The Operational Impact of QuikSCAT Winds in Perth, Australia: Examples and Limitations

LANCE M. LESLIE
School of Meteorology, University of Oklahoma, Norman, Oklahoma

BRUCE W. BUCKLEY
Bureau of Meteorology, West Perth, Western Australia, Australia

MARK LEPLASTRIER
Insurance Australia Group, Sydney, New South Wales, Australia

MANUSCRIPT RECEIVED 21 MARCH 2007, IN FINAL FORM 12 JULY 2007

ABSTRACT

The preparation of accurate operational weather forecasts and the timely issuance of severe marine weather and ocean warnings and advisories for major oceanic weather systems impacting both coastal areas and the open ocean are major forecasting problems facing the Australian Bureau of Meteorology's Regional Forecast Centre (RFC) and its collocated Tropical Cyclone Warning Centre (TCWC) in Perth, Western Australia. The region of responsibility for the Perth RFC is vast, covering a large portion of the southeast Indian and Southern Oceans, both of which are extremely data sparse, especially for near-surface marine wind data. Given that these coastline and open-ocean areas are subject to some of the world's most intense tropical cyclones, rapidly intensifying midlatitude cyclones, and powerful cold fronts, there is now a heavy reliance upon NASA Quick Scatterometer (QuikSCAT) data for both routine and severe weather warning forecasts.

The focus of this note is on the role of QuikSCAT data in the Perth RFC for the accurate and early detection of maritime severe weather systems, both tropical and extratropical. First, the role of QuikSCAT data is described, and then three cases are presented in which the QuikSCAT data were pivotal in providing forecast guidance. The cases are a severe tropical cyclone in its development phase off the northwest coast of Australia, a strong southeast Indian Ocean cold front, and an explosively developing midlatitude Southern Ocean cyclone. In each case, the Perth RFC would have been unable to provide early and high-quality operational forecast and warning guidance without the timely availability of the QuikSCAT surface wind data.

1. Introduction

Recent studies have underlined the operational utility of the near-surface wind data from the SeaWinds scatterometer on board the National Aeronautics and Space Administration (NASA) Quick Scatterometer (QuikSCAT) satellite. For example, Atlas et al. (2001) provide a detailed review of the impact of scatterometer data on numerical weather prediction and a discussion of the first successful use of QuikSCAT data by operational marine forecasters. Chelton and Freilich (2005) and Chelton et al. (2006) have assessed the impact of QuikSCAT data on the European Centre for Medium-Range Weather Forecasts (ECMWF) and the National Centers for Environmental Prediction (NCEP) operational models highlighting, for example, the role QuickSCAT data can play in providing necessary higher-resolution additional spatial structure to the marine weather systems analyzed and predicted in those models. A recent study by Von Ahn et al. (2006)
describes the crucial role of the NASA QuikSCAT data in the preparation of operational forecasts of severe marine weather at the National Oceanic and Atmospheric Administration/Ocean Prediction Center (NOAA/OPC). Von Ahn et al. (2006) illustrate the dependence of the NOAA/OPC on QuikSCAT data and point to the particular value of QuikSCAT data in detecting intense hurricane force extratropical cyclones and also to the associated role of the QuikSCAT data in the issuing of NOAA/OPC wind warnings and predictions of dangerous coastal and open-ocean conditions.

Our aims are twofold. First, in section 2, we describe how the QuikSCAT data have a similarly important role in forecasting severe weather for the coastal and open-ocean areas of forecast responsibility of the Perth Regional Forecasting Centre (RFC) and the Perth Tropical Cyclone Warning Centre (TCWC), in the Bureau of Meteorology, Australia. In particular, we indicate how the QuikSCAT data are employed by the Perth RFC and TCWC, and discuss some of the present limitations of these data. Then, in section 3, we present three examples, drawn from numerous, almost routine cases, of the impact of the operational application of QuikSCAT data over an entirely different part of the globe from that addressed by Von Ahn et al. (2006), namely the western region of Australia. The Perth RFC has an area of responsibility covering the vast region south from the equator to the Antarctic continent and across the entire south Indian Ocean. The actual forecast and warning areas of direct responsibility are smaller, but the larger region is necessary because weather features must be identified and tracked well before they arrive at the boundaries of the area of formal responsibility. A detailed location map of the region and the place names mentioned herein, and of the regions of operational forecast responsibility of the Australian Bureau of Meteorology, are shown in Figs. 1a and 1b, respectively.

2. QuikSCAT data availability in the Perth RFC and TCWC

As in the case of the NOAA/OPC, the Perth RFC and TCWC regard the QuikSCAT data as one of the key marine weather and oceanographic datasets available to it. At times, it provides the sole basis for the issuance of warnings for severe marine weather and ocean conditions. Given that the Indian Ocean occupies the entire region from the coast of Western Australia across to the African continent and the Southern Ocean from the southern coastline of Australia southward to Antarctica, the identification of the structure and intensity of weather systems across these vast ocean areas relies heavily, and in some situations almost exclusively, upon satellite-based data. Although there is an irregular array of drifting buoys and the occasional voluntary observing ship, no conventional observational data source is capable of providing the detail and coverage of ocean surface winds that is generated by QuikSCAT. Moreover, as will be discussed further below, although the Perth RFC operational forecasters have access to a wide range of satellite and radar data to analyze and forecast near-surface marine winds and to issue associated warnings, they rely most heavily on the NESDIS QuikSCAT data. While data also are available from the newer NOAA satellite-derived winds from the polarimetric radiometer (WindSAT) instrument, the swath widths of the WindSAT overpasses are narrower than those for the QuikSCAT satellite and there is greater directional uncertainty in the wind vector solutions.

a. Use of QuikSCAT data

The QuikSCAT data are used extensively every day by the Perth RFC for mean sea level analyses of the Indian and Southern Oceans, as well as for detailed tropical cyclone (TC) analyses. These data are essential for the identification of the wide variety of weather events that form in and traverse the region, including cold and warm fronts, trough lines, high pressure centers, ridge axes, easterly waves, trade wind surges, monsoonal surges, and, possibly most important of all when they occur, TCs. The operational analysts often relocate weather features quite significantly based solely upon scatterometer data, thereby influencing the forecasts and warnings that follow from the analysis. On many occasions forecasters will revise, issue, or cancel high seas and coastal strong wind, gale, storm, and hurricane warnings based exclusively on the QuikSCAT data. All marine forecasts and warnings are issued based upon 10-min mean 10 m above sea level winds speeds, with knots the units for wind speed, and hence this unit will be used throughout this paper when describing wind speed (1 kt = 0.5144 m s⁻¹). In the Australian region, strong winds are defined as encompassing the 10-min mean wind speed range from 26 to 33 kt, gale force winds from 34 to 47 kt, storm force winds from 48 to 63 kt, and hurricane force winds 64 kt or stronger.

In the Western Australian TCWC, QuikSCAT data are the primary source used by forecasters to identify such key TC parameters as the radius to gales and radius to storm force winds, as well as identifying asymmetries in the circulation. The scatterometer processing algorithms continue to have difficulty in resolving the correct wind solutions in the regions near the center of
TCs, due to the well-documented effects of heavy rain produced by deep convection (see, e.g., Draper and Long 2004). The TC analyst uses the QuikSCAT ambiguity data to help pinpoint the center of developing TCs and those with a dense overcast covering the eye. These data also provide information to the forecasters on intensification or weakening of the TCs, even though the wind characteristics close to the center cannot be determined to the required degree of accuracy. There are several reasons for this, including the occurrence of extremely heavy rainfall in and near the eyewall region, the very strong gradients in wind speed and rapidly changing wind directions in this region of a TC, and the relatively small radius of maximum winds, typically 15 n mi, and often much less, for TCs in this part of the world.
QuikSCAT data also are an excellent means of tracking developing monsoonal surges through the South China Sea and the waters of the Indonesian archipelago, as these surges are important for the development or strengthening of tropical lows and cyclones in the Australian region.

The authors have used the QuikSCAT data to develop the first climatology of storm force–producing weather systems in the southern Indian Ocean (Buckley et al. 2004). We also have undertaken a series of sensitivity studies to investigate the impacts of the inclusion of scatterometer data into regional high-resolution numerical models for a variety of high-impact weather systems including cutoff low pressure systems and rapidly intensifying tropical cyclones. The impacts have been positive in every case investigated, resulting in more skillful prediction of the severe weather phenomena associated with the lows and TCs. For example, Buckley et al. (2007) have demonstrated how a combination of QuikSCAT and other satellite data can make a very large difference to the predictions of the future intensities and tracks of tropical cyclones in the northwest Australian region.

b. Limitations of the data

As was the case for Von Ahn et al. (2006), the following limitations of the QuikSCAT data must be mentioned. They are raised as a means of identifying issues that need to be addressed in order for solutions to be developed, and are intended as constructive comments on the scatterometer observation program given its critical role in the provision of quality meteorological services in this remote and sparsely populated part of the world.

QuikSCAT does not provide complete spatial coverage with each set of overpasses—the largest gaps between successive passes occurring in tropical regions. Frequently, the center of the weather feature of interest is located in the data gap between satellite passes at the times when the data are most needed. This is illustrated in Fig. 2 where most of the circulation of severe TC George (which was in the process of changing direction by over 100° at the time) falls between successive QuikSCAT passes. Operationally, the preferred source of QuikSCAT near-surface wind data for the Perth RFC is from the National Environmental Satellite, Data, and Information Service (NESDIS) “manati” Web site (http://manati.orbit.nesdis.noaa.gov/quikscat/). The real-time availability of the data stream is not continuous, as there are outages, more common during the overnight period in the United States or during weekends. The authors realize that the NESDIS manati Web site is not an operational Web site, but at present it provides, by far, the best ongoing real-time access to

Fig. 2. QuikSCAT passes across the northwest Australian region between 0906 and 1048 UTC 7 Mar 2007 with the location of the center of severe TC George (category 4) shown as a dot. (QuikSCAT images are courtesy of RSS.)
the QuikSCAT data to the Perth RFC operational analysts and forecasters. The Remote Sensing Systems (RSS) data usually are not available to the Perth RFC in real time, but are used extensively in postanalysis work. The geostationary satellites are used extensively, especially for continuity of imagery, but not for providing the detailed surface wind fields that are so important to the operational analysts and forecasters. Altimeter data for confirming wave heights are not currently available in real time, but they are used only in postanalysis studies. Atmospheric Infrared Sounder (AIRS) data are ingested directly into the numerical models but generally are not available to the Perth RFC in real time. Finally, radar data are used for systems that are within range.

The Perth RFC operational forecasters also realize there are persistent problems with the data that are well known and are certainly not unique to this region. Because of the familiarity that has developed from daily use of QuikSCAT data, corrections can be applied to the data and allowances are made to accommodate the known errors and weaknesses. The rain-affected wind vectors are known to be overestimates at times (e.g., Draper and Long 2004). Operational experience where the forecasters compare rain-affected wind vector solutions against nearby coastal or ship observations, when they are available, confirms these effects. However, in many circumstances, the data that have been rain flagged are often assessed by the forecasters or analysts as being reliable. A prime example of when many rainflagged wind vectors can be used occurs when the rain is assessed by the forecasters as not being heavy, based on other satellite information, such as the Tropical Rainfall Measuring Mission (TRMM), other polar-orbiting satellites, and, to a lesser extent, geostationary satellites. Not surprisingly, this occurs more often for midlatitude systems than for tropical systems surrounded by intense convective complexes. However, even for tropical systems, feedback from vessels operating under or near these systems has shown that it is not uncommon for the tropical-rain-affected vectors to provide reasonable estimates of the strength of the wind squalls from the associated deep convection, even if the mean wind speeds are incorrect and overestimates. This may be due to the automatically produced higher wind speed solutions being less impacted by the rainfall contamination than are the lighter wind speed solutions. The decrease in accuracy near the edge of the satellite passes (and less often directly below the satellite) also is a concern but can be allowed for. An example of this swath-edge effect is shown in Fig. 3, where the automatic wind vector solutions show a much stronger region of winds with an abrupt directional change in a region where the forecasters know there to be a relatively stable and homogeneous southeast trade wind flow, off the upper west coast of Australia near 105°E. Blocks of aliased winds, or incorrect solutions applied to generate the vectors, usually are easy to recognize. The use of microwave imagery during tropical cyclone events can often help identify the true centers of the cyclones, with the QuikSCAT data helping to quantify their strength, structure, and geographical extent.

Operational forecasters invariably have issues with the timeliness of the data. Forecasts and warnings are usually issued according to inflexible timelines and the availability of the data may not match these somewhat artificial deadlines. In essence, the overriding requirement is for the data to be made available as close to real time as possible, even if the data are incompletely quality controlled.

Many of the forecasts and warnings relate to waters immediately adjacent to the coast. However, the solutions to the data do not start until approximately 30 km or more away from the coast, with the problems being exacerbated in waters with numerous fringing islands or reef systems. It is possible higher-resolution solutions and improved near-coastal land mapping techniques may improve this deficiency.

Although the earlier QuikSCAT data issues were important, the potentially extreme impacts of severe tropical cyclones on the marine and coastal communities are such that the need for more reliable wind vector solutions close to the center of tropical cyclones remains the highest priority requirement for those operational centers, like Perth, which have tropical cyclone forecast and warning responsibilities.

3. Examples of the operational impact of QuikSCAT data

In this section, three examples are provided to illustrate how effective the QuikSCAT data have been for the Perth RFC, as was the case for the NOAA/OPC, described in Von Ahn et al. (2006). The first example is severe TC Glenda, which reached category 5 during its life cycle. The second example is a short-lived but severe windstorm that affected the southern coast of Western Australia. The third example is an intense Southern Ocean cyclone that was first detected by the Perth RFC from the QuikSCAT data as it moved westward and intensified rapidly, generating storm force winds and massive seas that caused severe damage in two Australian states (South Australia and Tasmania). Without QuikSCAT data, all three marine weather events would have been poorly forecast, or possibly not even detected, until they had affected populated areas.
Explosive tropical cyclogenesis: Severe TC Glenda, 25–31 March 2006

Tropical Cyclone Glenda was the most intense TC in northwest Australia to affect coastal and offshore communities and vital infrastructure during the 2005–06 Australian TC season. It began as a tropical low over land and developed a full tropospheric structure while still over land, not an unusual form of TC initiation in that region. The developing TC produced extensive flooding during its initial time over land. The tropical low moved off the coast during the night of 26 March 2006 (see Fig. 4a) and then deepened explosively into TC Glenda. Figure 4a also shows an earlier tropical cyclone, TC Floyd, situated well to the south of TC Glenda and about to make landfall. Glenda then intensified to a category 5 TC by 28 March (Fig. 4b), with an estimated central pressure of 910 hPa, 10-min sustained wind speeds of 115 kt, and wind gusts to 160 kt. The QuikSCAT pass closest to this time had a data gap over TC Glenda so it is not shown. Glenda then weakened slightly during the following 24-h period to an estimated 920 hPa (Fig. 4c) and was a category 4 TC when the northwestern section of its eyewall passed over the North Rankin A (NRA) gas platform, which recorded a peak 3-s gust of 123 kt, while the 10-min mean wind speed was 117 kt. These peak winds also did not coincide with the overpass times of QuikSCAT, but did
FIG. 4. (a) Mean SLP analysis at 1200 UTC 26 Mar 2006 showing a tropical low first moving off the northwest Australian coast. (b) As in (a) but at 1200 UTC 28 March 2006, showing Glenda as a category 5 TC. (c) As in (a) but at 1200 UTC 29 Mar 2006, with TC Glenda off the northwest Australian coast as a category 4 TC. (d) The QuikSCAT pass centered on 0950 UTC 26 Mar 2006 showing the sustained winds to at least 30 kt. (e) As in (d) but for the pass centered on 1012 UTC 29 Mar 2006 when the cyclone was at category 4 intensity. The NRA gas platform is denoted by a boldface N and the HPR3 buoy by a boldface H. (f) As in (e) but for the pass centered on 2241 UTC 29 Mar 2006. (All scatterometer images are courtesy of RSS.)
serve to confirm the strength of TC Glenda. However, the QuikSCAT data remained the only source available to provide information about TC Glenda throughout its life cycle, defining trends in wind speed and direction, and identifying and adjusting areas likely to be affected by TC Glenda. The QuikSCAT data also were used to calculate other critical aspects of TC Glenda such as its radius of maximum winds and the ongoing identification of areas with winds above gale force and storm force. As such, the QuikSCAT data were the key source of near-surface information on which operational forecast warnings were based, especially as TC Glenda was outside of radar range for much of its life cycle.

In Figs. 4d–f, the available QuikSCAT passes show clearly how important the QuikSCAT data were in the analysis and diagnostic processes used by the analysts and forecasters. In Fig. 4d, the QuikSCAT pass centered on 0950 UTC 26 March 2006 confirmed the development of a surface low over the ocean with a tight curvature and sustained wind speeds of at least 30 kt when the tropical low was moving from land to the sea. This was during tropical cyclogenesis and the QuikSCAT data enabled the operational analyst to conclude in a timely manner that the low was rapidly reaching TC intensity. In Fig. 4e, the QuikSCAT overpass at 1014 UTC 29 March 2006 shows clearly the symmetrical structure of TC Glenda, which was then a category 4 storm, and accurately defined the region of gale and storm force winds, thereby confirming the severity of the system. In Fig. 4f, the QuikSCAT overpass centered on 2241 UTC 29 March 2006 again depicted the TC circulation very well. The radius of gale force winds was confirmed by a postanalysis of a number of multiple surface- and island-based weather stations, including a highly detailed analysis of the data from the NRA platform and the offshore HPR3 buoy.

Verifying observations of QuikSCAT data for TC Glenda came from two main sources: NRA and the instrumented meteorological–ocean buoy, HPR3. Wind data from two successive QuikSCAT overpasses at 1014 and 2241 UTC 29 March 2006 are shown in Figs. 4e and 4f. These QuikSCAT data passes were at times when the center of TC Glenda was well away from NRA, but nevertheless agreed well with the NRA observations at 1000 and 2240 UTC 29 March 2006, as shown in Table 1a. Glenda was situated closer to HPR3 during these QuikSCAT overpasses. The HPR3 recorded 3-m, 10-min average wind speeds of 57 and 91 kt at 1000 and 2240 UTC 29 March, respectively, and in Table 1b they are seen to compare well with the nearby QuikSCAT wind speeds of 50 and 85 kt from the 1014 and 2241 UTC 29 March overpasses. The observed and QuikSCAT wind directions also are in good agreement in Tables 1a and 1b at both NRA and HPR3.

b. Severe local winds and squalls over the Southern Ocean

QuikSCAT data formed the basis of marine weather warnings issued for the passage of a rapidly moving cold front that produced a short-lived burst of storm force winds with severe wind squalls along the western south coast of Western Australia. The weather station at Cape Leeuwin, located on the extreme southwest corner of the Australian continent (see Fig. 1a), recorded a 10-min mean wind speed of 55 kt with maximum wind gusts to 70 kt during the passage of the cold front. The operational mean sea level pressure (SLP) analysis valid at 1200 UTC 19 August 2006 in Fig. 5a shows the position of the cold front, as derived from the QuikSCAT data. The QuikSCAT 12.5-km-resolution image closest to this time was from the 1011 UTC overpass (Fig. 5b) and it revealed a narrow line of storm force winds with rain-affected wind vectors in the 50–60-kt range over the ocean just to the south of Cape Leeuwin. The wind record from Cape Leeuwin verified encouragingly well with the QuikSCAT data, for both the sustained wind speed and direction and the wind gust recorded at Cape Leeuwin at 1000 UTC 19 August 2006 (see Table 2). QuikSCAT data from the over-
passes approximately 12 and 24 h earlier had been largely responsible for defining the structure and intensity of this cold front with enough lead time for coastal and land-based wind and severe weather warnings to be issued (see Figs. 5c and 5d). In particular, data from the 1011 UTC 19 August 2006 overpass were the basis for issuing warnings and the identification of coastal regions that were likely to be affected by the severe weather event. In addition, the operational availability of QuikSCAT data provides forecasters and emergency managers with near-real-time feedback confirming the occurrence of predicted severe weather events. Without the QuikSCAT datasets, it would have been several days before confirmation from remote locations that a forecast severe event had occurred, particularly if communication lines had been damaged.

c. An explosively developing Southern Ocean cyclone

It is difficult to verify the true intensity of explosively developing low pressure systems over the Southern

<table>
<thead>
<tr>
<th>Time and date</th>
<th>Observed wind direction and speed (kt)</th>
<th>QuikSCAT wind direction and speed (kt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 UTC 19 Aug 2006</td>
<td>NW 37 kt; gusts up to 70 kt*</td>
<td>1011 UTC 19 Aug 2006</td>
</tr>
</tbody>
</table>

* Recorded maximum wind gust of 70 kt at Cape Leeuwin.
** A 60-kt, rain-affected, wind vector from the QuikSCAT pass.
Ocean because conventional observations are so scarce, even by the standards of the Australian region oceans. During the period from 19 to 21 September 2006, a midlatitude low pressure system deepened rapidly, producing a period of hurricane force winds over the Southern Ocean to the south of Australia. This system then moved eastward over Tasmania, where it produced storm force winds with widespread damage during 21 and 22 September. Strong gales from the outer circulation of this low pressure system also caused substantial damage throughout the southern populated areas of South Australia. The most relevant SLP chart is Fig. 6a, which shows the developed cyclone at 0000 UTC 21 September 2006. The QuikSCAT passes from 0947 UTC 20 September 2006 through the pass centered on 2015 UTC 20 September to the pass centered on 0048 UTC 22 September, as shown in Figs. 6b–d, provide a well-defined time sequence of the near-surface winds associated with the cyclone. As the only data available near the storm center, they formed the basis of the operational marine and coastal storm warnings that were issued by the Australian Bureau of Meteorology. The QuikSCAT data enabled forecasters to identify the early stages of the existence of the system, to track its speed and direction of movement, to decide which areas were under threat and when, and to moni-
tor changes in the development of the cyclone, especially the transition to its most intense phase.

Verifying observations of the cyclone during its life cycle were few and largely indirect. The storm passed close to two drifting buoys during its most intense phase. The locations of these buoys are shown as black dots at 43°S, 118°E and 43°S, 123°E, respectively, in Figs. 6b–d. At 2220 UTC 20 September 2006, close to the time of the QuikSCAT overpass of 2015 UTC 20 September (Fig. 6b), the measured pressure gradient between these two drifting buoys was a massive 20 hPa, over just 5° of longitude. A pressure gradient of this magnitude implies the existence of the storm to hurricane force winds. In addition, a ship located at 36°S, 131°E at 0000 UTC 22 September, and which was 840 n mi distant from the center of the cyclone, reported 45-kt sustained winds, further confirming the intensity of the system by comparison with the QuikSCAT pass of 0048 UTC 22 September in Fig. 6c.

Without the QuikSCAT data, diagnosing the strength of this cyclone would have been very difficult. In the absence of ground truth data, forecasters are less likely to issue the rare, high-end warnings that were required for this event. The fact that the warnings for this extreme event were issued at all, and especially in a timely manner, can be attributed to the availability of near-real-time QuikSCAT data across large areas of the southern Indian and Southern Oceans. In the absence of the QuikSCAT data, no warnings would have been issued.

4. Discussion

This note describes the crucial role played by QuikSCAT data in the operational forecasting of marine weather and the issuing of severe weather and sea state warnings in the coastal and open-ocean areas for which the Perth RFC and TCWC has responsibility. As this Australian operational forecast center is located in a data-sparse region, with the vast expanse of the Indian and Southern Oceans to the west and south, the QuikSCAT data provide vital daily input to the daily forecast operations of the RFC and the TCWC in the tropical cyclone season.

The QuikSCAT data are not without limitations, as we have noted. Fortunately, some of these are currently being addressed (J. U. Von Ahn 2006, personal communication). The importance of the QuikSCAT data for the Perth RFC operations was illustrated by presenting three examples selected from the massive number available. The selection was deliberately broad, as it was intended to indicate the far-reaching impact of the QuikSCAT data recently pointed out for the NOAA/OPC by Von Ahn et al. (2006). The first case was severe TC Glenda, in which the QuikSCAT data were relied upon entirely to quantify key phases of the tropical cyclone, especially its developing and intensification periods. Moreover, the QuikSCAT winds verified well against wind speeds observed on a gas platform located close to the tropical cyclone’s path. The next example was a powerful frontal system that generated destructive storm force winds in a squall line south of Western Australia’s southern coastline. Although frontal systems are a regular feature of this region, forecasters relied on QuikSCAT data to determine the location, strength, and speed of movement of the front. Trends in QuikSCAT data were critical in the decision to issue marine weather warnings and, conversely, to cancel them. Again, there was good agreement with the nearest observing station. Finally, the third example was an explosively developing extratropical cyclone. Despite being relatively common, these systems are very difficult to detect and to quantify as they form over the data-sparse open Southern Ocean. In this case the QuikSCAT data verified well against two ocean drifting buoys, a ship, and a wave rider buoy. None of the three severe weather events would have been forecast, and the relevant warnings issued so early or so well, without the availability of the QuikSCAT data.

Acknowledgments. This study was funded partially by NOAA Grant NA17RJ1227 and by the Office of Naval Research Grant N00014-0021-1-0181.

REFERENCES


