Analyzing Gaps in Hurricane Rain Coverage to Inform Future Satellite Proposals

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IOVWST Meeting

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Motivation

- Remote sensing has become an increasingly popular way to estimate properties of various meteorological and oceanographic phenomena (precipitation, SSTs, surface winds, ocean currents)
- Accurate tropical cyclone (TC) forecasting requires high-resolution surface observations from operational aircraft and satellites
- Determine if already proposed satellite mission can be used for this application
- Distribution of gap sizes in moderate to heavy rainbands that circulate around the main low pressure center has not been studied in this context

Satellite Mission Concept

- One such mission is a satellite to measure high resolution surface winds and currents
- There are a range of instrument design options that could be used to achieve the main scientific goals
  - Resolution
  - Accuracy
  - Coverage
Winds and Currents Mission

- Rodriguez et al. (2019) demonstrated WaCM measures ocean winds and surface currents accurately
  - Winds: observed by radars
  - Currents: police radar gun method (speed of ripples)
  - Wide swath & fast sampling = less aliasing of time-averaged currents and derivatives
    - Mitigate noisier single-pass measurements

Comparison of WaCM and SWOT Measurement Swaths
(Bourassa and others 2019, Chelton et al. 2019)

WaCM Measurement Concept - pencil-beam Doppler scatterometers measuring winds from Ka or Ka/Ku sigma signals at multiple azimuth angles (Bourassa and others 2019)
Objectives

Determine instrument design characteristics that allow the satellite concept mission (e.g. Winds and Currents Mission (WaCM) & Sea surface Kinematics Multiscale monitoring (SKIM)) to offer knowledge of surface under tropical cyclones (ocean vector winds, oceanic surface currents, waves, etc.).

These characteristics depend on knowledge of:

a. Rainband gaps (areas through which a satellite can see surface)
b. How these gaps change depending on type of storm
Data Used: NOAA Aircraft Radar

- Aircraft: NOAA’s WP-3D Turboprop (N42RF, N43RF)
- Radar: Lower Fuselage (LF)
- LF radar system changed in 2018, using old system here
- Calculations in plane-relative coordinates
- HRD’s MATLAB function converted to Python for plotting and numerical calculations
- Benefits:
  - Data availability
  - Resolution
  - Spatial coverage

WP-3D N42RF NOAA aircraft containing flight-level data sensors, airborne radars, remote sensors, and cloud physics instrumentation (HRD 2014)

Single Lower Fuselage Sweep of Hurricane Harvey (HRD 2018)
Estimating Rain Rates

- Simple rainrate used as proxy for columnar integrated rain rate
- Assumed constant height column reflectivity up to freezing level
  - Verified by HRD Tail Doppler (TDR) imagery
- LF radar measures in reflectivity (dBz) of clouds/precipitation
- Applied Marshall-Palmer conversion formula based on commonality and easy computation
- Apply chosen thresholds to computed rates to determine rain-free regions

Marshall-Palmer Conversion Formula
(Marshall, Langille, and Palmer 1947)

\[ RR = \left( \frac{10^{(dBz/10)}}{200} \right)^{0.625} \]
Case Study Selection

- Ignore viewing angle (“looking straight down”)
- Selected input parameters to test:
  - Footprint Sizes: 1.375, 2.75, 4.125, 5.5 km
  - Viewing Areas: 2.75, 5.5, 8.25, 11 km
  - Rainrate Thresholds: 0.1 - 10.0 mm/hr (Draper and Long 2004)
- Incorporated storms with varying environmental stresses (wind shear, moisture influx, dry air intrusions)
- Rationale:
  - *Harvey*: rapid intensification, slight land interference, radiofrequency interference
  - *Irma, Maria*: symmetric, weak vertical wind shear, large/strong storms
  - *Jose, Nate*: antisymmetric, strong vertical wind shear, relatively smaller/weaker storms

<table>
<thead>
<tr>
<th>Storm</th>
<th>Date, Time (UTC)</th>
<th>Vmax (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL092017 Harvey</td>
<td>Aug. 25th, 2017 16:54:53</td>
<td>112</td>
</tr>
<tr>
<td>AL112017 Irma</td>
<td>Sept. 5th, 2017 9:45</td>
<td>171</td>
</tr>
<tr>
<td>AL122017 Jose</td>
<td>Sept. 18th, 2017 1:57:11</td>
<td>92</td>
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<tr>
<td>AL142017 Maria</td>
<td>Sept. 24th, 2017 8:14:29</td>
<td>94</td>
</tr>
<tr>
<td>AL152017 Nate</td>
<td>Oct. 7th, 2017 10:48:44</td>
<td>82</td>
</tr>
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</table>
Viewing Area Structures

Shapes of constructed viewing areas with diameters: (a) 2.75, (b) 5.5, (c) 8.25, and (d) 11 km

- Coarse resolution prevents perfect circular shape
- Loop through each radar sweep to determine rainfree areas & observable areas
- Ensured each part of footprint remained on radar sweep & rain-free
0.1 mm/hr Threshold (Ka-Band)

2.75 km Footprint

4.125 km Footprint

5.5 km Footprint

0.1 mm/hr rainrate threshold applied to reflectivity data for Maria (September 24th, 2017 8:14:29 UTC) with three shades:
- **blue**: rainrate threshold met and surface observable
- **yellow**: rainrate threshold met but surface not observable,
- **red**: rainrate threshold not met and surface not observable
0.6 mm/hr Threshold (Ku-Band)

2.75 km Footprint

4.125 km Footprint

5.5 km Footprint

0.6 mm/hr rainrate threshold applied to reflectivity data for Maria (September 24th, 2017 8:14:29 UTC) with three shades:

- blue: rainrate threshold met and surface observable
- yellow: rainrate threshold met but surface not observable,
- red: rainrate threshold not met and surface not observable
8.0 mm/hr Threshold (C-Band)

8.0 mm/hr rainrate threshold applied to reflectivity data for Maria (September 24th, 2017 8:14:29 UTC) with three shades:
- blue: rainrate threshold met and surface observable
- yellow: rainrate threshold met but surface not observable,
- red: rainrate threshold not met and surface not observable
Lower Fuselage Reflectivity
Hurricane Jose - Valid: 2017-09-18 01:57:11 UTC
0.1 mm/hr Threshold (Ka-Band)

2.75 km Footprint

4.125 km Footprint

5.5 km Footprint

0.1 mm/hr rainrate threshold applied to reflectivity data for Jose (September 18th, 2017 1:57:11 UTC) with three shades:

- **blue**: rainrate threshold met and surface observable
- **yellow**: rainrate threshold met but surface not observable,
- **red**: rainrate threshold not met and surface not observable
0.6 mm/hr Threshold (Ku-Band)

2.75 km Footprint

0.6 mm/hr RR Threshold using 2.75km Footprint
Hurricane Jose - Valid: 2017-09-18 01:57:11 UTC

4.125 km Footprint

0.6 mm/hr RR Threshold using 4.125km Footprint
Hurricane Jose - Valid: 2017-09-18 01:57:11 UTC

5.5 km Footprint

0.6 mm/hr RR Threshold using 5.5km Footprint
Hurricane Jose - Valid: 2017-09-18 01:57:11 UTC

0.6 mm / hr rainrate threshold applied to reflectivity data for Jose (September 18th, 2017 1:57:11 UTC) with three shades:

- **blue**: rainrate threshold met and surface observable
- **yellow**: rainrate threshold met but surface not observable,
- **red**: rainrate threshold not met and surface not observable
8.0 mm/hr Threshold (C-Band)

8.0 mm/hr rainrate threshold applied to reflectivity data for Jose (September 18th, 2017 1:57:11 UTC) with three shades:
- **blue**: rainrate threshold met and surface observable
- **yellow**: rainrate threshold met but surface not observable,
- **red**: rainrate threshold not met and surface not observable
## Rain Contamination Assessment

### Percentage of Rain Contamination (Serious and Side Lobe) using 2.75 km Footprint.

<table>
<thead>
<tr>
<th>Storm</th>
<th>Ka-Band (%)</th>
<th>Ku-Band (%)</th>
<th>C-Band (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvey</td>
<td>38.581414</td>
<td>16.802261</td>
<td>0.162331</td>
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<tr>
<td>Irma</td>
<td>29.070700</td>
<td>11.328826</td>
<td>0.196707</td>
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<tr>
<td>Jose</td>
<td>38.411000</td>
<td>22.161955</td>
<td>0.003819</td>
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<tr>
<td>Maria</td>
<td>34.110363</td>
<td>13.342632</td>
<td>0.017196</td>
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<tr>
<td>Nate</td>
<td>27.912528</td>
<td>12.463712</td>
<td>0.042016</td>
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</tbody>
</table>

### Percentage of Rain Contamination (Serious and Side Lobe) using 5.5 km Footprint.

<table>
<thead>
<tr>
<th>Storm</th>
<th>Ka-Band (%)</th>
<th>Ku-Band (%)</th>
<th>C-Band (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvey</td>
<td>49.448073</td>
<td>26.607081</td>
<td>1.455253</td>
</tr>
<tr>
<td>Irma</td>
<td>36.929452</td>
<td>16.460049</td>
<td>1.388411</td>
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<tr>
<td>Jose</td>
<td>45.859434</td>
<td>29.893048</td>
<td>0.928189</td>
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<tr>
<td>Maria</td>
<td>42.825206</td>
<td>20.779195</td>
<td>0.970651</td>
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<tr>
<td>Nate</td>
<td>35.166157</td>
<td>17.910618</td>
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</table>

### Percentage of Rain Contamination (Serious and Side Lobe) using 8.25 km Footprint.

<table>
<thead>
<tr>
<th>Storm</th>
<th>Ka-Band (%)</th>
<th>Ku-Band (%)</th>
<th>C-Band (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvey</td>
<td>51.974714</td>
<td>28.971391</td>
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<td>Irma</td>
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<tr>
<td>Jose</td>
<td>47.729182</td>
<td>31.860198</td>
<td>1.478227</td>
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<tr>
<td>Maria</td>
<td>45.089422</td>
<td>22.896285</td>
<td>1.534316</td>
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<tr>
<td>Nate</td>
<td>37.226890</td>
<td>19.619938</td>
<td>1.629106</td>
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### Percentage of Rain Contamination (Serious and Side Lobe) using 11.0 km Footprint.

<table>
<thead>
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<th>Storm</th>
<th>Ka-Band (%)</th>
<th>Ku-Band (%)</th>
<th>C-Band (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvey</td>
<td>61.678316</td>
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<td>4.066482</td>
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<tr>
<td>Irma</td>
<td>47.387418</td>
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<td>Jose</td>
<td>54.436592</td>
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<td>Maria</td>
<td>53.691531</td>
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<td>Nate</td>
<td>45.261650</td>
<td>25.412528</td>
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Conclusions

OBJECTIVE: Determine characteristics that improve present WaCM satellite technologies

- Largest 5.5 km footprint does provide sufficient rain-free coverage in the eye to make practical conclusions about intensity changes, but substantially more coverage would occur with smaller footprints

- Control variables (rainrate threshold, footprint size, case study) independent of TC structure

- Ideal parameters: > 0.6 mm/hr threshold, footprint size < 4.125 km, highly sheared system
  - Compromise between spatial resolution and penetrating power given current technologies
  - Produced least sensitivity to aforementioned biases
  - More power with smaller footprints
  - Big antenna and longer wavelength (C-band) are preferred for hurricane wind research, though it is more expensive to achieve the desired resolution at such wavelengths
Acknowledgements:
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References


