Second year report of the project CRN-2094

The Impact of Land Cover and Land Use Changes on the Hydroclimate of the La Plata Basin

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1. Introduction

This project is based on the fact that 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. These changes may affect the physical properties of the surface, with changes in albedo, net radiation, evapotranspiration, surface roughness and many other parameters. 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. 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.

The CRN-2094 seeks to determine the extent of the impact of land cover and land use changes (LCLUC) in the La Plata Basin hydroclimate and specifically assess whether there are consequences for the duration and magnitude of extreme events, including seasonal floods and droughts. The overall goal of this project is ***to investigate the impact of changing land use and land cover conditions on the regional hydroclimate and extreme events of the La Plata Basin.***

Specific objectives are:

1. Develop 25-year (1980-2005) datasets employing a Land Data Assimilation System at adequate resolutions with all possible in situ and remotely sensed observations including land use and land cover changes, useful for agricultural and hydrological assessments and applications.
2. Assess the impact of LCLU changes on the hydroclimate of the La Plata Basin, and the physical mechanisms by which the impacts take effect, by means of regional model simulations employing the lower boundary conditions determined in Objective 1.
3. Investigate the role of LCLU changes in the intensity and length of extreme events (floods and droughts).
4. Investigate the potential changes in the hydrological character (soil moisture, infiltration, and runoff) of the La Plata Basin due to the changes in LCLU.

This report summarizes the achievements during 2010. In April we had the second PIs meeting (see program in Annex 1) which had the objective of presenting progress in our activities and the planning of activities during the year. It also had the participation of students and invited guests who gave short presentations and participated of the discussions to motivate them to get involved.

We also provide a brief report of the subproject on agroclimate with Clyde Fraisse in crop modeling and applications for stakeholders.

2. Capacity Building

The Year 2 Report informed on the Summer School taught at Itaipu in Nov 2009, “The international summer school on land-cover change and hydroclimate of the La Plata Basin”. Since then, the success of this Summer School was recognized by many other actors. The University of Buenos Aires has given credits to Ph D students that attended the course, and other universities are in the process of doing the same.

Both GEWEX/WCRP and CLIVAR/WCRP have developed respective sets of “Imperatives” (Priorities), and both refer to our Summer School as an example of Capacity Building. We are preparing a note that will be submitted to the Bulletin of the American Meteorological Society (the editor has agreed to the proposed theme of the note).

We are evaluating the possibility of teaching a second summer school.

3. Principal Investigators Meeting

The second PIs meeting took place in San Luis, Argentina, during 28-30 April 2010. In this meeting, members of the CRN-2031 (Esteban Jobbagy), representatives of INTA (local and Castelar, Buenos Aires) and faculty of the School of Agronomic Sciences of the University of Buenos Aires participated. This meeting had the objective of (a) discussing progress on the project, (b) present our investigations to experts in agriculture, and (c) develop links with this community. The meeting included a field trip to discuss ecosystems and their properties in semi-arid Argentina. The agenda is presented in Annex 1, and soon we expect to have a web site with the presentations and other useful information

4. Estimating land surface conditions from Ecosystem Functional Types for use in regional models

(Alcaraz-Segura, Berbery, Paruelo).

Ecosystem-climate feedbacks are a central problem for modeling the land-atmosphere interactions of the climate system. Climate is the main regional driver of the structure and function of ecosystems, while ecosystems influence climate through multiple pathways, primarily by changing the energy, momentum, water, and chemical balance of the atmosphere (e.g. albedo, longwave radiation, surface roughness, evapotranspiration, green-house gases, and aerosols). To represent the former land surface-atmosphere interactions and feedbacks, current regional and global circulation models employ land-cover maps and tables with their corresponding physical properties. However, these land-cover classifications are difficult to update in a yearly basis and are mainly dictated by structural attributes of vegetation that have little sensitivity to environmental changes. This representation of vegetation may result in a delayed response and reduces the ability of models to represent rapid changes including land-use shifts, fires, floods, droughts, and insect outbreaks. In addition, vegetation physical properties are usually determined from limited observations and assumed constant throughout the same land-cover (e.g. a cropland or a needleleaf forest will have the same properties anywhere in the world, Siberia or the tropics, even though the observations may have been taken at few locations). Improving the way spatial and inter-annual variability of vegetation dynamics are considered in land surface models is thus necessary to account for land-use/cover change effects on circulation models.

We are doing progress in a method to replace the traditional land-cover types and their biophysical properties in regional models by time-varying Ecosystem Functional Types and their corresponding properties. For this, we first produced annual EFTs maps from 1982 to 1999 using satellite-derived NDVI attributes. Then, we obtained their land-surface properties values based on the Noah land-surface model parameterization for the USGS land-cover classes. Finally, we formally evaluated the effect of our approach on the spatial and inter-annual variability of land-surface properties across natural and agricultural systems of South America.

The Ecosystem Functional Types (median for 1982-1999) presented in Fig. 1c show an average characterization of ecosystem functioning. On average, ecosystems of temperate South America show maxima in autumn and summer. EFTs with summer maxima tend to show medium-to-low productivity and high seasonality, while EFTs with autumn and spring maxima represent most of the possible combinations of productivity and seasonality. EFTs with NDVI maxima during winter tend to exhibit either very low or very high productivity under very low seasonality values. Strong differences in the EFTs distribution are observed between 1988 and 1999 due to climate factors (e.g., Figs. 1a,b). In 1998 EFTs with high productivity and low seasonality dominated temperate South America, and particularly La Plata basin. On the other hand, in 1988 the dominant EFTs showed high seasonality and medium to low productivity.

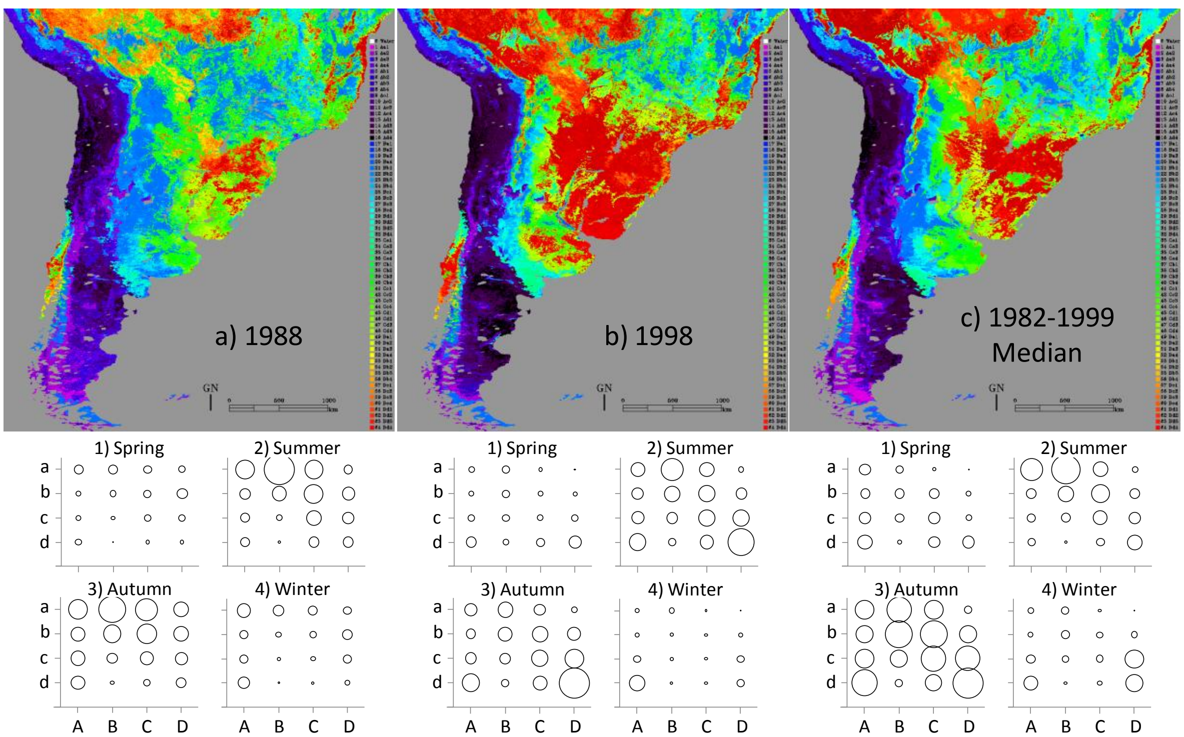


Fig. 1. Ecosystem Functional Types distribution in South America based on the NDVI dynamics for the 1988 and b) 1998 years and for the c) median distribution of the 1982-1999 period.

The evaluation of the effect of our approach on the spatial and inter-annual variability of land-surface properties revealed that the large scale regional patterns of all surface properties were similar between the USGS and the EFTs derived maps (**Figure 2**). However, some properties showed larger differences between the two approaches than others throughout the whole region. For example, Minimum Leaf Area Index (Fig. 2b) and Radiation Stress (Fig. 2e) accumulated the largest differences, while the minimum albedo (Fig. 2f), the smallest differences. In some regions, local differences were repeatedly observed across all properties. Such differences mainly occurred in shrublands of Patagonia, drylands of the Andes, and agricultural areas of southeastern Brazil and eastern Bolivia. In some properties, the local heterogeneity observed in the EFTs derived map was larger than in the USGS ones (Figure 2), for instance, for Stomatal Resistance (Figure 2d) in northern Patagonia.

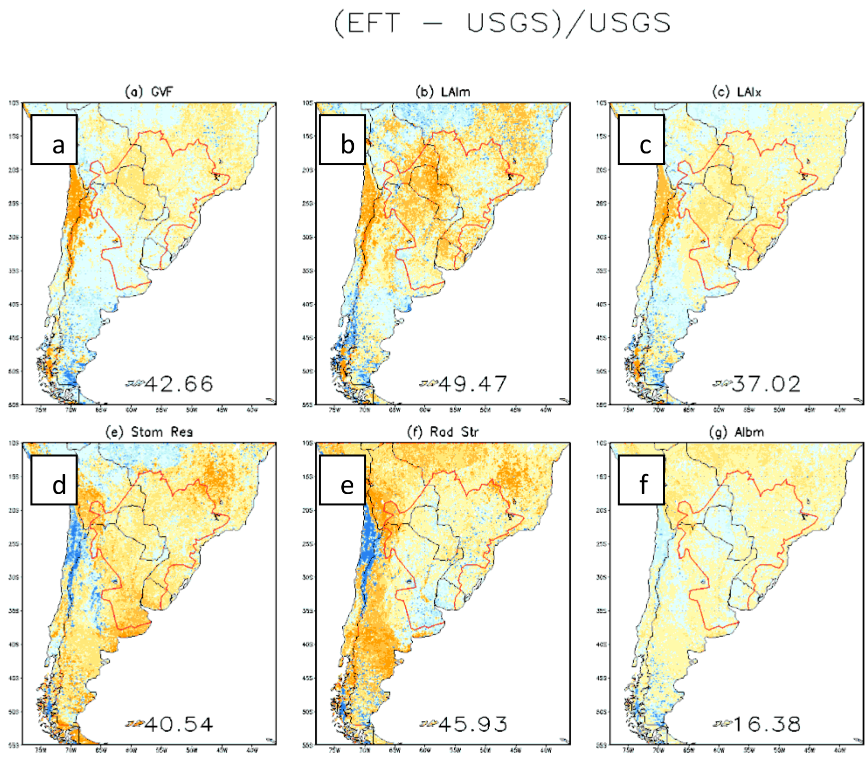


*Figure 2: Relative difference between the EFTs-derived biophysical properties (1982-1999 median) and USGS-derived biophysical properties (1992). The relative difference was calculated as follows: (EFTs – USGS) / USGS * 100. a) Green vegetation fraction, b) minimum leaf area index, c) maximum leaf area index, d) Stomatal resistance, e) radiation stress, f) minimum albedo.*

The interannual variability of vegetation properties is presented in Fig. 3. Great interannual variability was found for Surface Roughness, Stomatal Resistance, and Minimum Leaf Area Index (Figs. 3a-d). Low interannual variability was observed for Emissivity and Radiation Stress (Figs. 3e-g). Rooting Depth, Background Albedo, Green Vegetation Fraction, and Maximum Leaf Area Index showed intermediate variability. On average, the interannual coefficient of variation of the entire study area across all biophysical properties was relatively low (13%). However, some regions (e.g., semi-arid areas of the Patagonian steppe, the NW-SE transect from southeastern Bolivia to Uruguay, and the Brazilian Atlantic Plateau) repeatedly presented high interannual variability across all properties

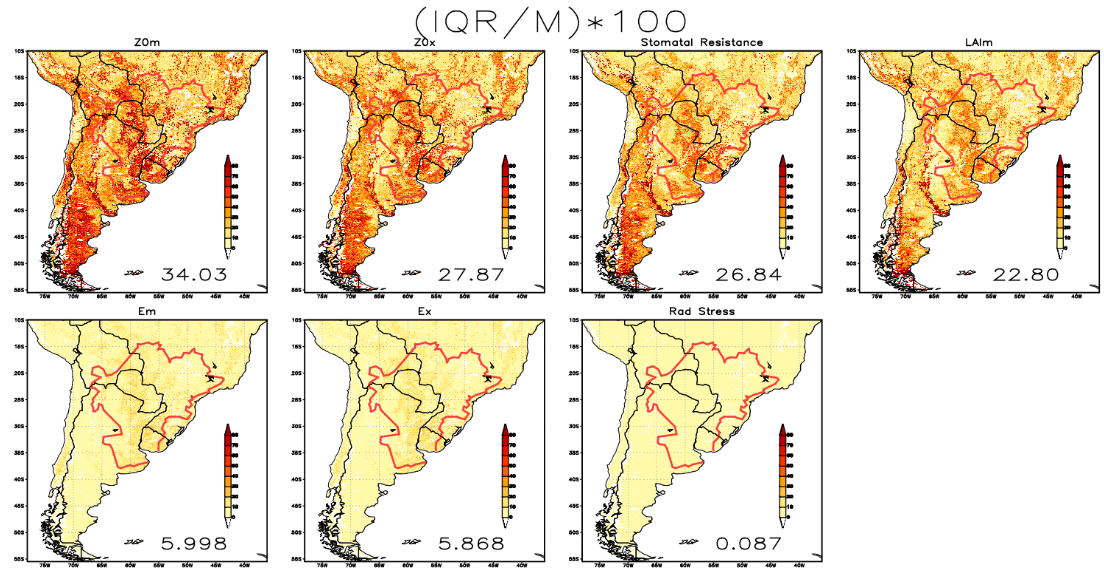


Figure 3: Interannual variability of different biophysical properties measured as the interquartile range over the median (in %). The variability is based on the interannual variation of the EFTs distribution for the 1982-1999 Top row, selected parameters with large variation. Bottom row, selected parameters with small variation. a) Min surface roughness, b) Max surface roughness, c) Stomatal resistance, d) Min Leaf Area Index, e) Min emissivity, f) Max emissivity, g) Radiative stress.

5. Sensitivity of regional model simulations to lower surface conditions.

(Lee, Berbery)

The sensitivity of near surface temperature and precipitation to the interannual variability of EFTs was tested with the WRF regional model by performing seasonal simulations for a low productivity year (1988) and a high productivity year (1998). Simulations were done with the corresponding EFT types, and a second set of simulations was performed reversing their order (a low productivity year was simulated using the EFTs of the high productivity year and vice versa). Figures 4a,b show that when using EFTs with high productivity and a weak seasonal cycle the near surface temperature for the 1988 and 1998 springs tends to increase by as much as 1° C in the central and western portions of La Plata Basin. Figures 4c,d show that the precipitation differences where in general positive, regardless of whether it was a dry or a wet year. However, the patterns are not uniform and exhibit certain patchiness with drier conditions. This note shows that using Ecosystem Functional Types instead of the Land Cover Types opens up the possibility of incorporating interannual changes of biophysical properties into land-surface and climate models.

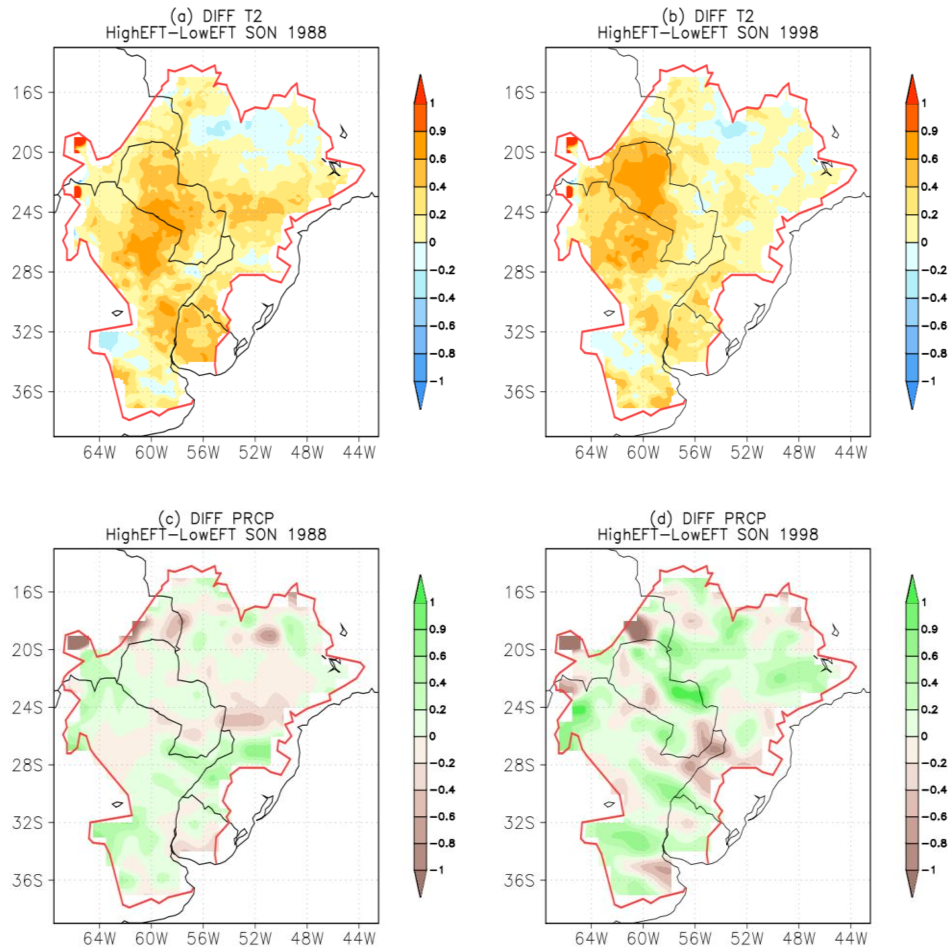


Figure 4. Sensitivity studies showing the impact in temperature (top row) and precipitation (bottom row) of using high or low productivity EFTs. 1988 was a dry year, while 1998 was a wet one.

6. A South American Land Data Assimilation System - control run 1979-2004.

(Gerd, de Goncalves, Herdies)

This section describes the activities performed during the second year of this project 2009/10, in connection to the item (a) on Section 3 ("Activities and Findings") from the 2008 Progress Report (PR): "Develop 25-year (1980-2005) datasets employing a Land Data Assimilation System at adequate resolutions with all possible in situ and remotely sensed observations including land use and land cover changes, useful for agricultural and hydrological assessments and applications"

A control run from 1979-2004 using the Noah LSM and MERRA atmospheric forcing was generated over the entire South American continent. João Gerd Z. de Mattos is a PhD student at the National Institute for Space Research (INPE) under supervision of Dr. Dirceu Herdies and Dr. Luis Gustavo G. de Gonçalves. He completed successfully at CPTEC/INPE a control run using the Noah LSM and MERRA atmospheric forcing. The control run spans from 1979 to 2004 in 10Km spatial resolution over the entire continent with output every 3 hours. The output variables are listed below:

Net Shortwave Radiation	Subsurface runoff	Average layer soil temperature
Net Longwave Radiation	Snowmelt	Average layer soil moisture
Latent Heat Flux	Change in soil moisture	Total soil wetness
Sensible Heat Flux	Change in snow water equivalent	Interception evaporation
Ground Heat Flux	Average surface temperature	Vegetation transpiration
Snowfall rate	Surface Albedo	Bare soil evaporation
Rainfall rate	Snow Water Equivalent	Root zone soil moisture
Total Evapotranspiration	Snow Depth	Total canopy water storage
Surface runoff	Snow Cover	

The main objective of this work is to produce a set of simulations of land surface states over South America using atmospheric data sets from different sources to force the NOAH land surface model. The first set of simulations is from South American Land Data Assimilation System (SALDAS) for the period from January 2000 to December 2004. The second set is forced by the Modern Era Retrospective-analysis for Research and Applications (MERRA) from January 1979 to December 2006. These two sets of simulations will be used as control runs for subsequent experiments focusing over the La Plata Basins.

Figure 5 shows monthly means averaged over the La Plata region from January 2001 to December 2001 for precipitation, evapotranspiration, surface runoff and baseflow. It is noticeable that the land surface model partitions water differently from one set of atmospheric forcing to another (i.e. SALDAS and MERRA). These results show that there are low runoff and baseflow values produced by NOAH when forced by MERRA (red line named NOAH-MERRA). Consequently this simulation is being investigated in more details. Nonetheless this result shows the importance of using different sources of information, because each source can produce different responses of the land surface model over same region.

Figure 6 shows that NOAH simulations forced by MERRA result in more water in the soil when compared to the MERRA reanalysis only. This result could be explained by the fact that the NOAH model represents more accurately the soil levels in addition to better partition water in the soil column.

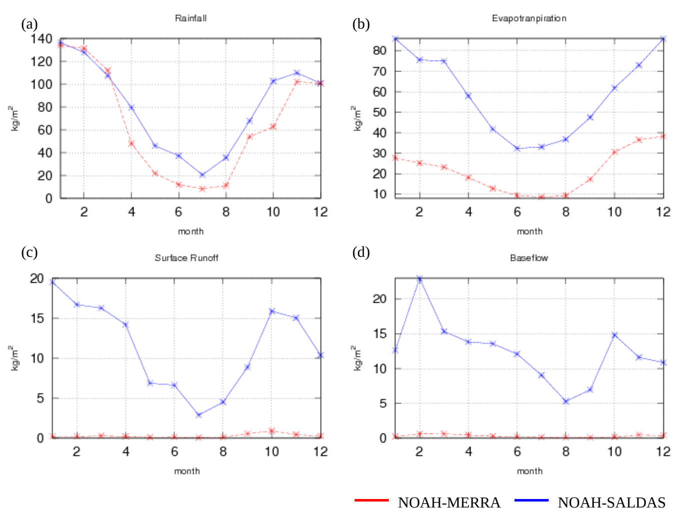


Figure 5: Monthly Mean over La Plata Basin for January 2001 to December 2001 of (a) rainfall, (b) Evapotranspiration, (c) Surface Runoff and (c) baseflow

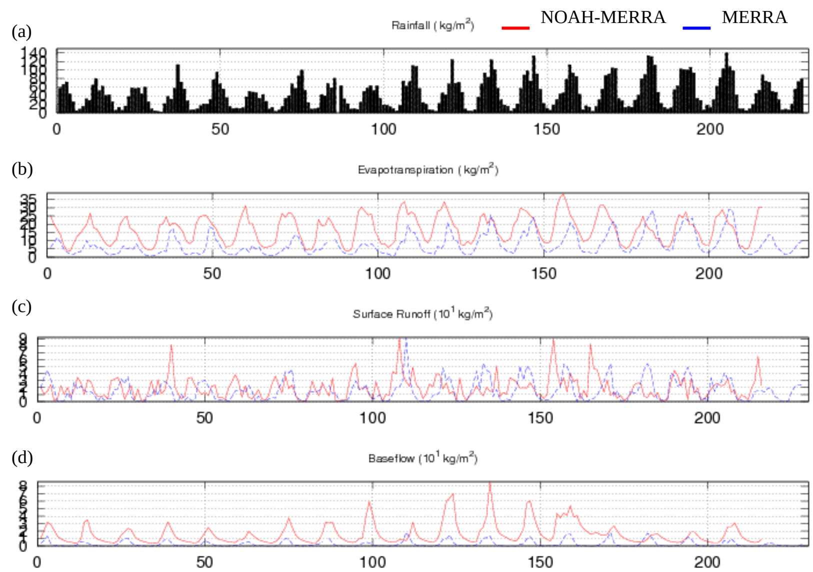


Figure 6: Monthly Mean over La Plata Basin from January 1989 to December 2004 of (a) Rainfall, (b) Evapotranspiration, (c) Surface Runoff and (d) Baseflow

7. Evaluation of the hydrological cycle over South America through the new generation Reanalyses

(Quadro, de Goncalves, Herdies, Berbery)

This study compared the main characteristics of precipitation over South America as estimated from six atmospheric reanalysis (MERRA, ERA-Interim, ERA-40, NCEP 1, NCEP 2 and CFSR). Five observation-based precipitation products (SALDAS, CPC, CMAP, GPCP and GLDAS) are employed for evaluation and to obtain a measure of the uncertainties in observations. Differences up to 1 mm day-1 are found among the observational datasets, while larger differences exist among the reanalysis. The CFSR, which is the latest reanalysis dataset available, presents the smallest biases probably due to the assimilation of GLDAS products. Taylor diagrams show that the observational products tend to be tightly grouped and close to the reference points (selected from the Climate Prediction Center observed precipitation), whereas most of reanalyses show correlation coefficients below 0.6. CFSR however, presented higher correlation coefficients relative to the others.

The moisture budgets of MERRA and CFSR do not fully close; while in general the imbalance is of the order of tenths of 1 mm day-1 for most regions, MERRA has a negative bias that exceeds 1 mm day-1 in the tropics, while CFS has a similar imbalance over LPB.

8. Estimating evapotranspiration over the La Plata Basin using MODIS/AVHRR Leaf Area Index (LAI)

Goergen, de Goncalves)

Estimates of evapotranspiration over the region of the Plata Basin were prepared using data from leaf area index obtained from remote sensing, via MODIS sensor. The method used to accomplish the estimation of evapotranspiration is known as the Penman-Monteith. This technique uses beyond the atmospheric forcings as net radiation, air temperature, relative humidity and vapor pressure parameters related to vegetation and soil.

During the first months of the year, work has focused on acquiring and evaluating data of leaf area index, estimated by remote sensing (MODIS sensor, **figure 7**). Weights were also made on the atmospheric forcing derived from South American Land Data Assimilation System (SALDAS). These forcings are used as input in the equation. The SALDAS is a data assimilation system which provides the forcing for the entire South American continent, in a time interval of three hours and with a spatial resolution of 0.1 °.

The following steps were targeted in order to generate monthly maps of evapotranspiration over the La Plata Basin for the period 2001 to 2004 (**Figure 8** – monthly mean March). The monthly average values of evapotranspiration over the basin were compared to estimates made by models based on the calculation of energy balance, and the results showed that the use of data from leaf area index in the equation of Penman-Monteith reproduced satisfactorily the spatial variation as the seasonal variation of evapotranspiration.

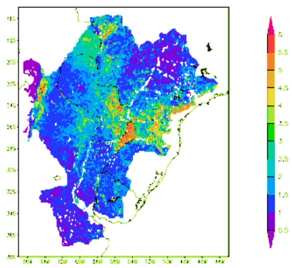


Figure 7 – Leaf area index in La Plata Basin from MODIS sensor (mean 2001-2004)

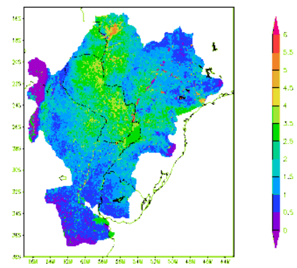


Figure 8 – Monthly mean (March) Evapotranspiration in La Plata Basin

9. Remote Consequences caused by Amazon deforestation in the La Plata Basin

(Guedes, Herdies)
The doctoral candidate at INPE, Marília Guedes do Nascimento under the supervision of Dr. Dirceu Herdies investigated during the second year of this project the impacts of Amazonian deforestation in the water balance of the La Plata Basin. The Amazon region is an important source of atmospheric moisture to the La Plata, responsible for maintaining processes such as Mesoscale Convective Complexes (MCC) and the South Atlantic Conversion Zone (SACZ) relevant to the precipitation regime over that region. This is an ongoing research consequently only planning activities and preliminary results are described in this project as follows.

The main objective of this work is to perform a climatology (1979-2008) of the water balance over South America in order to investigate how the moist atmospheric components over the Amazon region can influence the water balance on the La Plata Basin. The specific objectives we seek to answer the following research questions: a) The Amazon region behaves as a source or sink of moisture to South America? b) The central region of South America, including the Alto Paraguai Basin, contributes to moisture transport from tropics to extratropics? c) The La Plata Basin rainfall is modulated by water balance over Amazon and central South America regions? d) What the possible impacts of the Amazon land use changes ond the La Plata Basin rainfall?
The following steps were performed:

1) Review of the bibliography
2) Acquisition and organization of datasets
3) Validation for the period of 10 years (1999-2008) of the MERRA X TRMM and NCEP-3 X TRMM.

The table below show in summary form the results found through this validation for the La Plata Basin region:

Table 1 – Validation of the MERRA and NCEP-3 reanalysis.

	1999-2008	Summer	Autumm	Winter	Spring
Mean Error	539.4 mm/yr	576.6 mm/yr	530.9 mm/yr	330.4 mm/yr	535.9 mm/yr
MERRA Underestimate	41.5%	30.33%	41.58%	56.22%	42.91%
Mean Error	235.3 mm/yr	359.8 mm/yr	84.7 mm/yr	33.3 mm/yr	279.5 mm/yr
NCEP-3 Underestimate	18.11%	18.92%	6.64%	5.67%	22.38%

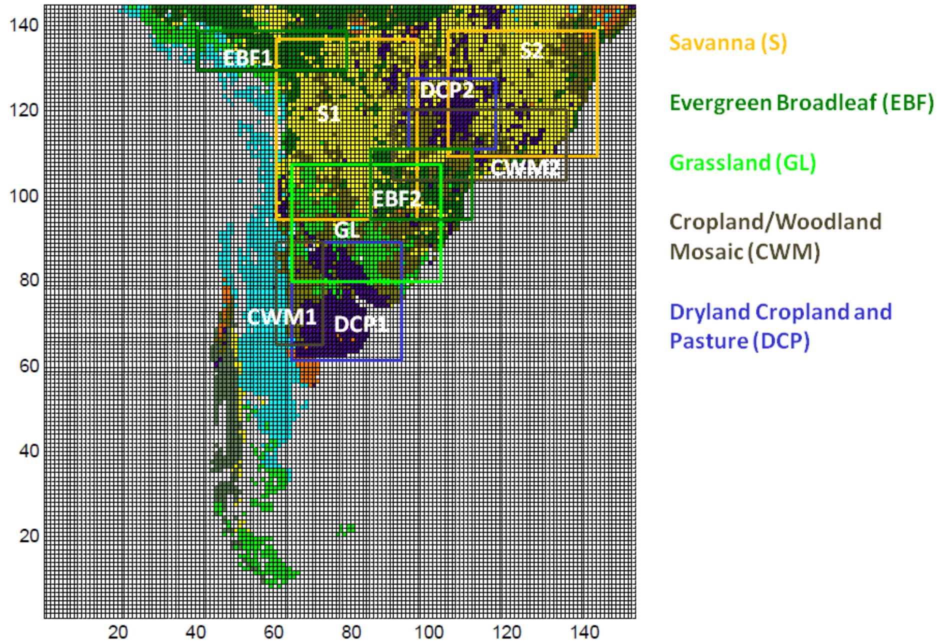
Based on these results it was decided to use the NCEP-3 reanalysis to carry out the proposed water balance, because these data show a better performance than the MERRA data with respect to variable rainfall.

10. Spin-up-analysis for different types of land covers

(Sorensson, Berbery)

As the lower boundary of the climate system over continents, the land surface influences the climate on a wide range of spatial and temporal scales. The partitioning of the net radiation at the surface into sensible and latent heat fluxes is an important factor for the near surface temperature, moisture and winds. The soil moisture evolution, which acts as a low frequency modulator of the climate is directly determined by the partitioning of heat fluxes. These fluxes have a great spatial variability that depends to a large extent on the land surface cover (LSC). That is, given the same atmospheric input to the surface (e.g., radiation, precipitation), desert, crops, pastures and forests will return different fluxes to the atmosphere.

Since the regional climate model (RCM) is initialized with fields from another model, the initial fields are not in equilibrium with the RCM dynamics and this will cause noise during a period of adjustment. This period of adjustment is commonly known as spin-up time (Anthes et al., 1989), and it is well known that the spin-up of the atmospheric processes is about 2-10 days (Seth and Giorgi, 1998). The spin-up of the soil moisture is a slower process and, depending on the region, the season of initialization, the regional model and the initial fields it can be up to one year for South America (Sörensson, 2010). When studying land surface – atmosphere interaction, it is important to have an estimate of the soil moisture spin up time to avoid erroneous interpretation of the results. The spin up time will be defined as the time that any linear trend can be seen in the soil moisture, and the subsequent simulations will be analyzed taking the spin up time into account. Two experiments were carried out, one started in July (JU) and the other in January (JA). The analysis focuses on several regions of La Plata Basin representing specific land cover types, as indicated in the figure. Results for selected regions will be discussed.



In some regions, such as EBF 1, LHF and SHF are more clearly governed by SM than by radiation budget, in other regions there is a mix of those two factors, and in some regions, grassland e.g. heat fluxes are more radiation budget controlled (when analyzing this one has to look at the JU simulation where soil moisture and atmosphere are in equilibrium). Another interesting thing is the capacity of Savanna 2, CWM2 and DCP2 to use soil water from the 4th layer, although there are no roots in this layer. Grassland does not show this characteristic, in spite of a dry period of similar extent. For the other regions no extended dry periods are found within these 90 days, so it is left to confirm.

Heat fluxes behave very differently in EBF 1 and EBF 2 (once again, looking at JU). This could be a result of the more saturated soil in EBF 2, but due to the similarity in heat fluxes behavior among EBF 2, CWM2 and DCP2, it could be interesting to look at LAI.

11. Agricultural component (Clyde Fraisse)

The main objectives of the agricultural component of our project are to learn the needs of agricultural producers in the region as related to climate information and forecast, investigate the potential impacts of climate variability on crop production, implement capacity building activities, and introduce the application of climate information and forecast into stakeholders' decision making process. Specific objectives include:

1. Establishment of weather monitoring sites in Paraguay
2. Calibration and validation of crop models for main crops
3. Development of a drought monitoring system for the region
4. Implementation of a web-based decision support system
5. Assessment and evaluation activities
6. Evaluation of crop yield forecast based on the combination of climate regional circulation models with crop models.

Significant progress has been made in most of the project objectives. The Federation of Cooperatives in Paraguay developed a project to install 20 weather stations in the main production areas of the country (Appendix A). Most of the stations (17) will be installed in Eastern Paraguay. The system will be funded and operated by the federation of Cooperatives and will provide data to the web-based climate information and decision support system proposed under Objective 4 of our project. As stated previously, the lack of historical and current weather data is a main constraint for the development and implementation of strategies to reduce production risks associated with climate variability in Paraguay. The cost of the network is estimated at $60,000 and will be entirely by the cooperatives in the region.

Progress made in crop modeling activities (Objective 2) has been mainly related to data collection and organization. A research assistant, Alicia Eisenkolbl, has been hired to help carry on the data collection and assessment activities. Alicia has a degree in Agronomy from the University Católica Nuestra Señora de la Asunción. We decided to concentrate efforts in locations for which a minimum dataset required for performing crop model simulations is available. Management practices such as typical crop rotations are being inventoried. (Table).

Under Objective 3, development of a drought monitoring system, the web development component is quite advanced. Implementation was originally planned for after the installation of the weather stations as the proposed drought index depends on real time (daily) weather data to estimate potential evapotranspiration (ETo) and other components of the soil water balance such as runoff, infiltration, and deep percolation. Nevertheless, during our last project meeting in March 2010 we decided to implement a prototype version that will estimate the index using a simplified equation for determining ETo (Hargreaves or Priestley and Taylor) for a limited number of stations that are already operational. Arrangements are being made for uploading temperature and rainfall data from these stations.

Table. Examples of typical crop rotations in the region.

Rotation		Crop / Season					
1	Crop	Soybeans	Wheat	Soybeans 2nd	Wheat		
	Season	Sep- Mar	Apr - Oct	Oct - Apr	May - Oct		
2	Crop	Soybeans Early Maturity	Maize 2nd or Sorghum	Sunflower	Soybeans 2nd	Wheat	Soybeans
	Season	Sep - Feb	Feb - Jun	Jul - Dec	Dec - May	May - Oct	Nov - Apr
3	Crop	Maize	Maize 2nd or Sorghum	Sunflower	Soybeans 2nd	Wheat	Soybeans
	Season	Early Sep - Jan	Jan - Jun	Jul - Dec	Dec - May	May - Oct	Nov - Apr
4	Crop	Sorghum	Sorghum 2nd	Sunflower	Soybeans 2nd	Wheat	
	Season	Late Sep - Jan	Natural regeneration until May/Jun	Jul - Dec	Dec - May	May - Oct	
5	Crop	Sorghum	Sorghum 2nd	Fallow			Soybeans
	Season	Late Sep - Jan	Natural regeneration until May/Jun	Jul - Oct			Oct - May

A server has been purchased by the University of Passo Fundo to host the Open AgroClimate system being implemented. Temporarily the address to the system is: http://mosaico.upf.br/~py/. Pages are in the process of being populated and will include a main page with news and outlooks, El Niño Southern Oscillation (ENSO) phase forecast and discussion, background information about ENSO, a page with the basics of climate change and potential impacts on agriculture, an “about” page with information about Open AgroClimate and a list of links of interest. Tools will include a climate risk tool for a reduced number of stations (5) with a reasonably long data series that can be used for establishing climatology. In addition we are in process of developing a tool that will provide crops statistics (Figure 1) under the perspective of ENSO phases. We have also established an agreement with NOAA-CPC to provide weather forecasting products for the expected precipitation amounts and anomalies during the next one or two-week time frame.
Clyde Fraisse provided a 20+ report (most in Spanish). I can forward it to IAI’s management if desired

12. Publications

Alcaraz-Segura, D. H. Berbery, S.J. Lee, J. Paruelo, 2011: Use of ecosystem functional types to represent the interannual variability of vegetation biophysical properties in regional models. *Variability of the American Monsoon System Newsletter*.

Alcaraz-Segura D, Chuvieco E, Epstein HE, Kasischke E, Thishchenko A., 2010: Debating the greening vs. browning of the North American boreal forest: differences between satellite datasets. Global Change Biology, 16(2), 760-770.

Alcaraz-Segura D, Berbery H, Paruelo JM, (To be submitted) Using ecosystem functional types in land-surface modeling to incorporate the inter-annual variability of vegetation properties. Global Change Biology

Alcaraz-Segura D, Paruelo JM, Epstein HE, Cabello J. (To be submitted) Considering interannual variability and trends in the definition of Ecosystem Functional Types. Global Ecology and Biogeography.

Alcaraz-Segura D, Epstein HE and Paruelo JM. Drivers of the functional diversity at the ecosystem level across environmental and land-use gradients in the Rio de la Plata basin. Global Ecology and Biogeography (to be submitted).

Baldi, G., D. Alcaraz-Segura, E. Jobbágy. In revision. The role of biophysical and human contexts shaping productivity in the dry subtropics. Global Ecology and Biogeography

Berbery, E. H., D. Herdies, Domingo Alcaraz-Segura, L. G. G. de Goncalves, Dennis P. Lettenmaier, D. Toll, 2011: Summer School Summary: The international summer school on land cover change and hydroclimate of the La Plata basin. Manuscript in preparation, to be submitted to the Bull. Amer. Meteor. Soc.

Lee, S.-J., and E. H. Berbery, 2011: On the Effects of Land-Cover Change on the Climate of the La Plata Basin. Manuscript in preparation to be submitted to J. Hydrometeor.

Paruelo, J., D. Alcaraz-Segura, J. Volante. In press. El seguimiento del nivel de provisión de los servicios ecosistémicos en Argentina. Valoración de Servicios Ecosistémicos: Conceptos, Herramientas y Aplicaciones Para el Ordenamiento Territorial. Ed. J. Paruelo, E. Jobbágy, P. Laterra.

Quadro, M. F. L., M. A. Faus da Silva Dias, D. L. Herdies, L. G. Gonçalves de Gonçalves, E. H. Berbery, 2011: Evaluation of the hydrological cycle over South America through the new generation Reanalyses. Submitted to the J. Geophys. Res.

Volante, J., D. Alcaraz-Segura, M.J. Mosciaro, J. Paruelo. Accepted. Assessing the effect of land clearing on ecosystem services provision in north-western Argentina. Agriculture, Ecosystems and Environment

13. Meetings (oral and poster presentations)

Alcaraz-Segura, D., E. Hugo Berbery, José Paruelo, E.G. Jobbagy. (2010). Detection of inter-annual trends in land-surface properties of La Plata Basing using Ecosystem Functional Types derived from LTDR (1981-2000) and MODIS (2000-2010). American Geophysical Union Meeting of the Americas. Iguaçu, August 2010.

Bastarz, C F, D L Herdies, J P Reyes Fernandez, 2010: Impact of Precipitation Assimilation in CPTEC?S RPSAS System: A Case Study of Mesoscale Convective Complexes. American Geophysical Union Meeting of the Americas. Iguaçu, August 2010.

Berbery, E. H., Alcaraz-Segura, D., S.J. Lee, O. M. Muller, 2011: On the use of Ecosystem Functional Types to represent lower boundary conditions in the WRF/Noah Model. 25th Conference on Hydrology, Amer. Meteor. Soc., Seattle, USA.

do Nascimento, M G, D L Herdies, D O de Souza, C F Angelis, 2010: Evaluation of Precipitation over South America in the Reanalysis MERRA. American Geophysical Union Meeting of the Americas. Iguaçu, August 2010.

do Nascimento, M G, C F Angelis, D L Herdies, D O de Souza, 2010: THE PRECIPITATION BEHAVIOR OVER THE LA PLATA BASIN UNDER INFLUENCE OF LOW LEVEL JETS. American Geophysical Union Meeting of the Americas. Iguaçu, August 2010.

de Mattos, J Z, L Goncalves, D L Herdies, 2010: Impacts of the Precipitation and Evaporation Patterns over the La Plata Basin Streamflow. American Geophysical Union Meeting of the Americas. Iguaçu, August 2010.

Ferreira, S H, M A Gan, D L Herdies, 2010: Energetics of South America Low Level Jets. American Geophysical Union Meeting of the Americas. Iguaçu, August 2010.

Quadro, M L, M A Silva Dias, L Goncalves, D L Herdies, E H Berbery, 2010: Characterization of the Regional Hydrologic Cycle of the South America. American Geophysical Union Meeting of the Americas. Iguaçu, August 2010.

14. Data

Distribution of data is expected to start later in the year.

Following suggestions from other groups in land use, we are exploring the possibility of making relevant information available to the community through maps in Google Earth, a tool that is becoming popular with stakeholders in agriculture. **Figure 10** presents one of our first tests, which presents precipitation (low resolution in this case) for South America. The plan is to have these maps focusing with more detail on La Plata Basin.

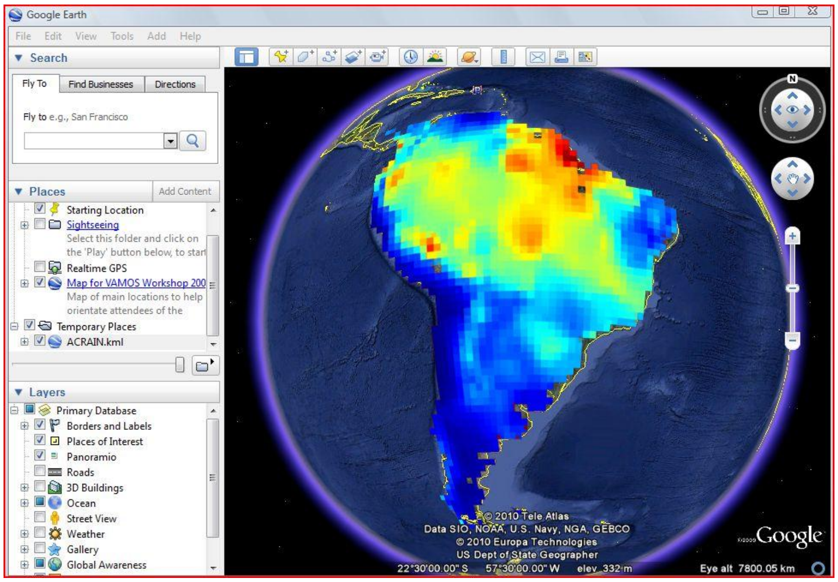


Figure 10. Example of South American precipitation in the Google Earth environment.

ANNEX 1

Second PIs Meeting
San Luis, San Luis, Argentina, 28-30 April 2010

Agenda

April 28:

Field trip

Involved 3-4 stops showing key land use changes and ecosystem types in the area of San Luis

Stop 1 – Gradients in the region, biome transitions, historical land uses
Stop 2 – Water cycle, water demands, irrigation (afforestation)
Stop 3 – Deforestation and dryland agriculture

April 29:

9:00	Hugo Berbery	Introductions, the CRN-2094 Project
9:30	Dirceu Herdies	Status of datasets, DAS/CPTEC
9:50	Gustavo de Goncalves	Status of SALDAS
10:10	Anna Sorensson	Rooting depth/Ecoclimap
10:30-11:00		**Coffee Break**
11:00	Esteban Jobbagy	CRN-2031 + other activities in San Luis (30 min)
11:30	Domingo Alcaraz-Segura	Ecosystems
11:50	General discussion (25 min)	
12:15-14:00 Lunch		
14:00	Dennis Lettenmaier	Hydrologic modeling in the La Plata Basin
14:20	Juan Pablo Martini + Diego Steinaker *	
14:40	Javier Houspanossian + Marcelo Nosetto *	
15:00	Victoria Marchesini + Roberto Fernandez *	
15:20	Debora Roberti	Flux Towers/Cruz Alta, further plans

(*) Each couple represents grad student + advisor, should be enough to give a perspective of ongoing work and leave time for general/group discussions

15:40-16:10 Coffee Break

16:10 – 17:30 Discussion and plans for possible future collaborations

April 30:

9:00-10:20 Students

- Joao Gerd: LDAS
- Claudia Ramos: Soil moisture assimilation
- Carlos Bastarz:
- Marilia Nascimento:
- Guilherme Goergen: Evapotranspiration
- Mario Quadro:

10:20-10:50 Coffee Break

10:50	Hugo Berbery	Report of First Summer School
11:10	Alfredo Garcia + Carlos DiBella	
11:30	Eugenia Kalnay	OMR update
11:50	Mario Nuñez	UMI (+ ERA Interim)

12:10-14:00 Lunch

14:00
Any additional talk that may be needed
Final Discussion (future collaborations, activities)
Plans for year 3
Plans for a Second Summer School
Funding
…

ANNEX 2

Estimación de las anomalías mensuales del índice de vegetación mejorado (EVI).
(Jose Paruelo)

Introducción

El forraje es el principal insumo alimenticio de los rodeos ganaderos argentinos. A pesar de la crucial importancia en la dieta, solemos desconocer cuál es la productividad forrajera de amplias regiones de Argentina con un detalle que permita:

a) el manejo, la planificación y el ordenamiento de los rodeos ganaderos y

b) un diagnóstico en tiempo real de situaciones anómalas como los déficits o excesos de forraje.

Para el desarrollo de seguros ganaderos necesitamos conocer la productividad con buen detalle en el espacio y en el tiempo. Dada la imposibilidad de efectuar técnicas de tasación tradicionales, la lógica que emplearemos es la de generar bases de datos más o menos extensas de productividad forrajera que nos permitan evaluar la cantidad y frecuencia de anomalías de al principal fuente de alimento del ganado. Esta aproximación se basa en el hecho de que la producción de forraje tiene un impacto directo sobre la producción animal. Además, a escala regional la productividad está mucho mas controlada por las condiciones ambientales (precipitaciones, temperatura, tipo de suelo, características estructurales de la vegetación dominante) que por las decisiones de manejo de cada productor particular. Entonces, conocer la productividad forrajera permitirá, por un lado, cuantificar la frecuencia de anomalías causadas por variables ambientales en un contexto histórico y establecer así la probabilidad de ocurrencia del siniestro. Por otro lado, el seguimiento continuo en el tiempo y espacio de la productividad forrajera permitirá establecer en tiempo real la cuantía y extensión de una anomalía (ver por ejemplo Grigera et al 2007 y Oyarzabal 2008).

Afortunadamente, desde hace un tiempo la tecnología satelital permite realizar estimaciones de la productividad de la vegetación. Los sensores a bordo de satélites miden luz reflejada por la superficie terrestre que, para el caso de coberturas vegetales, está estrechamente asociada a actividad fotosintética y por lo tanto al crecimiento o productividad. Gracias a esta particularidad y al hecho de que existen datos satelitales desde la década del 80 hasta el presente, podemos hoy generar bases de datos de productividad más o menos extensas en el tiempo y, potencialmente, de toda la superficie terrestre.

En este informe presentamos la puesta a punto de la metodología para la generación de mapas de anomalías en el funcionamiento de la vegetación. Elegimos un área piloto de del NW de la Patagonia para la cual ya tenemos mapas de tipos fisonómicos de vegetación gracias a que algunos investigadores del LART vienen trabajando en el área desde hace aproximadamente 10 años (Paruelo et al. 2004). Utilizamos información provista por un sensor (MODIS) a bordo de un satélite TERRA/AQUA. Estas imágenes MODIS fueron seleccionadas debido a que es la única plataforma satelital de alta resolución espacial y temporal que llega a la actualidad.. Específicamente usamos un índice de vegetación (EVI) como subrogado de la productividad primaria neta aérea. El índice abarca el período comprendido entre el año 2000 y la actualidad La metodología aquí presentada para la obtención de mapas de anomalías para cada tipo de vegetación, será fácil y directamente aplicable a la obtención de mapas de anomalías específicos para los tipos de uso / tipos de recurso presentes en el SW bonaerense una vez que tengamos confeccionado el mapa de coberturas de esta región.

Métodos

La información satelital utilizada en esta puesta a punto de la metodología para la estimación de las anomalías de la productividad, proviene del de índice de vegetación mejorado (EVI, por sus siglas en inglés) provisto por las imágenes MODIS-TERRA (producto MODIS 13Q1). Estas imágenes poseen una resolución espacial de 250 metros y una resolución temporal aproximadamente quincenal y están disponibles para el período que se inicia en febrero del año 2000.

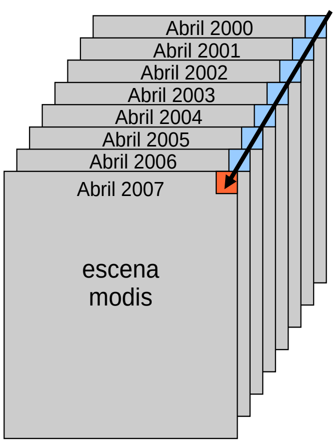
El EVI es un estimador de la fracción de radiación fotosintéticamente activa interceptada por la vegetación, y por lo tanto de la productividad, la cual es el principal determinante de la disponibilidad de forraje (Oesterheld et al. 1992, 1998, Paruelo et al. 1999). La ecuación de este índice es la siguiente

$$EVI = G \cdot \frac{\rho_{IRC} - \rho_R}{\rho_{IRC} + C_1 \cdot \rho_R - C_2 \cdot \rho_A + L}$$

Donde ρ representa la reflectancia con correcciones atmosféricas en el infrarrojo cercano (*IRC*), el rojo (*R*) o el azul (*A*), C_1, C_2 y L son coeficientes. Este índice fue desarrollado con el fin de mejorar la sensibilidad a la vegetación y disminuir las influencias del sustrato y la atmósfera, respecto a otros índices de vegetación.

Previo a todos los análisis la serie de valores de EVI para cada píxel fue mensualizada (figura 6). Debido a la gran cantidad de pixeles MODIS que el área abarca (mas de 9 millones), todo el procesamiento para al calculo de las anomalías fue realizado mediante programas *ad hoc* implementados en los lenguajes Python e IDL.

Con el fin de ilustrar la metodología, las anomalías mensuales, en términos de la desviación estandarizada porcentual respecto a la media mensual para el período considerado, fueron estimadas para dos años "piloto", con niveles de precipitación contrastantes: 2007 (año de sequía importante) y 2009 (año con condiciones normales de precipitación). Para el año 2007, las anomalías fueron estimadas considerando las medias mensuales para el periodo 2000-2006, mientras que para el año 2009, considerando las medias mensuales del período 2000-2008. Esta aproximación nos permitirá determinar hasta que punto la metodología propuesta logrará discriminar la respuesta de la vegetación en condiciones contrastantes.



$$anomaliaEVI_{abril\,2007} = \left(\frac{EVI_{abril\,2007} - mediaEVI_{abril\,2000-2006}}{mediaEVI_{abril\,2000-2006}} \right) \times 100$$

Figura 6. Representación esquemática del cálculo de las anomalías del EVI para un mes específico.

En una etapa posterior, las anomalías serán calculadas para todos los meses de todos los años de la serie con el fin de estimar la frecuencia de anomalías por debajo de un determinado umbral, el cual determinara las acciones a tomar por parte de las aseguradoras. La comparación de la anomalía para un determinado mes (por ejemplo abril de 2009) con la distribución de frecuencias de las anomalías de abril (de todos los años) para un área dada, permitirá determinar si dicha área se encuentra en una situación de siniestro.

Con el fin de determinar las anomalías características de las unidades de vegetación dominantes, así como la variabilidad de las mismas, los mapas de anomalías serán cruzados con una reclasificación de las unidades de vegetación, generada en base a la clasificación de unidades fisonómicas presentada en Paruelo et. al (2004).

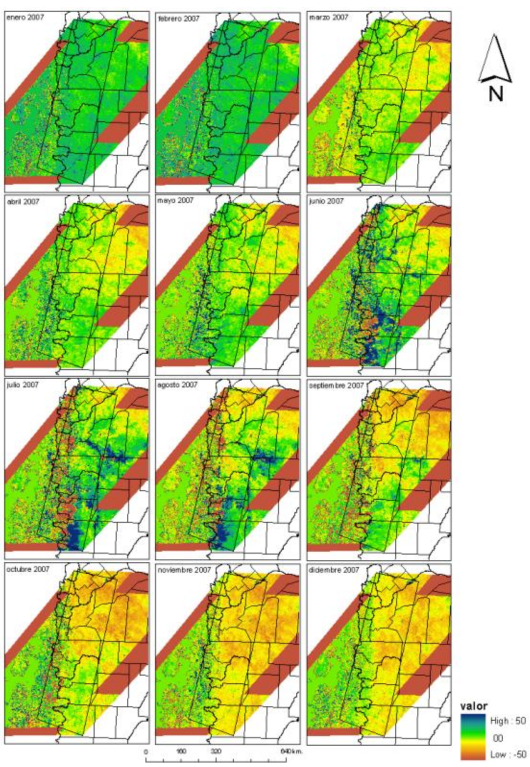
Resultados

Las mapas de anomalías muestran notables diferencias sobre todo en los meses en los que comienza a aumentar el stress hídrico (fin de la primavera – verano). Concretamente en los mapas correspondientes a 2007 (figura 7) se observa que durante los meses de septiembre a diciembre hay una mayor incidencia espacial de déficits (mas de 50% del área considerada) en la productividad (mayor incidencia de naranjas-amarillos).

En los mapas correspondientes a 2009, (figura 8) y para los meses invernales (lluviosos) se observa una mayor incidencia espacial anomalías positivas, por encima de los promedios históricos de productividad (incidencia de azules en el mapa).

En general los departamentos localizados al noroeste son los que muestran una mayor incidencia de anomalías negativas en ambos años. Por otro lado la mayor incidencia espacial de anomalías se da hacia el oeste y suroeste. Posiblemente estos patrones en las anomalías estén reflejando el fuerte gradiente de precipitación W-E presente en la región.

En la tabla 1, se muestra el porcentaje del área en distintas clases de anomalías negativas (por debajo de la media, un 25% por debajo de la media y un 50% por debajo de la media), para cada mes de los dos años considerados. En esta tabla se puede apreciar que a partir del mes de abril, la incidencia de anomalías negativas es consistentemente más alta en 2007. Dada la heterogeneidad espacial en la distribución de las anomalías, los porcentajes en cada clase de anomalía variaran si consideramos los mismos para los distintos departamentos o unidades de vegetación.



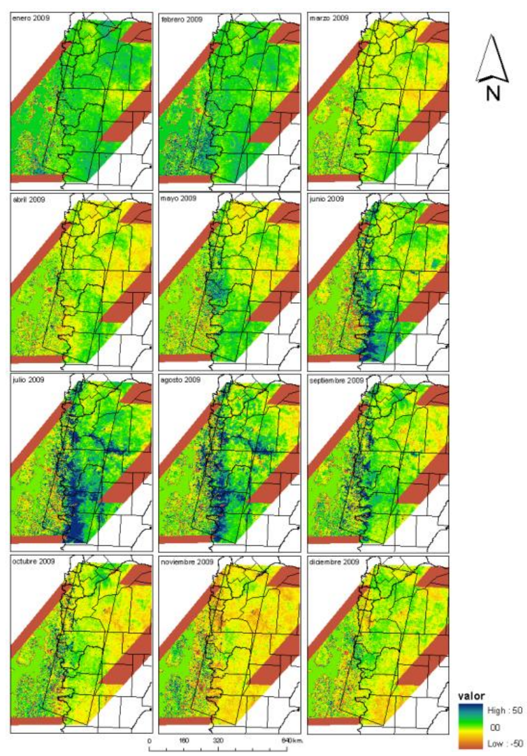


Figura 7 (left panel). Mapas de anomalías mensuales de EVI para el año 2007, superpuesto sobre un mapa de la región con los límites departamentales argentinos y una delimitación del área para el cual se cuenta con el mapa de tipos de vegetación

Figura 8 (right panel). Mapas de anomalías mensuales de EVI para el año 2009. superpuesto sobre un mapa de la región con los limites departamentales argentinos y una delimitación del área para el cual se cuenta con el mapa de tipos de vegetación.

Tabla 1. Porcentaje del área (en términos de píxeles) en las distintas clases de anomalía para los meses en cada uno de los años considerados: <0, por debajo de la media histórica, <25%, 25% por debajo de la media histórica y <50%, 50% por debajo de la media histórica.

		2007	2009
	<0	12,77	23,67
enero	<25%	4,25	4,24
	<50%	2,83	2,73
	<0	12,2	25,35
febrero	<25%	3,87	3,95
	<50%	2,62	2,09
	<0	56,58	58,96
marzo	<25%	6,29	5,7
	<50%	3,04	2,43
	<0	57,03	54,92
abril	<25%	4,21	4,02
	<50%	3,52	2,9
	<0	45,67	41,17
mayo	<25%	6,98	9,29
	<50%	3,03	3,75
	<0	39,6	32,99
junio	<25%	5,35	4,68
	<50%	4,65	2,09
	<0	41,3	33,43
julio	<25%	14,99	9,14
	<50%	9,26	4,62
	<0	43,12	37,52
agosto	<25%	15,92	14,26
	<50%	8,29	5,62
	<0	60,76	47,31
septiembre	<25%	18,85	7,59
	<50%	7,78	4,39
	<0	66,96	60,79
octubre	<25%	19,32	9,43
	<50%	4,98	1,26
	<0	70,09	64,32
noviembre	<25%	17,36	15,63
	<50%	4,39	2,77
	<0	68,2	61,4
diciembre	<25%	12,38	8,89
	<50%	3,39	3,56

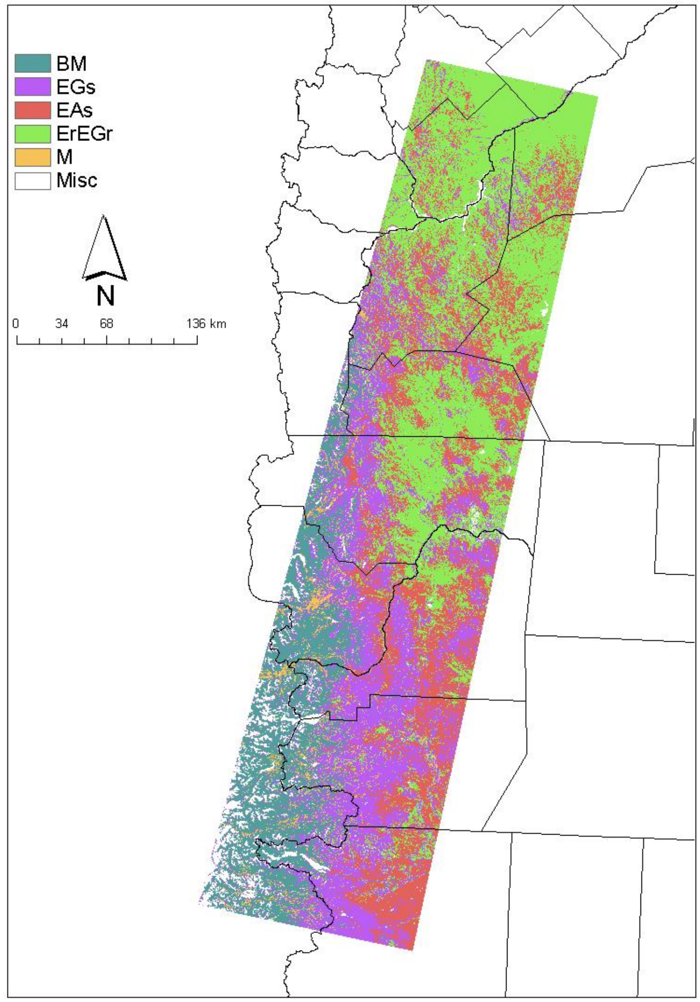


Figura 9. Reclasificación de los tipos de vegetación sobre la base de la clasificación presentada en Paruelo et. al (2004). Las clases son las siguientes: BM, bosque y matorral, EGs, estepas graminosas y graminoso-arbustivas, EAs, estepas arbustivas y arbustivo graminosas, ErEGr, eriales (semidesiertos) y estepas graminosas ralas, M mallines, Misc, miscelaneos (roca, nieve y agua).

Estimación de la productividad en base a información espectral proveniente de dos plataformas satelitales diferentes

Varios índices espectrales han sido diseñados para la estimación de la productividad siendo el mas utilizado el índice de vegetación normalizado (Piñeiro et al 2006, Paruelo et al. 2004). Este índice integra dos aspectos espectrales clave de los tejidos fotosintéticos: su baja reflectancia en las longitudes de onda correspondientes al rojo y su alta reflectancia en las longitudes de onda correspondientes al infrarrojo cercano. El IVN es calculado de acuerdo a:

(1) $$IVN = \frac{IRc - R}{IRc + R}$$

Donde *R* es la reflectancia en el rojo e *IRc* es la reflectancia en el infrarrojo cercano.

El IVN ha sido relacionado con la productividad primaria neta aérea de la vegetación (PPNA), así como con el índice de área foliar (IAF) y por lo tanto con la fracción de radiación fotosintéticamente activa interceptada por la vegetación (fPAR). La relación entre IVN y fPAR permite estimar la radiación fotosintéticamente activa absorbida (APAR), multiplicando la fPAR (derivada del IVN) por la radiación fotosintéticamente activa incidente (PAR). Finalmente, la PPNA puede ser obtenida mediante la aplicación del modelo de Monteith (1972) el cual establece que

(2) $$PPNA = \varepsilon \cdot \int APAR$$

Donde ε representa la eficiencia en el uso de la radiación y $\int APAR$ representa la integral de la radiación absorbida en un determinado periodo de tiempo. Todo este proceso es esquematizado en la figura 10.

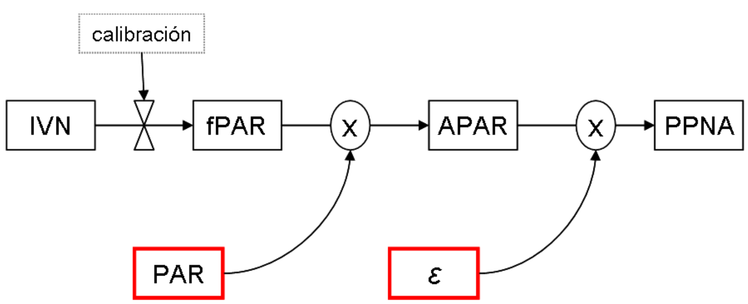


Figura 10. Esquema del proceso de obtención de la productividad primaria neta aérea (PPNA) en base a información espectral proveniente de satélites (IVN), información de radiación fotosintéticamente activa incidente proveniente de estaciones meteorológicas (PAR) e información de eficiencia de uso de la radiación proveniente de bibliografía y desarrollos metodológicos previos (ε).

La información de eficiencia en el uso de la radiación es específica del tipo de cobertura del suelo. Su valor sera derivado entonces de las clasificaciones del uso del suelo que se estan desarrollando en paralelo.

Obtención de las series mensuales de índices de vegetación

Si bien existe información espectral proveniente de sensores a bordo de diferentes satélites desde 1980, a la actualidad no contamos con un registro contínuo y unificado en términos de resolución temporal y espacial. Por esta razón la obtención de una serie contínua de fPAR implica el empalme de la información proveniente de (en nuestro caso) 2 plataformas satelitales con diferentes características (Tabla 2).

Tabla 2. Plataformas satelitales utilizadas para la obtención de las series de fPAR y sus características principales.

plataforma	Resolución espacial	Resolución temporal	Periodo
LTDR serie 2	≈2500 has	Diaria	1981 -1999
MODIS	5 has	16 días	2000 - presente

La plataforma LTDR (por sus siglas en ingles “long term data record”) combina una alta resolución temporal con una resolución espacial moderada. Esta plataforma provee información de calidad que nos permite estimar la utilidad de la información brindada por los índices de vegetación, y eventualmente descartar información de baja confiabilidad.

La plataforma MODIS (por sus siglas en ingles “moderate resolution imaging spectroradiometer”) a bordo del sistema de observación terrestre de la NASA (EOS-NASA) combina una alta resolución espacial y moderada resolución temporal, y al igual que la plataforma LTDR, provee información adicional que permite estimar la calidad de los índices de vegetación. Esta plataforma provee además un índice de vegetación mejorado (EVI, por sus siglas en ingles). Este posee una mayor sensibilidad a la señal espectral de la vegetación respecto al IVN. Por esta razón utilizamos este índice.
Para obtener series con una resolución mensual para cada índice (IVN proveniente de LTDR, y EVI de MODIS) aplicamos la tecnica de maximo valor compuesto quincenal, seleccionando como representativo de cada quincena el día con mayor valor del índice. Posteriormente el valor mensual fue obtenido como el promedio de los valores quincenales.

Posteriormente a la obtención de valores mensuales, el píxel MODIS fue degradado a píxel LTDR. De este modo obtuvimos un valor mensual de EVI MODIS correspondiente al promedio de todos los pixeles MODIS que caen dentro de cada píxel LTDR (un píxel LTDR equivale a aproximadamente 400 pixeles MODIS). Este proceso es esquematizado en la figura 11.

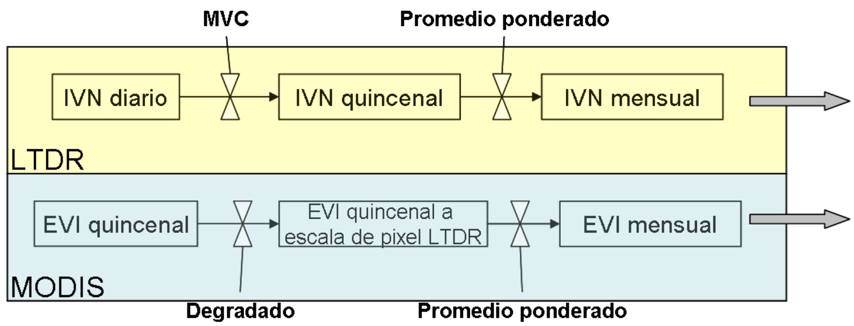


***Figura 11**. Esquema del proceso de obtención de los valores mensuales de Índices de vegetación, para su uso posterior en la obtención de los valore mensuales de fPAR.*

Calibración de la relación entre los índices de vegetación y la fPAR.

Para estimar la fPAR en base a los índices de vegetación utilizamos la aproximación empírica que asume una relación lineal entre los índices (IVN o EVI) y la fPAR. Para esto seleccionamos alrededor de 1000 pixeles LTDR correspondientes a salinas (en donde asumimos una fPAR del 1%) y 1900 pixeles LTDR correspondientes a selva no perturbada (en donde asumimos una fPAR del 95%). Para esos mismos pixeles extrajimos tanto la serie mensual de IVN LTDR y de EVI MODIS, de modo de asociar los valores mas bajos de IVN y EVI en las salinas (el percentil 2%) a los valores inferiores de fPAR y los valores mas altos de IVN y EVI de las selvas (el percentil 98%) a los valores mas altos de fPAR. El proceso es esquematizado en la figura 12. Con los puntos extremos de la relación IVN-fPAR e EVI fPAR, obtuvimos la relación lineal que nos permite pasar de índice de vegetación a fracción de la radiación fotosintèticamente activa interceptada. Estas calibraciones son mostradas en la figura 13.

Las ecuaciones asociadas a las calibraciones para IVN LTDR y EVI MODIS fueron las siguientes

(3) $$fPAR_{LTDR} = \min(0.95, (\max(0.01, -0.0343 + 1.176 \times IVN_{LTDR})))$$

(4) $$fPAR_{MODIS} = \min(0.95, (\max(0.01, 0.0071 + 1.0277 \times EVI_{MODIS})))$$

Mediante estas ecuaciones obtenemos estimaciones de la fPAR para cada píxel LTDR para el período que va desde 1980 a la actualidad.

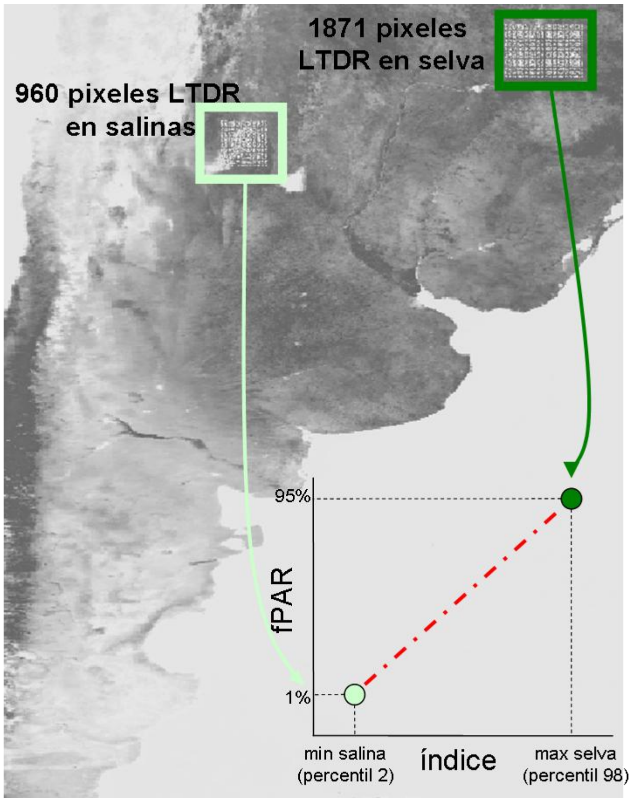


Figura 12. *Esquema del proceso de calibración de la relación entre los Índices de vegetación y la fracción de radiación fotosintéticamente activa absorbida por la vegetación.*

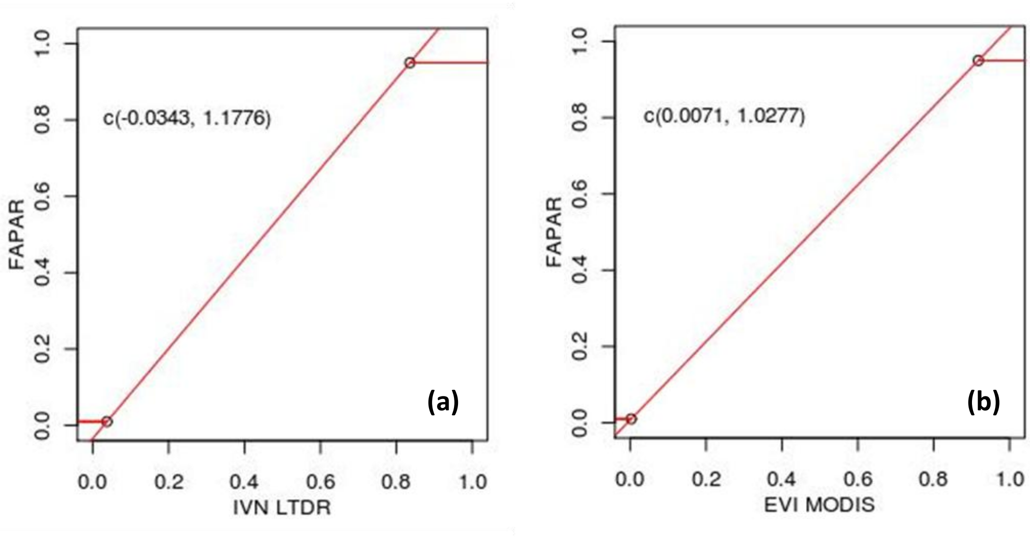


Figura 13. *Calibraciones lineales entre (a) el IVN LTDR y (b) el EVI MODIS. Los parámetros de la calibración lineal son mostrados en el ángulo superior izquierdo de cada gráfico.*

Bibliografía

Grigera G, Oesterheld M, Durante M, Pacín F. 2007b. Evaluación y seguimiento de la productividad forrajera. Revista Argentina de Producción Animal 27:137-148.

Monteith JL. 1972. Solar radiation and productivity in tropical ecosystems. Journal of Applied Ecology 9:747–66.

Oesterheld, M., Sala, O. E., and McNaughton, S. J., 1992. Effect of animal husbandry on herbivore carrying capacity at a regional scale. Nature, 356:234-236.

Oesterheld, M., Di Bella, C. M., and Kerdiles, H., 1998. Relation between NOAA-AVHRR satellite data and stocking rate of rangelands. Ecological Applications, 8:207-212.

Oyarzabal M, Oyonarte C, Giorno A. 2008. Propuesta de un sistema de seguimiento y alerta para la gestión de espacios protegidos: el caso del Parque Natural Cabo de Gata-Níjar (Almería, España). Ecosistemas 17(3): 98-107

Paruelo JM, Epstein HE, Lauenroth WK, Burke IC. 1997. ANPP estimates from NDVI for the central grassland region of the US. Ecology 78:953–8.

Paruelo, J.M., Golluscio, R.A., Guerschman, J.P., Cesa, A.,Jouve, V.V., Garbulsky, M.F. 2004. Regional scale relationships between ecosystem structure and functioning: the case of the Patagonian steppes. Global Ecology and Biogeography 13,385-395.

Paruelo JM, Oesterheld M, Di Bella M, Arzadum M, Lafontaine J, Cahuepe´ M, Rebella C. 2000. Estimation of primary production of subhumid rangelands from remote Sensing data. Applied Vegetation Science 3:189–95.

Piñeiro, G., Oesterheld, M., Paruelo, J.M., 2006. Seasonal variation of aboveground production and radiation use efficiency of temperate rangelands estimated through remote sensing. Ecosystems 9:1-19.