The Operational Impact of QuikSCAT Winds at the National Oceanic and Atmospheric Administration Ocean Prediction Center

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Abstract— **The primary responsibility of National Oceanic and Atmospheric Administration's (NOAA) Ocean Prediction Center (OPC) is to issue marine warnings and forecasts of winds and seas for the High Seas and Offshore waters of the Atlantic and Pacific Oceans. This covers vast open ocean areas from the subtropics to the near arctic. Accurate and timely surface data are necessary to make these warning decisions. Although conventional observations from buoys and ships of opportunity are very useful to marine forecasters, their distribution is sparse, often being limited to trade routes or continental waters. Over the past twelve years, forecasters have come to rely more and more on remotely sensed data. Special Sensor Microwave/Imager (SSM/I) winds have been used to help fill in the gaps between conventional observations. However the SSM/I retrievals are not available in areas of liquid cloud and precipitation and are restricted to the lowest wind warning category (GALE). Wind retrievals from various scatterometers flown onboard satellites have been available to OPC forecasters over the last ten years and were used with some success. QuikSCAT winds are now fully integrated into OPC operations and have proven to be invaluable. The wide swath width and all weather capabilities have enabled OPC forecasters to use these winds routinely to determine the extent and magnitude of strong winds, the location of fronts and pressure systems, and wind gradients associated with oceanographic thermal features. Since the inclusion of QuikSCAT into OPC operations the marine forecaster's ability to accurately assess wind conditions over the open oceans has never been better.**

I. INTRODUCTION

The National Oceanic and Atmospheric Administration's (NOAA) Ocean Prediction Center (OPC) is responsible for issuing marine wind warnings and forecasts of winds and seas for the extratropical High Seas and Offshore waters of the Atlantic and Pacific Oceans. OPC wind warnings and forecasts, in part, fulfill the United States requirement to provide marine warnings and forecasts under the International Safety of Life At Sea Convention. Wind warning categories are: GALE (17.5 to 24.2 m s^{-1}), STORM (24.7 to 32.4 m s^{-1}) and HURRICANE FORCE (32.9 m s^{-1} or greater.)

OPC forecasters are responsible for issuing wind warnings over vast open ocean areas from the subtropics to the near arctic. The OPC waters are often frequented by Meteorological "bombs" during the winter season [1] and by re-curving or transitioning tropical cyclones during the summer and fall. Accurate and timely surface data are necessary to make warning decisions. Although conventional observations from buoys and ships of opportunity are very useful to marine forecasters, their distribution is often sparse being limited to trade routes or continental waters.

Over the past twelve years, forecasters have come to rely more and more on remotely sensed data to help fill in the gaps between conventional observations. OPC forecasters have used special Sensor Microwave/Imager (SSM/I) winds with limited value. SSM/I Retrievals consist of wind speed only and are restricted to the lowest wind-warning category of GALE. Also, in areas of liquid cloud and precipitation there are no wind retrievals at all. These contaminated areas are of great interest as they often contain high winds [2].

Scatterometer derived winds have been available to OPC forecasters for periods of time over the last ten years. The European Space Agency's ERS-1 and ERS-2 winds were used by forecasters with minimal success as the swath width was narrow and therefore the chances of retrieving wind vectors over a particular area of interest were small. In 1996, The NASA Scatterometer (NSCAT) was launched onboard the Advanced Earth Observing Satellite (ADEOS-I) and provided 90% coverage of the ocean areas within a 2-day period [2]. OPC forecasters used NSCAT data routinely and for the first time were able to view ocean vector winds over large ocean areas. NSCAT also provided a wide range of retrieved wind speeds that extended well into the STORM Force category. For the first time forecasters were able to see retrieved winds over entire storm systems and differentiate between GALE and STORM Force winds [2]. Unfortunately, the satellite lost power in 1997.

In 1999, as a quick fix to the loss of NSCAT, NASA launched the Quick Scatterometer Satellite with a SeaWinds scatterometer (henceforth referred to as QuikSCAT) onboard [2]. The QuikSCAT winds were accessible to OPC forecasters shortly after launch and became available in the OPC operational National Centers All Weather Interactive Processing System (NAWIPS) [3] workstations in October 2001. At this point QuikSCAT winds were fully integrated in the OPC analysis and warning process.

Several characteristics of QuikSCAT have made it a very popular tool for OPC forecasters. The very large swath width (1800 km) provides ocean vector winds across 90% of the world oceans daily. This gives OPC forecasters two looks at each ocean each day. QuikSCAT measures wind speeds up to 30 m s^{-1} (near HURRICANE FORCE) with an accuracy of ± 2 m s^{-1} [4], although OPC forecasters have often observed QuikSCAT winds in excess of 32.9 m s^{-1} in association with extratropical cyclones [5]. The data is available to the forecasters in near real time. Although wind retrievals in areas of moderate to heavy rain can often be contaminated this does not significantly detract from its use to forecasters in the extra tropics. QuikSCAT has become a very heavily used tool by OPC forecasters. With QuikSCAT, OPC forecasters are now able to more accurately assess the conditions over the open oceans than ever before. The placement of fronts and high and low pressure centers on OPC surface analyses and the assessment of warning conditions have never been more exact.

In this paper we have attempted to quantify the impact of QuikSCAT winds on the OPC analysis and warning process. Results of several forecaster surveys will be presented and discussed in

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Section 2. The ability to differentiate HURRICANE FORCE conditions will be discussed in Section 3. QuikSCAT winds have also revealed strong wind speed gradients across the oceanic thermal fronts of the western Atlantic. The impact of forecasters ability to see the sensitivity of near surface winds to the adjoining ocean surface temperature will be discussed in Section 4. Summary and conclusions will be given in Section 5.

II. Impact on OPC Operations

Over the past two years, four studies were conducted to try to quantify the impact of QuikSCAT on OPC operations. The first three studies (Fall 2002, Spring 2003, Fall 2003) examined the impact of QuikSCAT winds on determining short-term wind warnings over both the North Pacific and Atlantic Oceans. OPC forecasters produce 4 analyses of sea-level pressure, weather systems, and fronts each day. Areas of high winds are labeled with the appropriate warning category on each of these analyses as shown in Fig. 1.

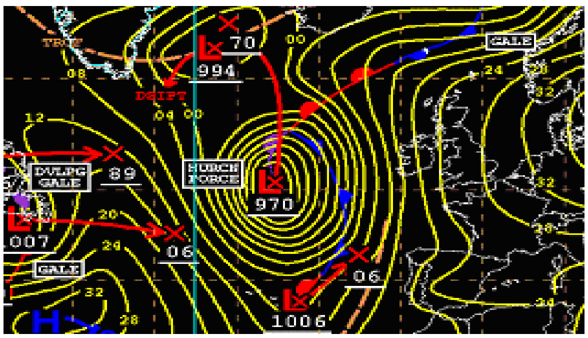

Figure 1. OPC surface analysis with wind warning labels

For each month long study all warning labels were counted. These were considered to be warnings with QuikSCAT. Forecasters filled out survey sheets after each analysis to indicate what warning category would have been used had QuikSCAT not been available. Based on forecaster comments the appropriate changes to warning categories were then applied to the warning categories with QuikSCAT. This then gave us a data set of the warning categories that would have been issued had QuikSCAT not been available (warnings without QuikSCAT). The two data sets were compared and represent the impact of QuikSCAT winds. Results shown in Fig. 2 indicate that more wind warnings were indeed issued when QuikSCAT winds were used in the warning decision process.

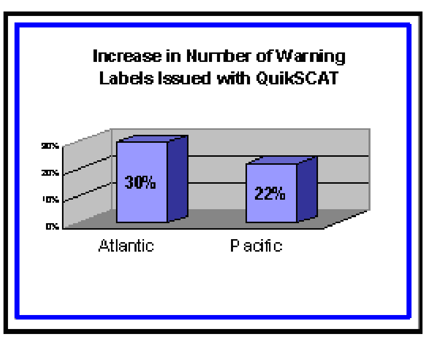

Figure 2. When OPC forecasters used QuikSCAT winds in the warning decision process the number of wind warnings increased.

The impact was more significant in the Atlantic (30%) than in the Pacific (22%) and most importantly with the higher warning categories [5]. The impacts during the spring and fall 2003 were far less impressive than the original study in the fall 2002. For the spring 2003 study this difference was attributed to a lower number of significant wind events than fall 2002. The results from fall 2003 were both surprising and disappointing. Fall 2003 was no less active than the previous fall, so it was fully expected that the results of this study would be comparable with those of the first. Instead we measured far less impact. Because of this there were concerns that the QuikSCAT data was not being utilized to its full potential. In querying the forecasters it became obvious that they did not fully understand rain-flagged data and routinely disregarded all rain flagged data. Prior to the fall 2003 study, timelines that display the exact time the scatterometer data was taken were added to NAWIPS workstation displays. Forecasters have apparently become more discriminating regarding the timeliness of data to use in an analysis. Forecasters also have varying ideas as to what data is considered too old to use.

To address these concerns, an additional study was conducted from February 15th to March 15th 2004. This study was different than the previous studies. In addition to evaluating the impact on the number of wind warnings on the surface analyses, the changes to warning category, aerial extent of warnings, and location of pressure systems and fronts were also considered. For this study an event was defined as one warning area or low pressure system.

QuikSCAT wind retrievals were available to use in the decision process 35% of the time in the Atlantic (173 events) and 63% of the time in the Pacific (294 events). As shown in Fig. 3, during the times that QuikSCAT was available changes were made to more than half of the events (118 in the Atlantic and 146 in the Pacific). As in the previous studies using QuikSCAT resulted in an increase in the number of wind warnings issued for both oceans (10% for the Atlantic and Pacific).

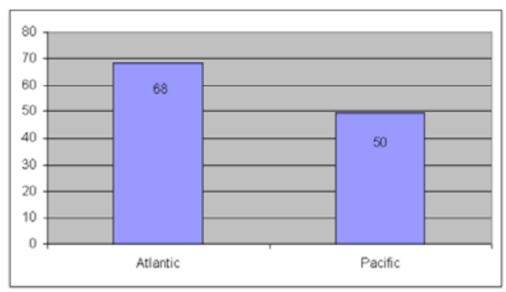

Figure 3. Percentage of events change when QuikSCAT was available.

Fig.4 and Fig.5 show the percentage (by change type) of the total number of changes made to the surface analysis. Changes to wind speed and wind warning category accounted for more than half of the total in both oceans.

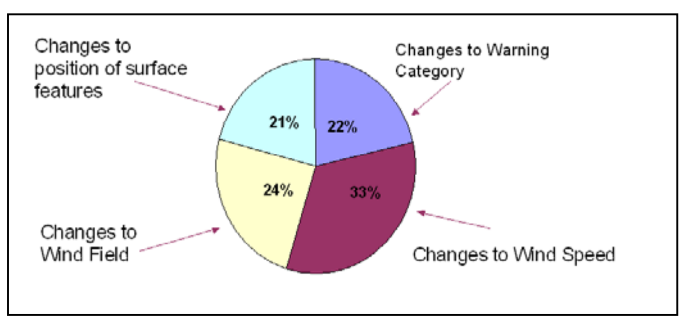

Figure 4. Percent of changes(by change type) made to the Atlantic surface analysis using QuikScat

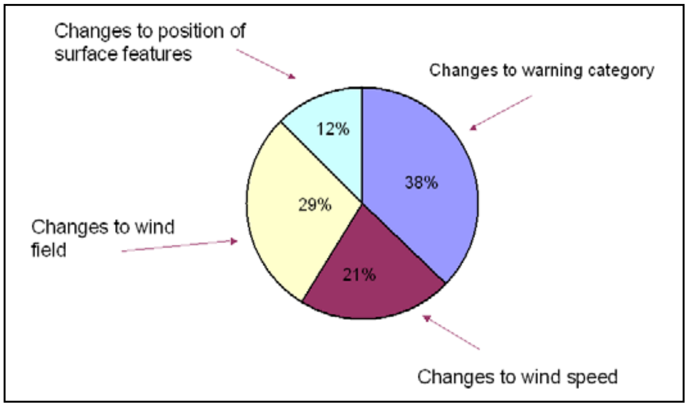

Figure 5. Percent of changes (by change type)made to the Pacific surface analysis.

Changes to the wind field made up more than 25% of the total. Changes to surface features were changed the least (21% in the Atlantic, 12% in the Pacific).

Given that QuikSCAT is only available twice daily for a specific area and that the area of interest may fall within a data gap this is a significant impact. Another SeaWinds scatterometer was launched onboard the MIDORI-2 Satellite in December 2003. Unfortunately the satellite failed and OPC forecasters were never able to utilize QuikSCAT and SeaWinds in dual scatterometer mode.

III. HURRICANE FORCE EXTRATROPICAL CYCLONES

Hurricane Force (HF) extratropical cyclones are a significant threat to safety at sea. Dangerous winds and waves associated with these extreme cyclones can cover vast ocean areas and can result in the loss of cargo, damage or loss of vessels, loss of life, and economic loss. Prior to QuikSCAT, there was no data source that consistently observed HF winds in extratropical cyclones. Unfortunate merchant ships would infrequently observe extreme conditions but not enough for forecasters to be able to consistently differentiate the extreme from the more common storm force cyclone. Due to QuikSCAT winds, forecasters can now reliably differentiate these high impact events from weaker storms. This ability has lead to an increase in the number of advance warnings for hurricane force conditions by OPC forecasters.

Due to the capability of QuikSCAT to detect winds in excess of minimal HF, the OPC Ocean Applications Branch has carried forth a significant effort to understand these cyclones [5]. The number of separate HF events observed over the past three winter seasons for the North Atlantic and Pacific is shown in Table 1.

TABLE I. NUMBER OF HF EXTRATROPICAL CYCLONES OBSERVED

Period of Study	Atlantic	Pacific
2001-2003	22	15
2002-2003	23	22
2003-2004	15	22

It can be seen that on average 15 to 23 HF events occurred in each ocean basin for each period of study. The Pacific has shown a maximum of activity in November and December with a lull in activity in January. The Atlantic has consistently had a maximum of occurrence in January. Similar to studies by [1], peak activity occurred across the western portion of each basin. Both ocean basins show preferred tracks for these extreme cyclones. Reference [5] also showed that on average HF conditions lasted less than 24 hours. It is no surprise that in verifying 48 and 96- hour cyclone forecasts it was discovered that these extreme wind conditions are very difficult to forecast at the day 4 forecast step [6]. Effort is currently underway to composite wind fields from several cyclones to better understand where QuikSCAT frequently observes extreme winds in relation to the cyclone center. The use of cyclone phase diagrams as described by [7] as a potential forecast tool is also being investigated. Lastly, extreme cyclone frequency is being compared to trends in climate indices such as the North Atlantic Oscillation (NAO). The OPC will continue to study these high impact cyclones with the goal of providing improved forecasts. QuikSCAT has raised forecasters awareness concerning these high impact ocean storms.

IV. GULF STREAM APPLICATIONS

The all weather capability of QuikSCAT has helped to reveal significant near surface wind gradients across sea surface temperature (SST) gradients or fronts as described by [6]. Reference [8] observed a nearly 50% reduction in near surface wind speed across the Gulf Stream north wall from aircraft. Stronger winds were observed over the Gulf Stream with weaker winds over the cooler slope waters. It was surmised that this dramatic wind speed gradient was due to changes in the marine atmospheric boundary layer (MABL) stability [8]. A deep well mixed MABL existed over the warm Gulf Stream with a highly stratified shallow MABL over the cooler slope and shelf waters. The QuikSCAT winds from March 21, 2003 are shown in Fig. 6. GALE force winds were observed over the warm Gulf Stream waters with wind half that strength over the cool waters. The present state of numerical guidance fails to predict such strong wind gradients.

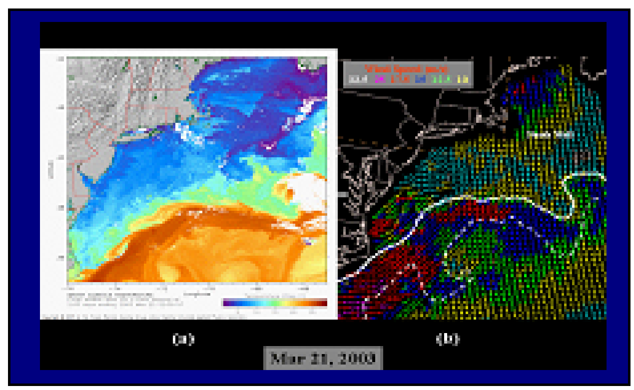

Figure 6. (a)3-day SST composite and (b)QuikSCAT winds from March 21,2003. The U.S. Navy Gulf Stream North Wall(white solid line) and South Wall(white dashed line) analyses are shown in (b). Note the strong winds are observed by Quikscat over the warmer waters of the Gulf Stream

V. SUMMARY AND CONCLUSIONS

Any new data sets designed to aid forecasters in making decisions must be easily accessible, timely, reliable, and compliment conventional data (data that forecasters have come to trust). QuikSCAT near-real time winds certainly meet these tough criteria and have indeed become fully integrated into the OPC warning and forecast process.

In section 2 it was demonstrated that a significant percentage of warning decisions made by OPC forecasters are based on QuikSCAT winds. Subsequent impact studies showed a decreasing percentage of warning decisions based on QuikSCAT as compared to the first. This was some cause for alarm. It was identified that forecasters were becoming more discriminate regarding the age of data used as timelines were introduced to NAWIPS displays. In addition, forecasters did not fully understand rain flagging and were thus discarding good data. This issue was addressed through increased training. Lastly, it has become evident that OPC forecasters have gained a significant trust in the numerical guidance winds from the NCEP Global Forecast System (GFS) [11]. This trust has stemmed from the everyday comparison of GFS and QuikSCAT winds. Forecasters treat GFS winds with near as much weight as an observation. This was a surprising result of the impact studies.

While the first three studies focused on the number of warning decisions the last study perhaps best illustrates the impact of QuikSCAT winds on OPC operations. When available, QuikSCAT winds impacted surface features and wind areas on OPC surface analyses 68% (Atlantic) and 50% (Pacific) of the time. One can only imagine the impact that two wide swath scatterometers with 4 looks per day would have had on operational marine forecasting.

Five years ago the highest category of wind warning issued by the U.S. National Weather Service (NWS) for extra-tropical cyclones was STORM for winds 24.7 ms^{-1} and greater. In December of 2001, the NWS began issuing a higher category HURRICANE FORCE wind warning for winds 32.9 $ms^{-1}$and greater. Until QuikSCAT, no observing system was able to consistently observe or infer winds in excess of 32.9 ms^{-1} over the open ocean. QuikSCAT's wide swath, all weather capability and large wind retrieval range has given forecasters the confidence to observe and forecast these most severe cyclones. During the winters of 2002-03 and 2003-04, OPC forecast verification statistics have shown that one of the most difficult forecast challenges is to forecast the intensity and position of HF cyclones at the 96 hour forecast time step [6]. This is a critical forecast period since four days of lead-time would give ship's crews time to alter course to avoid the anticipated conditions. The OPC will continue to focus on and attempt to improve forecast skill for these extreme cyclones.

Forecasting near surface winds over the dynamic waters of the western North Atlantic continues to be a challenge. QuikSCAT has observed strong wind gradients in the vicinity of SST fronts. These gradients are attributed to large differences in MABL stratification. The use of QuikSCAT has helped forecasters to understand the relationship between low-level stability and near surface winds. Forecasters now factor low-level stability into their wind forecasts. A variety of numerical guidance tools and fields are available to forecasters to aid in the wind forecast process. Forecasters routinely use numerical model based lifted indices, height of the boundary layer, winds from a variety of low levels, and detailed numerical model soundings to forecast near surface winds. In summary, QuikSCAT winds have helped to change the way forecasters predict near surface winds for the better.

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REFERENCES

[1] Sanders, F. and J.R. Gyakum, 1980: Synoptic- dynamic climatology of the "bomb". Mon. Wea. Rev., 108,1590 – 1606.

[2] Atlas, R., N. Hoffman, S.M. Leidner, J. Sienkiewicz, T-W. Yu, S.C. Bloom, E. Brin, J. Ardizzone, J.Terry, D. Bungato, and J.C. Jusem, 2001: The effects of marine winds from scatterometer data on weather analysis and forecasting. Bull. Amer. Meteor. Soc., 82, 1965-1990.

[3] desJardins, M. L., K. F. Brill, and S. S. Schotz, 1991:Use of GEMPAK on UNIX workstations. Proceedings, 7th Int. Conf. On Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, New Orleans, LA, Amer. Meteor. Soc., 449-453.

[4] Shirtliffe, G.M., 1999:QuikSCAT science data product user's annual, overview, and geophysical data products, version 1.0, Jet Propulsion Laboratory, Pasadena, California [JPL D-18053].

[5] Von Ahn, J.U., J.M. Sienkiewicz, J. Copridge, J. Min, and T. Crutch, 2004:Hurricane force extratropical cyclones as observed by the QuikSCAT scatterometer. Preprint 8th Symposium on Integrated Observing and Assimilation Systems for Atmophere, Oceans and Land Surface. AMS Annual Metting January 12 16,2004 Seattle, Washington. In press.

[6] Sienkiewicz, J.M., D. Scott Prosise, and Anthony Crutch, 2004: Forecasting oceanic oyclones at the NOAA ocean prediction center symposium on the 50th anniversary of operational numerical weather prediction. June 14 17,2004 College Park, Maryland. In press.

[7] Hart, R.E., 2003: A cyclone phase space derived from thermal wind and thermal asymmetry, Mon.Wea.Rev, 131, 585-616.

[8] Sweet, W., R. Fett, J. Kerling, and P. LaViolette, 2001: Air-sea interaction effects in the lower troposphere across the north wall of the Gulf Stream, Mon. Wea. Rev., 109, 1042-1052

[9] Benjamin, S.G., J.M. Brown, K.J. Brundage, D.Devenyi, G.A. Grell, D. Kim, B.E. Schwartz, T.G. Smirnova, T.L. Smith, S.S. Weygandt, and G.S. Manikin, 2002: RUC - the 20-km version of the rapid update cycle. NWS Technical Procedures Bulletin No. 490 [FSL revised version available through RUC web site at http://ruc.fsl.noaa.gov]

[10] Black, T.L., 1994: The new NMC mesoscale eta model: description and forecast examples. Wea. Forecasting, 9, 265-278.

[11] Kanamitsu, M., 1989: Description of the NMC global data assimilation and forecast system. Wea. and Forecasting, 4, 335-342.