USC
UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

Facultade de Bioloxía
Dpto de Edafoloxía e Química Agrícola

Freistaat Bayern
RegioneEmiliaRomagna
Catalunya

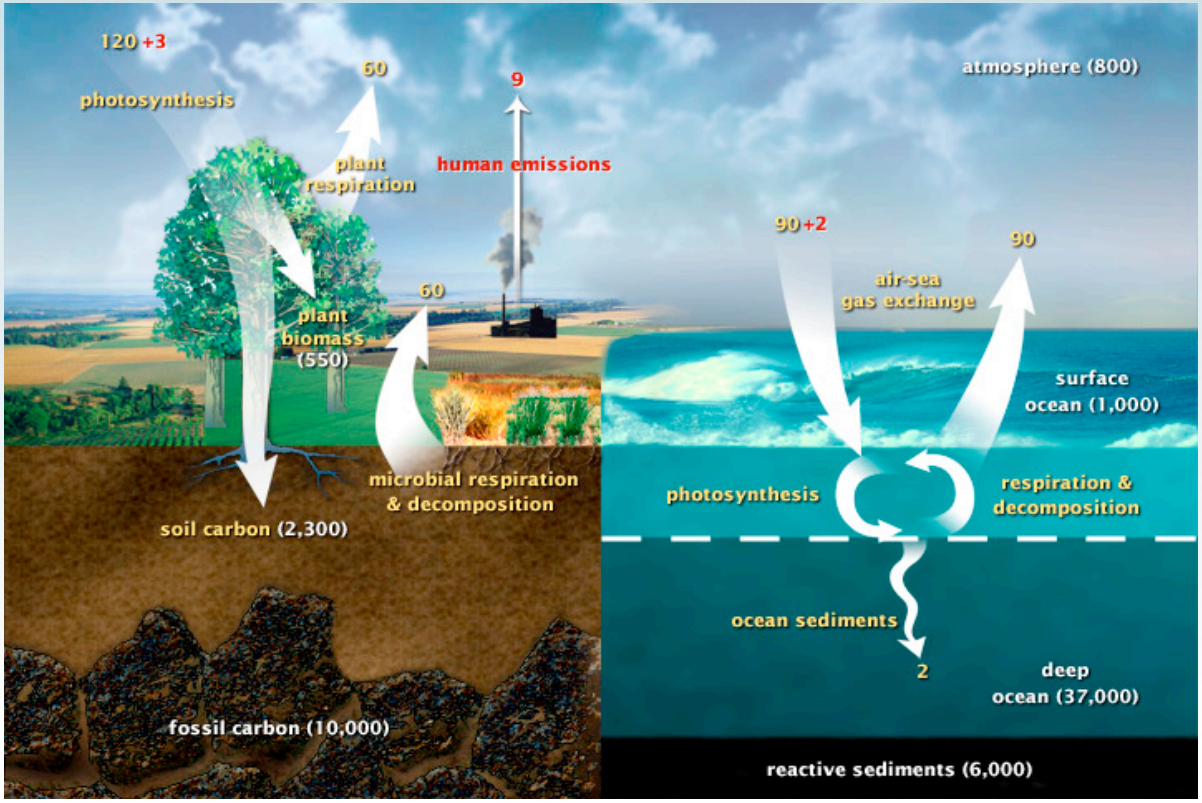
8th EUREGEO
Barcelona | Catalonia | Spain | june 15th - 17th 2015

MAPPING SOIL ORGANIC CARBON USING SPECTROSCOPIC DATA

Marcela Rial, Antonio Martínez Cortizas, Luis Rodríguez-Lado

Importance of soil organic carbon (SOC)

CARBON CYCLE WITH FLUXES AND STOCKS IN GIGATONS (Gt)



adapted from U.S. DOE, Biological and Environmental Research Information System.

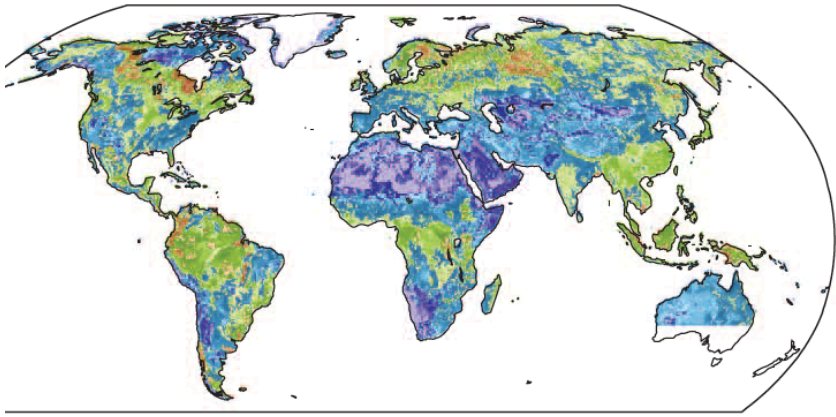
FACTORS THAT PROMOTES THE ACUMMULATION OF SOC

- Climate: high P, low T
- Geology: Fe and Al oxy-hydroxides (mafic rocks)
- Land use and management: conversion of crop to grassland

Methods for mapping and quantifying SOC

STATISTICAL METHODS FOR MAPPING

- Multiple Linear Regression
- Ordinary kriging
- Regression-Kriging
- Geographically Weighted Regression
- Random Forest
- Partial Least Squares Regression



adapted from Carvahlais et al., (2014).

TRADITIONAL METHODS

Walkley Black

Total Combustion

INCONVENIENTS

- Time consuming
- Expensive

WALKLEY-BLACK METHOD

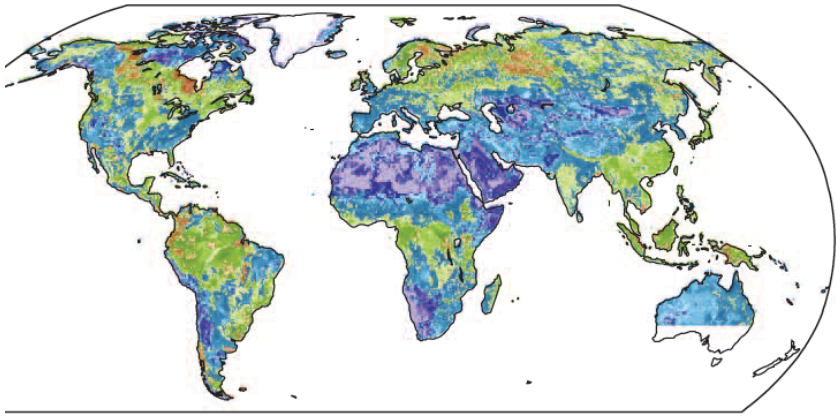
$2\ Cr_2O_7^{2-} + 3\ C^0 + 16\ H^+ \rightarrow 4\ Cr^{3+} + 3\ CO_2 + 8\ H_2O$ oxidation

$Cr_2O_7^{2-}$ (exc) $+ 6\ Fe^{2+} + 14\ H^+ \rightarrow 2\ Cr^{3+} + 6\ Fe^{3+} + 7\ H_2O$ reduction

Methods for mapping and quantifying SOC

STATISTICAL METHODS FOR MAPPING

- Multiple Linear Regression
- Ordinary kriging
- Co-Kriging
- Regression-Kriging
- Geographically Weighted Regression
- Random Forest



adapted from Carvahlais et al., (2014).

TRADITIONAL METHODS

Walkley Black

Combustion

Inconvenients:

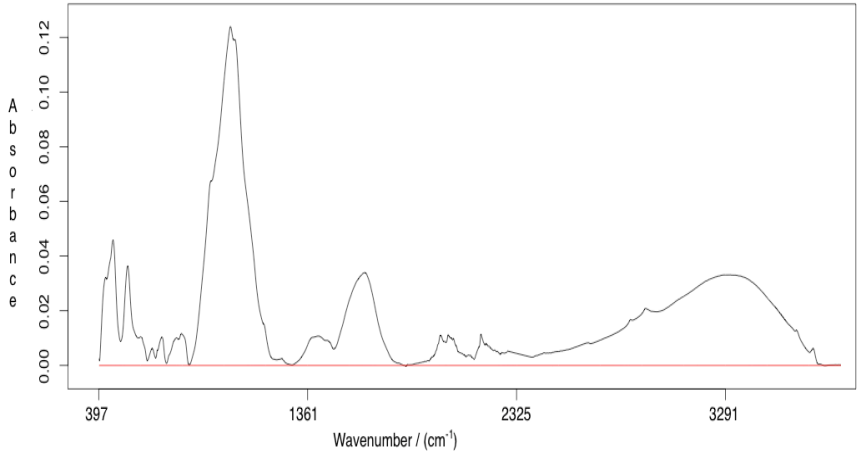
- Time consuming
- Expensive

ALTERNATIVE METHODS: SPECTROSCOPY

VIS

NIR

MIR (FTIR-ATR….)



How to predict SOC from spectroscopic data?

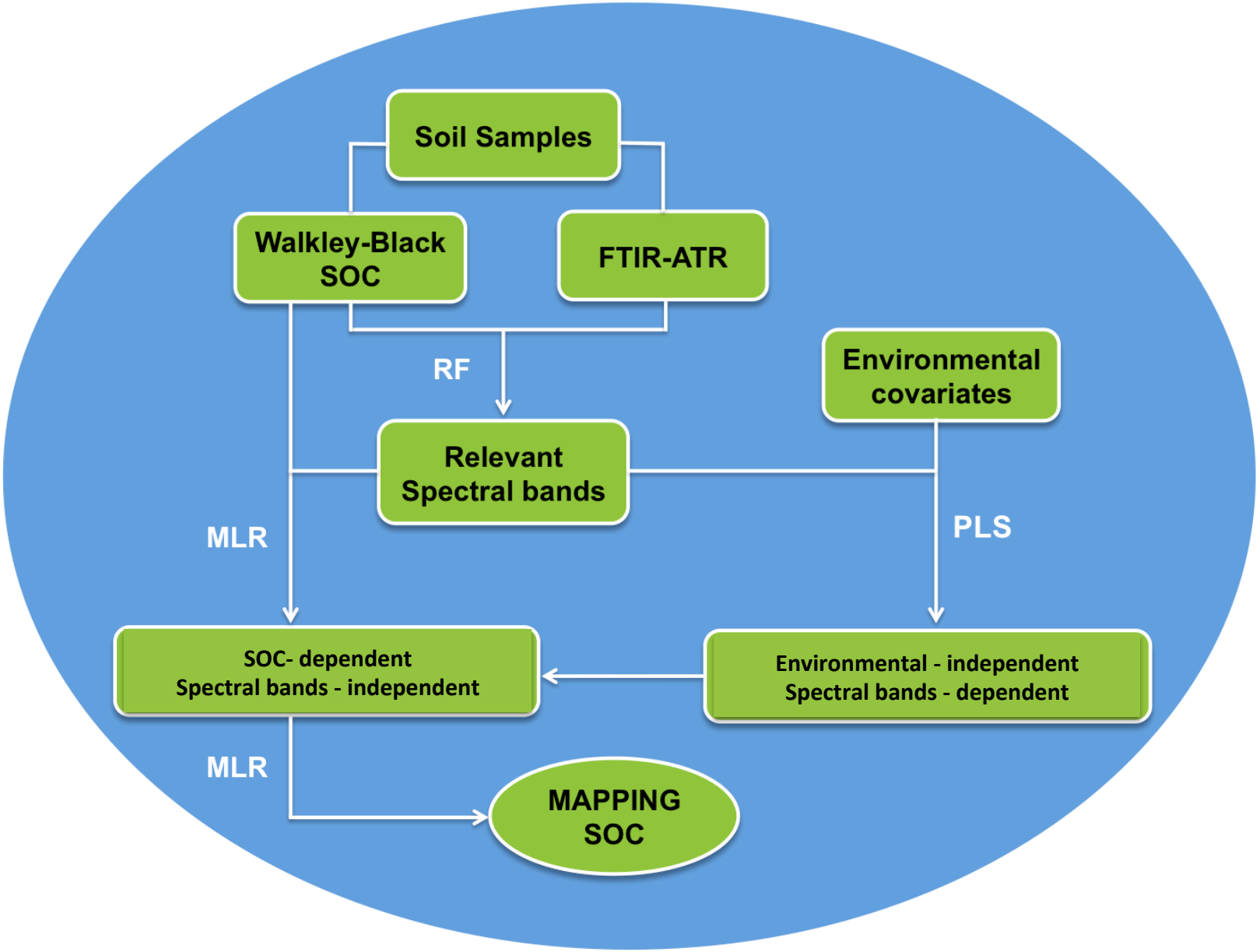
- Multiple Linear Regression (MLR)
- Principal Component Regression (PCR)
- Partial Least Squares Regression (PLS)
- Artificial Neural Networks (ANN)
- Multiple Adaptive Splines (MARS)
- Random Forest (RF)

SUMMARY OF THE GOODNESS FIT OF MODELS FOUND IN BIBLIOGRAPHY

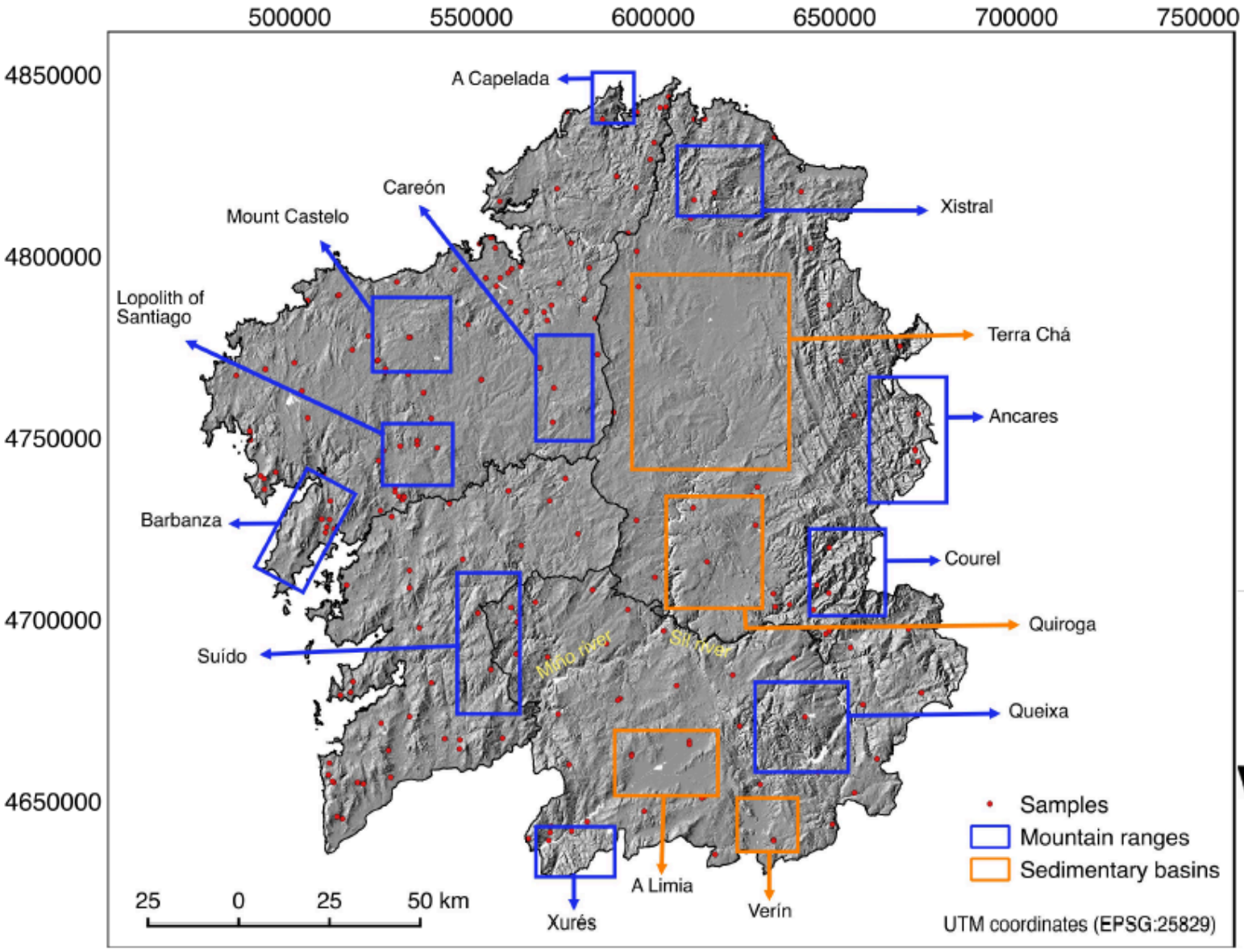
- High R^2 values
- Only at sample scale

Location	N	LV	R^2 val	RPD	Reference
Texas, USA	270	11	0.77	2.1	Ge et al. (2014)
France	2084	23	0.90	3.0	Grinand et al. (2012)
Australia	298	9	0.92	-	Janik and Skjemstad (1995)
Australia	116	-	0.77	-	McBratney et al. (2006)
Central USA	273	19	0.94	4.1	McCarty et al. (2002)
Central USA	237	15	0.94	-	Reeves (2010)
Australia	118	9	0.73	1.7	Viscarra Rossel et al. (2006)
Germany	60	7	0.78	2.1	Vohland et al. (2014)
Switzerland	111	12	0.94	4.1	Zimmermann et al. (2006)

Statistical methodology



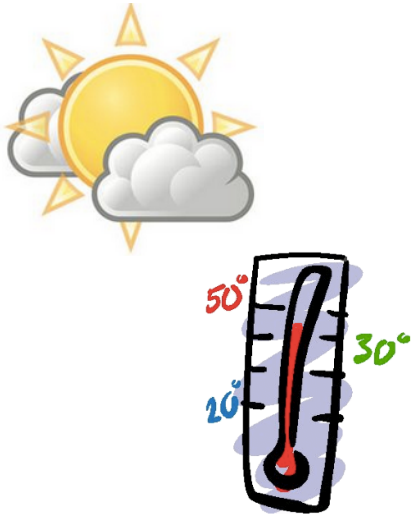
Soil sampling



Study site: climatic conditions

- Transitional climatic area from oceanic hyper-humid to sub-humid
- Soil moisture regimen: udic, ustic with a transition towards xeric in the SE
- Soil temperature regimen: thermic and mesic
- W-E gradient of temperature

Parameters	Min-Max	Mean
Temperature – T (ºC)	6.6-14.7	12.2
Accumulated precipitation – P (mm)	589-1809	1245
Potential evapotranspiration – ET_0 (mm)	485-814	688
Water balance – P-ET_0 (mm)	-6.1-1094	557
Annual ombrothermic Index – Ios	4.3-20.4	9.0
Ombrothermic index June-July – Ios_2	0.7-3.6	1.6
Ombrothermic index June-August – Ios_3	1.0-4.5	2.2
Ombrothermic index May-August – Ios_4	1.6-6.4	3.1
Index of continentality – Ic	9.8-14.8	12.0
Thermicity index – It	52-342	255



Study site: geology and land use

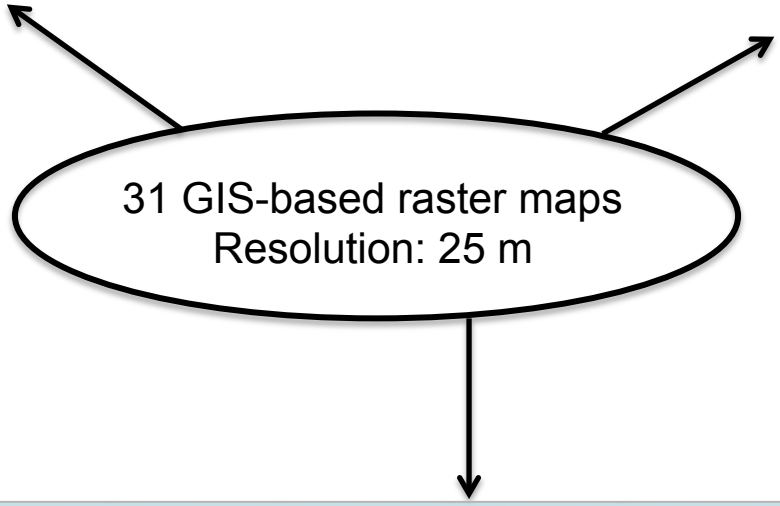
- High geological diversity
- Granites, schist and slates predominant parental materials
- Soil texture varies from sandy to loamy
- High amounts of exchangeable aluminium
- Moderate depth
- pH 4.5-5.5
- Low eCEC
- Low fertility

Land use type	Total area (ha)	Total area (%)
Forests	1,159,426	39.20
Scrubs	566,671	19.17
Grassland	1,017,464	34.39
Crops	130,934	4.43
Infrastructures	46,659	1.58
Water bodies	20,877	0.71
Mining	9,696	0.33
Beaches and rock outcrops	5,686	0.19

Environmental covariates

GEOLOGY

- Granitic rocks
- Gneises
- Mafic rocks
- Peat
- Quartzites
- Tertiary deposits
- Quaternary deposits
- Serpentinites
- Shales
- Slates



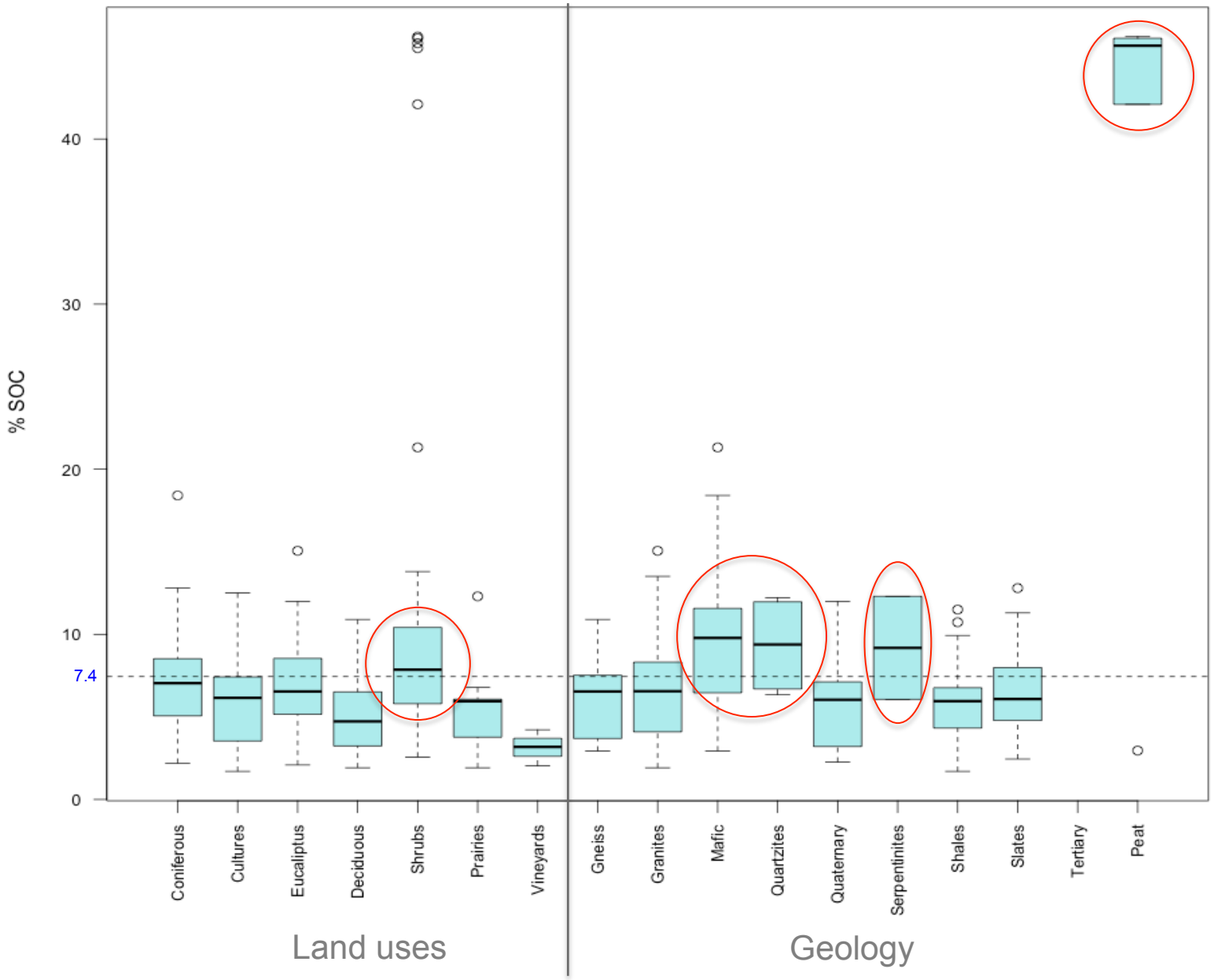
LAND USES

- Coniferous
- Deciduous
- Eucalyptus forest
- Shrubs
- Crops
- Grasslands
- Vineyards

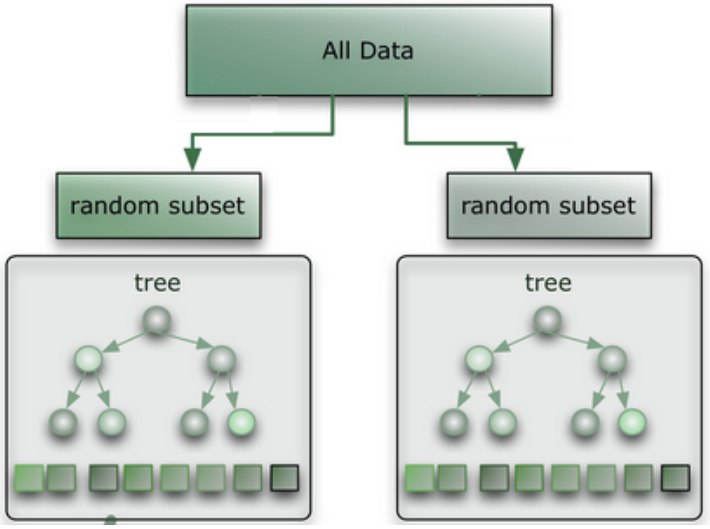
CLIMATE

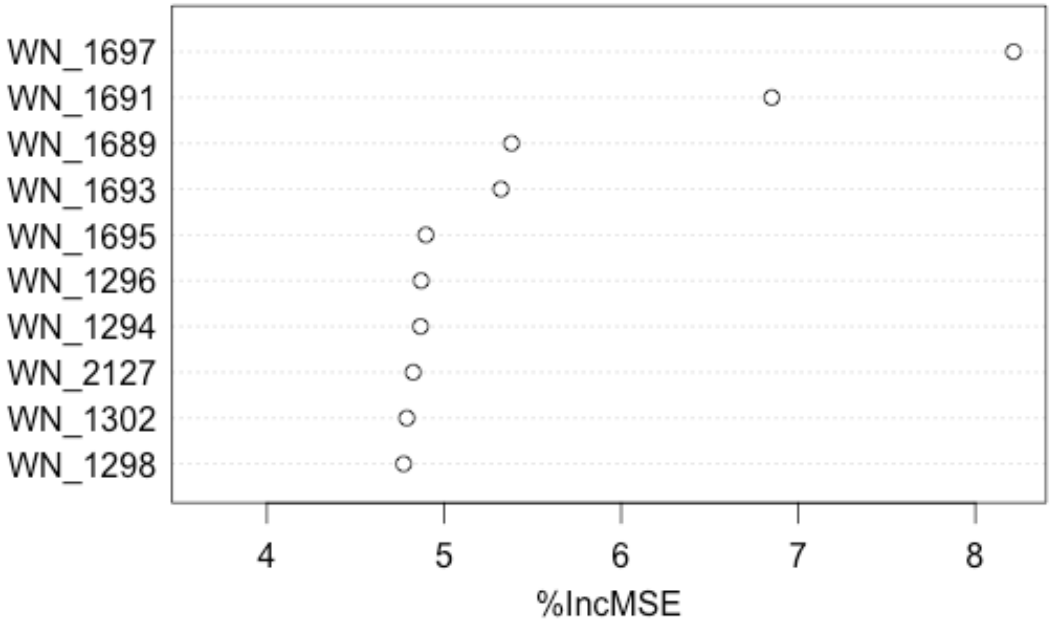
- Temperature (T)
- Acumulated precipitation (P)
- Potential evapotranspiration (ET_0)
- Water balance ($P\text{-}ET_0$)
- Annual ombrothermic index (Ios)
- Ombrothermic index June-July (Ios_2)
- Ombrothermic index June-August (Ios_3)
- Ombrothermic index May-Aug (Ios_4)
- Continentality index (Ic)
- Thermicity index (It)

SOC content in samples



Relevant spectral bands for SOC prediction





R^2 = 0.95
RMSE = 1.39

3 GROUPS OF BANDS

1) 2127 cm^{-1}
2) 1697 cm^{-1}
3) 1296 cm^{-1}

Correlation analysis
1697 cm^{-1}
$C{=}O_{st}$

Aldehydes, ketones and carboxilic acids from hydrofobic and hydrophilic compounds of SOM

Modelling the spatial distribution of spectra data

PLS PERFORMANCE

Spectral data (1697 cm^{-1}) environmental proxies

3 LV

Validation method: CV

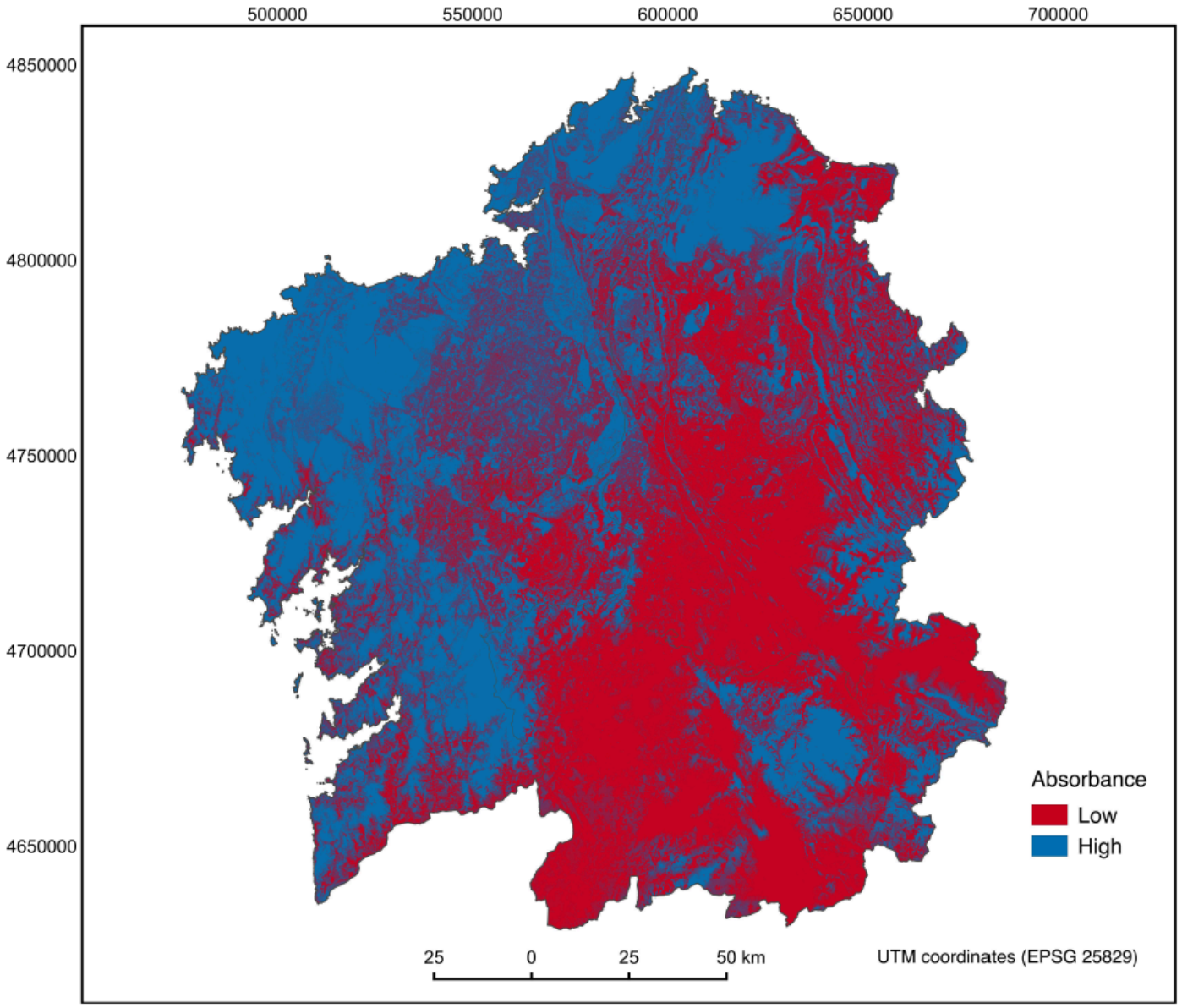
R^2 = 0.70

RMSE= 0.57

What is each LV?

Parameters	LV_1	LV_2	LV_3
T	-0.46	0.30	**-0.76**
P	**0.80**	-0.17	-0.47
ET_0	-0.09	0.42	**-0.83**
P-ET_0	**0.86**	-0.32	-0.22
Ic	-0.45	-0.38	**0.63**
It	-0.25	0.38	**-0.84**
Ios	**0.93**	-0.21	0.09
Ios_2	**0.93**	0.03	-0.16
Ios_3	**0.96**	-0.03	-0.07
Ios_4	**0.98**	-0.13	0.01
Coniferous	-0.09	0.18	-0.14
Cultures	-0.06	-0.23	-0.07
Eucaliptus	0.00	0.16	-0.28
Deciduous	-0.16	-0.17	0.08
Shrubs	0.36	0.07	0.29
Prairies	-0.10	-0.01	0.11
Vineyards	-0.11	0.04	-0.03
Gneiss	0.01	-0.04	-0.20
Granites	-0.12	0.06	-0.26
Mafic	0.22	-0.09	-0.09
Quartzites	0.02	-0.12	0.19
Quaternary	-0.14	-0.01	0.27
Serpentinites	0.03	-0.08	-0.05
Shales	-0.19	0.29	0.01
Slates	0.01	**-0.43**	0.16
Peat	**0.62**	0.51	0.42
1697 cm^{-1}	0.74	0.37	0.13

Modelling the spatial distribution of spectral data



Linear regression model for SOC prediction

SAMPLE SUBSET

70% calibration

30% validation

LINEAR MODEL

$$SOC = -4.23 + 1115\ \tilde{\nu}_1$$

where $\tilde{\nu}_1 = 1697\ cm^{-1}$.

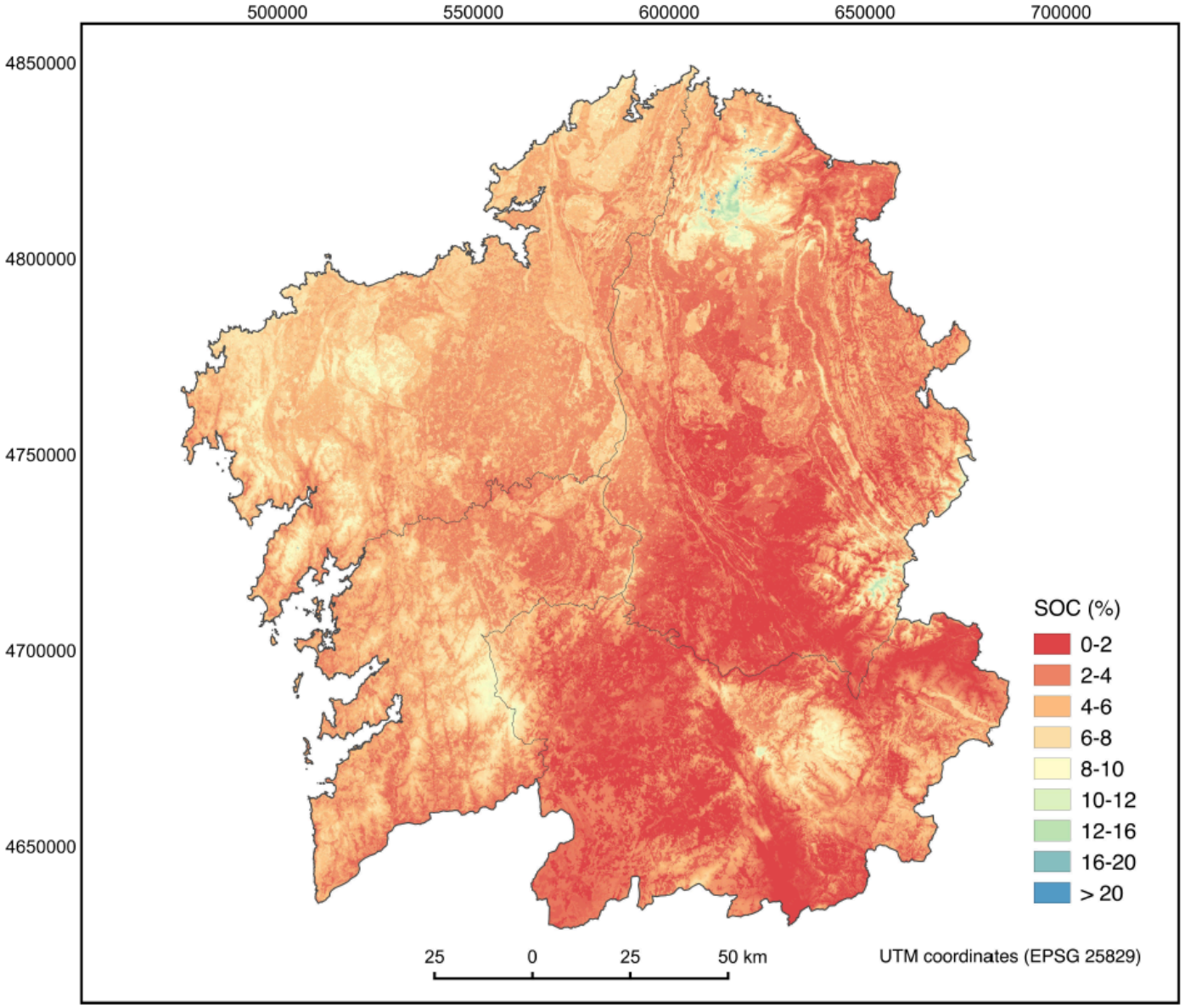
EXTERNAL VALIDATION

$r^2 = 0.88$

RMSE= 2.14

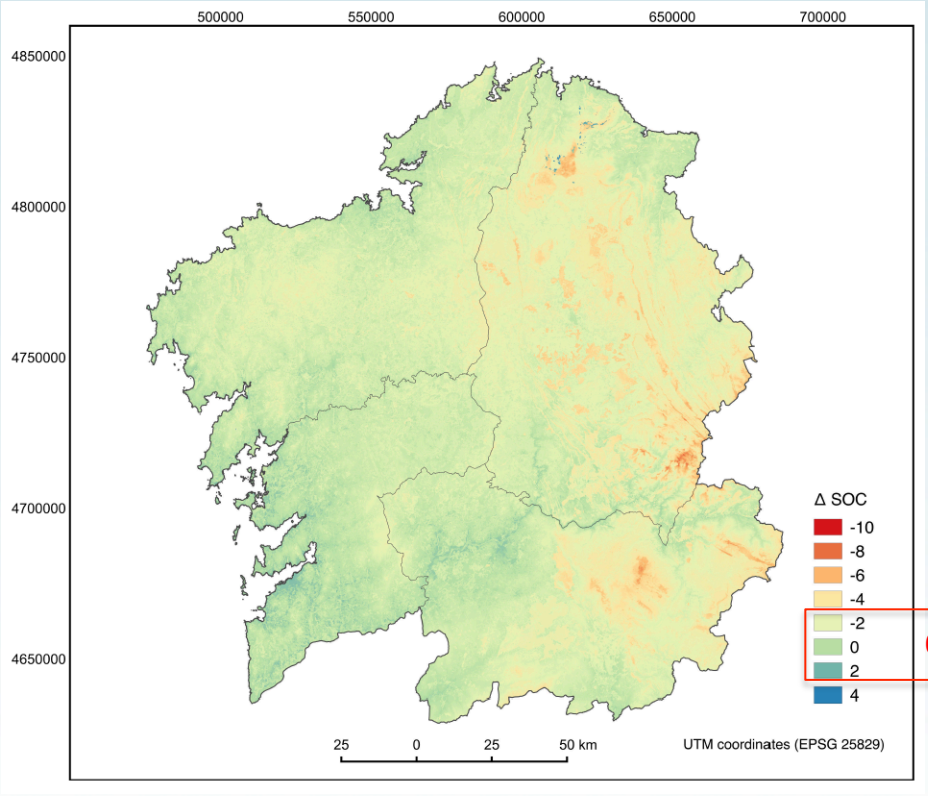
ME = 0.05

Modelling SOC using FTIR-ATR data



Checking the results

- Results similar to those obtained using Walkley-Black measurements and environmental proxies → Map of SOC (PLS)
- Map of differences: $SOC_{(FTIR-ATR)}$ - $SOC_{(WB)}$



65% total surface

Measurements	R^2	RMSE
Walkley-Black	0.81	2.41
FTIR-ATR	0.74	2.81

Next steps - European Scale

MAPPING SOC IN EUROPE TOPSOILS

LUCAS DATABASE

JRC EUROPEAN COMMISSION

≈ 20 000 sample points

25 countries (grid 2x2km)

Properties

- Coarse fragments (%)
- Particle size distribution (% clay, silt, sand)
- pH
- Organic Carbon (g/Kg)
- Carbonate content (g/Kg)
- Phosporous content (mg/Kg)
- Total Nitrogen content (g/Kg)
- Extractable Potassium content (mg/Kg)
- Cation Exchange Capacity (cmol(+)/Kg)
- Multispectral properties: VNIR

Current publications on this dataset: SOC and VNIR

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

Stevens et al. (PLOS One 2013)

Multivariate statistics (SVM, Cubist)

R^2

	Organic	Cropland	Grassland	Woodland
spect	0.76	0.67	0.71	0.75
bands+sand/clay		0.79	0.87	0.89

Nocita et al. (Soil Biology and Biochemisty 2014)

PLS

R^2

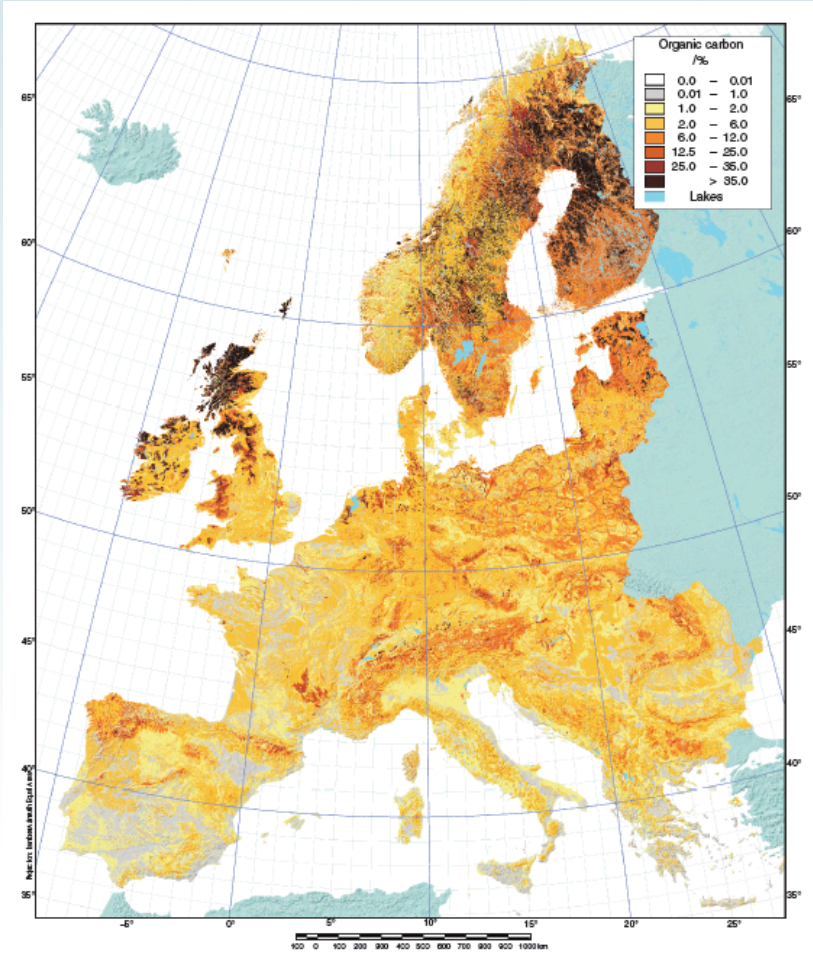
	Organic	Cropland	Grassland	Woodland
spect	0.76	0.79	0.81	0.79
spect+sand		0.84	0.84	0.85

What is current published? SOC maps

Jones et al. (2005) - OCTOP

ESDB data

Pedotransfer rules



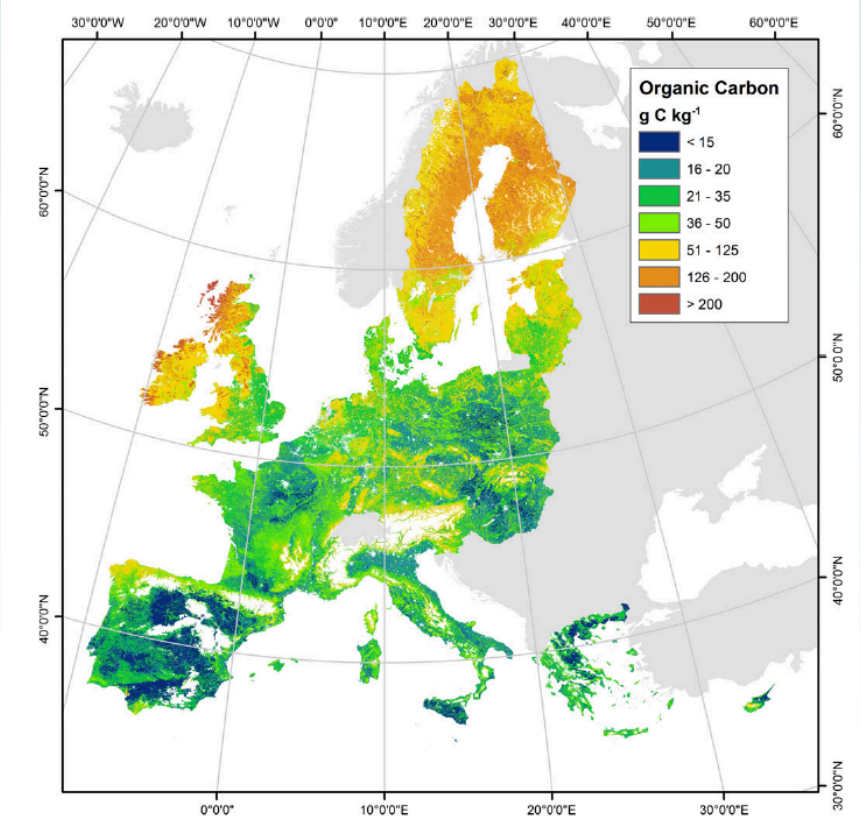
de Brogniez et al. (2015)

LUCAS data

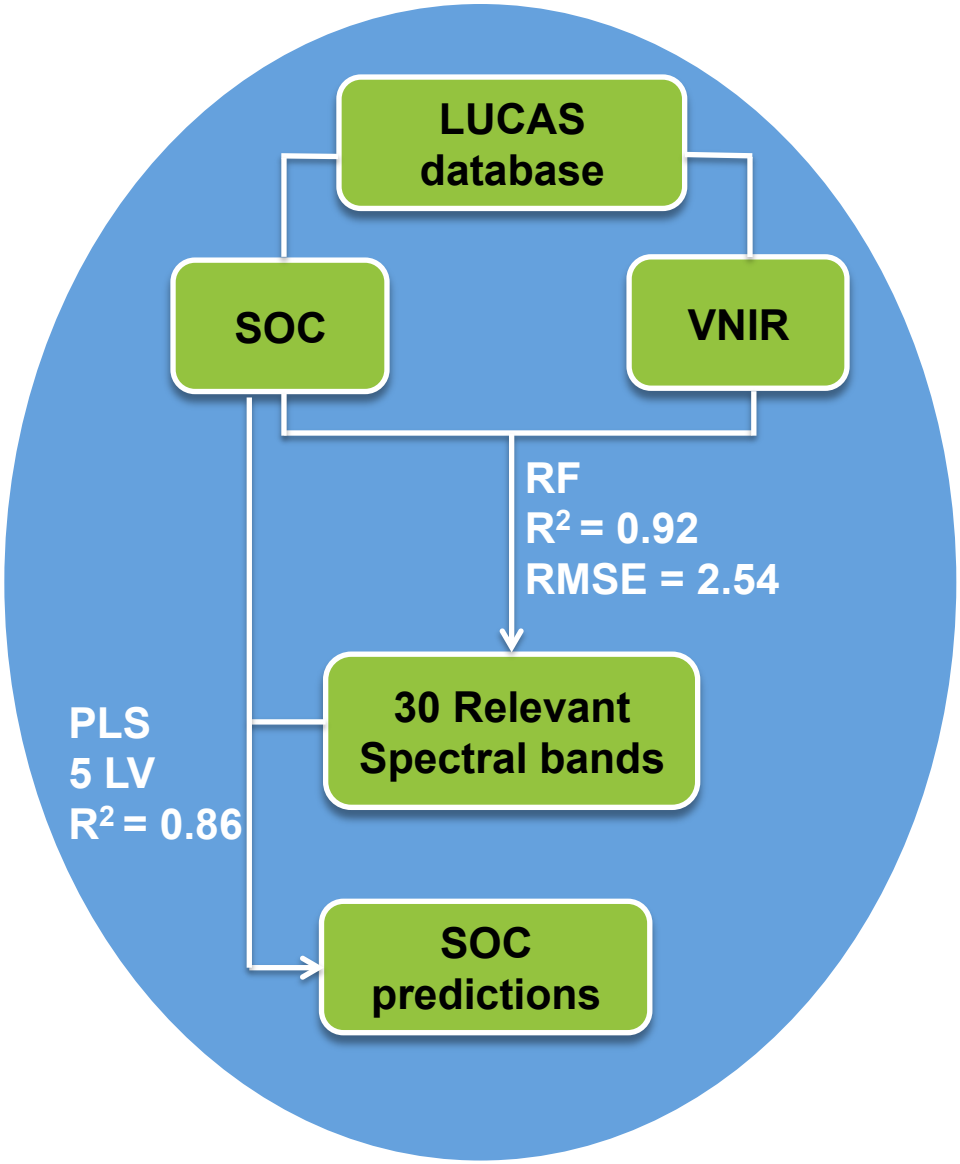
DSM (GAM)

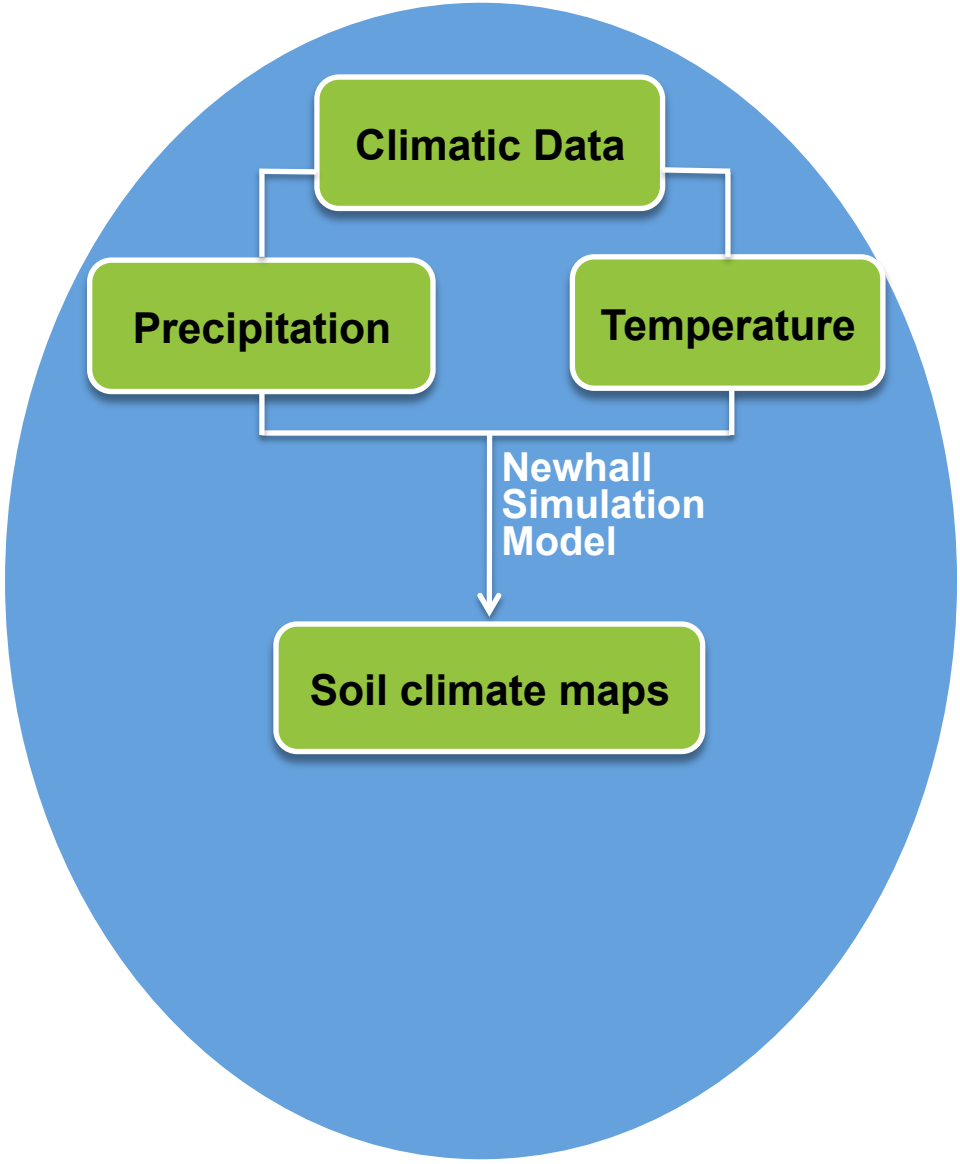
R^2 = 0.27

R^2 (mineral)=0.21; R^2 (Scandinavia)=0.06



What have we done?

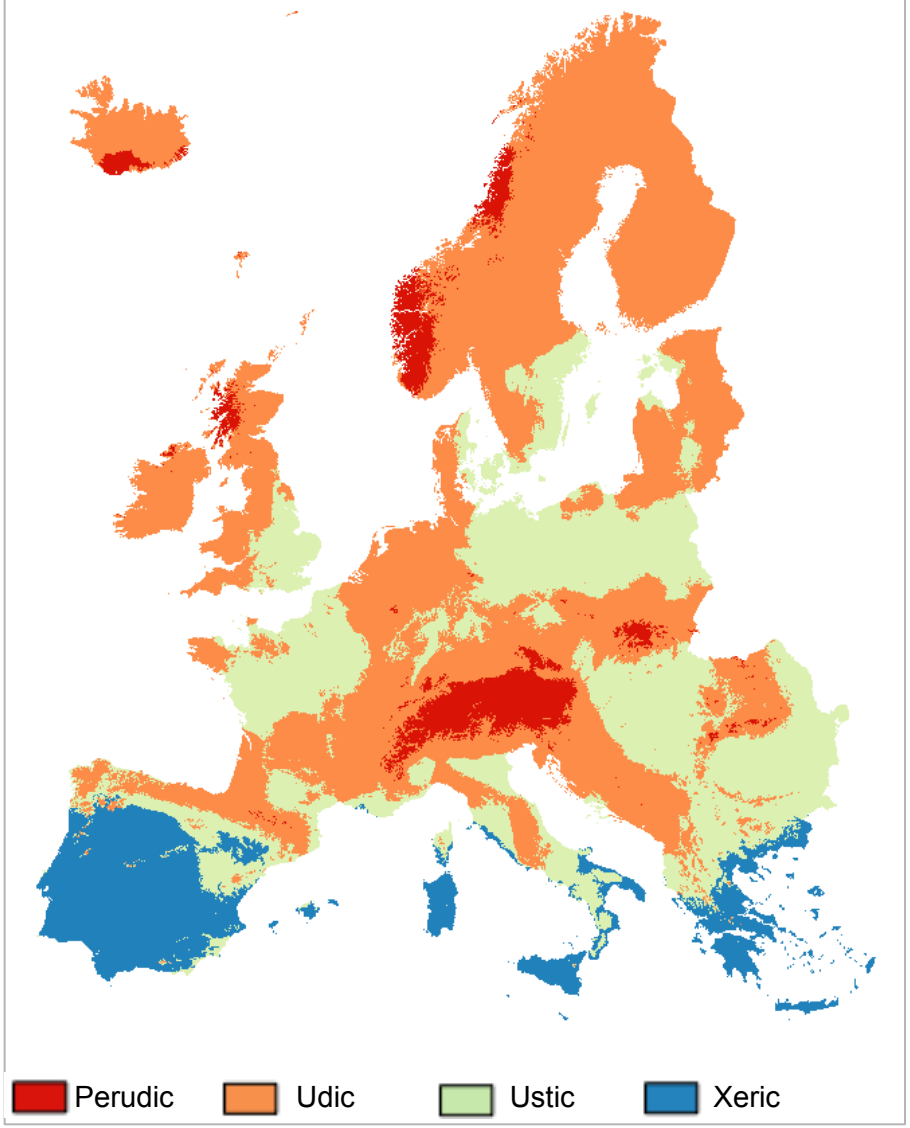




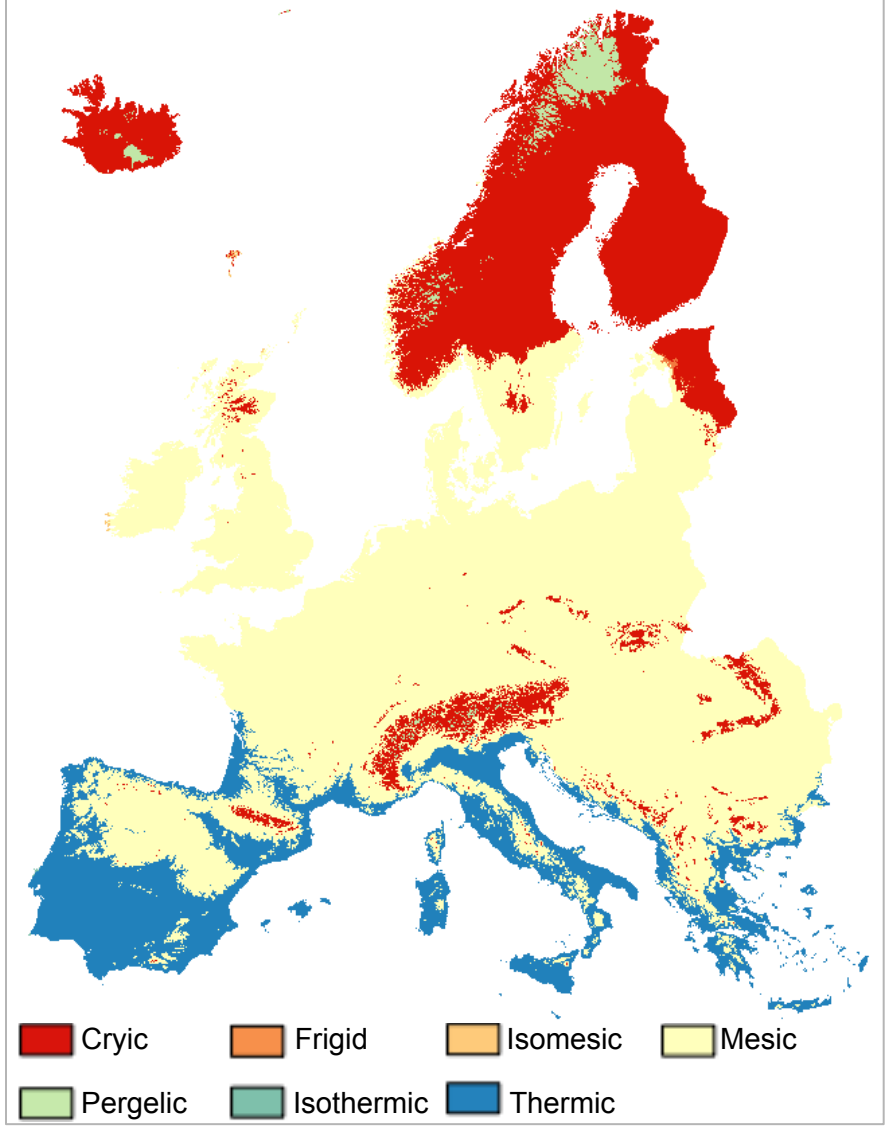
What have we done?

USC
UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

Soil moisture regimen



Soil temperature regimen



USC
UNIVERSIDADE
DE SANTIAGO
DE COMPOSTELA

MANY THANKS FOR YOUR ATTENTION

QUESTIONS?