Towards the Verification of Dual-wavelength Radar Estimates of Liquid Water Content Using Microwave Radiometer Measurements

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Background

- LWC estimates using radar reflectivity are difficult due to $D^6$ dependency
  - Drizzle dominates reflectivity
  - Cloud drops dominate LWC
Background

- Attenuation first proposed to retrieve LWC by Atlas (1954)

Advantages
- Attenuation directly related to LWC
- Independent of DSD (and drizzle!)

Difficulties
- Requires two or more radars at different wavelengths
- Beam matching
- Ambiguity between attenuation and Mie scattering effects
- Measurement variance
- Dependency on temperature
- Presence of ice...
Background: S-PolKa

- NCAR S-PolKa radar measures S-band (10 cm) and $K_a$-band (0.8 cm) simultaneously
  - Matched 1 deg beam widths
  - Matched 150 m range gates
- S-band is low-attenuating
- $K_a$-band is heavily attenuating
- For Rayleigh scatterers the S and $K_a$-band reflectivity differences are due to liquid and gas attenuation at $K_a$-band

<table>
<thead>
<tr>
<th>Frequency band (wavelength)</th>
<th>Liquid Attenuation $\text{dB km}^{-1} (\text{g m}^{-3})^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-band (10 cm)</td>
<td>0.005</td>
</tr>
<tr>
<td>$K_a$-band (0.9 cm)</td>
<td>0.70</td>
</tr>
</tbody>
</table>
LWC Retrieval Method

• Estimate total liquid attenuation ($A_{TL}$, dB) along ray segment ($> 2$km) of echo by comparing $Z$ at $S$- and $K_a$-band (DWR)
  – Avoid regions of non-Rayleigh scattering:
    • Large drops (> 1mm)
    • Ground clutter
    • Biological scatterers
    • Bragg scattering
  • Estimate the range resolved attenuation following Tuttle and Rinehart (1983)
    – $A_L = C z_s^p$ ($z_s$ in units of mm$^6$ m$^{-3}$)
  • Differential measurement
    – Immune to radar calibration
    – Immune to partial beam blockage
  • Similar to radar/radiometer retrievals
LWC Retrieval Method

• Compute LWC and MVD
  - $LWC = 0.74A_L(T)$ (Vivekanandan et al. 1999)
    • Temperature correction
  - $MVD^3 = 2.16 \times 10^{-4} \frac{z}{LWC}$ (Vivekanandan et al. 1999)
    • Assumes an exponential DSD!

• The method is an extension of dual-wavelength LWC retrievals developed by Hogan et al. (2005) and Williams and Vivekanandan (2010) to scanning radars

• The final result is LWC and MVD at the resolution of the radar
Field Campaigns with S-PoIKa

- RICO – Barbuda, West Indies
- REFRACTT – Boulder, Colorado
- DYNAMO – Addu Atoll, Maldives
LWC Estimate: Results (RICO)

DBZ

LWC g m\(^{-3}\)

Vr

MVD mm
dBZ Versus Retrieved LWC

Analogous to prescribing Z-LWC relationship using measured attenuation over ray paths of $> 2$ km
LWC Verification??

• Validation of LWC estimated from S-PolKa is difficult

• Several options
  – Aircraft comparisons (RICO)
    • OK for qualitative comparisons to radar LWC
    • Qualitative evaluation problematic
  – Measure clouds that are expected to be adiabatic
  – Compare with collocated scanning radiometer (DYNAMO)
Dynamics of the Madden Julian Oscillation (DYNAMO)
Radar Super-site on Addu Atoll

- Radars at supersite chosen to document cloud spectrum
- Systems were complimentary and worked together
S-PolKa at DYNAMO IOP

- 24/7 operations of S- and K\textsubscript{a}-bands October 1, 2011 to January 15, 2012
  - Manned from 6AM to 8PM
  - Unmanned from 8PM to 6AM the next day
  - Possible because of new fault monitoring system
- Scanned PPI volume and numerous RHIs on a 15 minute cycle
- Data available to everyone 1 year after end of ops
LWC Verification Using a Radiometer

- S-PolKa collocated with scanning radiometer from UM
- Scanned radiometer to ensure overlapping beams with the radar
- Compare radar LWC integrated in range to the radiometer LWP
- First quantitative verification for dual-wavelength LWC!
Radar Radiometer Comparison Status

• S-PolKa
  – Final QC’d data set recently completed
  – LWC analysis has begun
  – Results look similar to RICO
  – Several good radar/radiometer comparison periods identified
Example of LWC, October 20 2011 – 3.5 degree elevation

S-band dBZ

K_a-band dBZ

DWR

LWC g m^{-3}
Radar Radiometer Comparison Status

• Plan to compare scans at 7, 9 and 11 degree elevation
• Radiometer DQ still in progress
• Radiometer has 3 degree beam width
  – Necessitates angular averaging
• Calibration using “tip-cal” technique
• Need to determine and correct surface radiation at low angles

Example of real-time radiometer product from Oct 10. Data are vertically pointing:

- Black: WVP
- Red: DOE sonde
- LWP
Future Work

• Keep testing LWC retrievals in different environments
• Develop real-time product
• Test double moment DSD retrieval using Z and $K_a$-band attenuation
Humidity Profiles Example

P3 Dropsondes near S-PolKa

Dual-wavelength humidity profiles

Gan sonde

20111208-09Z

Median profiles plotted, color coded by sector.
If no valid retrievals, no line is plotted.
Bars contain 90 percent of retrieval points.
Solid black line represents sounding.

P-3 Dropsonde Vapor Density 20111208: blue=west, red=east

Vapor Density (g m⁻³)

Height (m)

Vapor Density (g m⁻³)

Height (km)

Courtesy Scott Powell, U Wash