Proximal and remote sensing synergies for monitoring and modelling key vegetation biophysical variables in tree-grass ecosystems: a study case in central Spain

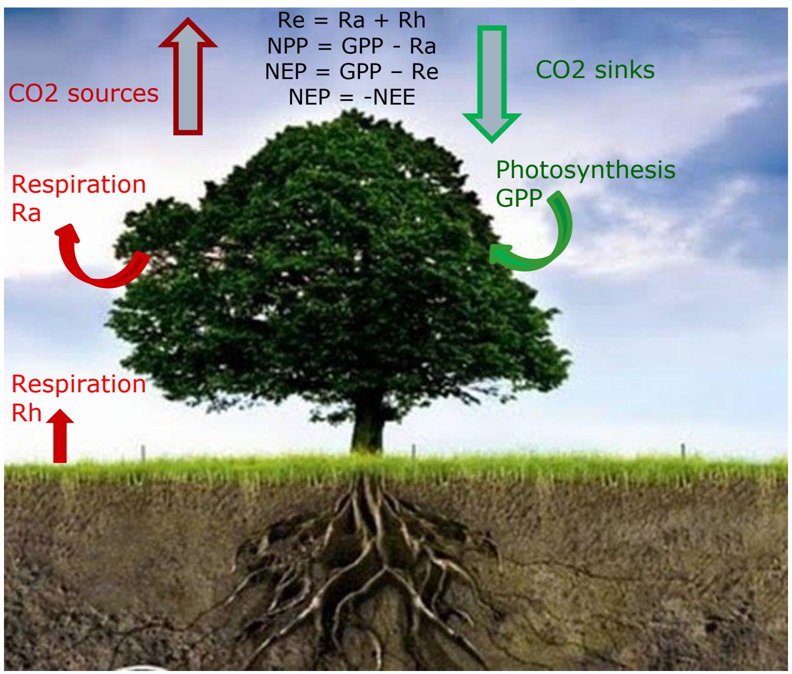
M. Pilar Martín

Environmental remote sensing and spectroscopy laboratory (SpecLab)

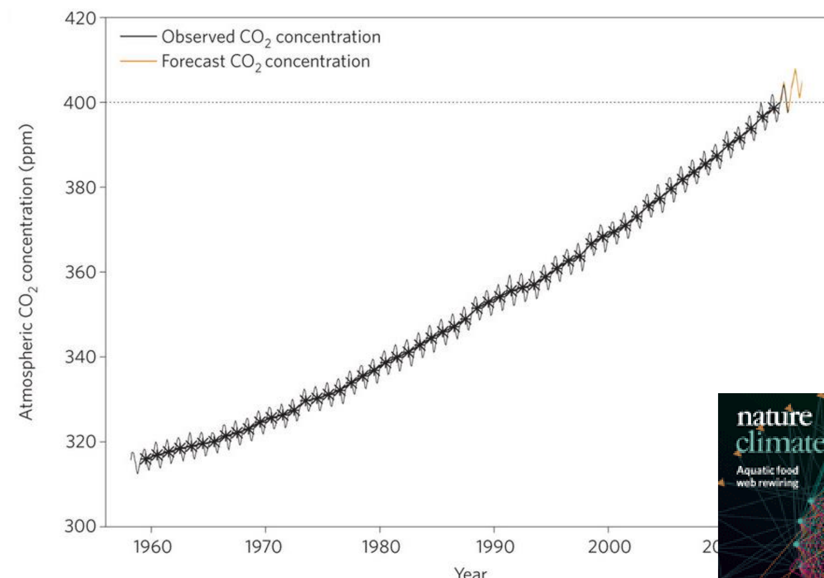
Spanish National Research Council (CSIC)

Monitoring Terrestrial Carbon fluxes

- NEP quantification a key issue to improve our understanding of the feedbacks between the terrestrial biosphere and the atmosphere



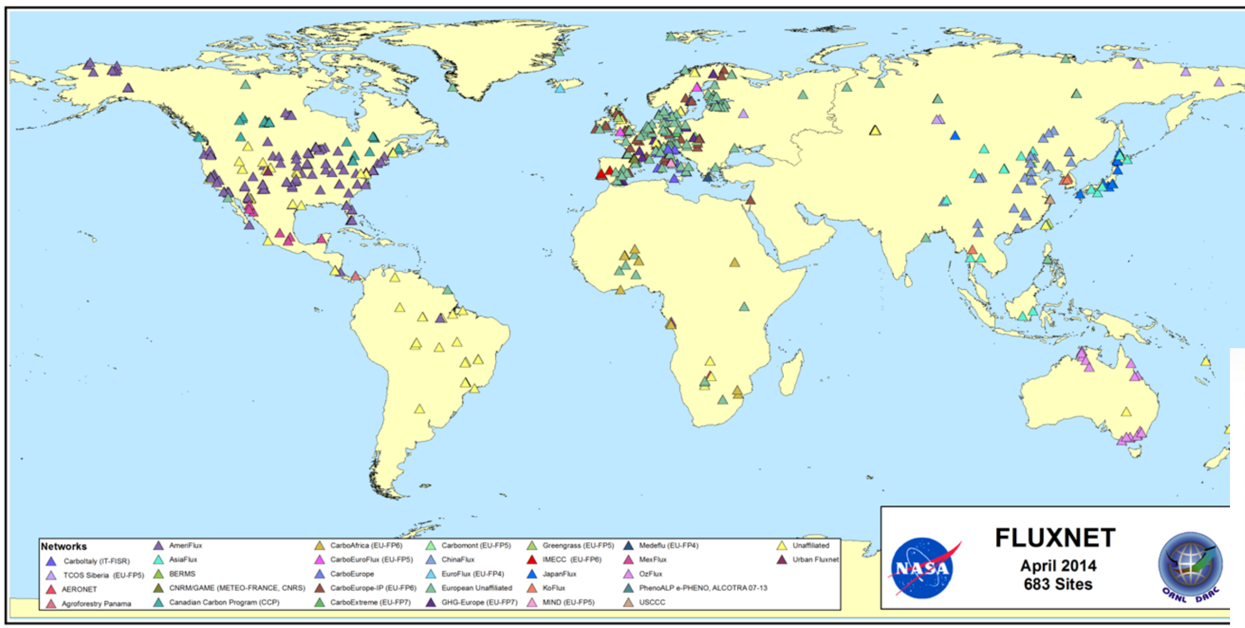
Observed and forecast CO_2 concentrations at Mauna Loa



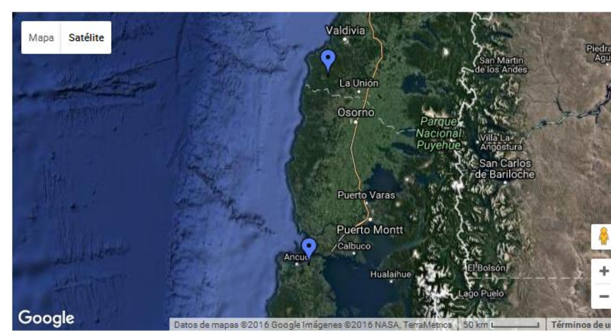
From El Niño and a record CO_2 rise
Richard A. Betts,Chris D. Jones,Jeff R. Knight,Ralph F. Keeling& John J. Kennedy
Nature Climate Change 6, 806–810 (2016)

Eddy covariance systems

- Eddy covariance (EC) flux towers have been providing continuous measurement of ecosystem level water and carbon exchanges since the early 1990s



Fluxnet Sites in Chile



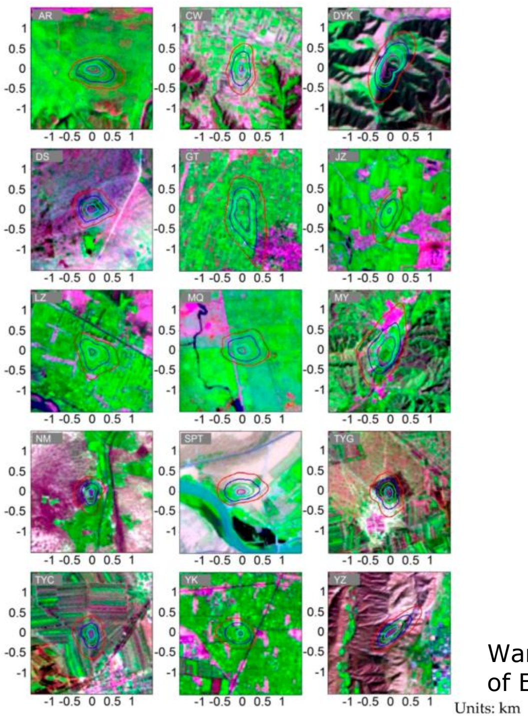
3 sites

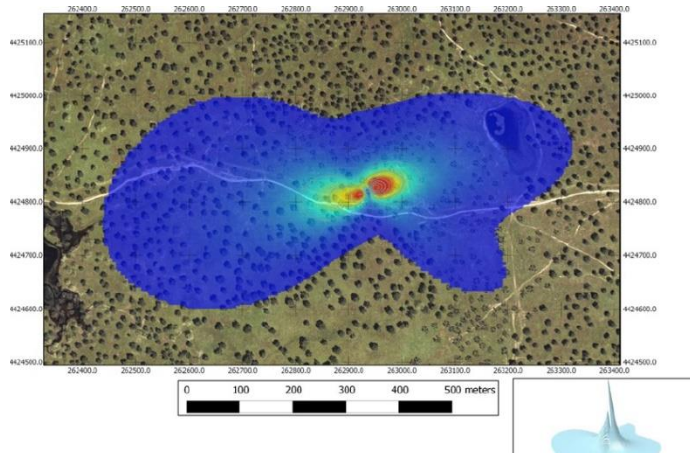
Site Name	Site Code	Latitude	Longitude
Alerce Costero National Park	CL-ACP	-40.172267	-73.445203
Senda Darwin Forest	CL-SDF	-41.883	-73.676
Senda Darwin Peatland	CL-SDP	-41.879	-73.666

https://fluxnet.ornl.gov

EC measurements need to be scaled up

- The restricted spatial representativeness of EC fluxes measured at site level has limited the scope of the studies based on this data

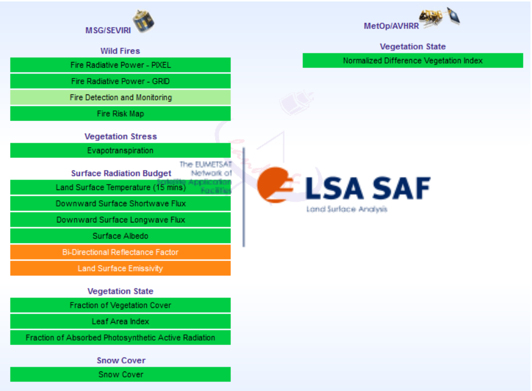




- Small footprint (< 1 km)
- Network of Towers is Discrete in Space

Wang, H., Jia, G., Zhang, A., & Miao, C. (2016). Assessment of Spatial Representativeness of Eddy Covariance Flux Data from Flux Tower to Regional Grid. Remote Sensing, 8

Remote sensing: a tool to monitor land parameters



- Remote Sensing is an important data source to quantify canopy structure and ecosystem function and phenology
- Reflectance can be converted into biophysically meaningful descriptors of the ecosystem: LAI, fCover, fPAR, LST, CWC, biomass, albedo..
- Some of these variables are being systematically monitored at coarse spatial resolution by global remote sensing programs
- Spatial mismatch between EC measurements and coarser grid-cell of satellite information
- Lack of accuracy in complex ecosystems

Copernicus
Europe's eyes on Earth

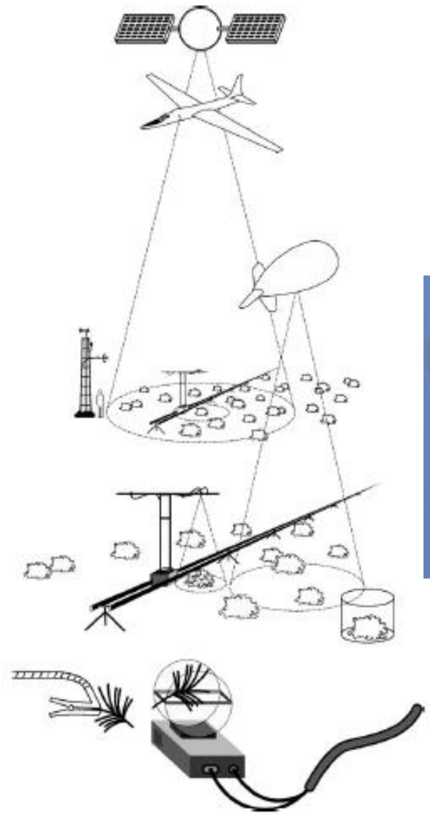
Theme	Near-Real Time Product	Spatial Resolution	
		Coarse >=1km	Medium 300m
Vegetation	Fraction of photosynthetically active radiation absorbed by the vegetation	In production	In development
	Fraction of green vegetation cover	In production	In development
	Leaf Area index	In production	In development
	Normalized Difference Vegetation Index	In production	In production
	Vegetation Condition Index	In production	N/A
	Vegetation Productivity Index	In production	N/A
	Dry Matter Productivity	In production	In development
	Burnt Area	In production	In production
Energy budget	Land Surface Temperature	In production	N/A
	Top Of Canopy Reflectance	In development	In development
	Surface Albedo	In development	In development
Water	Soil Water Index	In production	N/A
	Water Bodies	In production	In development

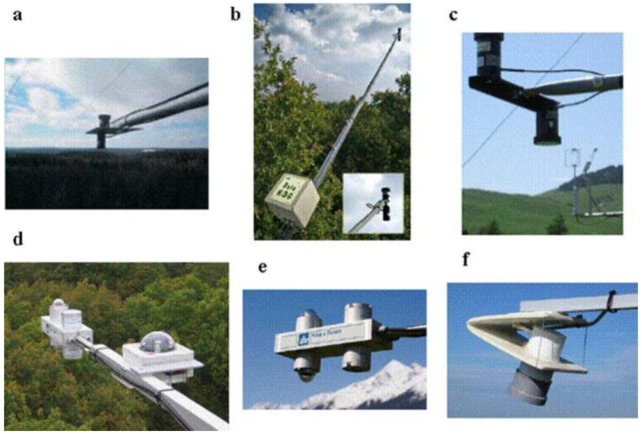
MODIS Land

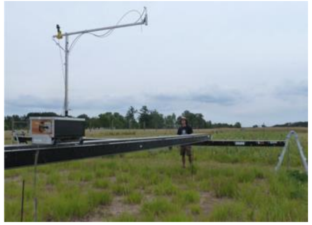
Product	Acronym	Name	Frequency (Days)	Resolution (Meter)
MOD13Q1	NDVI/EVI	MODIS/Terra Vegetation Indices (NDVI/EVI) 16-Day L3 Global 250m SIN Grid [Collection 5]	16	250
MYD13Q1	NDVI/EVI	MODIS/Aqua Vegetation Indices (NDVI/EVI) 16-Day L3 Global 1km SIN Grid	16	250
MCD12Q1	LC	MODIS/Terra+Aqua Land Cover (LC) Type Yearly L3 Global 500m SIN Grid	annual	500
MCD12Q2	LCD	MODIS/Terra+Aqua Land Cover Dynamics (LCD) Yearly L3 Global 500m SIN Grid	annual	500
MCD43A1	BRDF	MODIS/Terra+Aqua BRDF/Albedo (BRDF/MCD43A1) 16-Day L3 Global 500m SIN Grid	16	500
MCD43A2	BRDF/QA	MODIS/Terra+Aqua BRDF/Model Quality (BRDF/MCD43A2) 16-Day L3 Global 500m SIN Grid V005	16	500
MCD43A4	NBAR	MODIS/Terra+Aqua Nadir BRDF-Adjusted Reflectance (NBAR) 16-Day L3 Global 500m SIN Grid	16	500
MOD09A1	SREF	MODIS/Terra Surface Reflectance (SREF) 8-Day L3 Global 500m SIN Grid	8	500
MYD09A1	SREF	MODIS/Aqua Surface Reflectance (SREF) 8-Day L3 Global 500m SIN Grid	8	500
MOD11A2	TEMP	MODIS/Terra Land Surface Temperature/Emissivity (LST) 8-Day L3 Global 1km SIN Grid	8	1000
MOD15A2	LAI/FPAR	Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation (FPAR) 8-Day Composite [Collection 5]	8	1000
MOD16A2	ET	MODIS/Terra Evapotranspiration (ET) 8-Day L4 Global Collection 5	8	1000
MOD17A2	GPP	MODIS/Terra Gross Primary Production (GPP) 8-Day L4 Global [Collection 5.1]	8	1000
MOD17A3	NPP	MODIS/Terra Net Primary Production (NPP) Yearly L4 Global 1km SIN Grid	annual	1000
MYD11A2	TEMP	MODIS/Aqua Land Surface Temperature/Emissivity (LST)8-Day L3 Global 1km SIN Grid	8	1000
MYD15A2	LAI/FPAR	MODIS/Aqua Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation (FPAR) 8 Day Composite	8	1000
MYD17A2	GPP	MODIS/Aqua Gross Primary Production (GPP) 8 Day L4 Global	8	1000

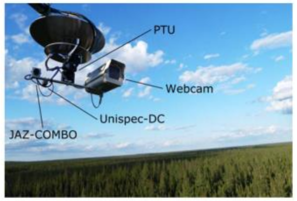
New sensors, platforms and methods

- New approaches can help to fill the gap between field and satellite observations
  - Platforms: UAVs, towers, trams…
  - Sensors: led, miniaturized hyper and multi spectral, smartphones
  - Methods: data integration (sensors and platforms), continuous observation, multiangular data….









Gamon, J.A., Rahman, A.F., Dungan, J.L., Schildhauer, M., & Huemmrich, K.F. (2006). Spectral Network (SpecNet) - What is it and why do we need it? *Remote Sensing of Environment, 103, 227-235*

Field ("real") data

- *"Collecting real data gives you insights on what is important and provides necessary information to parameterize and validate models. You must get your boots dirty"* (D. Baldocchi, UCB)

Biophysical parameters

Characterize the site at different scales: from plot to ecosystem

- Link the information with EC measurements and other field sensors
- Link the information with spectral measurements: ground, airborne and satellite to…
  - Calibrate/validate empirical models
  - Parameterize/validate radiative transfer models
  - Validate standard RS products

Spectral data

- Spectral calibration of remotely sensed data acquired from UAV/airborne and satellite platforms.
- Develop spectral library: spectral characterization of vegetation targets (spatial and temporal dimensions)
- Link the information with EC measurements and other field sensors
- Link the information with biophysical parameters
- Calibrate/validate empirical models
- Parametrize/validate radiative transfer models
- Integration and upscaling

Monitoring changes in water and carbon fluxes from remote and proximal sensing in a Mediterranean "dehesa" ecosystem

"Linking spectral information at different spatial scales with biophysical parameters of Mediterranean vegetation in the context of global change"

Landsat-8 + Sentinel-2: exploring sensor synergies for monitoring and modelling key vegetation biophysical variables in tree-grass ecosystems

- FLUXPEC
  - National funded project: Ministry of Economy and competitiveness
  - 2013-2016

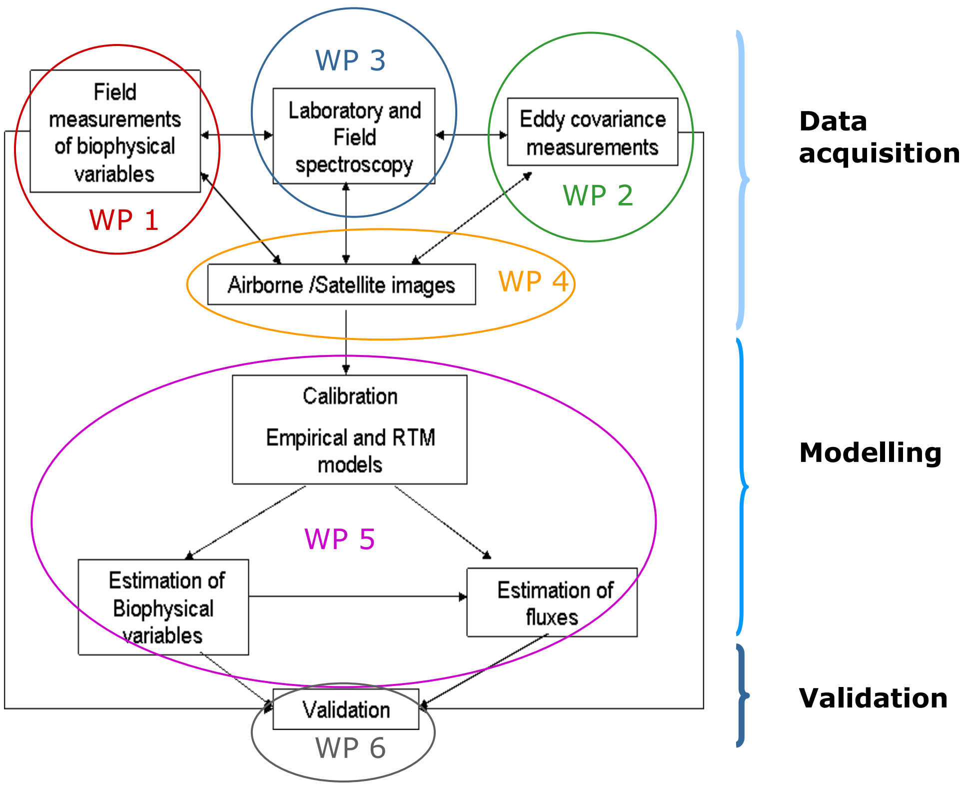
Partners

Key collaborators

- BIOSPEC
  - National funded project: Ministry of Science and Innovation
  - 2009-2012

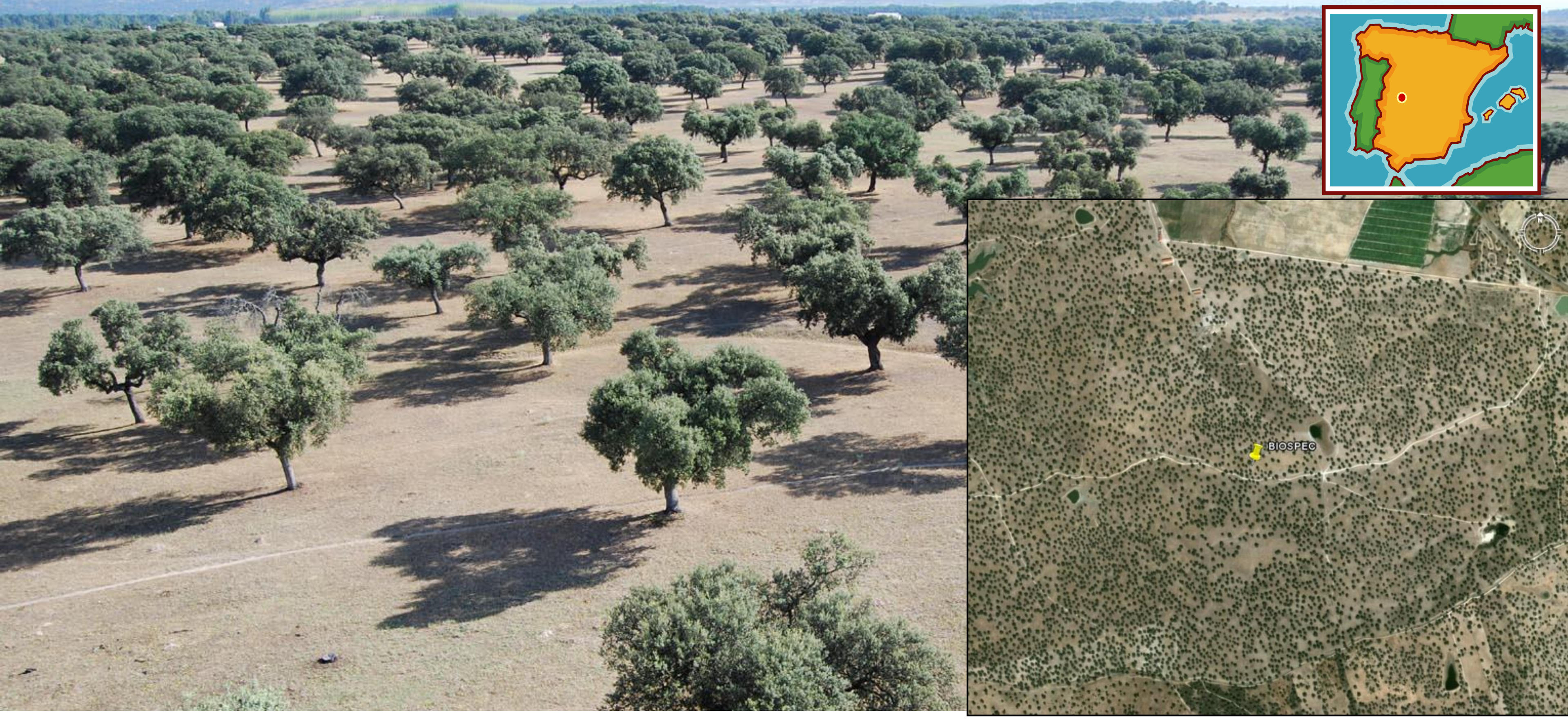
- SynerTGE
  - National funded project: Ministry of Economy and competitiveness
  - 2016-2018

BIOSPEC- FLUχPEC:
Structure and objectives



- **Improvement of remote sensing products** to estimate vegetation biophysical parameters and water and carbon fluxes in **tree-grass** ecosystem
- **Integration** of multi-source proximal and remote sensing data: **optical, thermal, LiDAR**
- To establish relationships between **multi-scale** spectral data, the estimation of relevant vegetation parameters and the Earth-atmosphere fluxes (EC towers) using **empirical** as well as **physical based models** (RTM)
- To assess the capacity of proximal and remote sensing to track the **dynamics of vegetation and EC fluxes at different temporal scales**: daily, seasonally and inter-annually

Las Majadas del Tietar (39°56‘29'' N, 5°46'24'' W), Extremadura, Spain



Ecosystem: ***dehesa*** **Mediterranean Holm Oak open woodland (Savanna)**

Mediterranean Climate: annual T = 16.7 ºC, annual Prec = 700 mm LAI = 0.4 (trees) + 1-1.5 (grass)

Soil: Stagnic Alisols, depth > 2m. Texture: sandy loam. soil C is 8.5 g/kg and soil N is 0.82 g/kg (0-20cm layer).

Tree canopy: 98% *Quercus Ilex;* 25 tree/ha; mean DBH = 45cm; canopy height = 7-10 m; canopy fraction = 10-20%

Management: tree pruning every 25 years to optimize acorn production

Herbaceous layer: high biodiversity (easy to find > 20 species within 4 m^2); different composition below tree / open;

Management: continuous grazing (cows)

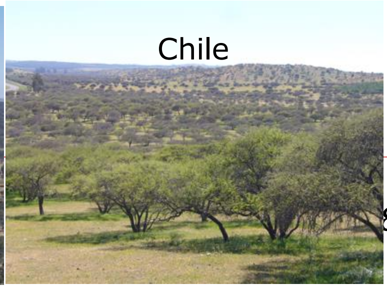
Why a tree-grass ecosystem?

- Mixed tree-grass and shrub-grass vegetation associations are one of the most spatially extensive and widely distributed forms of terrestrial vegetation on earth. Found in tropical, subtropical and temperate bioclimatic regions, occupying nearly a quarter of the terrestrial surface (27 million km2)

- They face an uncertain future given pressures from land use change and climate. Vital for livestock production.

- They represent a gap in Earth Observation capabilities, and a serious challenge for the earth observation and modeling science community.

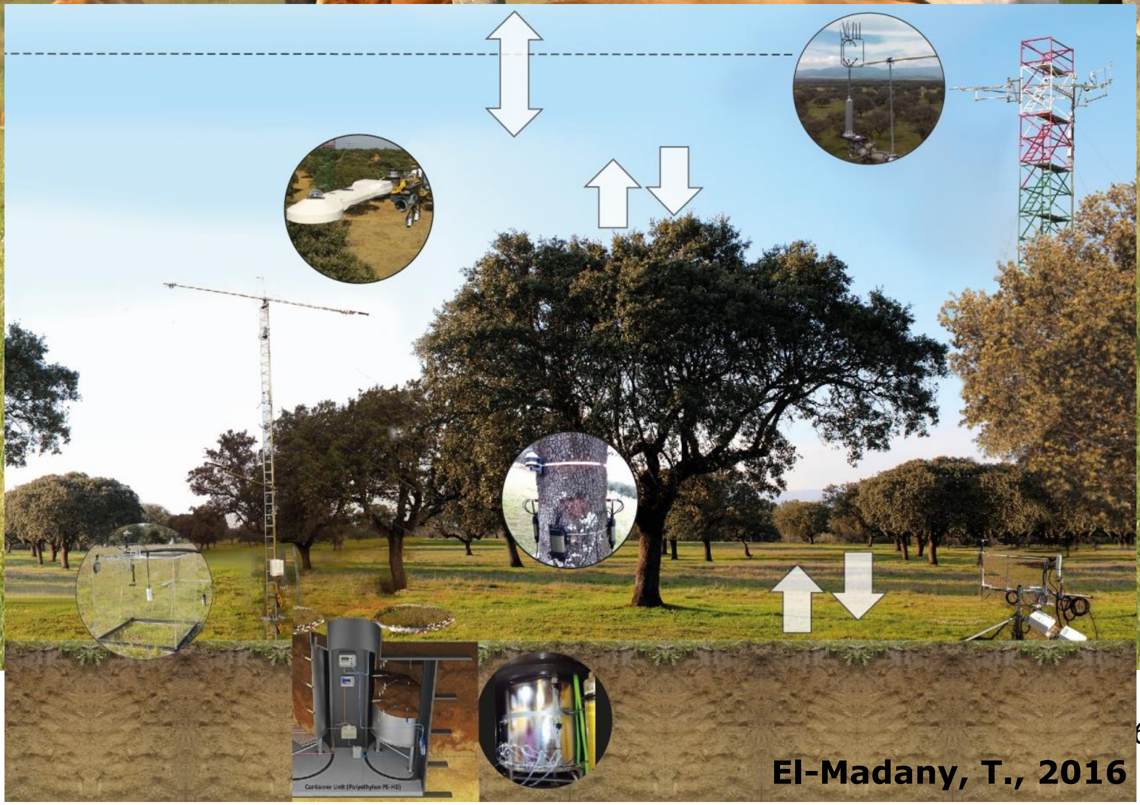
- Recent and emerging technologies and instrumentation offer new opportunities



… and why Majadas?

a beautiful ecosystem…

…but also a well stablished experimental site

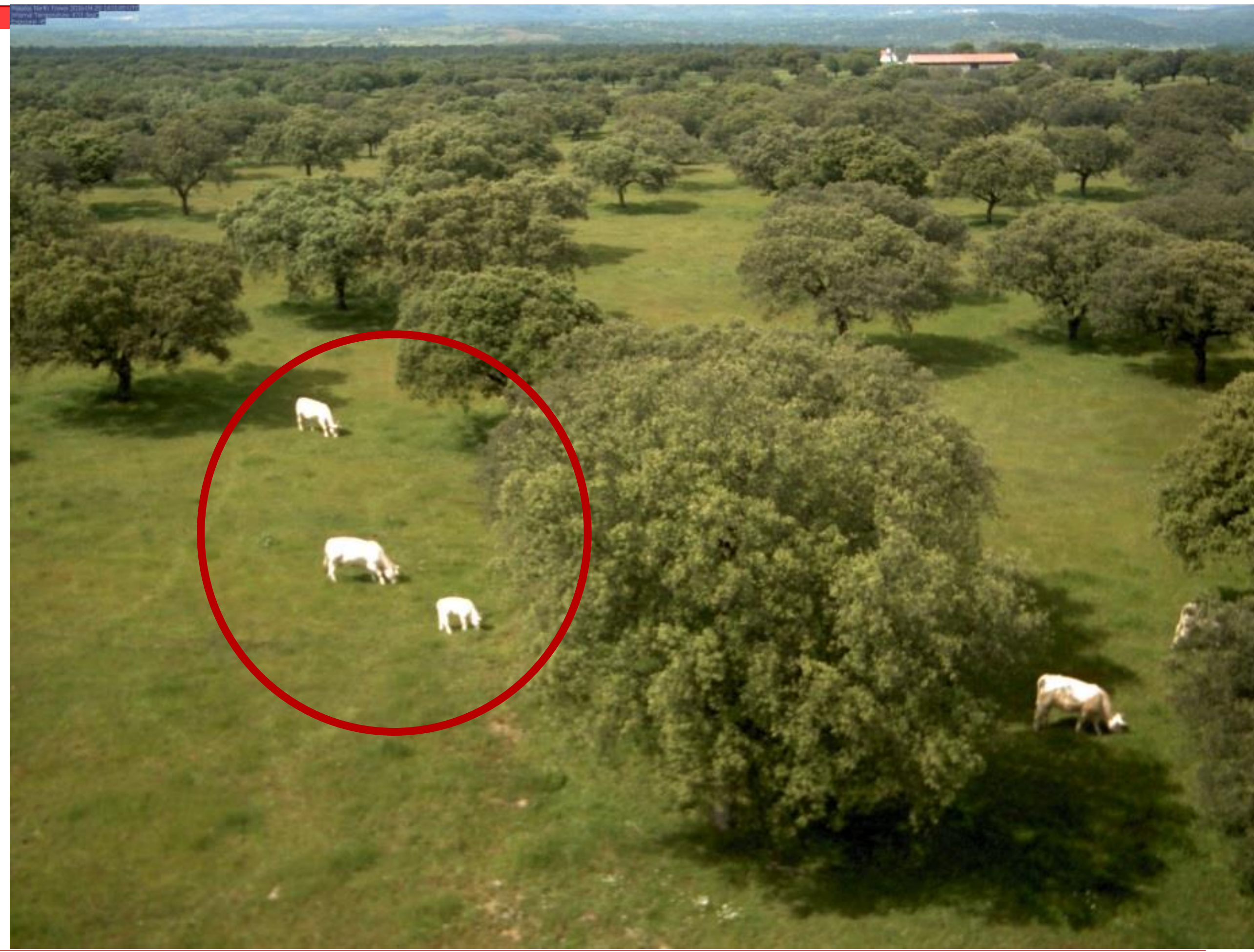


A two layer system

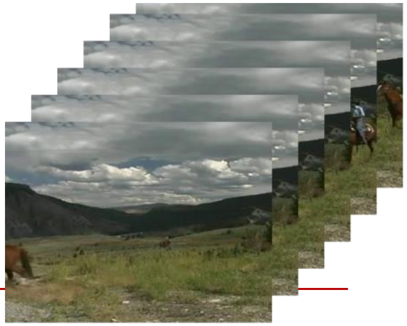
Spring

Summer

Autumn



A two dimensional analysis

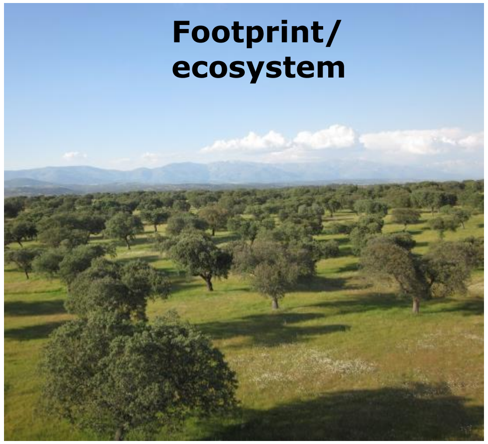


- Temporal: to capture main phenological periods in each stratum but also daily and intra-daily variations (CWC,LUE).

- Spatial: different spatial scales need to be considered: sub-plot - plot – pixel - footprint - ecosystem

Sub-plot

plot

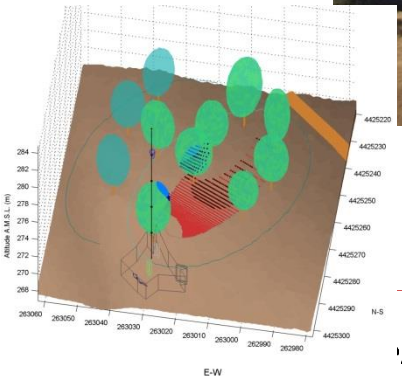


Field data: Temporal dimension

- Seasonal and inter-anual
  - Veg-bio: Regular destructive sampling campaigns (50 from 2009 to 2016)
  - Field spectroscopy campaigns (ASD Fieldspec 3 VIS-NIR-SWIR)
  - EC data
- Daily and intra-daily
  - Continuous multiangular hyperespectral system (AMSPEC-MED) 2013-2015
  - EC data

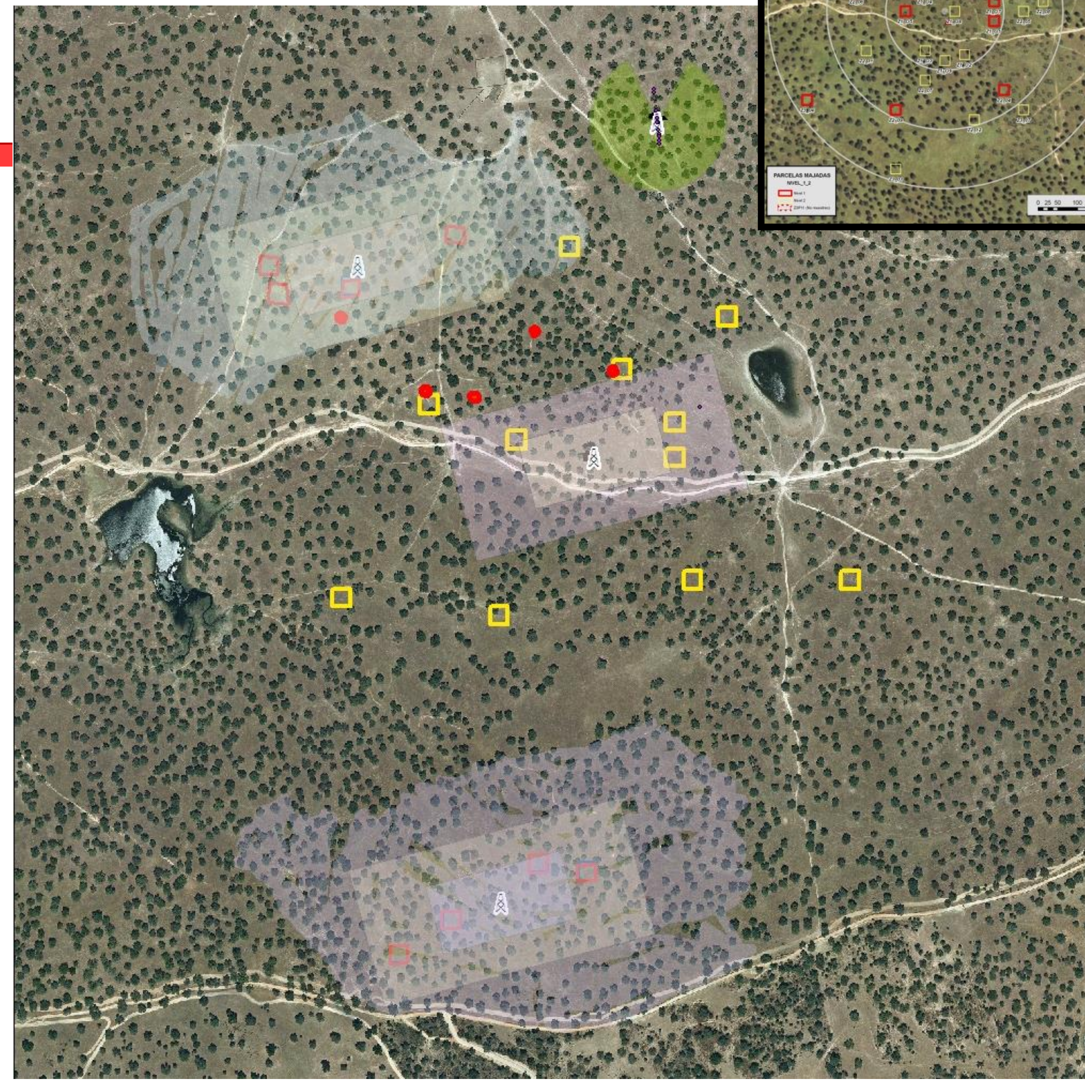







Field data: Spatial dimension

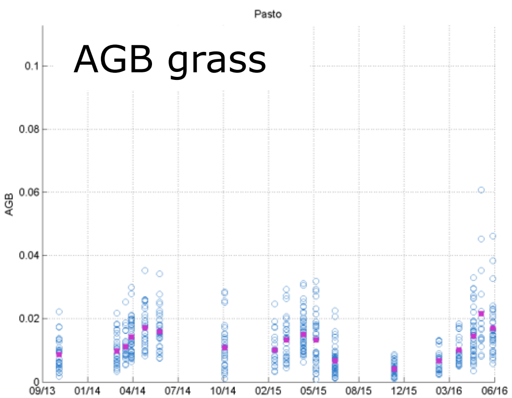
- Different spatial scales
- Logistic limitations
- Grass
  - 25x25 m plots (established location since 2009)
  - Started with 40 (upper left image)
  - 11 Biospec-Fluxpec plots (yellow boxes)
  - 4 plots North T + 4 plots South T (red boxes).
- Trees
  - Started with 10 trees
  - 5 Fluxpec trees (2 Biospec/Fluxpec + 3 Fluxpec) (red dots)

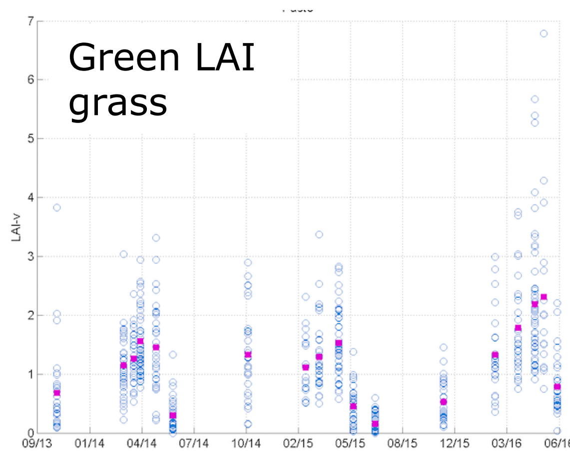


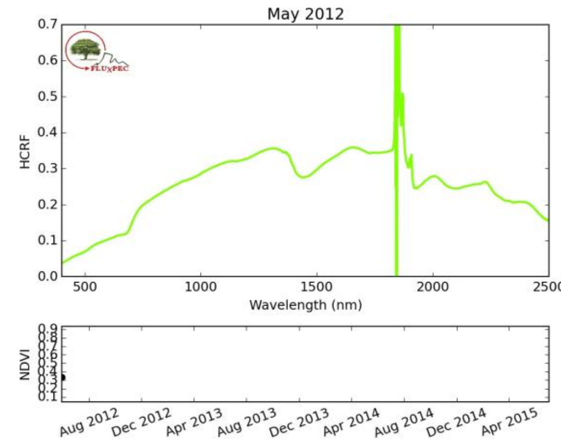
Variables

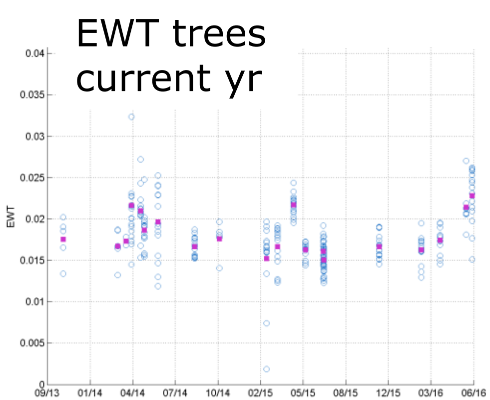
Parameter	Measurement scale	Sampling interval	Field Measurement tool/method
LAI, SLW, SLA (total, green and not green fractions)	Canopy/ecosystem	Seasonally adapted (~6/year)	Destructive sampling + hemispherical photo + terrestrial lidar+
fCover	Canopy/ecosystem	once (Biospec)	Aerial Photography
canopy structure + vegetation height	Canopy/ecosystem	Once (Biospec	Forest inventory sampling + LIDAR
Chlorophyll and carotenoids	Leaf (only trees)	Seasonally adapted (~6/year)	SPAD+ spectrophotometer (calibration)
water content (EWT, CWC, FMC)	Leaf	Seasonally adapted (~6/year)	Destructuvie sampling, gravimetric methods
AGB (total, green and not green fractions)	Canopy	Seasonally adapted (~6/year)	Destructive sampling
Carbon and Nitrogen and other nutrients	Leaf	Seasonally adapted (~6/year)	Destructive sampling + laboratory

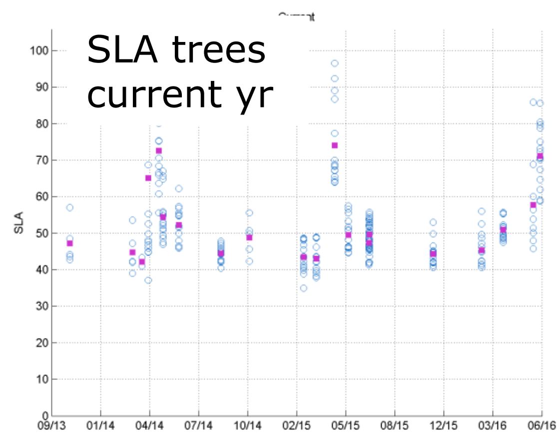
Biophysical and spectral data allows to monitor seasonal dynamics

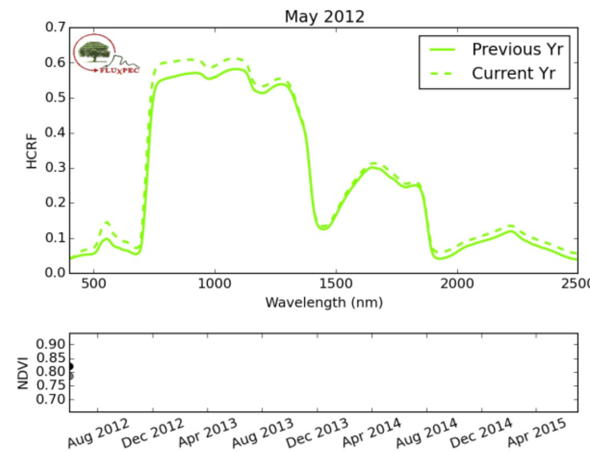






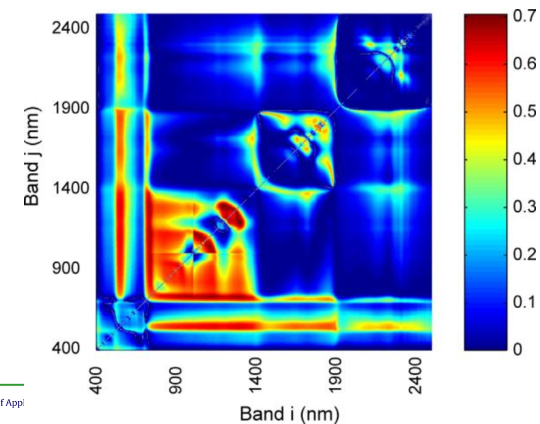






Estimation of vegetation biophysical parameters using field spectroscopy (VIS-NIR-SWIR)

- Water content grasslands: empirical vs RTMs, canopy
- Nitrogen content trees: empirical, leaf



Biogeosciences, 12, 5523–5535, 2015
www.biogeosciences.net/12/5523/2015/
doi:10.5194/bg-12-5523-2015

Biogeosciences
Open Access

Seasonal variation in grass water content estimated from proximal sensing and MODIS time series in a Mediterranean Fluxnet site

G. Mendiguren[1,2,3,4], M. Pilar Martín[2,4], H. Nieto[5], J. Pacheco-Labrador[2,4], and S. Jurdao[4,6]

[1]Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, 1350 Copenhagen K, Denmark
[2]Instituto de Economía, Geografía y Demografía, Centro de Ciencias Humanas y Sociales, Consejo Superior de Investigaciones Científicas (CSIC), Albasanz 26–28, 28037, Madrid, Spain
[3]Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Voldgade 10, 1350, Copenhagen K, Denmark
[4]Associated Research Unit GEOLAB[2 & 6]
[5]Instituto de Agricultura Sostenible, Consejo Superior de Investigaciones Científicas (CSIC), 14080 Córdoba, Spain
[6]Department of Geography and Geology, University of Alcalá, Calle Colegios 2, 28801, Alcalá de Henares, Spain

International Journal of Appl

Contents lists available at SciVerse ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

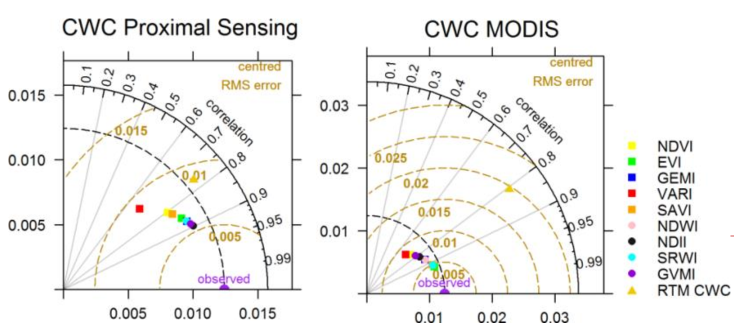
ELSEVIER

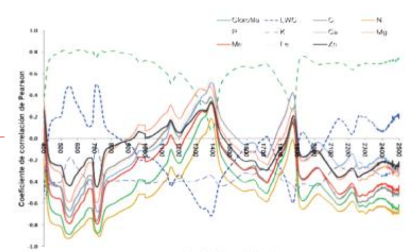
Understanding the optical responses of leaf nitrogen in Mediterranean Holm oak (*Quercus ilex*) using field spectroscopy

CrossMark

Javier Pacheco-Labrador[a,*], Rosario González-Cascón[b], M. Pilar Martín[a], David Riaño[a,c]

[a] *Laboratorio de Espectro-radiometría y Teledetección Ambiental (SpecLab), Instituto de Economía, Geografía y Demografía, Centro de Ciencias Humanas y Sociales, Consejo Superior de Investigaciones Científicas (CSIC), C/Albasanz 26-28, 28037 Madrid, Spain*
[b] *Departamento de Medio Ambiente, Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA), Ctra. Coruña, Km. 7,5, 28040 Madrid, Spain*
[c] *Center for Spatial Technologies and Remote Sensing (CSTARS), Department of Land, Air and Water Resources, University of California, One Shields Avenue, Davis, CA 95616-8617, USA*





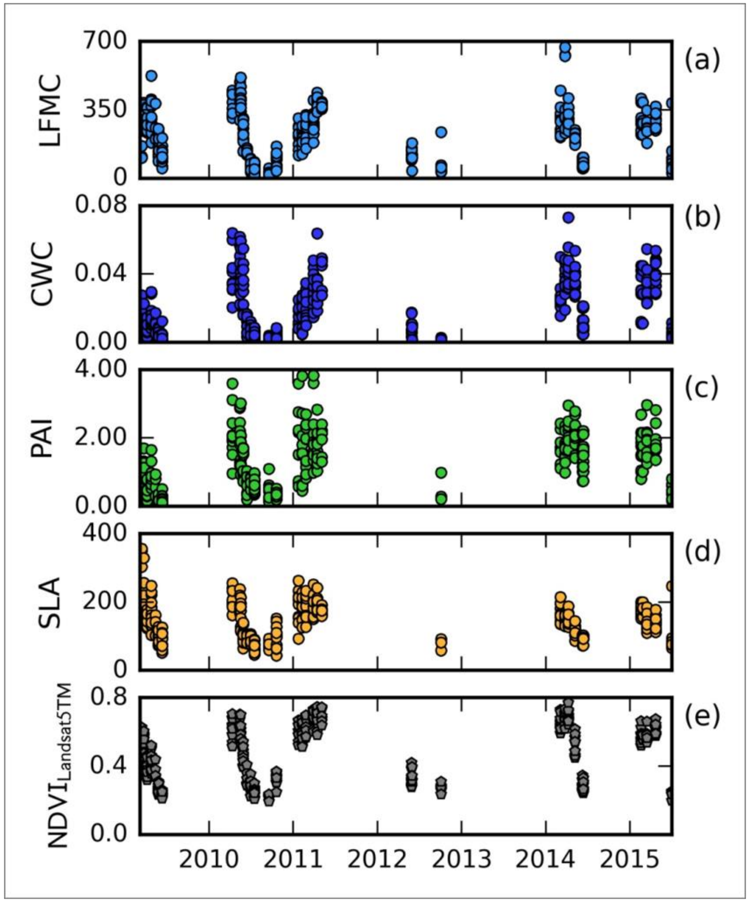
Recibido: 30/04/2016
Aceptado: 1/06/2016

REVISTA DE TELEDETECCIÓN
Asociación Española de Teledetección
(2016) 46, 31-43
ISSN 1133-0953
EISSN 1988-8740
http://dx.doi.org/10.4995/raet.2016.5688

Evolución del comportamiento espectral y la composición química en el dosel arbóreo de una dehesa

González-Cascón, R.*[1], Pacheco-Labrador, J.[2], Martín, M.P.[2]

Estimation of vegetation biophysical parameters using field spectroscopy (VIS-NIR-SWIR)



Non-parametric linear: Partial Least Squares Regression (PLSR)

Biophysical variable	R_{cal}^2	$RRMSE_{cal}$ (%)	R_{val}^2	$RRMSE_{val}$ (%)
LFMC	0.59	35.53	0.63	37.48
CWC	0.71	42.71	0.77	37.68
PAI	0.58	39.62	0.53	45.16
SLA	0.47	30.07	0.58	36.27

Non-parametric non-linear: Random Forest Regression (RFR)

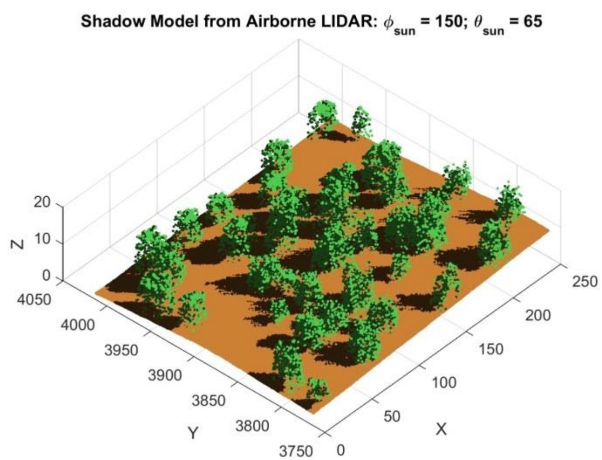
Biophysical variable	R_{cal}^2	$RRMSE_{cal}$ (%)	R_{val}^2	$RRMSE_{val}$ (%)
LFMC	0.62	34.07	0.58	39.33
CWC	0.69	44.08	0.68	43.49
PAI	0.65	36.20	0.50	45.51
SLA	0.48	29.57	0.53	25.60

Vilar et al. 2016

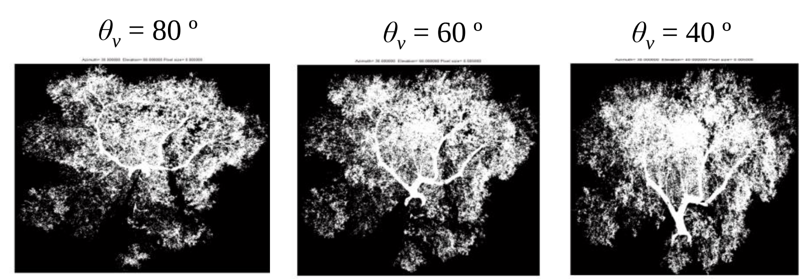
Additional spectral information: LiDAR

- LiDAR allows accounting for spatial heterogeneity in the study of Tree-grass ecosystems
- Useful information can be also obtained from RGB cameras on board UAV systems

- Airborne LiDAR
  - PNOA: 0.96 – 0.41 points / m^2
  - Classification (Terrascan) → DGM and CHM
  - Used to:
    - Support proximal sensing (BRDF modelling)
    - Spatialize radiation regimen



- Terrestrial LiDAR Scanner + Hemispherical photography
- Used to:
  - Estimate GAP fraction and clumping index
  - Estimate angular dependence of crown transmissivity
  - Monitor tree growth (seasonal and interanual changes in tree crown)



Continuous multi-angular hyperspectral measurements: AMSPEC-MED

- Based on AMSPEC II system
  - Hilker et al., 2010
- Unispec DC spectroradiometer (400-1500 nm) + PTU (Azimuth: 20º - 330º / Zenith: 40º – 69º)
- Objectives
  - Provide spectral information
    - Continuous
    - Directionally corrected
    - Spectrally unmixed
  - Relate with
    - Veg. biophysical parameters
    - Light use efficiency
    - Other remote observations
- Acquisition period
  - August 2013 – March 2016

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING

Nonlinear Response in a Field Portable Spectroradiometer: Characterization and Effects on Output Reflectance

Javier Pacheco-Labrador and M. Pilar Martín

OPEN ACCESS
sensors
ISSN 1424-8220
www.mdpi.com/journal/sensors

Article

Characterization of a Field Spectroradiometer for Unattended Vegetation Monitoring. Key Sensor Models and Impacts on Reflectance

Javier Pacheco-Labrador * and M. Pilar Martín

Characterizing integration time and gray-level-related nonlinearities in a NMOS sensor

Javier Pacheco-Labrador,[1,*] Alejandro Ferrero,[2] and M. Pilar Martín[1]
[1]Environmental Remote Sensing and Spectroscopy Laboratory (SpecLab), Instituto de Economía, Geografía y Demografía, Consejo Superior de Investigaciones Científica (CSIC), C/ Albasanz 26-28, 28037 Madrid, Spain
[2]Instituto de Óptica "Daza de Valdés", Consejo Superior de Investigaciones Científicas (CSIC), C/ Serrano 121 28006, Spain
*Corresponding author: javier.pacheco@cchs.csic.es

Received 24 July 2014; revised 17 October 2014; accepted 19 October 2014; posted 21 October 2014 (Doc. ID 217517); published 7 November 2014

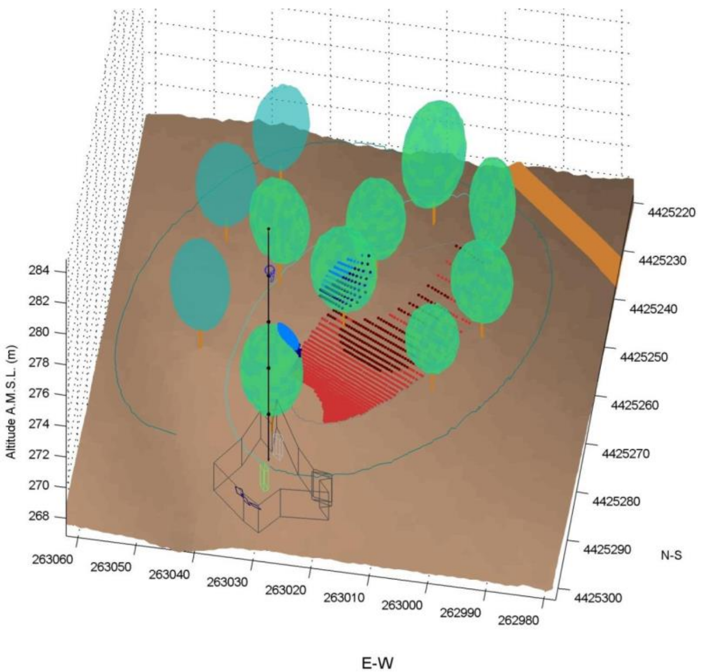

Remote Sensing of Environment 187 (2016) 447–457
Contents lists available at ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse

New approaches in multi-angular proximal sensing of vegetation: Accounting for spatial heterogeneity and diffuse radiation in directional reflectance distribution models

Javier Pacheco-Labrador [a,*], M. Pilar Martín [a], David Riaño [a,b], Thomas Hilker [c], Arnaud Carrara [d]
[a] Environmental Remote Sensing and Spectroscopy Laboratory (SpecLab), Institute of Economic, Geography and Demography (IEGD-CCHS), Spanish National Research Council (CSIC), C/Albasanz 26-28, 28037 Madrid, Spain
[b] Center for Spatial Technologies and Remote Sensing (CSTARS), University of California, Davis, One Shields Avenue, 139 Veihmeyer Hall, Davis, CA 95616, USA
[c] University of Southampton, Department of Geography and Environment, Southampton, SO17 1BJ, UK
[d] Fundación Centro de Estudios Ambientales del Mediterráneo (CEAM), Charles Darwin 14, Parc Tecnològic, 46980 Paterna, Spain

BRDF modeling

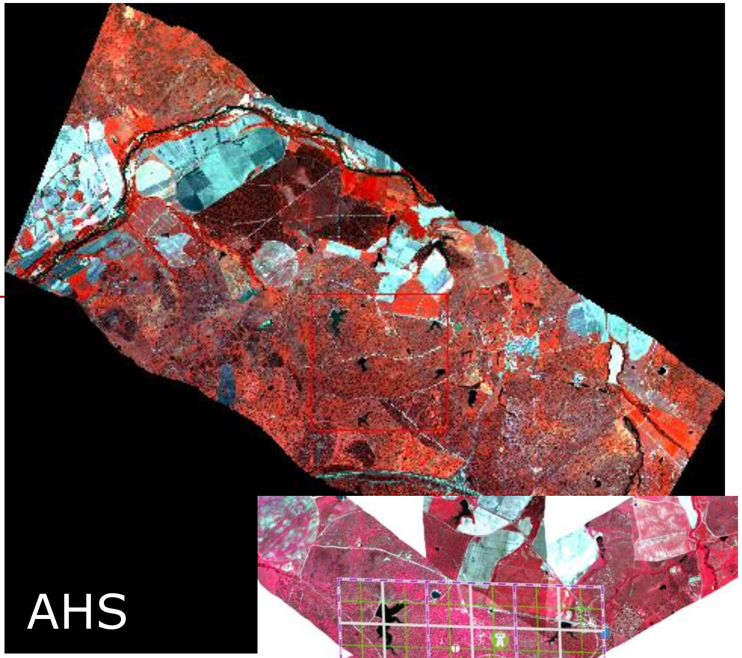
- Approach
  - Kernel-driven BRDF functions
  - Deal with spatial heterogeneity (trees + shadows + grass)
  - Include effects of diffuse radiation
- Needs
  - Complete characterization of the sensc
  - Characterization of FOV, and observ. geometry
  - Model spectral diffuse-to-global radiation ratio
  - Modify BRDF kernel functions
- Model validation by comparing with MODIS BRDF product and field spectroscopy

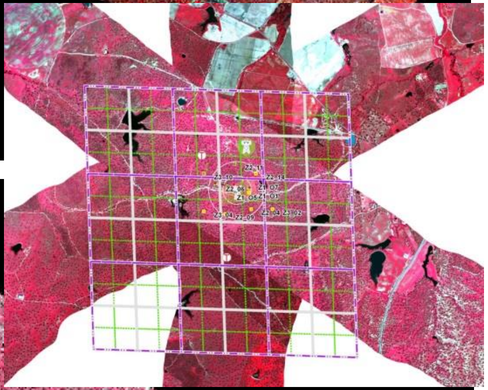


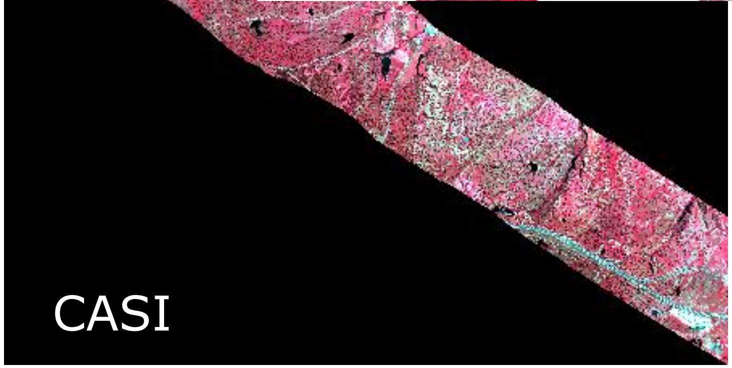
From plot to ecosystem: Airborne hyperspectral images

	CASI	AHS (VSWIR)	AHS (Thermal)
Bands	144	63	17
FWHM (nm)	5.0	18 - 90	300-450
SSI (nm)	4.75	~	~
Pixel Size (m)	1.1x1.7	4.8x4.8	4.8x4.8

- 6 campaings from 2010 to 2016: spring-summer
- max. of 8 overpasess/campaign
  - Different configurations
  - Spatial overlap (BRDF and LST)



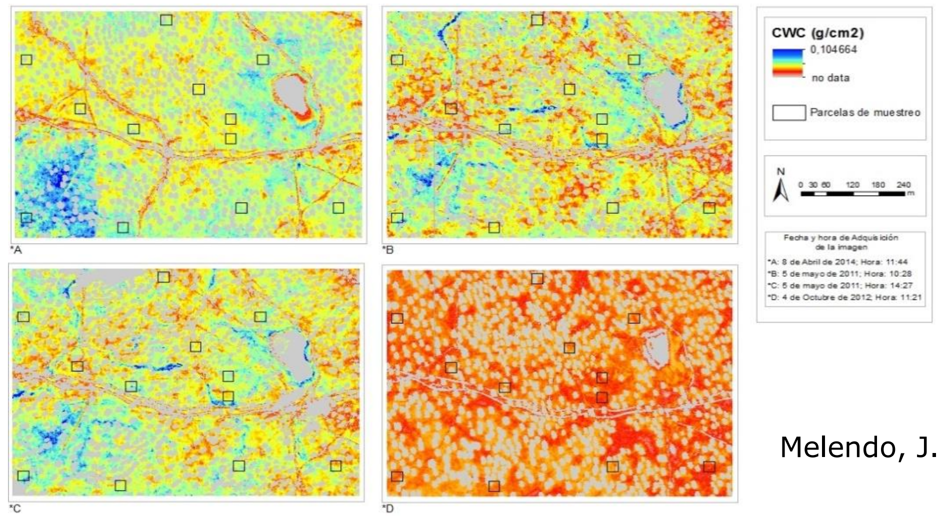




From plot to ecosystem: Airborne hyperspectral images

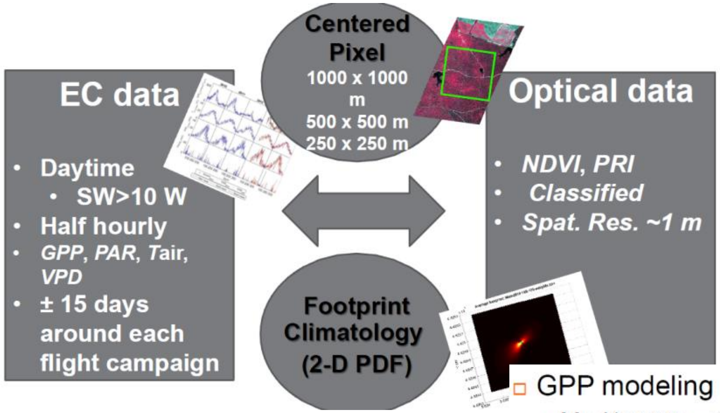
Variable	Model	R^2	RRMSE (%)
FMC	-117,833+1027,038*SAVI	0,875	15,2
CWC	-0,013+0,0306*MSR	0,843	25,1
LAI	-1,218+4,675*NDVI	0,752	28,8
Cm	0,016+(-0,014)*NDVI	0,637	23,4
AGB	-0,005+0,025*NDVI	0,702	28,8

- Mapping biofisical parameters (grass layer)
  - Vegetation indices
  - Regression analysis



Melendo, J.R. 2015

- Modeling GPP
  - Images -> geocorrected HDRF (ATCOR + Empirical Line)
  - Classification (Mahalanobis):Grass / Trees and Shadows+Water / Roads+Soil
  - NDVI ~ fPAR
  - PRI ~ ε (carefully)



- GPP modeling
  - Mod1: $GPP = (a + bx\ SVI)$
  - Mod2: $GPP = (a + bx\ SVI)\ x\ Rg$
  - Mod3: $GPP = (a + bx\ SVI)\ x\big(a + bx\widehat{LUE}\big)\ x\ Rg$
    - PRI (Gamon et al., 1992)

Leassons learned

- **Field data is a must**!!! necessary information to understand the ecosystem and parameterize and validate models
  - Difficulties to properly characterize the ecosystem at different spatial scales

Left: Apparently homogenous grass cover (plot).
Right: Very heterogeneous at sub-plot scale

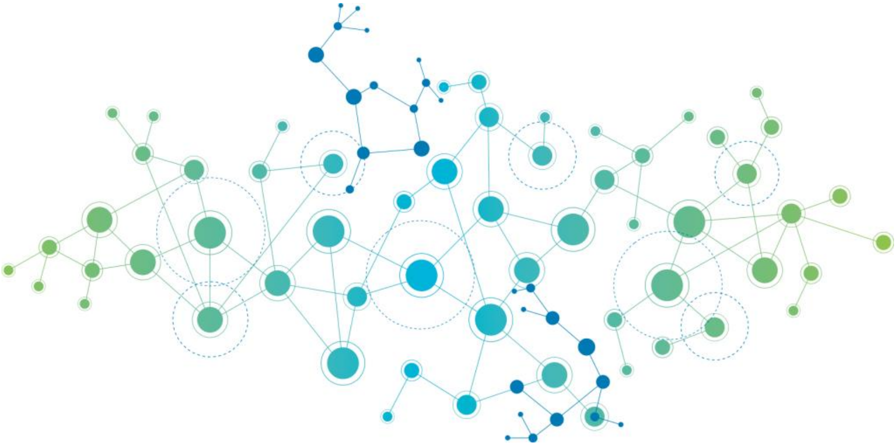
  - Difficulties to get spectral data at the crow level: tower based systems and UAVs are a promising alternative
  - Field protocols adapted to tree-grass ecosystems are needed

- Automated tower-based multiangular hyperspectral systems dedicated to detailed study of vegetation properties and status is feasible in heterogeneous ecosystems. However, a detailed characterization of the system optics and observation geometry is required – LiDAR key complementary data
- Empirical models outperformed those using RTM in the estimation of biophysical parameters. RTM models need to be adapted (plant species and ecosystem variability!!!)

The magic words

- Integration
  - Data
  - Methods
  - Expertise

- Networking
  - Sharing information
  - Metadata vs standarization



Research collaborations at Majadas site

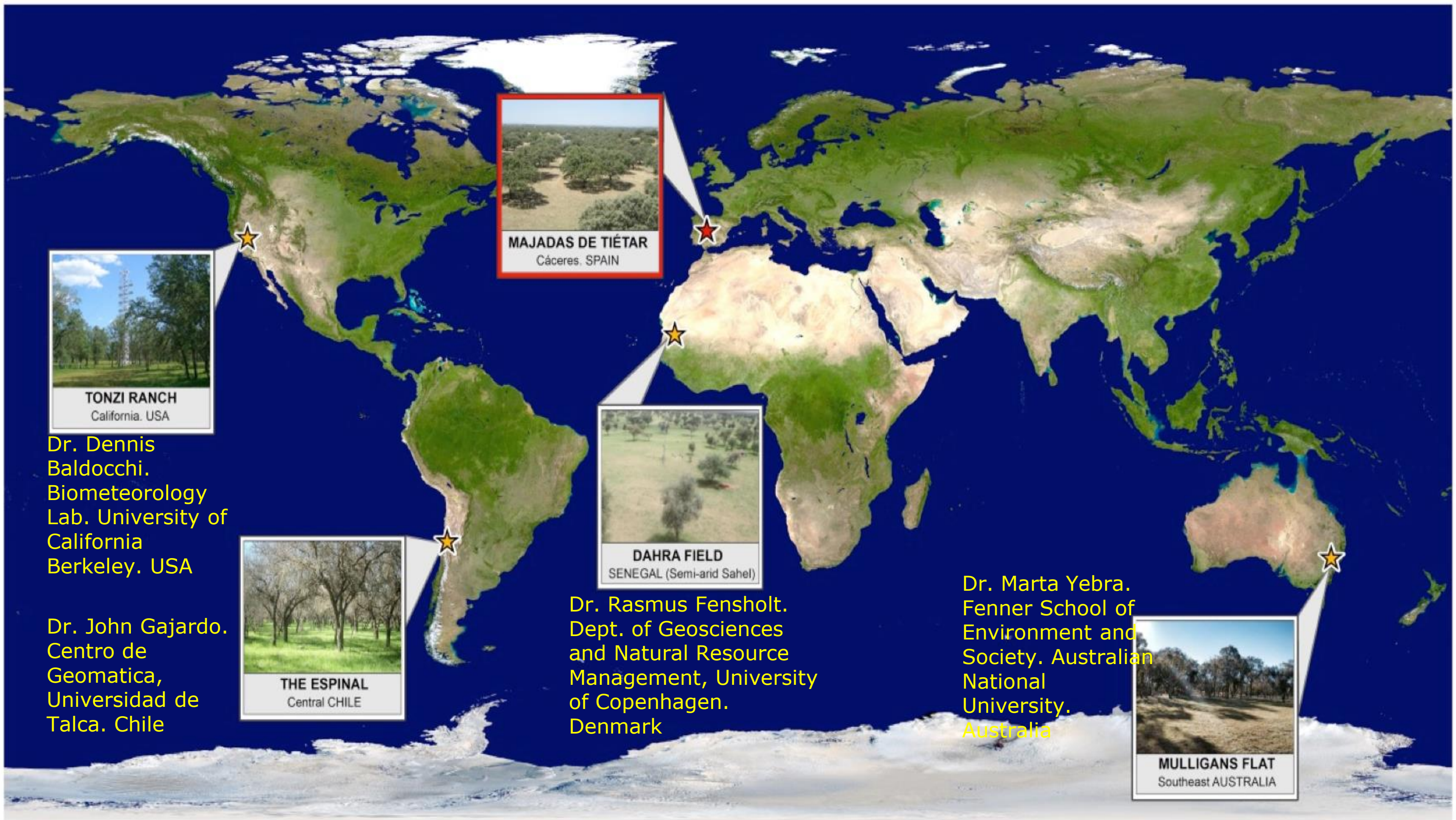


Figure 3. SynerTGE main study site (red star) and potential validation sites (yellow stars)

THANKS FOR YOUR ATTENTION!

Biospec http://www.lineas.cchs.csic.es/biospec/

FLUXPEC http://www.lineas.cchs.csic.es/fluxpec/

SynerGE http://www.lineas.cchs.csic.es/synertge/