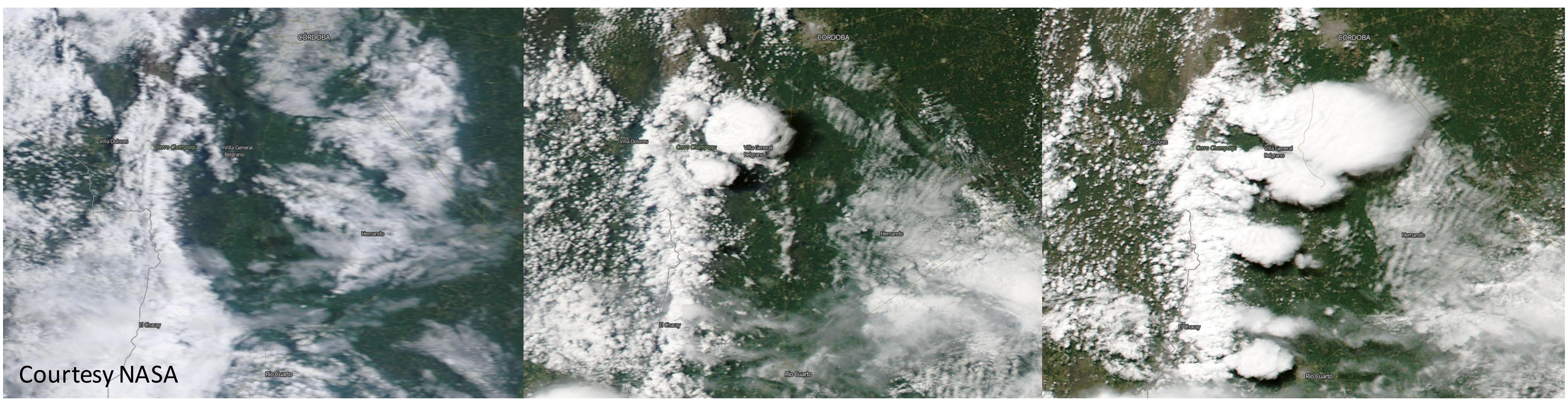
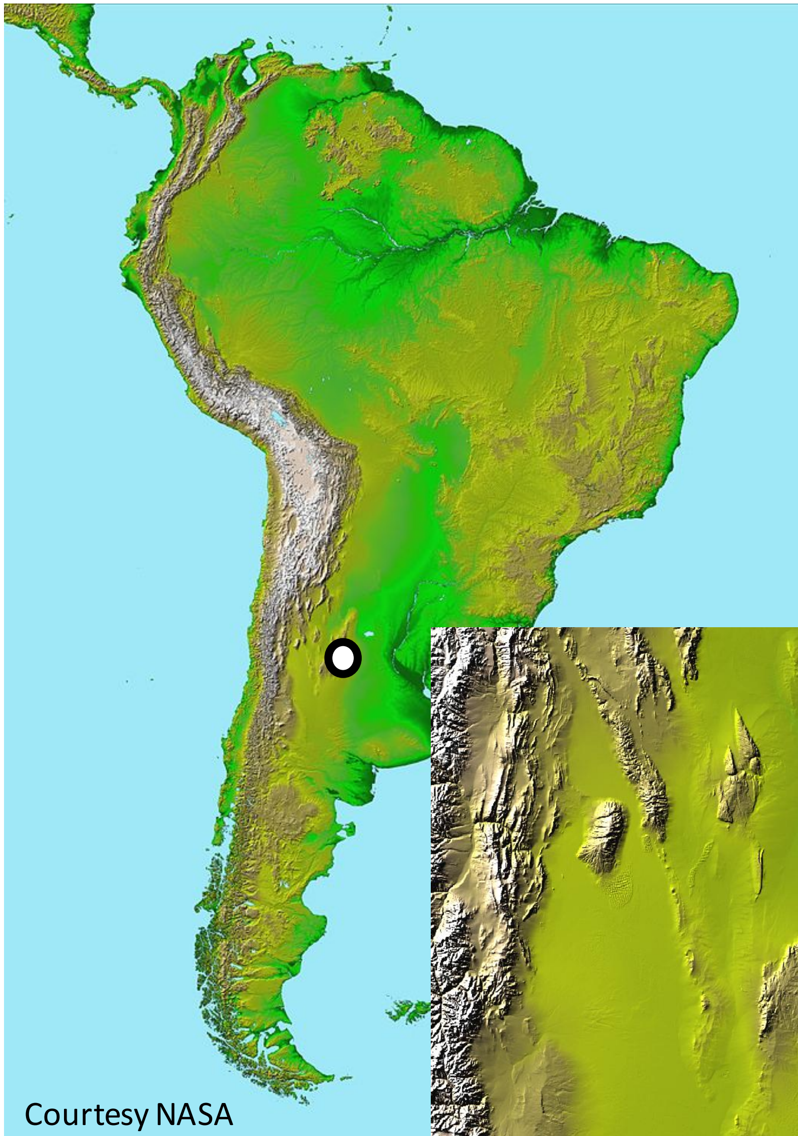
The Cloud, Aerosol, and Complex Terrain Interactions (CACTI) ARM Field Campaign



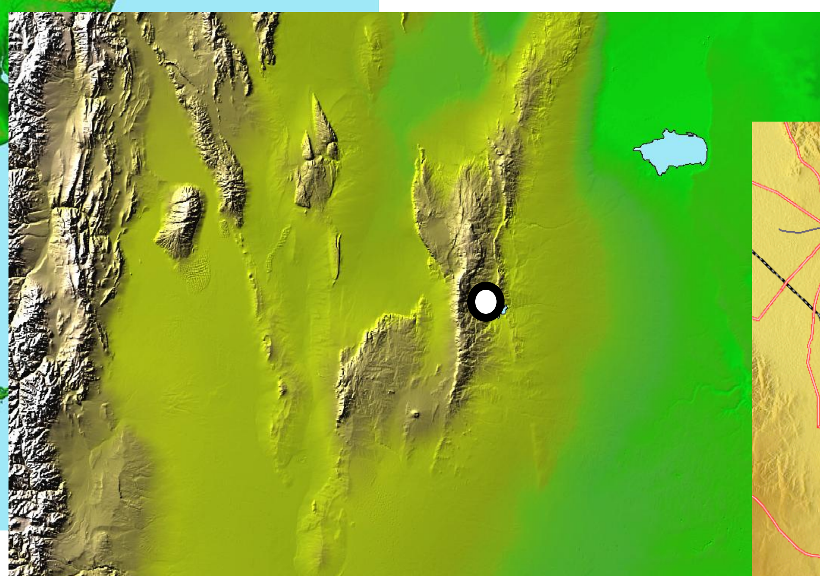
Outline

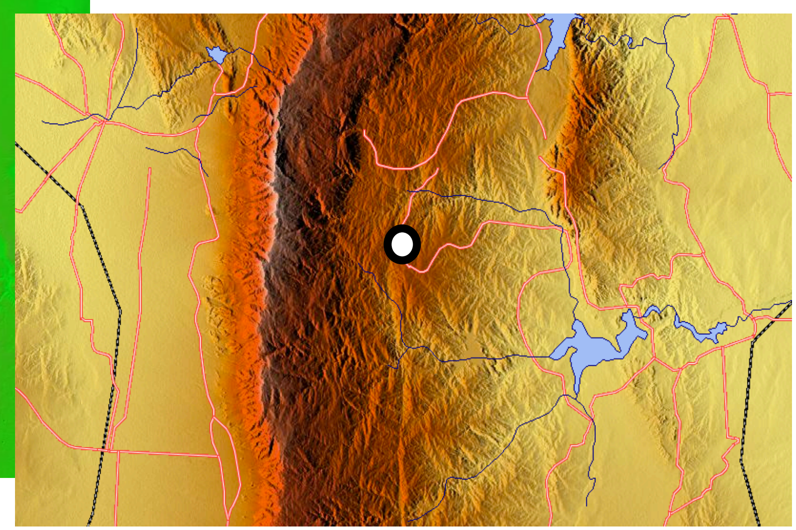
- Overview
- Experiment Rationale
- Science Questions
- Measurement Strategy
- Potential Research

Overview



Courtesy NASA





Timing: 15 August 2018 – 30 April 2019

Location: Villa Yacanto, Argentina (32.1°S, 64.75°W)

Secured Resources: AMF-1 (reconfigured), INP and stereo camera measurements

Potential Resources: C-SAPR2 radar, G-1 aircraft

Overlap with potential RELAMPAGO (NSF) field program and ALERT.AR (SMN)

Investigators

<u>Principal Investigator</u>

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Ruby Leung, Pacific Northwest National Laboratory

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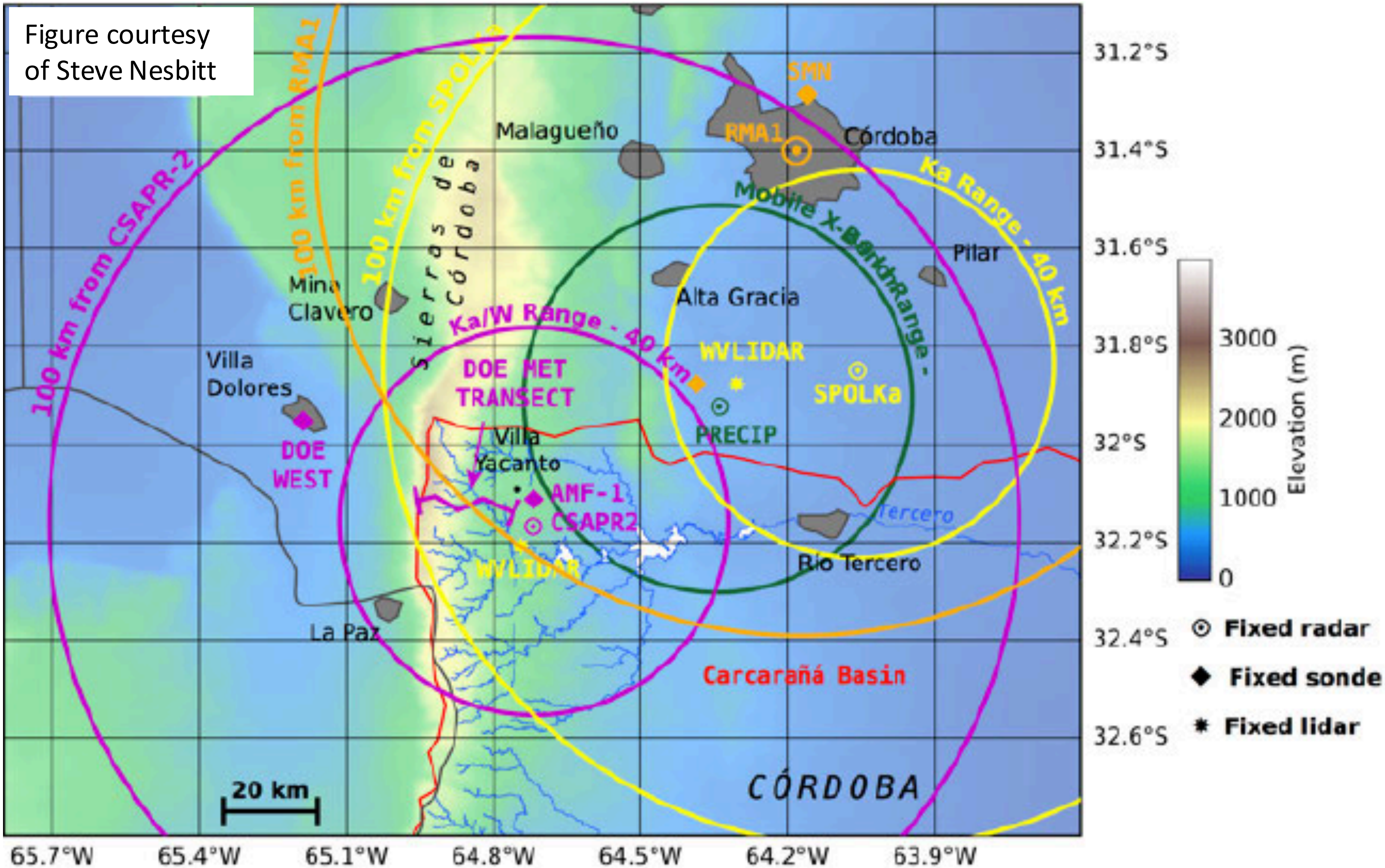
David Gochis, National Center for Atmospheric Research

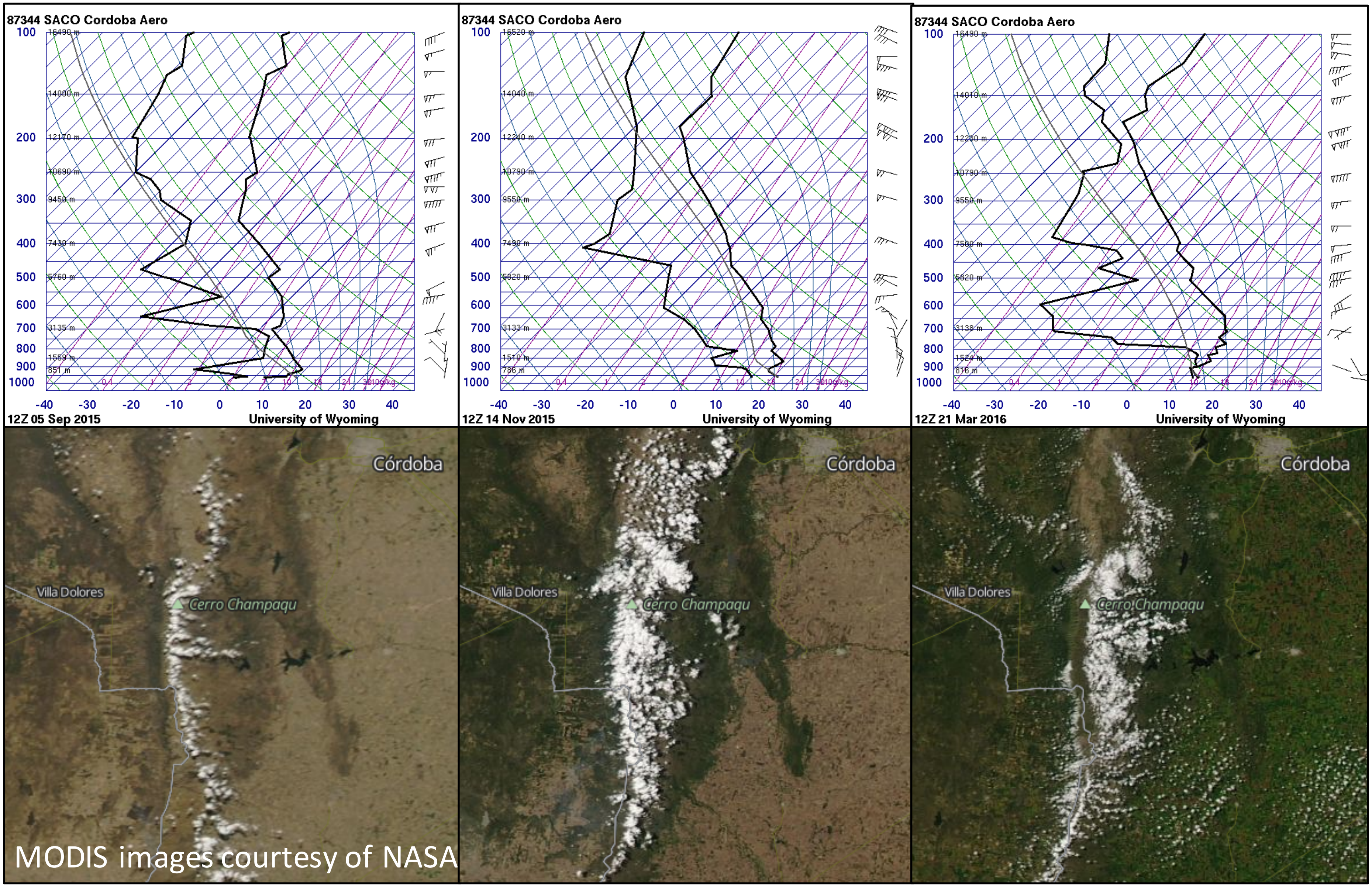
Eldo Avíla, Universidad Nacional de Córdoba

Christopher Williams, University of Colorado-Boulder/NOAA

Experiment Rationale: Location



Experiment Rationale

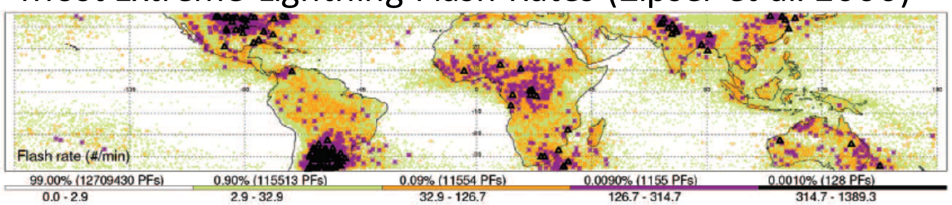


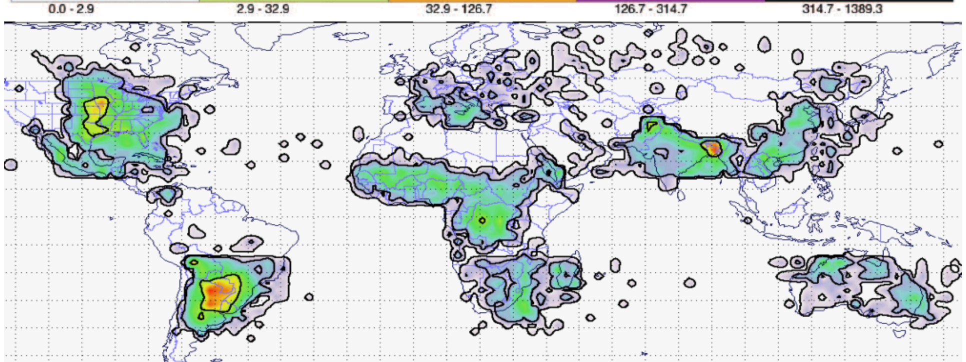
Experiment Rationale

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Orographic Cu	13	19	15	22	19	24	22
Orographic Sc	6	3	2	5	1	1	4
Orographic Cb	1	7	9	6	8	8	2
Overcast	2	3	6	1	7	5	4
Scattered Non-Orographic Clouds	6	2	4	4	1	0	0
Clear	4	3	3	0	0	1	3

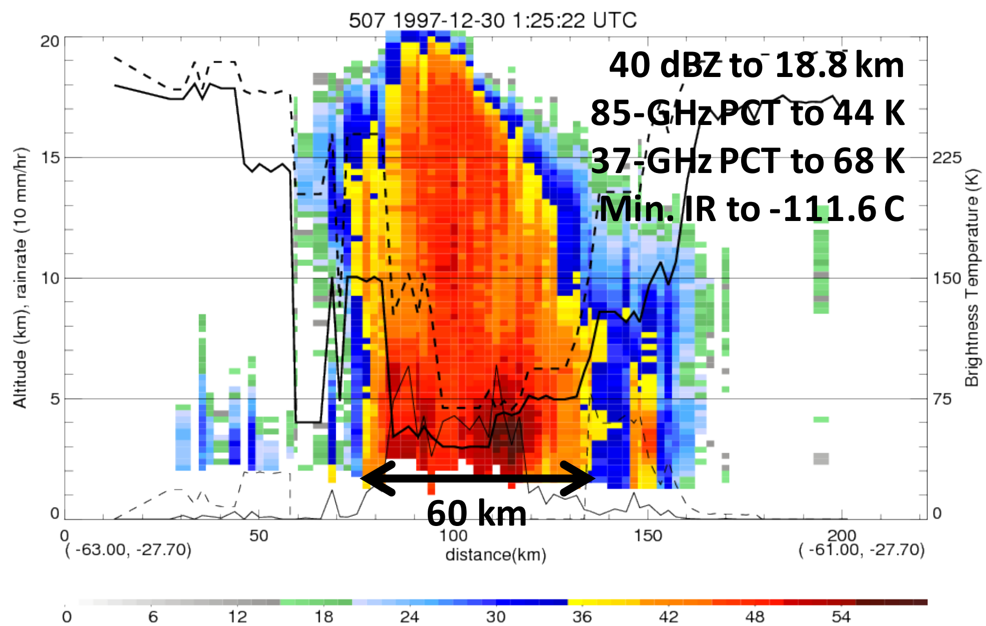
These numbers are for the area observable by the AMF-1 (< 25 km away) from one season estimated from MODIS images.

Most Extreme Lightning Flash Rates (Zipser et al. 2006)





Severe Hail Frequency Estimated from AMSR-E (Cecil and Blankenship 2012)



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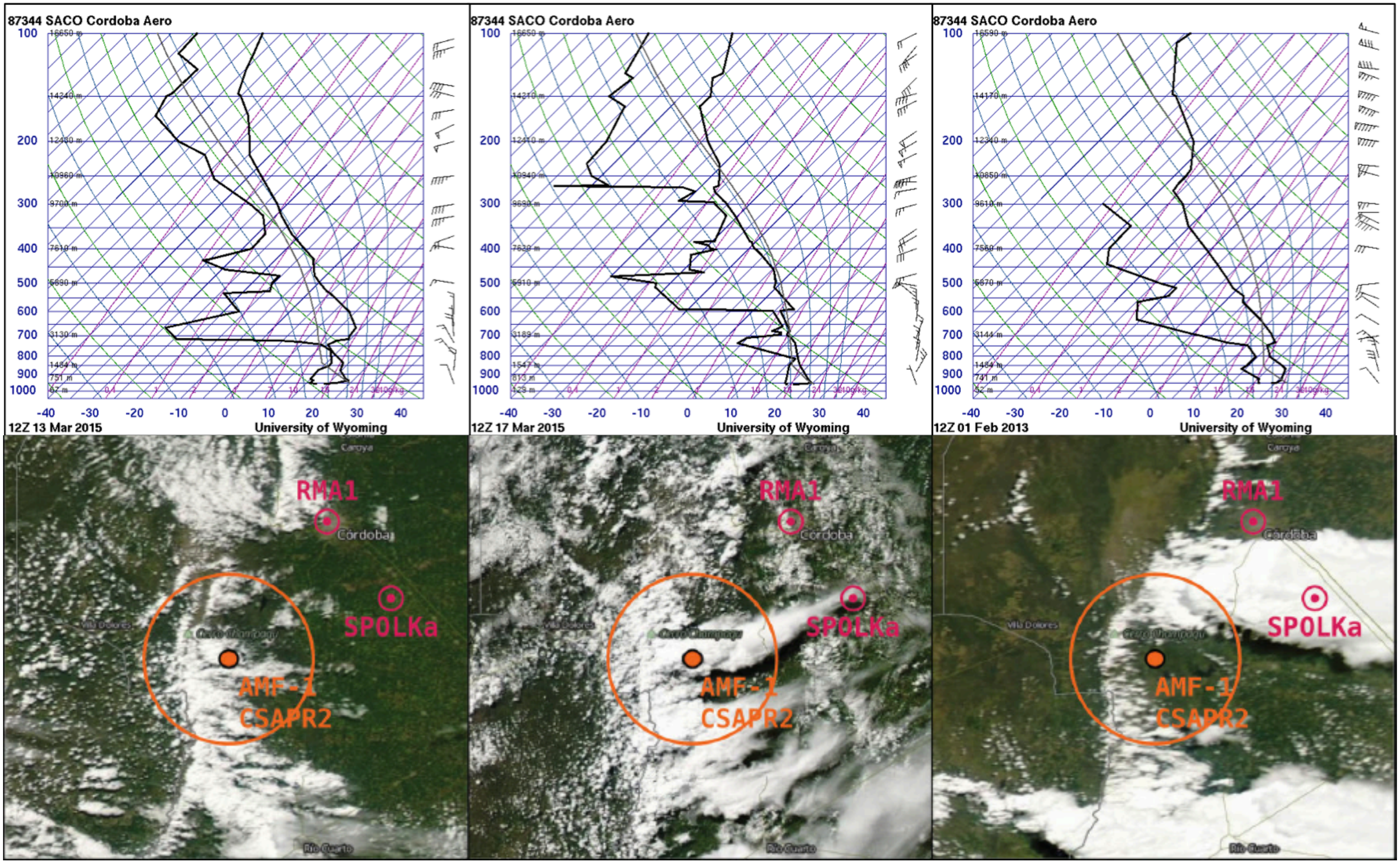

MODIS images courtesy of NASA

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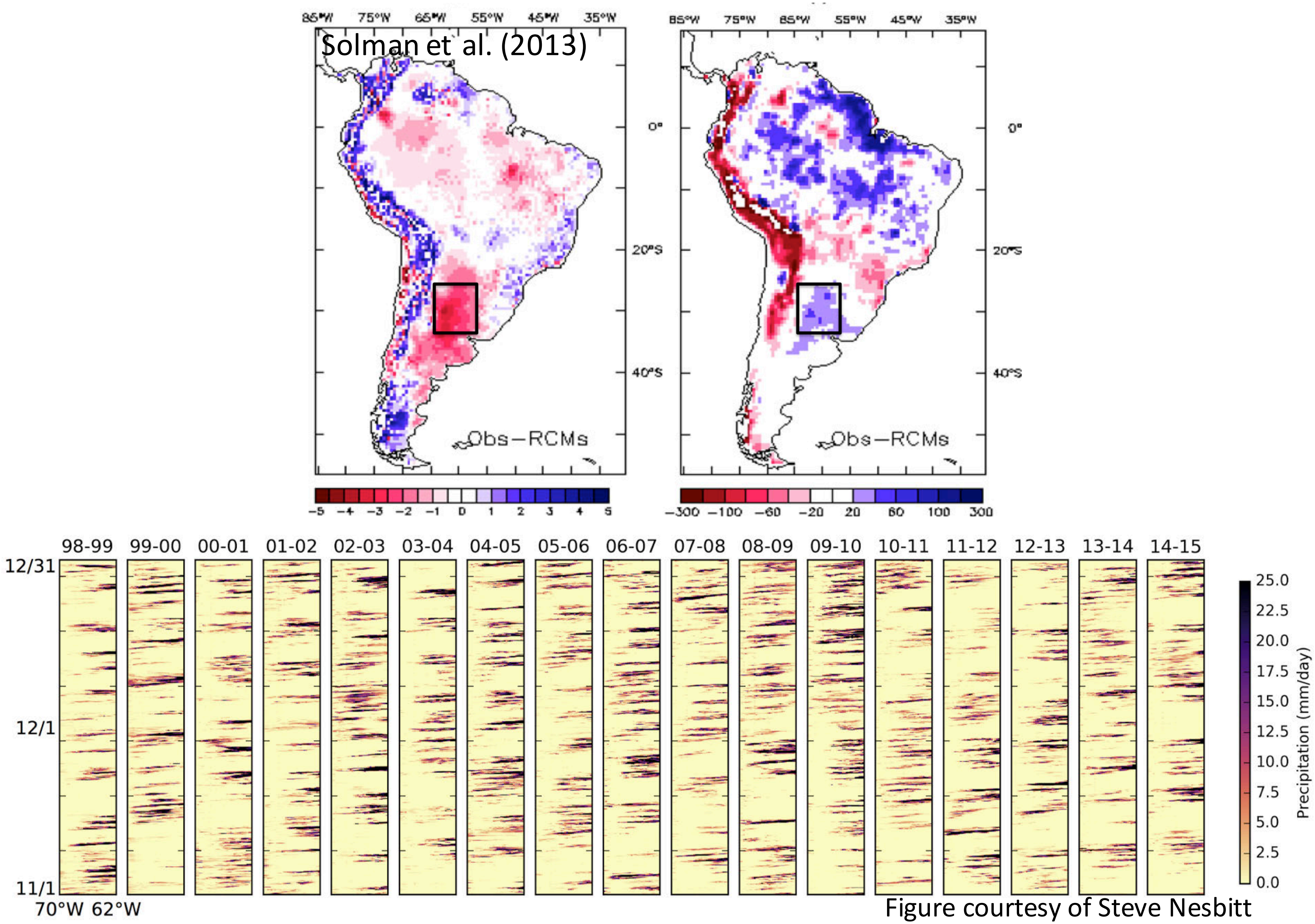
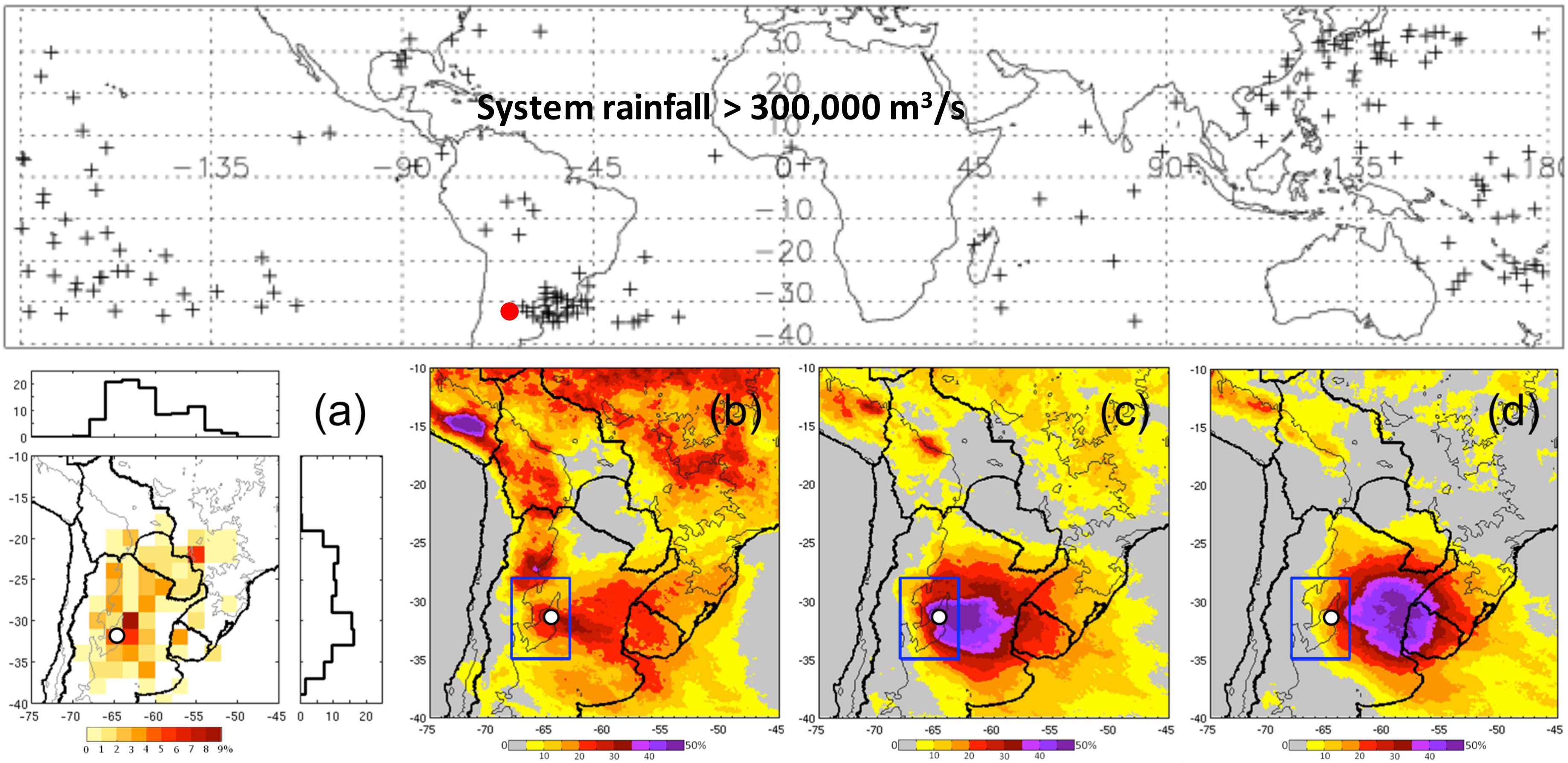


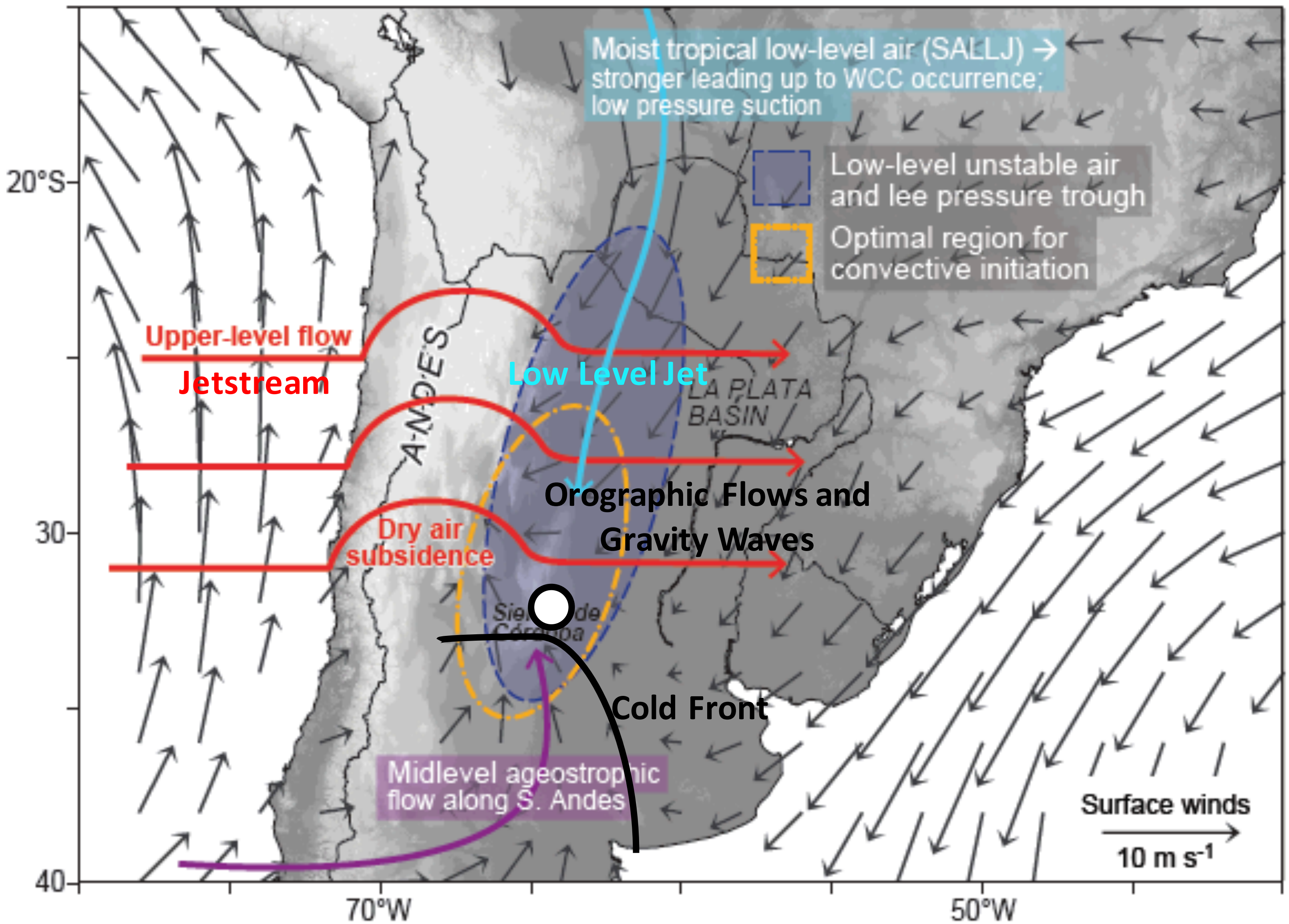
Figure courtesy of Steve Nesbitt

Experiment Rationale



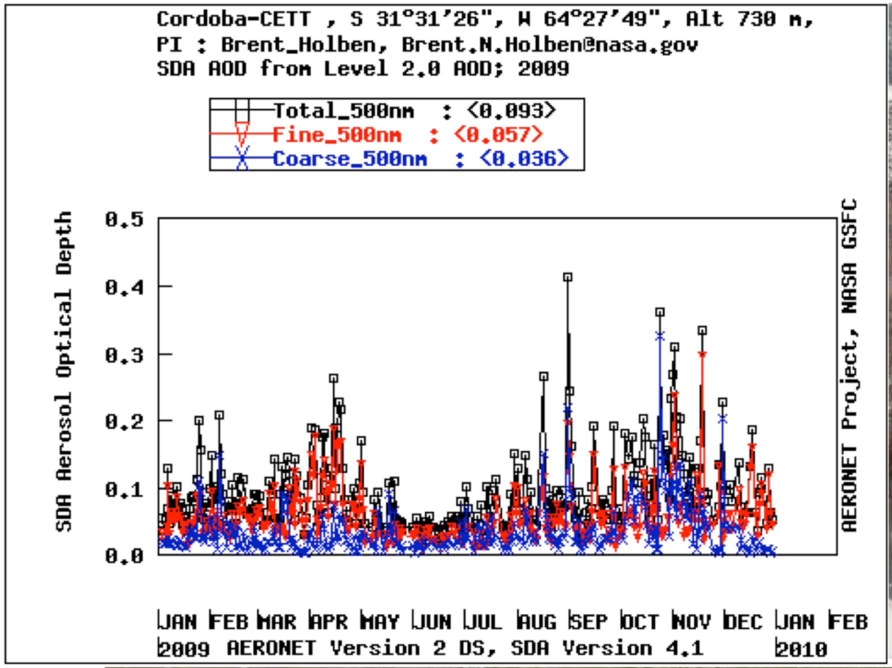
Vidal and Salio (2014)

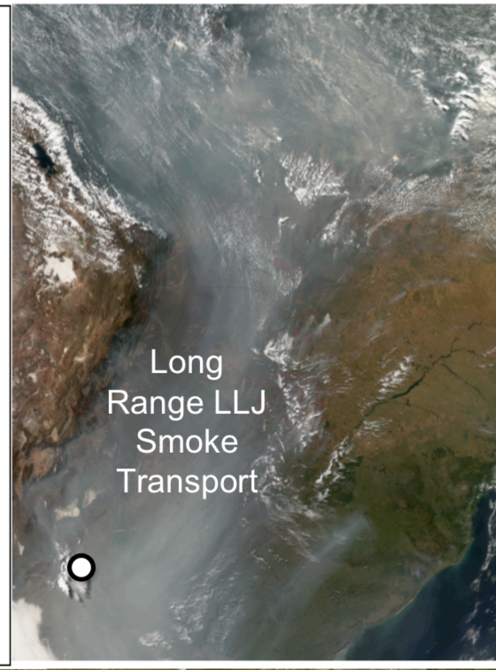
Experiment Rationale

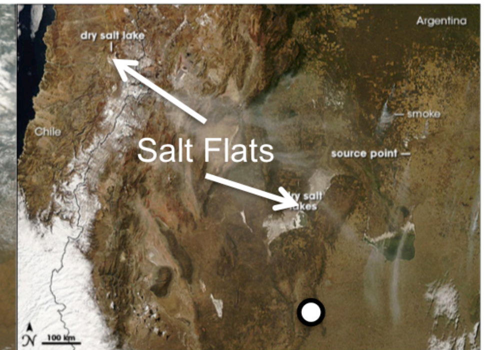


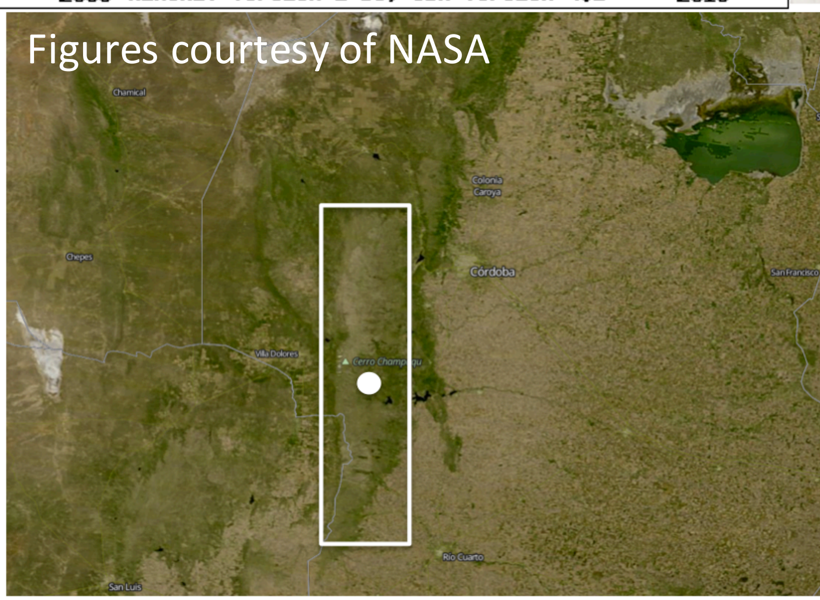
Rasmussen and Houze, 2016

Experiment Rationale









Science Question #1

How are the properties and lifecycles of orographically generated boundary layer clouds, including cumulus humulis, mediocris, congestus, and stratocumulus, affected by environmental kinematics, thermodynamics, aerosols, and surface properties? How do these clouds types alter the lower free troposphere through detrainment?

- Measure the scales and velocities of individual cloud updraft and downdrafts including how they evolve in time, and relate these to measurements of cloud microphysical and macrophysical features.
- Investigate the ways in which aerosol properties and cloud dynamics impact precipitation and ice initiation in a growing congestus cloud including the ways that these initiations impact subsequent cloud and precipitation evolution.
- Explore the predictability of cloud coverage, depth, and radiative properties given large-scale environmental conditions, and investigate the impacts of mesoscale circulations and land surface interactions on local environmental conditions and cloud lifecycles.
- Quantify cloud effects on the environment.

Science Question #2

How do environmental kinematics, thermodynamics, and aerosols impact deep convective initiation, upscale growth, mesoscale organization, and system lifetime?

How are soil moisture, surface fluxes, and aerosol properties altered by deep convective precipitation events and seasonal accumulation of precipitation?

- Quantify the mechanisms that transition congestus to deep convection while relating deep convective dynamical motions to microphysical signatures and macrophysical characteristics of the clouds and precipitation.
- Investigate the predictability of deep convective cloud and precipitation properties including mesoscale organization given knowledge of large-scale environmental conditions, and determine the mechanisms most important for continued growth and/or organization of deep convection. This includes the ways in which cold pool properties depend on environmental and precipitation characteristics.
- Investigate the impact of deep convective precipitation on boundary layer aerosol and cloud properties through alteration of surface conditions across a range of timescales from hourly to seasonally.

AMF-1/MAOS/C-SAPR2/Guest Instrumentation

Land Surface/PBL

Soundings, Surface Met, ECOR, SEBS, AERI, Doppler Lidar, SODAR

Free Troposphere

Soundings, Microwave Radiometers, SODAR, RWP

Aerosols (not fully set yet)

MPL, Doppler Lidar, MFRSR, Sun Photometer, Size Distribution (UHSAS, SMPS), CCN, UCPS, CPC, INP Filter Collections, SP2, Extinction (PASS-3, PSAP, Aethelometer, Nepholometer), Growth (HDTMA, Humidigraph), composition (ACSM)

Clouds/Precipitation

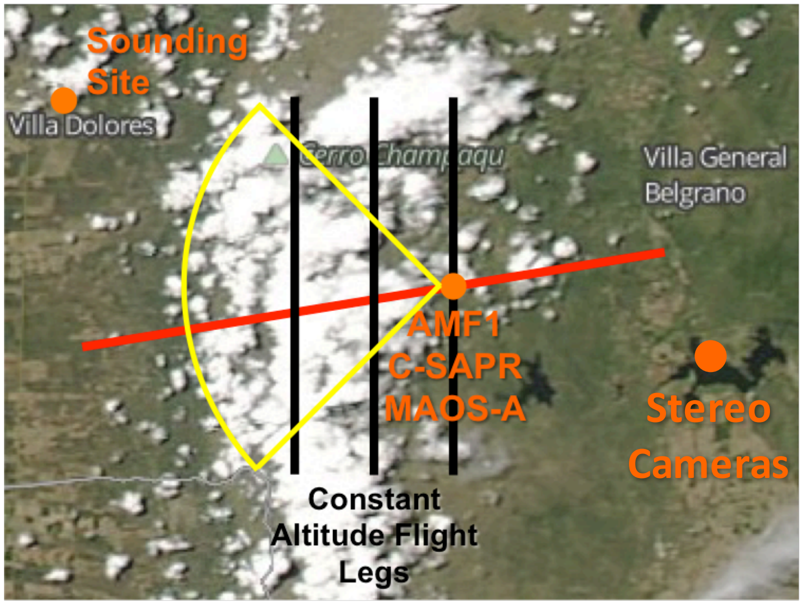
W/Ka-SACR, C-SAPR2, KAZR, RWP, ACDC, Ceilometer, TSI, Microwave Radiometers, Laser Disdrometer, Tipping Bucket and Optical Rain Gauges

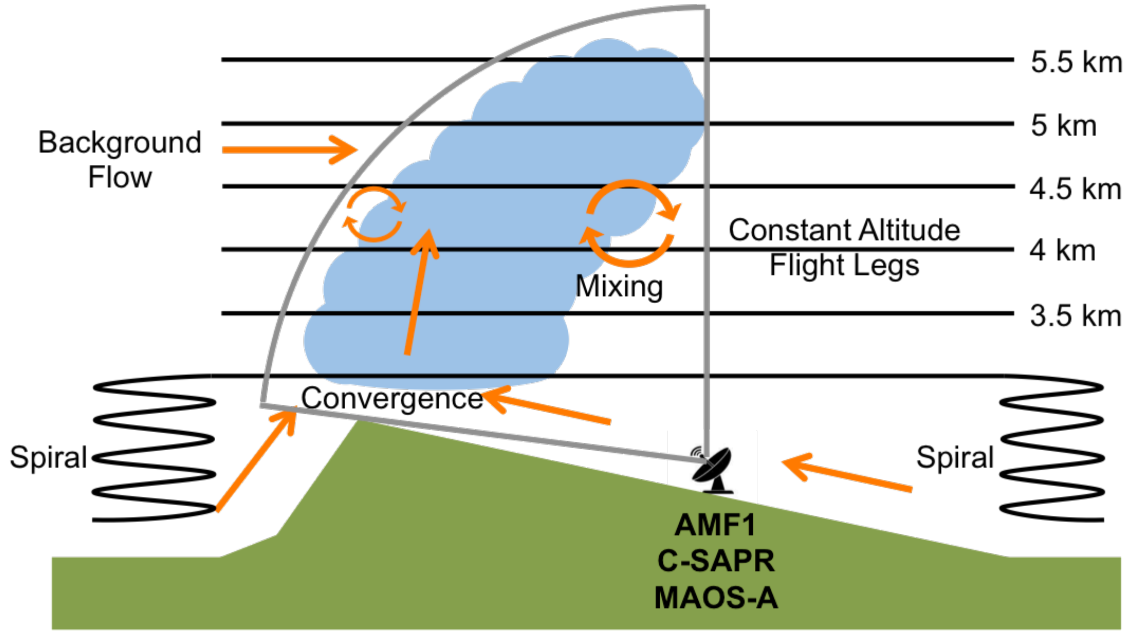
Radiation

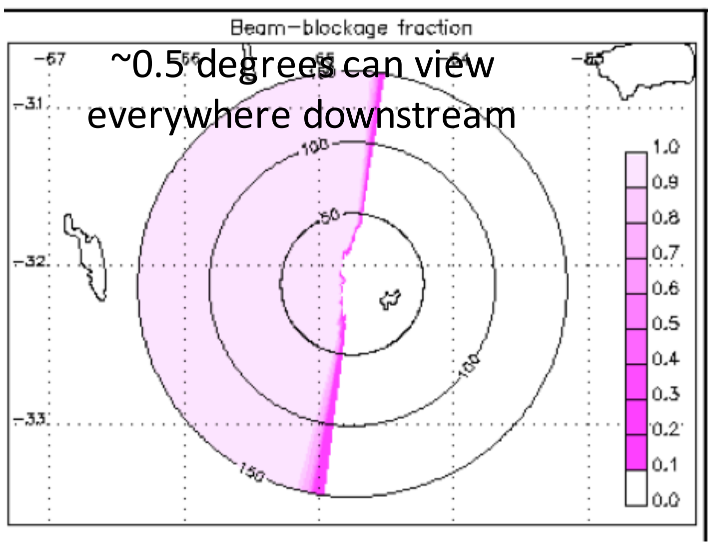
Microwave Radiometers, AERI, MFRSR, Ground/Sky Radiometers

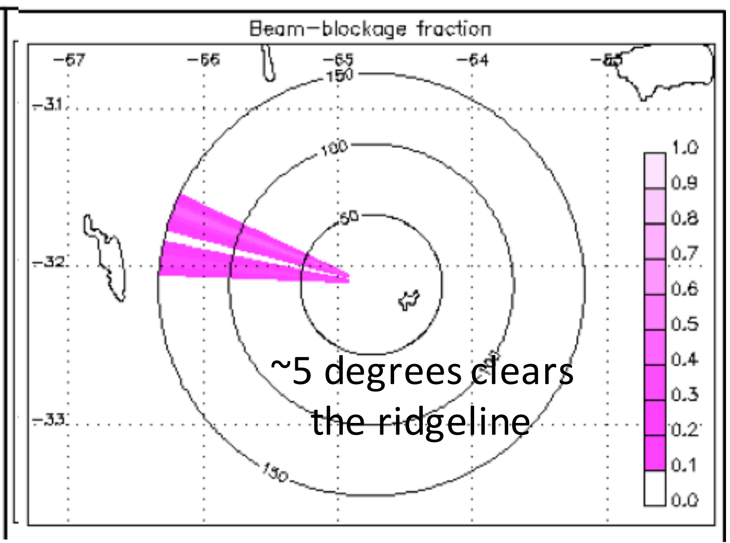
We hope to have the G-1 aircraft participate for an IOP in November-December as well so that in situ cloud and free tropospheric aerosol properties can be obtained and extended using remote sensing.

Measurement Strategy – Orographic Cu

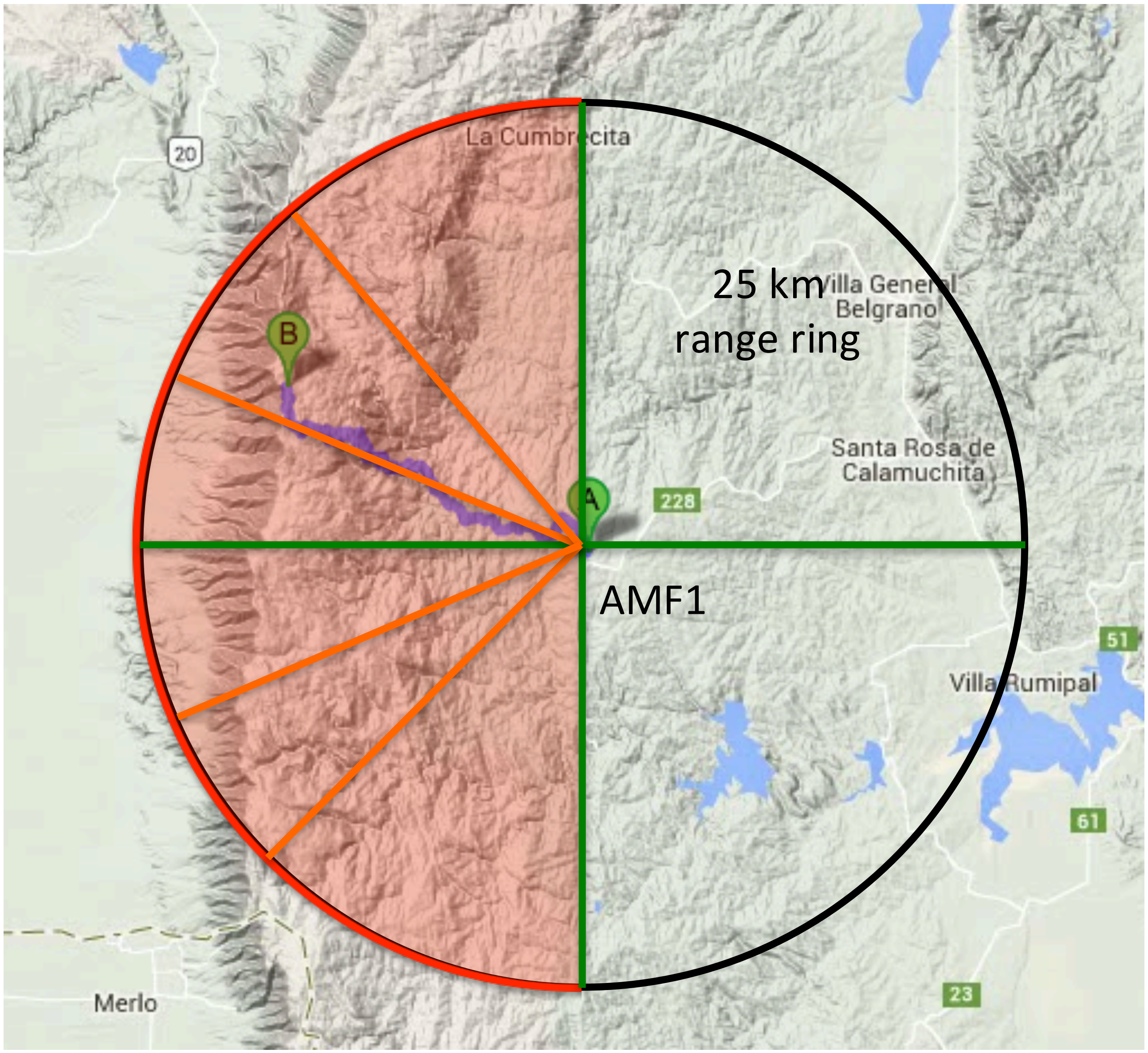








Measurement Strategy – Cloud Evolution



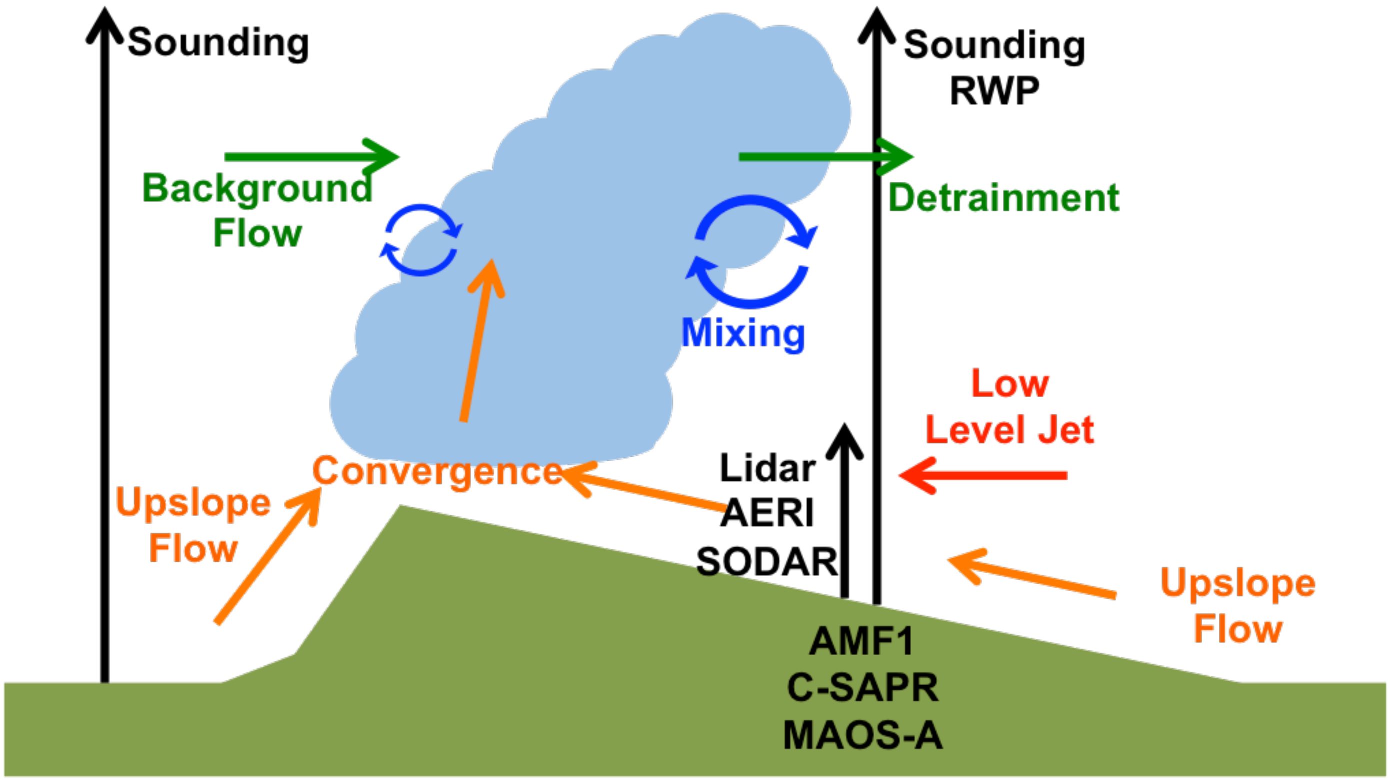
180-360 deg. azimuth PPI at lowest elevation angle with no beam blockage (context)

0-90 deg RHIs crossing crest at 4-6 azimuths (detailed vertical structure of clouds and their variability, but limit to get high temporal sampling)

0-180 deg horizon-to-horizon RHIs for W-E and N-S (clouds shearing overhead past site)

Repeat every 2 minutes

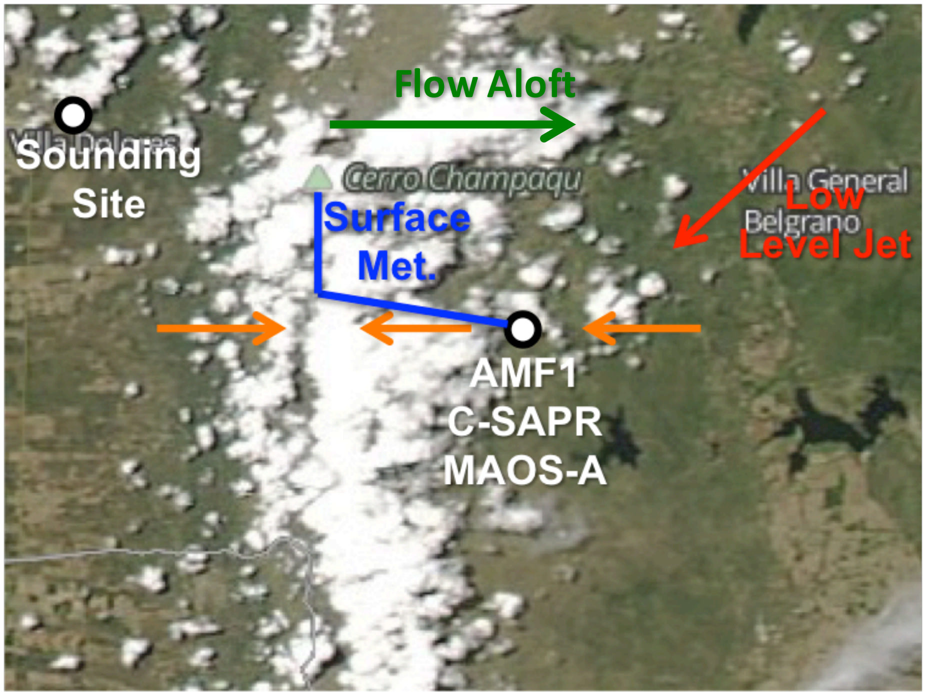
Measurement Strategy – Environment



Strategy is to measure interactions between all local environmental variables, focusing on the role of clouds and precipitation

Measure the inflow to cloud base with in situ/radar cloud measurements and detrained air into the free troposphere over the site

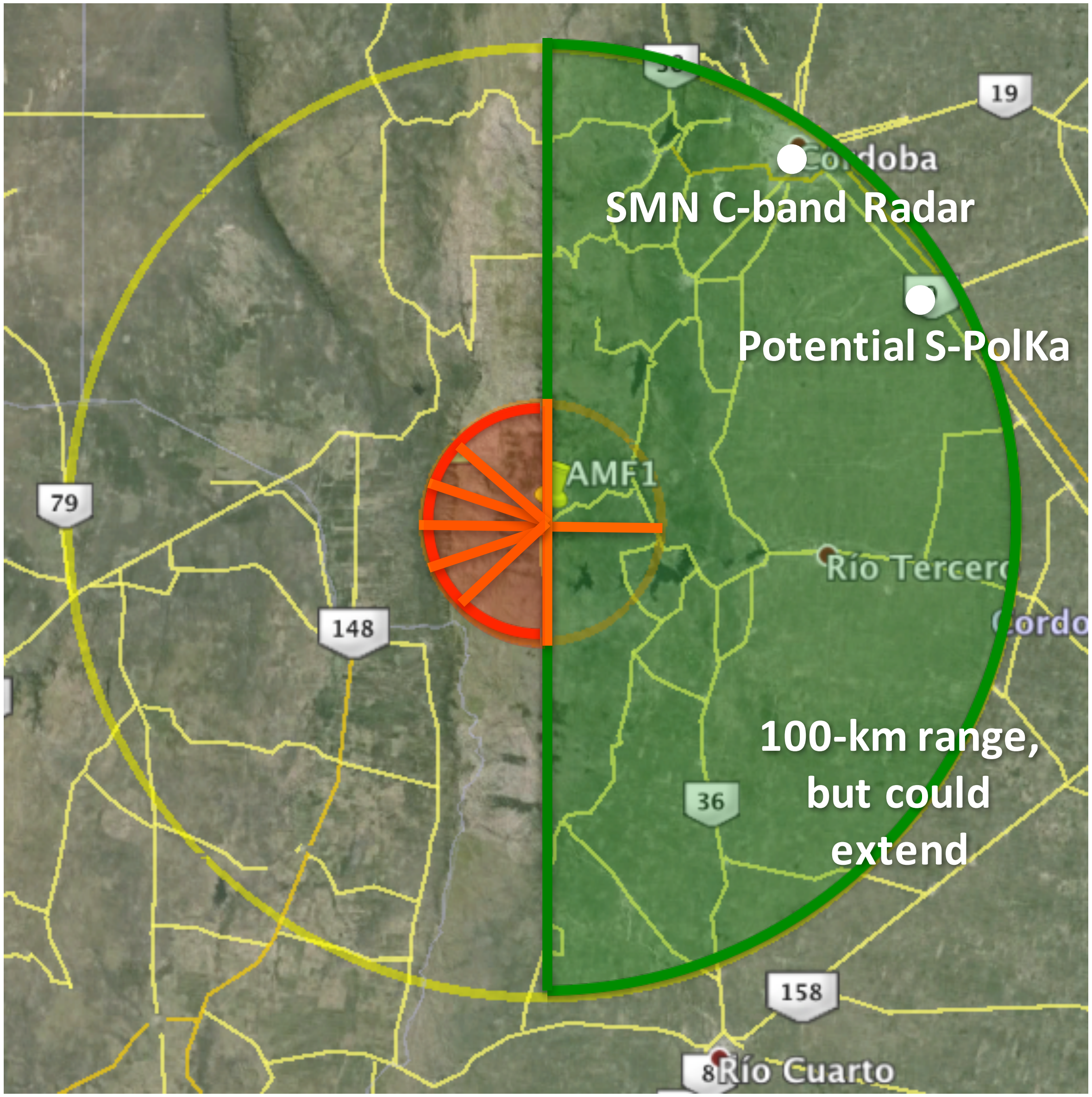
Measurement Strategy – Environmental Thermodynamic and Kinematic Evolution



Operations will be limited to daytime with 1.5-3 hourly AMF site soundings depending on the situation, and 3-6 hourly upstream soundings

We hope to set up surface meteorological stations along a road to the top of the ridge

Measurement Strategy – Deep Convective Initiation/Upscale Growth



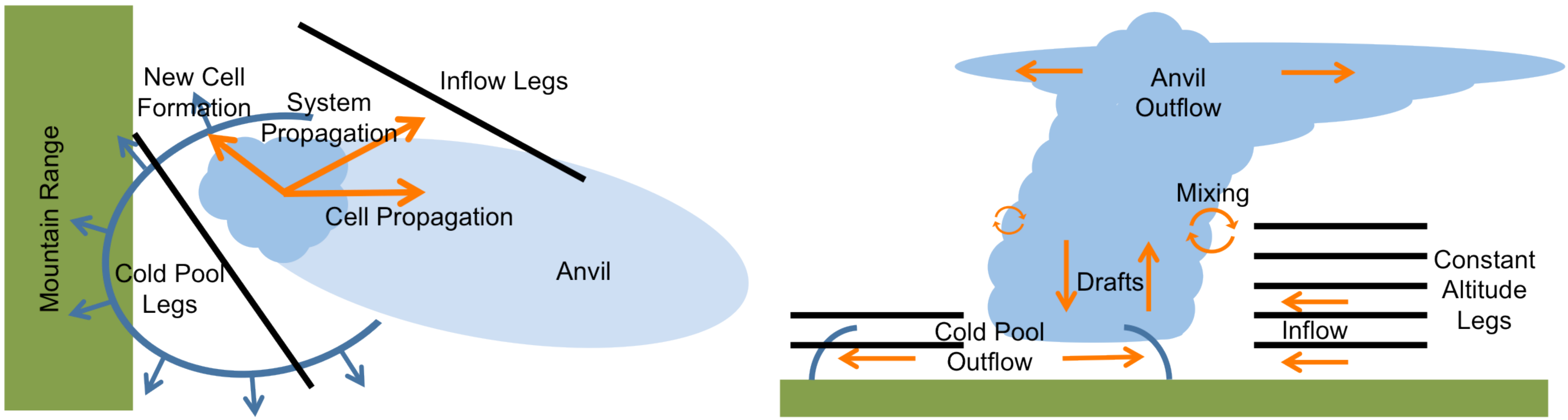
180-360 deg. azimuth PPI at lowest elevation angle with no beam blockage (context)

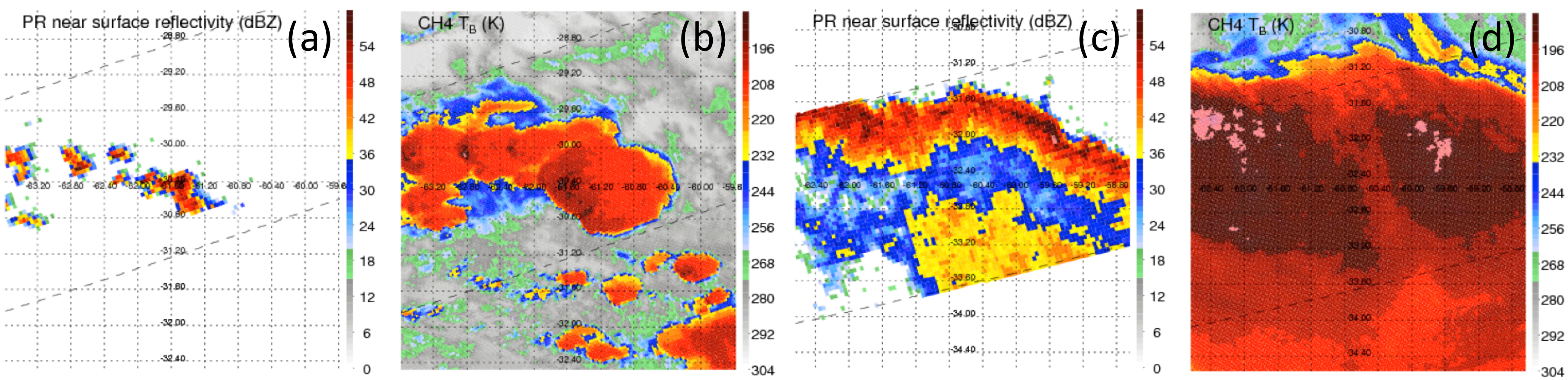
0-90 deg RHIs crossing crest at same azimuths as Ka-SACR trying to match as closely as possible – 2 minutes? (detailed structure of initiating precipitation, deep convection)

~0-180 deg azimuth volumetric scan - 4 minutes? How many elevation angles needed to observe near site? (observe upscale growth to east)

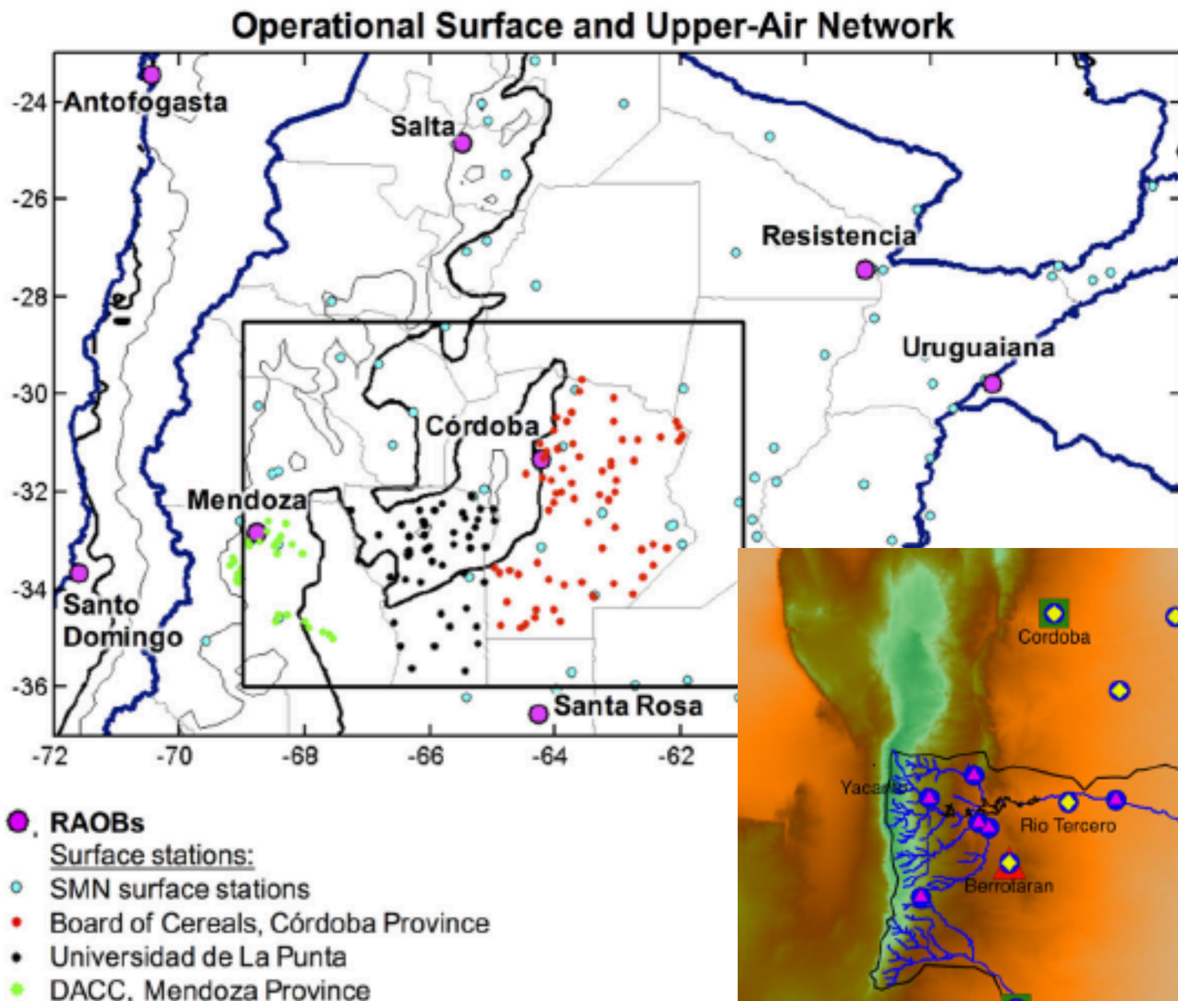
Repeat pattern every 6 minutes

Measurement Strategy – Deep Convective Initiation/Upscale Growth





Argentinean /RELAMPAGO Resources



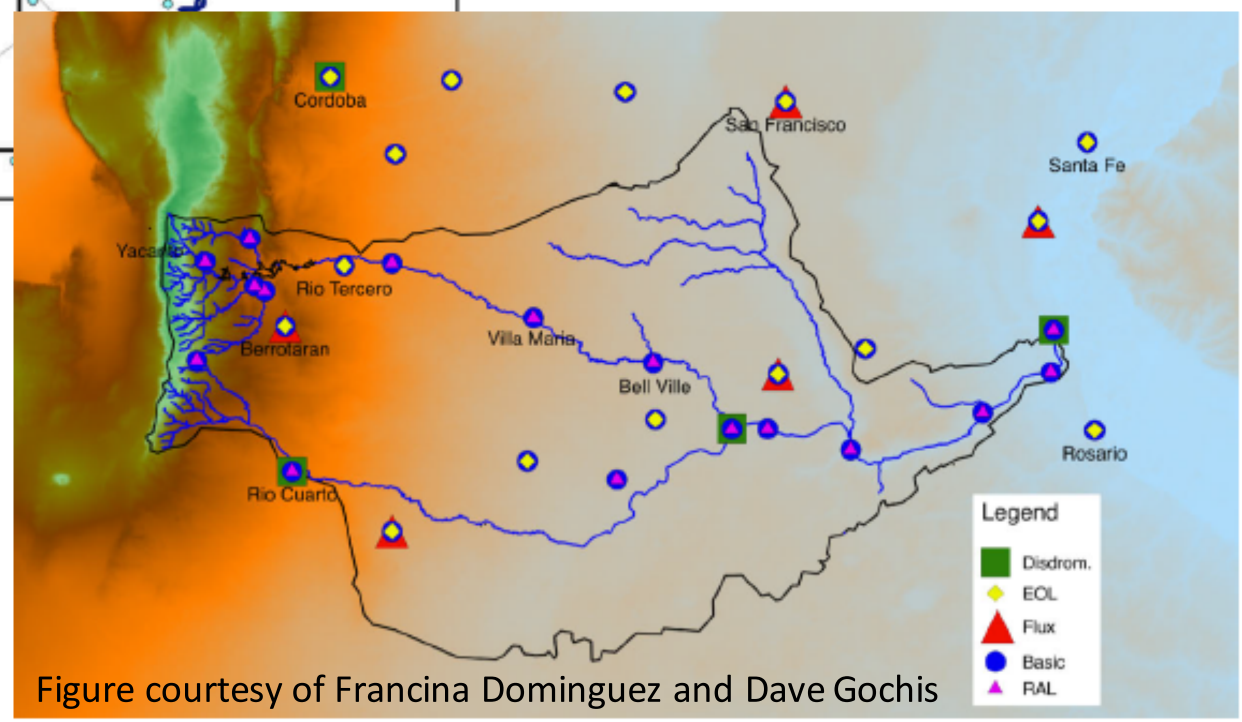
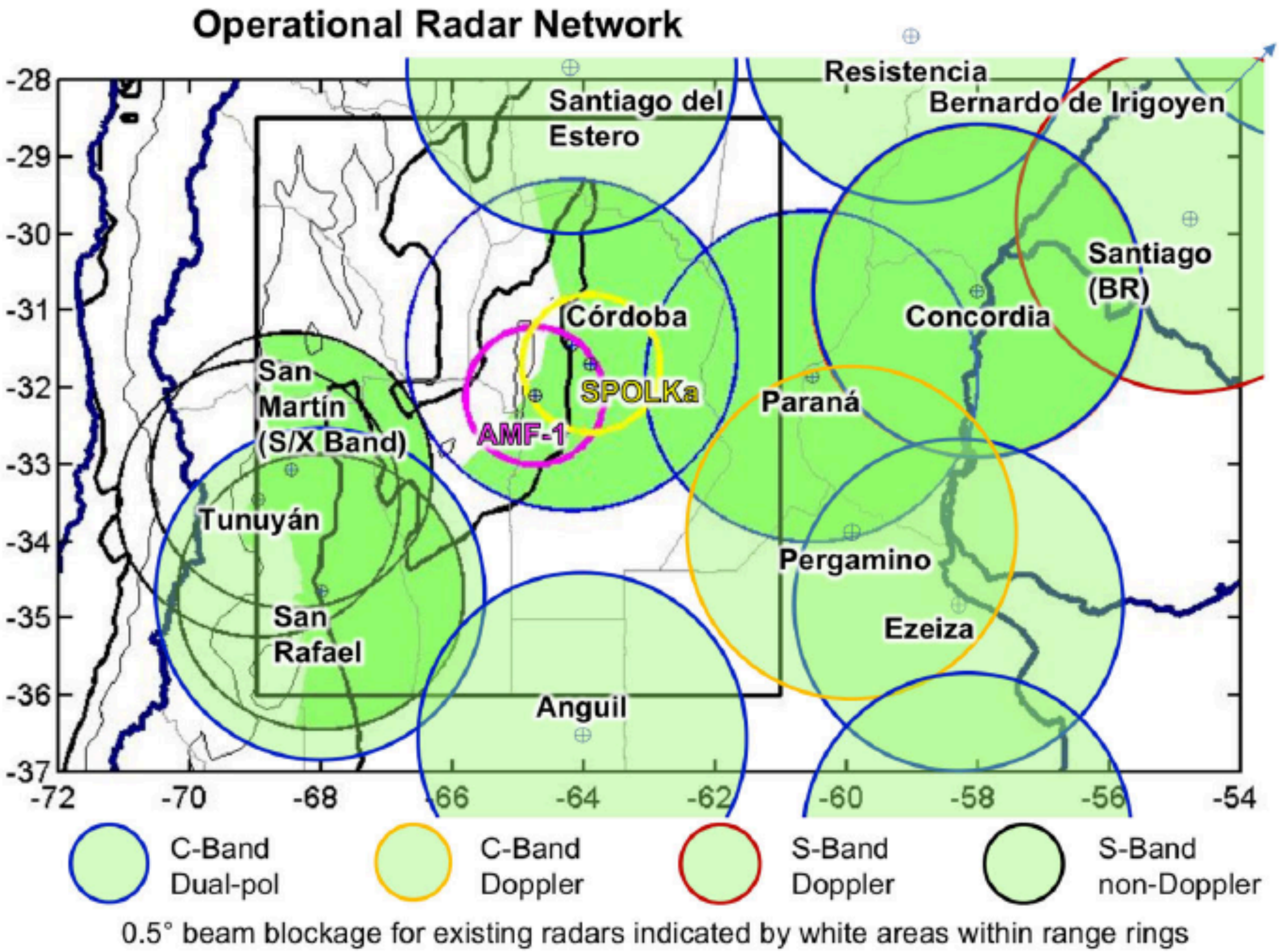
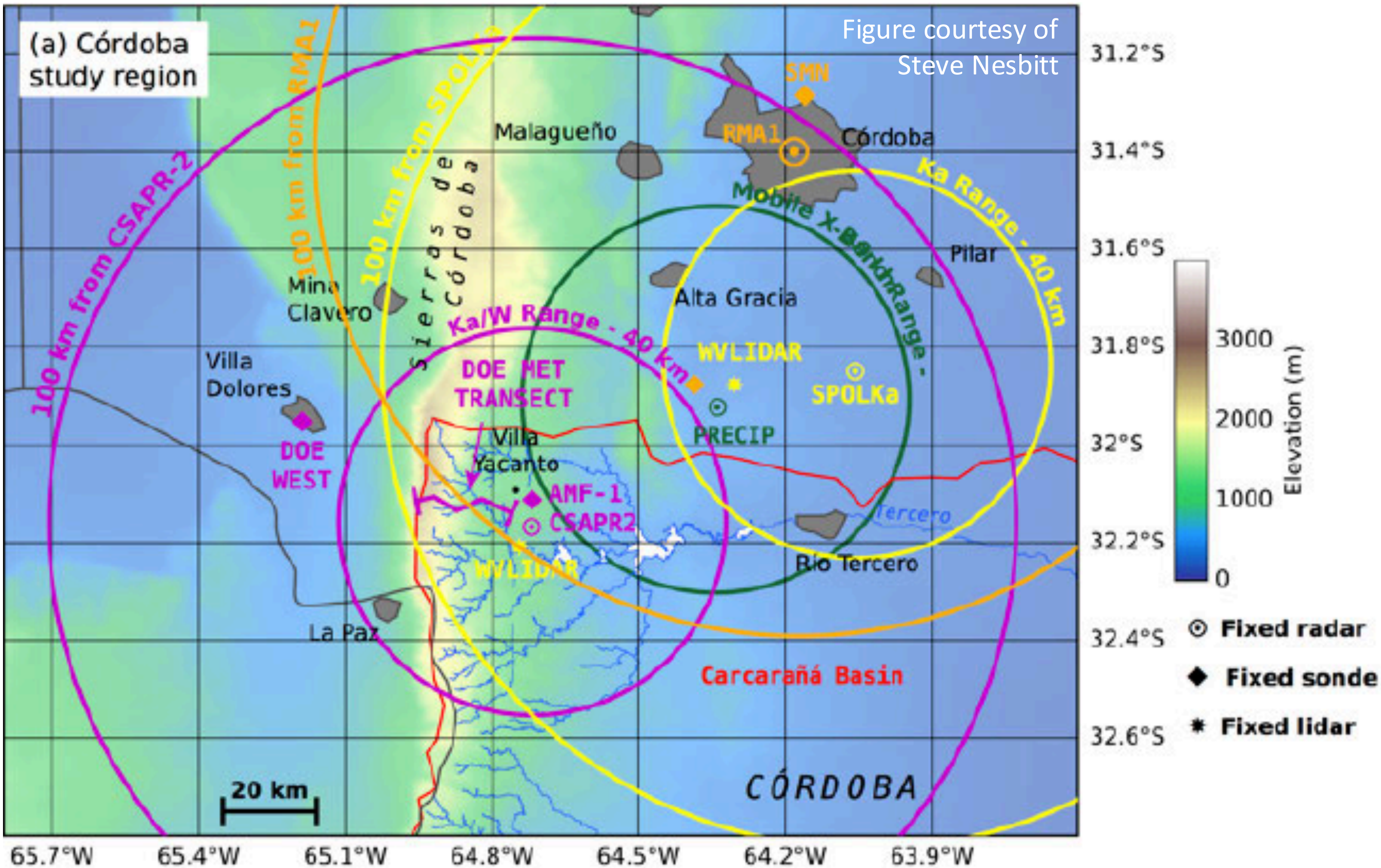


Figure courtesy of Francina Dominguez and Dave Gochis

Argentinean /RELAMPAGO Resources



CACTI-RELAMPAGO



Research using CACTI measurements

- ***INTERACTIONS BETWEEN BOUNDARY LAYER CLOUDS AND THE ENVIRONMENT***
  - Land Surface Properties
  - Boundary Layer Circulations
  - Free Tropospheric Interactions
  - Aerosol Effects
  - Model Validation and Improvement
- ***DEEP CONVECTIVE INITIATION AND ORGANIZATION***
  - Transition from Congestus to Cumulonimbus
  - Dynamical, Microphysical, and Macrophysical Relationships
  - Factors Controlling Mesoscale Organization
  - Impacts on Aerosols and Land Surface Properties

Questions? Comments?

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INTERACTIONS BETWEEN BOUNDARY LAYER CLOUDS AND THE ENVIRONMENT

Land Surface Properties

- How do surface conditions such as soil moisture and vegetation, as well as atmospheric conditions such as atmospheric relative humidity and wind speed, impact the Bowen ratio?
- How does the Bowen ratio impact the evolution of boundary layer temperature, relative humidity, depth, and turbulence?
- How does the coupling between surface conditions and boundary layer structure impact boundary layer aerosol and cloud properties?
- Can single column and LES models reproduce observed sensitivities of boundary layer evolution to surface conditions? If not, what causes differences?

INTERACTIONS BETWEEN BOUNDARY LAYER CLOUDS AND THE ENVIRONMENT

Boundary Layer Circulations

- How is the evolution of upslope flow affected by surface fluxes and the horizontal and vertical distributions of atmospheric temperature, humidity, and winds?
- How do background mesoscale circulations, such as low level jets or cold fronts, interact with the topography and alter thermal upslope flows?
- How do boundary layer circulations and thermodynamics impact cloud location and depth as a function of time?
- How well do multi-scale models reproduce boundary layer circulations and observed sensitivities of boundary layer growth and cloud formation to these circulations? What are sources for model biases?

INTERACTIONS BETWEEN BOUNDARY LAYER CLOUDS AND THE ENVIRONMENT

Free Tropospheric Interactions

- How do the cloud entrainment and dilution rates vary as a function of environment, and what impact does it have on cumulus dynamics, microphysics, and macrophysics?
- How does cloud detrainment modify the lower free tropospheric humidity and stability?
- How do orographic, low level jet, and synoptic circulations modify the free tropospheric humidity and stability, and what are the relative time scales of these modifications?
- How does free tropospheric modification by circulations and clouds impact subsequent circulations and cloud evolution?
- How well do multi-scale models reproduce the interactions between cloud lifecycle and free tropospheric evolution? When do models perform well and when do they not perform well? What are sources of model biases?

INTERACTIONS BETWEEN BOUNDARY LAYER CLOUDS AND THE ENVIRONMENT

Aerosol Effects

- As a function of meteorology, how does the low level CCN concentration impact cloud microphysics, dynamics, macrophysics, and radiative forcing?
- How does CCN correlate with CN and AOD for different meteorological conditions and as a function of the diurnal cycle?
- How do out-of-cloud, in-cloud, and cloud-processed aerosol properties relate to one another?
- How well do surface aerosol measurements predict in-cloud aerosol and cloud droplet properties?
- How well do high-resolution simulations with state of the art aerosol and microphysics schemes reproduce observed sensitivities of clouds to aerosol properties, particularly the size distribution and CCN number concentration?

INTERACTIONS BETWEEN BOUNDARY LAYER CLOUDS AND THE ENVIRONMENT

Model Validation and Improvement

- How well do different combinations of surface, PBL, free troposphere, and aerosol variables predict cloud macrophysical, microphysical, and dynamical properties as a function of time in observations and models?
- Can LES simulations using an ensemble of physics schemes reproduce relationships between surface conditions, boundary layer structure, aerosol properties, and cloud properties when given the range of conditions that were observed? What are the primary causes for differences between simulations and observations?
- Can GCM and NWP simulations reproduce cloud characteristics as a function of environment and different time scales (diurnal and seasonal)? What are the primary causes of model biases?

Research using CACTI measurements

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- ***DEEP CONVECTIVE INITIATION AND ORGANIZATION***
  - **Transition from Congestus to Cumulonimbus**
  - **Dynamical, Microphysical, and Macrophysical Relationships**
  - **Factors Controlling Mesoscale Organization**
  - **Impacts on Aerosols and Land Surface Properties**

DEEP CONVECTIVE INITIATION AND ORGANIZATION

Transition from Congestus to Cumulonimbus

- How predictable is the transition from congestus to cumulonimbus, and which combinations of environmental variables are the best predictors of this transition?
- Does warm rain form in congestus, and if so, what conditions support warm rain formation, and how does warm rain impact subsequent cloud and precipitation evolution?
- When and where in growing clouds does ice initiate, how does ice initiation depend on INP properties and other environmental conditions, and how does ice initiation impact subsequent cloud and precipitation evolution?
- How well do models with differing setups and parameterizations predict deep convective initiation? What model aspects produce the best and worst predictability? Are environmental predictors of initiation the same in models and observations?

DEEP CONVECTIVE INITIATION AND ORGANIZATION

Dynamical, Microphysical, and Macrophysical Relationships

- What size and strength are convective drafts in congestus and cumulonimbus clouds, and how do draft properties depend on environmental conditions (PBL depth, CAPE, vertical wind shear, and free tropospheric humidity)?
- How do cloud dynamical and microphysical features (e.g., regions of large precipitation rate, supercooled water, or specific ice properties) co-evolve in time, and what impacts do they have on cloud macrophysical evolution?
- How do CCN and INP properties impact deep convective dynamics and ice microphysics, and how does this affect cloud top height, anvil expanse/thickness, and rainfall?
- How do simulated relationships between cloud macrophysics, microphysics, and dynamics compare to observed relationships as a function of the convective life cycle? How do comparisons change with model setup (grid spacing, physics schemes)?

DEEP CONVECTIVE INITIATION AND ORGANIZATION

Factors Controlling Mesoscale Organization

- How predictable is the upscale growth and mesoscale organization of deep convection, and which combinations of environmental variables are the best predictors of these processes?
- Which combinations of cold pool strength/depth and ambient environmental conditions promote upscale growth and organization of convection to the east of the mountains and which do not? How important are the SALLJ and gravity waves?
- Which environmental properties best predict convective mode?
- What impacts do aerosols have on mesoscale convective properties (e.g., cold pool strength), and how does organized convection alter the distribution of aerosols?
- Are multi-scale models able to predict when deep convection organizes or doesn't organize? Which models perform best and why?

DEEP CONVECTIVE INITIATION AND ORGANIZATION
Impacts on Aerosols and Land Surface Properties

- How does deep convective rainfall impact soil moisture and vegetation on daily and seasonal time scales?
- How do convective downdrafts feeding cold pools and precipitation alter CCN and INP properties at the surface and in the boundary layer?
- How do surface and boundary layer conditions that change as a result of precipitation feedback to boundary layer cloud properties and probability of further precipitation (e.g., through the altered probability of cloud formation, warm rain, or convective initiation)?
- Do aerosol and surface schemes in models accurately reproduce observed changes in surface and aerosols that result from precipitation on daily and seasonal time scales?