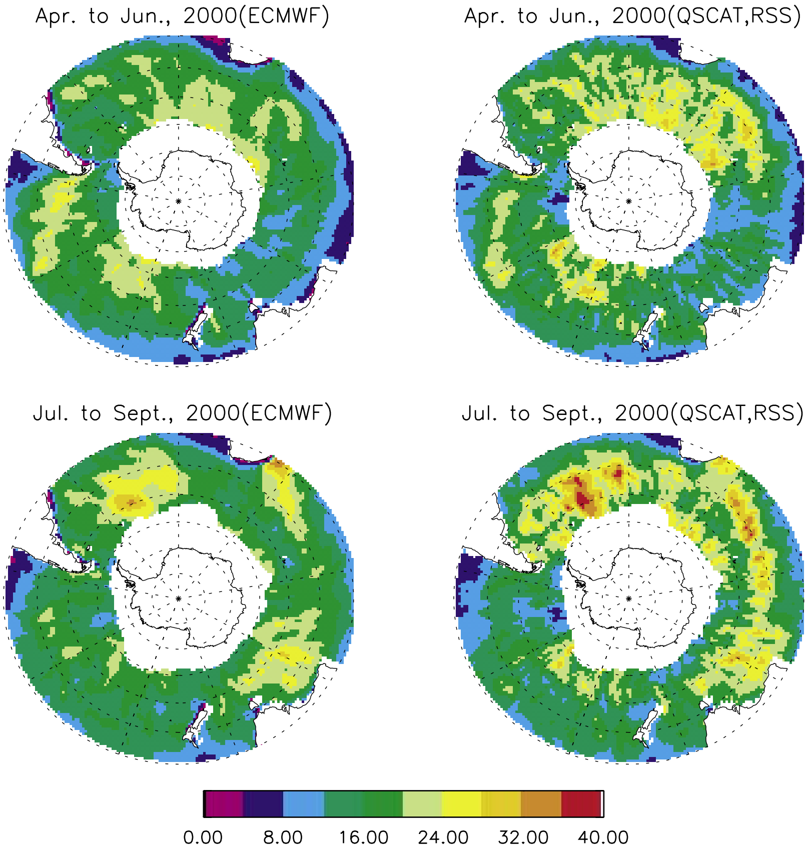

Figure 8. Seasonal storm track intensity approximated by averaging daily $v'v'$ (m^2/s^2) from (left) ECMWF and (right) QSCAT-RSS winds in austral fall and winter 2000.

twice daily. If multiple wind cells were extracted from one swath pass, the mean *u*, *v*, time, and distance to the station were then calculated. The number of cells extracted from a single swath pass varies from 1 to 9. The mean distance from selected wind cells to the weather station is $\sim$40 km. The selected and averaged wind for each pass is then paired with the weather station wind in the nearest hour, yielding 643 pairs of winds for QSCAT-RSS. The largest temporal difference between collocated winds reaches 90 min. In the meantime, ECMWF six-hourly surface winds at the nearest grid point (54°24′S, 158°38′E) are also selected for comparison.

[16] The mean difference between 643 pairs of weather station and QSCAT-RSS winds, for example, yields 0.37 m/s (suggesting stronger scatterometer winds) during the study period. This bias comes mainly from situations where paired scatterometer and weather station winds have extremely large discrepancies. Only about half of those erroneous situations fall into the high-wind band. Many factors may account for these large discrepancies between collocated winds, such as high-frequency wind variability (gusts), spatial variability due to inexact collocation, and other unknown reasons. To eliminate those erroneous comparisons, the data pairs with absolute differences larger than 2 standard deviations of the difference series (accounting for less than 5% of the samples) are deleted from the collocated data set. The resulting data set yields a negligible bias (0.02 m/s). A scatterplot shows that scatterometer and weather station winds are in good agreement after erroneous data pairs are removed (Figure 6). On the other hand, the mean speed bias between 643 pairs of collocated QSCAT-RSS and ECMWF winds is also negligible, while the mean RMS of wind speed differences averaged over the study period yields 1.99 m/s, which is very close to the same mean RMS averaged over the Southern Ocean (1.93 m/s).

[17] To further examine the wind speed bias at the high-wind band, high-wind (speed >15 m/s) series are generated from collocated wind products. Table 1 lists the mean speed differences between the high-wind series at the Macquarie Island and the mean high-wind-speed differences between QuikSCAT and ECMWF winds over the entire Southern Ocean. All the mean high-wind-speed differences listed in the table are significant at 99.5% confidence level except the one between QSCAT-RSS and weather station winds when erroneous points were taken out; the confidence level of the latter is reduced to 95% level. A few points stand out from this table: First, the scatterometer always observes stronger high winds than the ECMWF simulations. Second, the weather station observes stronger wind speeds than the ECMWF simulations. Third, although the bias between the scatterometer and weather station high winds varies with different wind retrieval methods, it is much smaller relative to the bias between QuikSCAT and ECMWF high winds and the bias between weather station and ECMWF high winds. Finally, the mean weather station high winds are even stronger than QSCAT-JPL mean high winds and stronger than QSCAT-RSS high winds when erroneous

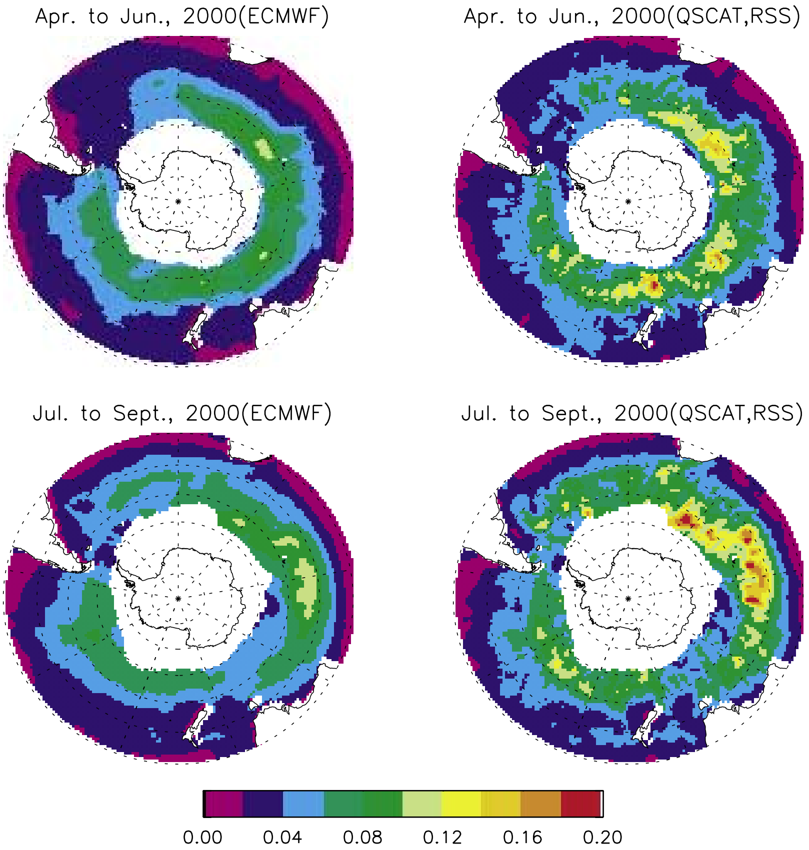

Figure 9. Seasonal u_*^3 calculated from daily (left) ECMWF and (right) QSCAT-RSS winds in austral fall and winter 2000.

points are removed. These results clearly indicate that ECMWF simulation underestimates the high-wind strength.

[18] In terms of the monthly mean wind speed the QuikSCAT agrees relatively well with the ECMWF and weather station winds (Figure 7a). Weather station and QuikSCAT wind speeds do not present a consistent bias across all months even for the monthly high-wind (speed >15 m/s) occurrence and high wind speed (Figures 7b and 7c). In contrast to the Southern Ocean average (Figure 3), QuikSCAT winds at this location reveal no systematic monthly bias against the weather station winds, suggesting that QuikSCAT does not consistently overestimate the monthly wind speed at the high-wind band. The removal of erroneous data pairs does not change the results from this comparison, suggesting relatively consistent high wind speeds for weather station and QuikSCAT winds. On the other hand, monthly mean ECMWF high winds are usually lower than the other two wind products (Figure 7c).

[19] The surface roughness changes from ocean to land and needs to be considered in the comparison of QuikSCAT and weather station winds. Even though both scatterometer and weather station winds are adjusted/recorded at 10-m height, the friction change would result in weaker winds on land. Such wind strength reduction is not adjusted in this study because of lack of in situ observations in the ocean near the island. However, the data in this study suggest that QuikSCAT winds are slightly stronger than weather stations winds in general and both QuikSCAT and weather station winds are consistently stronger than ECMWF winds. The adjustment of the wind speed reduction on land will not change the conclusion that simulated products likely underestimate wind strength and scatterometer measurements are likely closer to the true winds at high-wind bands.

5. Impact of High Winds on Energy Fluxes

[20] Although high winds, particularly extremely strong winds (less than 1% of daily coverage), occur sporadically, the cumulative impact on the air-sea coupled system is significant. For example, seasonally averaged storm track intensity (approximated by $v'v'$) has shown apparent differences between ECMWF and QuikSCAT winds over most parts of the Southern Ocean. The scatterometer observes much stronger synoptic storm activities than does the model simulation. For example, the model simulation misses an important storm track in the South Indian Ocean near 40°S and south of Africa in the austral winter 2000. QuikSCAT observed a 40% stronger storm track intensity than the ECMWF does in the South Indian Ocean during fall 2000 and in the South Atlantic during winter 2000 (Figure 8). Consequently, the scatterometer has observed much stronger surface kinetic energy fluxes approximated by the friction velocity cube (u_*^3), particularly in the South Indian Ocean and South Pacific (Figure 9). In these areas, QuikSCAT observes up to 80% more energy flux than that of ECMWF. The differences between scatterometer obser-

vations and model simulations are more profound in austral fall and winter.

6. Summary

[21] This study validates scatterometer winds against in situ wind observations from the Macquarie Island Weather Station and compares scatterometer winds to ECMWF analysis and NCEP/NCAR reanalysis products in the Southern Ocean from September 1999 to December 2000. Two QuikSCAT products from the QSCAT-1 model function and Ku-2001 model function are used. The Southern Ocean is a unique geophysical region with persistent strong winds over a huge open ocean and rich cyclone activity. This study investigates the discrepancy between QuikSCAT and model simulations at different wind speed bands and finds that QuikSCAT observed stronger wind speed than model simulations, particular at high-wind bands. The weather station data are then used to decide if QuikSCAT overestimates, or model simulations underestimate, the surface winds.

[22] Even though the monthly mean QuikSCAT winds averaged over the Southern Ocean are in relatively good agreement with ECMWF and NCEP/NCAR winds, satellite-observed wind distributions are significantly different from model-simulated winds at synoptic timescales. These discrepancies are functions of space and season. There is an inverse relationship between discrepancies in wind speed and those in wind direction. For example, the largest wind speed discrepancy between scatterometer and simulated winds occurs in the westerly regions of the South Indian Ocean, the Southeast Atlantic, and south of Australia; the discrepancy is most profound during austral winter and autumn. The wind direction discrepancy, however, is minimal in these regions and seasons. The largest wind direction discrepancy exists in the regions north of 40°S in austral summer and spring where and when the wind speed discrepancy is minimal.

[23] The most significant discrepancy in wind speed comes from the high-wind band (speed >15 m/s). QuikSCAT observes more strong wind events, and its mean high wind speed is greater than both ECMWF and NCEP/NCAR winds. Monthly mean high-wind differences between scatterometer and reanalysis consistently reach 1–2 m/s for winds with speeds higher than 20 m/s throughout all the seasons. Although the high wind (speed >15 m/s) and extremely high wind (speed >20 m/s) only account for 5% and 1% of the total wind observations, respectively, during the study period, they have a significant impact on the storm track intensity and energy flux across the air-sea interface. In particular, the scatterometer observes much stronger storm activities and stronger energy fluxes than model simulations in austral fall and winter. In regions such as the South Indian Ocean, the strength of storm activities and kinetic energy fluxes observed by the scatterometer is up to 80% stronger than the model simulations. Therefore accurate wind measurements are crucial in climate studies.

[24] In situ measurements at the weather station on Macquarie Island are used to cross-validate both QuikSCAT and model-simulated winds. The results reveal no systematic bias between in situ winds and satellite observations in both monthly mean and monthly average of high wind speeds, while weather station winds and QuikSCAT winds are consistently higher than ECMWF winds at the same location within the high-wind band. This study suggests that model simulations underestimate high-wind strength in the South Ocean. Low spatial model resolution and limited in situ observations input into the models likely cause the weaker high-wind strength in the simulations. On the other hand, the modern backscatter retrieval and surface wind retrieval model functions provide rather good estimates at the high-wind band, although there is still room for improvement. However, these conclusions depend on the single source of in situ measurements on Macquarie Island. Nevertheless, this study alerts us to problems in using model-simulated surface winds as observations in research. On the other hand, scatterometer observations provide critical surface wind measurements with high quality and high spatial/temporal resolutions for modern climate studies, particularly in this remote but climate-important region.

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