NOTES AND CORRESPONDENCE

Comments on "Scatterometer-Based Assessment of 10-m Wind Analyses from the Operational ECMWF and NCEP Numerical Weather Prediction Models"

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1. Introduction

We have noted with interest the series of scatterometer data studies carried out by Chelton, Freilich, and colleagues [see, e.g., Chelton et al. (2004), Freilich and Dunbar (1999), and in particular, Chelton and Freilich (2005, hereafter CF05)]. In CF05, the authors addressed at least three pressing needs. They provided a much-needed quantification of the gross, or bulk, error statistics of scatterometer observations. Equally as significant, they also showed that the use of scatterometer observations improved the accuracy of 10-m wind analyses and predictions in two of the major global numerical weather prediction (NWP) systems, namely those of the European Centre for Medium-Range Weather Forecasts (ECMWF) and the National Centers for Environmental Prediction (NCEP). Finally, CF05 presented a lucid and in-depth description of scatterometer instrument technology, which we suspect will make CF05 required reading for users of scatterometer observations. Before CF05, most of the literature on these three topics was confined to conference proceedings and various technical and other reports.

Here, we present work that is complementary to that of CF05. We describe our experience with scatterometer data in both operations and research over a specific part of the globe. Our operational and research goals are very different from the topics covered in CF05. Unlike CF05, we do not focus on the gross statistics of the scatterometer observations, but instead on the capacity of scatterometer data to detect, monitor, and provide more accurate analyses and predictions of individual severe and extreme weather events on a routine basis. We do so largely by describing two case studies, chosen from many that we have investigated, which demonstrate clearly the value of scatterometer observations for weather systems in data-sparse oceanic and coastal areas. We welcome comments from the authors of CF05 on the results we present below.

Our domain of interest is not global, but it is still a substantial region, covering the East Indian Ocean, the Southern Ocean, and the southwest Pacific Ocean, including the Tasman Sea. The region also spans a large range of latitudes, extending from the high latitudes, through the subtropics to the Tropics, and has a longitudinal extent from about 65° to 170°E. This region is very active meteorologically; however, it has been relatively neglected until recent years. It contains a number of countries that are routinely and adversely affected by severe weather, and there has long been exceptionally poor oceanic data coverage. The consequences of the data paucity include inaccurate initial analyses and subsequent operational forecast failures of NWP predictions on short-, medium-, and extended-range time scales. These failures usually occur when success is most needed. There have also been almost insurmountable problems in developing reliable climatologies, both atmospheric and oceanographic.

In this correspondence, we concentrate only on the intense cyclonic systems that regularly generate severe and extreme weather, as these have the most impact

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and usually present the greatest analysis and forecast difficulties. The cyclonic systems affecting the region include the midlatitude systems that cross the southern Indian Ocean between southern Africa and Australia, similar systems that traverse the Southern Ocean and southwest Pacific Ocean poleward of Australia and New Zealand, tropical cyclones in the east Indian Ocean, and subtropical and tropical cyclones in the Coral and Tasman Seas between Australia and New Zealand. Such a wide range of severe storms is a major analysis and prediction challenge, with the systems typically being either operationally underpredicted in peak intensity or even missed completely when they are of small size or are severe only for a relatively short part of their life cycle.

As CF05 indicate, prior to the availability of the scatterometer instruments numerical analysis, prediction, and verification over the oceans was severely limited. The lack of reliable, timely, and accurate observations of near-surface winds was an insurmountable problem because of the problems of identifying the position, track, size, intensity, and other characteristics of oceanic and coastal cyclonic weather systems. Moreover, the information from sequential passes of the scatterometer instruments now allows the observation of changes in these characteristics. This is highly valuable information that previously was virtually impossible to detect and especially to quantify. We therefore have a greatly increased capacity to follow, and eventually to understand, the evolution of this wide range of severe cyclonic storms.

We recently published a preliminary climatology, based heavily upon scatterometer and other satellite data, for south Indian Ocean and Southern Ocean midlatitude cyclones (Buckley and Leslie 2004). The QuikSCAT data have become sufficiently established to allow the development of this limited climatology, which is based on a careful interpretation of almost 5 yr of QuikSCAT scatterometer data. This climatology continues to be updated as the length of the record increases. We have almost completed a similar exercise for southwest Pacific Ocean cyclones. The south Indian and Southern Oceans have long been known to generate midlatitude marine cyclones of intensities seldom experienced in cyclonic systems that form away from the Tropics. Ship reports, buoy data, and the few available oil platform–, island-, and land-based station reports led to unsupported speculation amongst operational forecasters that these storms were far stronger than they had been defined in operational analyses, and in the few research studies available. The consequences of such an underestimation of the frequency and intensity of these cyclones have been profound for short- and medium-range NWP, and also for climate studies that employ these archived analyses. Chelton et al. (2004) clearly are aware of similar problems elsewhere. They listed a number of implications, including a lack of detail in the wind patterns both in the oceans and in coastal waters, leading to significant errors in computing the wind stresses that drive the ocean circulation and also feed back to the atmospheric models. It was not until the late 1990s, when scatterometer observations from the Seawinds scatterometer instrument aboard the National Aeronautics and Space Administration (NASA) QuikSCAT satellite became routinely available, that there was a sudden increase in regular and relatively reliable wind observations over these traditionally data-sparse oceanic areas. As a direct consequence, the above-mentioned suspicion that the cyclones were far stronger, and more frequent, than hitherto analyzed was confirmed. The scatterometer datasets now underpin the operational forecast and warning services of various national weather services that have high seas warning responsibilities in these waters.

Studies other than CF05 have also pointed out that accurate, near surface, and wind data are vital for the routine operational analysis and prediction of severe cyclonic systems, for case studies aimed at gaining increased knowledge of their life cycles, and for the compilation of climatological datasets. Chelton et al. (2004) have utilized the evolving high-resolution scatterometer dataset to identify persistent small-scale features in ocean surface winds, particularly those affected by proximity to the coast. Atlas (2004) has shown the importance of scatterometer data in numerical weather prediction, with the effects propagating well away from the swathe of the instrument within the first 6 to 18 h of the model prediction. Liu et al. (2004) have stressed the importance of high-resolution scatterometer wind vector observations in determining the ocean's response to high-resolution wind forcing.

To illustrate the improvement in analyzing and predicting severe cyclonic systems in our region of interest, we discuss briefly two case studies that illustrate the importance of the scatterometer data. This point is recognized only implicitly, rather than emphasized, in CF05. We present some ground truth observations from an island station and a gas production platform that support the growing confidence in the accuracy of the scatterometer data. A caveat is that the scatterometer-derived winds must be analyzed very carefully, with experience in the selection of the correct solution for the data and a detailed knowledge of the weather systems of interest both being important factors at this point in time.

2. Case studies

These cases of severe weather systems were detected and analyzed with a level of accuracy possible only since the advent of scatterometer data. Case 1 is an intense cyclone in the Southern Ocean, whereas case 2 is a severe tropical cyclone that traversed the near-coastal waters of the tropical east Indian Ocean over northwest Western Australia. Both cases were chosen because they provide rare examples of where high quality ground truth observations were available to verify the intensity and some features of these systems.

a. Case 1: The Southern Ocean midlatitude supercyclone of May 2004

As mentioned before, the lack of conventional data in the south Indian and Southern Oceans have made it very difficult for the intensity of intense midlatitude cyclones in this region to be analyzed accurately and predictions to be verified with confidence. However, that situation is now improving, as illustrated by case 1. During the period 29–31 May 2004, a midlatitude cyclone deepened explosively over the Southern Ocean waters south of Australia. Sea level pressures fell by a remarkable 75 hPa over a 48-h period, from about 1004 hPa at 0000 UTC 29 May, and continuing until they finally reached the record lowest officially analyzed central pressure (for a nontropical system in the Australian region) of about 929 hPa, at 0000 UTC 31 May 2004 (see Fig. 1a). The low subsequently weakened to 942 hPa over the following 24-h period. Both the intensity and the life cycle of this low, which also is the most extreme event of its type observed by the authors, were well captured by successive passes of the QuikSCAT scatterometer, the most relevant being that of 0630 UTC 31 May 2004 (see Fig. 1b). The initial low development started as a wave feature on a large cold front to the south of Western Australia. The scatterometer pass at 0630 UTC 30 May 2004 (not shown) identified a rapidly enlarging region of 50 to 60 kt unidirectional northwesterly winds that extended over an area 1000 km by 600 km, to the northeast of an almost linear shear line that marked the location of the front. Although most (but not all) vectors are shown as rain affected, they are considered realistic estimates of the surface conditions. The scatterometer data showed clearly that the greatest longitudinal extent of storm force winds were almost perpendicular to the first signs of a wave low development on the frontal boundary at 47°S. There was no identifiable surface low in this region prior to this time, with the parent low being located about 1200 km further south. The strength of winds to the west of the front was generally about 30 to 35 kt, which is close to the mean wind speed for these latitudes. During the following 14 h, the transformation of this system was substantial, as observed on the QuikSCAT pass at 2040 UTC 30 May 2004 (not shown). A significant low pressure system formed, with storm force winds in all quadrants, although it still maintained a relatively asymmetrical structure. Maximum sustained wind speeds remained close to 60 kt during this 14-h period.

Further intensification of the system occurred during the next 10 h. It was during this period that the cyclone began to affect the Australian Bureau of Meteorology's isolated weather station on Macquarie Island, located near 54.5°S, 159°E, as shown in Fig. 1c. Wind speeds measured on the island rapidly increased to a peak of 62 kt from the northwest at approximately 0800 UTC, 30 May 2004. The observed wind speed validates very well the accuracy of the nearby QuikSCAT wind vectors from the 0630 UTC 31 May 2004 pass, shown above in Fig. 1b. As an additional benefit of having ground truth available, we note that further to the west numerous wind vectors of up to 80 kt are clearly visible in Fig. 1b, with the zone of storm force winds arching around the low over a distance of approximately 1200 km. The relatively gradual increase in wind speeds from near the verifying observations on Macquarie Island, coupled with the location of these wind vectors beneath a tight spiral band clearly revealed on a Moderate Resolution Imaging Spectroradiometer (MODIS) satellite image recorded at close to the same time (not shown here), provided the confidence necessary to accept the 80-kt wind vectors as probably being accurate. Winds of this strength, with a relatively uniform direction, generate very high and steep seas, including breaking waves, thereby posing a very serious threat to shipping in the area.

b. Case 2: A severe tropical cyclone environment in the East Indian Ocean

The QuikSCAT scatterometer provides operational forecasters in the Australian Tropical Cyclone Warning Centers with valuable insights into the changing wind structures surrounding tropical cyclones while over the data-sparse oceanic areas that surround Australia. Forecasters value the data highly, but are very aware that care needs to be taken when interpreting the data near areas of deep convection, as the automatically generated "best solution" wind vectors may be badly rain-affected, or not the optimum solution. The scatterometer ambiguities display provides forecasters with all possible solutions enabling the scatterometer data to be used in conjunction with the growing arrays of satellite

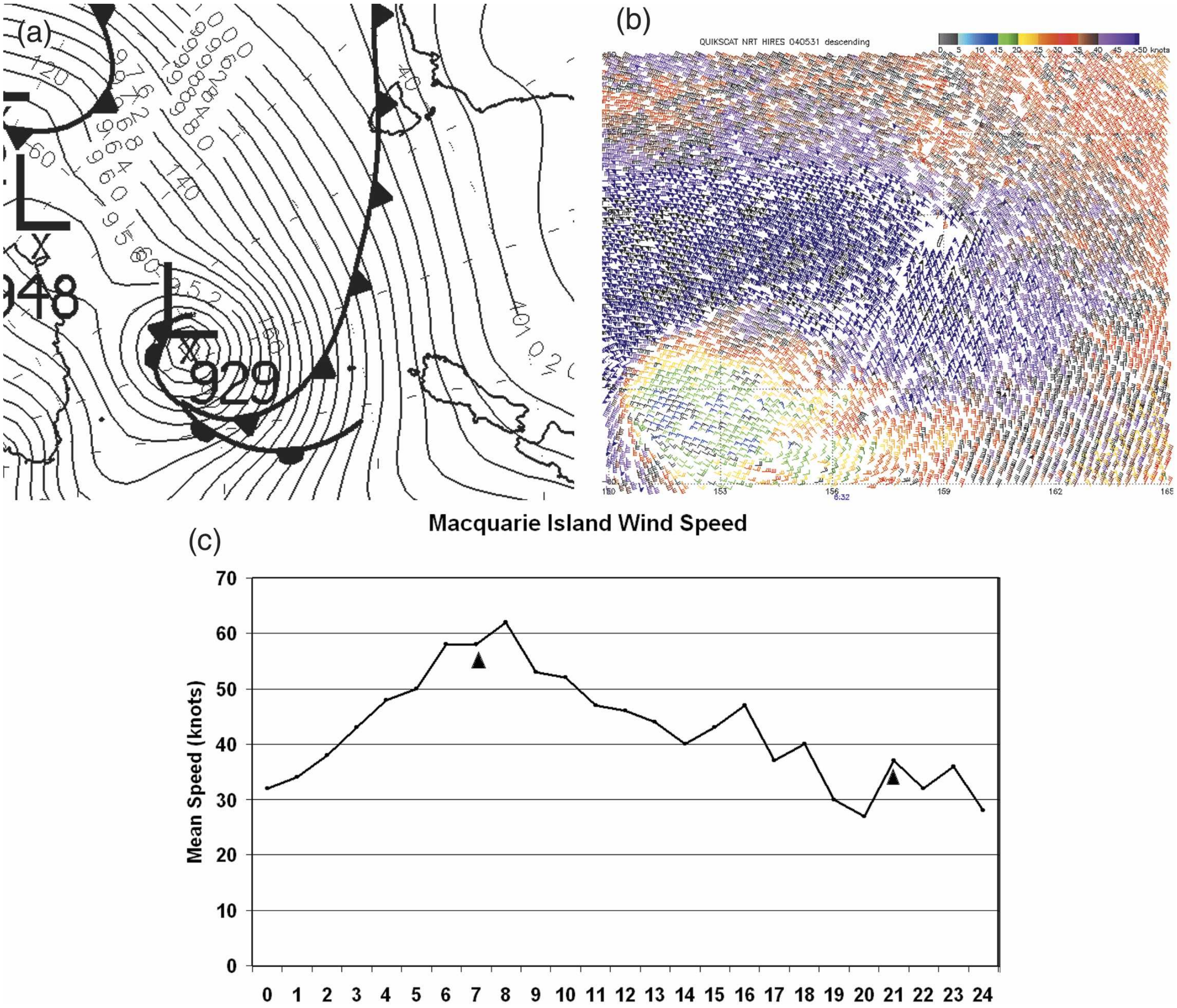

FIG. 1. (a) Mean sea level pressure analysis for the intense Southern Ocean cyclone, valid at 1200 UTC 31 May 2004, near the time of its peak intensity. (b) Southern Ocean QuikSCAT scatterometer 12.5-km resolution ocean wind vectors, (centered near 55°S, 157°E) at 0630 UTC 31 May 2004. Note Macquarie Island located near the center of the figure at 54.5°S, 159°E. (c) A 24-h plot of 10-min average wind speeds at 10 m above mean sea level, measured on Macquarie Island. Two coincident QuikSCAT observations, interpolated to the Macquarie Island anemometer location, are indicated by the filled triangles at the two available satellite overpass times.

based microwave radiometer data to better understand the true tropical cyclone structure. The resolution of the data and the current processing techniques are unable to fully resolve the true wind structures close to the eyewall of severe tropical cyclones but do provide valuable information over areas beyond the radius of maximum winds and asymmetries associated with the cyclone's middle and outer circulations.

Severe Tropical Cyclone (TC) Monty provided an excellent illustration of the value of scatterometer data. Figure 2a shows a composite image of severe TC Monty toward the end of a period of rapid intensification and nearing the time of its maximum intensity. The scatterometer ambiguity data identified a solution that tied in well with the observed center as depicted on visible and microwave satellite imagery. The solution with the eye correctly positioned indicated a region of 60 kt or higher winds to the south and southeast of the center. On this occasion there were a number of verifying observations from conventional surface instrumentation prior to and shortly after the time of the overpass. An oil facility HPR2 at (18.8°S, 117.1°E) measured 10-min average wind speeds of 80 kt at a height of 3.9 m above sea level at 1500 UTC on 28 February 2004 before the instrument failed. The North Rankin Gas Platform (near 19.5°S 116.2°E) recorded wind speeds at a dis-

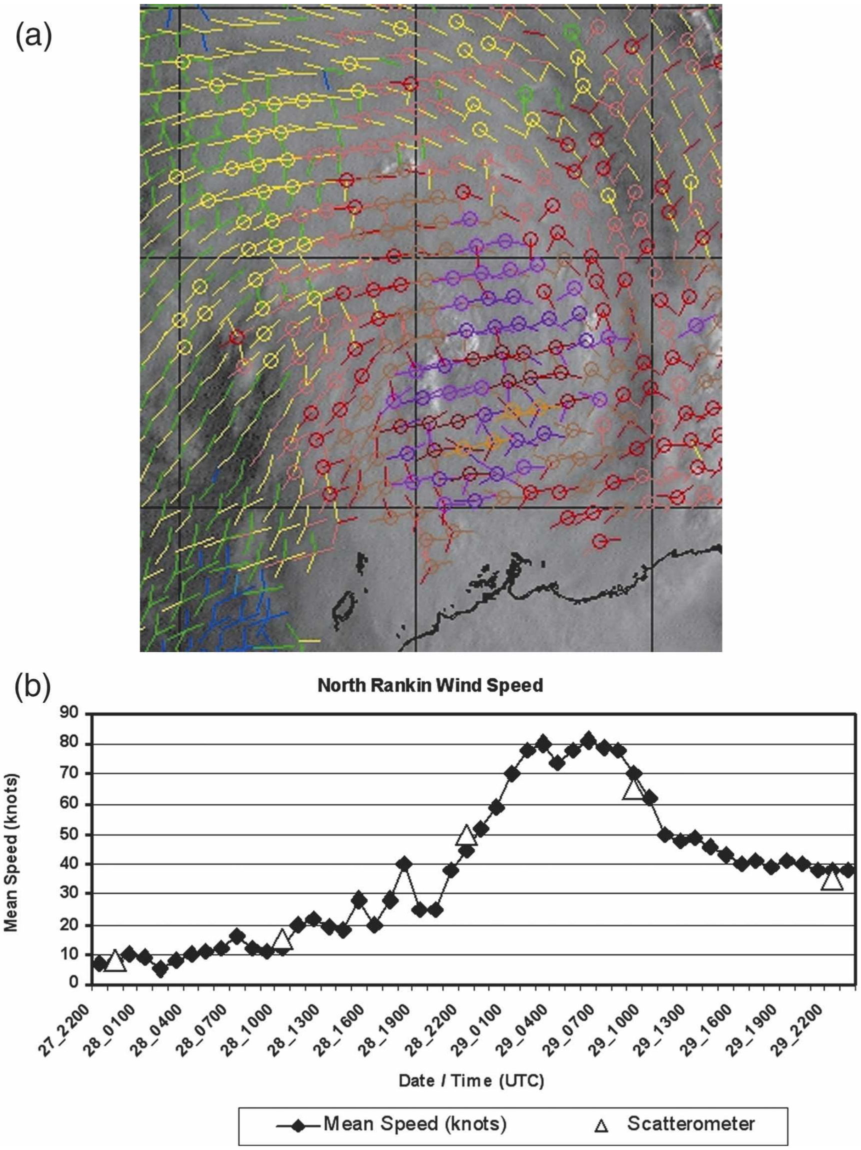

FIG. 2. (a) Composite satellite image showing the QuikSCAT scatterometer pass ambiguity solutions valid 2217 UTC 28 Feb 2004 superimposed upon the Geostationary Operational Environmental Satellite (*GOES-9*) Visual satellite image valid at 2325 UTC on the same day. The coastline shown is the northwest coast of Australia near 20°S, 117°E. Colors indicate the wind speed with shades of purple, red, and orange representing winds above 40, 50, and 60 kt, respectively. Image is courtesy of NRL Monterey. (b) A 48-h plot of the 10-min average 10-m above mean sea level wind speeds, measured on the North Rankin "A" Gas Platform (NRA) and compared with interpolated QuikSCAT scatterometer observations at the same location (open triangles). These observations span the passage of severe Tropical Cyclone Monty. The NRA data was provided by courtesy of Woodside Petroleum.

tance of 30 km to the southeast of the severe tropical cyclone that peaked at a 10-min average speed of 81 kt, gusting to 113 kt at a height of 36 m above sea level approximately 4 h after the time of this scatterometer overpass. The nearby Goodwyn Oil Platform recorded a central pressure of 950.9 hPa during the passage of the eye of Monty over the platform. Further to the southwest Barrow Island peaked at 65 kt, gusting to 91 kt and Varanus Island peaked at 81 kt, gusting to 95 kt as the cyclone moved past. The detailed time series wind profiles from these locations also verified well against scatterometer-derived winds, as illustrated by the North Rankin Gas Platform observations and interpolated scatterometer data shown in Fig. 2b.

3. Conclusions

CF05 stressed the importance of scatterometer-derived data by quantifying the accuracy of the observations, by demonstrating the positive impact of these data on the skill of global weather analysis and prediction models, and by providing a detailed description the functioning and characteristics of the scatterometer instrument and the data it generates. Here, we describe a very different role of scatterometer data that we believe to be equally as important. Our aim is to demonstrate the large positive impact of scatterometer data in improving the routine analysis and prediction of the tracks, intensities, and life cycles of individual severe and extreme atmospheric and oceanic systems over some of the world's most data-sparse ocean and coastal regions. Specifically, our work concentrates on the intense midlatitude cyclones, subtropical cyclones, and tropical cyclones that form over and traverse the East Indian Ocean, Southern Ocean, and southwest Pacific Ocean. We have shown, by comparison with ground-based observations, that the scatterometer data is very accurate and that its inclusion in numerical analyses has an impact on all time scales, from hours and days, through to the development of climatologies. In particular, the most powerful of the midlatitude storms, which we refer to here as super cyclones, is a primary focus of our work, as they have only recently been accepted as reaching the intensities that have been suspected for some time. We have found support in the work of Chelton, Freilich, and colleagues that scatterometer data, despite several known remaining problems, have now made possible a large step toward providing the accurate and timely warnings necessary to minimize loss of life and damage to property that can be caused by such severe systems. We have provided support for this view in the form of two examples in which ground truth was available for validation of the scatterometer data. These warnings are a vital and immediate requirement owing to their immense destructive potential and the fact that they form, develop, and move over data-sparse oceans before they make landfall. The continued development of techniques for optimizing the application of scatterometer-derived data is central to continued success.

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