Ceilometer Backscatter Applications to Ceiling and Visibility

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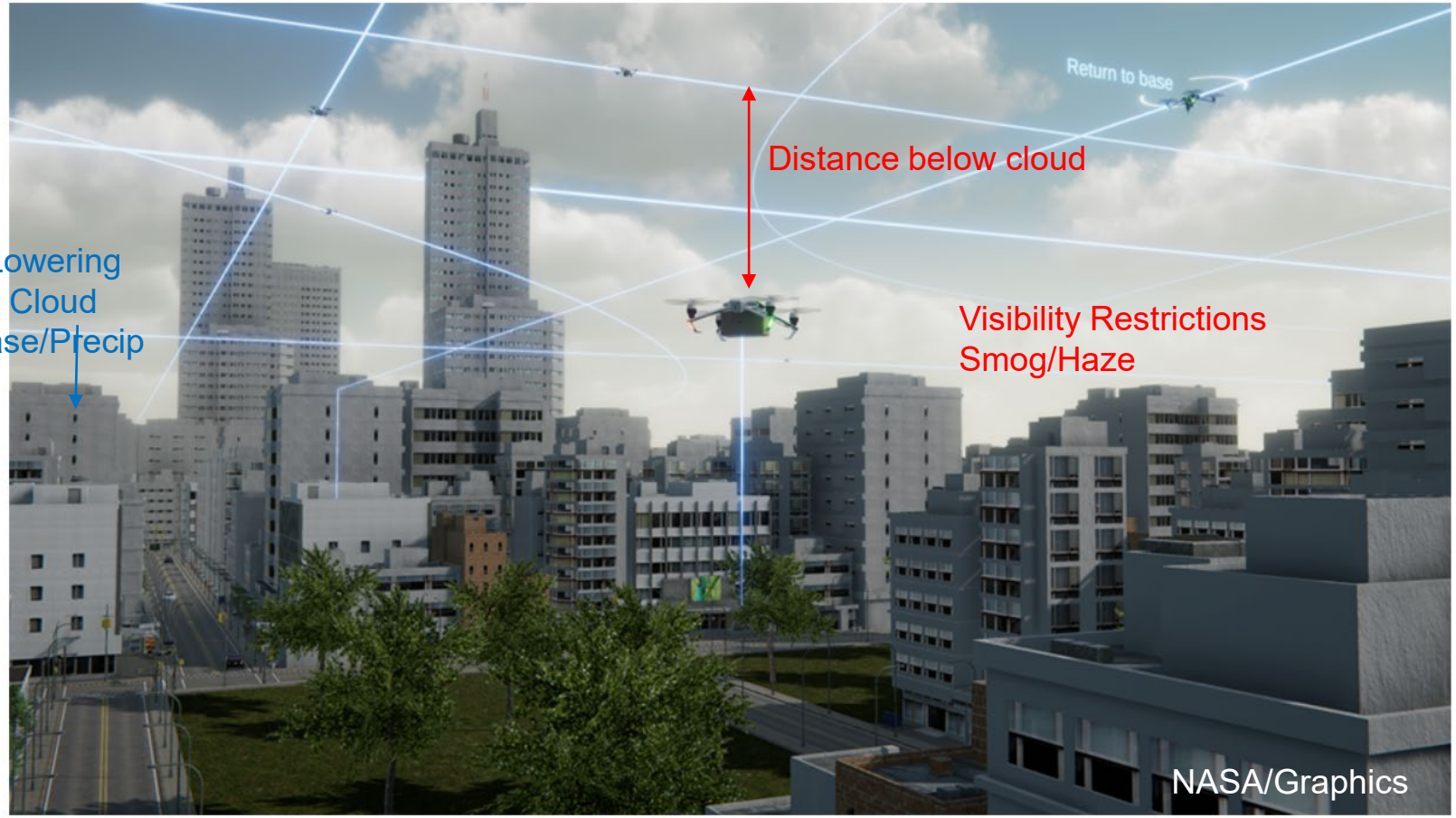
Improved C&V Sensing to Support the Next Generation of Emerging Modes of Transportation

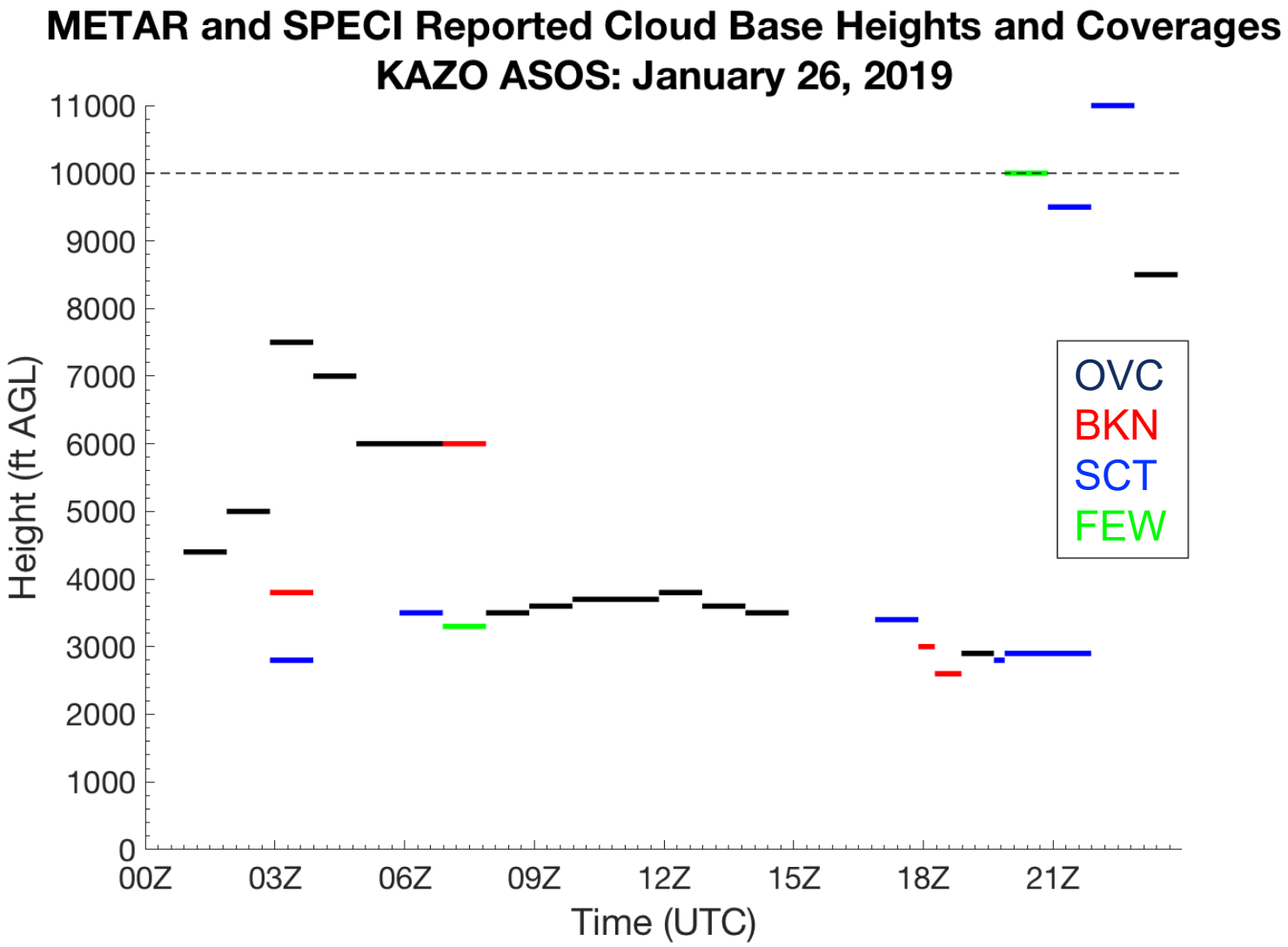


Potential Benefit of Unlocking Ceilometer Backscatter Profiles:

- Detect haze and elevated layers of lower visibility
- Profiles of visibility estimates and tendencies thereof
- Detect precipitation not reaching ground (esp. important in areas outside of radar coverage).
- Improved determination of cloud boundaries and coverage with higher rate data than reported.
- Improved estimation of trends in cloud base

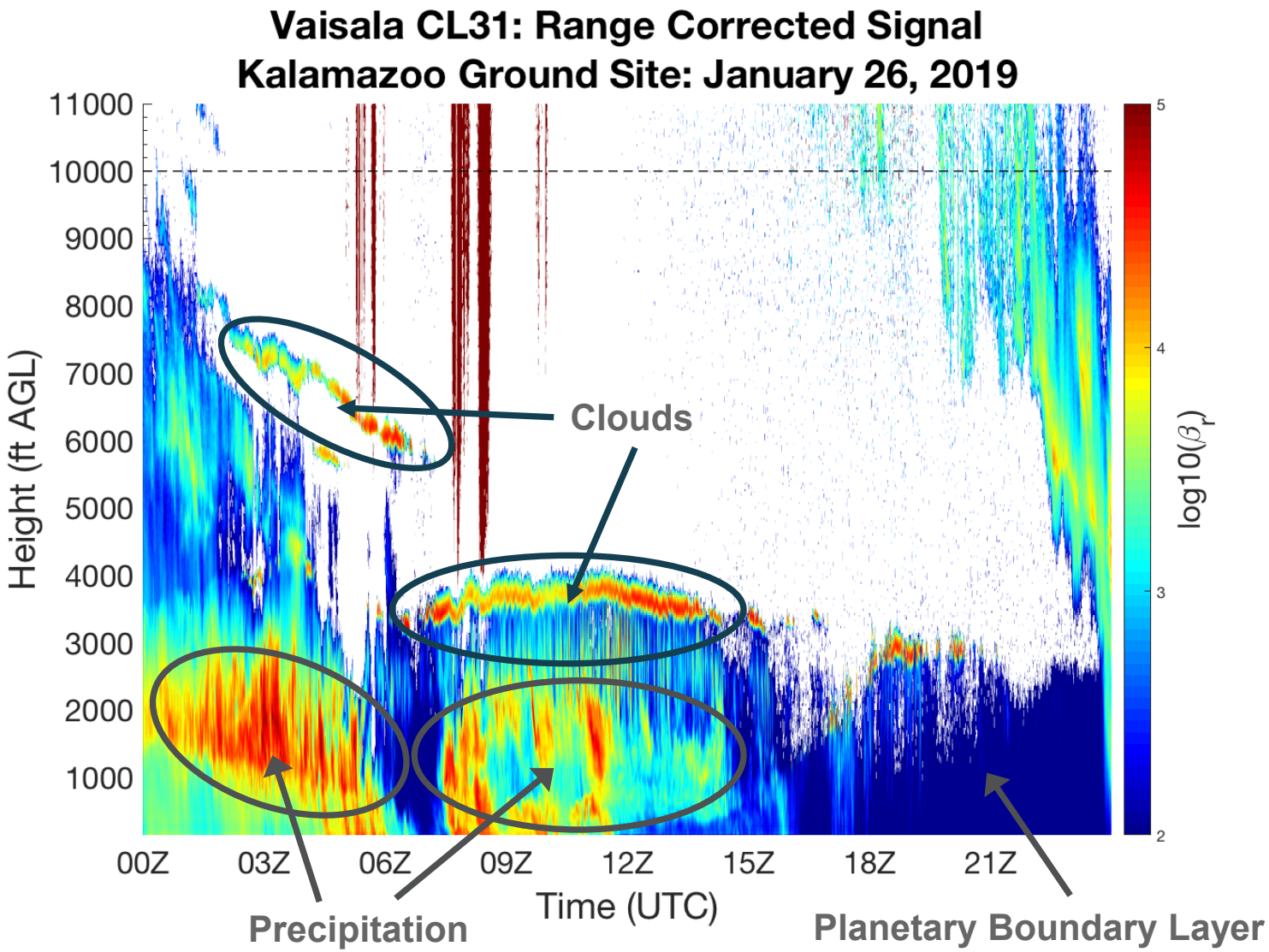
ASOS Ceilometer Operational Output

- All 900+ Automated Surface Observing System (ASOS) locations in the United States are equipped with a Vaisala CL31 ceilometer
  - METARs report up to three cloud base heights (up to 12,000 feet) and corresponding sky coverages
  - Vertical visibility reported if cloud base height cannot be determined due to attenuation (e.g. heavy precipitation)
  - Hourly updates or more frequent via SPECIs



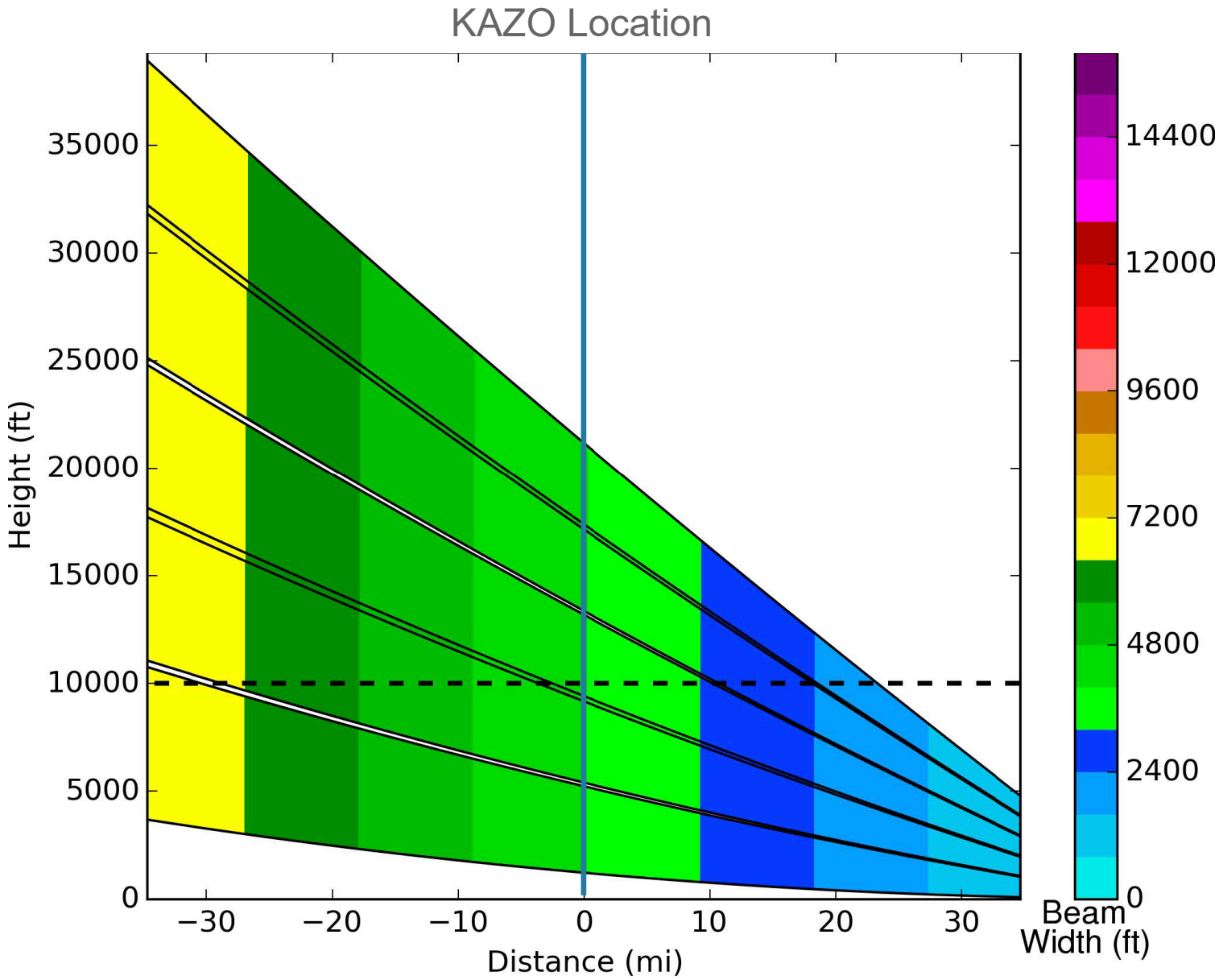
CL31 Filtered Backscatter Profile

- CL31 ceilometer installed at KAZO during ICICLE
  - In-Cloud Icing and Large-Drop Experiment
  - Full backscatter dataset collected and archived
- Backscatter profiles
  - 30 foot vertical resolution
  - 16 second time resolution
- Detectible features
  - Cloud layers
  - Precipitation
  - Planetary Boundary Layer
- ASOS ceilometers produce identical backscatter profiles but discard them after deriving sky condition

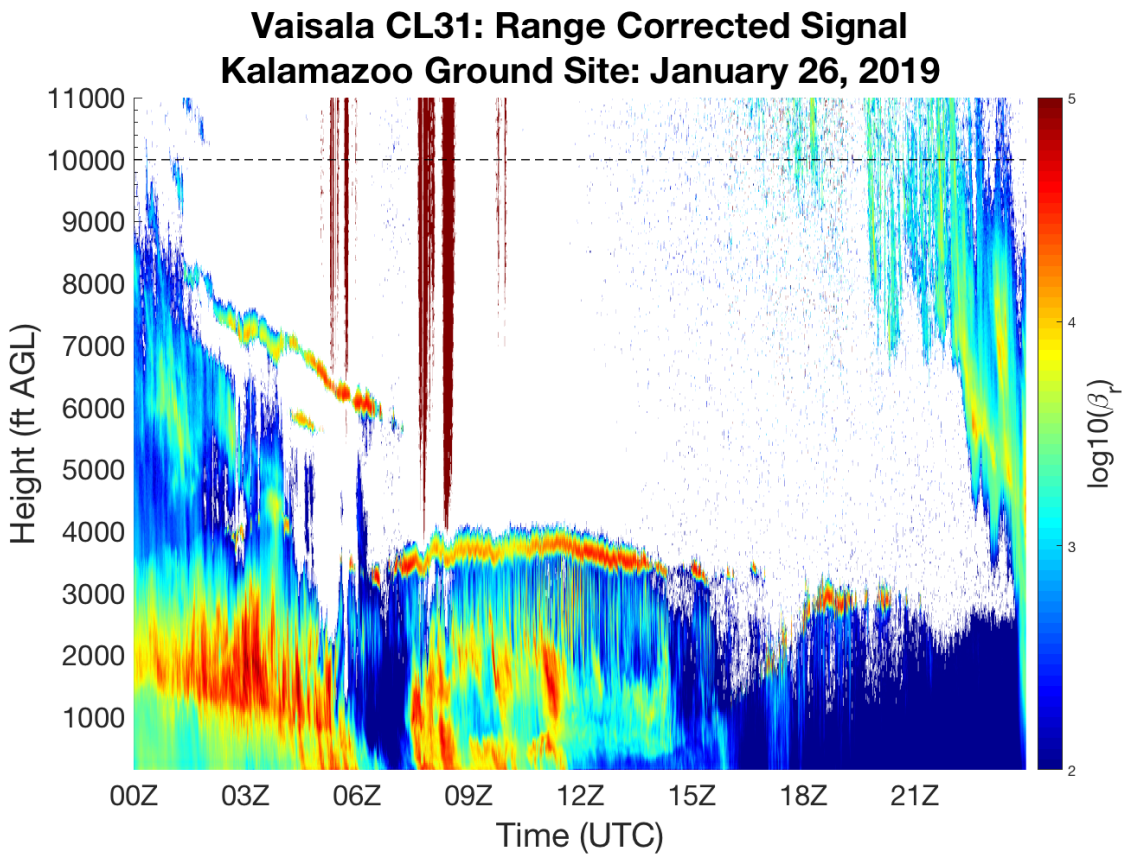


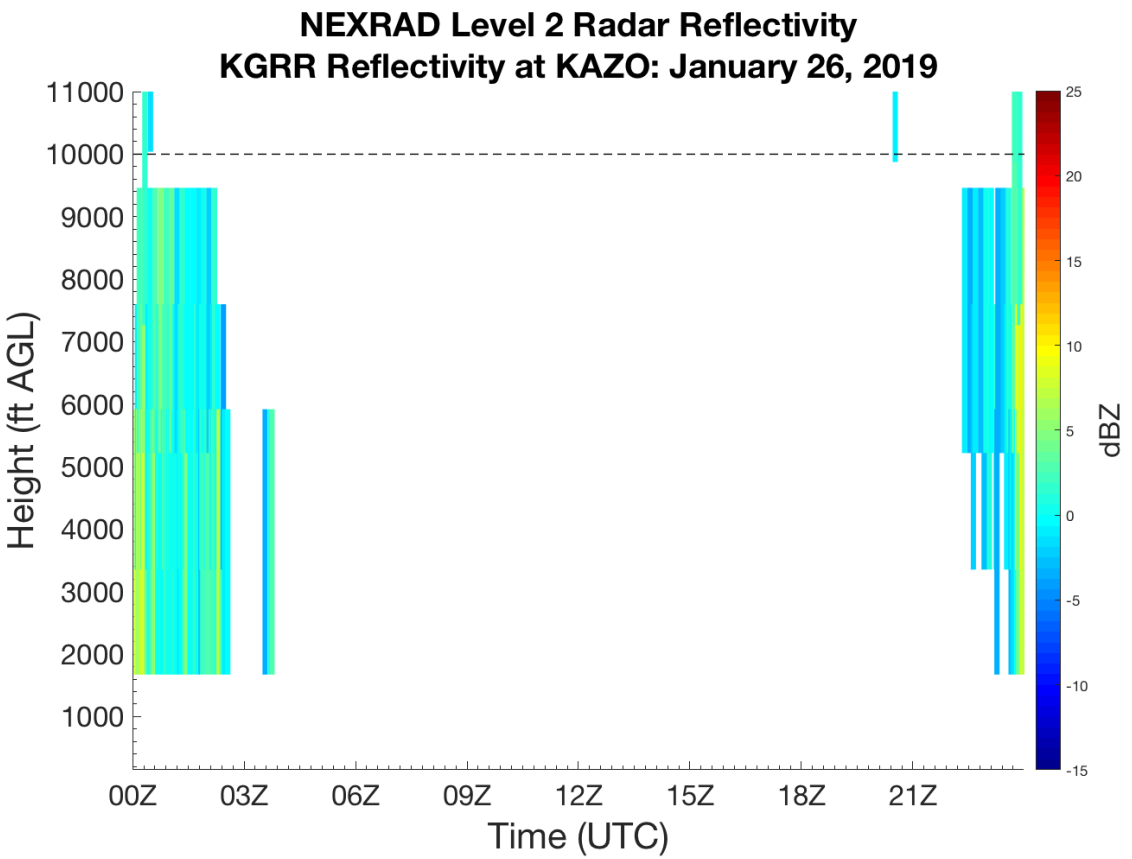
Radar Limitations

- Closest NEXRAD site to KAZO is Grand Rapids (KGRR), 46 miles north
- No coverage below ~1700ft
  - Assuming minimum scan angle of 0.5º
- KGRR NEXRAD volume depth nearly 3/4 mile at KAZO
  - CL31 resolution two orders of magnitude finer
- Overshoots low-level precipitation and virga
- Can fail to detect light precipitation



Detect Precipitation Beyond Radar/METAR Sensitivity



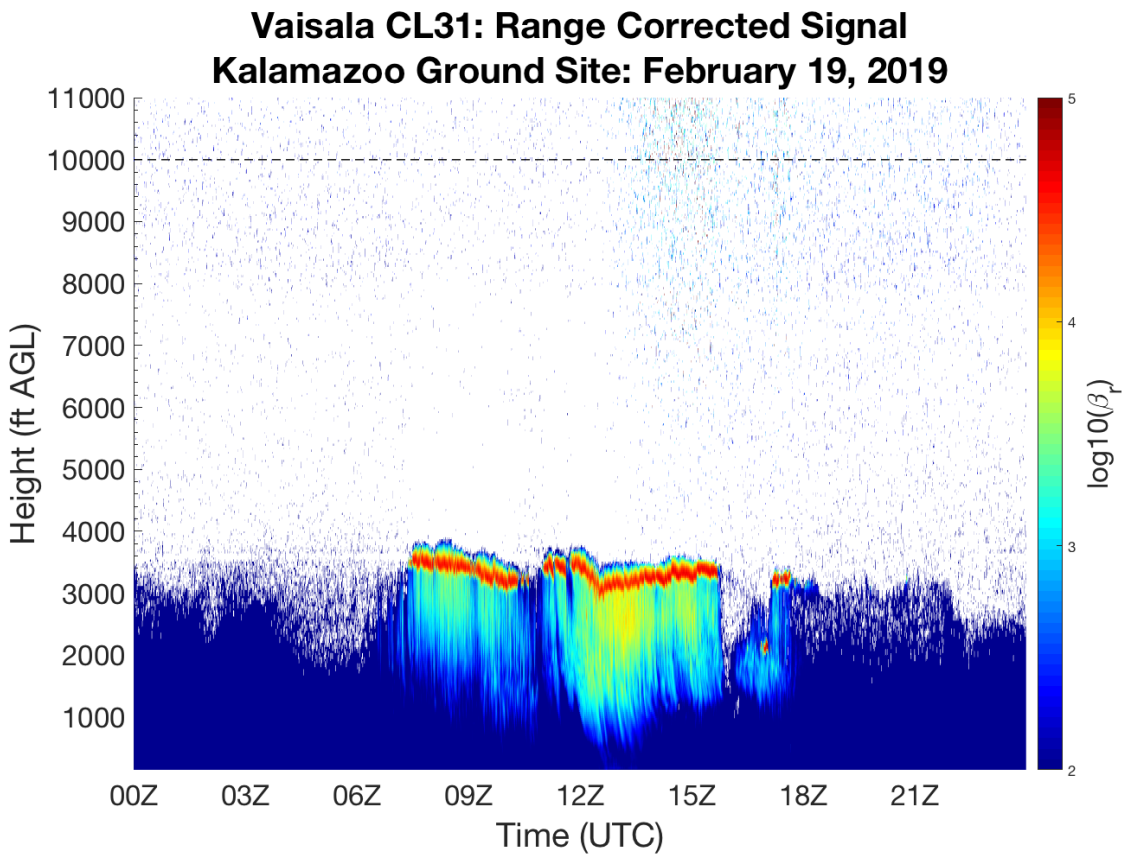


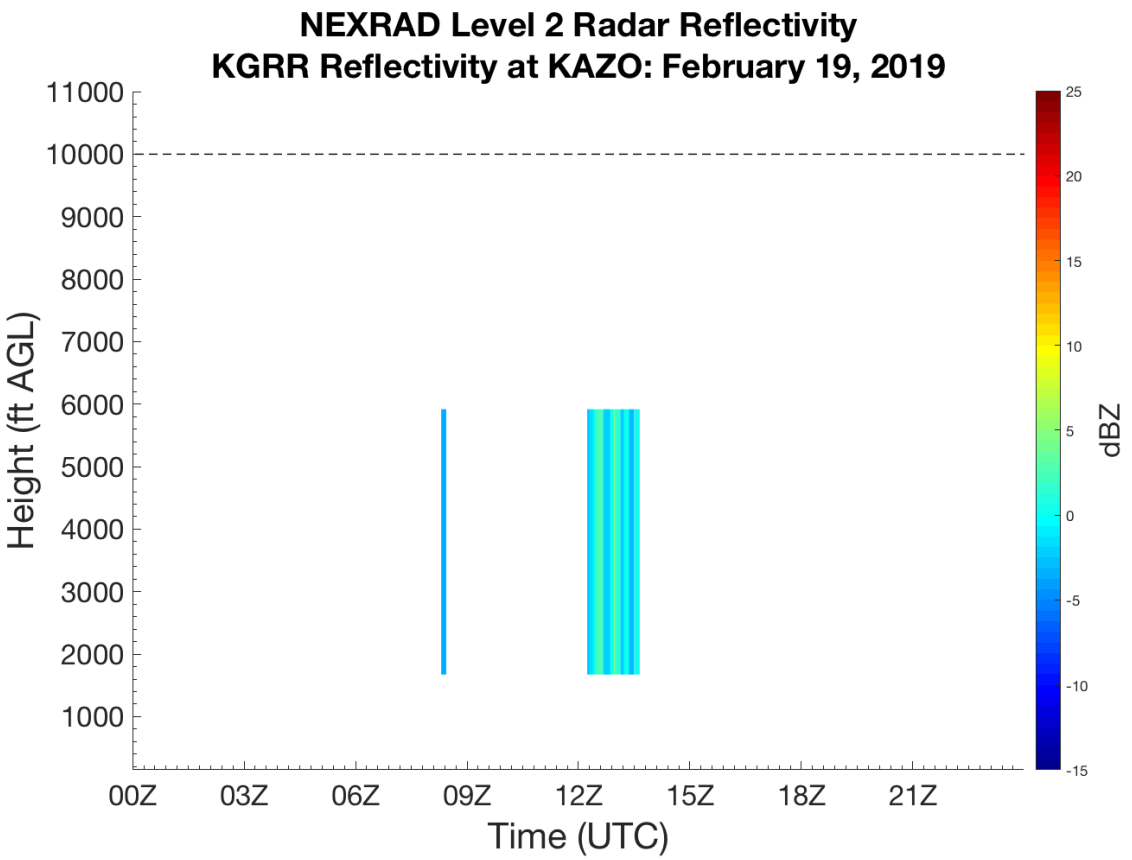
KAZO METAR: light snow from 00Z-03Z, 11Z-12Z; ICICLE ground suite sensors: snow from 00Z-06Z, 08Z-12Z

Ceilometer detects light precipitation missed by NEXRAD and ASOS

Ceilometer also detects elevated layer of probable precipitation from 12Z-15Z

Detect Precipitation not Reaching the Ground

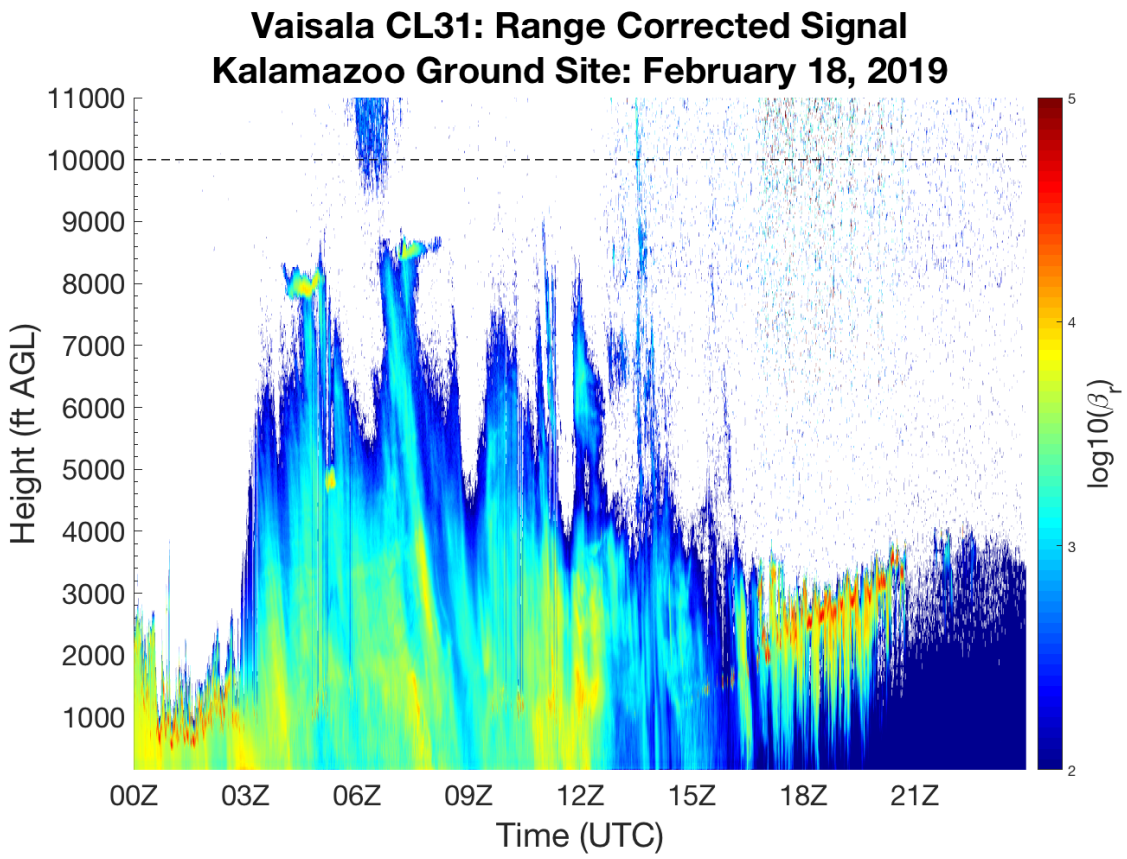


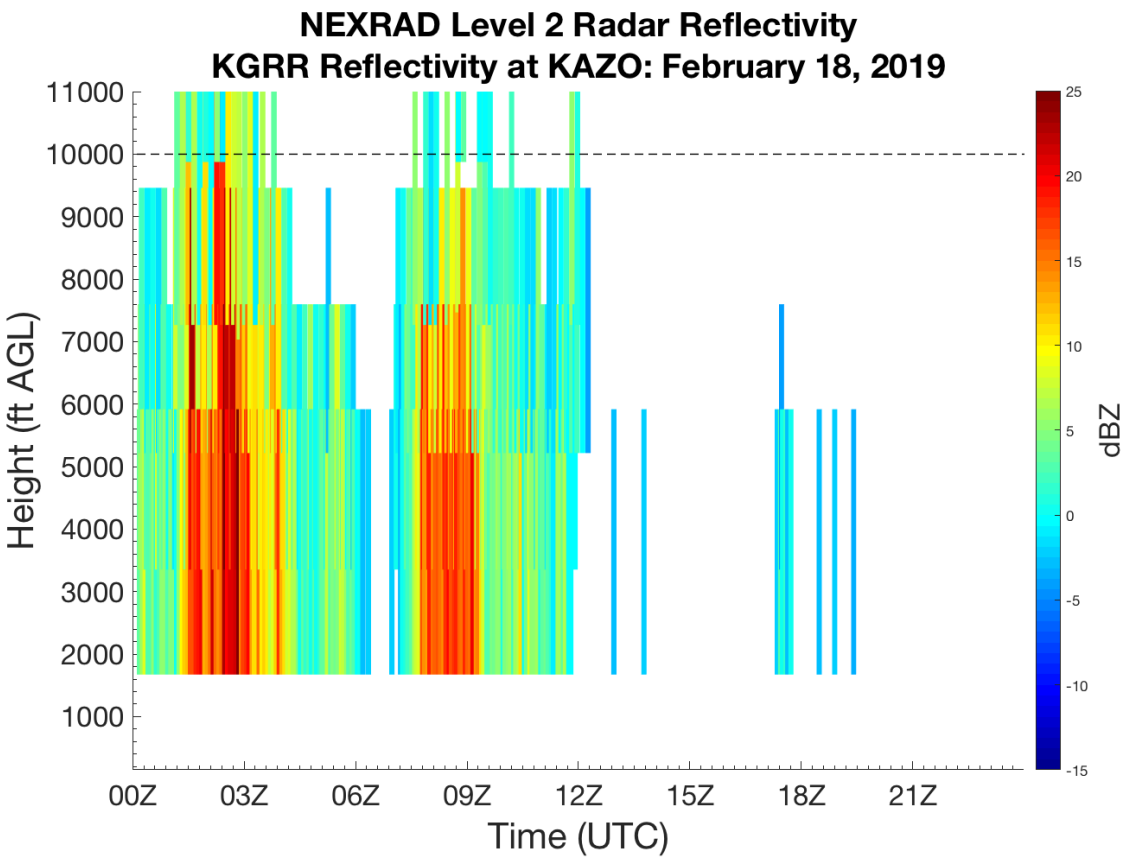


KAZO METAR: no precipitation; ICICLE ground suite sensors: snow from 13Z-14Z

Ceilometer detects light precipitation aloft that otherwise goes undetected

Supplementing Radar Observations





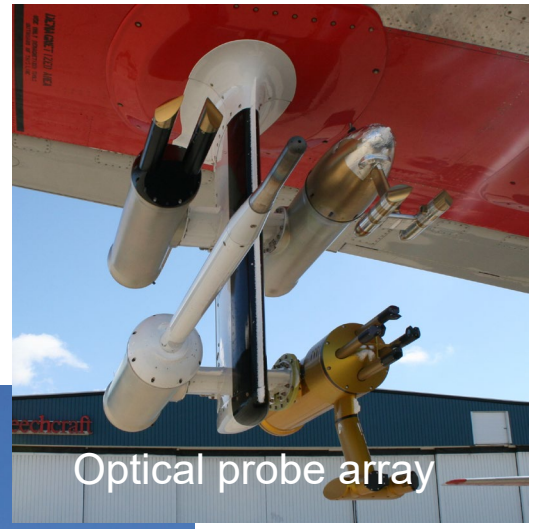
KAZO METAR: FZRA → SN before 12Z; ICICLE ground suite sensors: FZRA → SN before 12Z and rain/snow from 17Z-18Z

Ceilometer detects light precipitation aloft that is otherwise only partially detected

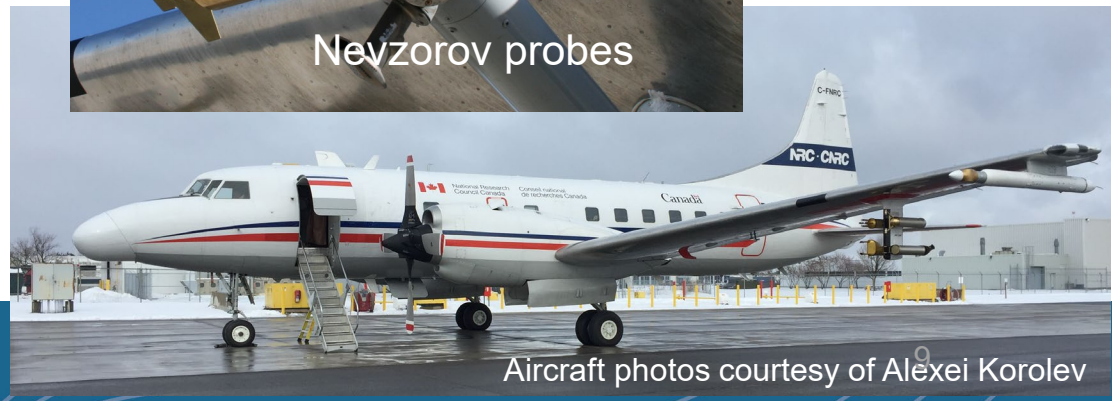
Ceilometer also detects light precipitation/obscuration from 12Z-15Z

Ceilometer Comparisons to Aircraft-Collected Microphysical Parameters

- NRC Convair 580 research aircraft
  - Nevzorov liquid, ice, and total water content (LWC, IWC, TWC)
  - Optical probe droplet concentrations
  - Cloud extinction probe (CEP)
- Consider flights with legs in the vicinity of KAZO
  - Aircraft less than 10km from KAZO
- Six ICICLE flights with missed approaches over KAZO
  - F11, F12, F21, F22, F26, F27
- Consider microphysical parameters relative to collocated ceilometer backscatter bin
  - Average 16 one-second aircraft observations to match CL31 resolution


Optical probe array


Nevzorov probes

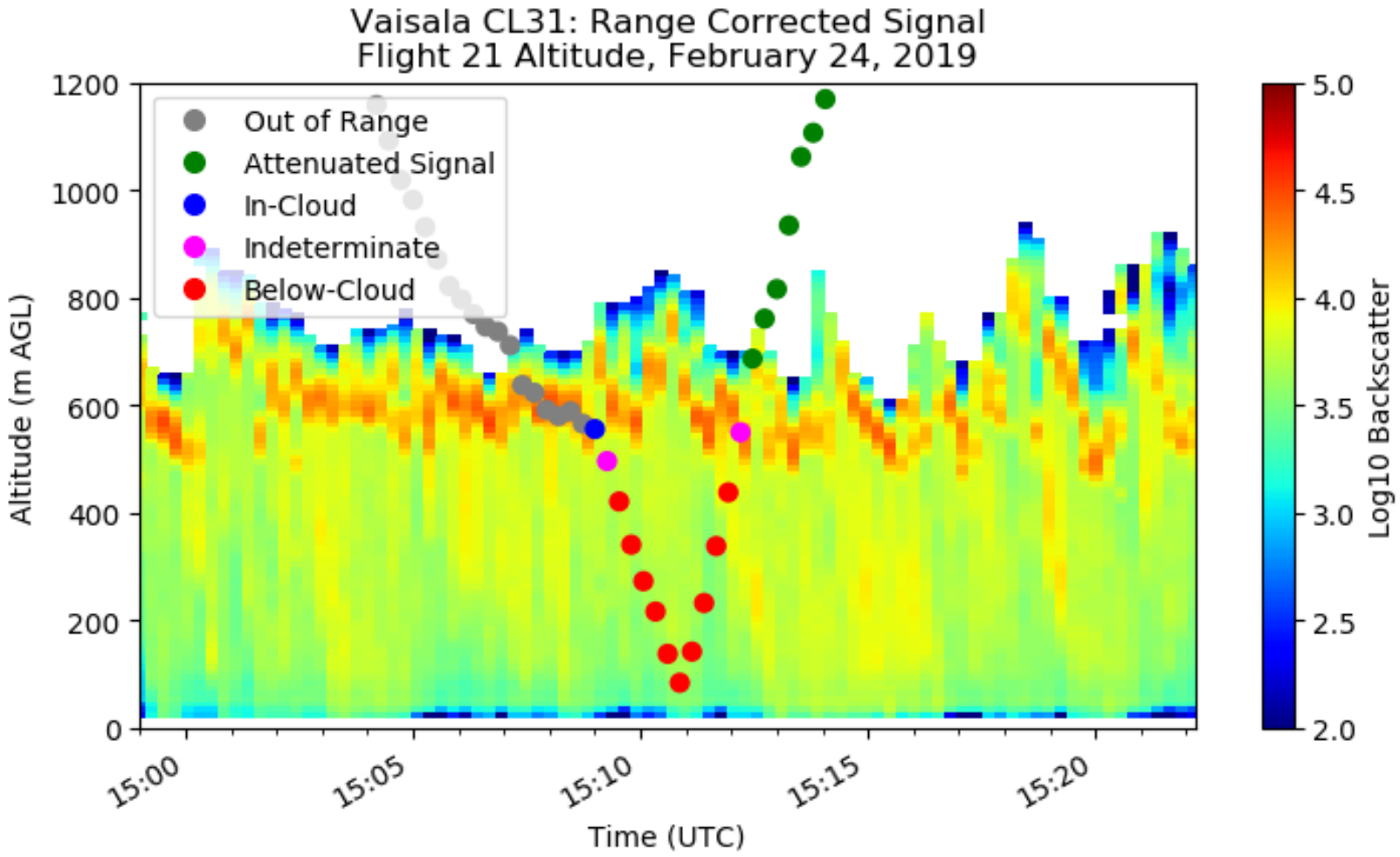


Aircraft photos courtesy of Alexei Korolev

Example: Flight 21, February 24, 2019

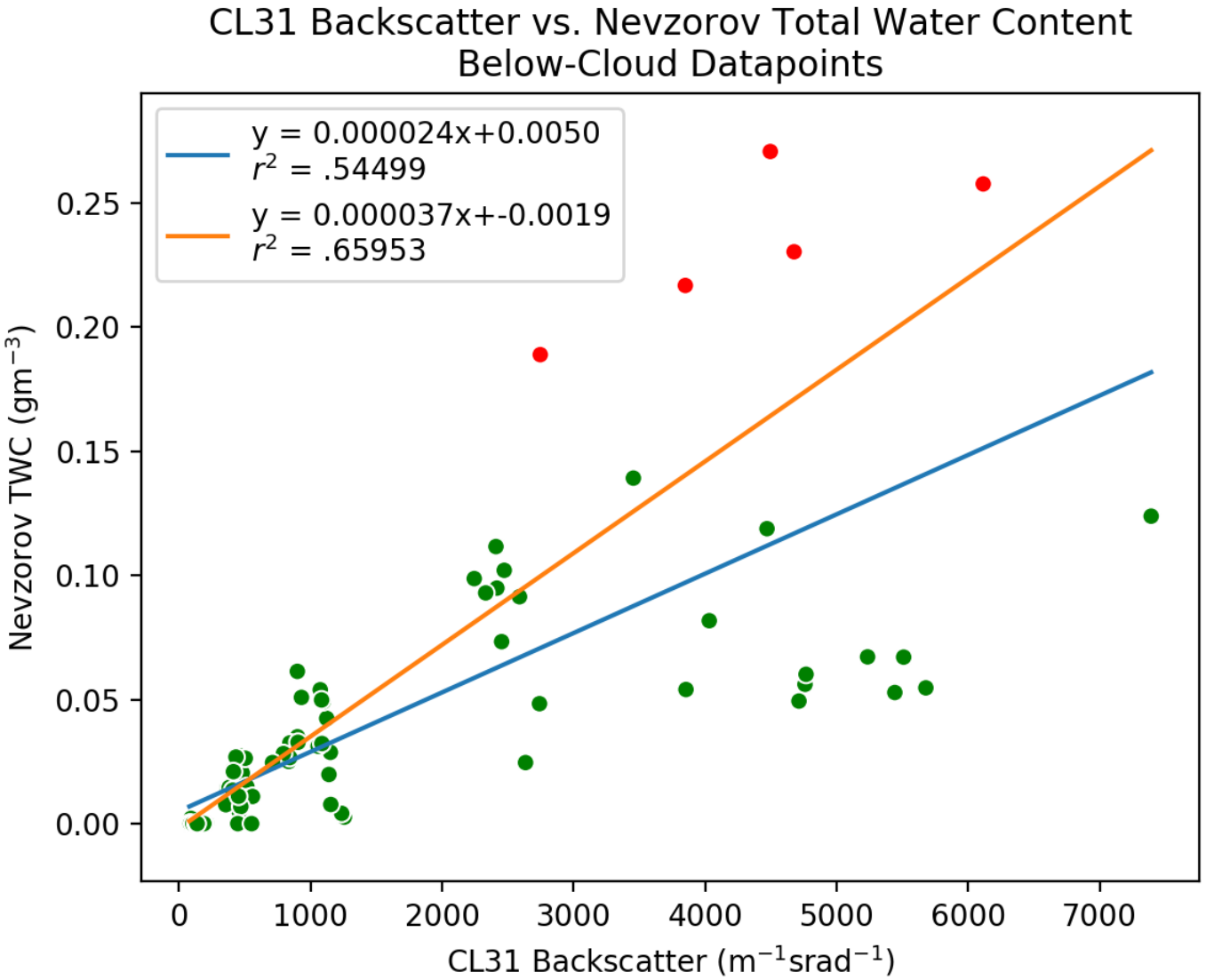
Flight 21

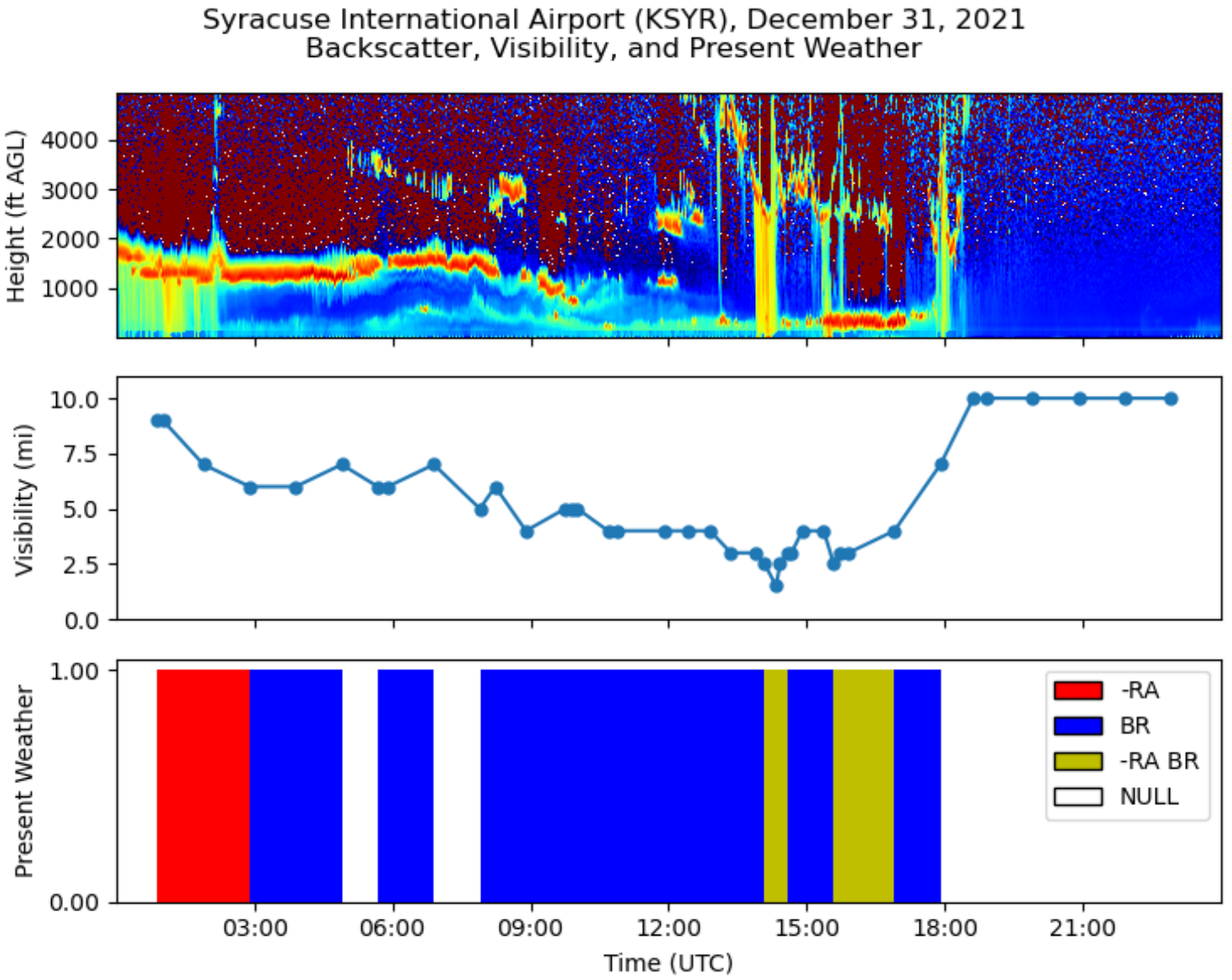
- Significant icing
- Multiple cloud layers
- Cloud base blurred due to precipitation attenuation
- One missed approach at KAZO
  - 15:09 - 15:12
- Categorized datapoints
  - In-cloud: 1
  - Indeterminate: 2
  - Below-cloud: 10
- Note several in-cloud data points during approach but beyond 10km



Total Below-Cloud Water Content

- 98 below-cloud points
- Weighted least squares (WLS)
  - Weight by horizontal distance between ceilometer and aircraft
  - r^2 = .65953
- Sub-aircraft attenuation
  - Flight 22 (red points)
  - Observed backscatter less than expected
- Ceilometer bin averaging
  - Aircraft ascent/descent through multiple height bins (not implemented)





Detect Haze and Elevated Layers of Reduced Visibility

- Mist is reported by ASOS during visibilities of 5/8 to 7 miles
- Backscatter coefficient values during mist range from 2 to 3 $m^{-1}srad^{-1}$
- Ceilometer indicates a mist descending upon KSYR from 8Z-10Z
  - Visibility drops during that same time
- Fine scale resolved by ceilometer

Application of Ceilometer Backscatter to Ceiling and Visibility

- High resolution information on cloud base height
  - Information on rising/falling cloud base heights
  - Identify trends in cloud base height?
  - Data assimilation of backscatter profiles into NWP models?
- Detect elevated and light precipitation beyond that identified by NEXRAD and METAR/SPECIs
  - Supplement/complement NEXRAD and operational ASOS observations
  - Identify precipitation base height
- Correlated with below-cloud total water content
  - Events studied included light rain and snow; what happens in heavier precipitation?
- Capable of detecting fine-scale mist structure
  - Relationship between backscatter and visibility in mist?
- Low-cost, low-maintenance, moderate data size
- Data assimilation

This research is in response to requirements and funding by the FAA. The views expressed are those of the authors and do not necessarily represent the official policy or position of the FAA.