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OCEAN SURFACE VECTOR WIND: RESEARCH CHALLENGES AND OPERATIONAL OPPORTUNITIES

In response to CGMS action/recommendation 39-12

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Abstract

The atmosphere and ocean are joined together over seventy percent of Earth, with ocean surface vector wind (OSVW) stress one of the linkages. Satellite OSVW measurements provide estimates of wind divergence at the bottom of the atmosphere and wind stress curl at the top of the ocean; both variables are critical for weather and climate applications. As is common with satellite measurements, a multitude of OSVW data products exist for each currently operating satellite instrument. In 2012 the Joint Technical Commission on Oceanography and Marine Meteorology (JCOMM) launched an initiative to coordinate production of OSVW data products to maximize the impact and benefit of existing and future OSVW measurements in atmospheric and oceanic applications.

This paper describes meteorological and oceanographic requirements for OSVW data products; provides an inventory of unique data products to illustrate that the challenge is not the production of individual data products, but the generation of harmonized datasets for analysis and synthesis of the ensemble of data products; and outlines a vision for JCOMM, in partnership with other international groups, to assemble an international network to share ideas, data, tools, strategies, and deliverables to improve utilization of satellite OSVW data products for research and operational applications.

Action/Recommendation proposed: Develop capacity and capability for delivering and utilizing harmonized OSVW data products for research and operational oceanography and marine meteorology applications

[1] For this paper, David Halpern represents IOC of UNESCO, a member of CGMS. JCOMM is supporting IOC to accomplish CGMS Action 39-12, which invited IOC to prepare a paper on guidance to CGMS members on ocean wind measurements

Ocean Surface Vector Wind: Research Challenges and Operational Opportunities

1 INTRODUCTION

The World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) established JCOMM in 1999. JCOMM represents the joint IOC and WMO mechanism for international coordination, regulation and management of oceanographic and marine meteorological observing, data management and service systems. The JCOMM Task Team on Satellite Data Requirements (TT-SAT) was established in November 2010 to improve the integration of satellite data with other remotely sensed and in-situ data, including real-time and delayed-mode data systems.

The JCOMM Management Committee in September 2011 advised TT-SAT to focus its activities on products and the integration of in-situ and satellite OSVW data products to improve such products for operational applications. The Management Committee further requested TT-SAT to develop an OSVW group to function like the Group on High Resolution Sea Surface Temperature (GHRSST). The aim of GHRSST is to provide the best quality sea surface temperature (SST) data for applications in short, medium and decadal time scales in the most cost effective and efficient manner through international collaboration and scientific innovation (https://www.ghrsst.org). GHRSST intends to deliver sustained production of stable, high-quality SST data products and services and increase the size of the user community. In May 2012, the Fourth Session of JCOMM (JCOMM-IV) endorsed the Management Committee proposal for TT-SAT; this high-level general assembly of JCOMM occurs at approximately 4-year intervals.

2 BACKGROUND

Assimilation of OSVW data in numerical weather prediction (NWP) models improves forecast skill. Error reduction in forecast of 500-hPa geopotential heights varied from 5.5% (Anthes, 2011) to 2% (Gelaro, 2011) with satellite OSVW data. These percentages were significant because the largest reductions in error were made by a satellite sounding data set and it ranged from 17% - 27%, depending on the type of analysis. Furthermore, Bi et al. (2011) noted an increase in 4- to 6-day forecast skill at 1000-hPa, which is the geopotential surface representative of the sea surface. Per type of observation, OSVW data had the greatest impact on NWP error reduction of all satellite data sets (Gelaro, 2011). For higher resolution regional NWP nowcasts over the coastal ocean, OSVW measurements are a critical data source (A. Stoffelen, personal communication, 2012).

SST gradients produce horizontal wind convergences and convection throughout the troposphere (Minobe et al., 2008; Chelton and Xie, 2010). The typical 12.5- to 25-km horizontal resolution of satellite OSVW measurements is about the same as the effective resolution of microwave SST data and approximately 10- to 20-times larger than that of infrared SST data, preventing satellite OSVW data from accurately resolving wind divergence associated with smaller scale SST gradients. A daunting challenge to the engineering community is development of satellite wind-measuring instruments that record OSVW measurements with 1- to 2-km horizontal dimensions; synthetic aperture radar (SAR) instruments produce OSVW data with sub-kilometer dimensions but SAR OSVW data products are not global, nor are directional accuracies sufficient. Furthermore, the ~ 100-km horizontal effective resolution of global NWP models is larger than the typical 25- or 12.5-km horizontal resolution of OSVW data. The mismatch of horizontal resolution of OSVW and NWP model grid size requires thinning of high-volume satellite OSVW data, which introduces spatial representativeness errors (Vogelzang et al., 2011).

While OSVW is a meteorological variable because it is located in the atmosphere, the oceanographic community has long championed improved OSVW data sets because upper-ocean currents are driven by surface wind stress vector (Ekman, 1905) and the large-scale ocean circulation is driven by surface wind stress curl (Stommel, 1948), among other variables. Also, the wind stress curl produced by SST gradients would generate ocean currents (Jin et al., 2009). Thus, in several space agencies, satellite OSVW instrument projects reside in an agency's ocean portfolio rather than in the atmosphere sector.

In addition to improved global weather forecasts and generation of ocean currents, OSVW data are critically important in a variety of applications, e.g., sea surface wave model development, surge forecasting, marine nowcasting, tropical and mid-latitude cyclone forecasting, ocean model forcing, improved understanding of the interaction of atmosphere and ocean, coastal safety and security, etc. (Chang and Jelenak, 2006; Chang et al., 2009; Bourassa et al., 2010).

3 OSVW DATA PRODUCTS

This paper inventories only currently operating satellite OSVW global data products and briefly mentions future OSVW missions. In accord with the Group on Earth Observations (GEO) data sharing principles (http://www.earthobservations.org/geoss_dsp.shtml), free and open OSVW data availability with minimum time delay is another criterion for inclusion in the inventory.

According to the Committee on Earth Observation Satellites (CEOS) OSVW Virtual Constellation, there are four currently operating satellite scatterometer missions (http://www.ceos.org/index.php?option=com_content&view=category&layout=blog&id=73&Itemid=72). (1) The Advanced Scatterometer (ASCAT) instrument is on the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Meteorological Operational (Metop-A) satellite. The continuity of ASCAT/Metop-A data, which began in October 2006, seems assured with the September 2012 launch of the Metop-B satellite carrying an ASCAT instrument identical to the one on

Metop-A. (2) Another dataset is recorded by the Indian Space Research Organisation (ISRO) Oceansat-2 scatterometer (OSCAT), which was launched in September 2009. (3) The launch of the People's Republic of China HaiYang-2A (HY-2A) mission in August 2011 provides the most recent OSVW dataset. (4) The United States (US) National Aeronautics and Space Administration (NASA) Quick Scatterometer (QuikSCAT) mission currently provides only backscatter data for calibration of other scatterometers because an age-related failure of a mechanism stopped the antenna from spinning in November 2009 after operating more than 10 years.

The CEOS OSVW Virtual Constellation focuses on OSVW measurements recorded from scatterometer instruments. In addition to a scatterometer instrument, a passive polarimetric microwave radiometer instrument has the capability to record OSVW. The US Naval Research Laboratory WindSat instrument on the US Department of Defence Coriolis satellite, which was launched in January 2003, currently measures OSVW.

Sections 3.1, 3.2, 3.3, and 3.4 list unique OSVW data products, which are representative and not totally inclusive due to outreach limitation. Data levels 1B, 2B and 3 refer to swath-pattern sensor data in radiance or backscatter units, swath-pattern data in geophysical units, and geophysical data aggregated in an arbitrary-sized north-south and east-west gridded pattern, respectively (http://www.wmo.int/pages/prog/sat/dataandproducts_en.php; http://science.nasa.gov/earth-science/earth-science-data/data-processing-levels-for-eosdis-data-products/). Level 1B data are distributed less than an hour after the time of measurement, many level 2B data products are distributed within 3 hours of recording time, and level 3 data are distributed 1 day later. All level 2B datasets can be used to create level 3 datasets. Data products differ in their choice of geophysical model function or radiative transfer model, quality control of pixels with rainfall, selection scheme of wind ambiguity, spatial averaging, influences of SST and ocean surface currents, and other features.

The large variety of unique datasets calls for the generation of OSVW datasets with as many common data processing features as feasible to enable increased utilization of the datasets for research and operational applications. An ensemble of user-friendly OSVW data products would emulate GHRSST.

3.1 ASCAT Instrument

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) produces level 1B backscatter measurements.

3.1.1. Koninklijk Nederlands Meteorologisch Instituut (KNMI)
Data level: 2B
Reference: OSI SAF ASCAT Coastal Product Viewer (http://www.knmi.nl/scatterometer/ascat_osi_co_prod/ascat_app.cgi)
Point of contact: Ad Stoffelen (ad.stoffelen@knmi.nl)

3.1.2. National Oceanic and Atmospheric Administration (NOAA)
Data level: 2B
Reference: Advanced Scatterometer Data Products.
(http://manati.star.nesdis.noaa.gov/products/ASCAT.php)
Point of Contact: Paul Chang (paul.s.chang@noaa.gov)

3.1.3. Center for Ocean-Atmospheric Prediction Studies (COAPS)
Data level: 2B
Reference: Scatterometry & Ocean Vector Winds: Satellite studies.
(http://coaps.fsu.edu/scatterometry/downloads/form.php?number=18)
Point of contact: Mark Bourassa (mbourassa@fsu.edu)

3.1.4. Remote Sensing Systems (RSS)
RSS intends to distribute in early 2013 a level 2B OSVW data product developed from ASCAT backscatter measurements, which will be consistent with the RSS QuikSCAT dataset.
Point of contact: Lucrezia Ricciardulli (ricciardulli@remss.com)

3.2 OSCAT Instrument

ISRO produces level 1B backscatter measurements.

3.2.1. ISRO
Data level: 2B
Reference: Welcome to scatterometer data products download page
(http://218.248.0.134:8080/OCMWebSCAT/html/controller.jsp?action=ScatHome)
Point of contact: K. V. Chandra Sekhar (chandrasekhar_kv@nrsc.gov.in)

3.2.2 NOAA
Data level: 2B
Reference: Oceansat-2 Scatterometer (OSCAT) Data Products
(http://manati.star.nesdis.noaa.gov/products/OSCAT.php)
Point of contact: Paul Chang (paul.s.chang@noaa.gov)

3.2.3 KNMI
Data level: 2B
Reference: OSI SAF Oceansat-2 50-km Product Viewer
(http://www.knmi.nl/scatterometer/oscat_50_prod/oscat_app.cgi)
Point of contact: Ad Stoffelen (ad.stoffelen@knmi.nl)

3.2.4 Jet Propulsion Laboratory (JPL)
JPL intends to distribute in 2013 a level 2B OSVW data product developed from OSCAT backscatter measurements.
Point of contact: Bryan Stiles (bryan.w.stiles@jpl.nasa.gov)

3.3 HY-2A Scatterometer

The National Satellite Ocean Application Service (NSOAS) produces level 1B backscatter measurements.

3.3.1. NSOAS
Data level: 2B
Reference: Microwave Scatterometer Product
(http://www.nsoas.gov.cn/NSOAS_En/Products/2_2.html)
Point of contact: Qingtao Song (qingtao@gmail.com)

3.4 WindSat Instrument

The US Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) produces level 1B radiometric brightness temperatures.

3.4.1. FNMOC
Data level: 2B
Reference: WindSat (http://www.nrl.navy.mil/windsat)
Point of contact: Michael Bettenhausen (bettenhausen@nrl.navy.mil)

3.4.2. NOAA
Data level: 2B
Reference: WindSat/Coriolis Measurement Data Products
(http://manati.star.nesdis.noaa.gov/products/WindSAT.php)
Point of contact: Paul Chang (paul.s.change@noaa.gov)

3.4.3 RSS
Data level: 3, and 2B beginning in 2013
Reference: Description for WindSat Data Products
(http://www.remss.com/windsat/windsat_data_description.html)
Point of contact: Lucrezia Ricciardulli (ricciardulli@remss.com)

3.5 Future OSVW Missions

Three of the four satellite missions currently providing OSVW geophysical datasets have scatterometer instruments. HY-2A and OSCAT scatterometers operate at Ku-band frequencies and the ASCAT scatterometer records backscatter measurements at C-band frequencies. Follow-on HY-2 and Metop missions with Ku- and C-band scatterometers, respectively, have been approved for launch in 2016-17. A dual C- and Ku-band frequency scatterometer has been approved for a China Meteorological Administration (CMA) satellite mission, which is scheduled for launch in 2017. A Ku-band scatterometer is scheduled for launch in 2015 on the Chinese-French Oceanography Satellite (CFOSAT) mission. Russia's scatterometer on the Meteor-M N3 satellite is scheduled for launch in 2015. India is considering a proposal to launch Oceansat-3 with an OSCAT instrument in as early as 2014.

The large variety of instruments on different spacecraft calls for the generation of OSVW datasets with as many common data processing features as feasible to enable increased utilization of the datasets for research and operational applications in oceanography and marine meteorology. An ensemble of user-friendly OSVW data products would emulate GHRSST.

OSVW datasets will be produced from one or more satellite instruments until about 2021; afterwards the continuity of satellite OSVW measurements is not known. The CEOS OSVW Virtual Constellation would be the optimal forum for discussions and coordinated actions to enable continuity of satellite OSVW missions because it operates with senior leadership of interested agencies, it established the OSVW Virtual Constellation activity in 2008, and it is the GEO component entrusted with present and future Earth observations from space.

4 DEVELOPING HIGH-QUALITY USER-FRIENDLY DATA PRODUCTS

Wind divergence/convergence and wind stress curl, which are critically important to advance atmospheric and oceanographic sciences, are computed from horizontal gradient of wind speed vectors and wind stress vectors, respectively. Developing high-quality user-friendly divergence and curl fields present daunting challenges to minimize errors in satellite OSVW measurements.

Creating corrected, quality-controlled, timely OSVW data products would facilitate use of all OSVW datasets. A new method is needed to reduce the time and effort to utilize multiple OSVW data products, which have different biases, errors, and other issues. For example, investigations of instruments' performances are warranted in a variety of environments, e.g., high wind and wave, high rain, and proximity to coastline and sea ice.

The JCOMM TT-SAT, perhaps through a Subgroup, will coordinate the open and transparent generation of high quality, user-friendly OSVW datasets through a process with the following eight attributes:

- Develop user-stated standards in processing, such as removing unreliable data through mutual agreed-upon quality control procedures, determining common schemes for location and time elements, providing estimates of uncertainty or quality of each wind vector, and describing specifications on accuracy, precision, spatial resolution, timeliness, delivery mechanisms, etc.
- Develop user-stated standard interfaces for integrating in-situ and other datasets used to compute dataset; provide access to auxiliary data.
- Exchange software, data products, statistical methodologies, and verification datasets for open and transparent comparison studies.
- Identify biases in datasets and correct them, if feasible, with joint inter-comparison studies, shared statistical methods and newly developed algorithms, joint field campaigns, etc.
- Deliver ensemble of OSVW datasets every day and wind divergence and wind stress curl fields every 2 days.

- Build intellectual capacity throughout the OSVW research and operational community through engineer and scientist exchange program and other activities.
- Generate climate-quality OSVW data products by reanalysis of previous mission data with new calibration information.
- Improve capability for estimates of wind divergence and wind stress curl within 100 km of coastline and sea-ice edge.

This approach must be inclusive and would consider all OSVW measurements recorded by in-situ platforms (including buoys, volunteer observing ships and research vessels), including delayed-mode and real-time data, and by satellites with either an active (scatterometer) or passive (polarimetric radiometer) wind instrument. This approach would consider OSVW an essential ocean variable, as defined by IOC (2012).

Data product protocols should be constructed to provide easy entry of new OSVW measurements because future satellite missions have been approved and others are planned.

Availability of OSVW data products through the Global Telecommunications System (GTS), File Transfer Protocol (FTP), EUMETCast, WMO Information System or other means should be primary operational mechanisms for distribution of corrected, quality-controlled OSVW data products.

5 VISION STATEMENT

JCOMM, in representing a user community of oceanographers and marine meteorologists with strong linkages to IOC and WMO, would establish a harmonization process of satellite OSVW datasets; examples of the variety of datasets were presented in Section 3. Experts, who are knowledgeable about past, present and planned OSVW datasets, would develop consensus standards and formats; examples of attributes were described in Section 4.

A potential JCOMM Vision Statement would be: *Develop capacity and capability for delivering and utilizing harmonized OSVW data products for research and operational oceanography and marine meteorology applications*.

The Vision Statement is intended to be long-lived, and the current paper is only a first step at achieving this long-term vision. The Vision Statement has four overarching themes:

- Reducing the vulnerability of society to natural hazards through improved provision of OSVW information
- Mainstreaming the use of OSVW data in decision making
- Strengthening the engagement of providers and users of OSVW information
- Maximizing the utility of OSVW infrastructure

The JCOMM Vision Statement will advance seven joint IOC-WMO goals:

- Improve predictions of weather, climate variability and climate change
- Strengthen the safety and efficiency of at-sea operations
- Enable sustained use of ocean resources
- Enhance mitigation efforts from natural and anthropogenic hazards
- Generate fundamental knowledge of ocean-atmosphere interaction processes
- Encourage a continuum of research to operational activities
- Improve the capacity of all countries to contribute to and benefit from user-friendly datasets

Six principles of the JCOMM Vision Statement are:

- Availability of OSVW data as an international public good to benefit all countries, whether a country is a data provider and/or a data user
- Importance of global, regional and national domains
- Free and open exchange of OSVW data, tools, and methods
- Fill gaps in knowledge, infrastructure, and distribution; do not duplicate
- Strengthen user-provider partnerships with all stakeholders
- Build capacity for increased utilization of OSVW data

6 COORDINATION WITH OTHER GROUPS

The JCOMM TT-SAT is not alone in its desire to improve utility of satellite OSVW data for research and operational applications. At least three other groups have similar ambitions, with varying tenure lengths and progress.

In 1994 the Coordination Group for Meteorological Satellites (CGMS) established the Working Group on Cloud Motion Winds; cloud motion winds were derived from cloud and water vapor trajectories estimated from geostationary satellites. In 2001 the Working Group expanded its focus to include OSVW from polar-orbiting satellites and the name was changed to International Winds Working Group (IWWG) (http://cimss.ssec.wisc.edu/iwwg/iwwg.html). The IWWG discusses and coordinates research and developments in wind vector data production, verification and validation procedures, and techniques for assimilation in NWP models. At about 2-year intervals the IWWG convenes a users workshop; inspection of recent agendas indicates that over 80% of presentations were related to winds derived from cloud and water vapor motions, which improve NWP forecast accuracy about two time larger than satellite OSVW data (Anthes, 2011; Gelaro, 2011). The expanded charter of the IWWG provides opportunities for discussion of wind shear in the planetary boundary layer (e.g., Halpern, 1979; Halpern and Knox, 1983). In addition, OSVW data could enhance the accuracy of low-level cloud motion vectors, e.g., by helping to determine outlier cloud motion values. The main focus of IWWG is wind vectors estimated from motions of clouds and water vapor with an approximate 10% devoted to OSVW, whereas the main focus of the JCOMM activity will be OSVW. JCOMM will explore the opportunity to utilize synergism with IWWG.

In 2008 the CEOS established the OSVW Virtual Constellation working group (http://www.ceos.org/index.php?option=com_content&view=category&layout=blog&id=73&Itemid=72) to harmonize different scatterometer systems, including timely, unrestricted and easy access to data products with consensus standards and formats; joint participation in calibration and validation efforts; and, collaboration in the use of OSVW data products for research and operational applications (Wilson et al., 2009). JCOMM differs markedly from the CEOS OSVW Virtual Constellation. JCOMM represents the IOC and WMO oceanography and marine meteorology research and operational communities with emphasis on integrating in-situ and satellite data; and provides a close interface with the operational management, enhancement, and utilization of OSVW data and metadata. JCOMM will generate deliverables similar to those of GHRSST and will have a similar bottom-up approach to develop a User Requirement Document (e.g., Kaiser-Weiss et al., 2012) for integrated in-situ and satellite OSVW deliverables. The CEOS OSVW Virtual Constellation has no such deliverables or activities and devotes its resources on developing a coordinated approach for satellite scatterometer missions, which is an extremely important activity for enabling the JCOMM Vision.

In 2010, NASA expanded the charter of the NASA Ocean Vector Wind Science Team into the International Ocean Vector Wind Science Team (IOVWST), which organizes and convenes an annual international OSVW science and technology workshop. Approximately 100 experts from about twenty countries participated in the 2012 workshop in Utrecht, where discussions ranged from microphysical properties and turbulence of the air-sea interface, performances of currently operating scatterometers, future instruments, weather and climate applications, and other topics (http://coaps.fsu.edu/scatterometry/meeting/past.php#2012).

The JCOMM Coordination With Other Groups Strategy will be built on three components or pillars:

- IOVWST and IWWG to promote meetings for operational users, researchers and information providers to interact at all levels
- CEOS OSVW Virtual Constellation to promote continuity of satellite OSVW missions
- JCOMM to facilitate research, modeling and prediction services for harmonized OSVW data products and expand capacity and capability for research and operational oceanography and marine meteorology applications.

Recognizing the “no duplication” principle, JCOMM would provide opportunities for synergy. JCOMM’s strategy would be consistent with that promulgated by the 2012 JCOMM-IV, which agreed that JCOMM should maximize interactions with and utilize existing mechanisms for dealing with satellites and satellite data products (e.g., CEOS and CGMS). Support and collaboration between CEOS, IOVWST, IWWG and JCOMM are vital to achieve the JCOMM Vision.

7 CONCLUSION

Knowledge of OSVW is extremely important in research and operations in both atmospheric and oceanographic sciences. In-situ surface measurements recorded by moored buoys anchored to the ocean bottom and by ships will forever be too few to adequately measure winds over the global ocean with sufficient fidelity in time and space to predict changing weather and ocean conditions. However, in-situ OSVW measurements are critical for calibration and validation of satellite OSVW data, and satellite OSVW measurements should be used to detect erroneous in-situ observations (e.g., Halpern, 1993). A satellite is the only measurement platform with capability to observe the daily global wind field over the ocean, albeit with aliased wind fluctuations at the diurnal period. Multiple satellites in coordinated orbits are needed to provide the desired sampling.

JCOMM, in collaboration with CEOS, IWWG and IOVWST, will develop a sustained effort for production of an ensemble of high-quality user-friendly OSVW datasets. JCOMM would enable “amplification of collective intelligence” (Vogt, 2012). To initiate the process, JCOMM and TT-SAT should nominate members and a leader for a new OSVW Subgroup and establish achievement milestones for the Subgroup. Then, the JCOMM TT-SAT OSVW Subgroup would prepare a user requirements document and implementation plan in partnership with CEOS OSVW Virtual Constellation, CGMS IWWG, and IOVWST.

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Acronyms

ASCAT	Advanced Scatterometer
CEOS	Committee on Earth Observation Satellites
CFOSAT	Chinese-French Oceanography Satellite
CGMS	Coordination Group for Meteorological Satellites
CMA	China Meteorological Administration
COAPS	Center for Ocean-Atmosphere Prediction Studies
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FTP	File Transfer Protocol

GEO	Group on Earth Observations
GHRSST	Group on High Resolution Sea Surface Temperature
GTS	Global Telecommunications System
HY	HaiYang
IOC	Intergovernmental Oceanographic Commission
IOVWST	International Ocean Vector Science Team
ISRO	Indian Space Research Organisation
IWWG	Internal Winds Working Group
JCOMM	Joint Technical Commission on Oceanography and Marine Meteorology
JPL	Jet Propulsion Laboratory
KNMI	Koninklijk Nederlands Meteorologisch Instituut
Metop	Meteorological Operational
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NSOAS	National Satellite Ocean Application Service
NWP	Numerical Weather Prediction
OSCAT	Oceansat Scatterometer
OSI	Ocean and Sea Ice
OSVW	Ocean Surface Vector Wind
QuikSCAT	Quick Scatterometer
RSS	Remote Sensing Systems
SAF	Satellite Application Facility
SAR	Synthetic Aperture Radar
SST	Sea Surface Temperature
TT-SAT	Task Team for Satellite Data Requirements
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States
WMO	World Meteorological Organization