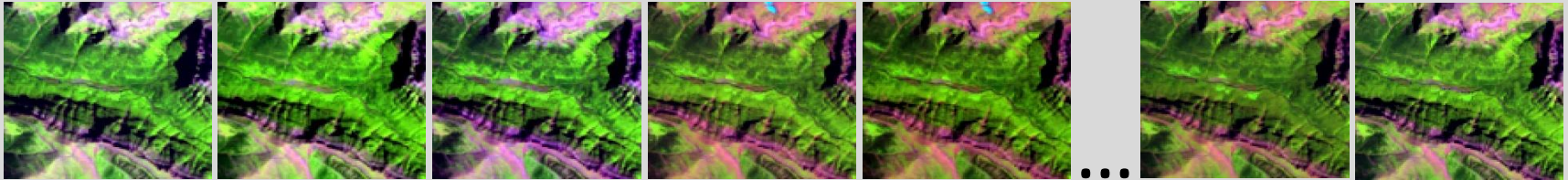


Integración de datos del IFN y Serie Temporal Landsat (STL) para el estudio de la dinámica forestal



1984

2015

Cristina Gómez

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https://www.researchgate.net/profile/Cristina_Gomez



1. INTRODUCTION

- Landsat
- Landsat Time Series

2. APPLICATIONS

- Characterization of carbon stocking trends
- Retrospective estimation of biomass
- Annual fire cartography
- Species dynamics

Landsat



Longest record of satellite Earth observations: 1972 - present

Periodic acquisitions

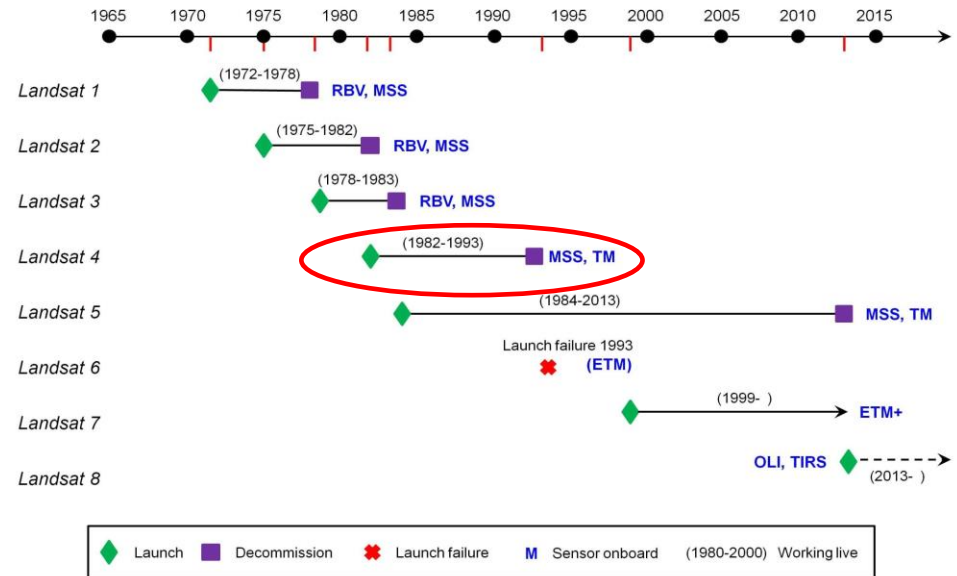
Continuity in data collection

Moderate spatial resolution (30 m)

Increasingly improved radiometry

Historical archive

SATELLITES AND SENSORS

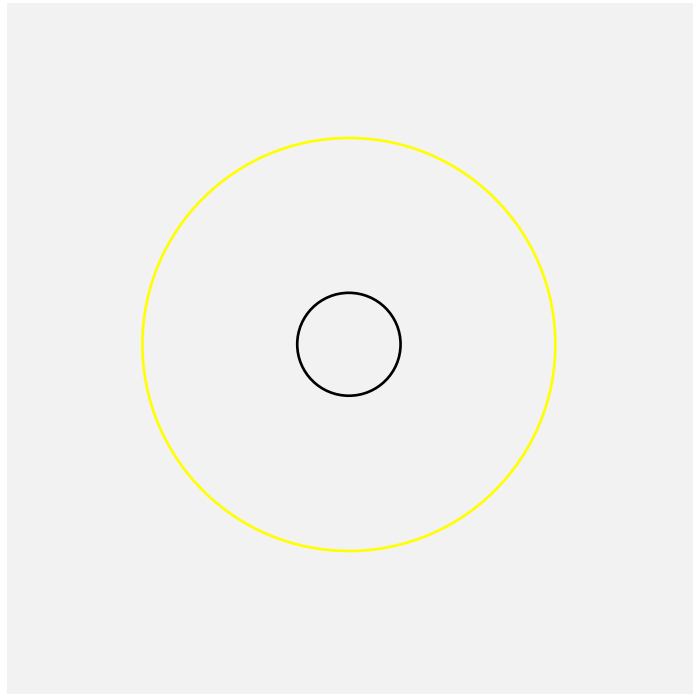


RADIOMETRY

| | MSS | | | TM | | | ETM+ | | | OLI | | |
|---------|-------|------------|---------|-------|------------|---------|-------|------------|---------|-------|------------|---------|
| | #Band | Width (μm) | GSD (m) | #Band | Width (μm) | GSD (m) | #Band | Width (μm) | GSD (m) | #Band | Width (μm) | GSD (m) |
| | | | | 1 | 0.45-0.52 | 30 | 1 | 0.45-0.52 | 30 | 2 | 0.43-0.45 | 30 |
| Visible | 4 (1) | 0.5-0.6 | 68x83 | 2 | 0.52-0.60 | 30 | 2 | 0.52-0.60 | 30 | 3 | 0.52-0.60 | 30 |
| | 5 (2) | 0.6-0.7 | 68x83 | 3 | 0.63-0.69 | 30 | 3 | 0.63-0.69 | 30 | 4 | 0.63-0.68 | 30 |
| NIR | 6 (3) | 0.7-0.8 | 68x83 | 4 | 0.76-0.90 | 30 | 4 | 0.76-0.90 | 30 | 5 | 0.84-0.88 | 30 |
| | 7 (4) | 0.8-1.1 | 68x83 | 5 | 1.55-1.75 | 30 | 5 | 1.55-1.75 | 30 | 6 | 1.56-1.66 | 30 |
| SWIR | | | | 7 | 2.08-2.35 | 30 | 7 | 2.09-2.35 | 30 | 7 | 2.10-2.30 | 30 |
| Pan | | | | | | | 8 | 0.50-0.68 | 30 | 8 | 0.50-0.68 | 15 |
| SWIR | | | | | | | | | | 9 | 1.36-1.39 | 30 |

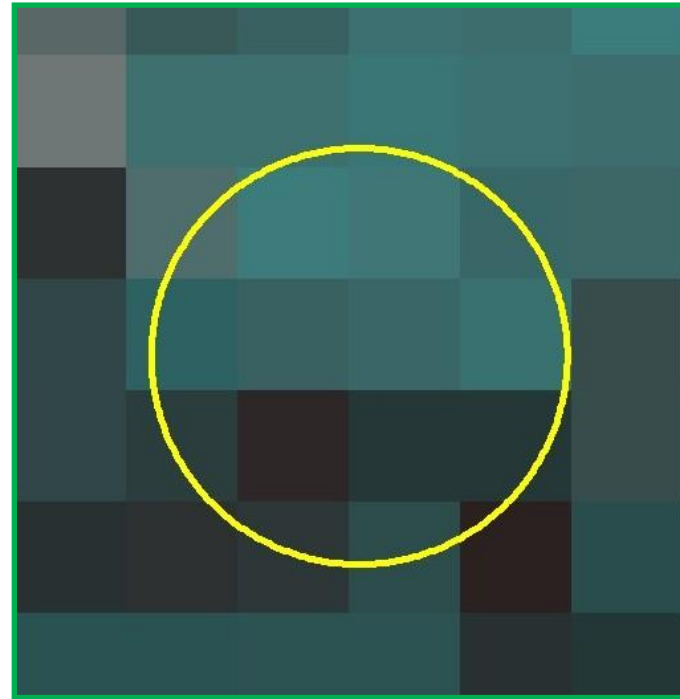
Forest structure

NFI



10 NFI plots

Landsat

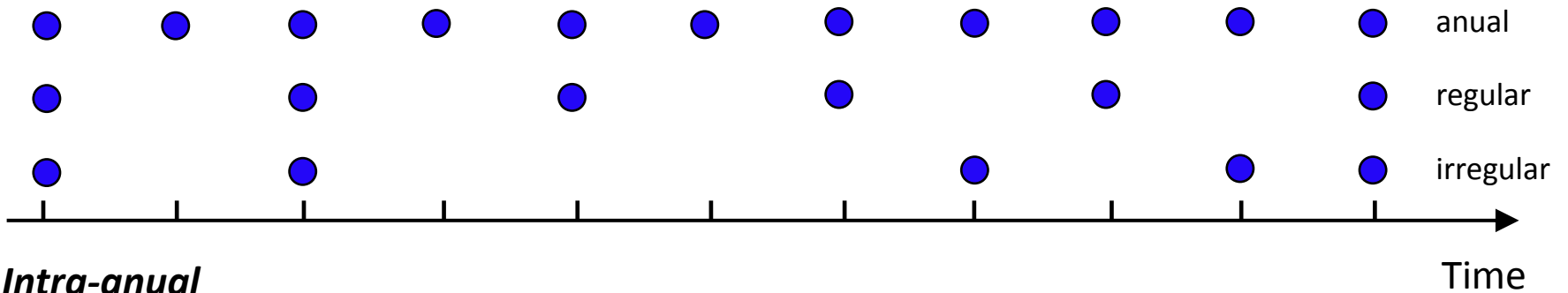


11 Landsat pixels

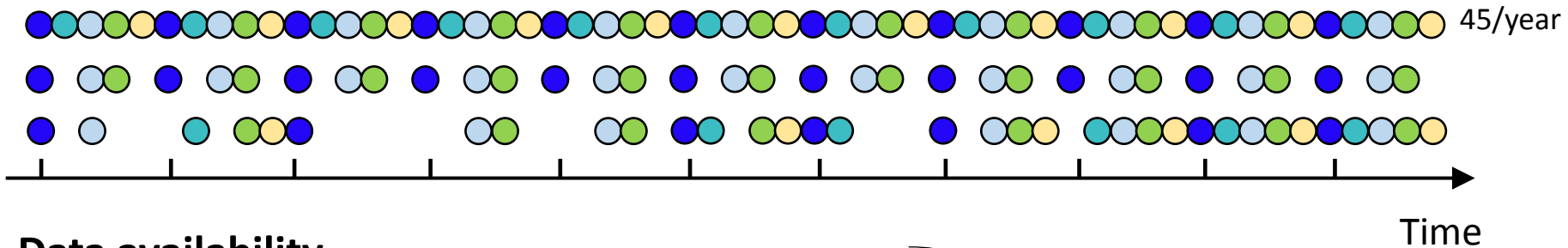
- Calibration / Validation
- Need of accurate location

LANDSAT TIME SERIES

Inter-annual

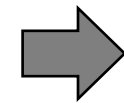


Intra-annual



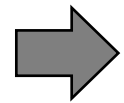
Data availability and usability

- Clouds
- ETM + SLC off
- Haze, smoke, atmospheric effects



Missing pixels

- International **cooperation**
- **Storage** and **transmission** capacity
- Long Term Acquisition Plan priorities



Missing scenes

- Data policies (e.g. USGS Landsat archive)
- Compatibility of data from different archives

LANDSAT TIME SERIES opportunities to inform FORESTRY

1. LAND COVER

Status

Change

2. STRUCTURAL VARIABLES

Density

Species

Biomass and C content

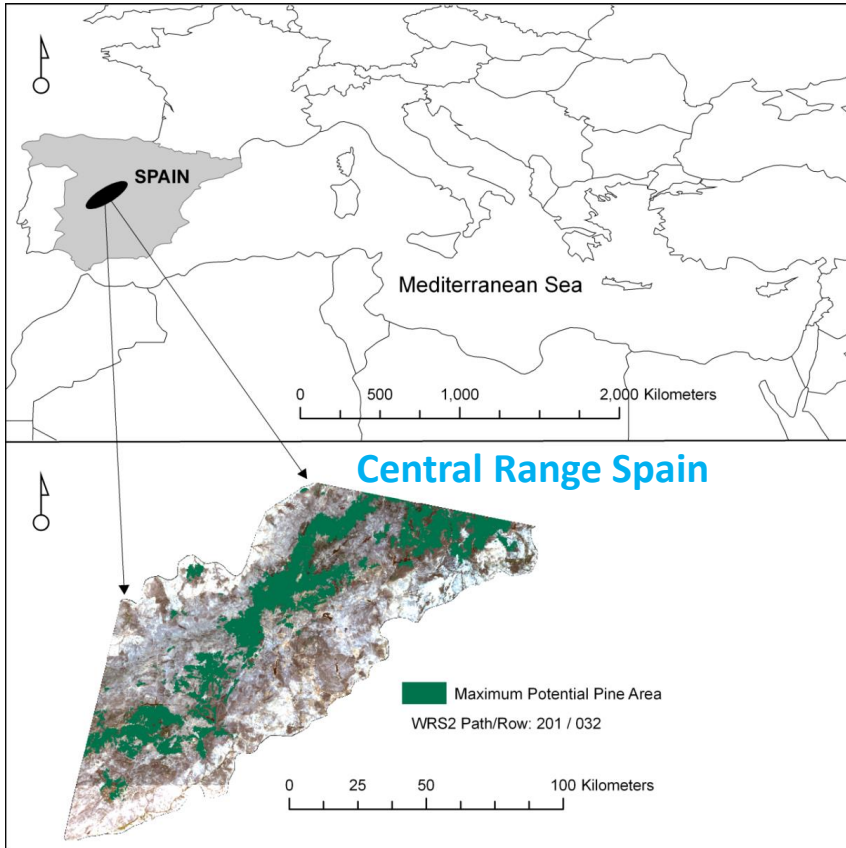
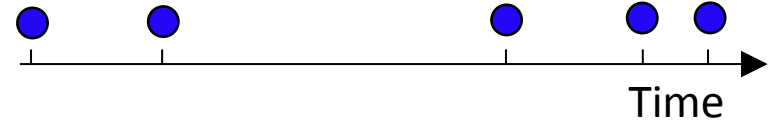
3. DYNAMICS

Spatiotemporal Change/No change

Processes of change

Forest extent, distribution and change. Carbon stocking

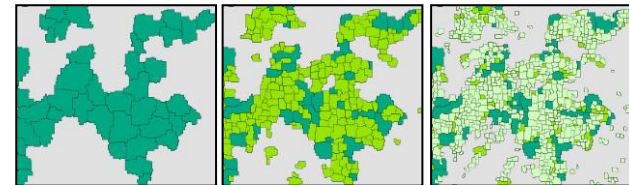
11 Landsat images (1984-2009) TM, ETM+



- Summer images
- Radiometric Normalization

Pine area identification

- Supervised classification:
1984, 1990, 2000, 2009
TCA (density proxy), B3, B4, B5
Seven class scheme
- Multi-level segmentation (3 levels)



Samples from ancillary information

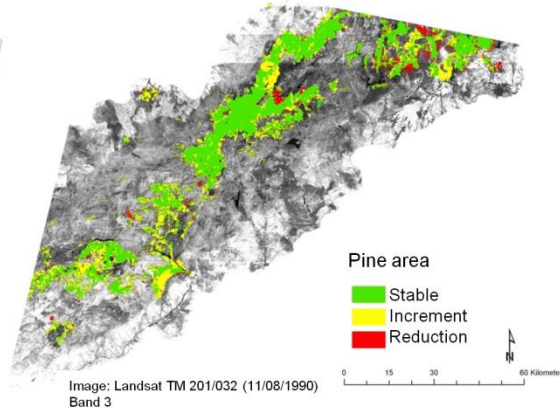
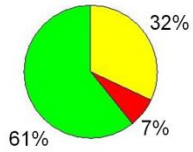
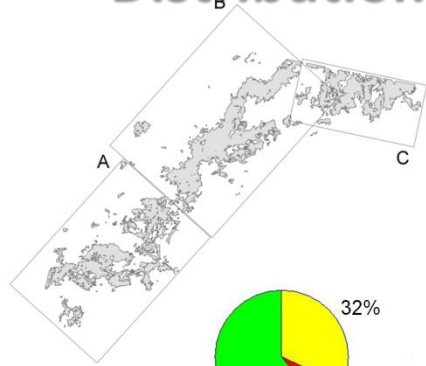
MFE

NFI plots

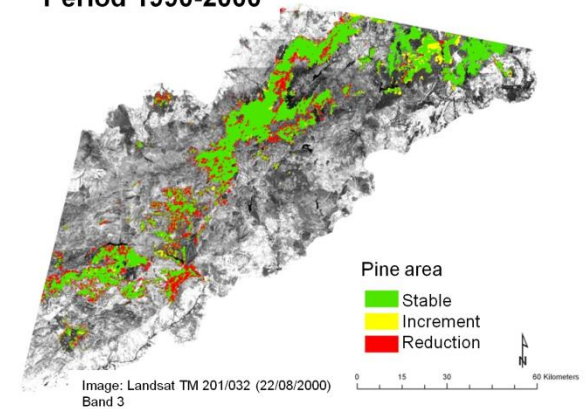
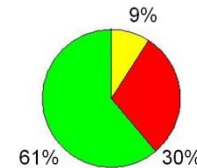
CARBON STOCKING

Distribution and change over time

Period 1984-1990



Period 1990-2000



Changes occurred at boundaries of permanent pines

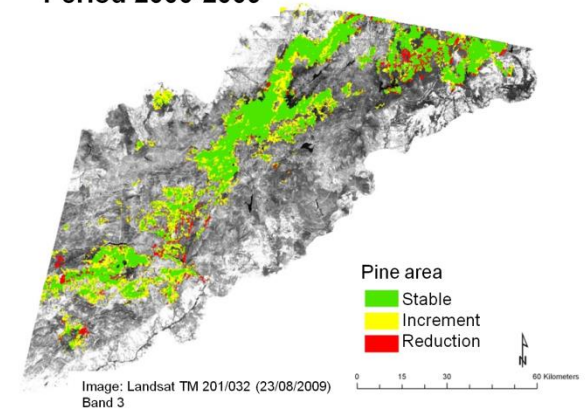
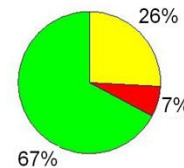
Increments:

- 1984-1990: A, B, C
- 1990-2000: C
- 2000-2009: A

Reductions:

- 1984-1990: C
- 1990-2000: A, B
- 2000-2009: A, C

Period 2000-2009



During period 1984-2009 there was a **net increase** in the pine area of **40%**
(121,144 ha to 169,825 ha)

Maximum Potential Pine Area (MPPA): overall union of pines during period 1984-2009

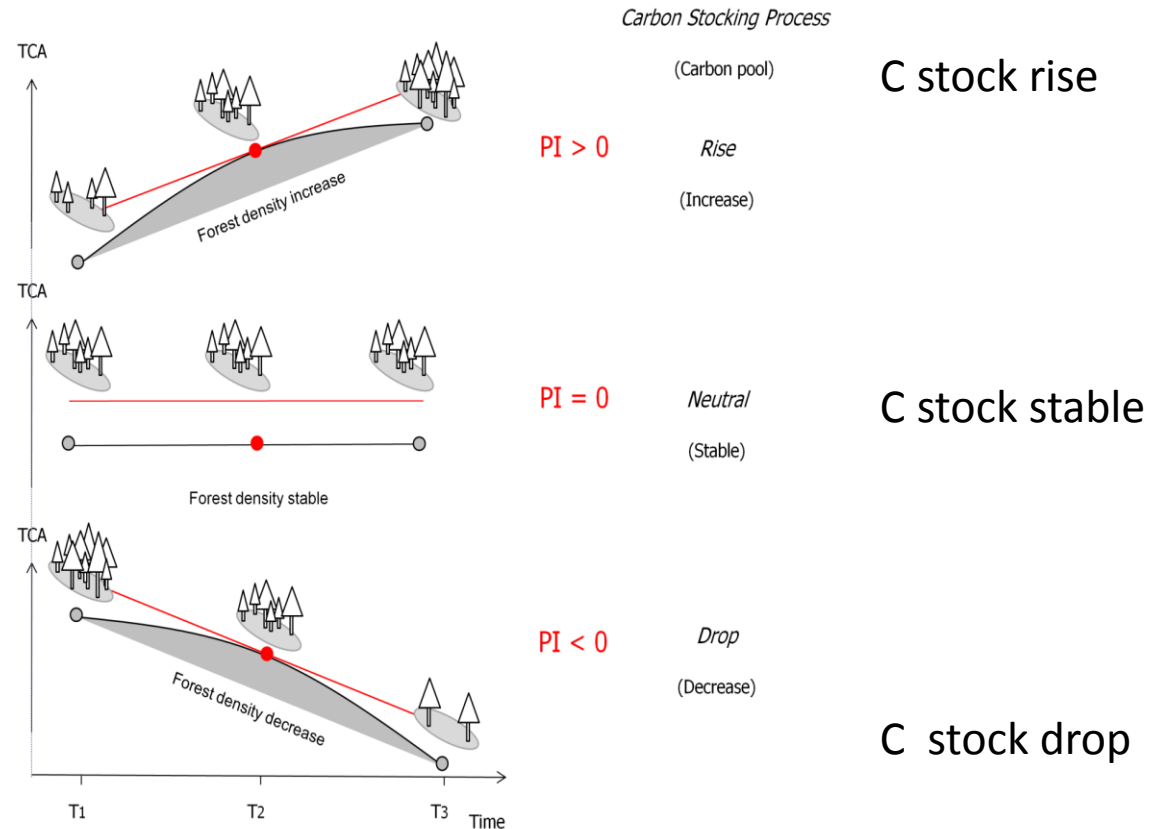
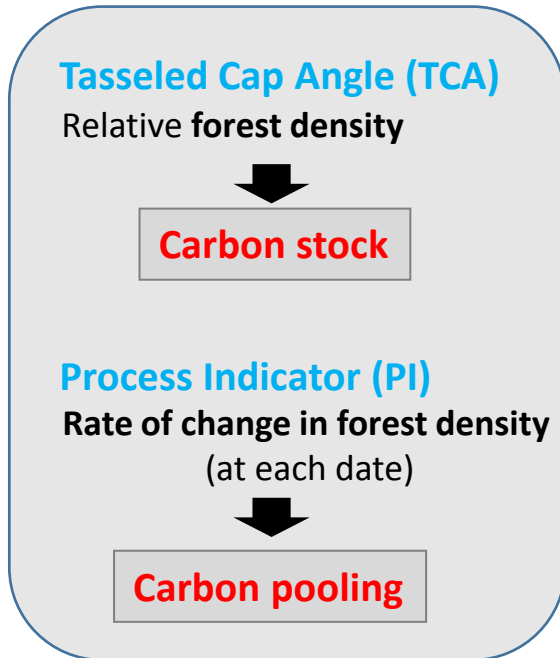
Permanent

Intermittent

CARBON STOCKING

Carbon stocking trends

Temporal series of spectral values: **TASSELED CAP ANGLE**



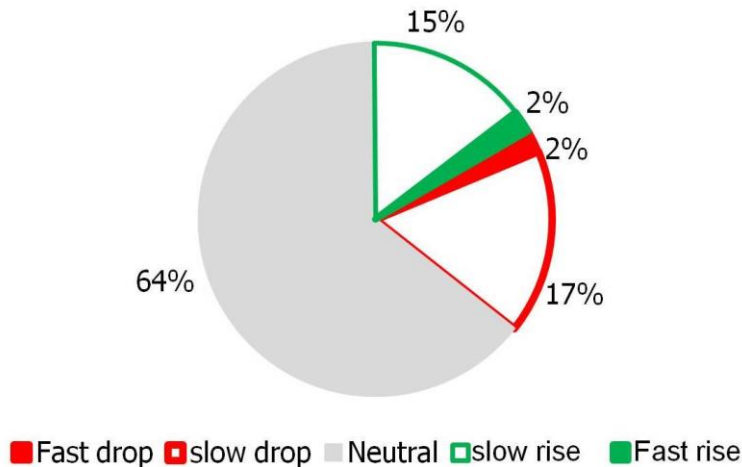
Maximum Potential Pine Area (MPPA) *Permanent*

Intermittent

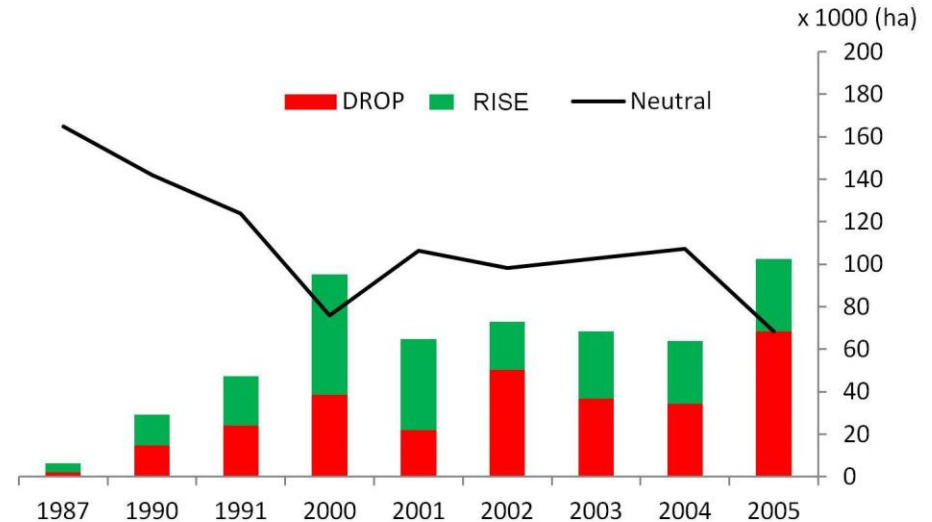
Spatial units defined by segmentation of TCA₂₀₀₀: density homogeneous objects

Overall carbon stocking process

Average area in carbon pooling groups



Carbon pooling area per date

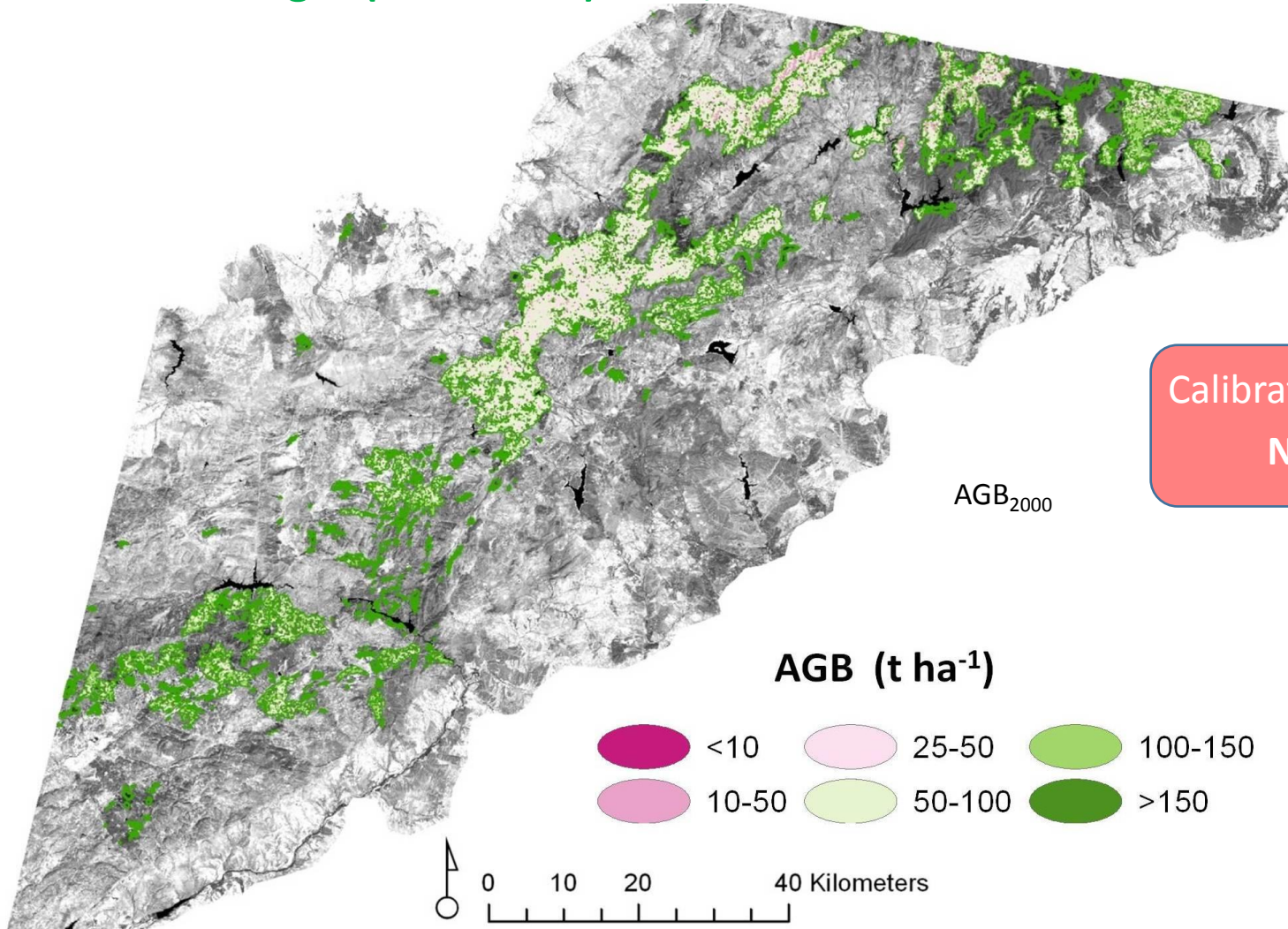
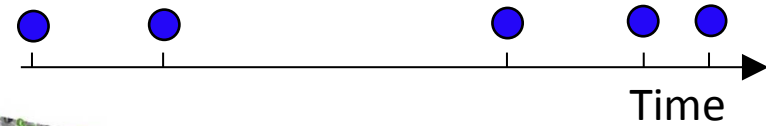


Globally, PI values are close to zero \Rightarrow neutral carbon pooling condition

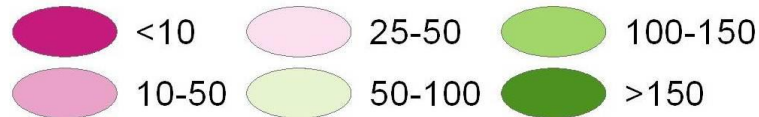
Areas of *intermittent pines* were more actively implicated in carbon fluxes.
Areas of *permanent* coverage were more stable

Historical forest biomass dynamics modelled with Landsat spectral trajectories

8 Landsat images (1984-2009) TM, ETM+



AGB ($t\ ha^{-1}$)



RETROSPECTIVE ESTIMATION OF BIOMASS

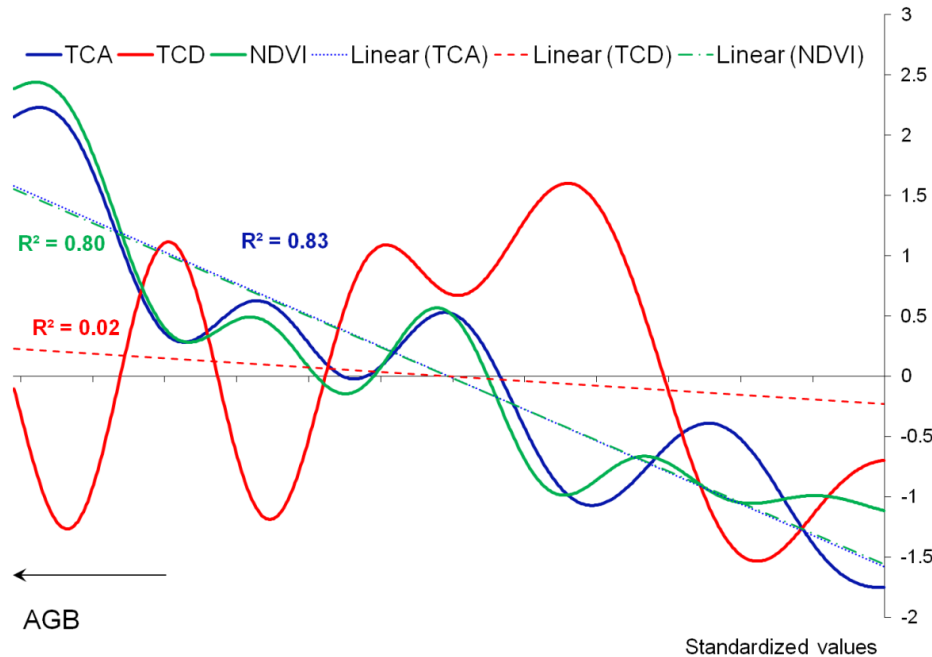
Explore Relationship of AGB and vegetation spectral indices

Wavelet transforms

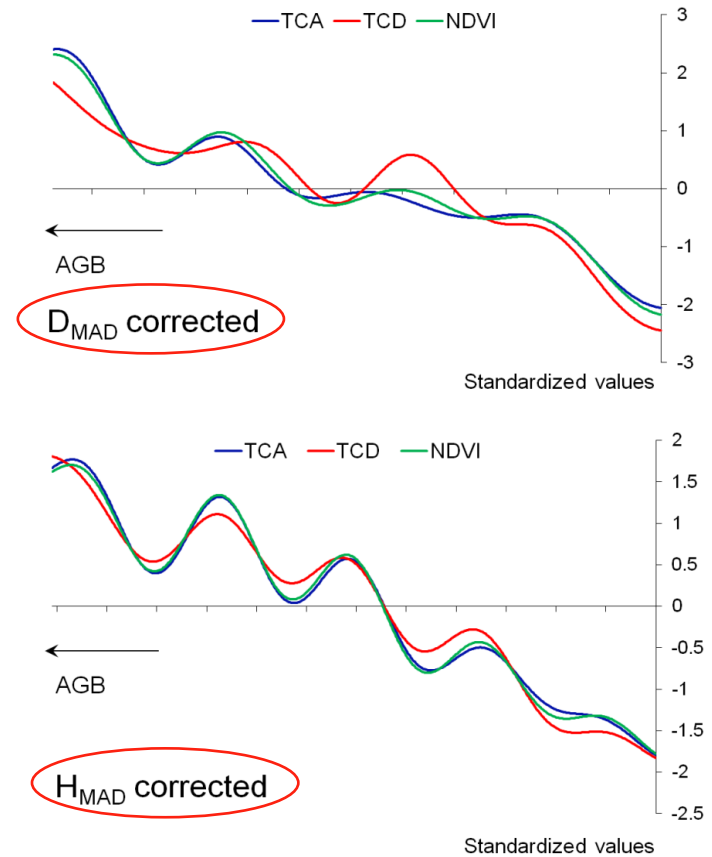
Multi-resolution analysis (MRA)

Approximation (trend) and Detail (high freq.)

Meyer family discrete WT (level 6)



Strong relationship



Conditioned by structural complexity

RETROSPECTIVE ESTIMATION OF BIOMASS

Modelling past AGB with spectral trajectories

NFI plots

AGB (plot)

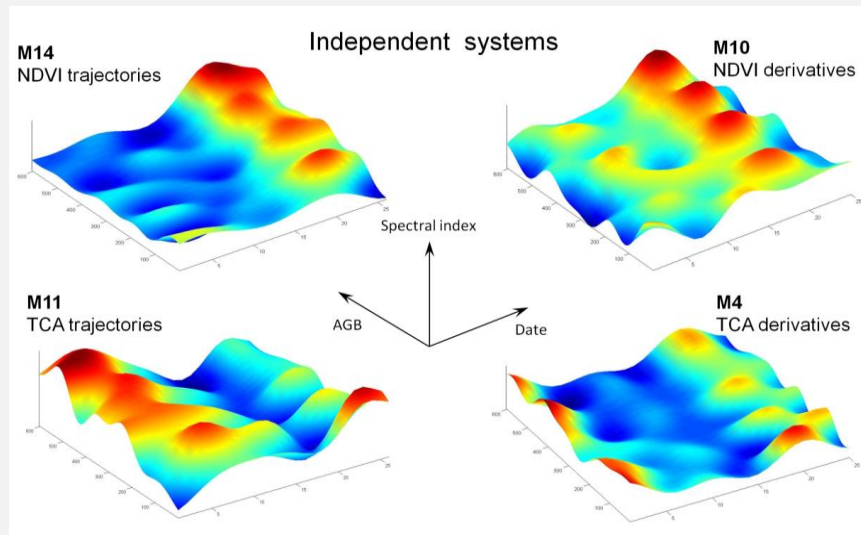
- **Static variables** (Single date spectral indices)
- **Dynamic variables** (Multi-date spectral data)
Spectral trajectories (*state variables*-change)
Temporal derivatives (*process variables*-speed)

2D wavelet transforms
Ordered trajectory systems

58 dynamic variables
Patterns of change
Patterns of change rate

25-year pattern
15-year pattern

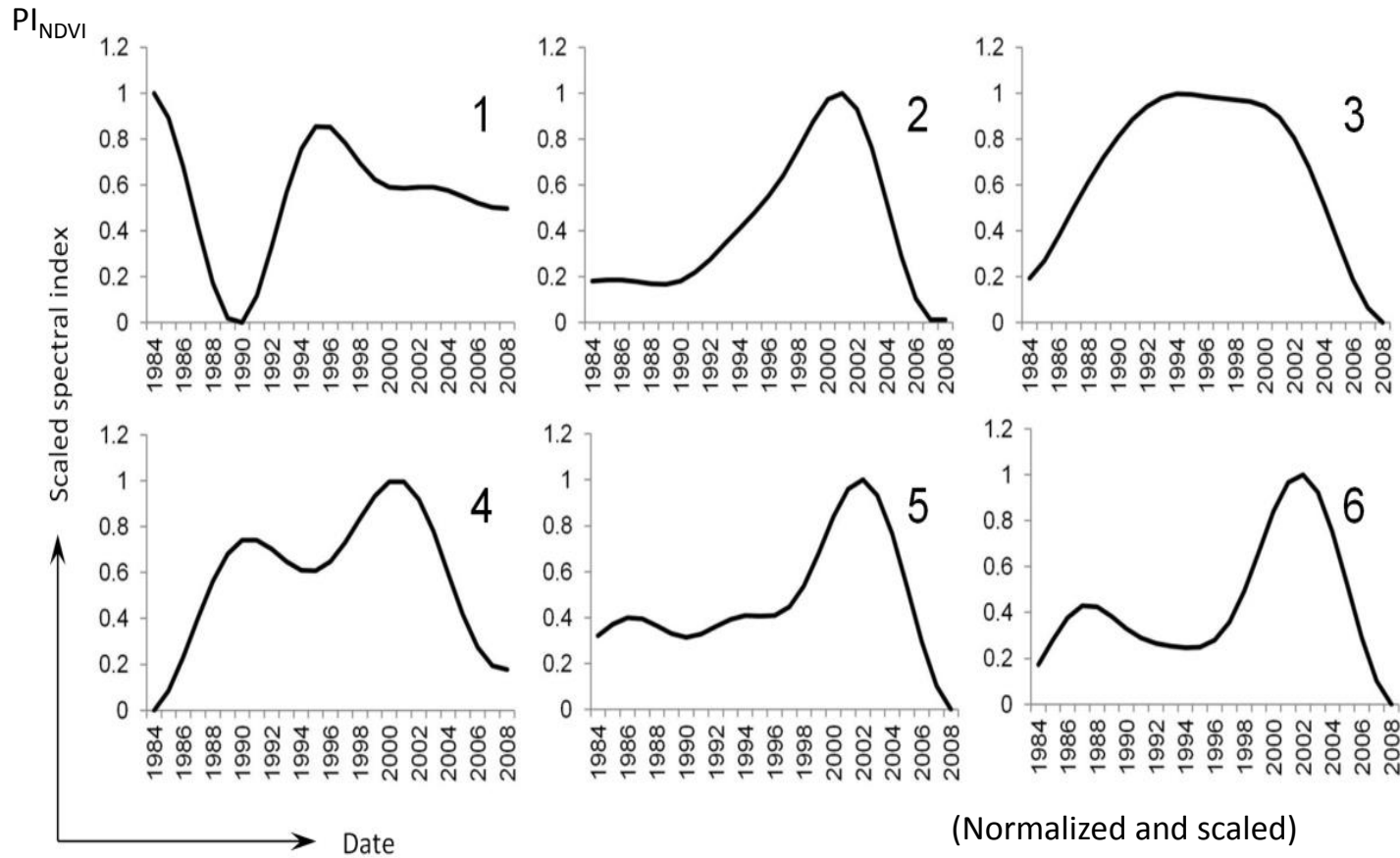
Attribution through DTW



RETROSPECTIVE ESTIMATION OF BIOMASS

Example of dynamic variable domain

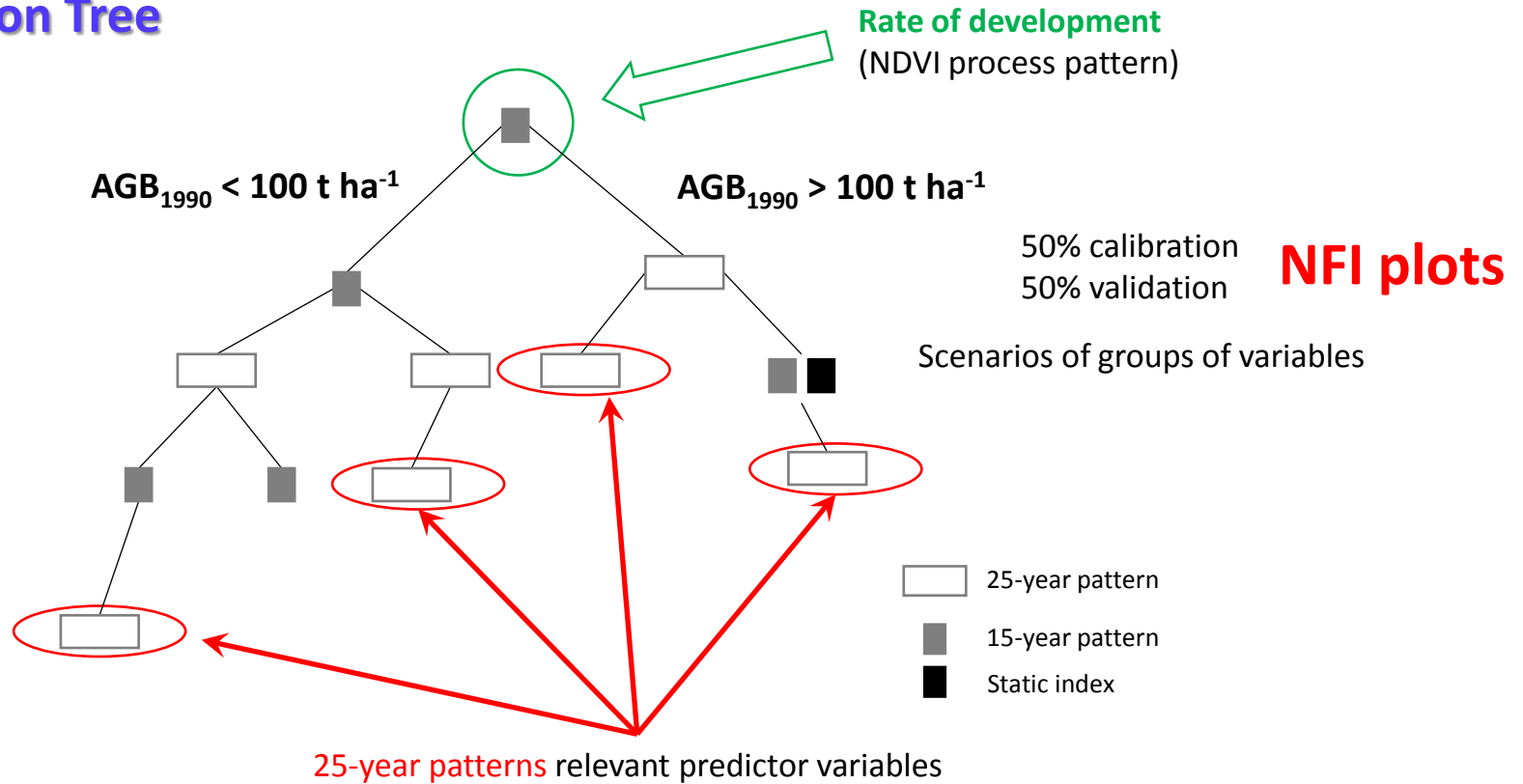
Dynamic process variable associated with rate of development
(NDVI temporal derivative modelled trajectories)



RETROSPECTIVE ESTIMATION OF BIOMASS

Binary model for classification

Decision Tree

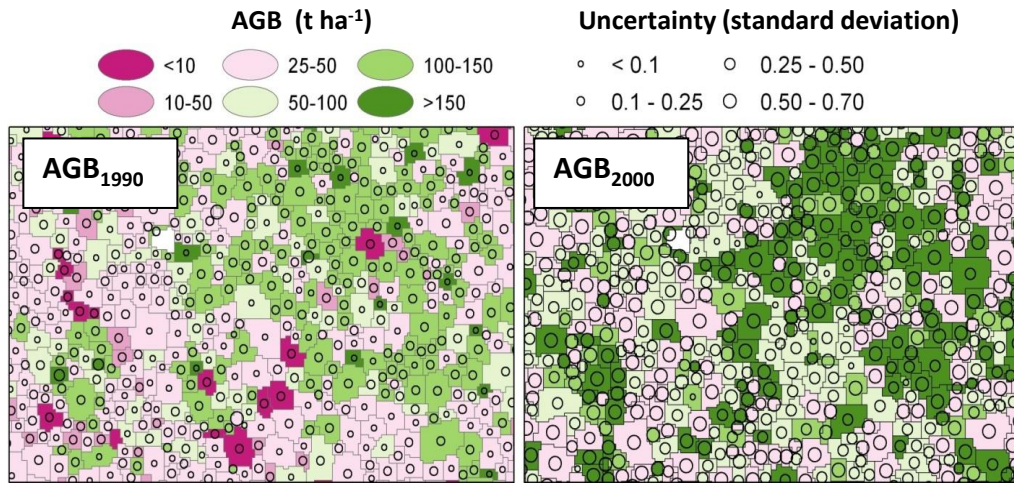


Best model of AGB_{1990} **RMSE = 32 t ha⁻¹ (ME = 34% on average)**

STRUCTURAL VARIABLES

RETROSPECTIVE ESTIMATION OF BIOMASS

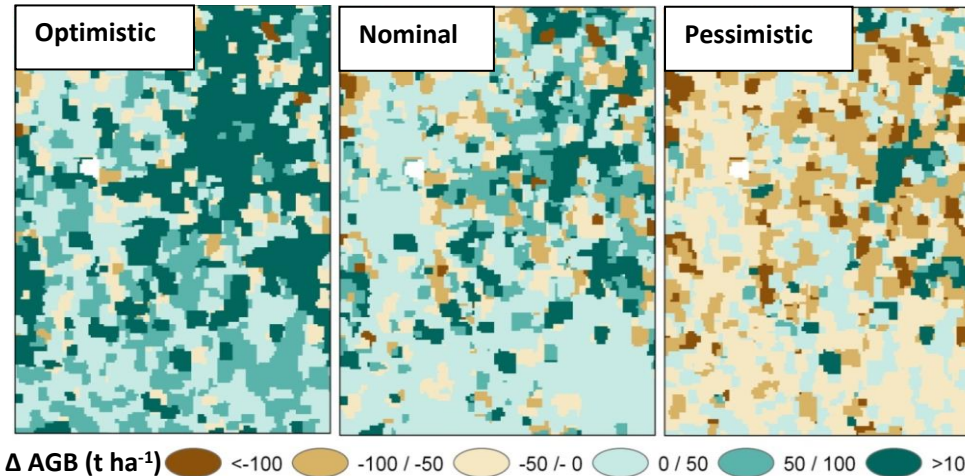
Mapping AGB and Δ AGB, uncertainty



AGB₂₀₀₀ higher uncertainty

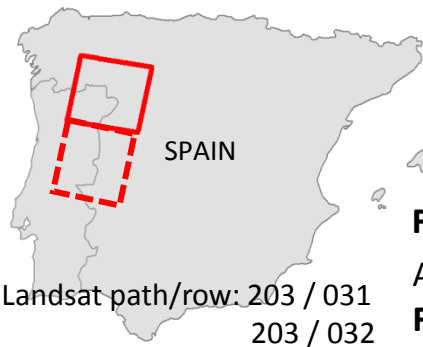
$$\Delta \text{AGB} = (\text{AGB}_{2000} - \text{AGB}_{1990}) \pm (E_{1990} + E_{2000})$$

Multi-layer map of Δ AGB

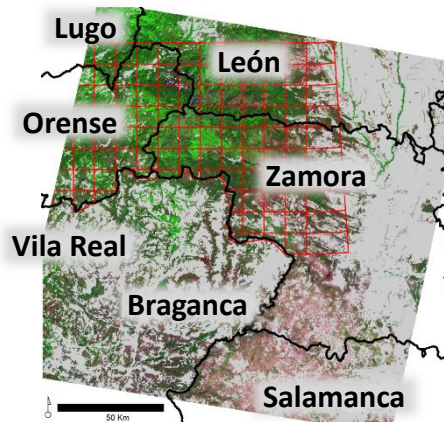


Annual cartography of forest fires (1985-2015) in the NW of Spain from annual Landsat time series and algorithm Composite2Change

34 Landsat images (1984-2016)
TM, ETM+, OLI



Forest mask (CORINE)
Area: 3 467 458 ha
Forest area: 1 869 096 ha



Forest ecosystems:

Treed

Quercus pyrenaica Willd.,
Quercus robur L.,
Quercus ilex L.
Pinus pinaster Ait.
Pinus sylvestris L.
Castanea sativa Mill.
Eucaliptus globulus Labill

Shrub

Herb

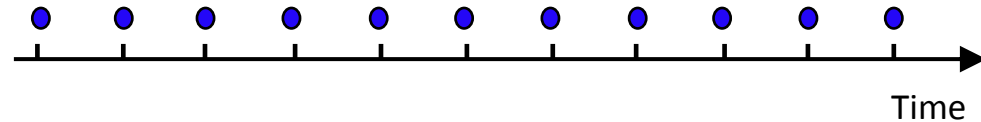
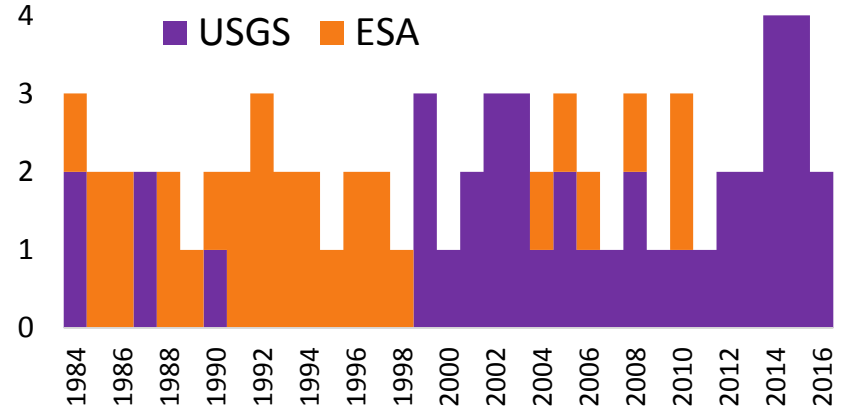


Image availability



Composited annual series

“End of summer fire season”

- Target DOY 259: 15 September
- 30 June-1 October
- < 70% cloud coverage
- TM, OLI, ETM+
- Archive: USGS > ESA

Composite2Change (C2C) algorithm

Breakpoint algorithm NBR
Spectral trend analysis
Non fire detection specific

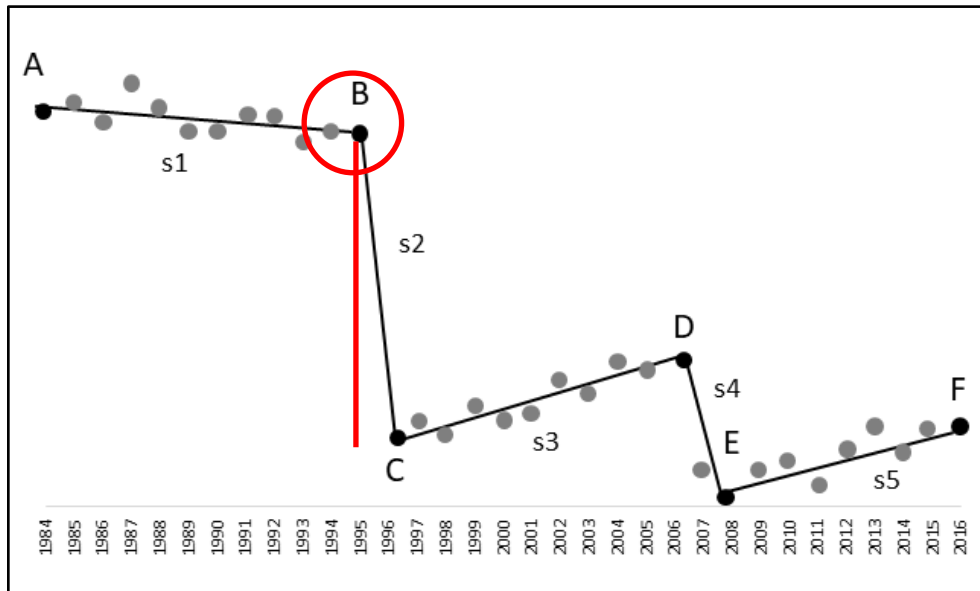


Natural Resources
Canada

Ressources naturelles
Canada

Hermosilla T, Wulder MA, White JC, Coops NC, Hobart GW, 2015
An Integrated Landsat Time Series Protocol for Change Detection
and Generation of Annual Gap-Free Surface Reflectance Composites.
Remote Sensing of Environment 158, 220–234.

Normalized Burn Ratio (NBR) spectral trend



Spectral Trend Analysis ➡ **Pixel** level
Maximum 6 segments ➡ 2 changes in 1985-2015
~20% changed pixels
Aggregation to **object**: minimum **0.5 ha**

| Trend Analysis Metric | |
|----------------------------------|---------------------------------|
| Pre-change ¹ | Pre-change magnitude variation |
| | Pre-change persistence |
| | Pre-change evolution rate |
| Change (negative segments) | Change year |
| | Change persistence |
| | Change magnitude variation |
| | Change rate |
| | First change year |
| | First change persistence |
| | Last change year |
| | Last change persistence |
| Post-change ¹ | Post-change magnitude variation |
| | Post-change persistence |
| | Post-change evolution rate |

METHODS

1. PRE-C2C PROCESSING

Input data
(L1T format)

Preprocessing
Geometric alignment
Fmask
IRMAD Normalization

Compositing
DOY
Sensor
Archive

2. COMPOSITE REFINEMENT AND CHANGE DETECTION

Annual composites

Temporal Domain

Spatial Domain

Noise detection

Breakpoint detection

Contextual Analysis

Data Gaps

Spectral Trend Analysis

Annual proxy composites

Change metrics

C2C

3. CHANGE ATTRIBUTION

Random Forest

Attributed changes

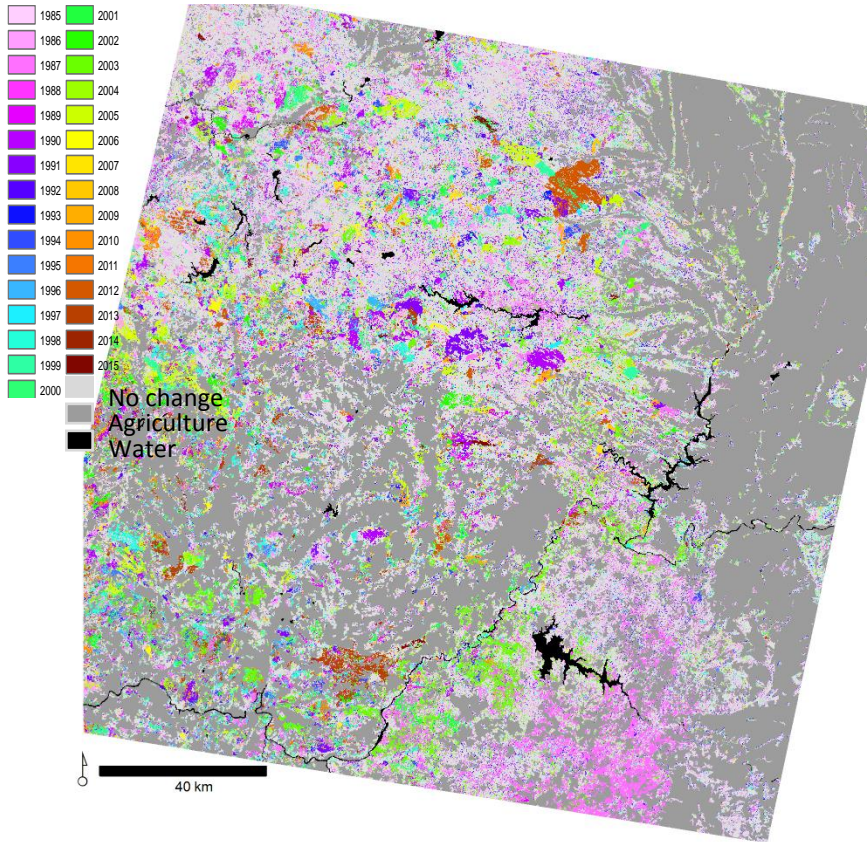
4. QUALITY ASSESSMENT

Validation

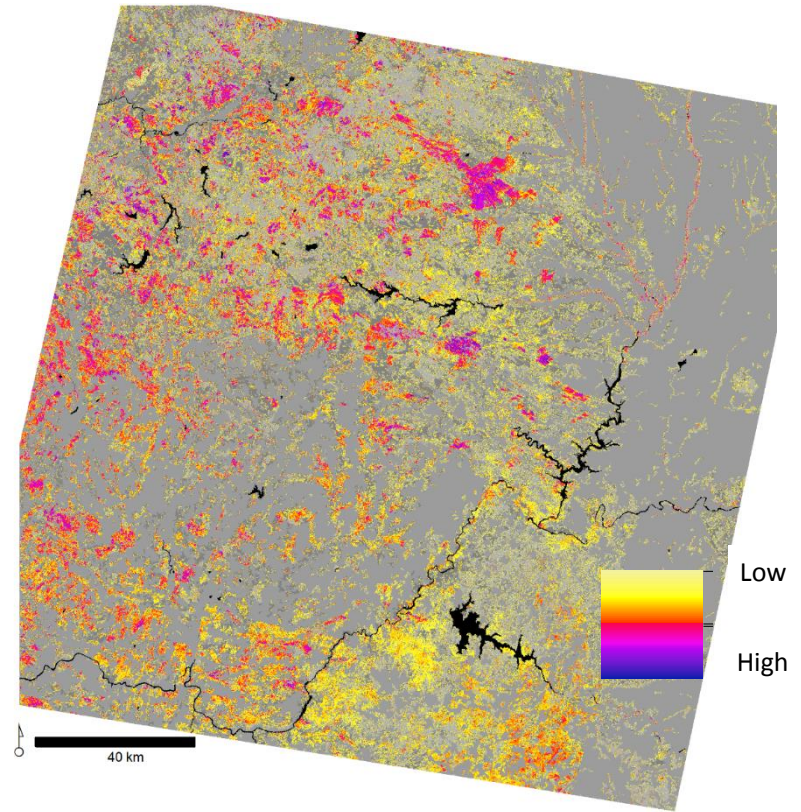
Comparison with statistics (EGIF)

ANNUAL FIRE CARTOGRAPHY

CHANGE DETECTION OUTPUTS



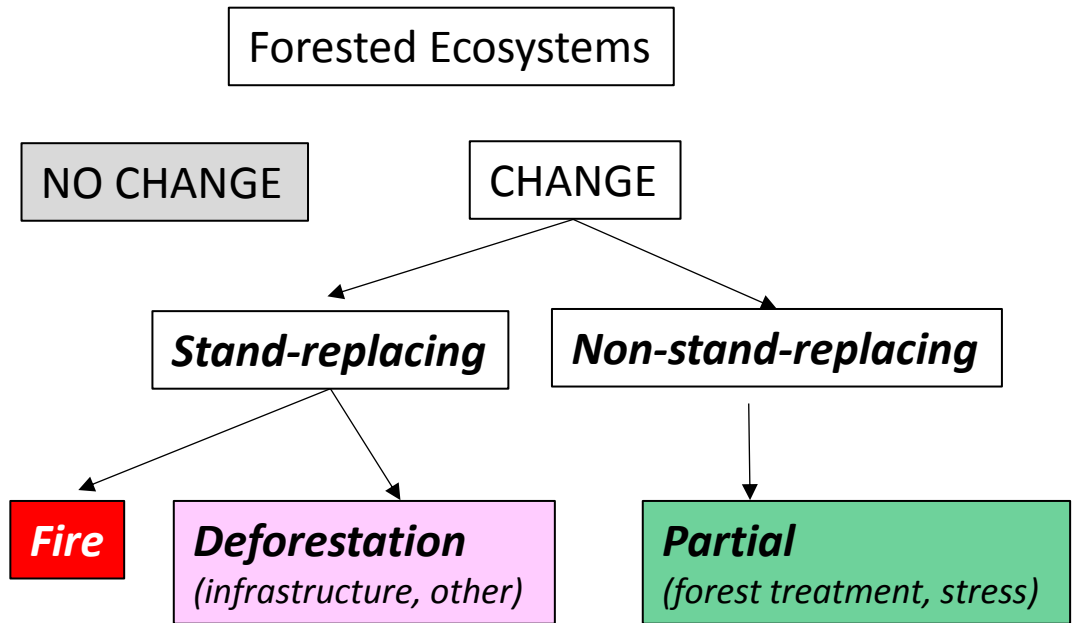
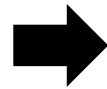
Change Year



Magnitude

CHANGE ATTRIBUTION

Hierarchical
classification



Random Forest
classification



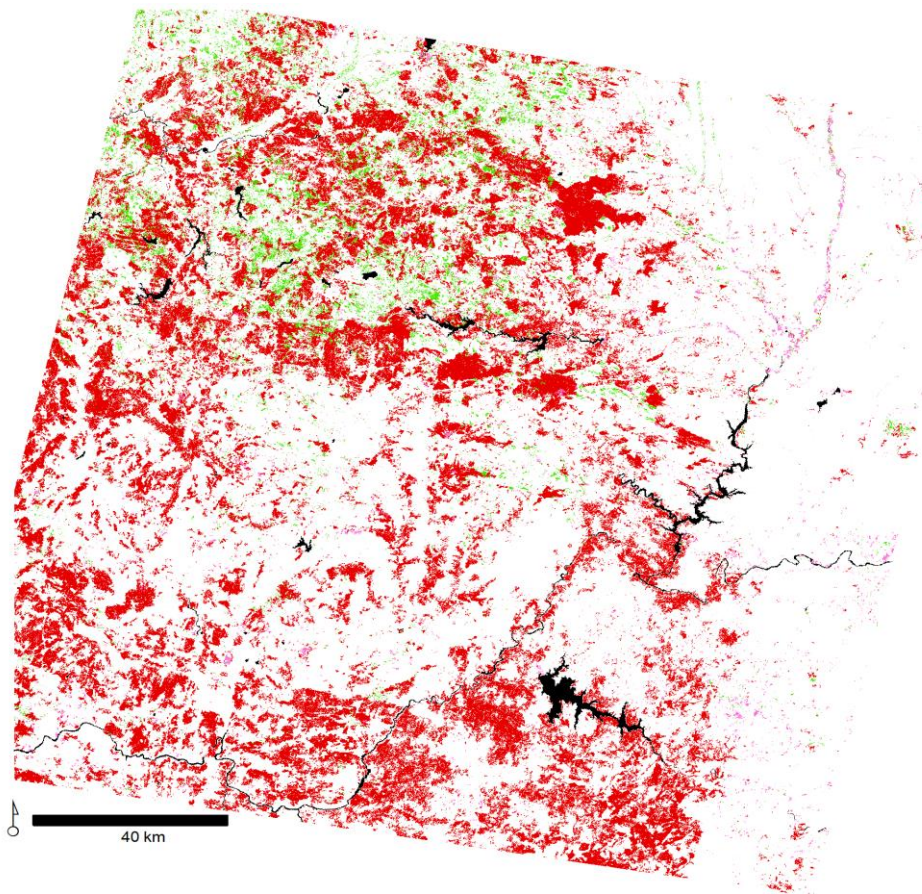
30 variables
(out of 55)

- Trend Analysis Metrics
- Spectral Metrics
- Geometrical Metrics

128 samples accross temporal series

Change Type

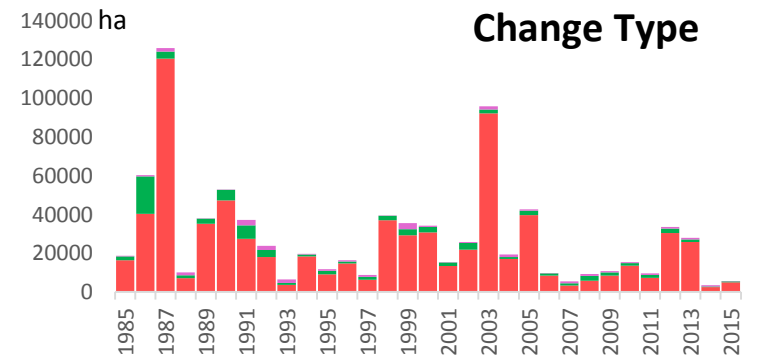
1985-2015



Fire **Deforestation** **Partial**

Random Forest error

- Change/No Change* ➔ **7.03% error**
- Type of Change* ➔ **10.94% error**



Summary

Validation

Change detection

201 pixel samples

Stratified random sample

| | Change | No change | User's accuracy | Commission error |
|---------------------|--------|-----------|-----------------|------------------|
| Change prop | 92 | 7 | 0.929 | 0.071 |
| No change prop | 8 | 93 | 0.921 | 0.079 |
| Producer's accuracy | 0.920 | 0.930 | | |
| Omission error | 0.080 | 0.070 | | |

Overall accuracy \pm margin of error = **92.5% +1.6%**

Change attribution

300 object samples

Stratified random sample

| | Fire | Deforestation | Partial | User's accuracy | Comm. error |
|---------------------|--------------|---------------|---------|-----------------|-------------|
| Fire | 142 | 1 | 0 | 0.993 | 0.007 |
| Veg replacing | 0 | 41 | 2 | 0.953 | 0.047 |
| Gradual | 1 | 0 | 48 | 0.980 | 0.020 |
| Producer's accuracy | 0.993 | 0.976 | 0.960 | | |
| Omission error | 0.007 | 0.024 | 0.040 | | |

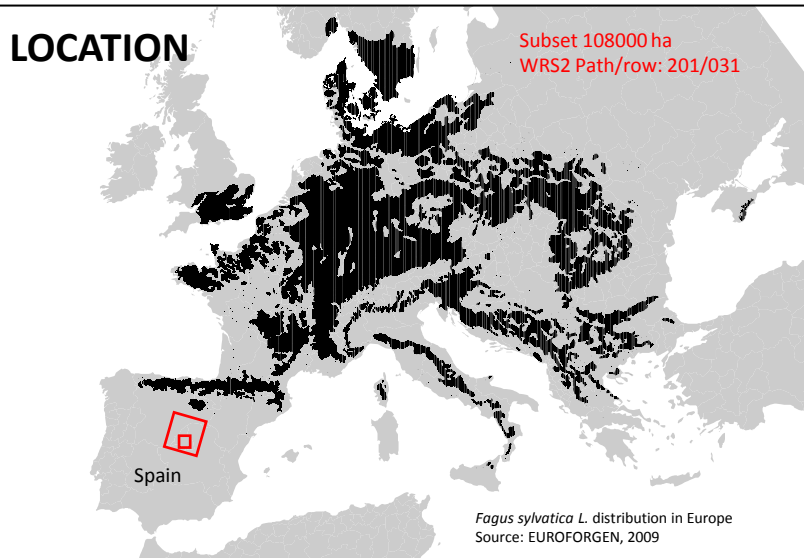
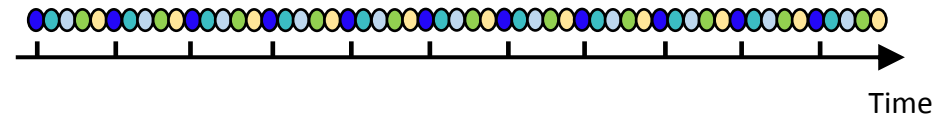
Overall accuracy \pm margin of error = **98.3% +1.6%**

Temporal accuracy

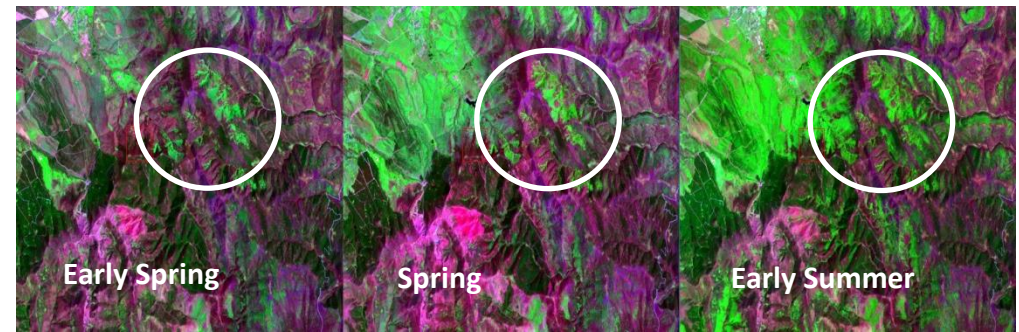
97% fires detected year of reference, 3% one year delay

Presence and recent dynamics of European beech in its Spanish southernmost limit characterized with Landsat intra-annual time series

619 Landsat images (1984-2017)
TM, ETM+, OLI



Fagus sylvatica early leaf-on \Rightarrow Distinctive spectral signature (mid-May)



(RGB: SWIR2/NIR/Green)

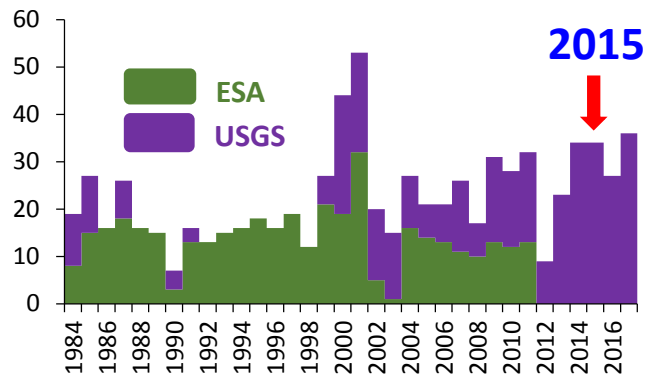
Southern limit \Rightarrow Mountain distribution

Historical recent circumstances: 1960s

- End of intensive **charcoal production** from wood (butane gas)
- Start of **urban migration**
- Decline of **livestock grazing** and the use of fire to create grasslands

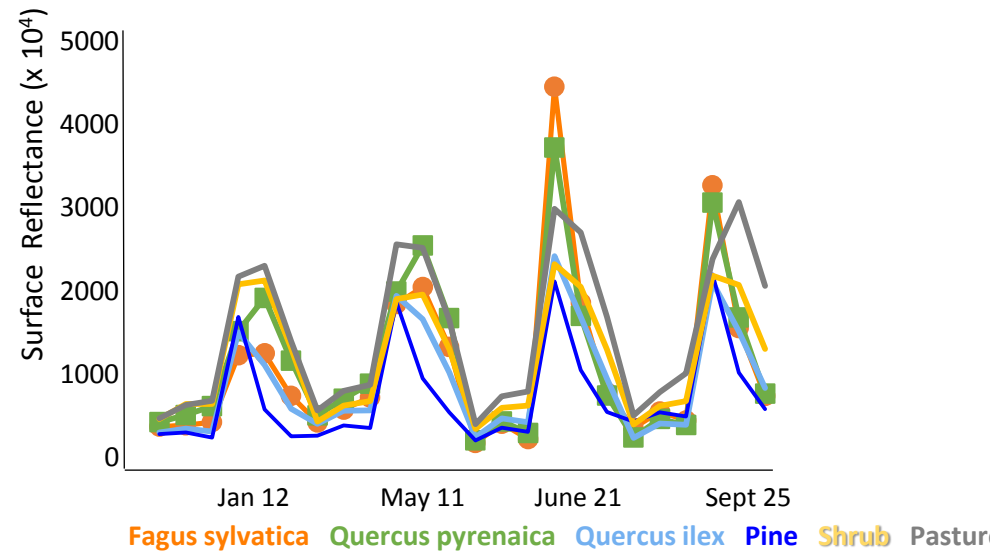
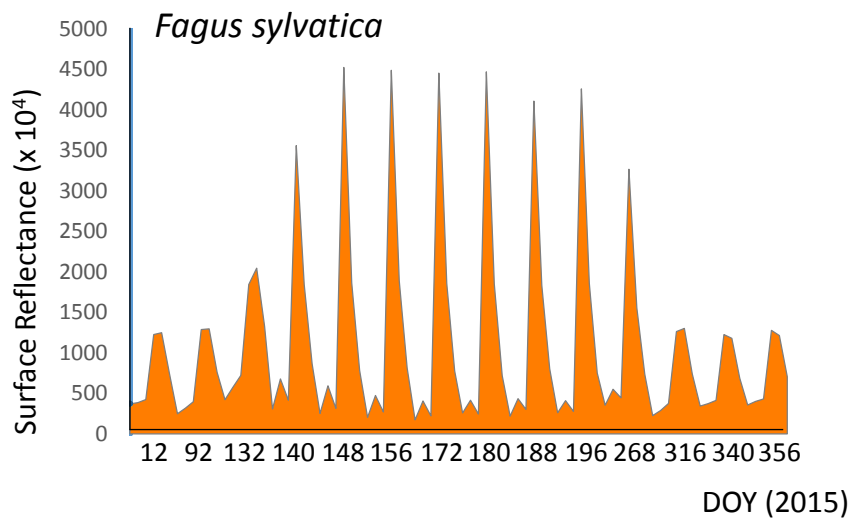
SPECIES DYNAMICS

ONE YEAR SPECTRAL CHARACTERIZATION



14 images (USGS): 7 ETM+ / 7 OLI

Samples from ancillary information
MFE
NFI plots



Spectral differences:

- Pines all year
- Quercus pyrenaica early Spring
- Pasture in Winter

Spectral similarities:

- Pasture + Fraxinus angustifolia
- Betula in streams

CLASSIFICATION

Support Vector Machine (SVM)

Four 2015 images for classification

- January 12 (Winter)
- May 12 (Spring)
- June 21 (Summer)
- September 25 (Autumn)

Composites with 2013/2014 pixels

Classification variables:

Surface Reflectance (SR)
Tasseled Cap Angle (TCA)
Tasseled Cap Wetness (TCW)

Samples: 176

Mask non-forest areas with **MFE**

Restriction > 1200m

Verification of presence / absence

Field visits

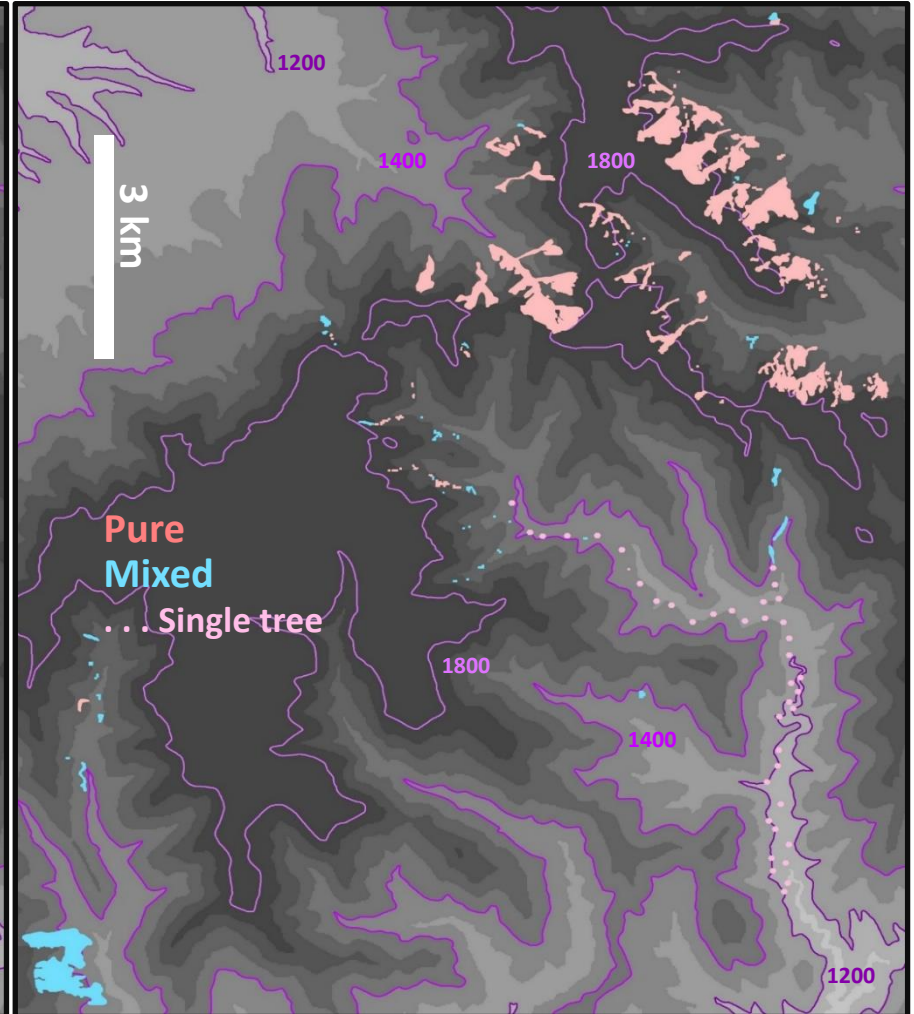
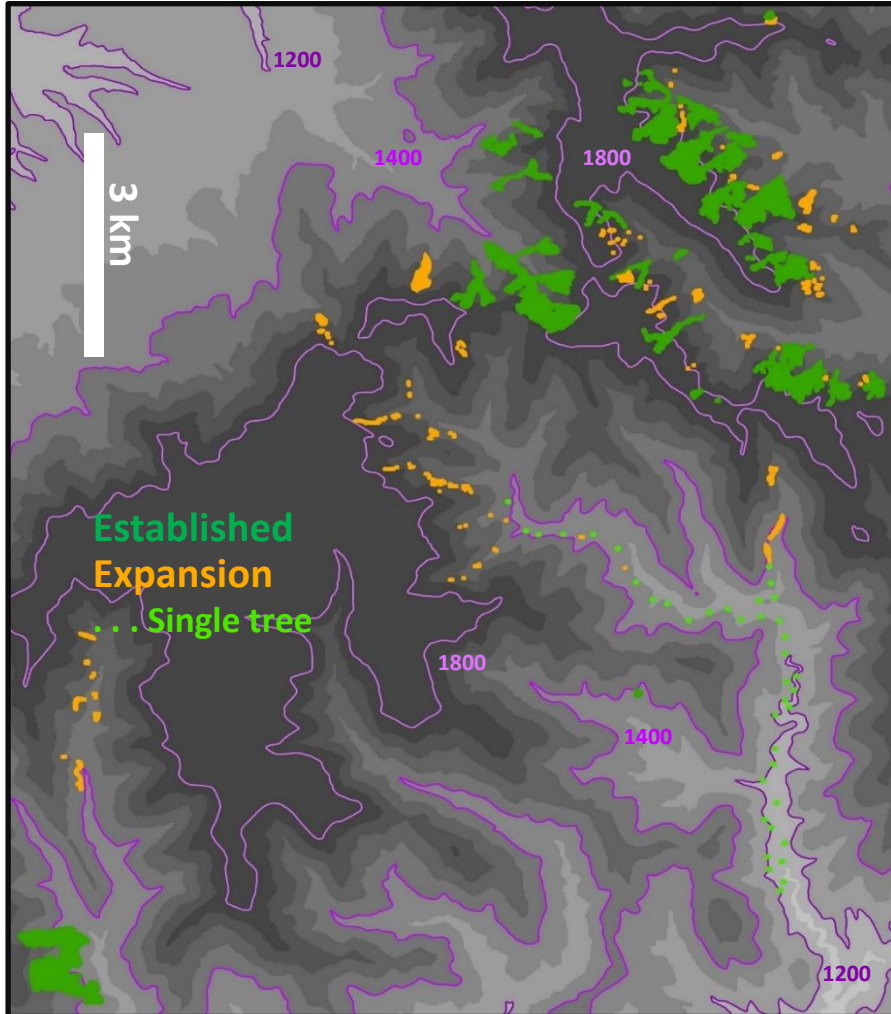
Field plots: 90 ForeStereo plots (dasometric variables)
32 Age plots (ecological variables)



Vegetation classes: 6

- **Fagus sylvatica**
- **Quercus pyrenaica**
- **Quercus ilex**
- **Pine**
- **Shrub**
- **Pasture**

CURRENT DISTRIBUTION



Altitude: 1200 – 1970m
458.86 ha
57.64 ha (12.5%)

412.95 ha
103.55 ha

CURRENT EXPANSION

Expansion in shrub



Expansion in pine forest



River expansion



Expansion in oak forest



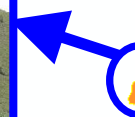
Established

Expansion

Disturbances

— 1km

1200 m



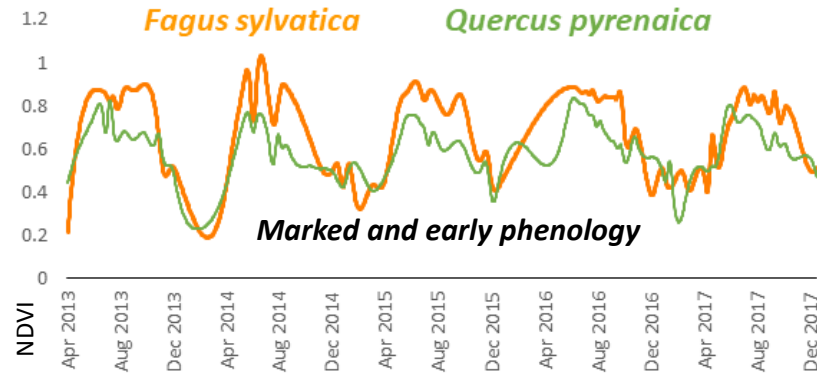
RECENT DYNAMICS

2013-2017 OLI ETM+ 147 images



VI Phenological signature

TIMESAT



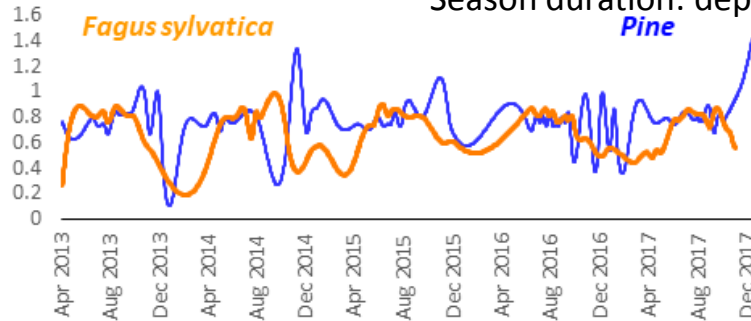
Season start: *Fagus* < *Quercus*

TCA > NDVI

Season duration: dependent on year

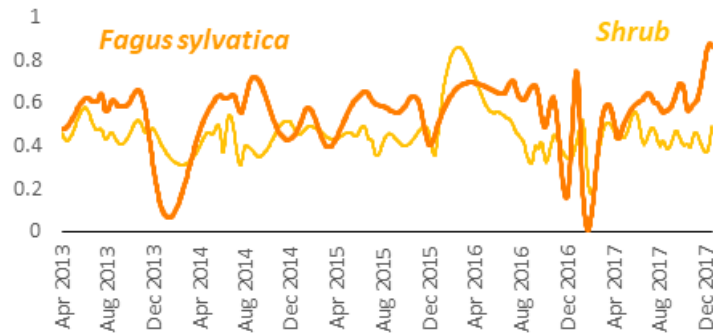
TCA < NDVI

Expansion in pine



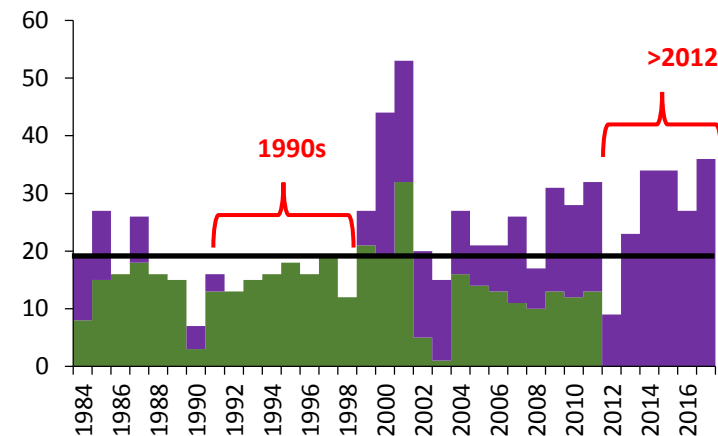
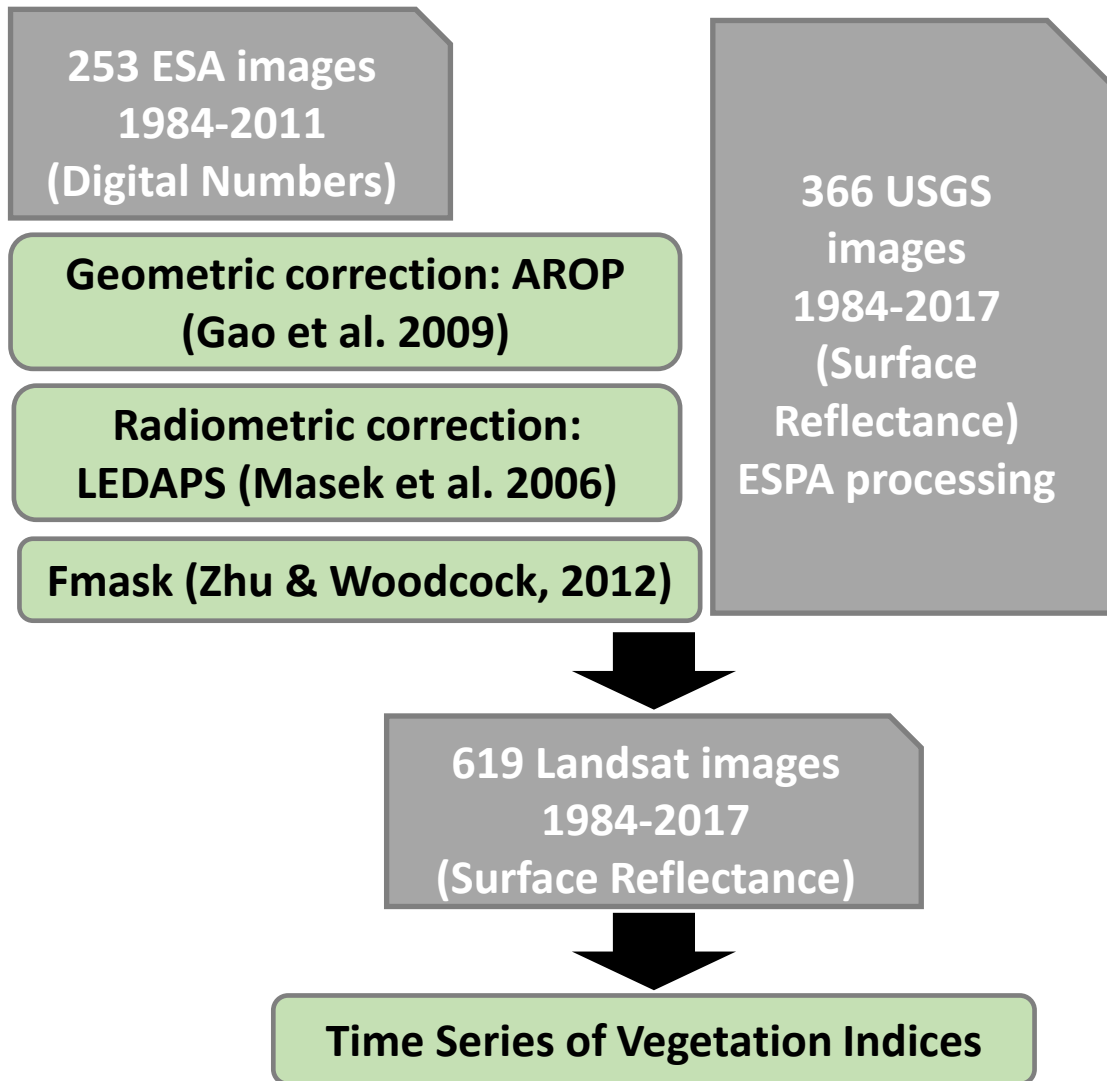
Marked phenology

Expansion in shrubland



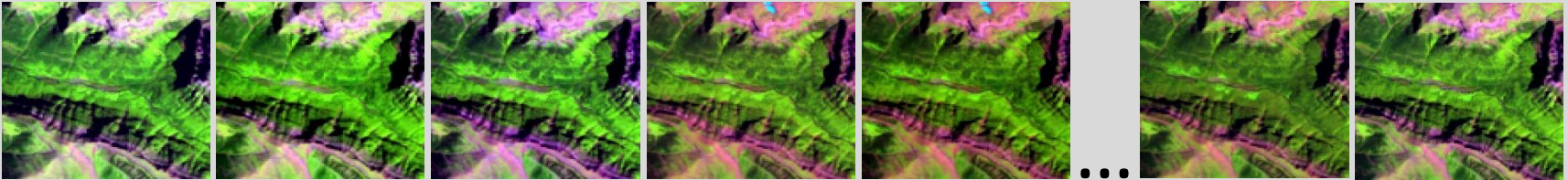
Transition to marked phenology

RECENT DYNAMICS



1990s only ESA
> 2012 only USGS

Gracias



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