Experimental Design Overview

RELAMPAGO: Remote sensing of Electrification, Lightning, And Meso-scale/micro-scale Processes with Adaptive Ground Observations (translates to lightning flash in Spanish and Portuguese)

CACTI: Cloud, Aerosol, and Complex Terrain Interactions

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1. Executive Summary

We propose to conduct the RELAMPAGO (Remote sensing of Electrification, Lightning, And Mesoscale/microscale Processes with Adaptive Ground Observations) field program from 1 Nov – 15 Dec 2018 in west central Argentina in the general vicinity of the Sierras de Córdoba (SDC) mountains and the Andes foothills near Mendoza. This region has among the most intense convective systems in the world with respect to the frequency of large hail, high storm tops, and extreme lightning activity, yet ground-based observations have been scarce, and much remains unknown about the intense convection in this region. The scientific objectives of RELAMPAGO, leveraging the repeatability of storms in the region, are to address science questions related to the *pre-initiation to initiation, initial organization/severe-weather generation, and upscale growth/backbuilding* stages of storm development, which are poorly understood. New insights into the tight connections between the extreme hydroclimate, high impact weather, and atmospheric dynamical processes in meteorological and geographical settings unique to the Sierras de Córdoba (SDC) and Mendoza regions can be obtained by bringing together NSF deployment facilities with (1) newly installed operational dual-polarization radars in Argentina, (2) significant contributions from international partners in Argentina, Brazil, Chile, NOAA, and NASA, and (3) a complementary funded U.S. Department of Energy Atmospheric Radiation Measurement major field campaign called Clouds, Aerosols, and Complex Terrain Interactions (CACTI). An integrated education outreach and societal impacts part of the project will involve, train, and inspire future generations of atmospheric scientists, social scientists, and engineers.

To address these objectives, RELAMPAGO-CACTI will obtain targeted, multi-platform observations from the subsurface through the depth of the troposphere throughout the region to characterize the synoptic scale, mesoscale, and convective scale thermodynamic and kinematic environmental evolution during convective events with varying morphologies, evolutions of cloud and precipitation properties, and severe weather and flooding characteristics. An adaptive ground-based and aircraft-based measurement network, including mobile weather stations, lightning instruments, soundings, fixed and mobile Doppler/dual-polarization radars (from W- to S-band), aerosol and water vapor lidars, microwave profilers, and surface flux measurements, will be used to characterize the (1) pre-convective and convective environments, (2) kinematic and microphysical evolution of clouds and precipitation, convective outflows, and atmospheric electrification and (3) interactions between convective systems and hydrometeorology in a region of repeatable observations. RELAMPAGO-CACTI will test the RELAMPAGO grand hypothesis:

> **The meteorological-geographical setting in the lee of the Andes Cordillera, including multi-scale interactions of synoptic disturbances, the South American Low Level Jet, and complex terrain characteristics produce unique kinematic, thermodynamic, and aerosol environments that serve as controlling mechanisms for convective initiation, intensification, and upscale growth. These factors contribute to a unique convective spectrum that governs high impact weather in South America. Intensive field observations and characterization of these physical mechanisms will yield new understanding of relationships between convective systems and the environment, and therefore improve the prediction of convection globally.**

SESA is a region with sparse observations, and poor weather and climate predictive skill, but one that offers a unique opportunity to study complex interactions between a variety of environmental conditions and the lifecycles of aerosols, clouds, and precipitation on a very regular basis. In particular, repeated orographic shallow cumulus formation, common growth into congestus, frequent convective initiation with copious lightning production, and frequent mesoscale convective organization relative to other global locations are observable in the SDC and Mendoza study regions, thus providing an ideal setting for studying the predictability of cloud properties, deep convective initiation, and mesoscale convective organization, and improving their parameterization in multi-scale models. **Detailed field observations of environmental thermodynamic and kinematic evolution, microphysical, electrification, and aerosol processes, and land surface properties are needed to test and improve multi-scale models.**

2. Program Rationale

The scientific rationale, background, and scientific questions of the RELAMPAGO project are given in the RELAMPAGO Scientific Program Overview (SPO). Here we summarize the SPO as a motivation for the experimental design of the project as an integrated part of a multi-national, multi-agency project that will occur from late 2018 through early 2019. RELAMPAGO will overlap and coordinate with a large US Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) ground/aircraft campaign that has already been funded called Clouds, Aerosols, and Complex Terrain Interactions (CACTI). The funded CACTI campaign will have an extended observing period (EOP) from 15 August 2018 - 30 April 2019 with the ARM Mobile Facility (AMF1) and the C-band Scanning ARM Precipitation Radar (CSAPR2) dual-polarization radar sited near Villa Yacanto in the Sierras de Córdoba (SDC) mountain range providing surface, aerosol, sounding, cloud, and precipitation observations in the SDC area. In addition, CACTI will provide the Gulfstream-1 (G1) aircraft, with highly overlapping sampling objectives as RELAMPAGO, for a 4-6 week period overlapping with the RELAMPAGO intensive observing period (IOP). Because of the timing of CACTI and significant contributions from Argentina, Brazil, Chile, NOAA, NASA, and other projects, it is highly desirable to conduct a hydroclimate-focused RELAMPAGO-HYDRO EOP for 1 year starting 1 June 2018 and a comprehensive RELAMPAGO IOP during a 45-day period from 1 November – 15 December 2018 to maximize the synergy of planned observations and the scientific community.

Based upon the scientific rationale of the program described in the RELAMPAGO SPO, the grand RELAMPAGO hypothesis is the following:

> **The meteorological-geographical setting in the lee of the Andes Cordillera, including multi-scale interactions of synoptic disturbances, the South American Low Level Jet (SALLJ), and the complex terrain characteristics produce unique kinematic, thermodynamic, and aerosol environments that serve as controlling mechanisms for convective initiation, intensification, and upscale growth. These factors contribute to a unique convective spectrum that governs high impact weather in South America. Intensive field observations and characterization of these physical mechanisms will yield new understanding of relationships between convective systems and the environment, and therefore improve the prediction of convection globally.**

To date, unified, systematic frameworks for observing the lifecycle of convective systems and high impact weather have rarely existed in regions of complex terrain. Interactions between complex terrain and convective systems are poorly represented in mesoscale and cloud-resolving models, while convective initiation and mesoscale convective organization processes are either deficient or missing in global climate models (GCMs) (Del Genio et al. 2012; Stanfield et al. 2014). Since complex terrain often initiates convection that influences many of the world's populated regions, improving prediction of the orogenic storm initiation on nowcasting (0-6 hours) to medium range timescales (5 days) is key to improving societal resilience to hazardous weather in locations experiencing the effects of these systems. Observing unique environmental and storm processes in central Argentina, where the convective spectrum contains arguably the most intense and organized convection on Earth, is likely to reveal new insights into the behavior of extreme convective storms that will lead to improvements in our ability to understand, model, and predict extreme events around the world. Indeed, *precisely why these convective storms are so extreme is not well understood*. This understanding will come by studying the convective systems in Southeast South America (SESA), where unique convective forcing and topographic configuration produce a high frequency of initiating and growing convection within our proposed observing network that will allow simultaneous characterization of the multi-scale environmental conditions, convective cloud and precipitation properties, severe weather generation, and convective hydrometeorological impacts in ways that have not been done previously.

SESA is a region that is known to produce the most extreme convective systems on the planet in terms of their vertical development and horizontal size (see RELAMPAGO SPO). The frequency of these systems is often the determinant of flood or drought conditions, yet the microphysical and kinematic properties of such systems are often poorly predicted in mesoscale and global models. In particular, MCSs are poorly represented, if at all, in GCMs and regional climate models (RCMs), the consequences of which include major model biases, including warm, dry biases downstream of the Rockies (Klein et al. 2006). RCMs overestimate orographic rainfall in the Andes but underestimate total rainfall downstream of the SDC, which is a result of underestimated heavy rainfall events (Carril et al. 2012). This is likely associated with insufficient moisture transport by the SALLJ and a lack of mesoscale convective organization in this region where up to 95% of warm season rainfall results from deep convection and MCSs (Nesbitt et al., 2006; Rasmussen et al., 2015). RCM precipitation biases also tend to be larger for South America than North America or Europe (Solman et al. 2013), and although these biases are large and consistent across models, observed rainfall has significant uncertainty because of scarce measurements in the region (Carril et al. 2012). A recent study by Matsudo et al. (2015) suggests that the timing of organized convection over SESA may be improved in convection-permitting models relative to RCMs, however the amount of precipitation relative to satellite precipitation retrievals that are themselves biased (Rasmussen et al. 2014; Salio et al. 2015) is still underpredicted. Indeed, the choice of microphysics parameterization strongly impacts the initiation, structure, propagation characteristics, and rainfall intensity of organized convective systems simulated with the Weather Research and Forecasting (WRF) model at convection permitting resolutions (Rasmussen 2014; Nesbitt et al. 2016, in preparation). These differences have significant implications for prediction of severe weather and hydrologic extremes.

SESA is clearly a region with sparse observations, and poor weather and climate predictive skill, but one that offers a unique opportunity to study complex interactions between a variety of environmental conditions and the lifecycles of aerosols, clouds, and precipitation on a very regular basis. In particular, repeated orographic shallow cumulus formation, common growth into congestus, frequent convective initiation with copious lightning production, and frequent mesoscale convective organization relative to other global locations are observable in the SDC and Mendoza study regions, thus providing an ideal setting for studying the predictability of cloud properties, deep convective initiation, and mesoscale convective organization, and improving relevant parameterizations in models. **Detailed field observations of environmental thermodynamic and kinematic evolution, microphysical, electrification, and aerosol processes, and land surface properties are needed to test and improve multi-scale models.**

2.1 Selection of Study Locations: SDC and Mendoza

In the RELAMPAGO-CACTI region, variations in convective morphology appear to depend on location, storm environment, and proximity to elevated terrain, which makes the region ideal for studying factors that control the initial development of organized, long-lived convection. Organized MCS-type convection dominates the precipitation climatology over the region (RELAMPAGO SPO; Rasmussen et al. 2014), particularly near the SDC and further east to plains areas. As shown in Fig. 2 of the RELAMPAGO SPO, tornadoes are also observed along and east of the SDC, however the proportion of hail, heavy rain, and tornadoes due to supercell versus non-supercell parent storms is unknown. The growth of severe hail is supported in supercell thunderstorms because of the relatively wide, strong updrafts of supercells, but also because of the mesocyclonic winds that allow recirculation of hail embryos through regions of supercooled liquid water. The supercell mesocyclone also serves as the parent circulation to tornadoes, and thus it is not too surprising that the geospatial distribution of severe hail corresponds well with that of strong tornadoes (Brooks et al. 2003). In contrast, the highest concentration of Argentinean hail is in the Andes foothills and the SDC, while Argentinean tornadoes are most likely to be found well east of the Andes (Rasmussen et al. 2014). From a remote sensing point of view, DCCs (TRMM PR echo top > 10 km) predominate near the Andes (e.g., Rasmussen et al. 2014; Fig. 3), but it is not clear whether these cores are associated with supercellular convection, since ground based Doppler radars are not available, however severe "multicell" storms similar to those observed on the US high plains may be more common (Foote 1984; Krauss and Marwitz 1984). Drawing from the global reanalysis based study of Brooks et al. (2003), the relative low frequency over Argentina of a tornadic supercell supporting environment (which heavily depends on vertical wind shear over the 0-1 km layer) as compared to the much higher frequency of a generic severe-thunderstorm environment (which depends only on CAPE and vertical wind shear over a 0-6 km layer) generally supports these inferences but does not clarify them.

ERA-Interim reanalysis severe weather related fields composited for DCCs show stark contrasts in the box-averaged low level shear profiles between storms that were observed in Mendoza versus the SDC (Fig. 1). Values of 0-1 and 0-3 km shear are much higher near the SDC than in the Mendoza region, and values of average 0-1 km storm relative helicity near the SDC exceed -100 m^2/s^2 (-298 m^2/s^2 in the extreme), but are smaller in the Mendoza region. Similarly, average values of significant tornado parameter (see Thompson et al. 2003) are less than -0.6 for DCC events in the SDC region (-1.6 in the extreme), but are near 0 in Mendoza (with an extreme value of -0.93). For all DCC events (374 in the

SDC and 351 in Mendoza), the mean (maximum) ERA-Interim most unstable CAPE and CIN values (in units of J/kg) were 1453 (4181) and -67 (-263) in the SDC and 1253 (3707) and -49 (-208) in Mendoza. This provides evidence that ample conditional instability is present in both regions, but there is slightly more CAPE and CIN, and much greater low level vertical wind shear in the SDC. Although reanalysis profiles may contain biases and correlations between vertical wind shear-instability combinations and severe weather are not perfect, supercell-type convection is likely to be supported more in the SDC region than in the Mendoza region.

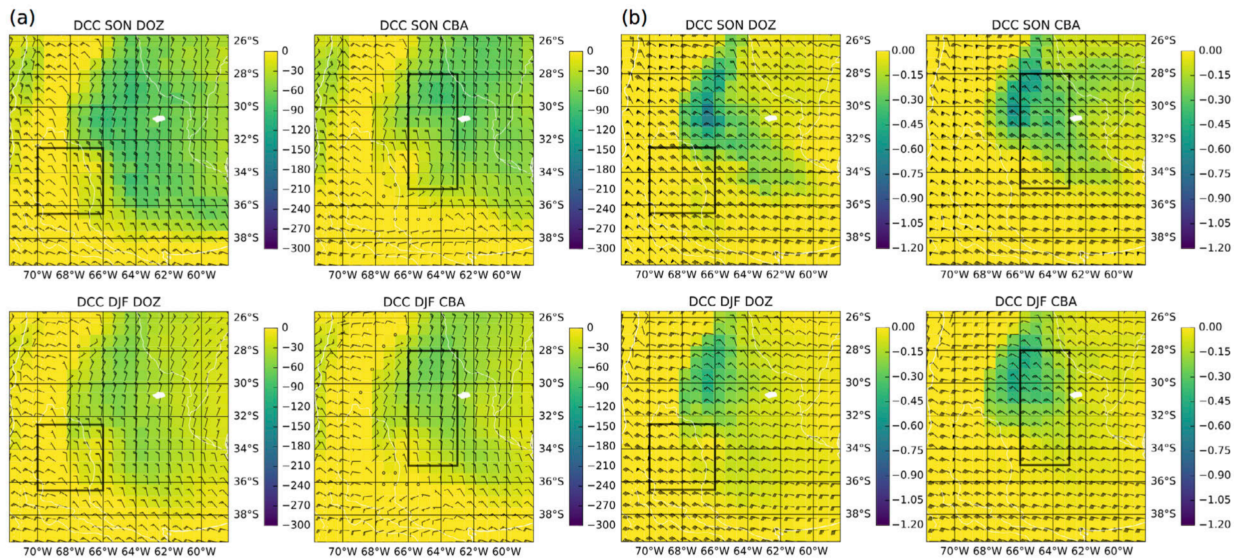

Fig. 1. Composites of 0-1 km storm relative helicity and 0-1 km shear vector (kt) (left four panels) and significant tornado parameter and 0-3 km shear vector (kt) at the closest prior ERA-Interim analysis time of TRMM-identified DCCs identified in Fig 1 of the SPO. DOZ = Mendoza study region, CBA = Córdoba study region. SON = September-October-November, and DJF = December-January-February. From Nesbitt et al. (2016, in preparation).

There is no analog to the steep terrain of the Andes nor the plains-protruding topography of the SDC in the Central US. The topography and land surfaces to the west of central Argentina the regions favoring severe convection are significantly different than the Rockies and their influence on the convective initiation and evolution is not well understood. Also, the Andes are taller and steeper than the Rockies, which appears to influence the nature of the capping inversion in soundings in SESA, and likely impacts the consequential location and timing of convective initiation though the production of anabatic flows and gravity waves, steep lapse rates, and configurations vertical wind shear. The close proximity of the SALLJ close to the terrain of the Andes and the SDC provides heat and moisture to the immediate proximity of the terrain. Precipitation ranges climatologically between 400 mm/yr west of the SDC to 700 mm/yr directly east of the Sierras. However, precipitation increases dramatically further east and climatological precipitation in east-central Argentina is around 1,200 mm/yr (only 100 km eastward from the SDC). This precipitation gradient causes very different land surface fluxes, which is important for boundary layer and convective processes, as well as hydrologic impacts when severe storms do occur, and could be a primary control of convective intensity in the region (e.g., Taylor et al. 2011; Taylor et al. 2013), which along with storm propagation and basin characteristics, feeds back on the type of flooding hazard that is presented (flash vs. riverine). It is not known how the lifecycle of convective systems and the hydrologic configuration of the region favors the production of intense rainfall and flooding in this region.

While the above inferences may be correct, it is necessary to conduct detailed field observations of the causal physical processes leading to differences in storm initiation, structure, and lifecycle, as well as extreme behavior such as severe weather, lightning production, and heavy localized precipitation production in this region. Moreover, **to leverage the distinct differences in observed severe weather production and storm structure between the SDC and Mendoza regions in answering our science questions, we are motivated to include both regions as IOP locations as part of the mobile field experiment, which is logistically feasible.**

3. Scientific Objectives and Hypotheses

To address the above grand hypothesis on page 2, the RELAMPAGO-CACTI observatory will focus on the following research themes:

- Convective initiation: Determine relevant environmental processes that lead to the initiation of convection near complex terrain features, and contrast the mechanisms near the Andean front *and* the lower mesoscale topography to the east, both of which produce frequent convective development and severe convective weather of different types. *We hypothesize that convective initiation processes in the SDC and Mendoza regions are different because of differences in stability, wind profiles, topographically and shear-generated gravity waves and bores, ice and precipitation initiation, boundary layer growth, orographic circulations, and penetration of the SALLJ.*

- Intensification and upscale growth of convection: Identify the kinematic, thermodynamic, and microphysical processes by which convection intensifies and grows upscale in the immediate vicinity of complex terrain features into extremely tall and broad convective systems, arguably more quickly and frequently in this location than anywhere else in the world, and contrast these mechanisms proximate to the Andes and along lower mountains to the east. *We hypothesize that convective upscale growth, intensification, and backbuilding are controlled by the proximity of the SALLJ to elevated terrain features, and interactions between cold pools, microphysical processes, anabatic circulations, and reconfiguration of vertical wind shear, lapse rates, and capping caused by the complex terrain. It is further hypothesized that these processes operate differently in the SDC and Mendoza regions to produce differences in convective morphology and hydrometeorological impacts.*

- Generation of hazardous convective weather: Observe the processes by which hail, strong winds, tornadoes and flooding are generated in environments close to the Andes and lower mountains to the east of the Andes, two regions that offer key meteorological and geographic contrasts to severe storm environments in the US. *We hypothesize that the unique elevated terrain features interact with the SALLJ and synoptic disturbances to fundamentally control the instability and vertical wind shear influencing hazardous weather generation by convective systems, which explains the observed differences in severe weather impacts between the SDC, Mendoza, and US regions.*

KEY SCIENTIFIC QUESTIONS FOR RELAMPAGO-CACTI:

1. What roles do topography, land surface fluxes, synoptic circulations, and mesoscale circulations play in convective initiation over and in the lee of the Andes Cordillera and Sierras de Córdoba?

2. Why are the convective updrafts in this region among the most intense in the world according to satellite proxies? What combination of mechanisms (buoyancy, vertical wind shear, cold pools, aerosols) produce such updrafts?

3. How do the complex terrain-initiated convective systems grow so rapidly upscale into intense, wide convective regions?

4. Why do storms in the region, despite being among the most intense in the world, produce copious hail, but relatively few reports of other types of severe weather (e.g., strong winds, tornadoes); how and why do these environments vary with proximity to terrain?

5. What convective life cycle modes lead to flooding, and how do mesoscale atmospheric processes (e.g. terrain influences, backbuilding) and land surface exchanges impact convective evolution and the production of flash and riverine flooding in SESA?

6. What processes lead to extremely high per-storm lightning flash rates, generation of low negative flash peak currents, high positive peak currents, and the generation of upper-tropospheric lightning discharges? How do these processes differ among convective storm types and environments?

Given the distinct storm evolutions, environments, and severe weather impacts of storms between Mendoza and SDC, and their relatively close proximity and infrastructure, RELAMPAGO-CACTI will leverage the large number and variety of convective systems in the Mendoza and SDC study areas to identify physical processes that cause differences in convective morphology and high impact weather related to convection. While convection undergoes lifecycles similar to the RELAMPAGO-CACTI region elsewhere on the globe, the environmental conditions and response of convective systems to them are likely unique in this region for reasons previously listed and outlined in the SPO, which motivates the deployment of resources to answer the key scientific questions listed in the blue box above.

Currently, we cannot address these questions because of a lack of observations in the RELAMPAGO domain. The unique meteorological and geographic environment of the project and the configuration of the terrain proximate to the experiment area will yield new insights into the global convective spectrum and a high probability of observing many events with all of the instrumentation in the project. The overarching goal of RELAMPAGO is to document the full life cycle from initiation to upscale growth, with a surface and sounding network designed to understand these processes at fine scales. RELAMPAGO will observe many convective modes, plus null cases where deep convection and upscale growth does not occur. The focused nature of the RELAMPAGO-CACTI experimental design will ensure that we leverage the ideal natural laboratory provided by the region to obtain many cases and a sufficient statistical sample for process studies and numerical experiments. By documenting intense continental convection in all regions of the globe, this will inform will teach us about convection globally and in the US, particularly extreme events which may be more common in Argentina. This will provide immediate benefit to countries in the region impacted by these storms, and also improve our conceptual models of severe convection as well as regional and global convective models and parameterizations for improved weather and climate prediction globally.

4. RELAMPAGO-CACTI Experimental Design

As motivated by the science objectives above and in the RELAMPAGO SPO, the primary observational science objectives (SOs) of RELAMPAGO are to:

SO1: Characterize impacts of complex terrain on storm environments, initiation, and upscale growth, including orographic flows, boundaries, cold pools, gravity waves, and boundary layer capping.

SO2: Characterize thermodynamics, vertical wind shear, and atmospheric composition upshear, within, and downshear of convection from pre-initiation through upscale growth phases.

SO3: Characterize the spatiotemporal variability of land surface fluxes and boundary layer moisture, as well as groundwater, streamflow, and soil moisture.

SO4: Observe vertical structures and evolution of hydrometeors relevant to rainfall, hail production, lightning, severe weather, flooding, storm structure, and dynamical processes.

SO5: Quantify length scales of and motions within convective systems.

Measurements required to address science questions. Since the time evolution of relevant processes is rapid in the development of convective systems, and the spatial variability of relevant parameters is high, a comprehensive, multi-platform network of facilities is needed to collect continuous data over a mesoscale domain (~100 km x 100 km) through the depth of the troposphere at time resolutions < 5 minutes and spatial resolutions of < 200 m in the lower troposphere (below 5 km MSL), and < 500 m in the mid-upper troposphere. This motivates the need for the following observational requirements (ORs) with SOs and primary US funding agencies noted:

OR1: In situ and remotely sensed measurements of temperature, wind, and humidity at the surface and in the vertical profile prior to and during convective development surrounding convective clouds and within them at relevant locations (convective drafts, gravity waves, bores, and cold pools) using soundings, mobile and fixed surface weather stations, aircraft, multi-Doppler radars, and satellites (SO1; joint NSF/DOE/NASA/NOAA objective)

OR2: In situ measurements of surface DSD properties (DSDs and hail) and retrievals of hydrometeor type and size at the surface and in the vertical column through remote sensing, and where possible, aircraft (SO1, SO4; joint NSF/DOE/NASA/NOAA objective)

OR3: Characterization of convective system kinematic and microphysical joint evolution through radar and satellite remote sensing, high speed cameras, and where possible, aircraft (SO1, SO4, joint NSF/DOE/NASA/NOAA objective)

OR4: Near surface measurements of surface fluxes, soil temperature and moisture, and groundwater using in situ observations and remote sensing (SO1-4; joint NSF/DOE objective)

OR5: Locations of severe weather damage and flooding (SO3-5; NSF objective)

OR6: Lightning path and stroke information from surface lightning mapping arrays, satellites, and long range lightning networks, GOES-R/S GLM validation (SO4; NASA/NOAA objective)

OR7: Aerosol property measurements at the surface and in the vertical column through in situ and remote sensing measurements (SO2; DOE objective)

South American agencies and scientists will also complement and benefit from the above-listed efforts. The RELAMPAGO-CACTI observatory described in detail below is designed to meet the above observational objectives in order to address our primary science questions and hypotheses.

4.1 Experimental Design and Observational Requirements

Climatology of the region. Table 1 shows that, during the 7-month 2014-15 wet season, there were > 134 days of orographic cumulus clouds observed by Moderate Resolution Imaging Spectroradiometer (MODIS) visible overpasses in the SDC, likely an underestimate because of limited sampling times. Daytime surface heating and boundary layer mixing create anabatic flows that converge near the mountain ridge top, while air masses advected toward the range can also be mechanically forced upward. Repeated cumulus formation in the same approximate location with predictable and measureable free tropospheric westerly winds make it possible to track individual clouds from birth to maturity with stereo cameras and radars while measuring their interaction with the environment. Table 1 also shows that cumulus clouds are, by far, the most common cloud type followed by cumulonimbus. On some days, cumulus clouds remain shallow, but on many days, they grow into vigorous congestus or cumulonimbus clouds several kilometers deep that typically shear eastward aloft toward AMF-1 site to the east, as shown in Fig. 2.

Table 1 shows that orographic deep convective initiation is also very common. In the US, there is no analog to the SDC mountain range that focuses much of the convective initiation (Rasmussen and Houze 2011; Rasmussen and Houze 2016). Figure 3a shows that deep convective systems have a much higher

Table 1. Subjective determination based on ~1030 and ~1330 LT MODIS imagery of the number of days by month in 2014-2015 that fit into cloud type categories **observable from the proposed CACTI-AMF-1 site**. Cu is cumulus, Sc is stratocumulus, and Cb is cumulonimbus. Because of limited overpasses, the number of cloud days is a lower limit. (Courtesy A. Varble, U. Utah)

	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**

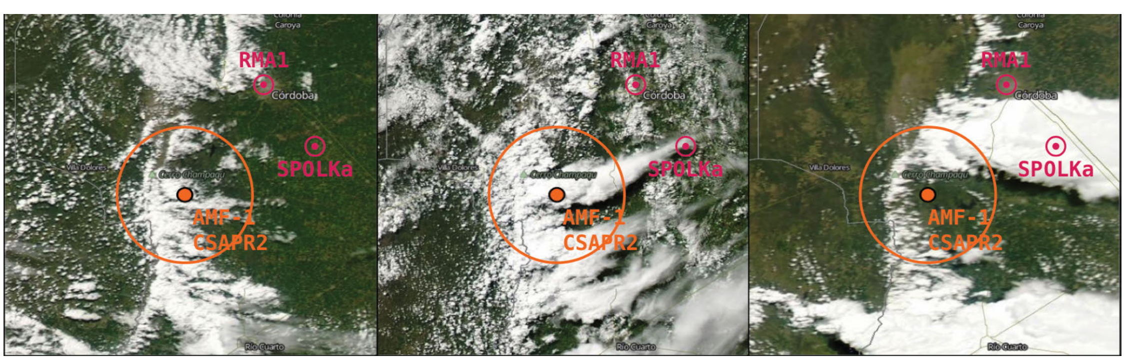

Fig. 2. 1330 LT MODIS images on separate days with cumulus to cumulonimbus development. The DOE AMF-1/CSAPR2 site is shown in orange with an approximate W/Ka-SACR range ring, and the SPOLKa and operational C-band radar sites are shown in pink. (Courtesy NASA, A. Varble, U. Utah)

probability of initiating to the immediate east of the SDC mountain crest than anywhere else in Argentina. As systems mature (Figure 3b-d), the cold cloud tops propagate eastward, but remain tied to the mountains. Two different deep convective situations are shown in the middle and right panels of Figure 2, one with significant instability and a SDC crest-level inversion at 750 hPa, and another with minimal instability and an inversion-based mixed layer starting at 600 hPa. A survey of other days on which MODIS shows deep convective initiation yields a diverse array of 12Z (8 AM LT) Córdoba soundings with a variety of surface-based and elevated instabilities, wind and humidity profiles, and capping inversion heights and strengths (not shown). The SDC and downstream region are different from many worldwide locations such as the U.S. Great Plains in that some deep convective cells quickly grow upscale and begin organizing close to the mountains, often with new convective growth upstream of the system (Anabor et al. 2008; Rasmussen et al. 2014), which is ideal for a fixed instrumentation site to observe the lifecycle of convection from shallow cumulus through mesoscale convective organization.

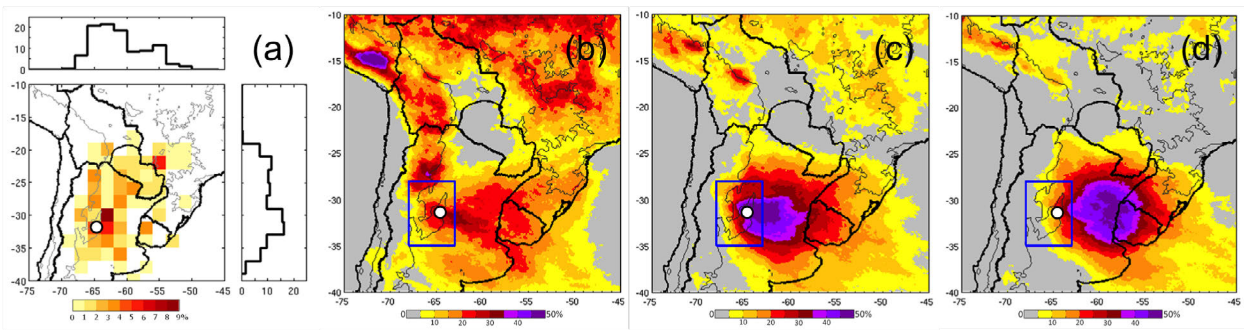

Figure 3. (a) Frequency of initiation for large MCSs (observed by TRMM satellite for Nov.-Dec. 2002-2010) tracked with IR brightness temperature (Tb). Frequency of IR Tb lower than 235 K for systems that initiate near the Sierras de Córdoba (blue rectangle) between 21Z and 3Z is shown for (b) 00Z, (c) +6 hours forward in time, and (d) +12 hours forward in time (Vidal 2014). The filled white circle shows the proposed AMF-1 location in the SDC.

Table 2. Monthly occurrence of severe storm reports derived from Rasmussen et al. (2014).

Month	Flood	Hail	Tornado
September	7	1	3
October	69	29	1
November	34	37	11
December	79	49	16
January	10	36	0
February	61	33	4
March	47	4	0

Severe weather is commonly reported in both the SDC and Mendoza regions. Rosenfeld et al. (2006) noted that 60% of warm season days (15 October - 31 March 2000-03) in Mendoza had deep convection, 18% had hailstorms, and 8% had severe hailstorms (> 2 cm hailstones). A monthly climatology of severe weather reports from Rasmussen et al. (2014) shown in Table 2 shows that in SESA, the optimal time period to observe flooding, hail, and tornadoes is late spring. An unpublished study by R. Mezher (INTA-Argentina, personal communication) shows that hail reports are maximized in October - December in Córdoba province, while the reports are more common in November - March in Mendoza. Given that intense convection that supports hail is most common in November - December, and that the highest frequency of convective initiation and heavy precipitation overlaps this timeframe, 1 November - 15 December 2018 is well justified as a time period for the RELAMPAGO-CACTI IOP.

The diurnal cycle of convective cloudiness in the region is quite different between the Mendoza and SDC regions. Figure 4 shows the spatial frequency of infrared brightness temperatures < 235 K (-38°C, shaded) and 210 K (-63°C, color contoured). In Mendoza (150 km range ring from San Martín, Mendoza is indicated in blue), cloud top temperatures meeting the 235 K threshold form in the early to mid afternoon in the Andes foothills (with a higher frequency in Mendoza in December compared with November). These cold cloud tops propagate slowly eastward, such that they appear to dissipate by midnight. This agrees with observations summarized in Rosenfeld et al. (2006) that hailstorms tend to commonly hit the region in the evening. Our field observations will target this afternoon-evening cycle of convection, capturing initiation and growth to maturity.

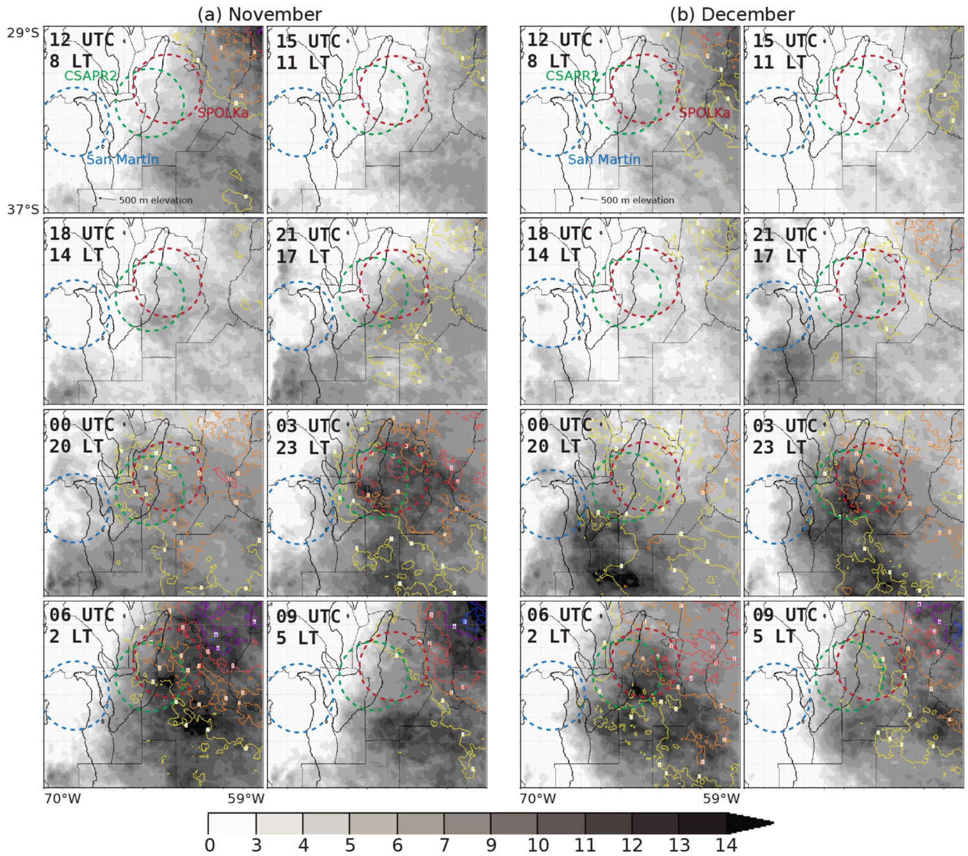

Fig. 4. Frequency of occurrence (%) of 4 km gridded 10.7-micron brightness temperature < 235 K (shaded) and < 210 K (contoured, colors) for the hour shown in each panel. Local (solar) time is calculated as UTC-4, which is valid at 60°W. Local standard time is UTC-3.

In the SDC, deep convection often occurs by early afternoon. Indeed, there is an increase in the frequency of cloud tops meeting the 235 K threshold at 14 LT (Fig. 4). By 17 LT, the frequency of cloud tops meeting the 235 and 210 K thresholds increases to the east of the SDC crest, meaning deep convection likely increases in intensity and spatial coverage in a short 3-hour period. This increase in frequency of 235 and 210K coverage continues east of the SDC through 23 LT, where it appears that a separate signal from deep convection to the south of the SDC region merges with the local signal. It is not clear from these analyses whether these signals are contemporaneous, however mature nocturnal convective systems can encroach on the SDC in the overnight hours. These systems provide additional targets of opportunity for study, but will not be a primary goal of the campaign. In summary, the period of 12-22 LT appears to be the prime sampling period to capture initiation and upscale growth of orogenic convective systems in the SDC.

From the perspective of heavy precipitation, satellite precipitation estimates from TRMM 3B42 version 7 (Huffman et al. 2007) from the last 17 warm seasons shown in Fig. 5 reveal that intense, propagating precipitation events are common throughout the warm season (October - March), occurring every 2-3 days, initiating near the RELAMPAGO-CACTI observatory (between 69 and 63°W), sometimes near

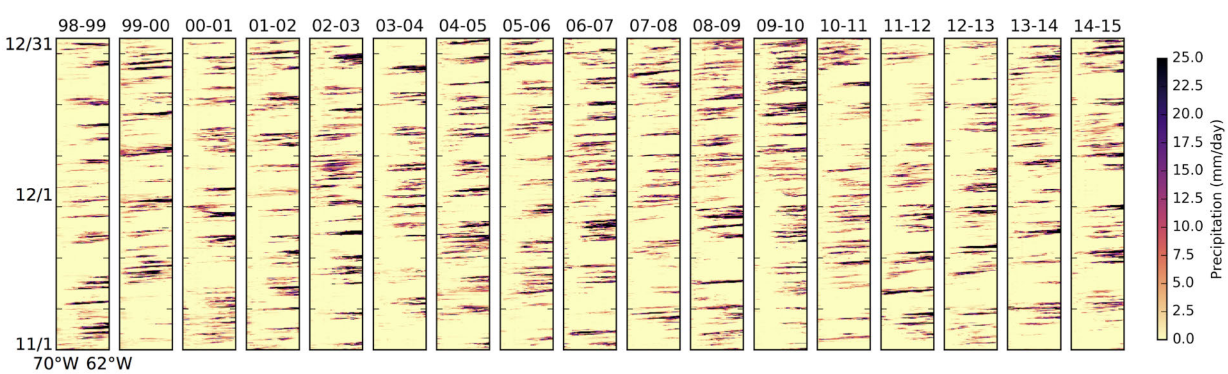

Fig. 5. TRMM 3B42 V7 Hovmöller diagram of 3-hourly precipitation at 0.25° resolution (mm/day) averaged between latitude (28 to 36°S) for Nov-Dec for 17 years (labeled at top of diagram).

Mendoza, and sometimes near the SDC. While it is likely that smaller, lower intensity events are missed with satellite precipitation estimates, the CACTI EOP and the RELAMPAGO-HYDRO EOP will capture many events during this time period, while the period of 1 November to 15 December, proposed for the RELAMPAGO-CACTI IOP, also has many rainfall events. Furthermore, the interannual variability of precipitation is small, and each year has many events to study. While the absolute accuracy of these satellite-based retrievals is unknown, it is clear that RELAMPAGO-CACTI will sample a large number of precipitation events, many of which are intense events. This underscores the need for an S-Band radar (as opposed to C-Band radars which exist in the region) and multiple X-Band radars that can be operated in a network configuration to minimize the effects of attenuation in heavy precipitation.

4.2 RELAMPAGO-CACTI Observation Periods

As outlined in the RELAMPAGO SPO, RELAMPAGO will consist of an EOP, focused on hydrometeorology, flooding, and land-atmosphere interactions in the Rio Carcarañá basin with a subset of instrumentation, and an IOP, which will focus on documenting convective storm initiation, upscale growth, and the production of severe convective weather, as well as interactions with the land surface. The **RELAMPAGO-HYDRO EOP** is proposed to extend prior to and through the warm season from 1 Jun 2018 - 31 May 2019. This will allow for the hydrometeorological measurements of parameters such as soil moisture to become equilibrated in the sub-surface in time for the warm season precipitation and the CACTI-EOP to begin. Subsurface, surface, and lower troposphere hydrology also require longer timescales to characterize and understand than those of the purely atmospheric processes. The **CACTI EOP** will consist of continuous measurements near to and surrounding the CACTI site from 15 Aug 2018 - 30 April 2019. The joint RELAMPAGO/CACTI IOP will occur for a 45-day period from 1 Nov 2018 - 15 Dec 2018. All measurements will be available during this time including fixed and mobile RELAMPAGO sounding, radar, lightning, and profiling observations. Argentina, Brazil, Chile, and NASA/NOAA will augment their operational networks during the IOP and provide contributions to the campaign as described in later sections. The DOE G1 aircraft will be available for flights in coordination with CACTI and RELAMPAGO objectives. An IOP operations center will be established and be fully operational, where 24-7 forecast operations will guide the deployment of fixed and mobile operations assets by the RELAMPAGO and CACTI PIs.

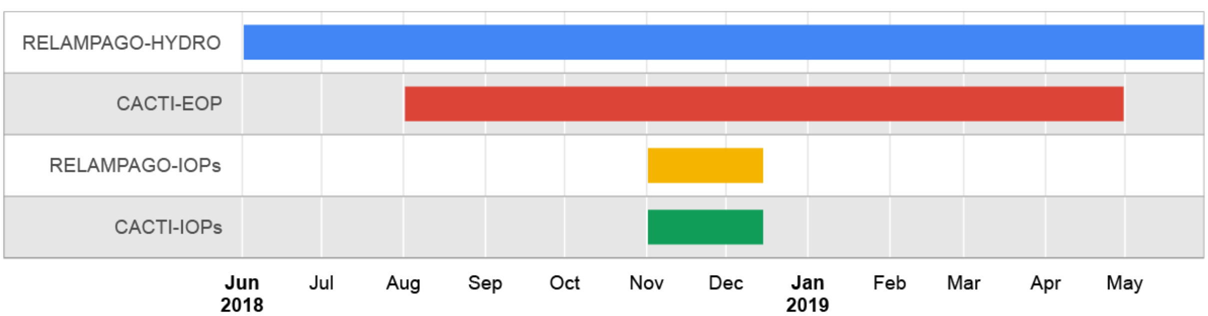

Fig. 6. Timeline of RELAMPAGO-CACTI Operations.

4.3 Operational Observing Network in SESA by 2018

Upper air network. Currently, the meteorological services maintain a network of stations at the sites indicated in Figure 7. Presently, only select Argentinean (SMN) stations launch a 12 UTC (0800 LT) sounding, and few, if any, launch 00 UTC (2000 LT) soundings. Soundings at 00 UTC typically contain nocturnal inversions, and are near complex terrain affected by downslope flows (particularly at Córdoba, Mendoza, and Salta). The SALLJ has a nocturnal maximum with a significant diurnal amplitude and directional variation that is not well sampled by this network. The variability of flows crossing the Andes, anabatic circulations near the Andes and SDC, synoptic disturbances, and boundaries (e.g. fronts, outflows, terrain-induced convergence zones) are also not well characterized by this network.

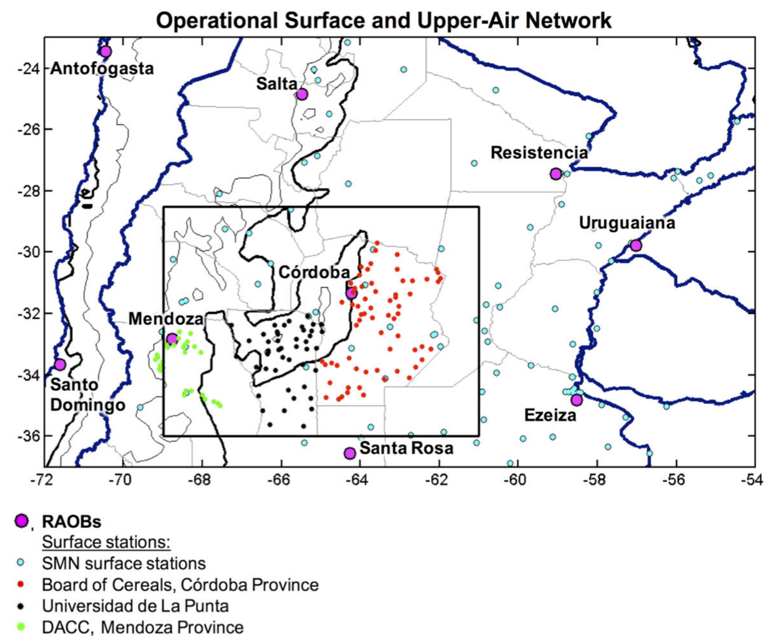

Fig. 7. Operational upper air, surface METAR/SYNOP, and mesonet station locations (see legend).

Surface network. The SMN also operates surface stations, which report manually-observed METAR and SYNOP reports at the locations shown in Fig. 7. Several local entities operate mesonet automatic stations, which report data every 15 minutes. These stations are operated by the Córdoba Board of Cereals in Córdoba Province, the University of La Punta in San Luís Province, and Mendoza Province. Currently, these data are available via a web interface for each network, and there is no sharing of data in real time. However, there is an effort underway by the SMN to collect these data into a unified database for assimilation into regional weather prediction models, and it is anticipated that this effort will be completed by the end of 2016.

Satellite data. In addition low-earth orbiting satellites operated by NASA, NOAA, ESA, Japan, and China, this region is covered by GOES-East, located at 75°W. Unfortunately, due to technical limitations of the current generation of GOES satellites (particularly during rapid-scan operations in the CONUS), the temporal resolution of imagery in the Southern Hemisphere degrades to hourly or lower time resolution. At times, only the mandated 3-hourly full disk imagery is collected. This makes the use of satellite data for nowcasting difficult in SESA. Fortunately, the next generation of GOES satellites, with GOES-R (GOES 16) set for launch in October 2016, and GOES-S launched in early 2018, will overcome this limitation. The Advanced Baseline Imager (ABI) will provide 15 minute or better full disk cloud and moisture coverage over this region at higher spatial resolution (500 m visible, 2 km IR/WV), and Geostationary Lightning Mapper (GLM) will provide continuous total lightning information. The GOES 16 satellite will be placed at 89.5W for a year of validation followed by a decision to make it operational in the east (75W) or west (137W) position. Should 16 be in the west, GOES S will be placed in the east position following a year of validation. Currently, the configuration of the GOES-R and GOES-S satellites is unknown (i.e., in testing phase, or operational at GOES-E or W). Regardless, 30 sec rapid scan cloud and moisture imagery in addition to the continuous total lightning may be possible in support of RELAMPAGO.

Radars. The Governments of Argentina and Brazil have made major efforts in developing a radar network over SESA. Fig. 8 shows the location of operational radars that will be operational by 2017 relevant to RELAMPAGO/CACTI. By 2017, all of the Argentinian C-band radars will be state of the art simultaneous transmit-receive dual-polarization radars (except for Pergamino, which is a Gematronik system but has not been upgraded to dual-pol). The C-band sites at Paraná, Anguil, and Pergamino are Gematronik METEOR 500 radars installed in the late 2000s, while all the others are/will be INVAP-SINARAME radars (which can collect moments and time series data). The DACC radars in Mendoza Province are 1980's Russian-heritage era S-band non-coherent radars, however digital recording and TITAN data processing was implemented in the early 2000s. The site at San Martín is a dual-frequency S/X-band non-coherent system that is functional. The Brazilian Air force operates S-band Doppler single polarization radars, with two S-band Enterprise Electronics Corporation S-band radars at Santiago and Canguçu, while the SIMEPAR operates an Enterprise S-band dual-polarization radars at Cascavel, and a single pol radar at Teixera Suares. Paraguay operates a C-band Baron Services VHDD-3500C Doppler radar at Asuncion, and this data is transmitted in real time to CPTEC in Brazil. Jointly among the US, Brazil, and Argentina, RELAMPAGO will create regional radar reflectivity and precipitation composites (blended with satellite

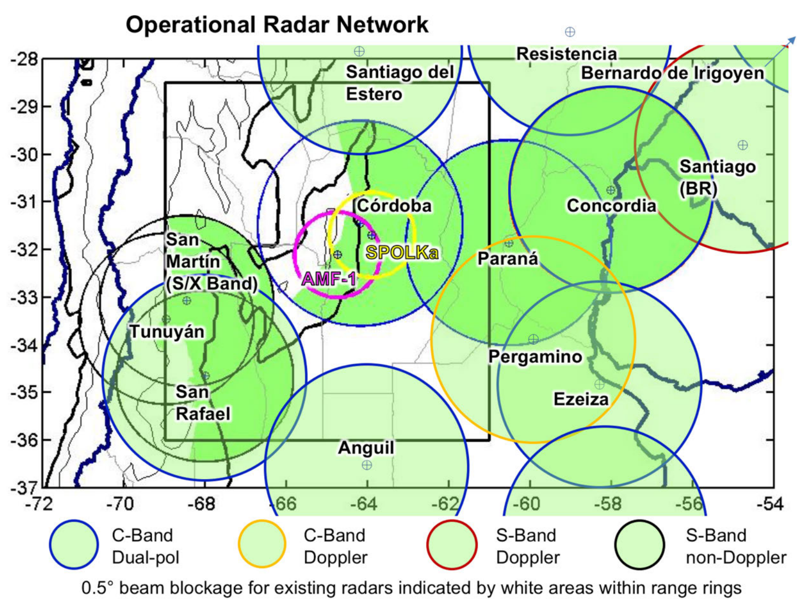

Figure 8. Locations of operational radars in SESA. The frequency, dual-polarization capability, and Doppler capability of each operational radar is indicated by the color of the range ring indicated in the legend. Beam blockage of existing radars are indicated at 0.5° elevation. Range rings for SMN and Brazilian operational radars are indicated at 240 km, while 200 km is indicated for the DACC radars. The SMN radars also collect a 480 km long-range reflectivity scan. The location of proposed RELAMPAGO (SPOLKa) and CACTI (AMF-1 and CSAPR-2) radars are indicated with 100 km range rings where high quality dual-polarization radar measurements will be collected.

data) that will serve as a key analysis that motivates future operational products in the region. Doppler velocities and velocity azimuth display (VAD) wind profiles will be provided across broad regions and many locations across SESA, which will be important for data assimilation and evaluation of regional and convective permitting model simulations and forecasts. In particular, low-level Doppler scans and VAD profiles from Santiago del Estero, Córdoba, and San Rafael will be important for observing the SALLJ and low-level shear profiles relevant to storms in the RELAMPAGO domain. However, the operational radars in SESA will not provide the spatial resolution, vertical structure, and customizable scanning strategies necessary for documenting the detailed structure and microphysical characteristics of the convection in order to address RELAMPAGO objectives. This is particularly true in hail, hail mixed with rain, and heavy rain due to attenuation, differential attenuation, non-Rayleigh scattering, and backscatter differential phase effects, as well as complete attenuation of the signal in path lengths of heavy precipitation, as well as three-body scatter/multiple scattering. **This highlights the need for S-Band dual-polarization radar operations in RELAMPAGO.**

4.4 RELAMPAGO-CACTI Field Campaign Instruments

An overall view of the RELAMPAGO operations area is shown in Fig. 9. NSF fixed and mobile assets will be focused in the mobile operations boxes shown in orange, which will allow for repeated observations of the initiation and upscale growth of convection contrasting events in the SDC and Mendoza regions to address RELAMPAGO science questions, while Brazil will coordinate with NSF and NASA/NOAA in studies near the SDC, as well as in a mobile fashion extending to near Uruguaiana, Brazil tracking systems with fixed lightning and moisture remote sensing, fixed and mobile lightning mapping arrays, and mobile radars and in situ sampling.

4.5 RELAMPAGO-CACTI EOP

4.5.1 NSF-funded EOP Assets

The instrumentation, which will address **SO1-5**, and **OR1,4-5** includes:

Hydrometeorological Observations. We selected the locations of the hydrometeorological observations based on three factors: 1) the existing streamflow observations by the Universidad de Córdoba, 2) the trajectory of the convective systems from the SDC to the east and northeast, and 3) accessibility through connecting roads. The location of the observations is shown in Fig. 10. The instrumentation will address **SO3** and **ORs 4-5** and includes:

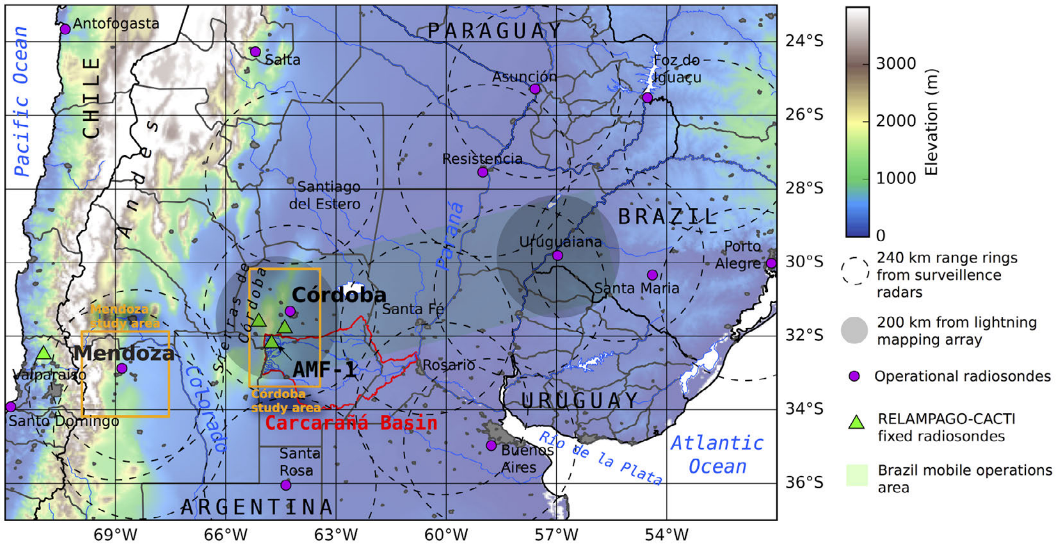

Fig 9. Broad view of the RELAMPAGO domain with fixed and mobile operations areas (boxes: NSF in orange, Brazil in light green).

- **5 NCAR Integrated Surface Flux System flux towers (Red Triangles)** – One located close to the SDC in the town of Berrotaran (to capture land surface interactions during the convective initiation phase) and the subsequent four towers along the gradient of humidity towards the climatologically more humid location south of Santa Fe, along the Parana River. The flux towers are part of the NSF-EOL facilities request.
- **31 Basic Meteorological Stations (Blue Circles)** – Measuring precipitation, temperature, relative humidity, near surface soil moisture, temperature, and incoming shortwave radiation. 16 operated by NCAR-RAL (magenta triangles) and 15 operated by NCAR-EOL (yellow diamonds).
- **16 RAL stations (Magenta Triangles)** – Primarily located along the river, will measure leaf wetness, water depth and river stage in addition to the basic meteorological observations.
- **4 Disdrometers** – 1 at Universidad de Córdoba, 1 at Universidad de Rosario, 1 at Universidad de Rio Cuarto, 1 in Universidad del Litoral in Santa Fe. These will be part of the NCAR instrumentation request.

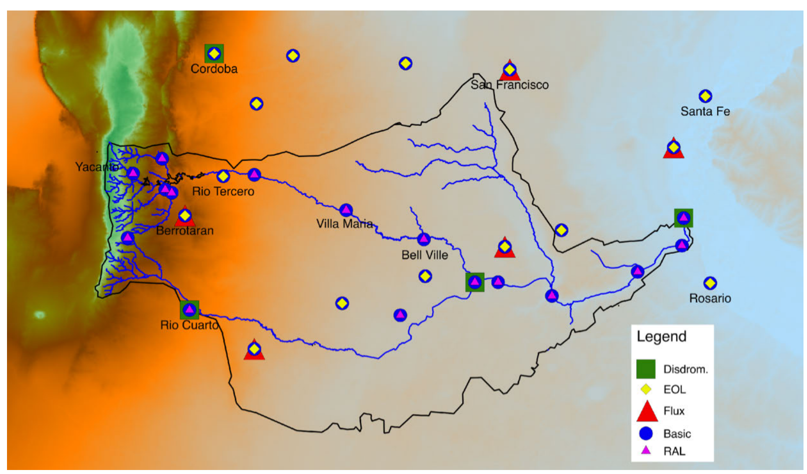

Figure 10. Proposed locations of the NSF hydrometeorological network that will operate for the RELAMPAGO-EOP.

- **1 Acoustic Doppler current profiler** – In order to have 2 mobile instruments to perform measurements (one in addition to the one from Universidad de Córdoba). These are mobile instruments. These will be part of the NCAR instrumentation request.
- For **groundwater observations**, we will rely on the existing wells in the region and will not drill.

There will be a 3-week period for the installation of flux towers, basic meteorological stations and disdrometers. During this time, we will also calibrate the instruments.

4.5.2 Non-NSF EOP Assets

DOE ARM Facilities. The CACTI campaign to take place between 15 August 2018 - 30 April 2019 is funded by the DOE ARM program and involves deployment of the ARM Mobile Facility (AMF1), Mobile Aerosol Observing System for Aerosols (MAOS-A), and C-band Scanning ARM Precipitation Radar (CSAPR2). The AMF1 and MAOS-A contain a wide range of instruments that make detailed measurements of clouds, aerosols, environmental winds and thermodynamics, surface fluxes, and radiative fluxes, as described in Appendix A1 Table A1-1. PI instrumentation that will be deployed includes filters to collect ice nucleating particles (INP) and stereo cameras to measure the location and evolution of high-resolution cloud boundaries. This instrumentation will be primarily located at the AMF1 site just south of Villa Yacanto, Argentina. The CACTI observations in the SDC will form a key, complementary set of instruments in and surrounding the complex terrain, and **will provide key long-term measurements that *greatly assist in addressing RELAMPAGO-CACTI SOs 1-5 and ORs 1-4 and* 7**.

<u>Cloud and Precipitation Observations.</u> A new deployable, scanning, dual-polarimetric, Doppler C-band radar (CSAPR2) will be located at the AMF1 site with clear views in most directions, but particularly to the SDC ridgeline and to the Plains to the east. Coupled with a scanning Doppler W- and Ka-band radar (W/Ka-SACR), detailed dynamical and microphysical properties of convective systems will be tracked from small cumulus stages to early deep convective stages. Cloud fraction (TSI) and cloud boundaries will be continuously monitored with the total sky imager, ceilometer, stereo cameras, KAZR, MPL, and W/Ka-SACR. Zenith-pointing measurements at Ka-band and 915-MHz will be crucial for linking microphysics to vertical motion and the surrounding environment at the AMF1 site. Stereo cameras will also monitor the growth and location of cloud boundaries, providing vital context to radar measurements.

<u>Tropospheric Observations.</u> Full tropospheric observations include soundings that will be launched 4 times daily from the AMF1 site and twice daily from a site to the immediate west of the SDC range. During expected deep convective events, these will increase to 8 times daily. Microwave Radiometers will continuously monitor changing precipitable and condensed water contents in the column, while the RWP continuously monitors the vertical profile of winds over the site, both of which fill in periods between soundings. Boundary layer turbulent motions, circulations, and winds will be measured using the Doppler lidar and SODAR, while the AERI gives continuous vertical thermodynamic structure. Combined with aerosol, cloud, atmospheric state, and surface energy measurements, the radiometer measurements will quantify the impact of aerosols and clouds on radiative fluxes and boundary layer thermodynamic properties.

<u>Surface Observations.</u> The AMF1 includes meteorological, precipitation, raindrop size distribution and fall speed, and surface heat flux and energy balance measurements. These measurements will focus on the (1) impacts of precipitation events on surface fluxes and boundary layer evolution, (2) cold pools relationships to precipitation structure and raindrop size distribution, and (3) impacts of surface conditions on the evolution of the boundary layer, circulations, and clouds. Additional deployment of a small network of soil moisture, surface flux, meteorology, and boundary layer profiling measurements is in the process of being proposed to ARM. If funded, one of these surface sites would be set up to the arid west of the SDC and one would be set up to the agricultural east. Additional sites would be setup between the AMF-1 site and the crest of the SDC just off of a dirt road and potentially to the north and south of the AMF-1 site. These sites would provide measurements of surface and boundary layer mesoscale variability and evolution.

<u>Aerosol Observations.</u> A number of in situ and remote sensing instruments that measure aerosol spatiotemporal distribution, size distribution, composition, and growth will be deployed at the AMF-1 site. Measurements of size distributions, cloud condensation nuclei, INP, and aerosol growth coupled with cloud and precipitation radar measurements will be key to understanding the role of aerosols in altering cloud and precipitation properties, as well as cloud and precipitation processing of aerosols. Additional composition and hygroscopicity measurements will separate roles of different aerosol types and sources in altering cloud and precipitation properties, while providing critical input into process models. Aerosol optical depth measurements will be used to place CACTI observations into the context of AERONET and satellite observations. The MPL will detect aerosol layers that will be compared against aircraft data

(described in a later section) and used to study aerosol impacts on radiation and cloud properties. In addition, the University of Córdoba will make ground-level measurements of INP at their campus. These measurements will address **SO2,5** and **OR7**.

4.6 RELAMPAGO IOP

4.6.1 NSF-Funded IOP Assets

Sounding Systems. Radiosonde observations (soundings) will be collected using a combination of fixed and mobile radiosonde systems, as described below in Table 4. Motivated by objectives **SO1** and **SO2**, and fulfilling **OR1**, these observations will help characterize the vertical structure of the wind, temperature, and humidity in the pre-convective environment, and then be used to reveal the mechanisms of convective initiation and subsequent convective organization and upscale growth. Per **SO5**, soundings will also be collected within the active convection, particularly in the convectively generated cold pool and in readily targetable updrafts. The use of two radiosonde systems within a single mobile unit, coupled with sondes capable of transmitting at different frequencies, will be employed for rapid sampling of such convective structure.

Table 4. Radiosonde observations during RELAMPAGO-CACTI.

Institution	**System Type**	**Mobile vs. Fixed (location)**	**Nominal Release Frequency: RELAMPAGO-IOP**	**Nominal Release Frequency: CACTI-EOP**
SMN	Vaisala RS90 + IMET	Fixed: Córdoba, Mendoza/ (Resistencia, Santa Rosa, Ezeiza, Salta)	8 x day/(2 x day)	2 x day
SMN	Vaisala RS90	Portable: Alta Gracia	1 x hr	
SMN	Vaisala RS90	Mobile	1 x hr	
DOE	Vaisala RS92	Fixed: Villa Yacanto/ (Villa Dolores)	IOP: 8 x day/(2 x day)	2 x day
Chile	Vaisala RS92	Fixed*: Santo Domingo, Antofogasta	2 x day	2 x day
Brazil	Vaisala RS92	Fixed: Uruguaiana	2 x day	2 x day
CSWR	GRAW (x 2)	Mobile	1 x hr	
CSU	MW41 Digicora	Mobile	1 x hr	
UIUC	IMET (x 3)	Mobile	1 x hr**	

*One additional Chilean fixed site has been proposed for NW of Valparaiso to characterize the flow prior to crossing the Andes
**The use of dual receiving systems within a single mobile unit, along with a mid-tropospheric termination, can reduce the frequency to 1 x 0.25 hr.

The operations of the fixed systems are straightforward, with sounding releases typically at uniformly spaced time intervals; those systems operated by SESA governments will follow their institutional protocols. The mobile-system deployments are mission dependent and will exploit experiences gained during recent field campaigns such as VORTEX2, MPEX, and PECAN (e.g., Trapp et al. 2016). As described in detail below, the basic mobile strategy will be to collect soundings within the area of anticipated convection initiation, followed by a redeployment of the mobile teams to enable storm-relative sampling. The deployment decisions will be based on optimizing coordination with other observing assets within RELAMPAGO-CACTI, such as the G-1. Given the differences in the radiosonde systems, an intercomparison will be conducted near the beginning of the RELAMPAGO-IOP.

Water Vapor Lidar. Two NCAR/U. Montana differential absorption water vapor lidars are requested to provide continuous high-resolution water vapor profiles in the lower troposphere. One will be located near at the DOE site in Villa Yacanto, where continuous extensive vertical profiling will be occurring with the CACTI instrumentation (including radiosondes and microwave/infrared water vapor profiling). This location will be important for characterizing the vertical profile of water vapor in connection with convective initiation in the SDC, to address **SOs 2-3**. A second site will be operated about 30 km west of SPOLKa that will host Brazilian surface and profiling instrumentation. This location will be ideal to monitor the SALLJ throughout the initiation and upscale growth phase of the convection, as well as cold pool structure after the passage of heavy precipitation to address **SO 1**.

CSWR Pods. To help address **OR1** and **OR5**, an array of unmanned surface weather stations (Pods; Wurman et al. 2012) will be deployed by mobile crews. The CSWR Pods obtain 1-m observations of temperature, relative humidity, pressure, wind speed and direction, and GPS location at a frequency of 1 Hz (or better). The Pods will be critical for capturing surface spatial and temporal variability of meteorological state variables that identify and characterize features, such as convergence boundaries and cold pool strength, that impact CI, upscale growth, convection longevity, and convection intensity. When deployed within multi-Doppler radar coverage, and within the region of upper-air observations, these ground-based instruments will provide an integrated data set of the thermodynamic and kinematic evolution of these developing systems from the ground up.

Fixed and Mobile Radars. Table 5 describes the measurement requirements and objectives of the RELAMPAGO-CACTI radar network, which will be critical (SPOLKa and the DOWs. The radar network particular) to address **SO1-2**,**4-5**. The radar networks will be focused on collecting convective to mesoscale kinematic structures, identification of boundaries and elevated moisture gradients/gravity waves through Bragg Scatter (Davison et al. 2013), moisture mapping and profiling (Ellis and Vivekanandan 2010), cloud liquid water retrieval (Vivekenandan et al 1999a), and documenting microphysical processes through hydrometeor identification (Vivekenandan et al. 1999b) and other retrievals. It is clear that this comprehensive network of radars focused on the SDC will take advantage of the strengths of each radar to address complementary, but distinct measurements. The network is spatially configured (see Fig. 11) such that the deployable shorter wavelength radars (W-, Ka-, and C-band) will be in higher terrain, located at the AMF1 site, where cumulus, cumulus congestus will develop and be best observed with the combination of cloud and precipitation radars at close range, while the longer wavelength radars, particularly SPOLKa, which will be deployed for 24-7 operations on the plains south of Córdoba (where partial beam blockage will be confined to the lowest 1° in elevation over a 30° sector to the west), with the ability to capture the pre-initiation, initiation, upscale growth, and severe weather production scales of convection, and provide high quality microphysical and precipitation measurements at ranges with quality dual-polarization measurements at ranges < 100 km, and will take over when systems grow upscale and have hail (where non-Rayleigh scattering will strongly contaminate polarimetric measurements at wavelengths < S-band), large attenuation, and long attenuation paths in organized convection. Given the overlap between S- and C-band radars (AMF1 and RMA1), this dataset will further the study of the utility of C-Band radars in strong convection and severe weather.

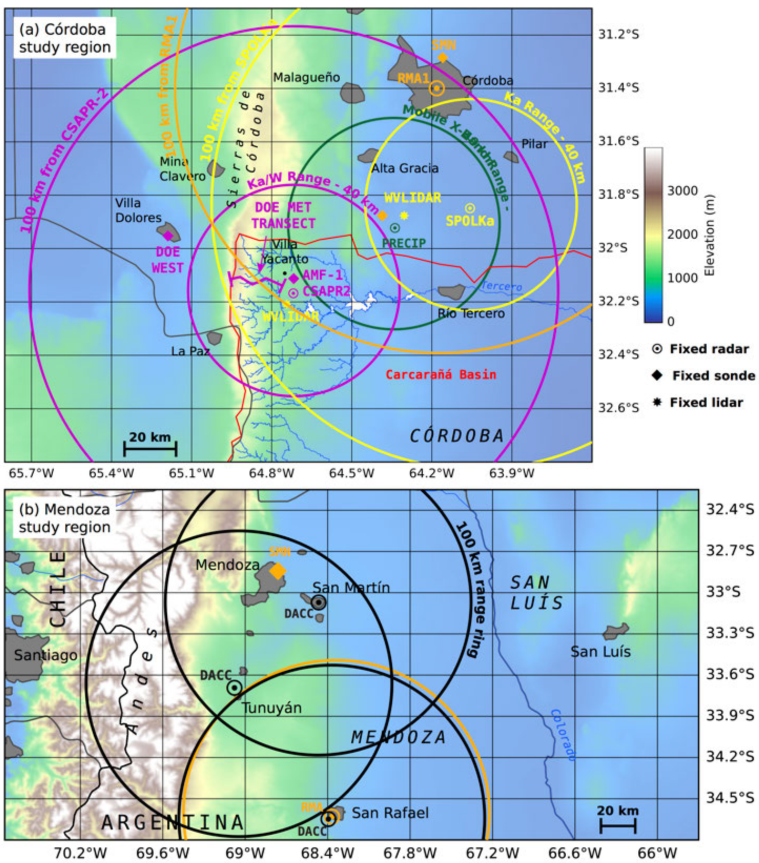

Figure 11. Experimental design for the RELAMPAGO fixed observatories in the SDC (top) and Mendoza (bottom) regions.

For each observing strategy (defined below), fixed radars will be operated in coordination with the mobile radars (DOWs and Brazil XPOL). At the core of the radar scanning strategy is to have overlap between the longer wavelength radars, which will be tasked with microphysical scanning (with PPI and

RHI sectors) covering the system for precipitation estimation and microphysical sampling (including quasi-vertical profiles), while the mobile radars, when deployed, will be focused on network collection of multi-Doppler/Doppler assimilation, with less of an emphasis on microphysical scanning. Despite the advantages of mobile X-band radars, which will allow us to obtain measurements both in Mendoza and SDC across a variety of objectives, the scan modes of microphysical scanning and Doppler volume scanning are often at odds, and the X-band (and even C-band) radars will suffer heavy attenuation and non-Rayleigh scattering that will make microphysical sampling ambiguous. This, along with the long range, low attenuation, high sensitivity (including to Bragg scatter at S-band), reliable microphysical retrievals, dual-wavelength capabilities, makes the deployment of SPOLKa important for addressing RELAMPAGO objectives. The frequent kinematic observations provided by high-resolution mobile X-Band radars alongside the microphysical measurements provided by S-Band radars (as well as Bragg scatter signatures, and water vapor and cloud liquid water retrievals near SPOLKa) will provide an unprecedented dataset to test hypotheses on factors controlling the lifecycle of convection and the attendant production of impacts (lightning, severe weather, flooding).

Table 5. Use of RELAMPAGO-CACTI radars individually and together (highlighted with the same color) to address observational requirements (OR) through relevant measurables.

Required Measurement	W-band	Ka-band	X-band	C-band	S-band	Profilers	OR
Bragg scatter (boundaries, elevated moisture variations)					SPOLKa		OR1 OR3
3-D kinematics (multi-Doppler analysis or assimilation)			DOW6 DOW7 DOW8				OR1 OR3 OR6
Vertical air motion (using Bragg scatter)						RWP	OR1 OR6
Velocity-azimuth display wind profiles	WSACR	KaSACR	DOW6 DOW7 DOW8 XPOL	CSAPR2 RMA			OR1
Quasi-vertical profiles in precipitation	WSACR	KaSACR	DOW6 DOW7 DOW8 XPOL	CSAPR2 RMA	SPOLKa		OR1 OR2 OR3 OR6
Non-precipitating clouds		KaSACR KaZR					OR2 OR3
Light rain	WSACR WACR	SPOLKa KaSACR KaZR	DOW6 DOW7 DOW8 XPOL		SPOLKa	RWP	OR2
Moderate rain		SPOLKa KaSACR KaZR	DOW6 DOW7 DOW8 XPOL		SPOLKa	RWP	OR2
Heavy rain		SPOLKa			SPOLKa	RWP	OR2
Hail, hail mixed with rain					SPOLKa	RWP	OR2
Water vapor (refractivity)				CSAPR2 RMA	SPOLKa		OR1
Water vapor (dual-wavelength)		SPOLKa KaSACR		CSAPR2	SPOLKa		OR1
Cloud water		SPOLKa KaSACR		CSAPR2	SPOLKa		OR2 OR3
Hydrometeor ID			DOW6 DOW7	CSAPR2	SPOLKa		OR2 OR3 OR6
Multi-wavelength retrievals (using dual wavelength ratio, polarization)	WSACR	SPOLKa KaSACR		CSAPR2	SPOLKa		OR2 OR3 OR6
Microphysical retrievals (using single or multi-wavelength Doppler spectra)	WSACR WACR	KaSACR KaZR		CSAPR2		RWP	OR2 OR3 OR6

Damage surveys. Confirmation of the occurrence (or lack thereof) of hail, tornadoes, and/or damaging surface winds during RELAMPAGO will be essential to satisfy **SO4** and **OR5**, and thus for assessment of hypotheses/key questions regarding severe-weather generation (e.g., Wheatley et al. 2006). Accordingly, information on the areal extent and severity of any damage to the built and natural environment will be gathered following the IOPs, for later comparison with the radar, sounding, and other data. Optimally, such damage surveys will be conducted immediately after the event, but may need to be delayed depending on availability of qualified personnel. The CSWR and UIUC PIs have extensive experience in surveys of severe convective weather damage. They will coordinate the survey efforts, enlisting the assistance of other RELAMPAGO and ALERT.AR (through a SMN public mobile phone app to report severe weather called ALERTAMOS) participants.

4.6.2 Non-NSF Assets

Precipitation Supersite. Brazil, Argentina, and the US will operate a supersite to the west of SPOLKa to capture surface conditions and atmospheric profiling during the intensification and upscale growth phase of the systems emerging from the SDC. This site will contain a backscatter lidar, Radiometrics MP300 radiometer, surface flux tower, and surface disdrometers. A fixed SMN sounding site will also be located here, able to launch soundings as frequently as 1 per hour during IOPs. This will address **SO3** and **SO4**, and **OR1** and **OR2**. NCAR will also operate a water vapor profiling lidar at this site.

GPS WV Transect. Brazil will operate a transect of 6 GPS integrated water vapor sensors from the precipitation supersite near Córdoba to Uruguaiana, Brazil to monitor the temporal evolution of the moisture content of the SALLJ. These will be integrated with existing SIRGAS GPS stations. This will help address all science objectives except **SO3**, and **OR1-3** and **OR7**.

Aircraft. The ARM Aerial Facility (AAF) Gulfstream-1 (G1) will be staged at Las Higueras Airport, Río Cuarto, Argentina (33.09°S, 64.26°W) approximately 2.5 hours drive from the AMF-1 location for 4-6 weeks between 1 November and 15 December 2018.

Lightning Mapping Arrays. For RELAMPAGO, we propose two long-term Very High Frequency (VHF) Lightning Mapping Arrays (LMAs; Rison et al. 1999). Fig 12 shows the notional networks, which would be deployed for 4-6 months including the RELAMPAGO IOP period. One LMA will consist of an estimated 10 stations centered on the primary domain in the province of Córdoba. This LMA will be provided by NASA Marshall Space Flight Center, pending funding from the NOAA GOES-R program. Stations will be collocated with RELAMPAGO (or RELAMPAGO-affiliated) sites, such as the S-PolKa, AMF1, or RMA1 sites. Other stations will be located near population centers, such as Villa Del Rosario, Almafuerte, and Monte Cristo. Actual locations will be chosen following a formal site survey that includes analysis of background noise, access to power and/or Internet (e.g., for any stations without solar arrays or good cellular data coverage), and other factors. Figure 12b shows a Monte Carlo simulation of VHF source vertical location errors following Chmielewski and Bruning (2015). A typical background noise level of -80 dBm is assumed for every station. As can be seen, better than 1-km vertical resolution is expected within ~200 km of the network, due to the relatively

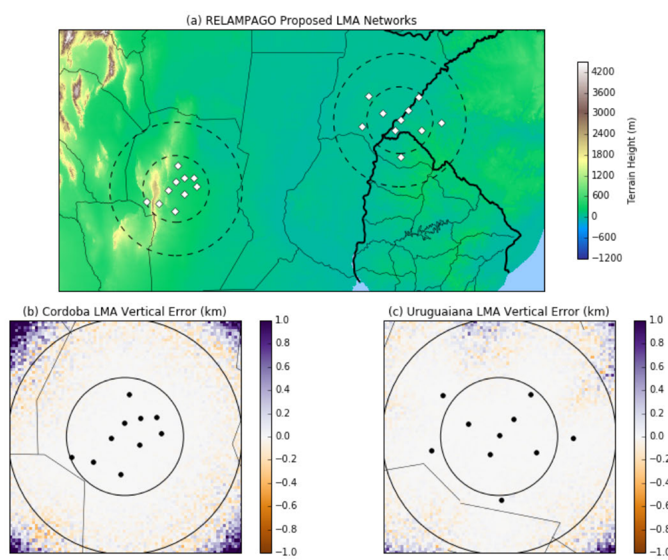

Fig. 12. (a) Relief map of greater RELAMPAGO domain showing locations of proposed Cordoba (west) and Uruguaiana (east) LMA networks. Diamonds are LMA station locations and circles are 100- and 200-km range rings. Thick black curves are international boundaries and thin curves are state/province boundaries. (b) Estimated vertical VHF source location errors for Cordoba network, based on Monte Carlo simulations. Dots are station locations and circles are 100- and 200-km range rings. (c) Same as (b) but for Uruguaiana network. (Courtesy T. Lang/NASA MSFC and R. Albrecht, USP)

wide spacing between stations. This is similar to the Colorado LMA configuration during the Deep Convective Clouds and Chemistry project (DC3; Barth et al. 2015). This provides excellent coverage of lightning within range of SPOLKa.

The second LMA, centered near Uruguaiana, Brazil (Fig. 12a), is another proposed 10-station network. This network, which would be provided (pending funding) by University of Sao Paulo, would consist of stations near population centers. It is relatively more spread out compared to the Córdoba network due to the very rural nature of this region. However, this network also will provide excellent vertical resolution of lightning sources over a large domain (Fig. 12c). While the two main networks are too far apart (~600 km) to be usefully combined, INPE has proposed 4 additional deployable LMA stations (see below). These will be positioned as the meteorology warrants. However, if they are placed between the two major networks, the stations could provide enhanced coverage, for example in Santa Fe province (Argentina). Such a configuration would be expected to play a similar role to the Southwestern Oklahoma LMA, which effectively merged the West Texas and central Oklahoma LMAs during DC3 (Barth et al. 2015). In addition to lightning mapping capabilities, the University of Córdoba will provide ground-level measurements of the electric field and electric charge of precipitation particles. These measurements will address **SO4** and **OR6**.

Brazilian Mobile Experiment. To complement RELAMPAGO's focus on convective initiation and upscale growth, a Brazilian component of RELAMPAGO will study convective systems from the SDC to the Brazilian border. This experiment will perform Lagrangian tracking of MCSs over long distances. The mobile instrumentation will operate in the region indicated in Figure 9Fig. 9, and encompass the following (to address **SO1-2,4-5** and **OR1-3**):

- Mobile X-Band dual polarization radar (XPOL), mobile radiosonde system, and surface station
- Mobile Micro Rain Radar (MRR2), electric field mill, and Parsivel disdrometer
- Mobile LMA (4 stations), which will compliment the fixed LMAs in Argentina and Brazil
- 15 balloon electric field mill soundings
- 10 additional cloud to ground lightning sensors (LINET)
- Mobile mesonet (operating in Brazil only)

Aircraft. The ARM Aerial Facility (AAF) Gulfstream-1 (G1) will be staged at Las Higueras Airport, Río Cuarto, Argentina (33.09°S, 64.26°W) approximately 2.5 hours drive from the AMF1 location for 4-6 weeks between 1 November and 15 December 2018. C-Band operational radars in Córdoba and Parana, the ARM radars, and potential RELAMPAGO radars will be used with rapid update satellite imaging for flight planning and direction. Its potential instrumentation payload described in Appendix A2 Table A2-1 will focus on in situ cloud, aerosol, kinematics, and thermodynamics measurements. These measurements greatly complement other assets because they provide detailed in situ measurements of the free troposphere not provided by any other funded or proposed instrumentation. These measurements will provide crucial data for answering science questions related to relationships between early convective system lifecycle stages (initiation, initial organization) and environmental conditions.

4.7 RELAMPAGO-CACTI Field Deployment Strategy

4.7.1 EOP Observing Strategy

Hydrometeorological Observing Strategy. After the instruments are installed and calibrated, we will have a mock RELAMPAGO campaign with the people from the Universidad de Córdoba. The idea is to have two teams – one led by Universidad de Córdoba and one led by University of Illinois/NCAR (each team will have senior personnel and students from both universities). Each team will be responsible for half of the observations. We will begin with the headwater stations and work our way east-northeast – following the trajectory of the MCSs. To understand how the river basin responds to extreme MCS events, we will use in-situ streamflow (following events across the Carcarañá basin from the headwaters to the terminus of the basin), precipitation (including disdrometer measurements), groundwater observations, flux tower observations of evapotranspiration, and soil moisture observations. We will calculate key metrics such as bulk runoff fraction, large-scale evaporative fraction, and runoff efficiency as a function of antecedent soil moisture conditions. Our hypothesis is that flooding in the region is strongly modulated by rising water tables – despite increases in evapotranspiration during flood periods.

CACTI Observing Strategy. Whereas proposed RELAMPAGO instrumentation is well suited to observe intense and/or severe storms as well as the large-scale environmental evolution, CACTI instrumentation is well suited to observe cloud formation, growth, deep convective initiation, and environmental evolution locally over the SDC. The overarching goal of ARM is to obtain measurements that improve prediction of climate, and CACTI will specifically focus on the well-known problem of deep convective initiation and mesoscale organization predictability in models with the goal of using observations to improve cumulus, microphysics, and aerosol parameterizations. To do this, measurements of all environmental factors that influence the convective lifecycle, including orographic, low level jet, and frontal circulations, surface fluxes, synoptic vertical motions influenced by the Andes, cloud detrainment, and aerosol properties, are needed for a large number of convective initiation, mesoscale organization, and null cases. Most CACTI measurements complement the proposed RELAMPAGO measurements for examining a range of science questions and hypotheses. More than simply additional soundings and an additional dual-polarimetric precipitation radar, AMF1, MAOS-A, and PI instrumentation funded as part of CACTI provide unique measurements of factors that influence convective initiation, convective and mesoscale upscale growth, and convective intensity.

Boundary layer depth and upslope circulations that force cumulus clouds that are precursors to deep convection will be continuously monitored along with boundary layer thermodynamic and aerosol properties that impact cloud properties, while radiosondes will be released every 1-3 hours during days forecasted to have deep convective initiation. Meanwhile, high temporal frequency W-, Ka-, and C-band RHI and narrow sector PPI scans over the SDC crest where convective initiation is most common will be performed, where focus will be placed on observing ice and precipitation initiation and evolution. Cold pool outflows will be tracked and related to precipitation measurements. G1 flights will provide measurements of cloud and environmental evolution in the free troposphere for periods of potential convective initiation and upscale growth. After deep convective initiation, cells will be tracked using W/Ka-SACR and CSAPR2, and as cells grow upscale moving eastward, CSAPR2 will shift to wider sector scans, in coordination with SPolKa during the IOP.

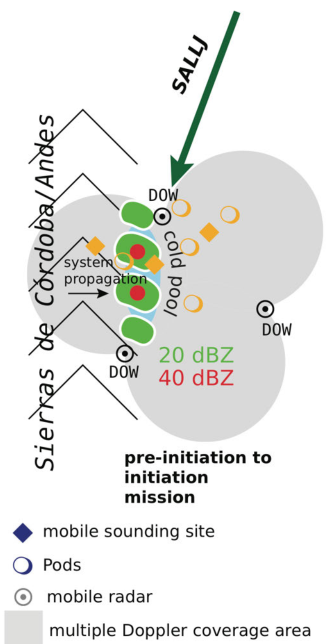

Fig. 13. Design of initiation missions for RELAMPAGO mobile assets. Initially, separate sampling missions will be called for each case, based on forecasts. Pre-organized sites and missions will be carefully designed to avoid safety, communication and coordination issues. As experience grows during the campaign, we will attempt to coordinate missions with more complex objectives given the infrastructure and communications.

4.6.3 IOP Observing Strategies

Initiation Missions. A primary goal of the initiation missions is to sample the full tropospheric structure of the mesoscale environment, prior to and in the region of anticipated convection initiation (CI). In the Córdoba study area, the local terrain including the SDC is a key means of CI, and thus the terrain will be the primary focus for the CI missions. As indicated in Fig. 13, the basic plan for the mobile sounding teams is to collect soundings both at relatively high and low elevations; upon CI, these teams will immediately begin sampling the nascent convective storms. One proposed deployment location for the high-elevation sounding is ~ 5-15 km west of Villa Yacanto, along the unfinished road that provides access to the 2800-m crest of the SDC. A proposed location for one of the lower-elevation teams is at the AMF1 site in Villa Yacanto, to supplement the three-hourly soundings to be collected at this DOE fixed site. When combined, these two mobile soundings and the two DOE fixed site-soundings (Villa Dolores and Villa Yacanto) will provide samples of the west-to-east atmospheric variation across the SDC.The two remaining mobile teams will be deployed 20-40 km east and/or north of the AMF1 site, towards Córdoba. These mobile soundings as well as the fixed sounding at Córdoba will characterize the modification of the low-level flow towards the SDC, and otherwise reveal the north/northeast to south/southwest atmospheric variation in the direction of the SALLJ. There are numerous road options and thus potential deployment sites towards Córdoba, allowing for deployment flexibility, especially on days with additional mesoscale influences on CI, such as a remnant cold pool and associated mesoscale boundary (Fig. 13).

In our experience, a complete radiosonde observation (balloon flight to at least the tropopause) can be completed in roughly 1 hr, including 10-15 min for sonde preparation and balloon inflation. As warranted by the particular meteorological situation of the day, we anticipate collecting 2-3 soundings before transitioning to the active-convection missions. As shown below in Fig. 15, this transition will involve soundings within the initial cold pools as well as within the initial updrafts, for comparison to such soundings in mature cold pools and updrafts. We note here that because the UIUC, CSWR, and CSU systems each are capable of radiosonde reception from a moving vehicle, redeployment to a new location immediately after sonde release is afforded and will facilitate the mission transition.

Surface meteorological observations at high temporal and spatial resolution will be used to characterize the pre-convective environment, including possible surface triggers for CI. Prior to CI, the Pods will be deployed, with a ~5-km spacing, within a linear array that is parallel to that of the sounding locations, and in an additional linear array that is roughly parallel to the SDC (such as along the paved north-south road through Villa Yacanto). Upon CI, the Pods will be redeployed in a similar arrangement, to begin sampling the nascent convective storms, particularly the cold pools generated by those storms.

As illustrated in Fig. 13, the soundings and Pod data optimally will be collected within the region of dual- or triple-Doppler radar coverage. Preliminary site surveys indicate suitable locations (and road access) for DOW deployments along the SDC, north-south from Villa Yacanto, as well as east-northeast from the SDC. The DOW/XPOL array will be set up with 20-30 km baselines, and will be tasked with coordinated PPI scanning to be used for multi-Doppler syntheses. The scanning of longer wavelength radars will be coordinated with PPI sectors and RHI volumes covering these regions.

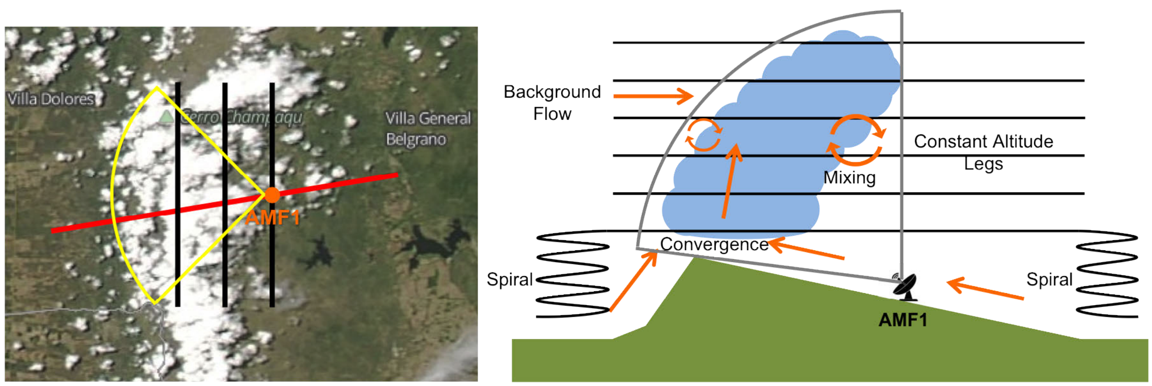

Figure 14. The flight strategy for orographic cumulus events in horizontal and vertical plan views. Meridional, RHI (~zonal), and spiral flight legs are shown in black. The vertical plan view is shown in red in the horizontal plan view. Typical circulations for these events are shown in orange, and AMF-1 location with radar scans are also shown.

The primary goal for CI G1 flights is to characterize in-cloud dynamics, microphysics, and aerosols as well as the environmental variability around the clouds focusing on conditions upstream (west) and downstream (east) of clouds at multiple altitudes in the vicinity of the AMF-1 site. A secondary focus is characterizing north-south variability in environmental conditions. The flight strategy for situations of potential deep convective initiation is shown in Fig. 14. Spiral legs will be flown upstream and downstream of the range at low-mid levels so that upslope flow on both sides of the range is characterized. At altitudes of between 3 km and 7.5 km, constant altitude legs will be flown across the range along radials emanating from the AMF-1 site while penetrating clouds when safely possible. North-south legs will also be included to maximize in-cloud sampling in some situations. Following initiation, the focus will be obtaining vertical profiles of environmental properties around the growing deep convection and in adjacent regions with congestus that is not initiating so that the differences in environment can be compared. Convective inflow and free tropospheric properties will be important for putting AMF-1 observations into context and for providing input for numerical simulations.

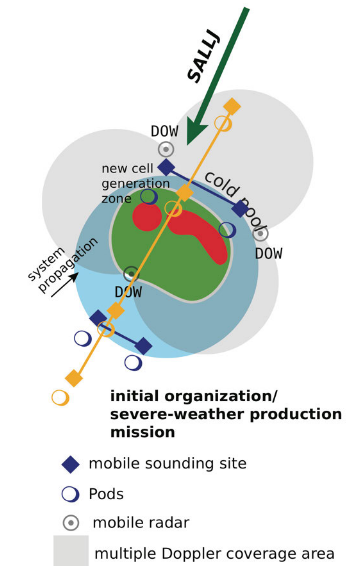

Fig. 15. As in Fig. 13, except for Initial Organization/Severe-Weather Production missions.

Initial Organization/Severe Weather Generation Missions. Within these missions we propose two basic strategies: In the *line-normal* strategy, an array of four mobile units is deployed normal to and across the active convective line segment, with two mobile units in the near and far pre-storm environment, and two mobile units within the cold pool at varying distances from the back edge of the active convection; the far-cold pool soundings will yield the additional information of how the cold pool interacts with the terrain. In the *line-parallel* strategy, two mobile units will be deployed ahead of and parallel to the convective line, and two mobile units will be deployed behind the convective line, within the cold pool. This strategy will be used to determine the extent of horizontal variability in the line-parallel direction. Figures 13 and 15 indicate that one of the pre-storm teams will make occasional soundings in mature updrafts. Thereafter, this team will re-deploy ahead of the convection and make near pre-storm soundings. Both pre-storm teams will make soundings over the entire troposphere. The cold pool soundings, on the other hand, need only be taken through the depth of the cold pool, which tends to span only a few kilometers. Thus, we propose that the cold pool soundings be terminated at ~5 km AGL, which will then allow for a higher release rate and thus higher temporal resolution within the cold pool. In the mobile units with two radiosonde systems, and with sondes capable of transmitting at different frequencies, we will release sondes every 15-20 min.

As in the Initiation missions, Pods will be deployed during nascent, developing convection in arrays that complement the sounding array, and will be used to sample the pre-storm environment as well as critical features/regions in developing convective systems. The Pod deployment pattern shown in Fig. 15 will allow for surface sampling of the spatial and temporal variability of the environmental inflow air, and then will provide samples of the cold-pool air as the convection propagates forward. Note that if severe straight-line winds are expected, some or the entirety of the Pod array will be deployed later, just ahead of evolving severe wind portions of the convective line, such as the apex of bowing lines/segment.

We will again endeavor to collect the soundings and Pod data within the region of dual- or triple-Doppler radar coverage, and also coordinate the operations of each of these ground-based mobile platforms with the aircraft operations (see below). Suitable locations (and road access) for DOW/XPOL deployments east/northeast from the SDC towards Córdoba are abundant. The idealized deployment strategy consists of two mobile radars in advance of the convective storm, with a 30 km baseline parallel to the the convective line segment (and perpendicular to the storm motion). The third mobile radar will be positioned behind the convective segment, with a 30-km baseline with the other radars. The three radars will conduct coordinated PPI scans of convective structures of the targeted storm, while the longer wavelength radars will focus on adjustable PPI and RHI sectors within the X-Band dual-Doppler domain, as well as surveillance precipitation estimation.

The idealized flight plan for convective systems that begin to organize and grow upscale is shown in Fig. 16. One focus will be on obtaining convective inflow environmental conditions and aerosol properties over a range of altitudes. A second focus will be in the low level cold pool outflow generated by convective downdrafts and the aircraft will be directed as low as is safely possible and allowed by air traffic control. Along with inflow properties, cold pool measurements are crucial for validating high-resolution models and understanding convective upscale growth and organization. G1 flights in the convective inflow, whether in the SALLJ and or not, will be outside of clouds and precipitation and thus be focused on characterizing the distribution of temperature, humidity, horizontal and vertical winds, and aerosol properties.

The G1 needs to stay away from deep convection in safe operating locations at all times, and flight plans will be designed to do so. We will develop several more flight scenarios than discussed here, from which we will choose the best one depending on meteorological conditions. All flights are expected to be during the daytime. Multiple science team members with experience directing aircraft in convective situations will be in the field to continuously monitor weather conditions using radar, satellite, and mesonet observations and to communicate with the G1 crew.

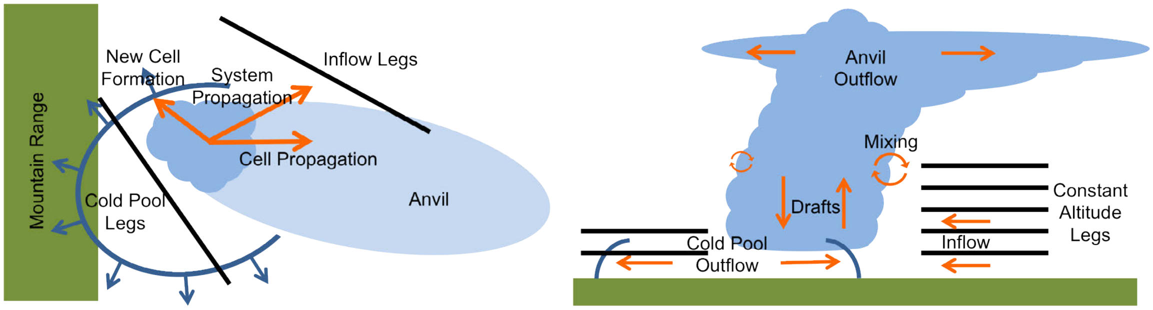

Figure 16. The flight strategy for deep convection in horizontal and vertical plan views. Convective inflow and outflow flight legs are shown in black and are flexible to changing depending on the evolution of each event.

Upscale Growth/Convective Maturation Missions. The sounding, Pod, and mobile radar deployments during these missions will be similar to those used during the Initial Organization missions, with exception of larger spacing between sounding/Pods to accommodate the larger systems (Fig. 17), and understand processes relevant to the growth to mature MCS structure, as well as backbuilding. The focus of the radar, surface, sounding, and aircraft observations will be on the zones of new cell generation on the upshear side of organized convection, where the cold pool is interacting with the LLJ, and possibly remnant or developing proximate cold pools or other boundaries in this location.

Pods and mobile soundings will be placed in a configuration similar to the Initial Organization/Severe Weather Generation Missions, however they will be shifted upshear to capture the vertical profile of relevant parameters in this region. The G1 will also fly in this region to sample the storm environments upshear ahead and behind the leading convection. Dual-Doppler mobile radar baselines will be operated at 30-40 km baselines to capture a broader evolution of the system, while maintaining focus on the new cell generation zone. In addition, the precipitation radars will map the microphysical structure of storms contemporaneously.

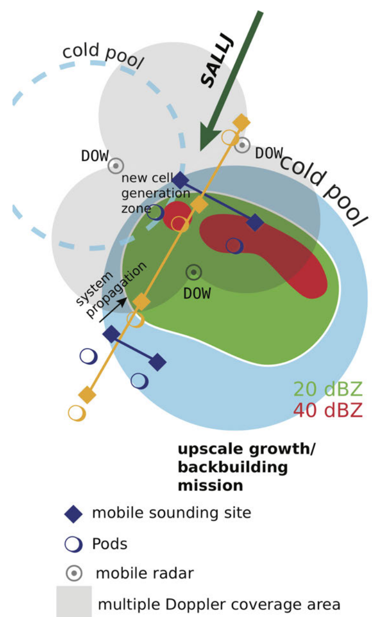

Fig. 17. As in Fig. 13, except for Upscale Growth/ Convective Maturation missions.

Sampling in the SDC Versus Mendoza Regions. The Initiation missions in the SDC study area and in the Mendoza study area will focus primarily on the role of the complex terrain in CI. Accordingly, we will use the same basic strategy of sounding and Pod arrays that are oriented from relatively high to relatively low elevations, followed by a mission transition that involves samples of the initial cold pools and updrafts. The organization/upscale growth missions in the Mendoza study area will be conducted in much the same way as those in the SDC study area. The Mendoza strategy will exploit the fact that the convective storms in the Mendoza study area tend not to move as rapidly. In both locations, we will identify 5-10 potential DOW and Pod sites during site surveys prior to the campaign.

5. Project and Field Management

Coordination and Site Selection. The requesting PIs have extensive field experience deploying instrumentation in and near a wide variety of severe weather, and two of the team members are the facility managers of the DOWs and deployable Pods. The PIs will develop a Safety, Policies, and Procedures document that addresses common hazards and mitigation, appropriate driving practices and etiquette, best practices for deploying in-situ instrumentation, best practices for entering/exiting vehicles, etc. Crews will be briefed on Safety, Policies, and Procedures at the beginning of the project.

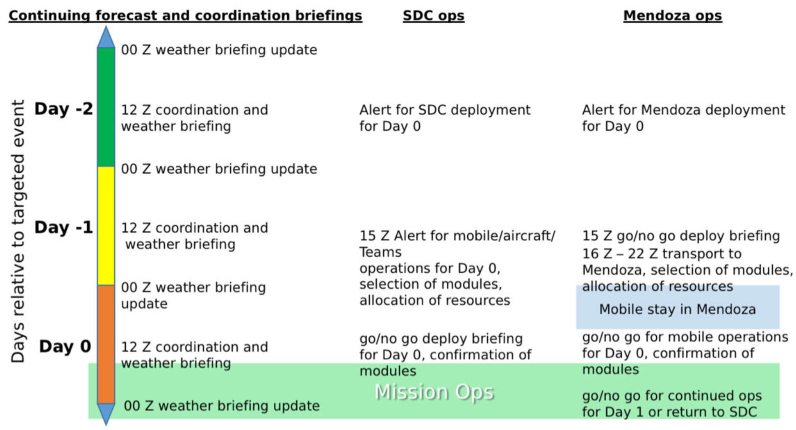

Fig 18. Field deployment time schedule for SDC and Mendoza operations. All decisions will be made in the RELAMPAGO-CACTI ops center, and communicated via regularly scheduled webinars.

In-field communication will be accomplished through cell-phone, chat room, text messaging, and/or VHF radio. All vehicles will be tracked and their location displayed in real-time using custom and/or commercially available software. CSWR uses satellite-based Delorme InReach vehicle tracking devices which also have emergency texting capabilities. These use satellite communications so are expected to be functional in Argentina. All vehicles will have cellular-based internet, though data coverage is available it has not yet been mapped in the study area.

During IOPs, coordinators will monitor the location of manned instrumentation/vehicles and proximity to identifiable hazards (e.g., tornadoes, flooding, hail) to inform deployment decisions. Frequent communication between coordinators and the crews will additionally inform deployment decisions. Fixed assets (particularly radar scanning strategies) and mobile assets will be coordinated from the Operations Center.

Operations Center. The operations center will be located near Córdoba, Argentina. Office space and a high-speed internet connection will be provided by the SMN and/or the University of Córdoba at no cost to NSF. Flight coordination with the DOE G1 aircraft will be handled at the operations center, where SMN, DOE, and SPOLKa real time displays will be transmitted via high-speed connections and available cellular networks. Here, meeting space will be used for forecast briefings and communications, while a separate forecasting center will be staffed with SMN forecasters and graduate students. Office space for PIs and their groups will also be provided.

Field Coordination and Support. RELAMPAGO will request support for an EOL field catalog and EOL project management. Once daily coordination calls amongst all interagency participants for forecast briefings and deployment discussions will be hosted and broadcasted online and by phone. The project will have defined roles, including a RELAMPAGO chief coordinator, radar coordinator, sounding mesonet coordinator, aircraft coordinator, and mobile team coordinator. These groups will have at minimum twice daily meetings following the weather briefings.

Forecast Operations. 24/7 forecasting activities will be led by SMN forecasters, and aided by graduate and undergraduate students from the participating institutions. Per the time schedule in Fig. 18, briefing materials as well as forecast information for coordination will be provided at 12 UTC, followed by a weather-briefing update at 00 UTC. Continuous nowcasting support will also be offered to the mobile crews during the IOP deployments through a forecast “hotline” and text messaging/XCHAT. Forecasting dry runs will be conducted prior to the campaign to ensure campaign readiness.

Modeling Support. Convection-allowing forecasts (including ensembles) over a 0-48 hr period will be generated over SESA by multiple agencies/universities in South America, the US, BRAMS from Brazil, and France. The forecasts will be initialized from operational analyses at 00 and 12 UTC, and employ horizontal grid spacings of 4 km or less. As has been consistently demonstrated in field campaigns conducted over the past 10 years, such forecasts will form an ‘ensemble of opportunity’ and be highly valuable for guidance in project planning and post project analysis.

6. Data Management Plan

Permanent Archival of Data. RELAMPAGO-CACTI will produce a vast amount of data amongst various organizations in the US and South America that requires a comprehensive data management strategy. We will coordinate with the project participants during planning meetings and site surveys to ensure that data collection needs are adequate, and that all data is available to all participants in a timely manner.

Quality controlled data collected by NSF-supported resources will be placed in a publicly-available archive in common data formats (i.e., netCDF, text, HDF) to be provided by NCAR-EOL within 1 year of the experiment. A master list of RELAMPAGO related publications and datasets will be maintained by the PIs on a permanent web site hosted by NCAR EOL. It is proposed that NCAR EOL curate a RELAMPAGO field catalog, including real time model results, satellite, operational radar, upper air, and surface data collected prior to and during the experiment (for pre-campaign planning and forecast/operations dry runs, campaign planning, and execution in the field (including quick looks from assets in the field), and post-campaign analysis. Long term data storage from NCAR deployment facilities and NSF-supported investigators are requested for data collected during the campaign for data from NSF supported facilities *and South American investigators. South American investigators shall adhere by the RELAMPAGO NSF 1 year QC data release deadline.* Data interchange among South American countries and US investigators will be open and rapid based on previous experience of the PI in collaborating extensively with Argentina and Brazil on projects such as CHUVA and ALERT.AR (which are all publically available). Datasets collected by other agencies such as NASA and DOE will be made available on their data centers following their own open data protocols, however, links to those relevant datasets and quick looks will be collected by NCAR EOL and maintained on the RELAMPAGO web site.

All three PIs, in addition to other investigators involved in the experiment, have extensive experience with the data to be collected in RELAMPAGO. They have participated in numerous field campaigns, and have experience coordinating data collection activities across all of the platforms (fixed and mobile radar, sounding, surface, remote sensing, and aircraft) proposed in the experiment. The PI is an advocate for open source software, and will work towards open data and science (code + analysis tools) using tools such as python and github in concert with UNIDATA and NCAR technologies for data analysis (e.g., IDV).

Field Catalog. RELAMPAGO will request that EOL design and implement a RELAMPAGO Field Catalog customized to meet project needs for in-field documentation. For specialized research data sets, the metadata would be the responsibility of previous investigators. The EOL Field Catalog is a web-based central repository of project planning documents, mission reports, facility status updates, field data images, satellite, and model products, and other information, which are all invaluable for in-field decision making and post-project reference. The catalog will help the project document activities in near real-time, provide a single point for updating status, and provide a repository for preliminary in-field research data products. The Field Catalog is further used following the field phase to assist in data analysis and to provide long-term record of the project. Project participants will work with EOL to prepare and test web-based forms that will provide the basis of in-field documentation. These include the daily operations summary, daily facility status reports, expendable resources status report, and daily weather forecasts.

In-project Coordination Data and Information Exchange. XCHAT software and phone-accessible web teleconference software is requested to be provided by NCAR EOL to assist with real-time coordination with NSF and non-NSF resources, and for forecasting/planning. These communications will be archived by NCAR EOL in the project data archive.

Educational Outreach. The educational outreach during RELAMPAGO will have three components. First, graduate and undergraduate students from participating universities and institutions will be assist in forecasting/nowcasting activities as well as in data collection, including operation of the radiosonde units, the surface mesonets, and the mobile radars. This will provide US, and a large number of South American students the opportunity to learn the use of state-of-the art equipment, and help train the next generation of field research scientists. We will form a rotating schedule of forecasting and data-collection teams that are international and inter-institutional. Thus, the students, operational forecasters, and scientists from different countries in South America and the US will interact in an unprecedented way during the campaign, establishing research and collaboration among all involved. Secondly, during the campaign, all participating students will be invited to convene at a student symposium dealing with RELAMPAGO science questions and measurement techniques. We will additionally hold seminars given by the participating PIs from the US as well as South America, to encourage further international collaboration. And thirdly, K-12 and university students will be invited in person (Argentina) and virtually (internationally via webinars) to visit surface installations and learn about the science in the campaign in a large outreach effort. We will enlist the assistance of EOL to help coordinate these efforts.

7. Appendix A1

Table A1-1. List of key CACTI instrumentation and measurements at the AMF1 site.

Measurement	Instrument
Precipitation radar reflectivity, Doppler spectra, polarimetric variables, and microphysics and wind retrievals	C-band Scanning ARM Precipitation Radar (CSAPR2)
Cloud/Precipitation radar reflectivity, Doppler spectra, and microphysics and wind retrievals	W/Ka-band Scanning ARM Cloud Radar (W/Ka-SACR)
Cloud/Precipitation radar reflectivity, Doppler spectra, and microphysics and vertical wind retrievals in detail over the AMF1 site	Ka-band ARM Zenith Radar (KAZR)
Backscattered radiation and polarization from aerosols or clouds	Micropulse Lidar (MPL)
High-resolution spatiotemporal evolution of cloud boundaries	ARM Cloud Digital Cameras (ACDC)
Vertical profiles of temperature, humidity, winds	Balloon-borne sounding system
Cloud base height	Vaisala Ceilometer
Cloud scene/fraction	Total Sky Imager (TSI)
Liquid water path, precipitable water vapor	Microwave Radiometers (MWR, MWR3C)
Surface pressure, temperature, humidity, winds, rain rate, visibility	Surface Meteorological Instrumentation
Raindrop size distribution, fall speeds, rainfall	Laser Disdrometer, Tipping Bucket Rain Gauges, Optical Rain Gauge
Surface latent and sensible heat fluxes, CO_2 flux, turbulence, soil moisture, energy balance	Eddy Correlation Flux Measurement System (ECOR), Surface Energy Balance System (SEBS)
Upwelling and downwelling radiation	Atmospheric Emitted Radiation Interferometer (AERI), Multifilter Rotating Shadowband Radiometer (MFRSR), Infrared Thermometer, Ground and Sky Radiation Radiometers
Boundary layer winds, turbulence, and aerosol backscatter	Doppler Lidar
Wind Profile	Sonic Detection and Ranging (SODAR) system
Surface Meteorology	Weather Transmitter (WXT-520)
Wind and Precipitation Profiles	915-MHz Radar Wind Profiler (RWP)
Aerosol optical depth	Cimel sun photometer, MFRSR
Aerosol particle size distribution	Ultra-high sensitivity aerosol spectrometer (UHSAS), Scanning mobility particle sizer (SMPS)
Cloud Condensation Nuclei (CCN) concentration at specified supersaturations (0.1 to 1.0%)	Dual Column Cloud Condensation Nuclei counter
Condensation Nuclei (CN) number concentration (diameters > 0.3 nm)	Ultrafine Condensation Particle Counter (UCPS)
Condensation Nuclei (CN) number concentration (omitting diameters smaller than 10 nm)	Condensation Particle Counter (CPC), Model 3010
Ice Nucleating Particle (INP) concentration	Filter collections for CSU ice spectrometer
Black carbon mass content	Single Particle Soot Photometer (SP2)
Black carbon extinction	Photo-acoustic Soot Spectrometer (PASS-3)
Black carbon absorption	Particle Soot Absorption Photometer (PSAP)
Black carbon absorption	7-Wavelength Aethelometer
Hygroscopic growth factor	Hygroscopic Tandem Differential Mobility Analyzer (HTDMA)
Aerosol scattering as a function of RH	Humidigraph
Aerosol extinction at 3 wavelengths	3 Wavelength Nephelometer
Aerosol chemical composition	Aerosol Chemistry Speciation Monitor (ACSM)

8. Appendix A2

Table A2-1. Key G1 instrumentation and measurements for CACTI.

Measurement	**Instrument**
Particle size distribution (2 to 50 μm)	Fast Cloud Droplet Probe (F-CDP) or Fast Forward Scattering Spectrometer Probe (F-FSSP)
Particle size distribution (10 to 3000 μm)	2-Dimensional Stereo Probe (2DS)
Particle size distribution (400 to 50,000 μm)	High Volume Precipitation Sampler 3 (HVPS-3)
Particle size distribution (25 to 1550 μm)	Cloud Imaging Probe (CIP)
Particle size distribution (0.5 to 50 μm)	Cloud and Aerosol Spectrometer (CAS)
Liquid water content	Particle Volume Monitor 100-A (PVM-100A)
Liquid water content	Multi-Element Water Content System (WCM-2000)
Liquid water content	Hot-wire probe from CAPS
Cloud extinction	Cloud Integrating Nephelometer (CIN)
Sample stream of dry aerosol	Aerosol Isokinetic Inlet
Sampling of evaporated cloud droplet residuals	Counterflow Virtual Impactor (CVI)
Aerosol size distribution (0.06 to 1 μm)	Ultra-high Sensitivity Aerosol Spectrometer (USHAS)
Aerosol size distribution (0.015 to 0.450 μm)	Scanning Mobility Particle Sizer (SMPS) or Fast Integrated Mobility Spectrometer (FIMS)
Aerosol size distribution (0.1 to 3 μm)	Passive Cavity Aerosol Spectrometer 100 X (PCASP)
Condensation Nuclei (CN) number concentration (diameters > 0.3 nm)	Ultrafine Condensation Particle Counter (UCPS)
Condensation Nuclei (CN) number concentration (omitting diameters smaller than 10 nm)	Condensation Particle Counter (CPC), Model 3010
Cloud Condensation Nuclei (CCN) at 2 specified supersaturations (0.1 to 1.0%)	Dual-column cloud condensation nuclei counters
Ice Nucleating Particle (INP) number concentration (immersion freezing mode from -5 to -25°C)	Filter collections for CSU ice spectrometer
Aerosol soot content	Single Particle soot Photometer (SP2)
Aerosol scattering coefficient at 450, 550 and 700 nm	3-wavelength Integrating Nephelometer, Model 3563
Aerosol absorption coefficient at 462, 523, 648 nm	3-wavelength Particle Soot Absorption Photometer (PSAP)
Aerosol scattering coefficient as function of RH	Humidigraph
Particle ionic composition	Particle in Liquid Sampler (PILS)
Concentration of CO_2, CH_4 and H_20	Cavity Ring Down (CRD) System
Concentration of SO_2, CO, O_3, NO, NO_2, NO_y	BNL Trace Gas System
True air speed, speed, altitude, angle of attack, side-slip, temperature, and relative humidity	Aircraft Integrated Meteorological Measurement System (AIMMS-20)
Winds	Gust Probe
Water vapor concentration	Hygrometer 1011C
Water vapor concentration	Hygrometer CR2
Water vapor concentration	Chilled Mirror Hygrometer – General Eastern 1011B
Pressure	Rosemount 1201F1
Temperature	Rosemount E102A/510BF
Aircraft position	C-MIGITS III (miniature Integrated GPS/INS Tactical System)
Aircraft position and velocity	GPS (Global Positioning System) DSM 232
Aircraft altitude, yaw/pitch/roll/angle	Triamble Advanced Navigation System (TANS) Vector GPS
Images of cloud penetrations	Nose Video Camera

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10. Section I SPO: RELAMPAGO Facilities Requested

NSF Lower Atmospheric Observing Facilities

Facility	*Investigator Contact(s)*	*Proposed Sponsor*	*Amount*	*Status*
NCAR SPOLKa	Steve Nesbitt, U. Illinois	NSF	$1,279 K	Proposed
NCAR ISFS	Francina Dominguez, U. Illinois	NSF	$371 K	Proposed
CSWR 3 DOWs, PODs 1100 sondes, helium, and expendables	Josh Wurman, CSWR/J. Trapp, Illinois/R. Schumacher, CSU	NSF	$700 K	Proposed

NSF Special Funds

Facility	*Investigator Contact(s)*	*Proposed Sponsor*	*Amount*	*Status*
NCAR/U. Montana water vapor lidar	Tammy Weckwerth, NCAR	NSF	$104 K	Proposed
NCAR Computing and Data Services	Mike Daniels, NCAR	NSF	$181 K	Proposed
NCAR Project Management Office + Computing and Web Infrastructure Group	Brigitte Bauerle, NCAR	NSF	$330 K	Proposed

Additional Deployment Requests to NSF for Support

Facility	*Investigator Contact(s)*	*Proposed Sponsor*	*Amount*	*Status*
CSU Radiosonde System	Russ Schumacher, CSU	NSF	$18K	Proposed
U. Illinois Radiosonde Systems	Jeff Trapp, U. Illinois	NSF	$30K	Proposed
NCAR RAL Hydromet Equipment	Francina Dominguez, U. Illinois/D. Gochis, NCAR	NSF	$105K	Proposed
Isotope measurements	Jessica Conroy, U. Illinois/David Noone, OSU	NSF	$75K	Proposed

Section I SPO: **RELAMPAGO Facilities Requested (continued)**

Other Agency and International

Facility	*Investigator Contact(s)*	*Proposed Sponsor*	*Amount*	*Status*
DOE-CACTI AMF-1 CSAPR2 MAOS Hydromet network G-1 Aircraft	Adam Varble, University of Utah	DOE	$7,400K (estimated)	Funded
NASA Lightning Mapping Array	Timothy Lang, NASA MSFC	NOAA	$450K	Proposed, letter of commitment received from NOAA GOES-R program
USP-Brazil Lightning Mapping Array	Rachel Albrecht, U. São Paulo	FAPESP, CNPq	$180K	Proposed
Argentina Fixed and mobile radiosonde stations, manpower, vehicles, additional operational soundings	A. Celeste Saulo, SMN/Paula Salio, U. Buenos Aires	SMN, CONICET	$300K	Funded, letter of commitment received
Brazil XPOL, Mobile radiosonde and 4 surface stations, 6-station GPS transect, Surface flux energy flux, MP300 radiometer, lidar	Luiz Machado, INPE	NSF	$100K	Proposed
Brazil - UFSM StickNet	Ernani Nascimento, UFSM	CNPq	$5 K	Proposed
Chile - U. Valparaiso Soundings	Diana Pozo, U. Valparaiso	CONICYT	$20K	Proposed

Dynamics and Microphysics of Orogenic Convective Systems Developing Near the Andes

Robert A. Houze, Jr., PI,
Angela Rowe Co-I

Prospectus

The PI brings experience from numerous studies of precipitating convective cloud systems that form near the Himalayas and Andes. His team has studied the climatological patterns of development of the most extreme forms of convection in both regions as well as the factors involved in storms that produce the greatest flooding and other types of severe weather in these regions. Since 2007 his team has produced 18 papers on these subjects. Several of these papers have brought attention to how mesoscale convective systems (MCSs) regularly form near the Sierra de Cordoba range and Argentinian foothills of the Himalayas when these regions are impacted by the South American low-level jet, especially when the jet is enhanced by the passage of waves in the westerlies. The premise that RELAMPAGO is an ideal place to study the initial phases of MCS development is based in no small part on these studies. A strong motivation of this prospectus is that despite our success in our studies of deep convection near mountains is that our studies in these regions to date have not benefitted from focused field campaigns deploying ground-based S-band dual-polarimetric radar and targeted soundings. As a result, we do not yet know much about the microphysics and dynamics of extreme convective and mesoscale systems in the vicinity of the Himalayas or Andes.

Houze and Rowe have considerable experience with research radars in field campaigns in other convective and synoptic environments; Houze and Rowe have used S-band dual-polarimetric radars in several field campaigns (MAP, IMPROVE, NAME, TiMREX, DYNAMO, and OLYMPEX). These projects have successfully used the combination of S-band Doppler and dual-Polarimetric radar data to determine the kinematic and microphysical characteristics of a wide variety of precipitating cloud structures. Most recently, Houze's group has used the dual-polarimetric and Doppler radar data along with sounding network observations obtained in DYNAMO specifically to revolutionize the description and understanding of oceanic tropical convection. We have bolstered the observations with key modeling studies constrained by the field data. We will use similar methodology in RELAMPAGO to understand the early stages of MCSs that form and begin their upscale growth into MCSs near the Andes. We will examine the S-band polarimetric data statistically, as we have done in NAME, TiMREX, and DYNAMO to determine the characteristics of the ice particles occurring in the convection of these forming and growing systems, which produce much damaging hail. Statistical characterization of the S-Pol dual- polarimetric parameters obtained in RHI sectors were key to progress in our understanding of the dynamics and microphysics of oceanic convection in DYNAMO and the variation of dynamics and microphysics relative to terrain in TiMREX and NAME. We expect equally informative statistics to be forthcoming from the RELAMPAGO S-Pol data. The S-Pol data in DYNAMO also obtained extremely valuable Bragg scattering signals from humidity discontinuities and nonprecipitating clouds that allowed us to analyze the early formation of clouds and gust front boundaries. These DYNAMO data were key to understanding the upscale growth of convection in the development of active phases of the Madden-Julian Oscillation. We will use the Bragg scattering and highly sensitive Rayleigh scattering of the S-Pol signals to determine how the convection grows upscale over the lower mountains of the Andes and Sierras de Cordoba range. A working hypothesis is that the early growth and upscale development is fomented by the SALLJ impinging on the foothills and Sierras and interacting with the cold pools of convection that has already formed over the mountains. The ability of the S-Pol to observe the cold pool boundaries will be used to derive a better understanding of the upscale growth process. By analyzing the RELAMPAGO radar in the context of sounding data and related diagnostic modeling we will bring the understanding of early-stage MCS development and its enhancement by flow interaction with the terrain to a new level.

We expect our budget to be in the vicinity of 150K per year for 3 years to support the research of the PI and his staff in this project. An additional ~20K can be expected for the field year in order to cover South American travel and per diem.

Proposal Title: Assessment of moisture recycling in the La Plata River Basin with stable water isotopologues

PI: Jessica Conroy, University of Illinois Urbana-Champaign
Co-PI: David Noone, Oregon State University **Anticipated Sponsor:** NSF-EAR Hydrological Sciences **Duration and start date:** 3 years, 06/01/17
Estimated Budget per year: $130K

In the La Plata River Basin, moisture recycling contributes substantially to precipitation, but limited data preclude evaluation of the relative roles of transpiration, surface evaporation and rain evaporation on hydroclimate. The stable isotopic composition of water is a powerful tool to trace water through the hydrologic cycle as the lighter nuclide of water (H_2O) diffuses more readily than the heavier nuclides (HDO, $H_2{}^{18}O$), whereas the heavier nuclides more readily condense. The process of evaporation is fundamentally unique from transpiration, in that diffusion is the dominant process during evaporation, producing vapor with a distinctly lighter isotopic value relative to transpired vapor. Thus, stable water isotopologues can be used to separate and define the relative roles of surface transpiration and evaporation as well as investigate processes such as sub-cloud rain evaporation, which may influence boundary layer humidity and convection.

Our research objective is to evaluate the contribution of transpiration, soil evaporation, and rain evaporation to boundary layer humidity and establish how these variables influence cloud and convection properties in the La Plata River Basin, where recycled moisture dominates the precipitation budget. Here, intense convection, high variability in evapotranspiration and strong soil moisture-evapotranspiration coupling hint at a strong influence of surface hydrology on boundary layer humidity and precipitation characteristics (timing, intensity, location), but their respective roles have not yet been clearly defined with in-situ observations. Stable isotopic measurements in vapor, precipitation, soil and plant water, to be taken at in conjunction with atmospheric, radiation, and soil measurements during the RELAMPAGO and CACTI field campaigns, will allow us to isotopically derive the transpiration and evaporation fractions of humidity and investigate the role of post-condensation process of rain evaporation in controlling precipitation and humidity.

The proposed research approach is multi-scale, as we plan to assess water isotope variability, transpiration, and surface and rain evaporation, and their subsequent relationship with convection and cloud properties on event, diurnal, synoptic, intraseasonal and seasonal timescales over the course of the investigation. We plan to install a field-deployable laser spectrometer (Picarro L2140-*i*) to measure in-situ water vapor isotopic values at several heights on flux tower installed in the town of San Francisco as part of the RELAMPAGO campaign. We will collect daily samples of precipitation and biweekly samples of soil and vegetation for stable isotopic analysis throughout the investigation. We will also sample more frequently—precipitation through individual events, and soil and plant waters at multiple times throughout the day—during the planned RELAMPAGO intensive observation period in November- December 2018. Soil and plant waters will be extracted and measured, along with precipitation, on a Picarro L2140-*i* in the PI's lab at Illinois.

Using the isotope-enabled Community Land Model (iCLM4) forced with site data, we will calculate optimal aerodynamic resistance factors and diffusion factors to achieve model-data agreement of the transpiration and evaporation fractions, an exercise that will benefit investigations of evapotranspiration in the La Plata River Basin and other sites across the globe. We will then couple iCLM4 to the isotope- enabled Community Atmosphere Model (iCAM5) to investigate the relationship between evaporation, transpiration, and atmospheric moisture variables in the La Plata River Basin. The results of this research will demonstrate the full potential of water isotopes as tracers of moisture flux between the land and atmosphere, which will benefit the growing community of scientists using this important tool.

Proposal Title: Studying Lightning Initiation

PI: Wiebke Deierling, University of Colorado Boulder
Anticipated Sponsor: NSF funds (Lightning Nowcasting and Thunderstorm Electrification of Hail Producing Storms)
Duration and start date: 3 years, 01/01/18

Estimated Budget per Year: $125K

Previous studies show that the severe storms targeted with RELAMPAGO produce significant amounts of lightning. We propose to document the evolution of lightning in these storms, based on existing ground based lightning detection networks and if available measurements from Lightning Mapping Arrays (LMA's) by NASA and Brazil. We propose to deploy a set of ground based field mills around NCAR's SPOLKa radar – possibly augmented by field mills from other groups – to measure properties of electric fields in these storms. In combination with other existing as well as proposed ground based lightning observing systems and ground based radars, including SPOLKa, the microphysical and dynamical structure of these storms can be investigated and related to the electrical characteristics.

Thunderstorms and lightning pose a serious safety risk to people working or pursuing recreational activities outdoors, and they also present a potential hazard to infrastructure and equipment used outdoors. Every year numerous people are injured or killed by lightning (López et al., 1995; Tan and Goh, 2003; Holle et al., 2005). The first goal herein is to study the evolution of electrical properties of storms, investigating the onset and cessation as well as intensity of lightning and its predictability. A lightning nowcasting system has been developed by Deierling et al. (2014) that monitors relevant storm information such as intensity, organization, and motion. It builds on a fuzzy-logic approach and combines radar derived storm characteristics to produce a lightning nowcast. Dual-polarimetric SPOLKa and other radar data in conjunction with electric field mill data and ground based cloud to ground lightning data from existing lightning detection networks will be used to investigate if prediction of lightning intensity increases and improved prediction of lightning initiation and cessation can be made.

RELAMPAGO targeted hailstorms likely contain abundant liquid water. These types of storms can often exhibit anomalous charge structures (Bruning et al. 2010, Emersic et al. 2011) and increased positive cloud-to-ground lightning discharges as previously observed in High Plains hailstorms (Carey and Rutledge 1998; Carey et al. 2007). Past studies have shown that a strong updraft within the mixed phase region of deep convection plays a major role in thunderstorm electrification resulting in lightning (Dye et al. 1989, Zipser and Lutz 1994, Deierling et al. 2008). It is thought that significant charging occurs through the collisions of mixed phase hydrometeors (such as graupel and ice crystals) particularly in the presence of supercooled liquid water (Takahashi and Miyawaki 2002, Saunders 2008). The amount and sign of charging depends on various factors including temperature and liquid water in the cloud. However it is unclear, if charging occurs under wet-growth conditions associated with hail production. Combining measurements from the ground based field mill network(s) and three-dimensional lightning information from LMA's, we propose to infer the location, polarity and amount of charge of these storms. We propose to estimate microphysical (presence of hail, liquid water content etc.) and dynamical storm information from dual-polarimetric, dual-wavelength and dual-Doppler radar measurements. From these measurements we plan to investigate the evolution of hail production, charge structure, amount of charge and lightning characteristics. The goals are to improve the understanding of the impact wet hail growth has on storm electrification and to determine if electrification characteristics can be used to indicate large hail production.

Proposal Title: Land Surface controls on heavy precipitation and flooding in the Carcarañá River Basin
PI: Francina Dominguez, David Gochis, Eleonora Demaria, Kirsten Rasmussen **Anticipated Sponsor:** NSF
Duration and start date: 3 years, Oct, 2016
Estimated Budget per Year: $130K

Located in central Argentina, in the southern La Plata River basin, the Carcarañá River drains a region that is ideally suited to perform observational/modeling hydrometeorological studies (Figure 1). The headwaters of the basin, in the foothills of the Sierras de Cordoba, experience the world's deepest convective storms (Zipser et al. 2006; Rasmussen et al. 2014). The Carcarañá basin, is greatly affected by hailstorms and rapid- rise flash floods (Rasmussen et al. 2014). Compared to the Great Plains of the United States, convection-organization and propagation in subtropical South America is confined to a much smaller region – which causes the Carcarañá river basin to be continuously affected by these severe storms, confines the spatial extent of the observational studies and increases the probability of capturing extreme events during a field campaign.

The overarching science question of this proposal is**: "What is the role of land surface in modulating the observed variability of heavy precipitation and flooding in the Carcarañá River Basin"**. We will address this overarching question with two subsidiary questions:
1. How does land cover heterogeneity (including human-modified land cover) impact convective precipitation at the local and meso-scale through land-atmosphere exchanges of moisture and energy?
2. How have changes in land cover affected the hydraulic conductivity and residence times of moisture in the terrestrial system within the Carcarana Basin?

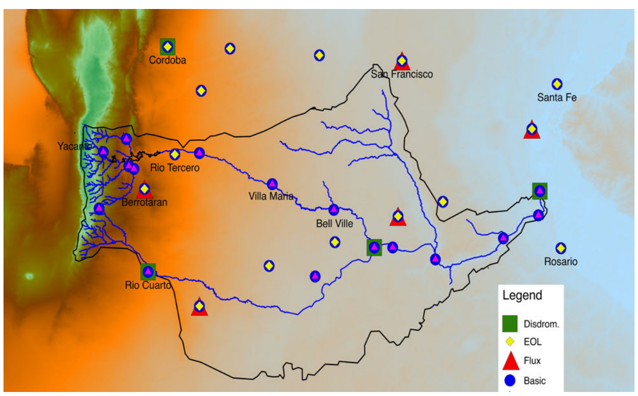


Figure 1 Location of Proposed Observations for the Flux Towers (red triangle), Disdrometers (green squares) and soil moisture/temperature sensors (yellow diamonds) and rain gauges (blue circles).

The tools we will use are: a) Existing local observations of precipitation, water table depths and streamflow, b) Proposed observations of precipitation, streamflow, groundwater, soil moisture, temperature and surface fluxes during the RELAMPAGO field campaign, c) Numerical simulations using the WRF-hydro model both in offline mode and coupled mode. The NCAR Earth Observing Laboratory (NCAR-EOL) via the RELAMPAGO proposal (under revision) and the NCAR Research Applications Laboratory (NCAR-RAL) will provide the instrumentation. In particular, the instruments we intend to deploy during RELAMPAGO include: 5 Flux towers, 31 basic meteorological stations (precipitation, temperature, relative humidity, soil moisture, incoming shortwave), 16 water depth and river stage stations, 5 disdrometers and 1 acoustic Doppler current profiler.

Rasmussen, K. L., M. D. Zuluaga, and R. A. Houze, 2014: Severe convection and lightning in subtropical South America. 1–8, doi:10.1002/(ISSN)1944-8007.
Zipser, E. J., C. Liu, D. J. Cecil, S. W. Nesbitt, and D. P. Yorty, 2006: Where are the most intense thunderstorms on Earth? Bull. Amer. Meteor. Soc, 87, 1057–1071, doi:10.1175/BAMS-87-8-1057.

Proposal Title: Contrasts in thunderstorm initiation and evolution in complex terrain between the lee of the Andes and Sierras de Cordoba Mountains and the lee of the Rocky Mountains PIs: Rita Roberts and Jim Wilson, NCAR Anticipated sponsor: undetermined
Duration and start date: 2 years, 10/1/2018 Estimated budget per year: $300,000

It is well known that some of the world's most intense thunderstorms occur in the lee of the Andes and Sierras de Cordoba (SDC) Mountains in Argentina, particularly in the vicinity of Mendoza and Cordoba urban regions; these major cities are located about 400 km apart. The RELAMPAGO field program will focus observations in these two regions. GOES satellite and limited Argentina radar data suggests the initiation and evolution of thunderstorms storms in these two areas may be different. One factor could be that the South American Low Level Jet (SALLJ) plays a more prominent role in the rapidly intensifying convection near Cordoba, while semi-stationary convergence lines and elevated gravity waves off the Andes may play more of a role in triggering the deep, hail-producing convection in Mendoza during late afternoon/evening. We propose to study the storm initiation and evolution between these two regions, and compare results with the well-documented processes of storm initiation and evolution in the lee of the Colorado Rocky Mountains.

Scientific questions:

1. What mechanisms are responsible for the initiation and evolution of intense convective storms in the lee of the Andes and the SDC?
    a. What is the role of thunderstorm outflows (originating from storms over the Andes and the adjacent plains) in the initiation and organization of convection?
    b. What is the role of pre-existing convergence line (such as dry lines, fronts and terrain induced convergence lines) over the Plains in storm initiation and evolution?
    c. What mesoscale low-level wind features, including the low level jet, impact the timing, development and intensification of local, severe storms?

2. What is the frequency and forcing mechanisms for elevated nighttime thunderstorms versus daytime near-surface triggered thunderstorms? How do these compare to elevated convection initiation events observed during the 2015 PECAN experiment?

3. What are the similarities and differences between severe storm evolution in Argentina and the U.S. Great Plains?

Instrumentation/Tools

S-Pol and the DoWs along with the Argentina operational radars will be key instruments for observing storm evolution and detecting clear-air convergence lines that are instrumental in storm initiation and evolution. S-Pol radar is especially desirable for its high sensitivity, uniquely accurate polarimetric measurements, ability to detect gravity waves from Bragg scattering, and ability to estimate low level moisture fields based on radar refractivity. In addition high density surface stations, soundings and high frequency GOES-R satellite imagery are required. Continuous vertical profiling of the atmosphere will be important for observing changes in atmospheric stability and other elevated processes.

Proposal Title: Nowcasting high impact convective storms during RELAMPAGO

PIs: Rita Roberts and Jim Wilson, NCAR Anticipated sponsor: undetermined Duration and start date: 2 years, 10/1/2018 Estimated budget per year: $150,000

Nowcasting Demonstration

Thunderstorms producing large hail, high winds, heavy rain and flash floods occur with unusually high frequency in the area of the RELAMPAGO field program. Presently the ability to provide warnings of such severe weather events with sufficient accuracy, that will motivate people to take action to save lives and property, is possible only in the 0-1 h time period. Nowcasts of severe weather on this time scale are presently only possible with the availability of high resolution observations and using heuristic nowcasting techniques. Providing severe weather nowcasts > 1 h requires a blending of observations with heuristic and Numerical Weather Prediction techniques. It also requires scientific understanding and conceptual models of storm evolution under various synoptic and mesoscale weather regimes.

The increased observations collected over the RELAMPAGO field observation area will provide the opportunity to a) document a number of severe weather events under different weather regimes, b) revise existing forecaster conceptual models for severe storm evolution, c) test existing severe storm, heuristic nowcasting techniques and d) test blending techniques. The Argentina National Meteorological Service (SMN) has obtained approval from the WMO Nowcasting and Mesoscale Weather Forecasting Group to conduct a Forecast Demonstration Project (FDP) for RELAMPAGO. This FDP provides the opportunity for international forecasters and researchers to test a variety of nowcasting concepts and systems and will include the nowcasting of severe convective weather. An important part of the WMO- sponsored FDP is the transfer of technology and scientific understanding to not only the Argentina weather service forecasters but to other weather service forecasters particularly from South America participating in the demonstration.

We propose to participate in the Argentina FDP conducted during RELAMPAGO, utilizing the RELAMPAGO observations and the heuristic nowcasting methods that we have developed and tested in several locations around the world.

Instrumentation

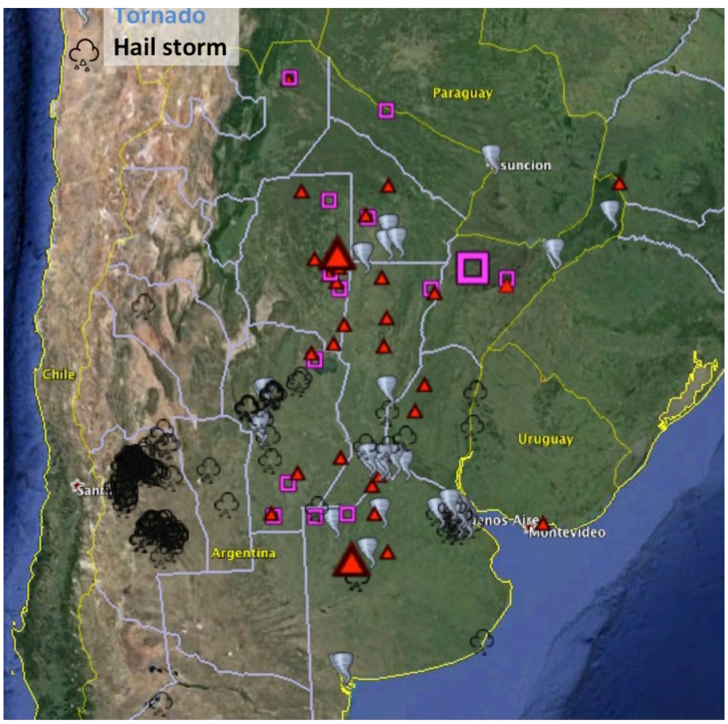
Particularly important for nowcasting severe weather is availability of high density and high frequency observations. The NSF deployment pool radars (S-Pol and 3 DoWs) would be a cornerstone of the increased dense network of observations. S-Pol would be particularly useful in determining limitations the recently-installed, Argentina national network of C-band radars may have in estimating heavy rainfall and nowcasting storm severity. The proposed, numerous RELAMPAGO soundings, increased surface stations, lightning detection array, vertical profiling systems and GOES-R satellite imagery would round out an excellent data set for testing nowcasting techniques.

Proposal Title: Probing Intense Convection Seen By Satellite in Northern Argentina

PI: Daniel J. Cecil, NASA Marshall Space Flight Center
Anticipated Sponsor: NASA
Duration and start date: -
Estimated Budget per Year: no funds requested from NSF

Several studies relying on satellite data highlight Northern Argentina as having some of the strongest, if not *the* strongest, thunderstorms detected anywhere on earth. The lowest brightness temperatures measured by passive microwave imagers often occur in storms there, as well as the tallest towers of high radar reflectivity (> 40 dBZ) measured by spaceborne precipitation radars. Convective systems from this region account for the highest per-storm lightning flash rates in spaceborne lightning sensor data. Some mesoscale convective systems there produce over 1000 flashes per minute. Reports of severe thunderstorms and tornadoes can be found from traditional and social media sources in the region, but the lack of systematic reporting prevents a full comparison with other hotbeds of severe weather.

Measurements obtained in RELAMPAGO will provide valuable information for understanding the temporal evolution, spatial structure, and morphology of the intense thunderstorms in this region.



Map comparing locations of the strongest storms seen over several years of records from multiple satellites' passive microwave imagers (from Cecil 2014), and newspaper reports of tornadoes and hail compiled by Rasmussen et al. 2014.

Ground-based radars will help distinguish between squall lines, supercells, and lines of supercells. Dual-Doppler and dual-polarization radar information will help characterize the dynamics and microphysics of these thunderstorms. It will also better indicate the likelihood of severe weather impacts at the ground, which can only be roughly inferred from satellite imagery. Lightning mapping array data may be used to evaluate the broader applicability of relationships developed between lightning and severe weather in the United States.

Learning how to better interpret satellite imagery is a particular focus for this PI, as it aids NASA interests in studying earth from space. That is done more effectively by leveraging high quality ground-based information, such as those proposed for RELAMPAGO.

References:

Cecil, D.J., 2015: Extremely low passive microwave brightness temperatures due to thunderstorms. 20th Conf. on Sat. Meteor. Ocean., Amer. Meteor. Soc., Phoenix, AZ.

Rasmussen, K.L., M.D. Zuluaga, and R.A. Houze, Jr. 2014: Severe convection and lightning in subtropical South America. Geophys. Res. Lett., doi 10.1002/2014GL061767.

RELAMPAGO Section J

Proposal Title: Understanding superlative lightning in intense South American mesoscale convective systems using the GOES-R Geostationary Lightning Mapper (GLM)

PI: Timothy J. Lang, NASA Marshall Space Flight Center
Anticipated Sponsor: NOAA GOES-R Program
Duration and start date: 3 years, 11/01/17

Estimated Budget per Year: $150K

Mesoscale convective systems (MCSs) often produce very large lightning flash rates (greater than a flash per second), and can also produce very long duration (>> 1 second) and large area (> 1000 km^2) lightning flashes that propagate through their stratiform precipitation regions. If a stratiform lightning flash produces a leader that reaches the ground, the resultant return stroke can be extremely powerful, and can cause a sprite or elve to occur in the upper atmosphere.

A single large, long-lived stratiform flash can produce multiple cloud-to-ground (CG) strokes over a distance spanning 100s of km. Often these CGs can occur in regions where the lightning threat is incorrectly perceived to be low due to the lack of strong convection in the area. Moreover, simply using a very low frequency (VLF) or low frequency (LF) CG detection network (e.g., Brazil's Sferics Timing And Ranging NETwork or STARNET, which provides coverage in Argentina) will not provide the in- cloud context that links seemingly separate ground strike points to a single superlative lightning flash.

The forthcoming GOES-R series satellites (launching 2016 and 2017) will each feature the Geostationary Lightning Mapper (GLM). This optical instrument will detect lightning flashes continuously from space, with a near-nadir resolution of 8 km. How well this instrument will map large, long-lived lightning in MCSs is not well understood, and the RELAMPAGO field campaign in Argentina is an excellent opportunity to validate the capabilities of GLM in mapping superlative lightning from space.

We plan to solicit funding from NOAA for a 3D lightning mapping array (LMA) to be placed near the heart of the RELAMPAGO domain in Cordoba state. This LMA will capture the initiation of intense convection and follow it through its upscale development into a nascent MCS. In addition, a second LMA is being proposed to Brazilian agencies (PI Rachel Albrecht, University of Sao Paulo), which will be placed near the Argentina/Brazil border, capturing the mature phases of the MCSs. These LMAs will provide crucial 3D, high resolution, in-cloud observations that can help us understand what processes GLM observes when these superlative stratiform flashes occur. In addition, the LMAs can map the frequent convective line lightning in MCSs, especially resolving the frequent small flashes (i.e., smaller than the GLM footprint) that occur in intense convection.

To summarize our objectives, using these LMAs, we will 1) Provide needed validation for GLM observations of MCS lightning (as discussed above); 2) Study the circumstances under which a convective-initiated flash will remain within convection vs. traveling into the stratiform region, and determining the flash behavior that is most conducive to the occurrence of multiple CG strike points far from convection; 3) Understand the MCS characteristics (e.g., kinematic and microphysical structures) that are associated with the occurrence of superlative lightning - for example, to help quantify the relative roles of charge advection vs. in situ charging in facilitating MCS stratiform lightning.

The RELAMPAGO field campaign, with intensive observations from a mixture of polarimetric and Doppler radars, along with environmental soundings and many other instruments, provides a unique leveraging opportunity to maximize the scientific return of an LMA deployment in support of GLM. In particular, the two planned LMAs will provide both early- and late-lifetime observations of the same MCS, while RELAMPAGO radars can be leveraged to provide 3D storm winds via multi-Doppler synthesis. These are unique capabilities that would not be available in the United States.

RELAMPAGO Section J

Proposal Title: Processes causing errors in deep convective initiation and upscale growth in high-resolution models

PIs: Adam Varble and Edward Zipser, University of Utah
Anticipated Sponsor: NSF
Duration and start date: 3 years, 06/01/19

Estimated Budget per Year: $130K

Incorrectly predicting deep convective initiation and upscale growth of deep convective systems as a function of environmental conditions leads to significant biases in weather and climate models (e.g., significant warm and dry biases) for regions dominated by organized deep convective systems such as the US Great Plains and central Argentina. High-resolution models should improve prediction of deep convective initiation and upscale growth, but also struggle to reproduce observations in many cases. This can result from a number of factors including but not limited to large-scale environmental biases, unresolved circulations, and sub-grid physics parameterization biases (e.g., microphysics, turbulent mixing, surface fluxes).

We will employ RELAMPAGO and CACTI observations to identify processes responsible for different timing and locations of convective initiation in observations and Weather Research and Forecasting (WRF) simulations. Additionally, we will identify processes responsible for different timing and locations of convective upscale growth (i.e., intensification and mesoscale organization). Convective evolution responds to the local environmental state including distributions of stability, winds, and convergence, and cloud processes including entrainment/detrainment, ice initiation, precipitation initiation, and cold pool production. Therefore, all of these factors will be analyzed in observations and model output along with processes such as synoptic and mesoscale circulations, surface fluxes, boundary layer mixing, advection of heat and moisture, and cloud detrainment that alter the environmental state on sub-daily timescales with the ultimate goals of identifying shortcomings in high-resolution models and improving model prediction.

We will run WRF as a regional climate model at 3-km horizontal grid spacing over a region covering Mendoza, the Sierras de Córdoba, and downstream of the Sierras de Córdoba for the 2018-19 warm season. This will allow analysis of model errors on timescales greater than 1 day and generate many convective system cases so that individual case studies from RELAMPAGO can be put into proper context. We will also run case studies from RELAMPAGO with 1-km horizontal grid spacing and nests down to 100 m over mountainous terrain where convective initiation is expected. Analysis of model errors on sub-daily timescales will be a focus for these case studies and sensitivities of convective initiation and upscale growth to resolved complex terrain, microphysics schemes (impacting aerosols, ice, precipitation, and cold pools), surface schemes, and turbulent mixing will examined.

A wide range of instruments and measurements will be needed to achieve our objectives. Synoptic and mesoscale environmental evolution will be measured by the RELAMPAGO sounding network, mesonets, and surface flux/soil moisture network. Additional CACTI soundings, G-1 aircraft environmental and cloud measurements, and localized measurements of surface heat and radiative fluxes, aerosol properties, wind profiles, and boundary layer structure over the Sierras de Cordoba will also be crucial to characterizing environmental evolution. Multi-frequency W- to S-band radar measurements from combined CACTI and RELAMPAGO resources coupled with rain gauge and disdrometer observations will provide essential data on cloud and precipitation evolution during convective initiation and upscale growth situations. Combined environmental and cloud/precipitation measurements during RELAMPAGO will provide an unprecedented, comprehensive dataset in a region with little data for evaluating and improving model prediction of deep convective systems.

RELAMPAGO

PIs: Jeff Trapp, Deanna Hence, Jim Marquis, Josh Wurman, Karen Kosiba, and Matt Kumjian **Anticipated Start Date:** 1 November 2017
Funding Agency: NSF
Anticipated Funding Amount: $2.2M

Summary: The satellite-based characterization of Argentinian thunderstorms as the tallest in the world (see Zipser et al. 2006, *BAMS*) serves as a key motivation for RELAMPAGO, the proposed field campaign to be conducted in Argentina in 2017. The extreme height of these storms implies a uniqueness to their convective structure and intensity, and perhaps in their ability to generate convective weather extremes. In addition to our desire to collect novel observations towards a process-level understanding of such convective structure and intensity, we will use multiple- frequency polarimetric radars and in-situ data to verify or refute the satellite-based assessment that these storms are among the most prolific hail producers in the world.

The convective structure and intensity appear to be related to the mechanisms of convection initiation (CI), which in turn have a strong link to the unique physical geography of the La Plata Basin. One of our hypotheses is that the orographically induced CI that results in the largest-diameter initial updrafts will ultimately be associated with the deepest and most intense updrafts, and by extension, the most intense downdrafts and cold pools. We propose to compare and contrast the mechanisms of convection initiation, storm morphology, and associated weather hazards using an integrated, targetable observation network. These will also help address the indication, based on limited surface observations, that storm structure differs from the Mendoza Province eastward to the Sierra de Cordoba, with severe weather possible/likely from a variety of types of convective morphology.

From the mobile, multi-platform observations, we will quantify storm kinematics, microphysics, and environmental conditions that trigger and sustain severe convection in these two different regions. Furthermore, high-resolution data assimilation experiments will supplement direct observations to fill in data gaps and to identify what observations (location and frequency) are critical for numerical weather forecasts for severe and hazardous weather in this region.

Key Foci:
- Characterize general flow in region
- Identify and understand the relative importance of CI triggering mechanisms, such as terrain effects, surface boundaries, and mountain waves, on storm morphology and intensity
- Develop an integrated understanding of storm-scale, mesoscale, and microscale dynamics and processes from initiation through upscale growth
- Identify, characterize, and quantify severe weather hazards for different convective morphologies
- Comparing/contrasting convection in the different Argentinian regions and analogous regions in the United States
- Determining which observation types are critical to improve forecasts of severe weather threats in the region

Key Instruments:
- 3 Doppler on Wheels (DOWs) mobile radars: 3D convective airflow, vertical storm structure
- Dual-pol DOWs and S-POL: Hydrometeor type and inferred microphysics
- Mesonets: Targeted transects of surface boundaries
- Portable weather stations (Pods): Targeted mesoscale network of surface observations
- Disdrometers: Classification of precipitation characteristics at the ground, verification of dual-pol observations
- Mobile radiosonde systems: environmental thermodynamics and wind shear

Proposal Title: Retrievals of Cloud Vertical Evolution

PI: V. Chandrasekar, Colorado State University
Anticipated Sponsor: NSF
Duration and start date: 3 years, 01/01/17

Estimated Budget per Year: $135 K

As mentioned in the RELAMPAGO overview document, it is very rare to find systematic observation of the life cycle of convective systems and high-impact weather in regions of complex terrain, especially with modern observing systems such as dual-polarization weather radar with full spectral capability. Complex terrain plays a fundamental role in driving portions of the earth's hydrologic cycle and climate, and provides a first order control on the life cycle of weather systems in their proximity. Insufficient understanding of convective processes near complex terrain yields poor predictability of convective systems that strongly affect regional climate and severe weather hazards in regions affected by continental convective systems. This lack of predictability arises from incomplete understanding of the combination of factors that dictate the initiation, organization and growth to maturity, and decay stages of convective systems. The impact of specific system characteristics is felt in potential severe weather (hail, strong winds, and tornadoes, flooding), atmospheric electrification, and the spatiotemporal distribution of precipitation. The major goal of this proposal is to document the vertical evolution (from cloud base to anvil) of the cloud microstructure in growing convective cloud elements, under various thermodynamic conditions using radar observations. More recently the hydrometeor classification capability of radars have advanced significantly to the point they can be used for both vertical profiling and time evolution both. In addition to simple hydrometeor classification, microphysical retrievals have also been advanced to DSD estimation from both parametric retrievals from dual-polarization techniques, and non-parametric techniques such as spectra based retrievals. These techniques can be combined to retrieve the following microphysical quantities namely:

a) Cloud base drop size distribution
b) The evolution of DSD with height
c) The cloud life cycle from the DSD, liquid and ice content and the mixed phase.
d) Retrieval of vertical distribution of warm rain and transition to super cooled state and freezing.
e) Rainout of warm rain before freezing
f) DSD evolution
g) Radar based documentation of freezing rain drops and riming of ice crystals.
h) Radar based detection of aggregates in convective clouds?
i) Observation of cloud electrification through polarimetric radar
j) Hydrometeor growth in anvil.

The main goal of this proposal is to develop comprehensive retrieval system , putting to work, lot of the cutting edge techniques developed and tested individually in the literature over the last couple of decades, with the main goal of radar based vertical profile evolution to specially address all the topics listed above. All these time-resolved vertical profile microphysical retrievals will be used to support the following basic science questions namely, Convective initiation in complex terrain and Intensification of convection. These retrievals will be used not only for time resolved remote microphysical retrievals, but also, model validation purposes.

RELAMPAGO Section J

Proposal Title: GRAVITY WAVE FORCING OF NOCTURNAL CONVECTION

PI: Robert M. Rauber, Greg M. McFarquhar and Brian F. Jewett
Anticipated Sponsor: NSF
Duration and start date: 3 years,

Estimated Budget per Year: $273,000

The authors were Principal Investigators in the Plains Elevated Convection At Night experiment (PECAN) in the Great Plains of the United States during the summer of 2015. Our current NSF funding for analysis of the PECAN data ends at the end of November 2017. We plan to submit a renewal proposal to continue the analysis of the PECAN data and to participate in, and analyze data from RELAMPAGO. The RELAMPAGO field campaign provides an unanticipated scientific opportunity for us to both expand the database related to the triggering and maintenance of nocturnal convection, and to understand how microphysically-driven gravity wave forcing differs in an environment influenced more strongly by orography. For RELAMPAGO, we will propose to use the SPOL and DOW radar data, particularly the polarization data and Doppler derived winds, along with complementary high-resolution numerical modeling studies with the Weather Research and Forecasting (WRF) model to test and refine our overarching hypothesis that **microphysical cooling processes in developing and mature stratiform regions of mesoscale convective systems (MCSs) force downdraft circulations that create mesoscale gravity waves and bores on the stable nocturnal boundary layer (SNBL) that subsequently focus, organize and maintain future convective activity**.

We will do the following to test this hypothesis: 1) characterize the microphysical and thermodynamic structure of the transition zone, notch region and rear anvil region in formative, mature and dissipative stages of RELAMPAGO MCSs by analyzing polarization radar signatures and radar reflectivity structure in context of the MCS kinematic structure derived from the radar and profiler measurements; 2) combine our data analyses with modeling studies to quantify how microphysical processes vary across MCSs during their lifecycles, assess their contributions to latent cooling and heating, and in turn understand how latent cooling impacts updraft and downdraft circulations, bores and gravity waves on the SNBL, and the rear inflow jet; and 3) determine how gravity waves give rise to lifting, and hence drive convection and subsequent generation of supercooled water and ice, and therefore maintain and organize nocturnal MCSs. We have unique collocated airborne microphysical and radar data from PECAN that we will use to interpret the polarization signatures observed in MCSs during RELAMPAGO. Our complementary WRF simulations will play a critical role in quantifying and understanding how and to what degree microphysical processes explain the observed evolution of the relative humidity and downdraft structures within the trailing stratiform region of the RELAMPAGO MCSs, and the roles of latent cooling processes in wave generation and convective triggering.

Role in RELAMPAGO: Our proposed work contributes directly to the second goal of RELAMPAGO, understanding the mechanisms of intensification and upscale growth of convection, particularly as the convection evolves to elevated convection following the transition from daytime to nighttime. Our work will contribute to identifying the dynamic, thermodynamic, and microphysical processes by which convection intensifies, and is maintained in the vicinity of terrain, and will allow us to contrast these mechanisms with those on the Great Plains of the United States.

Approximate budget: The PIs will request support from NSF to continue PECAN work, participate in RELAMPAGO and for subsequent scientific investigations. Costs are estimated as follows: personnel costs (1 month McFarquhar, Rauber, 3 months Jewett) $48k/year; 2 grad students ~$52k/year; benefits ~$22k/year; tuition remission ~$33k/year; indirect costs ~$98k/year; publications ~$3k/year, and travel ~$4.5k/year with an extra ~$44k in the first year for participation in the field. Adding miscellaneous expenses, the total budget submitted to NSF (start date 12/1/17) would be ~$825k for 3 years.

RELAMPAGO Section J

Co-PIs: Steve Nesbitt (University of Illinois) and Russ Schumacher (Colorado State University) **Collaborator:** Paola Salio (University of Buenos Aires, Argentina)
Anticipated start date: 1 November 2017 **Funding**
Agency: NSF
Anticipated funding Amount: $750K

Summary: In this proposal, we seek to understand and characterize the interplay of thermodynamic, microphysical, and dynamic processes in contributing to heavy precipitation in convective systems. Recent studies (e.g.,) have explored the convective spectrum to quantify the structures of convective systems that provide for extreme rain rates that are known to contribute to flooding, in particular in warm season Southeast South America. Convective storms in the regions near the Sierras de Cordoba and Mendoza, which will be well characterized during RELAMPAGO-CACTI are known to produce severe flash flooding (Rasmussen et al. 2014), and be among the most vertically intense in the world (e.g. Zipser et al. 2006). Fundamental questions arising from these observations are: *are the storms that produce extreme instantaneous precipitation rates (e.g., > 75 mm/hr) in SESA the same class of storms that produce extremely tall convection with strong, deep updrafts dominated by efficient Bergeron-Findeisen ice processes (e.g. Smith et al. 19XX), or are they more "low echo centroid" storms where warm rain precipitation efficiency is dominant (e.g., Petersen et al. 1999)? In low echo centroid storms, is ample moisture and microphysical factors such as high collision and coalescence efficiency alone enough to explain the generation of intense rain rates, or does some combination of stability (CAPE/CIN), low-level shear, or cold pool lifting also lead to strong low level updrafts capable of providing for heavy precipitation? How does convective life cycle, mode (supercell vs. Mesoscale Convective System), and storm environment (instability and shear) influence the relative importance of these processes? Are cases observed during RELAMPAGO similar in this way to historically observed storms in the US, which have different environments?*

We will use the detailed precipitation and hydrometeor structure, thermodynamic, kinematic, and observations collected in RELAMPAGO, as well as high-resolution model simulations constrained and evaluated through RELAMPAGO observations to address these scientific questions. Given the high frequency of convective storms across a spectrum of system morphologies in the RELAMPAGO domain, we expect to have many cases to evaluate our hypotheses, as well as leverage data from related field campaigns (e.g., PECAN). Our objectives of the proposal, across a variety of observed storm types, cases, and over system lifecycles, are to:

- Develop multi-wavelength quantitative precipitation estimates and microphysical retrievals using RELAMPAGO SPOLKa, Argentinian and DOE CACTI C-Band, DOW and Brazilian X-Band radars
- Use multi-wavelength hydrometeor identification to determine relative roles of collision coalescence versus ice phase precipitation, to identify dominant microphysical processes as a function of the morphology of convective systems, and to observe the co-evolution of precipitation characteristics during upscale growth of convective storms
- Use kinematic information from multi-Doppler analyses to constrain vertical motion profiles relative to observed radar and microphysical structures to understand feedbacks among updraft properties as a function of height, temperature, moisture, and shear (as observed from fixed and mobile soundings), and feedbacks on morphology (i.e., updraft forcing from non-linear dynamic effects vs. local cold pool generation vs. gravity waves/bores)
- Determine the roles of terrain forcing on modulating the growth timescales, spatial variations, and intensities of convective processes that lead to heavy precipitation rates through modulating the above mechanisms using observations and model simulations

RELAMPAGO Section J

Proposal Title: Environmental controls of the electrification processes over South American Mesoscale Convective Systems

PI: Rachel I. Albrecht and Carlos A. Morales – University of São Paulo Anticipated Sponsor:
FAPESP, CNPq

Duration and start date: 3 years, 11/01/17 Estimated

Budget per Year: $90K.

Cloud electrification in thunderstorms is tightly controlled by cloud updraft strength and the formation of precipitation in the mixed phase region. The updraft strength govern the number of ice particle collisions, and the amount of non-inductive charge transfer per collision depends on the relative difference between fall speeds(i.e., size) of graupeland ice particles, while the sign of the charging depends on temperature and the liquid water content (LWC)with a tendency for positive charging of graupel (rimer) in high LWC, based on most laboratory studies.This implies that cloud electrification has a strong connection with two major types of environmental controls: (i) the large-scale and thermodynamicalforcings (i.e., conditions that control and support the updraft strength, cloud base heights and warm cloud depth) and (ii) the cloud-aerosol-precipitation interactions (i.e., conditions that control cloud microphysics). Regarding South American Mesoscale Convective Systems (MCS), none of these aspects of environmental controls of cloud electrification have ever been addressed in the literature, although it is well established that this region holds the most intense storms on Earth in all aspects, including lightning activity, and is influenced by biomass burning pollution from local sources and transported from the Amazon.

Our objectives are 1) to identify and quantify the individual and combined roles of large-scale, mesoscale, local environmental (i.e., land cover, boundary layer, thermodynamics), and aerosol forcing in deep convection and MCS electrification; and 2)to characterize cloud charge centers (which indicate regions of robust mixed-phase microphysical processes) in space and time with aerosol type and concentration, hydrometeor type, mass content, temperature, and vertical velocity.

Essentially, we will take advantage of the RELAMPAGO field campaign proposed polarimetric and Doppler radars and environmental soundings to accomplish our objectives. Aerosol information will be provided by the Cloud, Aerosol, and Complex Terrain Interactions (CACTI) Experiment Proposal approved by DoE. To characterize the temporal evolution of charge centers and associated lightning activity we plan to apply for funding from Brazilian funding agencies (FAPESP, CNPq) for a collocated network of ground-based electric field mills (EFM) and 3D total (i.e., cloud-to-ground and intracloud) lightning mapping array (LMA) to be centeredat the Argentina/Brazil border, capturing the mature phases of the MCSs. The initiation of MCS will be captured by a LMA network placed near Cordoba, which being proposed by NOAA (PI Tim J. Lang, NASA Marshall Space Flight Center). Additionally, we plan to solicit funding to deploy a VLF/LF total lightning network (LINET – DLR/Nowcast) with a larger baseline (~100 km, 10 stations), centered between the two LMA networks and therefore cover the MCS life cycles from the initiation to maturation. University of Sao Paulo also runs the Sferics Timing And Ranging NETwork (STARNET) which provides cloud-to-ground lightning detection coverage in South America, with 60% detection efficiency on average in Argentina and South Brazil. Additional funding will be solicited for balloon-borne EFM soundings to better detail the vertical electrical fields inside the thunderstorms, and to deploy a storm-track trailer equipped with a K-band vertical pointing radar, ground-based EFM, disdrometer, and weather station.

RELAMPAGO Section J

Funding source: FaMAF-Universidad Nacional de Córdoba - IFEG-CONICET

The following activities are proposed during the campaign periods:

-Ground-level measurements of natural deposition ice nuclei.

- Ground-level measurements of the electric field.

- Ground-level measurements of the electric charge of precipitation particles.

-Real time detection of lightning and thunderstorm tracking by using Geo-Rayos with WWLLN data.

The team from the Atmospheric Physics Group of the University of Cordoba and CITEDEF-CEILAP is composed by the following researchers:
Eldo Ávila, M. Gabriela Nicora, Rodrigo Bürgesser, Rodolfo Pereyra, M. Laura López, Guillermo Aguirre Varela, Analía Pedernera.

Data assimilation at the convective scale during RELAMPAGO

Forecasting convection evolution and their associated phenomena is still a challenge. Improving our predictive skills over SESA convective systems, while mitigating their impacts, requires the combination of high-resolution observations with state-of-the art numerical modeling systems. This proposal aims to encourage the development of very short range (up to 12 hours) and short range (up to 72 hours) forecasts over South-Eastern South America as well as to advance in our general understanding of the challenges associated with forecasting in these time-scales.

There are many open questions about our ability to predict convection and how to improve our current level of skill. Some of these questions are tightly related to RELAMPAGO scientific questions about the dynamics of thunderstorms over central and Northern Argentina. A particularly critical issue is to explore the ability of different forecasting techniques in capturing convective initiation and how currently available observations provide information about the initiation processes. Another issue is related to the intrinsic predictability of convection and its relationship with large scale forcing and how this change in predictability affects the skill of the different approaches at different forecasting lead times. How can we anticipate changes in predictability from one situation to another?

There are also many issues related to modeling and data assimilation. Those include, but are not restricted to, the different ways to represent microphysical processes and small scale turbulence, how much resolution is required to adequately represent processes associated with convective initiation and evolution, which observations produce a more significant impact upon the accuracy of the initial conditions and the forecasts.

This proposal aims to evaluate the performance of high resolution ensembles and ensemble based data assimilation run at storm-scale implemented over South-Eastern South America. The data assimilation system is based on the WRF model and the local ensemble transform Kalman filter and is capable of assimilating reflectivity and radial velocity as well as conventional observations in order to obtain high resolution analysis at storm-scales. This system will be used to generate high resolution ensembles of analysis to initialize short range convective-scale ensemble forecasts (warm-start). A high resolution ensemble using WRF will also be evaluated using initial and boundary conditions provided by the Global Forecasting System (cold-start).

Before RELAMPAGO field campaign the warm-start and cold-start ensembles will be implemented and evaluated over a sample of cases characterized by the occurrence of deep moist convection over the area of interest. The cases will be selected during 2015-2016 using data from Cordoba radar site. Cases associated with different synoptic scale patterns as well as different mesoscale organization patterns will be selected in order to present a wide range of scenarios for training and forecasting tools evaluation.

During RELAMPAGO the cold-start and warm-start systems will be implemented over the area of interest of RELAMPAGO, using the data provided by the operational observation network in Argentina as well as the data provided by the field experiment. The performance of these two systems during the field campaign will be evaluated a posteriori using the observations from the field campaign.

In summary, RELAMPAGO campaign provides an unique opportunity to evaluate operational nowcasting applications based on data assimilation at convective scale in South America. This proposal pursues this objective to gain a better understanding of the performance of data assimilation at convective scale.

Researchers: Yanina García Skabar, Juan Ruiz, Manuel Pulido.

Phd Student: Cynthia Matsudo, Paula Maldonado, Maria Eugenia Dillon, Aldana Arruti. Assistant: Paula

Hobouchian

Research Projects presented in this research topics:

* Submitted in 2015: JICA SATREPS program
* Submitted in 2015 (in evaluation process): PICT Category V
* Granted: ALERTAR (Argentina), PIP2012 (CONICET Argentina), PICT 2014-1000 (AnPCyT Argentina), UBACYT 20020130100820BA (University of Buenos Aires, Argentina), PIDDEF 2014.

Soil - atmosphere interactions: flux measurements with the eddy covariance method and characterization of vegetation

The surface defined as the soil - vegetation subsystem, is the main region of heat and moisture exchange with the atmospheric boundary layer (ABL). Changes in the surface properties affect the temperature and evolution of moisture of the ABL through latent and sensible heat fluxes, depending on the properties of vegetation and soil. Because of this, the surface conditions may affect cloud formation, maintenance, and dissipation, considering the circulation associated with these changes. Surface is also the main source of aerosols which participate in the process of cloud formation. However, surface properties vary from daily to seasonal scales due to the inherent processes within the soil, the vegetation and the atmosphere as well as their complex interactions.
The processes that trigger precipitation of mesoscale convective systems still need better understanding, especially in regions that also tend to be the main inhabited or agricultural areas of the planet. It is clear then, that observations around the world are needed to understand the role of storms in the Earth system to improve their predictability considering its sensitivity to the presence of aerosols, the impact of surface characteristics and the conditions for formation of high impact weather events. Southeast South America presents a great complexity across different types of soil, vegetation and topography. Each of these ecosystems, have their own functional characteristics associated with the physical environment. The vegetation dynamics, with their seasonal variations and content of soil water dominated by the local hydrological characteristics are able to alter the mass and energy fluxes between the surface and the atmosphere. The aim of the proposed research group is to: determine the contribution of surface energy and mass fluxes to thunderstorm development in Southeast South America and, to study the dynamics of the small scale and its interaction with larger scales. These objectives require measuring fluxes with the eddy covariance method and the seasonal monitoring of vegetation through censuses on fixed sites and satellite monitoring. Concomitantly, monitoring the atmospheric content of airborne biological aerosols such as pollen, and the study of their long-distance transport with backward trajectories is also proposed. Numerical modeling also will be used to describe physical processes linking the small and larger scales in order to explain the surface energetic partition and its role in the development and evolution of storms.

Maria I. Gassmann and Gabriela Posse will be responsible for flux tower and soil water content measurements while María M. Bianchi, Claudio F. Pérez and Silvina Stutz will be in charge for monitoring vegetation phenology and airborne sampling of biological aerosols. Gabriela Posse and Carlos Di Bella will study the vegetation changes through satellite imagery. PhD students: Mauro Covi, Natalia Tonti, Lucia Curto and Nuria Lewczuk will participate in the fieldwork and data processing of flux and vegetation measurements. Ignacio Pisso will be in charge of the study and modeling of aerosol long distance trajectories, while Paola Salio will focus on the activity of the Low Level Jet (LLJ) in the study region. Juan Ruiz, María Gassmann and Natalia Tonti are going to perform simulations to study soil - atmosphere interactions within the small scale with Large Eddy Simulation models.

This group is part of the researcher staff of the grant ***"PICT-2015-1924 - Avances interdisciplinarios para la mitigación de los eventos meteorológicos de alto impacto"*** requested by Dr. Paola Salio to the National Agency for Scientific and Technological Promotion (ANPCYT - Argentina).

Collaboration of Centro de Informaciones Meteorológicas (CIM) at the Universidad Nacional del Litoral

Centro de Informaciones Meteorológicas (CIM) at the Universidad Nacional del Litoral (UNL, Santa Fe, Argentina) is an operational services unit whose objective is to generate knowledge and hydrometeorological technologies, transferring to the community weather information, hydrometric levels and hydrometeorological warnings. CIM operates systematically the weather station at the UNL campus, which is referential for the city of Santa Fe.

CIM´sa ctivities are related to processing and updating basic meteorological and hydrological data in a single database into Salado basin, with the following systems information:

- Temperature, humidity, atmospheric pressure, daily rainfall, cloudiness observation, windspeed
- and direction, soil temperature, radiation, and soil moisture (collected from measurement stations
- installed throughout the territory of the Santa Fe state belonging to different institutions and public agencies).
- Hydrometric Levels at surrounding rivers (Paraná river, Salado river, etc.).
- Historical records of precipitation, temperature and meteorological data from ex-railway stations and ex-government institutions.

Since its inception, the CIM has carried out highly specialized services, such as advice to the inspection monitoring networks of different basins within the territory of the Santa Fe state (Salado river, Ludueña and Saladillo streams and Carcarañá river), and it has also provided similar services in the extension to the Santiago del Estero state of the Salado river basin (Argentina, 2006 – 2015).

The staff is qualified to perform installation, operation, calibration, maintenance and repair of mechanical and electronic instruments of different hydrometeorological variables. It also develops Instruments at comparative low cost, applying new technologies to capture hydrometeorological information, and adapting existing measurement equipment.

Additionally Supports and advises to different government and educational institutions on normative of the World Meteorological Organization, installation and operation of meteorological instruments and the prevention of hydrometeorological phenomena.

Director: Dr. José L. Macor
Staff: Ignacio M. Cristina
Guillermo F. Contini
María del Valle Morresi
Esteban R. Elizalde Carrillo

Mesoscale circulations related to the orography and its relationship to deep convection, high resolution numerical modeling.

Knowing the orographic mechanisms that drive the initiation and intensification of deep convection is important for forecasting purposes.
Those mechanisms include forced lifting of flow upstream and downstream of moderate-height mountains, blocked flow, the formation of convergence areas within flow modified by orography, differential warming, and leeward waves. The underlying mechanisms of orographic convective triggering in the area around and over the Sierras de Cordoba and San Luis is the focus of the research.
The problem is addressed through high-resolution numerical simulations of some selected orogenic MCS cases with the emphasis in their onset phase. Non-hydrostatic convection resolving model WRF will be used in a nesting mode. Idealized high-resolution numerical experimentation will be performed to investigate the sensitivity of the orographically modified flow and the formation and propagation of deep convection to initial conditions (mainly thermal stability and ambient winds) and to the lower boundary condition imposed by the topography. Evolution of orogenic deep convection propagation over the plains will be analyzed in the context of mesoscale circulations over the plains and/or convective cold pools triggering effects.

Researchers: Matilde Nicolini, Yanina Garcia Skabar, Juan Ruiz, and Henrique Repinaldo Proyect:

20020130100820BA
Asimilación de datos a escala regional basada en el filtro de
Kalman por ensambles. Saulo Andrea Celeste

Physical Processes associated with development and maintenance of deep convection in Central Argentina

Much progress has been made in the understanding of large scale atmospheric conditions favorable for the development of deep moist convection using observational networks and reanalysis from GCMs.
However, the study of precursor mechanisms that trigger MCSs worldwide still remains a challenge. Multiple authors have demonstrated a strong interaction in the subtropical area between South Eastern South America MCSs and the presence of the South American Low Level Jet (SALLJ). SALLJ advects moisture and heat from tropical latitudes creating ideal environmental conditions for the formation of convection. Aerosols and land/surface interactions are other key environmental variables that impact the formation and development of deep convection.
This group seeks to observe the life cycle of convective systems in continental subtropical South America, from initiation to maturity, by addressing observational strategies in the region in order to advance in the understanding of the onset of convection.
RELAMPAGO and CACTI information will be an essential dataset to understand physical mechanisms associated with:

- the onset of convection in the presence of dry lines in the center of Argentina
- the impact of the conditions of land use and soil moisture in the central area of the Sierras de Cordoba
- the impact of topography on the development of mesoscale circulations associated with the initiation of convection
- interactions between local and regional physical and chemical processes that affect development convection focusing on the contribution from aerosols
- the interaction of the above with cloud microphysical processes

This group will actively participate in the field campaign leading activities of the National Weather Service under the Alert.ar project, launching radiosondes, participating in forecast activities at operational centers, among many others.

Researchers: Paola Salio - Yanina Garcia Skabar - Juan Ruiz - Luciano Vidal - Victoria Galligani Postdoc Diego Gimenez
PhD Students: Maria de los Milagros Alvarez Imaz - Maite Cancelada - Hernan Bechis - Student: Martin Rugna
Projects
PICT CAT V submitted 2015, Granted: ALERTAR (Argentina), PICT 2013-1299 (AnPCyT Argentina), UBACYT (University of Buenos Aires, Argentina).

RELAMPAGO Section J

Proposal Title: Improving Cloud Resolving Models Skill to Forecast MCC Rainfall, Propagation and Severity.
PI: Luiz A.T. Machado (INPE), Rachel Albrecht (USP), Edmilson Freitas (USP), Daniel Vila (INPE), Luiz Sapucci (INPE).
Anticipated Sponsor: FAPESP – Temático Project SOS_CHUVA
Duration and start date: 3 years, 01/01/17
Estimated Budget per Year: $20K first year (2017), $60K campaign (2018), $20K last year (2019).

The skill of numerical weather predictions models in the Relampago region is very low to forecast rainfall, propagation and severity. During the CHUVA SUL campaign, covering part of the Relampago region, a specific activity called ensemble prediction using high resolution limited area models was designed. The main goal of this activity was to evaluate of the prediction of high impact weather events in the La Plata Basin using multi models in high resolution. The multi-model ensemble was composed of a core of 5 models, which were integrated using the CPTEC's supercomputing facilities, plus four other models, which were integrated on the participating institutions facilities. The core of 5 models was envisaged to be consistent in domain size, horizontal and vertical resolution (2 km of grid space and 41 levels), and also in output variables. Partner institutions (WRF-UBA-UNNE, WRF-Argentina SMN, WRF-UFSM and MESO- NH (France - CNRS)) participating in the project assisted composing the multi-model with their own model configurations. The conclusion from this activity was that all models, configurations and procedures fails to forecast the rainfall in the next 24 hours and to assign severity and propagation direction. Our primary objective is to improve the skill of cloud resolving models through the following activities: a) Evaluate the Boundary layer interaction with the Low level Jet and the cloud entrainment; b) The MCC life cycle evolution of the microphysical processes; c) The MCS severity signature based in lightning activity and d) The thermodynamics and dynamics that control cloud propagations.
We hypothesized that the interaction among the boundary layer, creating inhibition and the unstable and wet air in the low level jet is the key parameter trigger the controlling the convective initiation and the clouds to MCC upscale. The connection of the air parcel from a large inhibition Boundary layer entrainment into the layer of the low level jet are the main mechanism controlling the MCC intensity. Also, we hypothesized that the MCC propagation depends on the Steering level, the gradient of CAPE and the Low level Jet position. Finally, we believe that the severity of the system is based in the former mechanism and in the further development of several Zdr columns the formation of graupel above, the esterification process, followed by the collapse of the Ice negative Zdr starting large rainfall process and vorticity.
This process will be observed by active and passive instruments and the cases simulated in high resolution models testing turbulence and microphysics parameterization to improve description.
To accomplish these goals the following instruments and procedures will be employed: Instruments List:
1) Mobile radar X Pol
2) Mobile LMA instruments (4)
3) Mobile radiosonde and surface station (3)
4) GPS station (fixed)
5) Surface flux energy flux (fixed)
6) MP300 radiometer (multichannel – fixed)
7) Lidar (fixed)
Configuration of the instruments:
1) A line of 6 GPS to measure the LLJ intensity and position, centered at the average LLJ position
2) Surface flux, MP3000, radiosonde and Lidar at the convective initiation region
3) MCC tracking from the initiation region to Brazil using radiosonde, surface station, LMA and X POL radar.
Model: RAMS and WRF
Expect support – radiosondes, 3 cars and people to help and installation.

RELAMPAGO Section J

Santa Maria, Brazil, 24 December 2015.

The Meteorology Program of the Universidade Federal de Santa Maria (UFSM) will cooperate with the RELAMPAGO field campaign being planned for the austral spring of 2017 over subtropical Argentina. Our interest is justified by the fact that deep convective storms that initiate over north-central Argentina often cross the border with Brazil, producing heavy rain, large hail and damaging winds over our region.
The main contribution from UFSM will be in areas where our experience and infra-structure best match with the goals of the RELAMPAGO campaign:

** Focus area: synoptic to mesoscale processes.
Detection of cold pools and other convectively-induced surface mesoscale circulations: UFSM's Micrometeorology Laboratory operates a micro network (micronet) of five automated weather stations that sample data at high frequency. Data from this micro network, in addition to the regular operational automated network from Brazil's National have been used to document the occurrence of surface mesoscale features generated by deep convective storms, such as gust fronts, cold pools and mesocylones, and can be deployed to other regions of Rio Grande do Sul state (RS). It is possible that this system will be much expanded by 2017 and it can be employed in the monitoring of convective systems as they enter Rio Grande do Sul state in their mature stage of development. These surface observing systems are crucial for characterizing storm severity at ground level, adding information to the remote-sensing systems for the full description of the convective systems.

** Focus area: processes to prediction of high impact weather.
UFSM's Numerical Modeling Laboratory has a computer cluster consisting of 16 octacore Xeon E5-2670 processors, totaling 128 computing cores. ARW-WRF model is operationally run in this system in a daily basis (once a day) covering the entire La Plata Basin, which includes the main target area of RELAMPAGO. Output from this model with 12 km (and possibly 4 km over northern Argentina) grid spacing will be available during RELAMPAGO's main field campaign. The 12-km ARW-WRF has been used at UFSM to evaluate the forecast of severe convective weather in the La Plata basin through an ingredients-based approach. 1-to-4-km simulations have been conducted in research mode, focusing on MCSs that produce very heavy rain, large hail and damaging winds. During RELAMPAGO particular attention will be placed on MCSs that produce damaging winds, such as the bow echoes. A number of derecho (or derecho-like) events have been documented in southern Brazil in recent years, and RELAMPAGO will could be an important opportunity to detect their genesis in northern Argentina and to assess the value added by numerical weather prediction products in forecasting such episodes. In this context, the sensitivity of high-resolution simulations to the microphysical parameterization schemes is one topic to be addressed. Surface observations, such as the ones mentioned in the previous paragraph, will also be important to detect the evolution of cold pools, meso highs and gust fronts, necessary to evaluate and verify the numerical output.

Projects: UFSM's Micrometeorology and Numerical Modeling Laboratories have ongoing projects that are necessary to keep the aforementioned infra-structure, and new projects to expand both the surface observing system and the numerical modeling capabilities will be submitted to Brazil's Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) by late January.

Confirmed participants (at present moment): Ernani de Lima Nascimento, Éliton Lima de Figueiredo (PhD student); Murilo Machado Lopes (undergraduate student).

RELAMPAGO Section J

Elaboration of High Impact Weather early warning system between multiple actors.

The objectives of the work with decision makers are:

- Provide assistance to local decision makers to strengthen and improve their early warning system for natural and environmental disasters in order to mitigate the losses of human lives and economic damage.
- Generate information for local governments to be used as a tool for decision-making in territorial planning at a district scale.

Through active workshops with decision makers we want to improve knowledge about local risk. This goal involves the development and use of databases, register and analyze the state of art and statistic about floods and their risk.

All this sources of information will allows us to know local risks in warning situations

- Communication and delivery of the information. This goal involves subjects such as:
  - Build reliable and understandable meteorological information and warnings oriented to user's needs especially decision makers, authorities, mass media and vulnerable population.
  - Develop strategies of warning's divulgation using simple and intelligent technologies.

The activities we propose to accomplish our goals includes:

- Active workshops with civil defenses, fight fighters and decision makers.
- Active workshops with vulnerable population putting special attention to women, students and local flood assemblies.
- Building risks maps with communities
- Giving basics courses to decision makers about meteorological warning interpretation and meteorological references in warning situations.

The final goal consist in work closely with decision makers in order to develop different types of risks maps based on local knowledge to be used in interoperable and geo-referenced platforms.
This final product will help the hydrological, agricultural and emergency sector mitigate the damage caused by severe meteorological storms in Córdoba.

Members: Federico Robledo (CIMA-FCEN), Ignacio Gatti (IGN), Julia Chasco (SMN)

Impact of aerosol concentration on MCSs over SESA region during RELAMPAGO

Large uncertainties still remain on the effects of aerosols on clouds and precipitation, especially for mixed-phase convective clouds, since they are determined by complex dynamical, thermodynamical and microphysical processes and their interactions and feedbacks. Observational and modeling studies have shown that atmospheric aerosol concentrations influence cloud droplet size distributions, warm and cold rain processes, clouds lifetime, cloud base and top heights, the depth of the mixed phase region, the occurrence of lightning and even, tornadogenesis. How large is this influence, also depends on cloud type and environmental conditions such as: wind shear, relative humidity and CAPE. In addition, the aerosol indirect effect on convective storms potentially modifies the cloud's environment and its interaction with nearby clouds and secondary convection, being more complex the understanding of the indirect effect on mesoscale convective systems (MCSs).

Based on the above mentioned, we aim to better understand the impact of aerosol indirect effects on MCSs. To this end, we will perform sensitivity studies to aerosol concentrations under different environmental conditions to quantify its effects on convective initiation and development, and on the intensity, distribution, and type of precipitation. We will choose days with different low-level jet intensities, CAPE, convective inhibition (CIN) since it is known that these factors have an important role on convective initiation, as well as in the storm type and intensity that develop in the region.

High-resolution simulations will be performed over the Southeast South America (SESA) region using the WRF-ARW model. The aerosol concentration profile will be modified inside the two-moment microphysics scheme to emulate clean and polluted conditions. In addition, we will conduct sensitivity studies changing how hail is represented inside the microphysics scheme and we will study how this modification will change the aerosol influence on clouds and precipitation. Results from the simulations will be validated with observations available from the RELAMPAGO campaign selecting clean and polluted days.

We will conduct radiosonde launchings west of the Andes (30º14´S, 70º44´W) that together with the available observations in Chile will allow to characterize the atmosphere and the upwind westerly flow, whose interaction with the Andes will determine lee cyclogenesis, which is very important in the formation of MCSs over SESA. Radiosondes can also be assimilated into numerical simulations over the region or be used for validation purposes.

Researchers: Diana Pozo, Julio C. Marín (Dpto de Meteorología de la Universidad de Valparaíso, Chile) and Graciela Raga (Centro de Ciencias de la Atmósfera, UNAM, México)

Proposal Title: Investigating the Occurrence of Sprites and other Transient Luminous Events over South American Mesoscale Convective Systems
PI: Fernanda São Sabbas – INPE
Anticipated Sponsor: FAPESP
Duration and start date: 2 years, 11/01/17
Estimated Budget per Year: $40K.

Thunderstorm electrical activity is the source of Transient Luminous Events – TLEs. TLEs is the generic term attributed to upper atmospheric effects of thunderstorm electrical activity such as sprites, ELVEs, halos, blue jets, gigantic jets and others, associated with lightning discharges. Their optical emissions are observed in the atmosphere directly above thunderstorms using low-light level video cameras located
~150-1000 km from the producing thunderstorm, either on the ground or onboard airplanes, and onboard satellite. The observations are performed at night due to the low luminosity of the phenomena (a few hundred kR to a few MR). Their existence reveal the electrodynamical coupling of the several atmospheric layers, including the ionized regions, i.e. ionosphere and magnetosphere.

Mesoscale Convective Systems – MCS are large convective systems (area >= 30,000 km^2) known to
have intense electrical activity (more than 1 lightning flash per second) due to the large charge separation caused by strong updrafts and downdrafts that characterize these systems. They are considered to be the most efficient source of TLEs, and the study region in Southern South America is the center of the longest, largest and most intense MCS in the world. São Sabbas et al. [2010] have studied a MCS that originated near Cordoba, in Argentina, and developed towards the eastern border with Brazil producing more than 700 TLEs, mainly sprites, during its lifetime. The system ingested large amounts of
PM2.5 aerosols (concentration ~ 10,000 $\mu g/m^2$) during its growth phase due to ~200 forest fires, and
presented a multicelular convective structure throughout its lifetime. It was considered to be the third most abundant TLE producer ever documented.

During the RELAMPAGO experiment we plan to extend the coverage of the Transient Luminous Event and Thunderstorm High Energy Emission Collaborative Network in Latin America, LEONA network, to perform ground based observations of TLEs above convective systems over Argentina. The objectives are to 1) To evaluate the productivity of the convective systems based on the number of TLEs recorded, identifying the type of events produced; 2) To analyze the TLE activity in conjunction with lightning and aerosol data.

The RELAMPAGO experiment proposed to have a combination of polarimetric and Doppler radars, environmental soundings, aerosol measurements, plus a set of instruments to investigate cloud electrification and thunderstorm electrical activity. Among them are two Lightning Mapping Arrays – LMAs, that make 3-D measurements of intracloud and cloud-to-ground discharges. One of the LMAs, proposed to NOAA (PI Tim J. Lang, NASA Marshall Space Flight Center) will be installed near Cordoba, to catch the lightning activity during the early development phase of the convective systems. The second system, proposed to Brazilian agencies (PIs Rachel Albrecht and Carlos Morales, University of Sao Paulo), will be installed near the border with Brazil, which will permit observing mature systems. They also plan to deploy a VLF/LF total lightning network (LINET – DLR/Nowcast) composed by 10 stations, in the region between the two LMA networks in order to have coverage of the electrical activity of the full life cycle of the convective systems. We plan to solicit funding to install and operate two new LEONA TLE observation stations, one near Cordoba and one in Southern Brazil. The systems are composed by low light level video cameras, to perform the observations, a pan-tilt, to steer the cameras, a GPS time stamping device and a computer to control the cameras and record the data. The cameras can observe TLEs at ~200-800 km distance from the optical sites, providing very good coverage of the atmosphere above the thunderclouds. Combining the video data with the lightning signatures provided by the LMAs and VLF/LF network will allow characterizing the electrical activity that give rise to the TLEs. The Cloud, Aerosol, and Complex Terrain Interactions (CACTI) Experiment will also permit comparing the convective systems developed under different aerosol conditions and to analyze the aerosol contribution to TLE production.

A. Celeste Saulo, Director, Servicio Meteorológico Nacional, La República Argentina

Proposed funding agency – SMN, Argentina
Proposed funding amount – Approximately US$300K

This is to inform the National Science Foundation of our intent to support to the RELAMPAGO field campaign to be proposed in the region of Central Argentina in late 2018. The Servicio Meteorológico Nacional of Argentina plans significant support of this project as it compliments many of our research and development interests within the SMN and our partner university research laboratories in Argentina.

As part of this project, we are already planning an Argentinian-funded field project to coincide with the proposed field project funded by the National Science Foundation, Department of Energy, and other agencies. These include:

*A mobile meteorological station and personnel, with a surface station and radiosonde launch facilities (80 sondes)
*An additional fixed sounding site and personnel to compliment RELAMPAGO measurements (80 sondes)
*Enhancement of the existing Argentinian sounding network to 8 radiosonde launches per day for 10 IOP days (60 sondes at 4 sites)
*Personnel for field support, vehicles
*Operations center with high speed internet access
*Numerical model and forecasting support for field operations
*Coordination of Argentinian operational radar scanning strategies for optimization of field data collection
*Help with logistics in importing equipment, site surveys, and site procurement issues, working closely with established ties with the Earth Observing Laboratory and Research Applications Laboratory at NCAR

We hope that you consider this large contribution to RELAMPAGO by Argentina as you evaluate the project.