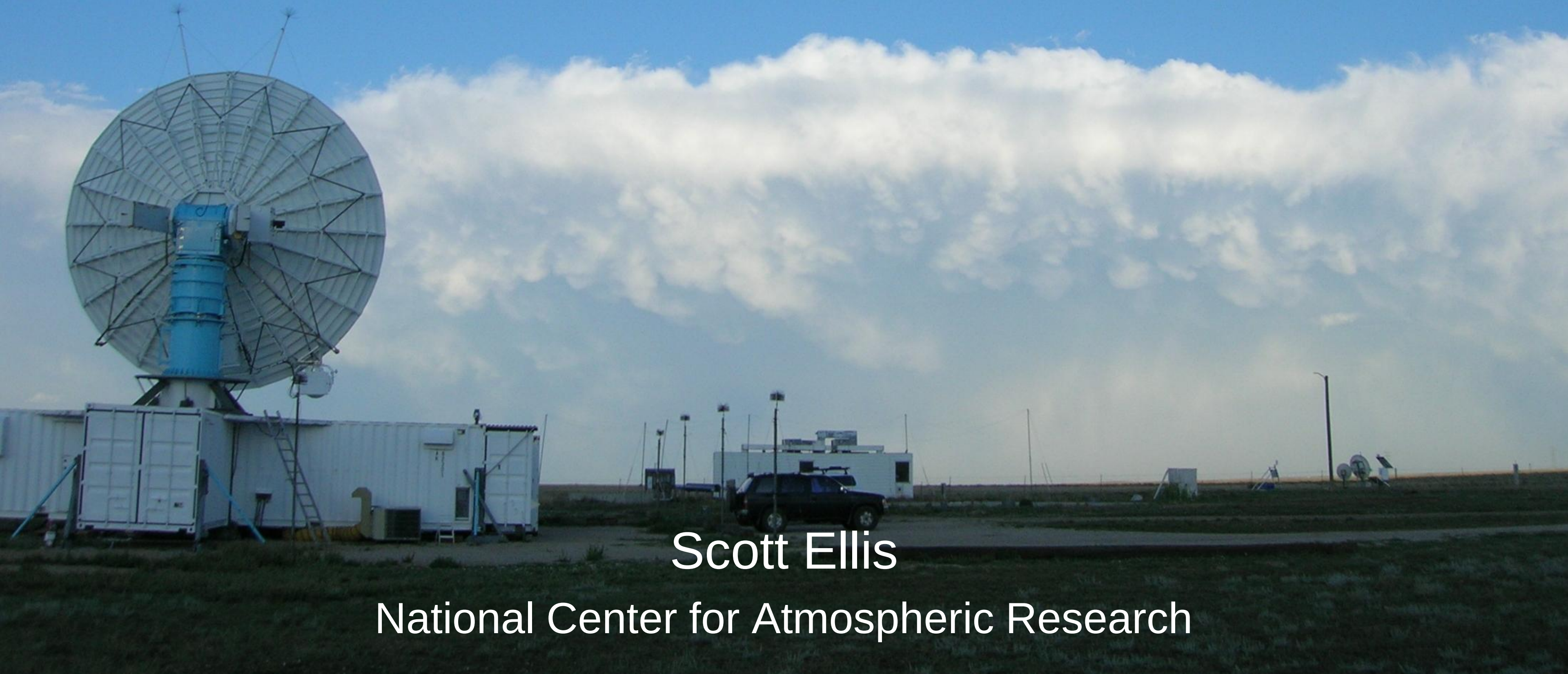
Humidity Estimates Using Simultaneous S- and K_a-band Radar Measurements

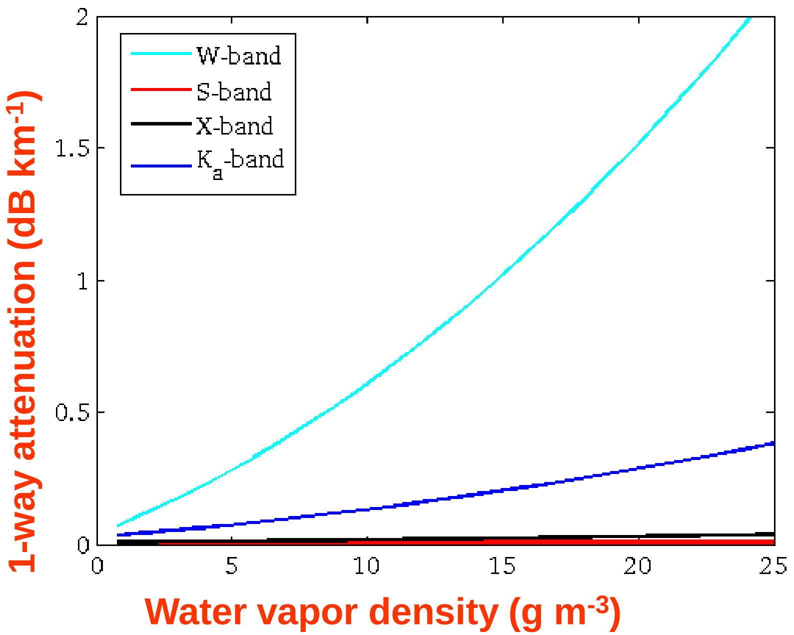


Scott Ellis

National Center for Atmospheric Research

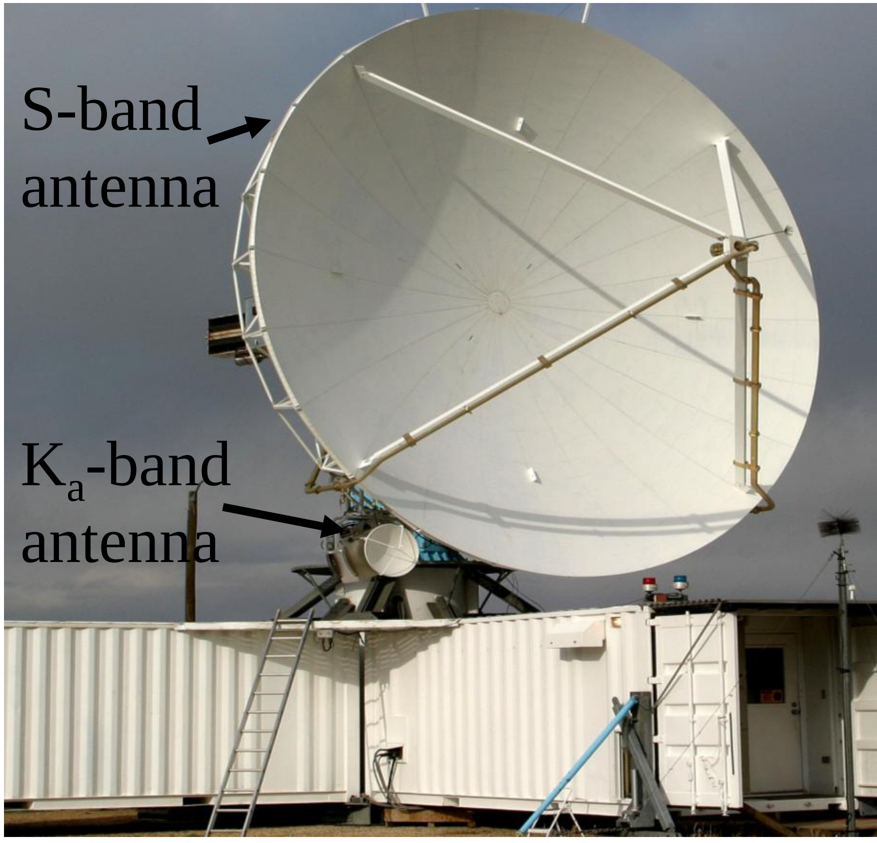
Humidity Estimate: Background

- 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

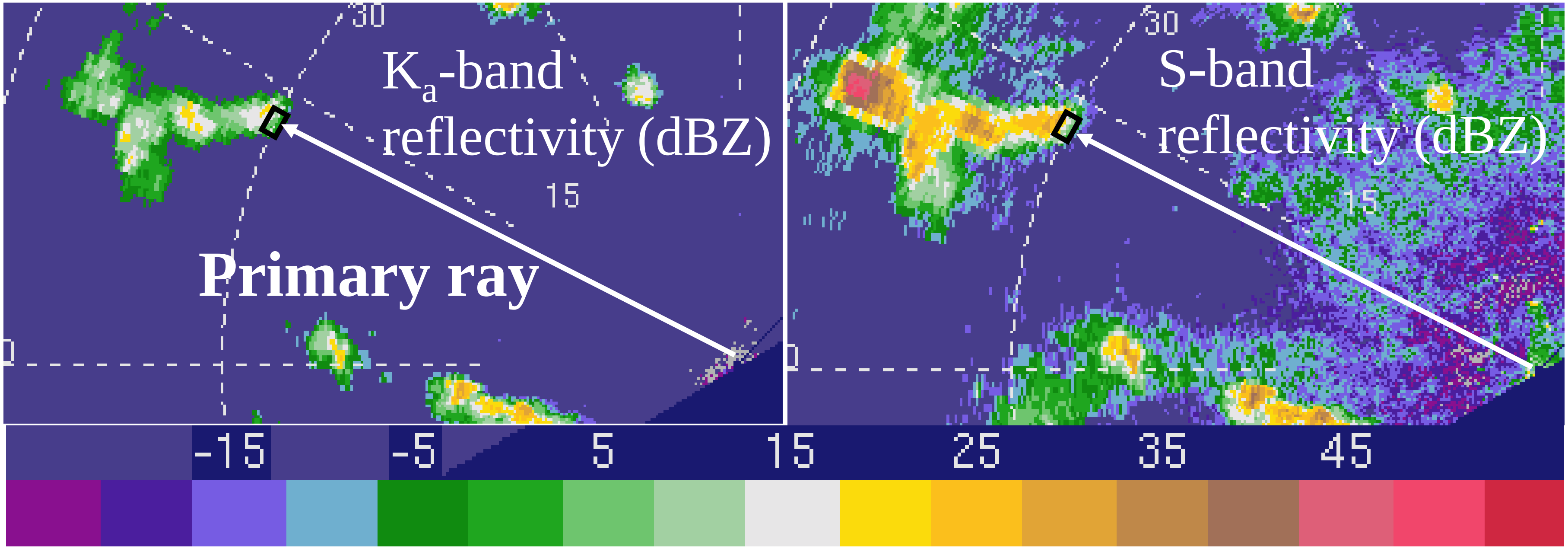


Humidity Estimate: Method

- 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

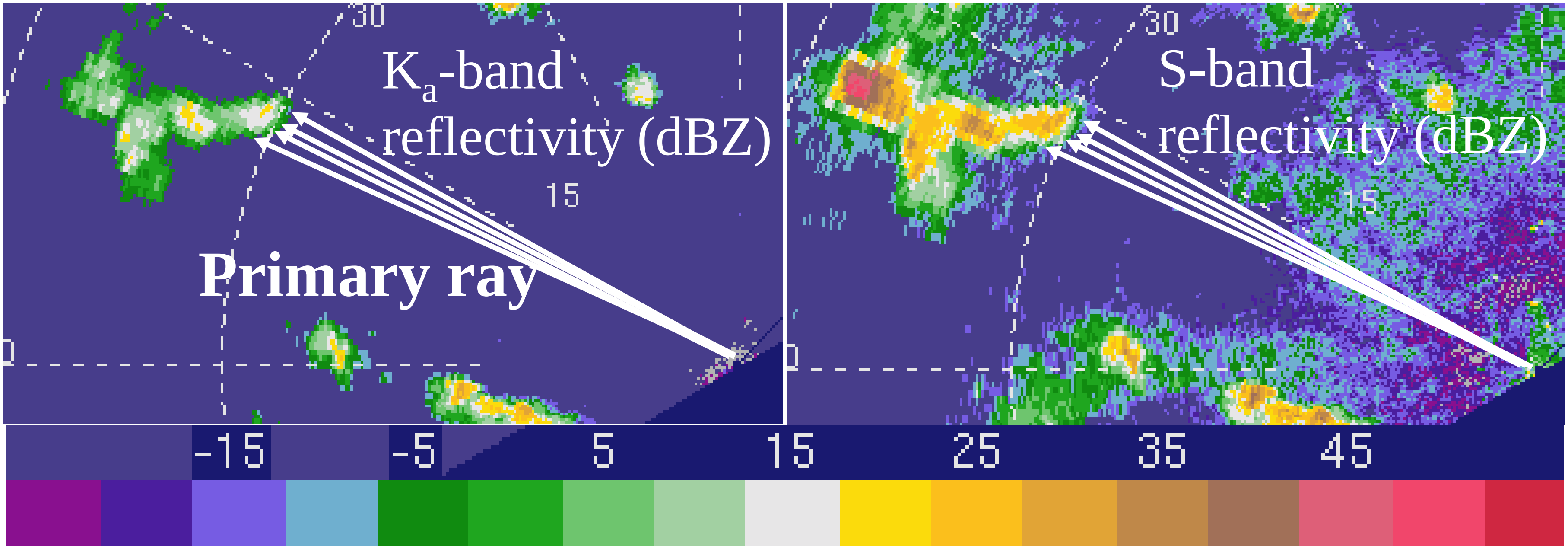
Humidity Estimate: Obtain Ray Segment

- 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})

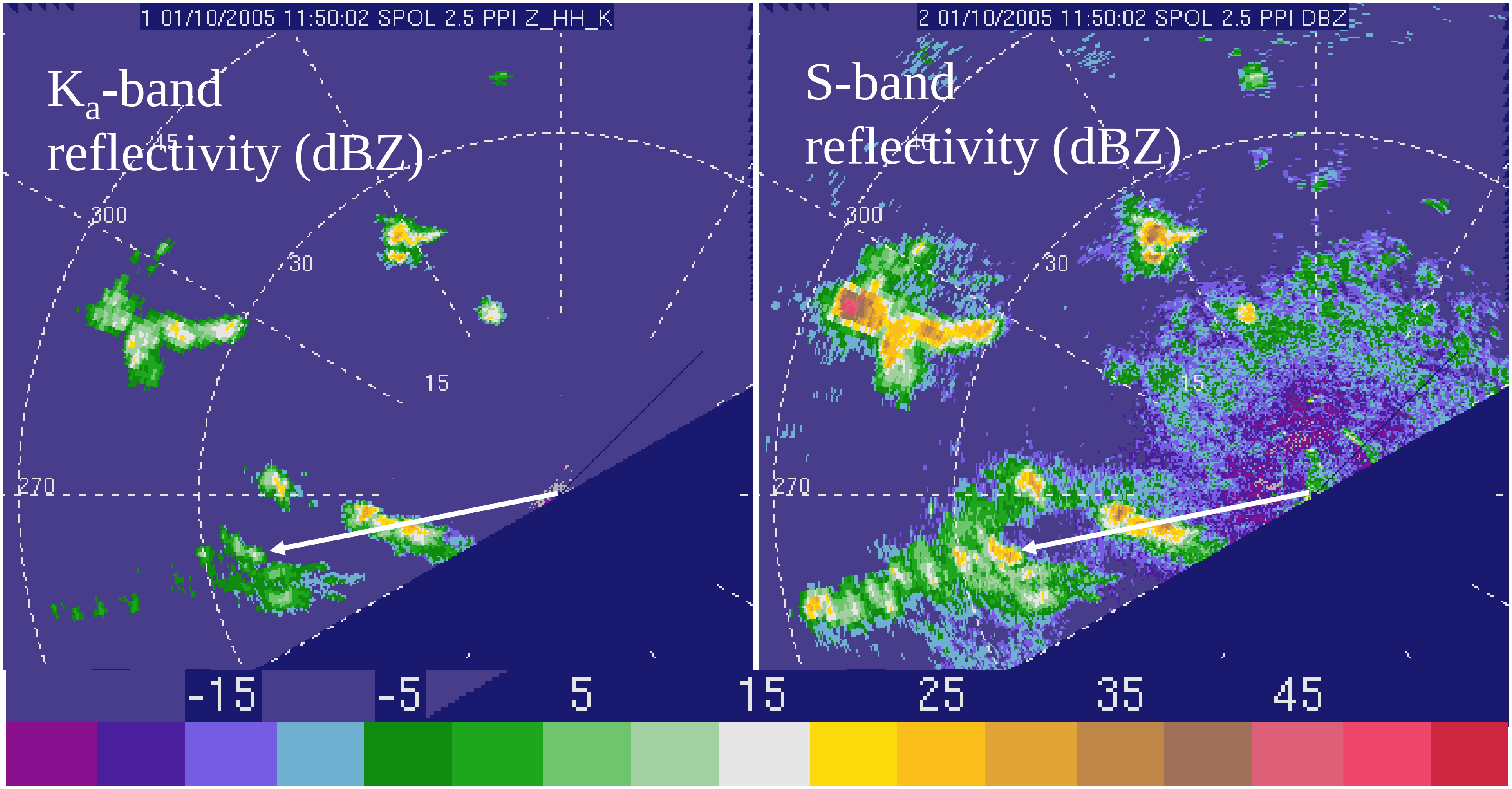


Humidity Estimate: Obtain Ray Segment

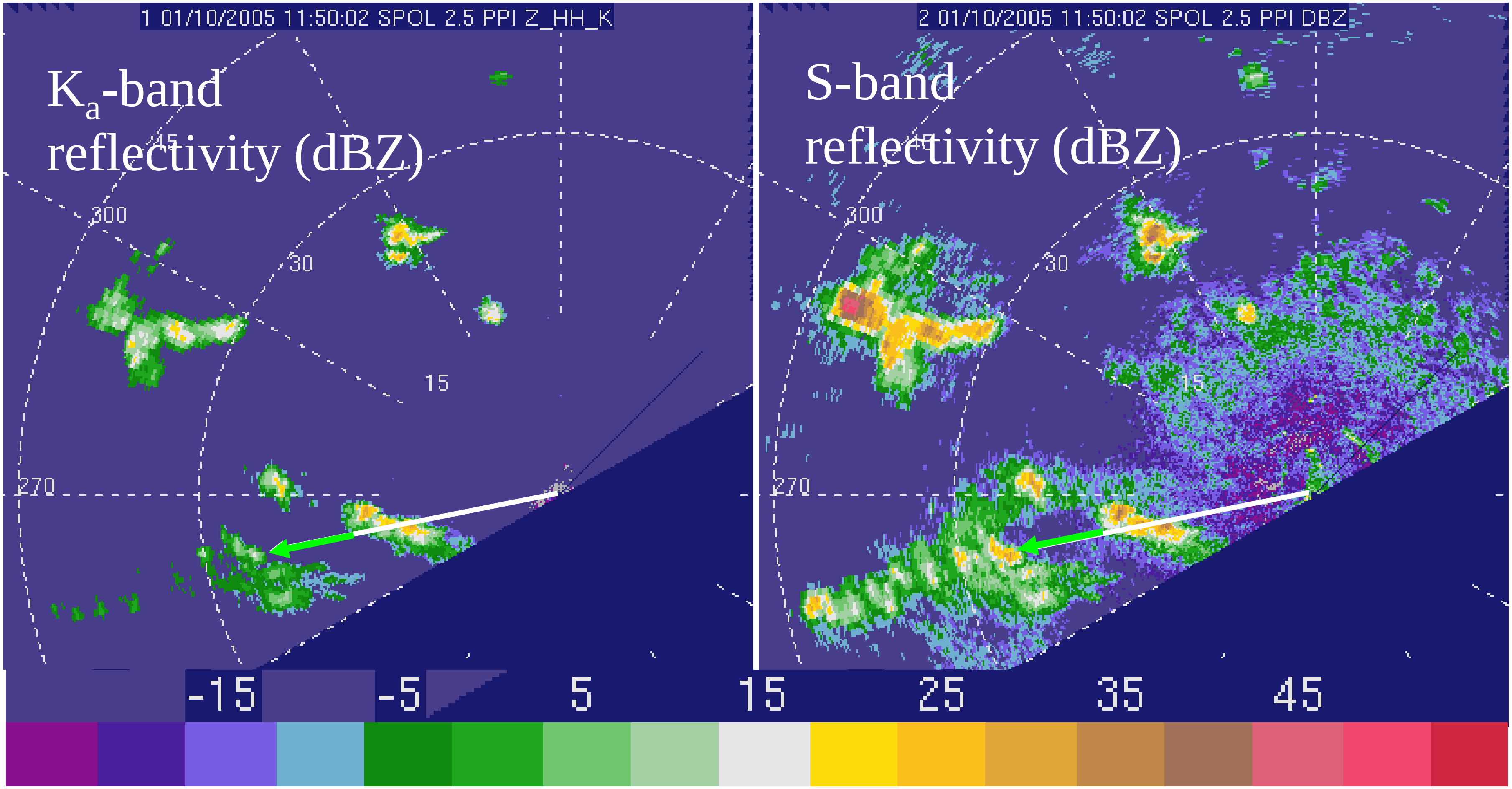
- Select small 2-D patches of cloud or precipitation echo (10 to 20 radar gates)
- Each data patch (kernel) results in one estimate of mean attenuation (dB km^{-1}) and humidity (g m^{-3})



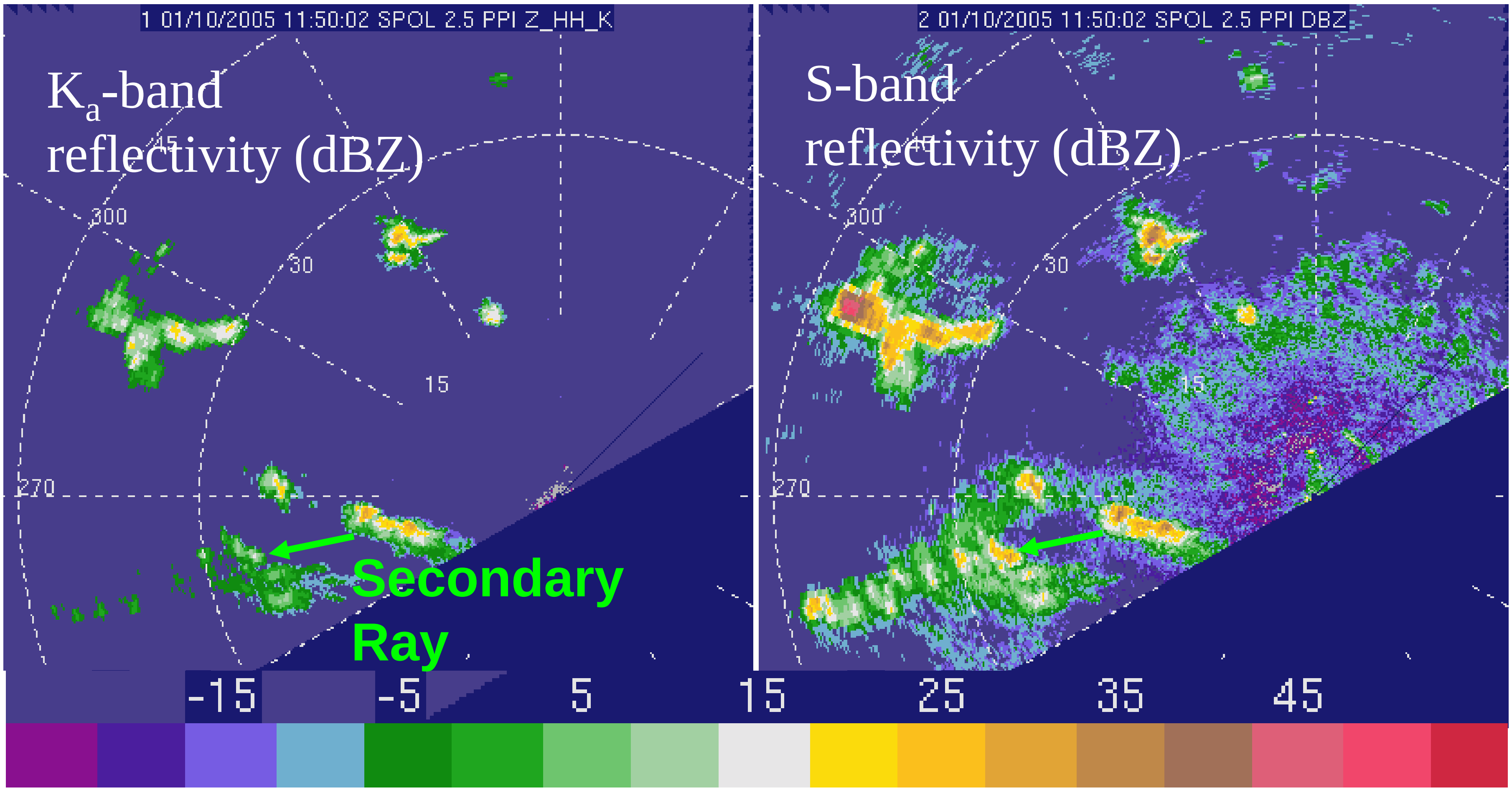
Humidity Estimate: Obtain Ray Segment



Humidity Estimate: Obtain Ray Segment

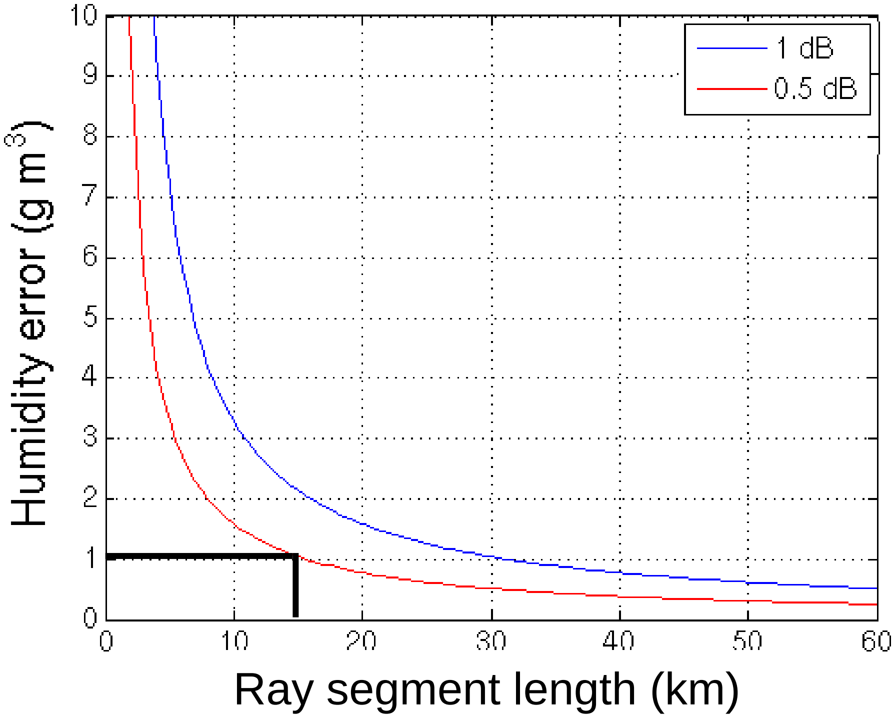


Humidity Estimate: Obtain Ray Segment



Humidity Method: Error Sources

- $A_g = (dBZ_S - dBZ_{Ka})/L = \Delta Z/L$
- Error in gaseous attenuation, and thus humidity estimates are a function of ray segment length



Humidity errors resulting from ΔZ errors of 0.5 and 1.0 dB as a function of L

- 1 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 Method: Error Sources

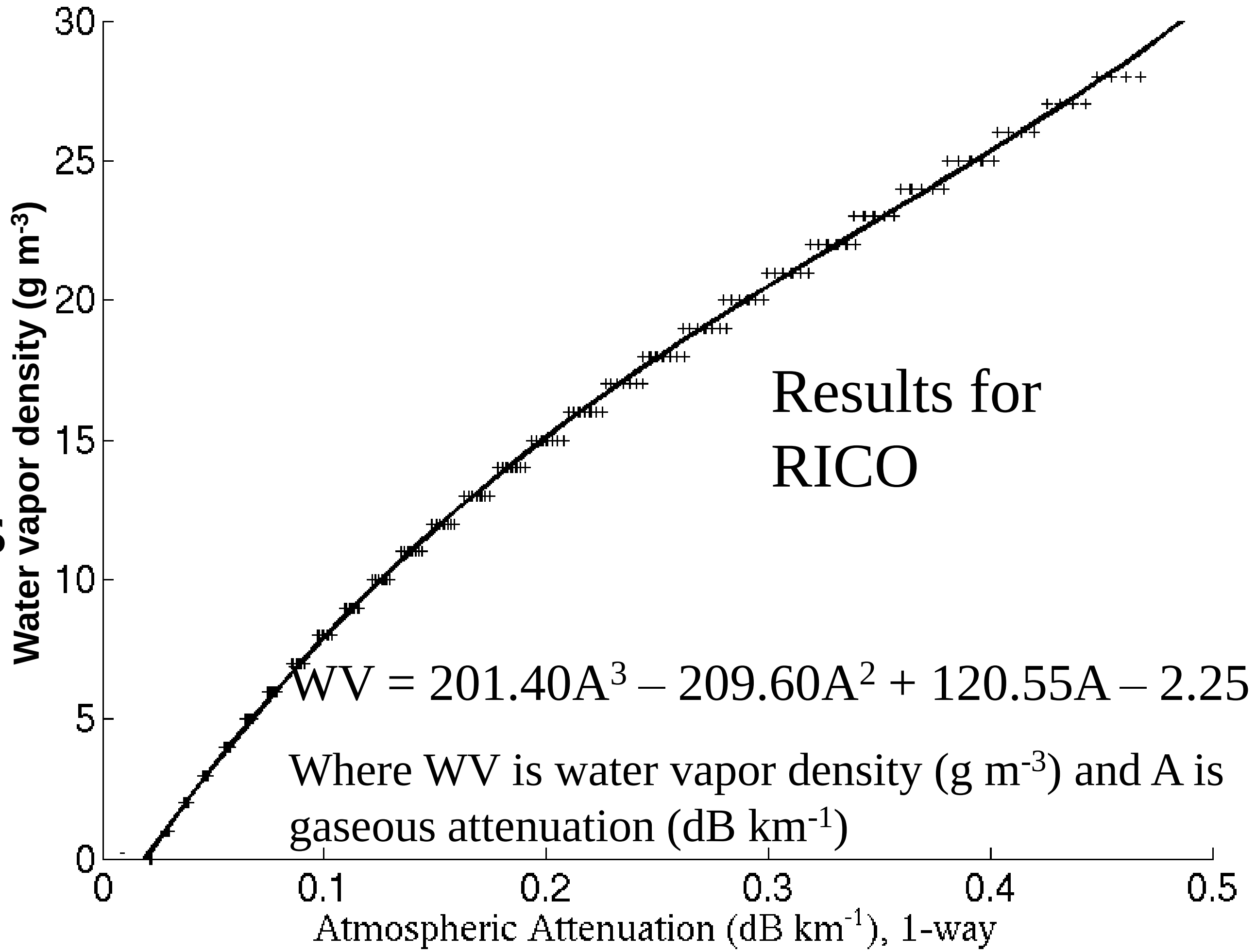
- Non Rayleigh scattering
  - Ground clutter
  - Point targets (birds aircraft)
  - Mie scattering at K_a-band (e.g. drops > 1 mm)
  - Bragg scattering at S-band
- Measurement noise (need to average 10 range gates for S-K_a-band pair)
- Attenuation by liquid
  - Within target echo
  - Intervening along 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
  - $A_g = (dBZ_S - dBZ_{Ka})/L = \Delta Z/L$

Humidity Method: Estimate Humidity

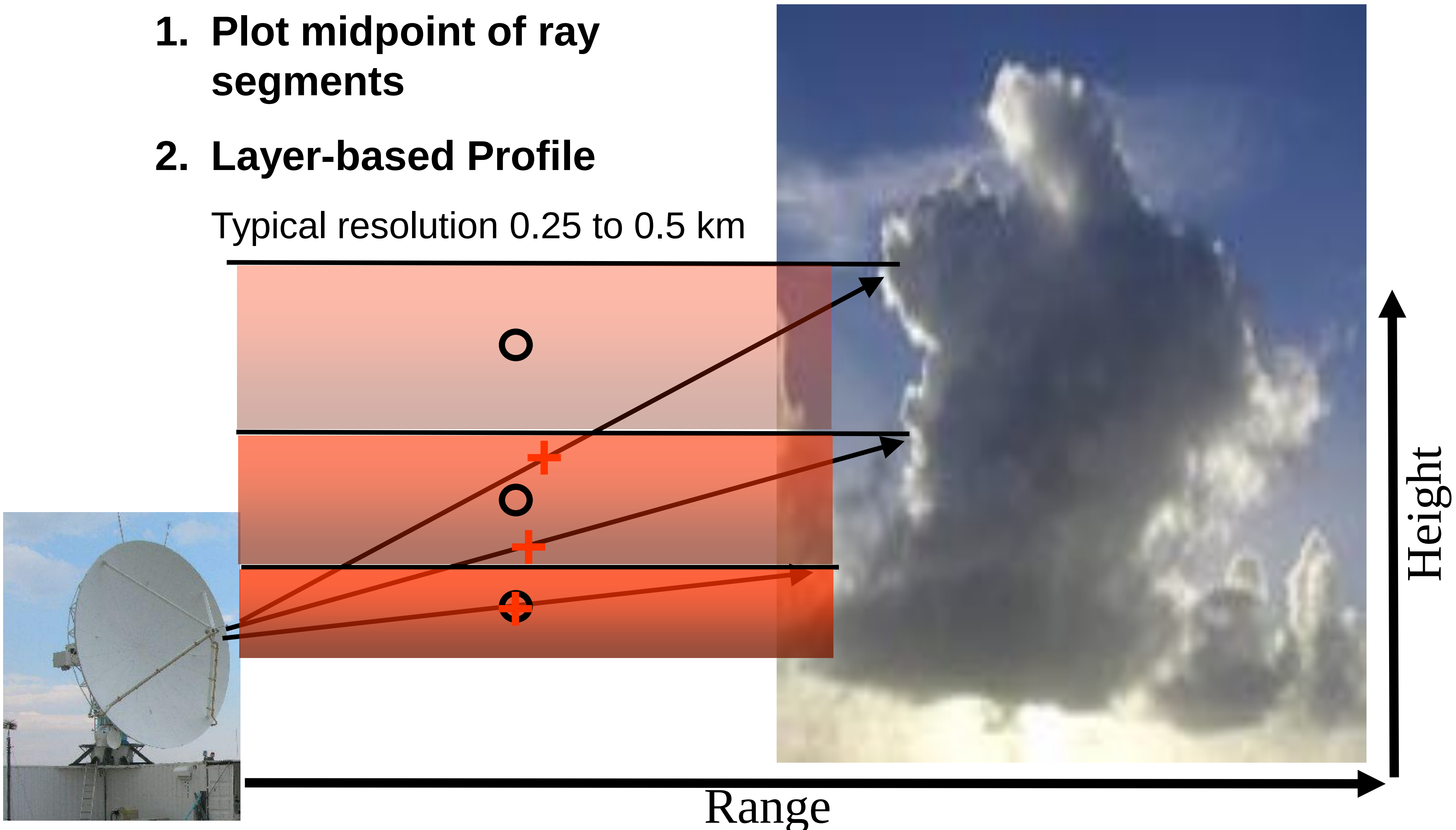
- Microwave propagation model computes A_g for P, T and Humidity
- Run Liebe (1987) model many times varying T, P and WV ($g\ m^{-3}$)
- Compute polynomial fit of WV to attenuation



Humidity Method: Creating Vertical Humidity Profile

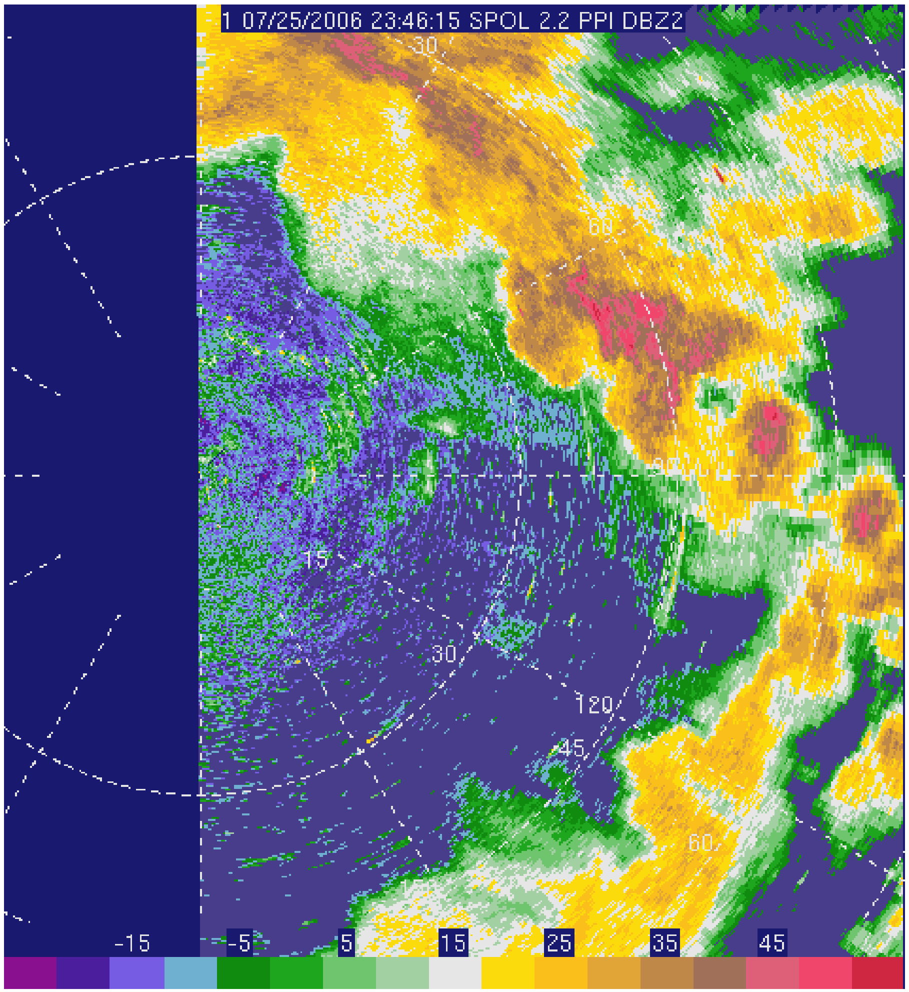
1. **Plot midpoint of ray segments**
2. **Layer-based Profile**

Typical resolution 0.25 to 0.5 km

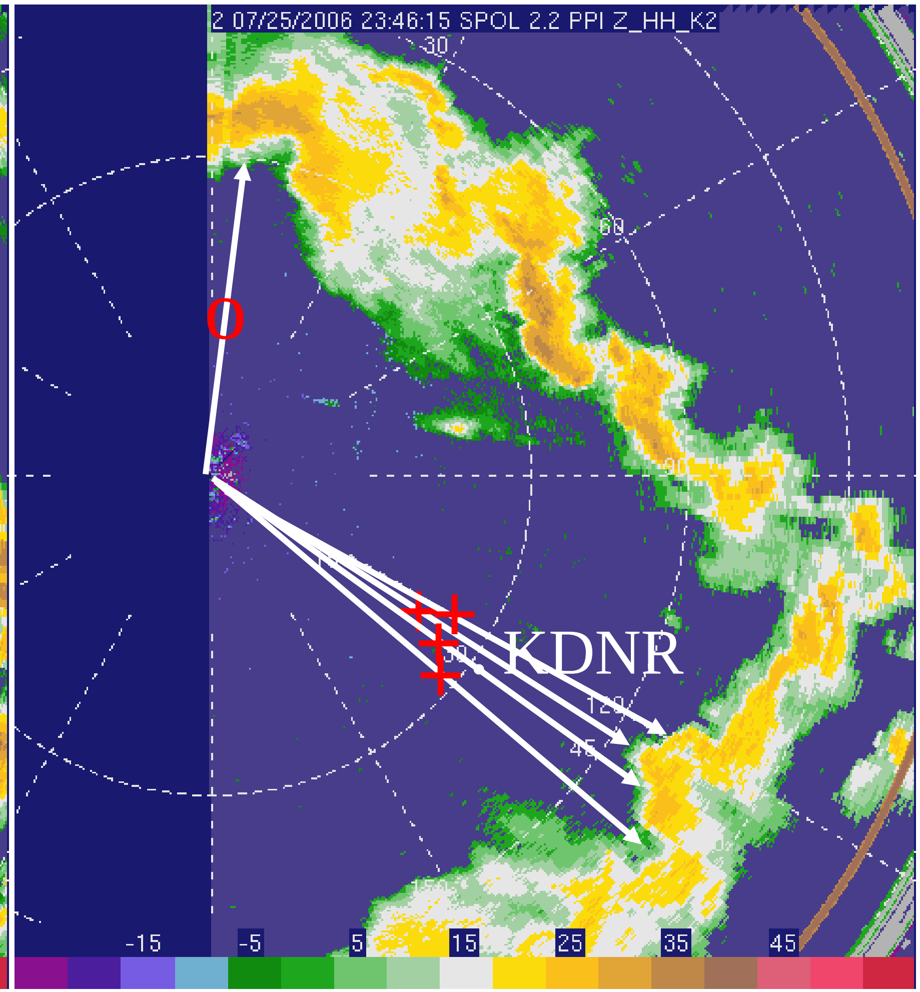


Humidity Results: REFRACTT

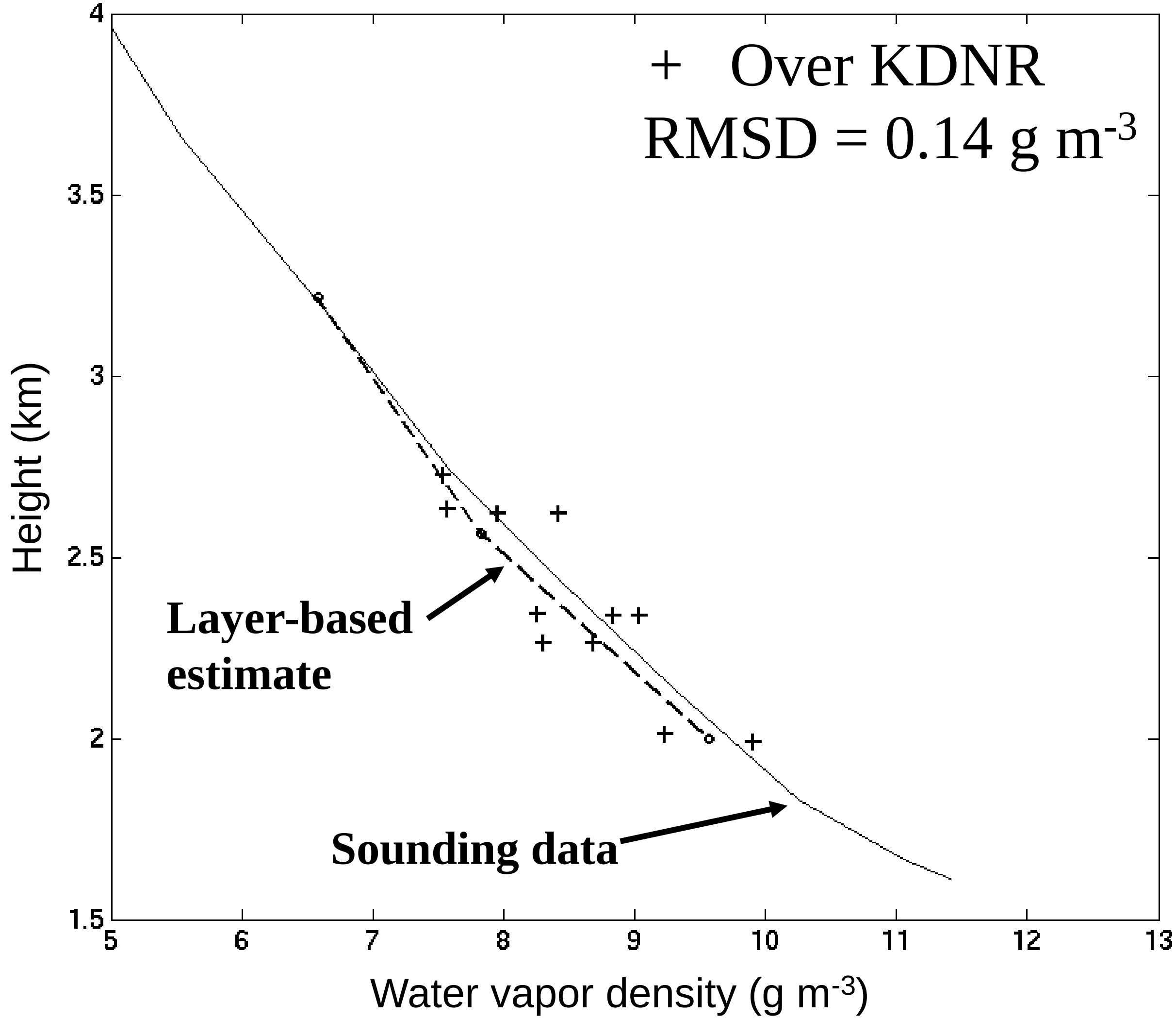
S-band reflectivity (dBZ)



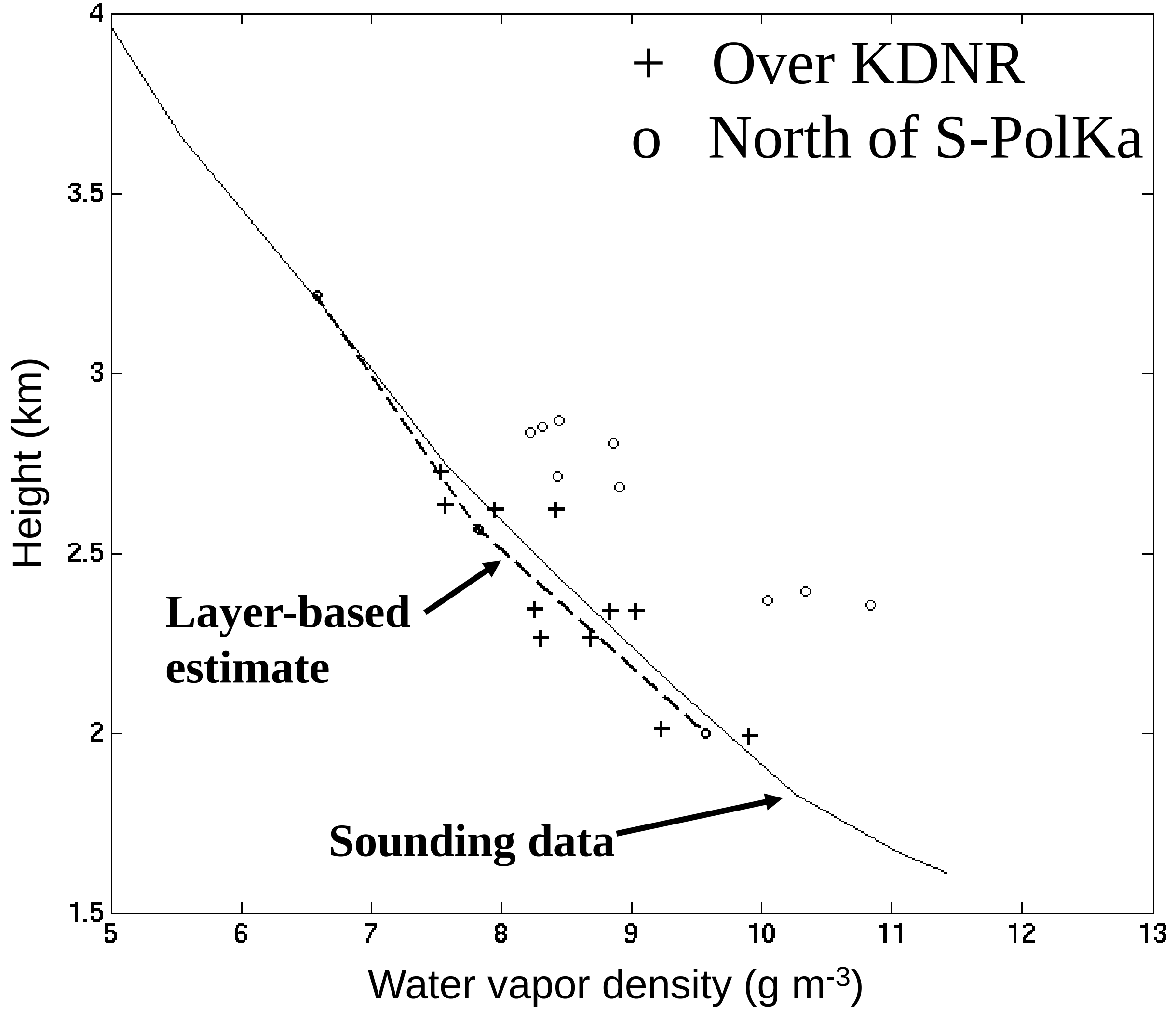
K_a-band reflectivity (dBZ)



Humidity Results: REFRACTT

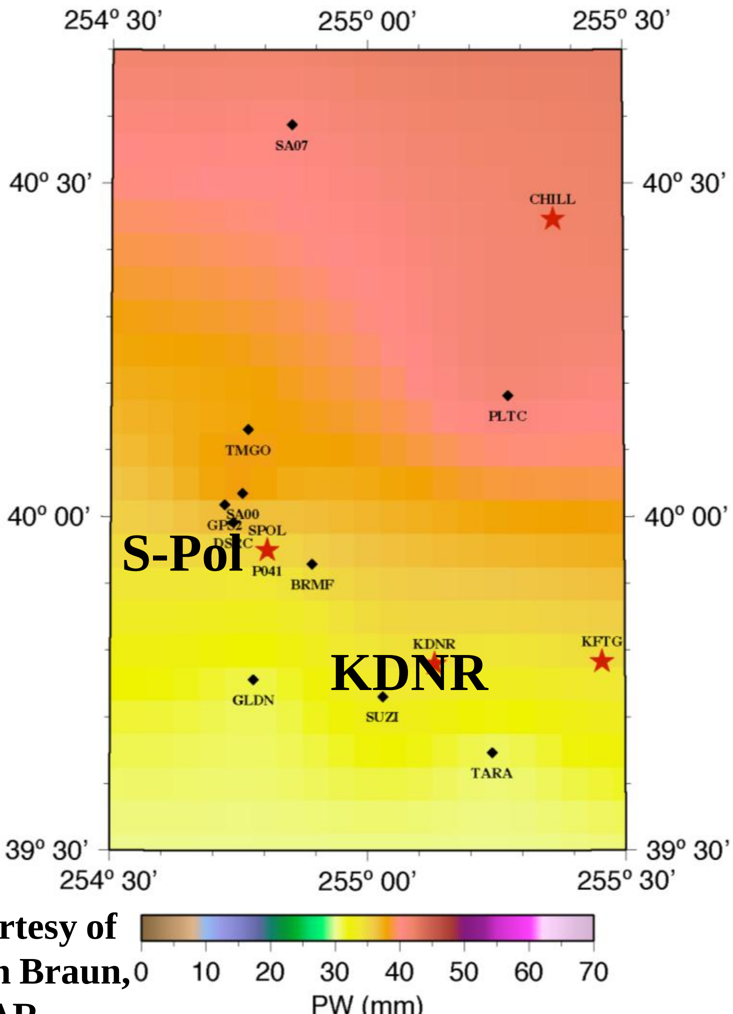


Humidity Results: REFRACTT



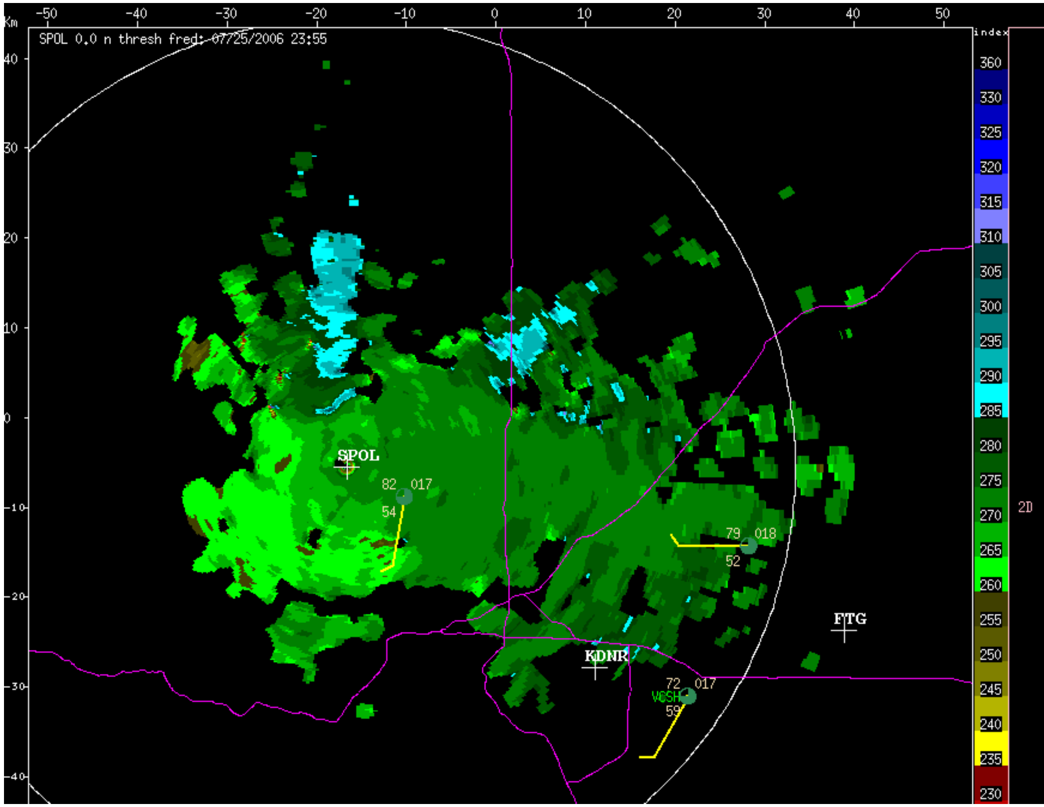
Humidity Results: REFRACTT

Precipitable Water content from GPS

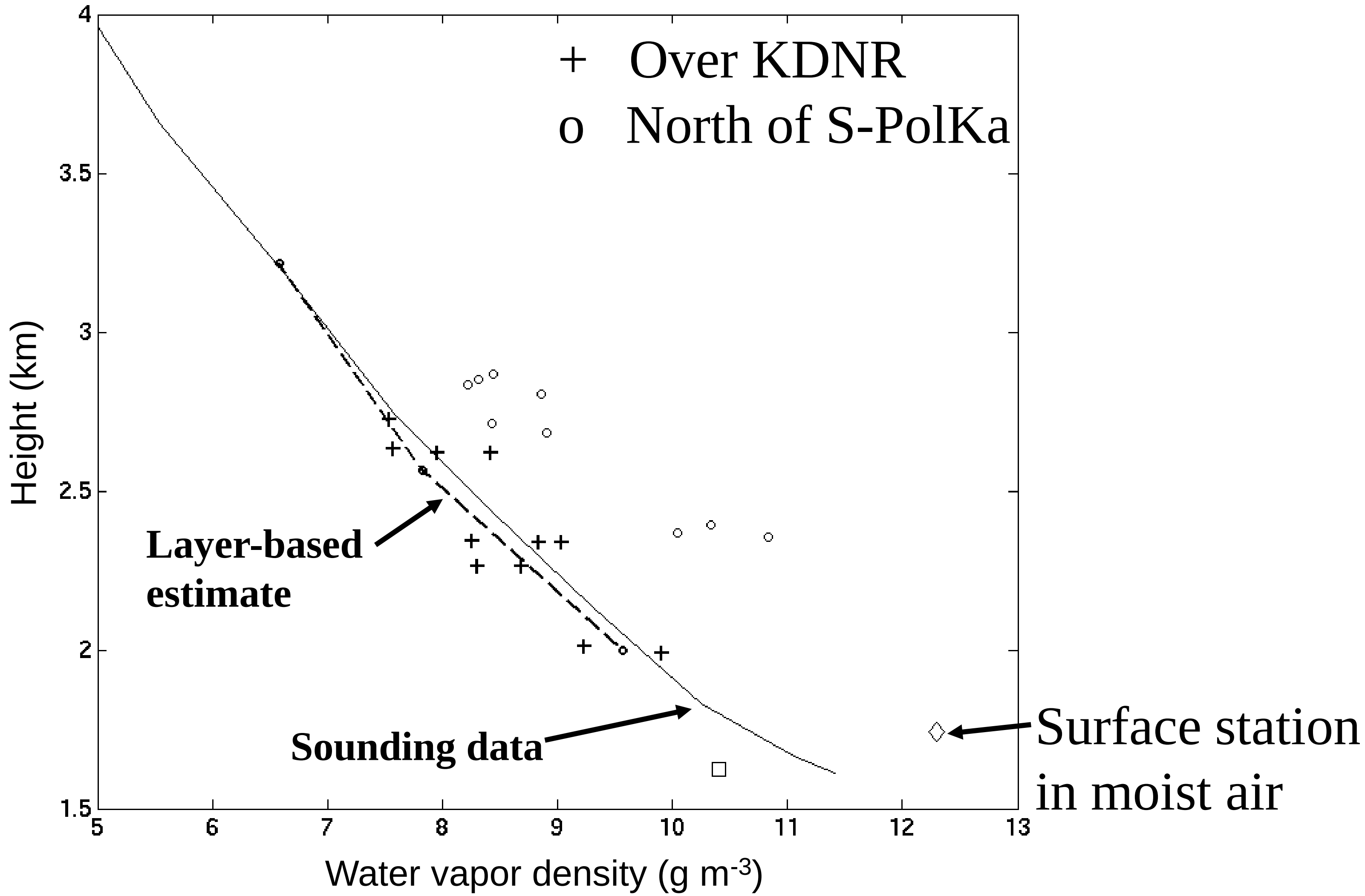


Courtesy of John Braun, NCAR

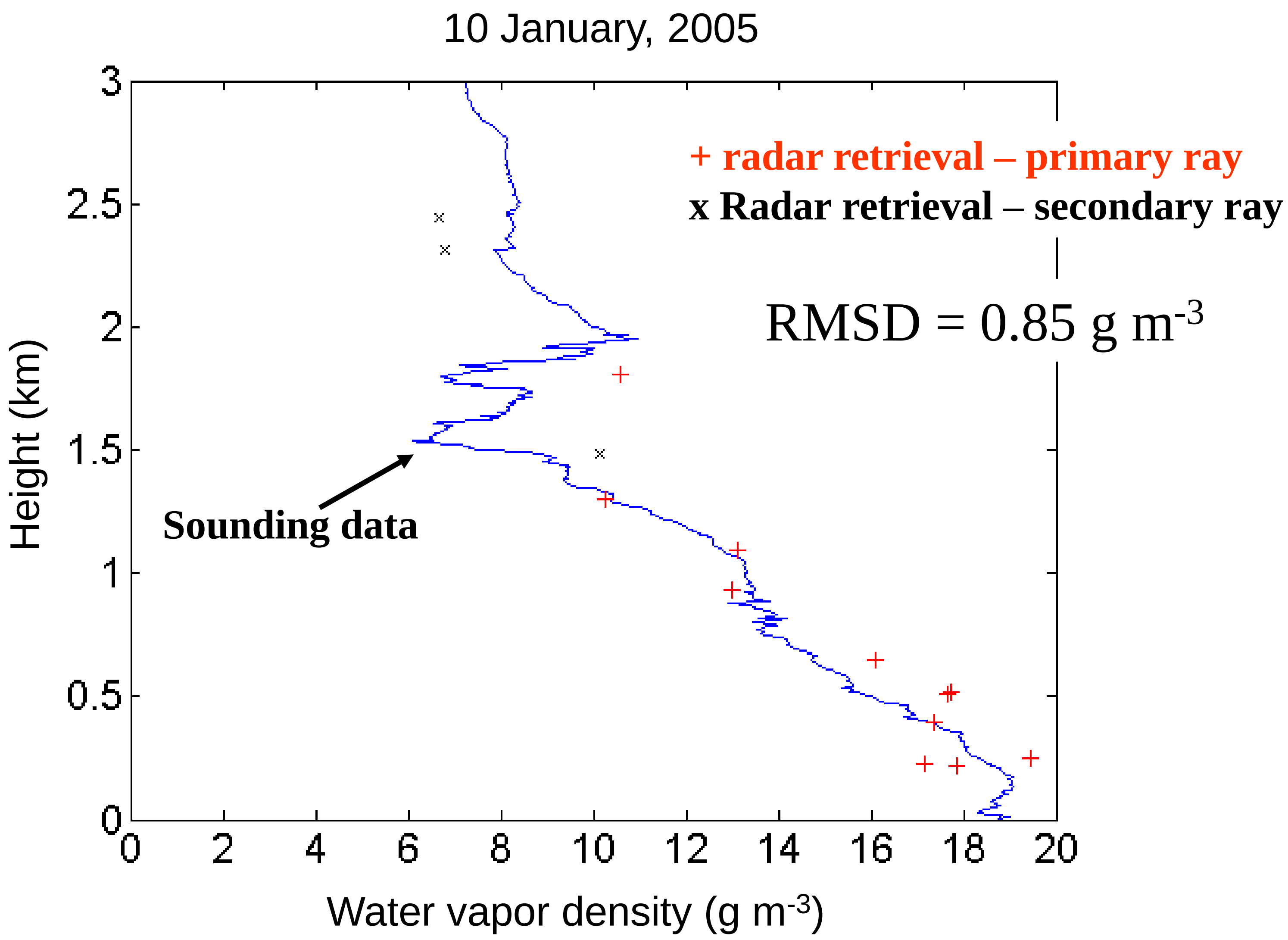
Low level humidity from refractive index measurements



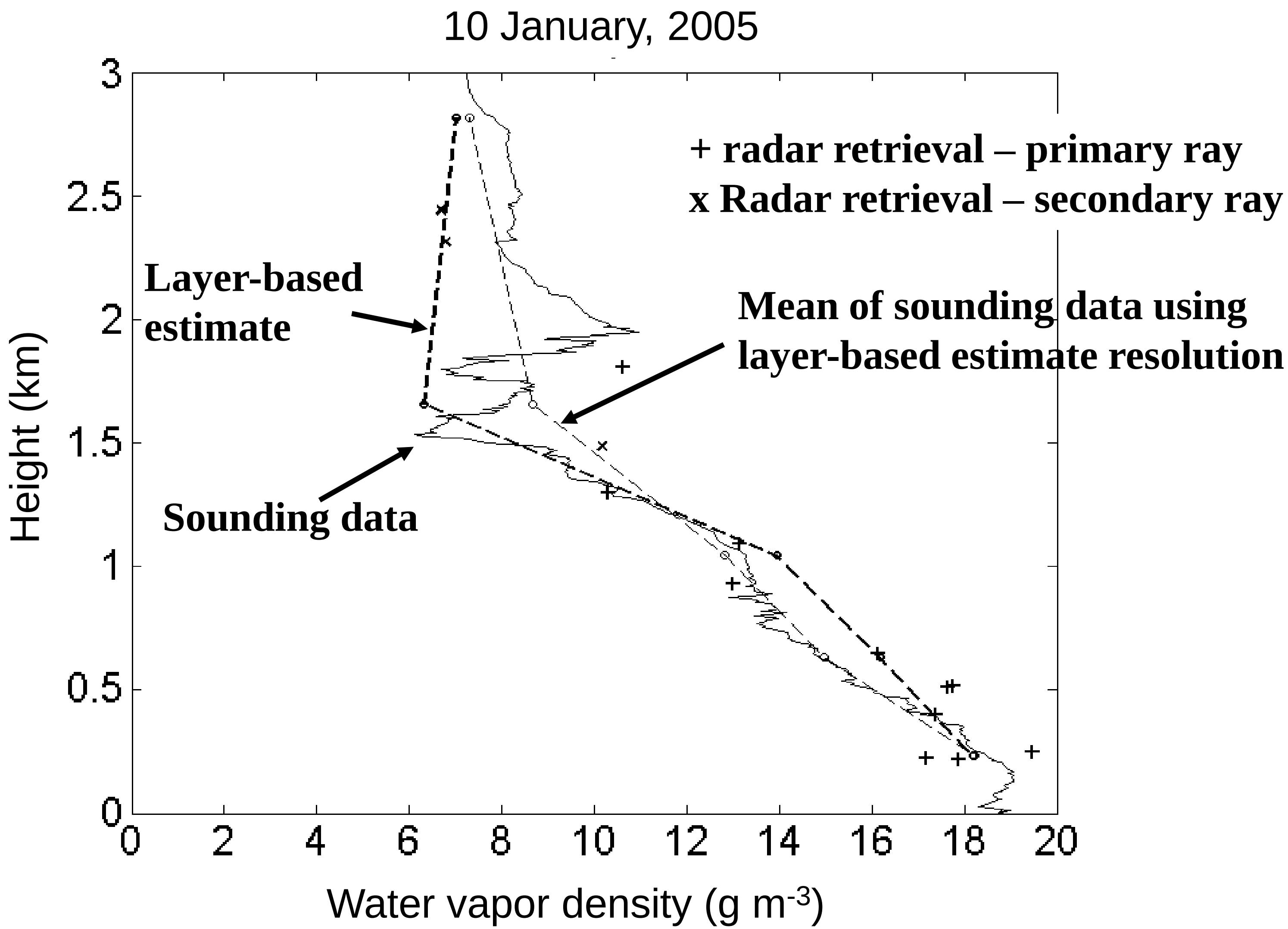
Humidity Results: REFRACTT



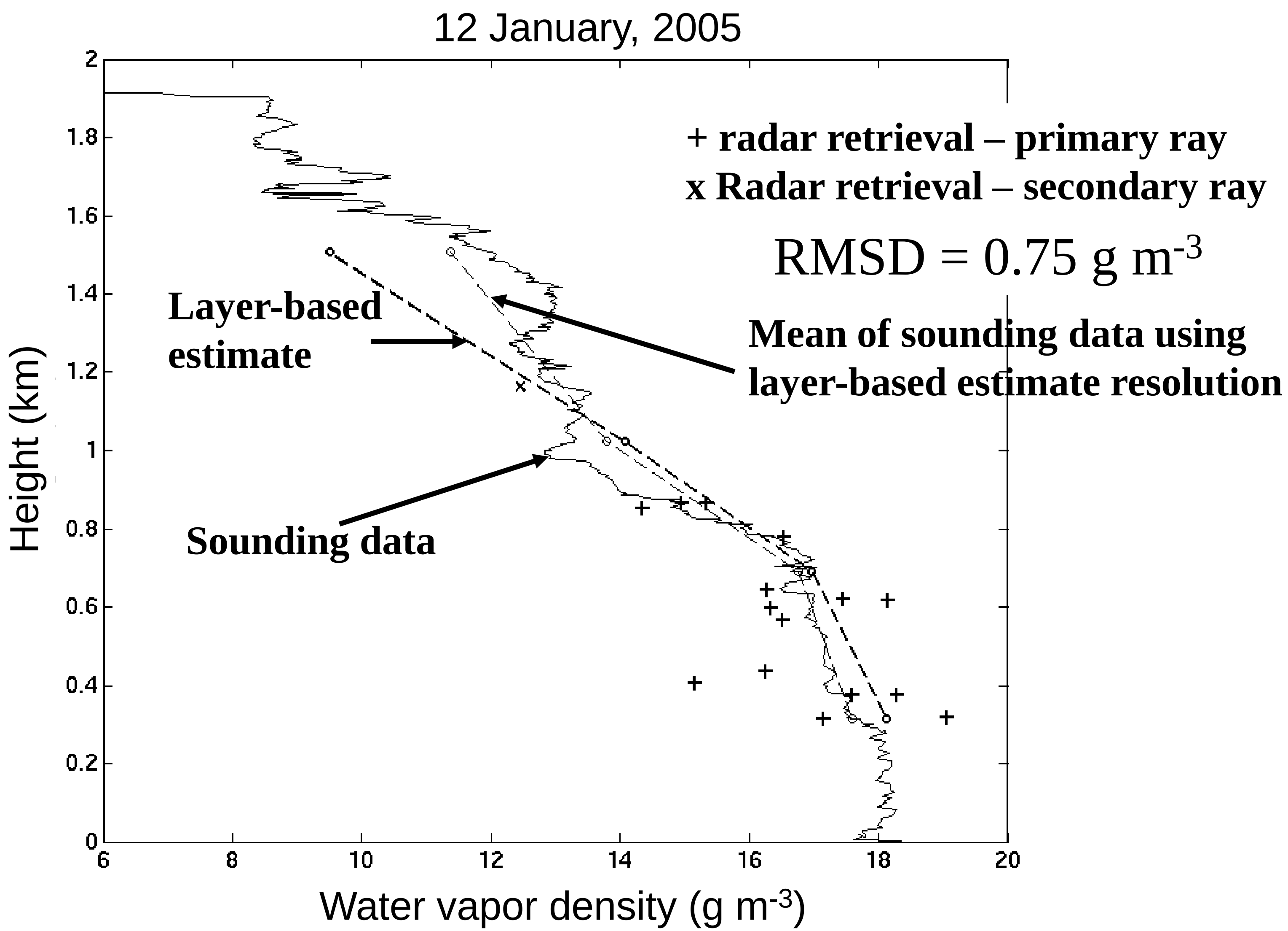
Humidity Results: RICO



Humidity Results: RICO



Humidity Results: RICO



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

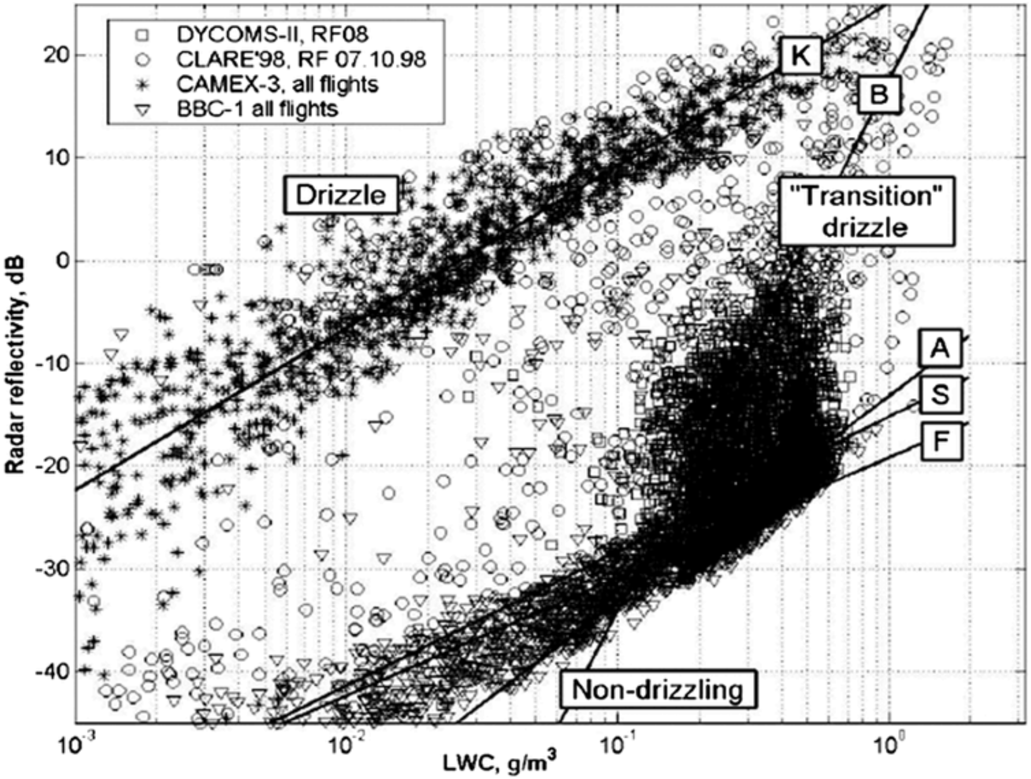
Discussion

- 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_a-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



Khain et al. (2008)

Photo by Bjorn Stevens

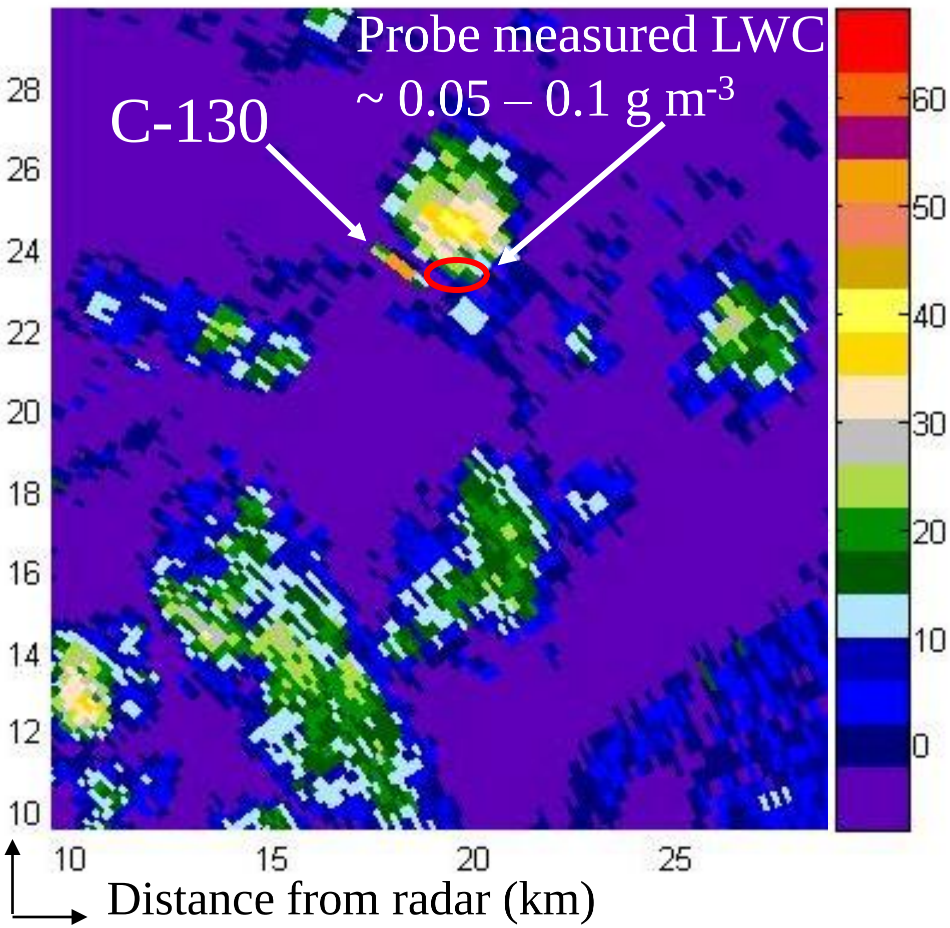
LWC Estimate: Background

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

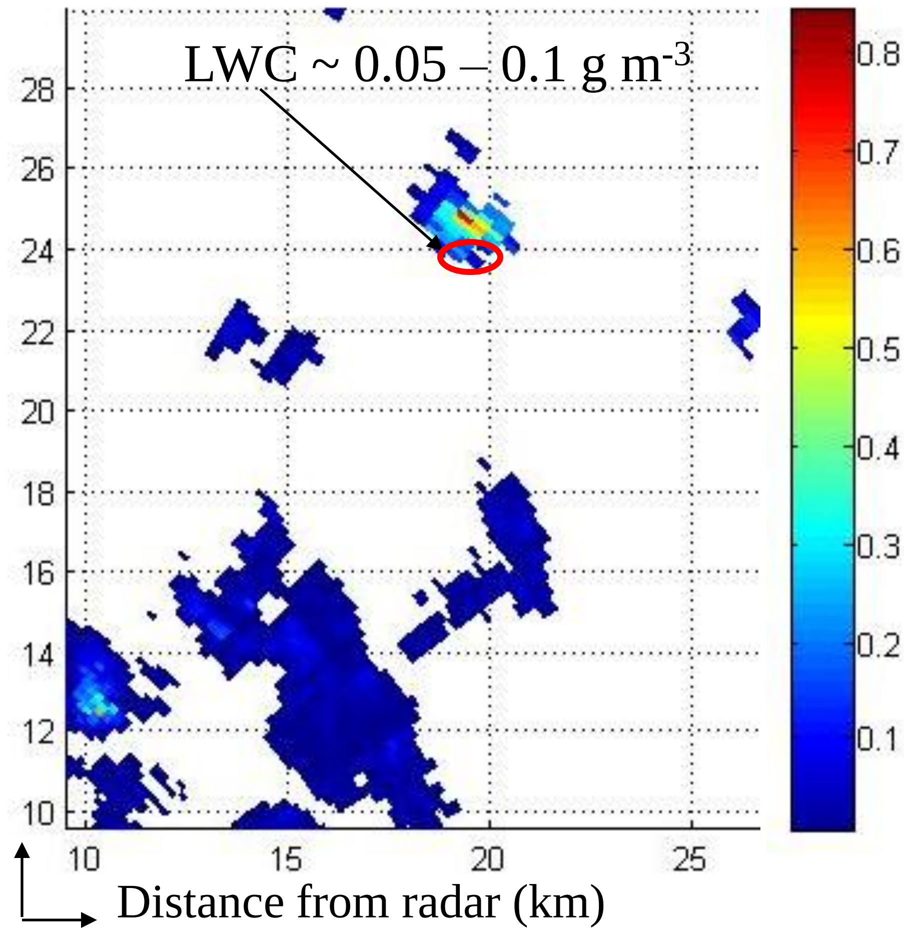
- Advantages
  - Attenuation directly related to LWC
  - Independent of DSD (and precip!)
- Difficulties
  - Requires two or more radars at different wavelengths
  - Beam matching
    - Straight forward with S-PolKa
  - Ambiguity between attenuation and Mie scattering effects
    - S-band dual-pol measurements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

LWC Estimate: Results

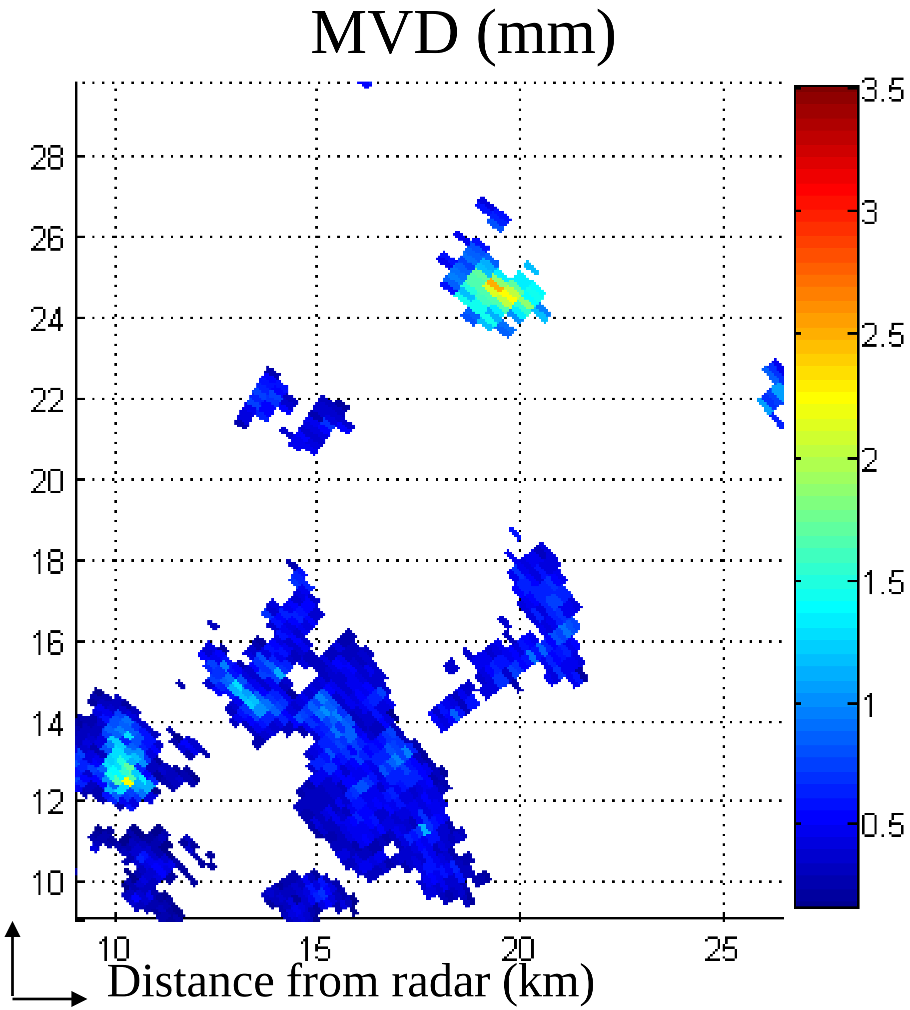
S-band reflectivity (dBZ)

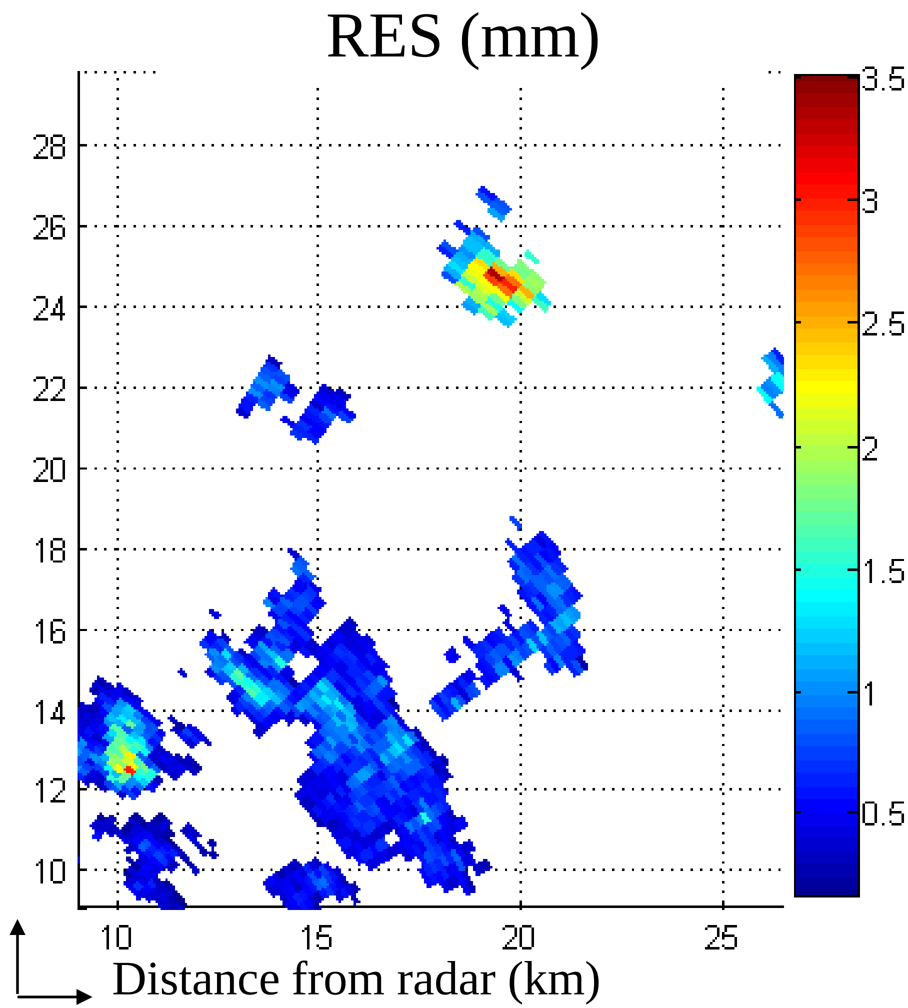


Retrieved LWC (g m^{-3})

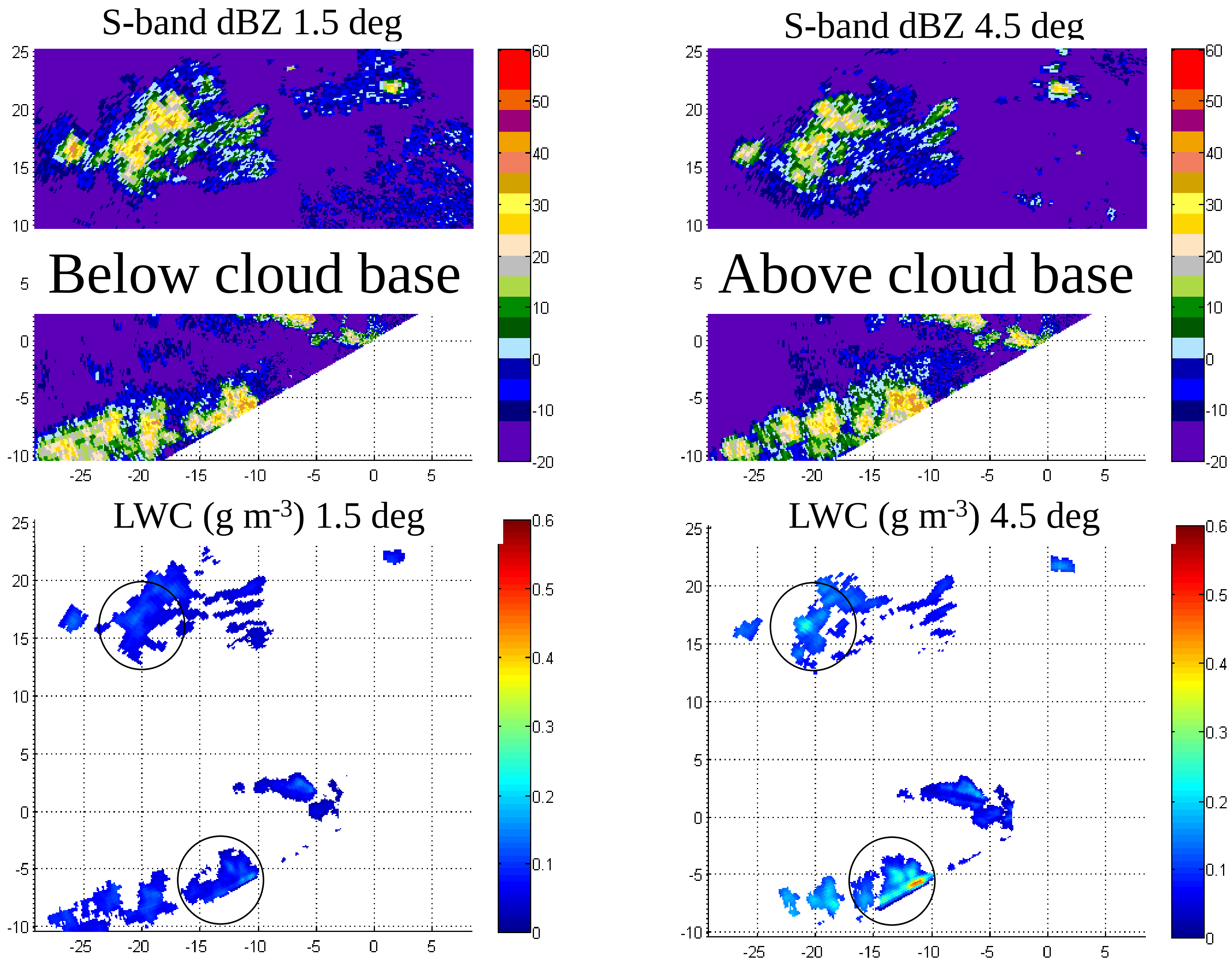


LWC Estimate: Results

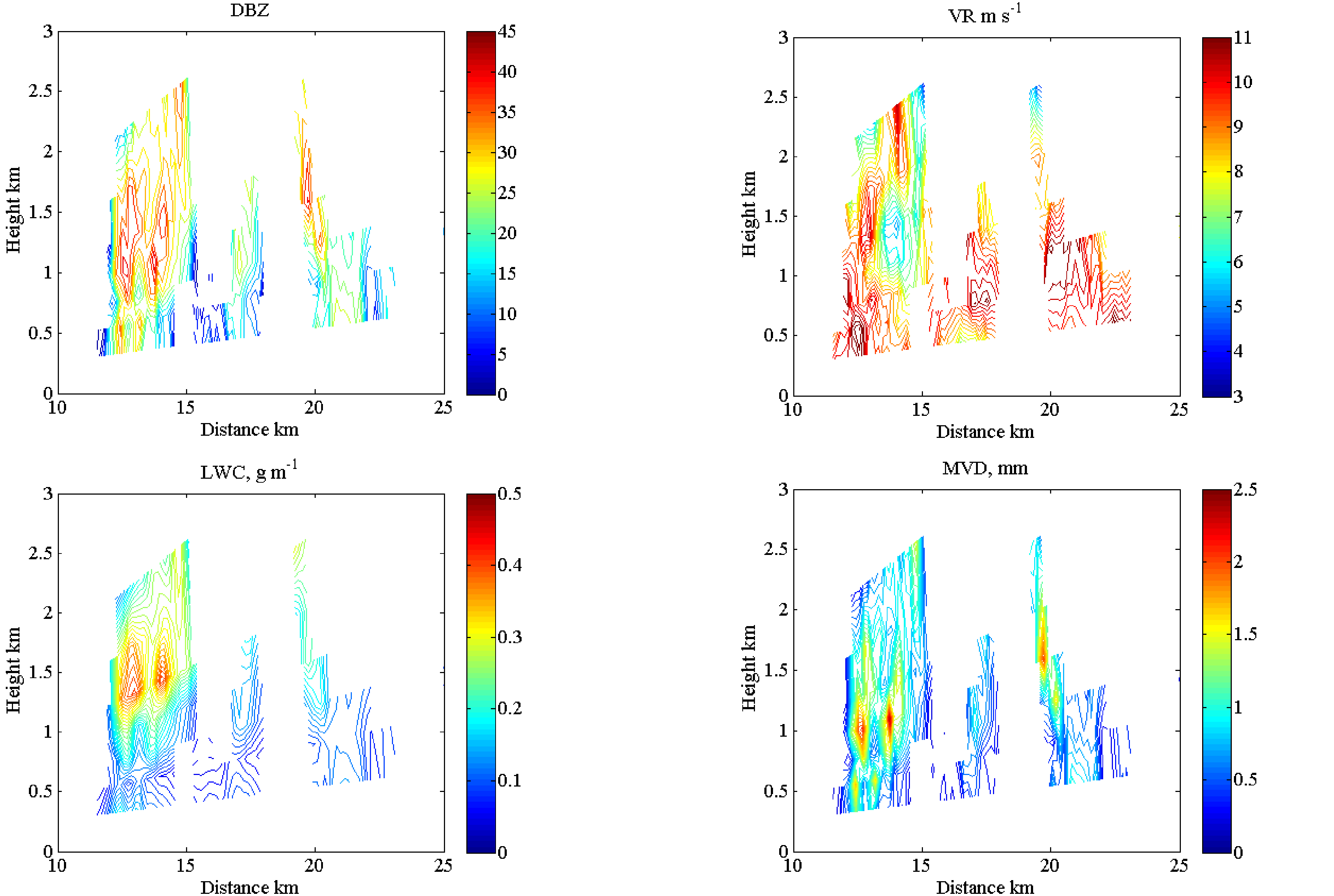




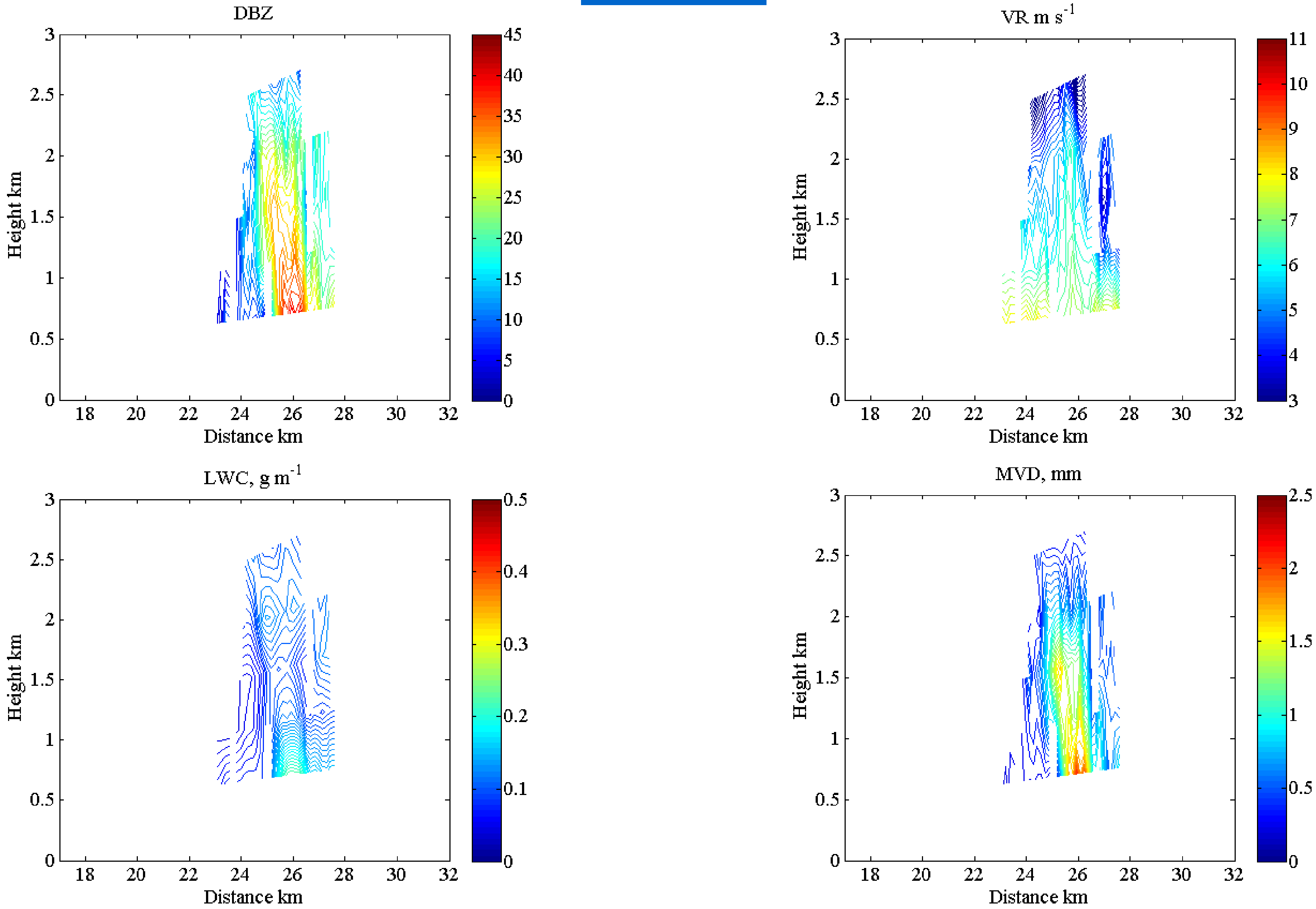
LWC Estimate: Results



LWC Estimate: Results

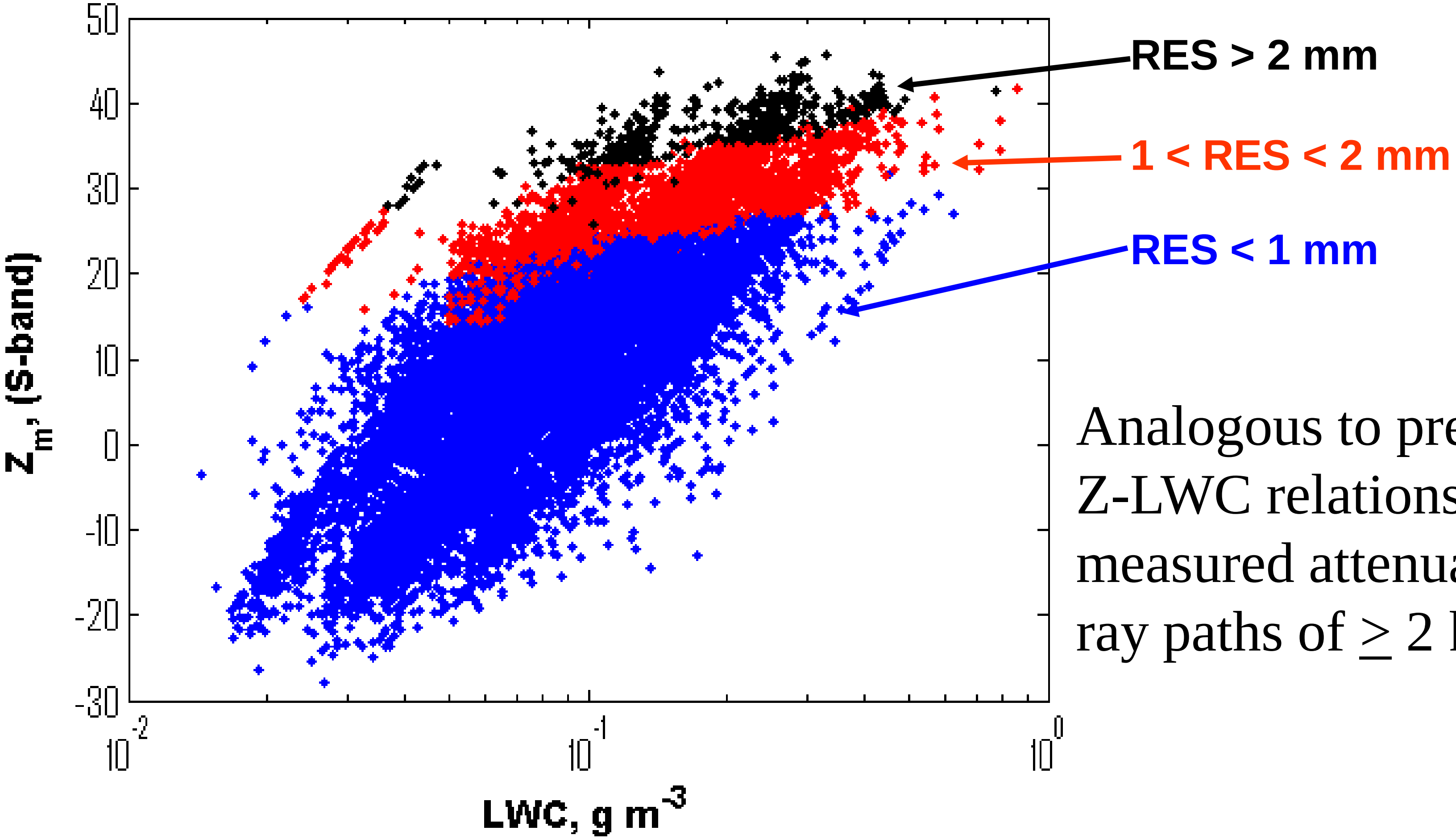


LWC Estimate: Results



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

- 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