

QuikSCAT Impacts on Coastal Forecasts and Warnings: Operational Utility of Satellite Ocean Surface Vector Wind Data

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(Manuscript received 15 October 2007, in final form 21 February 2008)

ABSTRACT

This study reports on the operational utility of ocean surface vector wind (SVW) data from Quick Scatterometer (QuikSCAT) observations in the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Weather Forecast Offices (WFOs) covering the coastal United States, including island states and territories. Thirty-three U.S. coastal WFOs were surveyed, and 16 WFO site visits were conducted, from late summer 2005 to the 2005/06 winter season, in order to quantify the impact of QuikSCAT SVW data on forecasts and warnings, with a particular focus on operations affecting marine users. Details of the survey design and site visit strategies are described. Survey results are quantified and site visit impressions are discussed. Key findings include (i) QuikSCAT data supplement primary datasets and numerical weather prediction fields, in the manual production of local public (weather) and marine forecasts and warnings; (ii) operational utility of satellite SVW data would be enhanced by SVW retrievals of finer temporal resolution, closer to the coasts; and (iii) rain flags in the SVW data have little impact on utility for WFO operations.

1. Introduction

The research value of satellite ocean surface vector wind (SVW) data has been well established over more than a decade of published work, across a broad range of studies. What is also emerging is that these data play essential roles in many operational applications as well, including (i) numerical weather prediction (NWP) and (ii) the manual production of forecasts, analyses, and warnings by trained analysts (i.e., forecasters). SVW impacts in NWP have been highlighted recently by Chelton and Freilich (2005). Impacts of SVW at the National Oceanic and Atmospheric Administration/Ocean Prediction Center (NOAA/OPC) were quantified in surveys reported by Von Ahn et al. (2006). Illustrative case studies of recent positive SVW impacts on high-seas forecasts issued by OPC were presented by Chelton et al. (2006; see also references therein). Chang and Jelenak (2006) summarize the conclusions of a June 2006 workshop on the broad range of operational utility of SVWs at NOAA, including hurricane

applications at the Tropical Prediction Center (TPC). This study complements the previous work by focusing on SVW impacts in day-to-day operations at coastal Weather Forecast Offices (WFOs) of the National Weather Service (NWS).

a. WFO operations

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.). Forecasters are trained for the specific responsibilities at each desk, and they rotate on a locally determined schedule from desk to desk within each WFO. A typical partitioning of forecast and warning responsibilities might include desks with specific focuses on local weather (sometimes called the public forecast desk), aviation, and marine issues. For coastal WFOs with larger than normal areas of responsibility (e.g., Juneau, Alaska; Honolulu, Hawaii; etc.) there can be a "satellite" desk that serves near-real-time (NRT) imagery needs for the other desks within the WFO.

The forecaster shift at a given desk includes several

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reporting deadlines for issuing analyses, forecasts, and possibly generating, updating and/or canceling warnings. Analyses, forecasts, and warnings are conceived, and often automatically generated from graphical displays in the Interactive Forecast Preparation System (IFPS), which is a tool within the Advanced Weather Interactive Processing System (AWIPS; for an introduction to IFPS, see the Web site www.weather.gov/ndfd/ifps2.htm; for background information on AWIPS, see the Web site www.nws.noaa.gov/ops2/ops24/awips.htm and related links). The AWIPS environment can be customized by each forecaster according to personal preferences and/or as needed for particular meteorological events. Forecasters can choose to overlay analysis and forecast fields with observations from a variety of sources, including SVW data from QuikSCAT. Alternatively, NRT SVW data from QuikSCAT are displayed on another monitor, adjacent to the AWIPS station. In this alternative case, the NRT SVW data are usually accessed from the NOAA/National Environmental Satellite, Data, and Information System (NESDIS) Web site (<http://manati.star.nesdis.noaa.gov>). The NRT SVW data are made available on the Web site within 3 h of a QuikSCAT overflight. An additional latency might be introduced in the transfer from NOAA/NESDIS to AWIPS displays at coastal WFOs. However, this potential delay did not arise as an issue in surveys and observations of WFO operations.

In IFPS, forecasters work with interactive graphical displays to adjust isolines on maps handed forward from the previous forecast shift. Gradients are sharpened or weakened to provide better agreement with current observations and the latest NWP forecasts. Once a map has been manually updated, an automatic text generator is used to provide an initial interpretation, and the forecaster edits this text before releasing the given product (e.g., a zone forecast, a 1-day marine forecast, or warning, etc.) to the public. The overlay–edit–text generation cycle runs continuously at each desk.

b. SVW data

Specifics of scatterometer SVW retrievals are carefully elucidated for the SeaWinds scatterometer that operates on QuikSCAT in the Algorithm Theoretical Basis Document by Freilich (1996). In broad overview, radar signals of precisely known properties (e.g., frequency, amplitude, polarization, and geometry with respect to the ocean surface target) are emitted from a spacecraft in low-earth orbit. These signals are scattered by gravity–capillary wave roughness elements on the ocean surface that are known to be in equilibrium with the shear stress imparted on the ocean by the sur-

face wind. The backscatter signals are detected at the spacecraft (so-called radar backscatter cross sections, σ_o) and carefully referenced to earth surface locations from which they emanate. Composites of the georeferenced σ_o (i.e., over so-called wind vector cells or WVCs) are used to retrieve SVW data via a geophysical model function. The area of the WVC impacts the number of σ_o entering each SVW retrieval, and this defines the spatial resolution of the SVW data. The QuikSCAT data have been provided at 25-km resolution for the duration of the mission, and most applications make use of QuikSCAT data at this resolution.

A 12.5-km resolution SVW product was introduced experimentally and, as of mid-2006, has become a standard QuikSCAT product as well. Smaller WVC area in the 12.5-km product, and therefore fewer σ_o per WVC, leads to a lower signal to noise ratio in the SVW retrieval. Also, despite higher spatial resolution, the 12.5-km SVW retrievals are not provided any closer to shore than in the 25-km resolution data (i.e., same land mask). This limits the value added from the perspective of the operational user at a coastal WFO.

Details of the SVW retrievals differ for NRT applications (i.e., Chang et al.; information online at http://manati.star.nesdis.noaa.gov/quikscat/nrt_release_notes.pdf) versus science applications (i.e., Ocean Vector Winds Science Team at the NASA Jet Propulsion Laboratory; see the Web site http://podaac.jpl.nasa.gov/ocean_wind/quikscat/L2B/doc). Hoffman and Leidner (2005) provide an excellent review of the NRT retrieval of SVWs from backscatter observations on QuikSCAT. Practical summary descriptions of the SVW retrieval algorithms for both the NRT and science retrieval cases also appear in recent papers with an operational focus in Chelton and Freilich 2005 and Chelton et al. 2006. Minimizing the turnaround time, or data latency period, from overflight to SVW retrieval drives the operational retrievals and product suite development for NRT SVWs. NRT processing algorithms composite σ_o differently than in the case of the science data algorithms; they employ a slightly different rain flag algorithm, and ambiguity removal is based on a different numerical weather prediction product. Otherwise, the vector wind retrieval algorithm is similar to the science data retrieval case (i.e., cf. Figs. 2 and 3), and the error properties of the NRT data are remarkably similar as well. NOAA/NESDIS also produces and posts a 12.5-km SVW NRT product, but at the time of this report, the 12.5-km data were not being provided via AWIPS to the coastal WFOs.

The first panel in Fig. 1 is an AWIPS presentation typical of the SVW data access at most U.S. coastal WFOs. Figure 2 is the corresponding NRT product as it

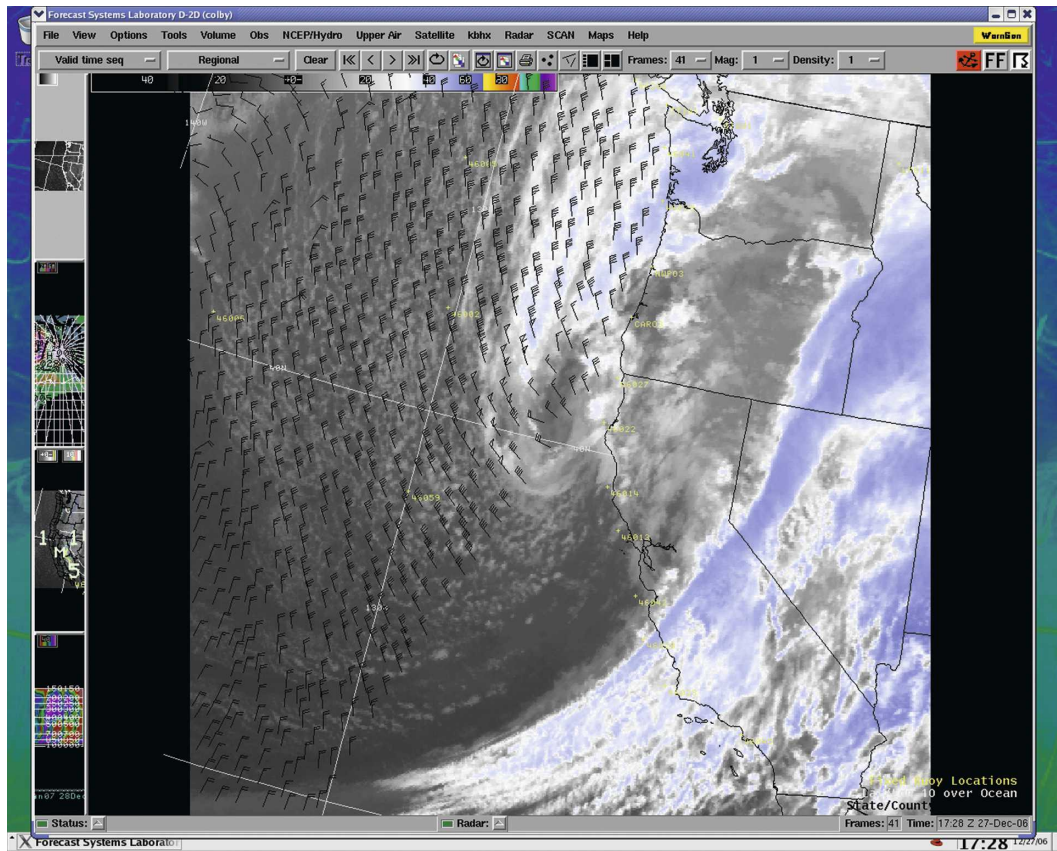


FIG. 1. A screen capture of a typical AWIPS display of NRT QuikSCAT SVWs retrieved for part of a descending branch of the QuikSCAT orbit on 27 Dec 2006, off the west coast of North America. Wind barbs indicate n mi h^{-1} (kt); each full barb represents 10 kt. The NRT QuikSCAT winds are superposed on false-color IR imagery from Geostationary Operational Environmental Satellites (GOES). (Image provided by M. Nordquist, SOO, NOAA/NWS WFO, Eureka, CA.)

would appear on the NOAA/NESDIS Web site. Figure 3 is a representation of the science data product from JPL (latest release or “R2”). The more commonly used 25-km resolution data are displayed in Figs. 1–3. Note the rain flag indicators in Fig. 2 (black wind barbs) and Fig. 3 (red SVWs) near 42°N , 125°W . The direction interval retrieval with threshold nudging option (DIRTH; Stiles 1999) in the standard science data product is activated for the sample swath in Fig. 3. The DIRTH option removes small-scale noise that occurs in wind direction retrievals for WVC in the midswath regions. In the AWIPS display (Fig. 1), the NRT SVW retrievals overlay high-resolution (1 km) satellite infrared (IR) imagery that coincides with the QuikSCAT overflight time to within 30 min.

As summarized above, scatterometry is an approach to SVW remote sensing that involves *active* microwave instrumentation and retrieval techniques. A *passive* polarimetric approach has been pursued for SVW remote sensing as well. The passive polarimetric technology is

less well developed than is scatterometry, and has yet to demonstrate an operational utility. The WindSat instrument on the *Coriolis* spacecraft was launched in January 2003 with a goal of proving the feasibility and practicality of the passive-polarimetric approach for SVW retrieval from a spaceborne system. The WindSat SVW retrieval algorithms continue to be refined and stabilized more than 4 yr post launch. At the time of our surveys and site visits, WindSat data were available via the NOAA/NESDIS Web site, but not available via AWIPS to the U.S. coastal WFOs. While this is still the case for WFOs, soon after our surveys and site visits were completed, WindSat data became available to the NOAA/National Centers for Environmental Prediction (NCEP; e.g., TPC and OPC) via the NCEP AWIPS (N-AWIPS) system.

Surface wind retrievals from synthetic aperture radar (SAR) sensors will eventually play a role in operational applications at coastal WFOs as well, but it is premature to investigate the operational role of SAR wind

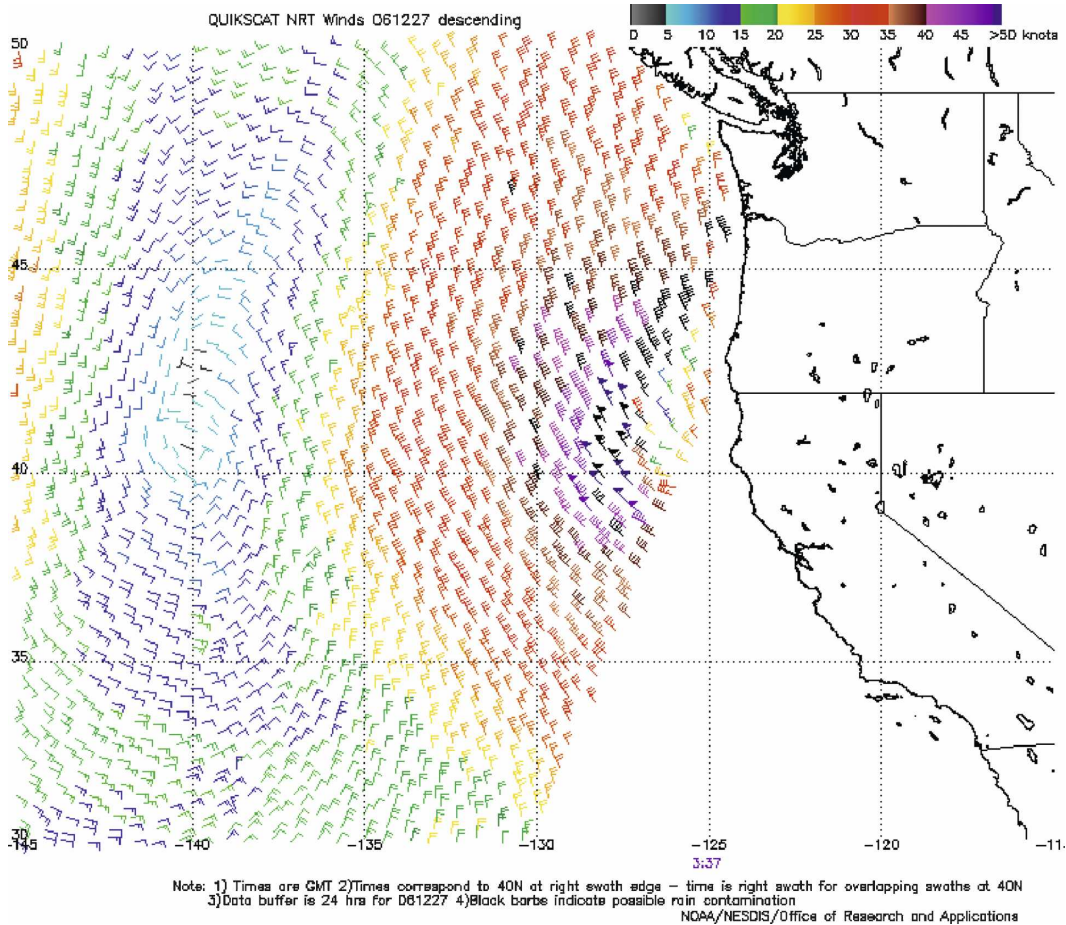


FIG. 2. Typical NRT QuikSCAT wind retrieval display from the NOAA/NESDIS Web page (www.manati.noaa.gov/quikscat). The NRT display is for the same winds as shown in Fig. 1 in AWIPS. Wind speeds are color coded (see color bar) and indicated in m s^{-1} (kt) as above. SVW retrievals possibly contaminated by rain are indicated in black; e.g., see 50-kt winds (barbs with flags) near 40°N , 125°W . (Image provided by P. Chang and Q. Zhu, NOAA/NESDIS).

retrievals at this time. Operational SAR products (e.g., for ship locations, oil spill and environmental monitoring, surface waves, etc.) are already available for high-latitude environments from U.S., Canadian, and European government agency sources. SAR SVW retrievals exhibit an order of magnitude finer spatial resolution, and more precise determinations of coastal boundaries, than can be achieved from scatterometer data. However, wind direction retrieval algorithms for SAR data require ancillary information (e.g., scatterometer winds). Future international plans for wide-swath and constellation SAR missions will alleviate present-day issues of instantaneous spatial coverage and revisit intervals that limit the operational utility of SVW retrievals from SAR data at mid- and low-latitude coastal locations now.

Written surveys and in-person site visits of U.S. coastal WFOs were conducted over a period from

Northern Hemisphere late summer 2005, through the 2005/06 winter season. Surveys were mailed to 33 coastal WFOs, and 16 multiday site visits took place over this period (Fig. 4). The surveys and site visits were designed to measure WFO forecaster familiarity with SVWs, identify forecaster access to SVW data, and to quantify the role satellite SVWs play in local weather and marine analyses, forecasts, and warnings issued by each WFO. A science operations officer (SOO) survey was also mailed to each coastal WFO, and site visits included presentations to the WFO staff to describe the details of the satellite SVW retrievals and SVW validation studies, particularly with respect to rain flags.

In the next section, the survey design and results are described. Impressions from the site visits are documented and discussed in section 3. A summary and recommendations are provided in a final section.

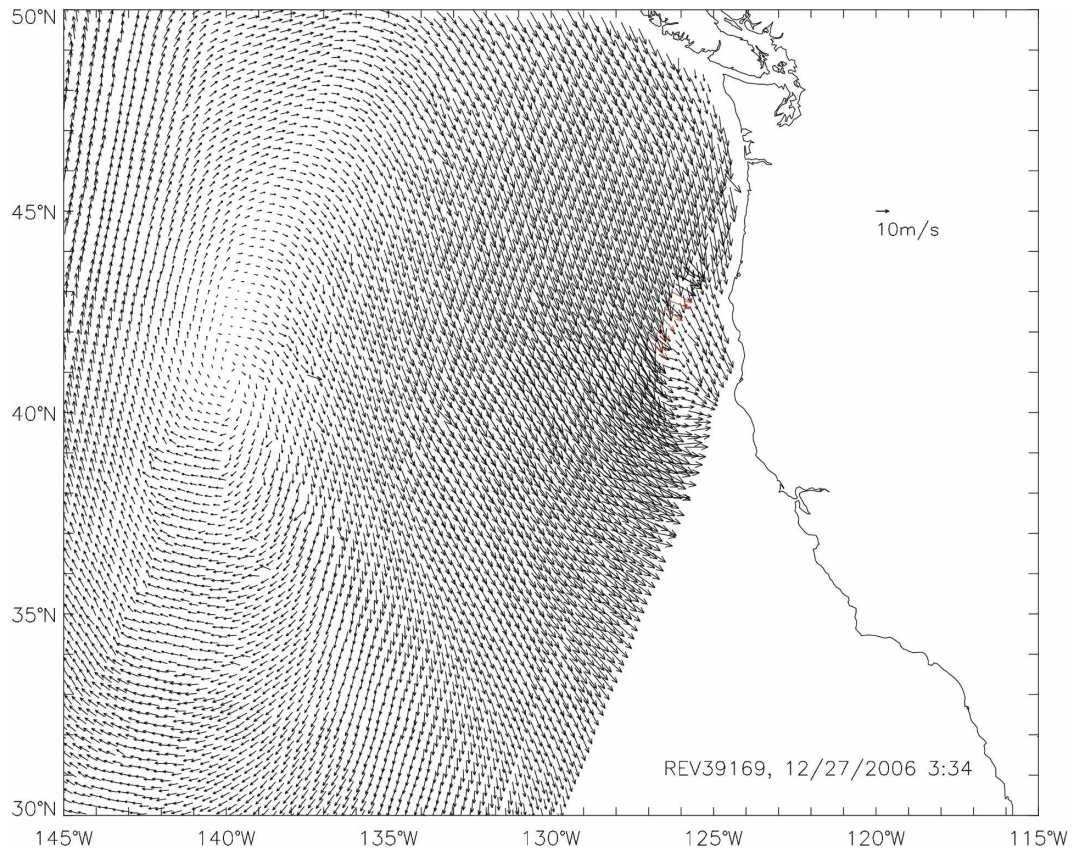


FIG. 3. Representation of QuikSCAT SVW for 27 Dec 2006 (same as in Figs. 1 and 2) from the level 2B science product (R2) (information online at <http://podaac.jpl.nasa.gov/pub/oceanwind/quikscat>). SVW components are reported in m s^{-1} . Wind vector length is proportional to speed (see scale). The fewer rain-flagged SVWs in the latest (R2) science product are indicated in red near 40°N , 125°W .

2. WFO surveys

The two-person team conducting surveys and WFO site visits combines backgrounds in weather forecasting and forecasting tool development (Stamus) with experience in earth science research using satellite SVW data (Milliff). These complementary perspectives influenced the survey design and the content of the technology transfer presentations at the WFOs.

a. Survey design

Multiple choice format surveys were designed for coastal WFO forecasters and SOOs. Prototype designs of the SOO and forecaster surveys were tested in the WFOs in Miami, Florida, and San Juan, Puerto Rico, on the initial site visits in late August 2005. Based on the responses and our interpretations of these sample surveys, minor modifications were implemented and the final form surveys were mailed to 33 U.S. coastal WFOs in October 2005. The multiple choice format was designed to minimize interruptions in the forecasters'

duty cycle. The multiple choice format also facilitates a variety of summaries as demonstrated below.

Design goals for the forecaster survey included the following:

- identifying data delivery and technology transfer pathways for satellite SVWs in the WFO operational environment;
- distinguishing among QuikSCAT and WindSat familiarity and impacts;
- ranking satellite SVW data with respect to other input data used in local weather and marine forecasts and warnings; and
- identifying satellite SVW data limitations and prioritizing potential improvements in the data stream.

b. Response rate

Cooperation from WFO forecasters and SOOs resulted in a 73% response rate by May 2006. Returns of 125 forecaster surveys and 24 SOO surveys accounted



FIG. 4. Written surveys (33 total) were sent to U.S. coastal WFO offices indicated on the map (all circles). Site visits (16 total) were conducted at the coastal U.S. WFO offices indicated by name (and solid circles) on the map. Site visits were conducted over the period fall 2005 through early spring 2006. Surveys were mailed to coastal WFOs in October 2005. A 73% response rate was achieved by spring 2006.

for average return rates of about 5 forecaster surveys and 1 SOO survey per responding office. The geographic distribution of coastal WFOs represented in the survey responses, and the variety of offices visited in person (16 WFOs), provide a realistic sample of the diversity of marine forecast situations in which satellite SVWs can be used (see Fig. 4).

c. Pathways

Forecaster introduction to and familiarity with satellite SVW data can be gained via several pathways, including training by the WFO SOO or other forecasters in the local office; review of a Cooperative Program for Operational Meteorology, Education and Training (COMET) training module (Freilich 2007); or via self-education using scattered resources on the Internet. For the Northern Hemisphere fall, winter, and early spring seasons of the survey, satellite SVW data from QuikSCAT were most commonly available to WFO staff via AWIPS, and secondarily via the NOAA/NESDIS Web site (<http://manati.star.nesdis.noaa.gov/quikscat>).

Five questions on the forecaster survey asked if QuikSCAT and/or WindSat data were used in general, and/or for specific purposes. Table 1 demonstrates that WindSat data were not used at the time of this survey.

As described above, the limited access to WindSat data, and the absence of any WindSat operational training materials, rendered this dataset a noncontributor to the results of this study. Thus, unless otherwise specified (e.g., Figs. 5 and 6), the generic term SVW data refers exclusively to the QuikSCAT data for the remainder of this report.

Table 1 also demonstrates that more than half of the survey respondents use QuikSCAT data, at least “sometimes” and more than 15% use it “usually.” Of the usually respondents, the majority used QuikSCAT for sea-state forecasts and warnings, followed by swell

TABLE 1. Several survey questions provided information to quantify forecaster usage of WindSat and QuikSCAT data. The responses for these questions were pooled from 125 forecaster surveys to yield the responses tabulated here. More than half of the responding forecasters used QuikSCAT data at least *sometimes*. WindSat data were not having an impact on forecasts and warnings at U.S. coastal WFOs at the time of the survey. In addition to 275 respondents who answered “no,” 138 respondents chose not to answer any questions regarding WindSat data usage.

	Yes, usually	Yes, sometimes	No
QuikSCAT	67	185	170
WindSat	5	14	275

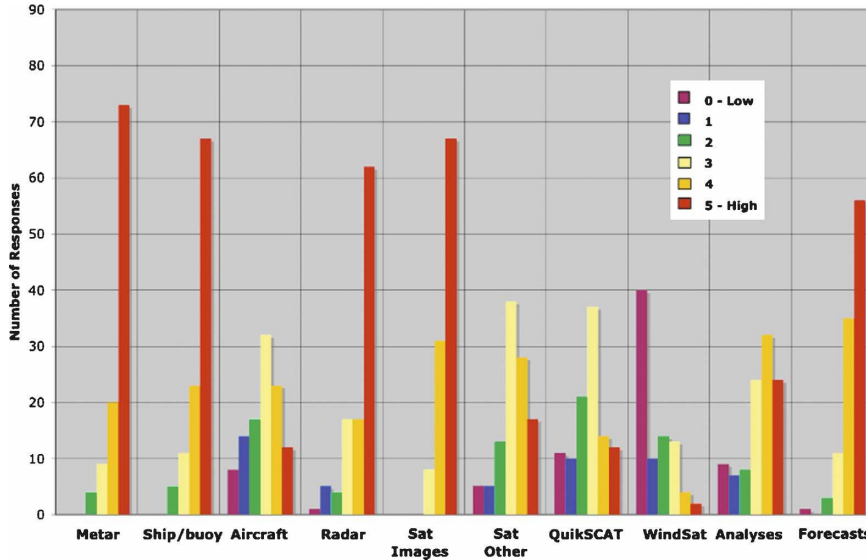


FIG. 5. Dataset utility rankings for short-term forecast and warning products at U, S, coastal WFOs. Datasets indicated along the x axis (see text) were ranked on a scale of 0–5, where 5 (red) indicates “highly important” for use in producing short-term WFO products and 0 (purple) indicates low or no utility for these purposes. The QuikSCAT data were seen as secondarily important (yellow bar), relative to METARs, ship and buoy observations, local radar, satellite imagery (e.g., visible and IR), and short-term forecasts (all red bars).

forecasts, wind waves, and as a validation of features in NWP forecasts and analyses.

d. Rankings

Forecasters were asked to rank the input dataset’s importance on a numeric scale from 0 to 5, where 5 is

“highly important.” Input dataset comparisons with satellite SVW data were made for the combined set of desk responsibilities, but broken down by lead-time category (i.e., “short term,” 1–2 days, and “long term,” 3 days and longer) The input sets listed in the rankings included aviation routine weather reports (METARs)

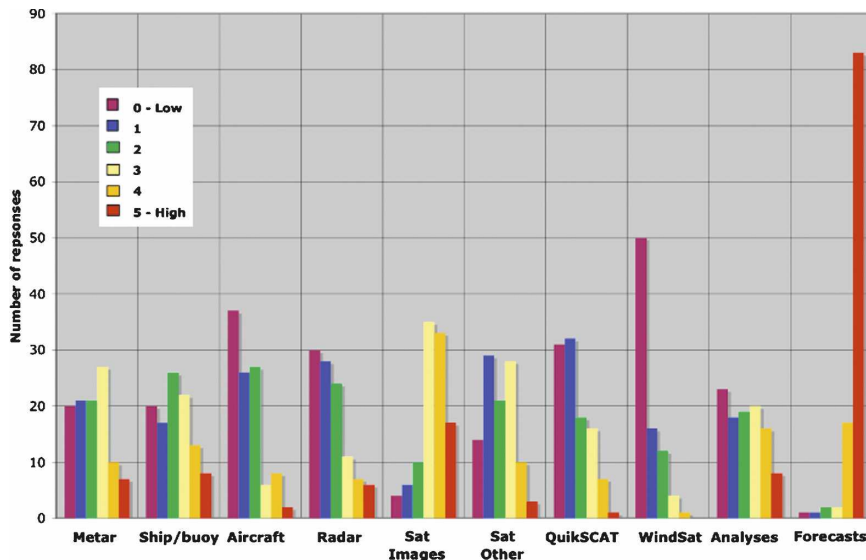


FIG. 6. Dataset utility rankings for longer-term forecast and warning products at U.S. coastal WFOs; i.e., for day 3 and longer. Datasets are indicated along the x axis as in Fig. 5. NWP forecasts are the sole dataset of high importance in the production of longer-term products at the U.S. coastal WFOs.

and other surface observations, ship and buoy reports, aircraft reports, radar [e.g., Weather Surveillance Radar-1988 Doppler (WSR-88D)], satellite imagery (e.g., visible and IR images), other satellite data (e.g., soundings, cloud vector winds, etc.), SVWs from QuikSCAT, SVWs from WindSat, numerical weather prediction (NWP) analysis fields (e.g., from the Local Analysis and Prediction System, LAPS; the Rapid Update Cycle Model, RUC; etc.), and NWP forecast fields [e.g., from RUC, the North American Mesoscale Model (NAM), the Global Forecast System (GFS)].

Figure 5 demonstrates that for short-term forecast purposes (i.e., day 1 and 2 products) the most important datasets, in order of number of level 5 rankings (right-most red bars in each dataset cluster), are local observations from METARs, ships and buoys, satellite imagery, radar, and NWP forecasts. The QuikSCAT data utility for day 1 and 2 forecast products falls in a second tier of importance (i.e., levels 2–4) that includes aircraft and other satellite data, and NWP analyses. Figure 5 shows the rankings for QuikSCAT data for day 1 and 2 products were based on 12 responses at level 5 (red), 14 at level 4 (gold), 38 at level 3 (beige), 21 at level 2 (green), 10 at level 1 (blue), and 11 at level 0 (purple).

The NWP forecasts are, by far, the most important datasets to survey respondents with respect to forecast products for day 3 and longer. Figure 6 demonstrates that the NWP forecasts obtained more than 80 responses at level 5, and no other dataset reached 20 responses in this category. In fact, with 17 responses at level 5, satellite imagery was the only other dataset with over 10 responses in this category. The QuikSCAT data relative importance profile for long-range forecast applications matches those of NWP analyses and all other near-real-time observational datasets (e.g., METARs, ships and buoys, radar, other satellite observations; Fig. 5). Not surprisingly, the operational QuikSCAT data are more useful for short-term forecast and warning applications than they are for the long-term products.

The distributions for the relative importance of the input datasets for special forecast and warning products (not shown) are nearly identical to the distributions in Fig. 5. The special products include marine and aviation forecasts, severe weather forecasts, and warnings. The most important datasets are satellite imagery and local observations from METARs, radar, and ships and buoys. NWP forecasts round out the datasets in the first tier of the importance rankings for specialized products. QuikSCAT data, other satellite data, and NWP analyses compose a second tier of importance rankings for these applications.

Q19: When is QuikSCAT data too old to be useful?

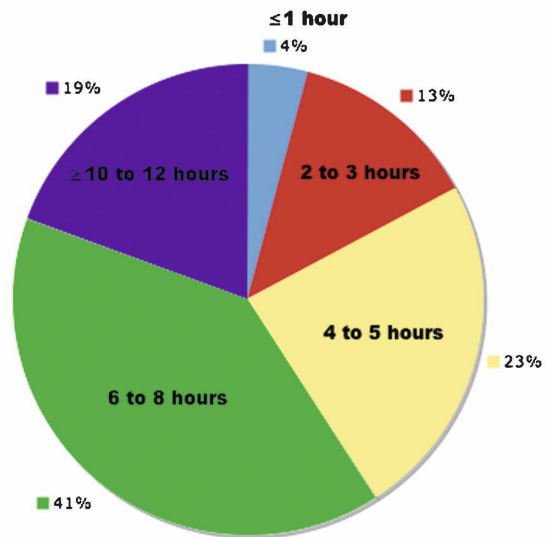


FIG. 7. QuikSCAT data latency constraints on SVW utility in operations at U.S. coastal WFOs. Forecasters indicated how many hours after overflight the SVW data from QuikSCAT lost all utility in WFO operations. The pie chart indicates that more than half the respondents found utility in SVW data from QuikSCAT beyond a 3-h data latency period.

e. Satellite SVW data limitations and potential improvements

Specific questions in the forecaster survey sought to identify critical limitations in the data from QuikSCAT in terms of rain flag effects, timeliness of the SVW data, and nearshore coverage. Follow-up questions sought to quantify the importance of potential improvements in these areas, and in improved displays on AWIPS. Two open-ended questions were posed to allow forecasters to input desired improvements for each of the SVW data systems (i.e., QuikSCAT and WindSat).

Figure 7 is a pie chart quantifying survey responses with respect to QuikSCAT data latency limitations. The QuikSCAT swath and orbit configuration is designed to maximize the global ocean coverage in minimum time. The system achieves about 90% coverage of the ice-free global ocean in 24 h. The “maximum coverage in minimum time” design goal impacts the frequency of the sampling at any given location. The revisit interval for QuikSCAT sampling is on the order of 12 h. Given current technology, the revisit interval cannot be reduced beyond this range for a broad-swath scatterometer instrument aboard a single platform in low-earth, polar-orbit orientation. For the brief period of April–October 2003, QuikSCAT and the second *Advanced Earth Observing Satellite-2 (ADEOS-2)* both

carried SeaWinds scatterometer instruments and they were in coordinated polar orbits such that the midlatitude revisit interval was about 7 h. *ADEOS-2* failed on orbit in October 2003.

Forecasters were asked when QuikSCAT data were too old to be useful for their tasks. Figure 7 demonstrates that data latency is indeed a limitation of the QuikSCAT data. Greater than 80% of the survey respondents found QuikSCAT data to be outdated for their purposes in a time period shorter than the revisit interval. However, it appears that about 50% of the survey respondents would be satisfied with SVW data latencies corresponding to revisit intervals achievable by two, coordinated, polar-orbiting platforms [i.e., $O(6\text{ h})$].

The SVW retrieval from scatterometer observations of radar backscatter can be confounded by the presence of rain. Rain contamination occurs in the following three ways: 1) the backscatter signal can be attenuated by rain in the atmospheric column between the sensor and the sea surface; 2) conversely, the rain in the atmospheric column can be a source of radar backscatter; and 3) raindrops impacting the ocean surface can alter surface roughness element amplitudes and densities that create radar backscatter. Wind vector cells (WVCs) over which radar backscatter returns are accumulated are flagged for potential rain contamination using a multidimensional histogram algorithm developed by Huddleston and Stiles (2000). Milliff et al. (2004) demonstrate that the rain flag algorithm in what had been the standard science product retrieval (R1) was overly conservative in that useful wind information existed in many rain-flagged WVCs. This has been alleviated in the latest retrieval (R2), and the entire QuikSCAT SVW record is now being reprocessed.

Forecasters were asked if rain flags affected their use of SVW data from QuikSCAT. Figure 8 is a pie chart documenting the response. Only 17% of responders either did not answer the question or stated that rain flags prohibited their use of the data. As such, rain flags do not appear to be a major impediment to the operational utility of satellite SVWs.

The forecasters were asked to rank possible improvements to the satellite SVW data stream. These included SVW retrievals within 10 km of shore, twice the number of SVW retrievals in the coastal WFO region of responsibility, three times the number of SVW retrievals, improved graphic presentation on AWIPS, and additional SVW data on AWIPS. Note that improvements in temporal resolution (i.e., reducing the revisit interval) were not included as possibilities in this question. Temporal resolution issues are dealt with in another question as described above (Fig. 7).

Q18: How do rain flags affect your use of QuikSCAT data?

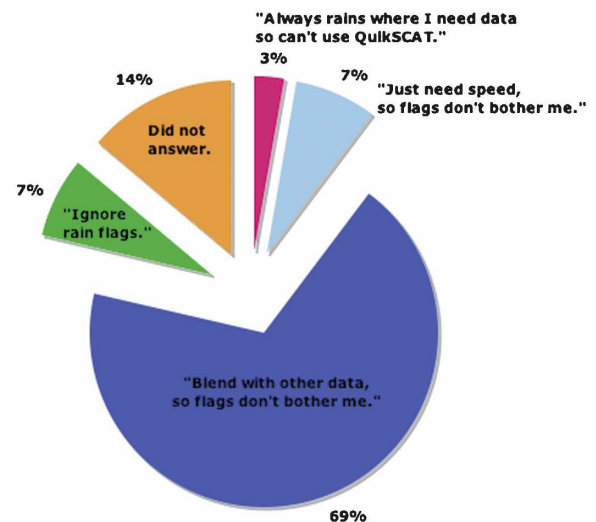


FIG. 8. Rain flag impacts on QuikSCAT data utility at U.S. coastal WFOs. The pie chart indicates that rain flags do not limit the utility of SVW data from QuikSCAT for most forecasters responding to the survey. Only 17% of the respondents either did not answer this question on the survey, or said they could not use QuikSCAT data because of rain flags.

The bar chart in Fig. 9 summarizes the responses. The greatest importance (greater than 60 responses in the "critical" and "very" categories) was placed on nearshore retrievals. Improving graphical displays on AWIPS was next in importance, with more "very important" rankings than "critically important" (Fig. 9). The least important possible improvement was increasing the data density of SVW retrievals (i.e., $2\times$, $3\times$ higher resolution) within the region of responsibility.

f. SOO surveys

The survey questionnaire for WFO SOOs consisted of nine questions. Two questions were aimed at determining SOO familiarity with SVW data from QuikSCAT and WindSat, and one question concerned SVW data training at the WFO. Several questions asked for SOO impressions of WFO staff usage of satellite SVW data in an overall office summary context. SOOs were also asked to rank the potential importance of possible improvements in data timeliness, coverage, and presentation. Not surprisingly, SOO responses did not differ from the forecaster responses in this regard.

3. WFO site visits

The purposes of WFO site visits were to (i) augment and validate impressions that might have been gained

Q20: How important are the following possible changes?

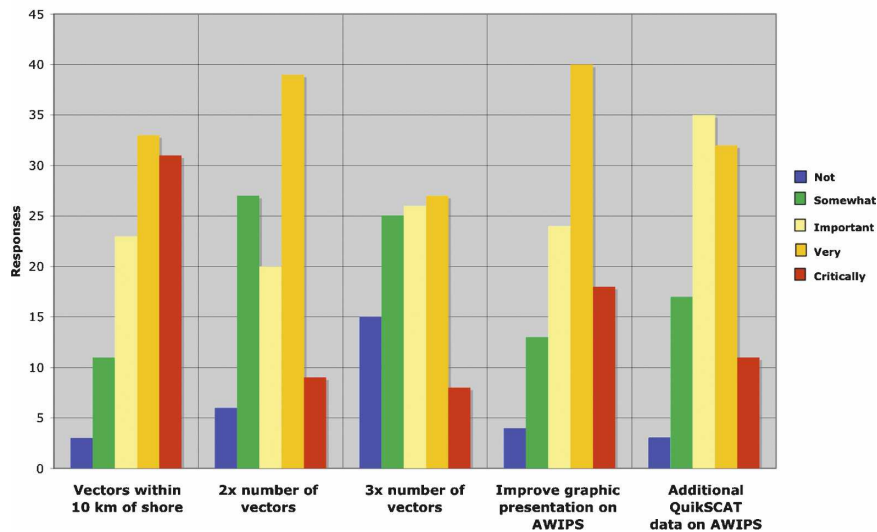


FIG. 9. Priority improvements in SVW data stream to add utility for operations at U.S. coastal WFOs. In addition to timeliness (see Fig. 7), five additional possible improvements in the satellite SVW data stream were ranked by WFO forecasters. Obtaining SVW retrievals closer to shore ranked as the most critically important (red) suggested improvement.

from written surveys and (ii) provide additional background on satellite SVW data for WFO staff. A typical visit spanned several forecaster shifts (i.e., more than a 1-day visit to each WFO). Most of the visit time was spent observing forecaster operations at the variety of forecast desks within each WFO, with a particular emphasis on desks with marine forecast responsibility. During each shift, we made brief presentations on SVW data access, retrieval methodology, and rain flagging in the SVW datasets. Site visits afforded the opportunity to observe how satellite SVW data could be used in location-specific applications. Our in-person visits were characterized by very high levels of cooperation and valuable input from WFO SOOs and forecasters. Impressions gained from the 16 WFO site visits were consistent with the summaries of the written surveys above.

Figure 4 depicts the geographic distribution of the 16 WFOs visited during the course of this project. Coastal WFOs to which we sent the surveys are also marked (but not named). Site visit locations were selected to span a variety of WFO settings. The canonical coastal WFO region of responsibility is organized into near-shore and offshore zones, where the nearshore zone extends from the coastline to 20 n mi and the offshore zone from 20 to 60 n mi. In reality, unique local settings and forecast issues seem to be the rule rather than the exception. Our site visits included WFOs with regions of responsibility that included inland/interisland waterways (e.g., Honolulu; Juneau; Mount Holly, New Jersey; Seattle, Washington; etc.), very large regions of

responsibility (e.g., Anchorage, Alaska, and Honolulu), and limited on-site resources (e.g., the one weather service office visited in Yakutat, Alaska). Local differences also had to do with individual WFO organizational structures, available input data streams, and the local analysis tools in use.

The set of WFO customers interested in marine forecasts and warnings consists of recreational users (e.g., shoreline activities, recreational boating and fishing), commercial fishing users, and maritime transport (e.g., ferries, commercial shipping). In many cases, the more vulnerable segments of the user population are the recreational users who are concentrated closer to shore. However, the data from standard input sources (see Figs. 4–6) are not optimal for WFO domains closest to shore. While the temporal resolution of METARs and some buoy observations can be on the order of tens of minutes to a few hours, moored buoy locations are typically not closer to shore than the outer domains of the WFO regions of responsibility (i.e., 20–60 n mi offshore), and METAR data are localized around airports. Local meteorological phenomena can be driven by coastal processes that occur well inshore of buoy mooring locations, for example, alongshore coastal jets off capes and coastal headlands, cross-shore jets due to gap flows off coastal topographic features, etc. In addition to suboptimal locations, meteorological buoy maintenance is costly and logistically difficult. It was common for some of the offshore buoys relevant to the WFOs we visited to be nonoperational, waiting for repairs.

As noted above, SVW data were most commonly accessed in AWIPS. However, the AWIPS software versions (or “builds”) were not the same everywhere. In some instances SVW data were not locally available, in others the AWIPS display had truncated the SVW data to only display SVWs in the swath nearest the coastal WFO region of responsibility, that is, excluding offshore swaths outside the forecast domain and/or swath data from adjacent WFO regions. When sufficient satellite SVW data were readily available (either from AWIPS or from the NOAA/NESDIS NRT Web site), and when these data happened to be timely, they were used to validate observations from point sources (i.e., METARs, offshore buoys), and to validate intensities and propagation characteristics for meteorological features (i.e., low pressure systems, mountain gap wind flows over the ocean, frontal boundaries, etc.) in NWP analysis and forecast fields.

Unfortunately, the satellite SVW data also fail to populate the nearshore regions of responsibility for the coastal WFOs, including intercoastal waterways, inter-island channels, etc. SVW retrieval algorithms employ land masks in nearshore regions to avoid land contamination in the radar returns (i.e., σ_o). The current land mask affecting NRT SVWs excludes retrievals within about 30 km of the nominal coastline. The same land mask is used for the 25-km resolution and 12.5-km QuikSCAT data. In the higher-resolution case, the land mask is too conservative. The land mask limits the available retrievals near the coast where WFO customers are concentrated.

WFO forecasters were interested to hear of ideas and methods for extending SVW data density and precision toward the shoreline (Fig. 9). Two related approaches make sense in this regard, with respect to the 12.5-km resolution data. First, research in progress now includes at least two efforts to refine SVW retrievals near coastlines (M. H. Freilich and D. G. Long 2005, personal communication). It is anticipated that the minimum offshore extent of the coastal land mask will be reduced from $O(30\text{ km})$ to $O(12\text{--}18\text{ km})$ in the refined retrieval cases. Second, we suggested ingesting SVW data into local analysis programs available to all NWS WFOs. One example is the Local Analysis and Prediction System (LAPS; Albers et al. 1996; Snook et al. 1998), which can be customized to include specific features of each WFO region of responsibility; including tall coastal topography, complicated shorelines, etc. LAPS is a NOAA/NWS software tool available within AWIPS. LAPS is run at regional resolution by the NWS Eastern Region office, and output fields are supplied to WFOs within the eastern region. In extending the utility and impact of satellite SVW data, LAPS can

be configured for each coastal WFO and run at higher resolution to include better representations of local coastal topography and meteorological phenomena. This can be done now with the 25-km resolution QuikSCAT data. Local implementation of LAPS has been demonstrated with satellite sea surface temperature data at the Miami WFO (Etherton et al. 2004).

Satellite visible and IR images were the most common “background fields” in use in AWIPS at the WFOs we visited (e.g., Fig. 1). These fields are spatially complete, at high resolution (e.g., IR images at 4-km resolution in AWIPS), over regions much larger than the WFO regions of responsibility. The visible and IR imagery are updated frequently enough (e.g., every 30 min) to be both consistent with the most recent point observations (i.e., from buoys, METARs, etc.) and amenable to “flipbook” animation such that qualitative tendency information could be extracted by the forecaster. Experienced forecasters could judge propagation and intensity evolutions in remote systems, impinging on the WFO region of responsibility. The coverage and temporal resolution properties of the visible and IR satellite imagery lead to the importance of the rankings demonstrated in Fig. 5. To match this level of importance at coastal WFOs, satellite SVW data must be refreshed more frequently and become available nearer the coastline.

4. Summary and recommendations

The utility and impacts of satellite SVWs in forecast and warning operations at U.S. coastal WFOs were investigated through written surveys and comprehensive site visits. Surveys were distributed to 33 coastal WFOs in fall 2005. By May 2006, 125 forecaster surveys and 24 SOO surveys were filled out and returned, amounting to a 73% office response rate, and an average of 5 forecaster survey responses per office. Multiday visits to 16 selected WFOs were completed over the period August 2005–April 2006 (Fig. 4). Site visits spanned several forecaster shifts in each office, where forecaster operations were observed and information on SVW retrieval methods, SVW validation, and rain flag effects was presented.

The written surveys can be summarized as follows:

- More than half of the survey respondents use QuikSCAT data at least “sometimes”; about 15% use it “usually” (Table 1). As of May 2006, WindSat data were not used by forecasters at U.S. coastal WFOs.
- QuikSCAT data were most typically accessed via AWIPS, less commonly from the NOAA/NESDIS Web pages. AWIPS builds and available input data

- streams differed from office to office. In some instances the SVW data were missing, in other cases the displays of SVWs were truncated.
- QuikSCAT data are of secondary importance in constructing short-range products at the coastal WFO (Fig. 5). Datasets of primary importance include METARs, ship and buoy observations, radar, and visible and infrared satellite imagery.
 - QuikSCAT data are less useful for the construction of long-range products (Fig. 6). NWP forecasts are the single most important input dataset for these purposes.
 - QuikSCAT data are again useful at a second level of importance in the construction of specialized products at the coastal WFOs. Specialized products include marine warnings, sea-state forecasts and warnings, aviation forecasts, and severe weather warnings.
 - QuikSCAT data lose value with increasing time after a local overflight (Fig. 7). More than 80% of the respondents say that QuikSCAT data are too old to be useful in a time period shorter than the revisit interval (about 12 h).
 - Confusion with respect to rain flags in the QuikSCAT data did not appear to be a major limitation of the dataset (Fig. 8). More than 80% of the respondents said they use QuikSCAT data at some level, regardless of the rain flags.
 - Improved nearshore retrievals are the most desired potential improvements in the SVW data (Fig. 9). Improved SVW displays in AWIPS was the second most desired possible enhancement.

The SVW data update issue was identified as a critical limitation in advance of the survey and was therefore not included in the list of potential enhancements to be ranked by each survey respondent. The QuikSCAT revisit interval is nearing technological limits for a single, broad-swath, polar-orbiting scatterometer in low-earth orbit. The pie chart in Fig. 7 demonstrates that two, coordinated, broad-swath scatterometer systems in polar orbits would provide revisit intervals $O(7\text{ h})$, sufficient to preserve SVW utility for more than half the survey respondents. Overall impressions gained from 16 site visits can be summarized as follows:

- Site visit observations and conversations were consistent with summaries gleaned from the written surveys.
- Each coastal WFO has unique local aspects affecting marine forecast and warning procedures. These can include local geographical and meteorological features, as well as local user needs and WFO organization.

- Advantages of moored buoy observations are data frequency and forecaster familiarity with the data stream. Disadvantages include limitations of single-point observations, suboptimal locations, and buoy downtime.
- Sea-state forecasts depend on local knowledge and remote information from the NOAA Wavewatch III model output. SVW data can be used to contribute to local enhancements, but are not used to impact remote forcing analyses.
- Locally customizable analysis packages (e.g., LAPS) are standard NOAA/NWS tools available in AWIPS, but they are not currently used to their full potential vis-à-vis satellite SVWs in WFO operations. The NWS Eastern Region Office supplied regional-scale LAPS output to Eastern Region WFOs. Ingesting satellite SVW data in local implementations of LAPS at each WFO should be explored.
- WFO staff appreciate in-person training regarding operational datasets and tools.

Land contamination in the set of near-coastal radar returns limits the proximity to shore for which an SVW retrieval is feasible. However, the current land mask is conservative in the sense of erring on the side of greater offshore masking than is necessary for the 12.5-km resolution data. Research in progress is refining the land mask to exclude SVW retrievals only within 12–18 km of the nominal coastline.

Using locally tuned analysis packages (e.g., LAPS) to ingest coastal SVW retrievals is a logical means of extending the offshore surface wind information toward the shore. The LAPS implementations will have to be tuned to the local geography so as to capture the effects of mountain gap winds, unique thermal gradients, etc. Test case implementations of this idea are in progress.

Finally, the surveys and site visits reported here provide a useful baseline for further monitoring of SVW utility at U.S. coastal WFOs. It would be interesting to repeat surveys of this nature in a few years to document changes in SVW utility as forecasters and SOOs become more familiar with the SVW data stream and more extensive local applications of the data (e.g., LAPS) can be demonstrated.

Acknowledgments. This study was supported by the Research and Operations (RO) budget line through NOAA/NESDIS. We thank Dr. Stan Wilson for his work in securing support for RO. Our project was administered by the Cooperative Institute for Oceanographic Satellite Studies (CIOSS) within the College of Ocean and Atmosphere Studies (COAS) at the Oregon State University. We thank Profs. Ted Strub and

Michael Freilich for their efficiency and collaborations in supporting our efforts. Dr. Paul Chang, NOAA/NESDIS, provided material and inspirational support throughout. Mel Nordquist, SOO, NWS/WFO, Eureka, California, kindly provided figure preparation assistance. Additional support for this work has been derived from a NASA Ocean Vector Winds Science sub-contract. Finally, we are pleased to note our appreciation of the professionalism and consistency that characterize the forecasters and SOOs of the U.S. coastal WFOs. We appreciate the hospitality and cooperation we encountered in all of our WFO site visits.

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