THE HYDROLOGICAL CYCLE OF THE AMAZON BASIN: CLIMATIC IMPACT OF DEFORESTATION

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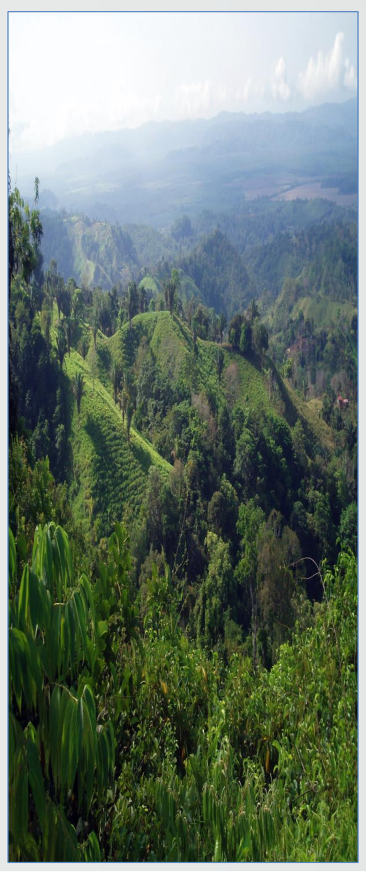
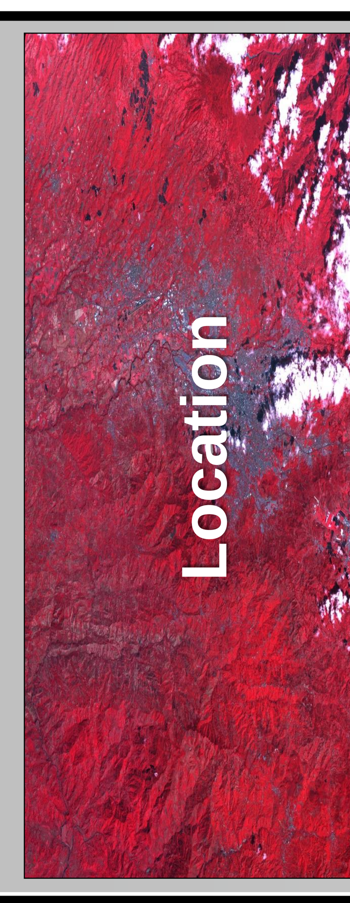


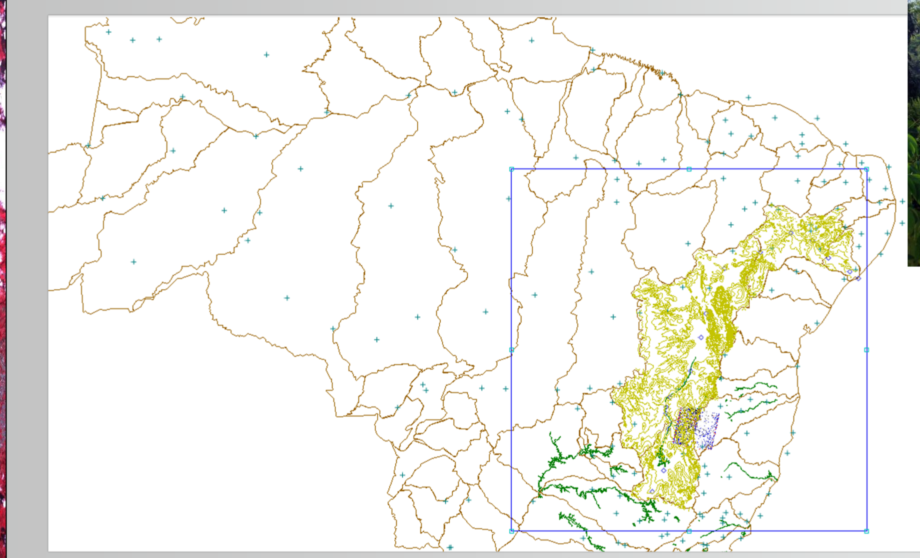
INTRODUCTION

Amazon is the largest rainforest in the world with a total area of about 7 million km2, representing about 56% of tropical forests on earth. In recent decades the Amazon is undergoing an accelerated process of occupation, which led to the deforestation of 16% of its area. This changes in Amazonian ecosystems can have an impact on atmospheric circulation in the global and regional moisture transport and hence in the hydrologic cycle. Past studies assumed that the change of the cycles of water, solar energy, carbon and nutrients, resulting from changes in land use in the Amazon could cause climatic and environmental consequences at local, regional and global scales.

This paper presents a historical review and current state of the hydrological cycle and the moisture balance components in the Amazon basin in order to quantify and understand the temporal changes of the Amazon surfaces caused by deforestation, affecting local and regional hydrological cycle. We have tested for this purposes multispectral images from SENTINEL-1, MODIS, ETM+ and OLI in a period between 2002 and 2015. The environmental impact of the basin has been studied through different vegetation indexes and soil patterns. Results are presented as an approach based on in situ validation whose main interest lies in the spatial correlation between land use changes and hydrological parameters on the area.



STUDY AREA



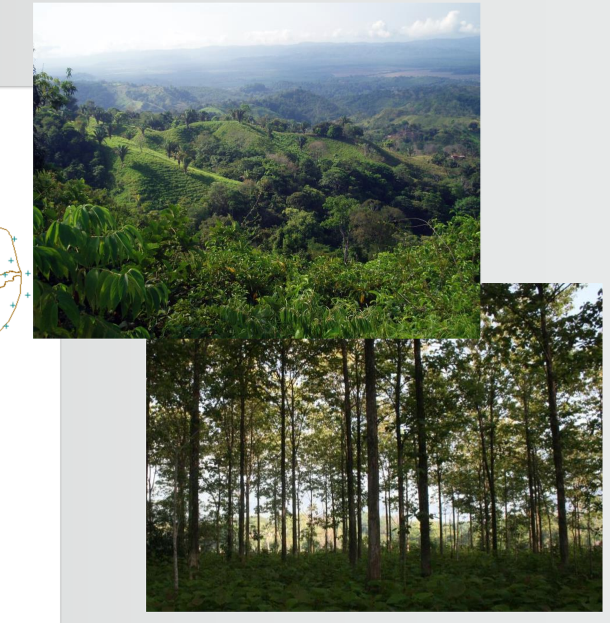


Figure 1. São Francisco river basin (2,051km²) and its representative watershed Pedro do Rio (411km²) are located in the mountainous region of Rio de Janeiro state – Brazil. In this region, the wettest trimester is **December - January - February**, which constitutes **45% of the average yearly amount**, around **900 mm** of the annual **2,000 mm**. In the lower region, the amount of this trimester is around **50%** of **the average yearly amount**, **650mm** of the annual **1,300mm**. The driest trimester encompasses June-July-August (CPRM, 2011). Altitude varies within the basin from 2,300 m on the ridge to 280m where Piabanha joins the main river Paraíba do Sul.

METODOLOGY

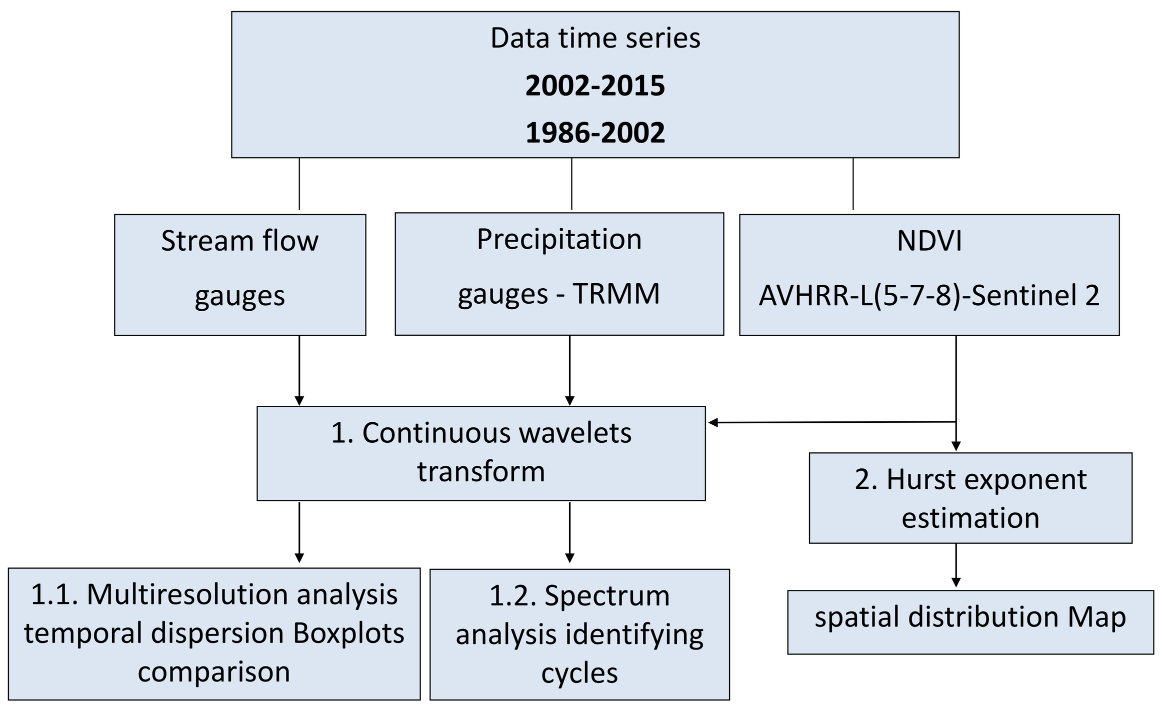


Figure 2. Synthesis of the methodology applied in this work.

TIME SERIES AND PROCESSING

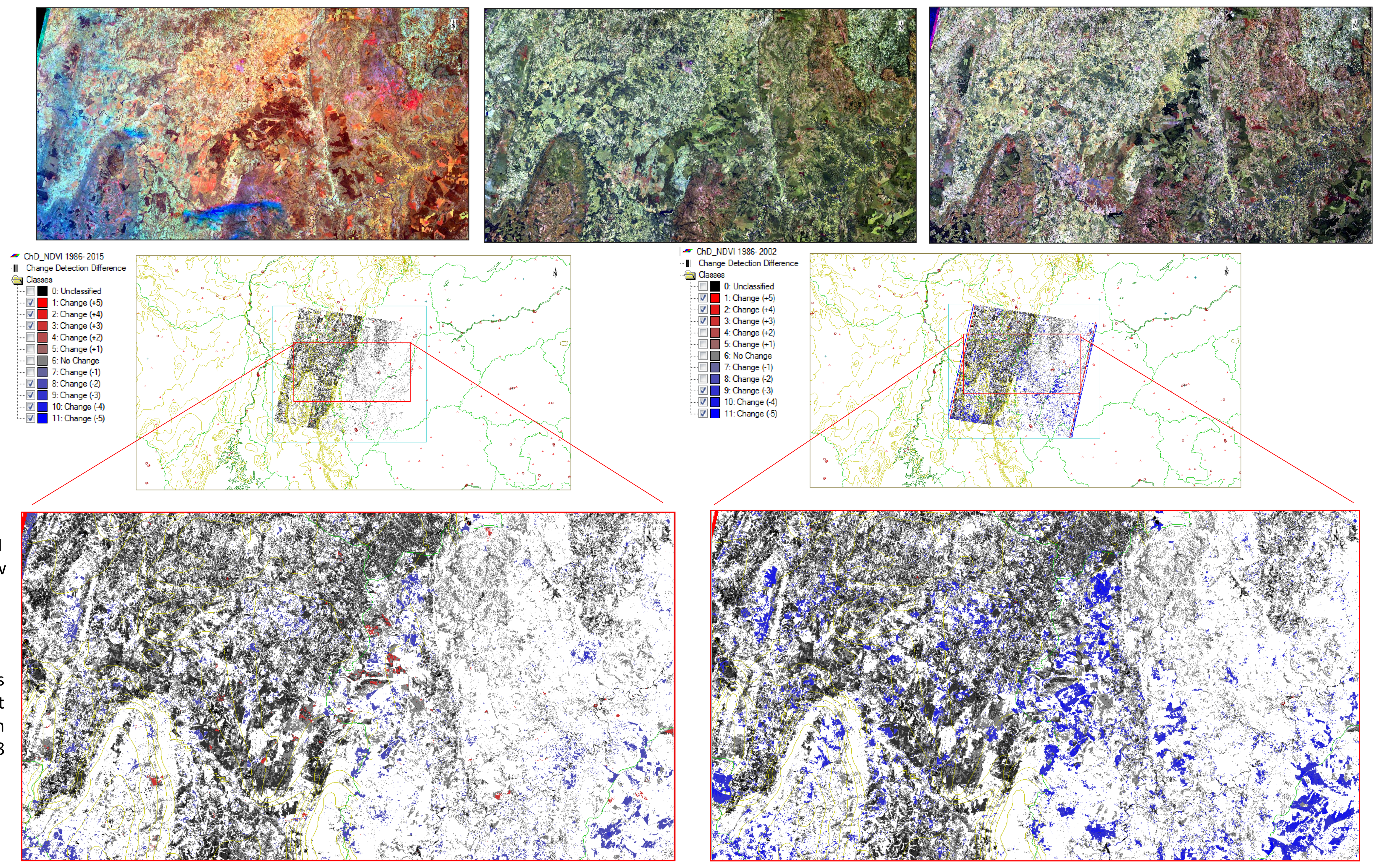


Figure 3. Examples of sub scenes of OLI (L(), ETM+ ((L7 and TM (L%) for 2015, 2002 and 1986, respectively (up). Examples of NDVI change detection (down) in Sâo Francisco river basin between 1986 and 2015 period (left) and 1986 and 2002 period. Its representative watershed Pedro do Rio (411km²) are located in the mountainous region of Rio de Janeiro state – Brazil. In this region, the wettest trimester is **December - January - February**, which constitutes **45%**

DATA AND RESULTS

Satellite based precipitation estimates (TRMM 3B42RT product) and biweekly vegetation index (NDVI -NOAA/AVHRR/L5,7,8/Sentinel 2) series are compared to daily observed precipitation and stream flow from 2001 to 2004 and from 2009 to 2015.

1. Continuous wavelets transform - results

Results of continuous **Haar wavelet transform** and **multiresolution analysis** (Haar 1910, Daubechies 1992) of data time series (1981-2006) - observational precipitation at a station and NDVI values at the pixel where the gauging station is located. The two more representative stations are shown (2243010 and 2243011). Successive details 2^{-j}: D1 = 1 month, D2 = 2 month, D3 = 4 month and D4 = 8 month to Δt = 15 day

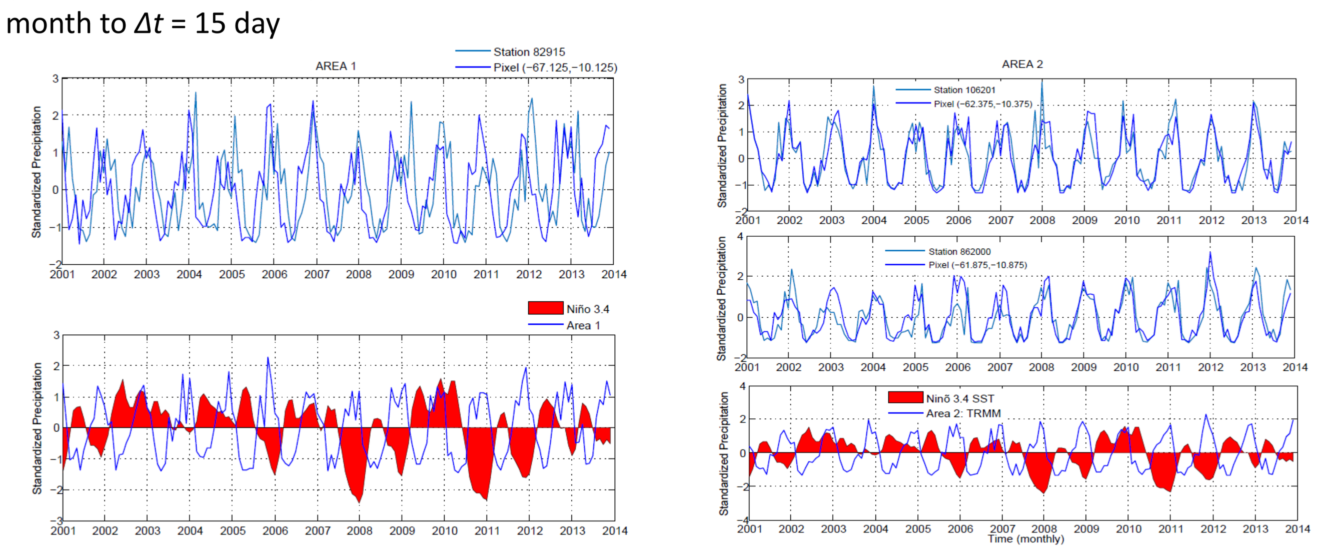


Figure **4**. Series temporales de la precipitación normalizada (mm/mes) observada - TRMM representativa para el AREA 1 (left). Series temporales de la precipitación normalizada (mm/mes) observada - TRMM representativa para el AREA 2 (right).

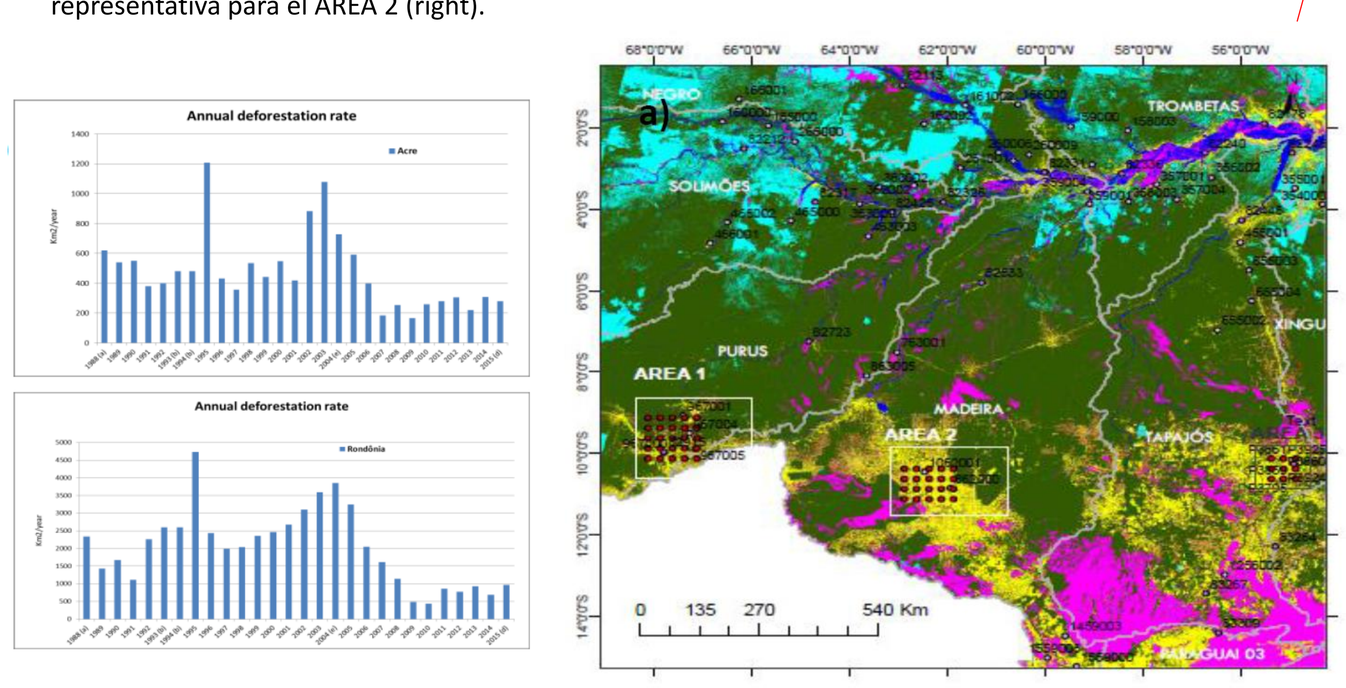


Figure 5. Mapa evolución anual de la deforestación durante el periodo 2000-2013 PRODES digital para el Amazonas Legal sobre áreas de estudio (right). Evolución anual de la Tasa de deforestación durante el periodo de 1888-2015 para los estados Acre –AREA1 y Rondônia-AREA 2 (left).

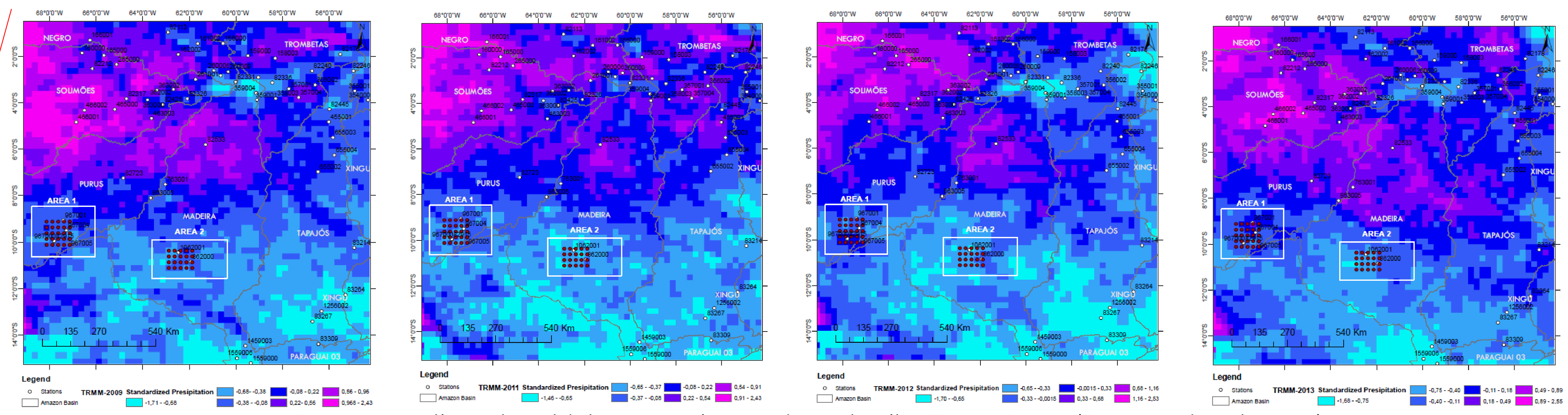


Figure 6. Anomalías total anual de la precipitación estimada por el satélite TRMM- 3B43_V6 (Enero 2009 diciembre 2013)

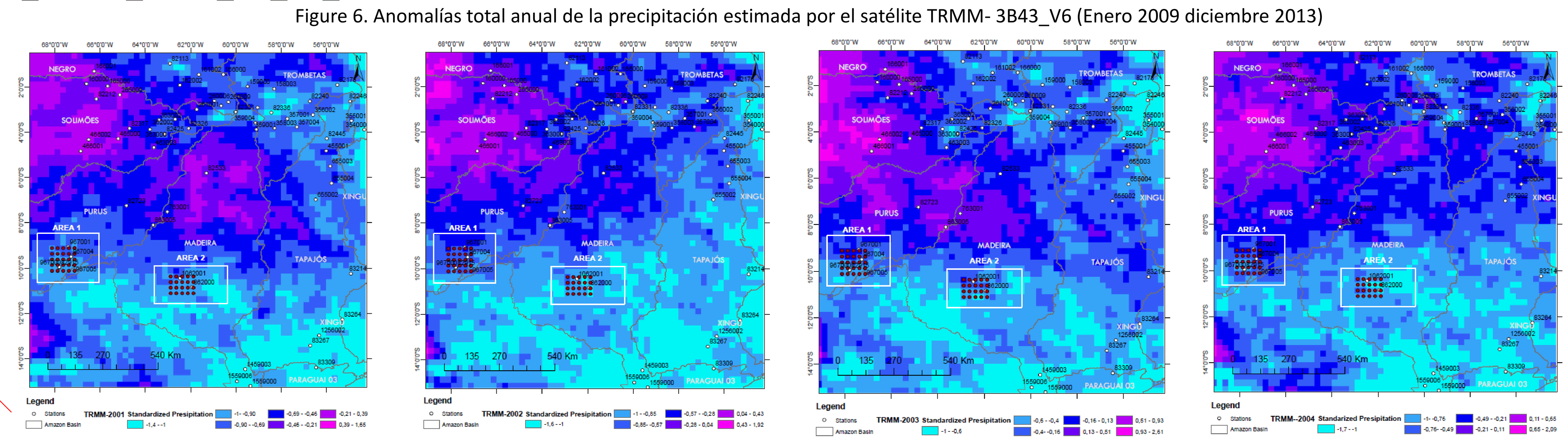
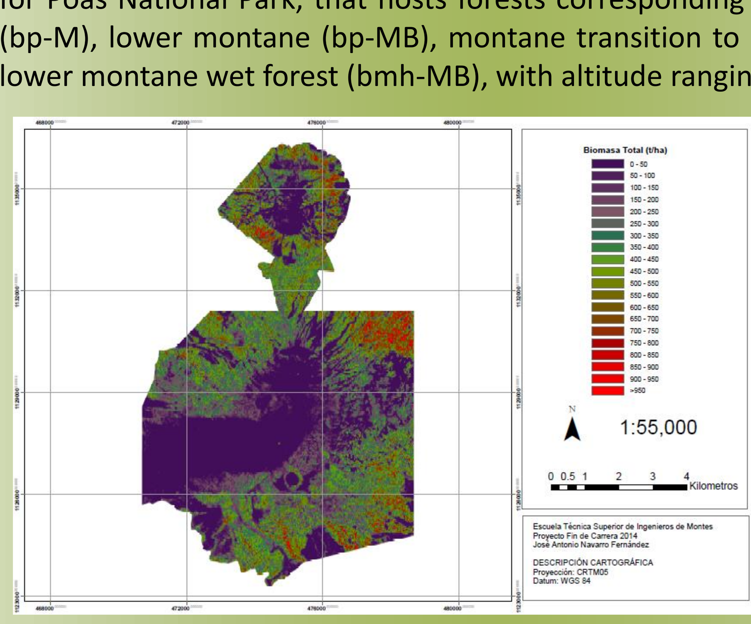
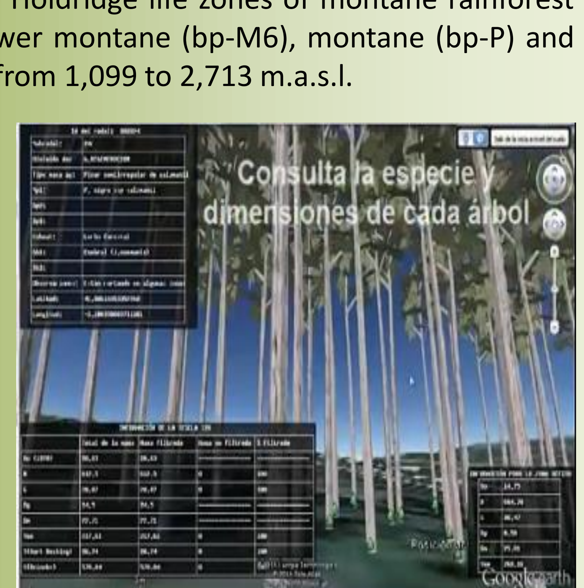


Figure 6. Anomalías total anual de la precipitación estimada por el satélite TRMM- 3B43_V6 (Enero 2001 diciembre 2004).

CENTRAL AMERICA experience

Airborne multispectral data technology was validated as a practical solution for the evaluation of **biomass and carbon for the Poas Volcano National Park** combined with in situ land cover Plots Networks. A **total aboveground biomass (AGB) model** was calibrated, depending on top of canopy heights (TCH) and regional approaches of basal area and wood density. The methodology was validated for Poas National Park, that hosts forests corresponding to Holdridge life zones of montane rainforest (bp-M), lower montane (bp-MB), montane transition to lower montane (bp-M6), montane (bp-P) and lower montane wet forest (bmh-MB), with altitude ranging from 1,099 to 2,713 m.a.s.l.





Total Biomass Estimation in Poas Volcano National Park (Navarro et al., 2013)

REDD+ implications & Further research

REDD + program requires **reliable mechanisms for Monitoring, Reporting and Verification (MRV)**. The combination of spatial data and In Situ validation Networks allows improving biomass with enough accuracy in low data environments, as tropical countries.

DISCUSSION AND CONCLUSIONS

In this work three procedures were applied in data time series analysis.

1) The Haar wavelet transform and multiresolution analysis were used to compare the temporal distribution of the variables showing consistency among them, indicating that TRMM - 3B42RT (pixel ~ 27.5km) precipitation estimates and NDVI - NOAA-AVHRR (pixel = 8km) are consistent with observational precipitation and stream flow data in the representative Piabanha river basin.

2) The Morlet wavelet transform with spectrum analysis were used in search for cycles in precipitation, NDVI and stream flow time series. For all the analyzed variables, an approximately 7-9 month cycle, possibly related to the most rainy period December to March, and another 3 year cycle, possibly related to El Niño Southern Oscillation (ENSO) or South Atlantic Convergence Zone (SACZ), were found. Both ENSO, specially its warm phase El Niño, and SACZ are responsible for the inter-annual precipitation variability and yearly amount climatology, that is higher than 1,500mm over most of the area.

3) For analyzing NDVI patterns, the re-scaled range (R/S) analysis (Hurst 1951, 1956, Sergei et al. 2003, Ashutosh et al. 2007), and the fractal dimension analysis (Mandelbrot 1969) were applied to the time series.

In general, for both studied periods, NDVI values follow closely the temporal precipitation variability. The non-persistent NDVI area consists of a lower region, with a flatter relief and is located on a different hydrogeological formation, having different land use and vegetation cover – grassland of a less dense type. The higher H values occur where forest is the predominant vegetation cover, an area limited by the 1,400mm contour on the yearly isohyets map. All these differences in physical characteristics between the areas, where persistent and non-persistent sets of NDVI pixels are located, suggest that the Hurst coefficient could be a good pattern recognition element for NDVI as vegetation and soil cover parameter.

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