Remotely Sensed Tropical Cyclone Wind Fields

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LONG-TERM GOALS:

Accurately derive the three-dimensional atmospheric wind fields 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) wind fields associated with tropical cyclones (TCs). Use remotely sensed data to determine the wind field from the surface to the upper-levels to better understand the storm structure and to assist in determining the storm's intensity, thereby providing an important link to tropical cyclone data assimilation and severe storm characterization efforts.

APPROACH:

Remotely sensed digital data from multiple satellite platforms are being utilized to augment the historically sparse *in situ* meteorological observations over the ocean. Tropical oceans, in particular, contain only a few island stations and fewer shipping lanes than the mid-latitudes, but experience some of the world's most severe storms and an increasing amount of Naval activity. The lack of observations must be alleviated by an creative combination of satellite remote sensing measurements.

The geostationary platforms operated by the U.S. (GOES-8,10) Japan (GMS-5), and Europe (METEOSAT-7) are the primary tools available to monitor tropical cyclones. Cloud-tracked winds (CTW) derived from sequential visible and/or infrared (vis/IR) imagery have been routinely created for over 15 years and mainly support *coarse* resolution global analysis/forecast efforts. This project will develop innovative, high-density cloud-tracked winds and take full advantage of the satellite spatial resolutions of 1-5 km and temporal sampling of 15-60 minutes.

The main CTW limitation is the fact that cloud targets must exist during the entire imagery sequence. This obstacle has been largely overcome in the upper-levels by applying similar methodologies to the water vapor (WV) imager data. WV-tracked winds (WVTW) occur within the 150-450 mb layer and DO NOT require the presence of clouds, but rather a measurable gradient within the moisture field. Thus, WV winds have the potential of filling the data void aloft in cloud-free areas as well as producing winds in the presence of clouds and very high moisture regions.

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This geostationary-derived wind data set is being supplemented with surface wind speed measurements from the Special Sensor Microwave/Imager (SSM/I), which covers a 1400-km swath. This 25-km resolution passive microwave derived surface data is also combined with ocean surface wind vectors from the active microwave ERS-2 and NSCAT scatterometers in order to map the surface wind field. These scatterometers provide surface wind vectors at a resolution of 25-50 km and augment the SSM/I wind speeds with crucial wind directional information.

WORK COMPLETED:

Algorithms to produce high quality, cloud and water vapor-tracked winds using GOES-8, GOES-10, GMS-5, and Meteosat-7 digital imagery has been successfully tested for a wide range of tropical cyclone conditions. Satellite derived winds have been compared with over 50,000 radiosonde winds for the western and eastern Pacific and the Atlantic basins. A corresponding 6.4 work unit has transitioned the initial capabilities and provides JTWC/NLMOC with near real-time cloud and water vapor-tracked winds via Gif images and ingest to the Navy Operational Global Atmospheric Prediction System (NOGAPS).

A digital data set with over 1,500 cases containing SSM/I surface wind speeds coincident with tropical cyclones has been processed. ERS-1,2 scatterometer wind data for 1992-1998 is online and is being collocated with SSM/I winds within a 6.4 developed data fusion software module. NSCAT surface wind vectors for the full time of operation are online at NRL-MRY and being integrated with the data sets noted above.

TECHNICAL RESULTS:

High density, low-level cloud-tracked winds have been produced from GOES-8/10, GMS-5, and Meteosat-7 for tropical cyclones in all basins. Comparisons with operational cloud-tracked winds indicate a substantial improvement in defining the 3-D wind field has been achieved (Velden, 1997). Substantial *asymmetries* in tropical cyclone inflows have been documented by tracking cumulus clouds at the full spatial and temporal sensitivity of the geostationary sensors. These winds have assisted in defining the radius of surface gale-force winds and have been successfully used experimentally by JTWC. NOAA work incorporating these winds into the Hurricane Research Divisions (HRD) composited surface wind fields has been very successful. Comparisons with scatterometer surface winds around the periphery and within sheared storm systems has been very positive.

Water vapor-tracked winds have readily shown their value to map upper-level synoptic and mesoscale features that directly impact storm tracks by turning many hurricanes northward into the central Atlantic and shearing others apart (especially evident in 1997 season). Height assignment errors are 40-50 mb, while wind speed RMS errors are 3-6 ms^{-1} (partially speed dependent errors over the range 10-100 ms^{-1}), based on over 50,000 matchups with radiosondes throughout the Pacific and Atlantic basins. Input from analysts has been very positive and data assimilation impact studies with atmospheric models have shown 10-15% improvement in 72-hour track forecasts with NOGAPS using GOES-8 winds in the Atlantic (Velden, et. al., 1997; Goerss, et. al., 1998). Additional recent studies with GOES-10 and Meteosat-7 winds confirm these published findings.

Water-vapor wind quality control (QC) has been improved by better height assignment methods. Revised 3-D QC techniques have reduced the RMS error and eliminated vectors that were previously given poor heights. The effort is still hindered in part by the model first guess fields, which typically lack the mesoscale detail revealed by actual storm conditions. Thus, efforts are underway with the Coupled Ocean Atmospheric Mesoscale Prediction System (COAMPS) to study the impact the WV winds may have on a mesoscale model. Initial COAMPS tests were conducted on hurricanes Bonnie and Georges during the summer of 1998.

In addition, water vapor channels from the GOES sounders have been successfully used to create water vapor images at 10-km resolution at multiple altitudes. WV features are then tracked in sequential sounder images (same basic method as for imager data) to produce mid-level WV winds. These 400-600 mb level winds are extremely important, since they represent the first extensive data set of winds within this height range. Filling in this data void is important as evidenced in recent model sensitivity studies carried out by NRL-MRY.

SSM/I surface wind speeds have shown value in defining the radius of gale-force winds, but are often stymied by the inability to produce retrievals in rain and high water vapor regions. Using scatterometer winds largely solves this limitation. Scatterometer wind vectors have proven valuable in permitting the analyst to detect when a system develops a “closed” circulation. This permits the analyst to upgrade a disturbance to a depression or tropical storm based on the wind speeds and is a crucial step in the warning process (Hawkins and Helveston, 1997).

NSCAT data has shown that the two 600-km swaths increased the surface wind vectors by more than a factor of two over that achieved by ERS-2. The revisit times for tropical cyclones were dramatically reduced and each TC was typically sampled once/day. NSCAT wind speeds typically exceeded the 25 ms^{-1} maximum experienced with ERS-2 data and were in excess of 30 ms^{-1} in many cases. These higher winds were a direct result of the 25-km footprint on NSCAT versus the 50-60 km cells for ERS-1,2. Coincident visible, infrared and SSM/I data indicate that NSCAT did encounter rain attenuation in heavy rainbands as expected. These winds must be flagged and used with caution. NRL-MRY efforts to map synoptic rainrates via a combination of SSM/I-IR data may prove useful for this purpose and we are working cooperatively with the Jet Propulsion Lab’s calibration/validation team. This effort is important in the potential use of QuikSCAT (NASA scatterometer due for launch in Feb. 1999).

IMPACT:

The expanded and new data sets described in this effort have a direct impact on the Navy’s ability to monitor tropical cyclones around the globe. The primary impact has been on the successful transition to 6.4 SPAWAR –PMW 185 efforts to incorporate these extensive wind data sets in operational warnings and inclusion in NOGAPS model operational runs. These wind data sets have explained storm track and intensity changes that otherwise would have only been postulated or discovered after the fact. Responses from these Naval units have been extremely positive and are now mentioned in warnings as a result of the successful 6.4 SPAWAR-185 efforts.

TRANSITIONS:

The basic algorithms from this 6.2 effort have been successfully transitioned to the SPAWAR 6.4-work unit noted below. Near real-time low-level cloud and upper-level water vapor winds are being created with both GMS-5 and GOES-8,10 data and are available to JTWC, NLMOC, NPMOC and San Diego. These winds were provided to each organization via the Internet in the form of graphics images with wind vectors superimposed on visible or water vapor imagery. In addition, the validation of the winds with radiosondes proved that they were superior to current operational winds from NOAA/NESDIS, and FNMOC began using the new winds from this transitioned effort in late July, 1996 for assimilation into NOGAPS. Efforts are in progress to transition the algorithms to regional sites using the Navy Satellite Display System – Enhanced (NSDS-E) platform.

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 operational wind data sets for Atlantic and Pacific oceans. Feedback from both JTWC and NLMOC has been extremely positive.

The three-year NRL 6.2 project entitled "Improved Severe Storm Characterization" was strongly related due to its focus on extracting tropical cyclone intensity information from both visible/infrared imagery as well as newer applications with passive microwave imagery from the SSM/I. This neural network based approach of analyzing SSM/I 85 GHZ imagery blends well with the 3-D wind field mapping effort, since understanding the environmental winds is crucial to forecasting storm intensity.

This project is also closely associated with the 6.4 SPAWAR-185 sponsored NOGAPS effort and has worked closely with Dr. Goerss by providing initial data sets and error analyses for successful global model tests. More recent efforts are being done in conjunction with COAMPS tropical cyclone runs on hurricanes Bonnie and Georges.

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