# **P4.3** NEW TROPICAL CYCLONE WEB PAGE MICROWAVE PRODUCTS

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## 1. INTRODUCTION

Microwave satellite sensors are able to penetrate through non-raining clouds and "view" vital tropical cyclone eyewall and rainband structures not observed by coincident visible and/or infrared (vis/IR) imagery. Passive microwave imagers and sounders and active microwave radars such as scatterometers are able to retrieve important storm parameters when persistent upper-level clouds created by vigorous convective action obscure vis/IR data. A suite of microwave sensors are thus used to create the unique tropical cyclone (TC) research and development web page hosted by the Naval Research Laboratory's (NRL) Marine Meteorology Division in Monterey, CA.

The NRL tropical cyclone web page combines the rapid temporal updates afforded by geostationary (GEO) vis/IR imagers (e.g., GOES and Meteosat) with a multi-sensor suite of low earth orbiting (LEO) microwave sensors. The microwave sensors do not match the 1-km spatial resolution surface footprints typical for visible imagery from both geostationary (GEO) or LEO spacecraft, but make up for it by enabling the user to map TC features critical to accurately fix the storm position and infer intensity. Storm location and intensity are required not only for real-time warnings, but also directly impact multi-day track and intensity forecasts vital to an ever-growing coastal population and marine commerce.

Select passive microwave channels respond strongly to large frozen hydrometeors (e.g., hail, graupel) that occur when raindrops are carried well above the freezing level by vigorous updrafts. Tropical cyclone eyewalls and rainbands are characterized by strong updrafts and large frozen hydrometeors, which prominently scatter radiation at 85 GHz and thus dramatically lower brightness temperatures (Tb) observed by spaceborne sensors. Tb differences in the range of 50 –100 K frequently occur and thus provide a healthy signal from which to map eyewalls and rainbands not viewable by vis/IR data blocked by cirrus clouds.

Other microwave channels respond more strongly to the cloud liquid water abundantly populating the TC cloud bands. The ability to delineate the cloud/rainbands from the upper-level clouds via the 37 GHz channels permits the user to map low-level moisture inflow, eyewalls and rainbands without a dense population of large frozen hydrometeors and does not suffer from parallax issues that can impact 85 GHz observations.

The current suite of passive microwave imagers will be augmented by the Special Sensor Microwave Imager Sounder (SSMIS) onboard the Defense Meteorological Satellite Program (DMSP) spacecraft. In addition, the WindSat polarimetric radiometer on Coriolis will add not only Tbs from the important 37 GHz channels, but will also retrieve surface wind vectors. The wind vectors (speed and direction) will assist in mapping the surface wind field now only feasible with the QuikSCAT scatterometer. Coincident scatterometer and passive microwave products will enhance our ability to interpret the impact of rain on scatterometer wind vectors.

Section 2 will describe the LEO microwave data sets and their use on the TC web page. Section 3 will outline how the user can extract TC characteristics from the passive microwave products. Section 4 will summarize the potential that exists in the near term for improved TC reconnaissance as a result of these satellite sensors become available.

## 2. Data Sets

The Naval Research Laboratory's TC web page has demonstrated the utility of passive microwave imagery and products for global tropical cyclone

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(TC) monitoring by developing a near real-time web page (Hawkins et. al., 2001). The web page incorporates near real-time (1-3 hour data latency) digital data from the following passive microwave sensors: a) Special Sensor Microwave/Imager (SSM/I), b) the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), c) the Advanced Microwave Sounding Unit (AMSU-B), and d) the Advanced Microwave Scanning Radiometer (AMSR-E, onboard the Earth Observing System (EOS Aqua platform).

The microwave data sets are available via extensive collaboration with the Fleet Numerical Meteorology and Oceanography (FNMOC) collocated in Monterey, CA with NRL, the National Aeronautic and Space Administration (NASA) TRMM Science Data and Information System (TSDIS), the National Oceanic and Atmospheric Administration (NOAA) and the NOAA/NASA Near Real Time Processing Effort (NRTPE) team respectively. Considerable effort and innovation has reduced data latency to 1-3 hours for all LEO data sets. Updated LEO data sets are crucial to near real time operations and successful demonstrations with warning agencies around the globe.

Each sensor has multiple strengths and weaknesses and will be enhanced in a positive manner by the addition of two new resources: a) the Special Sensor Microwave Imager Sounder (SSMIS) and b) the WindSat polarimetric radiometer on the Coriolis spacecraft.

The SSMIS instrument is the follow-on sensor to the heritage SSM/I. Eight SSM/Is have been launched since the first one in summer 1987 and the SSMIS represents a logical improvement to the SSM/I sensor. The SSMIS maintains the same suite of channels (19, 22, 37, and 91 GHz), with 91 GHz representing a slight change from the SSM/I 85 GHz (Swadley and Chandler, 1992). The SSMIS adds channels at 150 and 183 GHz for both mesospheric sounding measurements in addition to enhanced vertical profile retrievals. The SSMIS imager and sounder channels are collocated, thus permitting environmental data record (EDR) performance not feasible with the combined SSM/I and T1/T2 sensors on previous DSMP spacecraft. The SSMIS also provides a 1707-km swath versus the smaller 1400-km SSM/I swath.

The SSMIS instrument on F-16 will physically replace the SSM/I sensor on F-14 since they are in the same orbit. Thus, the SSMIS does not currently enhance temporal sampling much, but does provide improved coverage due to the expanded 1707-km swath. In addition, the sequence of five (5) SSMIS sensors slated to fly on F-16 through F-20 will provide the TC community with passive microwave imagery well into the National Polar-orbiting Operational Environmental Satellite System (NPOESS) era and the Conical Microwave Imager Sounder (CMIS).

The WindSat polarimetric radiometer was launched on the Coriolis satellite in January 2003. WindSat if a proof of concept mission to validate the retrieval of ocean surface wind vectors via measurement of the four (4) Stokes parameters via passive microwave imagery (Gaiser, et al., 2004). WindSat contains channels at (6.8, 10.7, 18.7, 23.8, and 37.0 GHz). All channels are dual polarized (horizontal and vertical), but more importantly, the 10.7, 18.7 and 37.0 GHz channels also measure at +/- 45 deg. WindSat does not contain an 85 or 91 GHz channel, but does have superb resolution at 37 GHz (8x13-km). The 6' antenna is similar in size to the AMSR-E and significantly larger than the heritage SSM/I sensor. High-resolution 37 GHz imagery is critical to mapping important TC eyewall and rainband features.

The set of passive microwave sensors are complemented by the active microwave SeaWinds scatterometer onboard the QuikSCAT spacecraft. The June 1999 launch provided an 1800-km swath of surface wind vectors (wind speed and direction) whereas the SSM/I, TMI, and AMSR-E can only provide the scalar quantity wind speed. Information on closing off the low-level wind circulation, the radius of gale force winds and mapping the wind field asymmetries are important information for both warnings and potentially for assimilation into forecast models.

The page also includes 72-hour track forecast graphics that incorporate the official warnings from the appropriate tropical cyclone operational center via the Automated Tropical Cyclone Forecasting (ATCF) system (Sampson and Schrader 2000). Official forecasts from the National Hurricane Center (NHC) in Miami, FL and the Joint Typhoon Warning Center (JTWC) in Pearl Harbor, HI enable the web page to cover storms anywhere on the globe.

The web page is driven entirely by the operational warning centers via software that permits the start, update and stop of a system anywhere within their area of responsibility. The popularity of the near real-time products and successful automation has lead to the operational transition of the TC web page to FNMOC. The NRL demonstration web page is located at:

http://www.nrlmry.navy.mil/tc_pages/tc_home.html

## 3. Data Interpretation & availability

Lee et al. (2002), Hawkins, et al. (2001), Velden, et al. (2003), and Hawkins, et al. (2004) illustrate some examples depicting how passive microwave imagery can assist the analyst in mapping important TC rainband and eyewall features. In addition, Hawkins and Helveston (2004) demonstrate the ability to frequently detect double or concentric eyewalls in strong (>120 kt) hurricanes, typhoons and tropical cyclones. The frequency is much higher than previously believed since upper-level cirrus clouds persistently deny analysts from viewing internal storm structure other than the primary eyewall.

The SSMIS data will be available in real-time during the September 2004 time frame and will be added to the NRL tropical cyclone web page product suite. The larger 1707-km swath will reduce the coverage gaps and decrease the temporal sampling between successive TC overpasses.

The WindSat polarimetric radiometer will provide high resolution 37 GHz imagery on par with the TMI and AMSR-E data sets. Since WindSat is in an orbit unlike either TRMM or Aqua respectively, temporal sampling of 11-km 37 GHz data will dramatically increase. Figure 1 is a 37 GHz horizontal polarization image of Hurricane Isabel while traversing the Atlantic at Cat 4 strength. The well-defined “clear” eye is visible in addition to the rather “thick” eyewall and several rainbands, mainly to the east side. Interpretation of 37 GHz imagery will be enhanced as the TC community accumulates TC overpasses and coincident 85 GHz and aircraft radar data during the 2004 Atlantic summer season and reprocesses key passes during 2003.

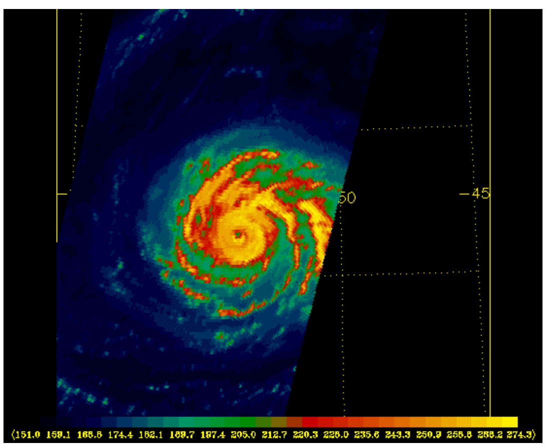


Figure 1. WindSat 37 GHz imagery of Hurricane Isabel as it transits across the tropical Atlantic

while a Cat 4 intensity. Data display does not exhibit full spatial resolution capabilities.

WindSat digital data will be released to the scientific community during August 2004 for evaluation and continued validation. Near real-time data is anticipated during Sept/Oct timeframe and will be added to the NRL TC web page product suite as soon as feasible.

Scatterometer surface wind products and passive microwave imagery have been inter-related since the SeaSat spacecraft launch in 1978. This pioneering sensor suite incorporated the Scanning Multi-channel Microwave Radiometer (SMMR) that assisted in determining which scatterometer wind retrievals were impacted by rain and permitted corrective action due to the collocated data sets. Unfortunately, no other scatterometer has flown on the same platform with a passive microwave imager until Adeos-2, but spacecraft power failed after nine months. However, with multiple microwave imagers currently operating, we can temporally match tropical cyclone overpasses between the QuikSCAT scatterometer and SSM/I, TMI, AMSR-E data sets.

The NRL TC web page currently has the full suite of passive microwave data sets in addition to the QuikSCAT single solution and wind vector ambiguities from FNMOC. A new combined product is created whenever TC overpasses occur for the same storm within +/- 2 hours between the scatterometer and microwave imager data sets. Figure 2 illustrates how the QuikSCAT wind vectors are overlain on 85 GHz horizontal polarization (H-pol) brightness temperatures using the standard H-pol false color temperature scale. Very low Tbs (~180-200K) occur in the eyewall due to huge scattering by large frozen hydrometeors. The red and yellow coloring within Typhoon Namtheun’s east side indicates strong asymmetries in the storm’s convection, highly indicative of westerly shear aloft.

The warmer Tbs (blue colors) on the west side map lower-level moisture and denote a distinct degradation in storm structure that can occur when strong wind shear rips storms apart and impedes convective cells from forming in one or more storm quadrants. Shear can frequently be monitored in microwave imagery prior to clear evidence in coincident visible and infrared imagery from both GEO and LEO sensors. Note the lack of rain-flagged wind vectors (circles at the foot of the wind barb) for most vectors on the storm’s western semicircle.

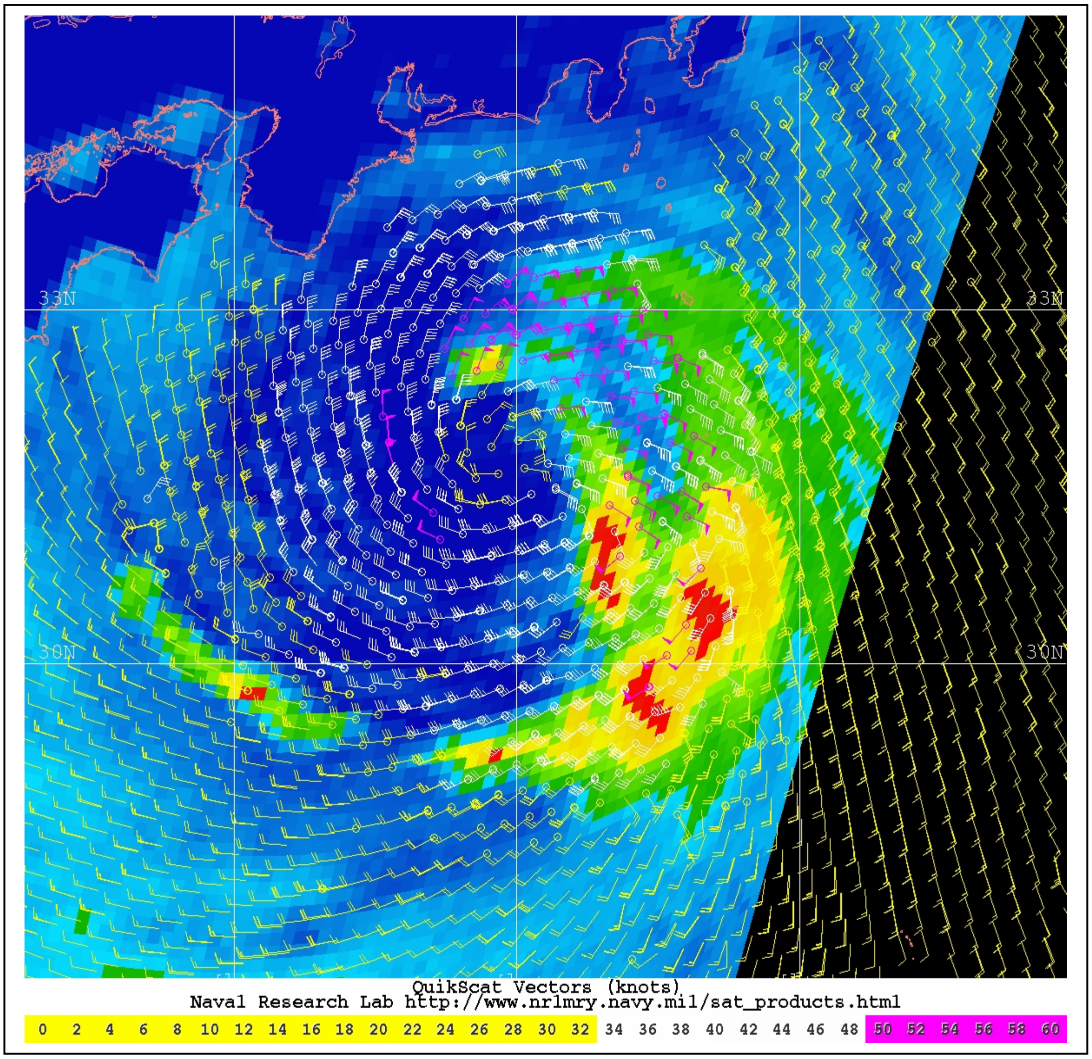


Figure 2. QuikSCAT scatterometer surface wind vectors overlain on SSM/I 85 GHz H-pol brightness temperatures for Typhoon 13W (Namtheun) on July 29, 2004. The scatterometer sampled the storm at 2020Z while the SSM/I data occurred 81 minutes later at 2141Z. Scatterometer winds below gale force are colored yellow (wind barbs rounded to the nearest 5 kts), gale force to 50 kts are white and all scatterometer retrievals > 50 kts are shaded purple. SSM/I 85 GHz Tbs are false colored with warmer Tbs colored blue and colder temperatures indicative of rain are colored yellow, orange and red. Latitude and longitude lines are plotted every two (2) degrees.

The "color" product uses the techniques noted by Spencer, et al. (1989) and demonstrated in recent examples by Hawkins, et al. (2001) and Lee, et al. (2002). Note how the lack of convection on the storm's west side not only permits the user to view the lower-level circulation as identified by low-level moisture fields, but also permits rain free QuikSCAT wind vectors ranging in speed from 20-50 kts. Tropical cyclone winds > gale force are typically accompanied by rain and thus may be contaminated depending on the rainrate intensity and distribution of rain within the scatterometer footprint. Figure 3 illustrates how QuikSCAT can readily assist in specifying the radius of gale winds within tropical cyclones.

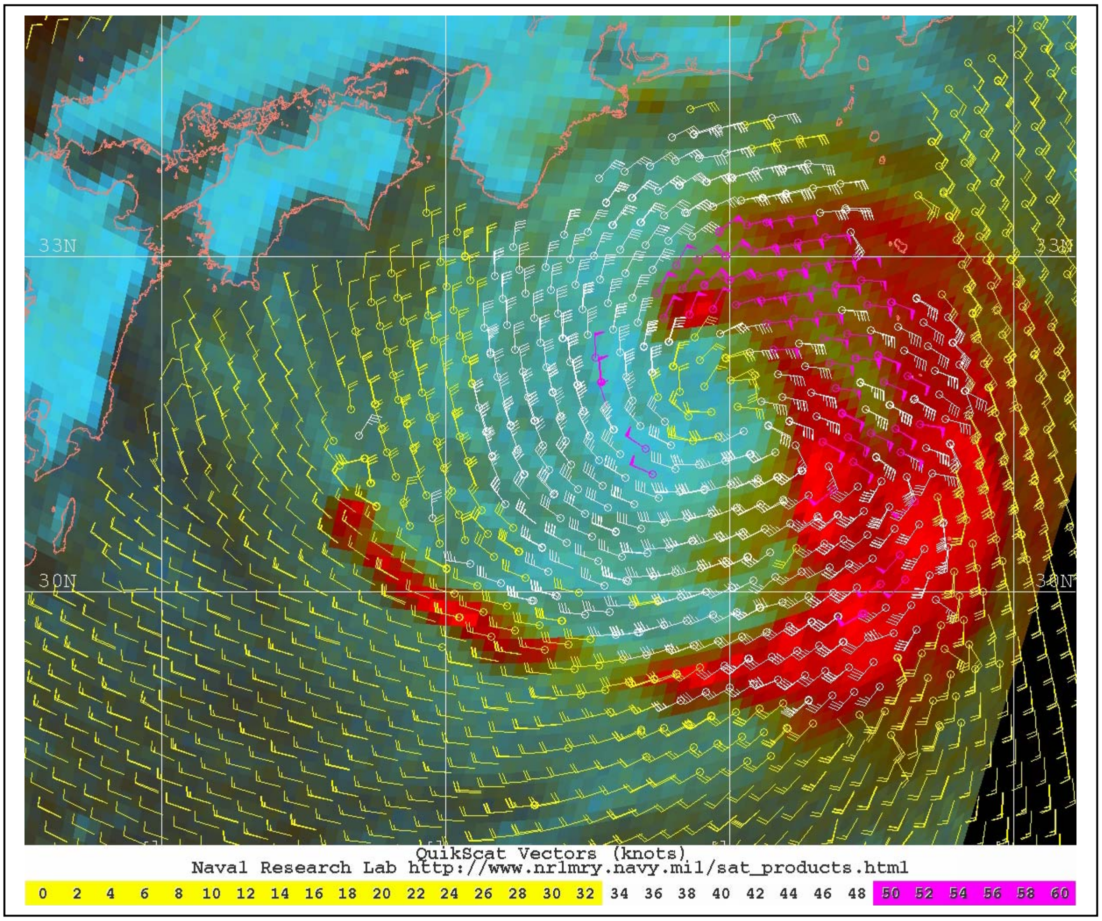


Figure 3. QuikSCAT scatterometer surface wind vectors overlain on SSM/I "color" composite as used on the NRL TC page for Typhoon 13W (Namtheun) on July 29, 2004 at 2020Z. The "color" product uses 85 GHz H and V pol data and the PCT to remove ambiguities between rain and cold ocean values. The exposed low-level circulation on the storm's western side is more clearly viewed and gale force winds are clearly mapped, as are winds near 50 kts. Latitude and longitude lines are displayed every two (2) degrees.

The right semicircle contains large convective regions that hamper high confidence wind vector retrievals. A large number of 50 kt wind vectors are collocated with "red" convective "color" signatures and are interspersed with a few weaker winds in between obvious rainband features. Convective rain cells will help in transporting high velocity winds down to the ocean surface, unlike the more stable environment on the west side. In addition, rainbands likely have local wind maximums poorly sampled by QuikSCAT's 25-km spatial resolution, resulting in wind speeds that are typically lower than the true maximum surface winds. The QuikSCAT winds can thus represent a "minimum" maximum wind for the tropical cyclone being sampled.

The lack of a collocated passive microwave radiometer on QuikSCAT is partially overcome by finding time and space coincident matchups over TCs with SSM/I, TMI, and AMSR-E near real-time data sets. The microwave imager data will be augmented shortly by adding both SSMIS and WindSat and increasing the matchup potential. The combined scatterometer and microwave imager product will be added to the NRL TC web page shortly.

## 4. Summary and Future Potential

Passive microwave imager digital data has assisted the tropical cyclone satellite analyst via the ability to view vital storm structure under all-weather conditions. The TC monitoring effort will be bolstered by adding the SSMIS and WindSat data sets which both have distinct positive attributes.

The SSM/IS will permit the continuation of the extremely valuable SSM/I data record stretching back to F-8's launch in 1987 and continuing into the next decade via launches on DMSP spacecraft through F-20. WindSat will provide excellent resolution 37 GHz data in addition to surface wind vectors and sea surface temperatures. The multi-pronged data set will provide key data to the TC research and operational community.

Combined microwave imagery and scatterometer data is now viable due to the wealth of passive microwave data available. The microwave imager constellation (SSM/I, TMI, AMSR-E, SSMIS and WindSat) provides opportunities not viable when only SSM/I and TMI data were the only sensors until recently.

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