AN AIRBORNE NARROW BEAM SIDE SCANNING G-BAND RADIOMETER

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2017 WMA Annual Meeting

Boise, ID

Aircraft Icing Detection and Avoidance

- US Navy Phase II SBIR Contract
- Aircraft Multichannel 170-183 GHz & Complementary Observations
- Cloud Seeding Aircraft provides a unique Cloud Liquid Observatory

Multi-Sensor Icing Flight Testing & Validation Study

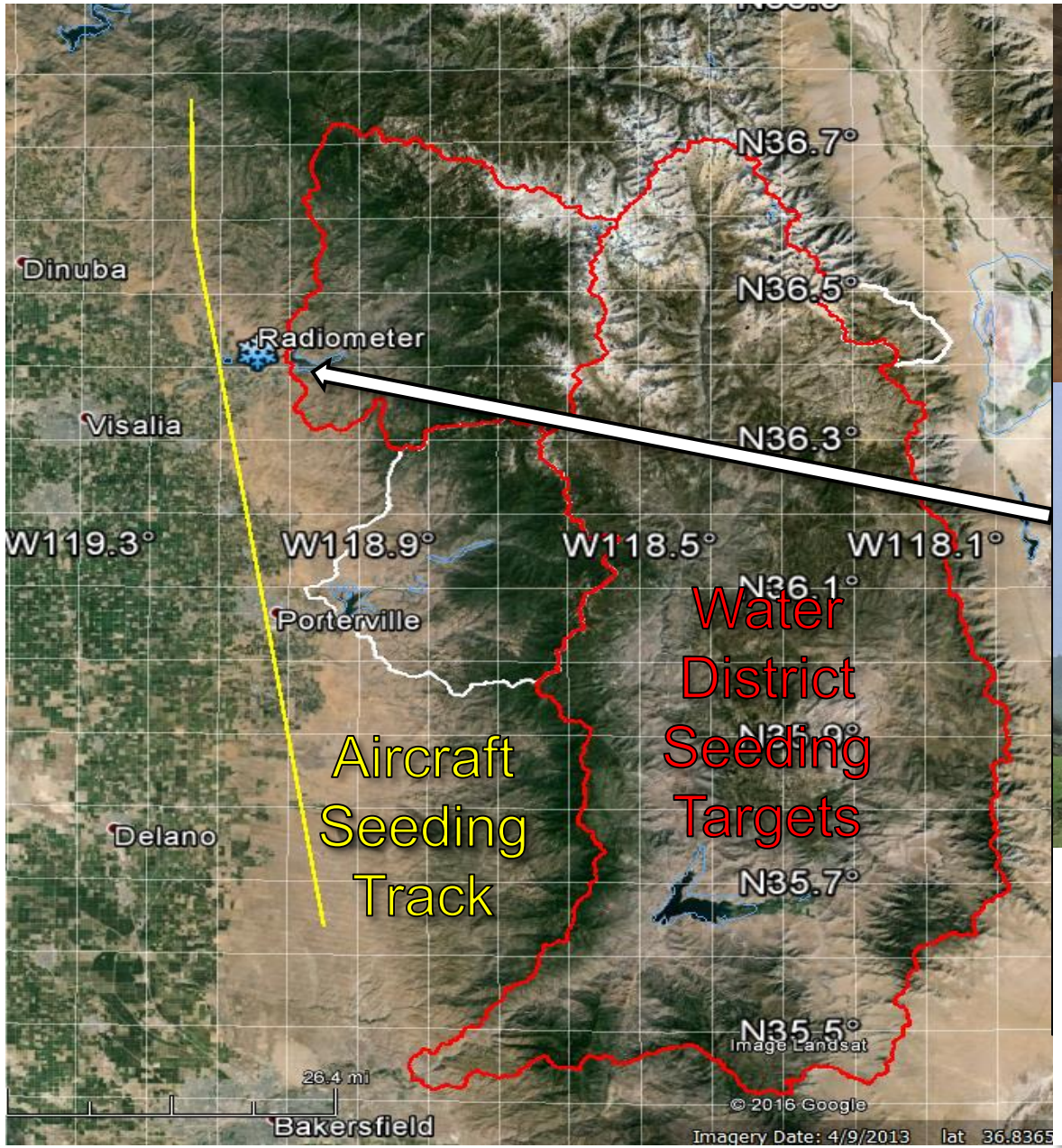
- Part of an ongoing Winter Seeding Program
- Incorporates several cutting edge airborne and surface-based remote sensing systems
- Goals
  - Improve icing risk detection and forecasting
  - Improve real-time cloud seeding opportunity recognition

Airborne Seeding Opportunity Recognition

- Scanning require to improve SLW detection (vertical and horizontal location and extent – area/volume vs ribbon)
- Pilots not extensively trained in cloud physics, meteorology and seeding strategies
- Time required to recognize opportunities can be excessive or missed altogether as a result of the lack of experience
- Need for real-time onboard guidance system
- Radiometric methods offer advanced capability over aircraft mounted sensors
- Smaller size and potentially lower unit cost of next gen G band radiometers attractive

SLW Detection via Radiometry

- Radiometer Profilers at X, K, V, and G-Band
- Atmospheric Profiling through **multivariate analysis**
  - Large datasets (decades) of **zenith-pointing** radiometer data are used to train neural net or other lookup table/machine learning algorithms
  - Trained algorithm generates atmospheric profiles, **compares against upper air (sonde/modeled) data with high accuracy**
  - Well established technique, in use by **commercial, government, and scientific teams** for years
- Requirement for Airborne SLW Detection: Off-Zenith SLW Detection capability
  - Requires **airborne measurements** and development
  - Requires **truth data** for **validation and algorithm development (lidar/sounding)**
  - Result: **significant high resolution flight** data, in a variety of relevant environments is expected



Radiometer and Cross-Pol Lidar at MacKay Point for thermodynamic and particle measurements downwind of aircraft seed track

Radiometer and cross-pol lidar at MacKay Point for thermodynamic and particle measurements along aircraft seed track

Cloud Seeding Aircraft/Test Bed

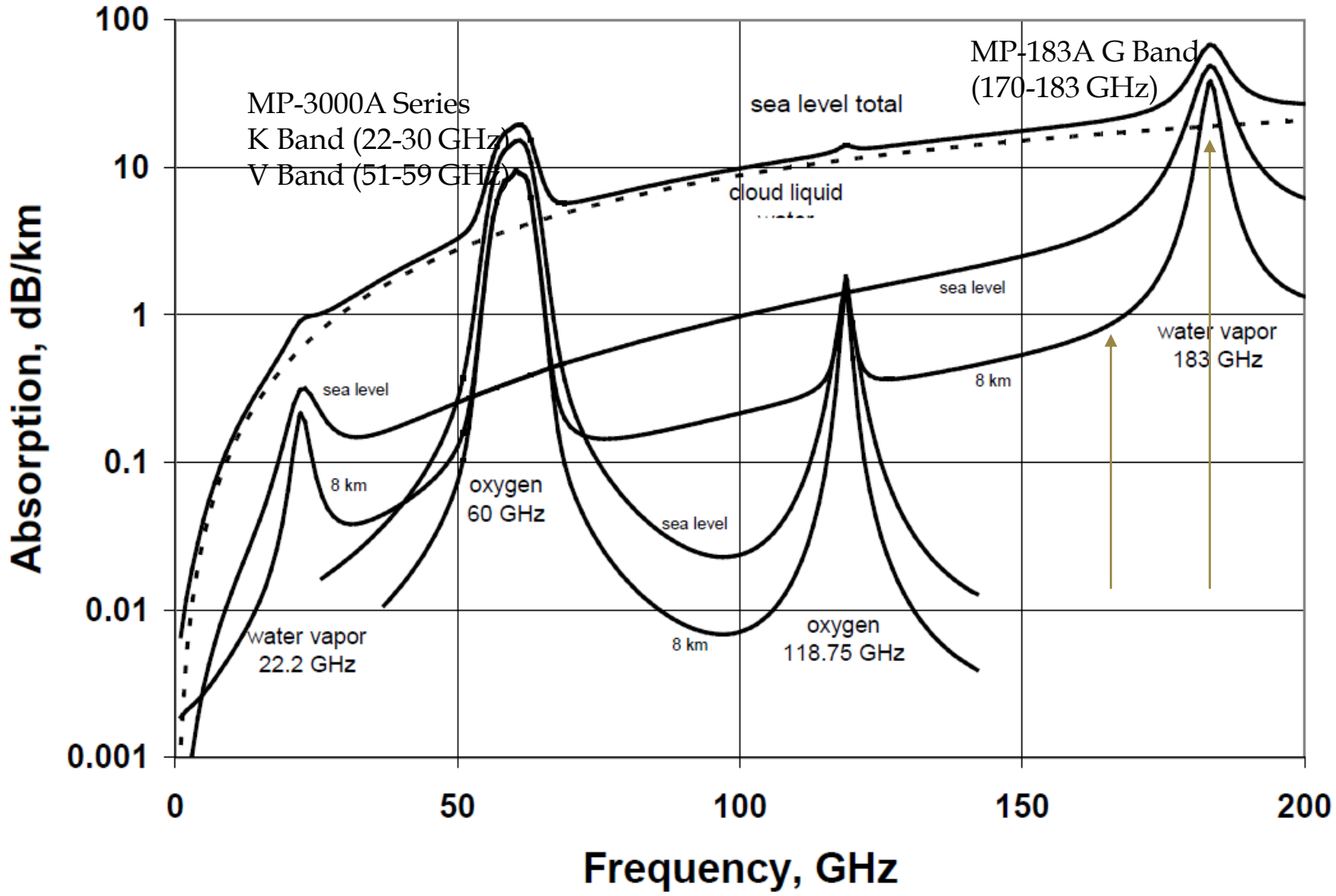
Configuration:

- Low Density Linear Polyethylene (low loss) Viewport
- G-Band Radiometer
- Hot Wire Liquid Water Sensor
- Cloud Droplet Size Distribution Probe
- Nose and Wing Video Cameras
- Ejectable and End-Burning Flares

Microwave Radiometer (G-Band)

- Multiple 170-183 GHz Channels
- Liquid Water Sensor
- 1 Degree Beamwidth
- 25 m to >50 km Clear Air Effective Range

Liquid and Vapor Spectra < 200 GHz



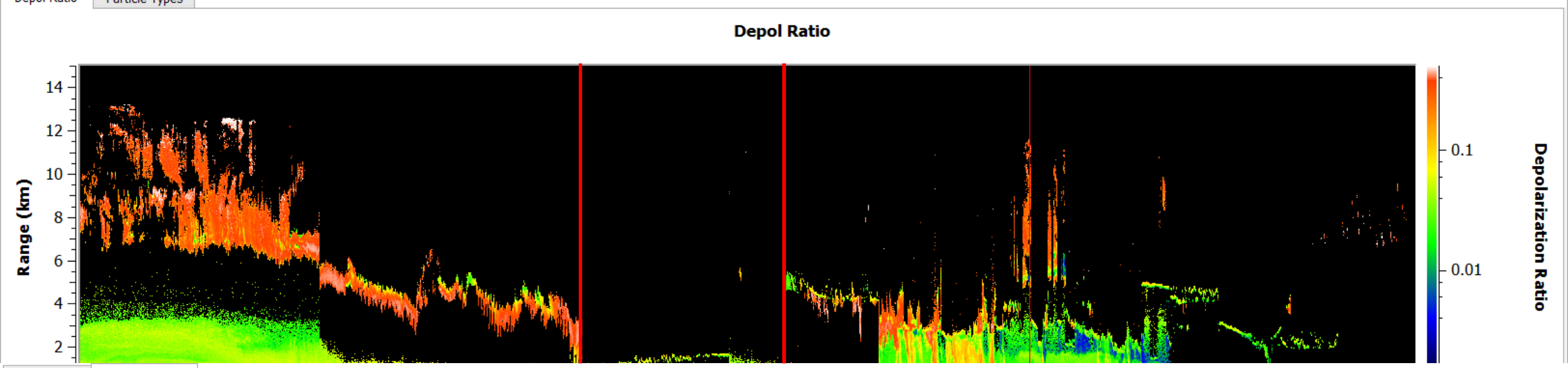
Mobile Microwave Profiler/ Cross Polarization Lidar

- Multiple K (20-30 GHz) & V Band (51-59 GHz) Channels
- Temperature, /Vapor & Liquid Profiler
- Complements Aircraft Observations

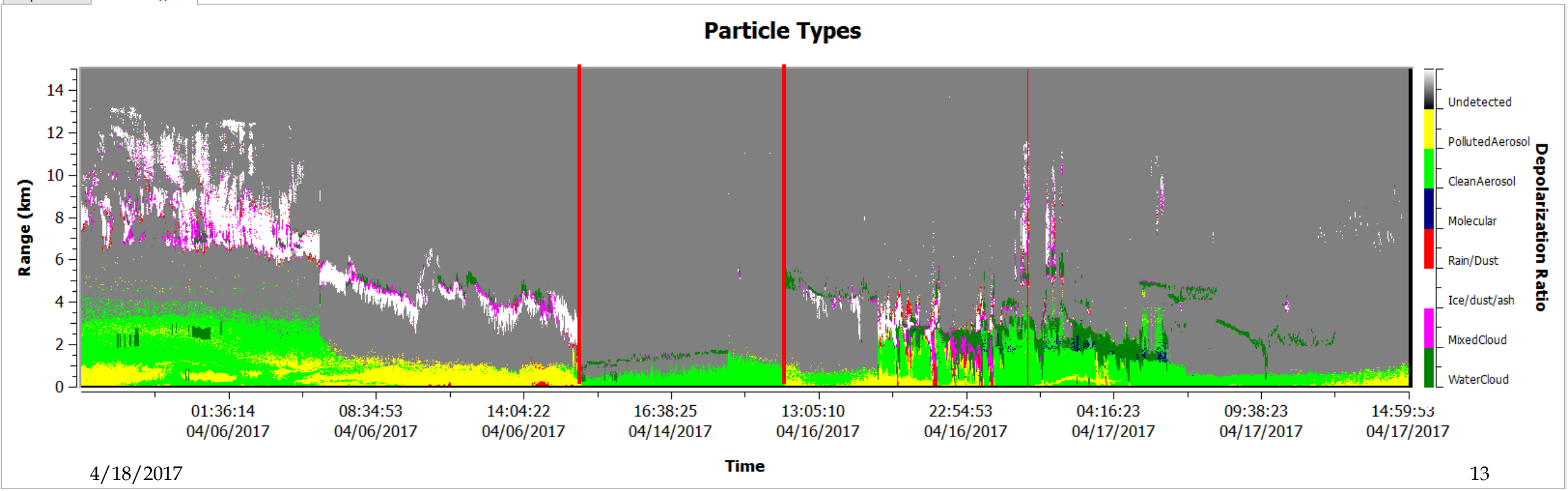
Cross-Polarization Lidar

Sigma Space MiniMPL

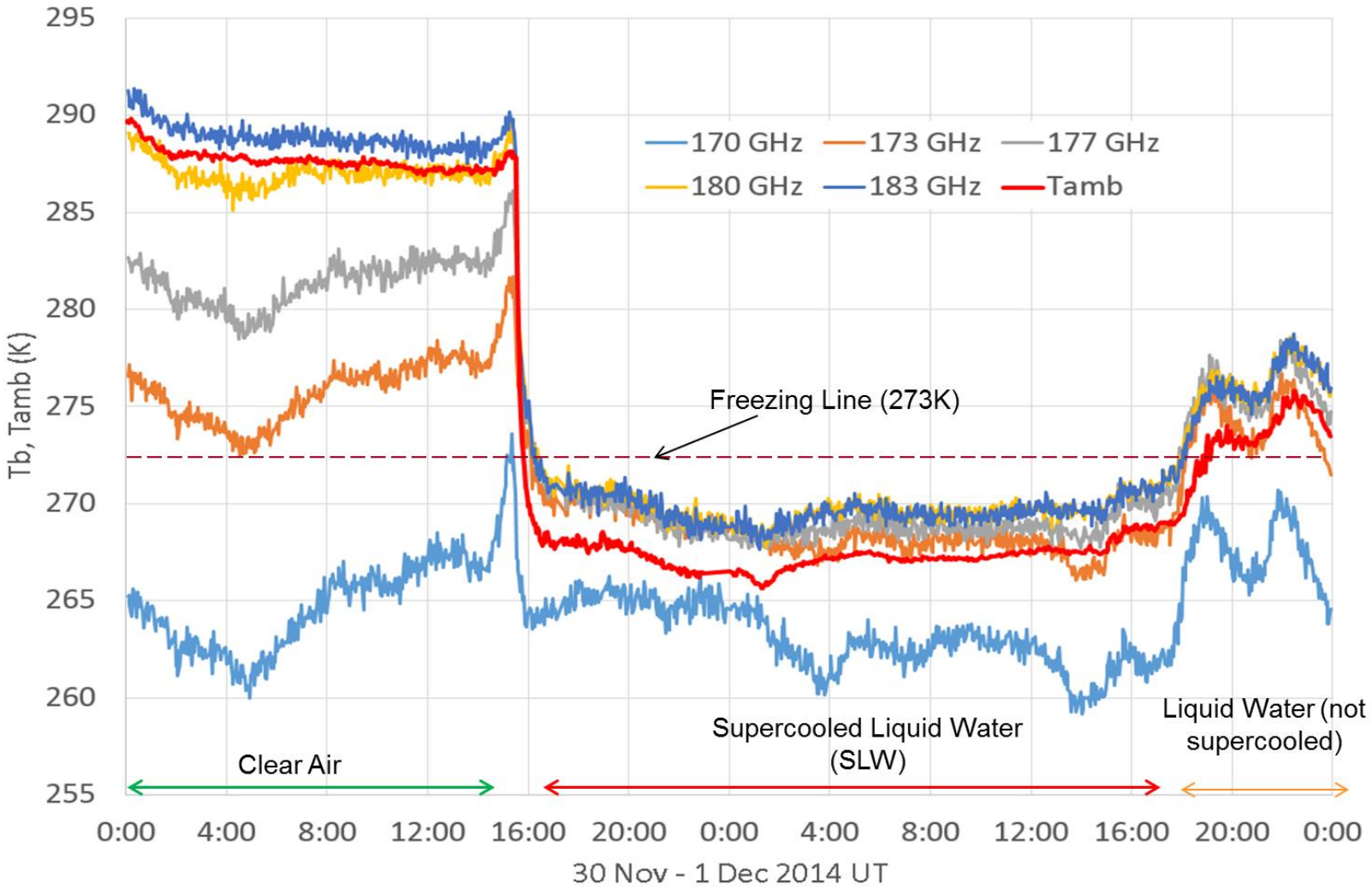
- Particle Range, Density & Type
- Optimize seeding productivity
- Ground or Aircraft Based
- Eye friendly laser



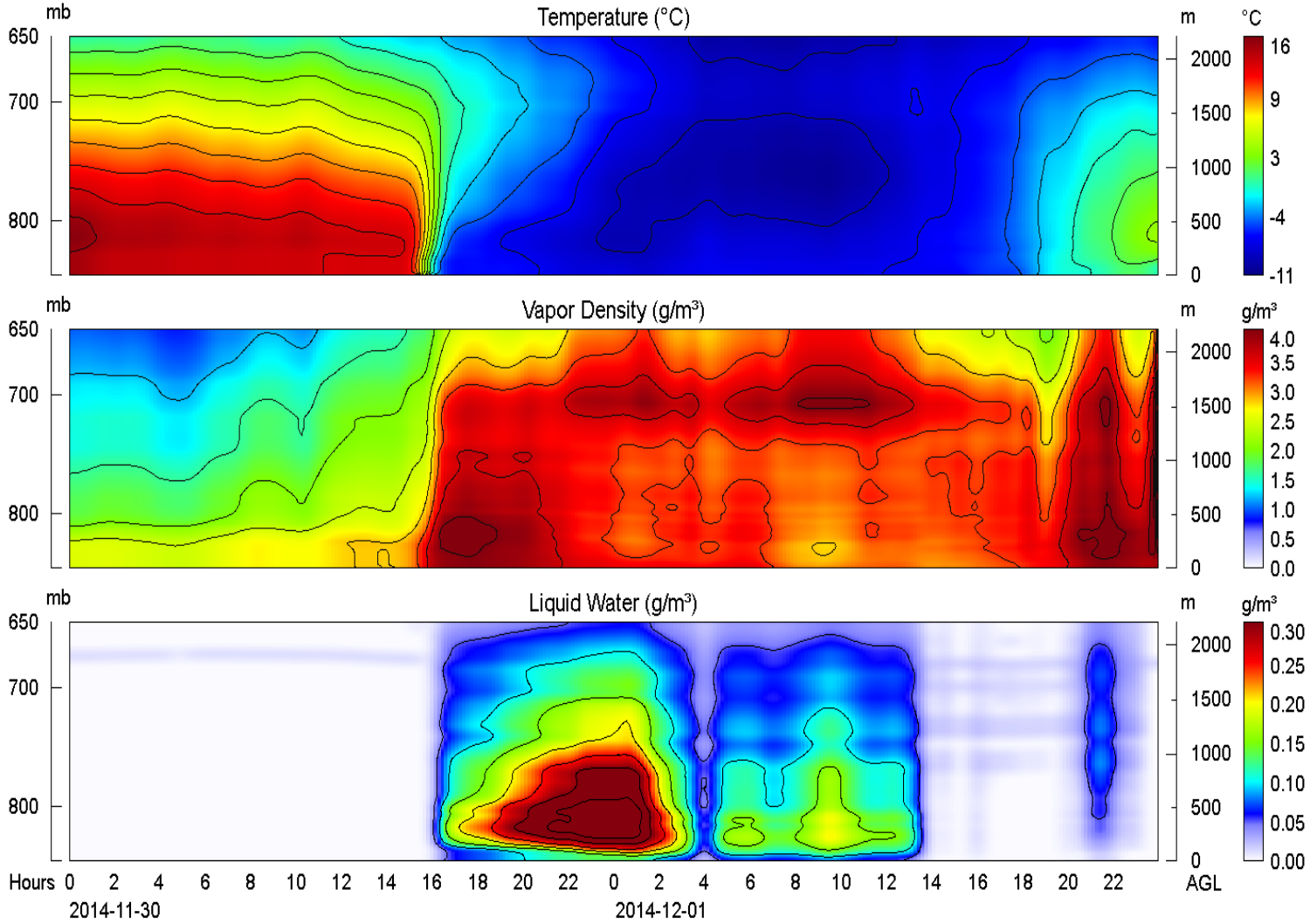
Depol Ratio | Particle Types



Horizon-pointed SLW Detection



Zenith-pointed Temp, Vapor, and Liquid Water Profiles

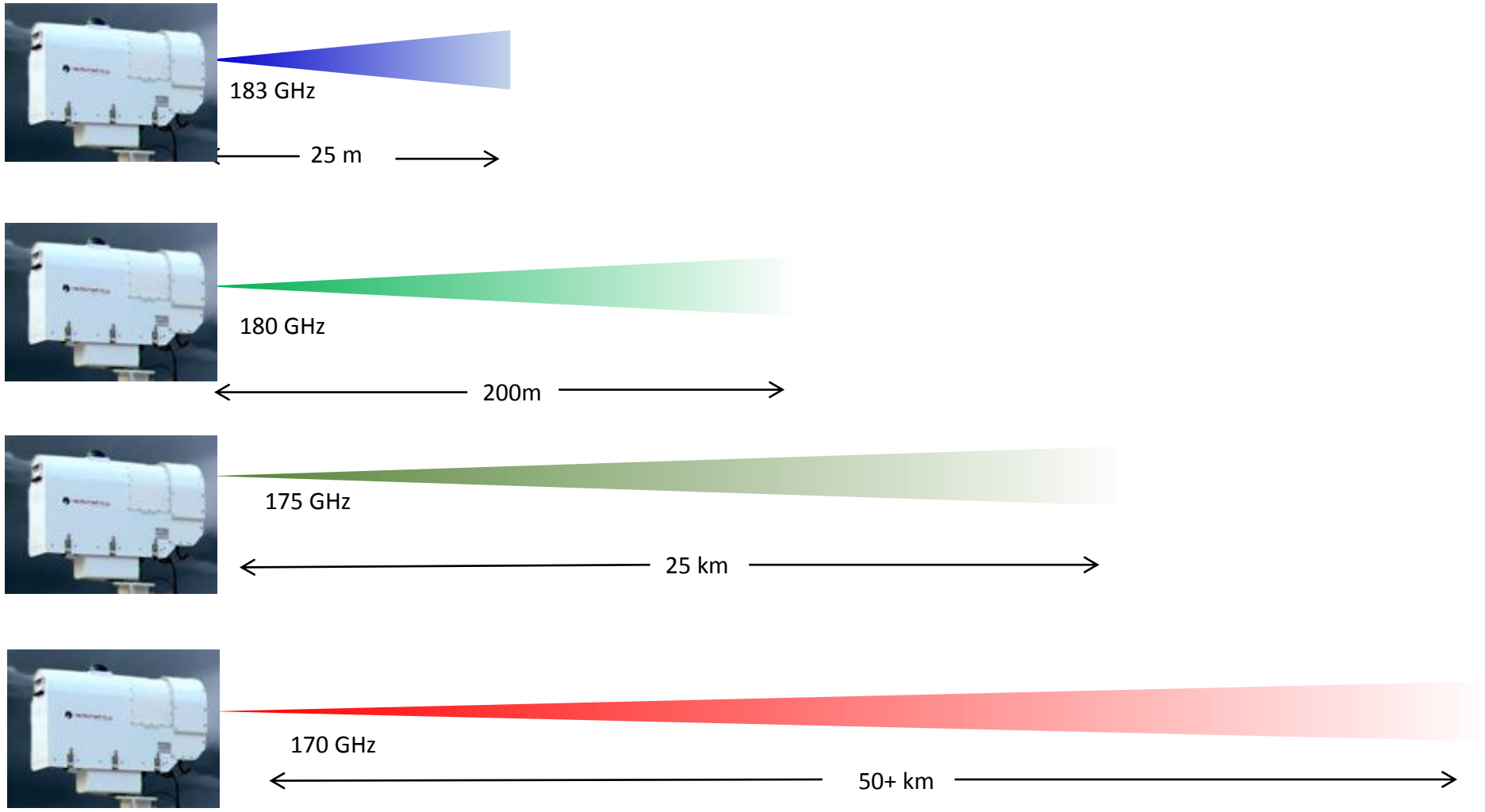


Upslope winter storm observed by a microwave profiler at Boulder

Flight Tests to Date

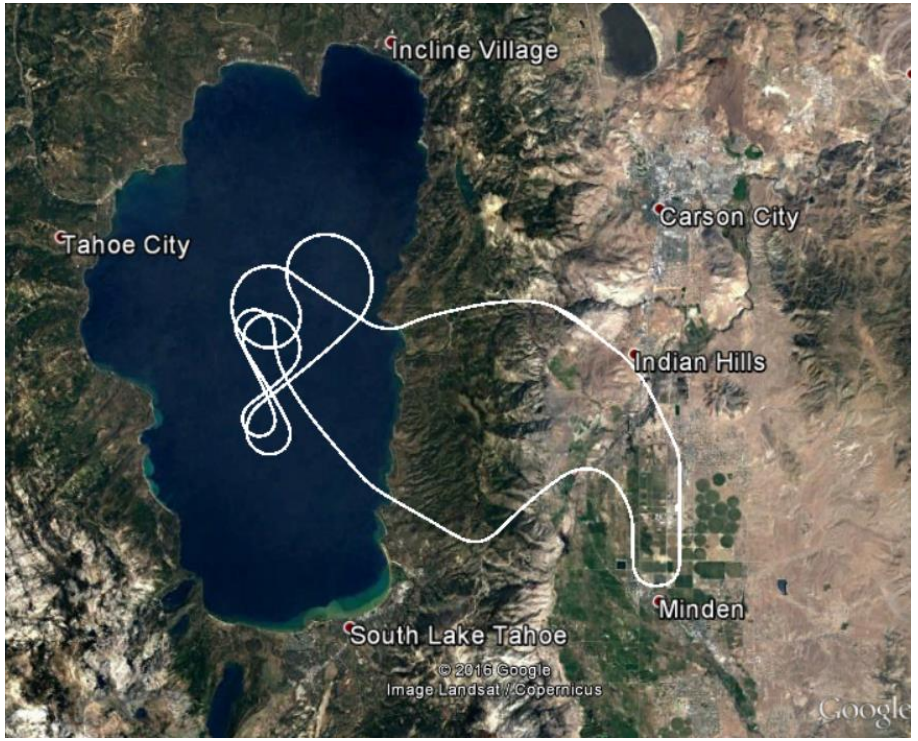
- 5 test flights
  - On going analysis of all flights.
- 2 clear air flights over Lake Tahoe
  - Established system functionality and demonstrated expected response in no wind conditions
- 1 cloud base flight
  - Conducted up and downwind of an orographic cloud that developed over the Pine Nut Range east of Minden.
  - Provides a good example of how the radiometer responses in light precipitation at cloud base and over mountain range at varying scan angle above the horizon. Scan pattern extended from 15 degree below to 30 degrees above the horizon
  - Very turbulent flight (parabolic dish/stepper motor lags under severe up and down drafts) .
- 2 IFR winter storm flights
  - One flight conducted near cloud top skimming in and out of cloud (temp +9 to -7C).
  - Shows liquid water response (climbout in-cloud leeside) to clear air response (windward side) transition on the radiometer.
  - One flight conducted in cloud with sustained light icing on track (0.05-0.1 g/m^3 , -1C to -5C, moderate precipitation and light turbulence

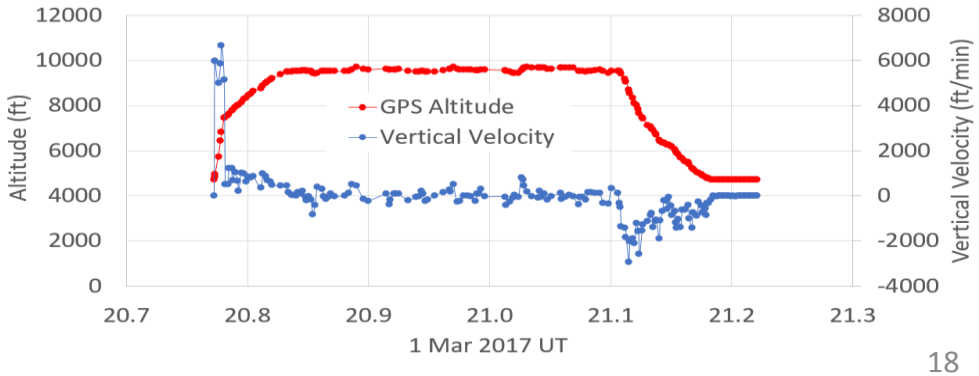
G-Band Clear-Air Operation



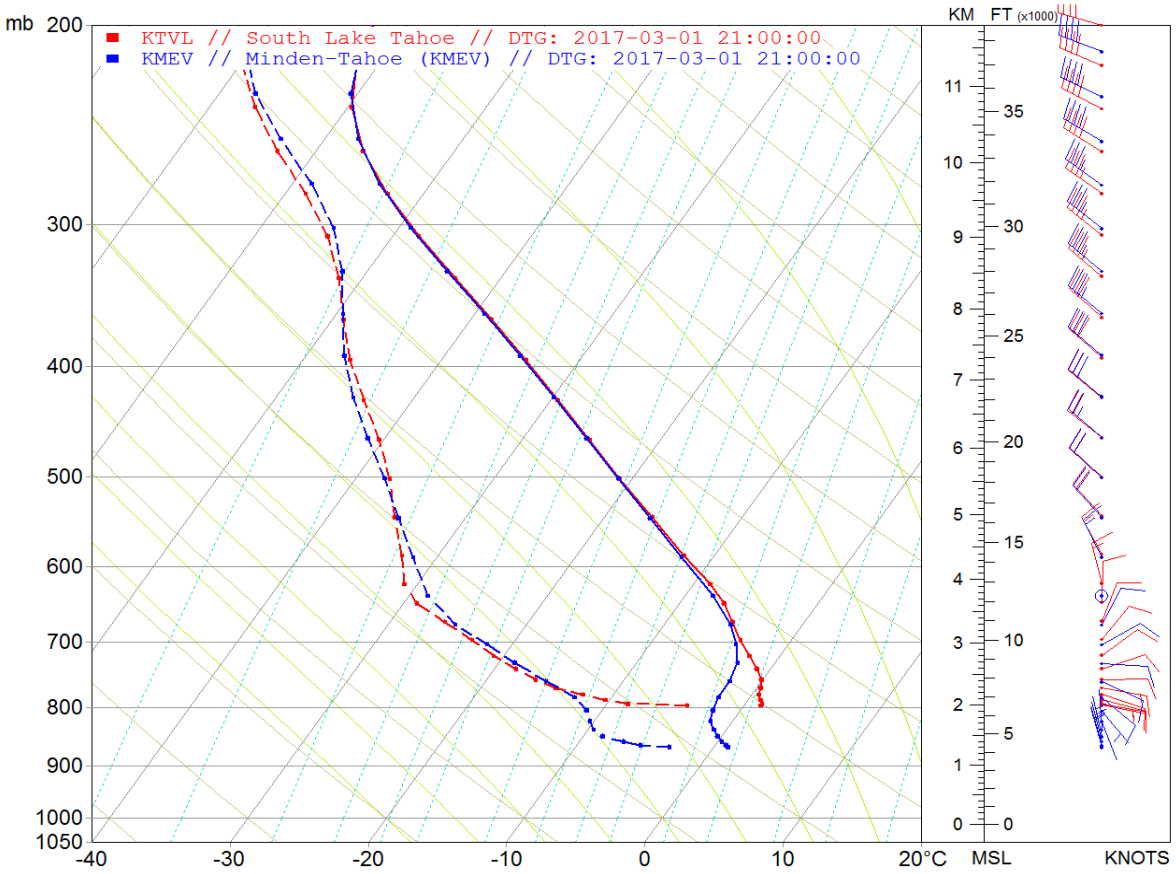
Initial Clear-Air Flight Test

- Verification of airborne radiometer operation
- March 1, 2017
  - Minden, NV - Lake Tahoe - Minden
  - Figure eight patterns over the Lake
  - Flight and measurements over water in clear, nearly isothermal air



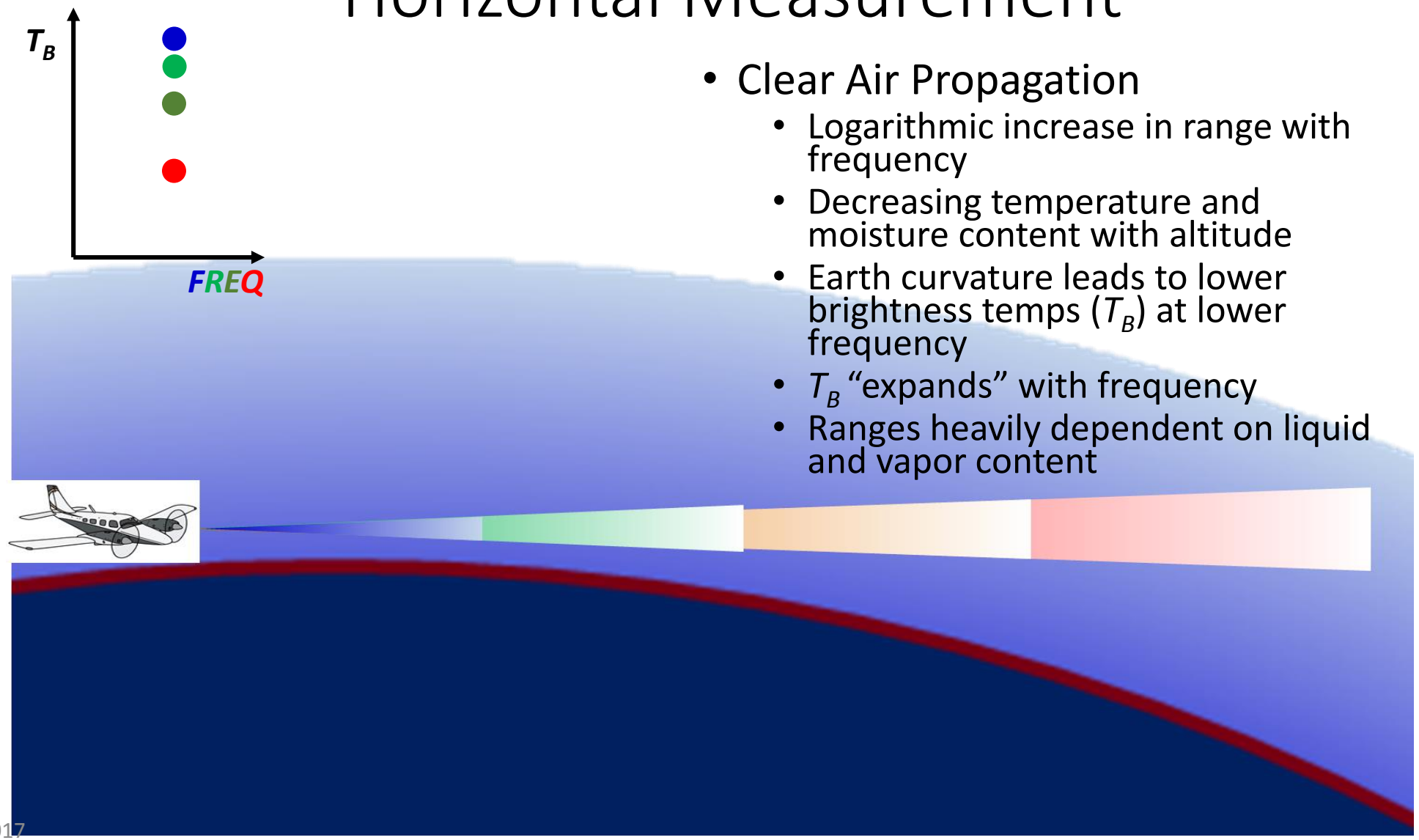


KMEV/KTVL 21Z Modeled Forecast Sounding



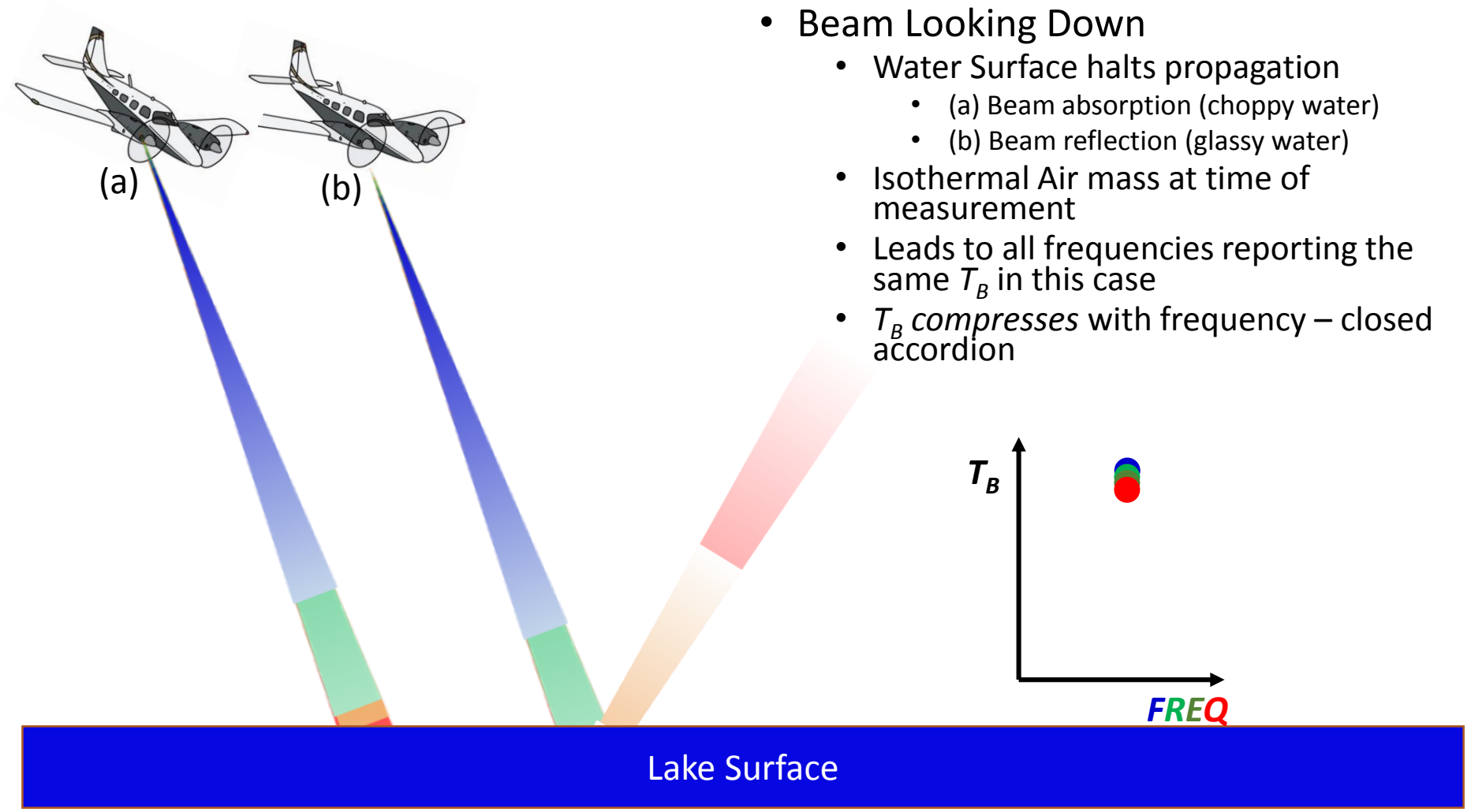
- ~2° C temperature variation from flight level to surface over Lake
- Low dewpoint/humidity (cold dry air)
- No/low wind speed < 1 m/s – glassy lake surface

Measurement Scenario 1 Horizontal Measurement



- Clear Air Propagation
  - Logarithmic increase in range with frequency
  - Decreasing temperature and moisture content with altitude
  - Earth curvature leads to lower brightness temps (T_B) at lower frequency
  - T_B "expands" with frequency
  - Ranges heavily dependent on liquid and vapor content

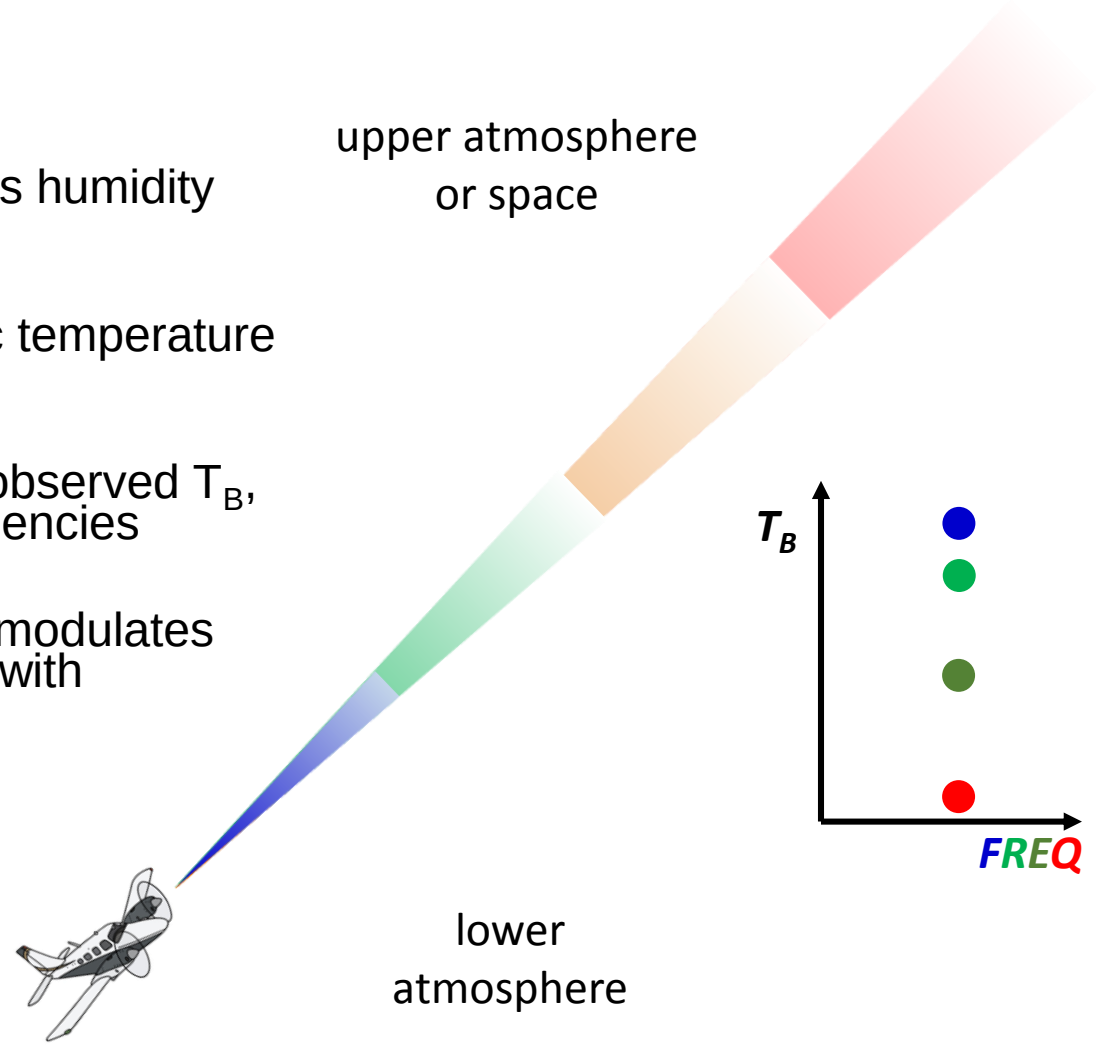
Measurement Scenario 2
Left Bank Over Water



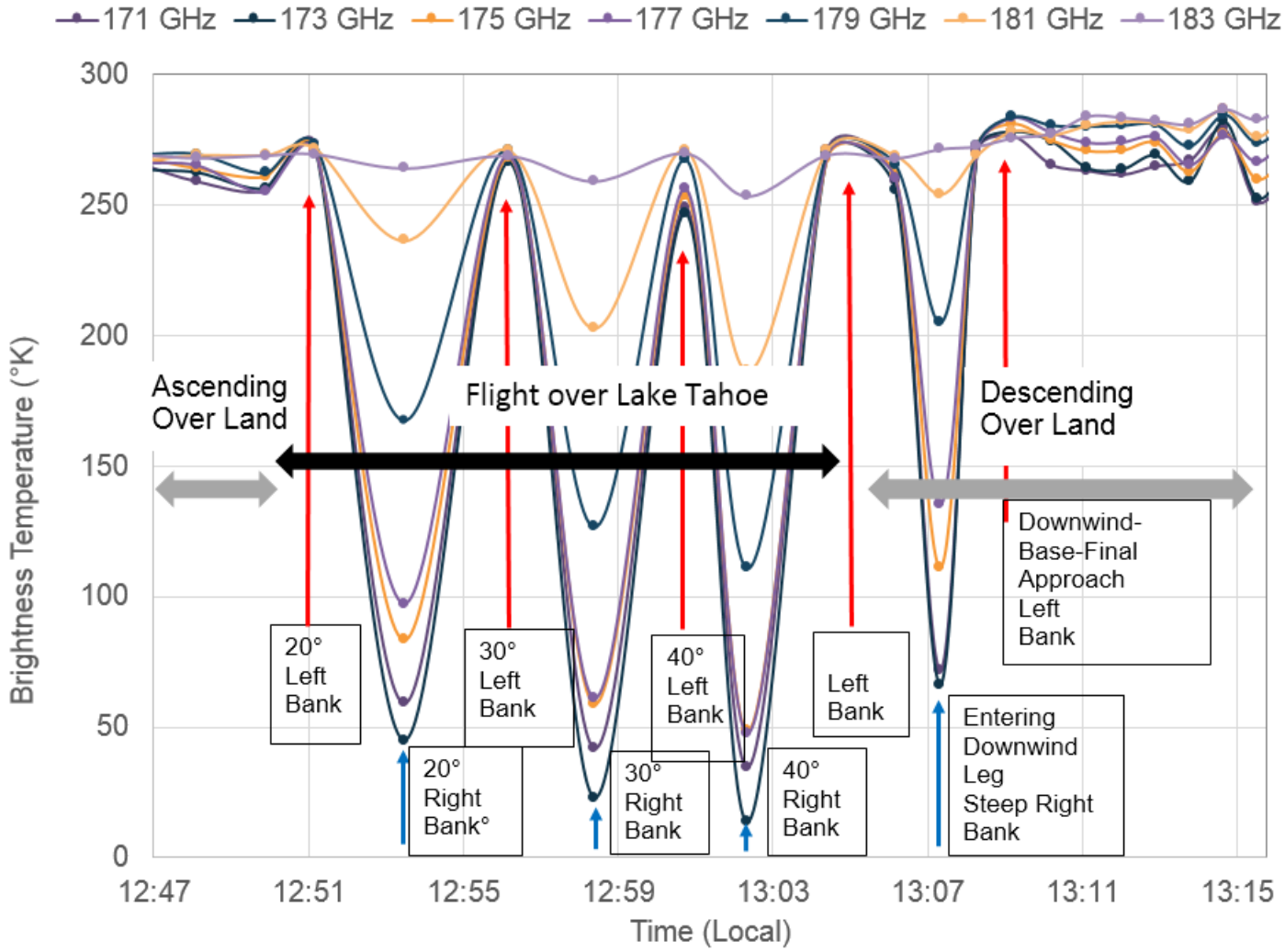
- Beam Looking Down
  - Water Surface halts propagation
    - (a) Beam absorption (choppy water)
    - (b) Beam reflection (glassy water)
  - Isothermal Air mass at time of measurement
  - Leads to all frequencies reporting the same T_B in this case
  - T_B *compresses* with frequency – closed accordion

Measurement Scenario 3 Right Bank

- Beam Looking up
  - Long ranges achieved as humidity drops with altitude
  - Decreasing atmospheric temperature with altitude
  - Significant reduction in observed T_B, especially at lower frequencies
  - Degree of bank directly modulates degree of T_B separation with frequency
  - Expanded Accordion



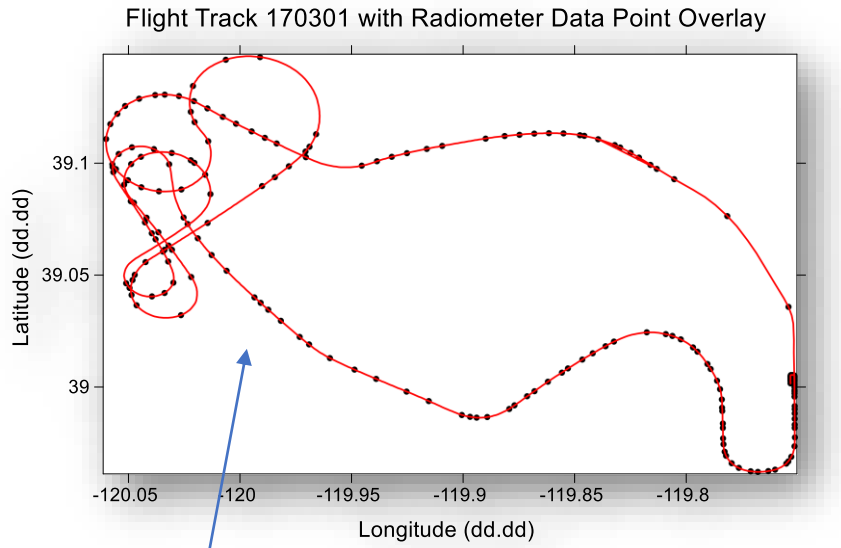
Clear-Air Flight Initial Measurement



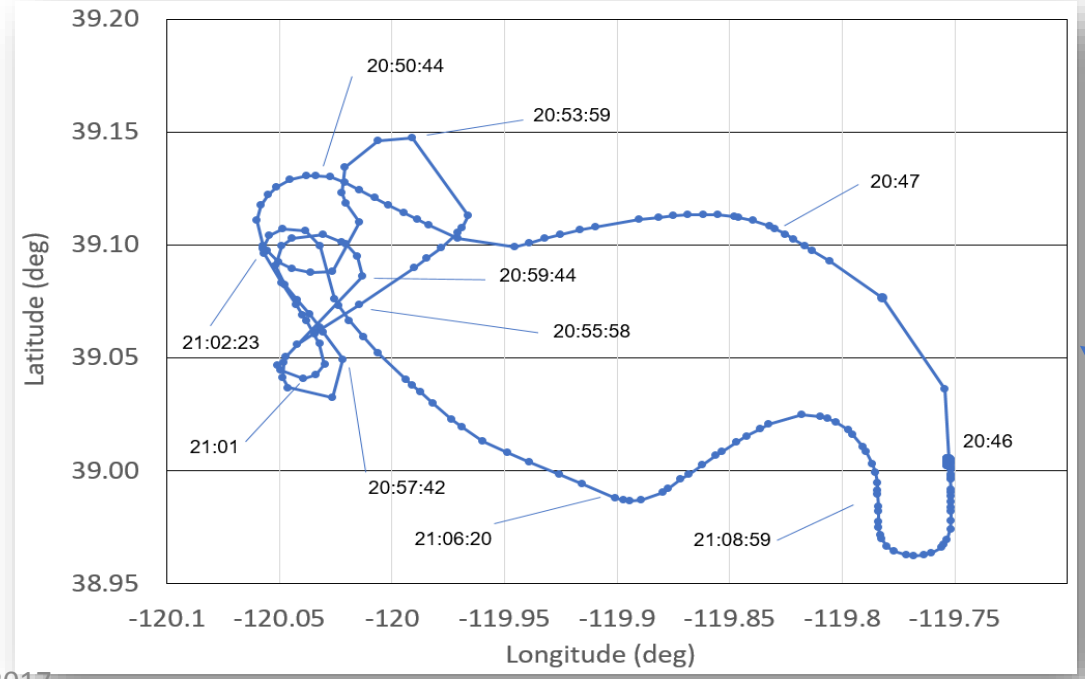
The radiometer performs as expected for the basic flight measurement scenarios

Instrumentation Performance

- Instrument designed for ground-based applications
- Turbulence and steep banked turns effect cycle times (high inertial loads)
- Fewer measurements taken during climbs, ascents and steep banks

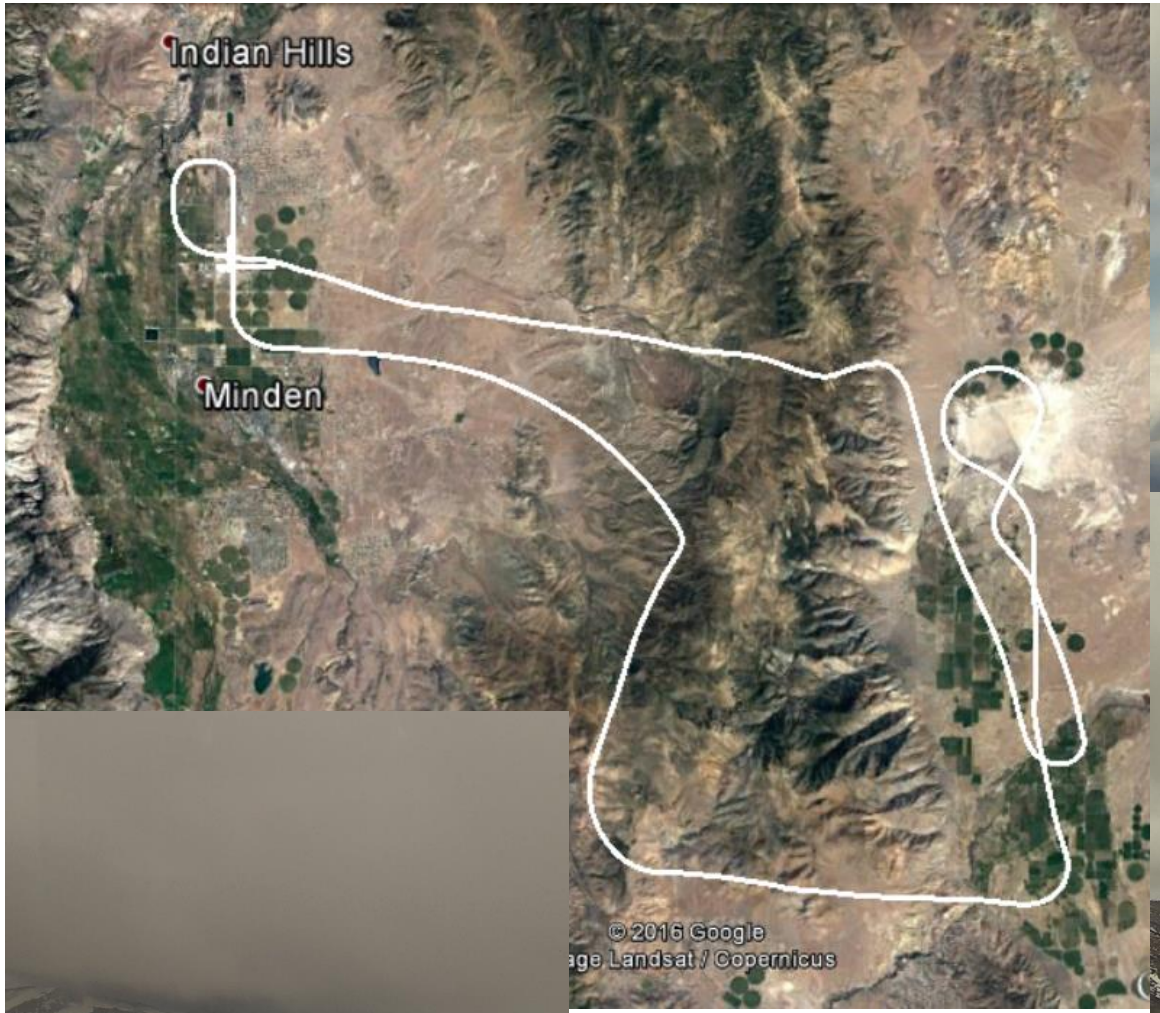


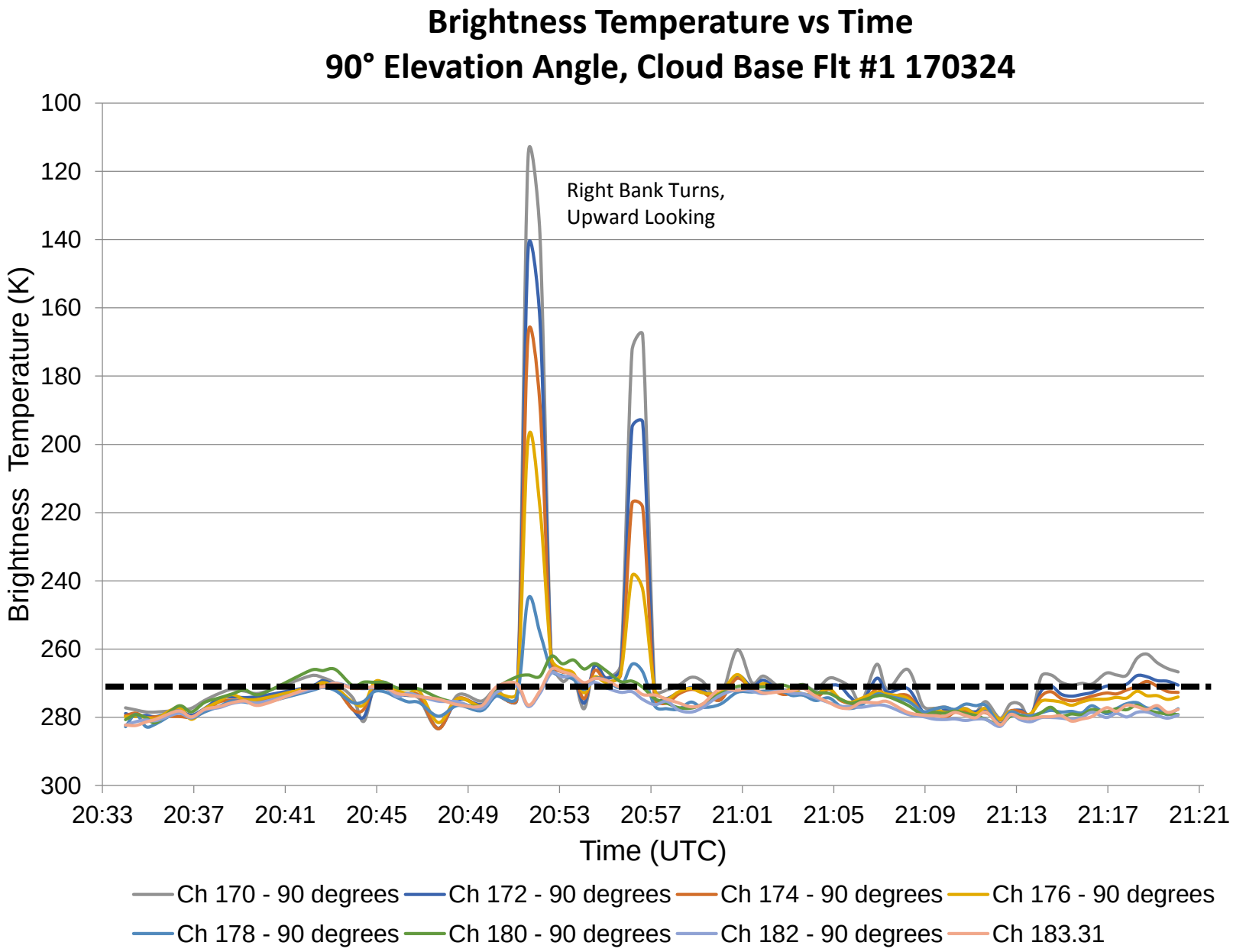
Flight Track w/ 1 Hz measurement points

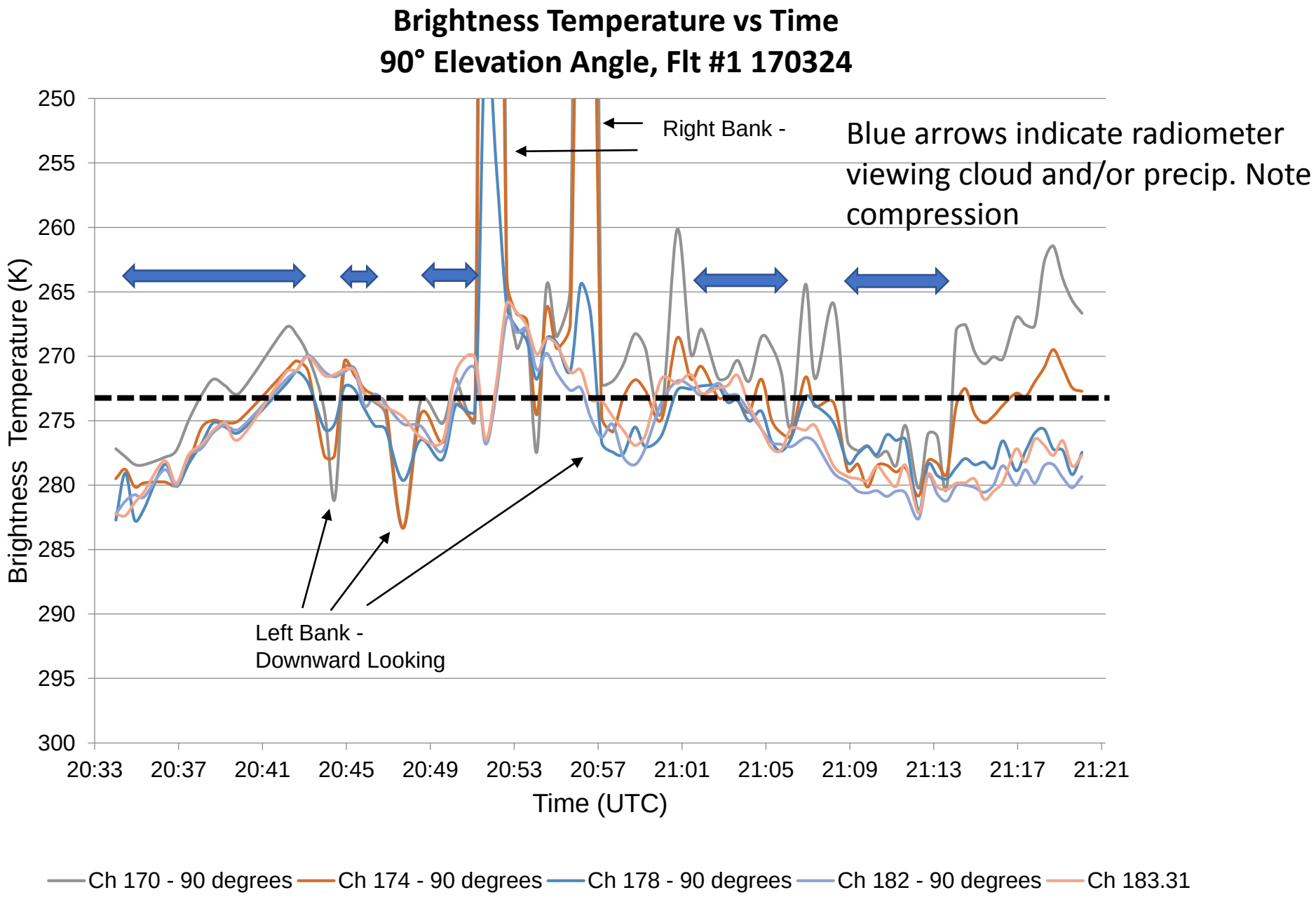


Radiometer measurement points (avg = 8 sec cycle, max = 59 sec at 45° bank

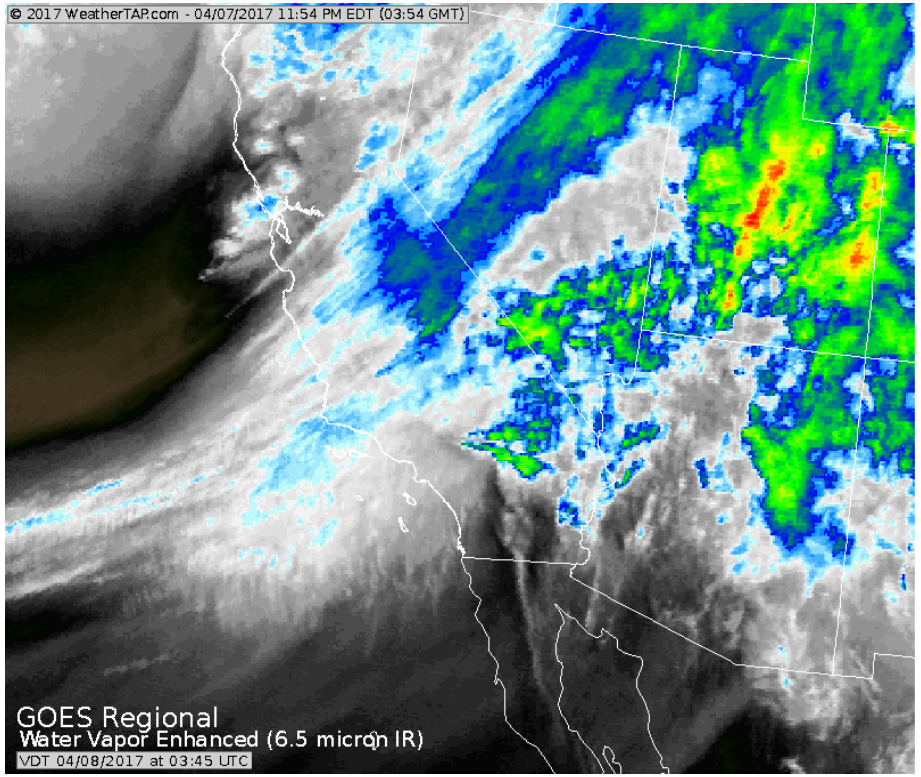
Cloud Base Flight 170324

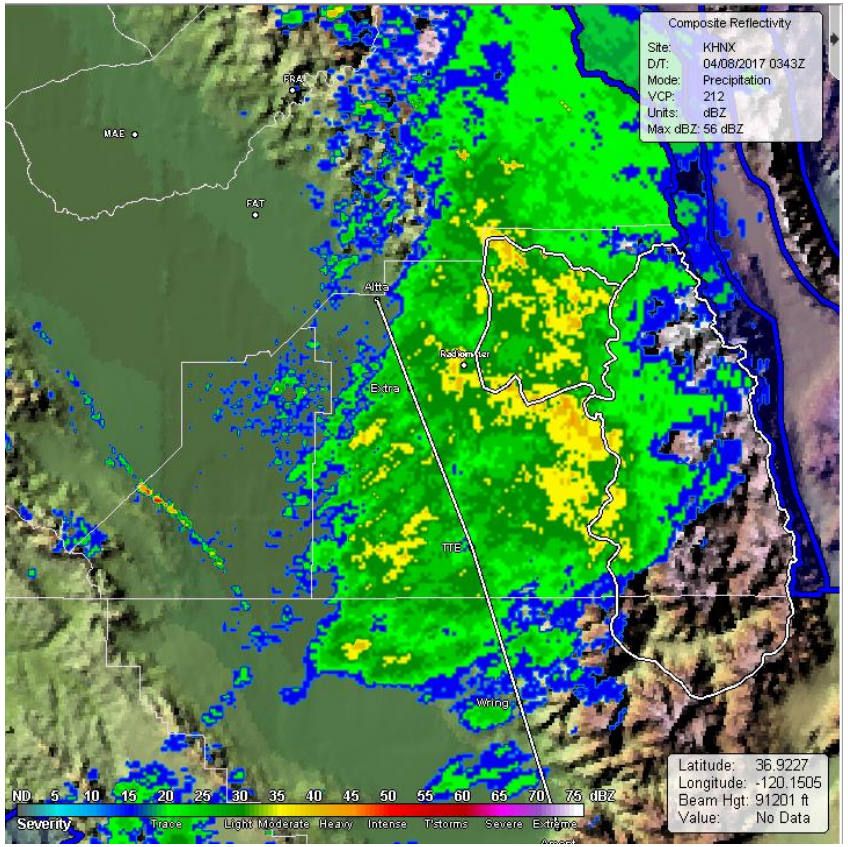



Brightness Temperature vs Time
90° Elevation Angle, Cloud Base Flt #1 170324
Right Bank Turns,
Upward Looking
Brightness Temperature (K)
100
120
140
160
180
200
220
240
260
280
300
20:33
20:37
20:41
20:45
20:49
20:53
20:57
21:01
21:05
21:09
21:13
21:17
21:21
Time (UTC)
Ch 170 - 90 degrees
Ch 172 - 90 degrees
Ch 174 - 90 degrees
Ch 176 - 90 degrees
Ch 178 - 90 degrees
Ch 180 - 90 degrees
Ch 182 - 90 degrees
Ch 183.31

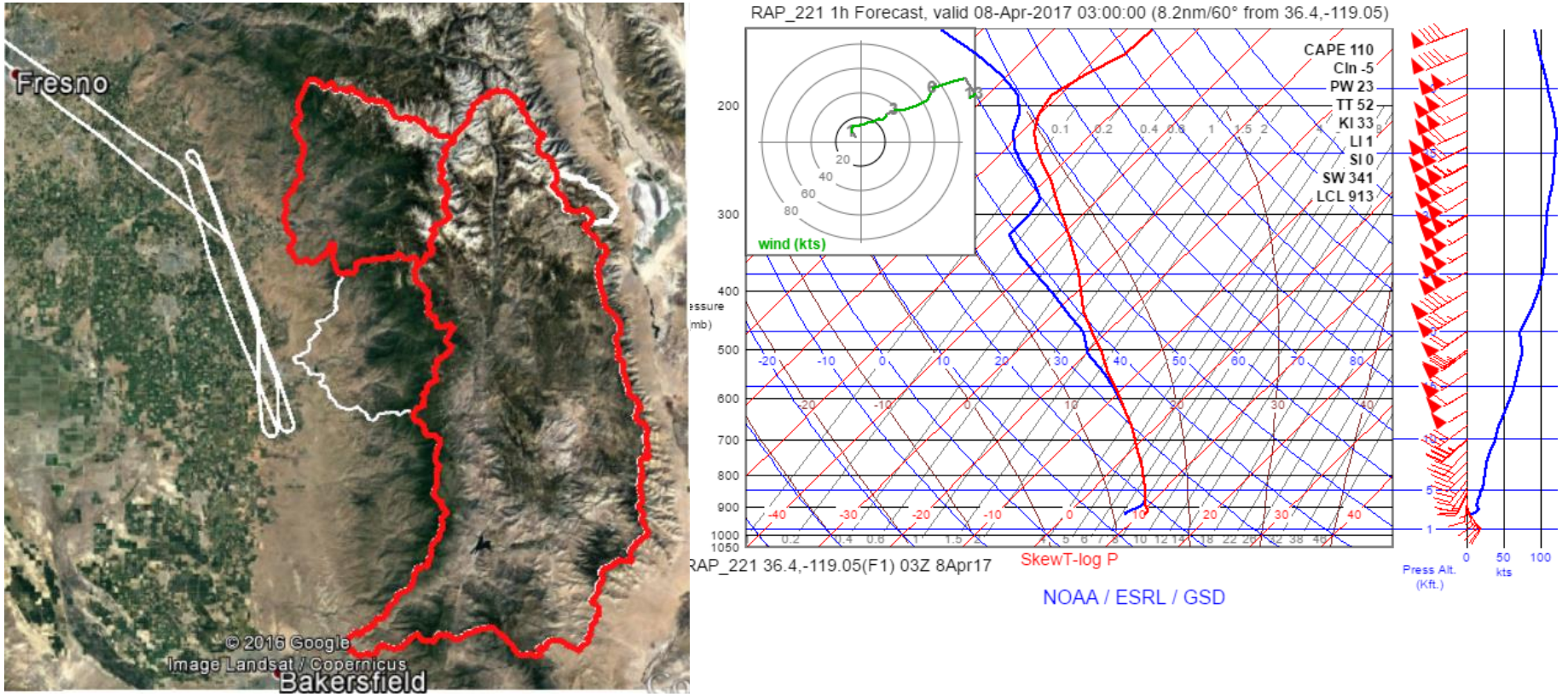

Brightness Temperature vs Time
90° Elevation Angle, Flt #1 170324
Brightness Temperature (K)
250
255
260
265
270
275
280
285
290
295
300
20:33
20:37
20:41
20:45
20:49
20:53
20:57
21:01
21:05
21:09
21:13
21:17
21:21
Time (UTC)
Right Bank -
Blue arrows indicate radiometer viewing cloud and/or precip. Note compression
Left Bank -
Downward Looking
Ch 170 - 90 degrees
Ch 174 - 90 degrees
Ch 178 - 90 degrees
Ch 182 - 90 degrees
Ch 183.31

Winter Storm Flight 170407- Composite Radar/Enhanced IR Satellite

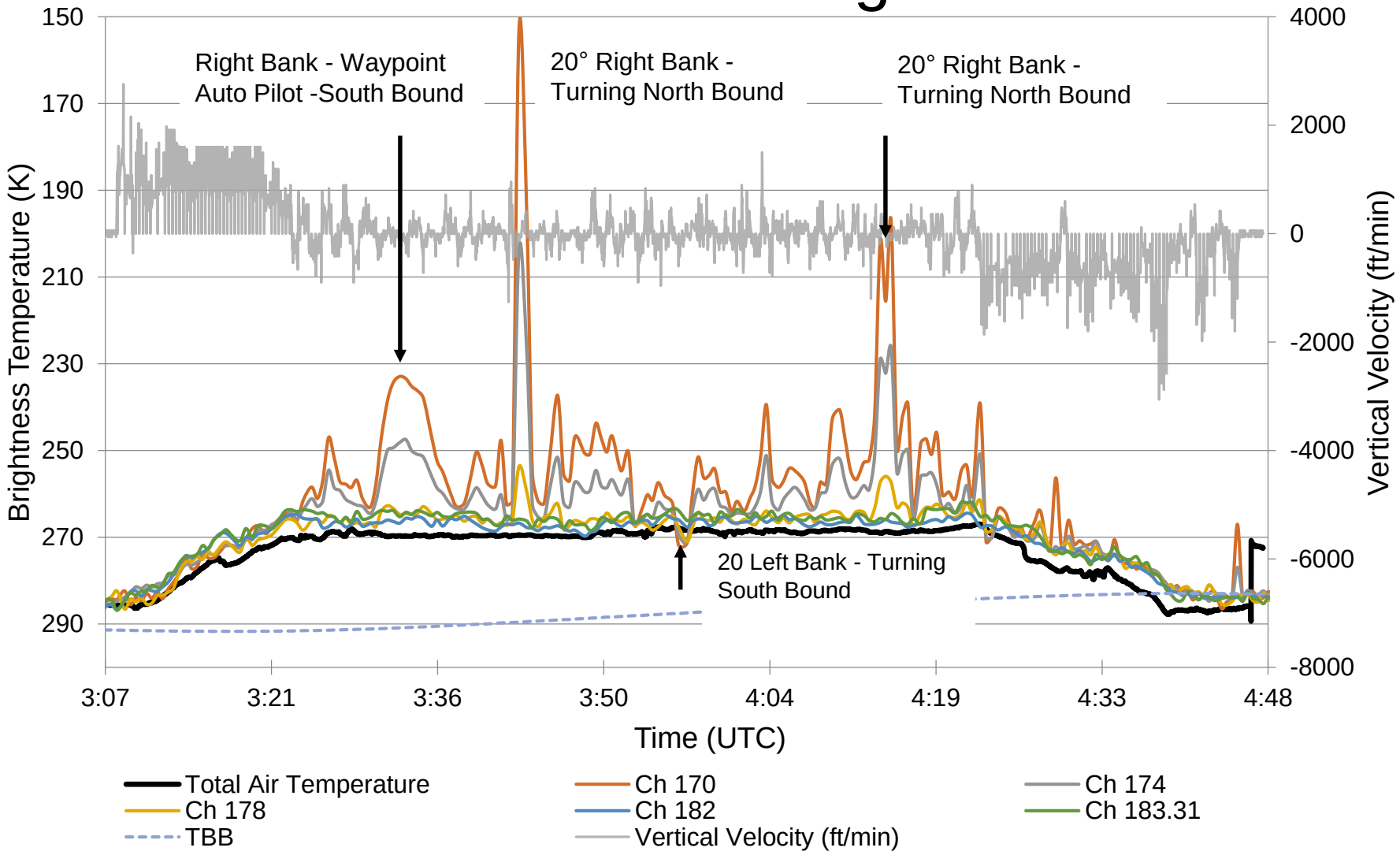




Flight Track and RAP_221 Forecast Sounding 170407



Brightness Temperature vs Time
90° Elevation Angle 170407



Accomplishments and Next Steps

- Initial Aircraft Observations confirm G Band Radiometry Accordion Model in clear air and precipitating winter clouds
- Future flights needed to investigate and demonstrate G Band Radiometry in Winter SLW Clouds, Marine Layer, Convective Clouds and higher colder environments
- Couple G Band Radiometer with Airborne Lidar and Upper Air Data to provide “truth” data. LIDAR measurements will provide insight into previous (timestep N-1) radiometer measurements
- Parallel receiver in next gen radiometer with 0.5 K accuracy, 5-10 ms integration time requirement.
- Main Focus: Demonstrate Icing Hazard Detection and Avoidance Feasibility
- Serendipity: WRF Aerosol Aware Microphysics Research (Thompson and Bin) and extend real-time area wide SLW detection to cloud seeding applications.
- High Resolution WRF modeling to provide additional “truth” data for Neural Nets and other Machine Learning Algorithms

Conceptual Package – G Band λ~1.64mm