Continuous satellite-based indicators for mapping subtropical forest degradation and its environmental impacts

REFORCHA

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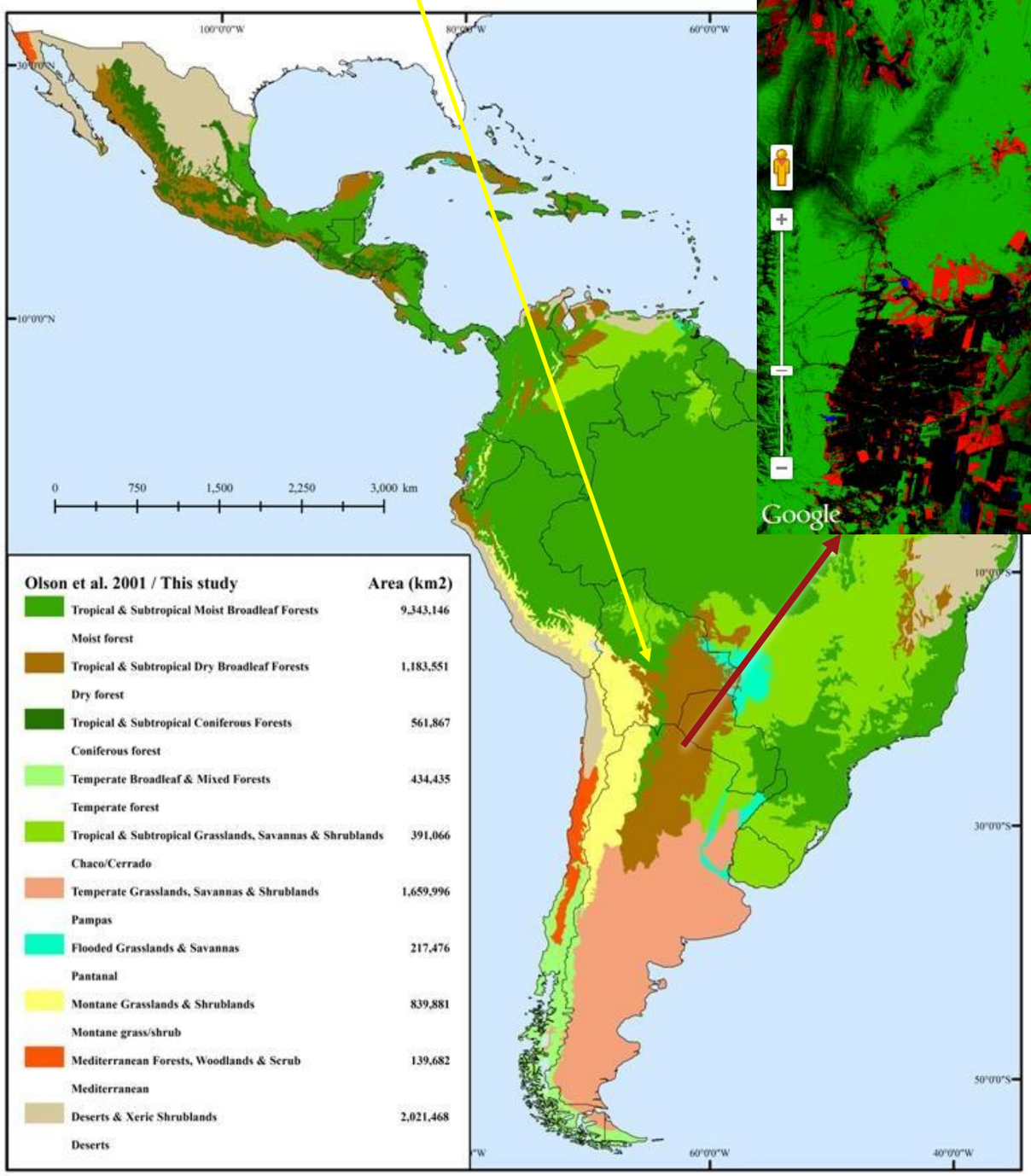
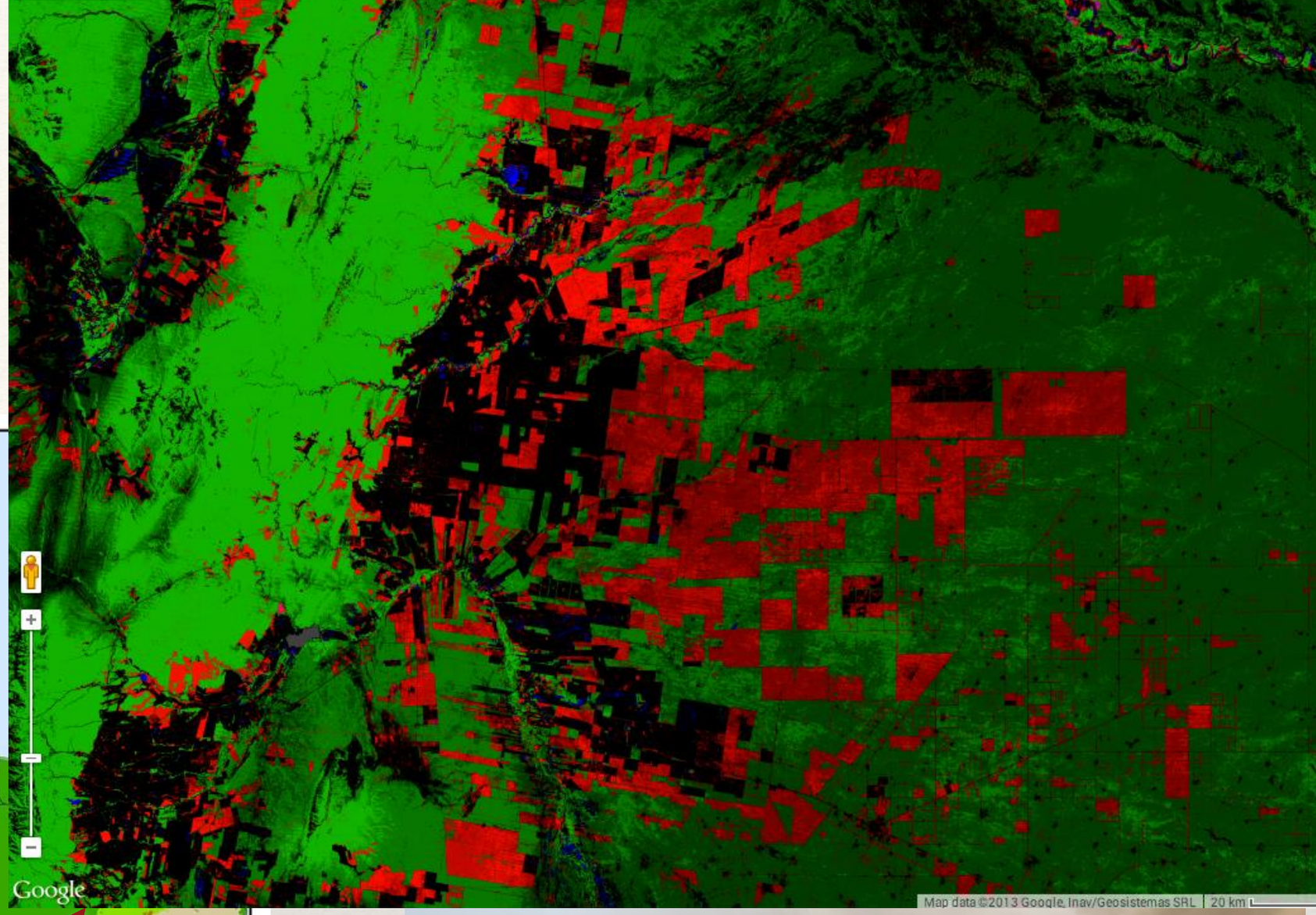
Gran Chaco:

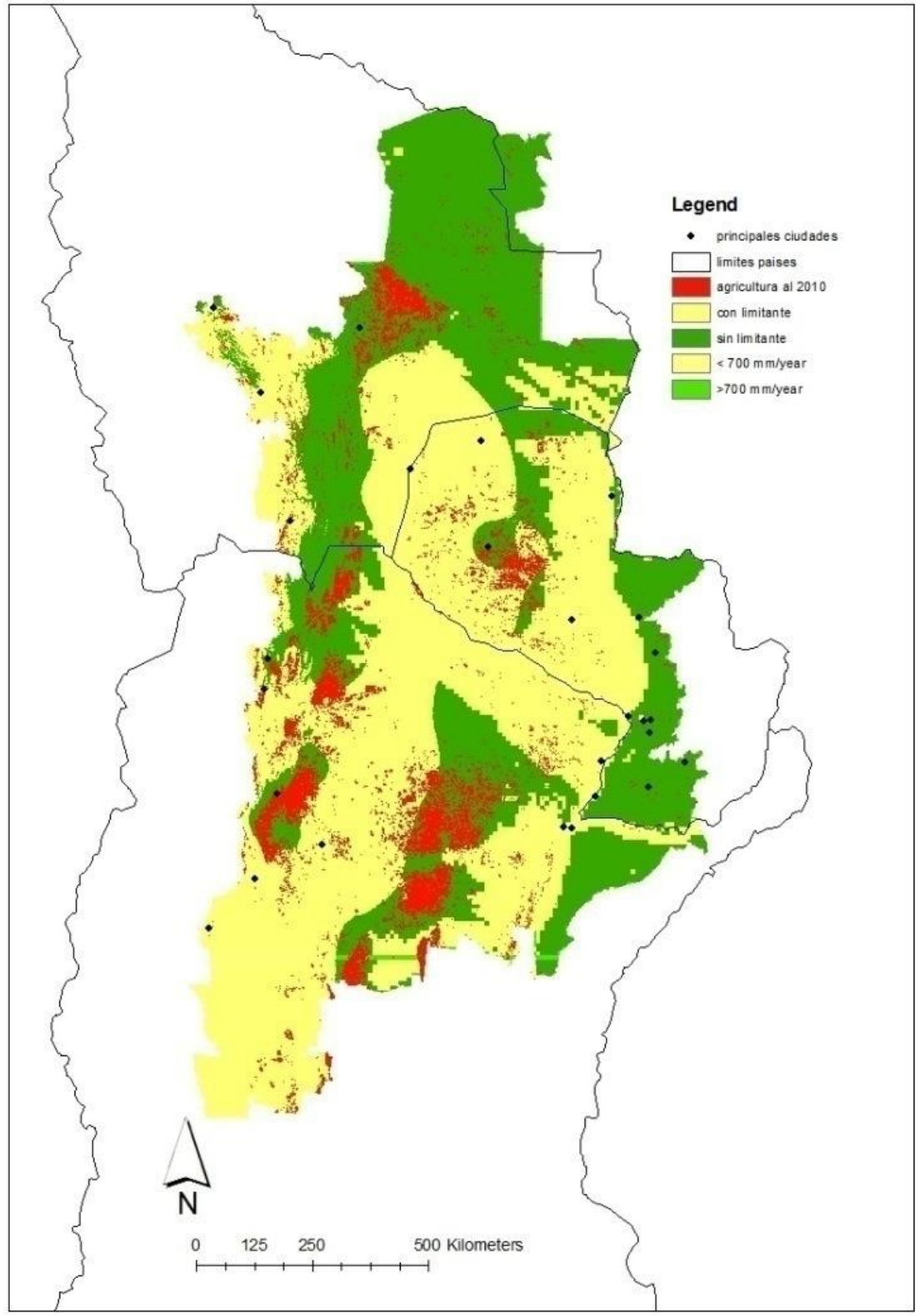
global deforestation hotspot





Geographic heterogeneity in environmental conditions

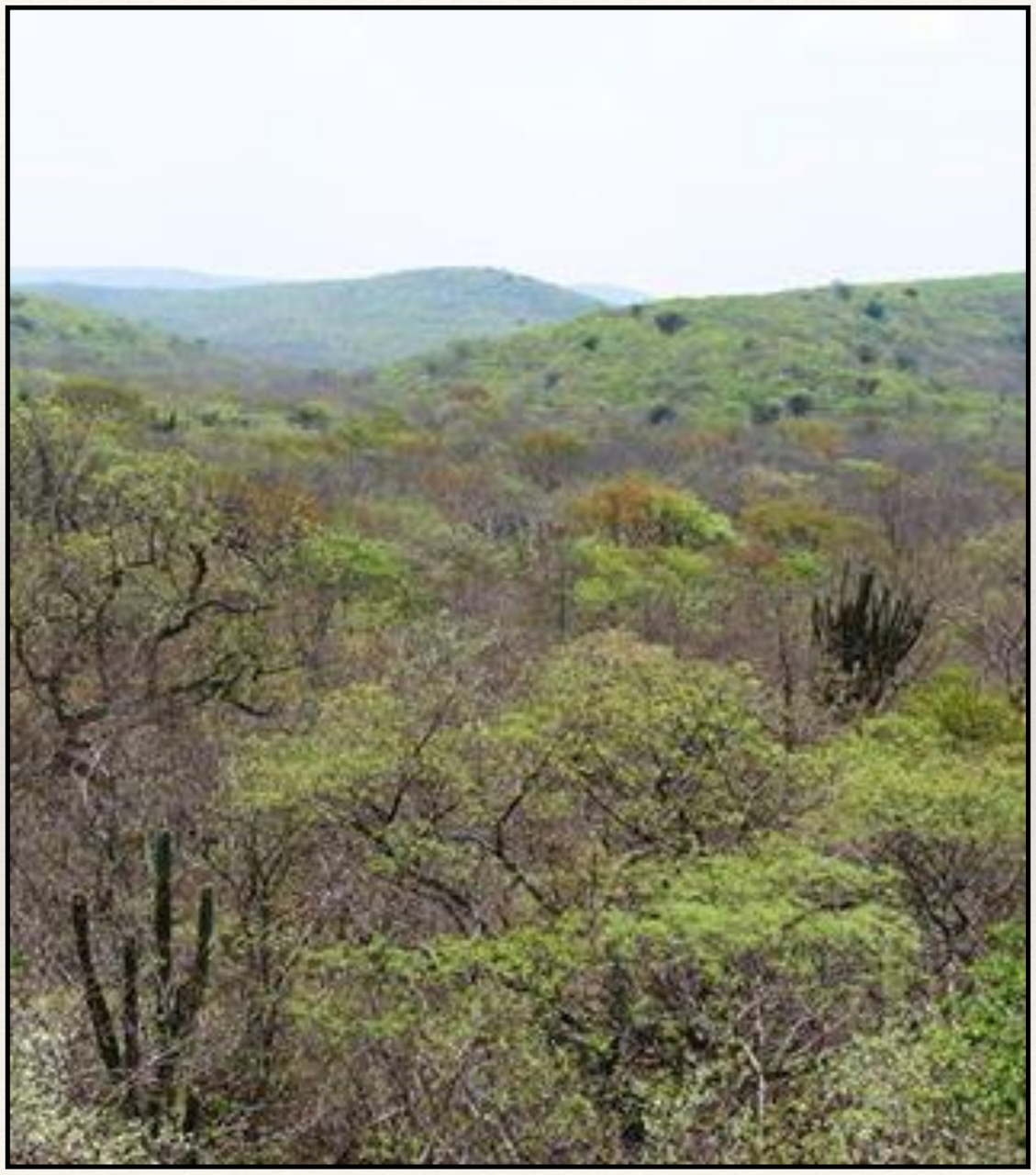
- Strong rainfall gradient: from ~1,200mm to 400mm (i.e., wet and dry Chaco)
- Natural vegetation: complex mosaic of forests, shrublands, savannas, wetlands, and grasslands
- More than 400 species of birds, 150 mammals, and 100 amphibians and reptiles
- More than 80 plant genera (3,400 species, 400 endemic)



Focus on subtropical woodlands and open forests

- Open forests are mixtures of trees, shrubs and grasses in which the tree canopies do not form a continuous closed cover.

- Highest rates of forest-cover changes have recently shifted to subtropical woodlands



Ecosystem degradation

- « The reduction in the capacity of the land to perform ecosystem goods, functions and services that support society and development, including vegetation and soil degradation »
- Measuring extent and severity of forest degradation, and their environmental impacts
- Remote sensing: key for this, but adequate tools are missing

Project objectives and Research frontiers

- Integrate multi-source remotely sensed data, field observations and land surface modelling to enhance our understanding of ecosystem degradation in drylands forests
- 1/ How can woodland degradation monitoring be improved using multi-sensor techniques ?
- 2/ How can remote sensing data be integrated in ecosystem models to assess ecosystem degradation ?
- 3/ How do land use actors and land use policies affect and are affected by ecosystem degradation ?

Monitoring woodland degradation using multi-source remote sensing techniques

Beyond traditional land-cover mapping based on classification

Use time-series of imagery to separate gradual from abrupt change in woodlands

Fusion low-temporal/high-spatial and high-temporal/low-spatial resolutions

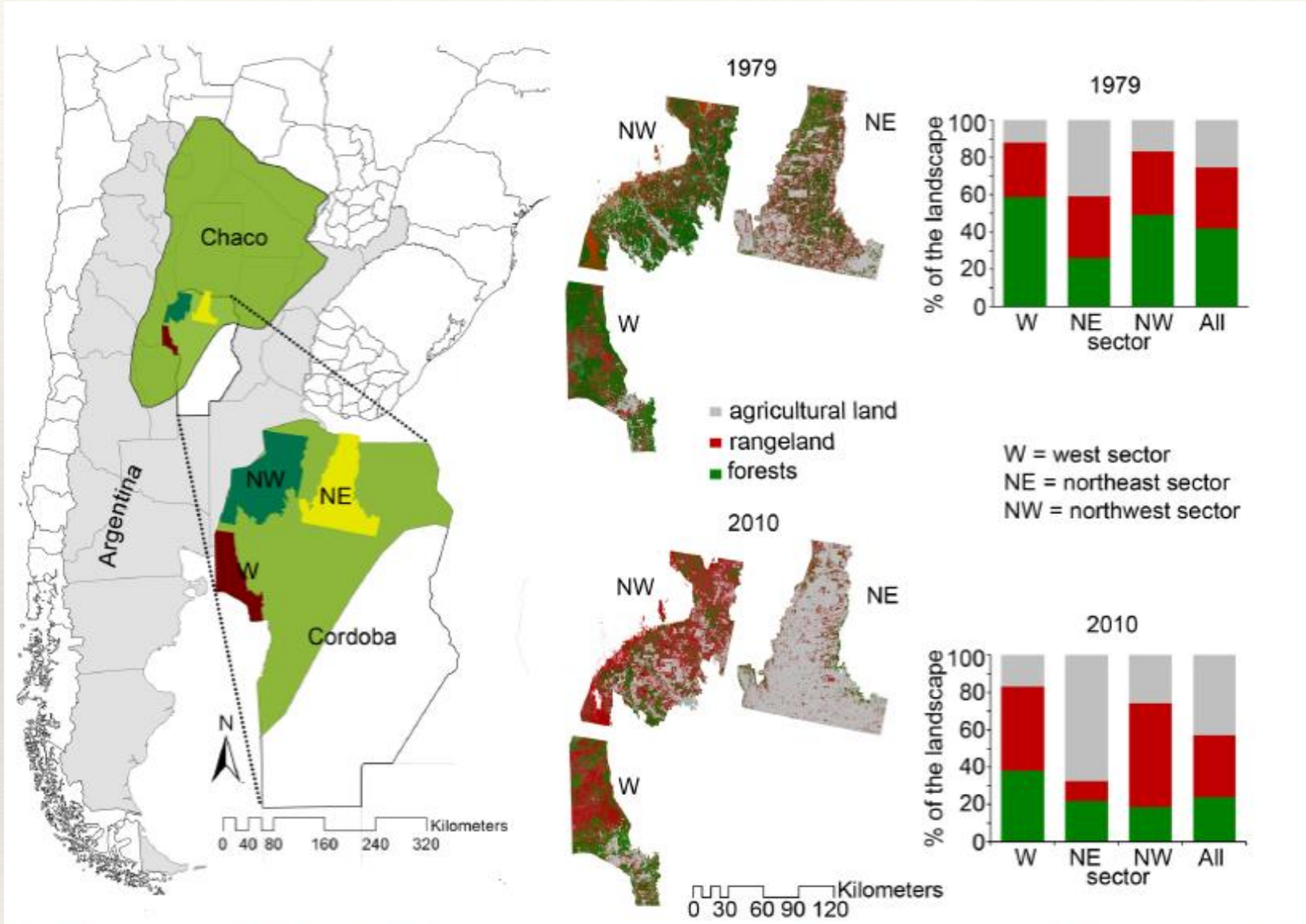
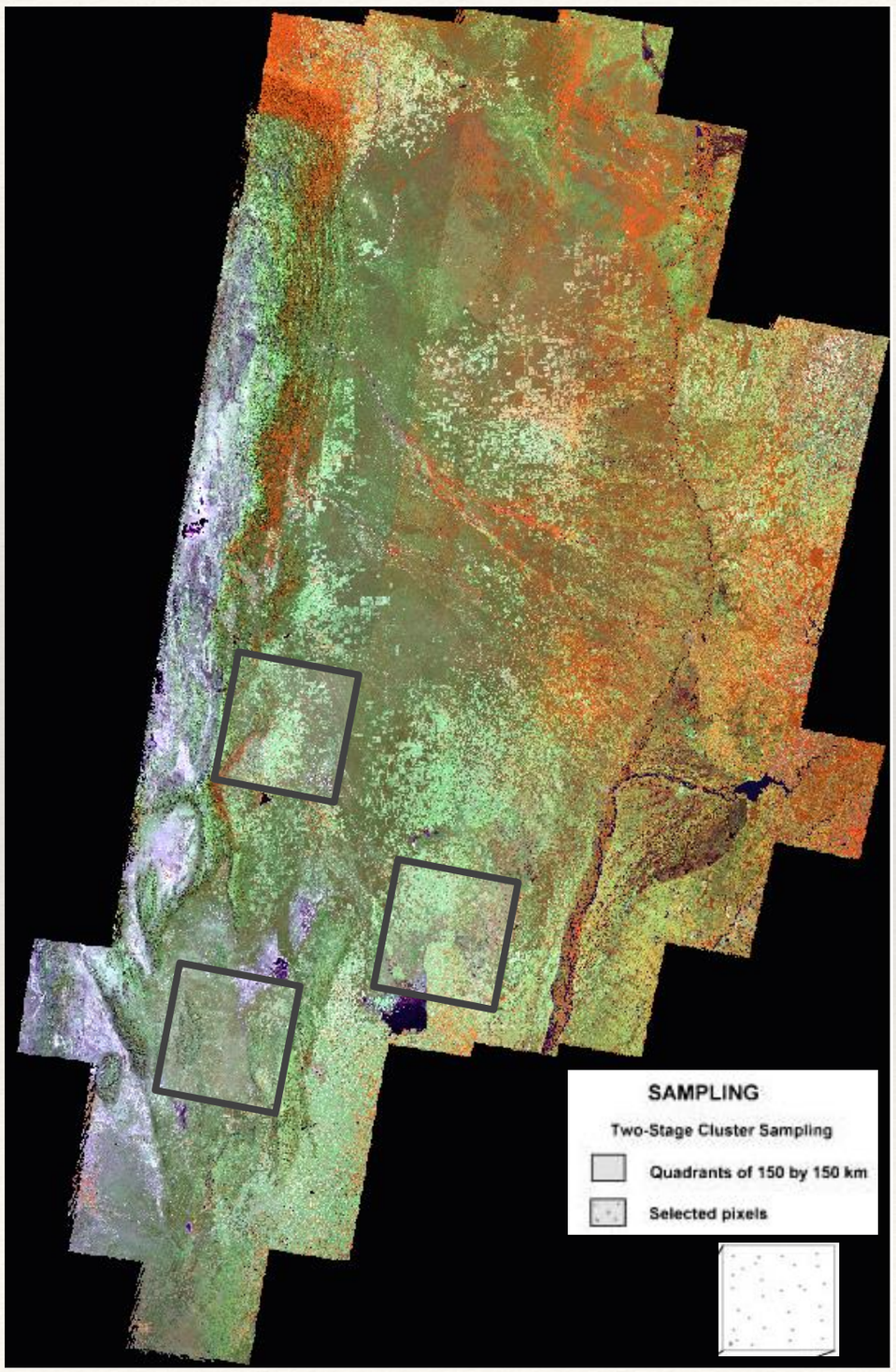


Fig 1. Study area. Location of the Gran Chaco Phytogeographical region, Cordoba Province, and the study sectors in Argentina. Maps of forest, rangelands and agricultural lands along with their relative percent of cover for the years 1979 and 2010 are also reported.

doi:10.1371/journal.pone.0142855.g001

Frate et al. (2015)

Multi-scale approach using probability sampling design



- Large-scale mapping of state-of-the-art vegetation information, based on vegetation indices (Argentinean dry Chaco)

- Site-scale analysis to monitor conversions and subtle changes in woodlands, soil degradation, and land use decisions and policies (focus sites in areas of high, intermediate and low forest change).

Development of new algorithms for monitoring of woodland degradation and soil degradation. Modelling of vegetation water use and plant-soil interactions (LSM)

- Validation/ground-truthing of remote sensing products in small 1 by 1 ha study sites (corresponding to forest inventory plots)

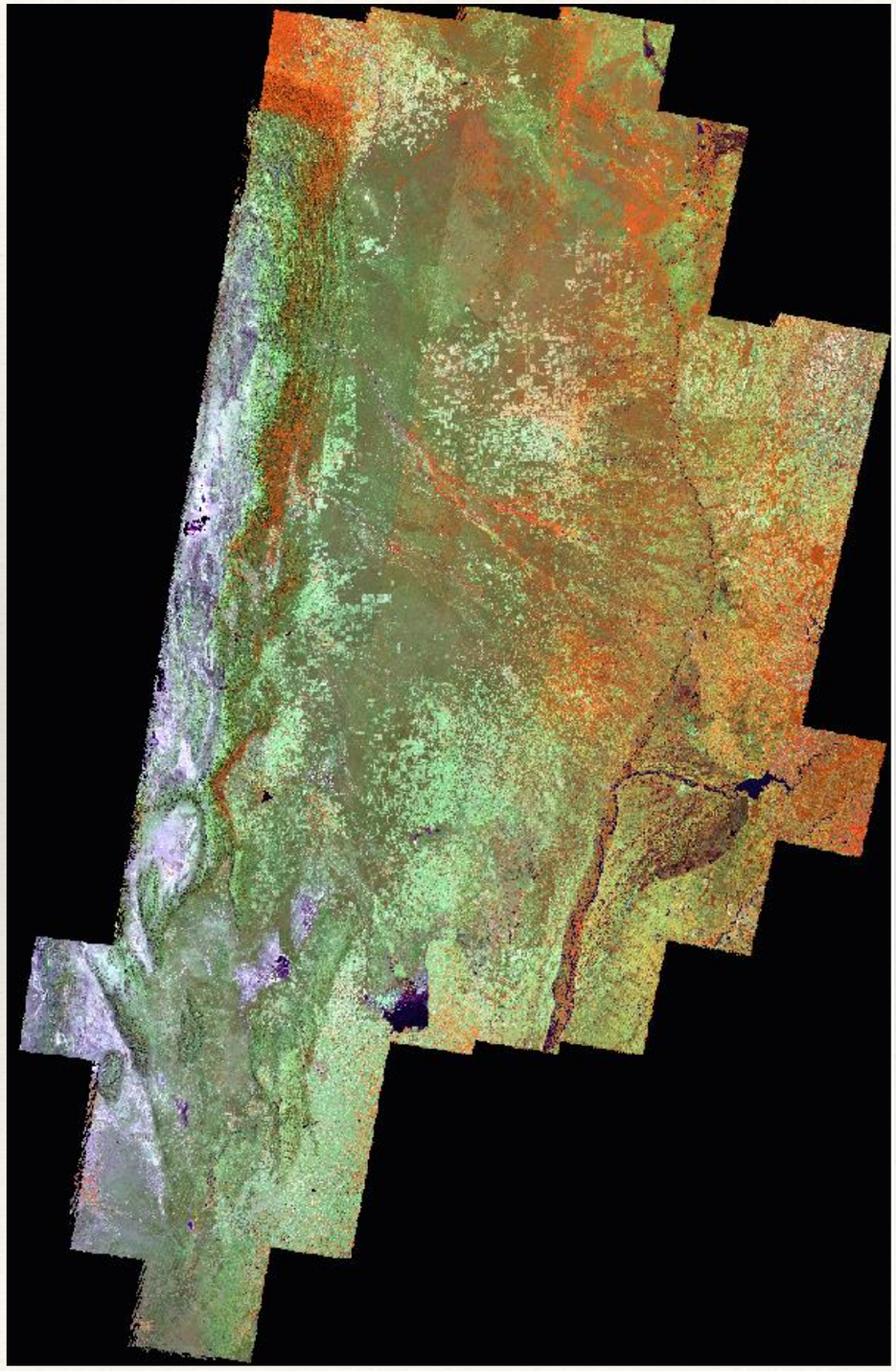
UAV-based remote sensing, soil degradation monitoring,evaluation based on counterfactuals

Pixel-based compositing of Landsat data

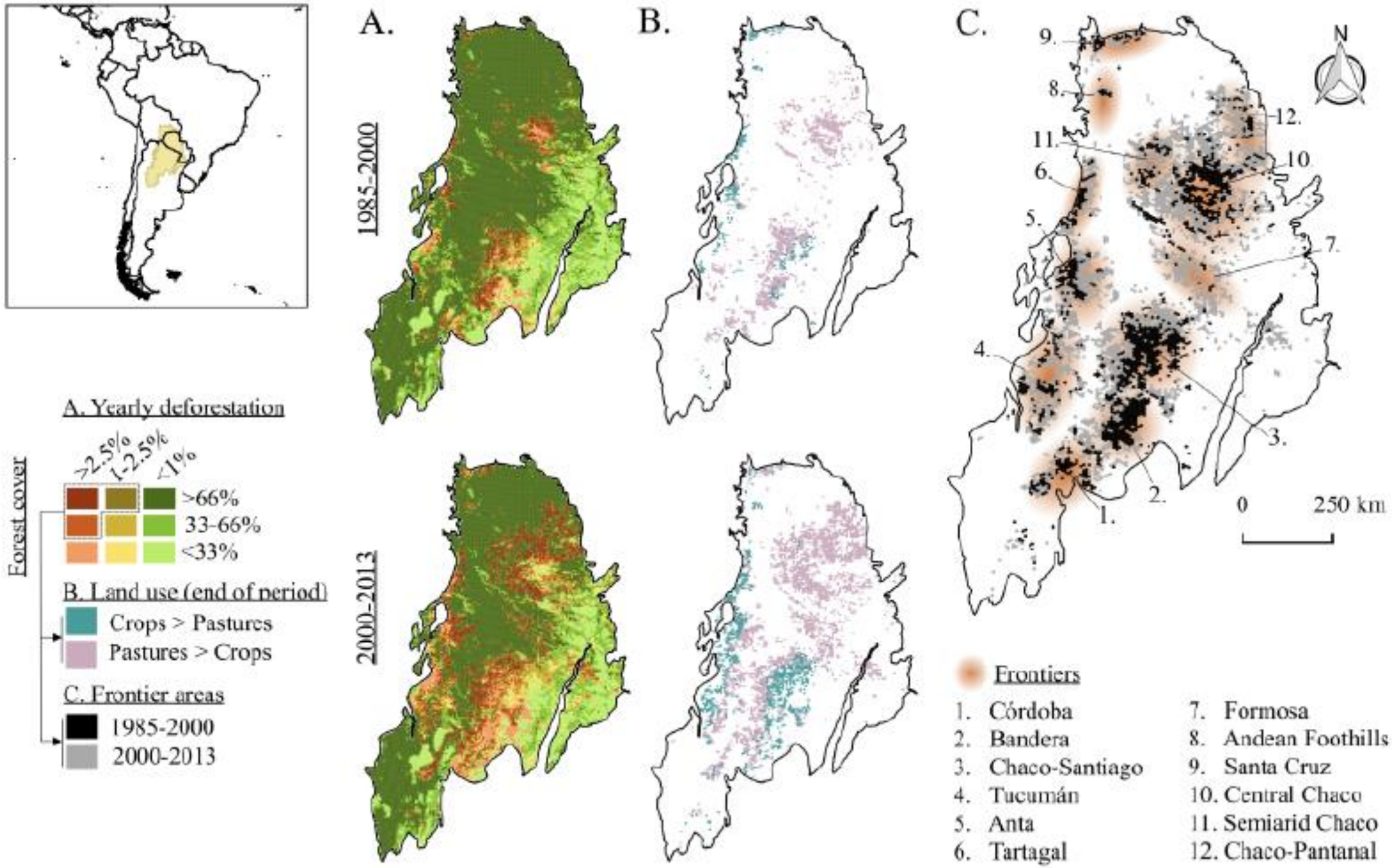
- Making full use of the Landsat archives (~15,000 images) to create image composites for 1985, 2000 and 2015 for dry Chaco following methods developed by Humboldt team *(Griffiths et al., 2014)*

- Streamline pre-processing protocols

- Create image composites at key phenological stages to map woodlands, grassland, and croplands and the transitions between these categories



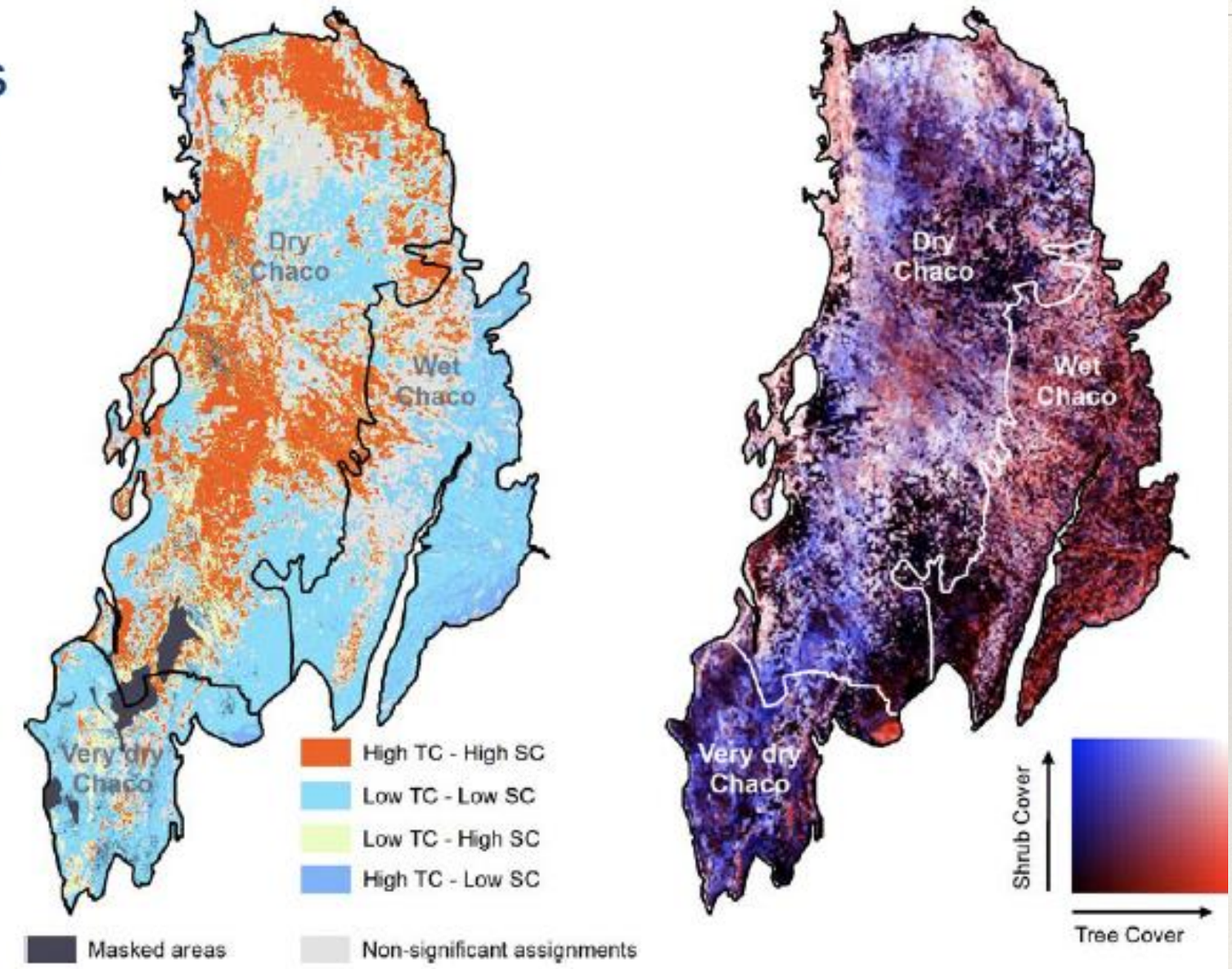
Identify major deforestation frontiers



Le Poulain de Waroux et al., in press

Identifying different types of Savannas

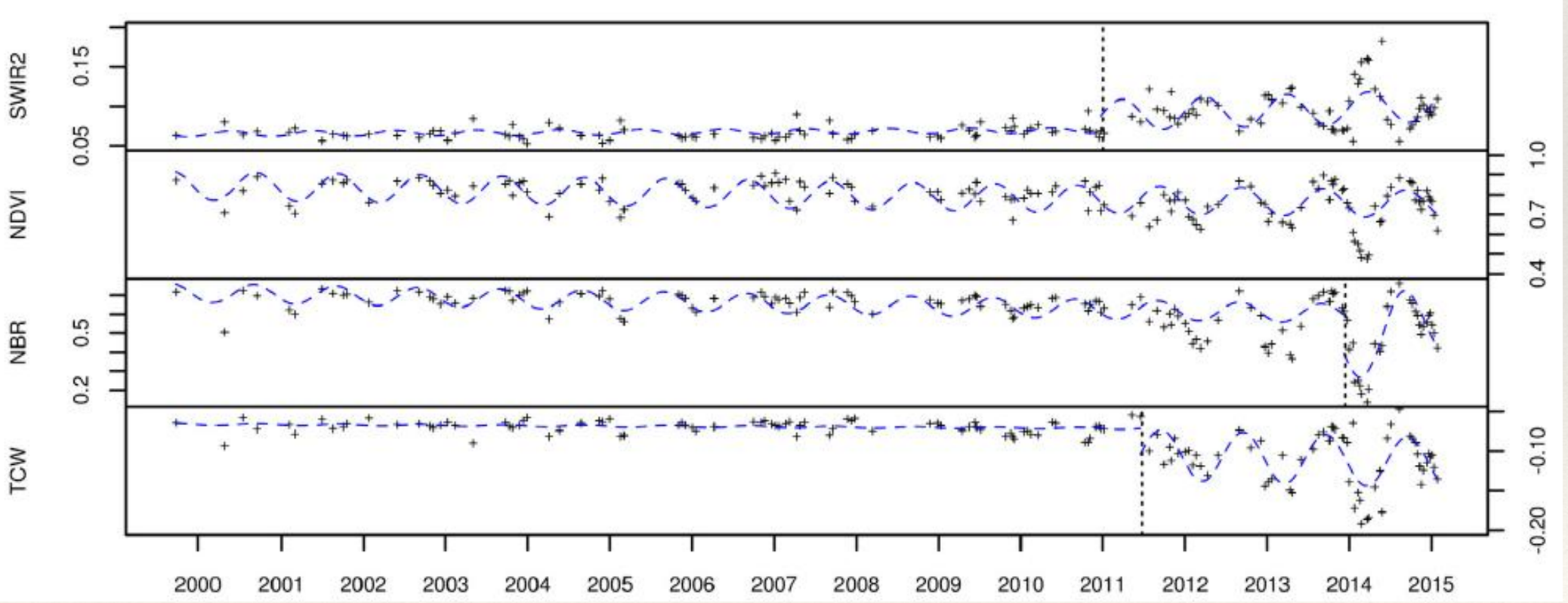
- Continuous measures of levels of tree- and shrub cover
- Categorical identification of clusters



Baumann et al., in prep.

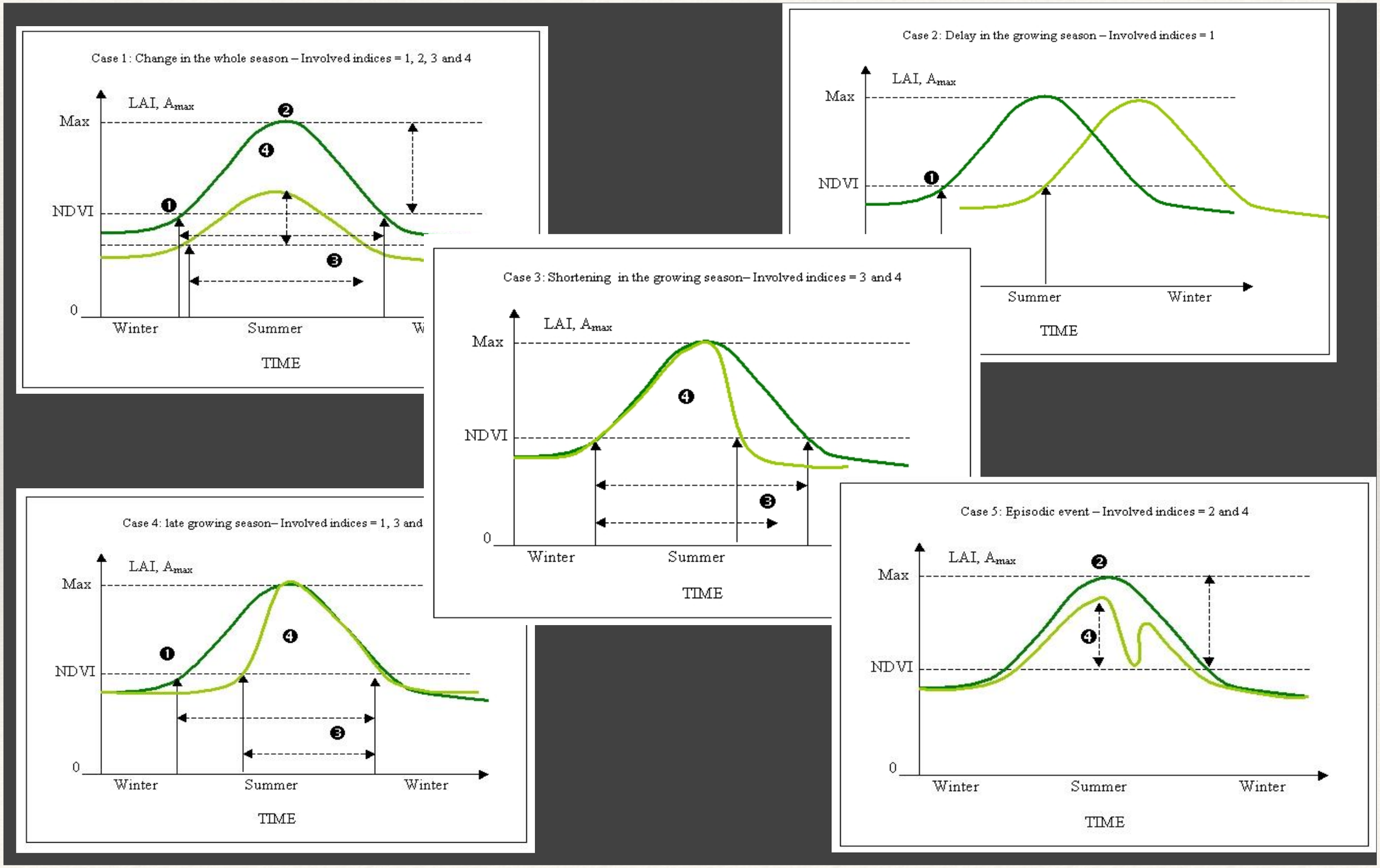
Dense time series of Landsat data

- Dense stacks of images allow deriving the variability of spectral information in a given time window, which is very powerful for detecting gradual and abrupt change
- Potential to extract best-pixel composites and image metrics annually and at key phenological stages



Devries et al. (2016) PloS One

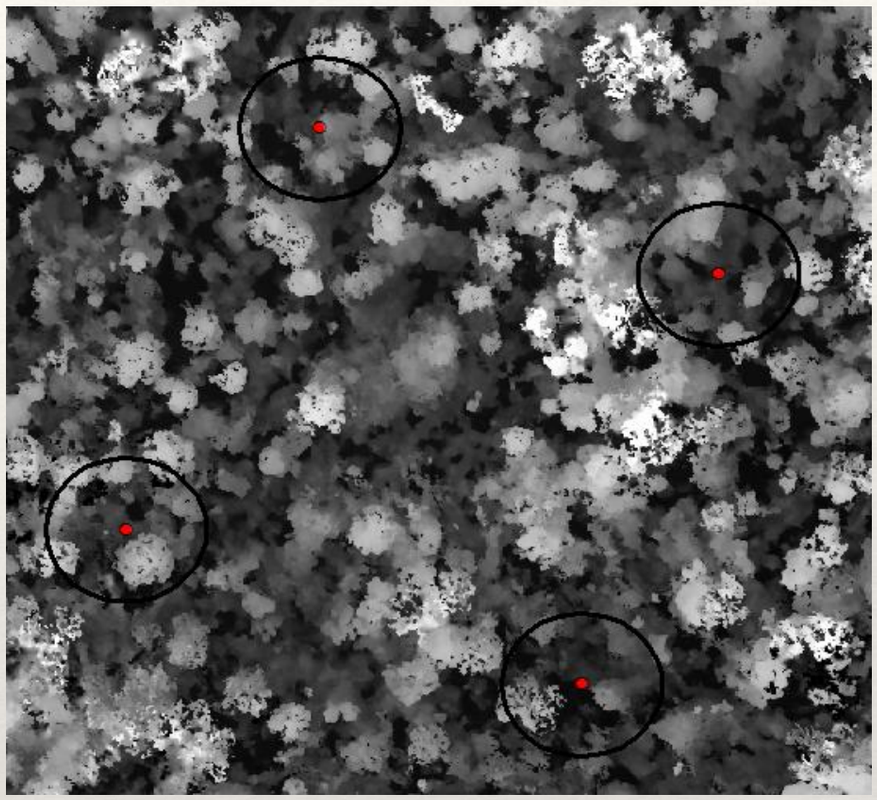
Time series analyses to separate gradual woodland degradation from conversion

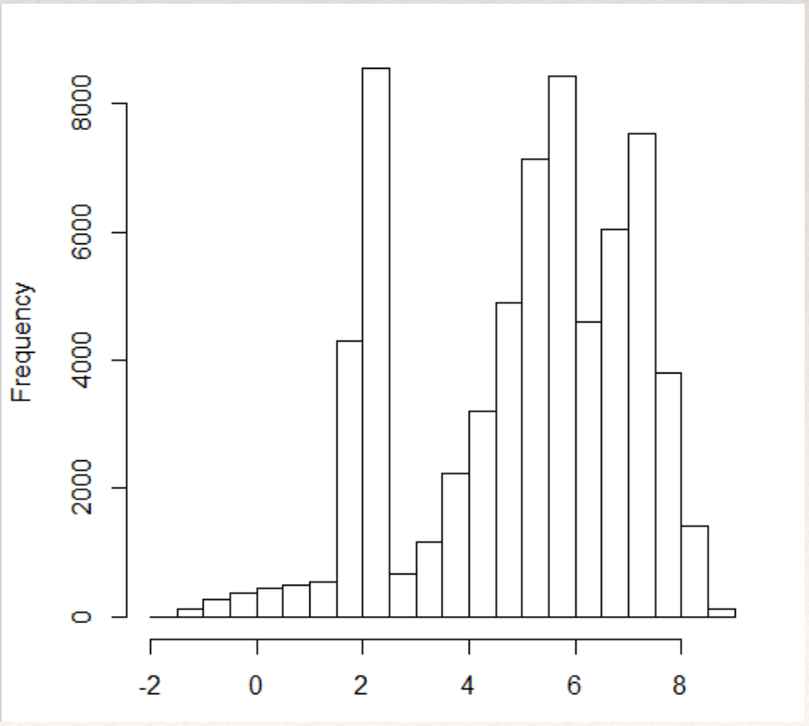


Ground-truthing - UAS images to derive forest degradation indicators

Canopy Height and Structure

- Drone flight: Phantom 3
- Structure from motion algorithm
- 3D point cloud showing canopy structure





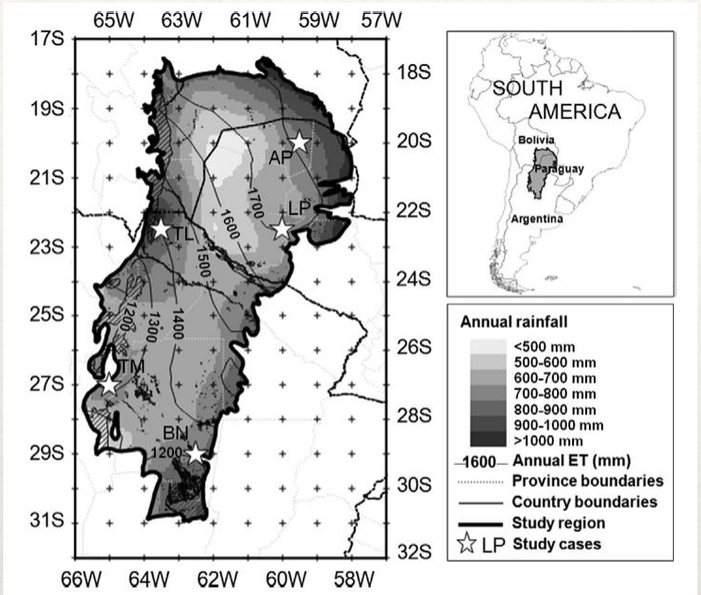
Patch-scale vegetation metrics

- Vertical stratification of point cloud
- FRAGSTAT: vertical and horizontal complexity of the forest patches

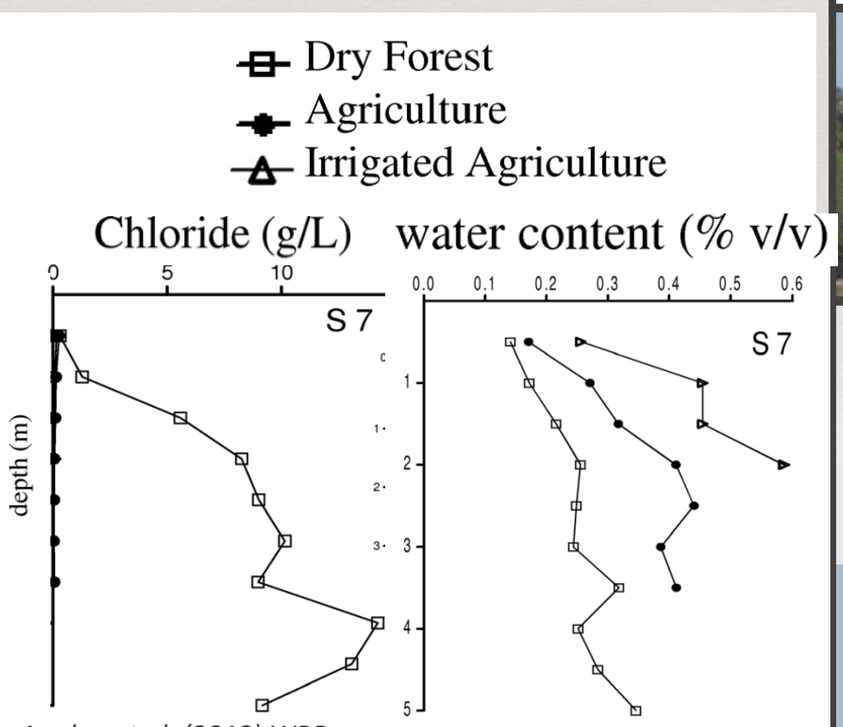
Image segmentation

- Segmentation of images to derive individual trees
- Spatial variables of canopy structure

Integration of remote sensing data in ecosystem models to assess soil degradation



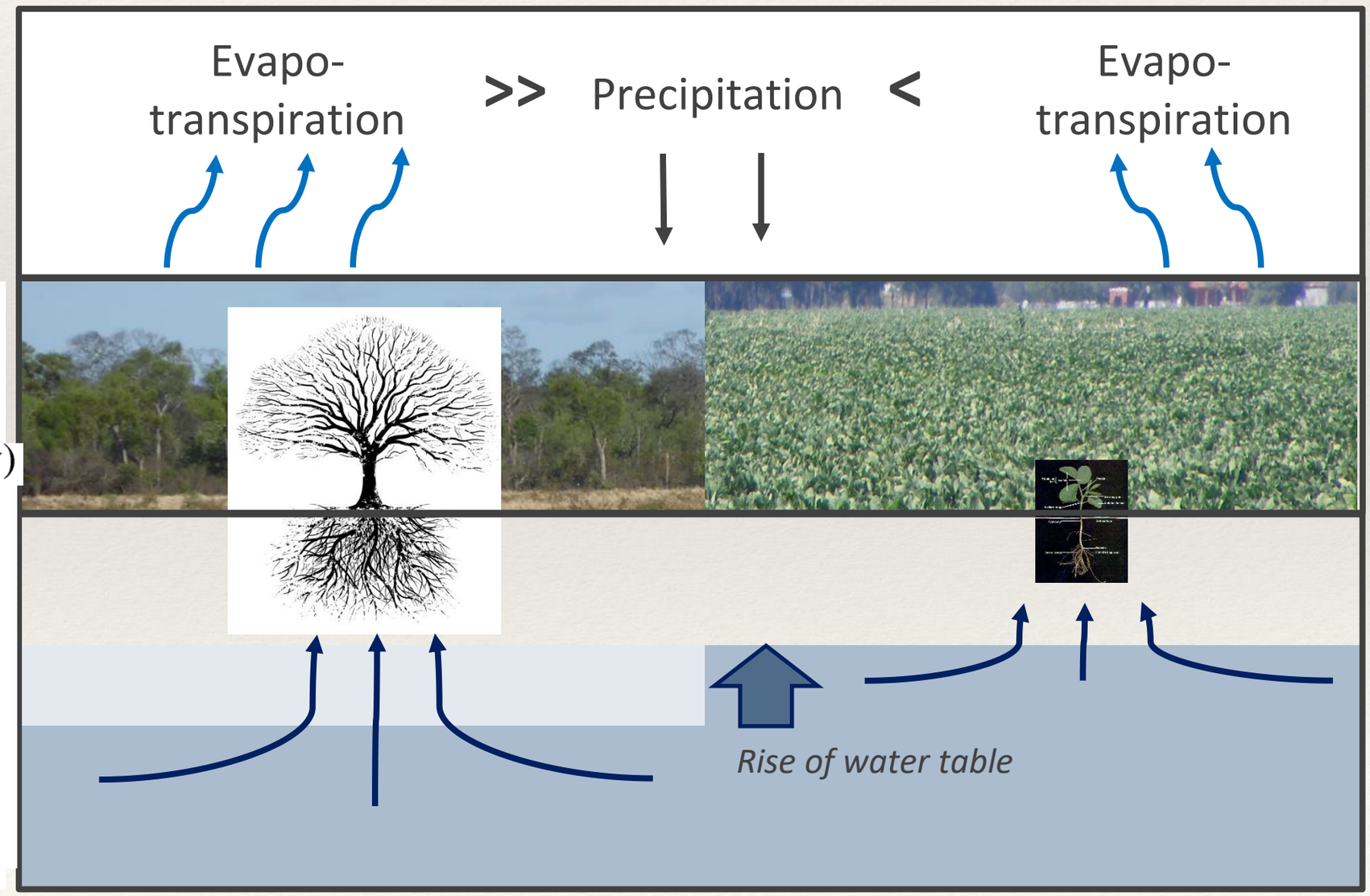
Gimenez et al. (2014) J Arid Env.



Amdan et al. (2013) WRR

Semi-arid Chaco : soil water deficit (ET > P)

Woodland degradation and conversion has potentially large impacts on soil water balance, drainage and soil salinity



Early detection: spatial field-based approach

Assess soil degradation resulting from changes in soil water balance following conversions and subtle changes in woodlands

- Matching of sites
- Sampling soils by hand auger : analysis of SWC, bulk density, pH, EC and Cl^- concentrations in soil samples
- Sampling of groundwater in observation wells, determination of EC and Cl^- concentrations following method of *Nosetto et al. (2012)*
- GLM predicts concentration of salts as function of land use history

Number of samples : 3 × 15 = 45 pairs

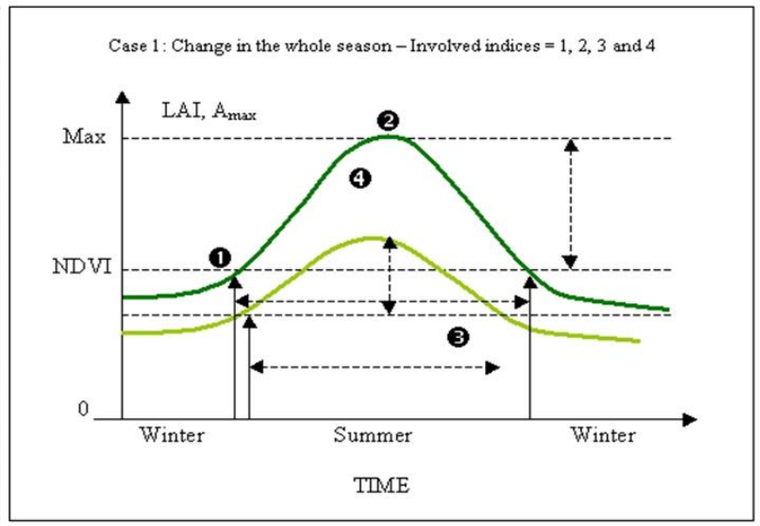
Matching : reference site – woodlands; test sites – agricultural plots with different land use history

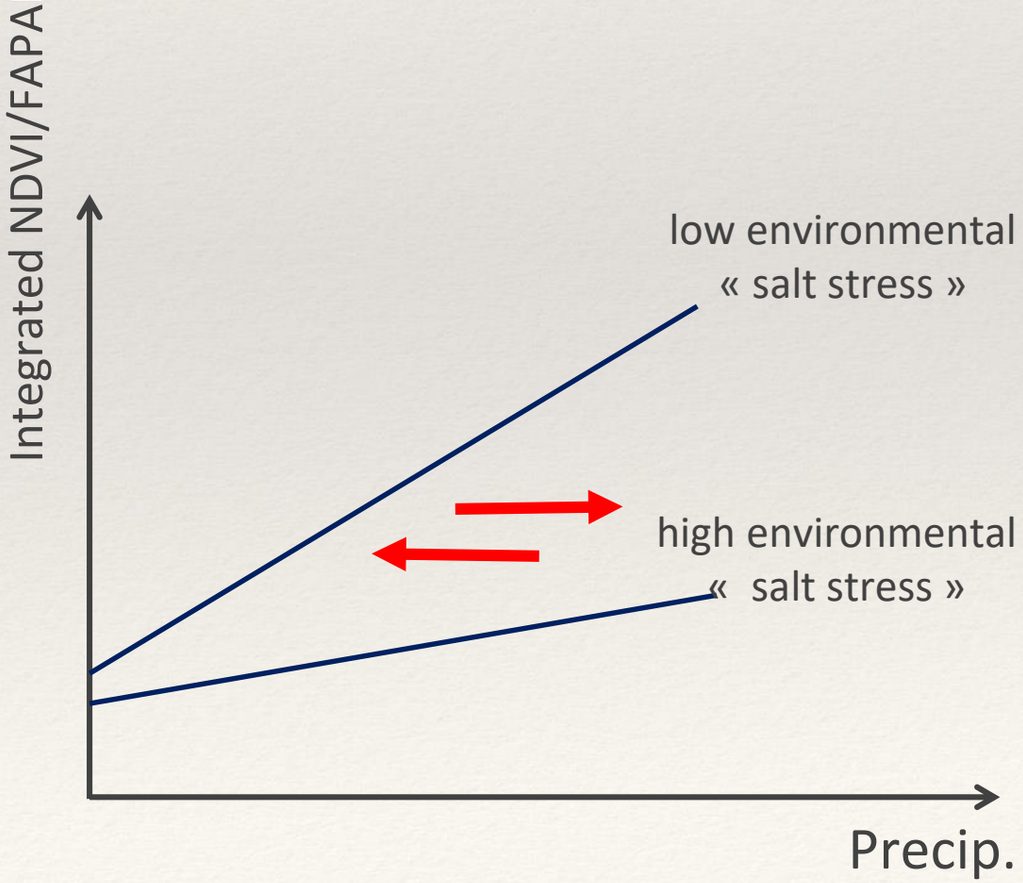
Early detection : temporal remote sensing approach

Soil degradation and salinity causes environmental stress, and are expected to have a measurable impact on the time series phenology derived from spectral vegetation indices (gradual changes).

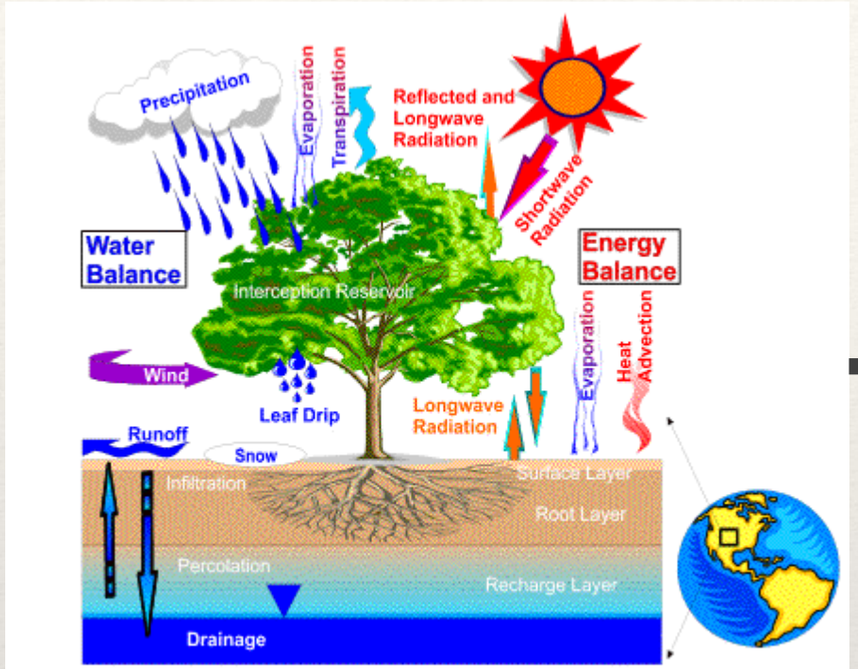
Based on field-based assessment of soil salinity, possible to identify pixels with low and high «salt stress»

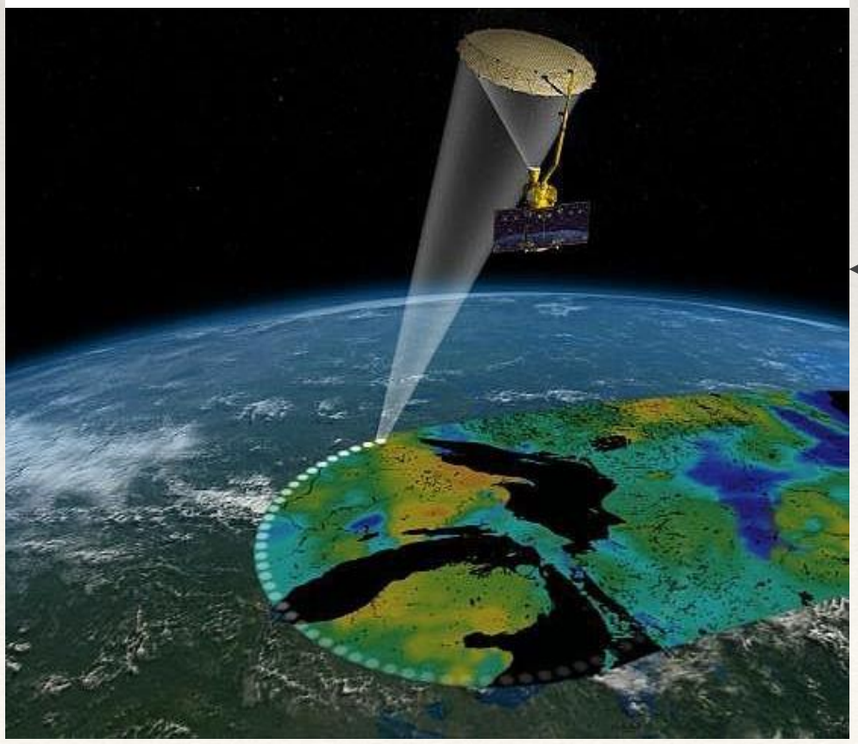
Assess trajectories of vegetation indices and phenological trajectory variables for areas with low and high environmental « salt stress » to quantify relationship between forest conversions and degradation, and soil degradation





Integration of remote sensing data in land surface model to assess land degradation



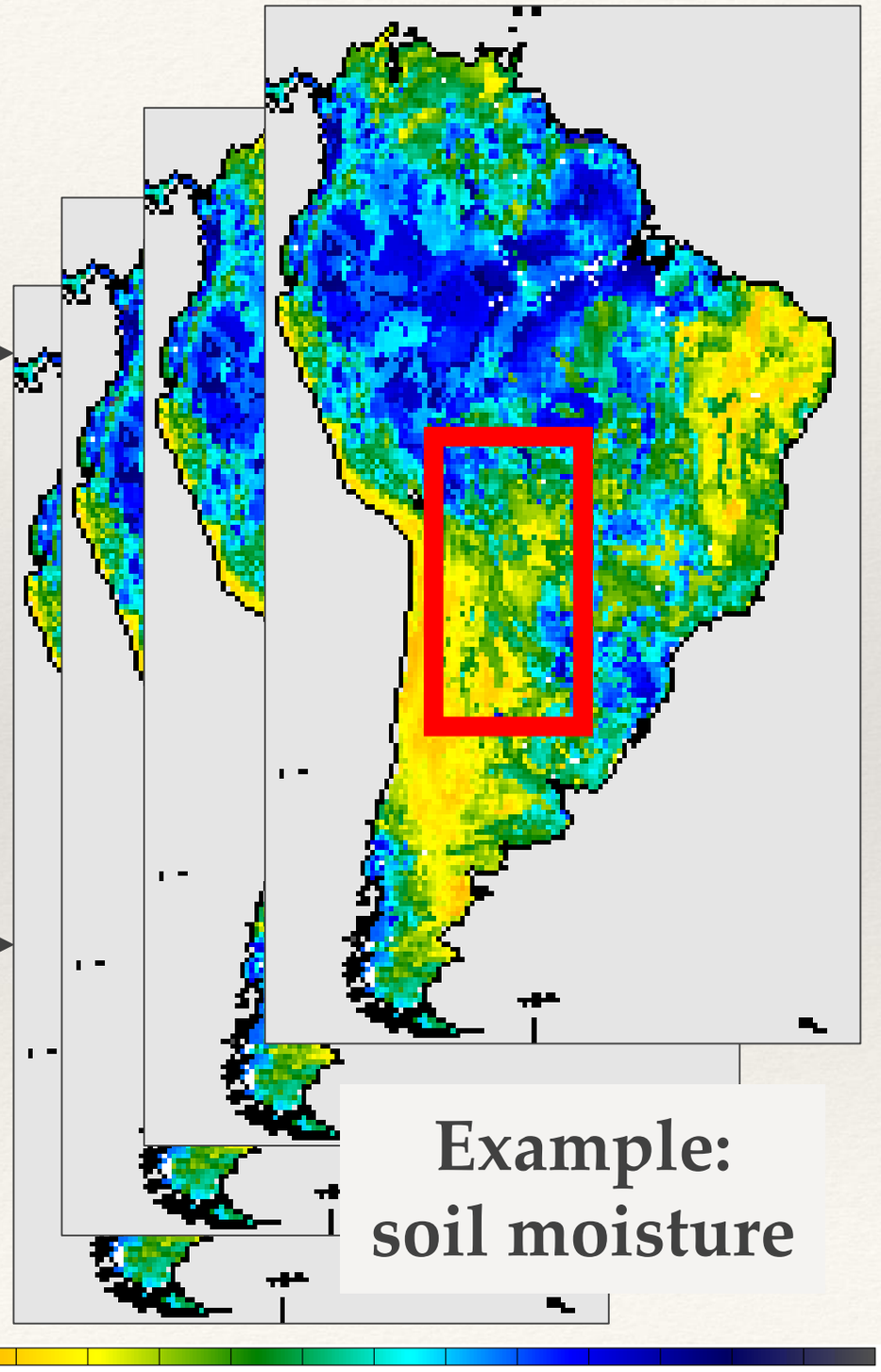


Ensemble models,
Land Information System
(NASA LIS)

Include vegetation changes

Evaluate simulations

satellite and in situ data
(e.g. soil moisture:
SMAP, SMOS;
evapotranspiration:
FLUXNET)



**Example:
soil moisture**

Land degradation and land use

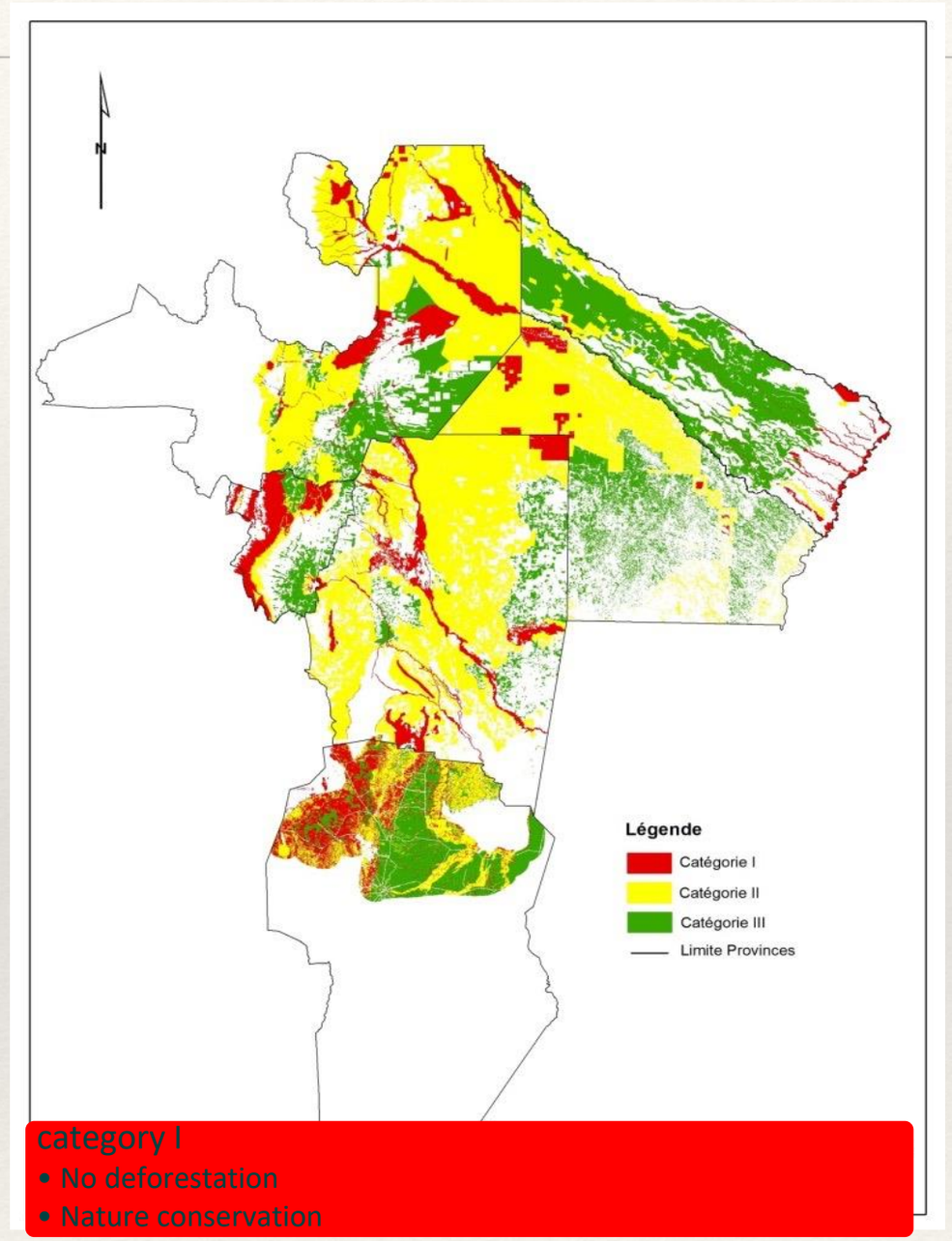
- Soy & cattle expansion
- Ranching/silvo-pastures
- Mobility of actors & capital

- Protected areas, corporate agriculture, ranchers
- Pathways of environmental degradation differ per group of actors

Le Polain Y. et al. 2016. Land use policies and corporate investments in agriculture in the Gran Chaco and Chiquitano, PNAS, 113: 4021-4026.

Land use policies: zoning

- 2007, Argentina voted a Forest Law as a response to unregulated loss of native woodlands
- *Ley de Presupuestos Minimos de Proteccion Ambiental de los Bosques Nativos* N°26.331
- Federal law, provincial implementation
- Difference-in-difference with matching method



category I
- No deforestation
- Nature conservation

Category II
- No deforestation
- Sustainable use of forests

Category III
- Deforestation allowed
- Crops & livestock

Significance

- Development of robust multi-source methods to monitor forest dynamics in subtropical woodlands
- First regional assessment of forest conversions and degradation for dry Chaco
- Assessment of the impact of forest dynamics on salinization, and adaptation or mitigation by different actors groups
- Dissemination of outcomes to local stakeholders through strong link with local partners