Remotely Sensed Tropical Cyclone Structure/Intensity Changes

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LONG-TERM GOALS

Accurately map the three dimensional structure and intensity changes of tropical cyclones via satellite remote sensing data for both real-time analyses and as input to numerical weather prediction models.

OBJECTIVES

Develop techniques to map the three-dimensional (3-D) structure of tropical cyclones (TCs) in all-weather conditions. Enable the analyst to determine whether a tropical system has changed intensity via the organization of relevant cloud/rain bands and the formation of an eyewall or eye. Derive a methodology that will work well at night when Infrared (IR) data is typically poor.

APPROACH

Passive and active microwave satellite data will be used to mitigate the current limitations of visible and infrared (vis/IR) data that now form the bulk of the data used to monitor the structure and intensity of tropical cyclones (TC) worldwide. Animated loops of TCs enable the users to determine storm motion and often storm intensity. However, the inability to see through upper-level clouds (cirrus shield created by vigorous convection in rainbands and eyewall) often impairs accurate storm position and intensity determination and thus negatively impacts real-time warnings. Inaccurate nowcasts then impair numerical model forecasts as a result of poor initial conditions.

The Special Sensor Microwave/Imager (SSM/I) is a seven (7) channel passive microwave imager onboard the Defense Meteorological Satellite Program (DMSP) polar orbiter satellite series. The launch of an SSM/I in 1987 marked the first time that the TC community had a high quality passive microwave imager with data available in a near real-time mode. The 85 GHz channel on the SSM/I is able to penetrate most non-raining clouds that have small ice crystals. The ability to see through most cirrus clouds is thus a major plus when dealing with tropical cyclones, since they typically have considerable upper-level cloud shields created by vigorous convection. The cirrus shield inherently limits the use of vis/IR data, since the user cannot see beneath the shield and vital position and structure information is lost or severely degraded.

The 85 GHz SSM/I imagery has a spatial resolution of 12x15-km and can effectively map most of the rainband and eyewall features when processed appropriately. Accurately mapping the rainbands and

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14. ABSTRACT
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15. SUBJECT TERMS

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eyewall and their changes during the day have the potential to increase our understanding of TC evolution. The ability to view TC internal 2-D structure around the clock is vital in knowing whether a system is intensifying, decaying, or remaining steady state. The SSM/I has a swath of 1400-km. The medium size swath means that multiple sensors are required in order to adequately map TCs several times/day anywhere on the globe. This goal has been accomplished since the early 90's when two or more SSM/Is have been operational.

The Advanced Microwave Sounding Unit (AMSU) is a passive microwave sounder that has two functions that assist in TC monitoring; 1) mapping the upper-level warm core temperature anomaly above a TC, and 2) using the 89 GHz channel to assist in determining eye size for the intensity estimation algorithm. Tropical cyclones are a heat engine and create an anomalous patch of warm air above them that is directly related to their enormous convection. The magnitude of this warm core aloft has been shown by aircraft surveys to be related to the storm's intensity. Therefore, if we can derive a method to map the warm core with satellite sounders, the community has an independent method to estimate TC intensities worldwide.

WORK COMPLETED

SSM/I passive microwave digital imagery from over 3,700 tropical cyclone overflights has been processed at NRL. The data processing techniques utilize specific image enhancement methods to produce high quality outputs. The 85 GHz images and rainrate products are analyzed by both human analysts and provided as input to an automated computer vision technique. The computer vision method has been applied to over 1,000 TC samples and is now gearing up to incorporate near real-time data for additional tests.

AMSU passive microwave sounding data from the NOAA-15/16 polar orbiters have been processed for the past 18 months over TCs in both the Atlantic and Pacific basins. Significant effort has been focused on the Atlantic basin due to the availability of high quality aircraft reconnaissance validation measurements. Near real-time processing is now online and providing the research team with invaluable insight on how to improve the algorithm and extend it to the western Pacific for eventual use at the Joint Typhoon Warning Center (JTWC).

TECHNICAL RESULTS

This 6.2 effort has led the way in mining the wealth of TC organization information available in passive microwave imagery. The ability to use the 85 GHz imagery to see through non-raining clouds and remove the inherent limitations with vis/IR imagery has enabled researchers to better understand the time evolution of TC development and decay. Direct comparisons with coincident vis/IR data have proven time and again that passive microwave data can assist in both the nowcast position (actual storm center can be anywhere underneath a central dense overcast [CDO] that might be as large as 100-175 miles across) and intensity.

Passive microwave data is especially relevant at night when the analyst only has 4-5 km IR data to view and may follow cold cloud tops that are not representative of the low-level circulation center (LLCC). Shear conditions remove many of the cold clouds, but low-level clouds associated with exposed LLCC are very hard to see with just IR data. The CDO and shear conditions come at critical times in a storm's timeline and need to be mapped in real-time in order for the warnings and model bogus to be accurate and effective. Examples are readily available on the NRL Monterey tropical cyclone web page: http://kauai.nrlmry.navy.mil/tc-bin/tc_home

A time sequence of 3-5 passive microwave TC views/day can greatly aid the TC analyst. Figure 1 is an example for Typhoon Herb in the western Pacific. Note the evolution of rainband organization and eyewall development mapped in these images. The 6.2 effort has taken over 1,000 images and used them to train a computer vision technique to recognize TC intensity when presented with a single image. The main task is to ensure the database represents the large number of variations present in the real world environment. Features have been selected that are highly correlated with intensity (e.g., presence of an eye, high rainrate values near the storm center) and are then used to estimate the intensity of a new independent storm image with information from the training data set. Results to date reveal an RMS error near 15-17 kts. The 15 kt value is achieved for well-defined storms (usually stronger ones), while the 17 kt value is associated with the weaker, harder to see systems.

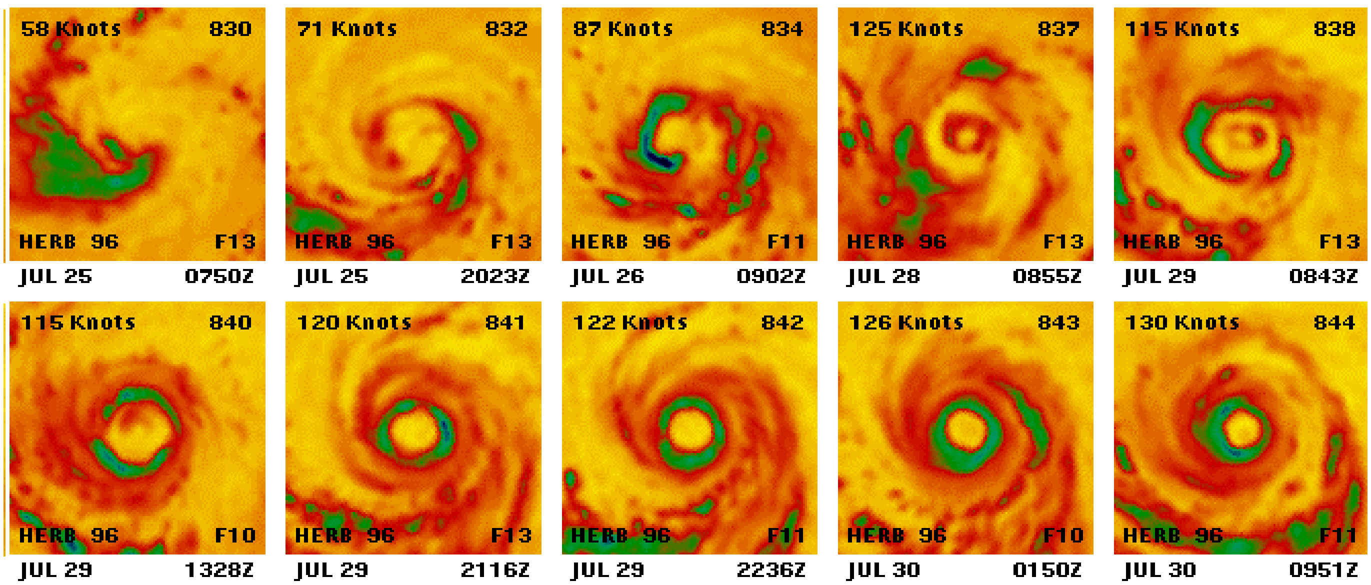

Figure 1. Time series of SSM/I 85 GHz imagery for Typhoon Herb. Evolution of the storm's eyewall and subsequent double eyewall is readily depicted.

The AMSU warm core temperature anomaly module has proven very successful. Initial tests in the Atlantic revealed that accuracies similar to Dvorak errors (~ 12 mb) were achieved when compared to aircraft minimum sea level pressures. These values have been subsequently decreased via refinements in mapping across scan biases in the AMSU data sets to near 8 mb. In addition, AMSU-B data is now being used to estimate eye size, since it is an important feature in the AMSU algorithm. The methodology has several advantages over directly observing TC rainband organization, since fully mapping the bands rapidly under all conditions can be difficult. The warm core aloft is also directly tied into the heat engine that fluctuates with time. Additional work is being done to incorporate SSM/I-TMI eye sizes as well.

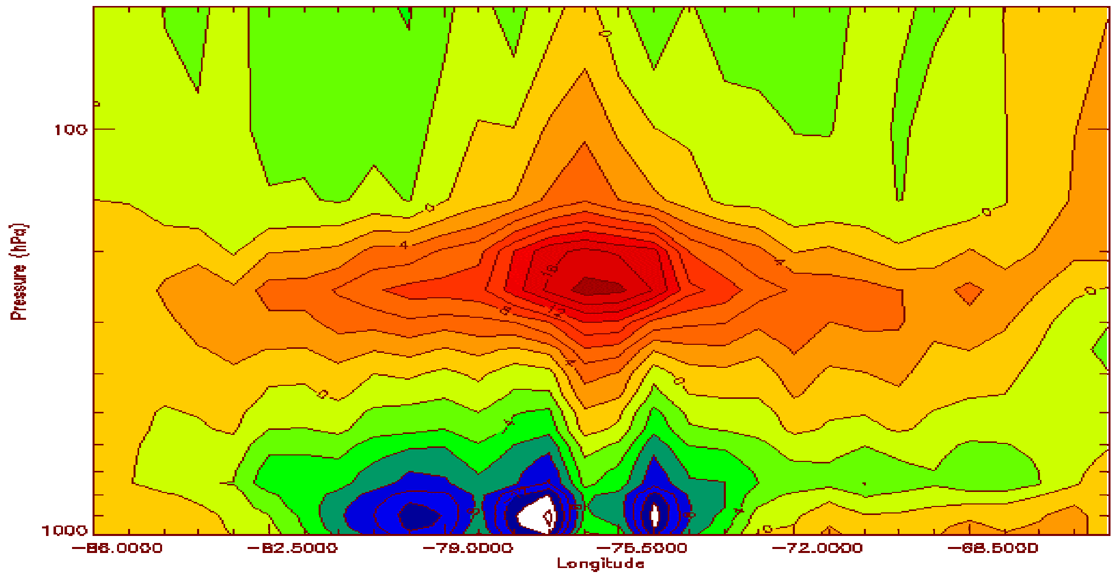

Figure 2. AMSU derived upper-level warm core temperature anomaly for Hurricane Bonnie off the East Coast of the U.S. Maximum warming is centered near 200-250 mb with values exceeding 16 degrees C.

IMPACT/APPLICATIONS

The TC web page and it's use of near real-time passive microwave imagery is having a direct impact on JTWC operations now in 6.4 demonstrations and transition to operations at FNMOC. The AMSU TC intensity estimates are now partially transitioned to 6.4 and feedback from JTWC has been very favorable. Remote sensing estimates of independently derived TC intensities will significantly assist JTWC due to their lack of in situ or recon data within their huge area of responsibility.

TRANSITIONS

The capability to view and utilize passive microwave for TC recon has been transitioned to 6.4 and more recently to operations at FNMOC. FNMOC is undergoing beta testing for their version of NRL-MRY's TC web page that uses passive microwave data as a key portion of the data set. The AMSU warm core temperature anomaly effort has moved a portion of it's effort to 6.4 and near real-time testing is underway with JTWC. The SSM/I intensity estimate module will be transition to 6.4 as soon as further data base additions are completed.

RELATED PROJECTS

This project is closely related to a corresponding 6.4 effort sponsored by the Space and Naval Warfare Systems Command (SPAWAR PMW-185) entitled “Multi-Sensor Atmospheric Applications”, funded under PE 0603207N. The 6.4 project serves as the transition vehicle, works closely with JTWC and NLMOC, and currently has taken the software partially developed in this 6.2 task and produced near real-time intensity estimates. Feedback from both JTWC, NLMOC and the National Hurricane Center in Miami, FL has been extremely positive.

SUMMARY

The use of passive microwave data for TC monitoring has blossomed as a result of this and corresponding 6.4 efforts. The NRL-MRY TC web page has gained worldwide acceptance and is routinely used operationally by all WMO TC warning centers. The automated intensity algorithms using computer vision and AMSU data aloft are gaining acceptance within the research community and are beginning to do the same within the operational centers. The vertical integration of the ONR 6.2 effort with the SPAWAR 6.4 work unit has enabled rapid progress and transition of these remote sensing TC monitoring tools.

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