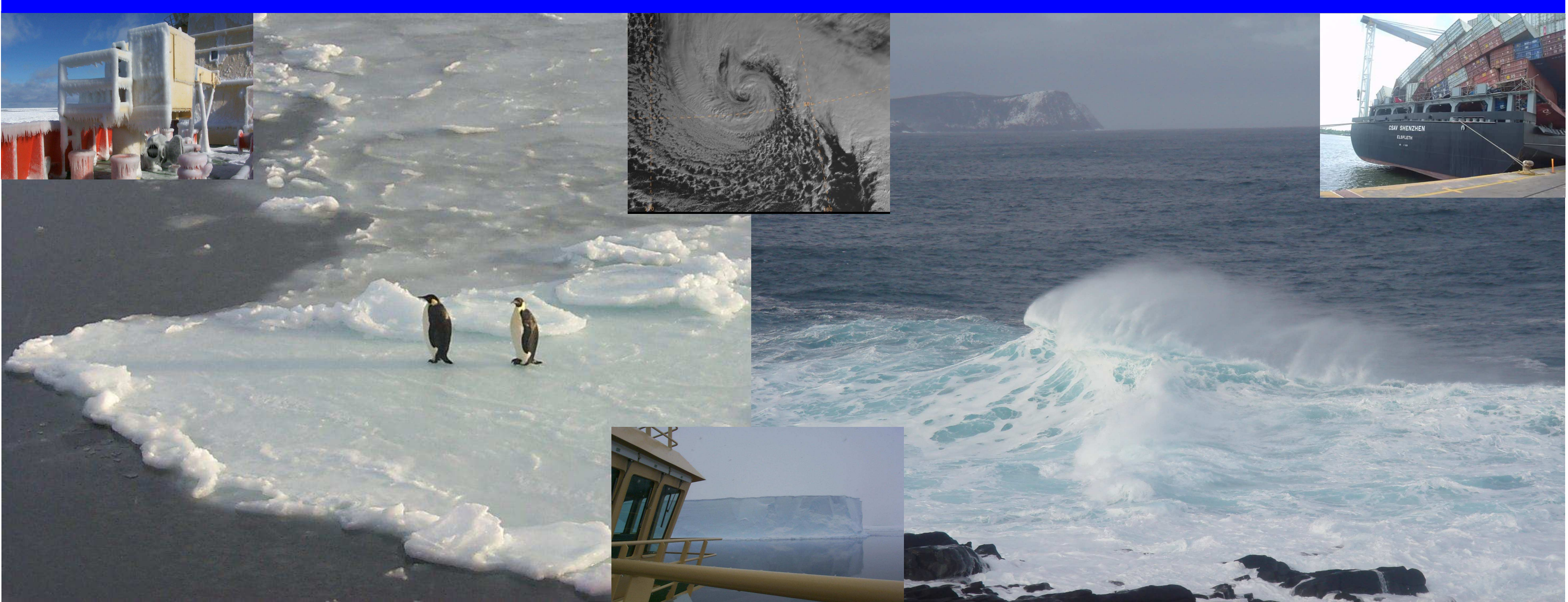
NOAA Operational Satellite Ocean Surface Vector Winds

QuikSCAT Follow−On Mission: User Impact Study Report

February 19, 2008



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Acknowledgments

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NWS/Western Region
NWS/Southern Region
NWS/Eastern Region
NWS/Central Region
NWS/NCEP/Aviation Weather Center
OAR/Atlantic Oceanographic and Meteorological Laboratory
Joint Center for Satellite Data Assimilation
National Ice Center
NWS/Office of Science and Technology
NWS/Office of Climate, Water and Weather Services

Cover: **Main picture: A ship in the North Atlantic waters off of Cape Spear in St. Johns, Newfoundland after the passage of a winter storm. Pictures along the bottom from left to right: the ice-covered bow of the ice breaker Nathanial B. Palmer resulting from sea spray during the Southern Ocean crossing, emperor penguins on an ice floe in the Ross Sea, a GOES visible image of a North Pacific winter storm, an iceberg in the Ross Sea, breaking waves along the Cape Spear coast resulting from a recent winter storm, and cargo damage suffered by the container ship Csav Shenzhen.**

QuikSCAT Follow-On Mission: User Impact Study

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1 *Executive Summary*

Satellite ocean surface vector wind (OSVW) data has revolutionized operational marine weather warnings, analyses, and forecasting. To maintain the significant improvements in operational weather forecasting and warning capability that have been realized from QuikSCAT OSVW data requires continuity of the OSVW data stream at a level that is equivalent to or better than that provided today by QuikSCAT. This report documents the results of the user impact study conducted to evaluate the impacts of a QuikSCAT equivalent and an advanced next-generation OSVW (XOVWM) follow-on mission on the marine weather warning and forecasting functions of the National Oceanic and Atmospheric Administration (NOAA). A significant result of this study is that the XOVWM mission would greatly enhance the detection and warning capability across a wide range of weather phenomena for nearly all of the National Weather Service's coastal, offshore, high seas, and Great Lakes marine areas of responsibility. An XOVWM capability would yield significant benefits over a QuikSCAT equivalent capability in the forecast and warning program with respect to extratropical cyclones, tropical cyclones, coastal regions, and the Great Lakes.

The operational use of satellite ocean surface vector wind (OSVW) observations has advanced considerably over the past decade. OSVW data from research (QuikSCAT and WindSat) and operational (ASCAT) satellite systems are now depended upon and utilized daily by operational weather forecast and warning centers around the world. Of these systems, NASA's QuikSCAT, which provides the highest quality global OSVW measurements, the finest spatial resolution, and the most complete coverage with 90% of the world's oceans covered in a single day, has had the largest impact in operational weather forecasting and warning.

With the oceans comprising over 70% of the earth's surface, the impacts of QuikSCAT OSVW data have been significant in meeting societal needs for weather and water information and in supporting the nation's commerce with information for safe, efficient, and environmentally sound transportation and coastal preparedness. Within NOAA's National Weather Service (NWS), the use of OSVW encompasses the warning, analysis, and forecasting missions associated with tropical cyclones (TC), extratropical cyclones, fronts, localized coastal wind events (i.e., gap winds), and the forecast of sea conditions driven by winds. **Today, OSVW measurements from QuikSCAT are an intrinsic part of everyday forecasting and warning processes at NWS operational centers and offices. The loss of quality QuikSCAT winds would result in:**

- **An 80 to 90% loss in detection capability for hurricane-force (HF) extratropical cyclones.**
  - To date, only QuikSCAT OSVW provides the consistency in retrievable wind speed range and coverage to detect these dangerous wind events.
- **A negative impact on the aerial extent and the wind strength forecasts over the North Atlantic, North Pacific, and Gulf of Alaska waters, as well as ice observations and forecasts.**
  - Since 2001, the NWS Alaska Region has shown a steady improvement in its wind speed and significant wave height forecast verifications by 25% and 32%, respectively. This improvement is the result of a combination of new ocean buoys, satellite sensors including QuikSCAT, and improved numerical model guidance.

- **The loss of one of the tools used for early detection of surface circulations in developing tropical cyclones (TC genesis) and for defining gale (34 kts) and storm-force (50 kts) wind radii.**
  - The information on wind radii from QuikSCAT is especially important for TCs outside the range of aircraft reconnaissance flights conducted in the Atlantic and Eastern Pacific basins, and for the regions where there are no reconnaissance flights (Central Pacific, Western Pacific, and Indian Ocean). Accurate wind radii are critical to both the Tropical Prediction Center (TPC)/National Hurricane Center (NHC), Central Pacific Hurricane Center (CPHC), and the Guam Weather Forecast Office (WFO) watch and warning process since they affect the size of tropical storm and hurricane watch and warning areas.
  - QuikSCAT is used by NHC to help detect the initial development of tropical cyclones, especially for systems beyond the range of reconnaissance aircraft. Prior to the availability of QuikSCAT OSVW data at NHC, a limited study by Katsaros et al. (2000) of the 1999 Atlantic season hurricanes showed that a surface circulation was identified by QuikSCAT approximately 3 to 49 hours before a tropical depression statement was issued for the system.
  - Between 2003 and 2006, QuikSCAT data were used at NHC 17% of the time to determine the wind radii, 21% of the time for center fixing, and 62% of the time for storm intensity estimates.
- **The loss of realized improvements in forecasting and warning of localized wind events (i.e., gap, coastal, and topographic influenced winds).**
  - 73% of the storm-force wind events in the Gulf of Tehuantepec were identified solely through the use of QuikSCAT measurements during the period of October 1999 to January 2007 at the Tropical Prediction Center.
  - QuikSCAT OSVW is often the only way for a forecaster to get a handle on a frontal position in the Gulf of Alaska or the Bering Sea. In the Anchorage WFO, the QuikSCAT winds are utilized 70% of the time for the wind intensity estimates in the warnings it issues.
- **The loss of the average 7% improvement in wind speed estimates in the one- to three-day forecasts from NWS global model.**
  - QuikSCAT OSVW data are routinely assimilated into the NWS Global Data Assimilation System in addition to the systems of numerous operational weather centers around the world.
- **The loss of an important tool used in the routine delineation of the sea ice edge and tracking of Antarctic icebergs.**
  - QuikSCAT is the highest resolution microwave data set available today that helps assess the distribution and dynamics of the seasonal ice in the North Pole region. It is especially important for High-Arctic sea ice analysis because of the North Pole blind spot in other available data sets.
- **The loss of an important tool used in issuing warnings, forecasts, and analyses of weather hazardous to aviation by the Aviation Weather Center (AWC).**
  - The Aviation Weather Center (AWC) uses QuikSCAT OSVW data operationally for the following products: Domestic AIRMET TANGO, Domestic Area Forecasts, Gulf of Mexico Area Forecasts (west of 85W), Caribbean Area Forecasts, Domestic

Convective SIGMETs, Domestic Collaborative Convective Forecast Products, and International SIGMETs (Atlantic to 40W, Pacific to 165E).

- **The loss of an important tool used in El Niño Watch and Coral Reef Watch.**
  - The fine spatial resolution and wide coverage of QuikSCAT OSVW data is used to compute the wind stress vectors and curl product used by El Niño Watch as an ENSO prediction tool. Coral Reef Watch utilizes the QuikSCAT accurate low-wind capability to identify regions of persistent low-wind conditions, which is an important environmental indicator of coral bleaching risk.

Improvements in weather forecasting and warnings directly parlay into benefits for maritime commerce, fishing, oil exploration and extraction, search and rescue, and hazardous spill mitigation. More than 95% of U.S. international trade by volume is transported by ship. The $200 billion global marine shipping industry is increasingly relying on accurate marine warnings and forecasts to keep ships on schedule and safe from dangerous ocean storms (Kite-Powell 2000). **Accurate forecasts of hurricane-force winter storms in the North Atlantic and Pacific result in annual savings of $60 to $370 million** for container ships from avoided storm exposure (Kite-Powell, 2008).

Accurate knowledge of the weather in the coastal marine environment directly impacts the daily lives of the majority of the nation's population. As of 2003, approximately 153 million people, or 53% of the nation's population, resided in the 673 U.S. coastal counties. There are over 12 million recreational boaters in the U.S. who frequently make safety-related decisions based on the current wind conditions and marine forecasts, primarily in nearshore waters. Further offshore, the U.S. oil and gas industry, which generates nearly $4 billion annually in bonuses, rents, and royalties for the federal government from oil and gas producing leases, depends upon accurate and timely observations of the current sea state and warnings of impending storms for efficient and safe drilling operations.

Accurate and timely knowledge of ocean surface winds is also required for the safe and effective deployment of resources for hazardous spill response and search and rescue activities. A 1% increase in oil spill containment and cleanup efficiency in the New England region would have yielded a savings of $7.5 million over 10 years, and nearly $100 million for the entire U.S. over that same time (Adams et al., 2000). Perhaps the most critical factor in ensuring a successful outcome for the Coast Guard's search and rescue (SAR) operation is the time it takes to reach the person(s) at risk; the SAR success rate decreases to around 4% when this time exceeds two hours. Knowledge of the currents and winds in the vicinity of the SAR target is crucial to locating and reaching the person(s) quickly.

Maintaining the improvements in operational weather forecasting and warning capability that have been realized from QuikSCAT OSVW data requires continuity of the OSVW data stream at a level that is equivalent to or better than that provided today by QuikSCAT. Toward this end, NOAA initiated a study with NASA's Jet Propulsion Laboratory (JPL) to develop the cost, technical readiness, and schedule estimates for a QuikSCAT-equivalent capability, a more advanced capability known as the extended ocean surface vector wind mission (XOVWM) that would also better address NOAA's operational OSVW requirements and constellation of two advanced instruments. JPL submitted both mission concepts and their simulated OSVW performance evaluations to current operational NWS users of QuikSCAT data.

The QuikSCAT equivalent instrument would continue the significant positive impacts in operational weather forecasting and warning that high-quality QuikSCAT OSWV data makes possible today. No other OSVW measurements provide the operational offices a data quality comparable to QuikSCAT. **Therefore, in order to sustain the improvements in the operational weather forecasting and warning program that result from the availability of QuikSCAT data, all NWS users have set the QuikSCAT-equivalent capability as a minimum or threshold OSVW capability.**

One significant conclusion from the NWS user impact studies is that the XOVWM mission would **greatly enhance** the detection and warning capability across a wide range of weather phenomena for **nearly all** of the NWS coastal, offshore, high seas, and Great Lakes marine areas of responsibility. **An XOVWM capability would yield significant benefits over a QuikSCAT-equivalent capability** in:

Extratropical cyclones

- Greatly improved detection of extratropical cyclones development and intensity and the evolution of wind fields associated with extratropical transition. This translates to significantly improved warnings for both tropical and extratropical coastal and marine areas.
    - More than 95% of the U.S. international trade by volume is transported by ships throughout the world's oceans. Weather hazards, particularly the strong winter ocean storms that reach hurricane-force (HF, >63 knots) wind strength and can produce waves to 100 feet over the open ocean are a major threat to the safety and efficiency of marine transportation.
- More accurate tracking of nearshore marine conditions resulting in more accurate short-range marine forecasts, advisories, and warnings.

Tropical cyclones

- More reliable estimates of TC intensity through **all** stages of development from depression to major hurricane.
    - The NOAA Weather and Water Goal Program Plan has designated intensity forecast improvements as a high priority, and the National Weather Service Science and Technology Infusion Plan describes the operational goals for intensity forecasts over the next 5 to 10 years.
- Improved analysis of the TC wind field structure (34, 50, and 64 kt wind radii) which will yield more refined watch/warning areas for the coast and marine areas.
- More accurate tracking of TC centers, earlier identification of developing systems, and more accurate initial motion estimates used as input into model guidance.

Coastal regions and Great Lakes

- By far, the most frequent perceived benefit of the advanced XOVWM scatterometer would be the availability of OSVW data **much** closer to the coast (2.5–5 km) than is currently available (20–30 km).
  - Marine coastal zones are divided into inner (within 0–20 nm) and outer (20–60 or 100 nm) zones. Most coastal marine user activity occurs within a few miles of the coast, and this is also the area where most marine deaths occur due to strong winds and associated large/steep waves.
  - These data would also provide important observational information to initialize and verify coastal ocean models.
- Significantly better definition of coastal wind features including orographically induced or enhanced low-level jets.
  - This, again, improves the safety in the coastal waters where the bulk of recreational boating and fishing activities take place.
- Better representation and understanding of terrain induced flow, allowing added detail in forecasts.
- Significantly better definition of ocean forcing for areas affected by phenomena such as upwelling along coastlines.

An XOVWM OSVW mission would significantly advance the improvements in operational weather and forecasting capabilities that are realized today and would better address the satellite OSVW requirements for operational weather forecasting and warning.

A sustained advanced operational satellite OSVW mission (XOVWM) would provide all NWS marine forecast offices the benefit of at least twice daily remotely-sensed OSVW across all areas of responsibility, coastal, offshore, and high seas. This would provide a consistent frame of reference across the areas of responsibility for the WFOs, Ocean Prediction Center (OPC), and TPC/NHC in the issuance of warnings and forecasts. This would significantly improve the safety in the coastal waters, where the bulk of recreational boating and fishing activities take place. From all inputs received from **NWS forecast offices and centers, the most significant conclusion is that even a single XOVWM would be a major step toward meeting critical aspects of OSVW operational requirements compared to a QuikSCAT-equivalent solution.**

2 *Why Measure Winds Over the Global Oceans?*

As the largest source of momentum for the ocean surface, winds affect the full range of ocean movement, from individual surface waves to complete current systems. Winds along the ocean surface regulate interaction between the atmosphere and the ocean via modulation of the air-sea exchanges of heat, moisture, gases, and particulates. As the oceans cover 70% of Earth's surface, this interaction has significant influence on both global and regional climate. NWS forecast offices rely on OSVW from across the global oceans to identify potential generation areas for swell. Only remote sensing allows for these measurements to be made systematically over the vast ocean areas.

While the primary benefits of satellite OSVW measurements described here are in the improvement of weather forecasting and warnings, knowledge of the winds and waves over the ocean is essential for the maritime transportation, fishing, and oil production industries, as well as for search and rescue (SAR) efforts and the accurate tracking and management of marine hazards such as oil spills. Therefore, the impacts of OSVW data spans through several of NOAA's programs: weather and water, commerce and transportation, and ecosystems and climate.

More than 95% of the U.S. international trade by volume is transported by ships through the world's oceans. Commercial ships have doubled in size, waterborne commerce has tripled, and the number of small boats and recreational water craft has increased during the last 50 years. While transport by water is generally the most economical and efficient means to move goods, half of all materials shipped through U.S. waters are hazardous (http://www.yoto98.noaa.gov/facts/naviga.htm). To keep ships safe from dangerous ocean storms and on schedule, the $200 billion global marine shipping industry relies increasingly on marine weather forecasts (Kite-Powell, 2000). Accurate wind and wave information helps marine traffic avoid hazardous weather and benefits Americans by keeping costs of goods down, thus making products more affordable (Fig 1). More than 90% of the goods imported into the U.S. arrive via the oceans. Maritime commerce results in a contribution of $78.6 billion annually and generates nearly 16 million jobs. One out of six jobs in the U.S. is marine related.

Furthermore, over 77 million Americans enjoy recreational boating, an industry that generates nearly $18 billion annually in sales of boats and related materials (NOAA Discussion Paper, 1998). Initial estimates suggest that the accurate forecasting of hurricane force winds in extratropical storms, such as those made by QuikSCAT measurements, results in annual savings between $60 and $370 million for container shipping in the North Pacific and Atlantic (Kite-Powell, 2008).

Fig 1: Knowledge of the winds and waves over the ocean is essential for the safe and efficient maritime transportation.

This study estimates losses associated with storm exposure to marine traffic under different levels of nowcast and forecast information about surface winds. In general, better information about the spatial and temporal occurrence of severe winds and waves allows ships to adjust their routes and reduce exposure. In making decisions about route changes, ship operators must trade off longer voyage times against expected (potential) losses due to storm exposure and these decisions can be made better with better forecast information.

There are also over 12 million recreational boaters in the U.S. who frequently make decisions based on the current wind conditions and/or marine forecasts (Fig. 2) (http://www.yoto98.noaa.gov/facts/naviga.htm). However, accurate assessment of current wind conditions and the generation of accuracy of forecasts are often lacking due to the limited monitoring capabilities in the coastal and offshore waters. As a result, boaters frequently encounter unexpected conditions, resulting in complaints to NWS offices that boaters' lives are put at risk by marine forecasts that underestimate wind and sea conditions, which is a direct result of limited monitoring capabilities (verbal communication with coastal NWS offices). Therefore, the lack of proper monitoring capabilities in nearshore waters is clearly a public safety issue.

Fig 2: Accurate wind and wave information are essential for recreational boating.

Coastal areas in the U.S. are also home to a wealth of natural and economic resources and include some of the most developed areas in the nation. The narrow coastal fringe that makes up 17% of the nation's contiguous land area is home to more than half of its population. In 2003, approximately 153 million people (53%) of the nation's population lived in the 673 U.S. coastal counties (Crossett et al., 2004).

Food drawn from the ocean also plays a significant role in the U.S. economy. The value of the U.S. marine catch is $3.5 billion per year (Fig 3). Annual catches of 5 million tons make the U.S. the world's fifth largest fishing nation. A study by Pendleton and Rooke (2006) shows that daily fishing expenditures for residents range from $44 in Washington to $250 in Alaska, whereas daily fishing expenditures for non-residents range from $116 in Oregon to $359 in Alaska. The same study also indicates that in the span of ten years, the nation will see an increase in fishing participation of 12%. Based on these national estimates, the expenditures associated with marine recreational fishing just in California alone could increase to between $230 million and $610 million annually by 2010.


Fig 3: One-third of total US fishing income comes from the Alaska region.

The U.S. offshore oil and gas industry has been in operation since 1947 and currently employs 85,000 Americans. The significance of this marine industry to the economy can be gauged by the fact the federal government collects nearly $4 billion annually in bonuses, rents, and royalties from oil and gas producing leases. Safe, efficient drilling operations depend on an accurate understanding of the current sea state and accurate and timely warning of impending storms (Fig 4).

Fig 4. Thorough knowledge of the historical wind and wave conditions at any specific location is crucial to the design of drilling platforms.

In the event of an oil spill, surface wind information is the key to determining how the oil will spread. Up-to-the-minute information on currents and winds is essential to effective deployment of oil spill containment and cleanup efforts. For example, a study of oil spills in the New England region showed that even a 1% increase in the efficiency of oil spill cleanup would have saved New England $7.5 million over the last ten years, and nearly $100 million in the U.S. over the same time (Adams et al., 2000).

Accurate and timely information about winds and currents can also dramatically influence the effectiveness of the U.S. Coast Guard's search and rescue (SAR) operations. Perhaps the most critical factor in determining the success of SAR is the time it takes the Coast Guard to get to the person at risk. The SAR success rate is only about 4% when this time exceeds two hours. For example, in the Gulf of Maine region, the U.S. Coast Guard conducts some 6,000 SAR missions and saves more than 500 lives each year. This represents about 15% of the Coast Guard's total SAR activity. Unfortunately, approximately 28 lives are lost each year in the Gulf of Maine region after the Coast Guard has been notified that they are at risk. Understanding the currents and winds in the vicinity of the SAR target is critical to locating and reaching the person quickly. For example, a 1% improvement in SAR effectiveness (from 90% to 91% lives-at-risk saved) in the Gulf of Maine would result in an additional six lives saved per year, with an economic value of some $24 million (assuming a conservative value for a human life of $4 million; see Viscusi, 1993). Additional benefits, as outlined by Kite-Powell and Colgan (2001), will be realized from reduced SAR costs and reduced risk to SAR personnel.

3 Background

Scatterometers are microwave radar instruments specifically designed to retrieve the ocean surface wind field. Wind retrievals in near all-weather conditions from the NASA QuikSCAT scatterometer mission (launched in June 1999) are fully integrated and heavily used in the routine work flow of the National Centers for Environmental Prediction (Ocean Prediction Center [OPC]; Tropical Prediction Center/National Hurricane Center [TPC/NHC]), the Central

Pacific Hurricane Center (CPHC), the U.S. Navy's Joint Typhoon Warning Center (JTWC), and the coastal NWS Weather Forecast Offices (WFOs). QuikSCAT data are also routinely assimilated into the numerical weather prediction (NWP) models at NCEP and other NWP modeling centers around the world, such as the European Centre for Medium-Range Weather Forecasting (ECMWF).

The successful research-to-operations transition of OSVW data from the QuikSCAT research satellite into NOAA's operations was in large part accomplished by establishing an operational OSVW validation group within NOAA. The membership of this working group included remote sensing experts and operational forecasters, and its membership has grown considerably over the years. Today the group's membership spans a broad cross-section of NOAA offices including NESDIS, OPC and the TPC/NHC, and the Southern, Western, Pacific, and Alaska Regions of the NWS. This group's work has resulted in:

- Developing training materials to help users more efficiently and effectively use QuikSCAT data.
- Assessing and documenting the impact that QuikSCAT data has on everyday NWS forecasting and warnings (Von Ahn et al., 2004, 2006; Chelton et al., 2006, Cobb et al., 2003, 2006; Sienkiewicz et al., 2004, 2006; Stamus and Milliff, 2008, Brennan et al., 2007).
- Assessing and documenting the limitations of QuikSCAT measurements as they apply to operational weather forecasting and warning.

The significant positive impacts that OSVW data from the QuikSCAT research mission has had on operational weather forecasting and warning is also evident by the following events over the past few years.

3.1 NOAA's Operational OSVW Requirements Workshop

In June 2006, a workshop on NOAA's Operational OSVW requirements was held at TPC/NHC in Miami, Florida (Chang and Jelenak, 2006). The primary goals of this meeting were to:

1) Document the utilization and impact of presently available satellite OSVW data in operational marine weather analysis, forecast and warning activities at NOAA,
2) Define the OSVW operational requirements within NOAA based on actual experience and phenomena observed, and
3) Explore sensor/mission concepts capable of meeting the requirements.

A conceptual instrument design combining the best of existing technologies and measurement heritage was presented. This conceptual instrument would increase both the science and operational capabilities of OSVW data by an order of magnitude, with a moderate risk in terms of mission design, complexity, and cost.

3.2 WMO International Workshop on Tropical Cyclones Recommendations

In November 2006, the 6th WMO International Workshop on Tropical Cyclones (IWTC) was held in San Jose, Costa Rica. The objectives of this workshop were to examine the current knowledge of and forecasting and research trends on, tropical cyclones from an integrated international perspective and to offer recommendations for future research with special regard to the varying needs of the different regions. The IWTC made the following priority recommendation:

"IWTC-VI urges the WMO Space Program to convey to all consortiums and entities involved in the development of satellite programs the importance of maintaining and even increasing the level of remote sensing coverage, with specific attention given to instruments that provide data for monitoring and prediction of tropical cyclones (microwave data, scatterometer data, altimeter data, total precipitable water data, etc.).

In particular the issue of decreased scatterometer data availability in the near-future is a matter of major concern to the tropical cyclone community." (http://severe.worldweather.org/iwtc/)

3.3 National Research Council Recommendations

In January 2007, the National Research Council's Committee on Earth Science and Applications from Space delivered to agency sponsors a prepublication version of its decadal survey final report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (National Research Council, 2007). This report was generated in response to a request from the National Aeronautics and Space Administration's (NASA) Office of Earth Science, the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite Data and Information Service (NESDIS), and the U.S. Geological Survey's (USGS) Geography Division to generate consensus recommendations from the earth and environmental science and applications communities regarding:

1) High-priority flight missions and activities to support national needs for research and monitoring of the dynamic Earth system during the next decade, and
2) Important directions that should influence planning for the decade beyond.

The committee took great care to point out the operational need for QuikSCAT wind data to issue forecasts and warnings for a variety of severe ocean storms such as tropical and extreme extratropical cyclones. One of the three missions recommended to NOAA by this report was the Extended Ocean Vector Winds Mission (XOVWM) for operational use. The recommended XOVWM concept follows that presented in the June 2006 NOAA Operational OSWV Requirements workshop (Chang and Jelenak, 2006).

3.4 Office of the Federal Coordinator for Meteorological Services and Supporting Research: *Interagency Strategic Research Plan for Tropical Cyclones – The Way Ahead*

The tropical cyclone forecast and warning program is an interdepartmental collaboration to provide the United States and designated international recipients with forecasts, warnings, and assessments concerning tropical and subtropical weather systems. The three centers that cooperate to provide the operational forecast and warning services are the Tropical Prediction Center/National Hurricane Center (TPC/NHC), the Central Pacific Hurricane Center (CPHC), and the Joint Typhoon Warning Center (JTWC). This plan, *Interagency Strategic Research Plan for Tropical Cyclones: The Way Ahead,* provides a strategy for continuing to improve the effectiveness of operational forecasts and warnings through strategic coordination and increased collaboration among the major players in the operational and R&D communities. The plan represents extensive efforts by the Joint Action Group for Tropical Cyclone Research (JAG/TCR), established by the Federal Coordinator for Meteorological Services and Supporting Research in 2005 to respond to a principal action item and proposed at the 58th Interdepartmental Hurricane Conference in 2004, to develop a comprehensive strategy for tropical cyclone R&D to guide interagency efforts over the next decade.

This plan emphasizes that to continue to advance operational tropical cyclone forecasting capability, the nation must be committed to supporting, through research, development, and transition to operations, the advanced observations, data assimilation technologies, Numerical Weather Prediction (NWP) models, and investment in human and infrastructural resources that are vital to the tropical cyclone forecast and warning program.

"Due to the importance of OSVW data for use by tropical cyclone forecasters and in tropical cyclone NWP systems, the JAG/TCR strongly endorses the development and acquisition of a capability to meet the OSVW observation requirements. This capability is absolutely critical to meeting the operational needs of the tropical cyclone forecast and warning centers" (http://www.ofcm.noaa.gov/p36-isrtc/fcm-p36.htm)

3.5 National Weather Association Recommendations

The National Weather Association (NWA) is a member-led, nonprofit professional organization that supports and promotes excellence in operational meteorology and related activities, and supports initiatives to modernize observing platforms and take advantage of new technologies to continue excellence in daily weather observing and forecasting for the public good. In October 2007, during the 32nd Annual NWA Meeting held in Reno, Nevada, a panel discussion on the future of OSVW measurements was held. As the result of the panel discussion, the NWA made the following recommendations to NOAA:

"To ensure continuity of quality OSVW measurements from space, the National Weather Association (NWA) recommends the following:

- Elevate the priority of and **accelerate and approve plans for continuous operational OSVW missions** to minimize the data gap and continue improvements in weather and oceanic forecasting and warning capabilities and climate studies that have already been realized today.

- Fund the Extended Ocean Surface Vector Winds Mission (XOVWM) as recommended by the National Research Council in the document found at the URL http://www.nap.edu/catalog/11820.html, and as designed and presented in a study by JPL to overcome limitations in current measurement capabilities and advance improvements in weather and ocean monitoring and forecasting, especially in coastal zones and for tropical cyclones."(http://www.nwas.org/committees/rs/)

3.6 Hurricane Forecast Improvement Project

NOAA established the Hurricane Forecast Improvement Project (HFIP) to develop a unified 10-year plan to improve one- to five-day tropical cyclone forecasts, with a focus on rapid intensity change. The outcome of this plan is to ultimately enable communities and individuals to reduce the nation's risk to hurricane impacts by delivering improved forecasts and tools for community planners and other decision-makers (http://www.nrc.noaa.gov/plans_docs/sab_hfip_plan_23Oct_Final.pdf)

NOAA focused the HFIP plan on the research and development issues identified by operational needs that will lead to improved operational forecast guidance and tools. The major components of the HFIP plan are to:

- Improve the Hurricane Forecast System (HFS)/Global Forecast System (GFS) to reduce error in track and intensity guidance (operational NWP models and data assimilation).
- Optimize observing systems to enhance capabilities for hurricane research, operational modeling, analysis, and forecasting.
- Expand and enhance forecast tools and applications to add value to the forecast model guidance and the direct use of observations.

In order to meet its objectives, one of HFIP suggested strategies is to **institutionalize and fully fund transition of research-to-operations to ensure an efficient process to get demonstrated research results in modeling, and observing systems and platforms transitioned to operations with sufficient operations and maintenance resources.**

The HFIP report further suggests that observing platforms and sensors should be evaluated with respect to its utility to enhance observing capabilities for TC forecasters and NWP systems. This proposed evaluation would then advise NOAA on its investment decisions for improvements in tropical cyclone analysis, reconnaissance/ surveillance, forecasting, and operational modeling.

The HFIP recommendation to evaluate observation platforms and determine their utility in addressing the hurricane intensity problem include:

– Three-dimensional wind structure from Doppler radars and lidars (airborne, ground-based, satellite-based)
– **Ocean surface vector winds (e.g., QuikSCAT, Advanced Scatterometer [ASCAT], WindSAT, Next-Generation Ocean Surface Vector Wind [XOVWM] mission)**

4 QuikSCAT Follow-On Mission Study

In June 2007, following the recommendation of the NRC decadal survey, NOAA initiated the QuikSCAT follow-on study and funded NASA's Jet Propulsion Laboratory (JPL) to provide a cost, technical risk, and design analysis for three possible mission options (Fig. 5):

1) **QuikSCAT Replacement**: This mission would be functionally equivalent to QuikSCAT. Due to changes in technology and the availability of parts, the instrument would have a different architecture from the original QuikSCAT. This option would be designed to be upgradeable to a higher capability mission in the long term.
2) **XOVWM**: This mission would implement the XOVWM mission recommended by the NRC decadal survey. The XOVWM payload has significant advantages over QuikSCAT for monitoring hurricane-force winds in all weather conditions and for monitoring the coasts, where the bulk of shipping, recreational boating, and fishing occur.
3) **XOVWM Constellation**: This option would examine the long-term cost advantages of flying two XOVWM spacecraft in formation to improve the revisit time of the measurements. This solution best meets NOAA user needs and is viewed as the ideal long-term operational scenario. (Rodriguez et al, 2008)

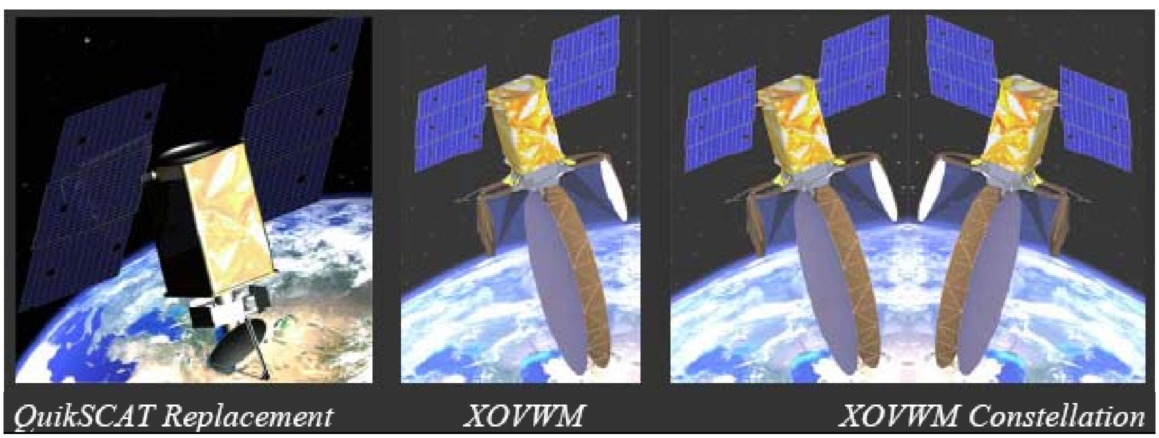


Fig. 5. Three QuikSCAT follow-on options considered in JPL study (Rodriguez et al 2008)

In the JPL study, the QuikSCAT Replacement (QSR) instrument is designed to be functionally identical to QuikSCAT from the OSVW performance parameters to the downlinked data stream. However, the actual implementation differs for two reasons. First, much of the technology used for QuikSCAT is obsolete or no longer available and, thus, it is not possible to manufacture a QuikSCAT instrument based on the original schematics and drawings. Second, the philosophy behind QSR is to develop that instrument that can be relatively easily upgraded to enhanced capabilities (Rodriguez et al, 2008)

In response to the community's requirements for a full-performance ocean vector winds measurement capability, a conceptual instrument architecture has been developed for the Extended Ocean Vector Wind Mission (XOVWM). The XOVWM instrument concept design uses the synergy between different measurements in a novel way and combines a Ku-band scatterometer (QuikSCAT heritage) in order to preserve wide-swath measurements, high temporal sampling capabilities, and achieve higher spatial resolution (up to 2.5km); a C-band scatterometer (ASCAT heritage) in order to provide accurate measurements in rain and achieve better performance in all wind speed ranges (up to Category 5 hurricane intensity); a larger antenna and synthetic aperture RADAR (SAR) processing for improved spatial resolution across the entire measurement swath; and an X-band polarimetric radiometer (WindSat and SeaWinds heritage) for additional capability to correct for rain and atmospheric effects and improved wind direction retrieval (Esteban-Fernandez et al., 2006).

The JPL-led study provides cost, schedule, and risk estimates for the two scatterometer options. In order for NOAA to make an optimal decision, it is also important to assess the additional impact that the next-generation scatterometer mission (XOVWM) would have on NOAA operations, and whether those improvements warrant the differences in cost, launch delay, and risk between two instrument options.

To assess the level of impact on operations that would result from a more capable next-generation scatterometer instrument (XOVWM), the NOAA-led operational validation group created a study plan to address the following objectives:

1) Define the threshold requirements for this mission based on the proposed XOVWM concept, and assess these requirements relative to NOAA's operational OSVW requirements.
2) Simulate and validate measurements and retrievals of the XOVWM and QuikSCAT-equivalent OSVW systems in tropical cyclones, extratropical cyclones, and coastal regions.
3) Based on these simulations, collect user feedback on the impact that the QuikSCAT and XOVWM capabilities brings to the users' respective areas of responsibility.

4.1 Operational OSVW Requirements

NOAA developed a multi-phased observational requirements process to formally collect, verify, validate, annually update, and manage environmental observing requirements to support NOAA-wide Observing System Architecture (NOSA) in central planning and integration. The NOAA Consolidated Observation Requirements List (CORL) is a collection of all of NOAA's environmental observation requirements needed to address the full range of NOAA missions. The CORL provides a comprehensive, standardized media for NOAA programs to document their environmental observation requirements providing associated data on their requirements' priority level, threshold, and objective level needs for attributes such as geographic coverage, spatial and temporal resolutions and measurement accuracy, and mappings to higher-level program outcomes and performance measures. CORL procedures are not finalized and continue to be developed and refined for verification and validation of these mission-based, platform-independent environmental observation requirements.

The CORL uses the well established NASA Global Change Master Directory (GCMD) science keyword structure to the fullest extent possible to characterize each environmental requirement at the topic, term, and variable levels. This same approach is applied to both the NOSA and information management system (IMS) databases. The NOSA database captures the observing capabilities of current, planned, and conceptual observing systems used, or with potential, to address NOAA environmental requirements. The IMS database captures the same level of associated data management system capabilities. This level of cross-standardization between the CORL, NOSA, and IMS databases allows fulfillment assessments of NOAA's environmental requirements, identifying observational gaps and investment needs. Annual reviews and updates of all three databases are conducted in the first quarter of each calendar year to assure the integrity of the information and to allow for observation requirement analysis assessments to be completed and provided in time for investment recommendations for annual NOAA Planning Programming Budgeting and Execution System (PPBES) cycles.

The requirements for OSVW measurements are spread among all four NOAA goal teams (Commerce and Transportation, Ecology, Climate, and Weather and Water), and the current CORL database shows that they are identified as first priority for seven NOAA programs as shown in Table 1. Priority 1 in CORL is defined as: "Mission critical data/cannot meet operational mission objectives without this data. Not having these data will prevent performance of the mission or preclude satisfactory mission accomplishment."

As shown in Table 1, 7 out of 31 NOAA programs identified OSVW as their priority 1 requirement.

Table 1 Requirements for OSVW measurements across NOAA goal teams and programs (CT – Commerce & Transportation, EC – Ecology, WW – Weather & Water, CL – Climate, MS – Mission Support)

	NOAA Goal/Program	Priority
Ocean Surface Winds Velocity	CT/Marine Transportation Systems	1
	CT/Marine Weather	1
	EC/Corals	1
	EC/Coastal and Marine Resources	1
	MS/MOD – Atmosphere, Marine Modeling	1
	WW/Coast, Estuaries and Oceans	1
	WW/Local Forecasting and Warnings	1
	WW/WWS – Tropical Cyclones, Ocean and Coastal Weather, Severe Weather	1
	CL/Climate Observation and Analysis	2

NOAA's operational requirements for satellite OSVW measurements were also discussed and redefined during the June 2006 workshop. The workshop OSVW requirements were defined in order to satisfy various OSVW applications across a wide range of NOAA programs. These requirements:

a) ensure accurate measurements in the presence of extreme wind conditions such as those found in intense storms and cyclones by extending the upper wind speed limit to 165 kt, (in the Category 5 hurricane range), and by requiring accurate measurements in the presence of rain;
b) increase the spatial resolution (decrease the characteristic dimensions) of individual measurements to allow definition of small-scale features in synoptic and mesoscale systems, provide accurate vector wind measurements closer to the coast, and allow estimation of the required 1 minute sustained wind speed from the instantaneous spatially averaged wind measured by the space-borne instruments; and
c) emphasize the overall operational requirement for an observing system (likely multi-platform) that satisfies revisit frequency requirements for measurements at every open-ocean location (Chang and Jelenak, 2006).

Table 2 CORL OSVW requirements and NOAA OSVW workshop requirements

	NOAA Program OSVW Requirements (Threshold Value)						
Attribute	**CL-COA Oceans Offshore**	**CT-MWX-Offshore**	**EC-CMR Coastal**	**MS-MOD Atmos. Coastal**	**MS-MOD Ocean-Coastal and Offshore**	**WW-LFW Coastal and Offshore**	**NOAA OSVW Workshop Requirements**
Geographic Coverage	**Global**	**Global**	**Coastal**	**Coastal**	**Coastal/ Offshore**	**Global**	**Global**
Distance from coast		**2.5 km**				**2.5 km**	**2.5 km**
Horizontal Resolution (speed)	**500 km**	**2.5 km**	**1 km**	**1 km**	**10 km**	**2.5 km**	**2.5 km**
Horizontal Resolution (direction)	**200 km**	**2.5km**	**1 km**	**1 km**	**10 km**	**2.5 km**	**2.5 km**
Measurement Range (speed)	**0-40 m/s**	**0-85m/s**	**0-50 m/s**	**0-50 m/s**	**0-50 m/s**	**0-85 m/s**	**0-85 m/s**
Measurement Range (direction)	**0-360°**	**0-360°**	**0-360°**	**0-360°**	**0-360°**	**0-360°**	**0-360°**
Accuracy (speed)	**0.5 m/s**	**1m/s**	**1 m/s**	**1 m/s**	**1 m/s**	**1 m/s**	**0-2 m/s 1 m/s 2-5m/s 1 m/s 5-80m/s 1 m/s**
Accuracy (direction)	**5°**	**10°**	**10°**	**10°**	**1°**	**10°**	**0-2 m/s no requirement 2-5 m/s 20° 5-80 m/s 10°**
Refresh	**1 day**	**1 h**	**15 min**		**1h**	**3h**	**45-60 min**
Comments		**All weather**					**All weather**

The Weather and Water (WW) and Commerce and Transportation (CT) goal teams updated their OSVW requirements in CORL in March 2007. Their new requirements closely match operational OSVW workshop requirements. The CORL OSVW requirements for six NOAA programs and workshop requirements are listed and compared in Table 2.

With the workshop recommendations and the continuity of QuikSCAT OSVW as a capability threshold used as guidelines, NOAA asked JPL to investigate a QuikSCAT-equivalent and a next-generation XOVWM capability in the QuikSCAT follow-on study. Table 3 lists the QuikSCAT-equivalent and XOVWM performance capabilities, as provided to NOAA by JPL, relative to the NOAA operational OSVW requirements as defined in the workshop report. This table shows that XOVWM complies with a majority of the workshop requirements and its spatial resolution characteristics do closely approach the spatial resolution requirements. Conversely, the QuikSCAT-equivalent capability does not satisfy the requirements for wind speed and direction accuracy at the spatial resolution required for higher wind ranges. The temporal revisit requirement for either mission cannot be achieved by a single satellite system.

Table 3 QuikSCAT-equivalent and XOVWM performance capabilities relative to the NOAA operational OSVW requirements as defined during the June 2006 workshop

Parameter	NOAA OSVW workshop requirements	QuikSCAT-equivalent	XOVWM	Comments
Data collection requirement	Global oceans all-weather			QuikSCAT lacks all-weather capability
Wind speed accuracy (RMS)	0-2 m/s 1 m/s (2σ) 2-5 m/s 1 m/s (2σ) 5-80 m/s 1 m/s (2σ)	3-20 m/s: 2 m/s 20-30 m/s: 10% 30-80 m/s: not specified	3-20 m/s: 2 m/s 20-30 m/s: 10% 30-80 m/s: 10%	
Wind direction accuracy (RMS)	0-2 m/s no requirement 2-5 m/s 20° (2σ) 5-80 m/s 10° (2σ)	3-30 m/s: 20° 30-80 m/s: not specified	3-30 m/s: 20° 30-80 m/s: 20°	QuikSCAT cannot reach accuracy requirements at desired resolution and high speed
Horizontal resolution	2.5 km	12.5 km	<5 km	QuikSCAT resolution: 25 km x 8 km XOVWM resolution: <5 km x 1 km
Closest distance to coast	2.5 km	20 km	<5 km	
Product latency	60 min			Depends on NOAA ground station availability
Worst case temporal revisit time	45 min-60 min			Can only be met with satellite constellation

	Complies with requirements
	Complies with requirements for the majority of conditions
	Does not comply with requirements

4.2 Simulating Scatterometer Measurements

To achieve the objectives of this study, the NOAA-JPL user impact study group identified several areas where the XOVWM (next-generation scatterometer) would be a significant advancement over a QuikSCAT-equivalent capability. The areas defined were:

- Finer spatial resolution measurements (~2.5–5 km vs 12.5 km)
- Measurements closer to the nation's coastlines (~within 5 km vs 30 km)
- Measurements in rain
- Measurements of high wind events (up to 80 m/s vs 40 m/s)

To help quantify the differences in performances between the two sensor options, two sets of simulation studies were conducted:

1) The first set of simulations was designed to study the performance of the two instruments in both tropical and extratropical cyclone environments. To achieve this we elected to simulate the development of Hurricanes Katrina and Rita from 2005 and the extra-tropical transition of Hurricane Helene from 2006. Since very high resolution OSVW are not available from any observing systems today, the surface wind "truth" used for these cases was obtained by running the NCAR Weather Research and Forecast (WRF) model in its cloud-resolving mode at a 1.3 km horizontal resolution.
2) A second set of studies was designed to help determine to what extent it will be possible to achieve better definition of coastal wind features, including orographically induced or enhanced low-level jets, with XOVWM. The coastal wind study concentrated on the dual low-level jets off of Cape Blanco and Cape Mendocino (along the California coast) that are difficult to predict and occur in the area of responsibility of the NWS Western Region WFOs, as well as high wind events along the Alaskan coast. Since existing NWP models can only provide hints of these coastal high wind events, "truth" wind fields for the measurement simulations were created using high-resolution SAR data for wind speeds and NWP model wind directions.

4.3 Tropical and Extratropical Storm Simulations

To fully simulate the capabilities of an XOVWM and QuikSCAT-like instruments realistic wind fields and the corresponding atmospheric fields such as rain and cloud liquid water are required. A numerical model such as the NCAR Weather Research and Forecasting Model is the only available source for high-resolution and dynamically consistent parameters in three dimensions. For the hurricane examples, the WRF model was run in the cloud-resolving mode. WRF is a state-of-the-art meteorological model developed collaboratively among several agencies (NOAA/NCEP, NOAA/GSD, NCAR) and designed to study mesoscale and convective scale processes. WRF can be run with multiple nested grids with different spatial resolution to allow resolving for both the 3D structure of convection and the extensive mesoscale circulations. For our case studies, the WRF model was run using a set of three nested grids with horizontal grid spacing of 12, 4, and 1.3 km, respectively. The outer-most grid covered the area of approximately 5,000 x 5,000 km while the most inner one covered the area of about 500 x 500 km. The high resolution of the inner-most grid assures that the processes in the hurricane eyewall are represented properly and that storm development is realistic. The design of the runs was such that the two inner grids moved following the motion of the vortex center.

In the case of Katrina the initial/boundary conditions were provided by a one-degree resolution NCEP GFS model run. For Rita and Helene, the Geophysical Fluid Dynamics Laboratory (GFDL) 1/6° model run was used. The WRF model output fields used in the scatterometer simulator were the following: the 10 m wind and the 3D precipitation structure (at a stretched vertical grid with 30 model levels). The 3D precipitation structure in the lowest 15 km was then interpolated to 30 vertical levels with 500 m vertical resolution. This precipitation structure was then used to simulate the attenuation (produced by precipitation, cloud, and vapor) and the volume backscatter (produced by the precipitation). Mie scattering code was used to compute the attenuation and the volume backscatter at the frequencies and the polarization of the XOVWM instrument. Furthermore, an incidence angle correction was made to account for the path of the scatterometer signal through the precipitation.

The surface and atmospheric parameters obtained for each storm were provided to NOAA for initial assessment before they were used as an input to simulate scatterometer measurements. In all cases it was noted that while simulations did depart somewhat from reality in terms of maximum winds and the actual eyewall structure, they were deemed realistic enough to use as an input to estimate the scatterometer measurements. While the XOVWM concept calls for polarimetric radiometer measurements at X-band, the emissivity of the radiometer was not simulated in this study and, therefore, radiometric rain information was not available for use in the retrievals of the OSVWs by the XOVWM instrument.

Using the WRF model output, forward simulations were run to estimate the Ku-band and C-band measurements at two polarizations to simulate the σ_0 measurements of the QuikSCAT-equivalent and XOVWM instruments. After the estimated σ_0 measurements were obtained using the WRF model output fields for the surface and atmospheric conditions, the OSVW retrievals were generated for the QuikSCAT-equivalent instrument using the Ku-band measurements at two polarizations at a spatial resolution of 12.5 km, and for the XOVWM sensor using the C and Ku-band σ_0 measurements at a 5km resolution. No external information regarding the corresponding atmospheric conditions was used in the retrieval process. The schematic representation of simulation and retrieval process is presented on Fig.6.

The geophysical model function (GMF) relates the measured σ_0 to the surface parameters (wind speed and direction) and the scatterometer parameters (incidence angle, azimuth angle, polarization, and frequency). For this exercise the GMF used for both the QuikSCAT-equivalent and the XOVWM simulations and retrievals was the high-wind model function developed from the Integrated Wind and Rain Airborne Profiler (IWRAP) measurements (Esteban-Fernandez et al. 2006) flown aboard the NOAA P3 aircraft. The IWRAP high-wind model functions show that only the C-band horizontally polarized measurement does not exhibit saturation as wind speed increases.

Retrieved wind fields for the QuikSCAT-equivalent and the XOVWM instruments together with the WRF model surface and rain fields were provided to NOAA for user evaluation.

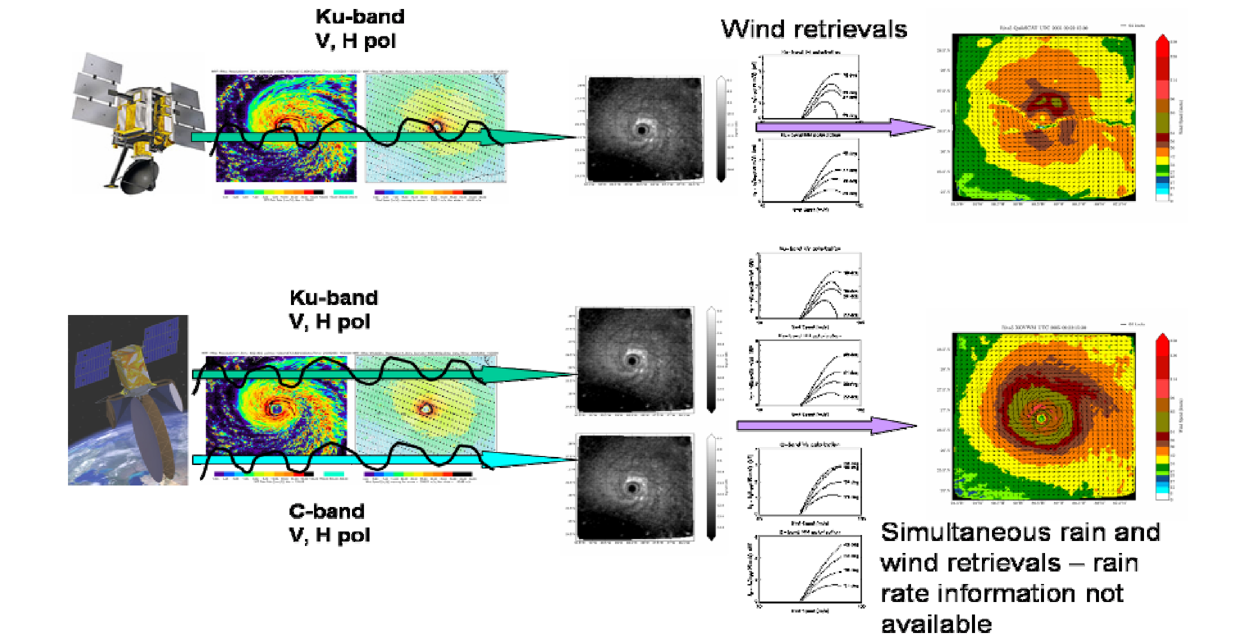
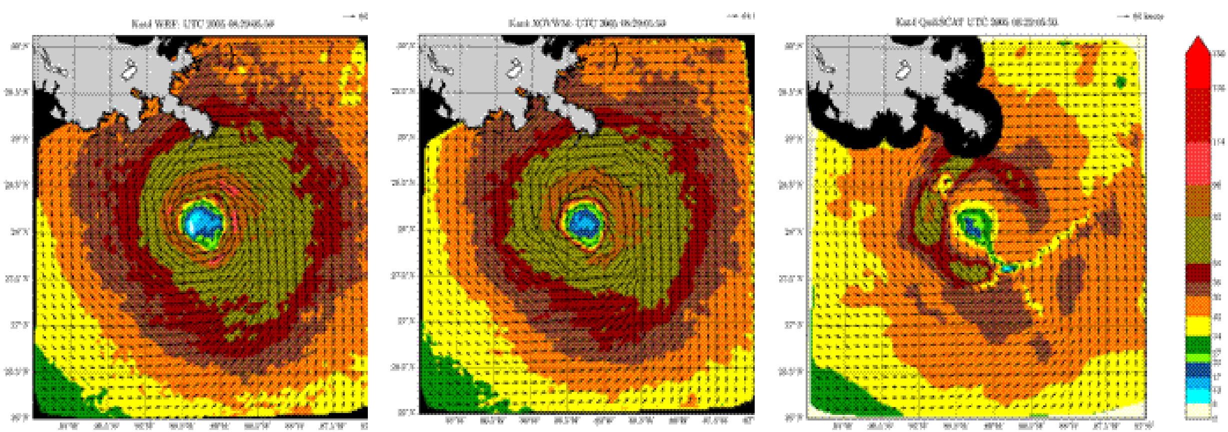


Fig 6. Schematic representation of scatterometer measurement simulations. WRF model field was used as an input to simulate scatterometer backscatter measurements. These simulated σ_0 measurements were than used to retrieve wind fields at a 12.5 km resolution for the QuikSCAT-equivalent instrument and at a 5 km resolution for the XOVWM.

4.3.1 Simulation Results – Hurricane Katrina Example

"Katrina was an extraordinarily powerful and deadly hurricane that carved a wide swath of catastrophic damage and inflicted large loss of life. It was the costliest and one of the five deadliest hurricanes to ever strike the United States. Katrina first caused fatalities and damage in southern Florida as a Category 1 hurricane on the Saffir-Simpson Hurricane Scale. After reaching Category 5 intensity over the central Gulf of Mexico, Katrina weakened to Category 3 before making landfall on the northern Gulf Coast. Even so, the damage and loss of life inflicted by this massive hurricane in Louisiana and Mississippi were staggering; with significant effects extending into the Florida panhandle, Georgia, and Alabama. Considering the scope of its impacts, Katrina was one of the most devastating natural disasters in United States history" (Knabb et al., 2006).

Following Hurricane Katrina on the 28 and 29 of August 2005, four measurement and retrieval simulations were run for the QuikSCAT-equivalent and XOVWM sensors. Results of the WRF model run and the corresponding QuikSCAT-equivalent and XOVWM retrievals at 0550 UTC on 29th of August 2005 are presented in Fig. 7. QuikSCAT-equivalent retrievals (Fig. 7c) produce a broad wind minimum where the tight eyewall wind gradient is actually present in the WRF model wind field. The QuikSCAT "circulation center" indicated by the directional vectors is elongated NW-SE and is displaced 60 nm southeast of the actual center in the WRF model. It is clear that the XOVWM retrievals (Fig. 7b) depict all facets of the TC wind field more accurately than the QuikSCAT-equivalent retrievals, including the maximum winds and the inner and outer wind field structure. The impacts of rain contamination are clearly visible in the QuikSCAT-equivalent retrievals, particularly in the isolated wind maxima seen in outer rain bands. These features are not present in the XOVWM retrievals, as these retrievals show much less sensitivity to the rain field produced by the WRF simulation (Fig 7a). The impacts of the increased resolution of the XOVWM retrievals are seen in the better resolution of both the wind minimum in Katrina's eye and of stronger winds in the eyewall. Additionally, the directional retrievals near the center from XOWVM are much more realistic looking and better define the center than those from QuikSCAT.



(a) (b) (c)

Fig.7 WRF model surface wind field at 3-km resolution (a) XOVWM wind vector retrievals at 5-km resolution, (b) with QuikSCAT-equivalent wind vector retrievals at 12.5-km resolution (c) from simulation of Hurricane Katrina at 0550 UTC 29 August 2005.

Fig. 8 shows the 50-kt and 64-kt wind radii defined from XOVWM (solid lines), QuikSCAT-equivalent (dashed lines), and WRF model (dotted lines). At 0600 UTC 29 August, NHC analyzed the 64-kt wind radius to be 90 nm, in complete agreement with WRF model and XOVWM retrieved 64-kt wind radii. The 50-kt wind radii from the QuikSCAT-equivalent retrievals encircled a much smaller area than shown by WRF or XOWVM and actually lines up with the 64-kt wind radii from XOVWM and WRF.

The WRF wind field shows several maxima exceeding 96 kt, so the simulated cyclone is a major (Category 3) hurricane. The XOVWM retrieval exceeded 96 kt in one of those small spots, northwest of the center, although it did not capture the other 96-kt maxima east of the center where the maximum wind probably was located. This means that, if this was an actual XOVWM overpass, it would have correctly estimated that this is a Category 3 hurricane (Fig 10). Fig. 9 shows a scatter plot of XOVWM and QuikSCAT-equivalent retrieved wind speeds vs. the WRF "ground truth" wind speed. The QuikSCAT-equivalent retrievals underestimate the highest wind speeds, a finding consistent with observed limitations in current operational QuikSCAT wind products in tropical cyclones (e.g., Brennan and Knabb, 2007). This underestimation is due to in part to lower resolution of QuikSCAT-equivalent retrievals, saturation of the Ku-band scatterometer model function, and the influence of rain on scatterometer measurements.

The full set of simulations were posted on the following web page and made available for user evaluation: http://manati.star.nesdis.noaa.gov/SVW_nextgen/user_impact_studies.html.

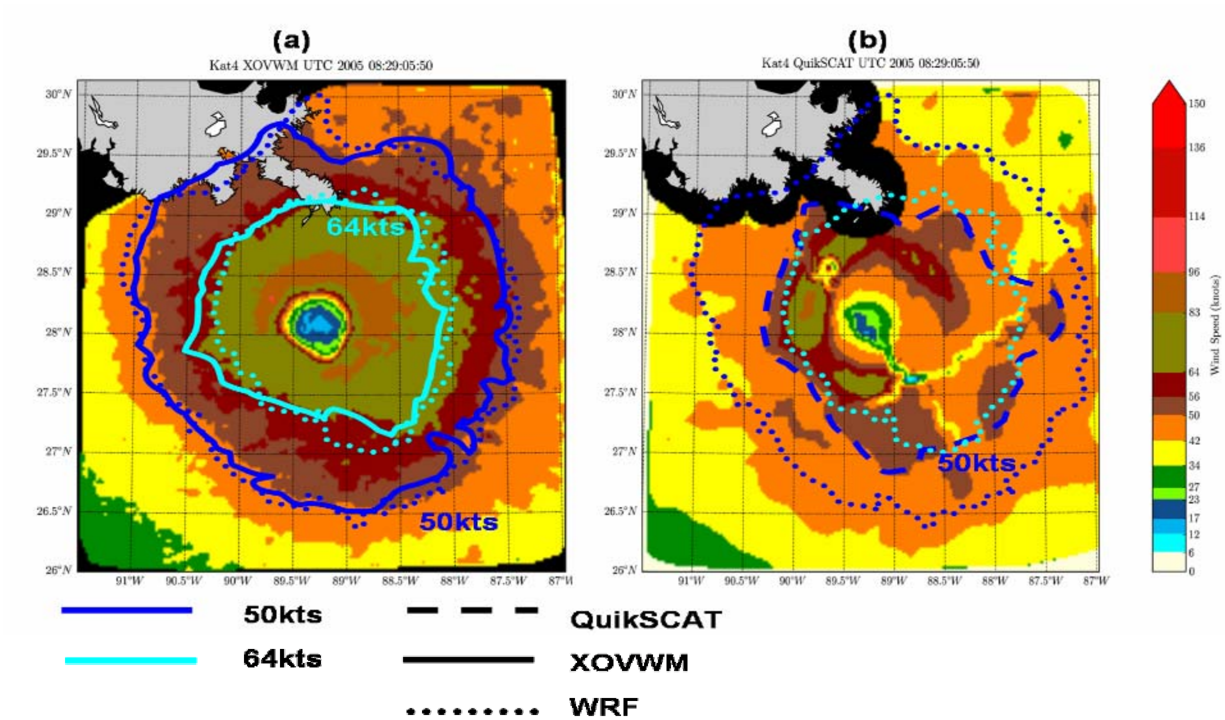
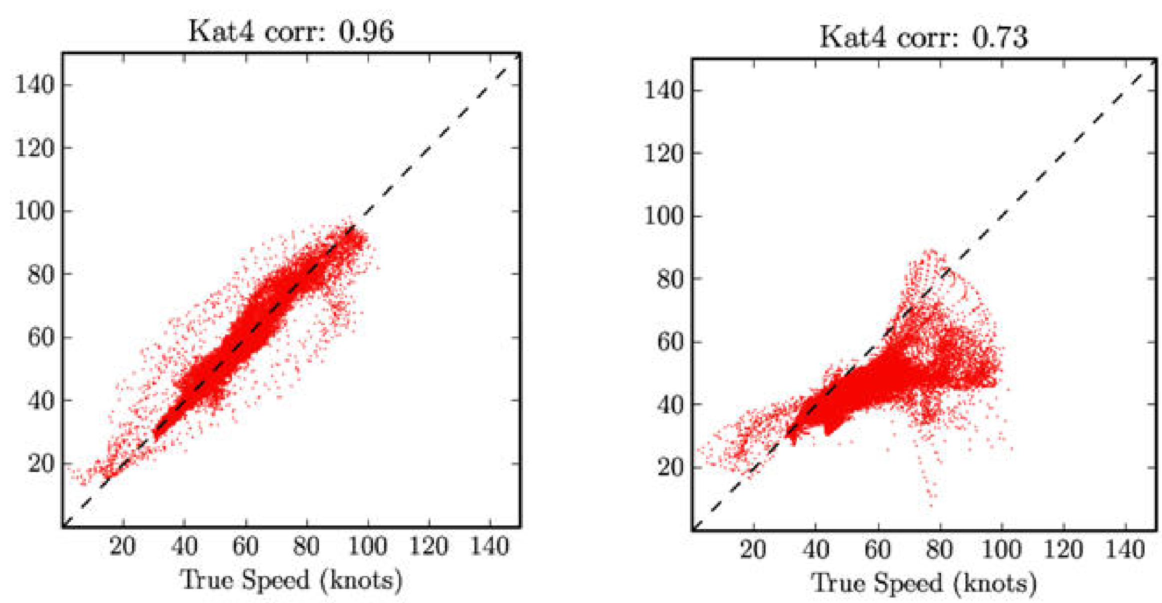


Fig. 8 The 50-kt and 64-kt wind radii defined from XOVWM (a) and QuikSCAT-equivalent, and (b) wind speed retrievals from the simulation of Hurricane Katrina at 0550 UTC 29 August 2005.



(a) **(b)**

Fig. 9 Scatter plots of XOVWM (a) and QuikSCAT-equivalent, and (b) retrieved wind speeds (knots, y-axis) vs. WRF model wind speed used as a "ground truth" (knots, x-axis) in simulation of Hurricane Katrina at 0550 UTC 29 August 2005.

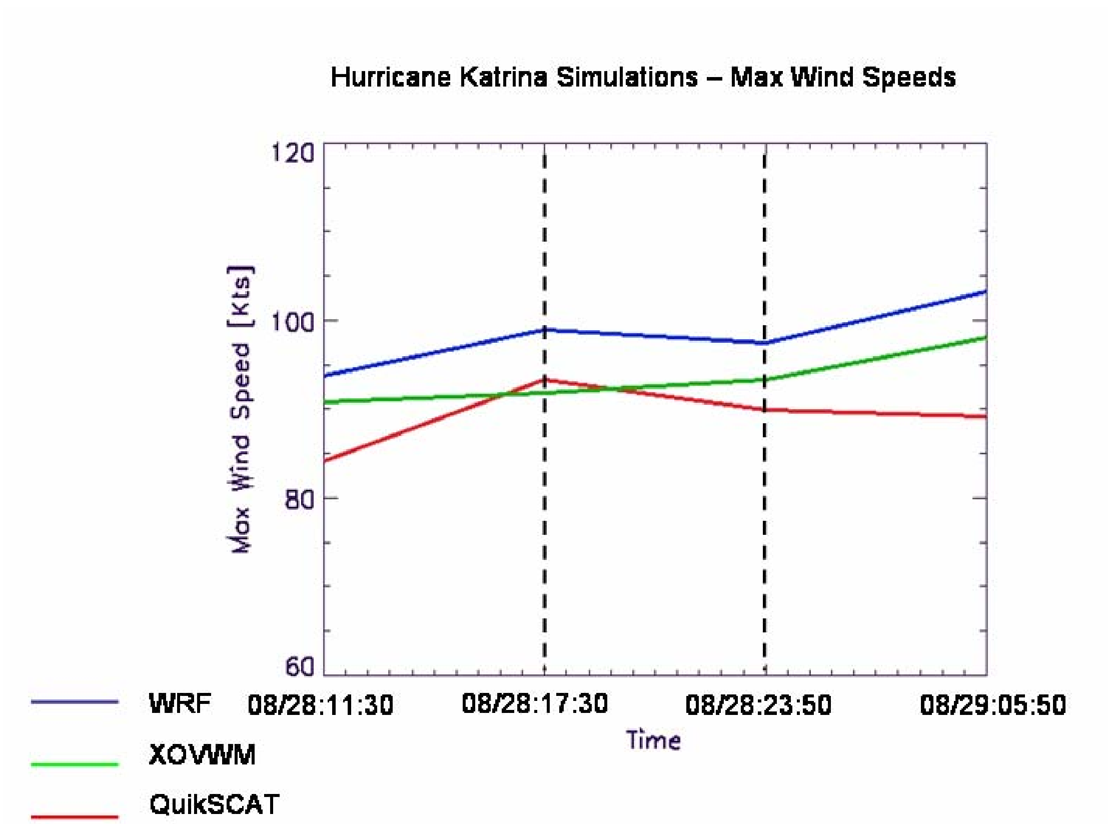


Fig. 10 Maximum wind speeds produced by WRF model (blue) and retrieved using XOVWM (green) and QuikSCAT-equivalent (red) for four simulation times during August 28th and 29th 2005.

4.3.2 NHC Evaluation of Hurricane Simulated Data

JPL has produced very useful results in a short amount of time, and NHC applauds the efforts of everyone involved. JPL conducted their study by making exclusive use of simulated data, for both the atmospheric data and the satellite retrievals themselves. Their simulation approach was scientifically rigorous, and it was similar in many ways to numerous past studies, which have used simulated data in order to assess a future satellite's performance and to support retrieval algorithm development in advance of a launch. Numerical model simulations of the atmosphere were required for this study because no observational data set contains sufficient horizontal and vertical resolution to reasonably replicate the real atmosphere of a hurricane for input to simulated OSVW retrievals. In addition, the model atmosphere provides realistic and internally consistent atmospheric dynamics that could not be ensured with limited observations. It is important to emphasize that the objective of this study was not to produce flawlessly accurate simulations of specific past hurricanes. Rather, the objective was to produce simulated hurricanes that are sufficiently realistic in structure to consider them as the "ground truth" for comparing the simulated QuikSCAT and XOVWM retrievals.

The model used in the study was the Weather Research and Forecast (WRF) model run at 1.3 km horizontal resolution, providing more than enough detail in the simulations to drive the retrieval simulations of both instruments. This approach is very well suited for direct comparison between QuikSCAT and XOVWM because the simulated retrievals, conducted using established radiative transfer modeling techniques, are fully consistent with the atmospheric data from which they were derived, and because both instruments received identical atmospheric input. In other words, it is straightforward to determine how accurate the simulated OSVW retrievals were at every grid point output by the WRF model. The only variables being examined in this study are the differences in raw measuring capability and the resulting differences in retrieval algorithms between QuikSCAT and XOVWM. Since the WRF model contains many grid points within the hurricane, JPL was able to produce a large sample size of OSVW retrievals to thoroughly compare QuikSCAT and XOVWM.

4.3.3 Extratropical Storm Helene

"Helene developed from a vigorous tropical wave and broad area of low pressure that emerged from the coast of Africa on 11 September. Moving west-northwestward over the tropical Atlantic Ocean, Helene steadily intensified and became a hurricane at 1200 UTC 16 September 2006. Helene continued to strengthen, attaining Category 3 status at 0000 UTC 18 September, and six hours later it reached its peak intensity of 105 kts. Helene turned east-northeastward over the open waters of the central Atlantic and retained hurricane strength until becoming extratropical by 1800 UTC 24 September about 275 nautical miles northwest of the Azores. On 25 and 26 September, the extratropical cyclone moved northeastward and weakened to a gale center before passing very near the west coast of Ireland on 27 September" (Brown, 2006). Helene's official best track is represented by the black line on Fig. 11.

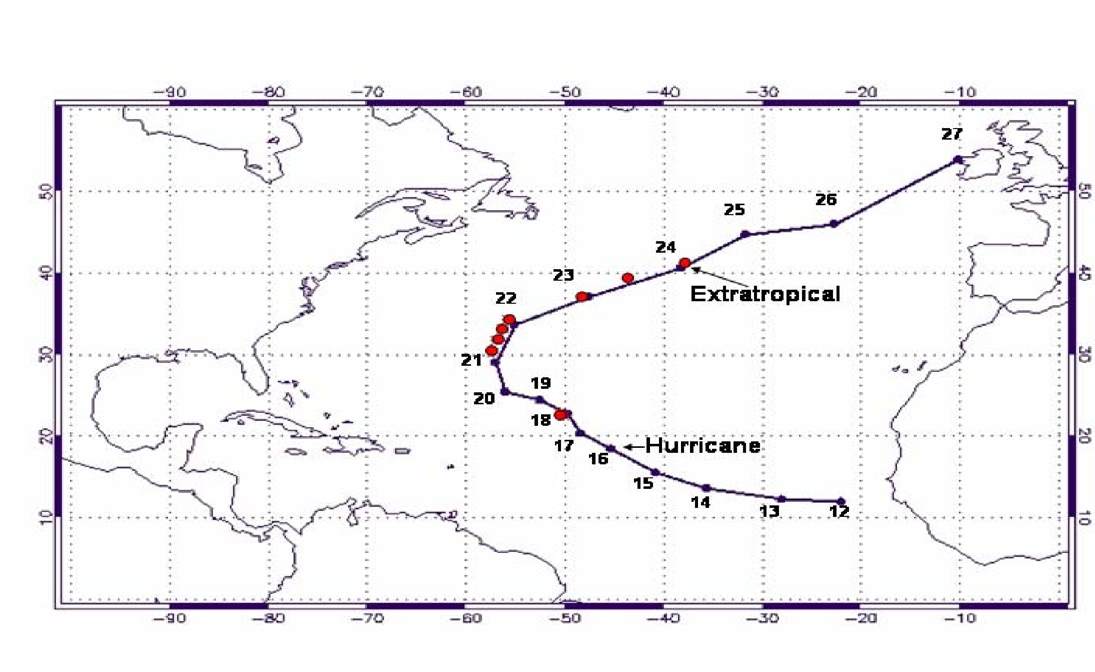


Fig. 11 Best track (black line) of Hurricane Helene from September 2006 that transitioned into an extratropical storm. Red dots represent the times and centers of Helene WRF simulations.

Observations in Helene included satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB), the Satellite Analysis Branch (SAB), and the U.S. Air Force Weather Agency (AFWA), as well as flight-level and dropwindsonde observations from several NOAA P-3 research missions into Helene. These missions were part of the Saharan Air Layer Experiment (SALEX) and the NOAA Ocean Winds Experiment. Stepped-Frequency Microwave Radiometer (SFMR) data (10 s averages) were also available on four consecutive days. Data from the NOAA aircraft missions were very useful in ascertaining the intensity of Helene during 17 to 20 September. Microwave satellite imagery from NOAA polar-orbiting satellites, the NASA Tropical Rainfall Measuring Mission (TRMM), the NASA QuikSCAT, and Defense Meteorological Satellite Program (DMSP) satellites were also useful in tracking Helene and assessing its internal structure.

QuikSCAT data on 22 and 23 September support the analysis of Helene as a hurricane until its extratropical transition on 24 September. A QuikSCAT overpass at 0916 UTC 23 September indicated a large area of hurricane-force winds over the southwestern semicircle of the circulation with maximum winds around 80 kt. Since there was no deep convection over this portion of the circulation, these winds did not suffer from rain contamination and are likely representative of the maximum winds at that time. This finding is consistent with the simulated QuikSCAT-equivalent data set on 23 September at 0000UTC Fig 11e. The area of hurricane-force winds is depicted on the image by the closed white contour line.

4.3.4 OPC Evaluation of Helene Simulated Data

Comparing the eight simulations for Hurricane Helene to an extratropical cyclone, the XOVWM wind fields show a significant improvement over the QuikSCAT simulated wind fields and nearly match the WRF control run wind fields. Here are specific comments for seven of the eight time steps.

21/09/06 – 2230 UTC Fig. 12a
WRF control shows a small area of Category 2 wind speeds to the south of the center. XOWVM has a uniform field of Category 1 winds with no Category 2. The shape of the wind field from XOWVM resembles the WRF simulations. The radius of 50-knot winds does appear to be a bit small in XOWVM than WRF, in particular, to the south of the cyclone center. The QuikSCAT simulations only show maximum winds to strong storm force of 56 to 64 knots in the northwest quadrant of the cyclone.

22/09/06 – 0430 UTC Fig 12b
WRF shows an asymmetric wind field with a larger radius of storm and hurricane intensity over the eastern semicircle. Maximum winds are in the minimal hurricane intensity of Category 1. XOVWM also shows winds to Category 1 intensity. The radius of 56 to 64 knots is a bit smaller than the WRF control. QuikSCAT shows a partitioned, noncontinuous wind field with maximum winds to 50 to 56 knots only to the south and southeast of the center.

22/09/06 – 0930 UTC Fig 12c
Reasonable agreement between WRF and XOWVM simulation with two areas of Category 1 hurricane intensity winds to the east and west of the center. XOWVM does show a bit smaller radius of winds to 56 to 64 knots north and south of the center than WRF. QuikSCAT simulation fails to retrieve hurricane intensity wind speeds and maintains an elongated presentation of the cyclone. At this point it appears the cyclone may be beginning to transition to the extratropical phase.

22/09/06 – 1400 UTC Fig 12d
The WRF simulation shows that the wind field is beginning to spread out and the inner wall of hurricane force winds has weakened partially with a large patch to the east. XOVWM is similar but north of the center shows an area of winds to hurricane intensity farther from the center than the WRF control. Similarly, QuikSCAT also shows hurricane intensity winds to the north that are farther away from the center than the WRF control. QuikSCAT continues to under-represent the full wind field.

23/09/06 – 0000 UTC Fig 12e
The wind field has become more asymmetric with highest winds now outward from the center over the west semicircle to Category 1 hurricane intensity. The XOVWM wind field is similar with Category 1 winds and a small area of Category 2 to the west south west of the center. The Category 2 winds are greater than the originating wind field, which is likely due to precipitation influence on the measurements. The area of Category 1 winds to the east is significantly smaller than the WRF. QuikSCAT does show winds to Category 1 strength only over the southwest quadrant.

23/09/06 – 1200 UTC Fig 12f
XOVWM continues to show a little larger area of Category 1 hurricane intensity than the WRF but otherwise matches the shape and wind speeds of the WRF control fairly well giving an excellent representation of the fully transitioned cyclone. QuikSCAT does show some of the asymmetry evident in the WRF wind fields but is quite under represented as far as structure and intensity.

24/09/06 – 0000 UTC Fig 12g
Helene has fully transitioned to an extratropical cyclone and intensified. The WRF winds show an impressive band of Category 1 intensity winds over 200 nm long over the west and southwest semicircles well outward from the center. XOWVM looks quite similar with isolated patches of Category 2 winds west of the center in the large strong band. QuikSCAT does fairly well to the southwest of the center but over the northwest quadrant woefully underestimates the strength of the wind speed.

WRF XOVWM QuikSCAT Equivalent

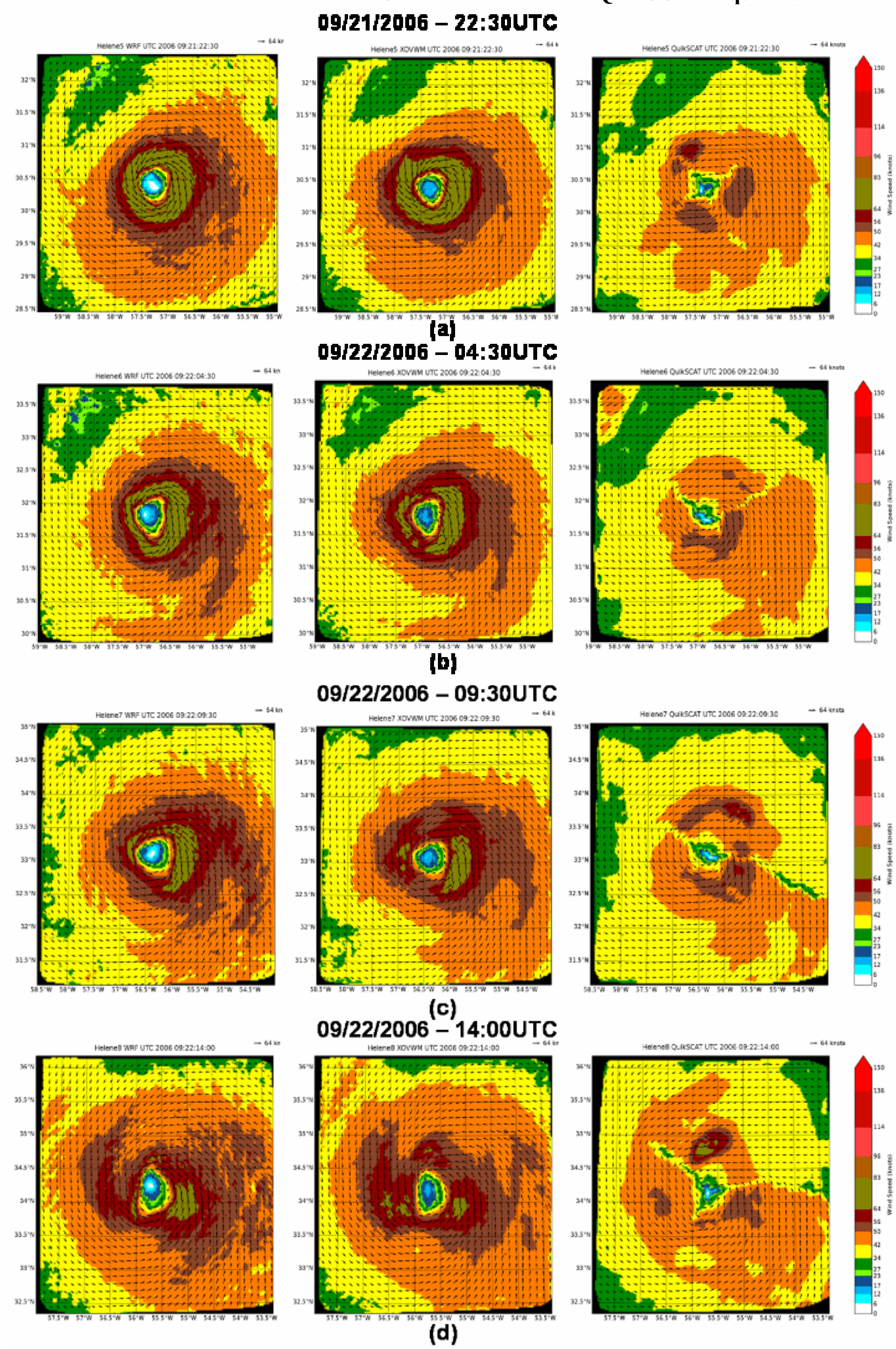


Fig. 12 WRF simulated wind fields (left) of Hurricane Helene in the period between 09/21/06 and 09/23/06 (a-f), its extratropical transitions on 09/24/06 (g-h), and the corresponding XOVWM (middle) and QuikSCAT-equivalent (right) retrievals.

WRF XOVWM QuikSCAT Equivalent

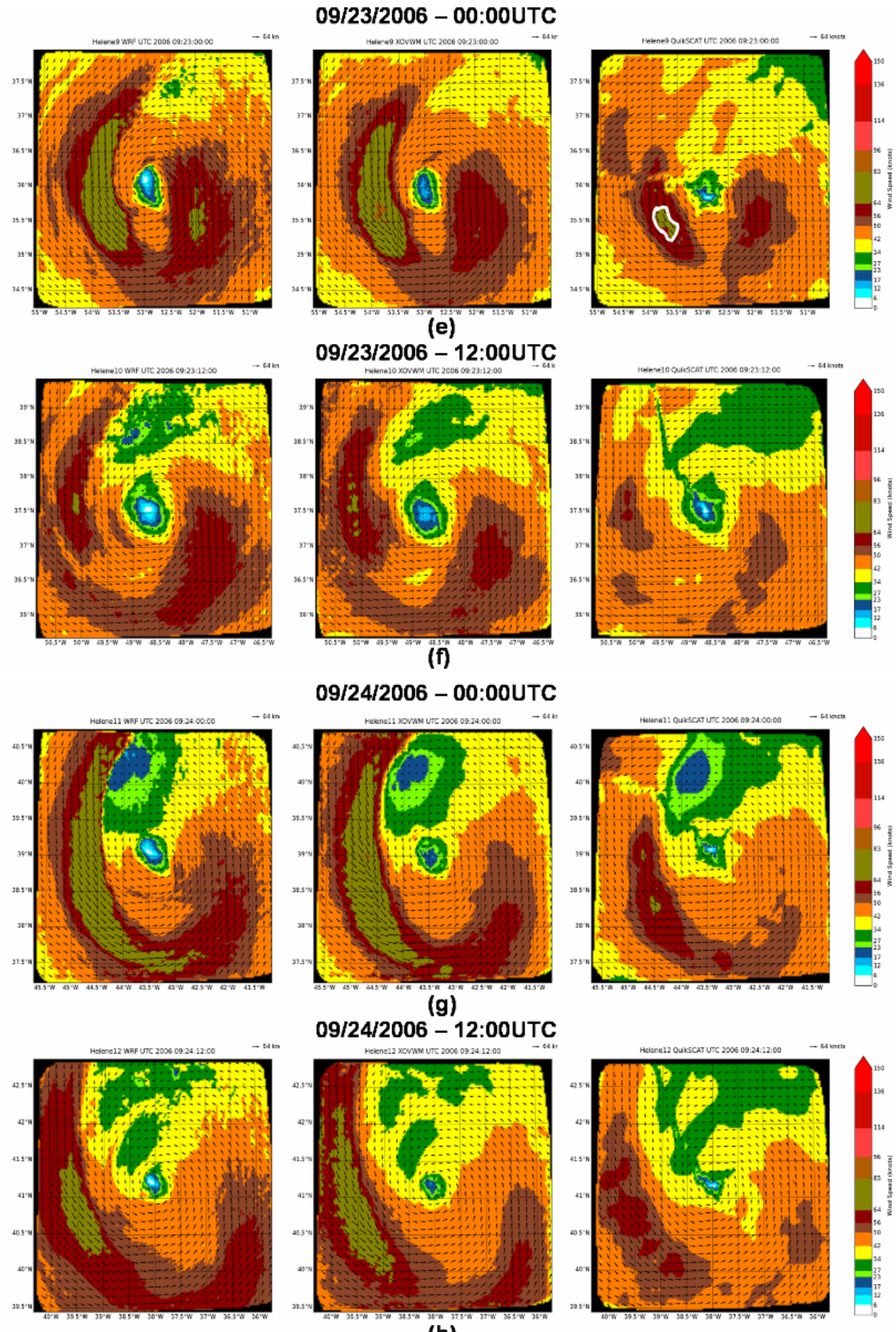


Fig. 12 WRF simulated wind fields (left) of Hurricane Helene in the period between 09/21/06 and 09/23/06 (a-f), and its extratropical transitions on 09/24/06 (g-h), and the corresponding XOVWM (middle) and QuikSCAT-equivalent (right) retrievals.

4.4 Coastal Measurement Simulations

4.4.1 Alaska Coast Examples

The coastal wind field simulations focused on the Gulf of Alaska and U.S. West Coast. These areas were selected in part because these waters are known for hazardous coastal winds in shipping lanes and fisheries. Alaska is surrounded by oceanic waters on three sides, and its waters, for example, produce nearly 50% of the nation's seafood catch. Its shores comprise approximately 54% of the nation's coastline, and over 70% of the state's population resides along this coastline. Sea surface winds and wave information are critical to the marine community that plies these waters around Alaska.

The coastal regions around the Gulf of Alaska are ringed by complex terrain with high mountain ranges and multiple gaps. The gaps are important because they provide a path for air masses from interior Alaska to flow into the Gulf. Additionally, the extratropical cyclone tracks typically traverse the Gulf. As a result, frequent landfalling synoptic low-pressure areas and fronts occur throughout the year, with the strongest storms occurring in the in fall and winter months. These synoptic systems interact with the terrain and with air flowing from interior Alaska through the aforementioned gaps, resulting in strong mesoscale forcing that leads to frequent, very high wind events throughout the coastal regions of the Gulf. Gaps in the terrain induce a complex horizontal structure within these windstorms. These complex mesoscale interactions with coastal topography provides an ideal test bed for assessing whether XOVWM can observe these intense wind phenomena closer to the coast than a QuikSCAT-equivalent instrument (Monaldo et al 2004).

Gap flows and barrier jets are two specific examples of mesoscale meteorological phenomena that occur frequently in the Gulf and are observable using SAR. Gap flows occur when cold continental air spills through gaps in the coastal terrain. Barrier jets occur when a stable atmospheric flow encounters a barrier in the local terrain. Sometimes both types of flow coexist and interact. These flows are often associated with gale-force (33–47 kts), storm-force (48–63 kts), and even occasionally minimal hurricane-force winds (≥64 kts). In fact, winds within both gap flows and barrier jets often vary from nearly calm to more than 50 kts over a span of several kilometres. Clearly, such winds pose a significant hazard to marine interests throughout the Gulf of Alaska. Many ships have sunk or experienced severe distress within these flows.

RadarSat SAR data provides high-resolution (100–500 m) wind speed information and are available for most of the Gulf of Alaska region. Since SAR data do not provide directional information, the wind direction data from the U.S. Navy's NOGAPS model were combined with the SAR wind speeds to provide the bases for simulating the scatterometer σ_0 measurements in the coastal waters (Fig.13). The model wind directions were interpolated to the SAR resolution, and the resulting combined information provided the wind vector "truth" was used as input for the scatterometer simulations.

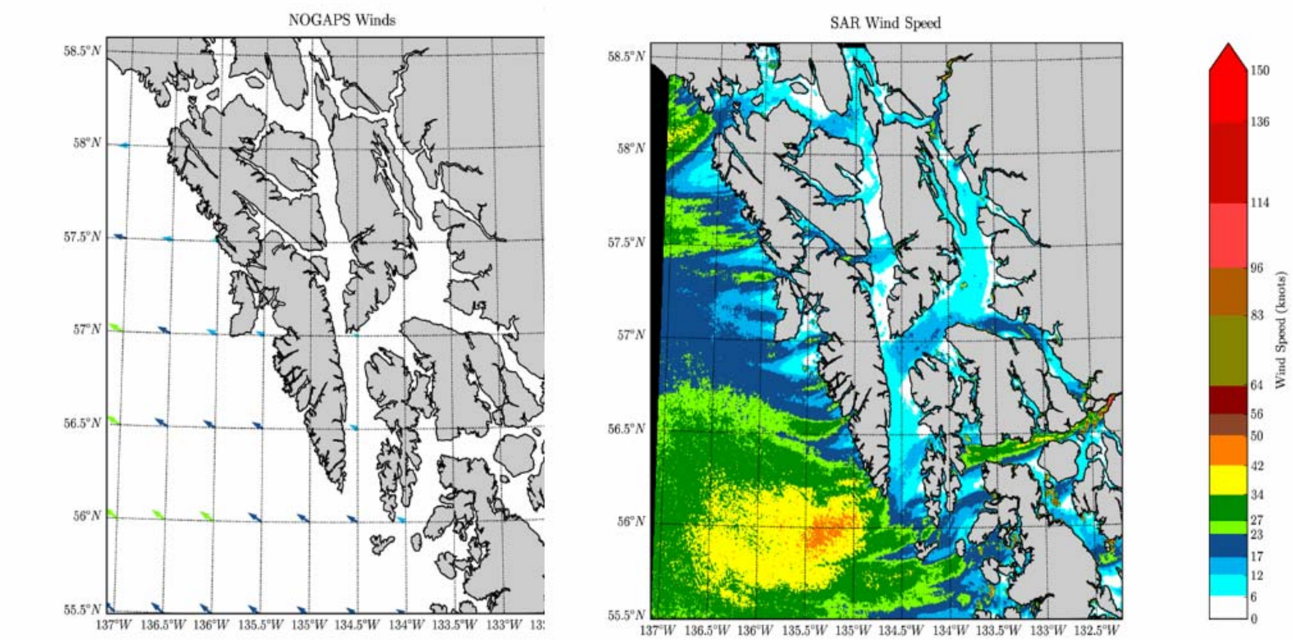
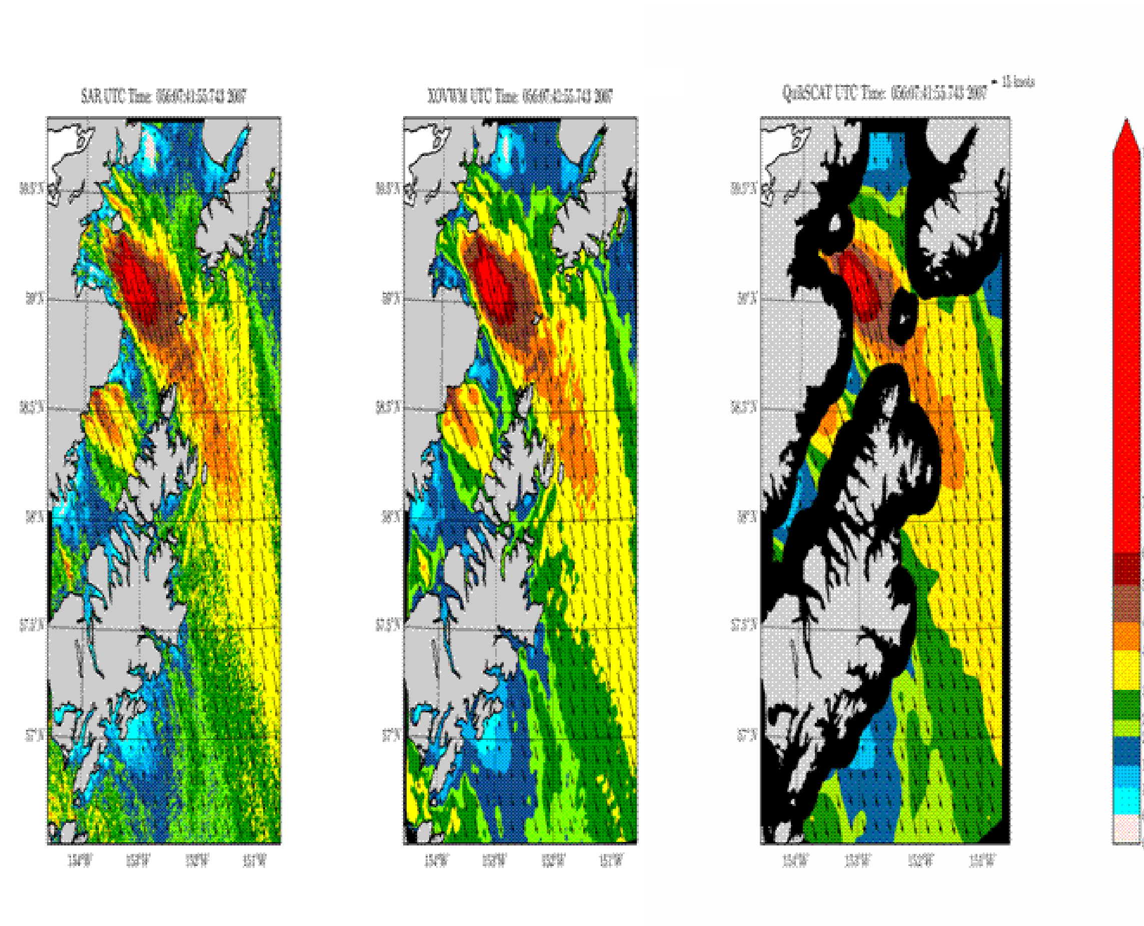


Fig. 13 To prove surface truth for simulations, SAR wind speed measurements were combined with NOGAPS model wind directions.

The simulation of scatterometer measurements and wind field retrievals were produced at a spatial resolution of 12.5 km and within 20 km of the coast for the QuikSCAT-equivalent instrument, and at a spatial resolution of 2.5 km and within 2.5 km of the coast for XOVWM. An example of SAR wind speeds overlaid with model directions and the corresponding QuikSCAT-equivalent and XOVWM wind field retrievals are shown in Fig.12. The north-northwest flow event across Shelikof Strait and the southern portion of Cook Inlet is shown in Fig.14 as well. Several intense areas of gap flows are evident, two in Shelikof Strait and the major flow in the lee of Kamishak Bay to Iliamna Bay. The SAR shows winds to hurricane force extending about halfway across Cook Inlet, and strong gale- to storm-force winds to the east of the northern tip of Kodiak Island. The XOVWM does an excellent job on this scale and picks up all of the outflow plumes seen in the SAR. Intensities are similar with HF and STORM force in similar areas. The two outflow plumes in Shelikof Strait also appear to be quite similar. The sharp gradient of wind across the southern Cook Inlet is well depicted by XOVWM.

In comparison, the QuikSCAT simulation smoothes the gradient out across southern Cook Inlet and is too high with the wind minima there. HF winds are seen, but the extent of storm force is not as far to the SE in QuikSCAT as seen in XOVWM and SAR. The land contamination and mask limits retrievals in Shelikof Strait, with one smaller outflow plume being missed.

The full set of simulations were posted on following web page and made available for user evaluation: http://manati.star.nesdis.noaa.gov/SVW_nextgen/user_impact_studies.html.



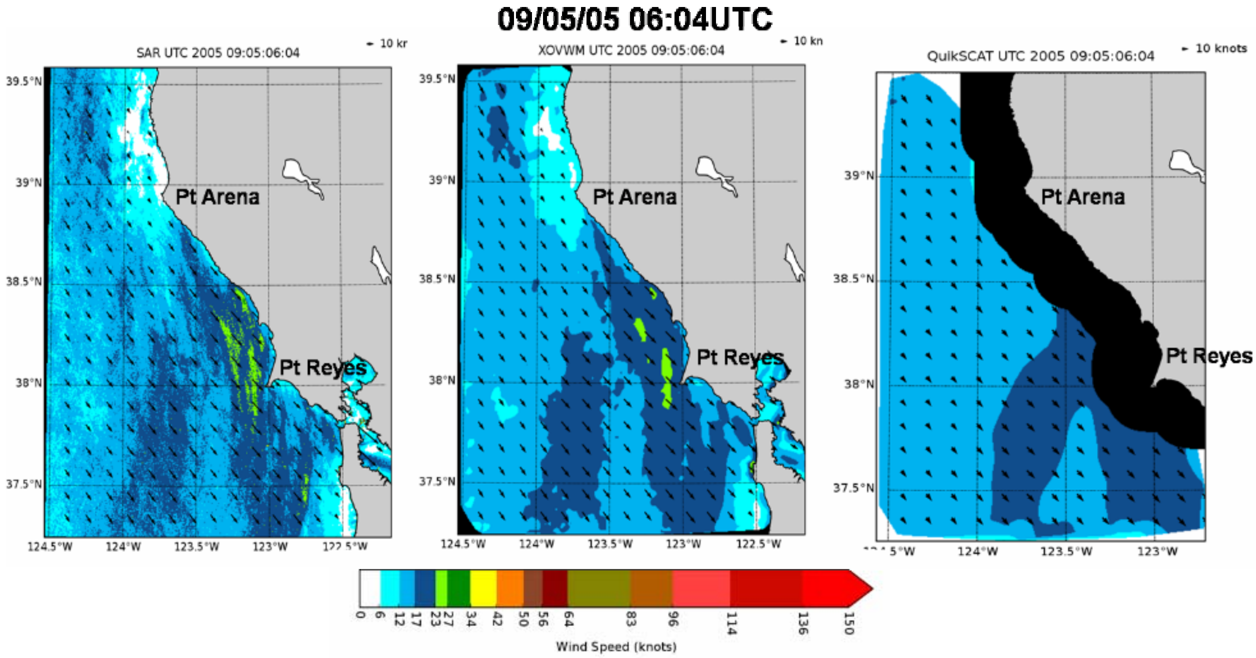
(a) (b) (c)

Fig. 14 SAR wind speed and NOGAPS wind directions (a) and corresponding XOVWM (b) and QuikSCAT-equivalent (c) OSVW retrievals. XOVWM winds were retrieved within 2.5 km of the coast and at 2.5 km resolution while QuikSCAT-equivalent retrievals were produced at 12.5 km resolution and within 20 km of the coast.

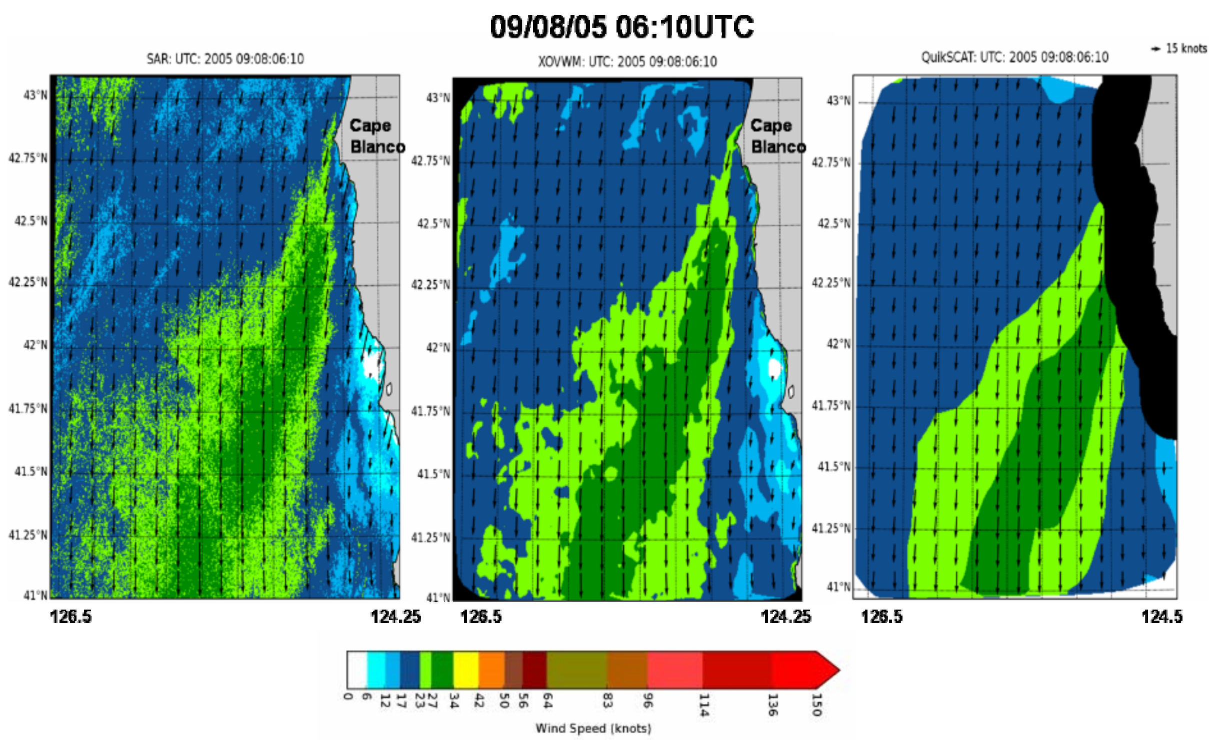
4.4.2 West Coast Simulation Examples

Coast-parallel, low-level jets are commonplace in the offshore environment along the West Coast of the United States during summer. The jet is a broad feature that extends well offshore and along the coast from Oregon to Southern California. Winds in the core of the jet (above the surface) have been measured in excess of 32 m/s. Associated surface winds routinely exceed 15 m/s. Improved understanding of the California coastal jet is an essential piece of the broader need to better describe and predict coastal processes in both the ocean and atmosphere. It is thus impossible to understand and accurately forecast warm season weather near the coast without a better understanding of coastal jet variability. These forecasts are of great importance to fishermen, recreational boaters, and the merchant fleet in this heavily utilized marine environment.

SAR Winds and NOGAPS Directions **XOVWM** **QuikSCAT-Equivalent**



(a)



(b)

Fig. 15 SAR wind speed and NOGAPS wind directions (left) and corresponding XOVWM (middle) and QuikSCAT-equivalent (right) OSVW retrievals along of US West Coast on 5(a) and 8(b) September 2005. XOVWM winds were retrieved within 2.5 km of the coast at 2.5 km resolution, while QuikSCAT-equivalent retrievals were produced at 12.5-km resolution and within 20 km of the coast.

In addition to the persistent warm season thermal trough-induced coastal jet pattern, a large portion of which occurs within the current 20-nm masked region, a coastal barrier jet is common along the California coast too. A coastal barrier jet usually develops ahead of a land-falling cold front and is a result of wind funneling as winds hit the coastal range at an oblique angle (from the SW). In this situation, low-level stability is sufficient to prevent the low-level winds from lifting over the coastal range and are instead funneled or vectored parallel to the coast. This will produce winds that are often much stronger than indicated by the model surface or boundary layer winds, and will often produce gale- to storm-force winds within 20 nm of the coast, currently not captured in the 20 nm QuikSCAT mask region.

Prime examples are wind events near Cape Blanco (Pomeroy and Parish 2001). Cape Blanco often catches winds nearer to the core of the barrier jet and often observed winds in these events are in excess of 80 kts. However, the buoy constellation available to forecasting offices near Cape Blanco is not capable of capturing these high winds. Buoy number 15 seems to often be outside of this region and, other than the Blanco buoy, which is not representative of ocean surface conditions buoys in the area are not in a good position to capture these types of events. Buoy number 229, which is a waverider down stream, observes wind waves that would be produced from this type of event, but very rarely does the current buoy configuration capture the actual winds that produce these waves.

Two examples of SAR-measured winds along California coast and corresponding XOVWM and QuikSCAT-equivalent retrievals for wind events on September 5th and 8th 2005 are shown in Fig 15a and b, respectively. As in the Alaska examples, XOVWM and QuikSCAT-equivalent winds were retrieved with resolution of 2.5 and 12.5 km and within 2.5 km and 20 km of the coast, respectively.

5 User Impact Study Methodology

In order to introduce and engage NWS users to the user impact study, a series of meetings were held during the last two months of 2007. The first gathering was a half-day Satellite Ocean Surface Vector Winds mini-workshop held at the TPC immediately following the annual NOAA Hurricane Conference on November 30, 2007. Approximately 30 participants took part in the workshop. These participants represented various parts of NOAA including: TPC/NHC, OPC, AOC, AOML HRD, NWS OST, NWS SR, and NWS ER. Additionally, six NWS WFOs (OKX, CHS, ILM, MHX, BRO, and MIA) were represented.

As part of the QuikSCAT follow-on studies, this workshop summarized the status of the ongoing studies and presented the user impact simulations. The meeting sought to enlist the participation of NOAA users and to establish a process by which they will assess the capabilities and utility to NOAA of a next-generation OSVW mission (XOVWM) versus a QuikSCAT-equivalent reflight.

Workshop highlights:

1) The workshop had a good mix of NOAA users and was extremely interactive. The participants were very interested in hearing about the QuikSCAT follow-on capabilities

that would enable improvements to those currently available at NOAA.

2) There was a consensus that a next-generation OSVW system (XOVWM) is a significant advance over what is currently available to NOAA, and that such a system has the potential to make major contributions.
3) The participants agreed that the simulation work was of great value (even for improving their understanding of existing QuikSCAT capabilities and limitations), and a strong desire was expressed to expand the simulation effort and continue this effort past the current QuikSCAT follow-on study delivery date of February 2008. It was suggested that it would be very beneficial to include additional cases in the validation pool for user analyses, such as Category 4 or Category 5 hurricanes (e.g., Felix, Charley), a marginal Category 1 hurricane, additional coastal cases (e.g., Long Island Sound, Gulf of Tehuantepec), extratropical cyclones, anti-cyclones, polar lows, and the Great Lakes.
4) Draft mission threshold requirements were presented by JPL for comments by the users. A concern expressed was that the data latency requirement presented was insufficient (180 minutes). The threshold data latency requirement being used was the same used by NOAA for QuikSCAT, which was dictated by the NWP model data assimilation process. For nowcasting purposes, a more stringent latency requirement is needed than that for NWP model applications. To improve the data latency, more than one ground station contact per orbit would be required.
5) The importance of including the costs for training and improved data display capabilities in the operational environment to enable full use of the data from the QuikSCAT follow-on mission was also discussed.

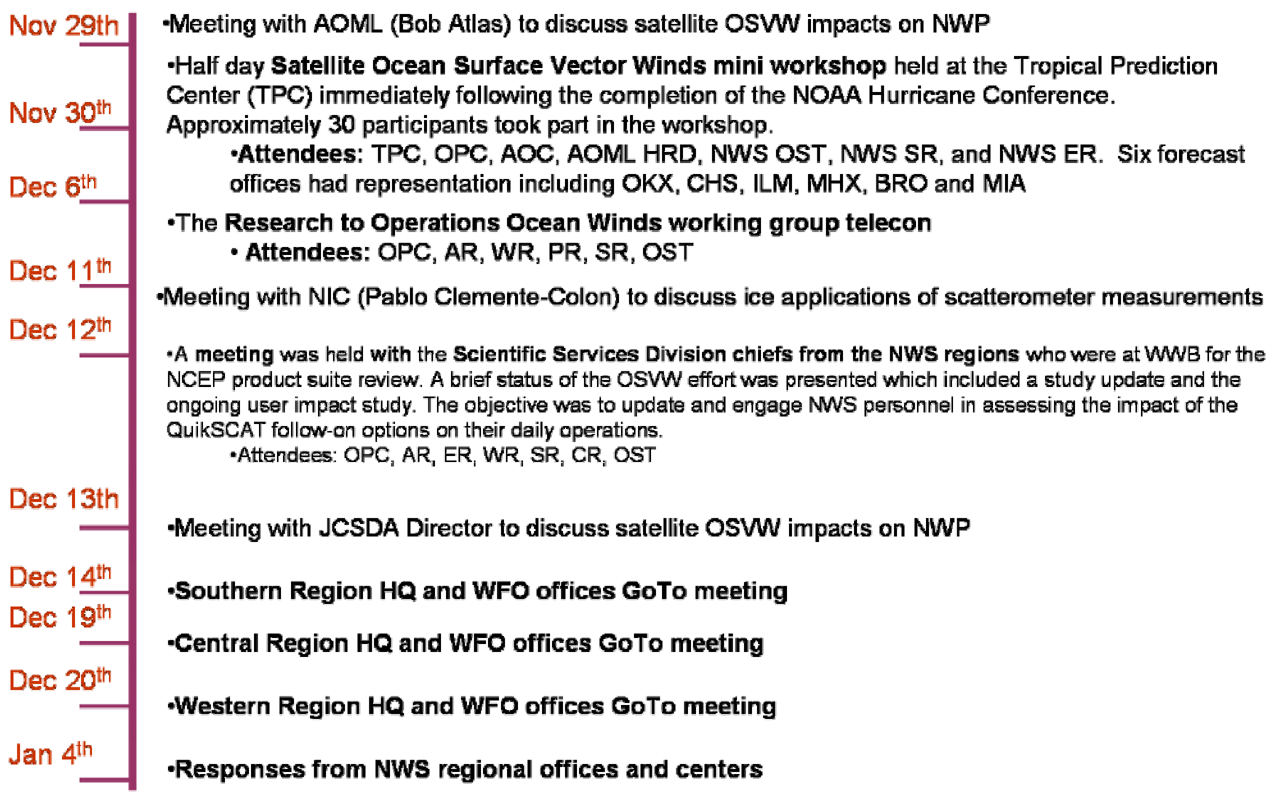


Fig. 16 Timeline and schedule of meetings organized in order to inform user NOAA user community about the

JPL QuikSCAT follow-on study and simulation results.

To ensure broad participation from the NWS operational OSVW users, additional meetings with the NCEP operational centers and regional WFO and headquarter offices were organized throughout December 2007. The meeting timeline and schedule is presented on Fig. 16.

After these meetings, written statements from the participating offices were sought addressing the following questions:

- What realized impacts on your daily work would be continued if a QuikSCAT-equivalent instrument is launched?
- Based on the simulation results presented, what is the perceived impact that a more advanced capability can bring to your areas of responsibility (for example, are there no buoys in particular areas of interest, are there wind events affecting your particular region that are not being observed, etc.)?
- Because of schedule constraints, the simulation study could only focus on a select number of cases. In order to obtain a more comprehensive understanding of an advanced OSVW capability, are there specific simulation cases that would be of interest for your specific area of responsibility?

For the purposes of this study, the assumptions were made that there would be a QuikSCAT follow-on mission and that this study was focusing on identifying the user impacts of a QuikSCAT equivalent mission and a more advanced XOVWM mission. There was no cost, schedule, or technical readiness information made available, and it was assumed that other existing programs/capabilities the NWS offices depended upon wouldn't be impacted.

6 User Impact – National Centers

6.1 Ocean Prediction Center

The Ocean Prediction Center (OPC) is an integral component of the National Centers for Environmental Prediction (NCEP). The primary responsibility of OPC is the issuance of marine warnings, forecasts, and guidance in text and graphical format for maritime users. OPC originates and issues marine warnings and forecasts, continually monitors and analyzes maritime data, and provides guidance of marine atmospheric variables for purposes of protection of life and property, safety at sea, and enhancement of economic opportunity. These products, in part, fulfill the U.S. obligation to the World Meteorological Organization and Safety of Life at Sea Convention (SOLAS) for marine warning and forecast services.

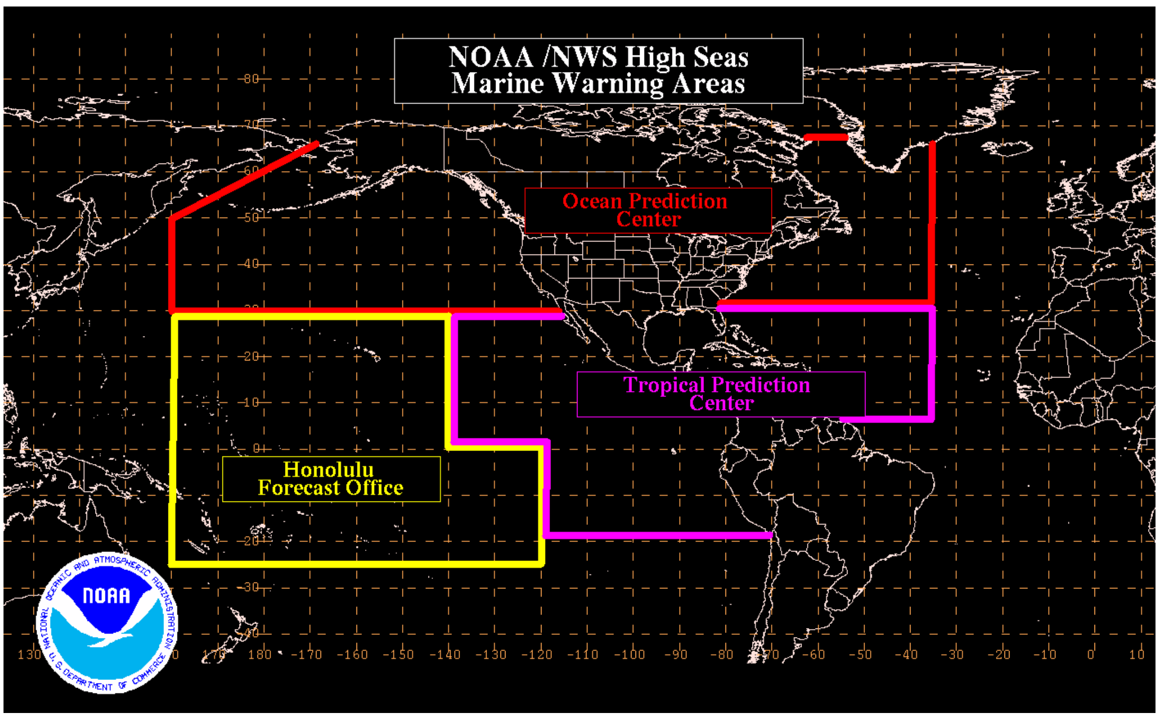


Fig. 17 OPC areas of responsibility. In emergency situations OPC acts as a backup to the TPC and the Honolulu National Weather Service Office taking over the marine functions.

OPC warning bulletins are required (as part of this obligation to the Global Maritime Distress and Safety System and the Safety of Life At Sea Convention) to be received and monitored by all commercial vessels of 300 gross tons and greater operating over the North Atlantic and North Pacific high seas and offshore waters. The OPC waters of responsibility (Fig.17) extend from the subtropics to the arctic from the 35° west (mid-North Atlantic) to 160° east longitude (western North Pacific). These waters include the Asia/North America and Europe/North America trade routes, the Valdez, Alaska/West Coast tanker route, the fishing grounds of the Bering Sea and Georges and Grand Banks, and cruising routes to Bermuda, the Lesser Antilles, and Hawaii. Customers include commercial mariners, fishermen, recreational sailors, the USCG, NOAA HAZMAT, and the U.S. Navy. In emergency situations OPC acts as a backup to the TPC and the

Honolulu National Weather Service Office, taking over the marine functions. These offices also act as backup to the OPC marine functions.

6.1.1 Use and Impact of QuikSCAT Data at OPC

QuikSCAT OSVW measurements became available at OPC six months after the launch of the satellite in January 2000 via a NESDIS web page and in the N-AWIPS workstations one year later. High-quality ocean surface vector winds (OSVW) from QuikSCAT have revolutionized the short-term warning and forecast process for OPC's large ocean areas of responsibility.

Extratropical cyclones that reach hurricane force intensity are a significant threat to the safety of life at sea and a risk to cargo and vessels (Fig 18).

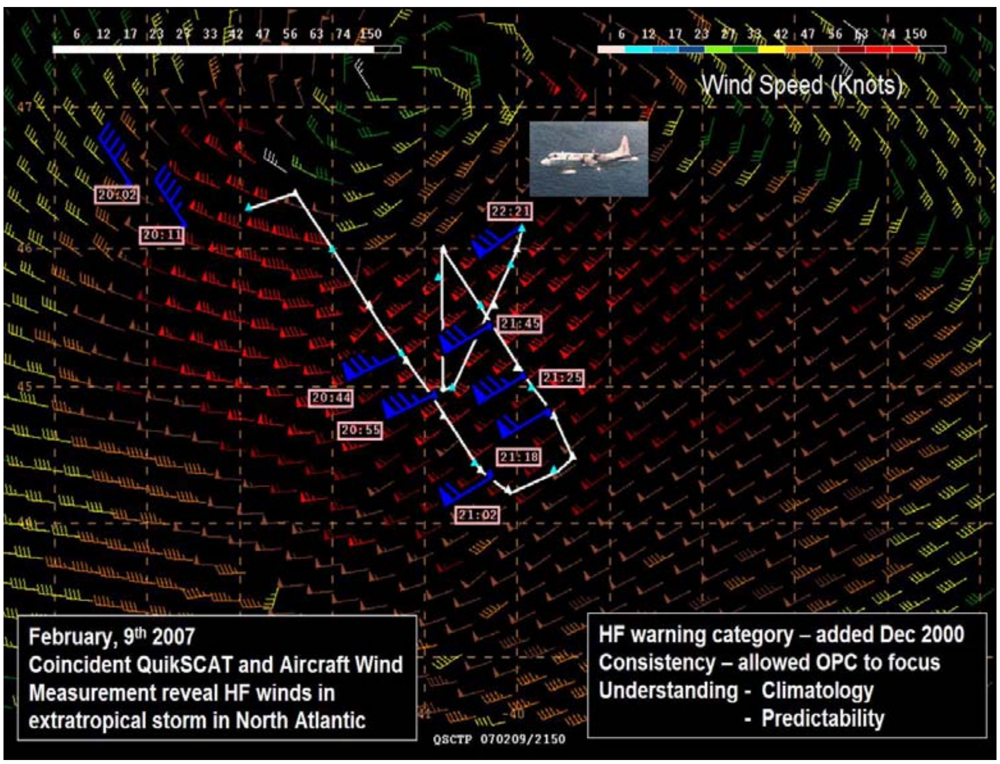


Fig.18 This blowup of the large North Atlantic February 9, 2007 cyclone shows QuikSCAT wind retrievals of Saffir-Simpson Scale into Category 3 hurricane intensity. Wind barb colors of hurricane-force intensity are shown in the table on the top. The aerial coverage of Category 1 and greater winds exceeded those of the very large Hurricane Katrina by a factor of approximately 3 1/3: 70,000 sq n mi vs 21,000 sq n mi. Even with the capability of QuikSCAT, it is not known how strong the maximum winds can be in an extreme extratropical ocean storm.

The OPC is the NOAA office responsible for warning and forecasts for the waters most frequented by these extreme ocean storms. Extratropical cyclones vary on scale from less than 100 km in diameter to 3,000 km or even 4,000 km in diameter and have an average life cycle of five days from genesis to death. Ocean cyclone intensification can be explosive, thus the term meteorological "bomb" to describe maritime cyclogenesis.

Associated wind conditions can vary from 10 to 20 knots to gale force (33 to 47 knots), storm force (48 knots to 63 knots), or hurricane force (greater than 63 knots); knowledge of the frequency of occurrence and distribution of hurricane-force winds in extratropical cyclones has been greatly enhanced by data from QuikSCAT in the past several years. Winds of gale force or greater can extend over several million square kilometers of open ocean. At any given time, five to eight (or more) individual cyclones can be impacting the Atlantic basin and seven to eleven (or more) impacting the Pacific basin. Movement of these cyclones during development can exceed 30 knots, and the movement slows as the cyclone matures and the vortex deepens through the troposphere. These facts pertain to the main extratropical storm tracks of the North Pacific and Atlantic. Dangerous winds and waves associated with these extreme cyclones can result in the loss of lives and property. The economic impact is far reaching and can consist of the loss of or damage to cargo or a vessel, increased transit times, increased fuel usage, lost time due to vessel damage, and late delivery of perishable goods.

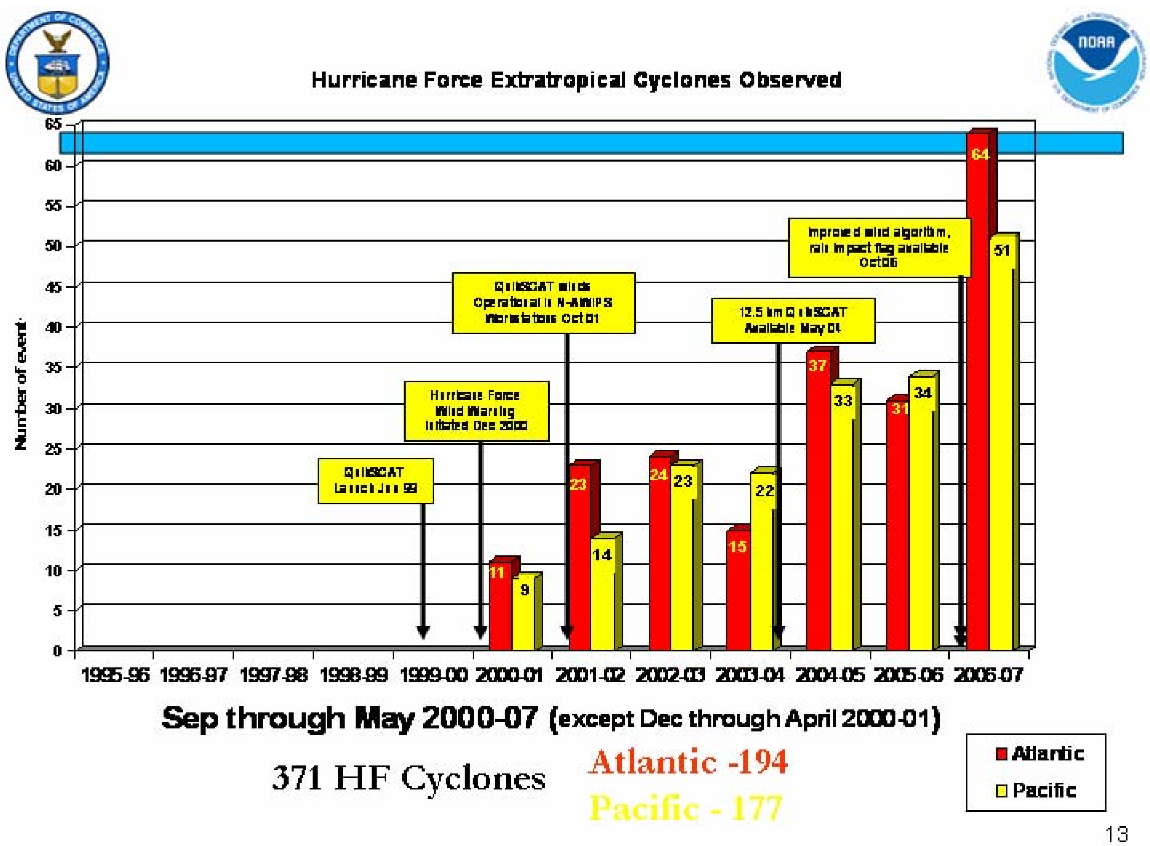


Fig.19 The timeline above shows the number of hurricane-force extratropical cyclones observed each winter season from September through May 2000 to 2007 (except December through May 2000-01). QuikSCAT milestones, such as the changes to the distribution, the increase in resolution, and an improved wind retrieval algorithm, are related to an increase in the number of hurricane-force cyclones observed.

Prior to QuikSCAT, OPC forecasters infrequently received ship observations of wind of hurricane-force strength but had no way to **consistently** detect or warn for these extreme conditions. The warning category of Hurricane Force (HF) was added in December 2000 once it became clear that QuikSCAT was able to consistently detect HF conditions. During the period from the fall 2006 through spring 2007, the OPC identified and issued warnings for 115 separate nontropical ocean storms that reached hurricane-force strength (64 in the Atlantic and 51 in the Pacific as seen in Fig .19). While many of these storm systems live their entire lives at sea, over the last two seasons hurricane-force conditions produced by extratropical ocean storms have impacted the coasts of Alaska, the Pacific Northwest, and New England. As an example a mid-December 2006 extratropical cyclone caused widespread tree damage across the states of Washington and Oregon and resulted in power outages to 1.5 million people.

The loss of QuikSCAT will result in an 80 to 90% loss in detection capability for hurricane-force winds from extratropical cyclones. To date, there is no other capability that provides the consistency in retrievable wind speed range and coverage for extreme winds that are available from QuikSCAT.

QuikSCAT winds are also used daily by OPC forecasters to:

- make warning decisions,
- determine frontal and wind field structure of cyclones, and
- diagnose and examine the validity of numerical weather prediction model analyses and short-term forecast fields.

6.1.2 The OPC Evaluation of Two Mission Options Presented

1. QuikSCAT equivalent

An operational OSVW capability similar to QuikSCAT would maintain all existing warning and short-term forecast benefits that the OPC now reaps from QuikSCAT. Hurricane-force extratropical cyclones would continue to be able to be detected and forecasters would be able to distinguish between wind warning categories. The limitations of QuikSCAT wind retrievals in areas of convection, tropical cyclones, moist extratropical cyclones, small extratropical cyclones, and coastal areas would continue to exist. The inability to accurately detect maximum winds associated with hurricane-force extratropical cyclones exceeding than 75 knots would continue.

2. XOVWM

The simulations of an XOVWM capability presented by NASA JPL for Hurricanes Katrina, Rita, and Helene, three wind events in the Gulf of Alaska, and one in the California coastal waters are quite impressive. The XOWVM, as demonstrated in these very high-resolution simulations, would be capable of retrieving winds in all weather (including heavy rain), winds to Category 3 intensity (96 knots) or higher, and winds very close to the coast.

The specific benefits to the OPC warning and forecast processes of an XOVWM capability are:

1. The ability to accurately detect and warn for the maximum winds (Category 1, 2, 3, or possibly Category 4 intensity) associated with hurricane-force extratropical cyclones. This would provide improved detection and warning capability for the most dangerous conditions on the high seas and significantly enhanced protection for merchant ships crossing the ocean.

2. Greatly improved detection of tropical cyclone development, intensity, and the evolution of wind fields associated with extratropical transition. This results in significantly improved tropical cyclone warnings for both tropical and extratropical coastal areas.

3. The ability to retrieve winds in all weather including squall lines, convective clusters, small intense extratropical cyclones such as polar lows, and in areas of moderate to heavy rain such as in advance of warm fronts and occlusions. This ability would significantly improve NWS warnings and forecasts for the coastal and offshore regions where most boating and fishing activities take place.

4. All NWS marine forecast offices would have the benefit of twice daily, remotely sensed OSVW across coastal, offshore, and high seas waters of responsibility. This would provide a consistent frame of reference for the WFOs, OPC, and TPC for the issuance of warnings and forecasts (QuikSCAT fully benefits NWS offices with large ocean areas of responsibility and less so for offices with coastal responsibility). This would significantly improve the safety in coastal waters where the bulk of recreational boating and fishing activities take place.

5. QuikSCAT has revealed significant wind gradients across sea surface temperature gradients of the Gulf Stream and Kuroshio systems. Similar gradients of wind likely exist across the upwelling regions of the West Coast but cannot be detected by QuikSCAT due to the need to mask the land influences on the retrievals. The less restrictive land mask of XOVWM would reveal the full wind field associated with the upwelling along the California and Oregon coasts. This would benefit coastal forecasts and provide important observational information to coastal ocean models.

6. Orographically enhanced wind features such as coastal jets in advance of frontal boundaries and tip jets associated with headlands would be able to be detected consistently. This, again, improves the safety in the coastal waters where the bulk of recreational boating and fishing activities take place.

7. Wind fields would be available (twice a day) on the resolution scale of digital forecast products and would be the basis for producing bias-corrected wind fields, serving as a verification data set. This scale of data is clearly not available today with QuikSCAT, and its availability would result in improved wind forecasts across all NWS waters of responsibility that benefit marine customers such as fishing, boating, marine transportation, search and rescue, and recovery and restoration of hazardous materials spills.

3. A constellation (2) of XOVWM instruments

A single instrument would result in two looks per day of evolving weather features. A constellation of two XOVWM instruments would provide information to forecasters at synoptic intervals or on the same time scales that analysis and text warning bulletins are produced. The orbit of the second instrument could be optimized to complement coverage and ensure that each point of the global ocean would be observed every 12 hours. A dual XOVWM capability would result in the ability to update warning categories and refine the aerial coverage of warning areas more frequently and with greater accuracy and confidence. The time rate of change of a wide range of phenomena would be able to be observed on synoptic time scales.

6.1.3 Summary of OPC Findings

The loss of QuikSCAT capabilities will be devastating to the OPC, especially for detecting and warning for extratropical cyclones with the most dangerous and severe conditions—those that reach hurricane-force intensity. There are limitations to the QuikSCAT capability, however, that hinder the day-to-day service. The JPL results for XOVWM would greatly address many of those limitations, especially the all-weather capability and high wind retrievals. It is significant that the XOVWM would be able to extend coverage nearly to the coastlines. These improved capabilities would allow OPC to detect and warn for extreme wind conditions in extratropical cyclones and to improve warnings for areas of rain such as convection, small moist extratropical cyclones, and north of warm frontal boundaries. The coastal capability would enhance coastal WFO's detection capabilities for a variety of phenomena including gap winds, coastal jets, and offshore convection.

OPC has benefited greatly from satellite remotely sensed OSVW; offices with mainly coastal responsibility have benefited much less so. An XOVWM would greatly benefit all NWS offices with marine responsibility and would bring OSVW capability to the realm of many, many marine users. Therefore, from the view point of service value and this improved technical capability, **XOVWM is by far the preferred solution.** A single satellite solution would give increased capabilities but temporal sampling would continue to be a problem for lower latitudes and for rapidly developing cyclones. It is requested that a two-satellite solution be given very serious consideration to address these needs.

6.2 National Hurricane Center

The mission of TPC/NHC is to save lives, mitigate property loss, and improve economic efficiency by issuing the best watches, warnings, forecasts, and analyses of hazardous tropical weather, and by increasing understanding of these hazards. One of the most significant challenges in accomplishing this mission is the scarcity of data over the oceans. Through international agreement, the NHC has responsibility within the World Meteorological Organization to generate and coordinate tropical cyclone analysis and forecast products for 24 countries in the Americas and Caribbean, and for the waters of the North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and the eastern North Pacific Ocean.

The Tropical Analysis and Forecast Branch (TAFB) is an integral part of the National Hurricane Center and performs a number of functions. TAFB's area of responsibility is presented on Fig. 20. TAFB products include marine high seas forecasts over the tropics and subtropics, offshore waters forecasts over the tropics and subtropics, tropical weather discussions over the tropics and subtropics, and surface weather analyses and forecasts over the tropics, subtropics, and mid-latitudes.

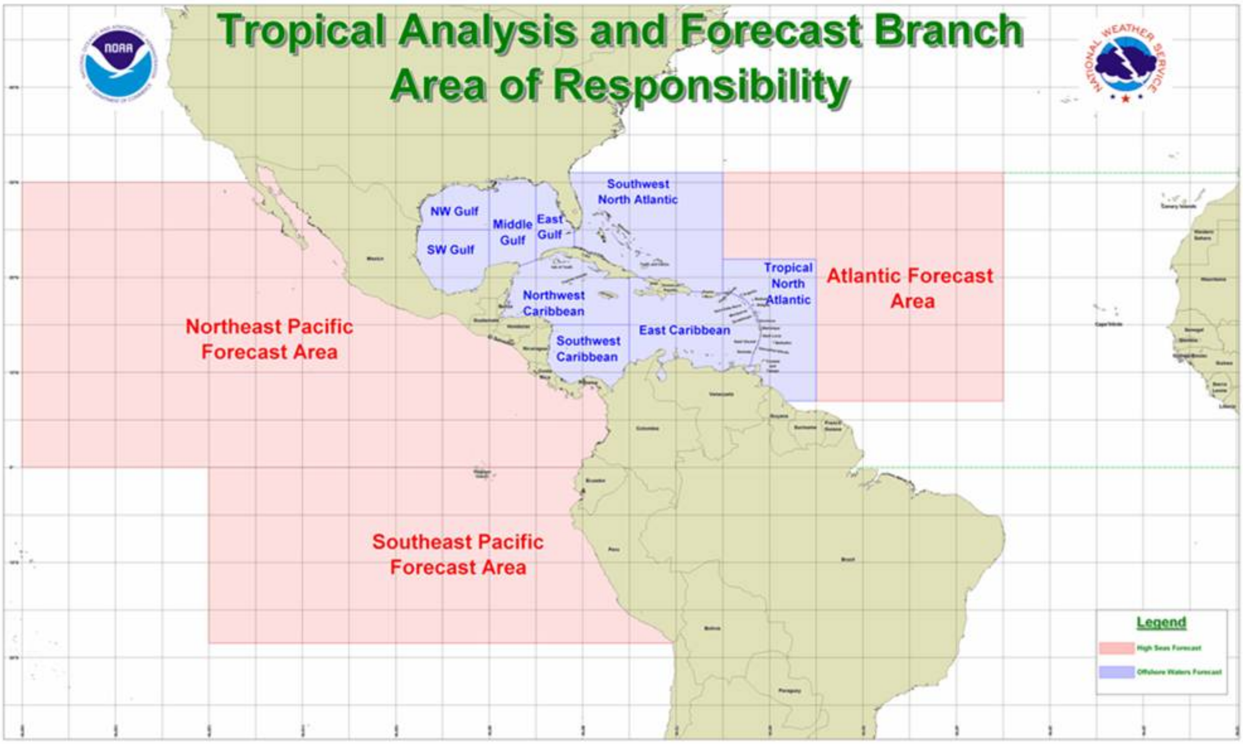


Fig.20 NHC/TAFB areas of responsibility.

6.2.1 Use and Impact of QuikSCAT data at NHC

The uses of QuikSCAT data within NHC have been well documented along with its impacts and limitations (Chang and Jelenak 2006, Brennan and Knabb, 2007, Brennan et al., 2007). The use of QuikSCAT data has increased steadily since 2000 resulting in:

- Improved definition of gale- (34 kts) and storm-force (50 kts) wind radii analysis in TCs, which further refine ship avoidance and warning areas for these systems.
  - Between 2003 and 2006 within NHC QuikSCAT data was used 17% of the time to determine the wind radii, 21% of the time for center fixing, and 62% of the time for storm intensity estimates.
- Earlier detection of surface circulations in developing TCs.
- Improved observation of and warning for gap wind events in the Gulf of Tehuantepec south of Mexico.
  - 73% of storm-force events in the Gulf of Tehuantepec were identified solely by QuikSCAT measurements during the period from October 1999 through January 2007.
  - Climatology of events developed based solely on QuikSCAT data led to a recognition of patterns that result in storm-force events and improved forecasts and warnings.
  - The resulting observational data set is used to evaluate models.

While the QuikSCAT data have been proven beneficial at NHC, the limitations of QuikSCAT measurements due to rain impact and resolution limit usefulness of this data in tropical cyclone applications.

6.2.2 The NHC evaluation of Two Mission Options Presented

Given NHC operational responsibilities for analyzing and forecasting hurricanes, we are naturally pleased that JPL work to date has focused on comparing the performance in hurricanes between QuikSCAT and XOVWM. A hurricane, and especially the inner core of a major hurricane, provides perhaps the greatest challenge for retrieval of OSVW from a satellite, due to the extremely strong wind speeds, very steep wind speed gradients, and large rain rates in that environment. Since these conditions are experienced in other weather systems, either individually or in combination, we believe that these results are informative for comparing the two instruments in a broader context for applications throughout NWS. Extreme wind speeds are encountered over the oceans in, for example, extratropical cyclones, which include hurricane-force events over the North Atlantic and North Pacific Oceans, and in high wind events near the coasts of mountainous land masses (such as Central America and Greenland). The high resolution needed to retrieve winds in the hurricane core is also required to retrieve winds close to the coastline and over narrow water features within complex coastal zones (e.g., Alaska). NHC urges consideration of the performance of XOVWM and QuikSCAT in the context of all relevant NWS forecasts and warnings.

If the simulations are anywhere close to being an accurate representation of what XOVWM data would look like in reality, there is just no comparison between XOVWM and QuikSCAT. The XOVWM simulations are clearly superior to QuikSCAT for estimating hurricane intensity. Improved intensity estimates from XOVWM would not only improve hurricane analysis in NHC's areas of responsibility, but also in other tropical cyclone basins of the world where aircraft reconnaissance is rarely, if ever, available. Improved monitoring of hurricane intensity worldwide, especially if a XOVWM or similar capability would be adopted long term, would serve well the efforts of the climate community to assess relationships between hurricanes and climate change.

On top of the simple intensity metric, the entire two-dimensional wind fields from XOVWM are far more comparable to the WRF model wind fields used as "ground truth" in this exercise (e.g., Fig.6-a), and, therefore, are much better representations of hurricane structure than those from QuikSCAT (e.g., Fig.6-c). This better overall agreement is confirmed in the wind speed scatter plots (Fig. 8b) corresponding to the simulations shown in Figs.6b, which convincingly show that XOVWM provides more accurate retrievals than QuikSCAT in most portions of the WRF-simulated circulation.

QuikSCAT wind direction retrievals do not even come close to accurately depicting where the center of the hurricane is located, while XOVWM directions do accurately depict the center. Also, QuikSCAT retrievals are not produced as close to the coast (northern portion of Fig.6c) as with XOVWM, which limits its utility in both estimating the extent of hurricane-force winds (wind radii) and in providing data for local NWS forecast offices. Given this comparison, an operational forecaster could place much more confidence in XOVWM when it passes over a hurricane.

A capability such as this to obtain a reasonably accurate two-dimensional wind field of even a major hurricane would represent a very significant enhancement to NHC operations. The benefits would be especially noticeable when aircraft reconnaissance data are not available (which is the case much of the time in the Atlantic and nearly all of the time in the rest of the world). In addition, XOVWM would also provide data with which to verify wind fields output by numerical weather prediction models focused on improving forecasts of hurricane intensity and structure. XOVWM could also be useful for providing initial data to such models.

6.2.3 NHC Conclusions

The current JPL study understandably did not address the issue of coverage and frequency of overpasses, which is a limitation of any single polar-orbiting satellite. In order to come close to meeting our operational requirements for OSVW, including in terms of temporal frequency, we would need more than one satellite. Nevertheless, it is our assessment, based largely on the JPL study results, that even a single XOVWM satellite would represent a major step toward meeting critical aspects of our operational OSVW requirements (such as retrievable wind speed range to include major hurricanes), which is not provided by the current QuikSCAT and would not be provided by a QuikSCAT duplicate. If XOVWM would be significantly more costly or risky than a QuikSCAT duplicate, we would understand the reluctance to select XOVWM. Our position, however, is that if XOVWM involves a comparable or an acceptably greater cost, risk, and development time, it is the highly preferred choice due to the tremendous benefits the more advanced platform would provide.

6.3 Central Pacific Hurricane Center and Pacific Region

Scatterometer data are vitally important to operations in the vast area of responsibility covered by WFO Honolulu’s National Marine Center and the Central Pacific Hurricane Center (CPHC), as well as the local forecast area which encompasses the main Hawaiian Islands. WFO Honolulu’s National Marine Center responsibilities include high seas forecasts for an area that covers approximately 15,000,000 square miles (about four times the size of the contiguous US) and extends as far north as 30N, as far south as 25S, and between 120W south of the equator and 140W north of the equator to 160E (Fig.21). In addition to the high seas forecasts for the North and South Pacific, the National Marine Center at WFO Honolulu produces a streamline analysis every six hours for an even larger area, from 30N to 25S between 110W and 130E.

The Central Pacific Hurricane Center, collocated with WFO Honolulu, has tropical cyclone forecast responsibility for the area between 140W and 180 longitude, north of the equator.

Tropical cyclones frequently make close approaches to islands (e.g., the Marianas) in the Pacific Region (Fig. 22). Accurate information about the definition of the TC wind field, estimates of TC intensity, and the location is essential for TC analysis and forecasting in this region by both

CPHC and WFO Guam. For WFO Guam and WSO Pago Pago, by the international agreement, the tropical cyclone data from Japan Meteorological Agency and Nadi Agency in Fiji, as well as the data from the Joint Typhoon Warning Center, is used as guidance as is the model data and observational data the offices can pull in to put together for their forecasts, watches, and warnings. It should also be pointed out that the WFO Guam and WSO Pago Pago offices do indeed have limited center-type responsibilities similar to that of the Central Pacific Hurricane Center and the National Hurricane Center. This is because the agencies that provide the tropical cyclone warning and forecast information do not produce all of the products these offices are required to produce.

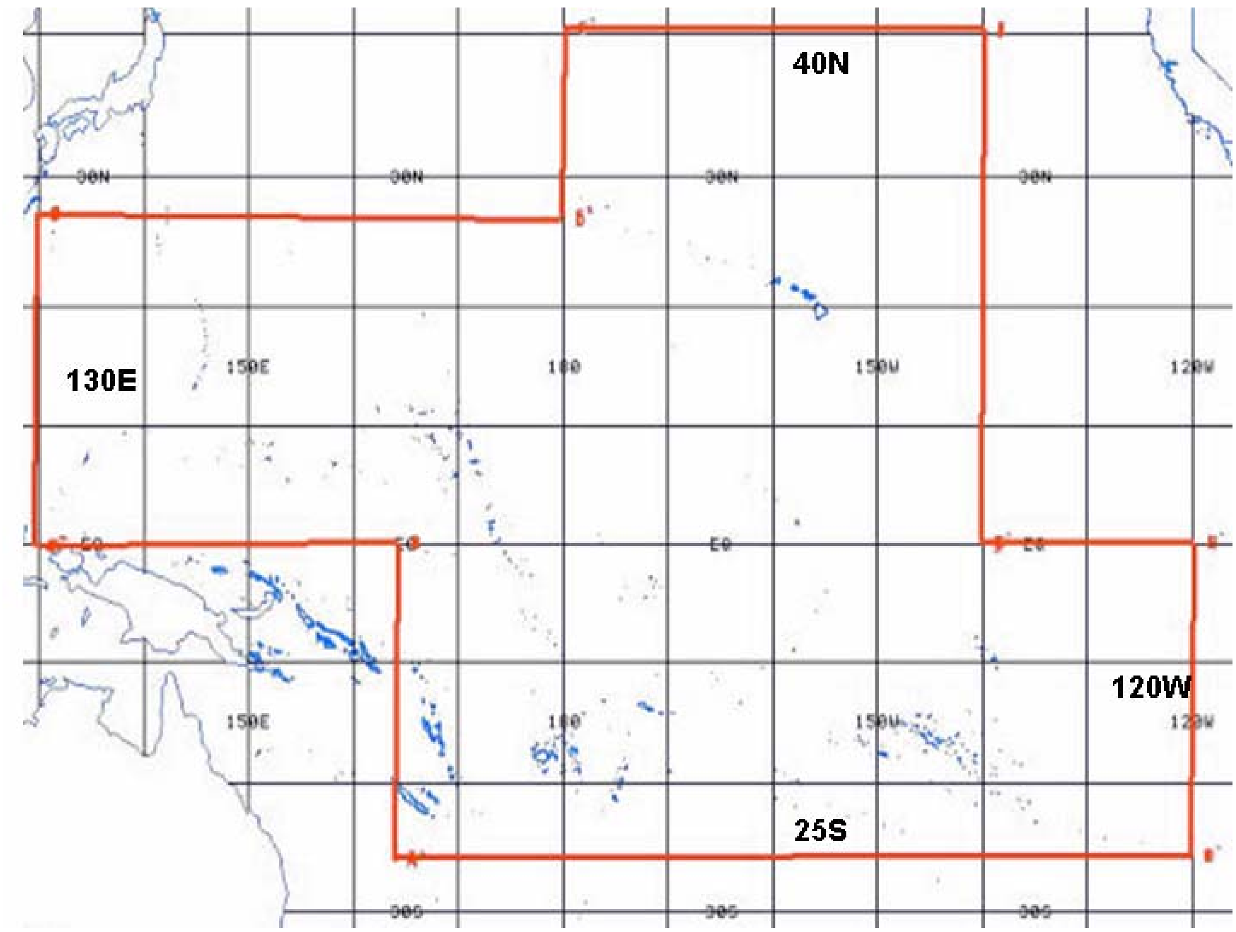


Fig. 21 Pacific region area of responsibility.

It is important to note that the Pacific Islands used to have several automated observation points that reported the synoptic weather observations via satellite every hour within the Micronesian Islands or roughly between 3N and 12 N from 175E to 130E. Nearly all of these sites have now ceased working as a result of two reasons:

– Safety, in regard to getting to these sites. There are relatively few or no boats capable of safely taking our folks to the remote island locations within Micronesia to properly maintain these sites without being totally cost prohibitive.
– Aviation. We have been informed that we are unable to fly into locales where there are no TAFs produced or manned towers for the runways. The loss of this data is very detrimental

in several ways: a loss of climatological data, a loss of very valuable forecast/warning information, and a loss of ground-truth verification for the polar orbiting data such as QuikSCAT.

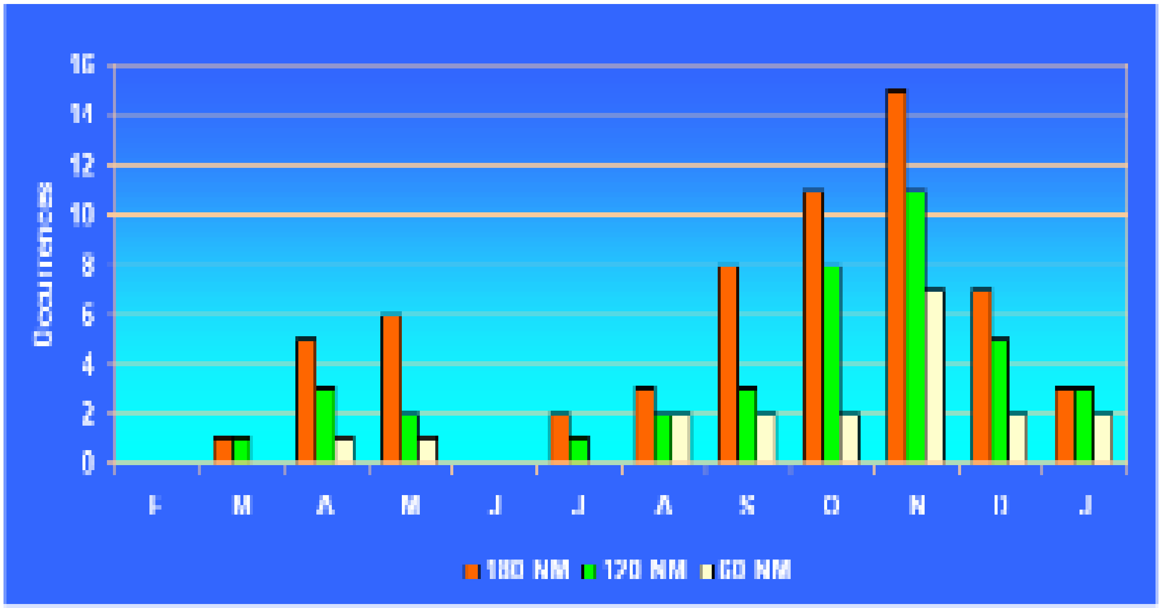


Fig.22 Number of typhoons within 180, 120, and 60 nautical miles of (Saipan) by month, 1945–2002.

6.3.1 Use and Impact of QuikSCAT Data at WFO Honolulu, Guam, and CPHC

QuikSCAT scatterometer data at WFO Honolulu, Guam, and CPHC:

1) Have been extremely critical for WFO Honolulu to produce surface analysis and forecasts. This information is vital to the safety of U.S. marine transportation, shipping, and deep sea fishing operations in this area, which contains few surface observations. Thousands of U.S. yachts and other shipping interests, especially in the South Pacific, depend on these analyses to make critical decisions involving safe sailing.
2) Have dramatically increased the detail the office can incorporate into the streamline analysis, which leads to better support to the office's users.
3) Feed vital information into the atmospheric models about previously undetected features across the tropical and subtropical Pacific, such as convergence zones and troughs, thereby improving the model performance and the ability of the office's forecasters to make better forecasts in data-sparse areas.
4) Have been crucial in the evaluation of developing tropical systems and are routinely incorporated into official tropical cyclone discussions and tropical weather outlooks. Without these data, the accuracy of the tropical cyclone track and intensity forecast would be degraded, thereby affecting the forecast information marine and land decision makers require.

5) Have been extremely useful to hurricane forecasters at CPHC in mature tropical cyclones, enabling them to identify the extent of certain critical wind fields with unprecedented precision, which, again, are extremely important for shipping users to stay out of harm's way.
6) Are necessary for our operations due to their ability to quickly and properly detect westerly wind bursts in the deep tropics that come from well west of our area of responsibility, or 130E. These events can have very detrimental effects on the islands in the Republic of Palau and the states in the Federated States of Micronesia. The westerly wind events can also be a key in strengthening the near-equatorial trough or monsoon trough depending on time of year and synoptics associated with each type. These systems can produce very heavy rain and have been known to release several tens of inches over the islands at a time.

QuikSCAT-quality winds emphasize the need for global ocean vector wind information in our region for the following reasons:

1) During La Niña events the near-equatorial trough is not nearly as prominent and tends to remain much further west in our area of responsibility. As a result, conditions are much drier through much of our area of responsibility, and tropical cyclones for the most part tend to form further west. Also, another marked difference during these events is stronger winds north of the equatorial region. This is very important for our forecasters to note as these higher winds tend to create much higher tides and dangerous surf events. It is not at all uncommon for some islands to have severe damage to their crops and coastal regions during high tides when the wind is strong. Therefore, QuikSCAT and tidal information is extremely vital in early detection of winds well upstream of our islands to help the people harvest early if need be, protect their property, and keep away from the coastal areas. Rip currents and hazardous surf are the most significant and problematic events we face. There are far more deaths, injuries, and loss of property from these events than any other single weather event in the Pacific Ocean on the whole.
2) There are also many differences that are quite notable with El Niño/La Niña events. In El Niño events, the sea surface temperatures are quite warm across the equatorial belt and more notable. The winds about and even north of the equatorial region are lighter. This supports the development of numerous weather events and the ability for tropical cyclones to develop much further east (near the date line or in the area of the Republic of the Marshall Islands). The near-equatorial trough remains very prominent during these years and is, of course, the producer of the tropical convective clusters and tropical disturbances. QuikSCAT global measurements allow us to predict these events prior to affecting our areas of responsibility.
3) The cyclic Madden-Julian oscillation (MJO) or Kelvin waves appear to play a critical role during the onset and termination phases of ENSO. Once well developed they can also be seen in QuikSCAT. These systems propagate into our area of responsibility (west of 130E) and can be very heavy rain producers. The global QuikSCAT data does indeed support the forecaster in predicting the weather associated with them.
4) It must also be noted that it is vital that we are able to detect and note events as far as there is a free path in the oceanic arena for potential hazardous surf events. It is not at all uncommon for locations such as the Republic of the Marshall Islands, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands or the Hawaiian Islands

to have hazardous surf events approach from more than 1,000 miles away. Events from several thousand miles south of the equator have caused severe damage to shorelines, crops, and even runways in the Hawaiian Islands, American Samoa, and the Republic of the Marshall Islands.

6.3.2 Possible Impact of XOVWM on Pacific Region Operational Products

Pacific Region local office marine forecast responsibilities include channels between the islands. Due to the extreme topography variations surrounding these channels, synoptic winds are often accelerated creating hazardous conditions. Scatterometer data are used to make marine warning decisions. Increasing commerce and recreational activities in these channels, such as ferries used to transport people and supplies, make accurate and detailed forecasts in these waters a critical requirement for our users; however, the current land-masking effects make scatterometer observations impossible in most channels. Therefore, a reduced land mask effect is required to enable valuable scatterometer observations to be made and used in these busy waterways.

Large swells produced by open ocean winds have historically been the biggest weather-related killer in the Pacific Region. In addition to loss of life, large swells have also produced damaging surf impacting roads and houses throughout these islands. These swells are often produced many thousands of miles away in the northwestern sections of the Pacific as well as the South Pacific. Scatterometer data input to the Global Wave Watch model are required for our forecasters to make accurate swell and surf forecasts for the protection of life and property. Because of the impacts, emergency managers have repeatedly stated their need for accurate and timely high surf warnings to make the decisions necessary.

An increase in global scatterometer frequency will:

- Provide input for each six-hourly NWP analysis cycle
- Provide timely input to support the six-hourly warning interval of most tropical cyclone warning centers
- Provide vital data during rapid changes in tropical cyclone motion, structure, and character:
  - Sudden changes in direction or speed, including rapid acceleration cases
  - Movements over water from over land and rapid development
  - Synoptic scale interaction with other synoptic-scale features such as fronts or lows or in a multi-TC situation
  - Initial development or change in warning criteria wind radii (34 kt, 50 kt, or 64 kt)
  - Rapid intensity change and existence or change in tropical storm (34 kt) or hurricane (64 kt) wind intensity criteria
  - Genesis and development of a closed circulation
  - Extratropical transition and transformation of wind structure

7 User Impact – Regional Weather Forecasting Offices

Coastal areas in the U.S. are home to a wealth of natural and economic resources and include some of the most developed areas in the nation. The narrow coastal fringe that makes up 17% of the nation's contiguous land area is home to more than half of its population. In 2003, approximately 153 million people (53%) of the nation's population lived in the 673 U.S. coastal counties (Crossett et al., 2004).

The National Weather Service has 47 coastal and Great Lakes forecast offices (WFOs) responsible for providing marine and small craft advisories and warnings. Within each WFO, forecast and warning responsibilities are grouped by user needs into so-called "desks." The groupings are location specific, depending on regional user community demands, staffing constraints, and meteorological and/or geographical features that might be unique to a given WFO region (e.g., tropical storms, coastal jet phenomena, sea ice extent, etc.).

QuikSCAT data has been available to WFO forecasters via the web page http://manati.star.nesdis.noaa.gov/QuikSCAT/ since January 2000 and in AWIPS workstations since November 2004. Only the standard 25-km resolution product with a 30-km coastal mask is currently available for display in AWIPS. QuikSCAT data was most typically accessed via AWIPS, and less commonly from the NOAA NESDIS web pages. AWIPS builds and available input data streams differed from office to office. In some instances the QuikSCAT data were missing, and in other cases the displays of data were truncated (Milliff and Stamus, 2008).

Milliff and Stamus conducted a study on the use of QuikSCAT OSVW data at coastal WFOs in order to quantify the impact that these data have on forecasts and warnings, with a particular focus on operations affecting marine users. Written surveys and in-person site visits to coastal WFOs were conducted over a period from late summer 2005 through the 2005–2006 winter seasons. Surveys were mailed to 33 coastal WFOs, and 16 multi-day site visits took place over this period. The surveys and site visits were designed to measure WFO forecaster familiarity with QuikSCAT OSVW, document forecaster access to QuikSCAT data, and to quantify the role satellite OSVW play in local weather and marine analyses, forecasts, and warnings issued by each WFO. Depending on the areas of responsibility and weather phenomena being forecasted, the majority of forecasters used QuikSCAT for sea-state forecasts and warnings, followed by swell forecasts, wind-waves, and as a validation of features in NWP forecasts and analyses. Major study conclusions are summarized in the bullets below:

- QuikSCAT data lose value with increasing time after a pass in the local area. More than 80% of the responders say that QuikSCAT data are too old to be useful in a time period shorter than the revisit interval (about 12 hours). (Fig 23)
- Improved nearshore retrievals are the most desired potential improvements in the QuikSCAT data. Improved displays of QuikSCAT data in AWIPS were the second most desired possible enhancement (Fig 24).

QuikSCAT data are again useful at a second level of importance in the construction of specialized products at the coastal WFO. Specialized products include marine warnings, sea-state forecasts and warnings, aviation forecasts, and severe weather warnings.

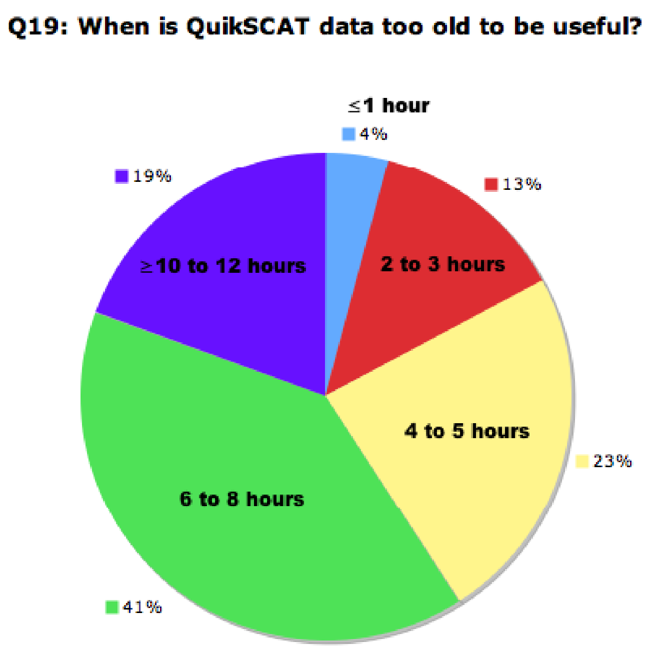


Fig. 23 QuikSCAT data latency constraints on SVW utility in operations at US coastal WFOs. Forecasters indicated how many hours after overflight the SVW data from QuikSCAT lost all utility in WFO operations. The pie chart indicates that more than half the responders found utility in SVW data from QuikSCAT beyond a three-hour data latency (Milliff and Stamus, 2008).

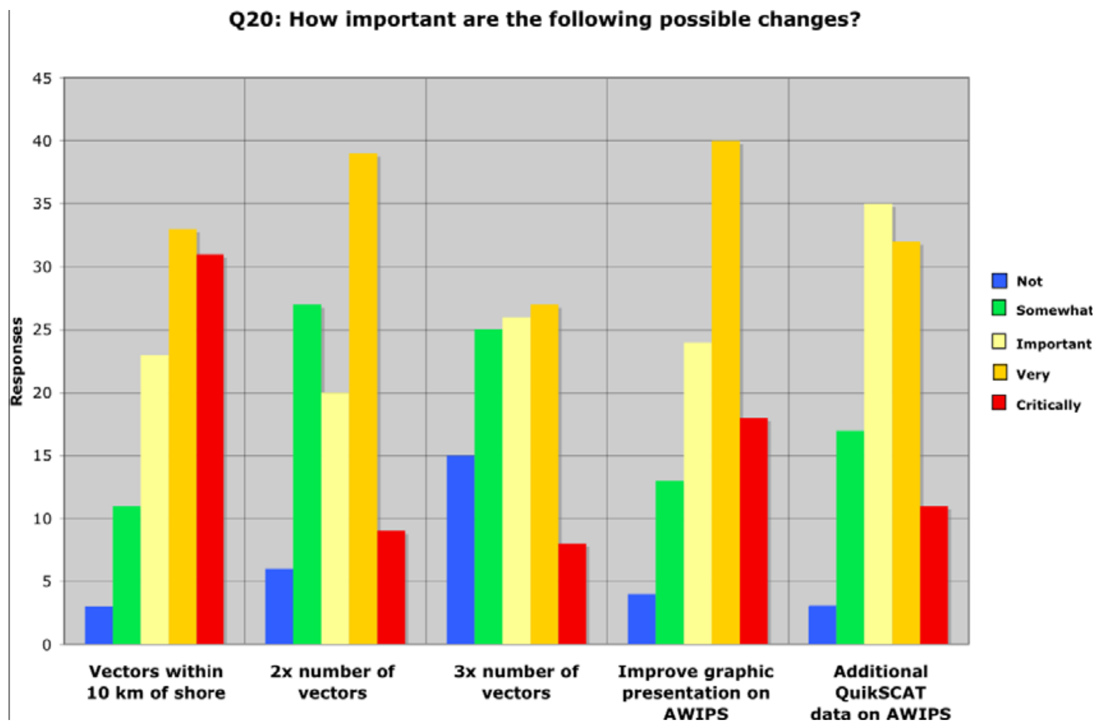


Fig.24 Priority improvements in SVW data stream to add utility for operations at US coastal WFOs. In addition to timeliness, five additional possible improvements in the satellite SVW data stream were ranked by WFO forecasters. Obtaining SVW retrievals closer to shore ranked as the most critically important (red) suggested improvement (Milliff and Stamus, 2008).

7.1 Alaska Region Coastal Offices

The National Weather Service, Alaska Region, has one of the largest marine areas of responsibility in the country: over 54% of the nation's coastline and four offshore ocean areas (Beaufort Sea, Chukchi Sea, Bering Sea, and Gulf of Alaska/North Pacific). These bodies of water are highly productive to commercial fisheries. For instance, the Bering Sea produces over 50% of the nation's seafood catch. In addition, over 70% of the Alaska's population lives along the coast. Many of these coastal communities are resupplied by marine shipping and are active in recreational and subsistence boating. Marine forecast and warnings are critical to the marine community. They must be both accurate and timely.

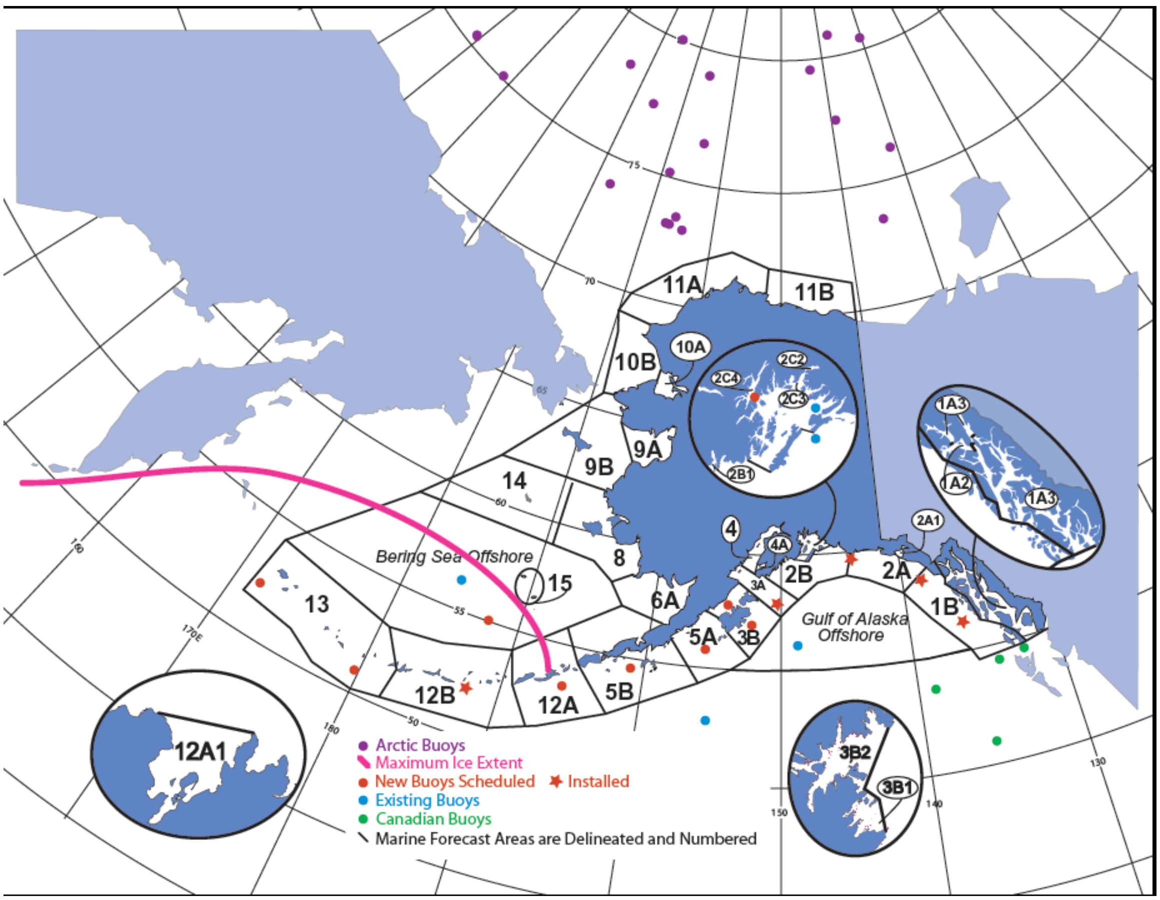


Fig. 25 Alaska Region area of responsibility.

7.1.1 Use and Impact of QuikSCAT Data in Alaska Region Forecast Offices

All three WFOs in Alaska rely heavily on satellite data, especially QuikSCAT. There are large areas of the coast and offshore with no buoys (there are only 13 buoys for all the waters around Alaska, Fig. 25) or other means of consistent, repetitive, surface observations. The main requirements of the marine community are winds and waves, and the QuikSCAT instrument provides critical real-time ocean vector winds that also provide information to derive ocean wind waves. In addition, critical information on sea ice is also provided by the instrument. The series "Deadliest Catch" on the Discovery Channel certainly demonstrates the importance of accurate wind, wave, and sea ice information to the fisheries.

Since 2001, the Alaska Region has shown a steady improvement in wind speed and significant wave height verification by 25% and 32%, respectively. This improvement is due to a combination of new buoys, better numerical model prediction (that uses QuikSCAT data), and real-time QuikSCAT information. The loss of the QuikSCAT information will certainly result in degradation of products and services not only to the marine community, but to the public as a whole. A unique use of the QuikSCAT data is to identify meteorological features in the ocean vector wind field, such as the location of storm centers and fronts that will eventually affect the inland weather.

7.1.2 Possible Impact of XOVWM on Alaska Region Operational Products

It is important to recognize that improvements to the marine forecast and warnings have been accomplished using 25 km ocean vector winds. The NWS Alaska Region has a requirement for much higher-resolution winds, especially in the complex coastal waters. For instance, in Southeast Alaska, much of the marine activity occurs in the inland waters where the vessels use the "Inland Passage." Although these waters appear at first to be protected, the islands contain high mountains, and there are major tidal current swings that can cause wind waves to stack higher. The 25 km QuikSCAT winds offer at most one data point along these inland passages. Ocean vector winds at 5 km resolution would provide sufficient information to assist the forecaster in making accurate and timely forecasts for these waters. In addition, 5 km resolution ocean vector winds would provide critical information much closer to the shore for Alaska's entire coastline. The higher-resolution winds would provide a more detailed look at the winds associated with marine storms that can reach hurricane force in Alaska. With newer technology, the forecaster would also obtain a full wind speed range that now cuts off at higher speeds with 25 km data. The high ocean vector winds would provide vital information between the few buoys that surround Alaska.

Last but not least, higher-resolution QuikSCAT data will greatly improve the sea ice information. The commercial fisheries prefer to set their nets and traps right at the sea ice edge. There is increased cruise ship traffic in the Arctic as sea-ice-free areas grow and the season lengthens. There is anticipated growth in marine transportation in the next few years as well. It is nearly impossible to put weather buoys in the Arctic where sea ice can destroy them. There will be nearly complete reliance on satellite-derived ocean vector winds and sea ice information.

7.1.3 Alaska Region Conclusions

The NWS Alaska Region fully supports the need for higher-resolution ocean vector winds. The benefits of this data have much greater implications than just for the Alaska Region. All NWS regions with coastal responsibility will benefit from this information.

Satellite-derived ocean vector winds fill the large gaps in between sparse point data platforms (buoys, ships). The density of high-resolution ocean vector winds is important because the data provide forecasters with a clearer picture of the conditions customers are experiencing, such as fetch distances, wind shifts, etc. And it's not just about the wind—even the rain-flagged "errors" provide some sense of where there is precipitation, which helps forecasters with analysis, model comparisons, and interoffice collaboration.

7.2 Southern Region Coastal Offices

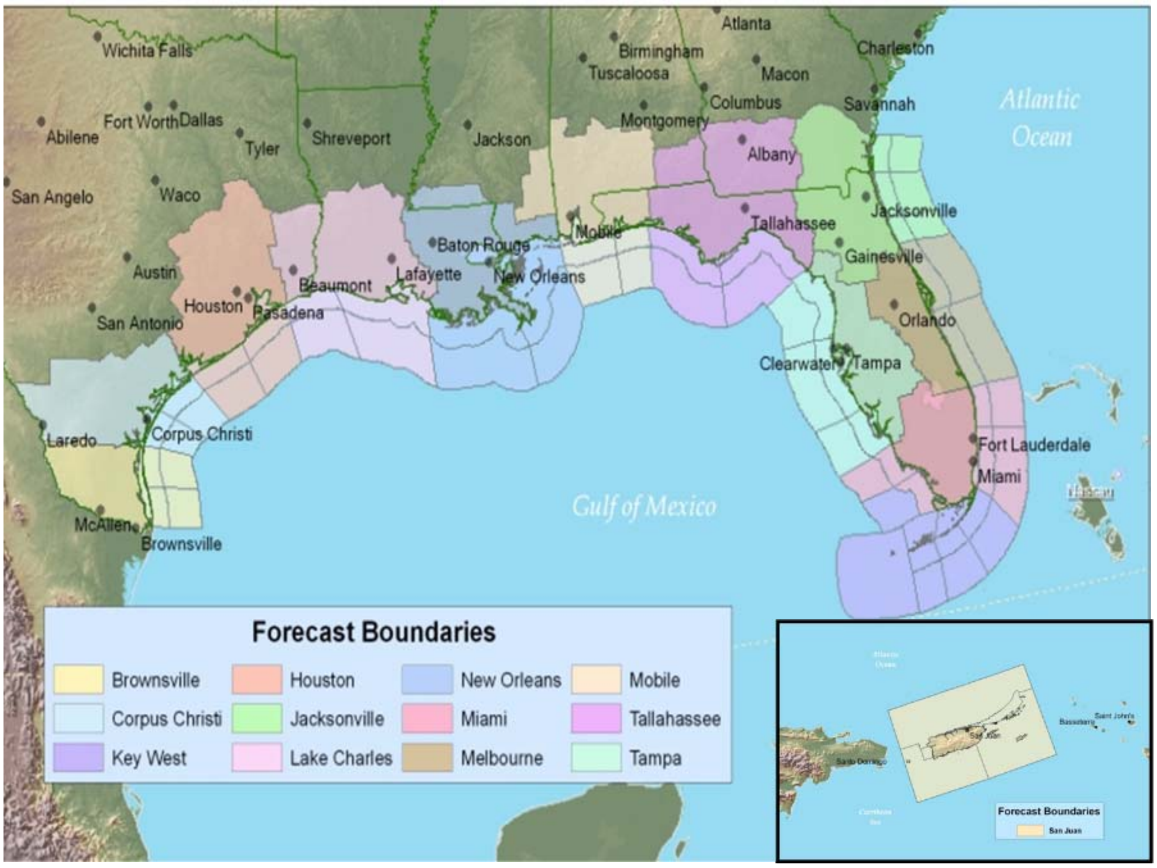


Fig. 26 Southern Region coastal WFO offices and areas of responsibility.

The Southern Region encompasses one quarter of the land of the contiguous United States and includes New Mexico, Texas, Oklahoma, Arkansas, Louisiana, Mississippi, Tennessee, Alabama, Georgia, Florida, the Commonwealth of Puerto Rico and the U.S. Virgin Islands in the eastern Caribbean. In this large area, 77 million people reside with more than 150 million visitors annually. In addition, the Southern Region's coastal responsibilities include major areas of the Gulf of Mexico, the Caribbean, and that portion of the Atlantic Ocean bordering Florida and Georgia (Fig.26). The Gulf of Mexico encompasses an area of about 600,000 square miles and is almost completely surrounded by the United States, Mexico, and Cuba. The Gulf of Mexico is a major asset to three surrounding countries, in terms of fisheries, tourism, agriculture, oil, infrastructure, trade, and shipping (Cato and Adams, 1999). Population along the Gulf Coast increased by 52% between 1970 and 1990, reaching 15.2 million people in 1990. The infrastructure for oil and gas production in the Gulf of Mexico (oil refineries, petrochemical and gas processing plants, supply and service bases for offshore oil and gas production units, platform construction yards, and pipeline yards) is concentrated in coastal Louisiana and eastern Texas. Oil production has a tremendous impact on the economy and other environmental and economic resources, especially since the Gulf of Mexico is a host to a multitude of oil and gas industries. There are nearly 1,600 outer continental shelf leases in production in the Gulf, comprising 97% of offshore production in the U.S. (Lynch and O'Brien, 2003)

Commercial fishing is an important component of the Gulf of Mexico's economy as well, contributing $707 million in 2002. The Gulf region contains one-fourth of the U.S. seafood processing and wholesale establishments. The Gulf of Mexico leads the nation in the level of recreational fishing and contains major shipping lanes with port facilities serving as important sources of employment. About $16 billion in yearly spending is generated by the millions of people who inhabit the coast in addition to the 25 million annual visitors. Many of the people living near the Gulf of Mexico coast are gainfully employed in such areas as fishing, oil and gas, maritime shipping, marine resources, or the tourism industry.

7.2.1 Use and Impact of QuikSCAT Data in Southern Region Forecast Offices

1) Along the Gulf Coast and the Atlantic Coast, QuikSCAT data is used to supplement the sparse coastal offshore observation network (i.e., buoys and Coastal-Marine Automated Network (C-MAN) stations). The lack of buoys makes the satellite wind data very useful.
2) WFOs routinely issue and amend coastal and offshore forecasts and warnings based on QuikSCAT data. This includes products specifically tailored for small craft and recreational boaters who are most at risk from adverse weather and who constitute far and away the greatest users of our marine products.
3) Winds over the coastal marine areas are difficult to predict with accuracy. Capturing events offshore that go undetected by the buoy network such as wind surges or coastal low level jets are what prompt WFOs to issue marine and small craft advisories and warnings. Likewise, QuikSCAT data helps prevent over-forecasting of conditions. In addition to being a safety issue, the accuracy of these routine forecasts affects the economy of coastal communities that are dependent on offshore industrial and recreational fishing. Most marine activity occurs well within 30 km of the coast. Of course this is the area currently masked by QuikSCAT. In this instance, while the QuikSCAT data is useful, the lack of data within 30 km of the coast leaves something to be desired.
4) QuikSCAT data either is or soon will be ingested into NWP models. Having the data available for the initial compilation of observed data is critical for ascertaining the most current and correct observed conditions for the initialization of the NWP models.
5) One of the inherent limitations of the current standard QuikSCAT product available is the inability to provide data within 30 km of the coast. Even with this inherent limitation, the

QuikSCAT surface data is still valuable. For example, the lowest elevation slice of the typical coastal WSR-88D is approximately 3,000 to 4,000 feet above ground level (AGL) at a distance of 20 km. The QuickSCAT surface vector wind data is still a great supplement to the radar data in this range when available and/or when buoy data or other fixed data sources are not available.

7.2.2 Possible Impact of XOVWM on Southern Region Operational Products

1) Certainly the most frequent perceived benefit of the advanced XOVWM scatterometer is the potential availability of surface vector wind data much closer to the coast. The current QuikSCAT masking of data within 30 km of the coast is precisely where most recreational boating occurs and where most marine deaths occur due to strong winds and associated large waves. Coastal topography plays a huge role in these events, and local effects are either not observed by QuikSCAT or are observed only peripherally.
2) With the Southern Region being the region most impacted by tropical activity, the XOVWM data would be invaluable in detecting the rapid intensification of tropical systems and associated winds and impacts within 20 km of the coast. For example, in the official products released by TPC, Tropical Cyclone Humberto officially became a hurricane at 05Z on 13 September 2007, about 10 miles southeast of High Island, Texas. However, in the NHC post-report, Humberto became a hurricane a little sooner based on closer examination of radar data: "*Radar data indicates that the tropical storm became a hurricane about 20 miles south of High Island, TX near 0400Z on 9/13/07….*" One can easily see where the critical intensification period occurred within and close to the coastal data cutoff region from QuikSCAT.
3) NWS WFOs are increasingly becoming inculcated with state and local Emergency Operations Centers (EOC). For example, during a landfalling tropical system, WFOs will be expected to brief state and local EOC personnel in real-time on potential impacts from the tropical system as it is occurring so they may better deploy resources for immediate post storm efforts to reopen major arteries to the coast for follow-up relief operations. Having an XOVWM pass with this detailed data available up to the coastline would assist WFOs in defining the radius of maximum winds (RMW) and local peak storm tide impacts for our customers. It would also allow the WFOs to issue local public warning products and statements that better fit the storm structure.
4) As part of the NWS' tactical meteorological support for our partners in the EOCs and first responders, the NWS is the primary federal agency responsible for providing meteorological information during hazardous material (Hazmat) spills along our coasts as well as oil spill forecasts. Having the XOVWM data available to the coast would support this initiative. Similarly, from a NOAA perspective, search and rescue (SAR) missions are synonymous

with the NOAA funded search and rescue satellite (SARSAT). The type of detailed information available in the XOVWM would be of great benefit in this core NOAA function.
5) Localized heavy rain events, which can dump 10 to 15 inches of rainfall in a short time along the coastal plains, are dependent upon the wind flow from the ocean establishing itself in a certain pattern. The detailed XOVWM data would help the WFO forecaster anticipate the low-level convergent bands while still offshore and assist in the issuance of flood watches and warnings.
6) Wind forecast verification over the marine area would likely be significantly improved by the XOVWM (two to four times per day). In addition, the satellite resolution would also match the Graphical Forecast Editor Real-Time Mesoscale Analysis (GFE RTMA) resolution.
7) Many WFOs have begun to investigate the utility of using/running mesoscale wave models. Incorporating the XOVWM data into such high-resolution models will result in a more accurate depiction of the current wind fields (two to four times per day), which, in turn, should lead to an increased accuracy of local wave forecasts.

7.2.3 Southern Region Conclusions

Compared to the current QuikSCAT capabilities, the Southern Region's coastal offices strongly prefer the increased capabilities of the Extended Ocean Vector Winds Mission (XOVWM) based on the information provided. The biggest benefit of the XOVWM is overwhelmingly the availability of wind data much closer to the coast. The current QuikSCAT data, while valuable as a supplemental source of coastal/offshore wind data, suffers from the land-masking of data within approximately 20 km of the coast. The timeliness of the passes (i.e., twice per day) is also not frequent enough to consistently and thoroughly resolve most significant wind events along the Gulf Coast or the Atlantic Coast.

Due to the shortcomings in the area of the timeliness of the passes, as mentioned above, many WFOs felt strongly that having two concurrent XOVWM satellites would be especially useful, providing data every 6 hours, rather than every 12 hours.

This expressed preference is based on the expectation, as described during our "Go To Meeting Video Conference," that the XOVWM option can be pursued with no impacts to other program areas.

7.3 Western Region Coastal Offices

Western Region coastal WFOs provide services to a wide variety of marine customers, including commercial and sport fishermen, recreational boaters, commercial vessels, the U.S. Coast Guard, local law enforcement agencies, other NOAA agencies (e.g., NOAA Fisheries and National Marine Sanctuaries), tourists, surfers, and local beach-goers. The areas of responsibility for the Western Region's coastal offices are shown in Fig. 27.

California ranks second only to Florida in the number of participants in coastal recreation (17.6 million participants). While California also ranks second to Florida in the percent of its population participating in some form of marine recreation (10.7% for Florida, 8.7% for California), its large population places California first in the nation in the number of residents that participate in marine recreation annually (12.2 million). Based on the 2000 participation estimates from Leeworthy and Wiley (2001), and an estimated value range of $75 to $200 per participant per day, the annual expenditures associated with recreational fishing in California ranged from $205 million to $545 million in the year 2000 (Pendleton and Rooke, 2006).

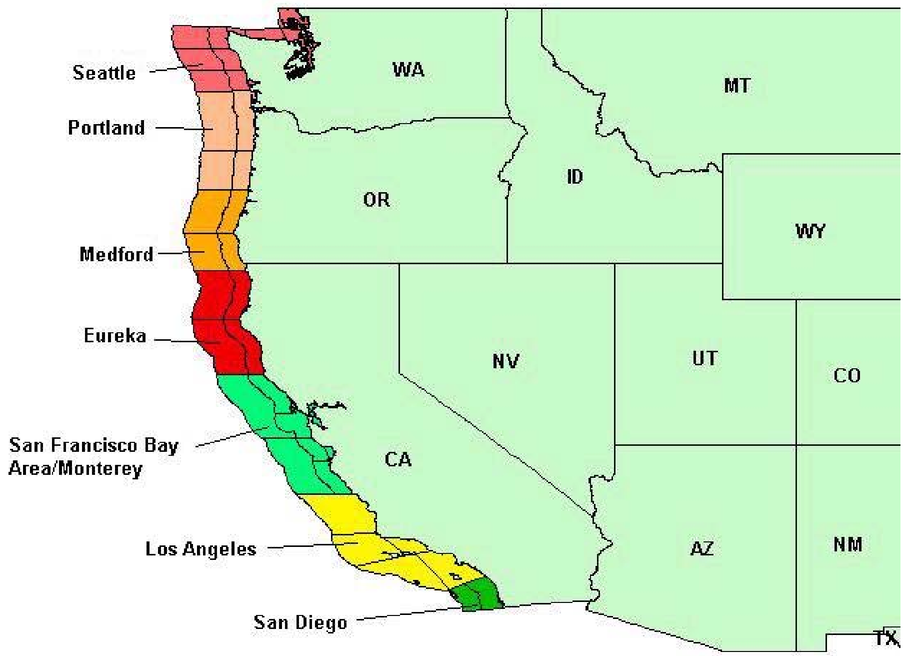


Fig. 27 Areas of responsibility of Western Region coastal forecast offices.

Fishing is the third most popular water-based recreation activity in the United States (after beach-going and swimming), and the fourth most popular coastal activity in California (Leeworthy, 2001). Recreational fishing also provides important economic benefits for states like California. As noted by Pendleton and Rooke (2006), recreational fishing in California (statewide) generates approximately $205 million to $545 million in expenditures related to fishing trips. As the population of California and the nation grows, so too will the number of people participating in recreational fishing. Leeworthy et al. (2001) estimate that participation in marine recreational fishing nationwide should increase by 12% in the year 2010 from 2000 levels.

7.3.1 Use and Impact of QuikSCAT Data in Western Region Forecast Offices

1) QuikSCAT data is mostly used in the Western Region as a supplement to the sparse coastal observation network (e.g., buoys, Automated Surface Observation Stations (ASOS), and Coastal-Marine Automated Network (C-MAN) stations). Surface wind data provided by QuikSCAT is important, due to the sparse nature of other marine surface weather data (e.g., buoys and ship observations).
2) However, most marine user activity occurs well within 20–25 miles from the coast, and this is the area currently masked by QuikSCAT. QuikSCAT data only overlaps portions of the Western Region's outer coastal waters (marine zones covering 20–60 nm from the coast). It is used to help verify marine wind advisories and warnings in the outer coastal waters (20–60 nm from the coast). However, QuikSCAT is of little help in issuing or verifying marine wind forecasts, advisories, and warnings in the inner coastal waters (0–20 nm from the coast), where most marine user activity occurs.
3) In Southern California, where marine user activity is heavy year-round, the current QuikSCAT data provides very little (if any) useful wind data in the coastal waters domain (0–60 nm from shore), due to the presence of the Channel Islands and associated coastal data masking.

7.3.2 Possible Impact of XOVWM on Western Region Operational Products

1) The most frequently cited benefit of an advanced scatterometer capability (i.e., XOVWM) among Western Region coastal offices regards the potential availability of surface vector wind data much closer to the coast (compared to the current QuikSCAT). Most West Coast marine user activity occurs within a few miles of the coast, which is well within the current QuikSCAT coastal masking area. Strong wind events are common on the West Coast in both winter (occasionally exceeding hurricane force) and summer (commonly up to gale force), yet the current QuikSCAT data masking prevents observation of winds close to the coast. This is also the area where most marine deaths occur, due to strong winds and associated large/steep waves. All Western Region coastal offices have noted the occurrence of significant coastal wind events close to shore at various times of the year, which are often influenced by coastal topography, such as coastal barrier jets, land-falling fronts, and eddies, which are either not observed or only peripherally observed by the current QuikSCAT. In most areas, the existing coastal observation network (e.g., buoys and C-MANs) is insufficient to consistently and reliably resolve these wind features.
2) QuikSCAT data masking is particularly severe in the Southern California Bight region due to the presence of the Channel Islands. Only a very small percentage of the coastal waters of Southern California are covered by the current QuikScat. Therefore, wind data provided by an advanced scatterometer capability (i.e., XOVWM) would provide (for all practical purposes) an entirely new source of wind observation data to the coastal waters along this portion of the California coast..

3) It would also provide additional wind data for other high-use coastal marine areas not currently covered by QuikSCAT (due to data masking), such as Strait of San Juan de Fuca, Puget Sound, San Francisco Bay, and Monterey Bay.
4) West Coast wind events are often brief and/or transitory in nature. Therefore, more frequent data (i.e., due to increased number of satellite passes), in concert with higher-resolution data closer to the coast, would greatly assist temporal and spatial resolution of such events.
5) Increased accuracy of wind data in areas of precipitation is also a perceived benefit, since strong winds often occur with winter season extra-tropical cyclones. Most recently, WR experienced winds in the coastal waters of the Pacific Northwest in early December 2007 in association with a major North Pacific storm system. More accurate scatterometer wind data would be highly beneficial in terms of supporting NWS forecasts and warnings in such events.

7.3.3 Western Region Conclusions

Western Region favors the increased capabilities of the Extended Ocean Vector Winds Mission (XOVWM) option, based on the recent simulation studies presented. In particular, the potential availability of wind data much closer to the coast is a potential major benefit of XOVWM. However, the Western Region's first priority is continuity of the current capability (as a minimum). Minimization of coverage gaps (i.e., if QuikSCAT fails) is also a priority. This desired capability is a function of development risk and cost (details were not available for this study). Therefore, potential trade-offs could not be addressed in considering the two primary options (QuikSCAT-equivalent instrument or XOVWM).

7.4 Eastern Region Coastal Offices

The Northeast region is the most populated coastal region in the United States. In 2003, 34% of the nation's total coastal population resided there. The areas of responsibility for the Eastern Region coastal offices are shown in Fig. 28.

Knowledge of the strength of the extratropical storms are of high importance for marine forecast services in Eastern Region field offices since these extreme storms impact southern New England coastal waters. Typically, these systems produce a strong low-level jet, but the presence of a marine inversion prevents the strongest winds from reaching the surface. Forecasters tend to rely on past experience in forecasting wind speed (i.e., gale warnings vs storm warnings) but do not have a solid handle on exactly how strong the winds are at the surface, due in large part to the sparse data network. A good example is the coastal storm that affected southern New England on April 15–17, 2007. This extratropical storm brought storm-force east-to-northeast winds as high as 58 knots to coastal waters, in addition to significant coastal flooding over several high tide cycles. Also, the Long Island Sound coastal waters are highly congested and vulnerable to local marine effect. Two areas of local concern are the "Race" located at the eastern end of Long Island Sound and the New York Bight at the entrance to New York Harbor.

A study by Kite-Powell and Colgan (2001) examined the potential economic benefits of coastal ocean observing systems concentrating on the Gulf of Maine and focusing on five important activities in that region: maritime commerce, commercial fishing, recreational fishing and boating, search and rescue, and pollution management, specifically oil spill management. Some 50 million short tons of maritime cargo move through US ports in the Gulf of Maine each year. More than 80% of this is oil and petroleum products. Gulf of Maine cargo represents about 4% of total US oceangoing cargoes. Oceangoing ships make use of information on currents, winds, and waves to optimize their routes for minimal transit time and exposure to severe weather. It has been found that 1% improvement of transit times would yield benefits of about $500,000 per year. Over 2,000 oil tanker and barge transits of the Gulf of Maine are made each year.

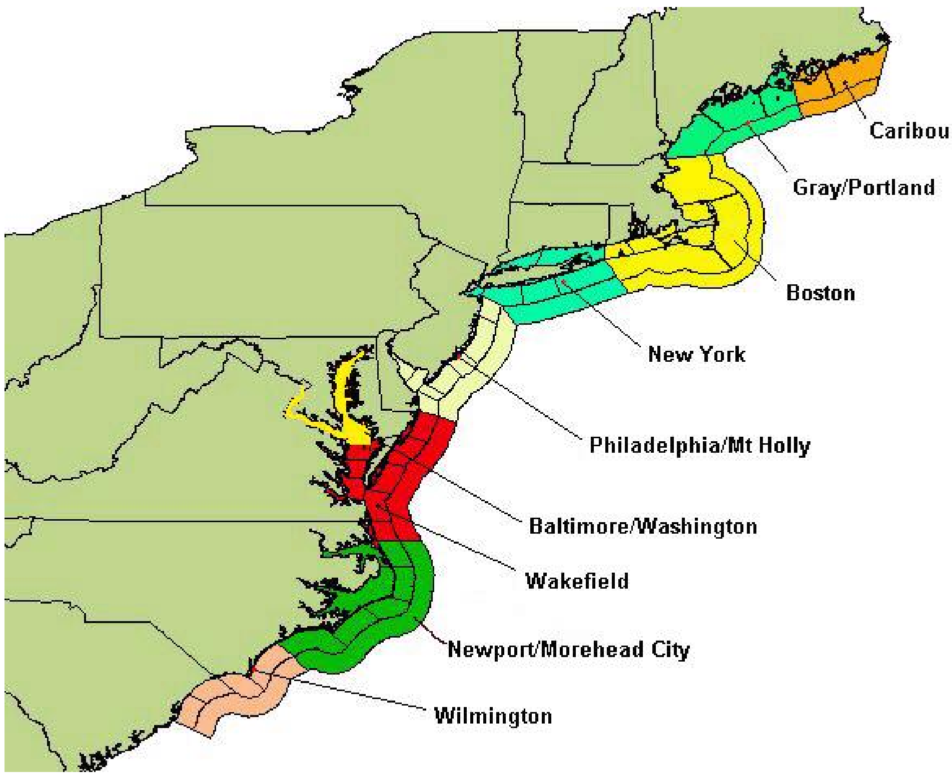


Fig. 28 Areas of responsibility of Eastern Region coastal forecast offices.

Portland, Maine is the largest oil port in the region, and the third largest (after New York and Philadelphia) on the East Coast. In addition to the activity on the US side of the Gulf of Maine, Saint John in New Brunswick is also a major oil refining and port center, where Very Large Crude Carriers (VLCC) service the largest oil refinery in Canada. The Gulf of Maine is a good example of an area at risk for oil spills. Accurate information of winds, waves, and currents in the region can greatly improve oil spill response and management time. It has been estimated that just 1% reduction in oil spills would lead to $750,000 savings in the Gulf of Maine alone (Kite-Powell and Colgan, 2001).

Currently, forecasters covering east shore marine zones rely on coastal buoys, MAREPS, and coastal mesonets for real-time information on winds and seas. However, the data set is sparse and does not always provide an adequate representation of conditions over coastal waters.

7.4.1 Use and Impact of QuikSCAT Data in Eastern Region Forecast Offices

Use of QuikSCAT data by forecasters is limited and used more on a case-by-case basis. Generally, late data, poor temporal resolution, and the lack of nearshore data make the data set hard to use operationally. This is particularly true for use over the Great Lakes. Nonetheless, forecasters do try to make use of the data. Forecasters on the Atlantic coast rely on QuikSCAT data to:

1. Supplement the limited observed data that are available over the coastal waters, especially during significant events such as extratropical storms during the cool season and for approaching tropical systems during the tropical season.
2. Verify model forecasts in the short term, which is critical to warning decision making.
3. Help them during occasional situations where the wind vectors over the Gulf of Mexico are useful.

Thus, a QuikSCAT-equivalent system would continue to provide some limited benefits toward enhancement of marine forecast services.

As an aside, one of the biggest uses of polar orbiter datasets is for ice cover (using MODIS) over the Great Lakes (this is discussed further below).

7.4.2 Possible Impact of XOVWM Data on Eastern Region Operational Products

The simulations suggest tremendous potential for improving wind and wave forecasts in our coastal waters, especially with the finer spatial resolution and coastal coverage.

1) Improving wind and wave forecasts over coastal waters is a high priority. Most recently, a number of coastal offices have implemented a nearshore wave model (SWAN), which is driven off NAM or GFS surface winds. The addition of XOVWM analyses would greatly improve the wind forecasts, especially in situations where low-level jets come into play. Other than using observed sounding data, forecasters have no way to verify model data as an event is taking place. This is crucial in the warning decision-making process. Improved wind fields associated with convection would also be useful.
2) Another potential application deals with coastal flooding. Some coastal offices are involved with other NOAA offices to develop coastal inundation models to be used to predict the severity of coastal flooding during winter storms. Eventually, these models could be used to provide routine water level forecasts to assist navigation or coastal habitats. One critical input is accurate wind data, of which XOVWM would be of great importance.
3) Data integration is important. Great Lakes offices would like to see wind data that could be coupled with ice coverage data. Any additional information that can aid in determining ice growth and decay on the Great Lakes would be very beneficial. Denser wind data

along and closer to the shoreline would be beneficial because this is where the ice typically forms first.

4) The increased spatial resolution and coastal proximity would increase the use of the data if both the latency and the frequency were improved. For instance, the data needs to be at the office within an hour of when it was received, and it is needed four times a day (accomplished by two identical satellites in complementary orbit). The data could then be used for real-time location of critical ocean boundaries as they move onshore, as well as currently undetected surges in wind.

7.5 Central Region – Great Lakes

The Great Lakes Region is the third most populated coastal region in the United States. In 2003, 27.5 million people, or 18%, of the nation's total coastal population resided there (Crossett et al., 2004).

Several National Weather Service Warning and Forecast Offices are tasked with the issuance of forecasts and warnings for the Great Lakes. These responsibilities, detailed in National Weather Service Instruction 10-312 (http://www.nws.noaa.gov/directives/sym/pd01003012curr.pdf), include routine wind and wave forecasts, small craft advisories, and watches and warnings for gales and storms when certain wind or wave thresholds are forecasted to be met or exceeded.

Forecast areas are divided between nearshore zones that extend from the coast out to 5 nautical miles (nm), and the Open Lake zones, which are larger segmented areas extended from 5 nm offshore to mid-lake (Fig. 29). The division at 5 nm offshore is made because significantly different wind and wave conditions typically occur near the coast, and this is where the vast majority of mariners are found. It is believed that dramatic differences occur far closer to the coast than 5 nm, but this can't be observed in real time.

Accurate weather forecasts heavily depend upon observations of the state of the atmosphere and the underlying surface. A forecaster is better able to diagnose current weather when there is access to more accurate, detailed, and frequent observations. Such observations also improve NWP models by giving them a better depiction of the initial state of the atmosphere.

Currently, routine observations in the Great Lakes come from the National Data Buoy Center and the Great Lakes Environmental Research Laboratory (GLERL). Unfortunately, coastal observations are least likely to represent wind conditions over the water because of land breeze/lake breeze circulations, surface roughness differences, and other factors. Also, coastal marine observation sites are not able to measure wave conditions or ice coverage.

The few available buoys measure winds and waves, but they exist only near the center of the lakes. Consequently, only a few open lake zones contain single point measurements of winds and waves, and none of the nearshore zones has buoy observations. Furthermore, buoys are removed during the winter to prevent potential damage from ice, resulting in no routine wind or wave observations over the Great Lakes for a brief period each year.

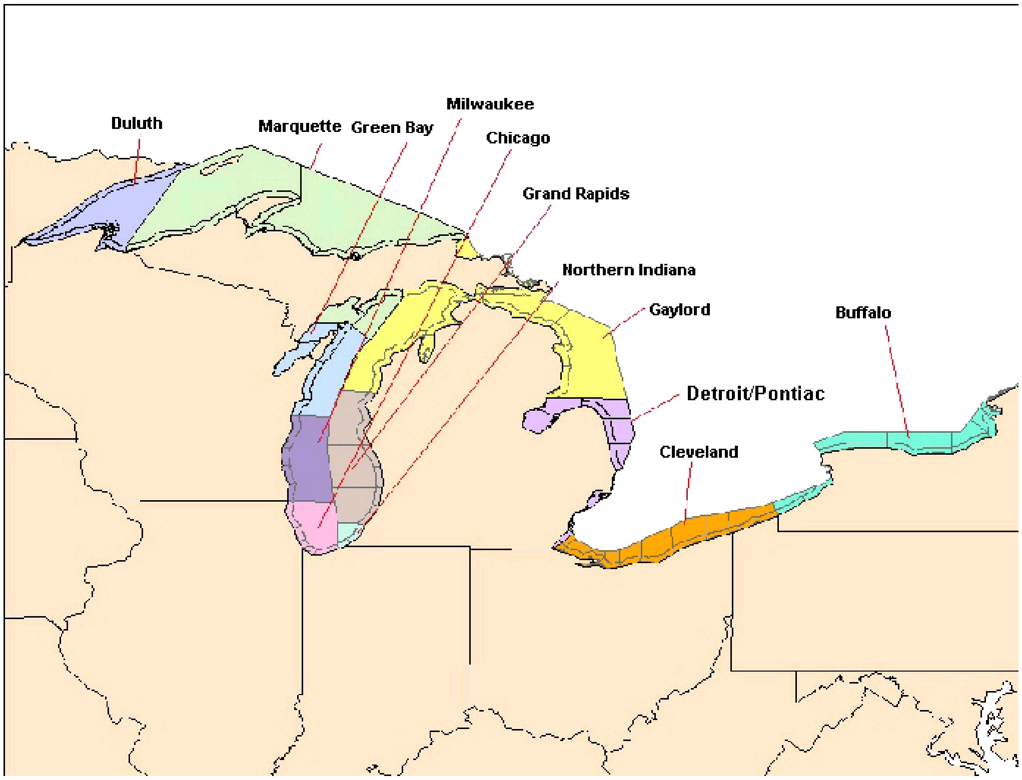


Fig. 29 Marine areas of responsibility for the western Great Lakes. Marine zones are depicted by the narrow black lines over the lakes.

Other routine observations used for monitoring the Great Lakes include web cameras (webcams) at the coast to infer winds from observed wave heights and Doppler radar. Located along the coast, webcams offer limited utility for reasons already stated. Doppler radar gives a fair representation of precipitation, but due to increased radar beam height at increasing range, winds can be inferred only at a height of several thousand feet above the lake surfaces.

Finally, nonroutine observations come in the form of moving maritime reports (i.e., ships with weather observing equipment) and public mariner reports (MAREPs). These reports often contain critical wind and wave information but, unfortunately, they are infrequent, sporadic, and typically don't occur within critical areas of interest.

7.5.1 Use and Impact of QuikSCAT Data in Great Lakes Forecast Offices

1) More accurate updates to short-term forecasts, warnings, and advisories are possible by combining data from QuikSCAT instrument with buoys and other nonroutine wind observations.
2) The QuikSCAT winds provide a way of assessing the accuracy of high-resolution NWP model forecasts (e.g., the Great Lakes Coastal Forecasting System,

http://www.glerl.noaa.gov/res/glcfs/) and NDFD grids over the lakes for a variety of situations.

3) Specific phenomena, such as lake/land breeze circulations, wind shift lines associated with fronts, and winds from mesoscale convective complexes (i.e., thunderstorm clusters) are sensed directly when data is available.
4) During offshore wind events our coastal sensors tend to see a sheltering effect as the winds lift up over the ridge. Wind advisories and warnings are seldom verified due to this sheltering effect. Satellite-based winds such as those from QuikSCAT give an idea of how far out the stronger winds begin to mix down.

7.5.2 Possible Impact of XOVWM Data on Great Lakes Operational Products

Each WFO with Open Lake forecast responsibilities will see a vast improvement in the spatial coverage of wind observations over the lakes. Instead of inferring winds between the buoys and the coastal marine stations, the instrumentation will provide a spatially continuous field of wind data, which will help the Great Lakes WFOs to collaborate their forecasts better, resulting in a more coherent and accurate NDFD forecast.

Terrain-induced flow is common over Great lakes. With XOVWM measurement this phenomenon would be better represented and understood, allowing added detail in forecasts. This is specifically true for the Green Bay Wisconsin office, whose marine forecast area is highly terrain influenced. Their forecast area includes the waters of the Bay of Green Bay and Lake Michigan off northeastern Wisconsin coast. A situation in which this new technology would help is with strong offshore flow that is prevalent during the fall and winter months. Running along the lakeshore of Door County south through Manitowoc County is a ridge line with a significant part of the shoreline characterized by bluffs.

The Bay of Green Bay is relatively shallow and tends to freeze up early and fast. The National Ice Center (NIC) tends to be slow on ascertaining the amount of ice on the bay, often due to prevalent cloud cover. The ice analysis produced by the NIC is put into AWIPS and is used in running local wave models both here and at GLERL. An inaccurate ice analysis leads to bad wave forecasts and over-forecast wave heights. QuikSCAT-equivalent or XOVWM can potentially provide additional, much needed ice data over Great Lakes

Annual discussions with commercial fishing personnel indicate that winds and waves in the nearshore and open waters of Lake Michigan are routinely over-forecast during the spring months. Windy conditions tend to only be seen along the immediate coast. The cold waters tend to stabilize things in the boundary layer. The buoys are not redeployed until late April. XOVWIM would give us actual wind data during these months.

Each WFO with Great Lakes marine responsibility creates forecasts of winds and waves over part of the Great Lakes in a gridded format with 5 km^2 spatial resolution and up to hourly temporal resolution. These grids are combined nationally with forecasts from all WFOs to form a

National Digital Forecast Database (NDFD discussed at http://www.weather.gov/ndfd/). The 5 km^2 spatial resolution is identical to that offered by the Extended Ocean Vector Winds Mission (XOVWM) instruments, as opposed to the 25/12.5 km resolution offered by QuikSCAT.

Each WFO with nearshore forecast responsibilities would be provided data never available before due to the current mask imposed by QuikSCAT. The impact should be tremendous. It is likely that many previously unobserved details in the wind will be uncovered, resulting in new local studies, better expertise in the WFO's area of responsibility, more accurate forecasts, and more meaningful warnings and advisories.

7.5.3 Central Region Conclusions

Compared to the current QuikSCAT capabilities, Central Region Great Lakes offices will see a vast improvement in the spatial coverage of wind observations over the lakes from the proposed Extended Ocean Vector Winds Mission (XOVEM). Specifically, offices with nearshore wind and wave forecast and warning responsibility will receive observations that are unavailable from QuikSCAT today due to QuikSCAT's coastal mask. Central Region Great Lakes offices, therefore, prefer the XOVWM based on the information provided and believe this advanced observing capability will result in improved services in both the nearshore and open waters forecasts and warnings.

8 The Increasing Need for OSVW Measurements for NWP Data Assimilation

Satellite surface wind data improve numerical weather prediction (NWP) model forecasts in several ways. OSVW data:

- Contribute to improved analyses of the surface wind field and, through the data assimilation process, atmospheric mass and motion fields in the free atmosphere above the surface.
- Provide important verification data for NWP model forecasts.
- Drive ocean models and surface wave models to calculate surface fluxes of heat, moisture, and momentum, and to construct a surface climatology.

8.1 Use and Impact of QuikSCAT Data in NWP models

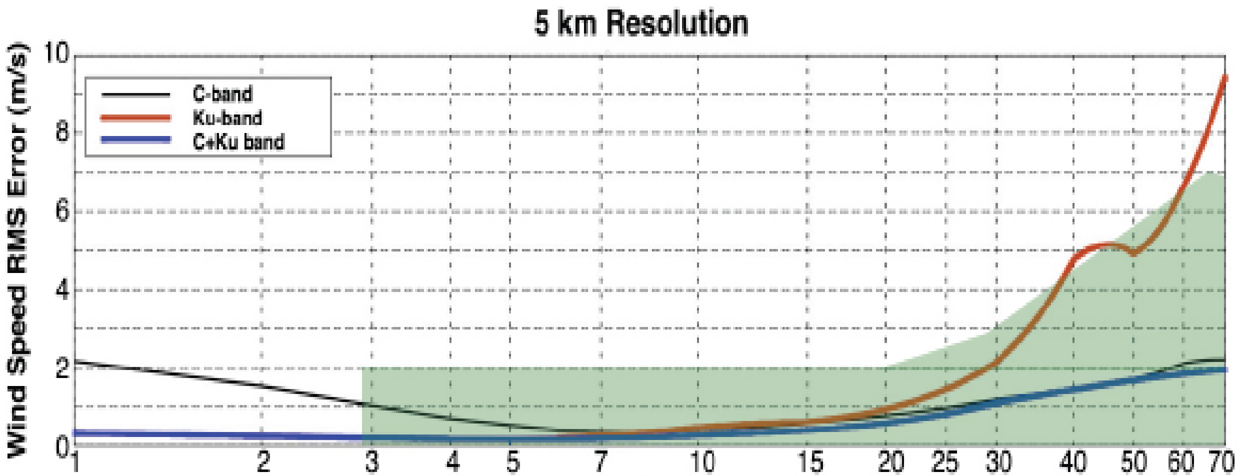
NCEP began assimilating QuikSCAT data into its global model on 15 January 2002, and preliminary data assimilation experiments (Yu, 2003 and Yu and Gemmill, 2004) demonstrated a positive impact. A preliminary data assimilation experiment was conducted for a forecast period from 2 October to 10 November 2001. The experiment involved 40 forecasts generated for a 45-day run of the NCEP Global Data Assimilation System (GDAS), and QuikSCAT data were utilized at a spatial resolution of approximately 100 km and within 3 hours of the assimilation time. The study results showed improvement in wind speed estimates in one- to three-day forecasts. The percentage of improvement spanned from 2.7% to 16%, with most values falling between 6% and 9%.

Today QuikSCAT data are assimilated into models run by the following national and international centers:

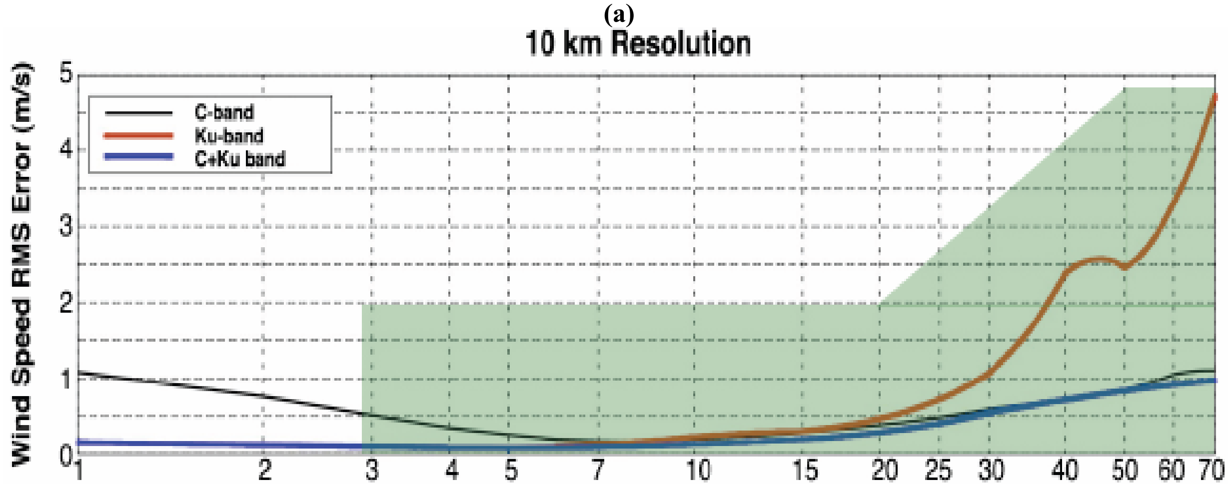
- U.S. NWS (GFS)
- U.S. Navy (NOGAPS)
- ECMWF
- UKMET
- MeteoFrance
- Japan Meteorological Agency
- Deutscher Wetterdienst, Germany
- Meteorological Services of Canada, Environment Canada
- High Resolution Limited Area Model, HIRLAM, regional (Denmark, Sweden, Finland, Netherlands, Iceland, Denmark, Ireland, Spain, and Norway)
- Norwegian Meteorological Institute
- Danish Meteorological Institute
- Royal Netherlands Meteorological Institute
- Australian Bureau of Meteorology
- Dept. of Science & Technology, Government of India
- Hong Kong Observatory
- Meteorological and Hydrological National Service, Peru
- CPTEC/INPE, Brazil
- Korea Meteorologica Administration
- China Meteorological Administration and First Institute of Oceanology, China

Different data assimilation impact studies performed on operational systems show positive effects raging from 1–16% for short-term forecasts

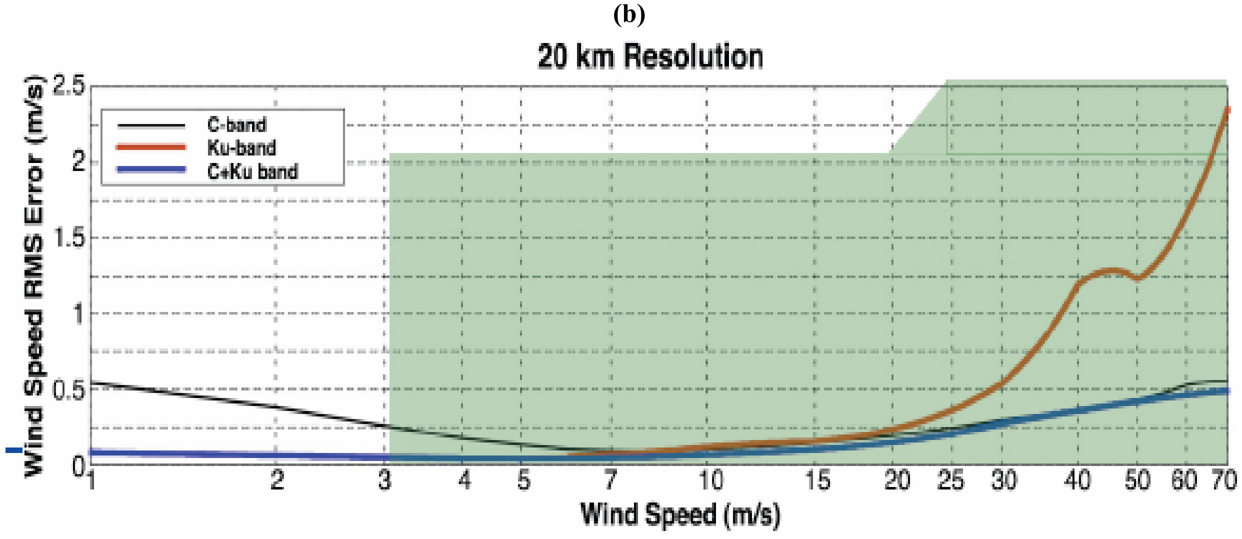
- An initial NCEP model impact study showed a 7% average improvement in wind speed estimates for one- to three-day forecasts: (Yu et al., 2003, 2004)
  - 3-8% improvements in 24–96 hours of 10 meter wind speed, 2-17% improvements in sea level pressure in mid-latitudes, and 2-7% improvement was obtained in tropical surface wind forecasts. These improvements were consistently seen from the RMS errors of first guess, and day 1 to day 5 forecasts in the mid-latitudes as well as in the operational global tropics, when QuikSCAT wind data were used in the GDAS.
- An initial NCEP track forecast study performed on a limited set of Atlantic tropical cyclones from 2003 showed that when QuikSCAT data were removed, 48-hour track forecasts were degraded by an average of 10%, and 72-hour track forecasts were degraded an average of 16%. However, there was a slight improvement in the 24-hour track forecasts when QuikSCAT data were withheld (Zapotocny et al., 2008). (A more comprehensive study is ongoing to test the impact on a larger sample of storms. However, the data assimilation scheme being utilized is the same and not much impact is expected.)



(a)



(b)



(c)

Fig. 30 Wind speed RMS error for OSVW products at 5 km (a), 10 km (b) and 20 km (c). The plot indicates that if lower resolution products are created from high-resolution measurements, RMS measurement error would decrease significantly, up to four times from the 5 km to 20 km product.

- A study using the U.S. Navy's NOGAPS model and data assimilation system performed on much larger data sample during the 2004 Atlantic hurricane season found little significant improvement of the track forecasts due to the inclusion of QuikSCAT OSVW beyond 24 hours, where an improvement of 3% was seen (2% improvement at 48 hours, and slight degradation at 72–120 hours) (Goerss and Hogan, 2006).
- A UK Met Office study involving QuikSCAT data assimilation showed a positive effect of approximately 3% on short-range forecasts of sea level pressure out to 72 hours, especially in the Southern Hemisphere (Candy and Koegh, 2006).
- A very limited storm track study by the UK Met Office showed a positive effect of QuikSCAT data (11% for one particular storm) (Candy and Koegh, 2006).
- Atlas et al. (2001, 2005) summarized the significant beneficial impact that scatterometer data have had on NASA NWP model forecasts, as well as the early QuikSCAT experiments that were conducted with both the NASA and NCEP NWP models. For the case of Hurricane Cindy, the 60-hour forecasts of track and intensity with QuikSCAT were found to be more accurate than the 24-hour forecast without QuikSCAT data.

Different NWP models employ different data assimilation schemes and direct comparison of their results is not possible, but the overall conclusion is that OSVW data have a positive effect on operational NWP models. However, all data assimilation experiments show that the positive effect of OSVW measurements is directly related to the measurement accuracy. Fig. 30 shows how measurement error can be significantly reduced if lower-resolution OSVW retrievals (i.e., 20 km) are obtained from high-resolution 5-km measurements of XOVWM.

XOVWM and QuikSCAT-equivalent simulation study results were presented to AOML and the Joint Center for Satellite Data Assimilation (JCSDA) during December 2007. While it was not possible to perform data assimilation experiments to quantify the impact that higher-resolution data would have on numerical models, general comments were obtained.

During a meeting with Lars Peter Riishojgaard, director of JCSDA, he indicated that while the operational global weather prediction model in the 2014 time frame won't be able to take advantage of high-resolution OSVW product from XOVWM, the lower-resolution but higher-accuracy OSVW product (Fig. 24) that could be generated from XOVWM measurements would have a positive impact on data assimilation in the NCEP global model.

8.2 Use and Impact of QuikSCAT Data at AOML

AOML and its partners currently use QuikSCAT data in its ocean, weather, and climate research. The QuikSCAT data has been extremely valuable in studies of:

- ocean chemistry and the carbon cycle,
- ocean circulation,
- weather phenomena over the ocean,
- air-sea interaction, and

– in the development of high-resolution global and regional models. For the latter application, QuikSCAT was one of the primary data sets used to validate 28 km and 14 km resolution global model simulations.

In general, QuikSCAT data is superior to all of the other available ocean surface wind data sets, but it is still limited by its resolution, range of measurement, and the effects of rain. The XOVWM would be substantially more useful and would be needed for the development, initialization, and validation of the higher (~1 km) resolution models that are needed to improve hurricane intensity forecasting and other applications.

9 Other Uses of OSVW Data from QuikSCAT at NOAA

9.1 Aviation Weather Forecasting and QuikSCAT

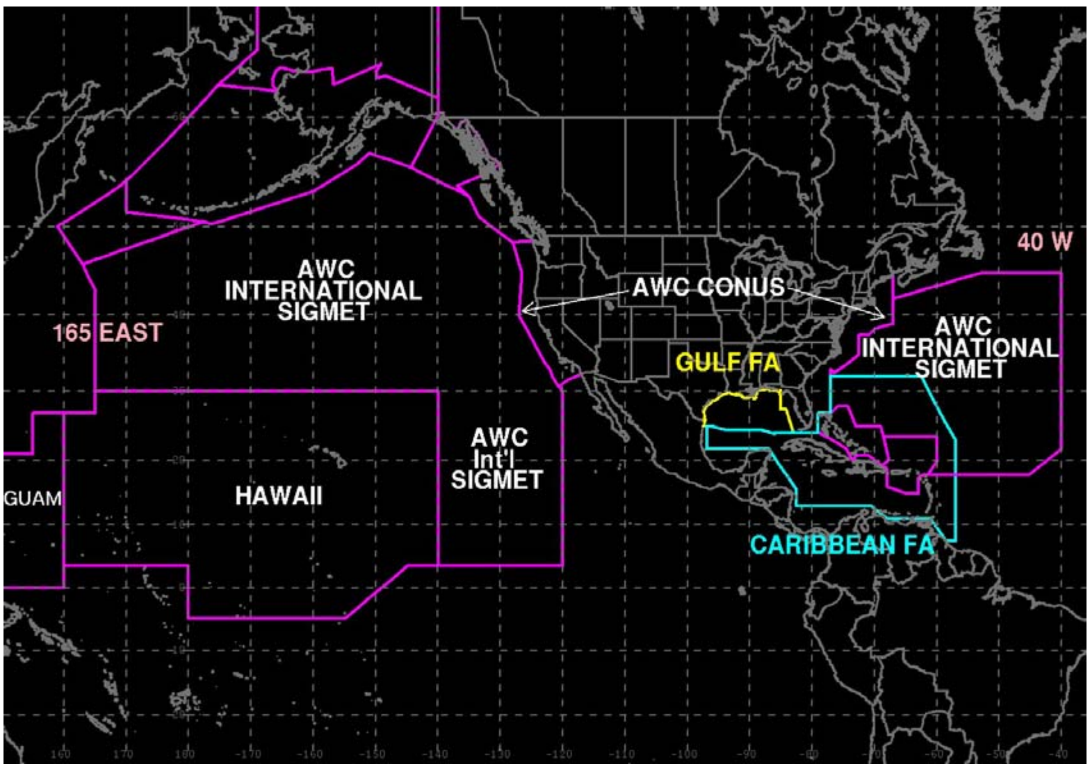


Fig. 31 AWC areas of responsibility.

With the mission of saving lives, protecting property, and enhancing the economic productivity of the national airspace, the Aviation Weather Center (AWC) issues warnings, forecasts, and analyses of weather hazardous to aviation. These efforts support the Federal Aviation Administration Air Traffic Control (ATC) responsibility to safely and efficiently manage the national airspace. The AWC is a source for domestic and international aviation forecasts and warnings (Fig. 31). These products are an integral part of an overall aviation program of the National Weather Service that also includes terminal and en route forecasts provided by local NWS offices, and weather information for air traffic management is provided by Center Weather Service Units. The AWC is a major component of the U.S. World Area Forecast Center (WAFC) and is an international Meteorological Watch Office. As such, the AWC incurs a mutual backup responsibility with the other WAFC center in Exeter, England. Each office covers an overlapping two-thirds of the globe. The resulting products are furnished as an obligation of international treaties.

The AWC issues a suite of products for the aviation community to ensure safe and efficient operations. Area forecasts are issued for six geographical areas three times daily and contain a brief synopsis of the position and movement of fronts and surface pressure, as well as clouds and other weather conditions.

- SIGMET advisories are issued to notify pilots, dispatchers, and air traffic controllers of nonconvective severe weather conditions of concern to all aircraft operating at or below 45,000 feet.
- Airmen's Meteorological Information (AIRMET) advisories are issued for weather phenomena less severe but still hazardous especially to single-engine and light twin-engine aircraft.
- The Collaborative Convective Forecast Product (CCFP) provides a single convective forecast for strategic planning of en route aircraft operations within the National Airspace System. The CCFP aids in air traffic flow management decisions including the reduction of traffic delays, rerouting, and cancellations due to convective weather.
- Convective SIGMETs are in-flight advisories for thunderstorms that are especially hazardous to aviation.

Information regarding these products is available at http://aviationweather.gov/static/info/pdf/AWC%20Brochure.pdf.

AWC uses QuikSCAT OSVW in N-AWIPS operationally for the following products:

1. Domestic AIRMET TANGO: low-level turbulence, surface winds greater or equal to 30 knots, and low-level wind shear in coastal waters
2. Domestic AIRMET SIERRA: instrument meteorological conditions over coastal waters and the Great Lakes
3. Gulf of Mexico Area Forecasts (west of 85 W): surface winds greater or equal to 20 knots, fronts and boundaries, convection and convective potential
4. Caribbean Area Forecasts: surface winds greater or equal to 20 knots, fronts and boundaries, convection and convective potential
5. Domestic Convective SIGMET: fronts and boundaries, convection and convective potential
6. Domestic Collaborative Convective Forecast Product (CCFP): fronts and boundaries, convection and convective potential
7. International SIGMET (Atlantic to 40 W, Pacific to 165 E): fronts and boundaries, convection and convective potential
8. NCEP model guidance from the GFS, NAM, and RUC, which incorporate QuikSCAT wind vectors in their analyses

9.2 El Niño Watch and QuikSCAT

The El Niño Watch is a monthly production of the West Coast Regional Node. It was started in January 1992, in response to the onset of El Niño conditions in the equatorial Pacific. One of the main El Niño indicators for the U.S. West Coast is the presence of warmer-than-average surface water (http://coastwatch.pfel.noaa.gov/elnino.html).

In an El Niño year, the easterly wind weakens and the equatorial upwelling is suppressed. The thermocline (a zone in the water column that shows a sudden change in temperature with depth) "flattens" and warm surface water surges eastward. The nutrient supply from the cold, deeper water is not tapped. The easterly wind retreats and the westerly wind rushes the convection process to the east of the International Date Line. This displacement of the convection causes a change in traditional rainfall patterns and the release of large amounts of latent heat into the atmosphere. The subsequent energy propagates within the atmosphere, affecting the weather in various ways and places and disrupting the normal rhythm of life across the Pacific Ocean. The ability to accurately predict El Niño would be of great benefit to countries around the world.

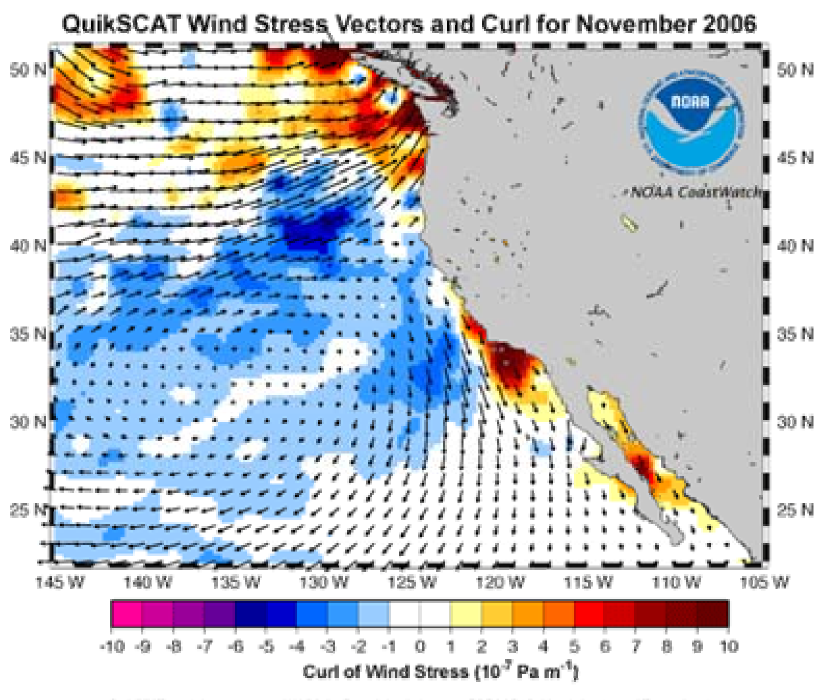


Fig. 32 NOAA's El Niño watch implemented QuikSCAT Wind Stress Vectors and Curls product as one of the ENSO prediction tools in 2005.

NOAA's El Niño watch implemented the QuikSCAT Wind Stress Vectors and Curls product as one of ENSO prediction tools in 2005 (Fig.32). QuikSCAT data are proved to be very useful for detecting the onset of El Niño. The onset is indicated as 180º wind direction change at wind speeds between 5 and 7 meters/second. A study by D. Chen (2003) showed that the wind product that includes satellite scatterometer data, used to initialize an intermediate ocean-atmosphere coupled model for ENSO prediction, has the highest scores. To calculate accurate spatial derivatives good spatial resolution is highly desirable. Therefore, this program would highly benefit from high-resolution XOVWM OSVW retrievals.

9.3 Coral Reef Watch and QuikSCAT

The mission of NOAA's Coral Reef Watch Program is to utilize remote sensing and in situ tools for near real-time and long-term monitoring, modeling, and reporting of physical environmental conditions of coral reef ecosystems. Coral Reef Watch aims to assist in the management, study, and assessment of impacts of environmental change on coral reef ecosystems.

Coral Reef Watch is an integral part of NOAA's Coral Reef Conservation Program, which supports effective management and sound science to preserve, sustain and restore coral reef ecosystems. The conservation program is a partnership between the NOAA Line Offices working on coral reef issues, including the National Ocean Service (NOS), the National Marine Fishery Service (NMFS), the Oceanic and Atmospheric Research (OAR) and the National Environmental Satellites and Information Service (NESDIS).

Each day, QuikSCAT provides both an ascending pass (6:00 a.m. LST equator crossing) and descending pass (6:00 p.m. LST equator crossing). A composite of these twice-daily passes are assembled on an approximately 0.25 x 0.25 degree global grid (Fig. 33). NOAA's CoastWatch, together with the Southwest Fisheries Science Center's Environmental Research Division, then compiles four-day running means of these data and provides them to NOAA Coral Reef Watch via the Ocean Watch Live Access Server. NOAA Coral Reef Watch then uses these data to identify regions of low wind conditions defined here as exhibiting a four-day mean of < 3 m/s and described as "doldrums." The duration of these doldrums events is then tracked by accumulating the number of days over which this condition is met (doldrums days). This product is still undergoing development and analysis to determine the best configuration for the algorithm and to test its utility against past bleaching events.

While basin-scale coral bleaching occurs as a result of large-scale climate phenomena, local weather patterns greatly influence bleaching variability among sites within the basin. Three related factors that influence local bleaching patterns are temperature, light, and mixing. One parameter that exerts a common influence to all of these is wind. As wind speed falls there is reduced vertical mixing, evaporative cooling, and sensible heat transfer, increasing the likelihood of adverse temperature excursions during summer time maximum water temperatures (Mumby et al., 2004, and Obura, 2005). In addition, the pronounced stratification that can result under low-wind conditions can enhance the photo-degradation of colored dissolved organic material, thereby reducing shading (Manzello et al., 2006).

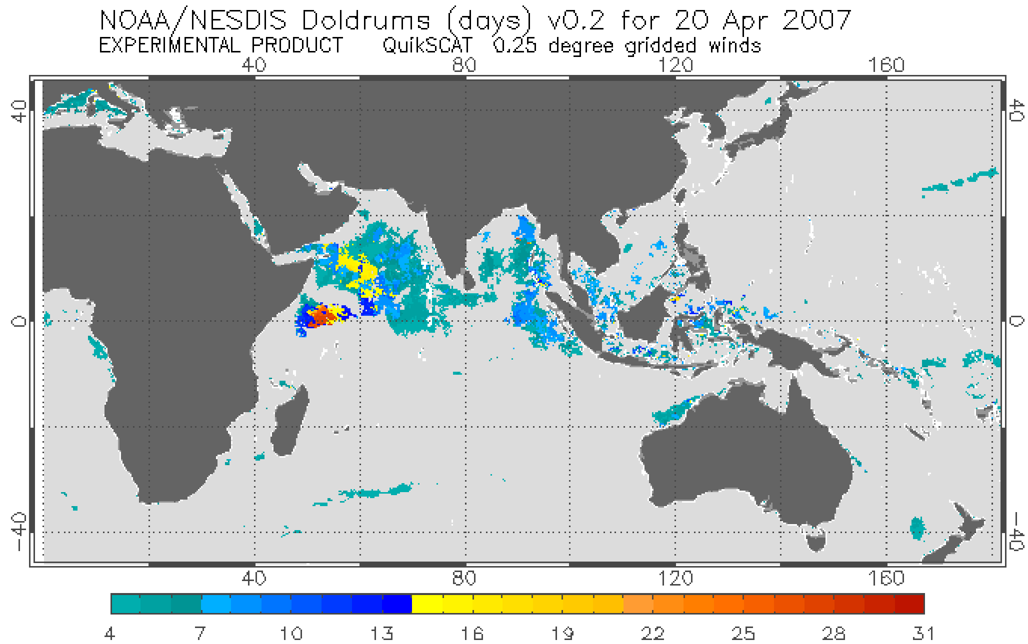


Fig. 33 A composite of these twice-daily passes of QuikSCAT OSVW data are assembled on an approximately 0.25 x 0.25 degree global grid and used to identify regions of low wind conditions.

10 QuikSCAT and Sea Ice Monitoring and Forecasting – User Impact

Although QuikSCAT was originally designed to measure ocean surface wind vectors, its data have proven useful to the ice services for sea ice and other cryospheric applications. For example, the development of enhanced nonocean scatterometer imagery and data products was supported early under a NASA Earth Science Enterprise grant, the Scatterometer Climate Record Pathfinder (SCP) project, which has been made widely available for use by the research community (Long et al., 2001).

10.1 National Ice Center Hemispheric Monitoring

The U.S. National/Naval Ice Center (NIC) is a unique interagency operational center with oversight from the Departments of Commerce, Defense, and Homeland Security. The NIC is operated through an exemplary partnership between components of these departments, namely, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Navy, and the U.S. Coast Guard (USCG), respectively. The NIC is the only operational ice analysis and forecasting center in the world with global responsibilities. The NIC has collaborated with NASA in QuikSCAT research activities since data became available and have used QuikSCAT imagery operationally for over five years. The wide-swath and high-temporal-resolution QuikSCAT backscatter data provide for large spatial coverage suitable for daily hemispheric mosaics. These QuikSCAT mosaics have proven to be a unique source of information for the routine delineation of the sea ice edge, complementing sparse higher resolution SAR observations, and tracking of Antarctic icebergs.

10.2 Anchorage Weather Forecast Office Ice Desk

The NWS Anchorage WFO staffs an ice desk that produces graphical analyses of sea ice and five-day sea ice forecasts year round for the Alaskan waters. Daily QuikSCAT ice images such as shown in Fig. 34 are used to help create the graphical products and are also used directly. In fact, these images have proven invaluable in building user confidence in the analyses graphics by providing an actual picture of the ice edge. These users include commercial fishing which is big business in the Bering Sea, where the landings from Alaskan waters account for half of the U.S. marine harvest. The native community also utilizes the daily QuikSCAT ice images to build confidence in the graphical analyses products they use for commerce purposes between the North Slope Borough and Canada. Marine trade often occurs between the communities as far east as Sachs Harbor on Banks Island and the Amundsen Gulf long before the marine route is open from the Chukchi Sea.

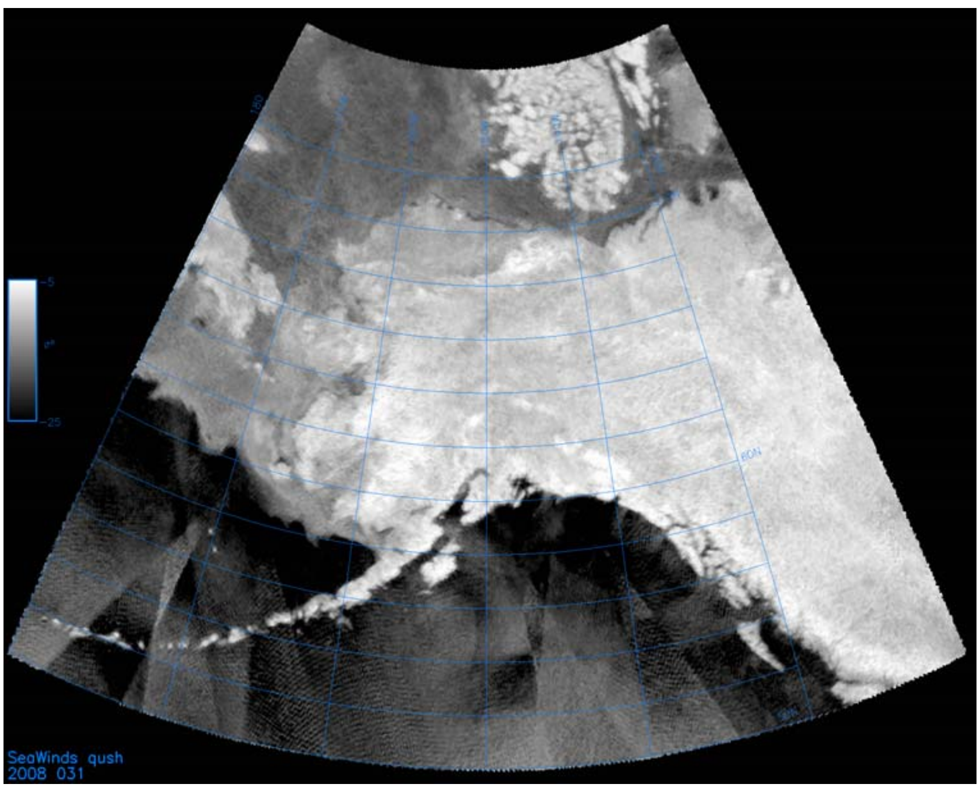


Fig. 34 A daily QuikSCAT ice image from January 31, 2008 covering the Alaskan region.

10.3 Global QuikSCAT Sea Ice Products and IPY Contributions

Although QuikSCAT was originally designed to measure ocean surface wind vectors, its data have proven useful to the ice services for sea ice and other cryospheric applications. For example, the development of enhanced nonocean scatterometer imagery and data products was supported early under a NASA Earth Science Enterprise grant, the Scatterometer Climate Record Pathfinder (SCP) project, which has been made widely available for use by the research community (Long et al., 2001). The NIC is using QuikSCAT data in support of numerous field experiment campaigns over the Arctic as well as Antarctic Ocean Regions as part of the International Polar Year (IPY) 2007-2008. QuikSCAT sea ice products are providing useful information to plan and successfully carry out IPY field campaigns. These efforts can certainly be enhanced with a NRT ability to obtain QuikSCAT sea ice products at the NIC for operational customers. Conversely, field observations and measurements from such campaigns are being used for verification and validation of sea ice products derived from QuikSCAT data.

10.4 New QuikSCAT Sea Ice Products

The latest addition of NASA JPL's experimental automated sea ice products that can be uniquely obtained from QuikSCAT data has proven invaluable in capturing recent record changes in the Arctic sea ice regime. The NIC is presently collaborating with JPL to fully develop and implement the operational use of these new sea ice products, which include ice classes and sea ice melt/freeze conditions. In fact, the near real-time (NRT) availability of these sea ice products is becoming critical for the operational characterization of the high Arctic given limitations of other available data sources including SAR to monitor unprecedented changes occurring near the North Pole. Algorithms are also being developed by JPL and NOAA GLREL to map different lake ice types (Nghiem and Leshkevich, 2003), although the spatial resolution of the present scatterometer becomes a limiting factor.

10.5 Key QuikSCAT Observations

The increasing importance of scatterometer sea ice applications has been underscored by NASA's funding of the ROSES 2006 IPY proposal entitled "The State of Arctic Sea Ice Cover: Integrated Decadal Satellite Observations of Properties and Processes in a Changing Environment." As part of this proposal, JPL is optimizing sea ice scatterometer algorithms to map different sea ice classes over the Arctic through reanalysis of the QuikSCAT time series and will produce refined automated sea ice geophysical parameters that can be used operationally. The NIC has strongly endorsed this effort and look forward to continued participation in the development of NRT processing technology for a suite of QuikSCAT sea ice products and to the transition of the processing into NIC operations.

The extension of the QuikSCAT mission and the new sea ice scatterometer applications have proven and will continue to be extremely beneficial to the NIC, NASA, and to the nation. For example, reprocessing of the 1999 to 2005 QuikSCAT time series for sea ice classification produced a unique record that captured the diminishing Arctic multiyear and summer sea ice extent conditions leading to a record minimum in 2005 (Nghiem et al., 2006). In particular, QuikSCAT sea ice products showed the extent of winter perennial sea ice (multiyear, old and thick ice class) decreasing in the East Arctic by nearly one half with an abrupt reduction of 0.96×10^6 km^2, while the West Arctic slightly gained by 0.26×10^6 km^2 between 2004 and 2005. This imbalance of the perennial ice distribution in 2005 resulted in a net decrease in the total perennial ice extent of 0.70×10^6 km^2, an area equivalent to the size of Texas as reported by Nghiem et al. (2006).

The importance of these findings was recognized by AGU, which identified the research as an AGU journal highlight paper. NASA and NOAA press releases were also produced in August 2006 highlighting these results.

10.6 Continued Need for Scatteromer Sea Ice Products

A second paper based on QuikSCAT sea ice products captured new MYI record minimum conditions in 2007 as shown in Fig. 35, leading once again to the truly unprecedented summer sea ice extent minimum record experienced by the Arctic that year (Nghiem et al., 2007) in monitoring and short-term sea ice forecasts.

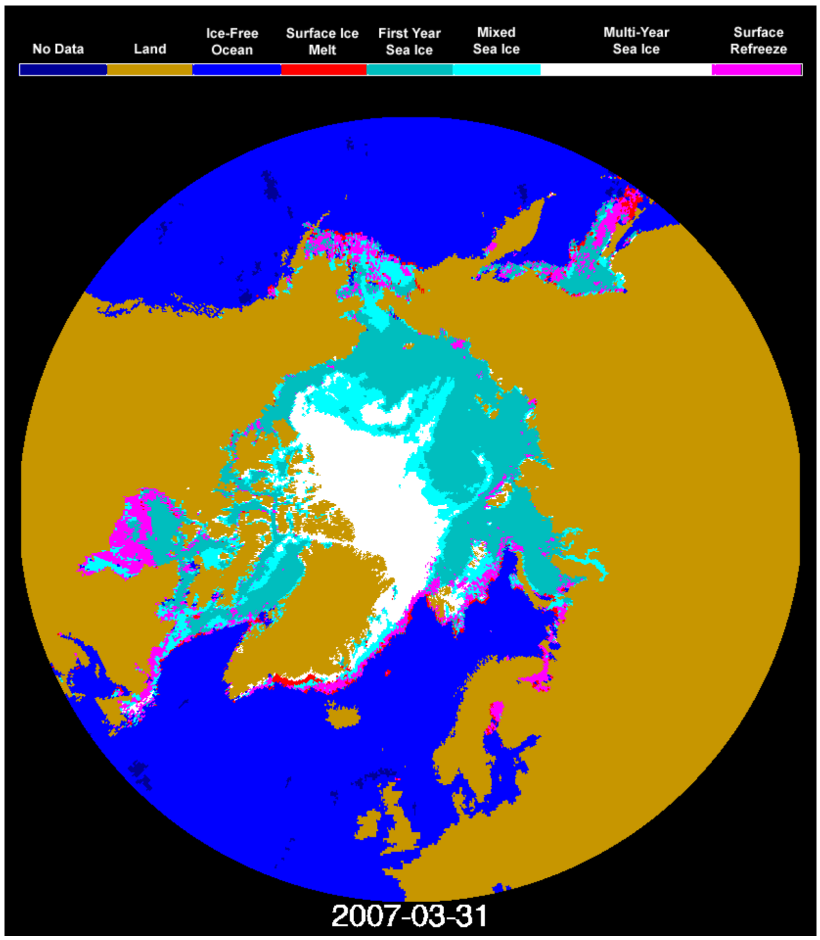


Fig. 35 Experimental NASA/JPL QuikSCAT sea ice classification product indicating an extremely low extent in the winter distribution of Arctic multiyear ice by March 31, 2007, five months before the 2007 summer minimum sea ice extent record was observed.

The extent of Arctic perennial sea ice cover was significantly reduced between March 2005 and March 2007 by 1.08 x 10^6 km^2, a 23% loss going from 4.69 x 10^6 km^2 to 3.61 x 10^6 km^2, as observed by QuikSCAT. In addition to confirming sea ice model observations, QSCAT observations revealed mechanisms contributing to the perennial-ice extent loss: ice compression toward the western Arctic, ice loading into the Transpolar Drift (TD) together with an acceleration of the TD carrying excessive ice out of Fram Strait, and ice export to Baffin Bay. Again, a major NASA press release was produced in October 2007 highlighting these results. As ice extent decreases, QuikSCAT native capability is providing complementary information on wind vectors and other atmospheric features over increased areas of ice-free ocean surface in the Arctic Ocean. Combined use of scatterometer sea ice observations and winds are increasingly proving to be a powerful tool for both NRT

10.7 Exploiting Unique QuikSCAT/XOVWM Capabilities

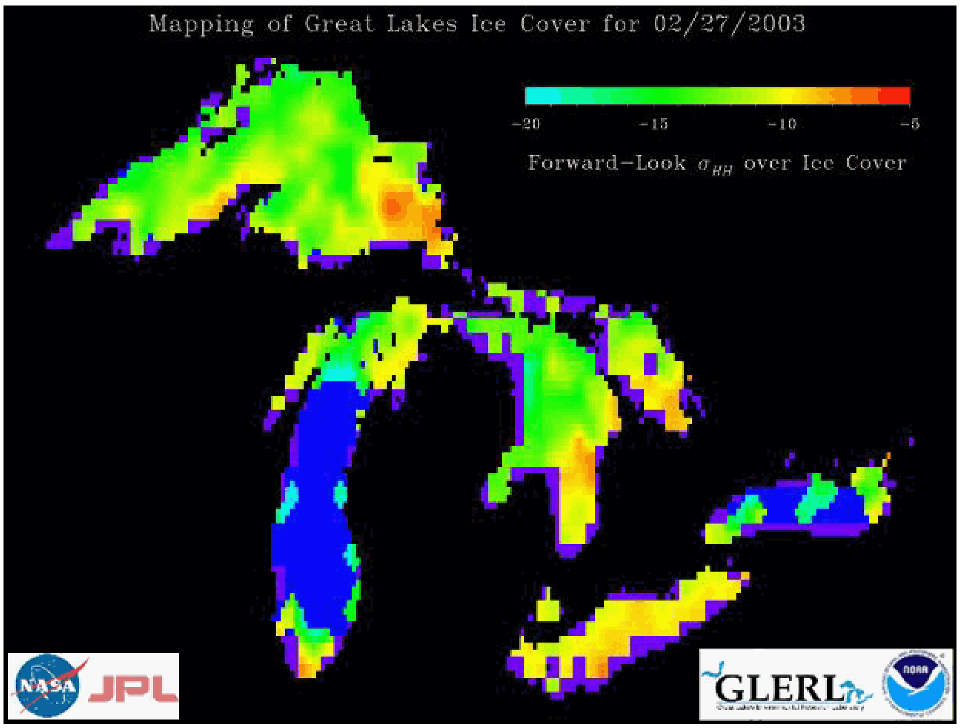


Fig. 36 Mapping of Great Lakes ice cover using QuikSCAT scatterometer measurements (Nghiem and Leshkevich, 2003).

One of the major changes in sea ice distribution has occurred in 2007 with the migration of the MYI-seasonal ice line to the North Pole Region. Seasonal sea ice has not been historically observed at the North Pole. Because of the blind spot produced by the key active and passive observing systems used to monitor Arctic sea ice, the presence of this MYI-seasonal ice interface cannot be properly monitored. Using V-pol QuikSCAT beam to identify and map sea ice classes, the blind spot issue has been addressed to provide monitoring of this newly observed phenomena. The increased resolution of the proposed XOVWM scatterometer along with its multi-frequency use will further improve the monitoring and forecasting of ice impacted ocean regions globally. While SAR is the imagery of choice for sea ice analysis, the XOVWM SAR imaging capability will provide NIC with unique high-resolution polar coverage that will fill in for less available SAR imagery as well as provide for significant automated sea ice classification improvements. The high-resolution (12.5 km) wind and ice measurements in the Great Lakes using QuickSCAT scatterometer data have been developed and validated (Fig. 36). Building on existing knowledge and experience, these existing products could be improved taking advantage of the higher resolution and perhaps a new combined open water wind and ice product developed.

11 Summary

The QuikSCAT follow-on user impact study presented here engaged a broad spectrum of ocean surface vector wind users from NOAA's operational weather forecasting and warning communities. The main objective of this effort was to assess the user impacts of OSVW data from a QuikSCAT follow-on mission, where the two options being considered are a QuikSCAT-equivalent mission and a more advanced system referred to as the extended ocean vector winds mission (XOVWM). Understanding the user impacts of both mission options are essential in helping NOAA determine the best path forward in transitioning a satellite OSVW capability from a research capability to a sustained operational capability. These impacts will used in conjunction with the cost, technical readiness, and schedule estimates from the QuikSCAT follow-on mission option study that JPL is conducting for NOAA. The summary of impacts that two mission options would have on different NOAA programs and its applications are shown in Table 4. Impacts were defined relative to instrument performances and its capabilities to provide information necessary for full application product support in order to fulfill different NOAA program mission goals.

Table 4. Impact of QuikSCAT-equivalent and XOVWM capability on different NWS applications across variety of NOAA programs.

Application		QuikSCAT-like	XOWVM
Marine Weather	High Seas	M	H
	Off shore	M	H
	Coastal wind	L	M-H
	Coastal swell	L-M	H
Tropical Cyclones	Intensity	L-M	H
	Genesis	M	H
	Location	M	H
Real-Time Diagnostics	Wind	M	H
	Swell	M	H
	Extratropical storm surge	M	H
	Inland Impact	L	H
Climatology	Extratropical cyclone	H	H
	Wind	H	H

Low impact – performance below threshold identified for satisfactory application product support

Medium impact – performance between threshold and objective requirements needed for full application product support

High impact – performance close or at objective requirements necessary full application product support

The results of the user impact studies show that the XOVWM mission would **greatly enhance** the detection and warning capability across a wide range of weather phenomena for **nearly all** of the NWS coastal, offshore, high seas, and Great Lakes marine areas of responsibility. An XOVWM capability would yield significant benefits over a QuikSCAT-equivalent capability in: Tropical cyclones:

- More reliable estimates of tropical cyclone intensity through all stages of development, from depression to major hurricane.
- Improved analysis of the tropical cyclone wind field structure (34, 50, and 64 kt radii) which will yield more refined watch/warning areas for the coast.
- More accurate tracking of tropical cyclone centers, earlier identification of developing systems, and more accurate initial motion estimates as input into model guidance.

Extratropical cyclones

- Greatly improved detection of tropical cyclone development, intensity and the evolution of wind fields associated with extratropical transition. This results in significantly improved tropical cyclone warnings for both tropical and extratropical coastal areas.
  - More than 95% of the U.S. international trade by volume is transported by ships throughout the world's oceans. Weather hazards, particularly the strong winter ocean storms that reach hurricane-force (HF, >63 knots) wind strength and can produce 100-foot waves over the open ocean, are a major threat to the safety and efficiency of marine transportation.
- More accurate tracking of nearshore conditions resulting in more accurate short-range marine forecasts, advisories, and warnings.

Coastal regions and Great Lakes:

- Availability of surface vector wind data much closer to the coast (2.5–5 km)
  - Marine coastal zones are divided into inner (within 0–20 nm) and outer (20–60 or 100 nm) zones. Most coastal marine user activity occurs within a few miles of the coast. This is also the area where most marine deaths occur, due to strong winds and associated large/steep waves.
  - This would benefit coastal forecasts and provide important observational information to coastal ocean models.
- Significantly better definition of coastal wind features including orographically induced or enhanced low level jets
  - This, again, improves the safety in the coastal waters where the bulk of recreational boating and fishing activities take place.
- Terrain-induced flow better represented and understood, allowing added detail in forecasts
- Significantly better definition of ocean forcing for areas such as upwelling along coastlines

In summary, all NWS marine forecast offices would have the benefit of twice-daily remotely sensed OSVW across their coastal, offshore, and high seas areas of responsibility. This would provide a consistent frame of reference for the WFOs, OPC, and NHC in the issuance of warnings and forecasts. More timely and accurate OSVW data would be available in the coastal waters, which would translate into improved safety in coastal waters where the bulk of recreational boating and fishing activities take place. All offices would prefer the advanced OSVW capability (XOVWM) versus a QuikSCAT-equivalent solution providing that the technical risk, cost, and readiness prove to be adequate for an operational mission.

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13 Table of Acronyms

AFWA	Air Force Weather Agency
AIRMET	Airmen's Meteorological Information
AOC	Aircraft Operation Center
AOML	Atlantic Oceanographic and Meteorological Laboratory
ASCAT	(EUMETSAT) Advance Scatterometer
AWC	Aviation Weather Center
AWIPS	Advance Weather Interactive Processing System
CCFP	Collaborative Convective Forecast Product
CL	Climate
C-MAN	Coastal-Marine Automated Network
CMR	Coastal and Marine Resources
CPHC	Central Pacific Hurricane Center
COA	Climate Observations and Analysis
CORL	Consolidated Observation Requirements List
CRP	Climate Record Pathfinder
CT	Commerce and Transportation
EC	Ecology
ECMWF	European Center for Medium-Range Weather Forecasting
EMC	Environmental Modeling Center
ENSO	El Niño-Southern Oscillation
EOC	Emergency Operations Centers
ER	Eastern Region
FNMOC	Fleet Numerical Meteorology and Oceanography Center
GLERL	Great Lakes Environmental Research Laboratory
GFS	Global Forecast System
GMF	Geophysical Model Function
GSD	Global System Division
HAZMAT	Hazardous Material
HF	Hurricane Force
HFIP	Hurricane Forecast Improvement Project
HFS	Hurricane Forecast System
HRD	Hurricane Research Division
IMS	Information Management System
IPY	International Polar Year
IWRAP	Integrated Wind and Rain Airborne Profiler
IWTC	International Workshop on Tropical Cyclones
JAG/TCR	Joint Action Group for Tropical Cyclone Research
JCSDA	Joint Center for Satellite Data Assimilation
JPL	Jet Propulsion Laboratory
JTWC	Joint Typhoon Warning Center
LAPS	Local Analysis and Prediction System
LFW	Local Forecasting and Warnings

MAREPS	Mariner Reports
MetWatch	Meteorological Watch program at NOCC
MOD	Modeling
MS	Mission Support
MSAS	Mesoscale Surface Assimilation System
MWX	Marine Weather
NAM	North American Mesoscale Model
NASA	National Aeronautics and Space Administration
NAWIPS	National Advance Weather Interactive Processing System
NCAR	National Corporation for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDFD	National Digital Forecast Database
NESDIS	National Environmental Satellite, Data, and Information Service
NHC	National Hurricane Center
NIC	National Ice Center
NMFS	National Marine Fishery Service
NOAA	National Oceanic and Atmospheric Administration
NOCC	Naval Oceanographic Command Center
NOGAPS	Navy's Operational Global Atmospheric Prediction System
NOSA	NOAA Observing System Architecture
NPOESS	National Polar-orbiting Operational Environmental Satellite Systems
NRC	National Research Councilor
NWA	National Weather Association
NWP	Numerical Weather Prediction
NWS	National Weather Service
OAR	Oceanic and Atmospheric Research
OPC	Ocean Prediction Center
OST	Office of Science and Technology
OSVW	Ocean Surface Vector Winds
RTOFS_ATL	Real Time Ocean Forecast System-Atlantic
QSR	QuikSCAT Replacement
TAFB	Tropical Analysis Forecast Branch
TC	Tropical Cyclone
TD	Transpolar Drift
TPC	Tropical Prediction Center
UKMET	United Kingdom Meteorology
UTC	Coordinated Universal Time
USCG	United States Coast Guard
USGS	U.S. Geological Survey
SALEX	Saharan Air Layer Experiment
SAR	Synthetic Aperture Radar
SFMR	Stepped-Frequency Microwave Radiometer
SIGMET	Significant Meteorological Information
SR	Southern Region

SWAM	Shore Wave Model
WAFC	World Area Forecast Center
WMO	World Meteorological Organization
WFO	Weather Forecast Office
WR	Western Region
WRF	Weather Research and Forecast
WW	Weather and Water
XOVWM	Extended Ocean Vector Wind Mission