Humidity Estimates Using Simultaneous S- and $K_a$-band Radar Measurements

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Humidity Estimate: Background

• Gaseous attenuation at microwaves is due to mainly to oxygen and water vapor
  – Depends on gas concentrations
  – Depends on wavelength
• S-band is non-attenuating
• $K_a$-band is strongly attenuating
• Water vapor can be related to $K_a$-band attenuation estimates
• For Rayleigh scatterers the S and $K_a$-band reflectivity differences are due to liquid and gas attenuation at $K_a$-band
Background: S-PolKa

- Estimates of $K_a$-band gaseous attenuation can be obtained by comparing simultaneous S- and $K_a$-band reflectivity
  - Matched 1 deg beam widths
  - Matched 150 m range gates
Humidity Estimate: Method

- Obtain Ray Segment
- Check for Rayleigh scattering
- Compute $K_a$-band Gaseous Attenuation (dB km$^{-1}$)
- Compute Path-integrated Humidity
- Compute Layer-based Vertical Profile
Humidity Estimate: Obtain Ray Segment

- Select small 2-D patches of cloud or precipitation echo (10 to 20 radar gates)
- Each data patch (kernel) results in one estimate of mean attenuation (dB km$^{-1}$) and humidity (g m$^{-3}$)
Humidity Estimate: Obtain Ray Segment

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\( K_a \)-band reflectivity (dBZ)

\( S \)-band reflectivity (dBZ)
Humidity Estimate: Obtain Ray Segment

K_a-band reflectivity (dBZ)

S-band reflectivity (dBZ)
Humidity Estimate: Obtain Ray Segment

K_a-band reflectivity (dBZ)

S-band reflectivity (dBZ)
Humidity Method: Error Sources

- $A_g = (\text{dBZ}_S - \text{dBZ}_{Ka})/L = \Delta Z/L$

- Error in gaseous attenuation, and thus humidity estimates are a function of ray segment length

- $1 \text{ g m}^{-3}$ is between 5 and 10 percent error
  - Requires dBZ difference errors less than 0.5 dB and ray segment length $> 15$ km

- Humidity errors resulting from $\Delta Z$ errors of 0.5 and 1.0 dB as a function of L
Humidity Method: Error Sources

- Non Rayleigh scattering
  - Ground clutter
  - Point targets (birds aircraft)
  - Mie scattering at Ka-band (e.g. drops > 1 mm)
  - Bragg scattering at S-band
- Measurement noise (need to average 10 range gates for S-Ka-band pair)
- Attenuation by liquid
  - Within target echo
  - Intervening along ray path
- Calibration errors
- Ground clutter filter
- Criteria designed to keep reflectivity difference errors < 0.5 dB
Humidity Estimate: Compute Attenuation

- Compute mean gaseous attenuation (dB km\(^{-1}\)) of ray segments of length L
  \[ A_g = (\text{dBZ}_S - \text{dBZ}_{Ka})/L = \Delta Z/L \]
Humidity Method: Estimate Humidity

- Microwave propagation model computes $A_g$ for $P$, $T$ and Humidity
- Run Liebe (1987) model many times varying $T$, $P$ and $WV$ (g m$^{-3}$)
- Compute polynomial fit of $WV$ to attenuation

Results for RICO

$WV = 201.40A^3 - 209.60A^2 + 120.55A - 2.25$

Where $WV$ is water vapor density (g m$^{-3}$) and $A$ is gaseous attenuation (dB km$^{-1}$)
1. Plot midpoint of ray segments

2. Layer-based Profile

Typical resolution 0.25 to 0.5 km
Humidity Results: REFRACTT

S-band reflectivity (dBZ)

K_a-band reflectivity (dBZ)
Humidity Results: REFRACTT

Over KDNR
RMSD = 0.14 g m\(^{-3}\)
Humidity Results: REFRACTTT

+ Over KDNR

o North of S-PolKa

Layer-based estimate

Sounding data
Humidity Results: REFRACTT

Precipitable Water content from GPS

Low level humidity from refractive index measurements

Courtesy of John Braun, NCAR
Humidity Results: REFRACTT

- Surface station in moist air
  Layer-based estimate
  Sounding data
  Surface station in moist air

- Over KDNR
- North of S-PolKa
Humidity Results: RICO

RMSD = 0.85 g m$^{-3}$
Humidity Results: RICO

Layer-based estimate

Mean of sounding data using layer-based estimate resolution

Sounding data

+ radar retrieval – primary ray
x Radar retrieval – secondary ray

10 January, 2005

Water vapor density (g m⁻³)

Height (km)
Humidity Results: RICO

12 January, 2005

+ radar retrieval – primary ray
× Radar retrieval – secondary ray

RMSD = 0.75 g m⁻³

Mean of sounding data using layer-based estimate resolution

Layer-based estimate
Sounding data

Height (km)

Water vapor density (g m⁻³)
Discussion

• Method depends on availability of suitable echoes
  – Unfavorable conditions include
    • No echoes
    • Heavy rain on the radar
    • Stratiform cloud deck (no vertical profile)
  – Favorable conditions
    • Scattered cumulus
    • Tropical trade-wind cumulus
    • Continental convective conditions

• Provides additional moisture measurements
Discussion

- Not a real-time product
- Non-automated parts of procedure:
  - Data kernels hand edited
    - S-band Bragg scatter criteria
    - Liquid attenuation contamination criteria
  - Layer based profile
- Automated parts of procedure
  - Rayleigh scattering criteria
  - Ground clutter/point target
  - Spatial correlation of S- and $K_\alpha$-band reflectivity over data kernel
- RSF trying to identify funding and staff to automate procedure – no guarantees
  - EOL engineering intern
  - CU senior engineering projects
  - CSU?
http://www.agu.org/journals/rs/papersinpress.shtml

Thanks!

Questions?
Motivation: LWC

- LWC estimates using only single wavelength radar reflectivity are difficult due to $D^6$ dependency
  - Drizzle/rain dominate reflectivity
  - Cloud drops dominate LWC

Photo by Bjorn Stevens

Khain et al. (2008)
LWC Estimate: Background

- Attenuation first proposed to retrieve LWC by Atlas (1954)
- Advantages
  - Attenuation directly related to LWC
  - Independent of DSD (and precip!)
- Difficulties
  - Requires two or more radars at different wavelengths
  - Beam matching
    - Straight forward with S-PolKa
  - Ambiguity between attenuation and Mie scattering effects
    - S-band dual-pol measurements
  - Measurement variance vs attenuation
    - Requires 2 km ray segments
LWC Estimate: Results

S-band reflectivity (dBZ)

Probe measured LWC
~ 0.05 – 0.1 g m⁻³

C-130

Retrieved LWC (g m⁻³)

LWC ~ 0.05 – 0.1 g m⁻³
LWC Estimate: Results

MVD (mm)

RES (mm)
LWC Estimate: Results

S-band dBZ 1.5 deg

Below cloud base

LWC (g m⁻³) 1.5 deg

Above cloud base

LWC (g m⁻³) 4.5 deg
LWC Estimate: Results

- DBZ
- VR m s⁻¹
- LWC, g m⁻¹
- MVD, mm
LWC Estimate: Background

dBZ Versus Retrieved LWC

Analogous to prescribing Z-LWC relationship using measured attenuation over ray paths of $> 2$ km
Humidity Method: Estimate Humidity

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- Compute polynomial fit of $WV$ to attenuation

$WV = 116.62A^3 - 162.02A^2 + 118.71A - 0.94$

Results for RICO

$WV = 201.40A^3 - 209.60A^2 + 120.55A - 2.25$

Where $WV$ is water vapor density (g m$^{-3}$) and $A$ is gaseous attenuation (dB km$^{-1}$)