The La Plata Basin Regional Hydroclimate Project: A short reference document

1. The La Plata Basin (LPB) Regional Hydroclimate Project

a. Background

La Plata Basin in southeastern South America is recognized as an area of great importance for the economic and social development of several countries. The scientific community of the region, aware of the sensitivity of this basin to potential changes, has developed a plan to assess the impacts of climate variability and climate change on the basin's extreme events, and to develop means to improve the prediction of seasonal floods and droughts. These activities are being developed in an international coordinated effort known by the name *La Plata Basin Regional Hydroclimate Project (LPB)*. The project was reviewed by experts in hydrology and climate, and has gained the endorsement of CLIVAR and GEWEX, two Panels of the World Climate Research Programme that focus, respectively, on Climate and Hydrology. LPB offers a sound framework to identify the priorities in hydroclimate research and applications of the basin.

The La Plata Basin covers parts of five countries, is home to about 50% of their combined population, and generates about 70% of their total GNP. Approximately 30% of the area belongs to Argentina, 7% to Bolivia, 46% to Brazil, 13% to Paraguay and 4% to Uruguay. The basin is important in different ways for the economies of those countries. Harvests and livestock are among the region's crucial resources, rivers are natural waterways, and surface transportation has greatly increased in recent years due to the integration of regional economies. Last, but not least, several hydroelectric plants provide most of the energy consumed.

The hydroclimate system of the La Plata basin presents several challenges that have become apparent along the years; from vulnerability to floods and droughts to efficiency of hydropower production. CLIVAR and GEWEX recognized the uniqueness of these components, and have endorsed LPB as a Regional Hydroclimate Project that will focus on improving the ….

b. Science questions

The main LPB hydroclimatic issues can be summarized in the following questions:

i) *What climatological and hydrological factors determine the frequency of occurrence and spatial extent of floods and droughts?*

ii) *How predictable is the regional weather and climate variability and its impact on hydrological, agricultural and social systems of the basin?*

iii) *What are the impacts of global climate change and land use change on regional weather, climate, hydrology and agriculture? To what extent can their impacts be predicted?*

The LPB implementation plan envisions two main activities, monitoring of hydroclimate variables and a field experiment to develop a set of unique data that will (a) help understand the land surface-atmosphere processes that may lead to persistent events, and (b) to calibrate and improve parameterizations in regional and global models employed for forecasting and prediction up to seasons.

For an extensive discussion of the science issues motivating these questions, please see Chapter 2 of the LPB implementation plan, available from http://www.eol.ucar.edu/projects/lpb/

2. Motivation for the LPB Field Experiment: PLATEX

a. Land-atmosphere interactions

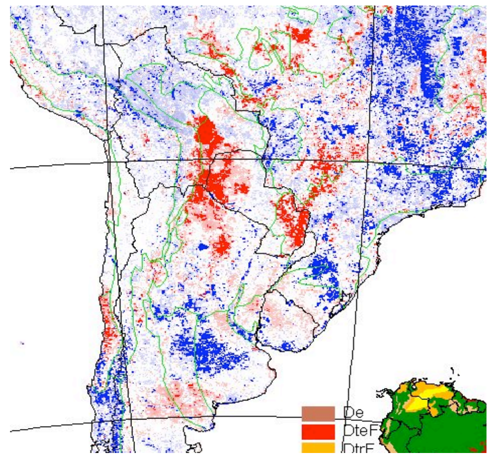


Figure 1. Normalized Difference Vegetation Index (NDVI) 1981-2000 trends: surrogate for primary production from NOAA-AVHRR images. Red: decrease Blue: increase. [Courtesy of Jobbagy.]

Vast areas of the La Plata Basin have experienced changes in land cover conditions due to the expansion of the agriculture (replacing natural vegetation), but also due to changes in crop types. In addition, pastures with a typical cycle of 4-5 years are being replaced by crops that have an annual cycle (Paruelo et al. 2005). Crop changes have also taken place in Brazil, where, among others, the planted area of sugar cane has increased from 1×10^6 hectares in 1970 to more than 5×10^6 hectares at present. Further significant changes could be expected as a result of biofuel, paper and cellulose and thermoelectric energy production that require specific types of crops such as sugar cane, palm trees and eucalyptus.

Simplified studies have suggested that the conversion of forest cover to crop cover results in a reduction of net radiation and evapotranspiration, while runoff is increased. On the other hand, changes from grassland to crops have the opposite effect (Twine et al. 2004). The expansion of eucalyptus plantations has had a remarkable impact on the Bowen Ratio (Rocha and Silva Dias 1994). Modeling studies have shown that surface conditions have a significant impact on weather and climate as changes in vegetation types imply changes in albedo and evapotranspiration, significantly altering the physical conditions of a region and thus affecting the overlying atmospheric state and the processes that modulate precipitation (e.g., Pielke and Avissar 1990; Pielke et al. 1999).

Changes in vegetation types (e.g., from forests to different kinds of crops) also involve changes in the root depth and thus in the deeper ground characteristics that affect the soil moisture content, the infiltration, subsurface and groundwater outflow, leading to changes in the volume, timing and quality of the water available at catchment scales.

There is persuasive evidence that variations in land surface conditions, particularly soil moisture and vegetation, can play a significant role in warm season precipitation variability over continental-scale areas. Because these land surface anomalies are themselves largely determined by fluctuations of precipitation, it has been suggested (Betts et al. 1996; Koster et al., 2000, 2004; Betts and Viterbo 2005; Luo et al. 2007) that there are important feedbacks between the atmosphere and land surface that can be either positive (in which case climate anomalies are self-sustaining) or negative (self suppressing).

Many studies have offered supporting evidence in the case of the 1988 drought and 1993 floods over the United States (e.g., Bosilovich and Sun 1999; Trenberth and Guillemot 1996; Paegle et al. 1996; Beljaars et al. 1996; Seth and Giorgi 1998 to cite some examples). Likewise, the role of soil moisture in perpetuating droughts has been discussed in the literature. All this body of research supports the hypothesis that a better knowledge of the land-atmosphere interactions can lead to improvements in the predictive skill of models.

Koster et al. 2004 proposed that certain regions with significant soil moisture memory effects may act as hot spots where land atmosphere interactions are strong and contribute to the predictability of regional climate. Although not discussed specifically, their figures show regions in South America with hot spots. Several diagnostic studies (Luo et al. 2007; Dirmeyer et al. 2008) with multiple observational datasets corroborate the hot spots regions based on a large number of land surface models driven by observations. Progress in the diagnosis of these feedback pathways will require significant advances in the quality of observations and land surface modeling.

The influence of soil moisture on the atmosphere is largest when the potential evaporation is large in comparison to the precipitation (Delworth and Manabe 1988, 1989). In extremely dry conditions, evaporation removes rapidly the soil moisture anomaly, while in very wet regions, evaporation tends to be close to the potential evaporation and thus it is insensitive to changes in soil moisture. In both cases the chances of having predictive skill from the soil conditions will be slim. The larger contributions to predictability come in *transition regions between dry and wet zones* where evaporation is large enough to modify the atmosphere and where it has a robust response to the soil moisture state (Koster et al. 2000). In such situation, it can be expected that the slowly varying soil moisture anomalies will persist enough time to affect the overlying boundary layer, and thus they can add predictive skill to the forecasts in the given region.

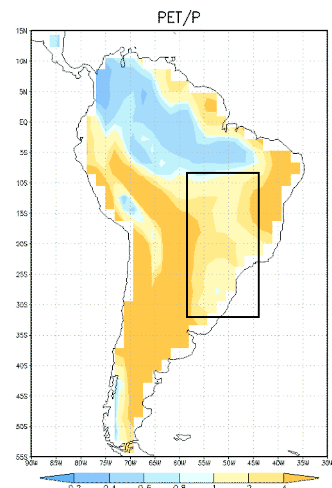
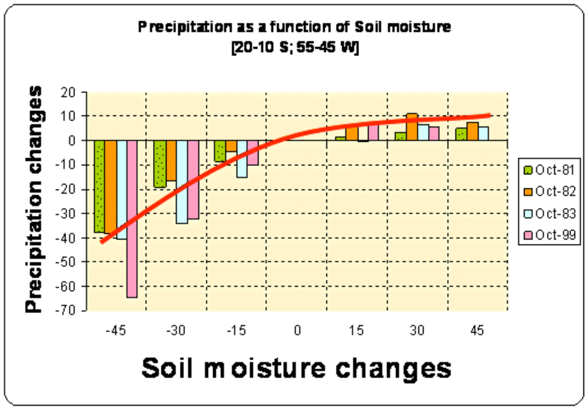


Figure 2. Ratio between potential evaporation and precipitation

Figure 2, based on the NCEP/NCAR global reanalysis, shows the springtime ratio between potential evaporation (PET) and precipitation (P), as in Delworth and Manabe (1988). The ratio is small over the Amazon region (due to abundant precipitation in comparison to potential evaporation), while large values of PET/P due to the lesser precipitation are found to the south (towards Patagonia). In support of the hypothesis presented here, a large portion of the La Plata basin is in a transition region where feedback effects leading to improved predictability of precipitation may exist (as in Koster et al. 2004).

Sensitivity experiments to soil moisture (Collini et al 2008) show an almost linear relationship is obtained when reducing the initial soil moisture (Fig. 3), with changes in precipitation responding to two basic mechanisms. On the one hand the reduction of soil moisture implies less availability of water for evaporation and an increased Bowen Ratio; on the other hand, the larger Bowen ratio also implies a deeper and drier boundary layer. As shown in Fig. 4, the deeper boundary layer also results in a more elevated Low-level Jet and given the lesser moisture content at higher altitude there is a consequent reduction of the moisture transports into the monsoon region. The two mechanisms (reduced evaporation and reduced moisture flux convergence) act concurrently to lessen the supply of moisture and, hence, the core monsoon precipitation.



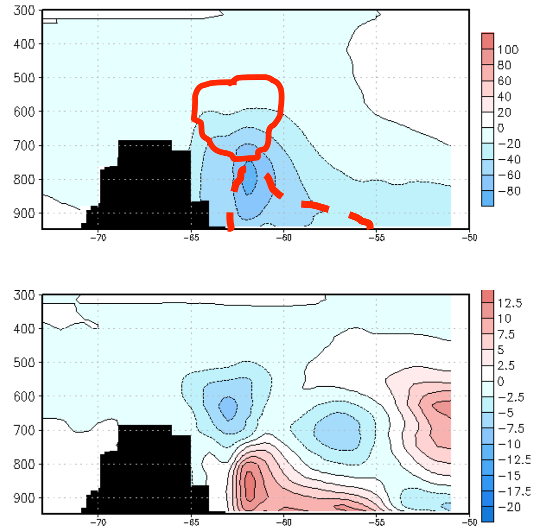


Figure 3. Sensitivity of precipitation to soil moisture changes in the monsoon region (each bar represents a one-month model simulation).

Figure 4. Changes in the structure of the Low-level jet due to changes in soil moisture: (a) Mean LLJ, (b) anomalies in the LLJ resulting from reduced soil moisture. Blue colors represent southward flow. The heavy lines in the first panel represent the location of the anomalies with respect to the mean LLJ.

In general, research in soil moisture-related land-memory processes is still limited by the comparative scarcity of soil-moisture data. It was this lack of relevant, regional scale observations of soil moisture that motivated the Land Data Assimilation System (LDAS) initiative. Notwithstanding the progress that has been made towards providing model-calculated soil-moisture fields using LDAS, the basic requirement for soil-moisture observations over extensive land areas remains. However, despite the poor representativeness of point measurements, they can serve to adjust parameterizations and calibrate remotely sensed, area average soil moisture. One focus of PLATEX will be on investigating how remotely sensed data could best be used in combination with in situ observations to improve prediction of climate and hydrologic variables at timescales from days to seasonal and to assess their usefulness for water resources management.

b. Mesoscale Convective Systems and biomass burning

Mesoscale Convective Systems are the larger scale convective systems or cloud clusters that have a lifetime of several hours and horizontal scales of a few hundreds of kilometers.

Several authors have looked into the preferred places of occurrence of South American MCC and MCS. The classical work by Velasco and Fristch (1987) presented the first climatology of occurrence of MCC in So. America. After that, Conforte (1997) determined the occurrence of MCC by following the Maddox criteria while others like Torres and Nicolini (1999, 2002, 2003) and Salio et al. (2004) used more flexible criteria but focused anyhow on the larger systems. Silva Dias (1999) present a review of MCS observed in Brazil with a discussion of their impacts in terms of hazards and disasters in the different regions. Laing and Fritsch (1997) presented a compilation of results from several authors in a global view showing that subtropical Americas are distinguished in a global perspective as the regions outside the tropics with high frequency of occurrence of MCCs. Figure 1 shows a compilation of results on location of MCS for South America including more recent work.

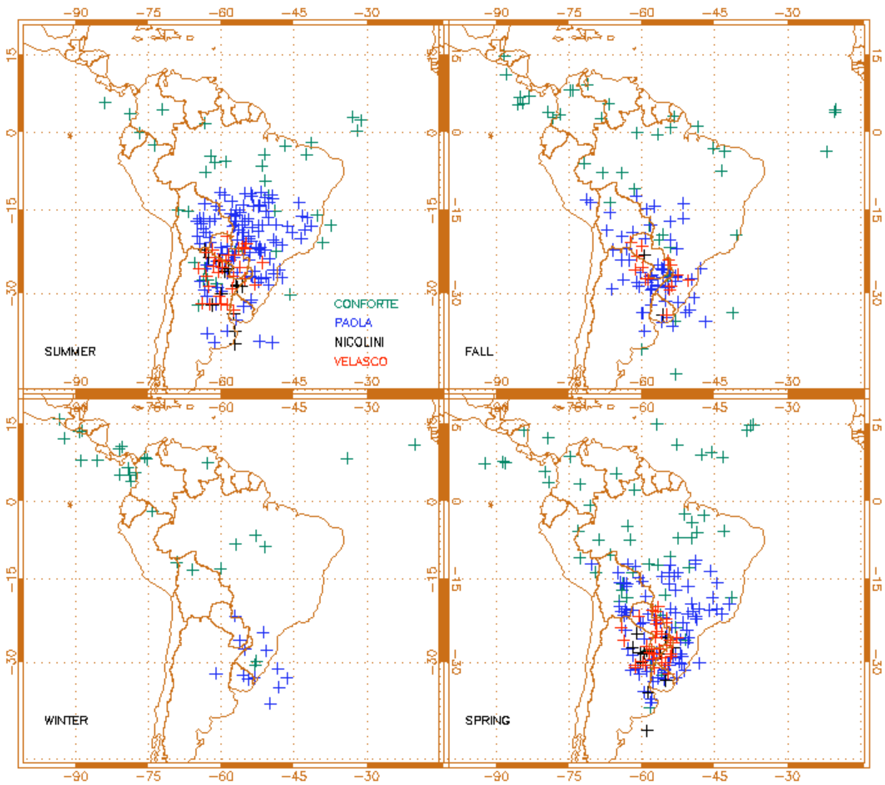


Figure 1. Mesoscale Convective Systems in South America

Vera et al (2006) describe the SALLJEX – South American Low Level Jet Experiment that had a focus on the relationship between the low level jet east of the Andes but also studied the simultaneous occurrence of Mesoscale Convective Systems - MCS. Results from Salio et al (2007) show that most of the MCSs during SALLJEX, have been related to the occurrence of meridionally extended low level jets, and tend to organize at the exit region of this current, that, in turn, coincides with the southern and central portion of LPB. Particularly, Saulo et al. (2007) – through the analysis of one event- show that there is a strong synergism between the low level jet and the organized convection at its exit region, with a positive feedback among both that tends to augment the northerly low level jet, enhance the convection and also accelerate the upper westerly jet. The MCS-LLJ synergism leaves a signature on the regional circulation that remains active for a long period and creates an environment favorable for the development of new convection.

Spring time in South America has another peculiarity: it is the time of the year with major biomass burning in Central Brazil, with regional transports of aerosol and trace gases over the LPB as may be seen in Fig.2.

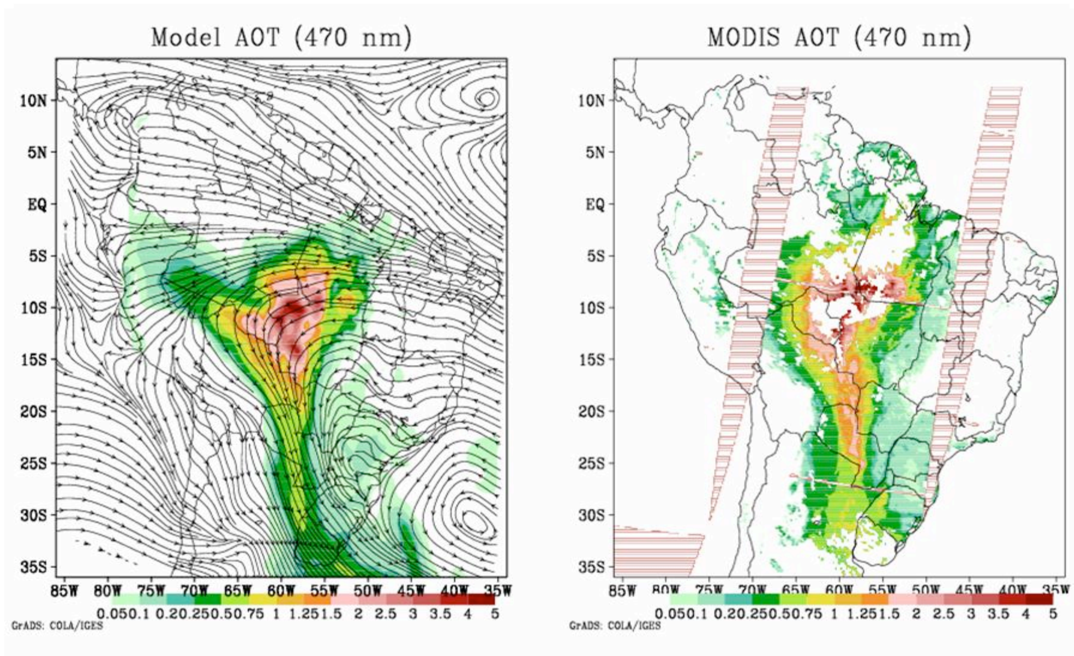


Figure 2 Numerical simulation and validation with MODIS of aerosol optical thickness. Freitas et al (2005)

The combination of vigorous convection with a large input of aerosol at variable heights poses the scenario for a quite complex interaction between radiation, cloud microphysics and the thermal structure of the atmosphere. The combined result represents a potentially large impact in the surface climate, precipitation and temperature. The sole impact of aerosol on radiation (shading effect) has been modeled by Longo et al (2005) and the effect is quite impressive as may be seen in Fig. 3.

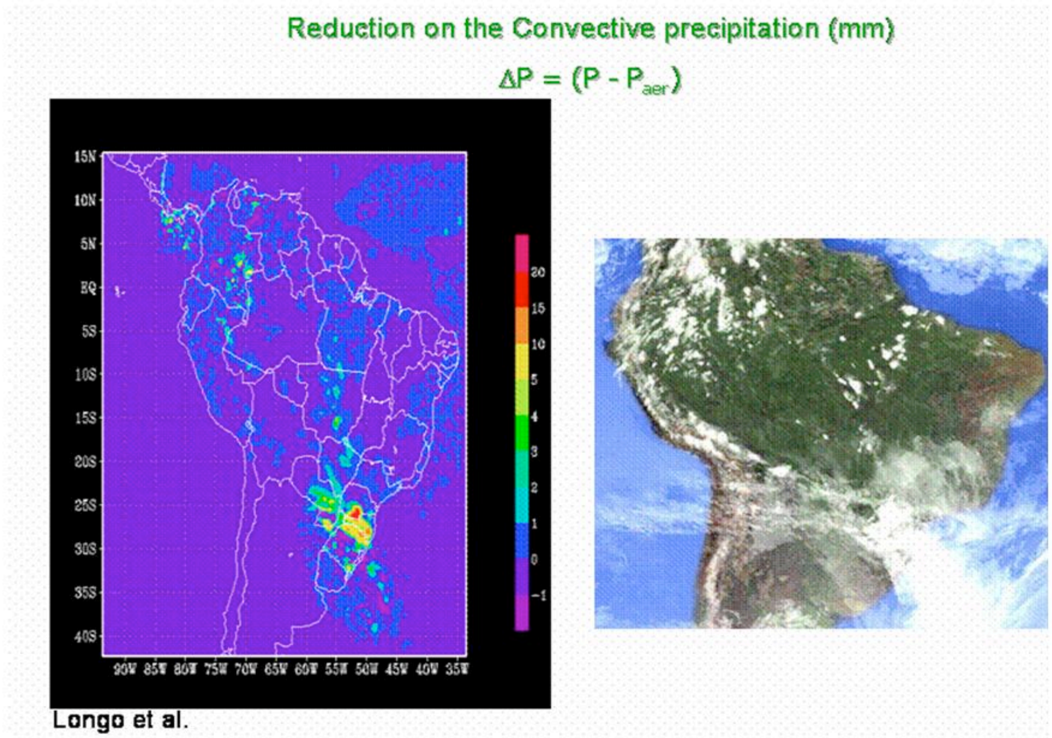


Figure 3.The figure on the left shows the difference in convective precipitation between two experiments without and with the aerosol-radiation interaction for the situation on the right, showing the corresponding satellite images. Red colors (positive values) indicated reduction in accumulated precipitation.

Understanding the processes involved is non trivial, mainly because the cloud microphysics impact is highly non linear. It is expected that predictability of weather systems, and quantitative rainfall prediction, are affected. Progress in scientific understanding requires special measurements, and thus the main motivation for a field campaign.

3. PLATEX specific scientific objectives

Land surface-atmosphere interactions

- *What is the role of land use and land cover change on the rainfall patterns in the LPB?*
    - *What role do soil processes play in the basin?*
    - *How are the surface fluxes of sensible and latent heat affected by agricultural practices?*
    - *Are the surface conditions as defined by land use, important for the convective development?*
    - *What developments and improvements in surface and atmospheric models are required to better represent the relationships between land surface parameters and surface fluxes?*

Mesoscale Convective Systems

- *Why are the LPB MCS so remarkable in a world wide perspective concerning their physical properties detected by remote sensing*
- *What is the role of biomass burning products in the evolution of MCS in the LPB?*
    - *What is the impact of advected aerosol on the surface heat and moisture budgets?*
    - *What are the typical cloud microphysical processes involved in local convection, mesoscale convective systems and cold fronts? How do aerosols contribute to the cloud processes in each case?*
    - *What is the radiative effect in the MCSs life cycle?*
    - *What is the typical microphysical structure of the convective clouds and how predictable is this microphysics structure?*
    - *What are the rain volumes associated with the MCS in the LPB?*
    - *Is the rain volume affected by biomass burning?*
    - *What are the controls on precipitation efficiency of the MCS in LPB?*
    - *What controls the exceptional lightning activity?*

In addition, there are several questions with respect to process understanding that require long term measurements. This can be achieved by a permanent three-dimensional super site. Besides an operational monitoring of rainfall and aerosol to help with the research towards the PLATEX questions, there is another set more related to the establishment of a **LPB Pilot Region**.

4. Strategy

The scientific questions of the previous section can only be answered through different approaches. Some require very specialized measurements that can only be taken in a campaign mode. Others need a longer time monitoring (about 5 years) with enhanced instrumentation, and finally others can be addressed with existing observations once they are fully accessible by the scientific community. Therefore, the LPB implementation activities to address the scientific questions will have three major approaches: (a) data rescue efforts, (b) Hydro-climate monitoring, and (c) a field experiment (PLATEX).

a. Data rescue efforts

Surveys are being prepared to identify the many regional raingauge networks, soil moisture measuring locations, and identification of Flux Towers that can be of use to LPB. The availability of these data could be extremely important if an agreement can be reached for their distribution to the scientific community. In addition a radar working group has been formed to identify the gaps in radar coverage, standardization of the products, and coordinate to allow accessibility of the data.

A second aspect to be considered within LPB activities is the conversion of many archives to digital format. Historical data are available at many centers, but they are in hard copy formats.

b. Monitoring activities

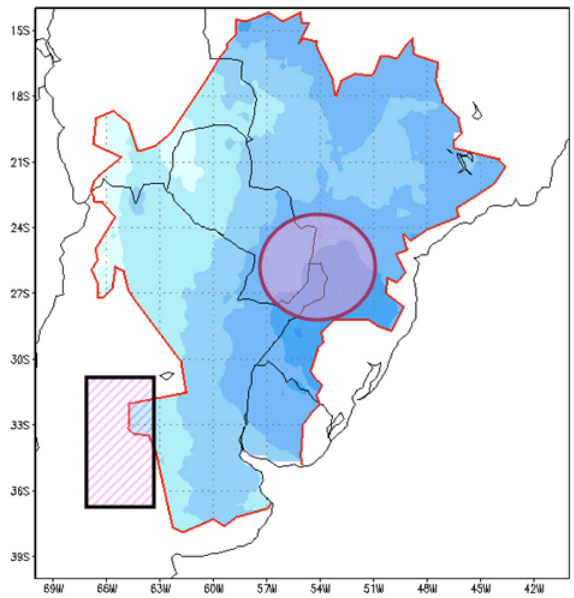
The monitoring system of LPB RHP will have three basic elements: (a) a network for monitoring the diurnal cycle of precipitation; (b) a flux tower that includes CO2 fluxes; and (c) lidar aerosol measurements. The feasibility of having radar nearby is currently being explored and a network of digital raingauges with high temporal resolution will be complementing the radar. Itaipú has a 50+ raingauge network that will serve to support activities in the central region of the basin.

c. The field experiment (PLATEX)

A comprehensive field experiment with a focus on MCS precipitation, the relevance of aerosols, and land surface atmosphere interactions is being planned as part of the LPB observational strategy.

5. The LPB Pilot Region

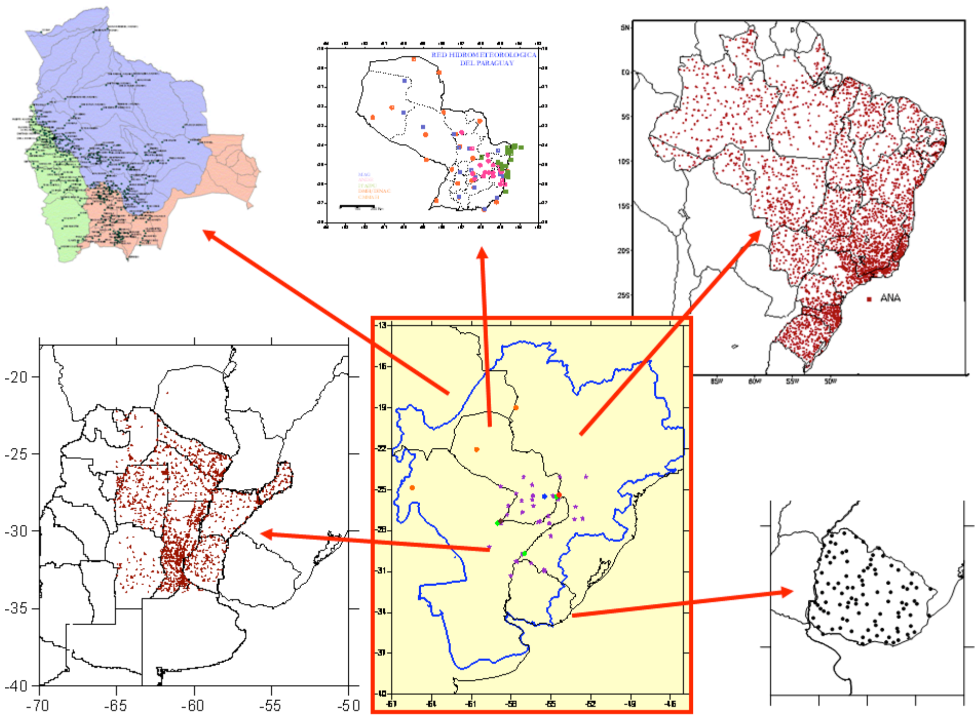
After assessments of several regions where a field campaign could be carried out, a consensus was reached that the region near the border of Paraguay, Argentina and Brazil offers several advantages (the circle in the figure). This is the region where the Itaipu hydroelectrical power plant, among the largest in the world, is located. The 3rd LPB planning meeting was precisely held at Itaipu, and pending a Framework Agreement, LPB is expected to be allowed to install instruments in safe regions within the secure regions.



[A second region, the square in the figure, is located in a region of large gradients of precipitation and where important increases of precipitation have occurred during the last decades. This region is also of interest for LPB, but it will not be discussed in the LPB Boulder meeting.]

6. Existing Networks

a. Raingauge networks



The LPB is covered by a network of surface and upper air instrumentation that is unparalleled in spatial distribution in South America. There are, however, gaps in temporal coverage due to different problems, the most common being budget limitations in the several countries involved.

b. Radar distribution

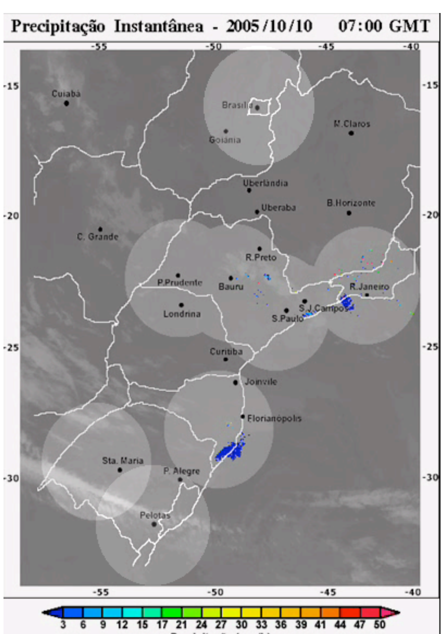
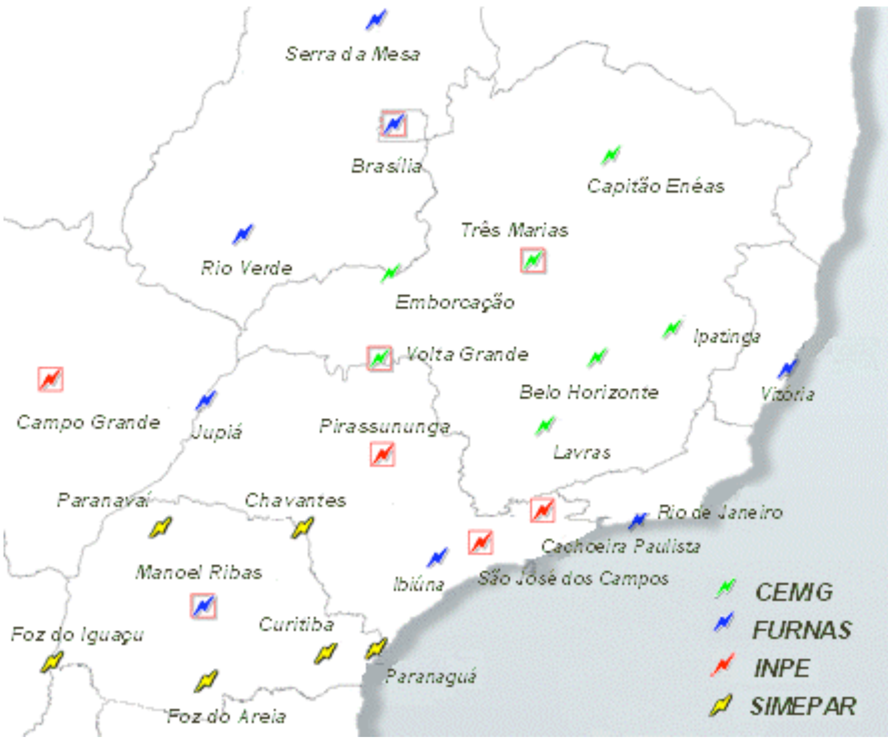


Figure Meteorological radar coverage in Southern South. America.

c. Lightning Network

Since we are measuring MCS activity, lightning information can be an indicative of MCS strength, since it is related to updrafts, water and ice content, and hydrometeors distributions. Later, very few campaigns focused on an intercomparison between different lightning networks to establish the real detection efficiency among the different instruments. Therefore, this campaign can provide a unique opportunity to establish this kind of validation and at the same time, provide 3D information of the lightning activity. Based on this concept, we can begin an interaction with atmospheric electricity community to participate in PLATEX.



7. NCAR Observation Facilities

(The content of this section should be written after the LPB Boulder meeting.)

ISFF (Flux Towers/ SM)
SPOL (Radar)
ISS (Radiosondes/ Profiler)
RAF (Aircraft)
Lidar