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The CACTI Field Campaign: Improving understanding of convective cloud processes in complex terrain

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U.S. DEPARTMENT OF ENERGY BATTELLE

The Cloud Aerosol and Complex Terrain Interactions (CACTI) Experiment

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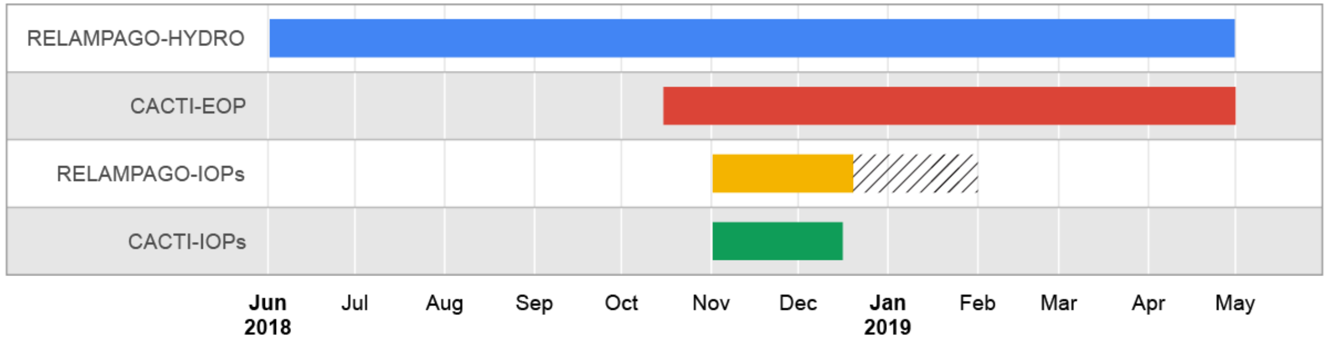
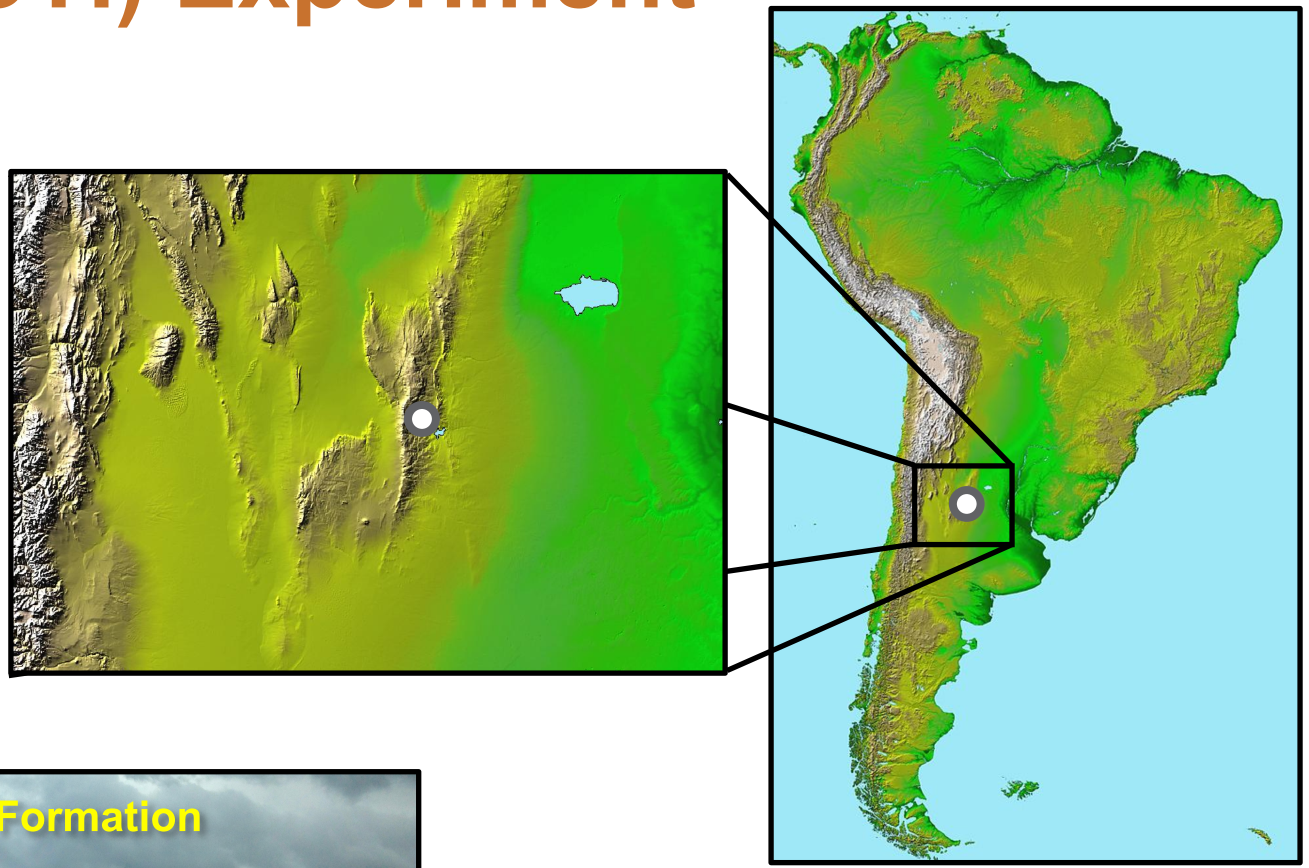
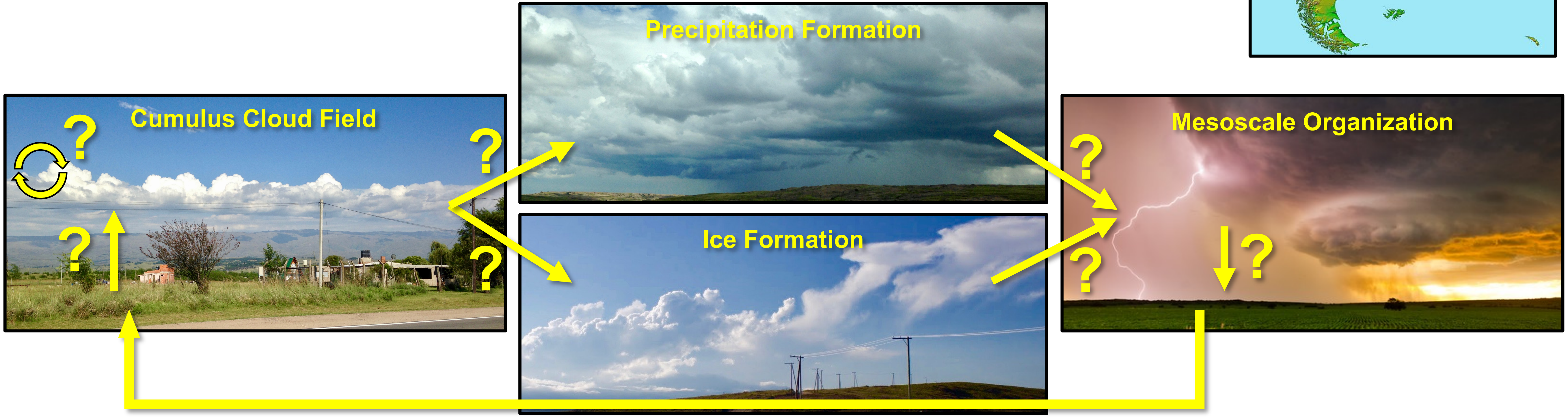
Facilities: DOE ARM AMF-1 (> 50 instruments), C-SAPR2 radar, G-1 aircraft (IOP, ~40 in situ instruments), and supplemental sites

Primary Goal: Quantify the sensitivity of convective cloud system evolution to environmental conditions by utilizing a natural hotspot for convective cloud development and organization







Siting

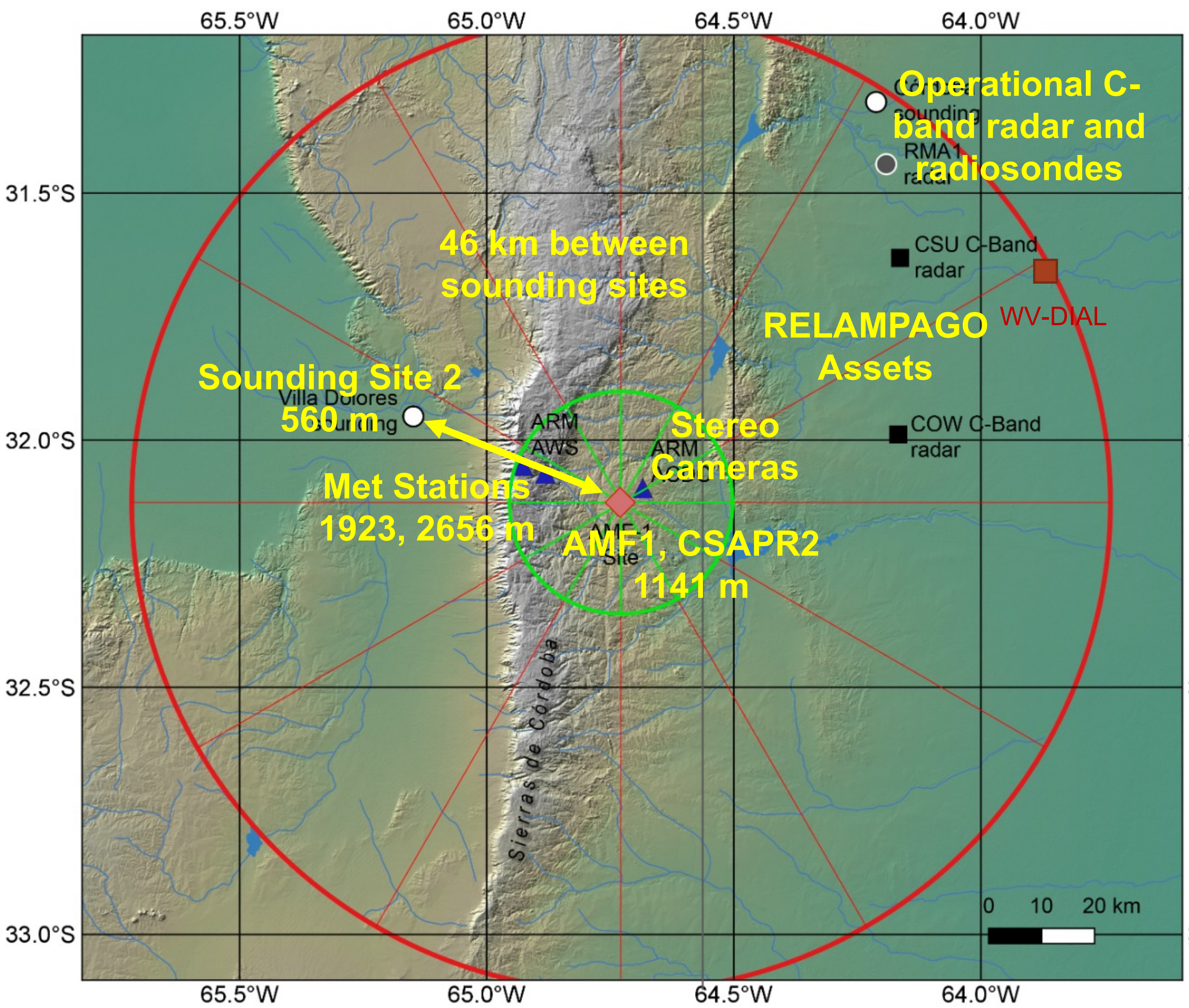
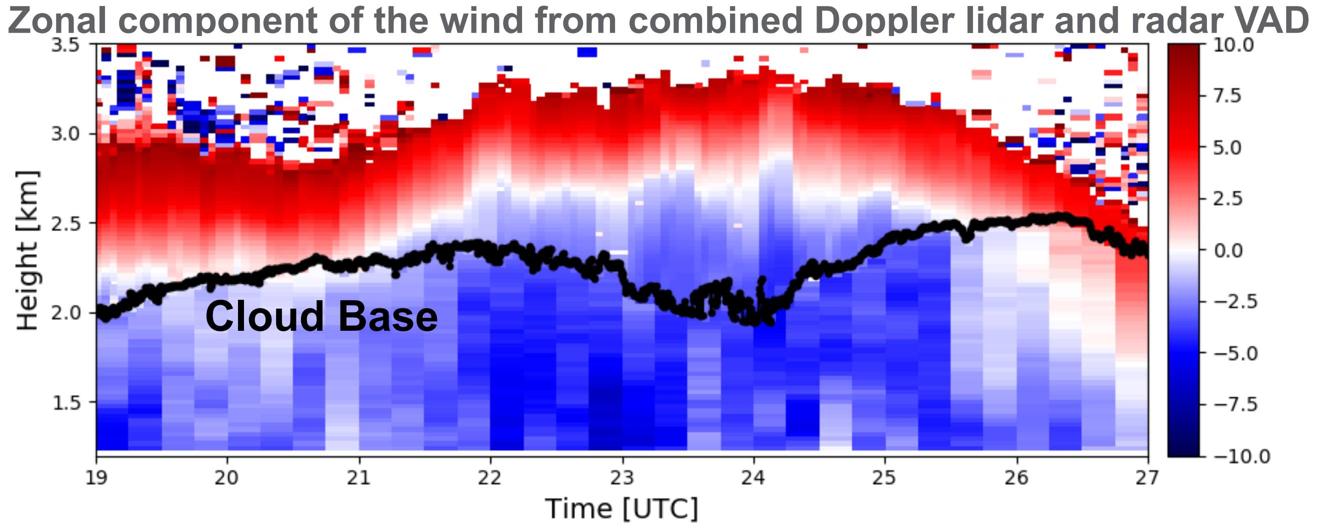


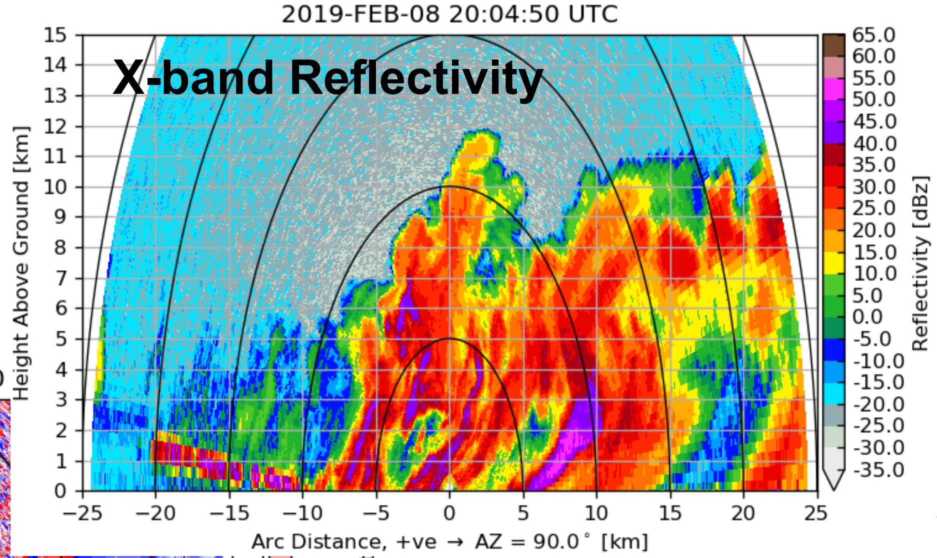

Photo by Jason Tomlinson

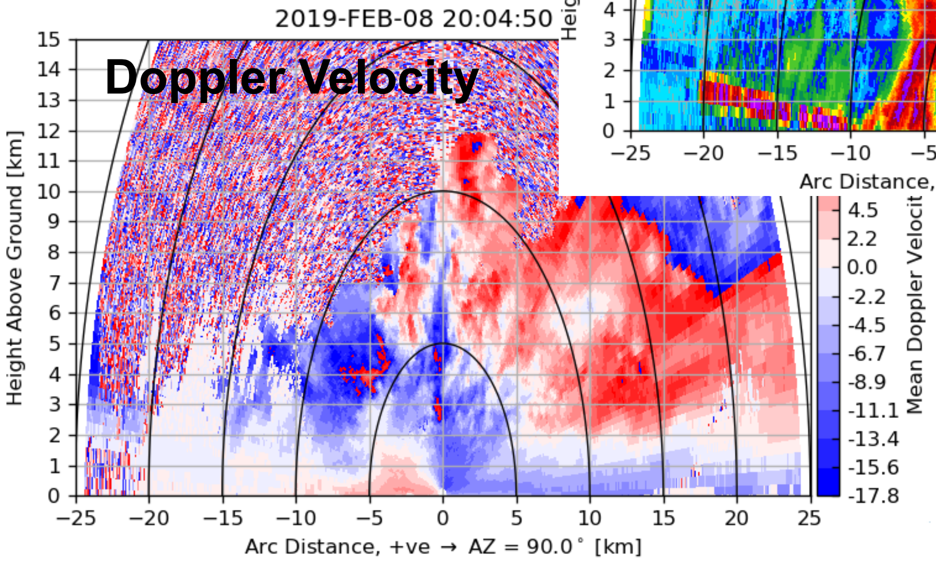

Photo by Jason Tomlinson

Ground Measurements

Property	Instrument
Hydrometeor radar reflectivity, Doppler velocity and spectra, cloud/precipitation kinematic and microphysical retrievals	C-band Scanning ARM Precipitation Radar Ka/X-band Scanning ARM Cloud Radar Ka-band ARM Cloud Radar 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 2D video disdrometer Tipping bucket rain gauge Weighing bucket rain gauge Optical rain gauge Present Weather Detector
Liquid water path, precipitable water	2-Channel Microwave Radiometer 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) Radar wind profiler Microwave radiometers
Boundary layer winds and turbulence	Doppler lidar Sodar
Surface latent and sensible heat fluxes, CO_2 flux, turbulence, soil moisture, energy balance	Eddy Correlation flux measurement system Surface Energy Balance System

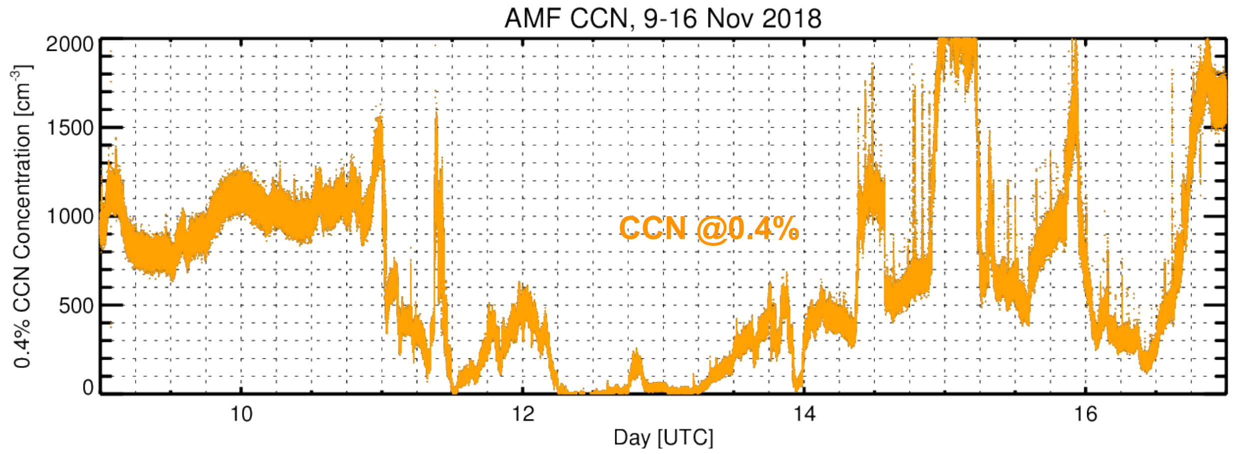


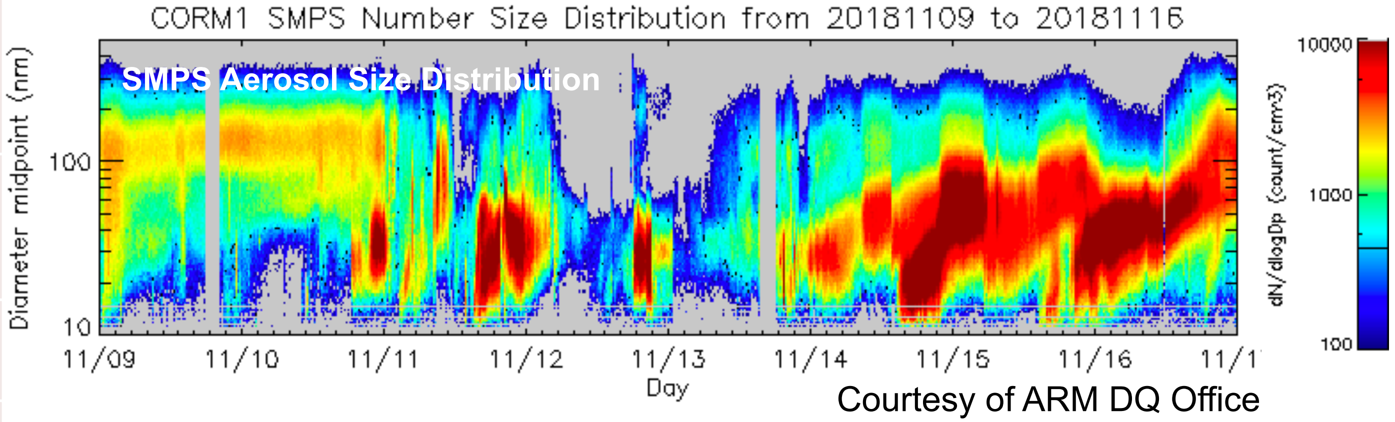




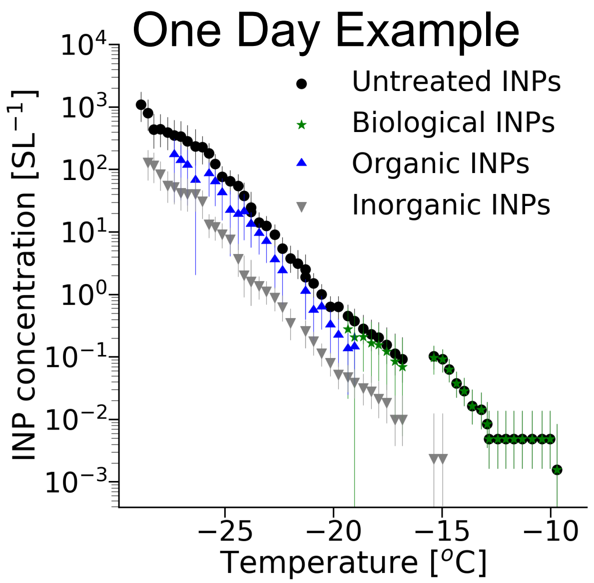
Ground Measurements

Property	Instrument
Upwelling and downwelling radiation	Surface Energy Balance System Infrared thermometer – ground and sky Atmospheric Emitted Radiation Interferometer Sky radiation radiometers Ground radiation radiometers Hemispheric Shortwave Array Spectroradiometer Zenith Shortwave Array Spectroradiometer Multifilter radiometer Multifilter Rotating Shadowband Radiometer Cimel Sun Photometer
Aerosol backscatter profile	Micropulse lidar Doppler lidar Ceilometer
Aerosol optical depth	Cimel Sun photometer 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 Scanning Mobility Particle Sizer Aerodynamic Particle Sizer
O_3, CO, N_2O, H_2O concentration	Trace gas instrument system



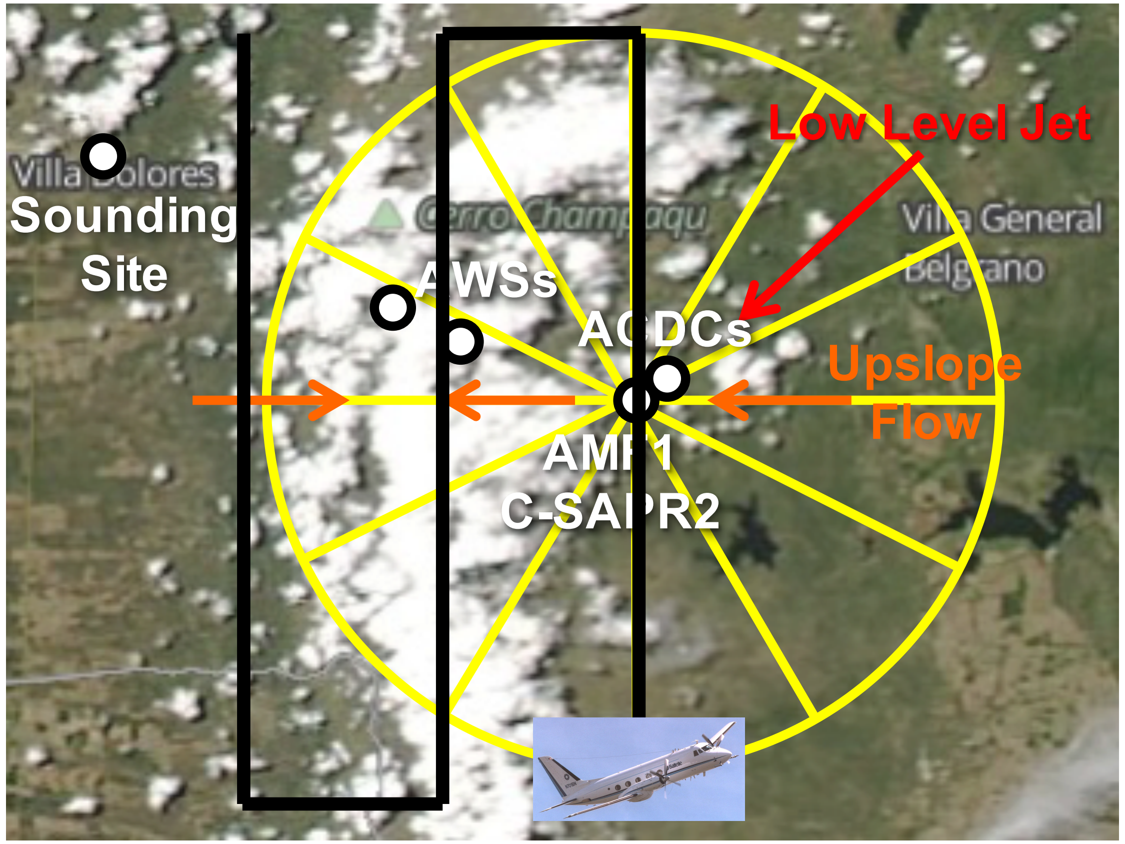


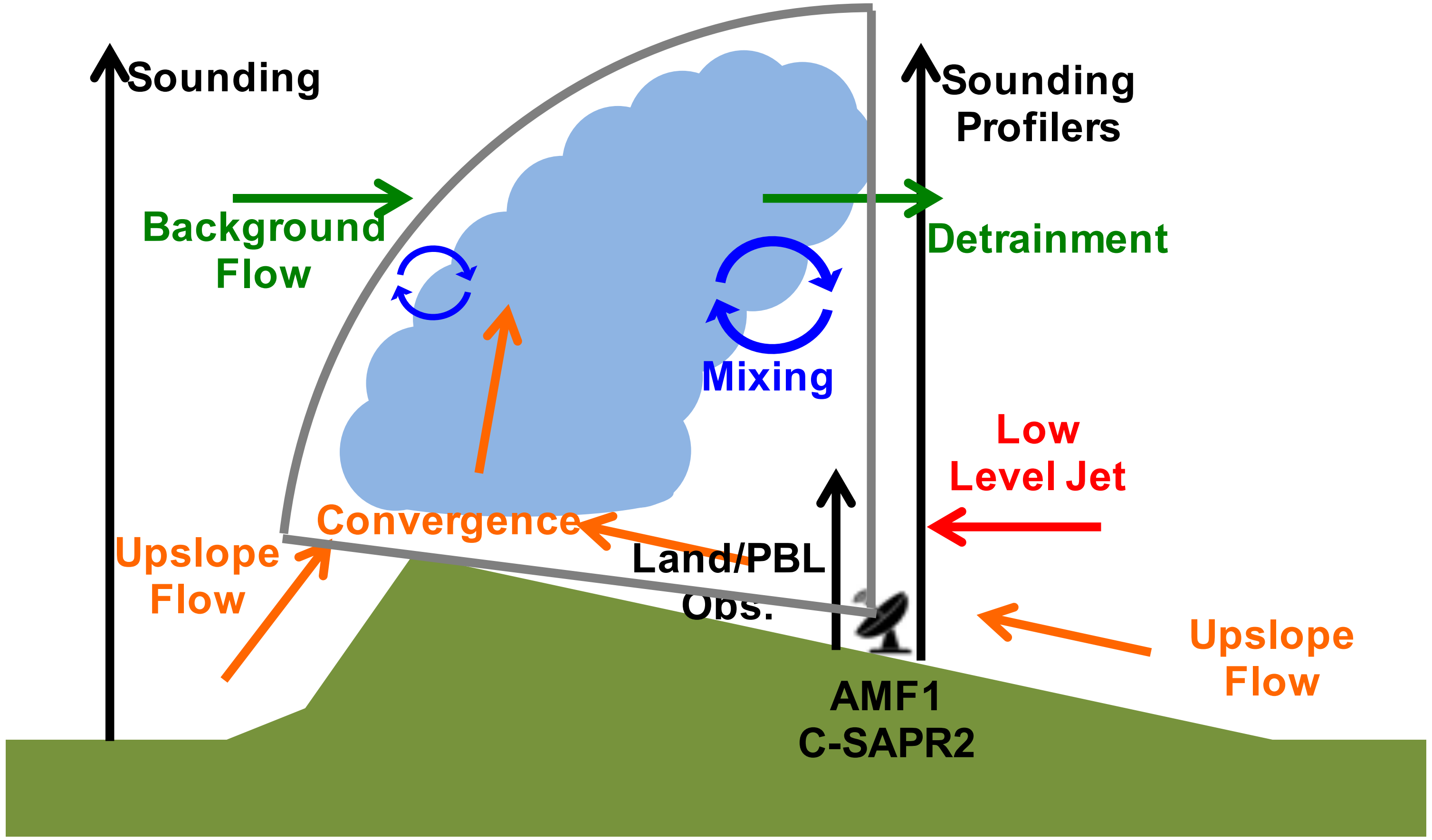
Courtesy of ARM DQ Office



Ice Nucleating Particle (INP) plot to right courtesy of Paul DeMott, Thomas Hill, Sonia Kreidenweis (CSU), and Baptiste Testa (U. Lyon)

Measurement Strategy





The goal was to 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

The purpose of G-1 aircraft measurements was to capture in situ conditions in and around cumulus clouds (pre-deep convection) during the IOP overlapping with the RELAMPAGO campaign (early Nov to early Dec 2018)

G-1 Flights

- 79.4 hours
- 8 flights with a primary focus on **orographic cumulus evolution**
- 8 flights with a primary focus on **deep convective initiation**
- 3 flights with a primary focus on **microphysics characterization**
- 3 flights with a primary focus on **aerosol characterization**

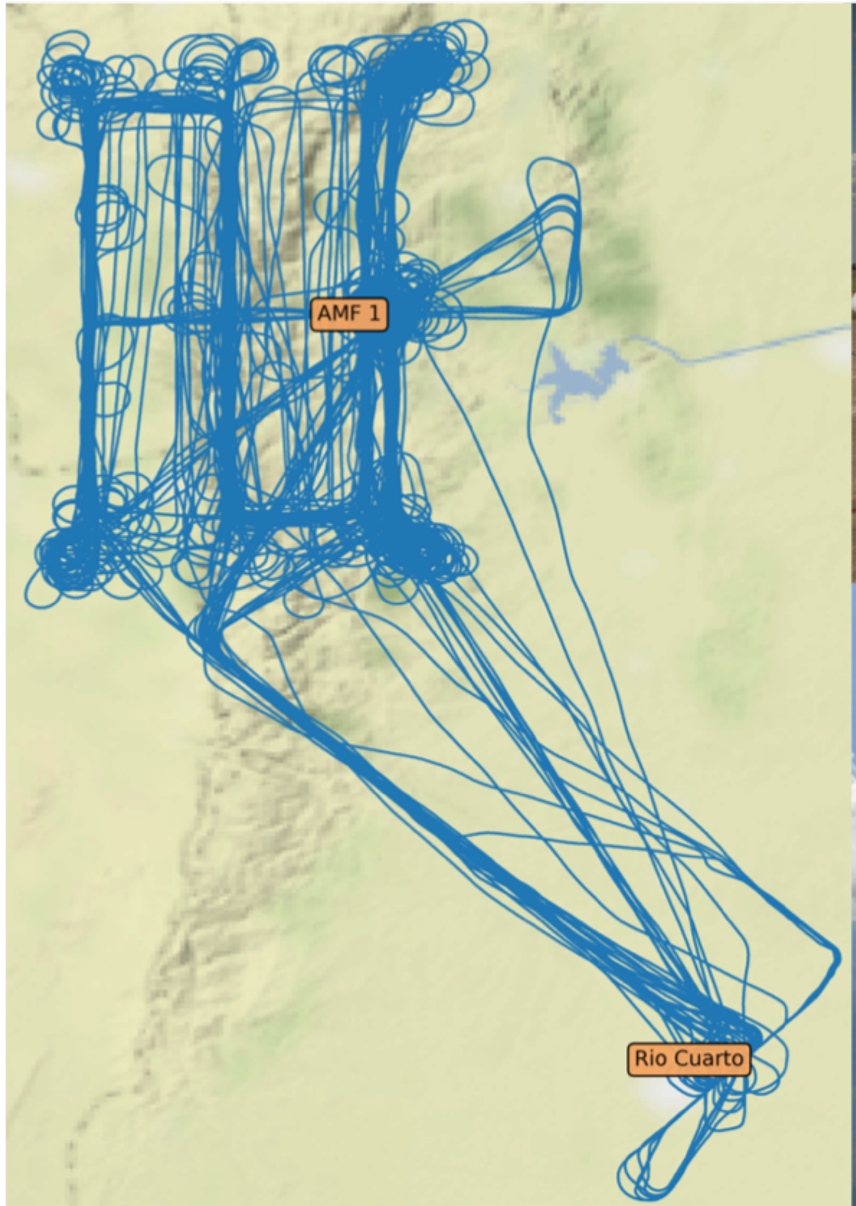
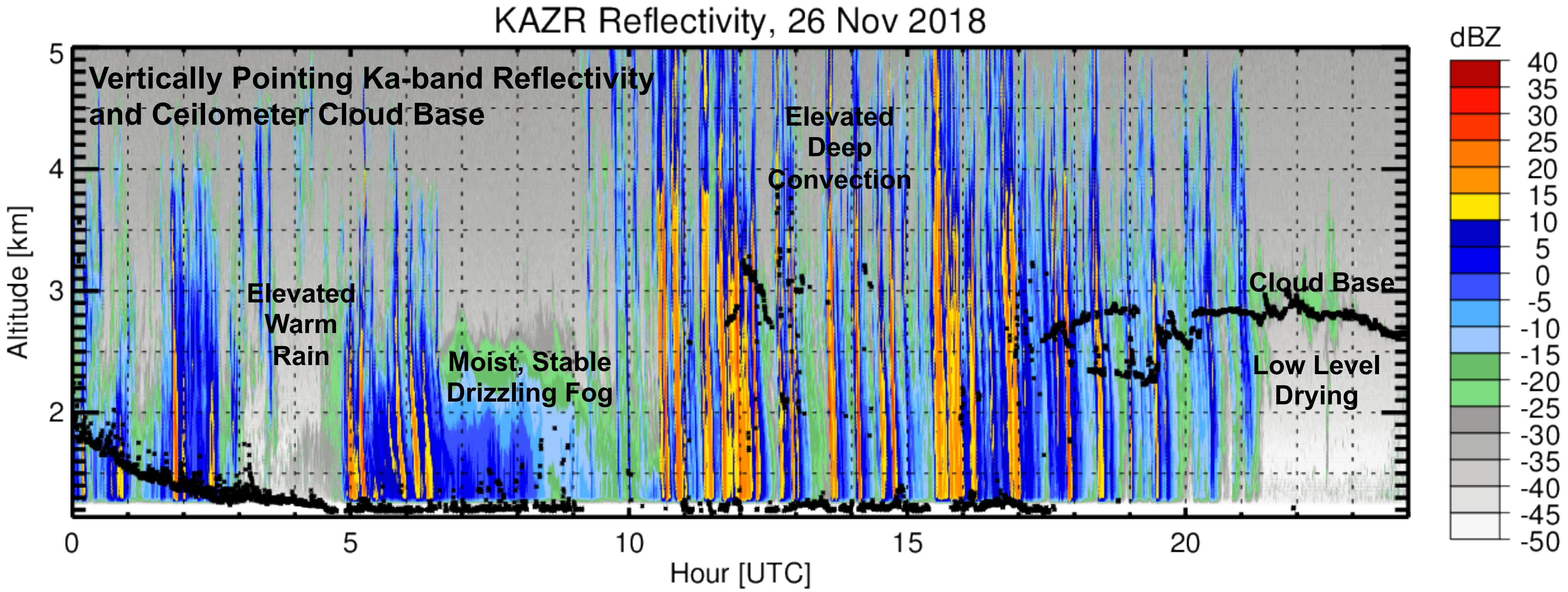


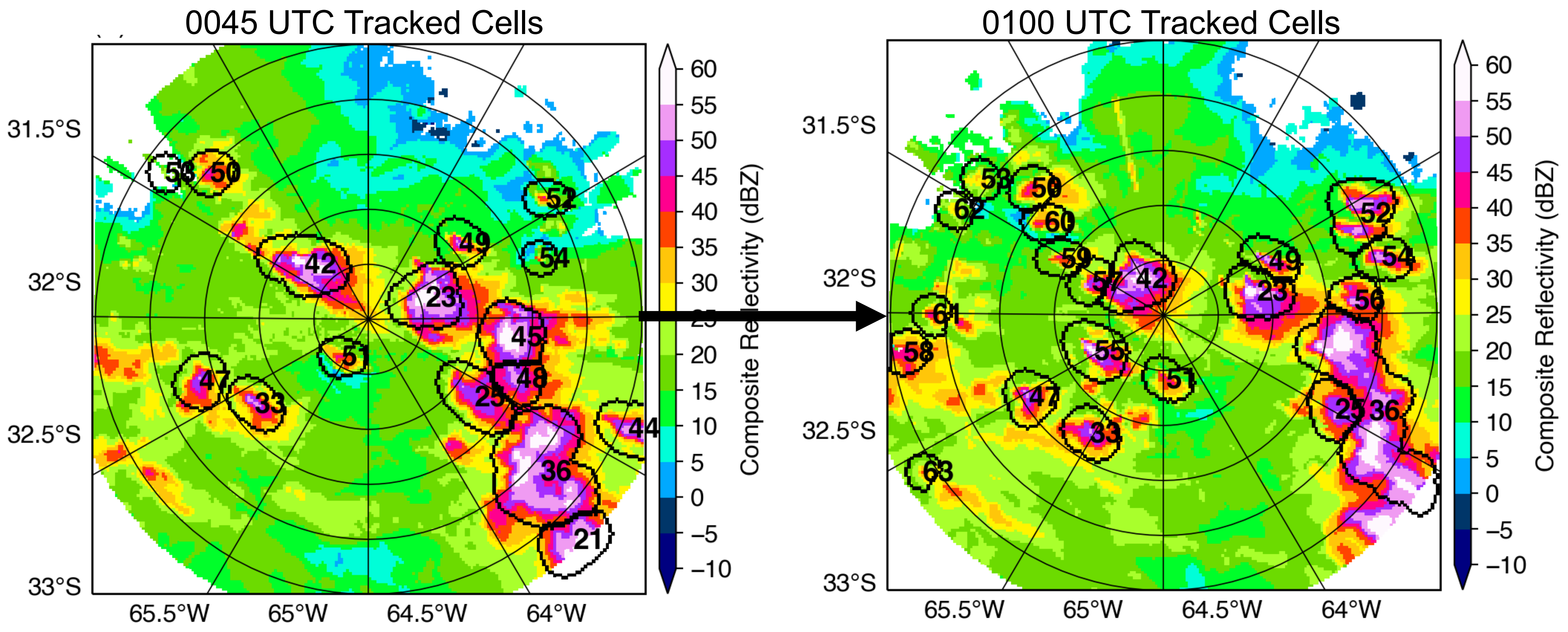
Photo by Jason Tomlinson

What was Observed?

- 173 of 197 days with cumulus or stratocumulus overhead
- 79 of 197 days with deep convection pass directly overhead
- 92 of 197 days with measurable precipitation at the AMF site
- As expected, there was frequent hail, “extreme” convection, elevated convection, and mesoscale organization; but warm rain formation, extremely variable aerosol conditions, and lightly drizzling fog were also common.



Convective Cell and Cluster Tracks

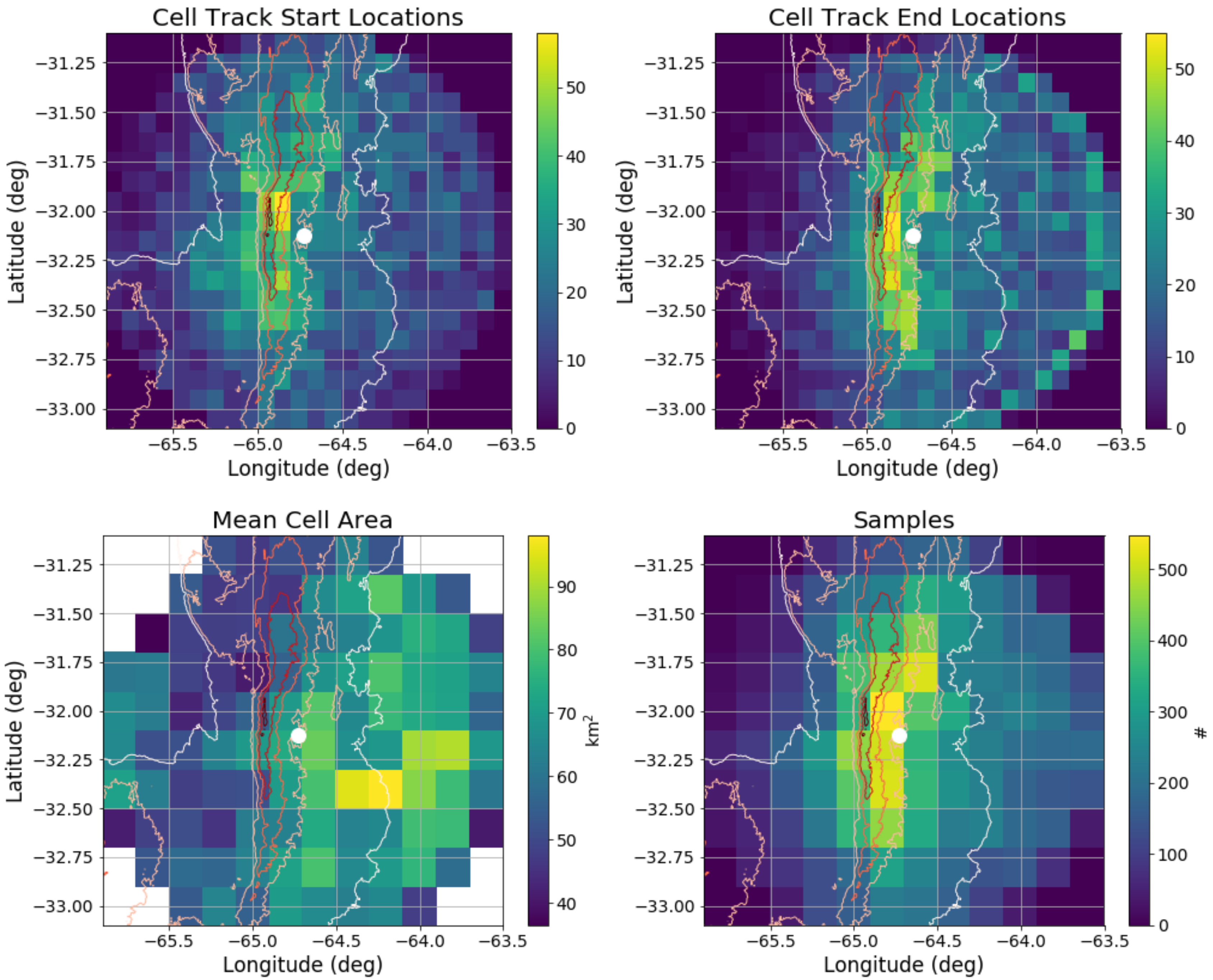


Version 1 convective cell tracks including mergers and splits using C-SAPR2 15-minute PPI volumes is completed. Post-processing statistics are underway. Clusters will be tracked next.

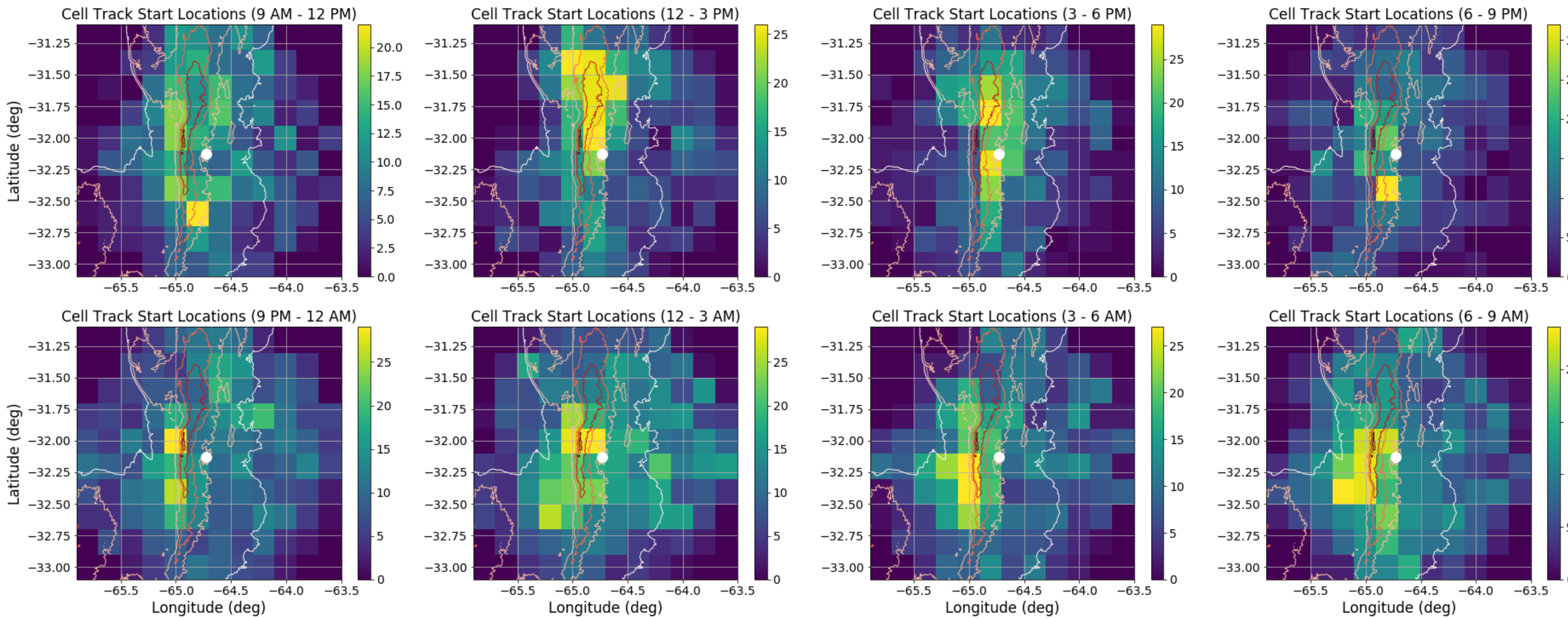
This is contributing to an expanding database of tracked cells with saved cloud, precipitation, and environmental properties that can be analyzed as a function of life cycle.

Tracked Convective Cell Centroids

- Upper plots: Cells start most frequently over the highest terrain (contoured every 500 m), specifically just east of the ridgeline top and NW of the observing site within a concave portion of the topography; end locations are shifted eastward
- Lower plots: On the order of 500 separate, tracked cells are observed to the immediate west of the observing site, decreasing east and west of the ridgeline; mean cell area increases eastward from the mountains onto the plains



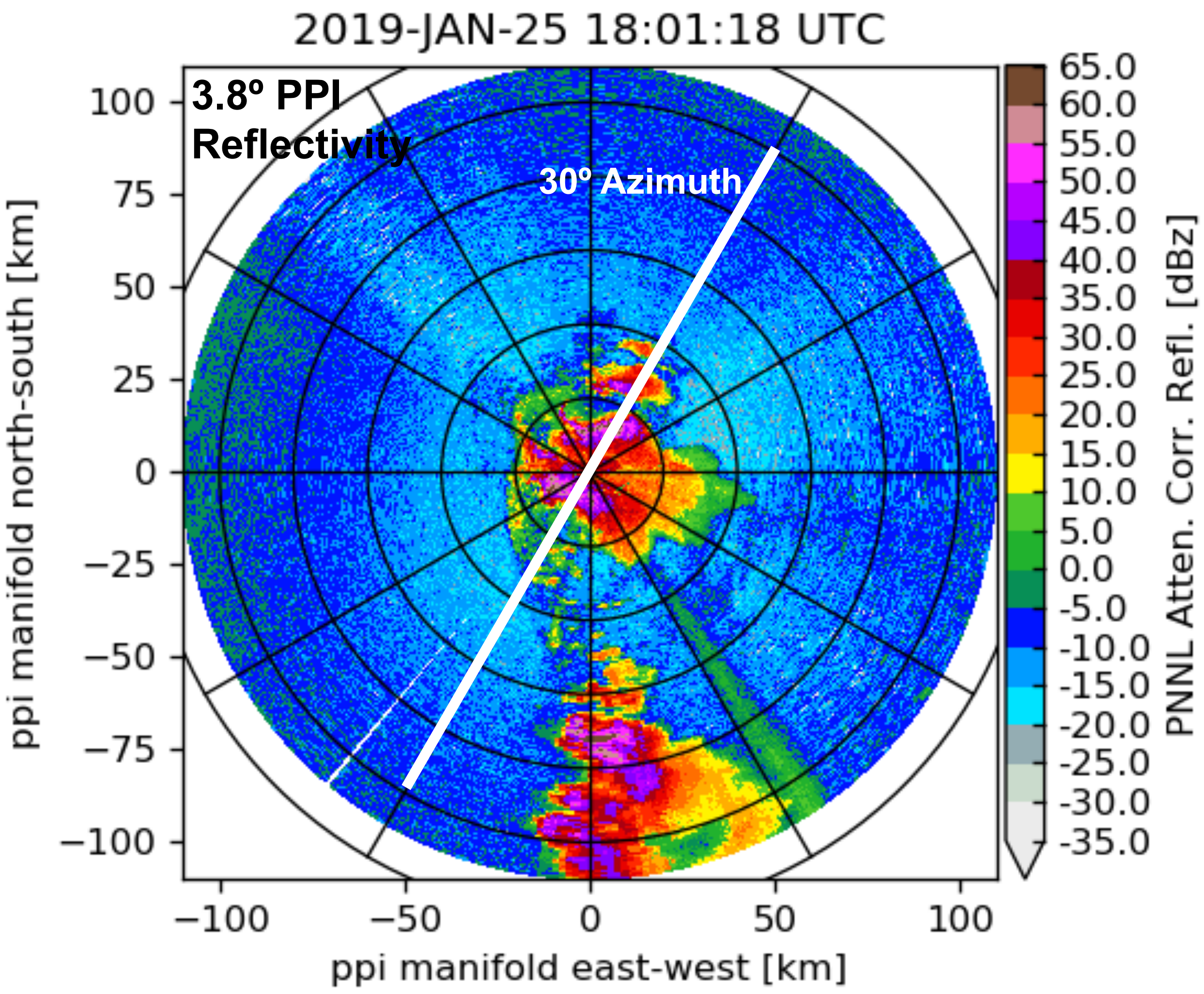
Tracked Convective Cell Diurnal Cycle

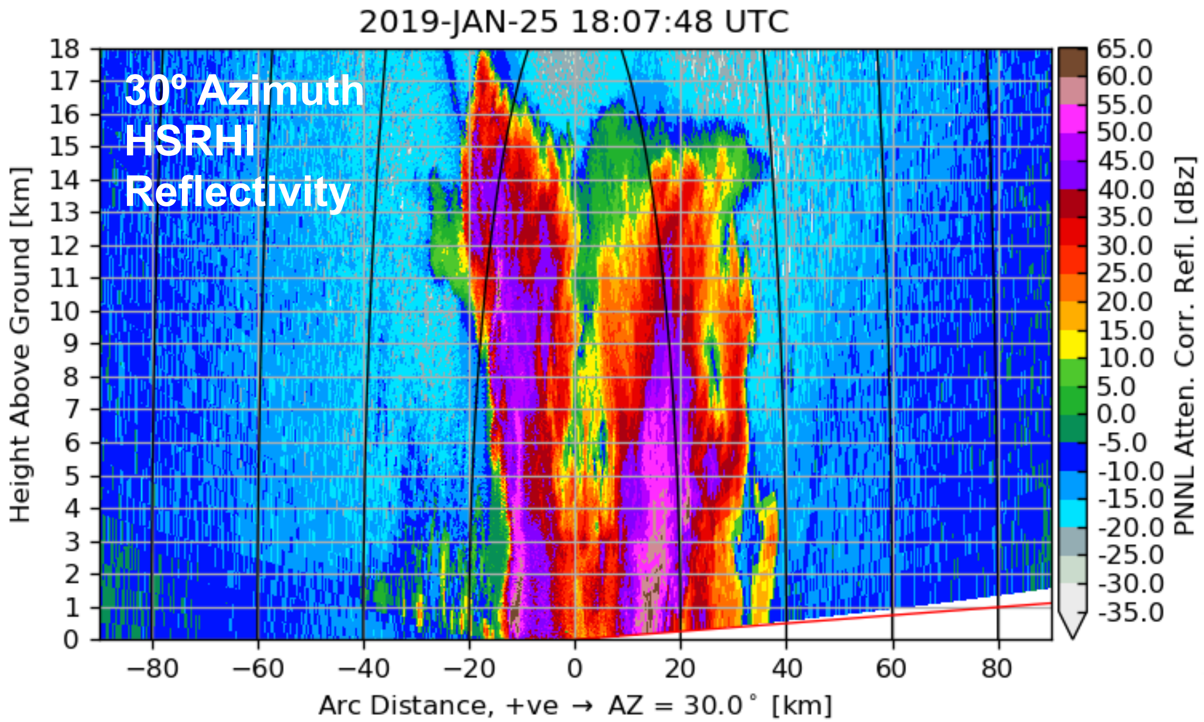


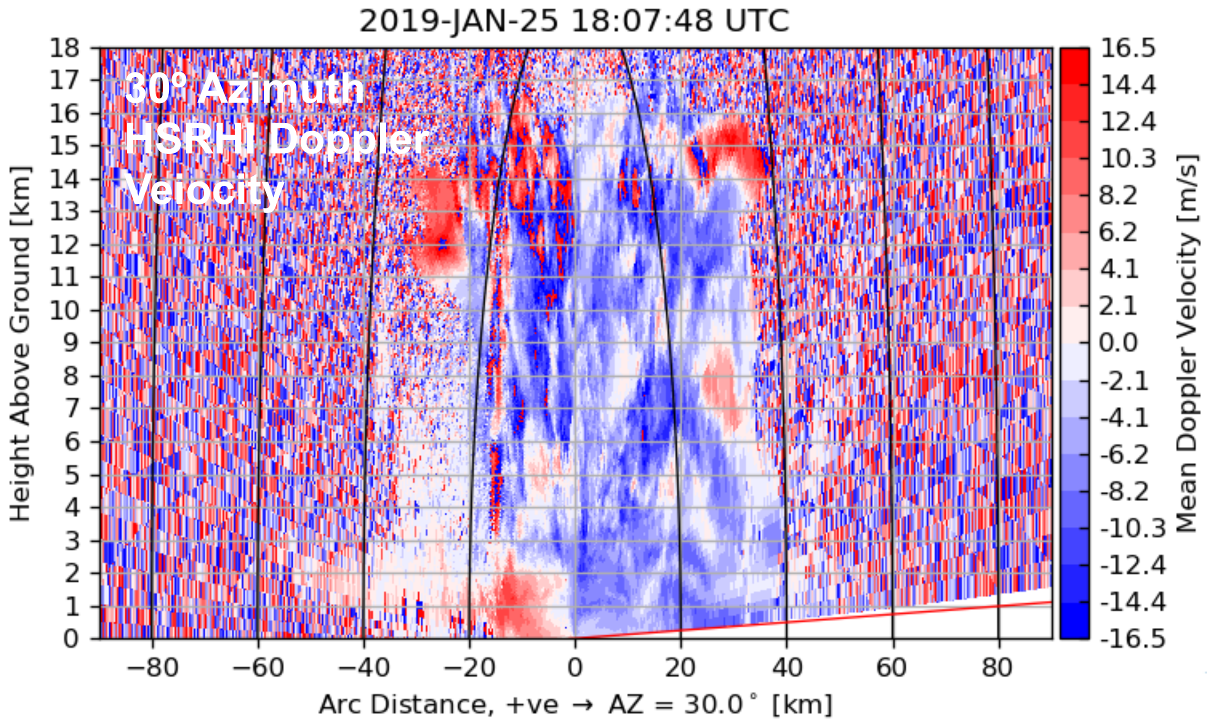
Cell starting locations exhibit a distinctive diurnal cycle beginning to the north over a high plateau in early afternoon before shifting south in late afternoon, becoming more widespread into the night with a plains frequency peak between 12-3 AM and a late night/early morning peak on the western edge of the ridgeline.

Correlation with Cloud and Precipitation Structure

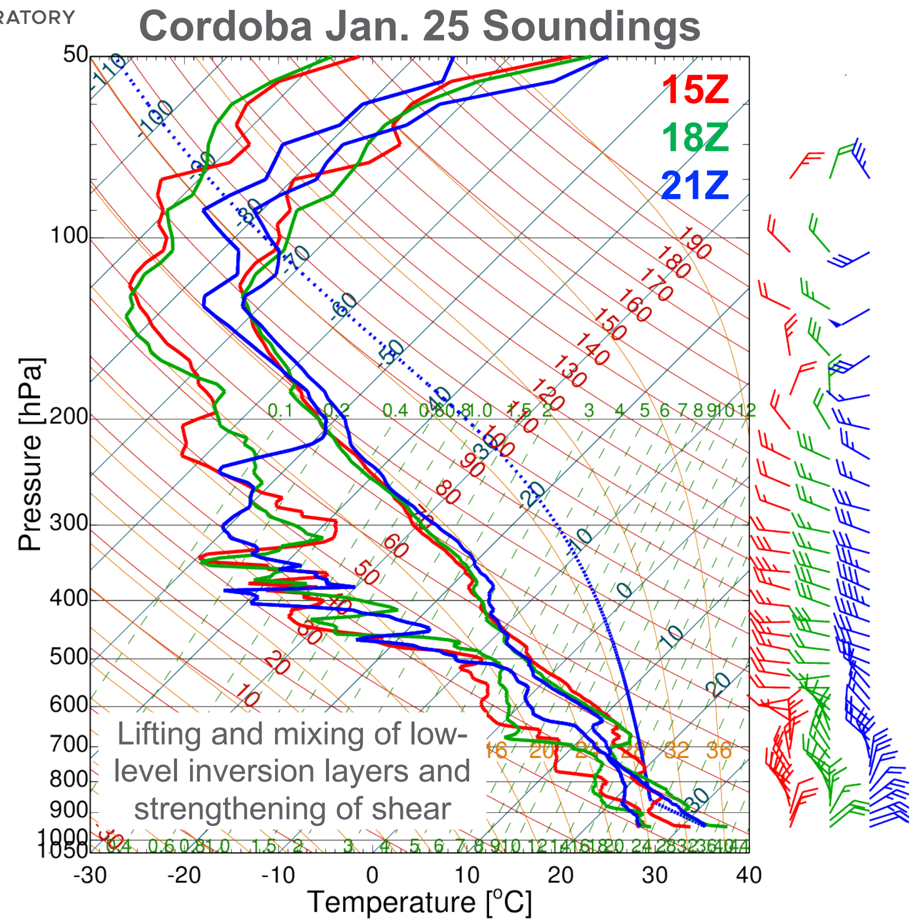
Tracked cells are being linked with rapid scan GOES-16 data and routine hemispheric RHI scans (e.g., 30º azimuth to right) along each radial spoke in the PPI view below

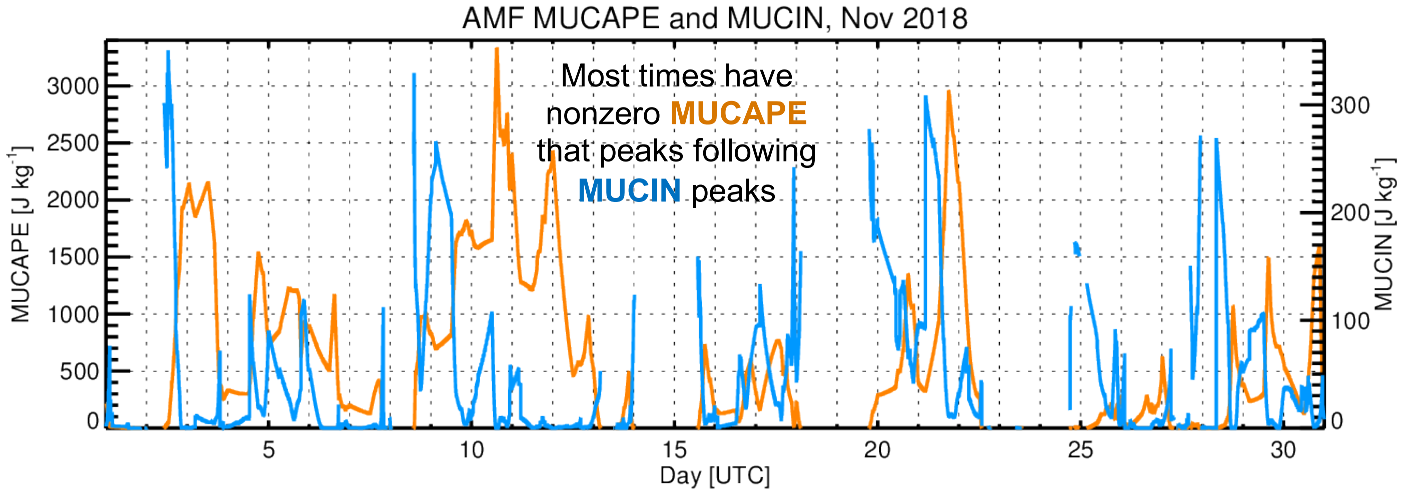


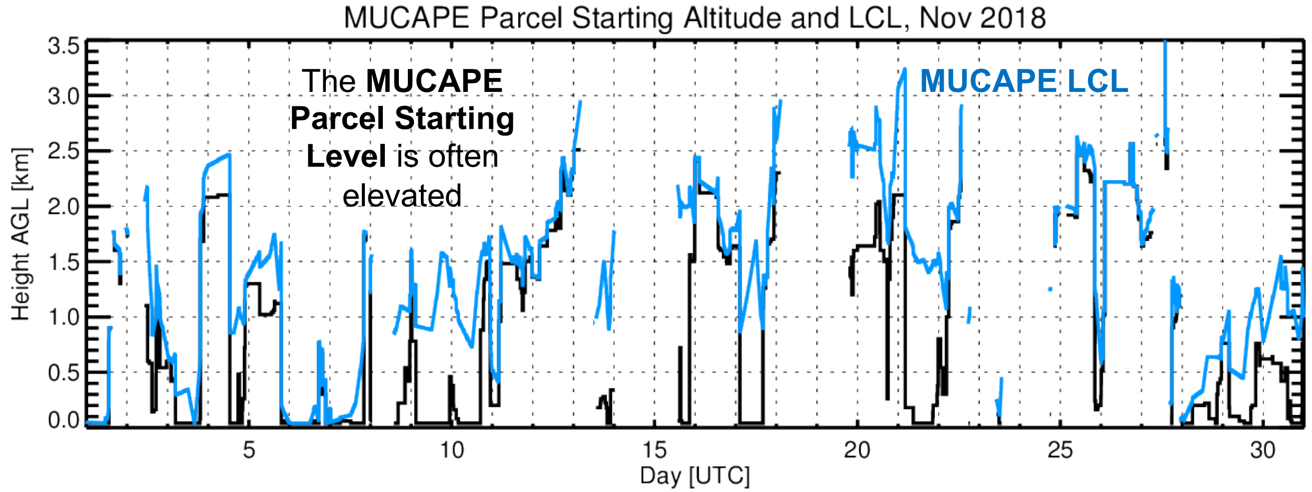


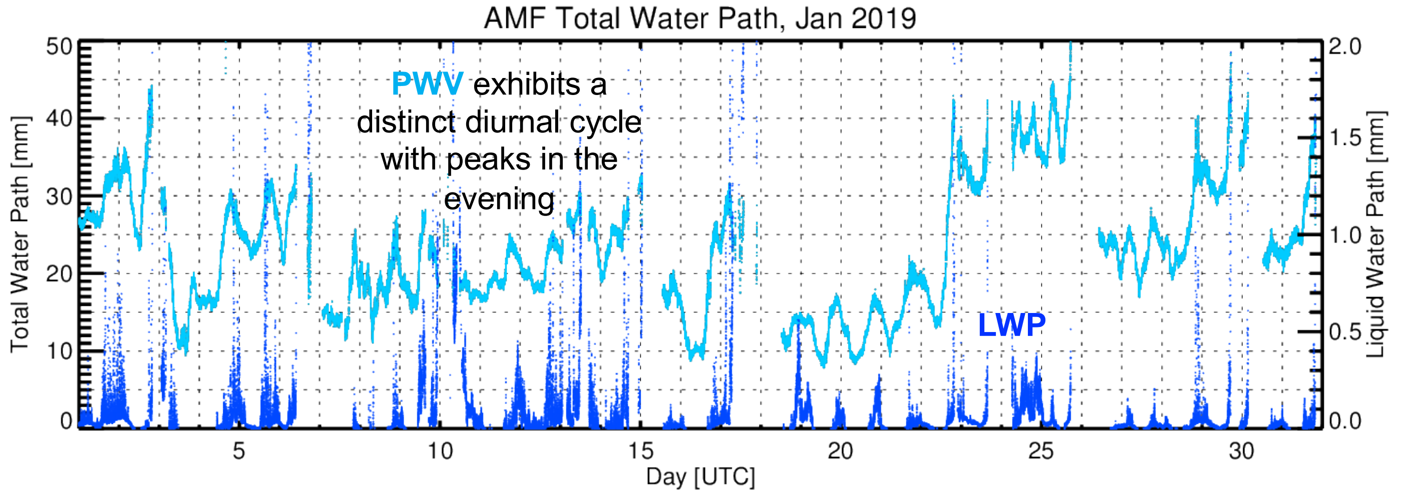


Correlation with Environmental Conditions









An example 3-hourly evolution ahead of the Jan 25 system on the previous slide (above) and examples of variability in convective parcel statistics in Nov 2018 (right top) and total/liquid water path in Jan 2019 (right bottom)

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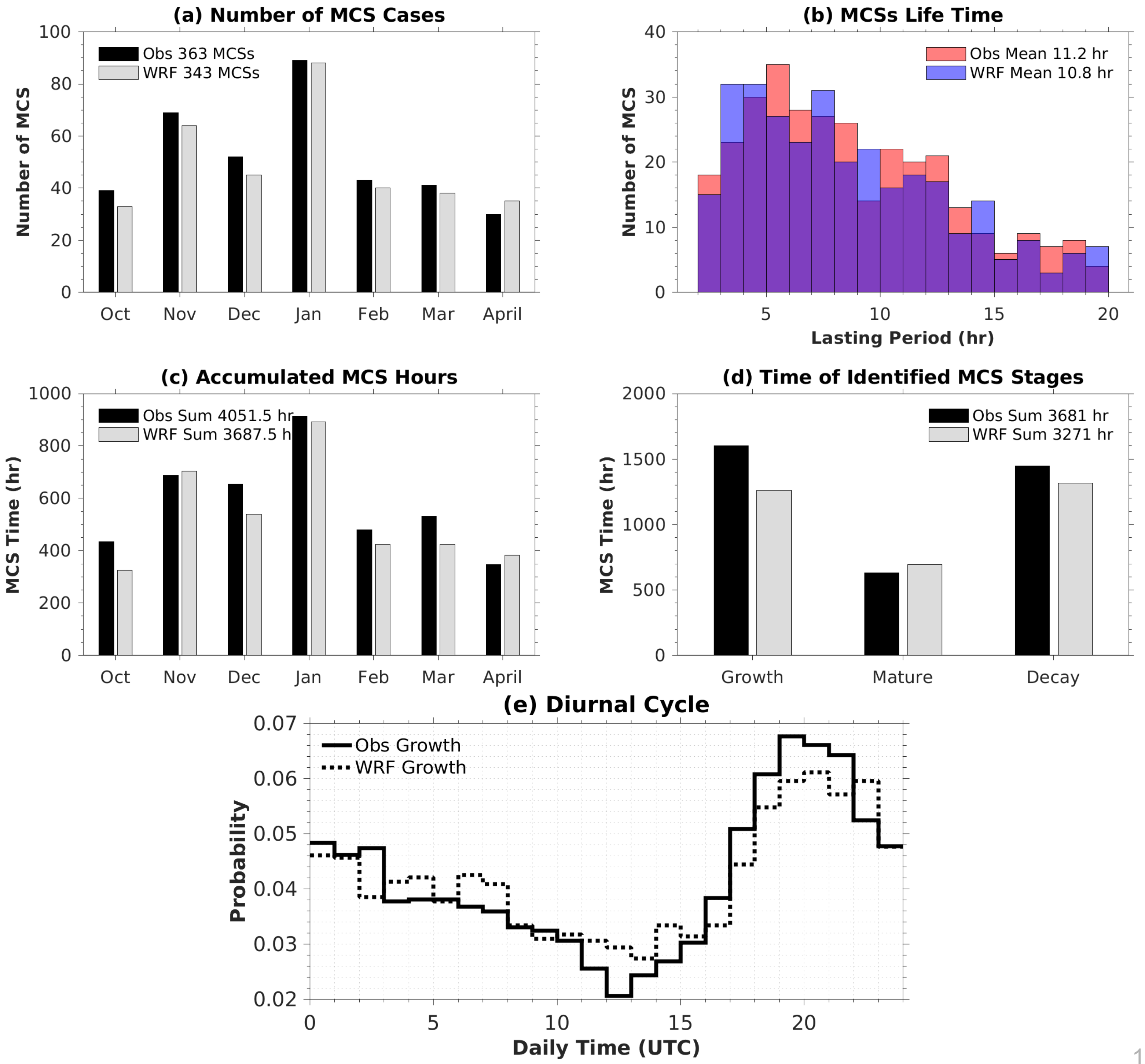
Model Evaluation

- A 6.5-month, 3-km, large domain WRF run is able to reproduce MCS timing and lifetimes (right) as well as cloud shield statistics but has more heavy rain and less light rain than retrieved
- Future work will focus on the ability of WRF to reproduce initial upscale growth stages using the radar-based cell track database
- ARM is also developing a nested LES setup through the LASSO project to simulate mini-ensembles of several orographic deep convective cases (https://www.arm.gov/capabilities/modeling/lasso)



Thank You

Thank you to a tremendous cross-nation, cross-institution team that made CACTI possible.

CACTI Information/Data:
www.arm.gov/research/campaigns/amf2018cacti

RELAMPAGO Information/Data:
www.eol.ucar.edu/field_projects/relampago

Many remote sensing products and retrievals are now available or will be soon. Please contact Adam Varble (adam.varble@pnnl.gov) for more information.


Courtesy Miguel Ottaviano


Photo by Vagner Castro