Pacific Northwest
NATIONAL LABORATORY

# Cloud, Aerosol, and Complex Terrain Interactions (CACTI) Background

June 24, 2020
2020 ARM/ASR Joint User Facility and PI Meeting


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U.S. DEPARTMENT OF ENERGY BATTELLE

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# Broad Overview of CACTI

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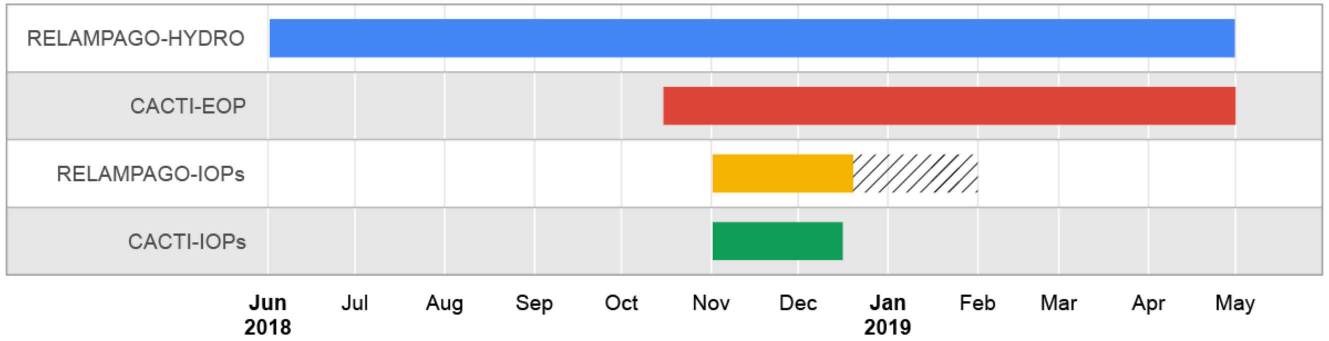
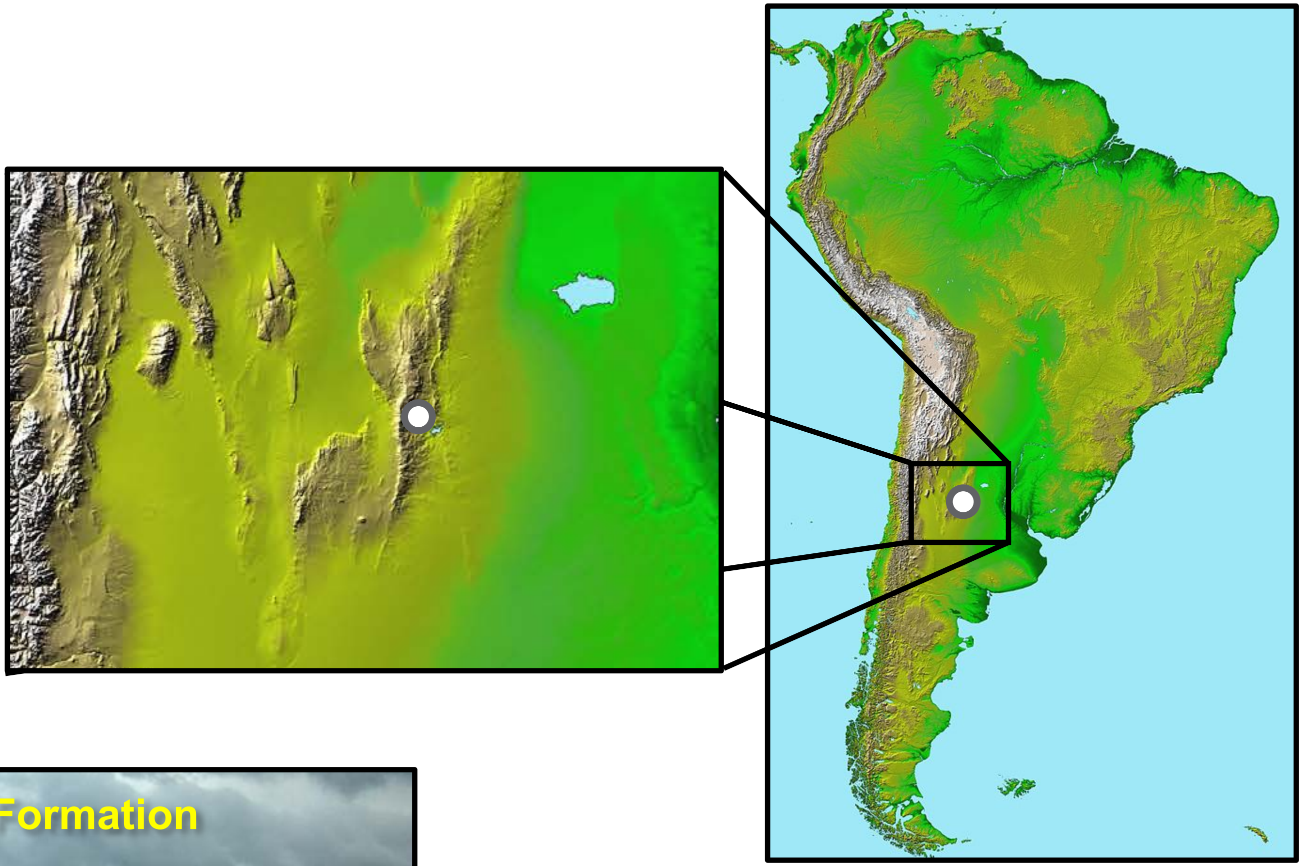
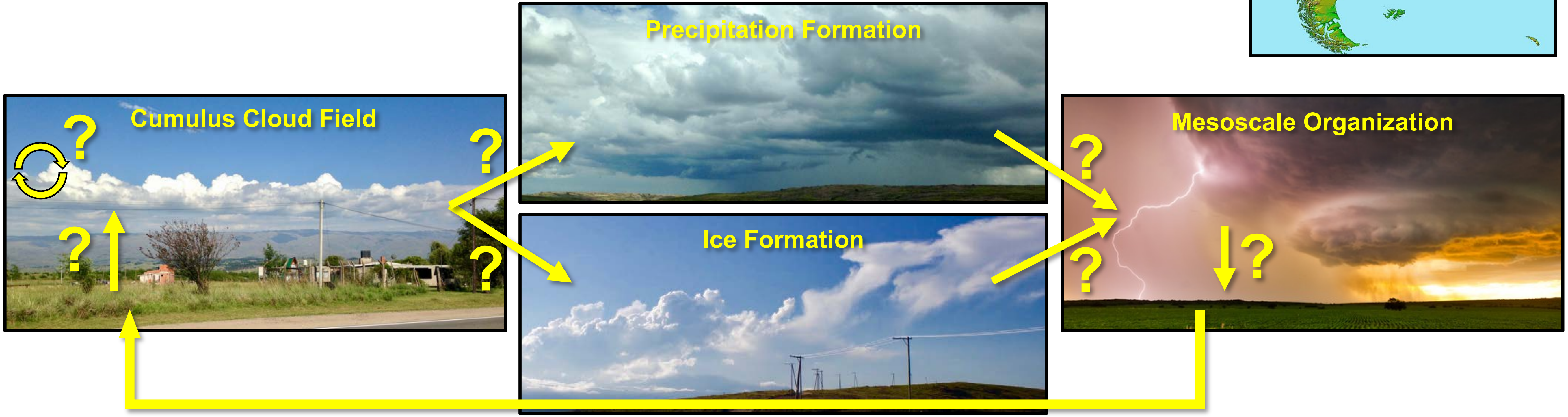
Facilities: DOE ARM AMF-1 (> 50 instruments), C-SAPR2 radar, G-1 aircraft (IOP, ~40 in situ instruments), and supplemental sites

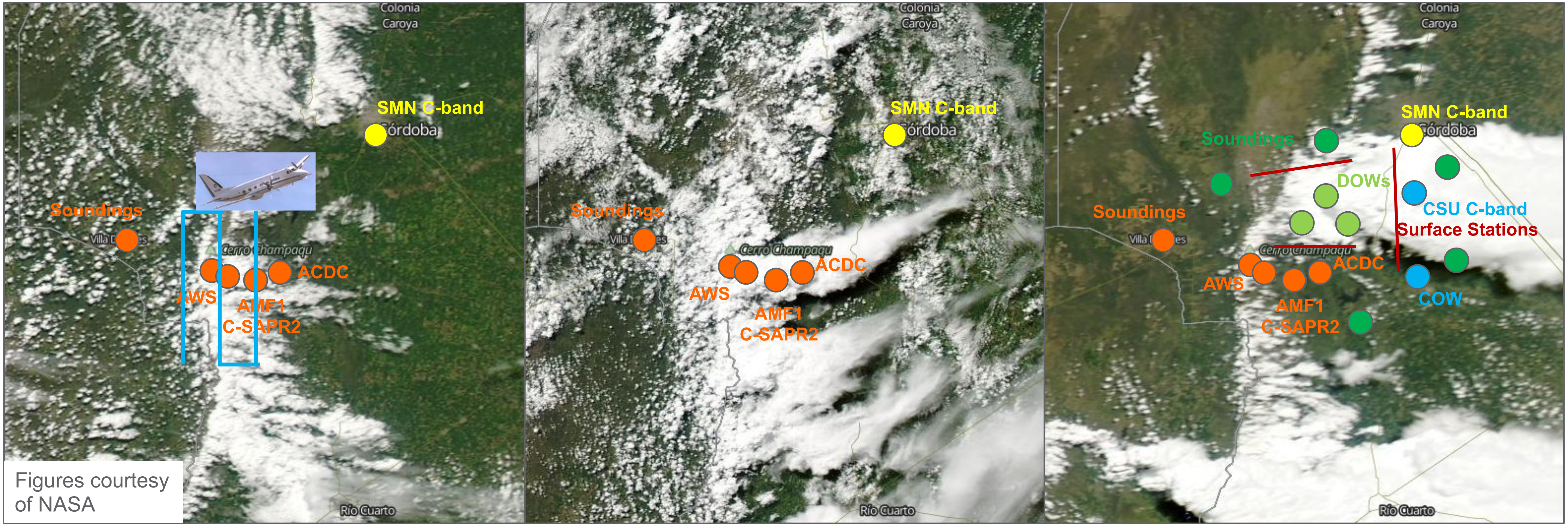
Primary Goal: Quantify the sensitivity of convective cloud system evolution to environmental conditions for the purposes of evaluating and improving model parameterizations





# Experiment Rationale: Repeated Deep Convective Initiation




Figures courtesy of NASA

# Siting

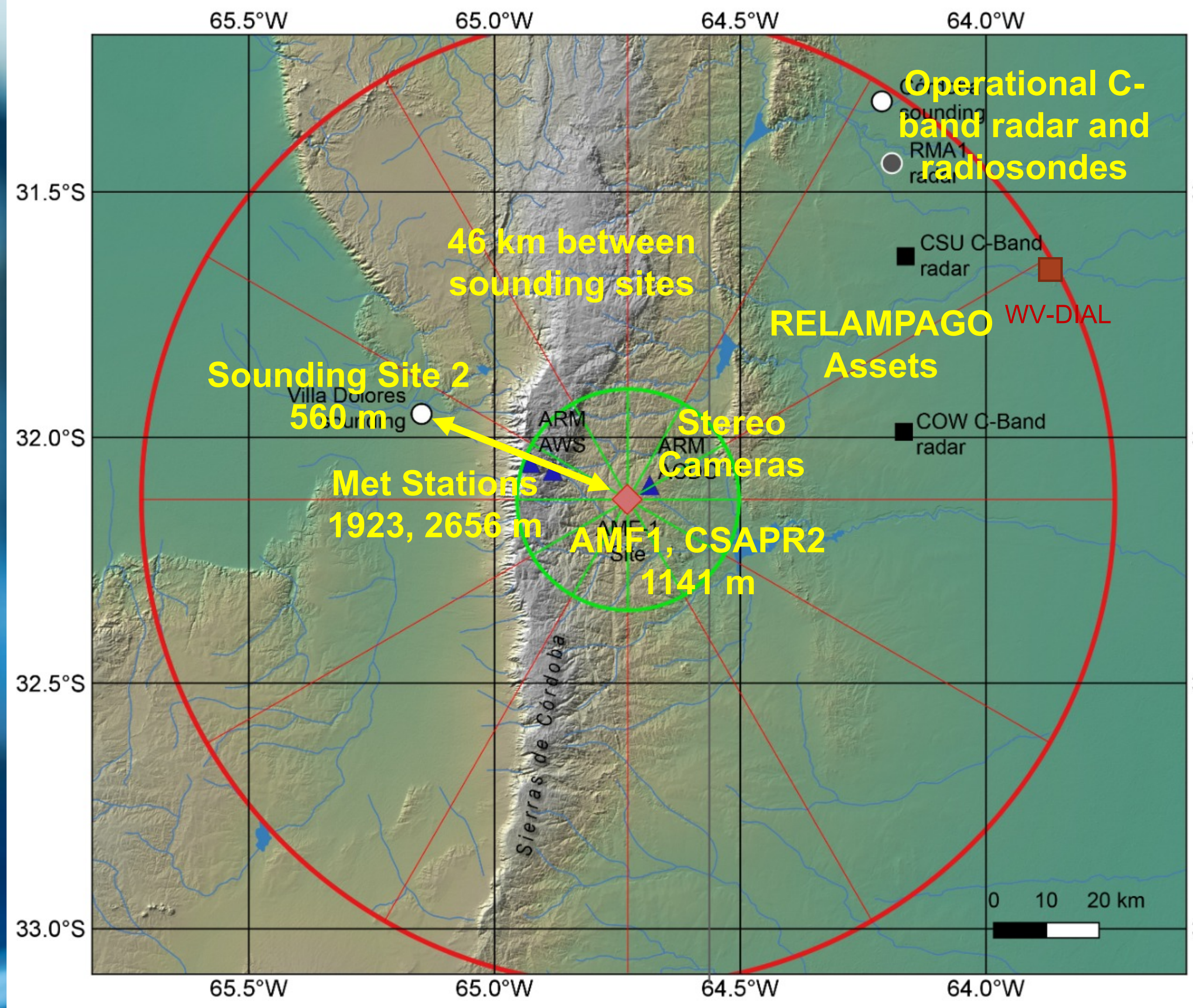


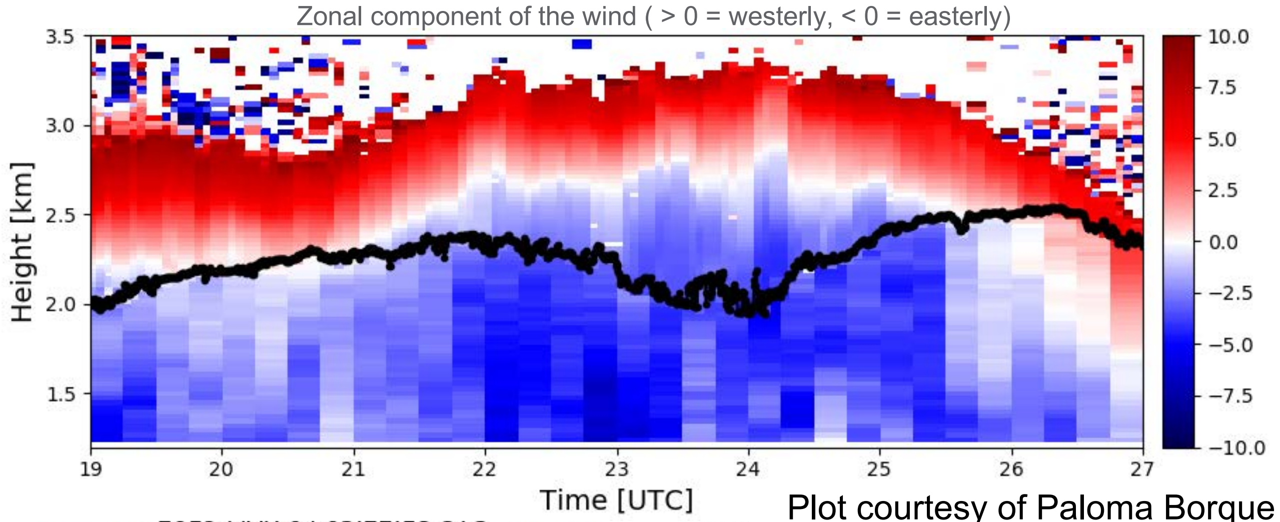

Figure courtesy of Steve Nesbitt

Photo by Jason Tomlinson

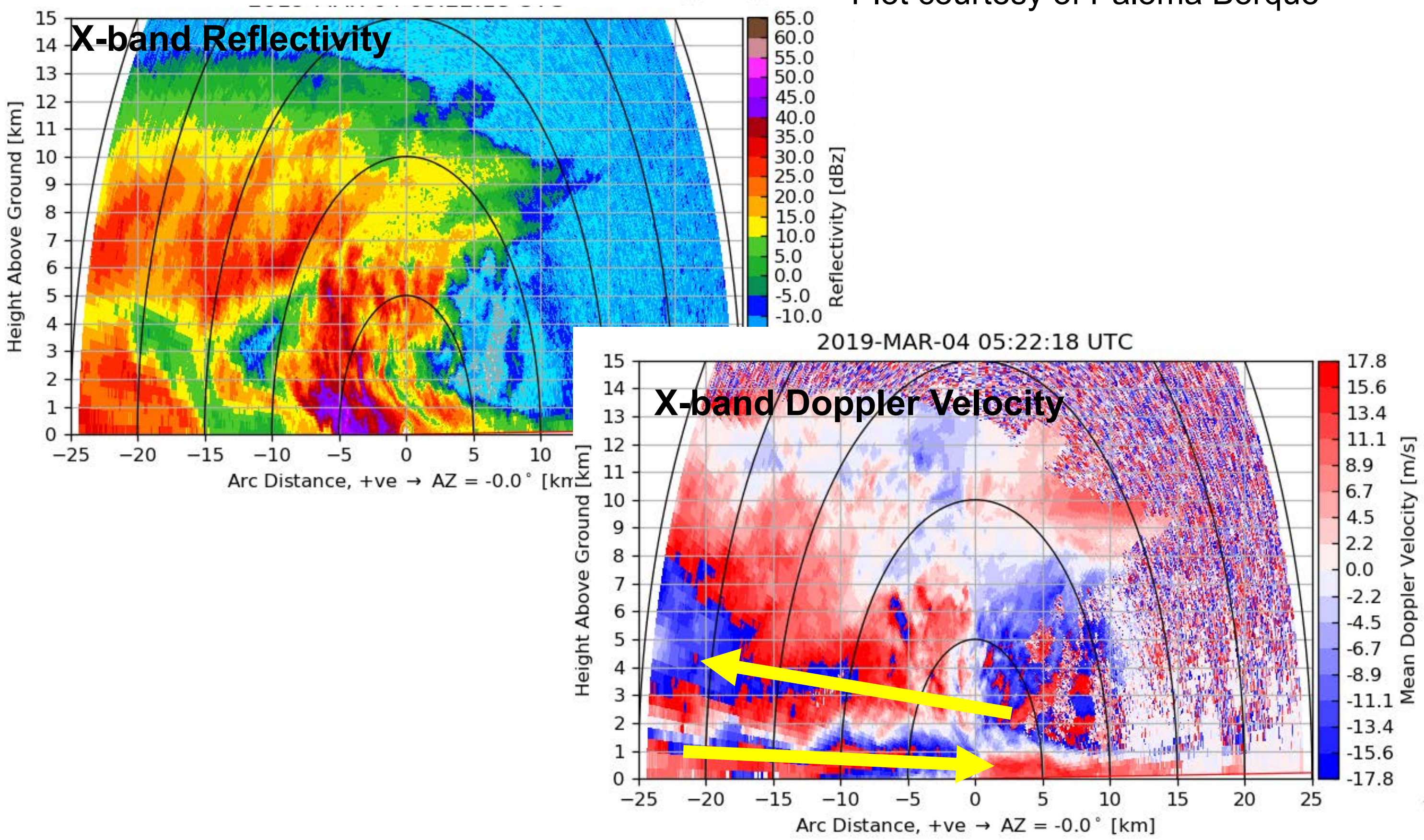
Photo by Jason Tomlinson

# Ground Measurements

| Property | Instrument |
|---|---|
| **Hydrometeor radar reflectivity, Doppler velocity and spectra, cloud/precipitation kinematic and microphysical retrievals** | **C-band Scanning ARM Precipitation Radar**<br>**Ka/X-band Scanning ARM Cloud Radar**<br>Ka-band ARM Cloud Radar<br>Radar wind profiler |
| Heights of cloud bases and tops, cloud sizes and vertical velocities | ARM Cloud Digital Cameras |
| Cloud base height | Ceilometer |
| Cloud scene/fraction | Total Sky Imager |
| Raindrop size distribution, fall speeds, rainfall | Laser disdrometer<br>2D video disdrometer<br>Tipping bucket rain gauge<br>Weighing bucket rain gauge<br>Optical rain gauge<br>Present Weather Detector |
| Liquid water path, precipitable water | 2-Channel Microwave Radiometer<br>High-Frequency Microwave Radiometer |
| Surface pressure, temperature, humidity, winds, visibility | Surface meteorological instrumentation (x4) |
| Vertical profiles of temperature, humidity, winds | Balloon-borne sounding system (x2)<br>Radar wind profiler<br>Microwave radiometers |
| Boundary layer winds and turbulence | Doppler lidar<br>Sodar |
| Surface latent and sensible heat fluxes, $CO_2$ flux, turbulence, soil moisture, energy balance | Eddy Correlation flux measurement system<br>Surface Energy Balance System |



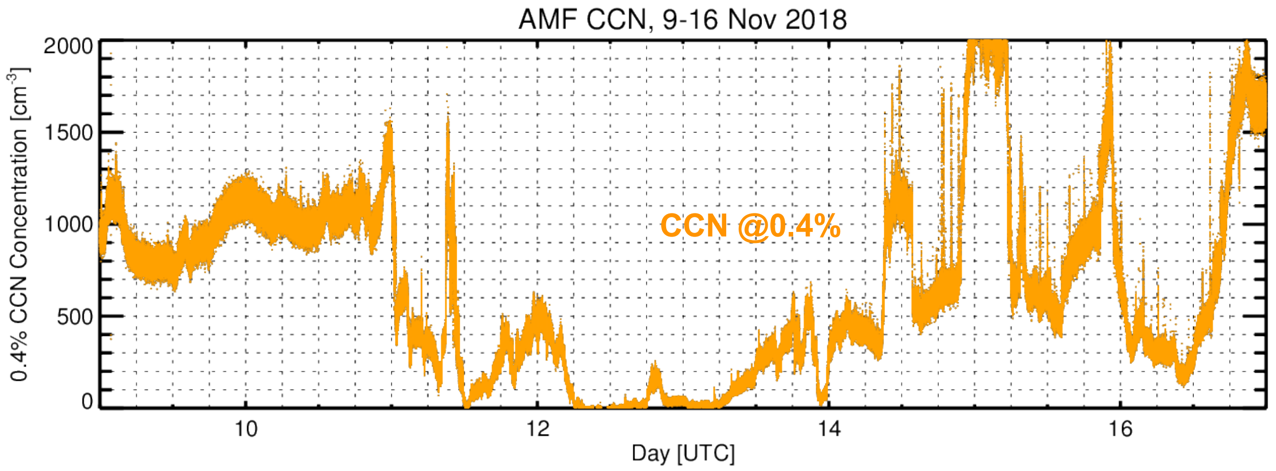

Plot courtesy of Paloma Borque

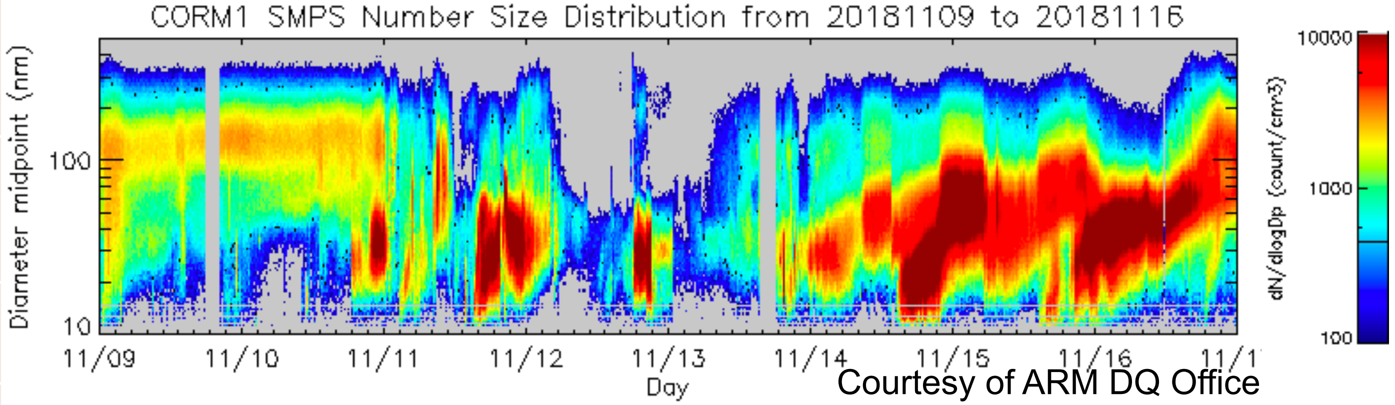



Plots courtesy of Joseph Hardin and Nitin Bharadwaj

# Ground Measurements

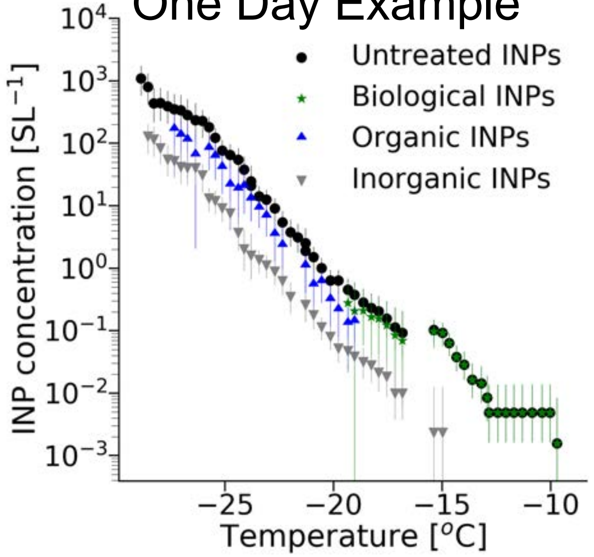
| Property | Instrument |
|---|---|
| Upwelling and downwelling radiation | Surface Energy Balance System<br>Infrared thermometer – ground and sky<br>Atmospheric Emitted Radiation Interferometer<br>Sky radiation radiometers<br>Ground radiation radiometers<br>Hemispheric Shortwave Array Spectroradiometer<br>Zenith Shortwave Array Spectroradiometer<br>Multifilter radiometer<br>Multifilter Rotating Shadowband Radiometer<br>Cimel Sun Photometer |
| Aerosol backscatter profile | Micropulse lidar<br>Doppler lidar<br>Ceilometer |
| Aerosol optical depth | Cimel Sun photometer<br>Multifilter Rotating Shadowband Radiometer |
| CCN concentration | Dual Column Cloud Condensation Nuclei counter |
| CN concentration | Condensation Particle Counters |
| INP concentration | Filters processed in CSU ice spectrometer |
| Aerosol chemical composition | Aerosol Chemistry Speciation Monitor |
| Black carbon | Single Particle Soot Photometer |
| Aerosol extinction | Ambient and variable humidity nephelometers |
| Aerosol absorption | Particle Soot Absorption Photometer |
| Aerosol particle size distribution | Ultra-High Sensitivity Aerosol Spectrometer<br>Scanning Mobility Particle Sizer<br>Aerodynamic Particle Sizer |
| $O_3$, CO, $N_2O$, $H_2O$ concentration | Trace gas instrument system |



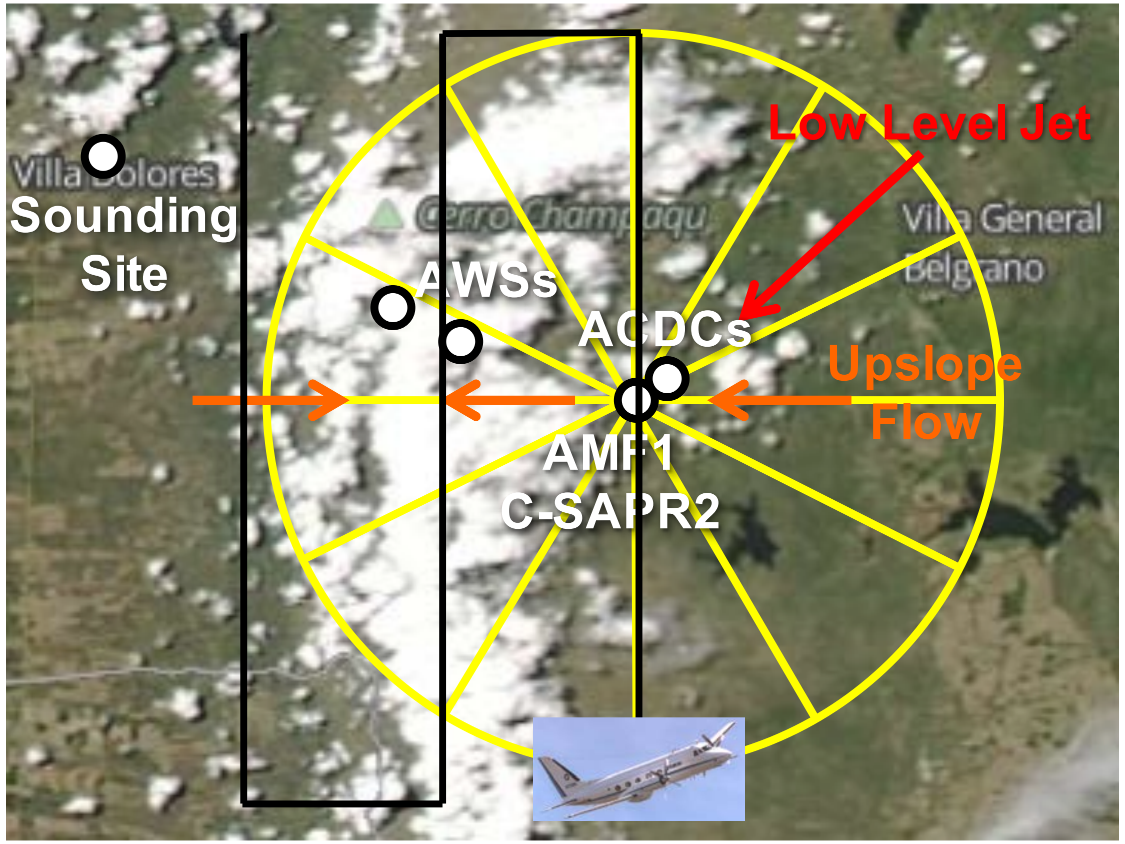



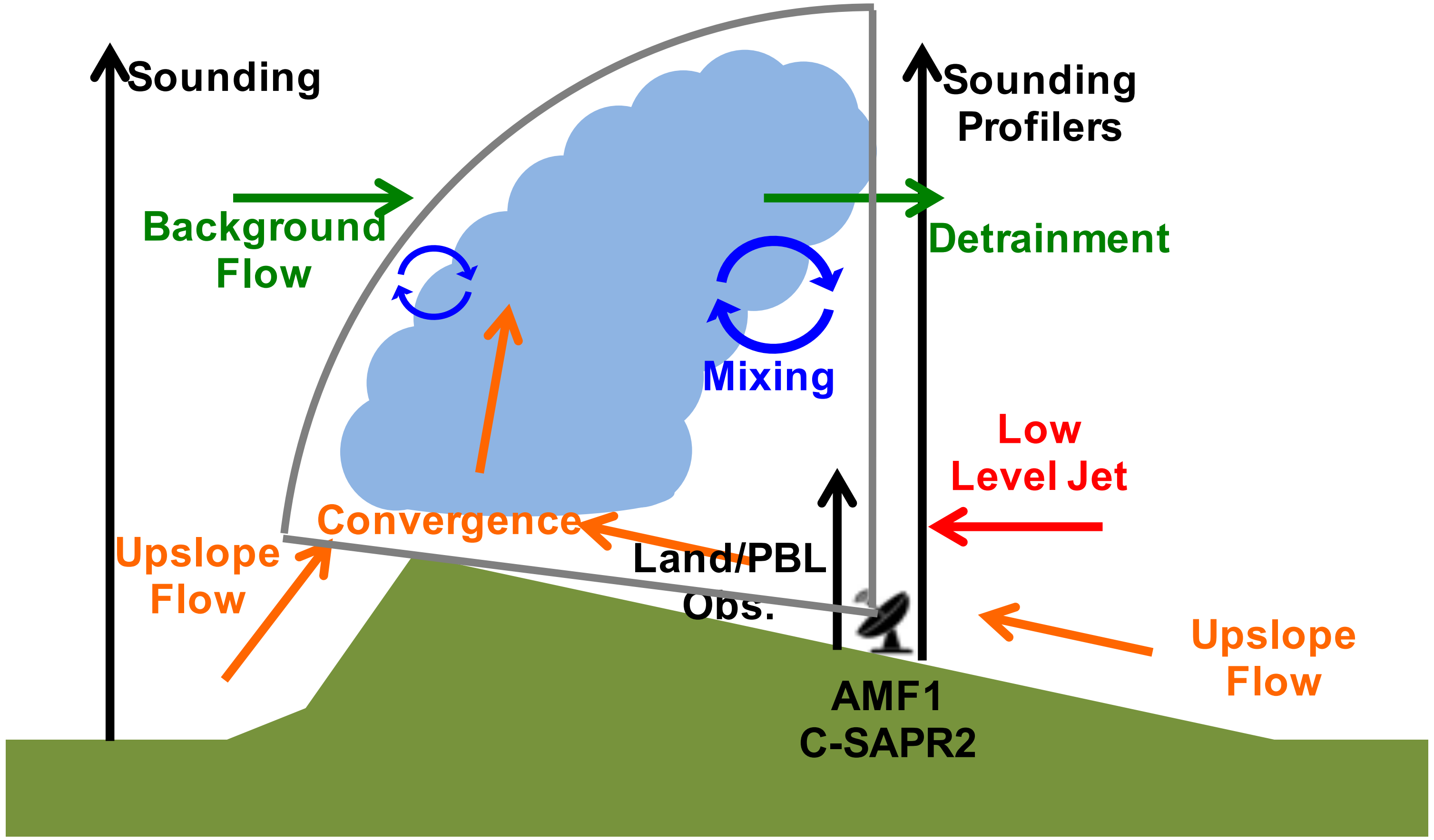

Courtesy of ARM DQ Office

Plot to right courtesy of Paul DeMott, Thomas Hill, Sonia Kreidenweis (CSU), and Baptiste Testa (U. Lyon)



# Measurement Strategy




- Measure cloud base inflow properties with in situ/remote sensing measurements of clouds, precipitation, and cloud-detrained air properties in the free troposphere, with a focus on daytime operations and consistent measurements for many cases over the length of the campaign
- Measure conditions in and around cumulus clouds (pre-deep convection) with G-1 aircraft in situ measurements during the IOP (early Nov to early Dec 2018)

# G-1 Flights

| Primary Objective | # of Flights | Dates |
|---|---|---|
| Cumulus-Environment Interactions | 8 | Nov 4, 16, 17, 20, 24, 25<br>Dec 3, 7 |
| Deep Convective Initiation | 8 | Nov 6, 10, 12, 21, 28, 29<br>Dec 4, 5 |
| Microphysics Measurements Within Radar Scans | 3 | Nov 22<br>Dec 1, 2 |
| Aerosol Characterization | 3 | Nov 14, 15<br>Dec 8 |

Photo by Jason Tomlinson

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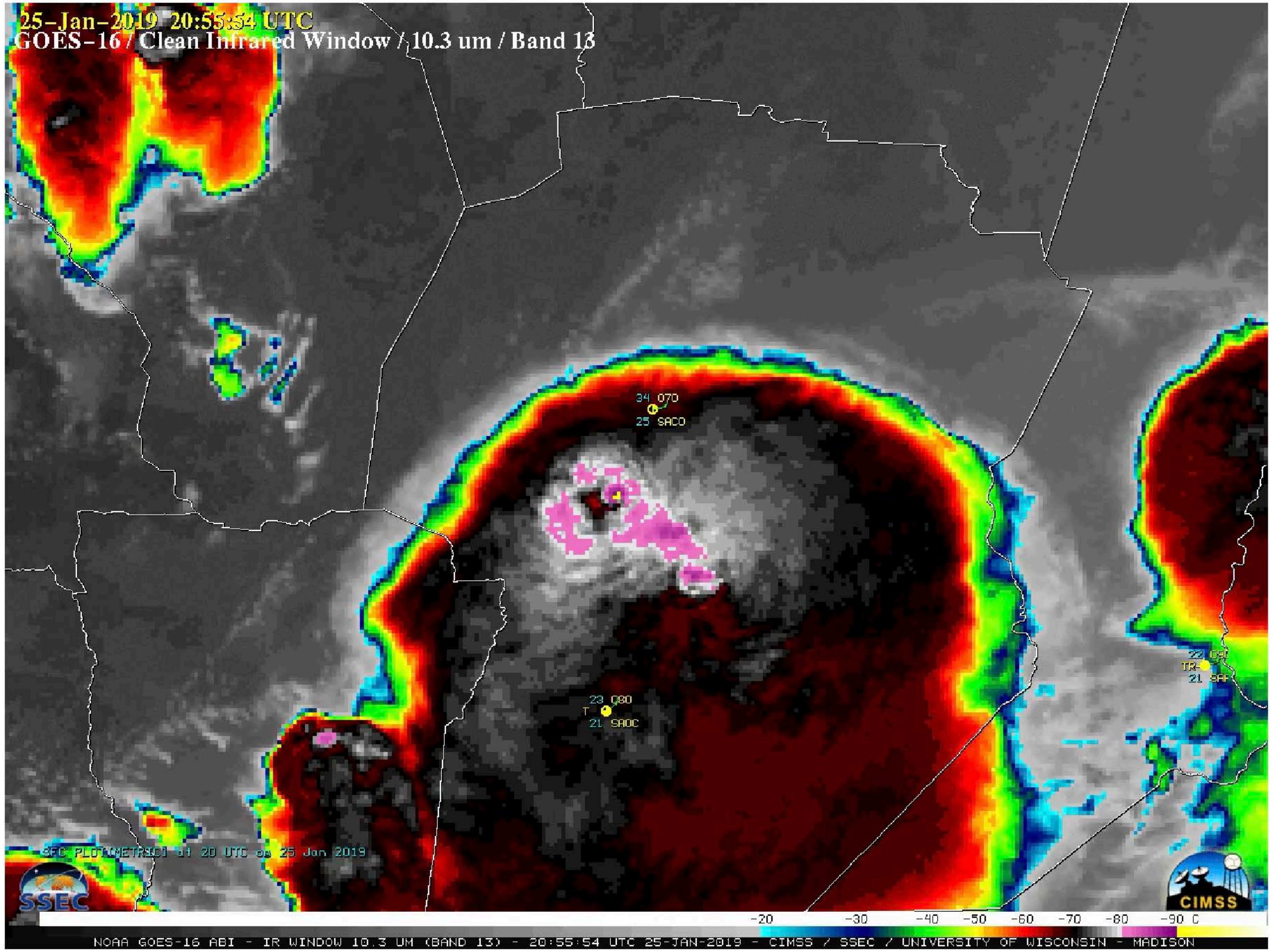
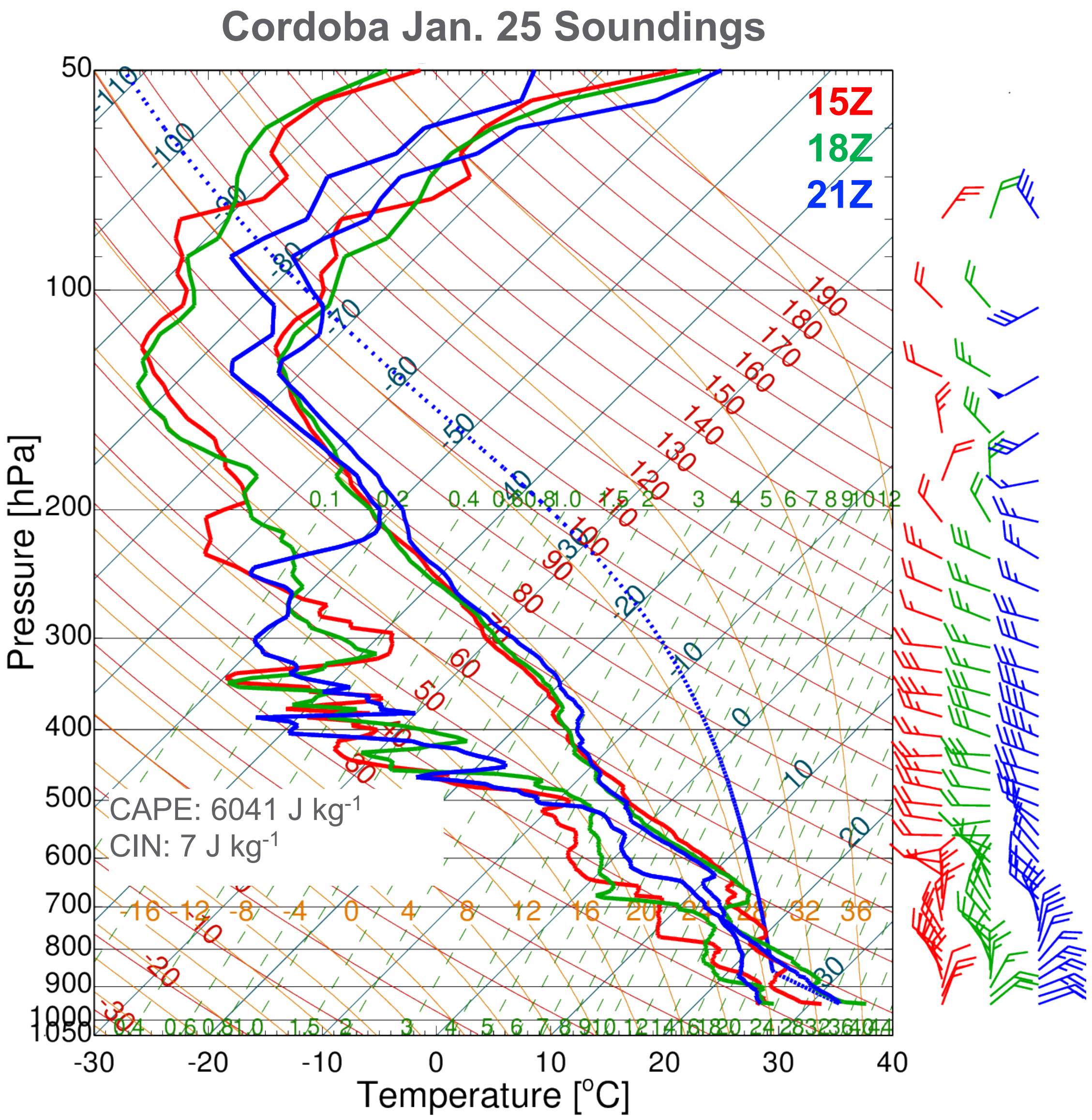
# What was observed?

- 173 of 197 days had cumulus or stratocumulus form overhead
- 79 of 197 days had deep convection pass directly overhead
- 92 of 197 days had measurable precipitation at the AMF site
- Time periods are now being categorized by cloud type and precipitation in more detail
- Close to 20 days have been identified as possible LASSO daytime shallow to deep transition cases with C-band or X-band radar volumes
  - 7 days have pre-convective initiation aircraft measurements
  - 8 days have mobile RELAMPABO missions
  - 14 days have GOES-16 rapid scan data

# Example Case #1: Intense and Organized



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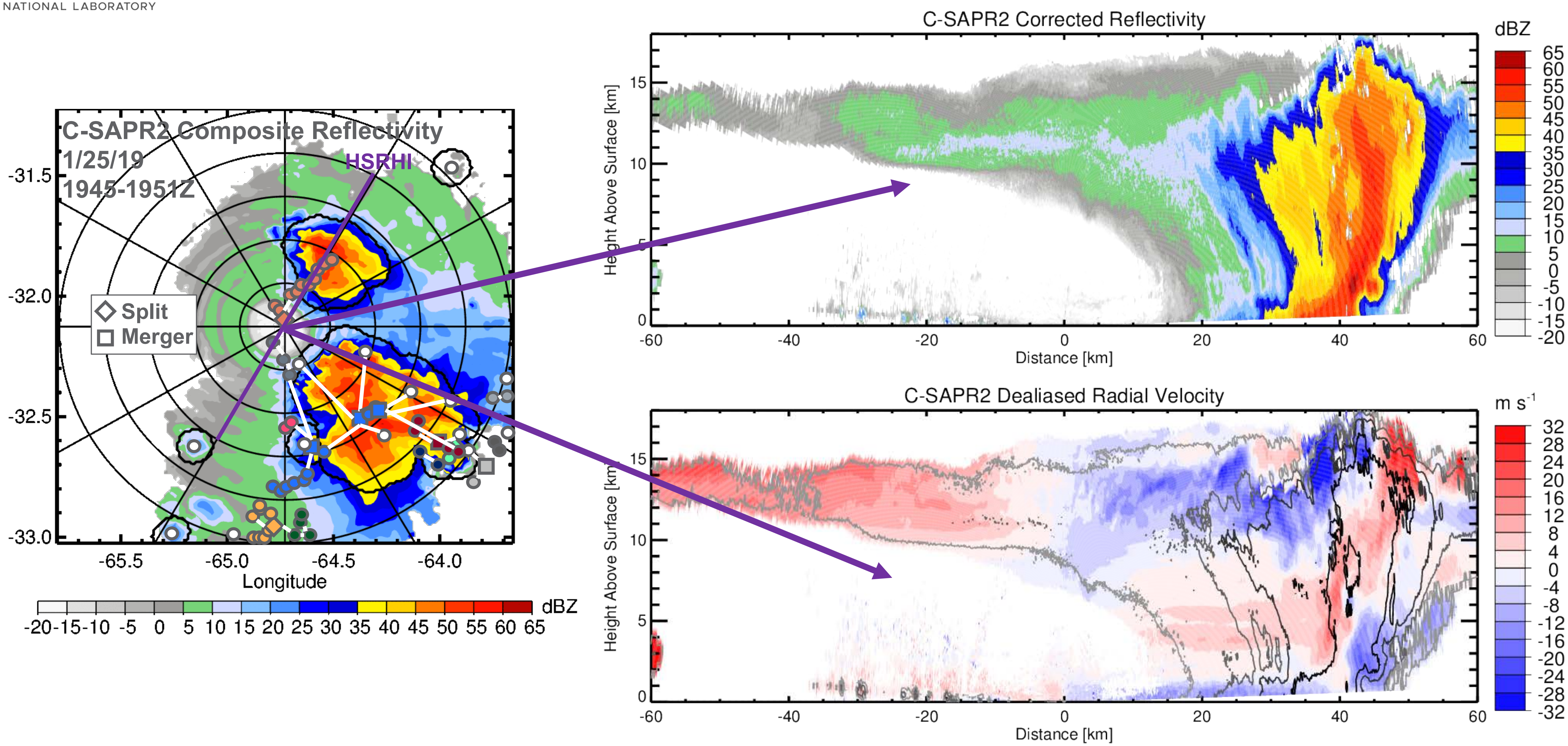
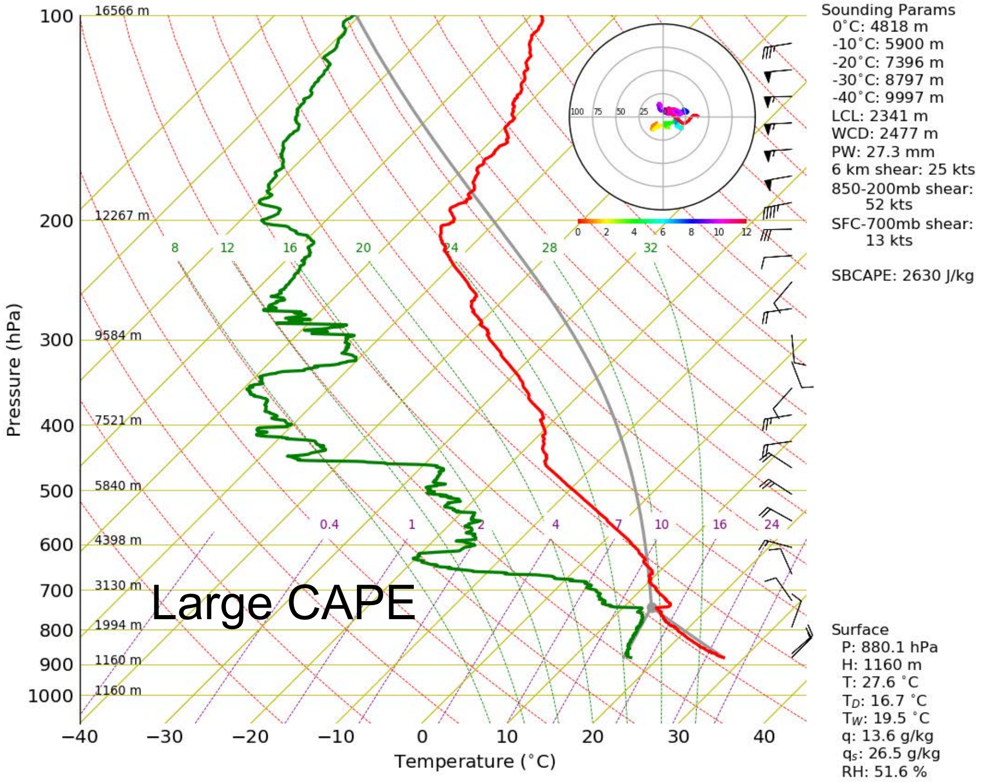
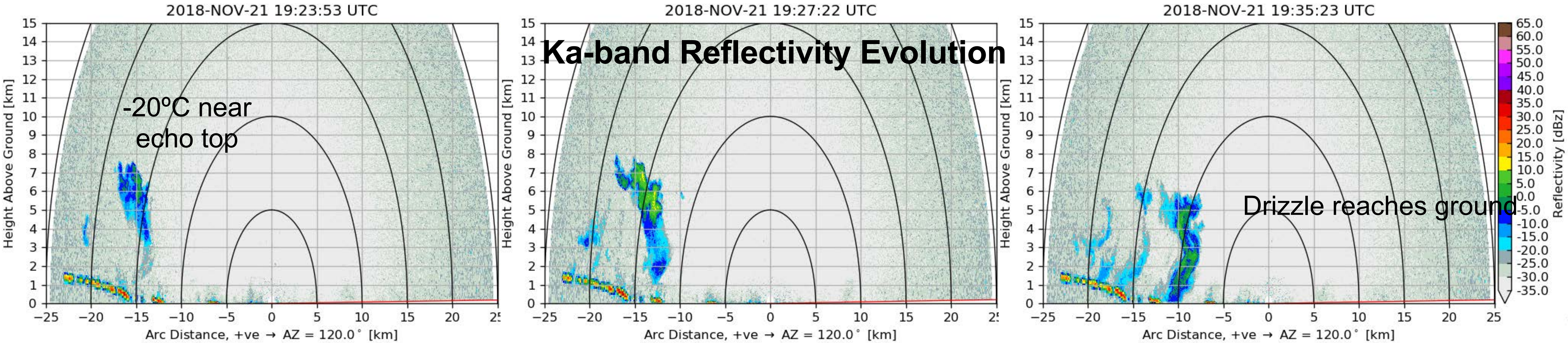


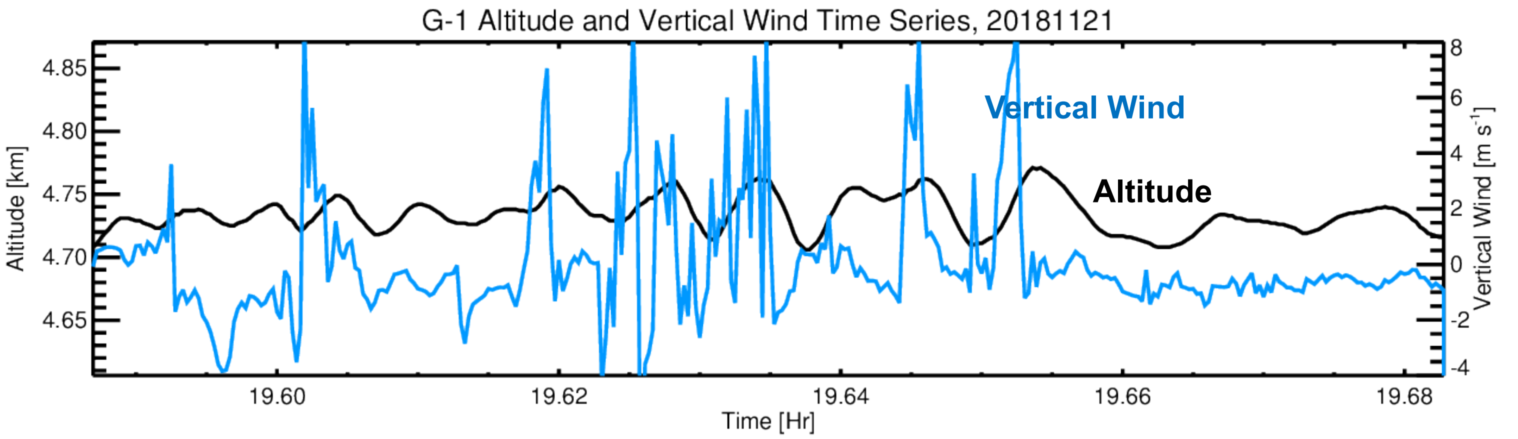
# Example Case #2: Weak and Unorganized

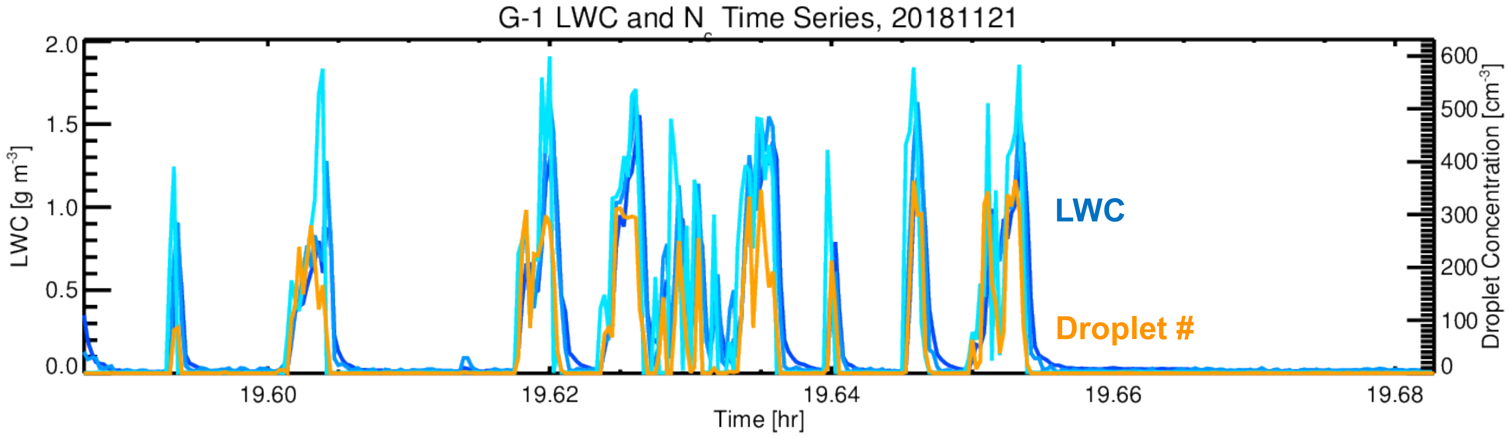



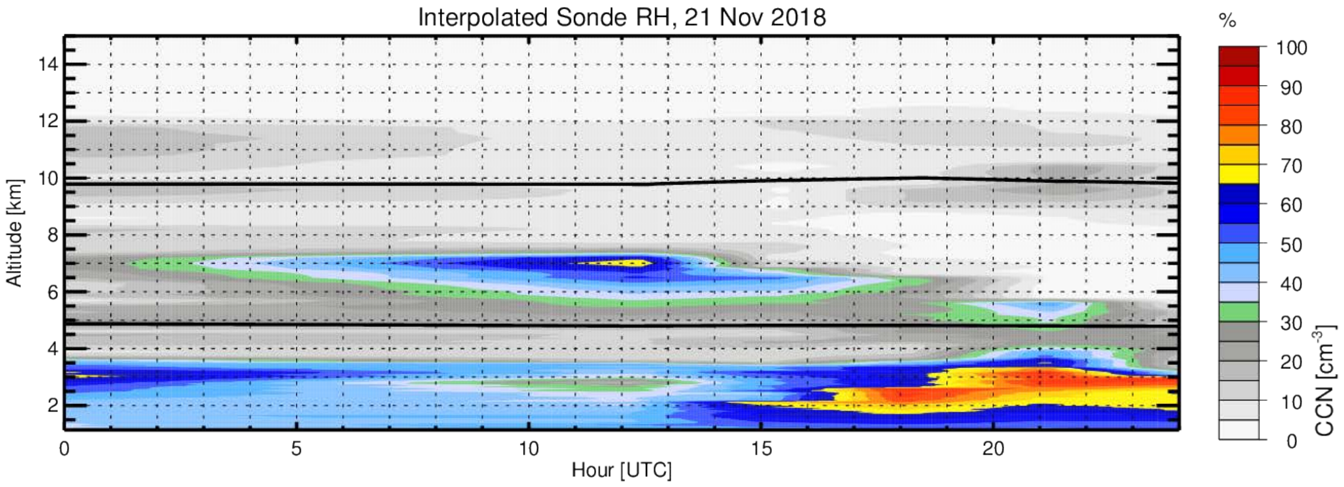



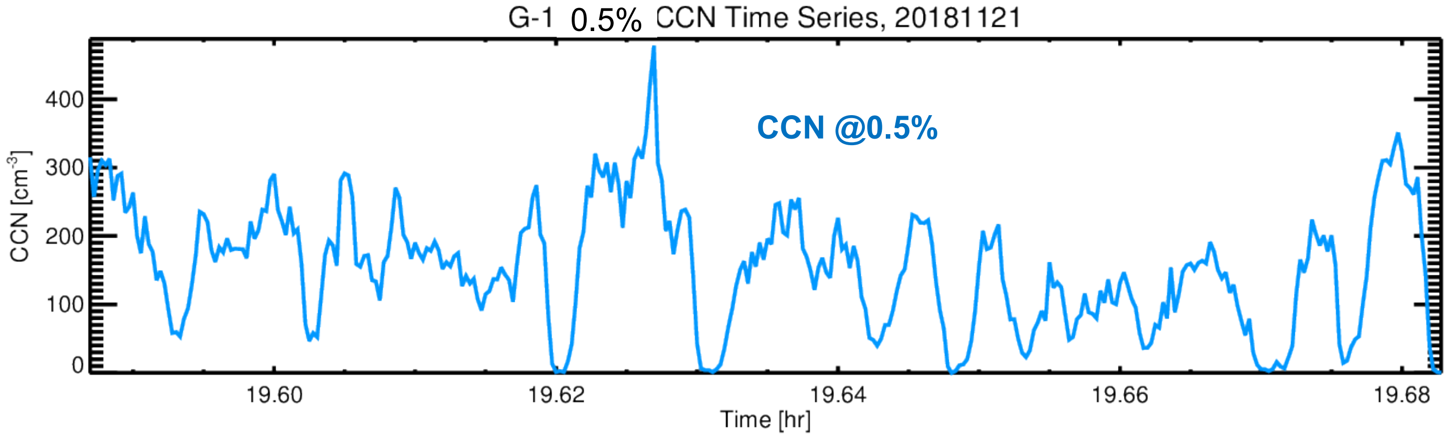

Images from Joseph Hardin and Nitin Bharadwaj

# Example Case #2: Weak and Unorganized

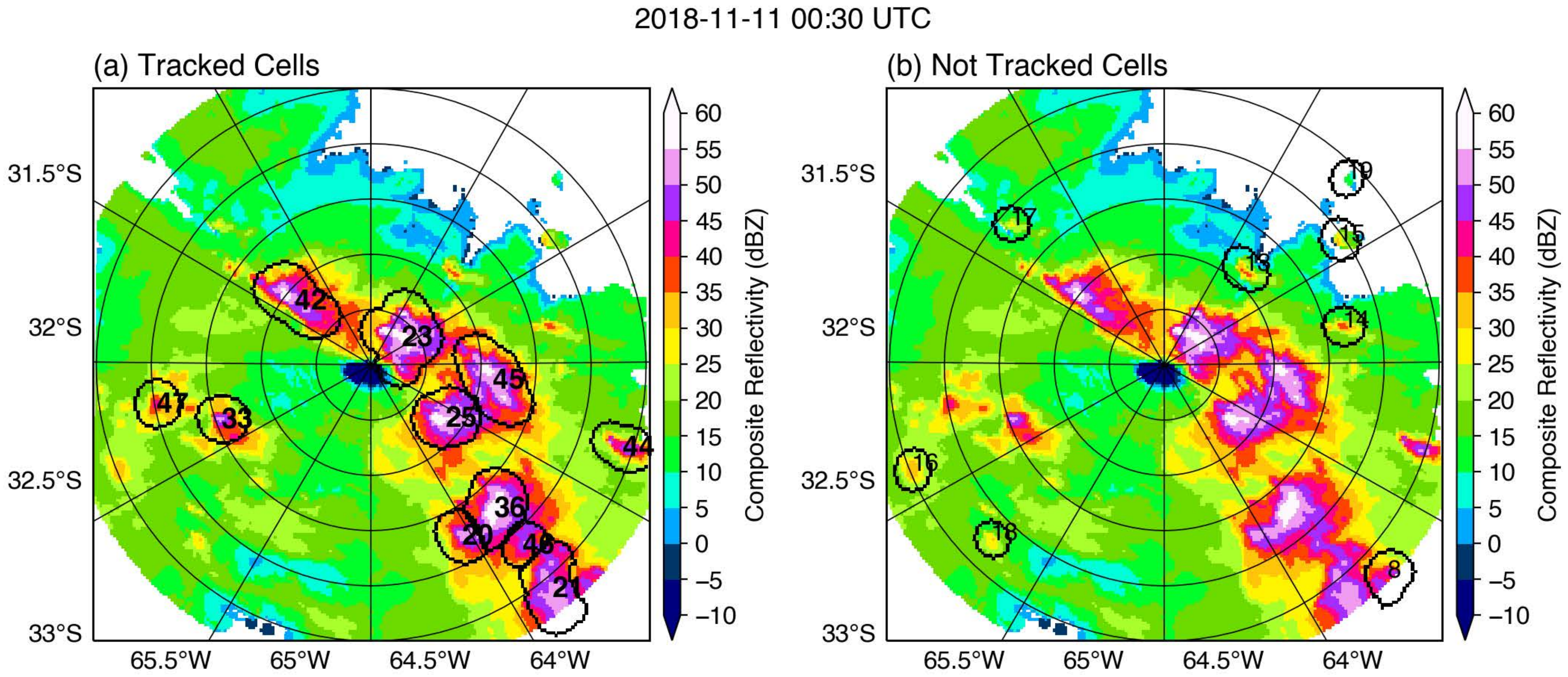



# Convective Cell and Cluster Tracks (Z. Feng, J. Hardin)



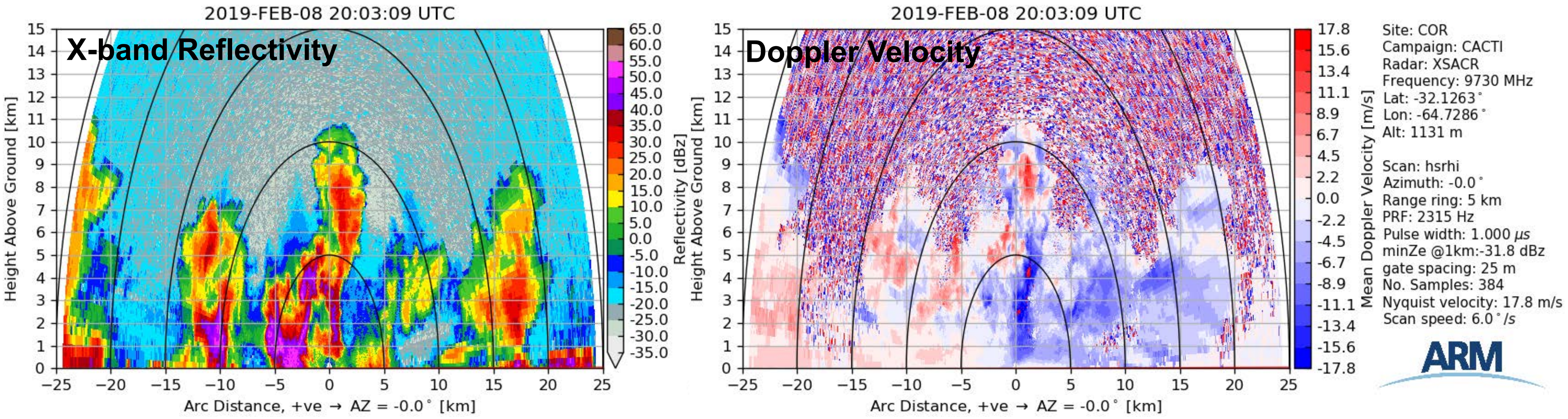

Version 1 code for tracking convective cells including mergers and splits using Taranis C-SAPR2 15-minute PPI volumes is completed. Clusters will be tracked next.

This will result in a database of tracked cells with saved radar-measured properties that can be analyzed as a function of life cycle.

Environmental measurements, detailed HSRHI scans, and parallax corrected satellite retrievals will also be tagged to tracked cells passing close to the site.

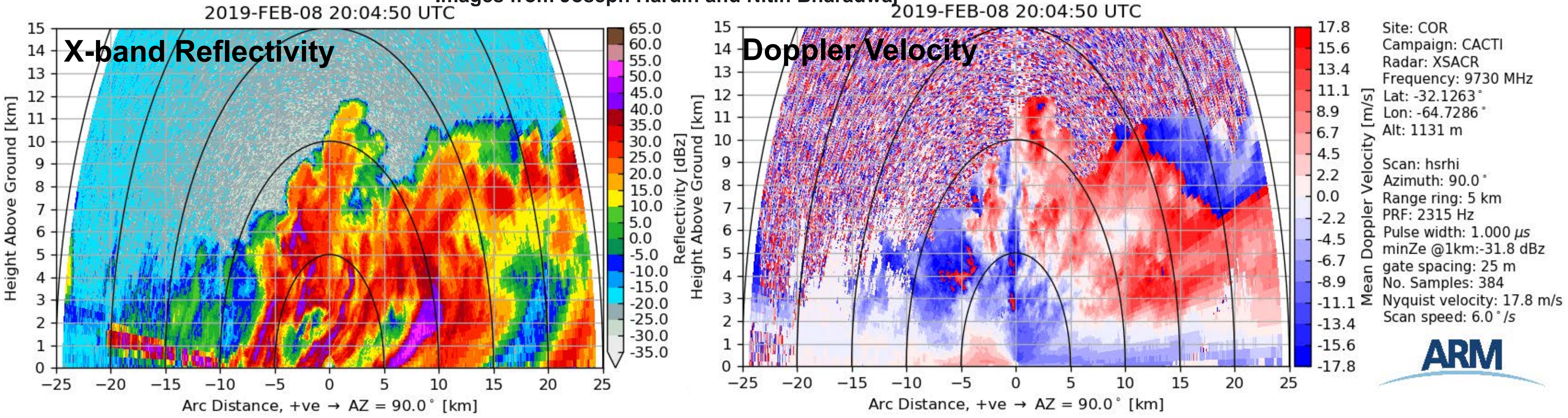
# Tracking detailed microphysical and kinematic evolution

South to North




Images from Joseph Hardin and Nitin Bharadwaj

West to East



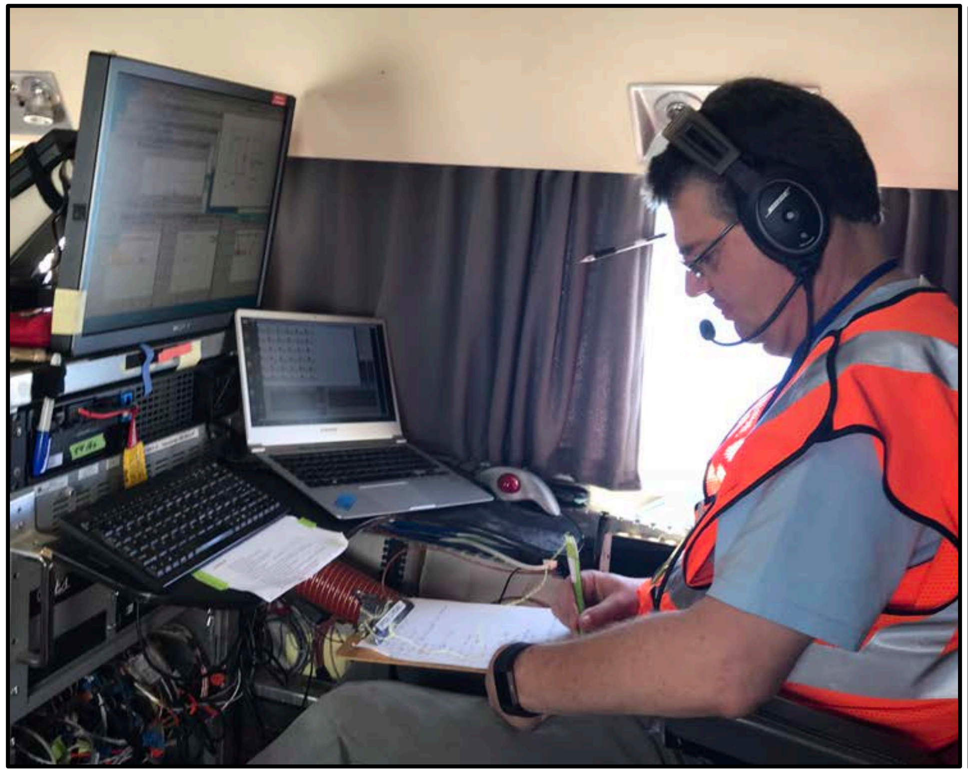
# Thank You

CACTI Background, Science Plan, and Final Report:
www.arm.gov/research/campaigns/amf2018cacti

CACTI Datasets (some retrievals still in progress):
www.archive.arm.gov
www.arm.gov/research/campaigns/amf2018cacti

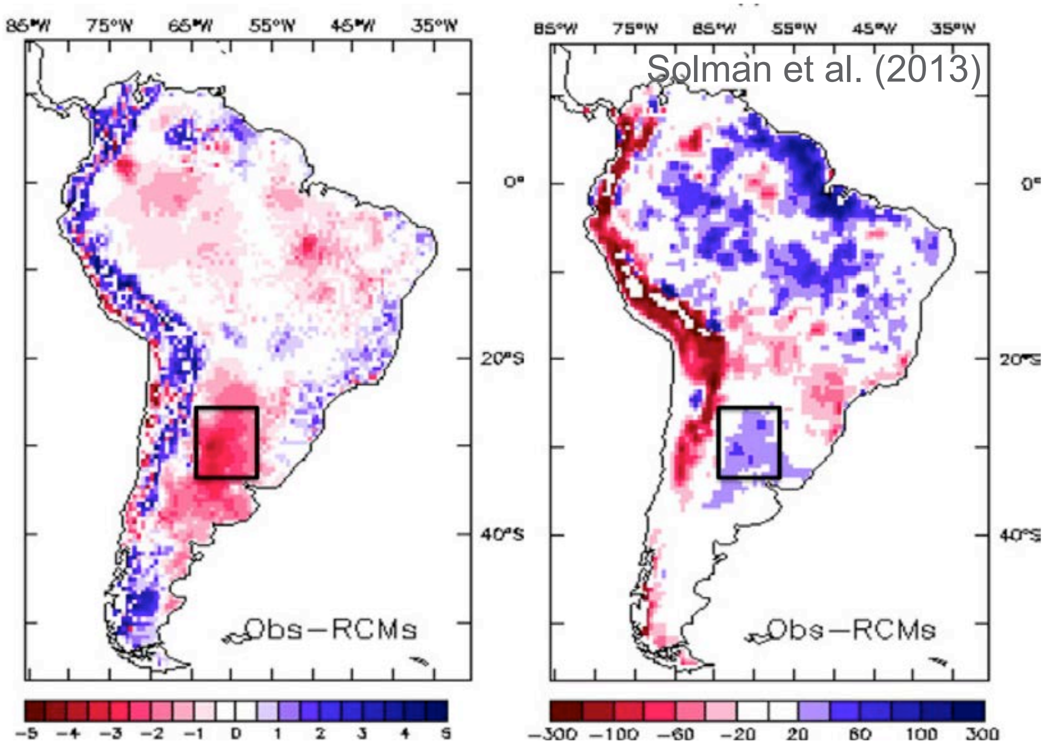
RELAMPAGO Field Catalog/Datasets:
https://www.eol.ucar.edu/field_projects/relampago

Contact: adam.varble@pnnl.gov



# Experiment Rationale: Frequent Deep Convective Upscale Growth (Mesoscale Organization)

- RCM ensemble mean summer temperature is warm-biased and precipitation is dry-biased from the Sierras de Córdoba eastward (right)
  - This is similar to the bias over the US Great Plains
- Also like the US Great Plains, an overwhelming majority of the precipitation in this region is produced by eastward propagating MCSs (bottom)



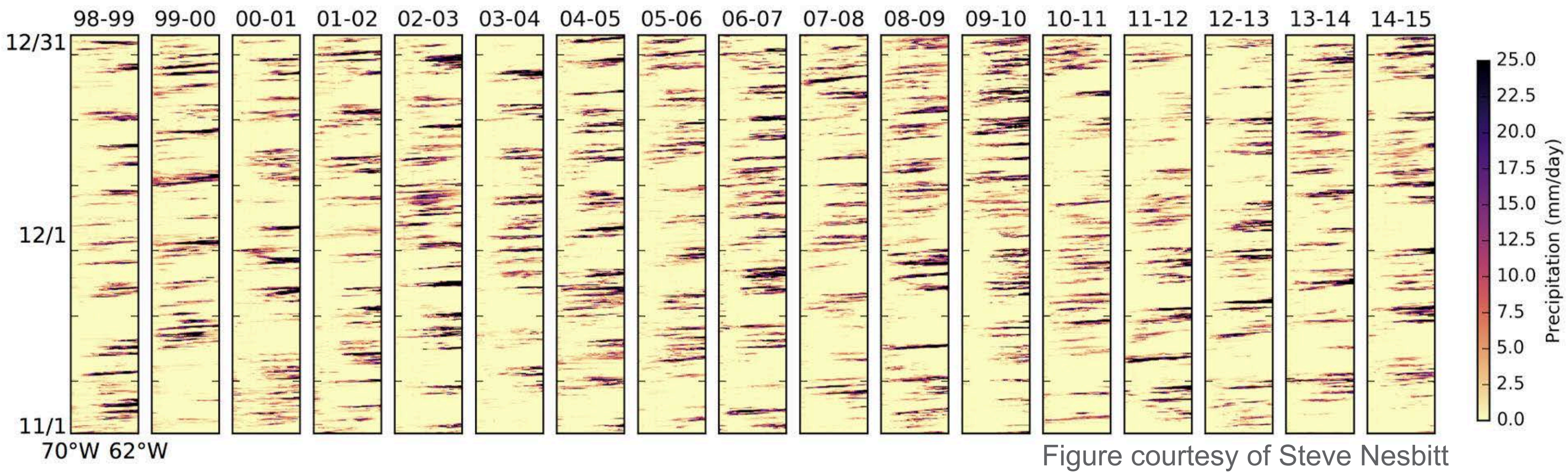




Figure courtesy of Steve Nesbitt

# G-1 Measurements

| Property | Instrument |
|---|---|
| Position/Aircraft parameters | Gust probe: Rosemount 1221F2 |
| | AIMMS-20<br>GPS (Global Positioning System) DSM 232<br>C-MIGITS III (Miniature Integrated GPS/INS Tactical System)<br>VectorNav-200 GPS/INS |
| | Video Camera P1344 |
| Meteorology | Aircraft Integrated Meteorological Measurement System |
| | Tunable diode laser hygrometer |
| | GE-1011B Chilled Mirror Hygrometer |
| | Licor LI-840A |
| | Rosemount 1201F1 |
| | Rosemount E102AL |
| Aerosol optical properties | Single Particle soot Photometer |
| | 3-wavelength Integrating Nephelometer, Model 3563 |
| | 3-wavelength Particle Soot Absorption Photometer |
| | 3-wavelength Single channel Tricolor Absorption Photometer |
| Chemical composition | Single Particle Mass Spectrometer (MiniSPLAT II) |
| Trace Gas measurements | N2O/CO -23r |
| | $O_3$ Model 49i |
| | $SO_2$ Model 43i |

| Property | Instrument |
|---|---|
| Hydrometeor size distribution | Fast Cloud Droplet Probe |
| | 2-Dimensional Stereo Probe |
| | High Volume Precipitation Sampler 3 |
| | Cloud Particle Imager |
| | Cloud Imaging Probe |
| | Cloud and Aerosol Spectrometer |
| Cloud liquid water content | Particle Volume Monitor 100-A |
| | Multi-Element Water Content System |
| | Hot-wire probe from CAPS |
| Aerosol sampling | Aerosol Isokinetic Inlet |
| | Counterflow Virtual Impactor |
| Aerosol size distribution | Ultra-high Sensitivity Aerosol Spectrometer |
| | Scanning Mobility Particle Sizer |
| | Passive Cavity Aerosol Spectrometer |
| | Optical Particle Counter Model CI-3100 |
| | Cloud and Aerosol Spectrometer – Dual Polarized |
| CN concentration | Ultrafine Condensation Particle Counter Model 3025A |
| | Condensation Particle Counter Model 3772 |
| CCN concentration | Dual-column cloud condensation nuclei counters |
| INP concentration | Filter collections for CSU Ice Spectrometer |

# Possible Daytime Shallow to Deep Cases for LASSO

| Case | Description | Observational Notes |
|---|---|---|
| October 26 | Shallow Isolated CI | |
| November 4 | Weak-moderate CI just north of and over site | Aircraft |
| November 5 | CI first to north, then west of mountains; not right over site | GOES rapid scan; RELAMPAGO mission |
| November 6 | Widespread warm rain transitioning to deep over and west of terrain | GOES rapid scan; Aircraft; RELAMPAGO mission |
| November 10 | Intense cell quickly moves off terrain and cells transition to intense, non-orographic elevated isolated, later organized | GOES rapid scan; Aircraft; RELAMPAGO mission |
| November 21 | Null case with deep congestus, ice initiation and drizzle | GOES rapid scan; Aircraft; RELAMPAGO mission |
| November 29 | Weak-moderate CI and merging near site | GOES rapid scan; Aircraft; RELAMPAGO mission |
| November 30 | Weak-moderate CI and merging near site | GOES rapid scan; RELAMPAGO mission |
| December 4 | Weak cell initiates and dies over site | GOES rapid scan; Aircraft; RELAMPAGO mission |
| December 5 | CI over and near site with some organization | GOES rapid scan; Aircraft; RELAMPAGO mission |
| December 19 | CI near and over site without upscale growth | |
| January 22 | CI near site, supercell, multi-cell, and decay | |
| January 23 | Widespread CI over terrain and then west of terrain with organization | GOES rapid scan |
| January 25 | CI close to site and growth into organized, very deep system | GOES rapid scan |
| January 29 | CI close to site and growth into organized, intense system | GOES rapid scan |
| January 31 | CI over and west of terrain with some intense and organized | GOES rapid scan |
| February 8 | CI and continuous growth of intense convection over site | GOES rapid scan; C-SAPR2 down partway through event |
| February 23 | Elevated CI over terrain | |
| March 14-15 | Weak-moderate CI over terrain | GOES rapid scan; X-band volumes; C-band W-E HSRHIs |

Note: Cases from Nov 10 through Jan 31 have CSU C-band radar data. Many unlisted nocturnal events also occur.