NRL Monterey
Satellite TC Monitoring

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IWSATC-2
International Workshop on Satellite Analysis of
Tropical Cyclones
Outline:

Spectral, spatial, and temporal sampling

1. Introduction
   - Location, intensity, structure
   - Updates on sensors, capabilities, and product access

2. Objective TC intensity extraction
   - Identifying intensity related “features”
   - Update on identifying new features

3. Future availability of microwave imagers

4. Summary
39 hr eyewall evolution of Typhoon Nuri (2008): IR vs. Passive Microwave

IR/VIS imagery inherently limited by mid-upper level cloud obscuration, microwave imagers – all weather
TC Spectral Sampling Needs

% time IR/VIS imagery encounters upper-level clouds, limiting TC structure analyses

IR/VIS imagery consistently (30-35%) can NOT view crucial TC structure (location, inner core, intensity) due to upper-level clouds (WPAC) that can be mitigated by microwave sensors
GCOM AMSR2’s large swath and excellent spatial resolution aids monitoring Typhoon Fitow near Okinawa and Taiwan straits via 89 GHz Tb imagery.

1330 LTAN augments existing constellation TEMPORAL sampling: May 2012
GMI provides superb spatial resolution
(~5km @ 89 GHz, with 904 km swath) June 2014

Non sun sync orbit enhances TEMPORAL sampling with superb spatial resolution: NRL 1st to display NRT
Spatial Resolution Considerations

- Overpass comparison between AMSR-2 (resolves inner core and eye) and AMSU (barley shows inner core) of Hurricane Patricia.
- Occurred while NOAA's WP-3D and ONR NASA WB-57 were observing.
- Important to relate analysis of signal to sensor resolution.
2015 SATELLITE RECON

- Over 4.5K fixes using geostationary imagery ~ 36%
- Over 7.3K fixes using microwave imagery from polar orbit ~ 57%
- Over 800 scatterometry fixes ~7%

Total PGTW Fixes by Sensor (12779 Total Fixes)

Microwave sensor data represented > 60% of JTWC fixes

Courtesy: JTWC
Automated Tropical Cyclone Forecasting (ATCF) System warning graphic

- Latest 1-km Visible/IR imagery (GEO/LEO)
- Microwave imager/sounder product suite
- Scatterometer & CloudSat
- Vis/IR imagery suite
- Storm Basins & Names

http://www.nrlmry.navy.mil/TC.html

FNMOC: https://www.fnmoc.navy.mil/tcweb/cgi-bin/tc_home.cgi
Day Night Band (DNB): Lunar illumination

- VIIRS day-night band (DNB) cloud product helps differentiate low (yellow) and high (blue) clouds.
- New multi-channel capabilities will be added as Himawari-8, GOES-R/S come online.
Future of NRL satellite applications

• In-house development of new processing software
  – GeoIPS (Geolocated Information Processing Software)
  – Processes Himawari-8 data in real-time (10-minutely analysis phased in over this hurricane season)
  – Goal: process and visualize all meteorological and oceanographic data

• Currently processes VIIRS, MODIS, geostationary vis/WV/IR, RapidSCAT
Cyclone Megh (2015) in Himawari-8

Full disk image courtesy CIRA
NRL Joint Hurricane Testbed Goals

• Provide real-time and archived products using updated processing methodology:
  – Recalibrate ice scattering channels to common 89 GHz
  – Provide high resolution interpolation for consistent output analysis
  – Recenter imagery using CIMSS ARCHER
  – Use python as a cleaner and open source visualization

• Update color tables based on physical break points
• Devise parallax correction based on feature heights
Enabling Consistent TC Temporal Sampling

W-band (85-91 GHz) H pol microwave imagery from multiple satellites

ARCHER centered, Tb corrected to 89GHz

Coming to NRL TC page soon

Greatly eases TC structure analyses in near real-time
Need for Parallax Correction

• Due to scan angle of imagery, atmospheric features are spatially displaced from their ground location.

• A parallax correction regression is currently being researched using passive microwave and radar data to improve TC center fixing.
Current vs Planned Comparison
New Channels and Color Visualizations
Microwave Imagers at NRL-TC (MINT)

• Current status of dataset
  – 100,000+ global cases
  – Processing 20 TB WINDSAT dataset with all Stokes parameters
Intensity Distribution Comparison

- Graph shows normalized histogram of TC intensities.
- The distribution of all microwave cases to the subset considered is nearly identical.
  - Very close to the best track
Objective Metrics in this Presentation
The distribution of global microwave imager eye sizes compares well (and expands upon) aircraft eye sizes from the Atlantic basin.
Example Structure Combinations

Eye Radius (shaded; in km)

Inner-Core Radius (shaded; in km)
Relating Structure to Intensity

- Eyewall replacement shown by cyclic re-defining of minimum brightness temperatures.
- Even with eyewall cycles, core size seems to expand with time.
- Such cycles may relate to intensity fluctuations.
Objectively produced structural features

- **Top TC features**
  - Deviation angle variance (Ritchie et al.)
  - Finding an enclosed eye at different T_B thresholds
  - Eye/eyewall T_B differences
  - % encirclement at selected T_B
  - Isotropy (symmetry)
  - Thickness and percent coverage of T_B rings around center
  - Various statistical measures (e.g., NW quadrant ave T_B)

- **Other shape calculations**
  - Perimeter size
  - Perimeter/area
  - Fractal Dimension
  - Compactness
  - Horizontal, vertical extent (and their ratio)
  - Elongation
  - Moments of inertia
  - Invariant moments
  - Eccentricity
  - Texture measurements

Features computed on MINT dataset with “best” combination of features selected for intensity estimation algorithm.
Deviation Angle Variance

- Stronger storms have more organized rainbands and eyewall features
  - Produces lower deviation variance values
- Weaker storms have disorganized convection and may lack spiral bands
  - Variance values are higher (lower axisymmetry).

Significant convection:
Intensity estimate too high without axisymmetry measure.

Minimal convection:
Intensity estimate too low without axisymmetry measure.

Best Track: 40 kts
Low gradient axisymmetry

Best Track: 90 kts
High gradient axisymmetry
First Results: Leave-One Cross Validation

Root Mean Square Error (RMSE): 11.9 kts and 9.8 mb
Mean Absolute Error (MAE): 9.2 kts and 7.4 mb

EXAMPLE RESULTS

<table>
<thead>
<tr>
<th>Best Track</th>
<th>ML Estimate</th>
<th>91 kts</th>
<th>92 kts</th>
<th>89 kts</th>
<th>110 kts</th>
<th>124 kts</th>
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<th>127 kts</th>
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<td>d</td>
<td></td>
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</table>

\[ \text{Errors with associated with “jumping the gun” on RI and weakening/shear onset.} \]

\[ \quad \text{Thus, for these rapid-changers, the algorithm may perform better at intensity forecast than intensity diagnosis.} \]
Satellite Tropical Cyclone Monitoring: Future

Problems:

1. Aging constellation of LEO microwave imagers and sounders failing and not being replaced
2. Scatterometers not being funded by US for long term use
3. Legacy sensors often deemed too expensive for next generation

Solutions:

1. Multi-national efforts (GPM), EUMETSAT, China, others
2. Gap fillers (DMSP F-20 cancelled, WSF questionable)
3. Data buys and ride “sharing”? 
4. SmallSats and CubeSats as technology enables miniaturization
What’s left in a few years after SSM/I & old R&D satellites fail

SSMIS

FY-3 MWRI

Megha Tropiques MADRAS no longer functioning

GCOM AMSR2

GPM GMI

WSF Status Unclear

METOP SG

| YEAR | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |

Launches  → Primary mission  → Extended mission  → Future
# Ocean Vector Surface Vector Winds Constellation

## Current status and Outlook – NRT data access

<table>
<thead>
<tr>
<th>Launch Year</th>
<th>Satellite</th>
<th>Region</th>
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<tbody>
<tr>
<td>10/06</td>
<td>METOP-A</td>
<td>Europe</td>
</tr>
<tr>
<td>06/99</td>
<td>Oceansat-2</td>
<td>India</td>
</tr>
<tr>
<td>03/04</td>
<td>HY-2A</td>
<td>China</td>
</tr>
<tr>
<td></td>
<td>HY-2B</td>
<td>China</td>
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<tr>
<td></td>
<td>HY-2C</td>
<td>China</td>
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<tr>
<td></td>
<td>SCATSAT</td>
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<tr>
<td></td>
<td>Oceansat-3a</td>
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<td></td>
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<td></td>
<td>RapidScat</td>
<td>USA</td>
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<tr>
<td></td>
<td>CFOSAT</td>
<td>China/France</td>
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<td></td>
<td>Meteor-M N3</td>
<td>Russia</td>
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<tr>
<td></td>
<td>Meteor-MP 3</td>
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<tr>
<td></td>
<td>GCOM-W2</td>
<td>Japan/India/USA</td>
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<tr>
<td></td>
<td>FY-3E</td>
<td>China</td>
</tr>
<tr>
<td></td>
<td>FY-3G</td>
<td>China</td>
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<tr>
<td></td>
<td>Scatt operational series</td>
<td>India</td>
</tr>
</tbody>
</table>

### Key Features:
- **Design Life**
- **Extended Life**

### Source:
WMO OSCAR database and direct interactions with agencies

### Courtesy:
Dr. Mark Bourassa

### Proposals:
- Post EPS Europe
- Approved
- Operating

Committee on Earth Observation Satellites
SmallSats & CubeSats

1. **CYGNSS**: NASA, U. Michigan, GPS constellation (2016 launch)
   - ocean surface wind speeds, all weather, non-real time
   - 8 sats, 35° inclined, all weather wind speeds, novel sampling

2. **MicroRad**: MIT, Mini ATMS sounders
   - two sensors flying by 2017

3. **RainCube**: NASA-JPL, Constellation of profiling rain radars
   - Ka-band, nadir, +10 dBZ, 250 m vertical, 5 km horizontal
Satellite TC Monitoring Status

Summary:

1. Significant strides made in creating accurate, automated algorithms to enhance TC location, intensity, and structure: sorely needed to harvest next generation GEO sensors.

2. Enhanced GEO-LEO techniques leveraging the inherent benefits (temporal, spatial, and spectral) of each sensor suite.

3. Old “long pole in the tent” microwave imagers/sounders waning in numbers while next generation GEOs coming online.

4. Will METSATS begin ride sharing with “Com” satellites and will “data buys” enter the market long-term?

5. Will DMSP F-20 SSMIS and WSF ever fly? Will CubeSats help fill the microwave temporal issues?