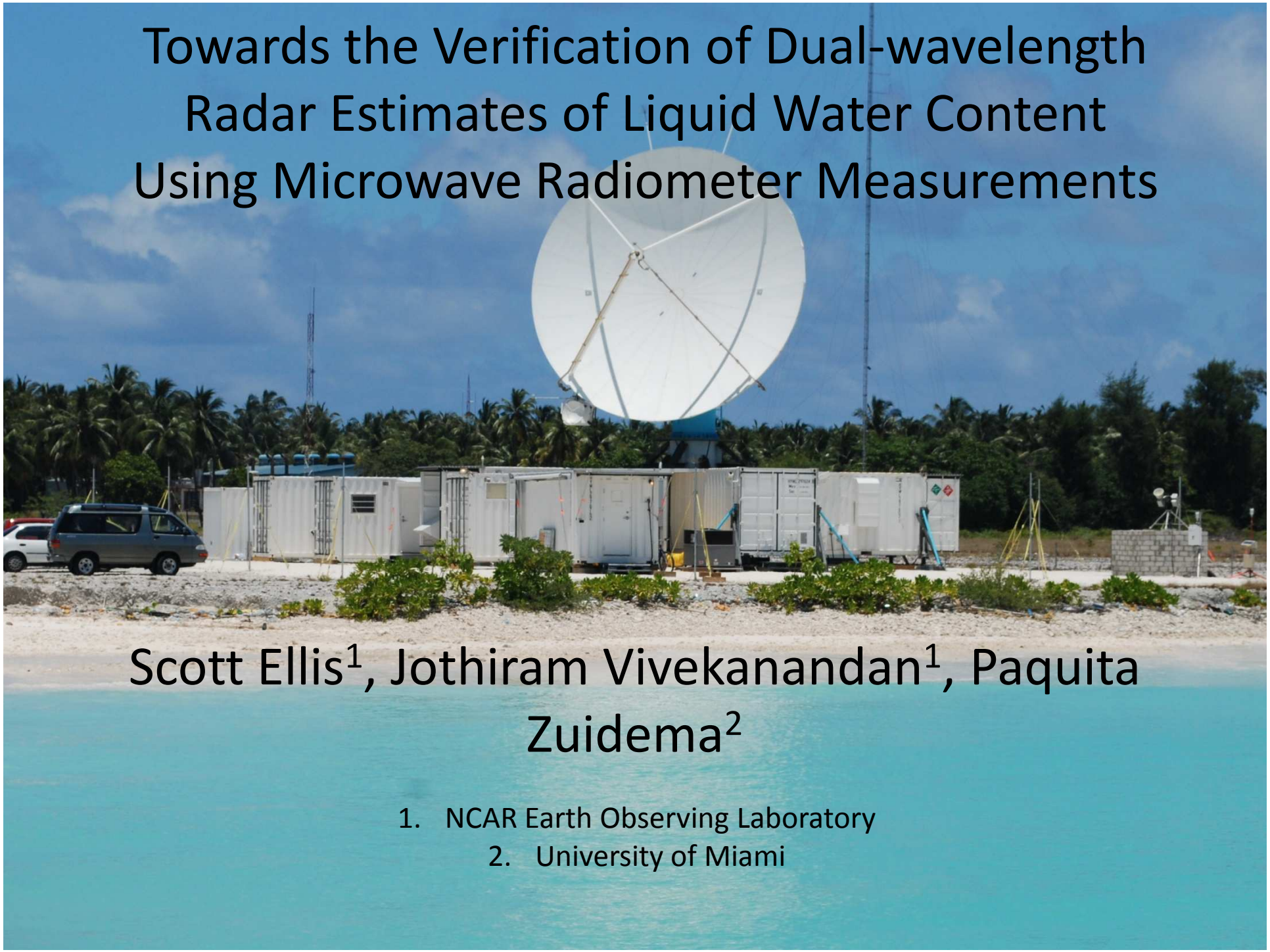
Towards the Verification of Dual-wavelength Radar Estimates of Liquid Water Content Using Microwave Radiometer Measurements



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Background

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

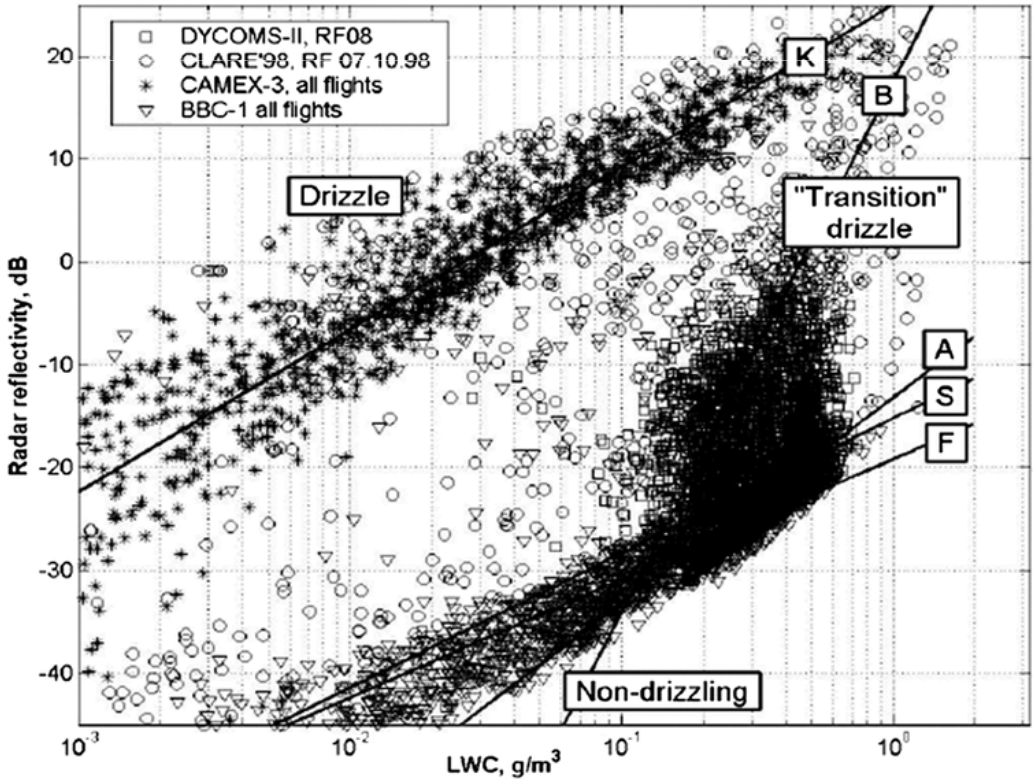


Photo by Bjorn Stevens

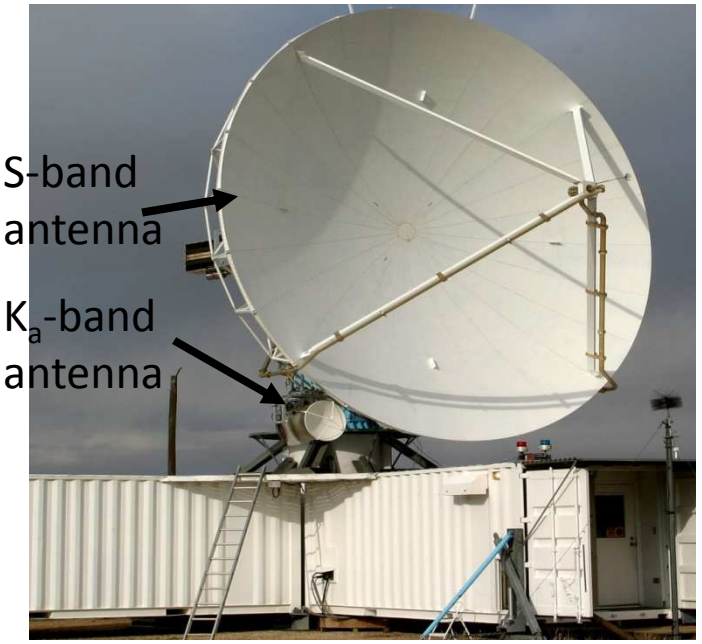
Khain et al. (2008)

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

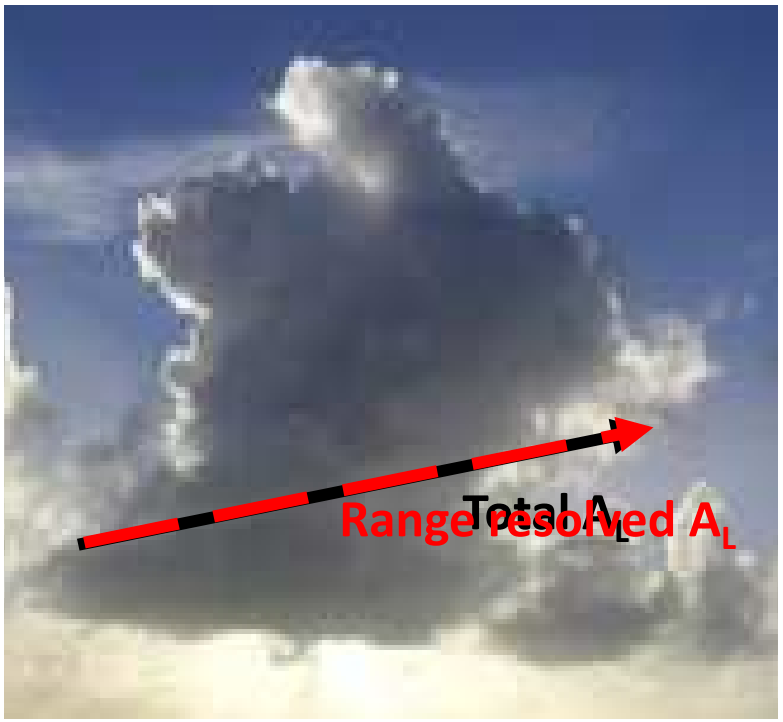


Frequency band (wavelength)	Liquid Attenuation dB km^{-1} $(g\ m^{-3})^{-1}$
S-band (10 cm)	0.005
K_a-band (0.9 cm)	0.70

LWC Retrieval Method

- Estimate total liquid attenuation (A_{TL}, dB) along ray segment ($\geq$ 2km) 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)
  - $A_L = Cz_s^p$ (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

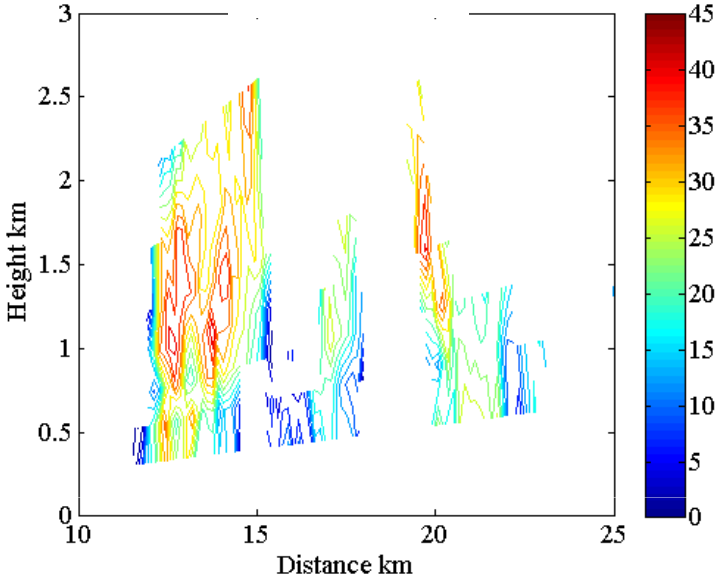
- Compute LWC and MVD
  - LWC = $0.74A_L(T)$ (Vivekanandan et al. 1999)
    - Temperature correction
  - $MVD^3 = 2.16 \times 10^{-4}$ z/LWC (Vivekanandan et al. 1999)
    - Assumes an exponential DSD!
- The method is an extension of dual-wavelength LWC retrievals developed by Hogan et al. (2005) and Williams and Vivekanandan (2010) to scanning radars
- The final result is LWC and MVD at the resolution of the radar

Field Campaigns with S-PolKa

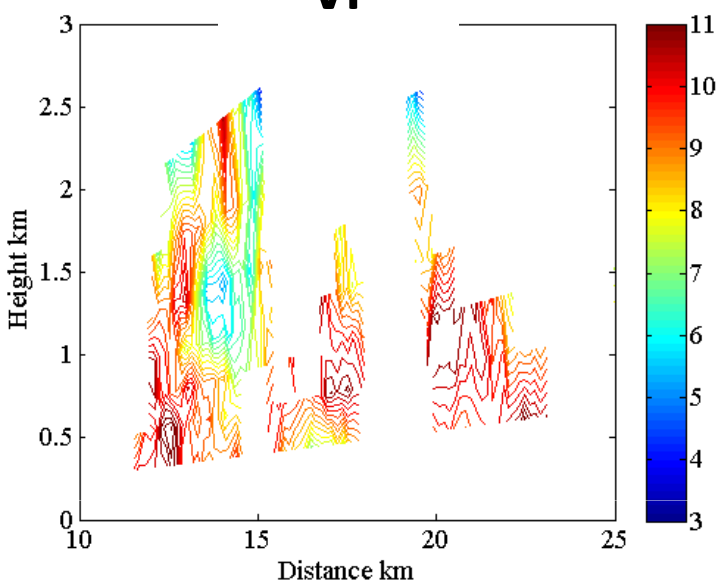
- RICO – Barbuda, West Indies
- REFRACTT – Boulder, Colorado
- DYNAMO – Addu Atoll, Maldives

LWC Estimate: Results (RICO)

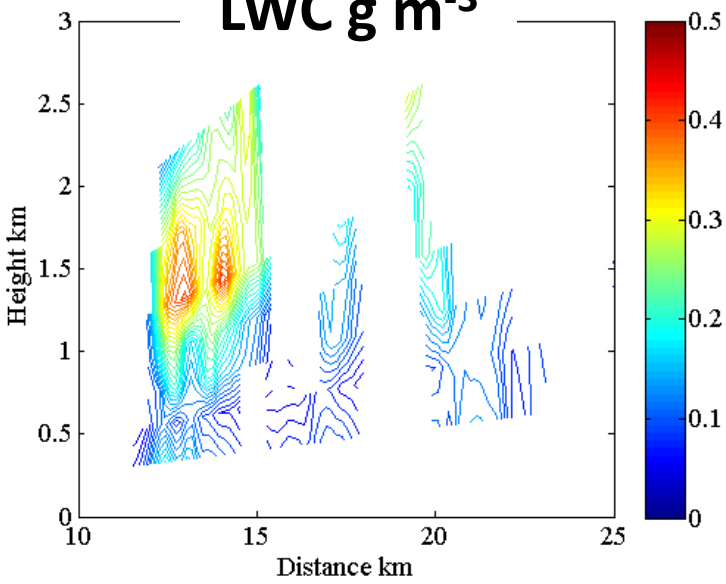
DBZ



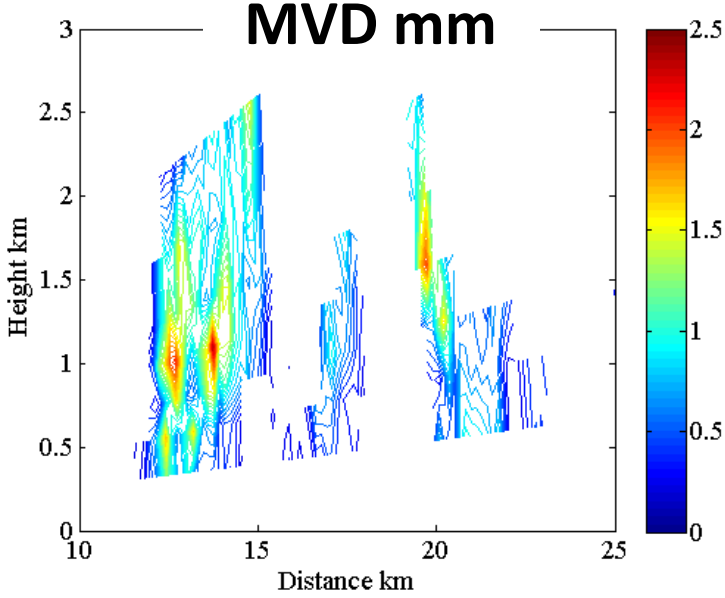
Vr



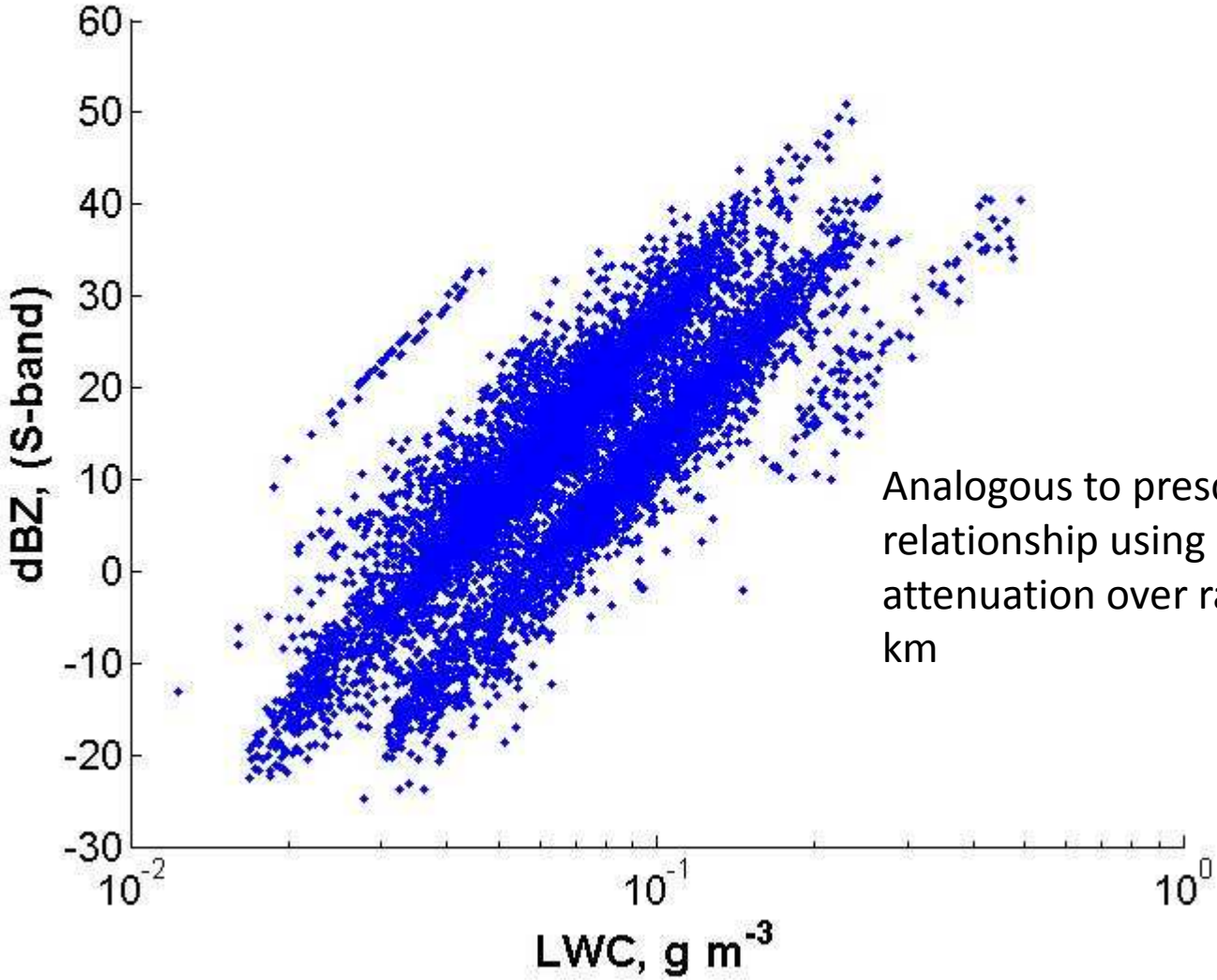
LWC g m^{-3}



MVD mm



dBZ Versus Retrieved LWC

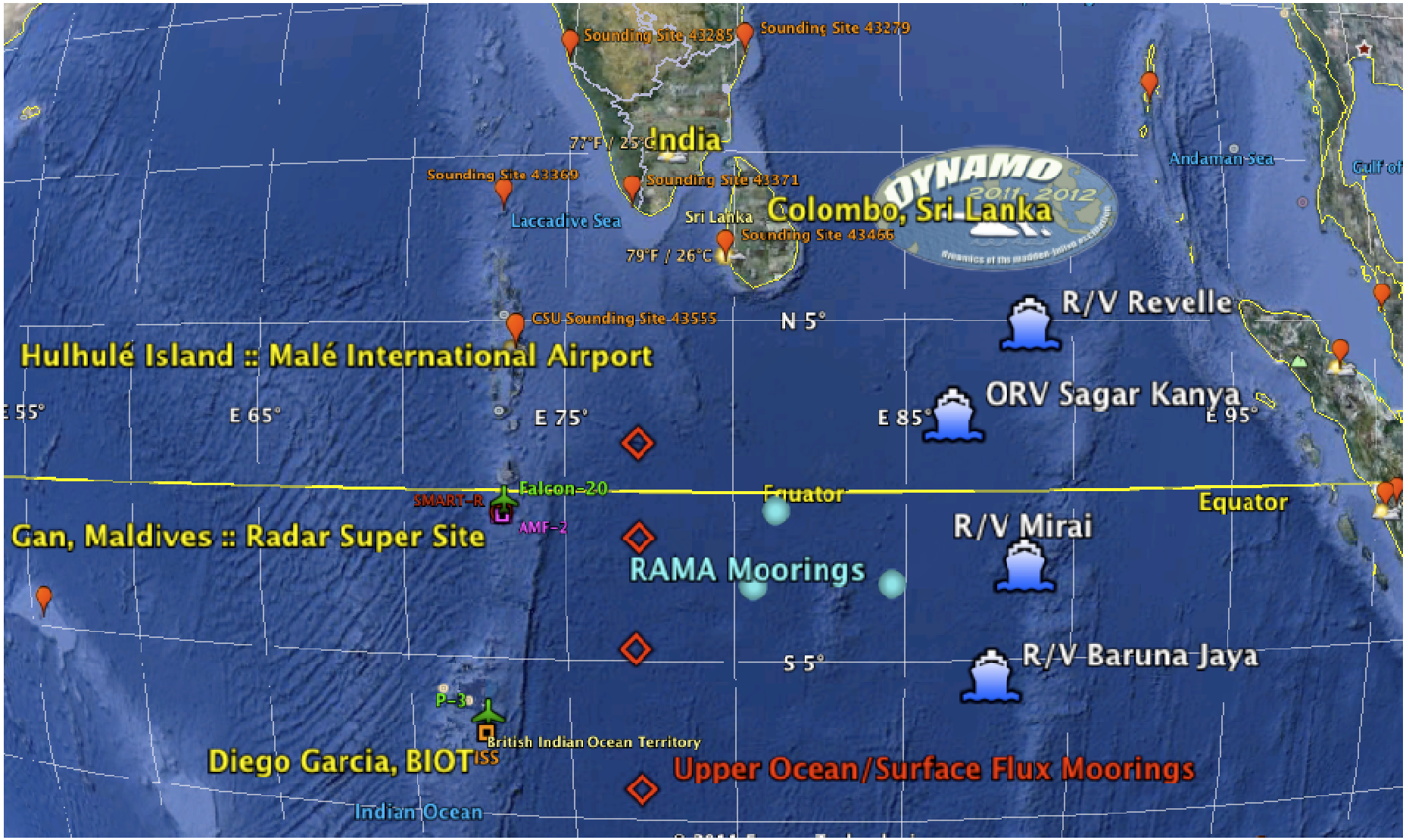


Analogous to prescribing Z-LWC relationship using measured attenuation over ray paths of $\geq$ 2 km

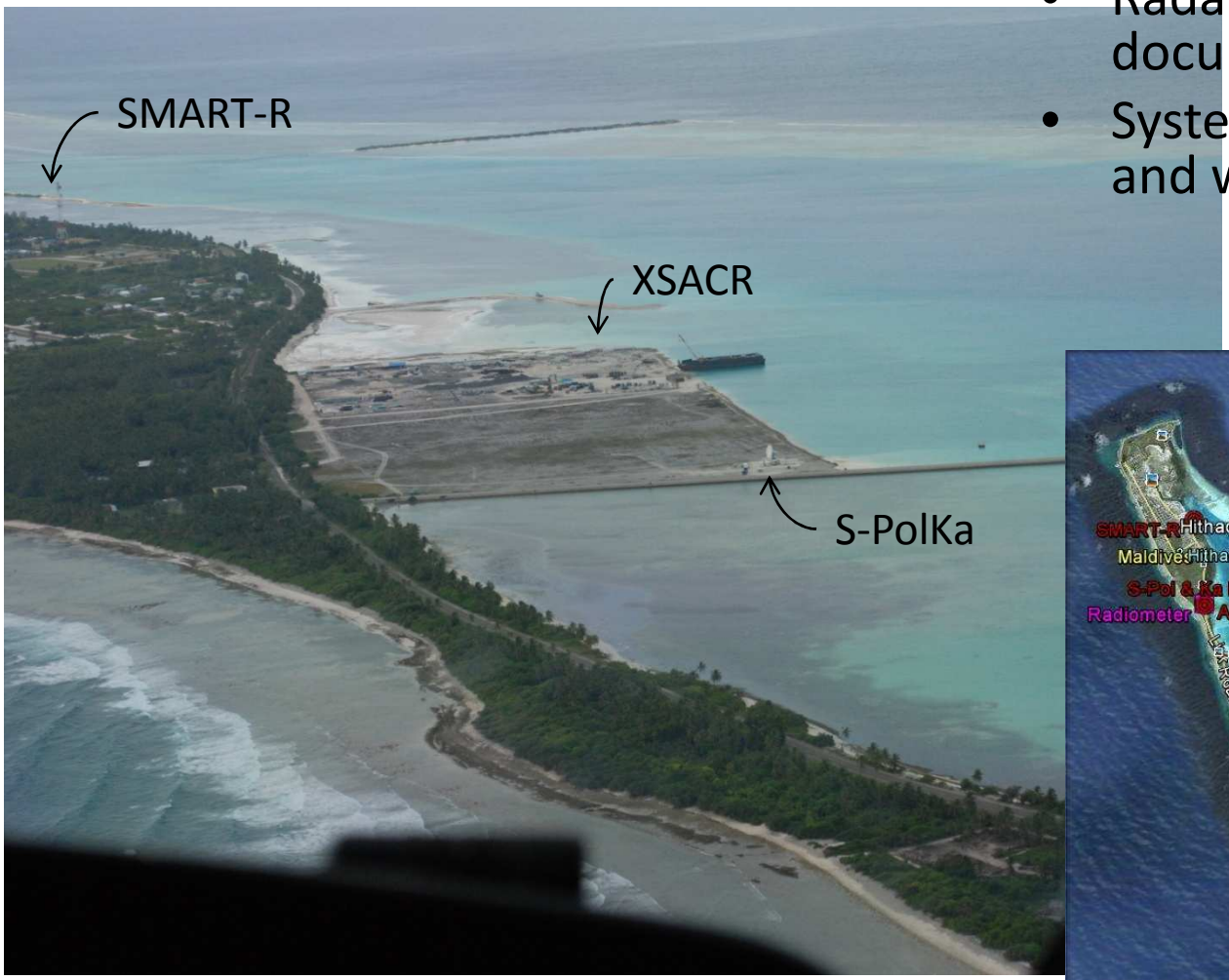
LWC Verification??

- 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)

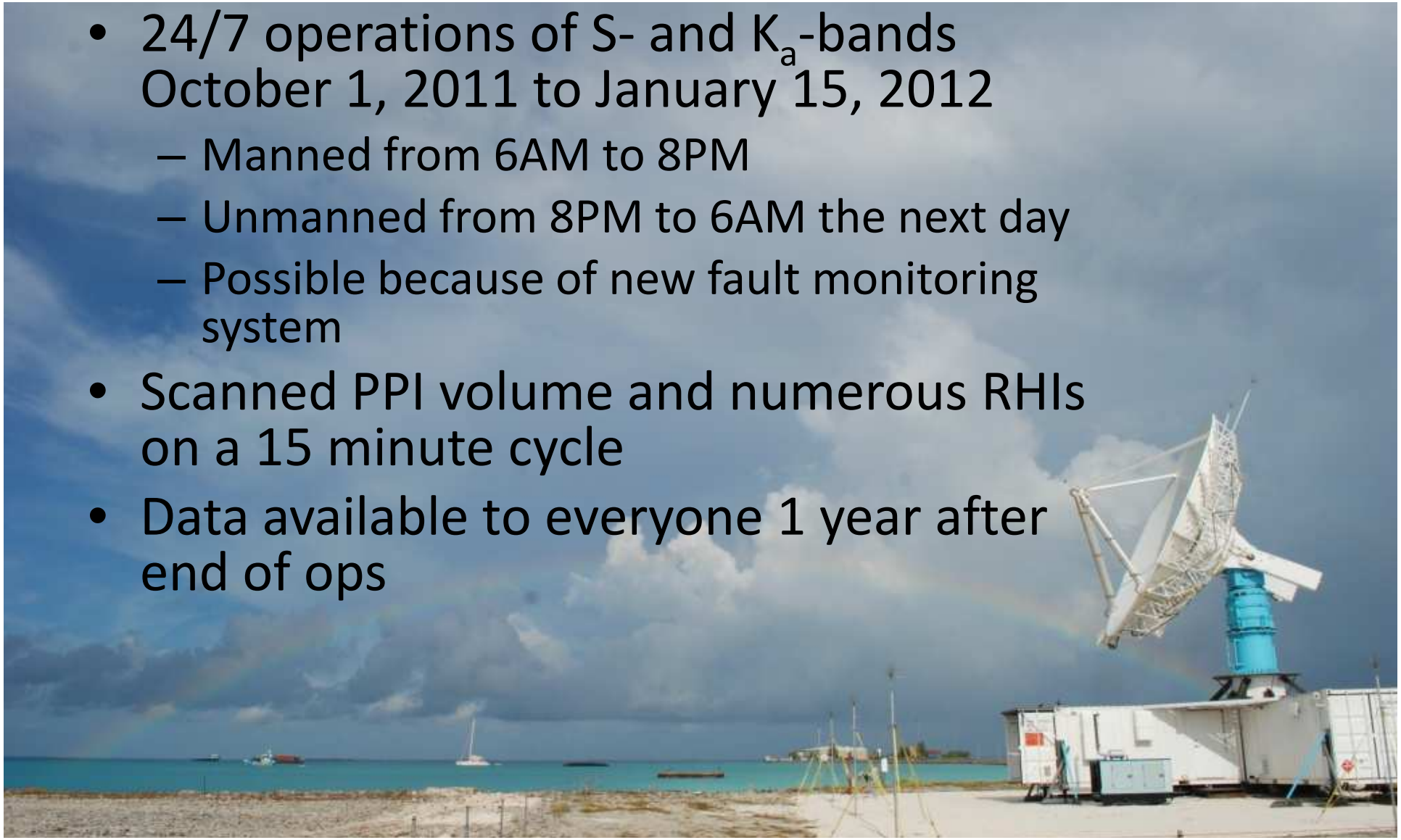


Radar Super-site on Addu Atoll



- Radars at supersite chosen to document cloud spectrum
- Systems were complimentary and worked together

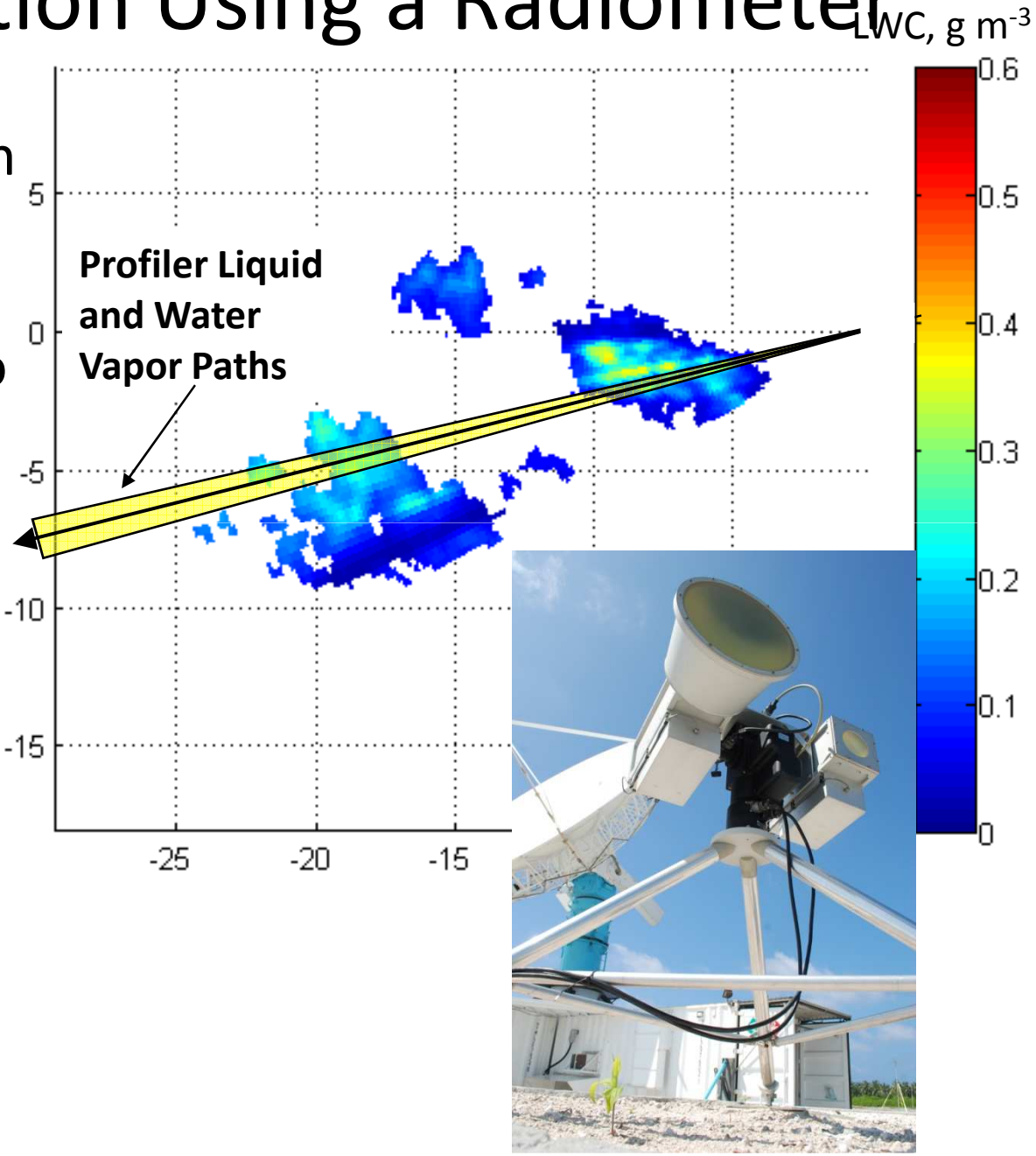
S-PolKa at DYNAMO IOP



- 24/7 operations of S- and K_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!

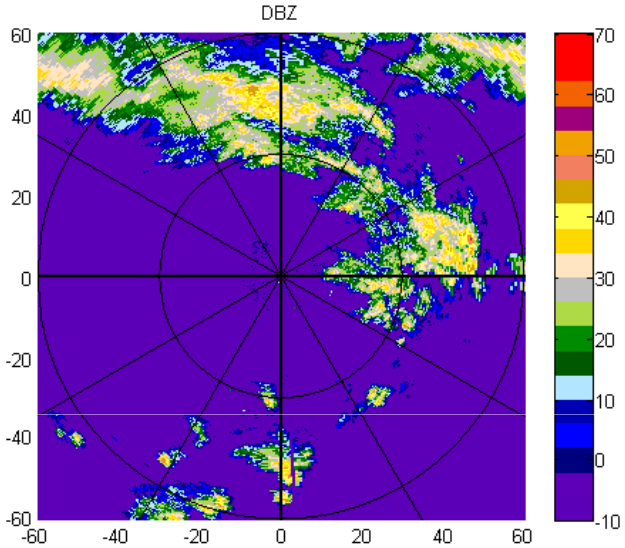


Radar Radiometer Comparison Status

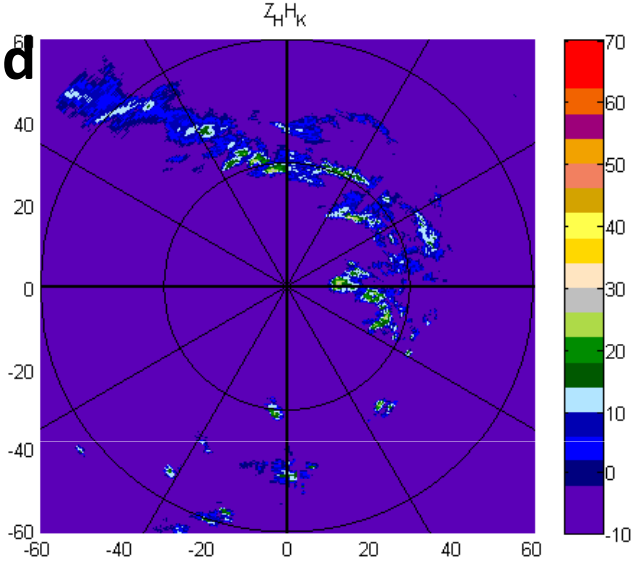
- S-PolKa
  - Final QC'd data set recently completed
  - LWC analysis has begun
  - Results look similar to RICO
  - Several good radar/radiometer comparison periods identified

Example of LWC, October 20 2011 – 3.5 degree elevation

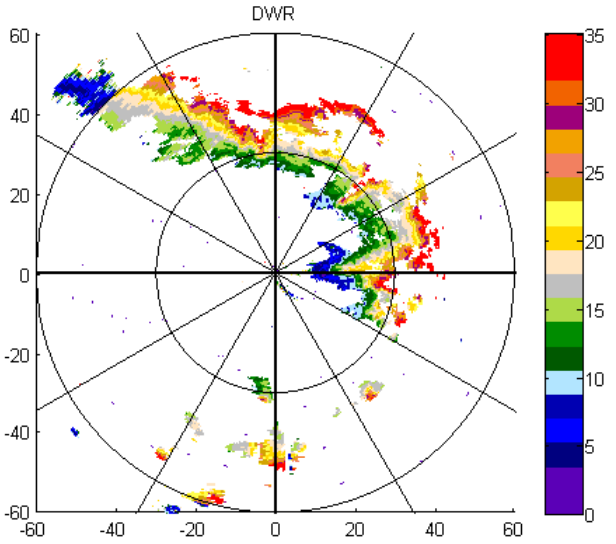
S-band dBZ



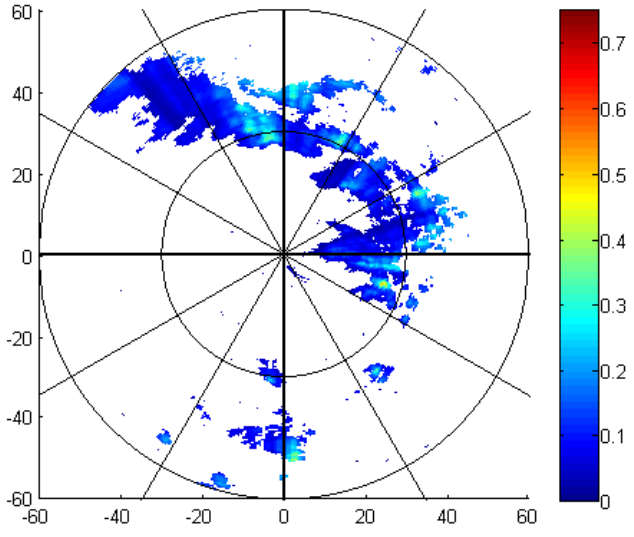
K_a-band dBZ



DWR



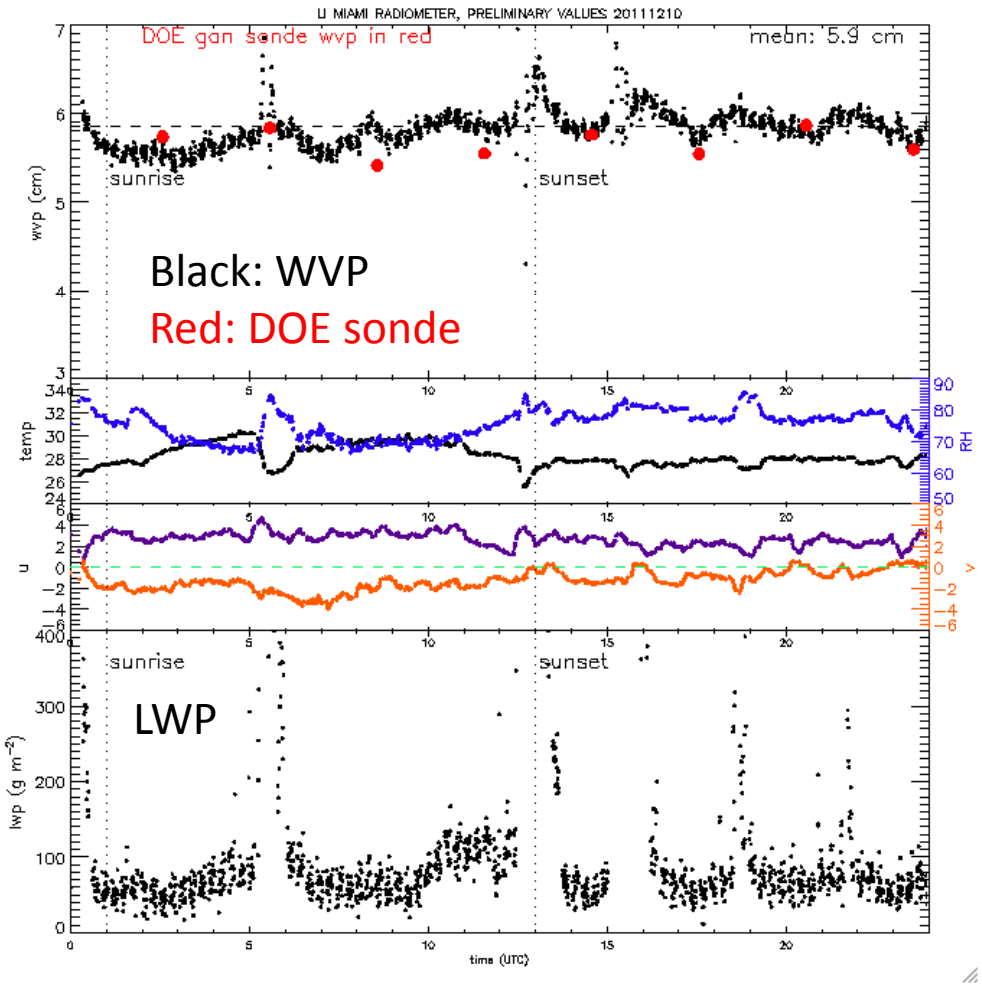
LWC g m^{-3}



Radar Radiometer Comparison Status

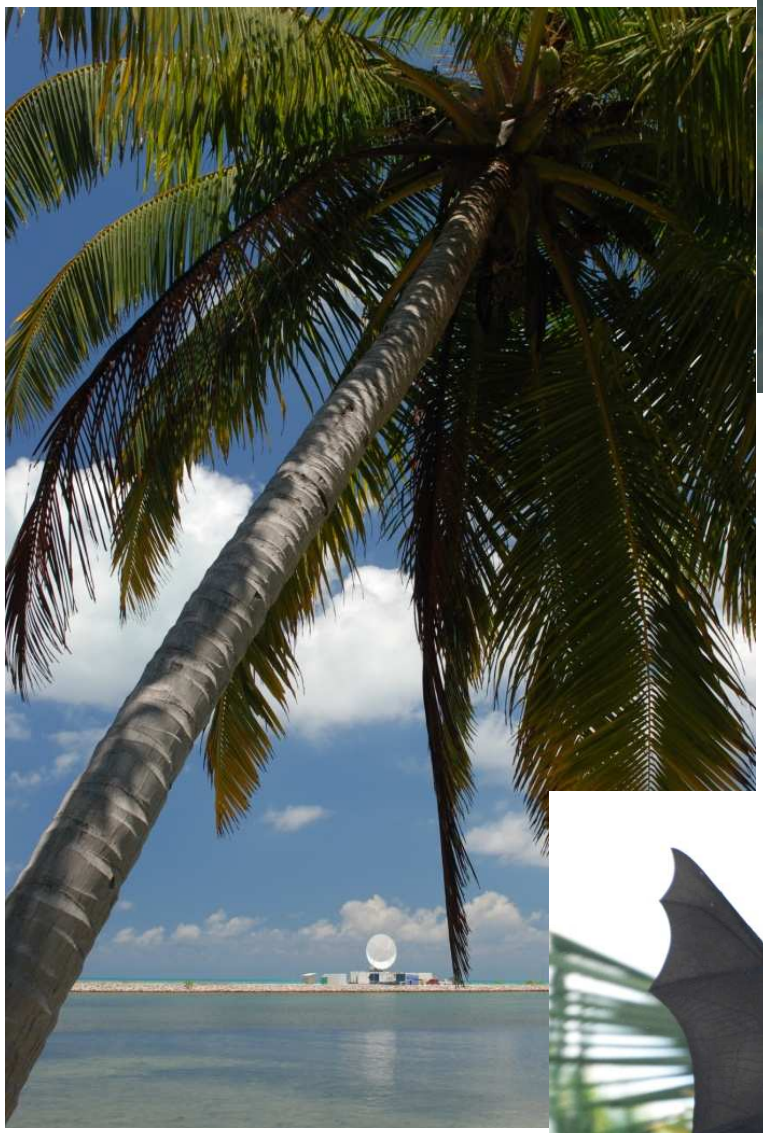
- Plan to compare scans at 7, 9 and 11 degree elevation
- Radiometer DQ still in progress
- Radiometer has 3 degree beam width
  - Necessitates angular averaging
- Calibration using “tip-cal” technique
- Need to determine and correct surface radiation at low angles

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



Future Work

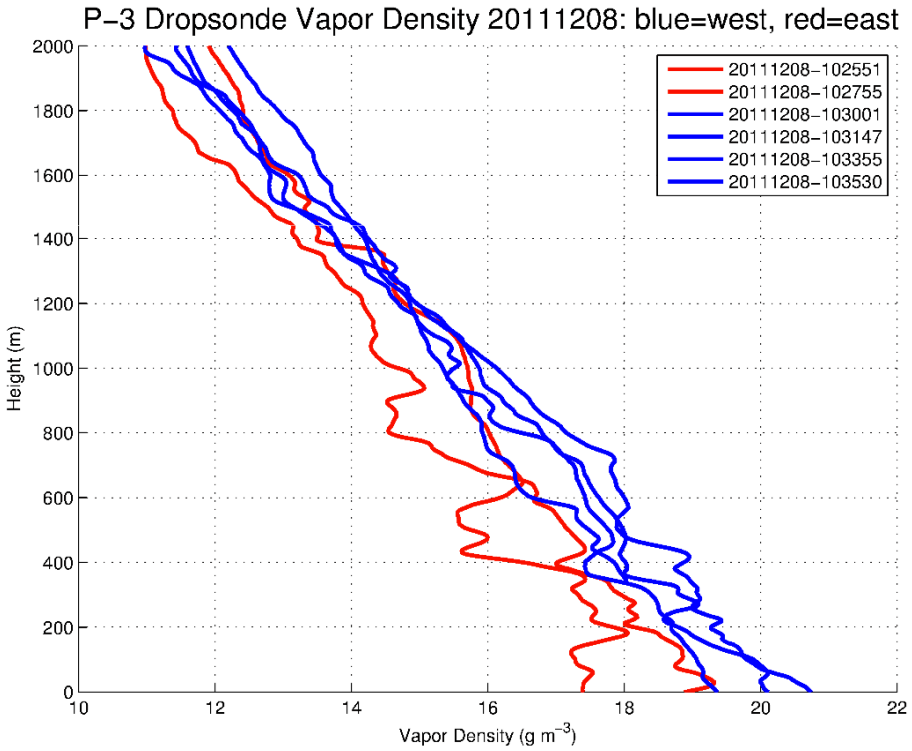
- Keep testing LWC retrievals in different environments
- Develop real-time product
- Test double moment DSD retrieval using Z and K_a-band attenuation



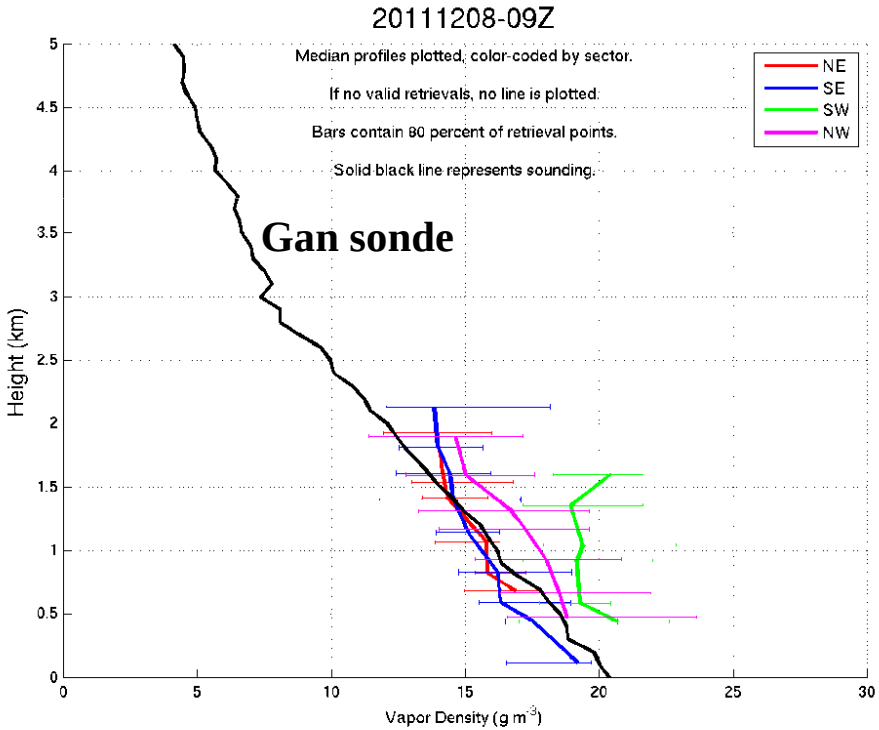
Thank You
Questions?
Comments?

Humidity Profiles Example

P3 Dropsondes near S-PolKa



Dual-wavelength humidity profiles



Courtesy Scott Powell, U Wash