

# **Remotely Sensed Tropical Cyclone Structure/Intensity Changes**

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Award #: N0001400WX20251  
[http://kauai.nrlmry.navy.mil/sat-bin/tc\\_home](http://kauai.nrlmry.navy.mil/sat-bin/tc_home)

## **LONG-TERM GOALS**

Our long-term goal is to understand the structure and organization of tropical cyclones around the clock, such that Navy estimates of location and intensity are highly accurate and successfully impact medium and short term decision-making.

## **OBJECTIVES**

Our objective is to accurately map the structure and organization of tropical cyclones throughout their lifetime and better understand the temporal changes under all-weather conditions. Accurate knowledge of the storm's structure will enable enhanced knowledge of storm location and intensity in near real-time.

## **APPROACH**

Passive microwave digital data will be utilized to mitigate the natural limitations inherent with both visible and Infrared (vis/IR) imagery when applied to the tropical cyclone (TC) monitoring mission. Upper-level clouds often obscure mid- and low-level cloud structure that is crucial in accurately accessing the current location and intensities of TCs around the world. Passive microwave frequencies can "see" below upper-level cirrus on a routine basis and permit the user to map the rainbands, eyewalls and eye structure not feasible with vis/IR imagery.

There are currently two satellite platforms that carry passive microwave sensors in polar orbit; a) the Defense Meteorological Satellite Program (DMSP) and its Special Sensor Microwave/Imager (SSM/I), and b) the Tropical Rainfall Measuring Mission's (TRMM) Microwave Imager (TMI). The 85, 37, 22, and 19 GHz frequencies on each sensor measure brightness temperatures that are directly impacted by the scattering due to medium-large ice particles aloft and absorption due to rain. These particles are well correlated with intense convection associated with TC rainbands, eyewalls and mesoscale convective systems. Thus, the scattering produces dramatically lowered brightness temperatures that effectively map out the TC structure desired and produces images "similar" to that of a land-borne radar. Jeff Hawkins, Joe Turk, and Tom Lee are the NRL contributors on use of the imagery, while Paul Tag, Richard Bankert and Juanita Sandidge are investigating the automated intensity analysis.

| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     | Form Approved<br>OMB No. 0704-0188                               |                                                     |                                    |
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| 1. REPORT DATE<br><b>30 SEP 2000</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    | 2. REPORT TYPE                      |                                                                  | 3. DATES COVERED<br><b>00-00-2000 to 00-00-2000</b> |                                    |
| 4. TITLE AND SUBTITLE<br><b>Remotely Sensed Tropical Cyclone Structure/Intensity Changes</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                                                  | 5a. CONTRACT NUMBER                                 |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 5b. GRANT NUMBER                                    |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 5c. PROGRAM ELEMENT NUMBER                          |                                    |
| 6. AUTHOR(S)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                                                  | 5d. PROJECT NUMBER                                  |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 5e. TASK NUMBER                                     |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 5f. WORK UNIT NUMBER                                |                                    |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>Naval Research Laboratory,,Monterey,,CA, 93943</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                    |                                     |                                                                  | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER         |                                    |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                                                                  | 10. SPONSOR/MONITOR'S ACRONYM(S)                    |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 11. SPONSOR/MONITOR'S REPORT<br>NUMBER(S)           |                                    |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release; distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                                                  |                                                     |                                    |
| 13. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                                                                  |                                                     |                                    |
| 14. ABSTRACT<br><b>Our long-term goal is to understand the structure and organization of tropical cyclones around the clock, such that Navy estimates of location and intensity are highly accurate and successfully impact medium and short term decision-making.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                    |                                     |                                                                  |                                                     |                                    |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                                                  |                                                     |                                    |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     | 17. LIMITATION OF<br>ABSTRACT<br><b>Same as<br/>Report (SAR)</b> | 18. NUMBER<br>OF PAGES<br><b>6</b>                  | 19a. NAME OF<br>RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |                                                                  |                                                     |                                    |

Project team:

|                       |                                      |
|-----------------------|--------------------------------------|
| Jeffrey D. Hawkins —  | team leader, satellite meteorologist |
| Joe Turk —            | satellite meteorologist              |
| Paul Tag —            | computer vision, expert systems, AI  |
| Richard Bankert —     | computer vision, expert systems, AI  |
| Juanita Sandidge —    | neural networks                      |
| Arunas P. Kuciauskas— | satellite meteorologist              |

## WORK COMPLETED

Over 3,500 SSM/I passive microwave images coincident with tropical cyclones have been processed. SSM/I data from 1987-1999 onboard DMSP satellites F-8, F-9, F-10, F-11, F-13, F-14 and F-15 (note that F-15 has been added since last year's report) have been processed with software designed to glean full capabilities from the 85 GHz images. Special processing has enabled 1-2 km resolution 85 GHz images to be directly compared with coincident OLS IR and geostationary vis/IR data sets. The data set includes systems from depression status (30 kt) to Super Typhoon or Category 5 (150 kt) in the Atlantic, Pacific and Indian Ocean basins. Computer vision and neural network methods have been applied to this unique data set.

TMI digital data has been received in near real-time from NASA-GSFC and processed for all active TCs around the globe for ~ 18 months. TMI data has been processed and collocated with coincident geostationary vis/IR data and is now an integral part of the NRL Monterey tropical cyclone web page:

[http://kauai.nrlmry.navy.mil/tc-bin/tc\\_home](http://kauai.nrlmry.navy.mil/tc-bin/tc_home)

Comparisons with SSM/I data at multiple frequencies have revealed capabilities of TMI not feasible with SSM/I data sets. These comparisons are possible due to the collocations and consistent image processing used for both the SSM/I and TMI data sets.

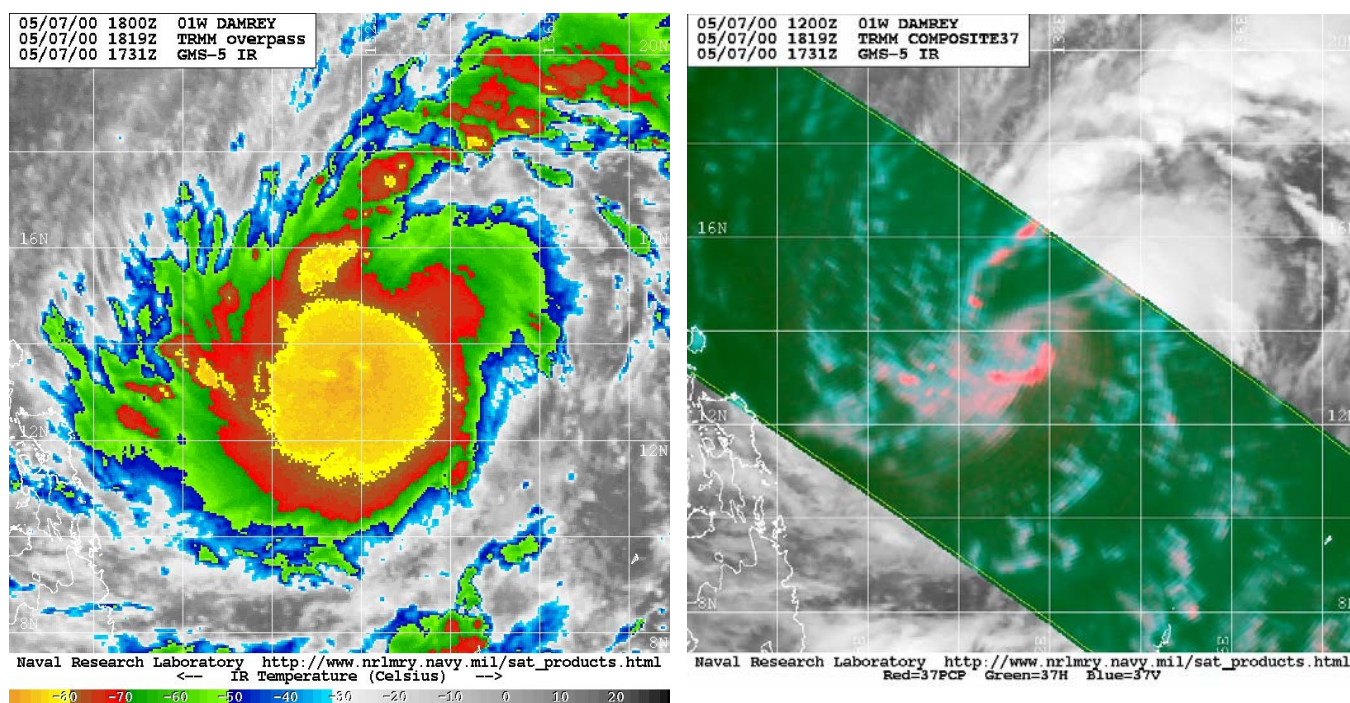
Advanced Microwave Sounding Unit (AMSU-A) data has been collected and processed for the 1999 and 2000 TC seasons to date. Excellent data sets for Dennis, Floyd, Gert, Irene and Jose that include multiple aircraft monitoring have provided the "ground truth" needed for this technique to evolve to the next level. Near real-time TC intensity results are being computed offline at CIMSS (Cooperative Institute for Meteorological Satellite Studies, U. of Wisconsin). Chris Velden from CIMSS heads this task and utilizes the near real-time storm position updates available at NRL.

## RESULTS

Computer vision and neural network algorithms have been applied to the enlarged passive microwave TC data set. Results when applied to individual storms throughout their lifetime are very encouraging and have likely reached the limits of the best track intensity database (~ 15 kt). These accuracy levels are on par with long-term Dvorak values and enable us to work collaboratively with a 6.4 Spawar PMW-185 work unit focused on TC applications.

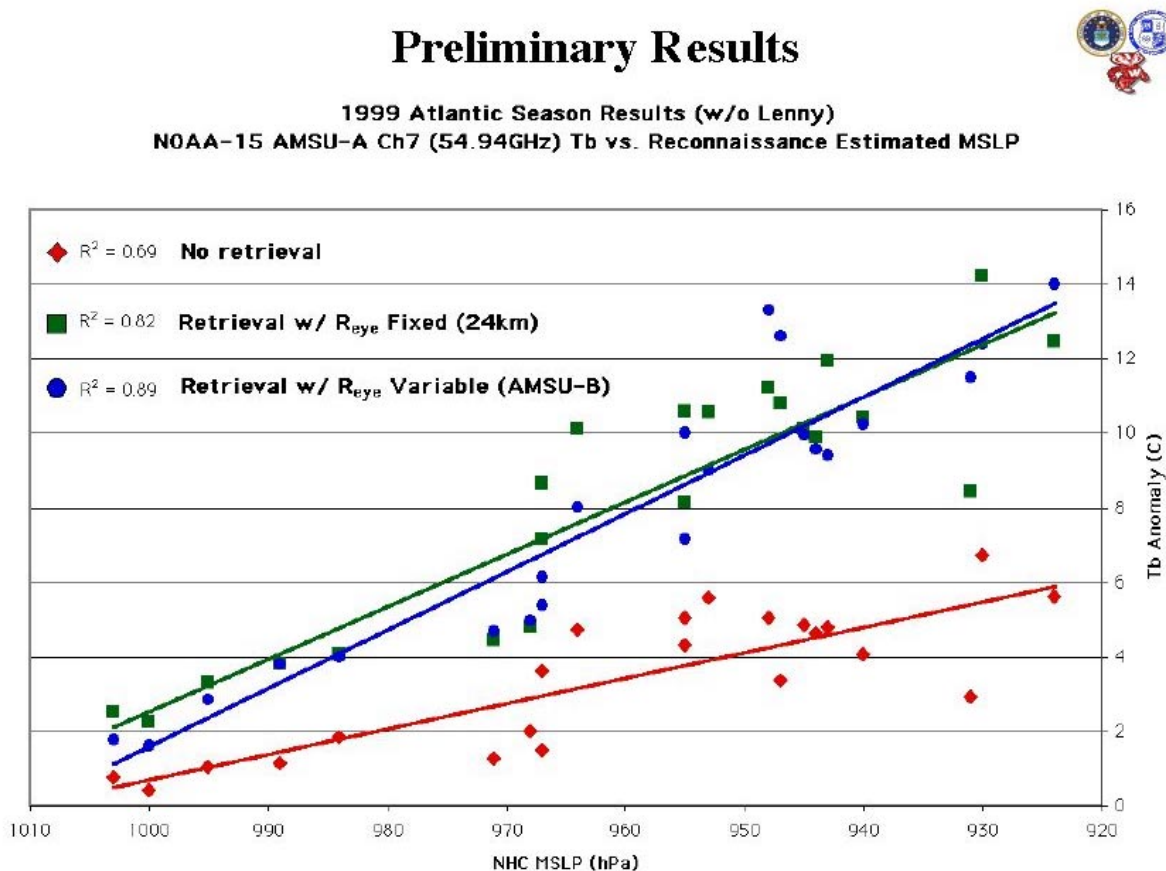
TMI data has supplemented SSM/I data in two ways; a) providing TC views at non-SSM/I times, and b) permitting much higher spatial resolution views at lower frequency channels. The TRMM orbit compliments the SSM/I constellation and increases the temporal updates. More frequent imagery has allowed better definition of TC concentric eyewall cycles, which have turned out to be important short-term intensity indicators. This project has shown that storms typically reach 120-140 kts before a secondary eyewall begins to form. First, the inner eyewall reaches a critical minimum diameter (8-10 nm), then the secondary eyewall begins to form and cut off inflow to the inner eye, and the inner eye begins to decay. The secondary eyewall then becomes the primary eyewall as convection builds and the eye shrinks in size as the storm reintensifies over the short term.

85 GHz imagery depicts the TC organization aloft in the eyewall since it is strongly impacted by large frozen hydrometeors above intense convection. One would like to use the 37 GHz channel on the SSM/I to see further down into the TC, but the SSM/I's resolution at this frequency is poor. However, the 37 GHz resolution on the TMI is twice that of the SSM/I and has shown promise in mapping TC structure not feasible with 85 GHz. Figure 1 below illustrates a typical central dense overcast (CDO). A convective burst has temporarily produced high clouds that obscure the view of the central TC core as evidenced by the huge area of cloud tops < 80 C. However, the 37 GHz product created using a 37 Polarization Corrected Temperature (PCT) and both 37 GHz channels readily reveals the storm's center location.



**Figure 1. Comparison of false colored IR image for Typhoon Damrey and 37 GHz TMI composite product on May 7, 2000 at 1819Z. IR image depicts CDO and hints at eye feature, while 37 GHz product leaves little doubt as to center location.**

Preliminary results from AMSU-A matchups with TCs indicate significant improvement in mapping the upper-level warm core temperature anomaly when compared with previous Microwave Sounding Unit (MSU) data. Limb and channel bias corrections have been initially completed and near real-time demonstrations are being done at CIMSS for storms worldwide. Comparisons with both aircraft recon data in the Atlantic and preliminary best track values in the WPAC are very encouraging as shown in Figure 2. Once validation has occurred, the team envisions creating a multi-pronged effort that uses Objective Dvorak, SSM/I and AMSU intensities to glean the best satellite intensity estimate possible.



*Figure 2: Comparison of AMSU-A values with NHC best track storm intensities.*

## IMPACT/APPLICATIONS

Intelligent use of passive microwave data over tropical cyclones can greatly increase our knowledge of TC structure and thus location and intensity. Tropical cyclone warnings are directly affected and they in turn have a direct impact on the course of action taken by Navy/Marine assets in a storm's path.

Even though the Navy fleet size is shrinking to near 325 ships, fewer ports are being used. Thus, large ports such as Norfolk are home to a larger number of ships as well as increased diversity (large and small). Note that a single Norfolk fleet sortie due to hurricane evacuation now costs > \$10M, thus accurate predictions are crucial and must begin with precise initial conditions. Accurate tropical cyclone

warnings/forecasts by the Joint Typhoon Warning Center (JTWC) and Norfolk can be strongly tied to ship routing and warnings at the myriad of Navy/Marine Corps facilities throughout the world.

## **TRANSITIONS**

Results from the two automated passive microwave intensity techniques have been transitioned to 6.4 Spawar PMW-185 work units. Near real-time SSM/I and TMI digital data is now sent to JTWC from NRL via the same 6.4 work unit. This capability to use both data sets has proven critical to JTWC operations and is now being transitioned to FNMOC. JTWC now views 37 GHz imagery as a direct result of this 6.2 work unit.

The NRL Monterey tropical cyclone web page is also being transitioned to FNMOC, where it will be relied upon by JTWC and other Navy METOC centers, as well as the NOAA National Hurricane Center in Miami, FL

## **RELATED PROJECTS**

This 6.2 effort has a collaborative 6.4 work unit entitled “Tropical Cyclone Intensity and Structure Via Multi-Sensor Combinations” funded by SPAWAR PMW-185, PE 0603207N. The vertical integration of these 6.2/6.4 efforts has been instrumental in obtaining rapid progress via shared data sets, resources, expertise and knowledge of what is needed by the operational end user. This project is in constant contact with airborne research work carried out by NOAA’s Hurricane Research Division and the TRMM team efforts at NASA/GSFC, especially the CAMEX field program.

## **PUBLICATIONS**

Hawkins, J.D., T.F. Lee, K. Richardson, C. Sampson, F.J. Turk, and J.E. Kent, 2000, Satellite multi-sensor tropical cyclone structure monitoring, Minor revisions in progress for acceptance to Bull. Amer. Meteor. Soc.

Karyampudi, V.M., J.D. Hawkins, E.B. Rodgers, R.M. Zehr, C.S. Velden, and J. Simpson S. Huntrakul, 1999, Estimating the amount of rainfall associated with tropical cyclones using satellite techniques, WMO Report No. TCP-42. (Chapter 2: Tropical cyclone structure and intensity change).

Hawkins, J.D., T.F. Lee, F.J. Turk, K.L. Richardson, C. Sampson, and J. Kent, 2000, Multi-satellite tropical cyclone structure (SSM/I & TMI), 24<sup>th</sup> AMS Conf. on hurricanes and tropical meteorology, 482-483.

Bankert, R.L., P.M. Tag, J. Sandidge, J.D. Hawkins, and M. Helveston, 2000, Automated passive microwave tropical cyclone intensity algorithms, 24<sup>th</sup> AMS Conf. on hurricanes and tropical meteorology, 189-190.

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, 24<sup>th</sup> AMS Conf. on hurricanes and tropical meteorology, 195-196.

Lee, T.F., J.D. Hawkins, F.J. Turk, K. Richardson, C. Sampson, and J. Kent, 1999, Tropical cyclone images now can be viewed “Live” on the web, EOS, Trans. Amer. Geophys. Union, 50, 612-614.