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# The DOE ARM Cloud, Aerosol, and Complex Terrain Interactions (CACTI) Field Campaign: LACI Measurements

June 10, 2019
2019 ARM-ASR PI Meeting

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U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

# Broad Overview

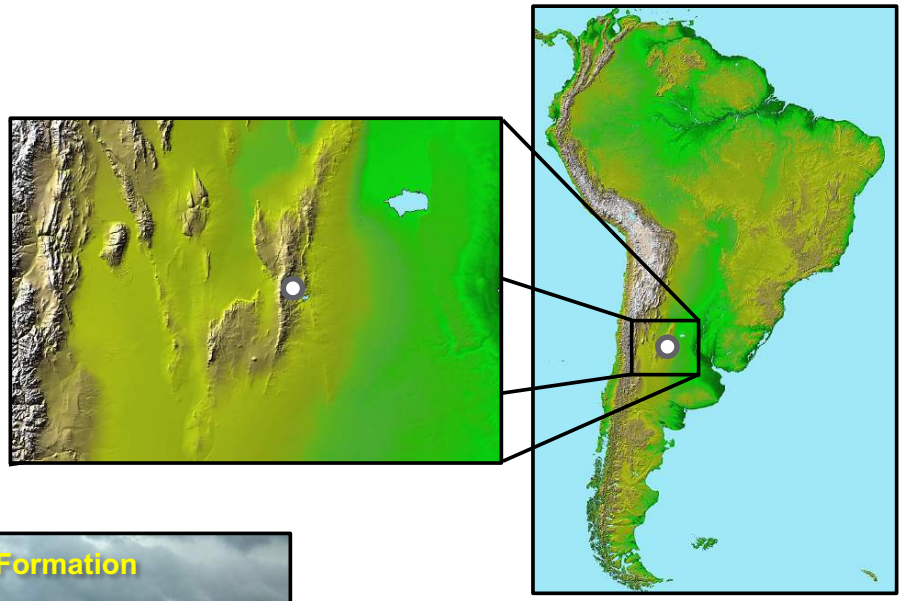
Timing: 15 October 2018 – 30 April 2019

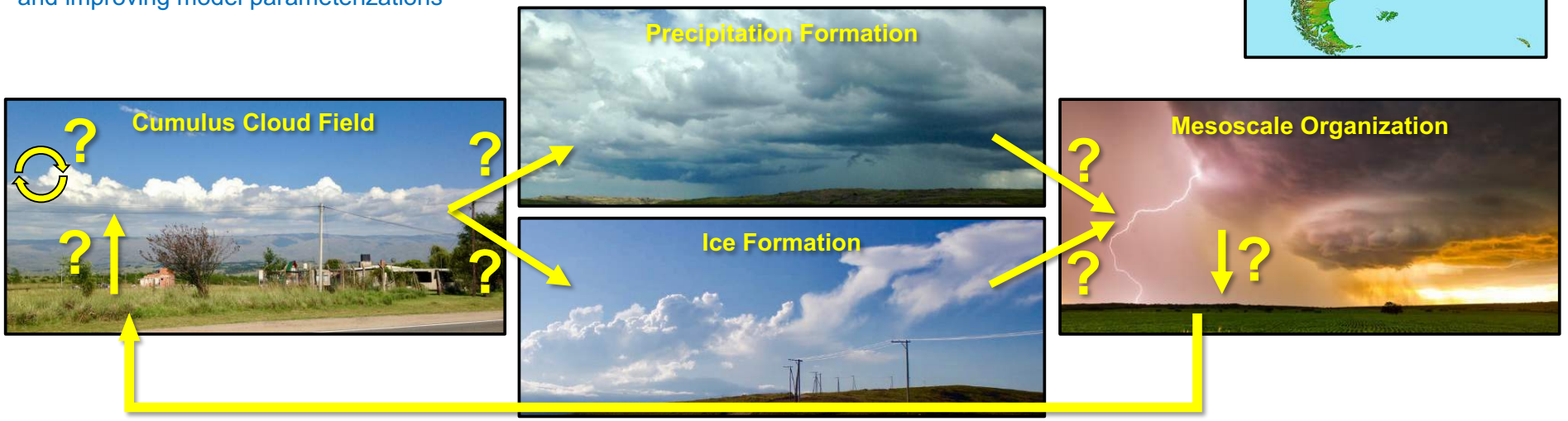
Location: Villa Yacanto, Argentina (32.1°S, 64.75°W)

Facilities: AMF-1 (> 50 instruments), C-SAPR2 radar, G-1 aircraft (IOP, > 50 in situ instruments), and supplemental AWS, photogrammetry and sounding sites

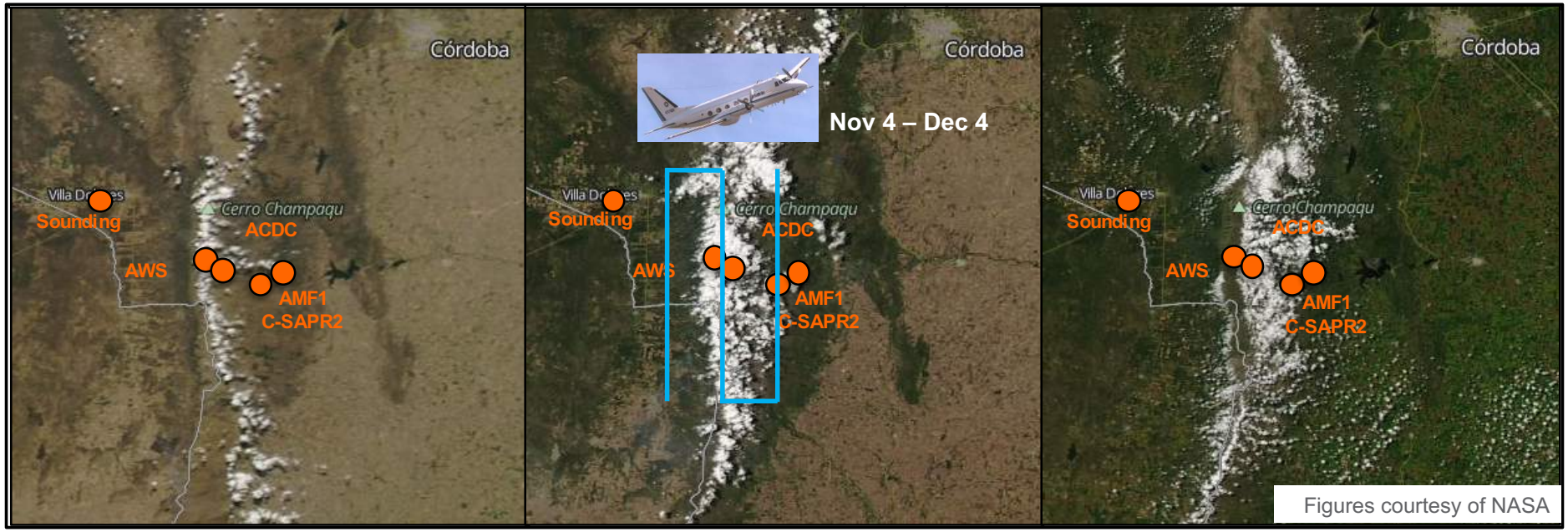
IOP was coincident with NSF-led RELAMPAGO field program from 1 Nov – 18 Dec 2018

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





# Repeated Cumulus Development with Variable Aerosol and Land Surface Properties




Figures courtesy of NASA

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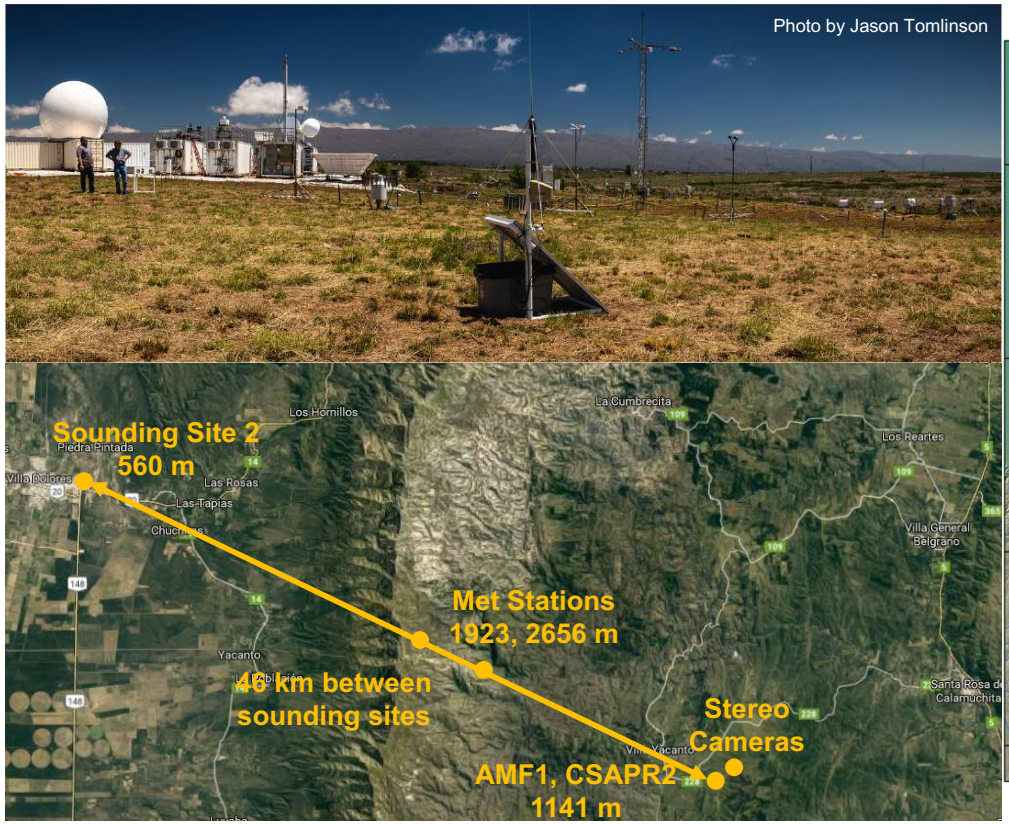
# Science Questions

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?**

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?**

**These questions are intentionally very general. The location in Argentina was primarily chosen because of its very high frequency of orographic convective clouds in a wide variety of environments uniquely observable from a fixed location.**

# Siting



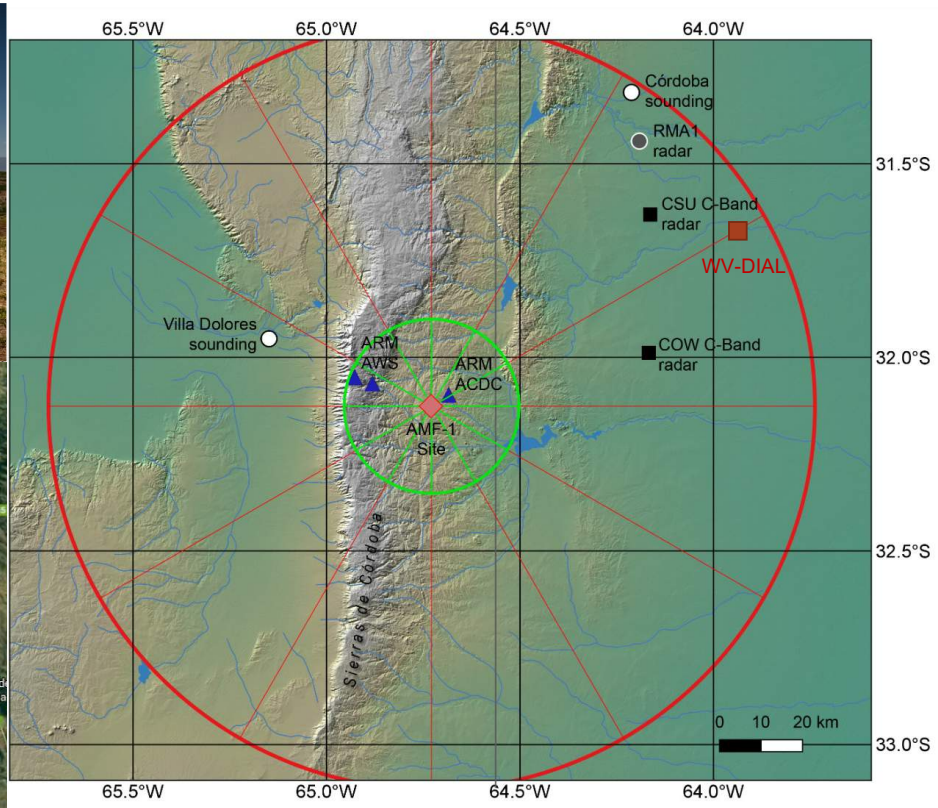




Figure courtesy of Steve Nesbitt

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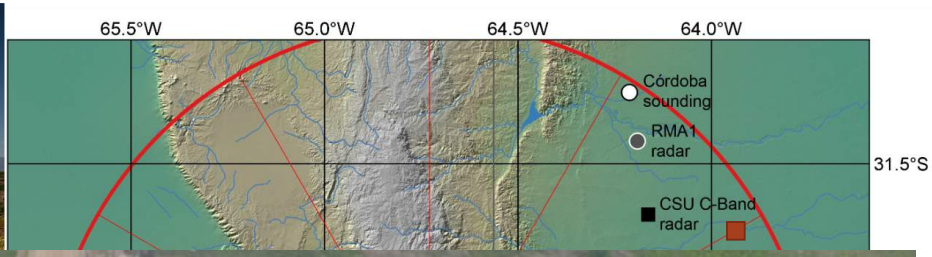
# Siting



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# Ground Instrumentation

| Property | Instrument |
|---|---|
| **Hydrometeor radar reflectivity, Doppler velocity and spectra, cloud/precipitation kinematic and microphysical retrievals** | **C-band Scanning ARM Precipitation Radar (C-SAPR2)**<br>**Ka/X-band Scanning ARM Cloud Radar (X/Ka-SACR)**<br>**Ka-band ARM Cloud Radar (KAZR)**<br>Radar wind profiler (precipitation mode) |
| **Heights of cloud bases and tops, cloud sizes and vertical velocities** | **ARM Cloud Digital Cameras (ACDC)** |
| **Cloud base height** | **Ceilometer** |
| **Cloud scene/fraction** | **Total Sky Imager (TSI)** |
| Raindrop size distribution, fall speeds, rainfall | Laser disdrometer<br>2D video disdrometer (2DVD)<br>Tipping bucket rain gauge<br>Weighing bucket rain gauge<br>Optical rain gauge |
| **Liquid water path,** precipitable water | **2-Channel Microwave Radiometer (MWR-2C)**<br>3-Channel Microwave Radiometer (MWR-3C)<br>Microwave Radiometer Profiler (MWR-P)<br>High-Frequency Microwave Radiometer (MWR-HF) |
| **Surface pressure, temperature, humidity, winds, visibility** | **Surface meteorological instrumentation** |
| **Vertical profiles of temperature, humidity, winds** | **Balloon-borne sounding system**<br>**Radar wind profiler (wind mode)**<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 (ECOR)**<br>**Surface Energy Balance System (SEBS)** |

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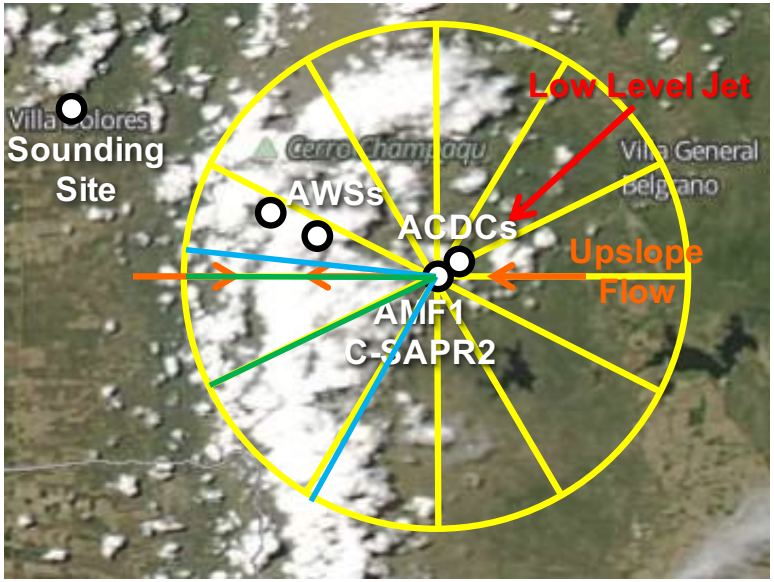
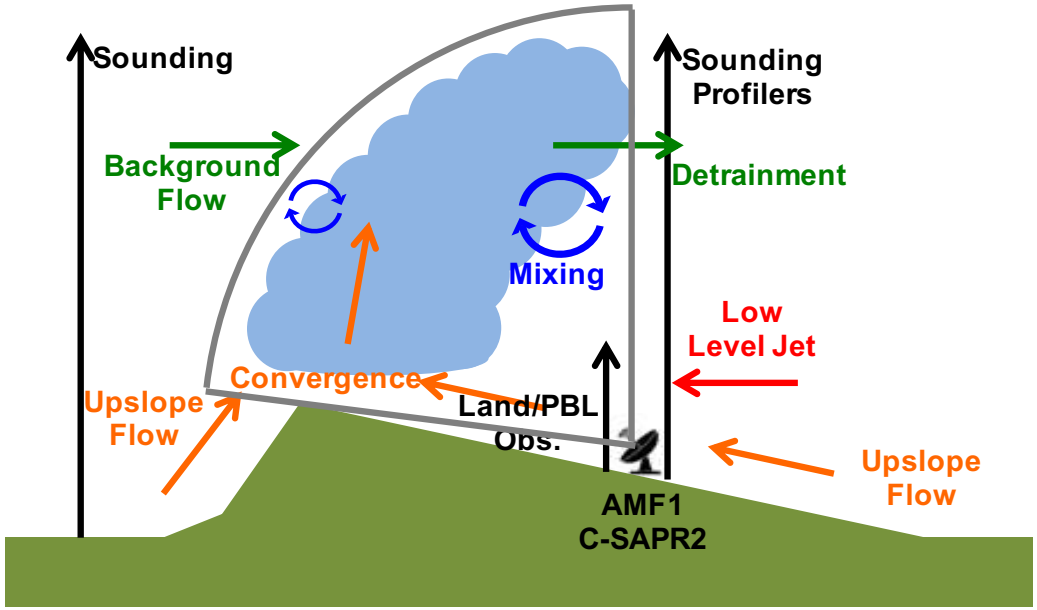
# Ground Instrumentation

| Property | Instrument |
|---|---|
| **Upwelling and downwelling radiation** | **Downwelling sky shortwave, infrared, and spectral radiometers**<br>**Upwelling ground infrared and spectral radiometers**<br>**Atmospheric Emitted Radiation Interferometer (AERI)**<br>**Multifilter radiometer**<br>**Multifilter Rotating Shadowband Radiometer (MFRSR)**<br>**Infrared thermometer – ground and sky**<br>**2-Channel Narrow Field of View Zenith Radiometer**<br>**Hemispheric Shortwave Array Spectroradiometer**<br>**Zenith Shortwave Array Spectroradiometer** |
| Aerosol backscattered radiation profile | Micropulse lidar<br>Doppler lidar |
| Aerosol optical depth | Cimel Sun photometer<br>Multifilter Rotating Shadowband Radiometer (MFRSR) |
| Cloud condensation nuclei concentration | Dual Column Cloud Condensation Nuclei (CCN) counter |
| Condensation nuclei concentration | Condensation Particle Counters (CPC, UCPC) |
| INP concentration | Filters for offline processing in CSU ice spectrometer |
| Aerosol chemical composition | Aerosol Chemistry Speciation Monitor (ACSM) |
| Black carbon | Single Particle Soot Photometer (SP2) |
| Aerosol extinction | Ambient and variable humidity nephelometers |
| Aerosol absorption | Particle Soot Absorption Photometer (PSAP) |
| Aerosol particle size distribution | Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)<br>Scanning Mobility Particle Sizer (SMPS)<br>Aerodynamic Particle Sizer (APS) |
| $O_3$, CO, $N_2O$, $H_2O$ concentration | Trace gas instrument system |

# Measurement Strategy




Measure cloud base inflow properties with in situ/remote sending measurements of clouds, precipitation, and cloud-detrained air properties in the free troposphere

On site operations is limited to daytime (9 AM to 9 PM local – 12Z to 0Z) with 4-5 AMF site soundings (every 3-4 hours) and 2-3 upstream soundings (every 6 hours)

Two automated weather stations at higher elevations and cameras for photogrammetry

Ka/X-SACR performs 30º sector RHI and 3 HSRHI patterns along yellow radials in 15 min

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# Categorized Days: Overhead Clouds/Precipitation

| Cloud Regime Over AMF Site | Dates (Note that the official campaign period was Oct 15-Apr 30) |
|---|---|
| **Cumulus Humulis, Congestus or Stratocumulus (183 days)** | October 1, 3, 4, 5, 6, 9, 10, 11, 12, 14, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30<br>November 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30<br>December 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20, 21, 22, 25, 26, 27, 28, 29, 31<br>January 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24, 25, 27, 28, 29, 30, 31<br>February 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 27<br>March 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31<br>April 1, 2, 4, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 30 |
| **Deep Convection (80 days)** | October 14, 17, 18, 19, 22, 24, 25, 26, 28, 30, 31<br>November 3, 4, 5, 6, 10, 11, 12, 13, 17, 22, 26, 27, 29, 30<br>December 1, 2, 5, 6, 10, 13, 14, 18, 19, 20, 27, 28, 30<br>January 2, 3, 6, 9, 10, 13, 14, 15, 17, 22, 23, 24, 25, 26, 29, 30, 31<br>February 1, 8, 11, 12, 19, 21, 23, 24<br>March 4, 7, 8, 9, 15, 16, 17, 20, 25, 31<br>April 1, 15, 20, 21, 22, 24, 30 |
| **Surface Rainfall (96 days)** | October 1, 11, 12, 14, 17, 18, 19, 20, 22, 23, 24, 25, 26, 28, 30, 31<br>November 1, 3, 4, 5, 6, 7, 11, 12, 13, 22, 26, 27, 28, 29, 30<br>December 1, 2, 5, 10, 13, 14, 18, 19, 20, 27, 28, 30<br>January 2, 3, 6, 9, 10, 13, 14, 15, 17, 18, 22, 23, 25, 26, 29, 30, 31<br>February 1, 3, 8, 9, 11, 12, 22, 23, 24, 25, 26<br>March 4, 5, 8, 9, 11, 12, 14, 15, 16, 17, 19, 20, 26, 26, 31<br>April 1, 15, 20, 21, 22, 24, 25, 26, 27, 30 |

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# ARM Value Added and PI Product Plans

| VAP | Measurement |
|---|---|
| AERINF | Longwave spectral radiances |
| AERIoe | Boundary layer temperature and humidity |
| AOD | Aerosol optical depth |
| AOP | Aerosol optical properties |
| ARMBE | Hourly best estimated climate relevant variables |
| CMAC2.0 | Corrected radar measurements and retrievals |
| KAZR-ARSCL | Cloud boundary time-heights with corrected KAZR reflectivity and velocity |
| DLPROF | 3D wind profiles |
| INTERPSONDE | Temperature, humidity, pressure, and wind time-heights (no ECWMF) |
| MERGESONDE | Temperature, humidity, pressure, and wind time-heights (including ECMWF) |
| MPLCLDMASK | Cloud mask and depolarization ratio from micropulse lidar |
| MWRRET | Precipitable water vapor and liquid water path estimates |
| PBLHT | Boundary layer height estimates |
| PCCPP | Cloud boundary locations and movements from stereo cameras |
| QCECOR | QC'ed latent and sensible surface fluxes |
| QCRAD | QC'ed surface radiative fluxes |
| RADFLUX | Clear sky downwelling broadband radiation for computing CRE |
| VARANAL | Large-scale advective tendencies |
| SatCORPS (Langley) | GOES-16 cloud retrievals at 1 or 15-min frequency depending on time period |
| Additional PI Products | Radar retrievals and Cartesian gridded products, and ice nucleating particle concentrations |

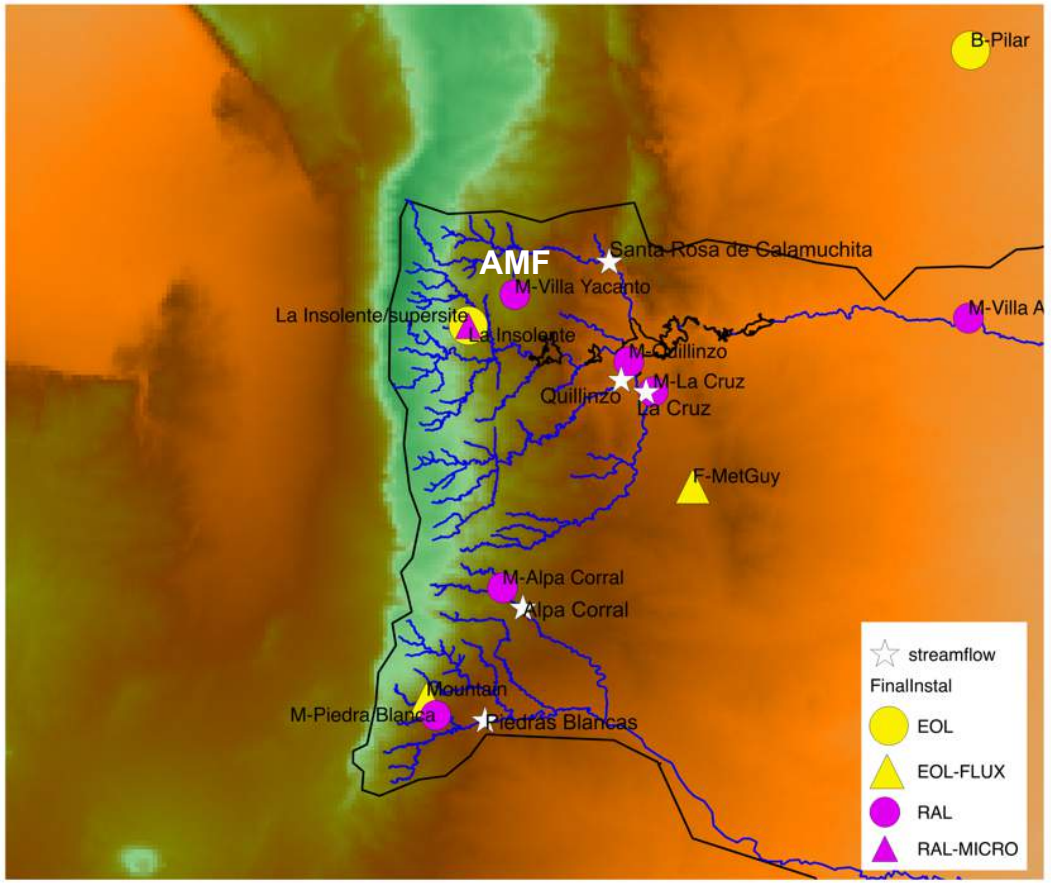
# RELAMPAGO-Hydro NSF Field Campaign

**PIs**

Francina Dominguez, University of Illinois
David Gochis, NCAR
Marcelo Garcia, University of Córdoba

**Measurements (June 2018 – April 2019)**

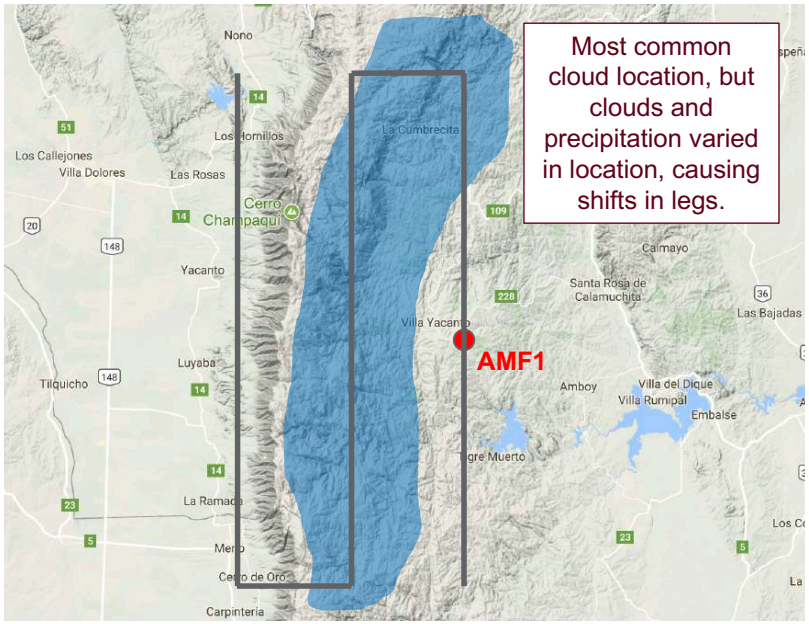
- EOL Stations
  - Tipping bucket rain gauge
  - Temperature, RH, pressure, winds
  - Near surface soil moisture, temperature, heat flux, heat capacity
  - Leaf wetness
  - Incoming/outgoing SW/LW Radiation
  - For a subset:
    - Surface fluxes (F-MetGuy, La Insolente)
    - Parsivel disdrometer (F-MetGuy, B-Pilar)
- RAL Stations
  - Tipping bucket rain gauge
  - Temperature, RH, pressure, winds
  - 5 and 25 cm soil temperature and moisture
  - Leaf wetness
  - Downward SW irradiance
- Plus, streamflow and local hydrologic network
- Datasets should be available by late 2019/early 2020



# G-1 Flight Strategy
## (see Alyssa Matthews poster #69, Wed 3:30-5 PM)

**22 flights between November 4 and December 8, 2018**

| | |
|---|---|
| Timing: | Mid morning to afternoon (2-4 hour flights) |
| Patterns: | North-south, constant altitude legs with vertical spiral over the AMF1 for some flights |
| Altitudes: | As low as possible in PBL, just below cloud base, mid cloud, and cloud top |




### Objectives

1. Follow changes in aerosol properties from the surface to just below cloud base to in and out of clouds in the lower free troposphere
2. Measure high-resolution in situ relationships between convective cloud kinematic, microphysical, and macrophysical properties
3. Measure spatially varying thermodynamic, kinematic, and aerosol conditions in and around convective clouds including relationships with cloud microphysical and macrophysical evolution
4. Use measurements of hydrometeors and winds to fine tune radar retrievals of cloud properties

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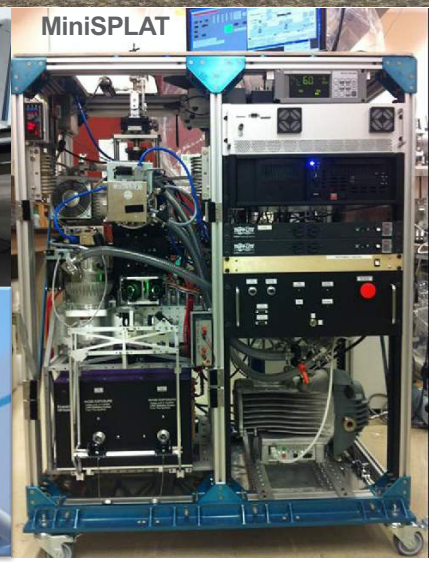
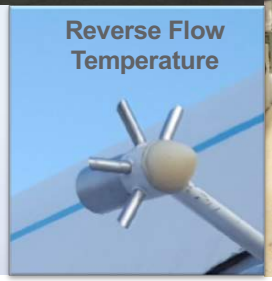
# G-1 Instrumentation
## (see Alyssa Matthews poster #69, Wed 3:30-5 PM)

| 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>VN-200 GPS/INS |
| | Video Camera P1344 |
| Meteorology | Aircraft Integrated Meteorological Measurement System (AIMMS-20) |
| | Tunable diode laser hygrometer (TDL-H) |
| | GE-1011B Chilled Mirror Hygrometer |
| | Licor LI-840A |
| | Rosemount 1201F1 |
| | Rosemount E102AL |
| | Reverse flow temperature probe (100 Hz) |
| Aerosol optical properties | Single Particle soot Photometer (SP2) |
| | 3-wavelength Integrating Nephelometer, Model 3563 |
| | 3-wavelength Particle Soot Absorption Photometer (PSAP) |
| | 3-wavelength Single channel Tricolor Absorption Photometer (STAP) |
| Chemical composition | Single Particle Mass Spectrometer (MiniSPLAT II) |
| Trace Gas measurements | N2O/CO -23r |
| | $O_3$ Model 49i |
| | $SO_2$ Model 43i |







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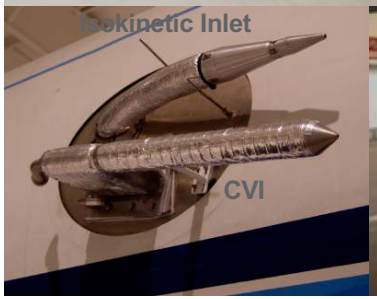
# G-1 Instrumentation

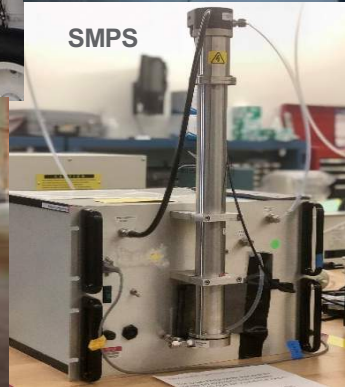
## (see Alyssa Matthews poster #69, Wed 3:30-5 PM)

| Property | Instrument |
|---|---|
| Hydrometeor size distribution | Fast Cloud Droplet Probe (F-CDP) |
| | Fast Forward Scattering Spectrometer Probe (F-FSSP) |
| | 2-Dimensional Stereo Probe (2DS) |
| | High Volume Precipitation Sampler 3 (HVPS-3) |
| | Cloud Particle Imager (CPI) |
| | Cloud Imaging Probe (CIP) |
| | Cloud and Aerosol Spectrometer (CAS) |
| Cloud liquid water content | Particle Volume Monitor 100-A (PVM-100A) |
| | Multi-Element Water Content System (WCM-2000) |
| | Hot-wire probe from CAPS |
| Cloud extinction | Cloud Integrating Nephelometer (CIN) |
| Aerosol sampling | Aerosol Isokinetic Inlet |
| | Counterflow Virtual Impactor (CVI) |
| Aerosol size distribution | Ultra-high Sensitivity Aerosol Spectrometer (UHSAS) |
| | Scanning Mobility Particle Sizer (SMPS) |
| | Passive Cavity Aerosol Spectrometer (PCASP-100X) |
| | Optical Particle Counter (OPC) Model CI-3100 |
| Aerosol number concentration | Ultrafine Condensation Particle Counter (UCPC) Model 3025A |
| | Condensation Particle Counter (CPC), Model 3772 |
| Cloud condensation nuclei | Dual-column cloud condensation nuclei counters (CCN) |
| Ice nuclei concentration | Filter collections for CSU Ice Spectrometer |







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# G-1 Flights

| Primary Objective | # of Flights | Dates |
|---|---|---|
| Cumulus-Environment Interactions | 8 | Nov 16, 17, 20, 24, 25, 28<br>Dec 3, 7 |
| Deep Convective Initiation | 8 | Nov 4, 6, 10, 12, 21, 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

Photo by Jason Tomlinson

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# Thank You

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

CACTI Datasets (Most already available with QC/retrievals in progress):
www.archive.arm.gov or www.arm.gov/research/campaigns/amf2018cacti

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

Contact: adam.varble@pnnl.gov