APR-2 Tropical Cyclone Observations

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Airborne 2nd Generation Precipitation Radar (APR-2)

- Dual-frequency operation with Ku-band (13.4 GHz) and Ka-band (35.6 GHz)
  - Geometry and frequencies chosen to simulate GPM radar
- Measures reflectivity at co- and cross-polarizations, and Doppler
- Range resolution is ~60 m
- Horizontal resolution at surface (DC-8 at 11 km altitude) is ~1 km

Image below shows 3D nature of APR-2 data; 50-degree data wedge underneath flight track.
<table>
<thead>
<tr>
<th>Date</th>
<th>Name</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/20/01</td>
<td>Chantal</td>
<td>Tropical storm</td>
</tr>
<tr>
<td>9/15</td>
<td>Gabrielle</td>
<td>Tropical storm</td>
</tr>
<tr>
<td>9/22</td>
<td>Humberto</td>
<td>Tropical storm</td>
</tr>
<tr>
<td>9/23</td>
<td>Humberto</td>
<td>Cat 1</td>
</tr>
<tr>
<td>9/24</td>
<td>Humberto</td>
<td>Cat 1</td>
</tr>
<tr>
<td>8/23/06</td>
<td>Debby</td>
<td>Tropical storm</td>
</tr>
<tr>
<td>9/12</td>
<td>Helene</td>
<td>Tropical depression</td>
</tr>
<tr>
<td>8/29/10</td>
<td>Earl</td>
<td>Cat 1 – developing eye</td>
</tr>
<tr>
<td>8/30</td>
<td>Earl</td>
<td>Cat 3-4</td>
</tr>
<tr>
<td>9/1</td>
<td>Earl</td>
<td>Cat 4</td>
</tr>
<tr>
<td>9/2</td>
<td>Earl</td>
<td>Collapsing eyewall</td>
</tr>
<tr>
<td>9/14</td>
<td>Karl</td>
<td>Genesis</td>
</tr>
<tr>
<td>9/16</td>
<td>Karl</td>
<td>Emerged from Yucatan</td>
</tr>
<tr>
<td>9/17</td>
<td>Karl</td>
<td>Landfall – orographic rain</td>
</tr>
</tbody>
</table>
Post-Experiment Processing

• First step - align raw radar data with the aircraft navigation data
• Both nav data and our Doppler surface measurements are used to estimate aircraft orientation and correct APR-2 Doppler in precip
  – In standard product, the radar correction is used
• Calibration uses cal-loop data then surface reflectivity at Ku and light precipitation at Ka
• Products to be examined here:
  – 13 and 35 GHz reflectivity and their ratio (DWR)
  – Linear Depolarization Ratio (LDR)
  – Vertical motion – direct measurement is hydrometeor motion; v-Z relation can be used to estimate vertical air motion
  – Cross-track wind
    • estimated from using Doppler at each altitude over scan
Calculated Products from Cross-Wind

- We approximate the vortex azimuthal (tangential) wind $v$ as the cross-track wind
  - a better estimate may be possible by correcting for scan angle versus hurricane radius vector
- Calculate the inertial frequency by
  \[ l^2 = \left( f + \frac{2v}{r} \right) \left( f + \frac{v}{r} + \frac{\partial v}{\partial r} \right) \]
- We can estimate
  - Boundary (Ekman) layer thickness
    \[ h = \sqrt{\frac{2K}{l}} \]
  - Rossby length, where rotational effects become as important as buoyancy effects $L = NH/l$
    - Larger inertial stability $\rightarrow$ smaller Rossby length $\rightarrow$ “stiffer” vortex
Pressure/Density/Temperature from Wind Structure

  - Assume axisymmetry, gradient and hydrostatic balance
  - Use anelastic approximation

\[
\frac{\partial p}{\partial r} = \rho_o \left( \frac{v^2}{r} + f v \right) \quad \frac{\partial \rho}{\partial r} = -\frac{1}{g} \frac{\partial}{\partial z} \left( \rho_o \left( \frac{v^2}{r} + f v \right) \right)
\]

- \( \rho_o \) is environmental density; 1.2 kg/m\(^3\) at surface
- \( p \) is pressure
- Use finite difference approximation to compute right side of second eqn
- Integrate to get pressure/density versus radius at each altitude
- Can get temperature from pressure, density, and gas law
Microphysics from Dual-pol/Dual-frequency

• LDR is generated by non-spherical particles
  – Mostly visible in mixed phase areas, even in convection
  – Primarily useful for qualitative applications, e.g., classification
• The dual-wavelength ratio (DWR) Ku/Ka is useful for identifying large ice particles
  – Larger particles tend to be in non-Rayleigh scattering regime at Ka-band but still in Rayleigh at Ku-band
  – Depressed Ka-band reflectivity results in non-zero DWR (in dB)
• In rain DWR is useful for identifying areas with heavy rainfall
  – Due to differential attenuation DWR becomes larger as rain rate increases
  – In very heavy rain DWR can potentially reach tens of dB
Passive Microwave Overview of Earl 8/29 & 8/30

Imagery courtesy NRL
Hurricane Earl – August 29

eye
Hurricane Earl – August 30
Earl – Rossby Length and BL Thickness

8/29/2010

- Similar to values calculated from recon flight level
- Both decrease toward center; both smaller on 30th
Earl – Density and Thermal Structure

8/29/2010

8/30/2010
Karl Genesis 9/14

Wind direction shift
Earl – CFADs for Inner Core Reflectivity and Velocity

8/29/2010

8/30/2010