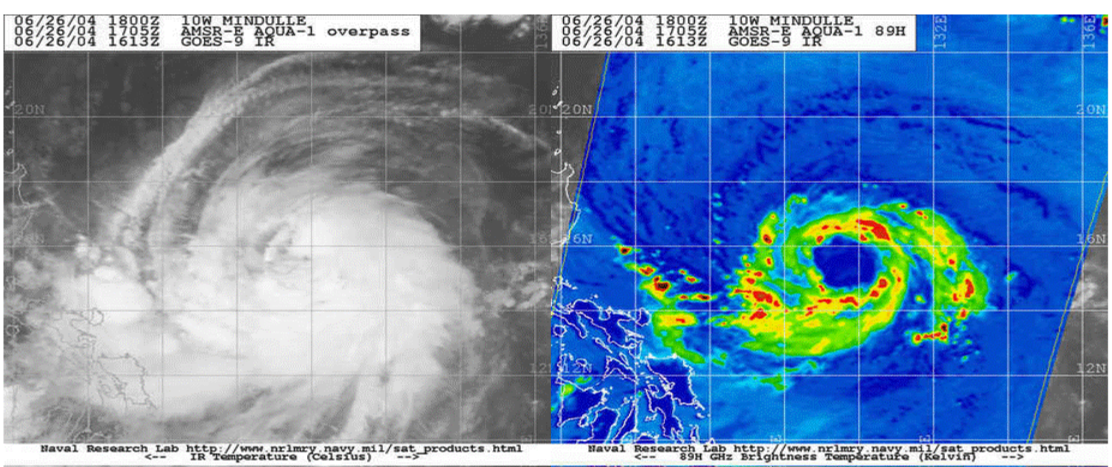
Near-Real-time Remote Sensing of Tropical Cyclones on the Web

Due to the lack of near-surface reports, satellites are used extensively to diagnose and forecast position and strength of tropical cyclones over the oceans. The primary tool for tropical cyclone forecasters is imagery from geostationary satellites. Animated visible and infrared imagery is routinely used to provide position estimates and monitor intensity trends. Water vapor imagery on such platforms also provides information on the upper-level atmospheric winds, vertical motion evolution and mid-level moisture. Automated techniques have been developed to use the geostationary imagery to produce cloud and feature track winds that are used to better initialize numerical weather prediction models and provide critical information on the vertical distribution of the wind field surrounding and interacting with tropical cyclones. Agencies all over the world use the Dvorak technique (developed in 1974 and updated in 1984 by Vern Dvorak) that provides intensity estimates and trend based on such visible and infrared satellite images.

Forecasters have also relied increasingly on passive microwave products and imagery from polar-orbiting satellites. Microwave-based products include: total precipitable water, which provides a good measure of the atmospheric moisture content around storms; rain rate; and ocean surface wind speed estimates. Microwave images from polar-orbiting satellites result in more precise tropical cyclone reconnaissance. Microwave imagery sometimes reveals features not seen in animated infrared and visible imagery, thus providing additional information that in turn creates better estimates of intensity and position. The left image below shows a GOES (Geostationary Operational Environmental Satellite) infrared image of Tropical Storm Mindulle. Unfortunately, the inner core is cirrus-covered, and little low-level storm structure appears. However, the geostationary perspective allows for time animations. In addition, although the GOES water vapor shows only the cold tops near the storm center, GOES water vapor data can be valuable in showing the interaction with dry air surrounding the storm which can eventually weaken it if absorbed into the circulation. The right side shows the corresponding Advanced Microwave Scanning Radiometer-EOS (AMSR-E) (89 GHz) image, revealing a large storm eye and allowing the analyst much improved inferences of center position and intensity.



This is just one illustration of the advantages of passive microwave data. Passive microwave sounders are also used to provide intensity-based magnitude of satellite-derived warm core structure that are both complementary and independent of estimates made using the Dvorak Technique. In addition to intensity estimates, microwave sounders also provide the three-dimensional structure of the tropical cyclone, albeit at the horizontal resolution of ~80km. These sounder-derived depictions provide information about the thermal structure or cyclone phase associated with tropical cyclones. Advanced versions of the objective Dvorak technique (under development) are incorporating microwave observations in the intensity estimates.

Passive microwave measurements from the Special Sensor Microwave Imager (SSM/I) on the Defense Meteorological Satellite Program (DMSP) spacecraft have been used over the last two decades to map ocean surface wind speed. These data are important to forecasters to help them position and determine the intensity of tropical cyclones, especially in the Pacific Ocean where there is no operational aircraft reconnaissance capability. More recently, passive microwave polarimetric measurements made by the WindSat instrument on the Coriolis spacecraft have been used successfully to map ocean surface wind vectors (speed and direction). The WindSat data are currently being evaluated for use in operational forecasting.

Active microwave instruments on low earth orbiting satellites also provide forecasters information about the ocean surface wind field and the heat content of the ocean. Scatterometry (i.e., active radar) provides ocean surface vector winds. Currently two such instruments are providing real-time data for forecasters: the National Aeronautics and Space Administration's (NASA) SeaWinds instrument on the QuikSCAT spacecraft and the European Space Agency's Advanced Scatterometer (ASCAT) on the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Meteorological Operational (MetOp-1) satellite. In addition to the ocean surface vector winds, space-based active microwave radar instruments provide altimetric measurements that are used to estimate oceanic heat content, which has been shown to be related to intensification of tropical cyclones.

Finally, one must not forget the importance of measurements from land-based radars and reconnaissance aircraft that provide detailed information on the location, rain rate wind speeds and structure of tropical cyclones as they make landfall. In the United States Doppler radar provides continuous coverage of coastal areas including Guam and Puerto Rico. There are a variety of satellite (and some radar) web sites providing near-real-time tropical cyclone support. Here is a partial list of resources:

<u>Operational:</u>

NOAA/NWS/NHC Satellite/Radar

http://www.nhc.noaa.gov/satellite.shtml GOES East/West images of loops of tropical cyclones; TRMM TMI and DMSP SSM/I(S) microwave imagery; Doppler radar.

NAVY

Fleet Numerical Meteorology and Oceanography Center Tropical Cyclone Web Page
_http://tcweb.fnmoc.navy.mil/tc-bin/tc_home.cgi

NOAA/NWS/NCEP

National Radar Page
http://www.nws.noaa.gov/radar_tab.php
AMSU-based global intensity/structure estimates (raw data)
ftp://ftpprd.ncep.noaa.gov/pub/data1/amsu

NOAA/NESDIS

Tropical Storm Position and Intensity Page
http://www.ssd.noaa.gov/PS/TROP/trap.html Tropical cyclone positions with accompanying visible, infrared and passive microwave images. Intensities based on Dvorak Classification scheme.
http://www.ssd.noaa.gov/PS/TROP/trap-img.html Tropical cyclone rainfall potential page.

Formation Probability Products: http://www.ssd.noaa.gov/PS/TROP/genesis.html

Research

NOAA/AOML

http://www.aoml.noaa.gov/phod/cyclone/data/ Tropical cyclone heat potential/ Oceanic Heat Content (global)

CIMSS

http://cimss.ssec.wisc.edu/tropic2 Global coverage of tropical cyclones, geostationary winds, the Advanced Dvorak Technique (ADT), Saharan dust layer analyses, AMSU intensity estimates, basin mosaics.

NOAA/CIRA

http://rammb.cira.colostate.edu/products/tc_realtime/ Visible/Infrared imagery, total precipitable water imagery, merged surface wind estimates, digital Dvorak estimates, AMSU intensity estimates.
http://www1.cira.colostate.edu/RAMM/rmsdsol/TROPICAL.html Geostationary satellite imagery over tropical cyclones and tropical cyclone basins
http://rammb.cira.colostate.edu/projects/gparm/genesis.asp Exprimental tropical cyclone formation product (Entire North Pacific and North Atlantic)

FSU

http://moe.met.fsu.edu/cyclonephase/ Experimental AMSU-base cyclone phase diagrams.

NASA

http://www.ghcc.msfc.nasa.gov/GOES/ GOES imagery of the Atlantic Hurricanes.

NOAA/NESDIS
QuikSCAT Storm Page
http://manati.orbit.nesdis.noaa.gov/cgi-bin/qscat_storm.pl Wind vectors and other information about worldwide storms.
Experimental ASCAT Page
http://manati.orbit.nesdis.noaa.gov/ascat/

NRL
http://www.nrlmry.navy.mil/tc_pages/tc_home.html
http://www.meted.ucar.edu/npoess/tc_analysis/ (COMET training on NRL Products)
Planetary tropical cyclones with geostationary images; microwave images from DMSP SSM/I(S), TRMM TMI, NOAA AMSU-B, AQUA AMSR-E. Sea surface wind vectors from QuikSCAT and WindSat.

Remote Sensing Systems, Inc
http://www.ssmi.com/hurricane/active_storms.html QuikSCAT and Microwave-based SSTs for active tropical cyclones (global)

References:

http://www7.nationalacademies.org/ssb/SSB_NPOESS2007_QuikSCAT.pdf
http://www7.nationalacademies.org/ssb/NPOESSWorkshop_NRC_Workshop_June07_zjelenak.pdf

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Remote Sensing Committee