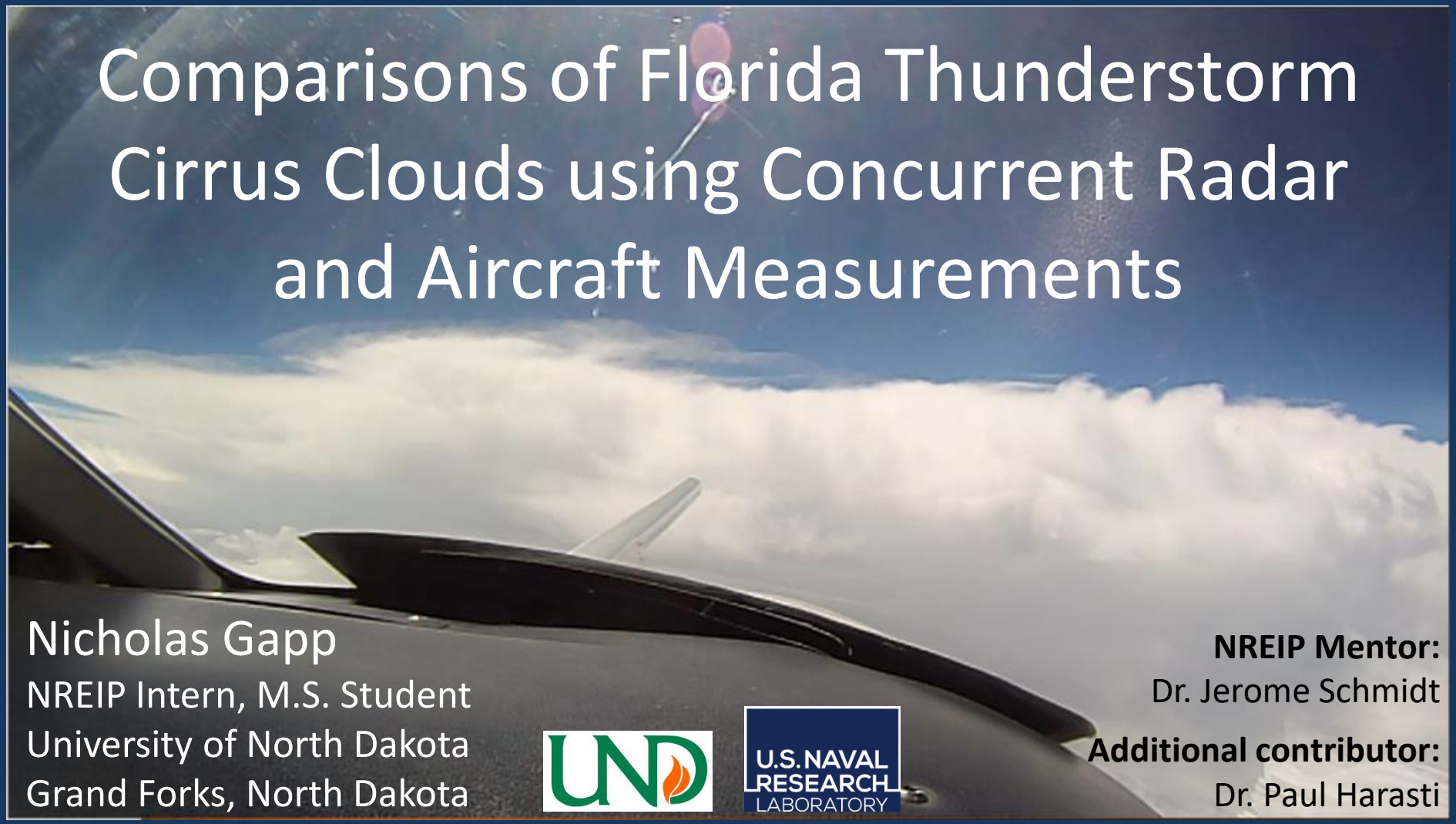
Comparisons of Florida Thunderstorm Cirrus Clouds using Concurrent Radar and Aircraft Measurements



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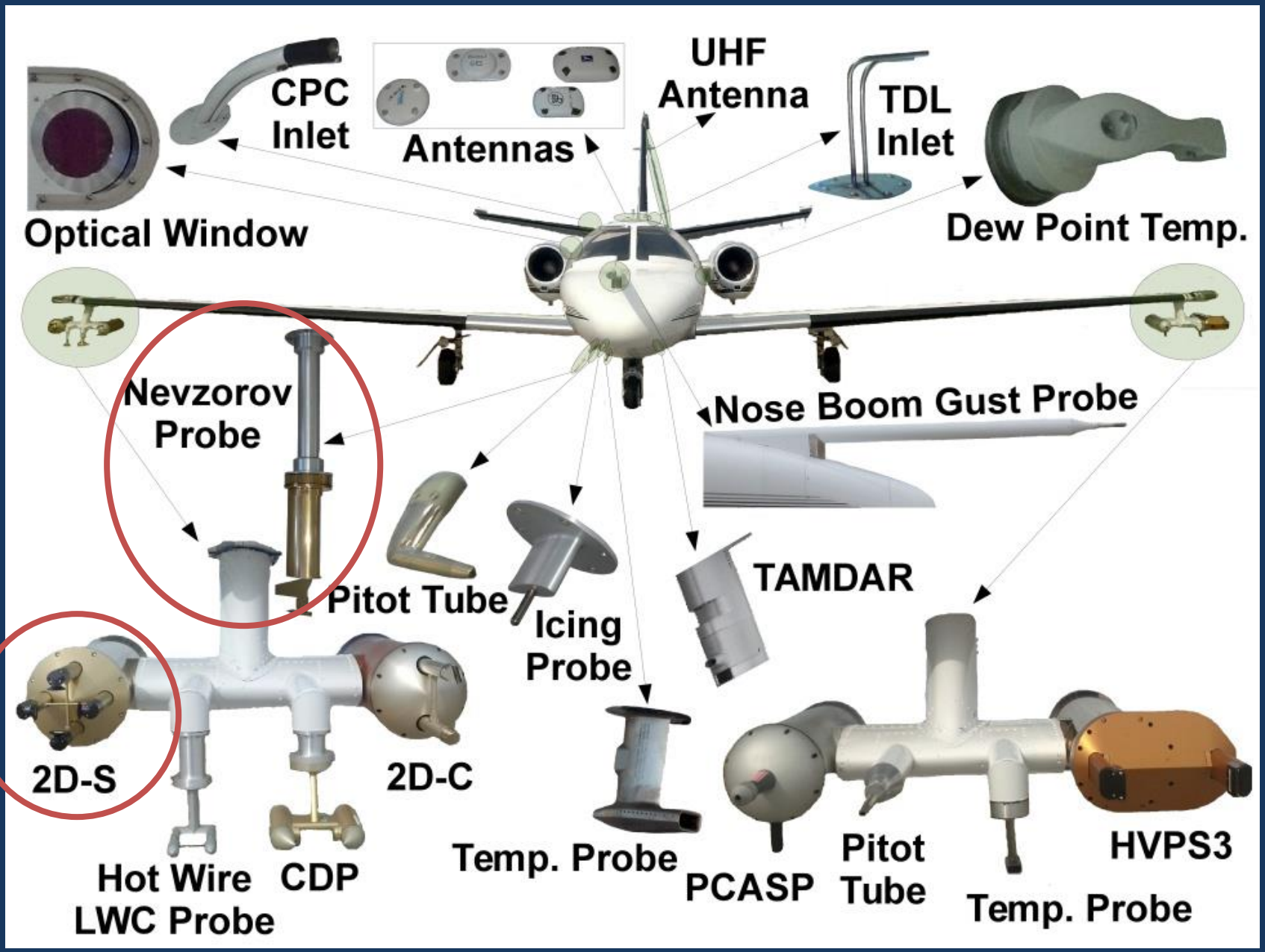
The CAPE2015 Field Experiment

- Near Cape Canaveral, Florida, from 28 July to 11 August, 2015
- Instrumentation included:
  - North Dakota's Cessna Citation II Research Aircraft
  - U.S. Navy's Mid-Course Radar (MCR)
  - Myriad of surface instruments
- Concurrent measurements between MCR and aircraft
  - Cirrus clouds in anvils from Florida thunderstorms
- Goals:
  - Derive vertical profiles of liquid/ice water content from MCR returns for weapons assessment (Z-LWC relationship)
  - Apply knowledge gained from land-based data to shipborne radars in remote areas of the world
  - Improved scientific understanding of cloud systems in both microphysical and dynamical senses to improve inputs in models

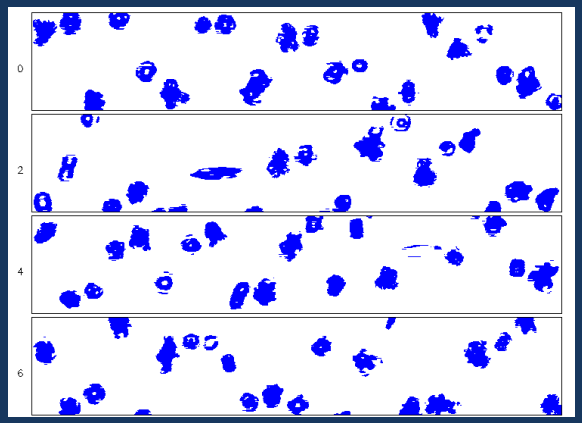
Aircraft Instrumentation



Aircraft Instrumentation

Two-Dimensional Stereographic Probe (2D-S)

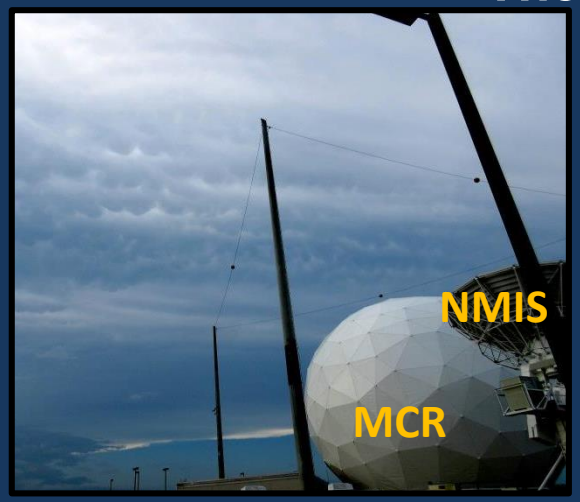
- Optical array probe with two lasers oriented perpendicular
  - 128 10-um diode lasers
  - Cloud particles shadow diodes and image is recorded
  - Data post-processing reconstructs images and sorts by diameter (29 size bins)

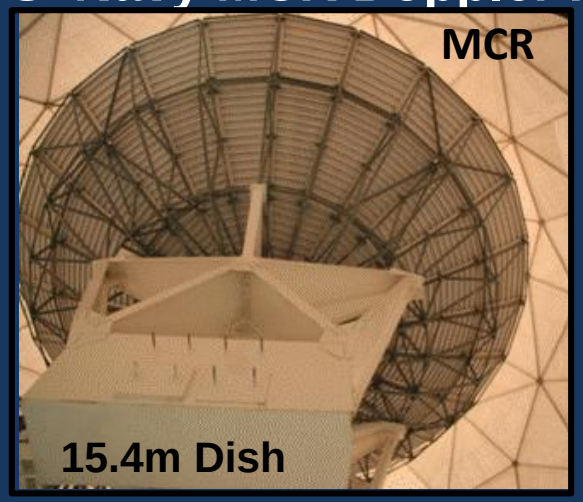


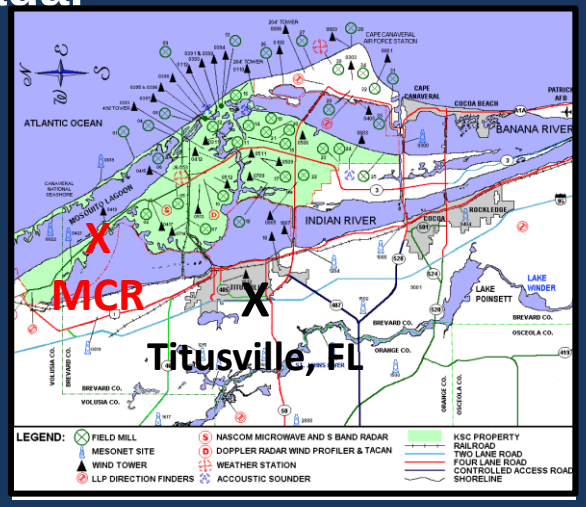
Nevzorov Water Content Probe (Nevzorov)

- Constant-temperature, hot-wire probe
  - Measures total and liquid water content with cone and wire, respectively

The U.S. Navy MCR Doppler Radar







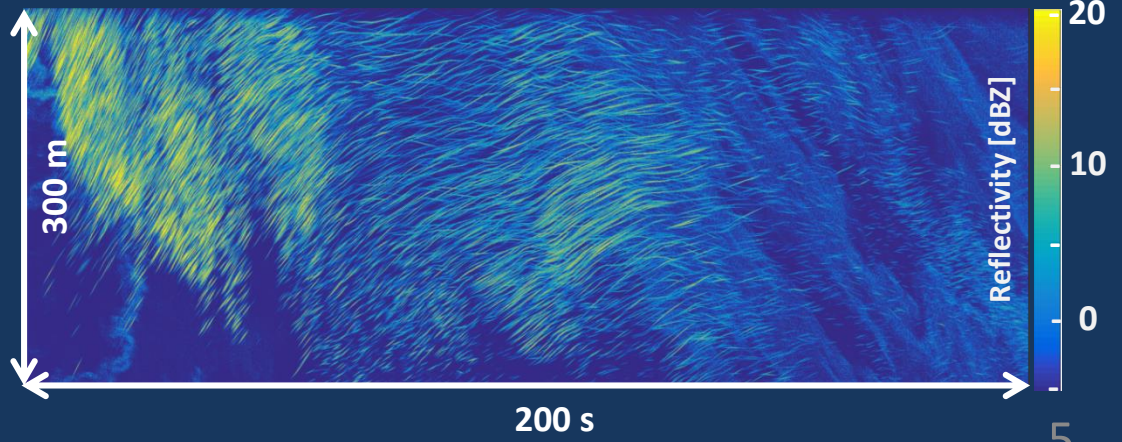
Waveform	PRF (Hz)	Frequency (GHz)	Beam Width (degrees)	Range Gates (m)	6db Range Width (m)	Band Width (MHz)	Pulse Length (µs)	Loop Gain (dB)	Peak Power (MW)	Nyquist Interval (m/s)
Narrowband	160	5.5	0.2°	11.25	~ 37	7.45	12.5	271	3	± 2.1
Wideband	160	5.65	0.2°	0.146	~ 0.5	500	12.5	271	3	± 2.1

Primary Features:

- C-Band dual polarization radar
- 0.2° Beam Width & 3 MW peak power
- Real-time Satellite & Aircraft tracking

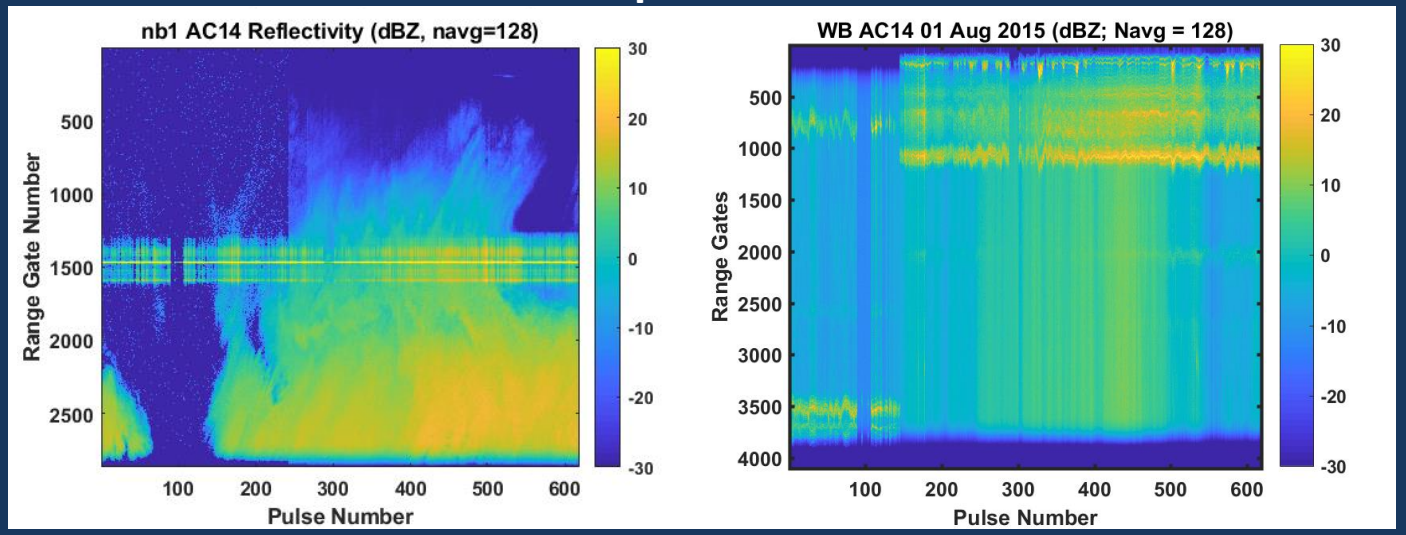
- Two primary wave forms:
  - Narrowband: 37m range resolution
    Two 75km range windows
  - Wideband: 0.5m range resolution
    Two 400m range windows

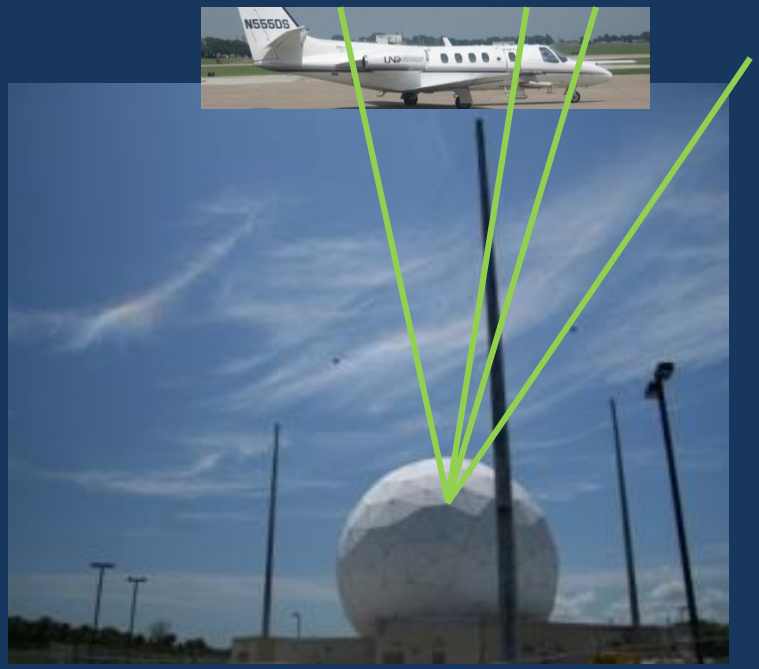
The MCR wideband reflectivity provides detailed cloud structure



Methodology

Option 2





- Two co-location options:
  - MCR operates in vertical stare and wait for aircraft to cross into beam (option 1)
  - Track the aircraft through the sky (option 2)
    - Never been done before
- Use microphysical measurements to get LWC and derive Z, compare Z to MCR, get Z-LWC relationship, then derive LWC from MCR Z
- Only discuss tracking results (option 2)

Methodology

- Derivation of in-situ radar reflectivity
  - Total particle volume V_{2DS} per second from 2D-S bin diameter D_n and particle concentration per size bin N_n

$$V_{2DS} = \sum_n \frac{\pi}{6} N_n {D_n}^3 \quad (1)$$

    - Assumes spherical particles
  - Effective total ice particle density ρ_{part} from Nevzorov particle mass m_{Nev}

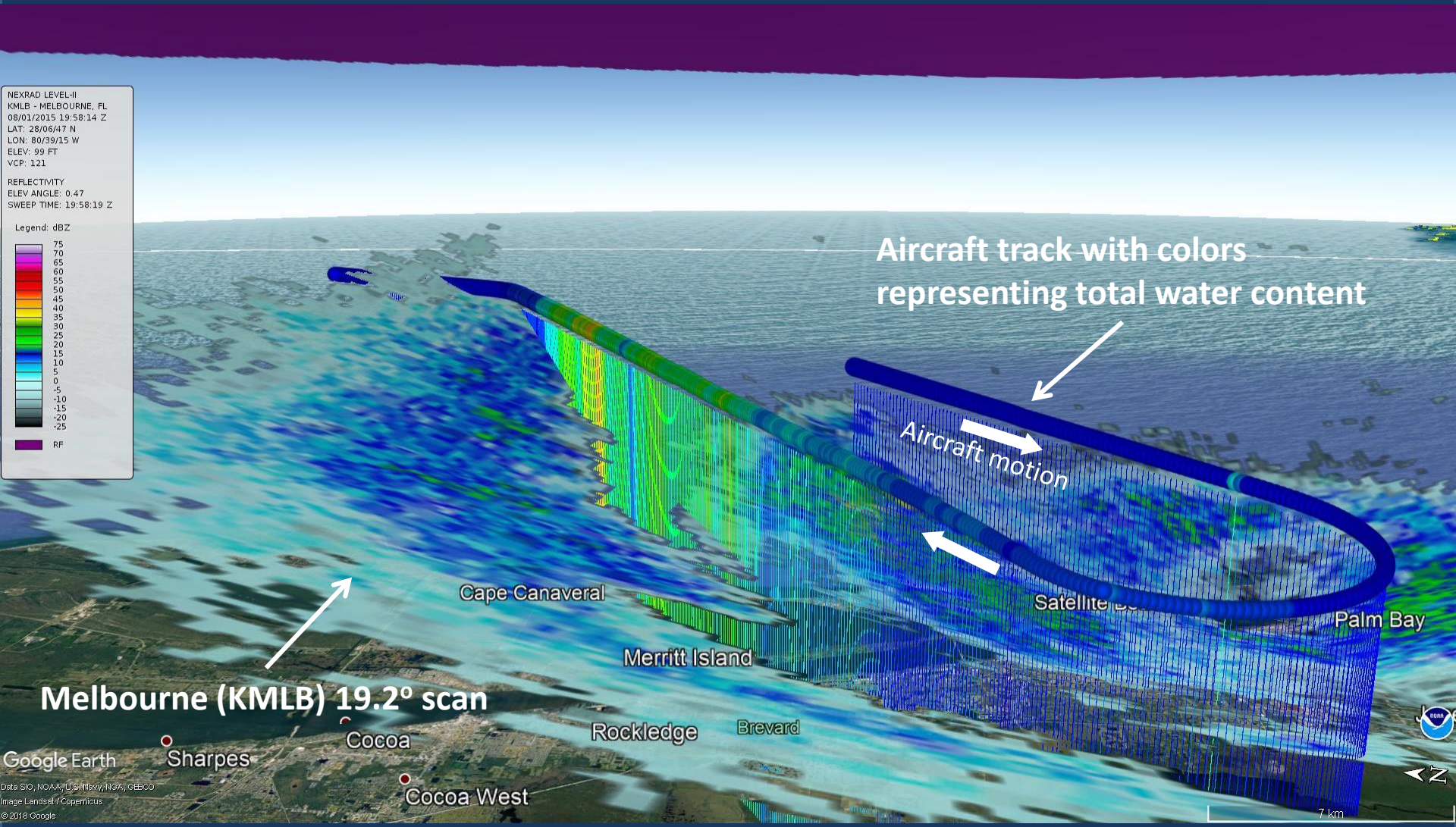
$$\rho_{part} = m_{Nev}/V_{2DS} \quad (2)$$

  - Effective liquid particle size (LED) per volume of 2D-S size bin V_n and density of water ρ_w

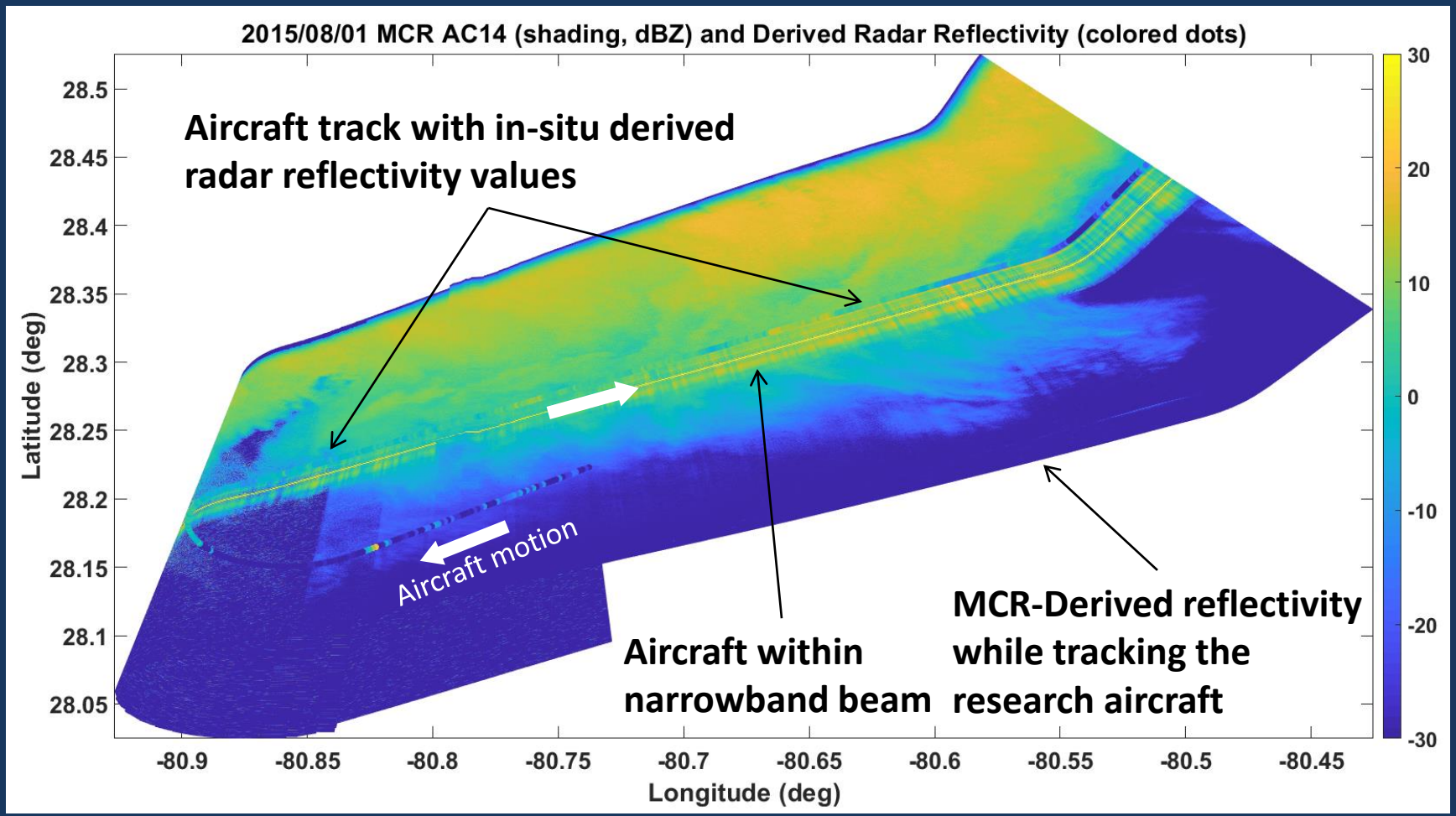
$$LED = \sqrt[3]{6V_n\rho_{part}/\pi\rho_w} \quad (3)$$

    - Assumes mass of ice equals mass of water
  - Dielectric factor of ice $|K|_i^2 = 0.208$ (Smith, 1984)
- Comparison between the MCR and aircraft data sets
  - Narrowband and wideband to aircraft

Aircraft Tracking Comparisons



Aircraft Tracking Comparisons

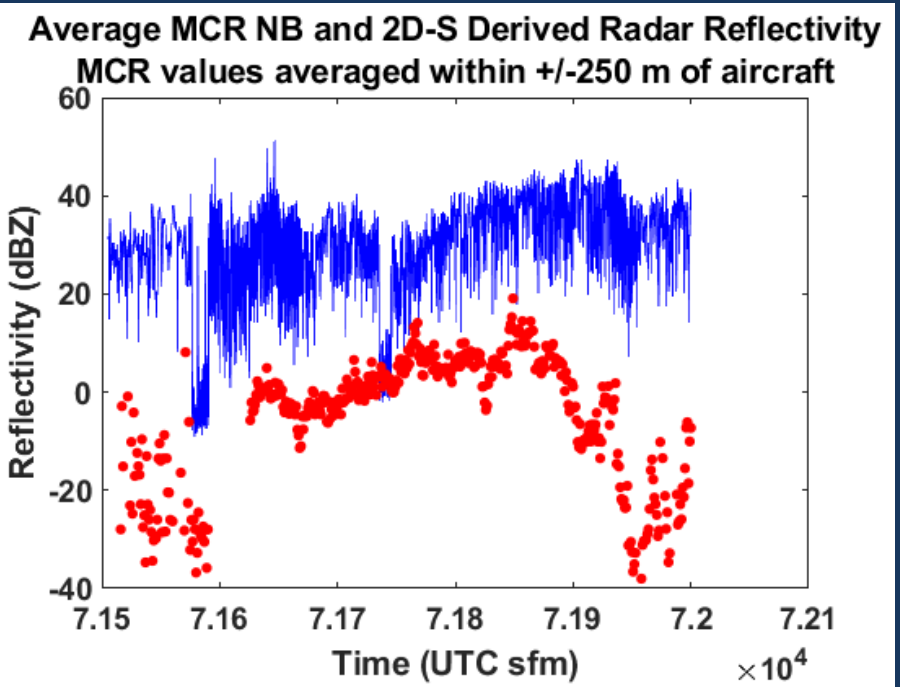


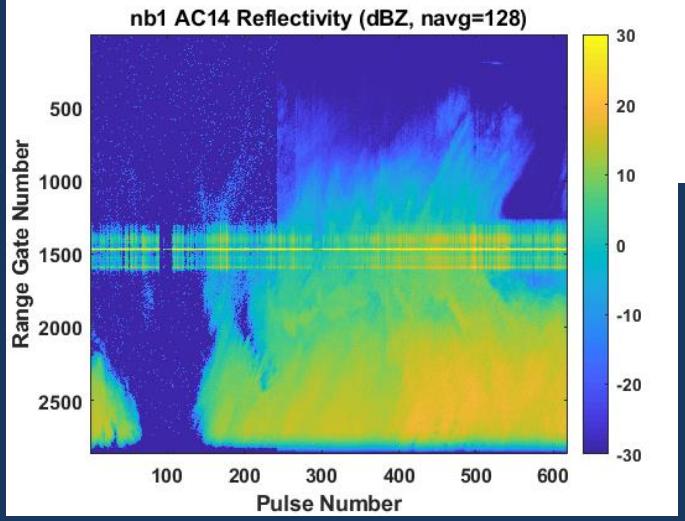
Takeaways:

- ❑ First successful demonstration that the MCR radar can track research aircraft in real-time
- ❑ Comparisons of the along-track reflectivity derived from the in-situ cloud microphysics show promising agreement with the radar-derived reflectivity values
- ❑ Such comparisons will allow Z-LWC relationships to be derived for use in remote U.S. Navy Weapon Performance Evaluations

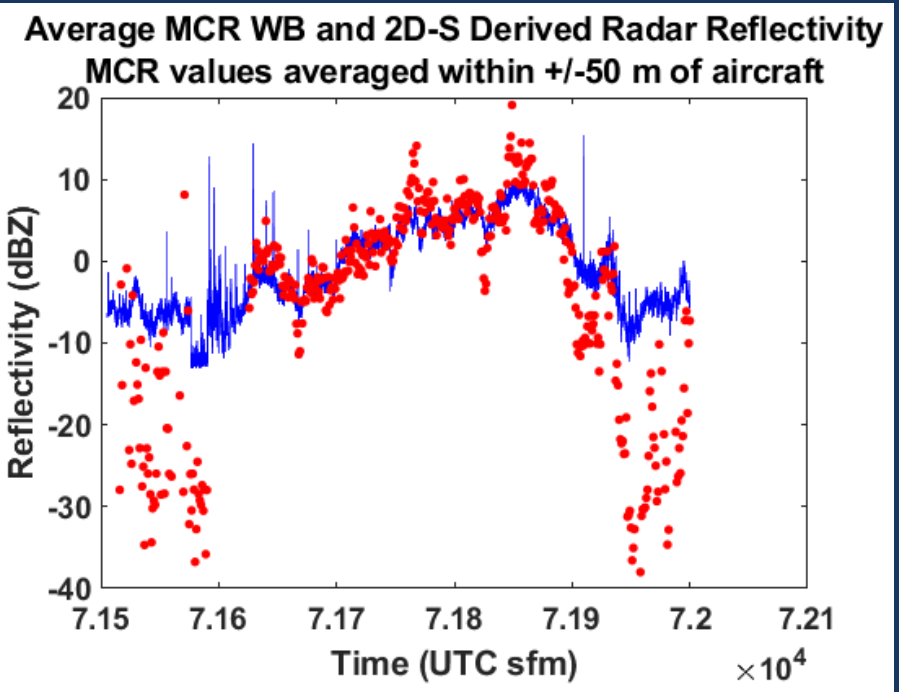
Aircraft Tracking Comparisons

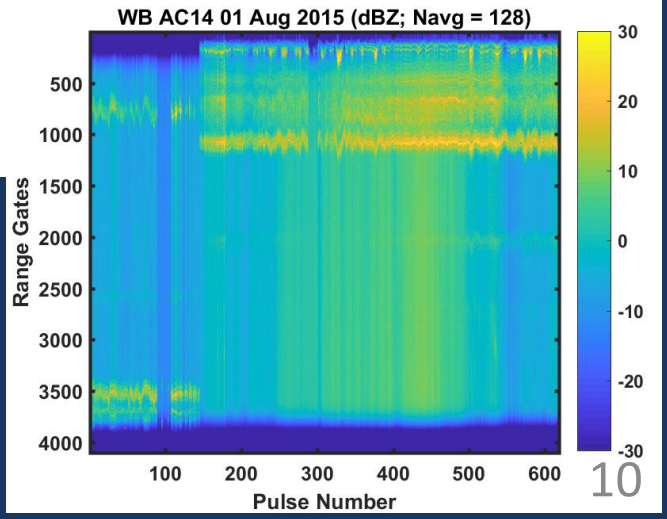
Narrowband





Wideband





Derived Reflectivity

MCR Reflectivity

Conclusions and Future Work

- The MCR and aircraft data can be co-located using both MCR scanning strategies
  - *Future work*: compare vertical stare data across length scale rather than time scale
  - *Future work*: reduce ~900 m separation between MCR and aircraft during tracking scans
- The MCR and aircraft data agree with each other
  - *Future work*: calculate uncertainties in both data sets
  - *Future work*: Z-LWC relationship
- The aircraft data is highly variable compared to the MCR data
  - *Future work*: determine a reasonable out-of-cloud threshold to apply to aircraft data to reduce measurement variability

Acknowledgements and References

- Thesis Committee
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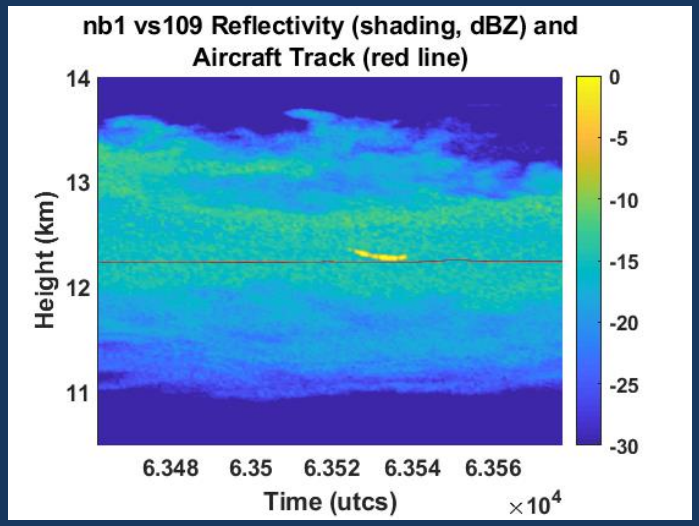
  - Peter Jones, L3 Interstate Electronics Corp.
  - NREIP
  - NRL

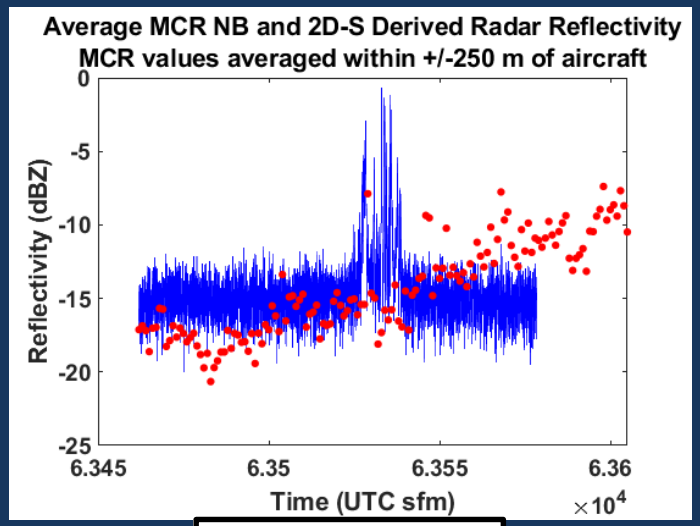
- References

  - Smith, P. L., 1984: Equivalent radar reflectivity factors for snow and ice particles. J. Climate Appl. Meteor., 23, 1258-1260, doi: 10.1175/1520-0450(1984)023%3C1258:ERRFFS%3E2.0.CO;2.

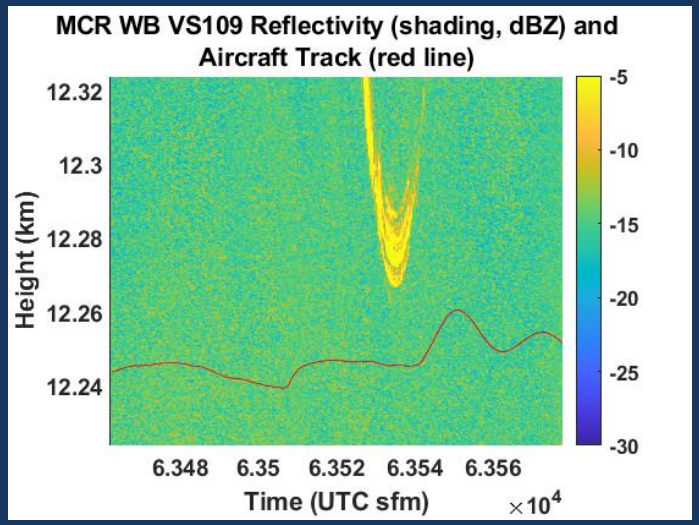
Vertical Stare Comparisons

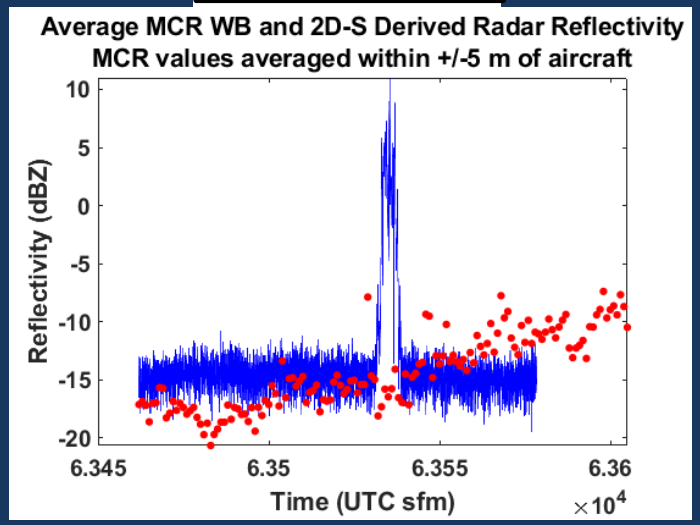
Narrowband



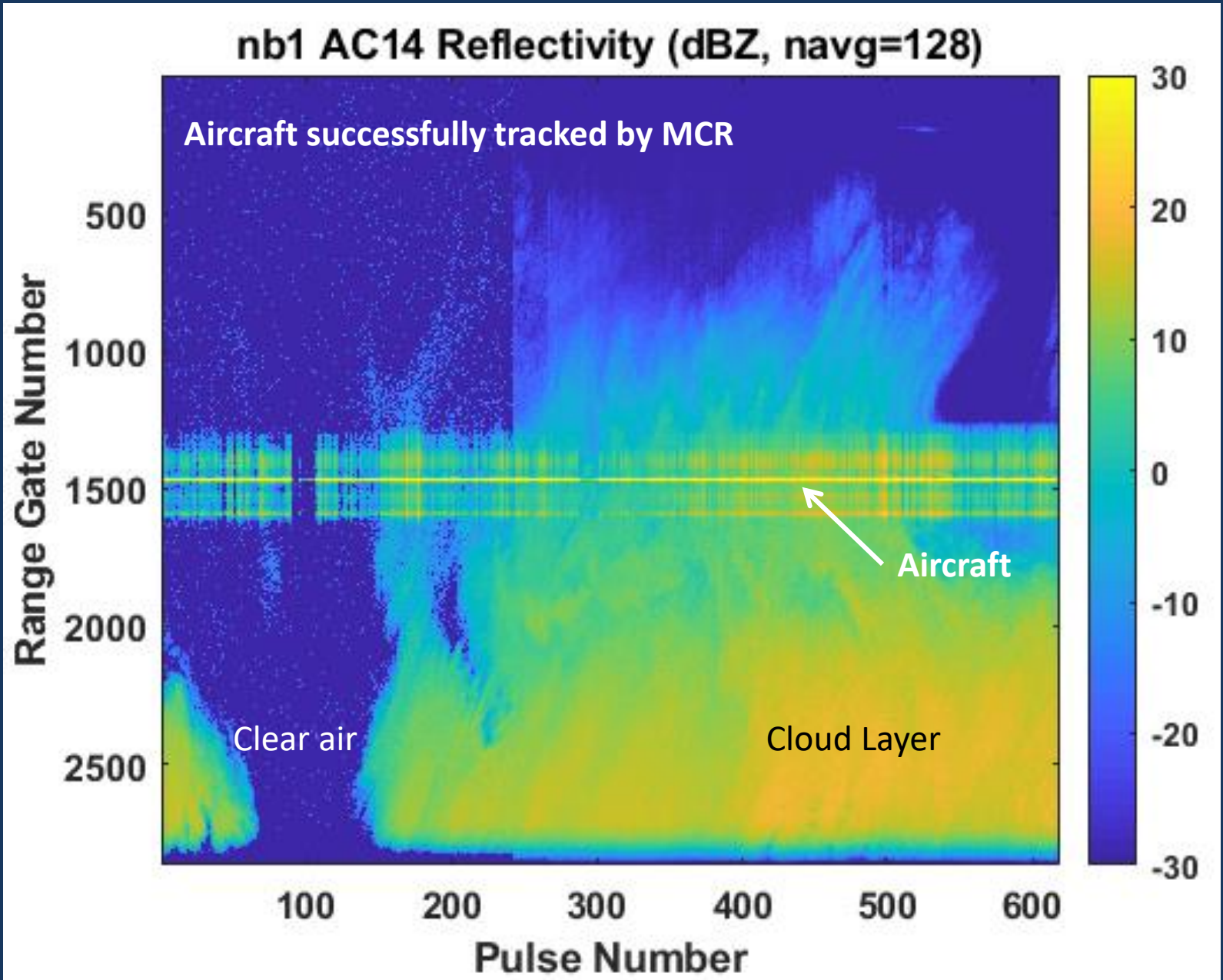


Wideband



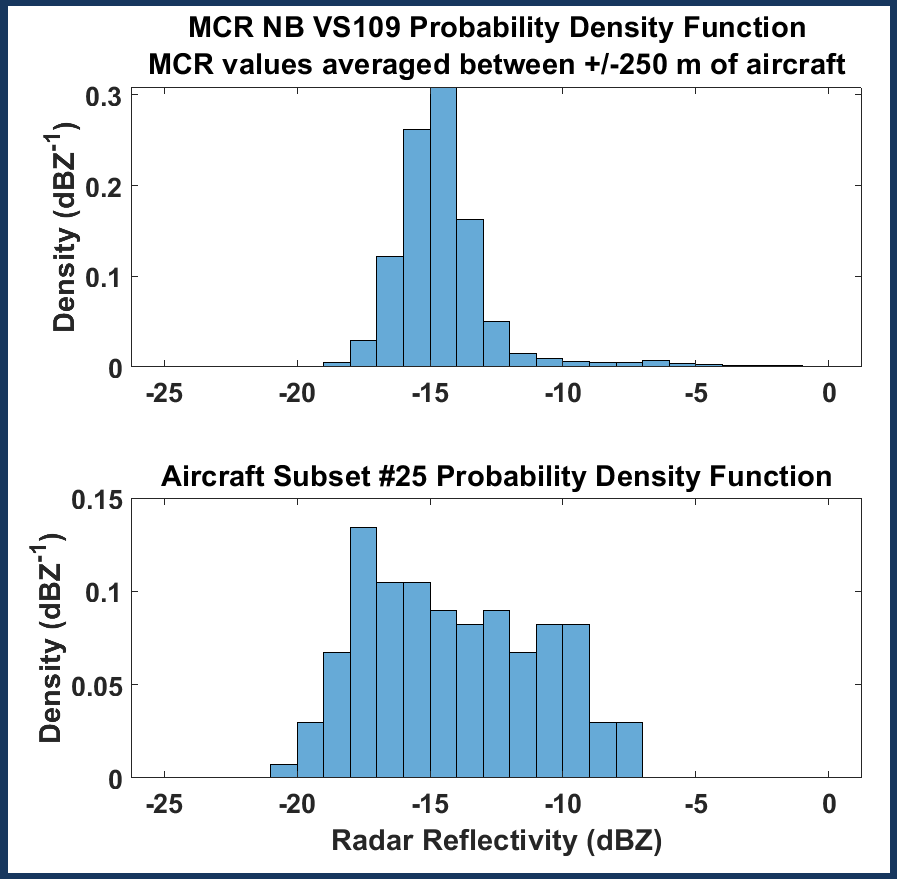


Aircraft Tracking Comparisons

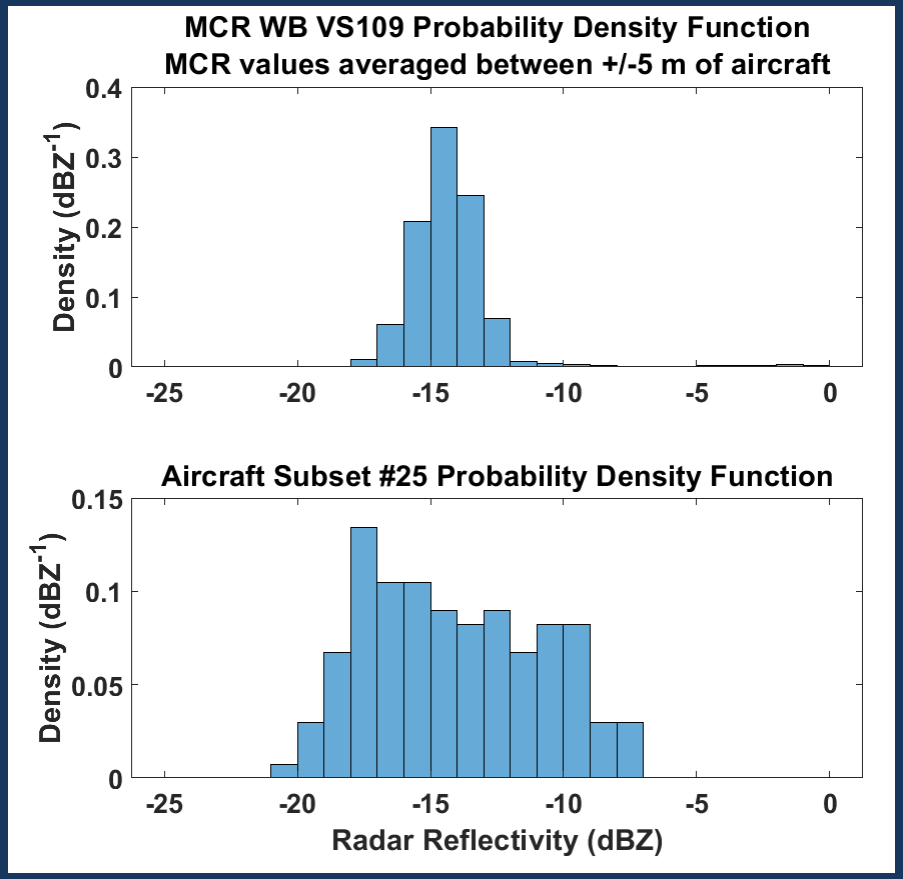


Vertical Stare Comparisons

Narrowband



Wideband



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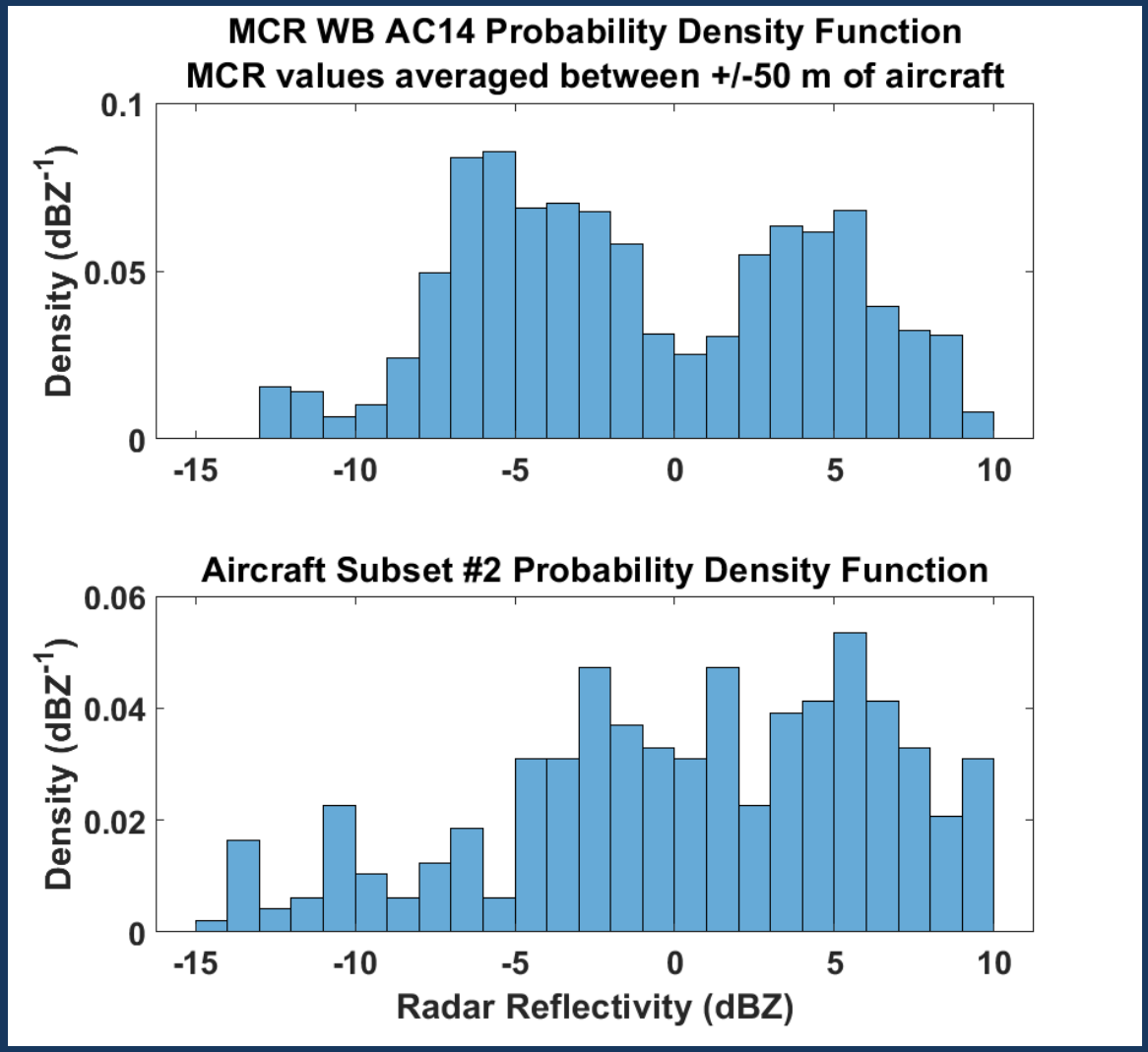
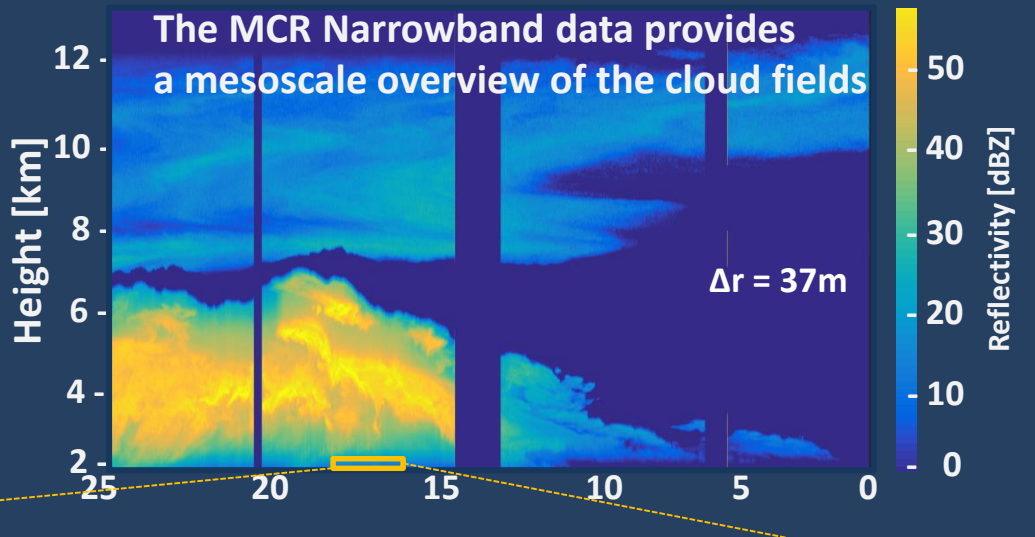
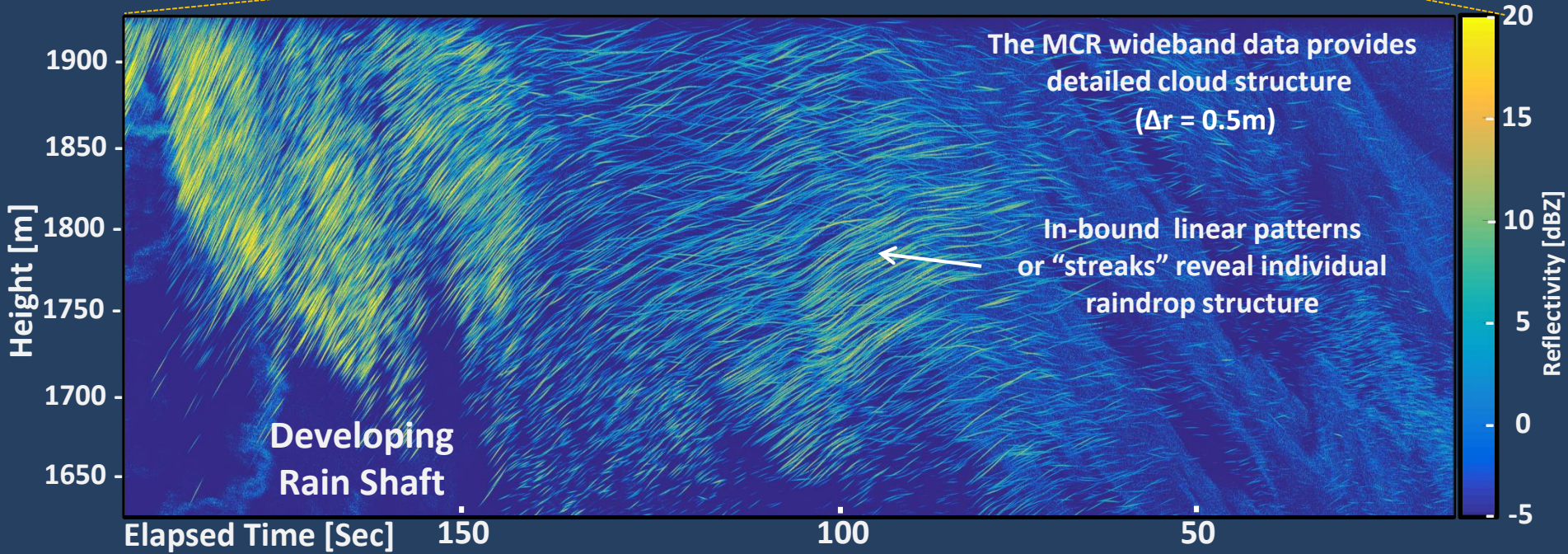


The U.S. Navy's MCR Radar

Photo Courtesy of Jason Nachamkin





Aircraft Tracking Comparisons