NAVAL UTILIZATION AND RESEARCH ON WIND REMOTE SENSING

Jeffrey D. Hawkins, Tom Lee, and Joe Turk

Naval Research Laboratory, Marine Meteorology Division,
Monterey, CA 93943

ABSTRACT

The U.S. Navy relies by necessity on remotely sensed winds to assist in mapping the three-dimensional (3-D) wind field. The scales of interest range from global and mesoscale analyses and input to numerical weather prediction models [NOGAPS and COAMPS] to tactical scales focused on 1-100 km. A sensor suite is incorporated to address the various requirements needed to cover both a large domain and high spatial resolution for particular applications. Therefore, a combination of geostationary (GEO) and low earth orbiting (LEO) sensors is operationally processed to extract accurate wind measurements and meet needs via data fusion.

The Navy currently uses both passive and active microwave sensors to map oceanic surface winds. Passive microwave surface wind speeds are produced using the Special Sensor Microwave/Imager (SSM/I). The 1400-km sensor swath has been providing valuable data since the first launch in 1987. The Navy now incorporates data from three active SSM/Is in near real-time around the globe to measure winds in non-raining areas for winds ranging from 3-25 m/s. Wind speeds are also produced by the Tropical Rainfall Measuring Mission (TRMM) Microwave Radiometer (TMI) and used to temporally update the more abundant SSM/I data set. Surface wind vectors are processed in near real-time for QuikSCAT at the Fleet Numerical Meteorology and Oceanography Center (FNMOC). The active microwave scatterometer winds have proven extremely useful for Navy nowcasting applications worldwide. Particular attention is given to their use in high winds in mid-latitudes and near tropical cyclones since the active microwave data can get closer to rain areas than the passive microwave sensors.

Geostationary cloud and water vapor-tracked winds have been a key backbone of the non-surface winds since the mid 1990s. Numerous studies done in concert with CIMSS clearly showed the value of geo-winds, especially the upper-level water vapor winds. The water vapor winds are critical in mapping the synoptic and mesoscale patterns in data void oceanic regions. Analyses with geo-winds are much improved and model forecasts have been shown to markedly benefit from properly assimilating this valuable data set. The CIMSS geo-wind algorithm is now running at the Air Force Weather Agency (AFWA) and FNMOC to produce high-density GMS-5 data and this will be expanded shortly.

The Navy is actively involved in wind research as evidenced by the lead role in both the Special Sensor Microwave Imager Sounder (SSM/IS) and the WindSat passive microwave polarimetric sensor and the partnership with NASA/NOAA on the upcoming GIFTS sensor. Specific examples highlighting the current capabilities and future needs will be presented.

1. Introduction

Naval/Marine Corp resources may be called upon to act on warfare, rescue and humanitarian missions anywhere around the world. The Naval elements may require wind information ranging from the ocean surface to high altitudes. Horizontal spatial scales can vary from 1 degree globally to less than 1-km in littoral and operational areas. Vertical wind resolution in the lower boundary layer is not currently sampled well enough except by some in-situ sensors. The combination of global requirements and horizontal/vertical needs inherently requires the ability to telescope from global, to regional, mesoscale and local domains as demanded by the particular application. Satellite-derived winds can directly answer many Navy operational requirements and augment other sensors via multi-sensor data fusion when sensor limitations arise.

The Joint Typhoon Warning Center (JTWC, Pearl Harbor, Hawaii) is a joint Navy/Air Force effort that readily illustrates the various wind needs around the world. The Area of Responsibility (AOR) covers much of the globe's oceanic basins except the Atlantic and Caribbean Sea. Relatively high spatial resolution winds are needed to adequately prescribe surface inflow needed for tropical cyclone (TC) genesis. Somewhat coarser winds aloft are required to accurately map the vertical wind shear that is essential to understanding TC health and future track/intensity.

The general public is well aware of Navy needs for surface winds and the direct impact on ship handling. Less well known is the simple fact that the Navy operates a wide range of ships, both in size of vessels and their ability to tolerate sea conditions. Much smaller vessels that have very strict sea state operational conditions often accompany aircraft carriers and other big deck ships. Thus, optimal ship track routing (OTSR) personnel must have access to both basin-wide wind forecasts to make 5-7 day prognostications and high resolution nowcasts in order to determine specific track changes as conditions warrant. Track adjustments may be made in order to satisfy mission goals while working within the "safe envelope" of wind/sea conditions for each Navy ship type.

The Navy operates aircraft that span the spectrum in terms of operating altitude ranges and sensitivity to winds and wind shear conditions. Aircraft carrier planes require accurate high-resolution winds in the vertical, both at the point of launch as well as around the goal/target/rescue point. Helicopters have obvious low-level wind needs resulting in strict nowcasting and short-term forecasting requirements. In addition, the Navy utilizes aircraft that routinely reach altitudes ranging from 20,000'-40,000' and cover long transit/refueling times. Coarser resolution wind information assists the pilots in determining transit/loiter times which are critical for multi-asset coordinated missions.

Unmanned Aerial Vehicles (UAVs) are rapidly coming online after successful demonstrations. Wind information requirements literally run the entire gamut since UAVs include platforms that can be held in a person's hand, to jet aircraft approaching the size of commercial airplanes. UAVs will significantly add to Naval wind needs and directly state that the major progress obtained in the last 5 years will need to be augmented and exceeded in many cases.

2. Data Voids

Data voids are the rule and not the exception when one considers the myriad of Navy resources that operate within the troposphere. The range of requirements attributable to hand-held UAVs to high altitude jet aircraft are rarely satisfied even over the relatively well instrumented continental United States. The lack of date becomes more acute over oceanic regions due to the scarcity of in-situ observations. The north Atlantic and Pacific Oceans have only a few islands supplying complete upper-air radiosonde measurements. Additional surface reports are available, but their number and distribution are woefully inadequate for all but local requirements.

Coastal and inland areas are also prime Navy/Marine Corp operating zones as dramatically illustrated in the Persian Gulf War, the Balkan conflict and the current Operation Enduring Freedom (OEF). These conflict regions will not be sending out routine meteorological reports since data denial starts no later than the first armed action by either side. The data denial efforts can start well before armed conflict as tensions increase and normal meteorological functions are cut-off from the global telecommunications service (GTS).

The three-dimensional data voids must be mitigated in order to safely and accurately carry out the multiple Naval/Marine Corp missions. A wealth of sensors is utilized in order to map the 3-D wind field and satellite sensors play a critical role.

3. Satellite Wind Sensors

Satellite-derived wind measurements fall into two classes, 1) surface-based oceanic winds, and 2) cloud and water vapor-derived winds above the earth's surface. Both satellite data sets can number in the tens of thousands globally each day, but have specific advantages and disadvantages that help and hinder a given mission needs. Surface-based oceanic winds are observed by using microwave sensors on LEO spacecraft (typically 700-850 km) while most cloud and water vapor-derived winds are produced from sequential geostationary imagers.

Passive microwave sensors flying on the Defense Meteorological Satellite Program (DMSP) spacecraft are capable of providing surface wind speed values at 25-km horizontal resolution. The ocean surface microwave emissions vary as the wind speed increases and surface foam changes the characterization of the ocean surface. The Special Sensor Microwave/Imager (SSM/I), first launched in the summer of 1987, has provided a wealth of ocean surface wind speeds (scalar quantity only) across its 1400-km swath. Since 1992, at least two SSM/Is have been operational, with a maximum of four and the current 3-ball constellation now supplying near real-time data. SSM/I data is available via the FNMOC (Monterey, CA), the Navy's regional centers which have access to real-time DMSP data capture and processing, and by most large ships equipped with SMQ-11 systems.

Figure 1 illustrates how SSM/I wind speeds can map oceanic mesoscale winds surrounding the rugged Japanese topography. High mountains routinely block low-level wind flow and create "lee" affects. The lee side has decreased wind speeds and is often used by sailors as shelter. Mountain gaps permit passage of strong frontal surface winds that are readily observed and create localized wind speed jets spurting out across the local mesoscale region. These "gap" winds are observed in many regions including the Mediterranean Sea, Caribbean Sea, many areas off the eastern coast of Asia and throughout Indonesia.

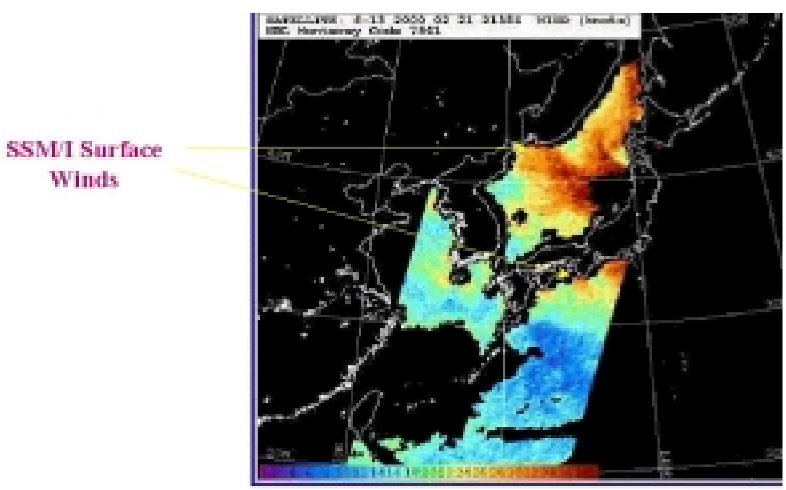

Figure 1: SSM/I surface wind speeds are displayed in false color form on the left. Low wind speeds are blue and higher wind speeds are yellow, orange and red respectively. Note the wind field jets just offshore between North Korea and China and to the east of Japan created by topographic mountain gaps.

SSM/I surface wind speeds have been assimilated into the Navy Operational Global Atmospheric Prediction System (NOGAPS) since 1990 (Goerss and Phoebus, 1992). The 80-km horizontal resolution model "super-obs" SSM/I wind speeds by averaging surrounding satellite winds produced at 25-km resolution. The averaging process reduces the noise and error of the initial retrieval, but also removes some of the mesoscale structure desired in the 25-km data set. This "super-ob" process is limited when using the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS). The triply nested COAMPS model is typically run with 81/27/9-km grids and can handle much of the SSM/I spatial information. Additional COAMPS runs using higher grid spacing are being tested.

Passive microwave wind speed assets will greatly increase with the successful launch of the SSM/IS series of satellites. SSM/IS is the follow on to SSM/I and represents a five (5) set of sensors. The collocated imager and sounder will permit enhanced geophysical retrievals and NRL-MRY is the calibration/validation core team for this new sensor. SSM/IS efforts will go in tandem with the WindSat polarimetric sensor due to launch at nearly the same time later this year or in early 2003. WindSat will provide surface wind vectors (wind direction as well as speed) for the first time from a passive microwave sensor. WindSat technology is a risk reduction effort for NPOESS and thus has great significance for long term space based oceanic wind vectors. WindSat cal/val is being headed up by NRL-DC.

Active microwave scatterometers have been available operationally since the launch of ERS-1 in 1991. Ocean surface wind vectors (speed and direction) are retrieved by processing the multiple "looks" afforded by multiple beams on antenna. ERS-1/2 were C-band scatterometers with the following characteristics; a) 500-km swath, b) 50-km wind vector horizontal resolution, and c) relatively unaffected by rain contamination. Calibration and validation programs proved these wind vectors were typically good to within 2m/s and 20 degrees within wind speeds of 3-20 m/s. Although the swath width was limited (both sensors have ceased to function as of today), these scatterometers provided a wealth of surface winds used not only for model assimilation, but also used in near real-time by Navy marine forecasters around the world. The JTWC routinely used these data sets for TC analysis/forecasting efforts (Hawkins and Helveston, 1998).

The NASA SCATterometer (NSCAT) data and its much larger swath were used briefly before the sensor terminated due to onboard power issues. SeaWinds scatterometer data on the QuikSCAT satellite has been instrumental in naval operations. The 1800-km contiguous coverage far exceeds the spatial sampling of previous scatterometers and the wind retrieval model function has proved to meet the specifications when rain is not present. However, rain causes major problems with wind directions and makes low winds too high and high winds too low. Additional research is needed to adequately assign rain and quality control flags to this data set.

Figure 2 is a QuikSCAT data set near tropical cyclone 13P in the South Pacific Ocean. The cyclone is beginning to create a well-defined surface wind field as noted by the wind vectors both in the clear region to the SW and within the cloudy and rainy region on the eastern side of the entire system. Rain flagged winds have circles at the base of their wind barbs. The scatterometer data is used routinely for mapping the radius of gale force winds, helping in center fixing when wind direction solutions permit and mapping wind asymmetries (Edson and Hawkins, 2000). Many TCs can have significant wind field asymmetries due to their interaction with synoptic features. Understanding the asymmetries is critical to wind and wave forecasts produced by the OTSR personnel.

NRL-MRY is working with a collaborative group including universities, NASA/NOAA and private companies to address the improvements needed for rain-flagged scatterometer winds. The upcoming ADEOS-2 launch will present an excellent opportunity due to its combined SeaWinds and Advanced Microwave Scanning Radiometer (AMSR) payload. AMSR (similar to the SSM/I, but with much better spatial resolution) will enable users to accurately identify scatterometer winds that are rain contaminated and potentially permit corrections and upgrade the final wind vector solution. In addition, the quality control flags assigned to each wind vector should be superior to those currently produced for QuikSCAT winds.

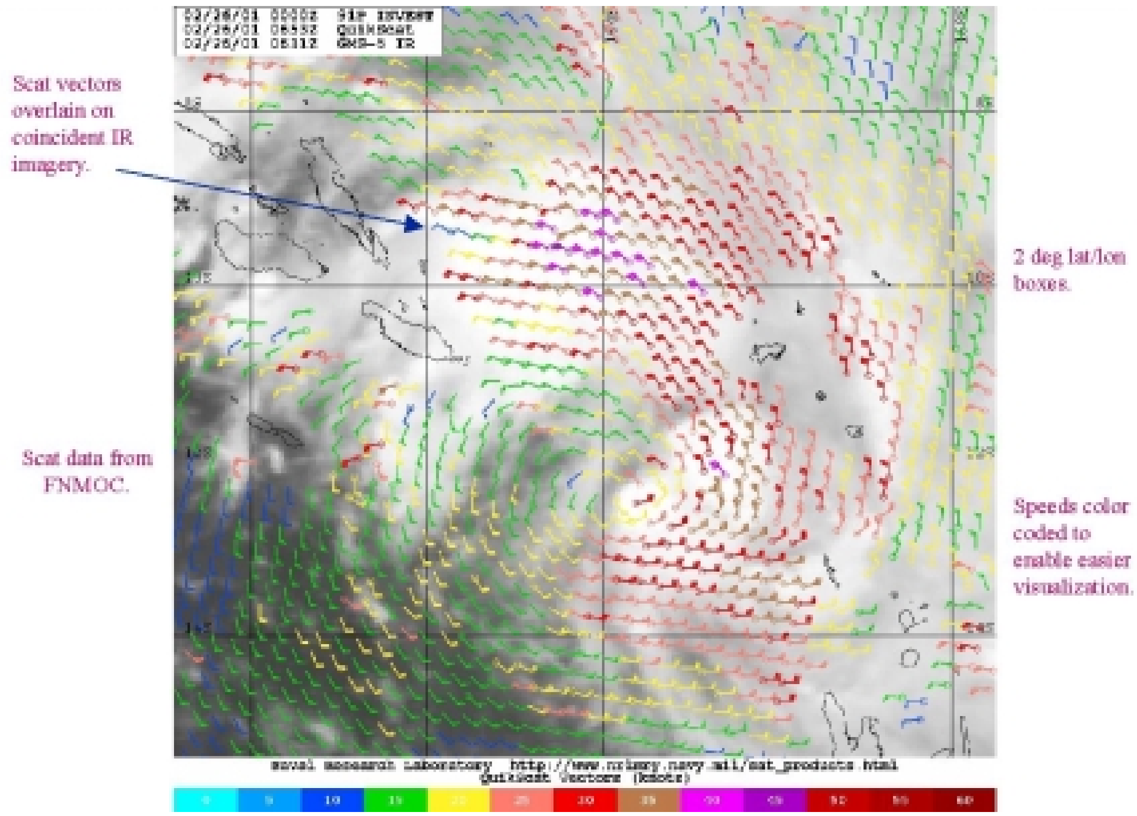

Figure 2: QuikSCAT surface wind vectors for tropical cyclone 13P in the early stages of its life cycle. Rain flagged winds have circles at the base of the wind barb. Wind barbs are color coded by their wind speed to help the user identify high wind regions.

Geostationary cloud and water vapor-tracked winds have been the **single** most important new satellite wind data set for Naval applications. The creation of high-density, accurate, multi-level wind vectors spanning the globe from five (5) GEO satellites has greatly assisted both nowcasting and forecasting efforts. GEO winds have greatly mitigated the previous oceanic data voids and also augmented declining land-based data sets. The ability to run automated algorithms with improved quality control checks has made this data set indispensable.

GEO winds have played a **huge** role in the way the JTWC analyses both upper-level and low-level oceanic wind fields. Previous 200 mb charts ready for analysis over the Pacific and Indian Oceans were typically quite sparse. One analysis could differ from the next 12-hr update significantly, with the inclusion of several new radiosonde reports, even though the analyst viewed animated GEO imagery. The inclusion of high-density GEO winds simply revamped the entire data set, upgraded the analysis quality and thus boosted the TC forecasting results as well.

NOGAPS began assimilating the high-density GEO winds starting with special wind data sets produced by CIMSS. Velden, et. al., 1997 and Goerss, et. al., 1998 outline the wind production methodology and a sample impact study using high density GOES-8 winds on NOGAPS tropical cyclone forecasts. All studies showed both enhanced initial analyses as well as positive forecast impact across the board. NRL and FNMOC were one of the first centers to use high-density GEO winds from in the west pacific basin in order to support JTWC.

The GEO wind success encouraged DoD to implement the CIMSS software at both AFWA and FNMOC in order to ensure back up processing existed for GEO data sets operationally. Figure 3 is a sample of both GMS-5 and Meteosat-5 winds produced by FNMOC. Severe sub-sampling is shown in order to cover the large domain illustrated.

The Navy has invested for the future by contributing to the GIFTS/IOMI (Indian Ocean METOC Imager). The interferometer holds great promise in enabling a major upgrade in the 3-D distribution, quality and quantity of cloud and water vapor-tracked winds. Nowcasting and forecasting efforts will be tuned in advance to properly assimilate GIFTS winds into operational products. Since GIFTS is the prelude to the sounder on GOES-R, developments for GIFTS will directly follow into applications for GOES-EAST and WEST in the 2010-2012 timeframe.

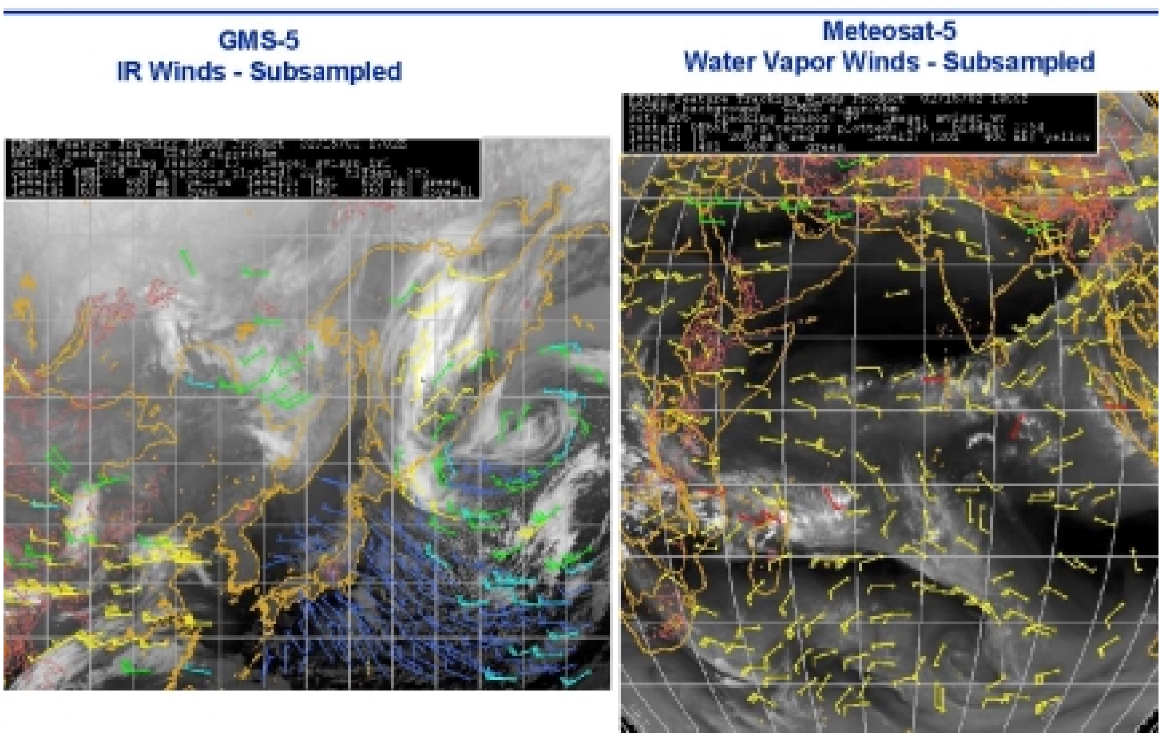

Figure 3: Geostationary IR cloud-tracked winds on the left from GMS-5. Meteosat-5 water vapor-tracked winds over the Indian Ocean are displayed on the right graphic. Both data sets were produced at FNMOC in near real-time using CIMSS transitioned software. All vectors have been sub-sampled to adequately view the entire domain. Users have the ability to drill down and observe higher resolution winds.

REFERENCES

Goerss, J., C. Velden, and J. Hawkins, 1998: The impact of multispectral GOES-8 wind information on Atlantic tropical cyclone track forecasts in 1995. Part II: NOGAPS forecasts**.** Mon. Wea. Rev., 126, 1219-1227.

Goerss, J., and P. Phoebus, 1992: The Navy's operational atmospheric analysis. Wea. Forecasting, 7, 232-249.

Edson, R.T. and J.D. Hawkins, 2000, A comparison of scatterometer-derived wind data over tropical cyclones as determined from ERS-2 and QuikSCAT data, 24th AMS Conf. on hurricanes and tropical meteorology, 195-196.

Hawkins, J.D., and M.J. Helveston, 1998, ERS-NSCAT capabilities/limitations in mapping tropical cyclone wind fields, AMS 9th Conf. on the Interaction of the Sea and Atmosphere, pp. 45-48.

Velden, C., C. Hayden, S. Nieman, W. Menzel, S. Wanzong, and J. Goerss, 1997: Upper-tropospheric winds derived from geostationary satellite water vapor observations. Bull. Amer. Meteor. Soc., 78, 173-195.