NASA'S OCEAN VECTOR WINDS SCIENCE TEAM WORKSHOPS

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Scatterometers are unique among satellite remote sensors in their ability to determine accurate wind vectors over water. They provide a wealth of wind velocity observations over the Earth's oceans that have a wide variety of applications, including weather forecasting, marine safety, commercial fishing, El Niño prediction and monitoring, and long-term climate studies. Yet, for its many strengths, there also remain weaknesses in the global scatterometer observing system for which improvements can be made. One weakness that has been noted since before the launch of the National Aeronautics and Space Administration's (NASA) Quick Scatterometer (QuikSCAT) is that there is no U.S.-funded follow-on mission for this polar-orbiting satellite. It has been anticipated for several years that too much friction would stop the rotation of QuikSCAT's antenna, preventing further wind retrievals. This occurred at 0707 UTC 23 November 2009, after more than 54,000 orbits about the Earth and more than seven years beyond its design life.

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THE 2008 AND 2009 NASA OCEAN VECTOR WINDS SCIENCE TEAM MEETINGS

WHAT: Approximately 70 oceanographers, meteorologists, engineers, and others from a wide range of satellite and weather research and operational organizations, including a large representation from the European Union and Japan, met to discuss applications of scatterometry and to identify the strengths and weaknesses of the global scatterometer observing system.
WHEN: 19–21 November 2008 and 18–20 May 2009
WHERE: Seattle, Washington, and Boulder, Colorado

The NASA Ocean Vector Winds Science Team (OVWST) met in the fall of 2008 and again in summer 2009 (prior to the loss of QuikSCAT) to work on removing or mitigating such weaknesses in the scatterometer observing system and to clearly define the operational and research needs for future scatterometer missions. Each meeting included 44 talks, with 17 posters in 2008 and 14 in 2009, aimed at discussing research and operational findings, as well as extended discussion periods that touched on nearly every facet of scatterometer instrumentation and applications.

TOPICS OF DISCUSSION. Topics at the OVWST meetings included plans for a post-QuikSCAT era, international collaboration, validation/calibration [including wind calibration from the new European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Advanced Scatterometer (ASCAT), and near-coastal wind retrieval for QuikSCAT], science relating surface vector winds to air–sea interaction and responses (described in this summary) in the atmosphere and ocean, issues with gridded products, high wind speeds and rain, and new products. Several talks described how changes in surface wind are linked to changes in sea surface temperature (SST). Other oceanographic studies examined how an estimate of diurnal wind forcing influences seasonal changes in the ocean's mixed layer temperatures and the importance of synoptic-scale wind variability in transporting Apalachicola River outflow off the Florida coast and into the open Gulf of Mexico. Meteorological studies included coupling between El Niño and Atlantic Niño through rainfall in South America. Several presentations relayed improved modeling of the atmospheric boundary layer, using scatterometer wind data to better resolve small-scale features associated with currents, orographic wind flow, and changes in the temperature of the air and the sea surface. One of the operational meteorology talks noted how influential QuikSCAT has been in producing warnings of hurricane-force winds in extratropical storms. Presentations from both meetings can be found online at http://coaps.fsu.edu/scatterometry/meeting/past.php. A list of workshop attendees and recommendations from both workshops are also located on the site.

MEETING RECOMMENDATIONS. There was a great deal of discussion during these workshops that led to the following statements of recommendation. The points are important not only to the people who routinely use satellite wind products but also to those who need surface wind or stress data for budgets of energy (heat), water, and CO_2. These statements should also impact data assimilation of satellite winds, and the use of numerical weather prediction (NWP) reanalyses for long-term variability and trends. Note that the original recommendations were made in 2008 and expanded upon in 2009; then portions were updated to reflect QuikSCAT's demise.

QUIKSCAT. With more than 10 years of successful operation, QuikSCAT became the first ocean vector wind mission to provide data coverage suitable for a wide range of climate studies. In 2008 the OVWST strongly recommended that QuikSCAT continue to collect data as instrument health allows. The reasoning was that QuikSCAT had become the baseline mission used to consistently extend the climate data record by cross calibration [as recommended by Global Climate Observing System (GCOS) principles] with other current and future scatterometers, such as ASCAT, the Indian Space Research Organisation (ISRO) Ku-band scatterometer (launched 23 September 2009), and the National Research Council (NRC)–recommended higher-capability National Oceanic and Atmospheric Administration (NOAA) scatterometer. Despite QuikSCAT's loss of wind measuring capability, its radar is still functional and can be oriented to match the viewing geometry of other scatterometers. Therefore, QuikSCAT can still be used for intercalibration.

Need for a higher-capability scatterometer after QuikSCAT. Initially foreseen as a three-year mission, the QuikSCAT scatterometer continued to perform very well at the time of these meetings and provided data to NOAA in real time, well beyond its designed lifetime. In the fall of 2009, however, the coupling between QuikSCAT's main body and the rotating antenna showed serious signs of wear, resulting in periods of excessive friction and a reduction in the rate of rotation, ultimately resulting in the demise of the instrument. The satellite-derived global winds community now needs to act quickly to minimize the climate data gap (as defined by GCOS principles) that is growing wider since the QuikSCAT data record ended in November. We strongly recommend the prompt launch of higher-capability ocean vector wind instruments since it is not expected that current or future operational scatterometers, such as the ASCAT series, will, by themselves, fulfill the need of the scientific and operational communities for global wind sampling at the appropriate combination of accuracy and temporal–spatial sampling. Such improved technology will provide all-weather, all-speed wind vector measurements, improve spatial resolution, reduce rain contamination, obtain measurements in coastal regions, and provide complementary temporal sampling with scatterometers launched by other space agencies. We are very encouraged by the possible collaboration of NOAA, the Japanese Aerospace Exploration Agency (JAXA), and NASA, which promises an opportunity to launch the first of a new generation of higher-capability ocean vector winds instruments. At the 2009 OVWST meeting we strongly recommended that this partnership move forward as soon as possible and that the instrument capabilities be leveraged not only for scientific and climate applications, beyond the needs of operational agencies, but also to develop future systems [e.g., the eXtended Ocean Vector Winds Mission (XOVWM)—

see sidebar] that better meet current operational and scientific goals related to a single instrument.

Calibration/validation. REVISED DEFINITION OF EQUIVALENT NEUTRAL WINDS. If a scatterometer responds to the flux of horizontal momentum from the atmosphere to the ocean—stress—as appears to be the case, then the conversion of equivalent neutral winds to stress is also a function of air density; that is, there is *not* a 1:1 conversion between equivalent neutral winds and stress. The traditional definition of equivalent neutral winds (1) (Ross 1985) is

$$U_{10\mathrm{EN}} = \frac{|\vec{\mathbf{u}}_*|}{k}\ln(10/z_o), \tag{1}$$

where $\mathbf{u}_*$ is the friction velocity, k is von Kármán's constant, and z_o is the roughness length. We recommend that a new definition of equivalent neutral winds (2), accounting for density in a manner designed to result in more accurate winds, be applied to future calibration efforts. This revised definition is

$$U_{10\mathrm{EN\ new}} = \sqrt{\frac{\rho_0}{\rho}}\frac{|\dot{\mathbf{u}}_*|}{k}\ln(10z_o), \tag{2}$$

which introduces ρ_0 as a reference density with a value of 1.0 kg m^{-3} and ρ as the near-surface air density. This definition differs from the traditional definition (Ross 1985) only by the term with the square root of the ratio of densities. It has been demonstrated to reduce spatial and seasonal biases in comparisons to in situ observations. Note that air density will still have to be used in the conversion of equivalent neutral winds to stress.

It is also essential to clearly define how each product is calibrated. For example, QuikSCAT was calibrated to the traditional definition of equivalent neutral winds, whereas ASCAT was calibrated to wind speed, resulting in a 0.2 m s^{-1} bias.

HIGH WINDS. Investigation of the consequences of either random error or limited spatial resolution in H*Wind on the high wind speed portion of wind retrieval model functions should be encouraged. Estimates of wind speed and direction from H*Wind—a finely gridded objective analysis of the surface wind field of tropical cyclones, produced at NOAA's Hurricane Research Division (Powell et al. 1998)—are used for comparison data to tropical cyclone–force wind vectors because they are considered more accurate than current alternatives; however, this was not an intended application of the H*Wind product, and the strengths and weaknesses of this application must be more thoroughly examined. For example, do these limitations account for the saturation seen in model functions estimated using H*Wind? Do they account for the inconsistency with aircraft-based Imaging Wind and Rain Airborne Profiler (IWRAP) observations?

VECTOR-DERIVED GRIDDED WIND PRODUCTS. The lack of easily understood information on the characteristics

NEXT-GENERATION SCATTEROMETER NEEDS PARTNERSHIP TO BECOME REALITY

The XOVWM was recommended in the National Research Council Decadal Review as an operational QuikSCAT follow-on mission to be lead by NOAA. The XOVWM capabilities include much finer spatial resolution (<5 km), much more accurate wind retrievals through heavy rain, and greater accuracy for tropical cyclone-force winds. All of these features are highly desirable for operational, science, and climate activities.

It was determined that while XOVWM was feasible with current technology, it required more resources for a U.S. launch than are available at NOAA. Subsequently, NOAA and NASA have formed a partnership with the Japanese space agency, JAXA, to examine the feasibility of flying a next-generation instrument in JAXA's Global Change Observation Mission (GCOM) satellites with an Advanced Microwave Scanning Radiometer (AMSR) instrument. These discussions resulted in plans for the Dual-Frequency Scatterometer (DFS) on GCOM-W2, which has been found to be technically feasible within the constraints of JAXA's 2016 launch schedule. An international science team has met multiple times and defined the mission goals and requirements that are consistent with the research and operational needs described in the second recommendation. The *GCOM-W2* DFS–radiometer combination will be the first system to provide multifrequency active and passive simultaneous microwave observations, allowing for the optimal intercalibration of all wind measurement systems. It remains to be seen if the scatterometer portion of this mission will be funded in a timely fashion, saving U.S. taxpayers the cost of a launch vehicle and satellite bus.

Domestic and international support for an enhanced ocean vector wind mission (XOVWM and DFS) is strong from the science, operational, and user communities. In the 6–7 years until the new satellite with these two instruments aboard is launched, it is recommended that the agencies involved and the science community develop new algorithms for the optimal scientific and operational use of this multifrequency, active–passive combination of instruments, which is also present in the XOVWM mission.

of vector-derived wind products (e.g., Schlax et al. 2001) has been a serious detriment to most researchers trying to use them. Characteristics of these wind products (e.g., regularly gridded vector winds and derivative fields, such as curl of the stress) should be better determined, in a manner that is useful to nonspecialists using the products. For example, it would be very useful to know the spatial and temporal scales for which products are limited by noise or by smoothing and to make this information readily available to users. This information indicates whether a product could be reasonable to use for specific applications. Similar examinations should be done for spatial derivative fields. A measure of the homogeneity of error characteristics would also be useful, as would an indication of the products' ability to smoothly represent propagating features.

MULTISATELLITE APPLICATIONS. One or even two satellites in low Earth orbit cannot globally sample ocean surface winds well enough to sufficiently resolve the diurnal cycle, which is likely to be important for climate-scale studies of the ocean and could be important for reducing biases in budgets of heat and moisture. Consequently, we encourage the intercalibration of vector and scalar wind sensors and consideration of complimentary orbits designed for better temporal sampling of surface winds.

We also encourage the consideration of temporal sampling in the planning of satellite orbits. The choice of metric is expected to depend on the application; therefore, no specific metric is recommended at this time. Note that the mean time between observations is not a well-suited metric, as very short time changes (which are not useful for most applications) could counter very long revisit times. For most applications, a metric should oppose long revisit times.

NEW PRODUCTS. A well-calibrated stress product is desired. Regardless of whether equivalent neutral winds can be properly converted to stress, using the newly recommended equivalent neutral wind definition, the large amount of noise in the calibration wind speeds will make a product designed for stress (proportional to wind speed squared or cubed) inconsistent with the equivalent neutral winds, even if density is considered. A product optimized for stress should be developed. A product optimized for gas transfer (dependent on speed cubed in some models) should also be considered after further consultation with the gas transfer community.

CONCLUDING REMARKS. Diverse topics discussed at the 2008 and 2009 NASA OVWST workshops led to many scientific and operational conclusions, including much-improved insights into the strengths and weaknesses of vector wind products. An ongoing goal of the OVWST is the development of methods for assessing and describing these characteristics in ways that are easily interpreted by nonexpert users. There are many users of satellite-derived gridded vector wind products who do not routinely attend the meetings and therefore miss out on the information discussed. We are now working with NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC) to improve the usefulness and availability of information on data products routinely provided to the vast user community.

With the loss of QuikSCAT and no timely U.S. replacement, the short-term future depends on international collaboration. An international OVWST was originally discussed in 2008 and is now being formed. The first meeting of this group will be held in Barcelona, Spain, from 18 to 20 May 2010.

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