IMPROVED SEVERE STORM CHARACTERIZATION
PE 0602435N (NRL BE-035-02-26)

Jeffrey D. Hawkins
Naval Research Laboratory
Monterey, CA 93943
Ph (408) 656-4833/ Fax (408) 656- 4769
hawkins@nrlmry.navy.mil

LONG-TERM GOALS:

Accurately determine severe storm environmental parameters (e.g. structure, intensity, rainrate) using remotely sensed data, to significantly upgrade warnings and long-term forecasts of severe tropical and extra-tropical cyclones over oceanic domains.

OBJECTIVES:

Develop innovative techniques to extract enhanced environmental information on severe oceanic storms from satellite sensors that permit global monitoring with rapid temporal sampling. Utilize the inherent advantages of multi-sensor digital data sets to probe and monitor the structure, intensity and location of ocean storms that frequently form and develop within remote, data sparse regions and then adversely impact Naval operations, shipping, air traffic and large populations. The new methods will be applicable globally and cover the full range of storm intensities encountered.

APPROACH:

Remotely sensed digital data from multiple satellite platforms/sensors are being utilized to augment the historically sparse *in situ* meteorological observations over the oceans in an effort to map important severe storm characteristics. Tropical oceans typically contain only a few island stations and fewer shipping lanes than the mid-latitudes. Thus, tropical cyclones (TC) will serve as the initial study focus since remote sensing data sets have significant untapped potential.

For over 15 years, the Dvorak pattern recognition technique has been routinely applied to visible and infrared data from geostationary and polar orbiter data to derive TC intensity estimates. The subjective nature of the Dvorak technique is a basic flaw, since analysts must spend considerable time training to competently apply the methodology. Still, the overall performance has been reasonably good, due in part to the rapid 30-60 minute refresh rate afforded by geostationary data. However, limitations associated with the cloud imagery -- the inability to see important low-level cloud features, rainbands, lack of visible data at night, handling rapidly changing storms, monsoon depressions, midget typhoons, and landfalling storms have produced a need for the next step in TC monitoring.

This study investigates the use of automated techniques to classify tropical cyclone intensities using both infrared (IR) data from geostationary satellites and passive microwave data from the Special Sensor Microwave/Imager (SSM/I). The IR method focuses on the temperature differential between the storm center and outer environmental values, while the SSM/I technique incorporates pattern recognition and a neural network (NN) approach.

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The SSM/I's 19, 22, 37 and 85 GHz channels provide information not feasible with visible or IR imagery, which cannot sense below the cloud tops. SSM/I data permits the user to see below the upper cloud deck, with the amount of penetration dependent on both cloud microphysics and the specific channel used. This capability is extremely beneficial since it enables us to more accurately define the rainband structure within TCs; these structures are highly correlated with storm intensity. The SSM/I method is based on using an Empirical Orthogonal Function (EOF) representation of the SSM/I imagery patterns to train a neural network to extract TC intensities.

Mapping rainrates associated with severe storms has been difficult at best, since satellite IR based estimates are inaccurate due to the imperfect relationship between IR cloud-top temperatures and rainrates. We attempt to resolve much of this problem by using the more physically-based SSM/I rainrates to train IR values. This approach takes advantage of the synoptic areal views and rapid refresh rates of the geostationary IR imagery with the fundamentally more accurate SSM/I rainrates.

WORK COMPLETED:

A new digital Dvorak method using IR digital geostationary imagery has been created and tested on a high quality Atlantic data set (Velden and Olander, 1997; Olander and Velden, 1998). The new algorithm incorporates the temperature differential between the storm center and outer environmental values, but derives much of its accuracy and utility by using pattern recognition rules that enable it to handle eye conditions that are less than optimal. A corresponding 6.4 Spawar 185 work unit has received this work as a transition.

We have selected and completed processing of over 1200 coincident SSM/I passes for storms of varying intensities. Best track intensities from both the JTWC and NHC were accessed and incorporated into the SSM/I TC data base. A refined data set of ~ 335 SSM/I 85 GHz images and best track intensities interpolated to the time of the SSM/I imagery has been used to train a neural network to extract maximum sustained surface winds. An independent set of 35 SSM/I 85 GHz images have been used to validate the neural network technique and have formed the basis for data base and neural net modifications. A revised data base consisting of > 700 storms is on the verge of being completed.

An initial rainrate algorithm incorporating SSM/I-IR digital data sets has been developed utilizing geostationary data from GOES-8,9 and GMS-5 and global SSM/I data..

TECHNICAL RESULTS:

Early Dvorak efforts demanded a "clear eye" in order to extract for successful intensity estimates, but this restriction has been removed. Validation using aircraft data in the Atlantic during 1995, 1996 and part of 1997 reveal the new technique is equal to or superior to the subjective estimates derived from all three operational analysis centers (NHC- Miami, NESDIS-DC, AFGWC, Offutt Air Force Base). In addition to being accurate, the method produces the same result each time and utilizes a fraction of the time used by the more manual method.

SSM/I imagery has been demonstrated to reveal important tropical cyclone (TC) features (e.g., rainbands, eyewall, eye) on a routine basis (May, et. al., 1997 and on the following web site:

http://www.nrlmry.navy.mil/sat-bin/tc_home). TC intensity is highly correlated with the presence and organization of the rainbands and eye features. This is evident when viewing a time series of SSM/I images for a given tropical cyclone. The formation of rainbands and eventually an eyewall is mapped very well with 85 GHz SSM/I data.

Our effort has focused on training a neural network to estimate TC intensity by using high resolution 85 GHz SSM/I data and coincident best track intensities. Original efforts using no a priori information other than the 85 GHz imagery for independent storm cases revealed an RMSE maximum wind speed > 20 kt. A priori intensity information in the form of "old" best track values was then used to determine what level of data was needed by the NN to achieve superior answers. We found that the use of 6 and 12 hour old best track data produced excellent intensities and revealed that the SSM/I imagery was providing a value-added improvement when compared to persistence intensities. However, best track a priori information is not available in an operational setting, so we replaced the 6 and 12 hour old intensities with an intensity estimate when the storms were in their formative stages.

Tests with Hurricane Marilyn indicate that a ballpark intensity estimate when the storm was a tropical depression is enough information to enable the neural net to produce viable results. The intensity input to the 2nd SSM/I Marilyn image is the output from the 1st image and so forth. Results reveal the NN catches the intensity trend well, both while deepening and weakening, but has large variability from one image to the next (Figure 1). Efforts are underway to decrease the variability as well as double the size of the training data set with additional cases.

An additional effort to effectively map rainrates for tropical cyclones and their environment has shown rapid progress. SSM/I data is used to "calibrate" IR digital data to create rainrate maps (Turk, et. al., 1997). The rainrate maps have the high temporal sampling afforded by geostationary IR sensors and have higher accuracies associated with the more physically-based passive microwave measurement techniques. Rain accumulation maps created for numerous storms indicate that diurnal changes in rainrates are readily captured using this multi-sensor method.

IMPACT:

Naval forces around the globe, whether at sea or shore-based, often encounter tropical cyclones and their associated damaging high winds and rains. Little improvement has been seen within the last 10 years in our ability to accurately monitor the structure, intensity and location of these potentially devastating storms. New and innovative methods are discussed here using satellite remote sensing data that have the potential to contribute towards dramatically increased knowledge of these weather systems that often form in data sparse regions, affecting Naval assets and civilian populations.

TRANSITIONS:

The digital IR method was transitioned to a 6.4 Spawar 185 work unit and is being tested on western Pacific data sets. The algorithm is being hosted on a Unix platform compatible with the Navy Satellite Display System - Enhanced (NSDS-E). Near real -time testing will begin in FY-98. The same 6.4 Spawar 185 work unit will receive the SSM/I neural network initiative in FY-98 for further test and evaluation due to positive findings. Results will dictate the pace for transition via 6.4 PE 0603207N to real-time fleet use at operational TC forecasting centers, the Joint Typhoon Warning Center (JTWC) in Guam and the Navy Atlantic Meteorology and Oceanography Center (NLMOC) in Norfolk.

RELATED PROJECTS:

This NRL project is related to a 6.2 effort funded by ONR, entitled "High Resolution Derived Wind Fields", which focuses on satellite multi-sensor derived atmospheric winds to define the 3-D wind field near TCs. This project is integrated with a corresponding 6.4 effort entitled "Multi-sensor Atmospheric Applications", funded by SPAWAR PMW-185 under PE 0603207N. The 6.4 project is the transition vehicle for this research and works closely with JTWC and NLMOC, which are the major Navy operational centers responsible for issuing tropical cyclone warnings to the Fleet.

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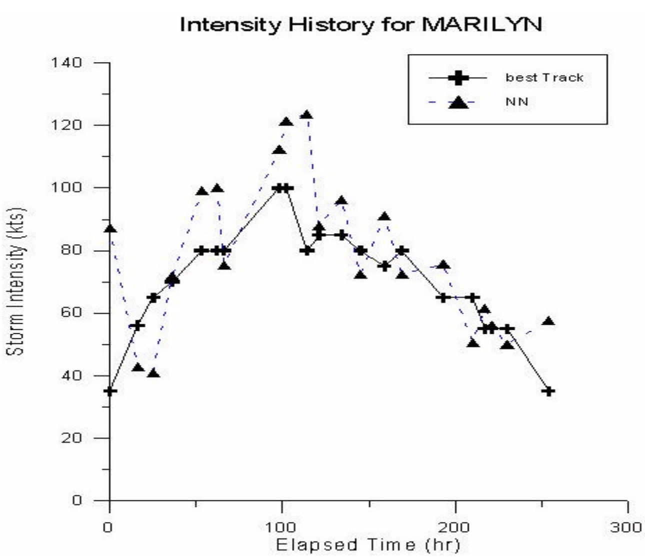

Figure 1. SSM/I neural net derived intensity values versus best track intensities for Hurricane Marilyn.