Coordinating and integRating state-of-the-art Earth Observation Activities in the regions of North Africa, Middle East and Balkans and Developing Links with GEO related intiatives toward GEOSS

GEO-CRADLE Project Meeting 2
16th November, 2016
Task 4.2

SOIL SPECTRAL INFORMATION IN THE ERA OF COMMERCIAL HYPERSPECTRAL SENSOR IN ORBIT: PRISMA PROJECT

imaa istituto di metodologie per l'analisi ambientale

S. Pignatti, F. Longo

stefano.pignatti@.cnr.it
francesco.longo@asi.it

asi

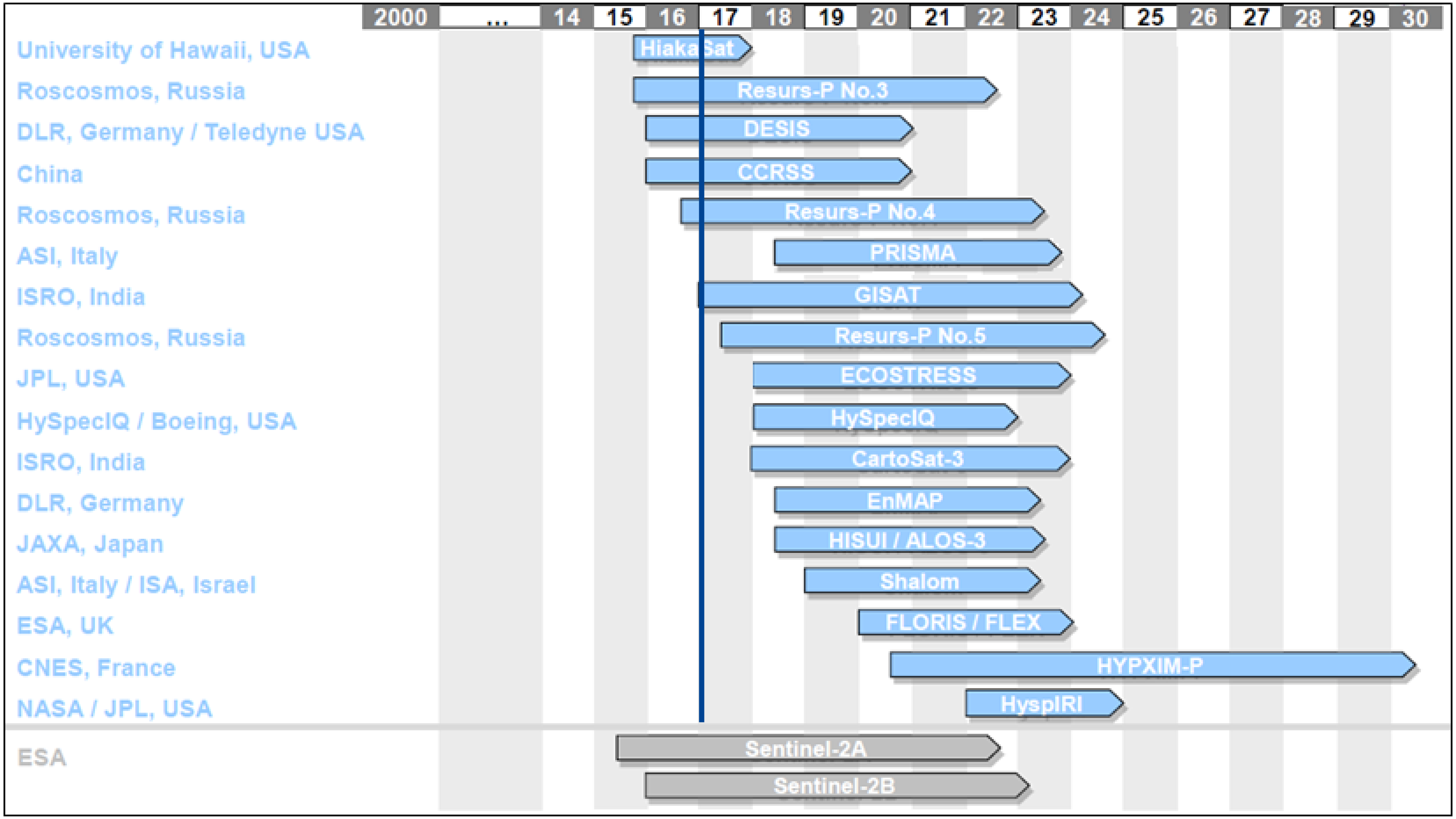
Eratosthenes Research Centre
Limassol, Cyprus

The GEO-CRADLE project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 690133.

outlines

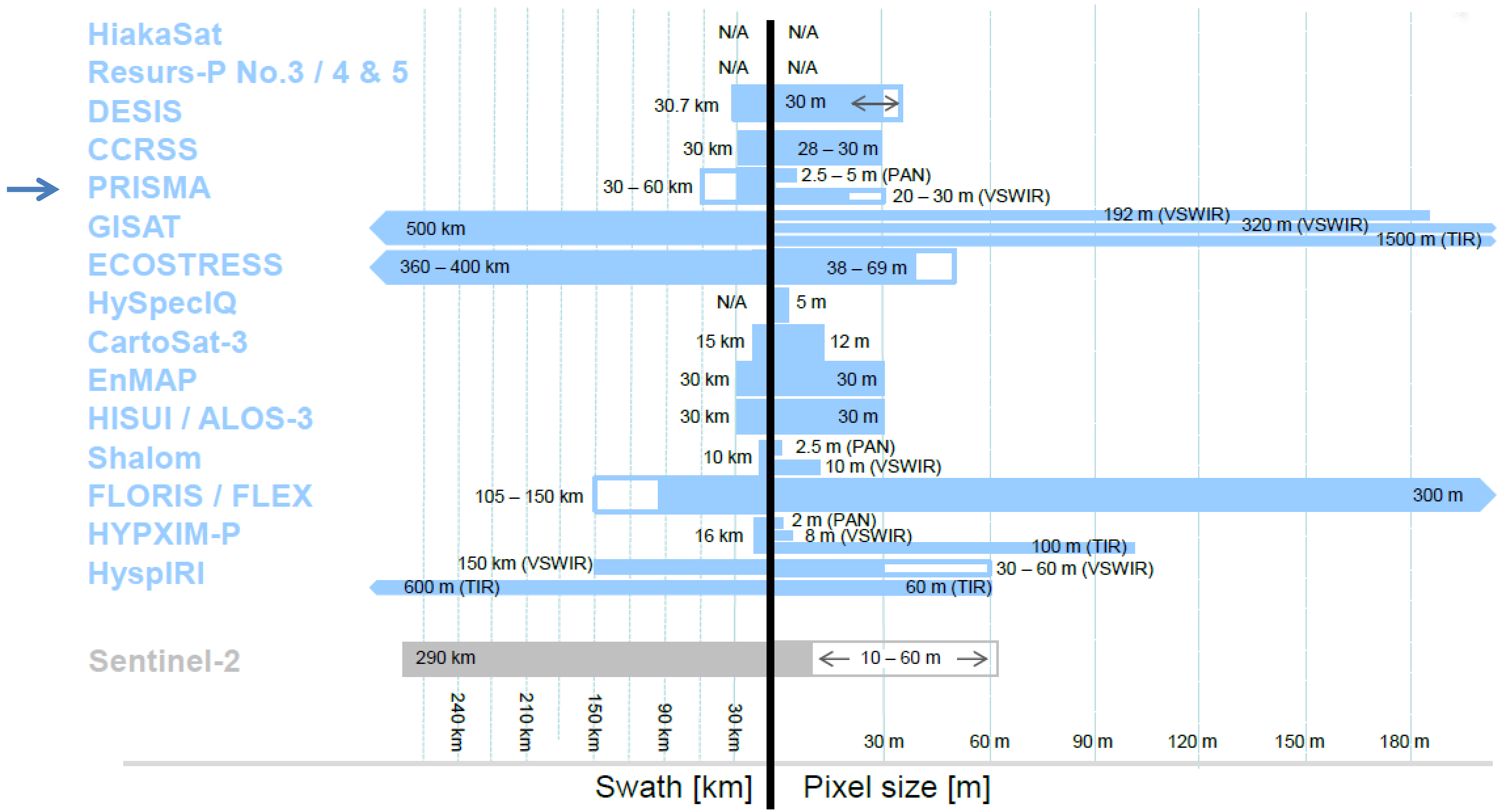
- ✓ The next spaceborne mission; PRISMA
- ✓ The impact of HYS missions for soil sciences
  - Texture (% of clay, silt and sand)
  - % of Soil organic carbon - SOC
  - Soil moisture
  - Soil contamination (?)
  - Soil vigour
- ✓ Related agronomical proxi variables related to food security issues

Future IS spaceborne missions



http://www.enmap.org/sites/default/files/pdf/Hyperspectral_EO_Missions_2015_06_22_FINAL.pdf

Future IS spaceborne missions

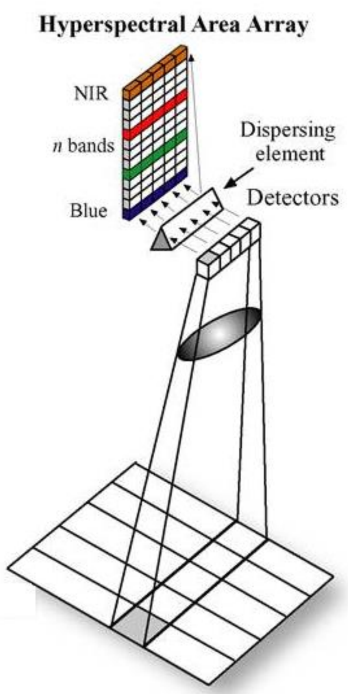


http://www.enmap.org/sites/default/files/pdf/Hyperspectral_EO_Missions_2015_06_22_FINAL.pdf

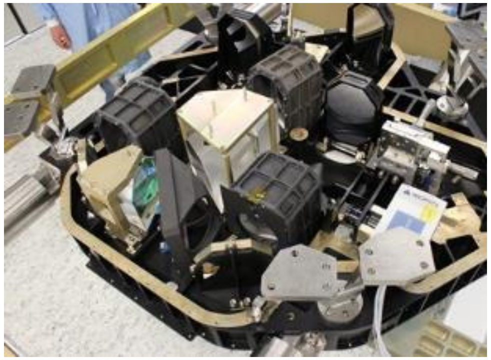
PRISMA Payload

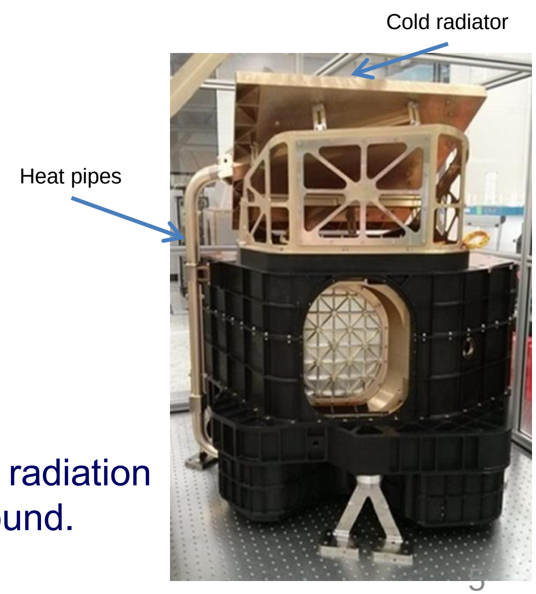
The PRISMA Payload operates with a Pushbroom scanning concept that records reflected radiation from the Earth surface in the PAN range, in the visible/near infrared (VNIR) range and in the short wave infrared (SWIR) range with a band width of 10 nm.

The PAN sensor is characterized by a ground sampling distance of 5 m (nadir at sea level); the VNIR/ SWIR GSD is 30 m.



Swath / FOV	30 km / 2.77°
Ground Sampling Distance (GSD)	Hyperspectral: 30 m / PAN: 5 m
Spectral Range	VNIR: 400 – 1010 nm SWIR: 920 – 2505 nm PAN : 400 – 700 nm
Spectral Width (FWHM)	≤ 12 nm
Radiometric Quantization	12 bit
VNIR SNR	> 200:1
SWIR SNR	> 100:1
PAN SNR	> 240:1
MTF@ Nyquist freq.	VNIR/SWIR along track > 0.18 VNIR/SWIR across track > 0.34 PAN along track > 0.10 across track >0.20
Spectral Bands	66 VNIR / 173 SWIR
Data processing	Lossless compression with compression factor 1.6 Near lossless compression
Thermal Control System	Double stage passive radiator (1 for each HYP channel) + stabilization heater
Mass (including 5% margin)	Optical Head: 175kg Thermal Shield: 25kg Main Electronics: 12kg
Power Consumption (including 10%margin)	Earth Observation /calibration: <105W Idle: <90W





The hyperspectral sensor utilizes prisms to obtain the dispersion of incoming radiation on a 2-D matrix detectors so to acquire spectral bands of the same strip on ground.

User interaction with the system

Capacity to acquire, download, process up to L0a (including quicklook) and archive all Hyperspectral and Panchromatic channels for a max of 200.000 km^2 on a daily basis

OLD DESIGN 108.000 km^2

- Imaging capacity:
  - 223 square images 30km x 30km instead of 120 (OLD DESIGN)

Capacity to daily process 200 hyperspectral scenes (30 km x 30 km) up to L2d

OLD DESIGN 30 scenes

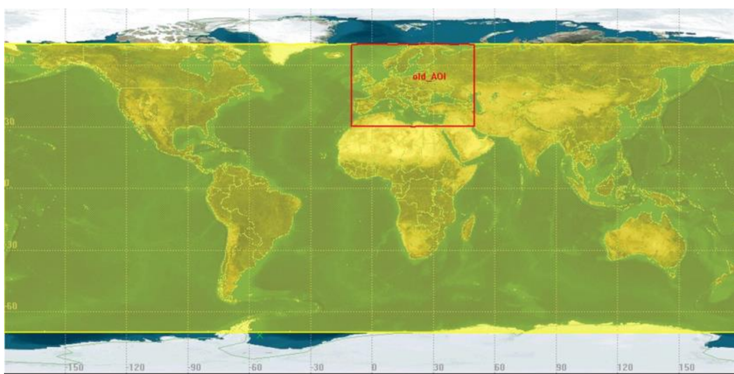
- Target access opportunities over the P-AoI:
  - duration/day: 240 minutes (28 min OLD DESIGN)
  - number of orbits/day: 15/15 (max 4/15 OLD DESIGN)

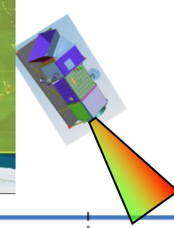
Data Acquisition Latency

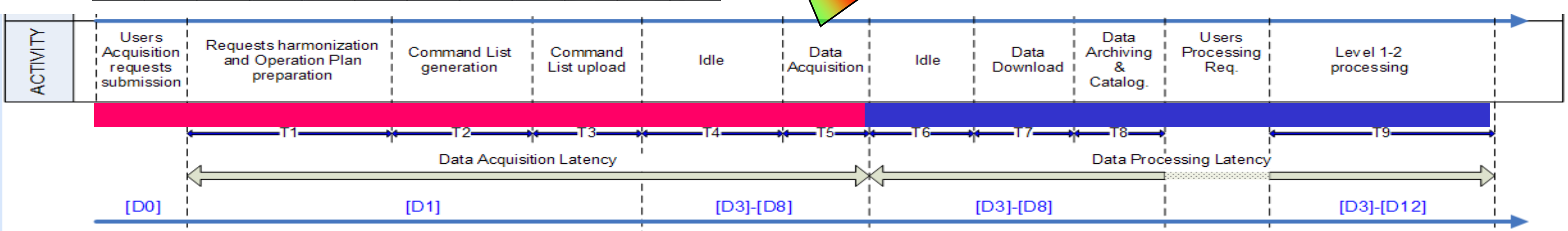
- User request submission
- Request harmonization
- System programming
- Commands upload
- Time to site
- Image acquisition

Data Processing Latency

- Time to receiving station
- Data download
- Data archiving & cataloguing
- Data processing
- Product availability at UGS
- Product delivery







PRISMA processing chain

- **Level 0:**
  - Instrument data decoding and decompression
  - PAN, HYP layers and ancillary data rearrangement
  - Cloud cover percentage calculation (for image cataloguing)
  - Image preview (for image cataloguing)

- **Level 0 data archiving**

- **Level 1 (upon user request)**
  - Image rediometric, spectral and geometric calibration
  - Additional: user surface cover map

- **Level 2 (upon user request)**
  - Atmospheric corrections
  - Atmospheric load estimation (columnar water vapour and aerosol load, thin clouds optical thickness)
  - Image geo-referencing/geocoding

IS versus
soil properties and crop parameters retrieval

Soil components

EO Products	Description	Unit	EO product maturity level	Notes
CLAY	Percentage of clay in the first 30 cm of soil	%	medium	limited to mechanically prepared bare ground
SILT	Percentage of silt in the first 30 cm of soil	%	medium	
SAND	Percentage of sand in the first 30 cm of soil	%	medium	
SOC	Percentage of organic carbon in the first 30 cm of soil	%	low	

Vegetation components

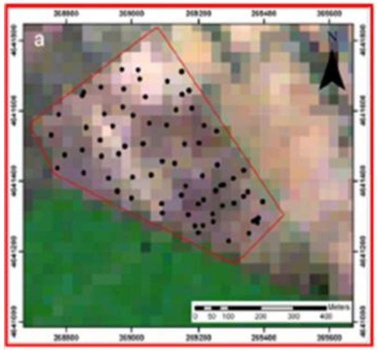
EO Products	Description	Unit	EO product maturity level	Notes
LAI	Leaf Area Index	-	high	limited to herbaceous crops
Cab	Chlorophyll a and b Content of in leaves per unit of area	mg cm^{-2}	high	
FPAR	Fraction of photosynthetically active radiation absorbed by vegetation cover	-	high	

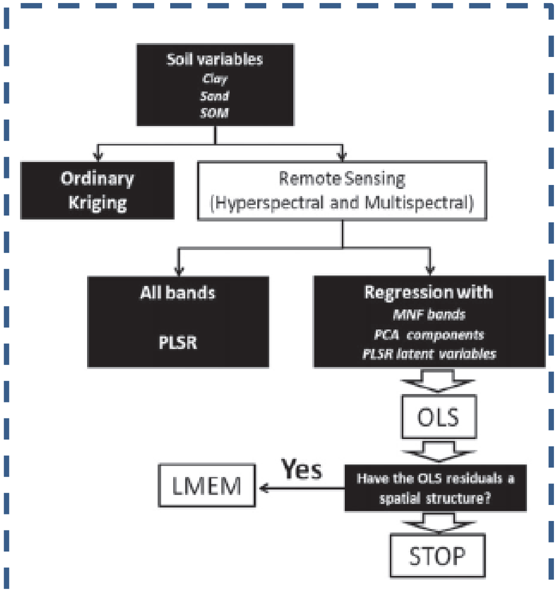
Agricultural components

EO Products	Description	Unit	EO product maturity level	Notes
YLD	Crop production	t ha^{-1}	low	limited to a cereal crop to be defined
QN	Content of nitrogen in the aboveground biomass	%	low	
GN	Nitrogen content in grain	%	low	
Nres	nitrate nitrogen (NO3-N-) in the soil at the end of crop cycle	kg ha^{-1}	low	

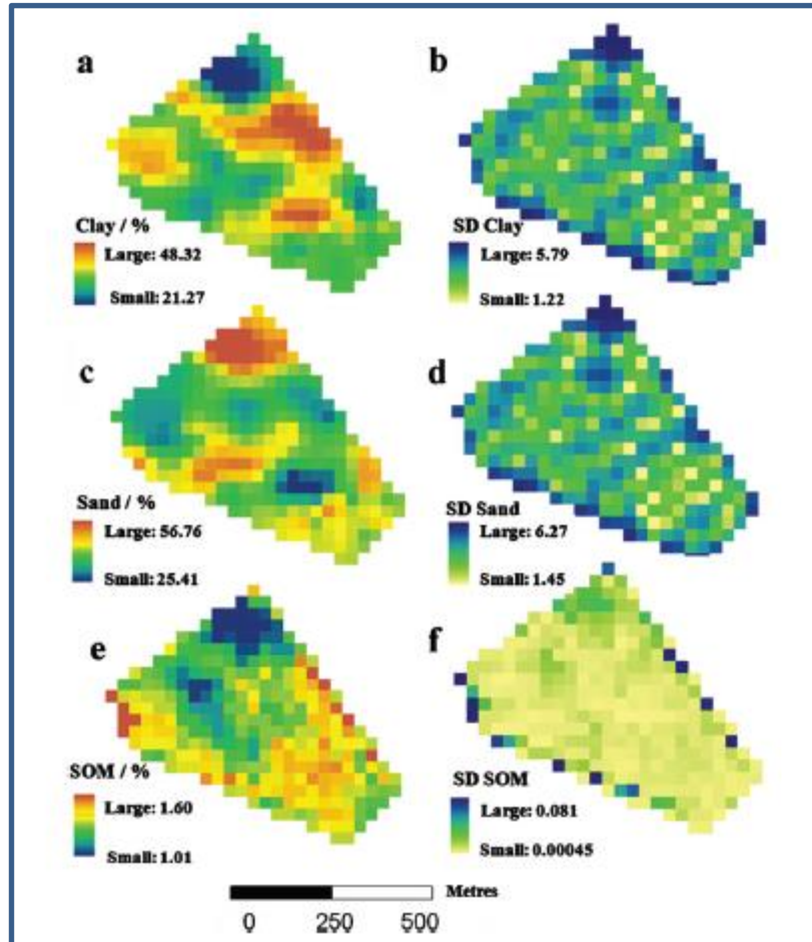
Soil component - texture

	n°	Min %	Max %	Mean %	sd	skewness
clay	72	18.37	49.61	37.91	6.78	-0.37
sand	72	23.10	60.43	36.55	7.48	0.95
SOM	72	1.07	2.67	1.69	0.44	0.64





		Clay	Sand	SOM
OK Ordinary K.	RMSE	4.46	5.18	0.33
	RIPQ	2.29	1.69	1.76
PLSR Partial least square regr.	RMSE	5.95	6.69	0.41
	RIPQ	1.64	1.31	1.41
LMEM Linear mixed effect model	RMSE	4.07	4.90	0.15
	RIPQ	2.40	1.79	3.87

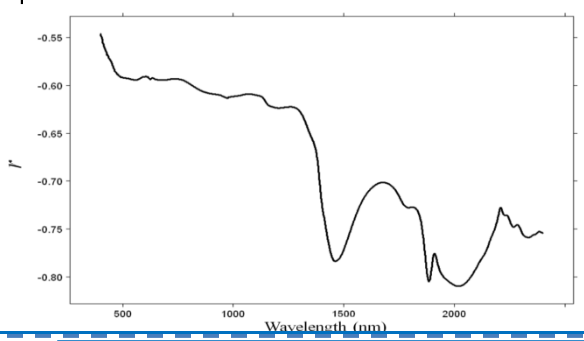


F. Castaldi, R. Casa, A. Castrignanò, S.Pascucci, A. Palombo and S. Pignatti *«Estimation of soil properties at the field scale from satellite data: a comparison between spatial and non-spatial techniques»* ESJ, Volume 65, Issue 6, pages 842–851, November 2014

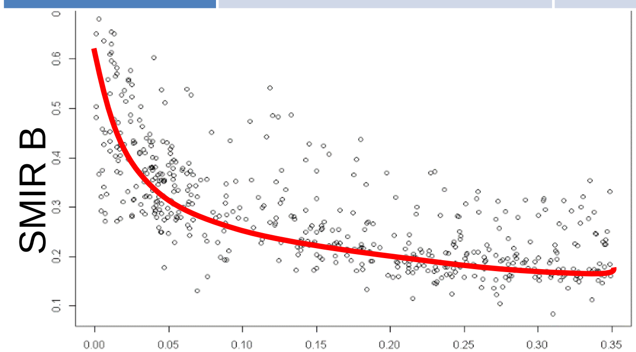
Soil component – soil moisture

	Spectral dataset	
	SOLREFLIU	**MAC**
N° samples	89	72
Type	Topsoil	Topsoil
Sampling Area	France & China	Italy
Spectral Meas.	Directional	Directional
Spectral range	350-2500	350-2500
Spectral Res.	1 nm	1 nm

Pearson's correlation coefficient (r) between Soil Moisture content and reflectance values of **MAC** and **SOLREFLIU** spectral datasets as a function of λ



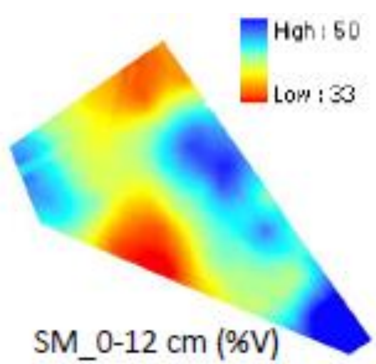
Soil Moisture Index	Formula	R	a	b	c	RMSE (%)	RPIQ
SMIR_A	$(R_{1770} - R_{2100})/(R_{1770} + R_{2100})$	0.89	0.03	1.63	−1.89	0.05	4.25
SMIR_B	R_{1506}/R_{1770}	−0.88	0.48	0.24	−0.75	0.05	4.25
NSMI *Normalized Soil Moisture Index*	$(R_{1800} - R_{2119})/(R_{1800} + R_{2119})$	0.88	0.50	−1.67	1.46	0.05	4.25



Cross-validation results Pearson's correlation coefficient (r), the coefficients of the quadratic regressions

$$SM = a + b*index + c*index^2$$

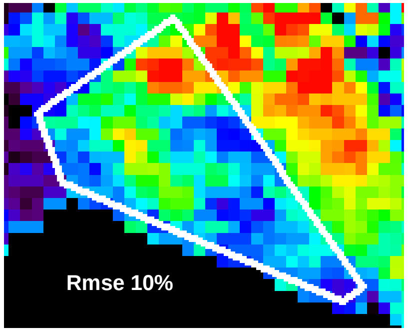
the root mean square error (RMSE) and the Ratio of the Performance to the Interquartile Range (RPIQ) are reported in the above tab



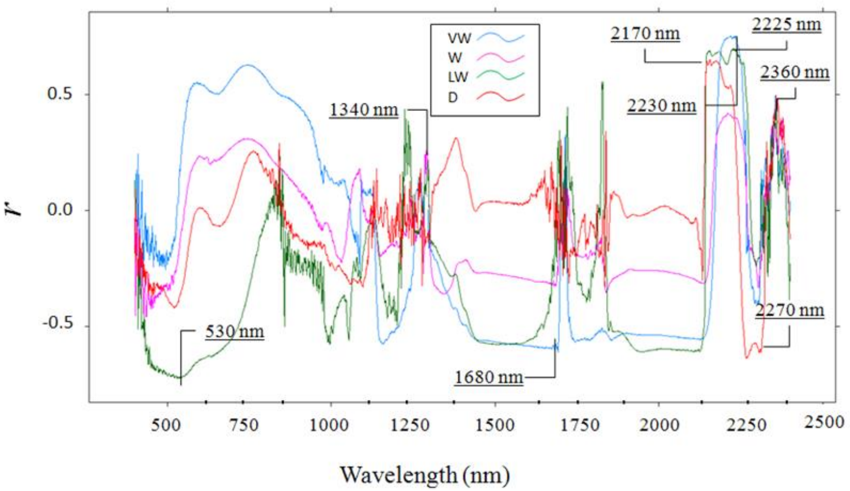
TDR Nov. 8, 12

Hyperion, Nov. 7, 12

SMIR - B



Soil component – soil moisture / clay



Pearson's correlation coefficient (*r*) between clay content and Band Depth spectral values for the four soil moisture classes of the **MAC** spectral library (**VW**: *very wet*; **W**: *wet*; **LW**: *low wet*; **D**: *dry*)

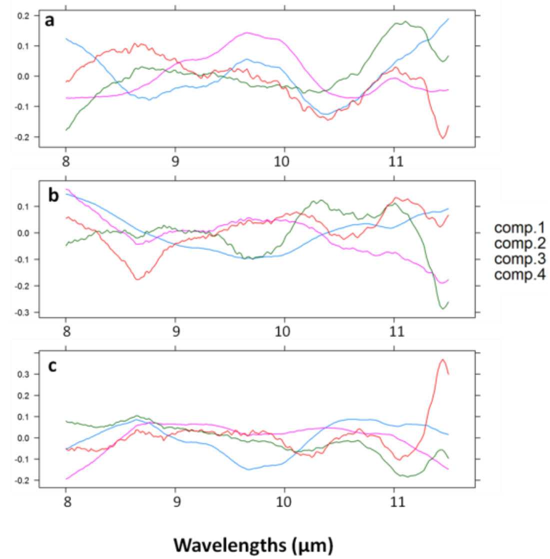
SM class	Clay index	r
VW	$(BD_{2230} - BD_{1680})/(BD_{2230} + BD_{1680})$	0.70
W	$(BD_{1340} - BD_{2360})/(BD_{1340} + BD_{2360})$	−0.73
LW	BD_{530}/BD_{2225}	0.65
D	$(BD_{2170} - BD_{2270})/(BD_{2170} + BD_{2270})$	0.75

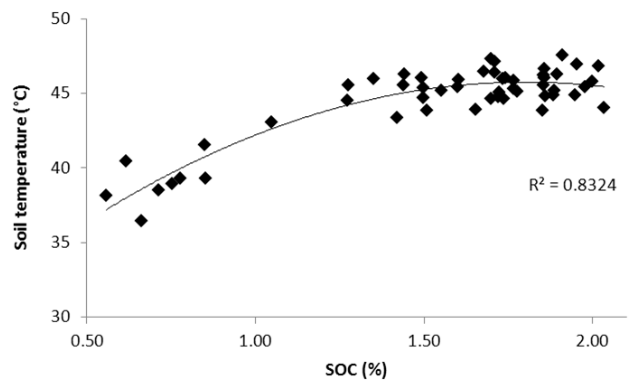
		CLAY ESTIMATION METHOD											
		Spectral indices						PLSR					
		Summer		Autumn		Winter		Summer		Autumn		Winter	
	SM class	RMSE (%)	RPIQ	RMSE (%)	RPIQ	RMSE (%)	RPIQ	RMSE (%)	RPIQ	RMSE (%)	RPIQ	RMSE (%)	RPIQ
Different spectral indices according to SM level	**VW**	6.6	2.6	6.3	2.7	6.3	2.7	7.1	2.4	6.7	2.5	7.4	2.3
	W	8.2	2.1	8.5	2	10.6	1.6	6.3	2.7	6.8	2.5	9.2	1.8
	LW	8.5	2	8.2	2.1	7.8	2.2	9.5	1.8	9.1	1.9	9.5	1.8
	D	5.9	2.9	6	2.8	5.9	2.9	4.7	3.6	5.8	2.9	7.3	2.3
	Mean	7.3	**2.3**	7.3	**2.3**	7.7	**2.2**	6.9	**2.6**	7.1	**2.4**	8.4	**2.3**
	D to all	13.2	1.3	13.3	1.3	11.9	1.4	15.8	1.1	15.6	1.1	10.4	1.6

Castaldi, F.; Palombo, A.; Pascucci, S.; Pignatti, S.; Santini, F.; Casa, R. Reducing the Influence of Soil Moisture on the Estimation of Clay from Hyperspectral Data: A Case Study Using Simulated PRISMA Data. *Remote Sens.* **2015**, *7*, 15561-15582.

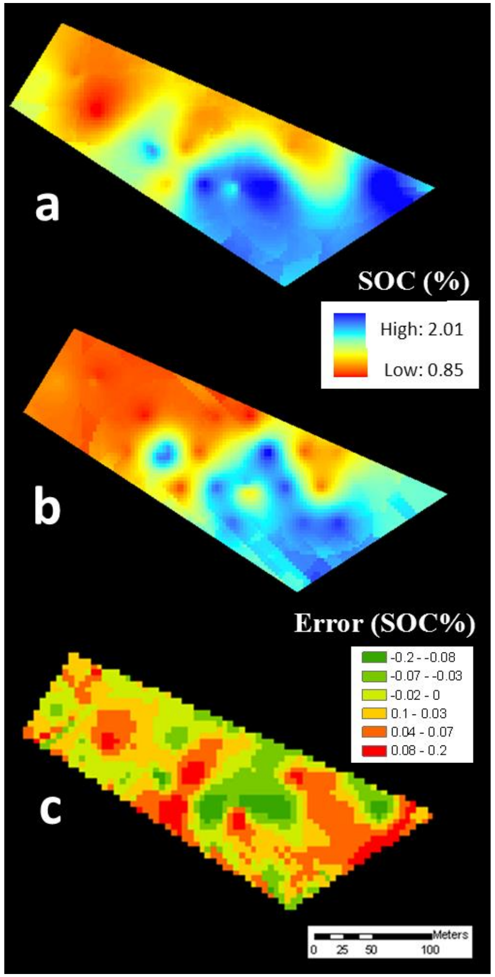
Soil component – SOC @ LWIR

Loading weights of the first four PLSR





temperature estimated by TASI-600 data against actual soil organic content in the sample points



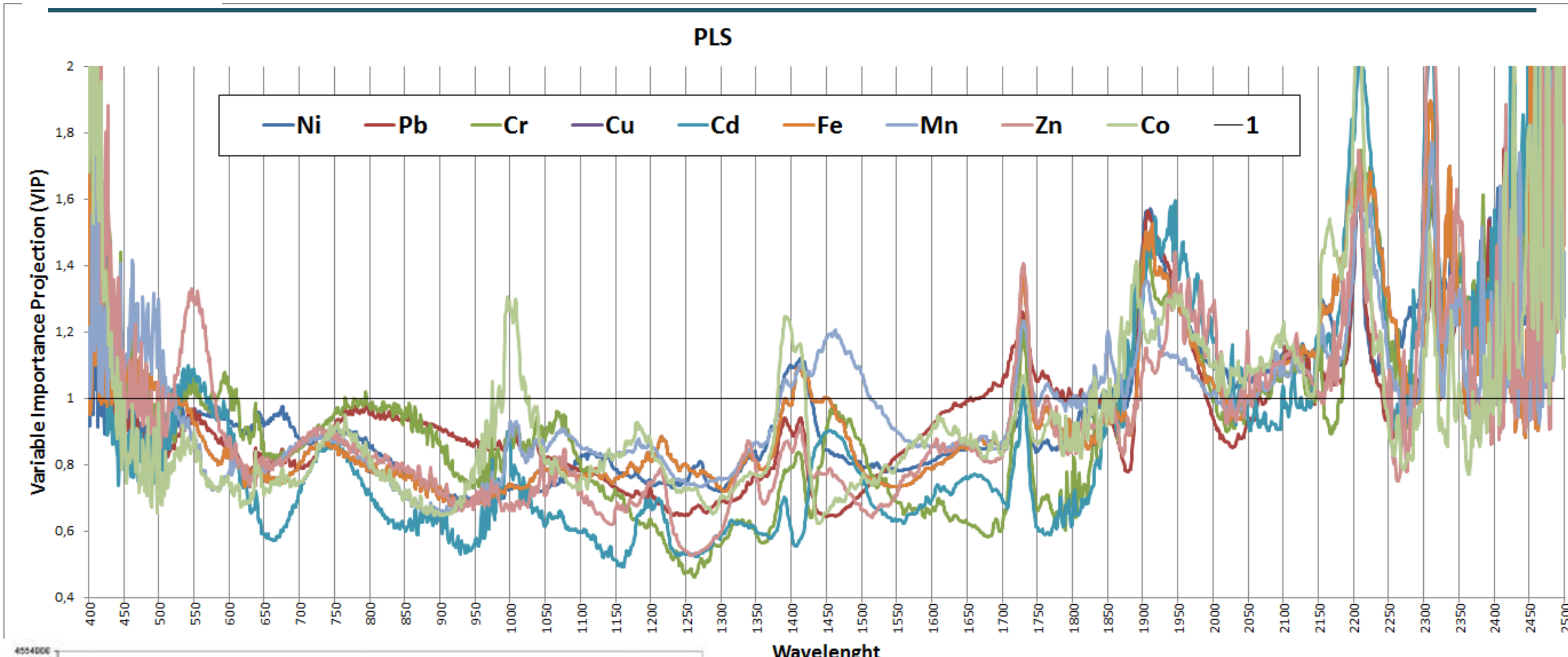
Soil Variable	Datum	No. of PLSR factors	R^2	RMSE	RPD	RPIQ
Clay	Emissivity	4	0.27	5.85	1.18	0.99
	MNF		0.42	5.15	1.34	1.13
Sand	Emissivity	2	0.10	4.77	1.10	1.50
	MNF		0.15	4.61	1.14	1.55
SOC	Emissivity	2	0.24	0.31	1.18	1.51
	MNF		0.53	0.26	1.46	**1.96**

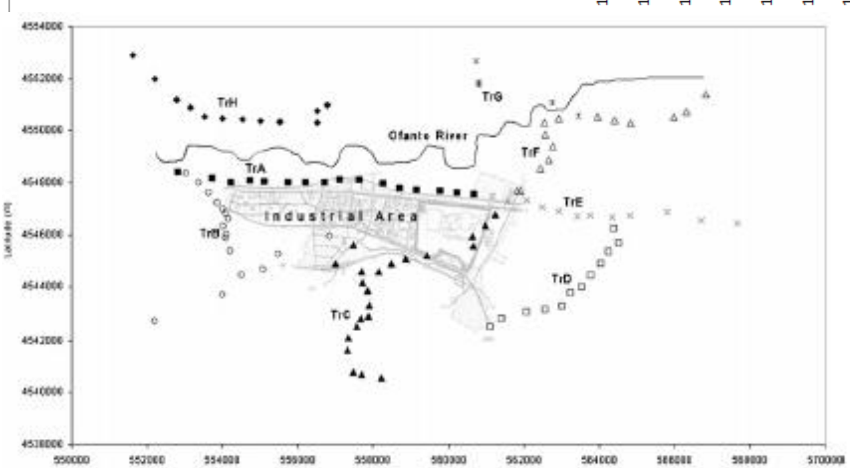
Ordinary kriging map obtained from actual SOC data (a) compared with (b) the ordinary kriging map from predicted values obtained by cubist calibration model using TASI-600 MNF data. The error map (c), expressed as difference between kriged predicted SOC (%) and kriged measured SOC (%),

Soil contamination – heavy metal

Spectral Library 110 samples

laboratory concentration (ppm) & ASD spectral measurements

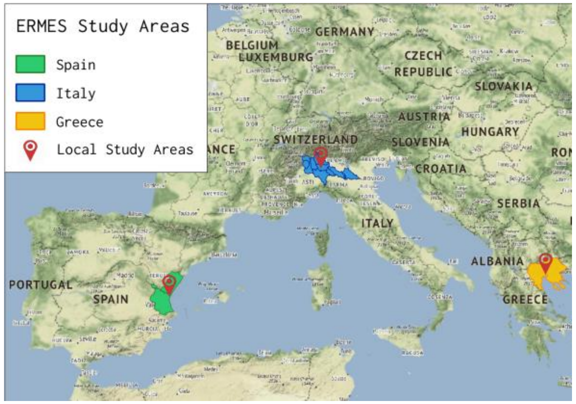




Soil component – spatial variability (vigour)

Soil and Biomass constant pattern maps

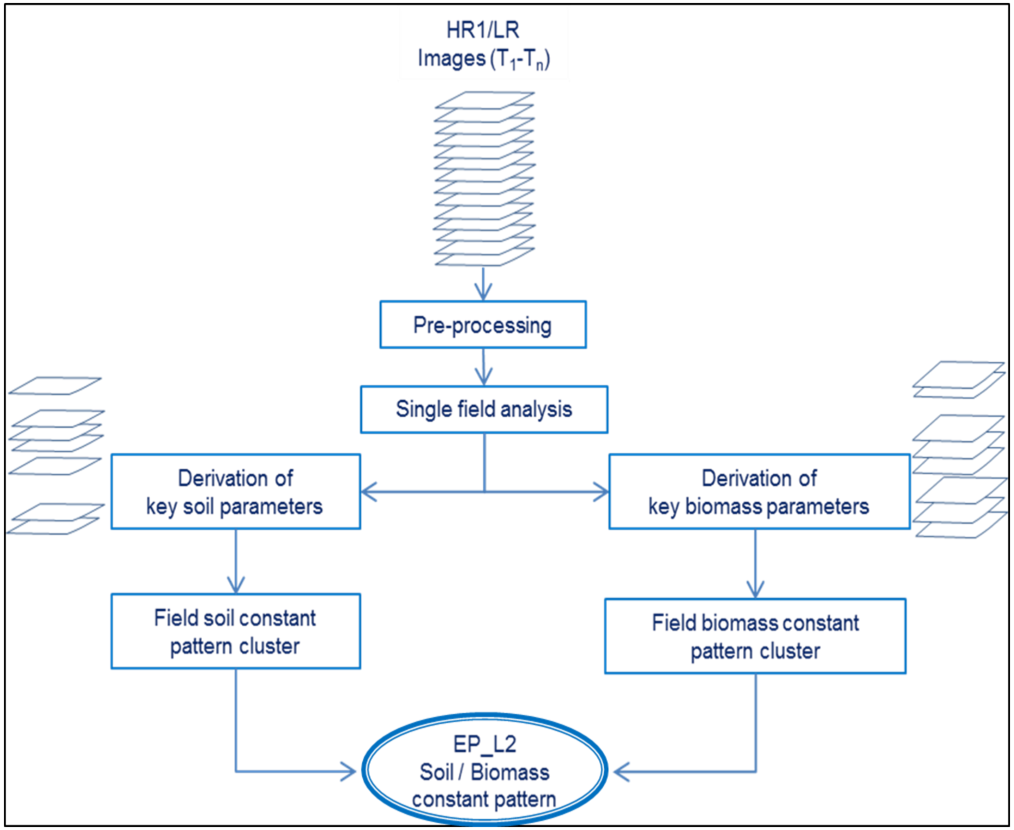
- Aimed at defining the local scale elementary units for crop growing models simulations either at the parcel or the within-parcel scale (static over the years)
- Foreseen the availability of the new spaceborne HIS data, multispectral (SPOT & Landsat) inter-annual time series of images (i.e. winter images for bare soil and summer images for biomass) have been used



Italy time-series: (2013-2014)
- 27 SPOT images / 385 fields
- 26 Landsat 7 ETM+ / 394 fields

Spain time-series: (2009-2014)
- 22 Landsat 5 and LC8-OLI
- 101 fields

Greece time-series: (2003-2015)
- 40 Landsat 5 and LC8-OLI
- 6934 fields

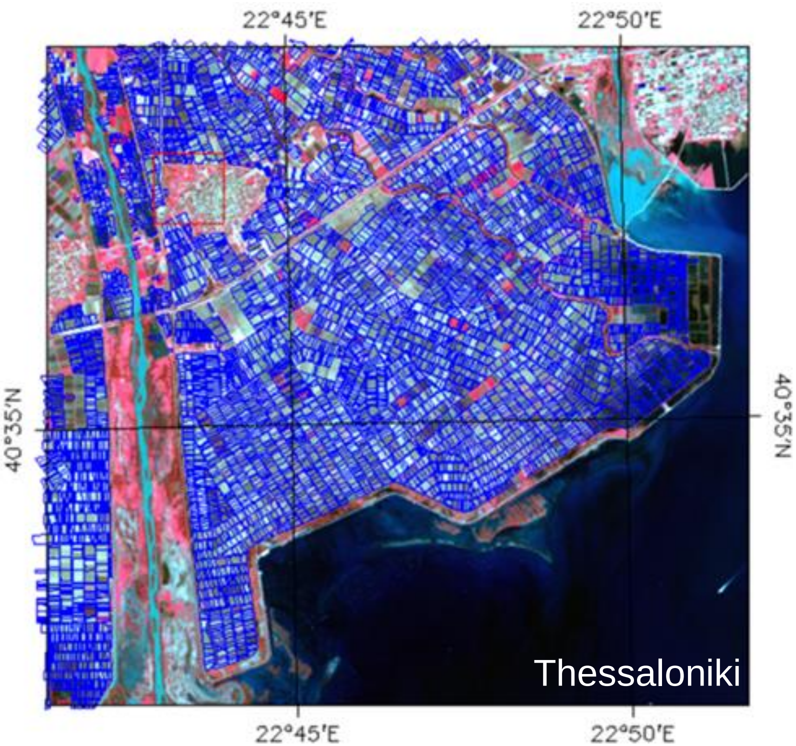


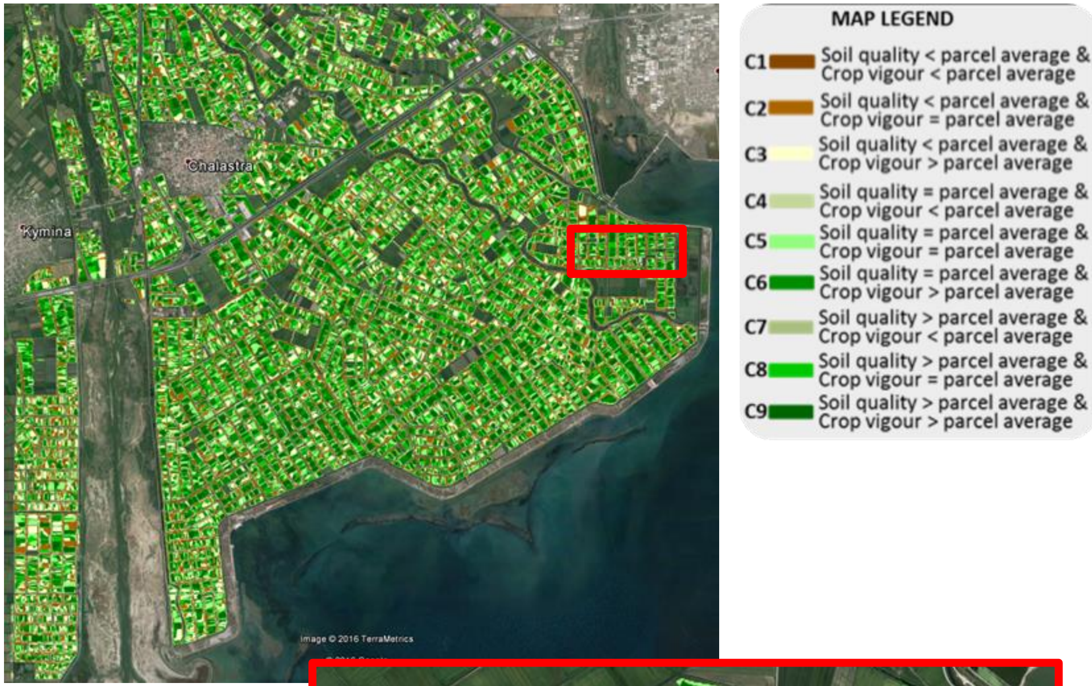
ERMES
AN EARTH OBSERVATION MODEL BASED RICE INFORMATION SERVICE

http://www.ermes-fp7space.eu/

A downstream service to support agro-production, planning and policy
‘Soil and Biomass constant pattern maps’

Greek time-series (2003-2015): 40 Landsat images (GSD 30 m) - 6934 parcels





2015 rice season, monitored parcels

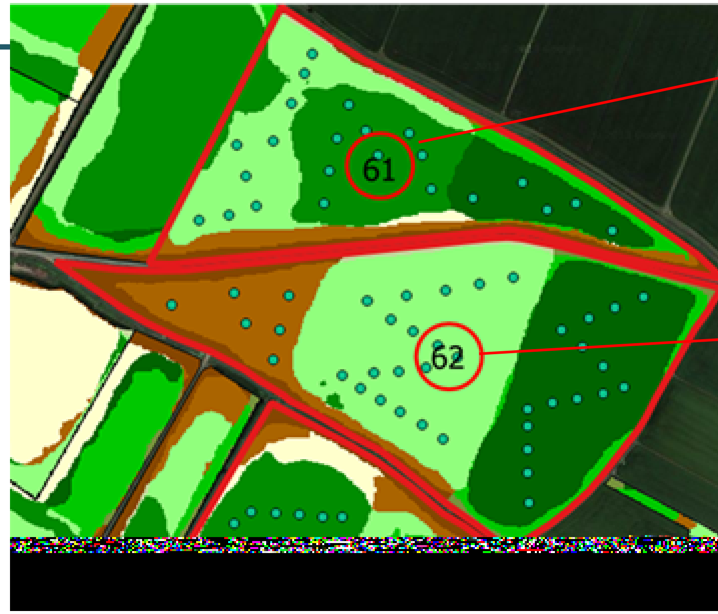
ERMES
AN EARTH OBSERVATION MODEL BASED RICE INFORMATION SERVICE

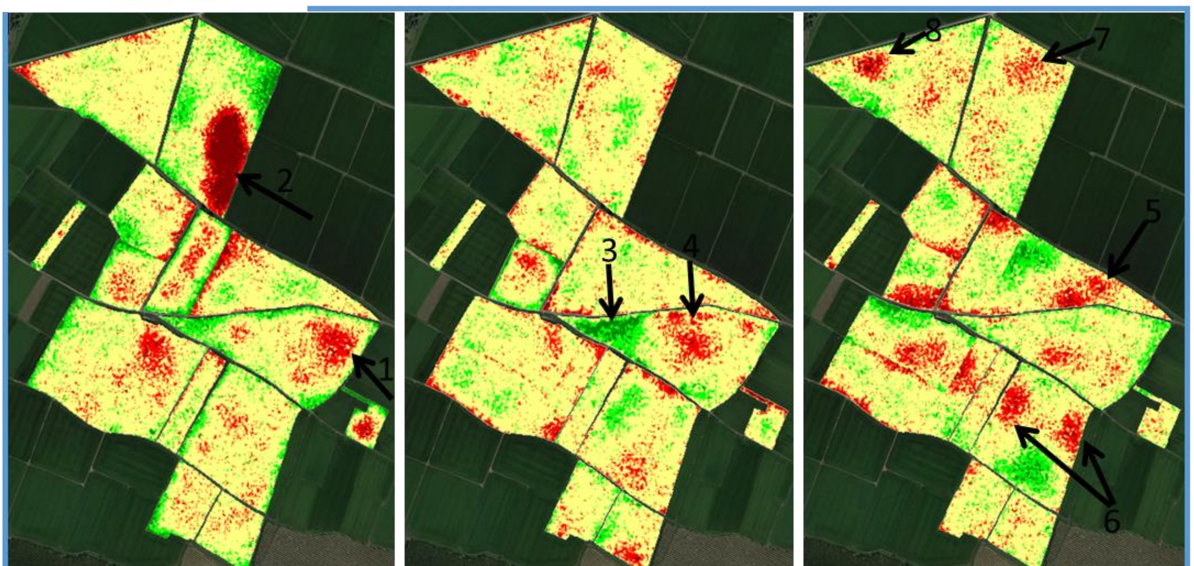
ERMES: Rice Farm in the Lomellina rice agricultural district (IT)
Optical (SPOT 5m) and Radar (COSMO-SkyMed 3m) time series

MAP LEGEND

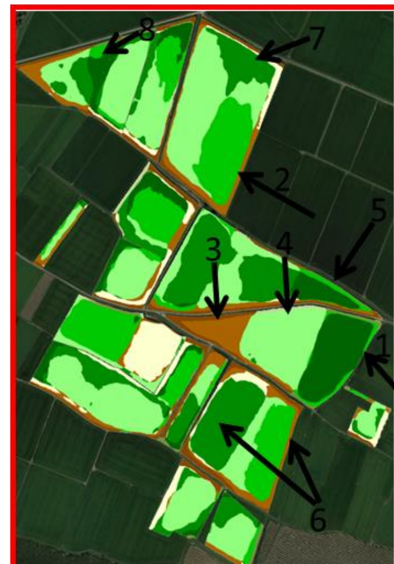
- C1 Soil quality < parcel average & Crop vigour < parcel average
- C2 Soil quality < parcel average & Crop vigour = parcel average
- C3 Soil quality < parcel average & Crop vigour > parcel average
- C4 Soil quality = parcel average & Crop vigour < parcel average
- C5 Soil quality = parcel average & Crop vigour = parcel average
- C6 Soil quality = parcel average & Crop vigour > parcel average
- C7 Soil quality > parcel average & Crop vigour < parcel average
- C8 Soil quality > parcel average & Crop vigour = parcel average
- C9 Soil quality > parcel average & Crop vigour > parcel average

ERMES
AN EARTH OBSERVATION MODEL BASED RICE INFORMATION SERVICE





A (5-21 May 2016) B (6-14 June 2016) C (30 June-8 July 2016)



D (2002-2014)

A,B,C
Cosmo-Skymed
(Radar X band)
2016 time variability maps (3m/pixel)

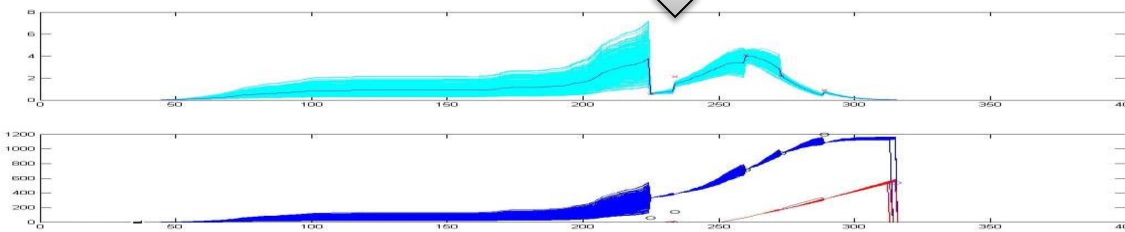
D
*Soil/Biomass constant pattern map obtained using **SPOT** 2002-2014 time series (5-10m/pixel)*

Assimilation of remote sensing variables into crop models

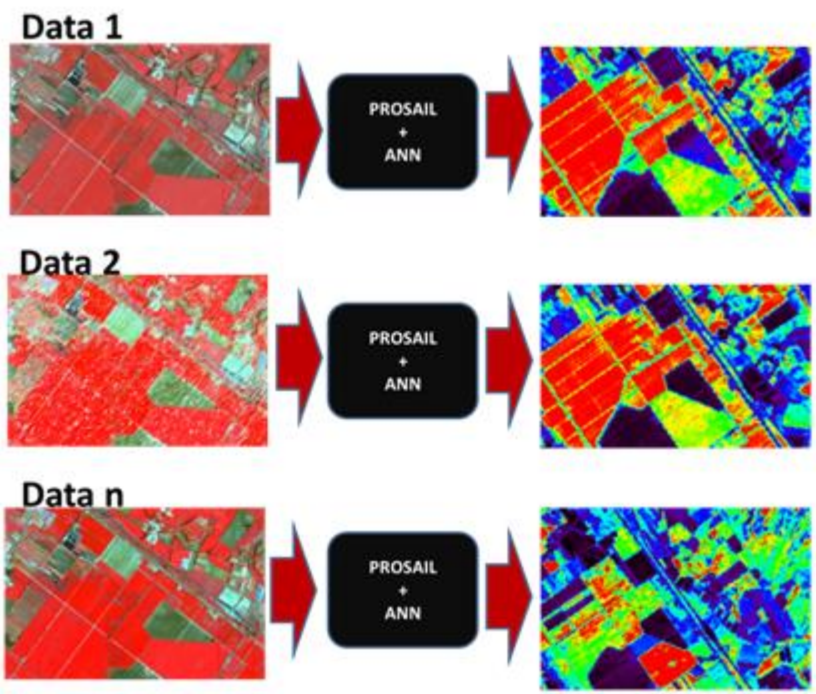
AQUACROP

CESBIO

SAFY

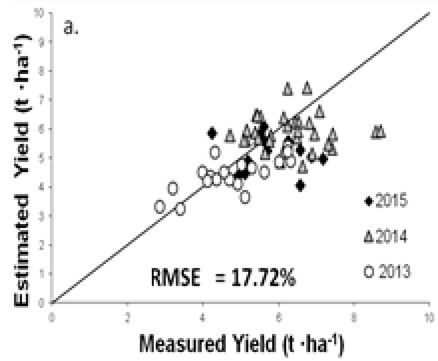


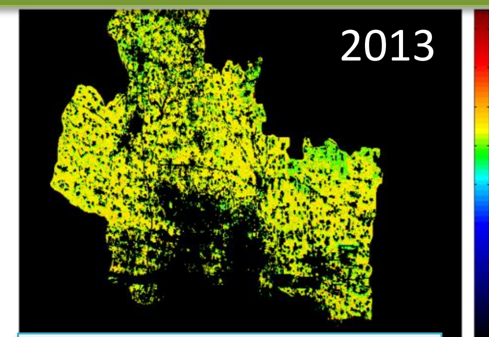
Example of LAI, Biomass and Yield simulation with EnKF assimilation for SAFY (7 Oct 2008, Xiaotangshan field experiments)



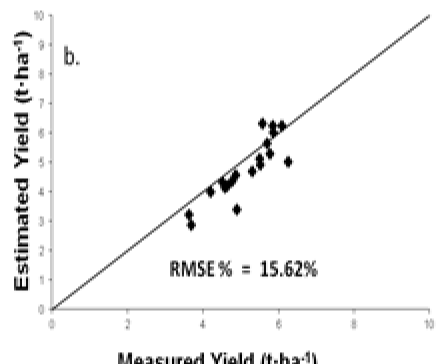
Satellite images **LAI maps**

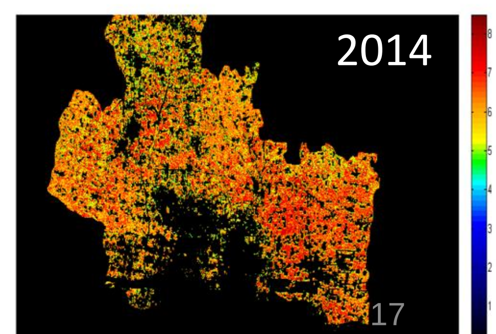
Wheat yield estimation





Yangling, Shaanxi





Conclusion I

- ✓ From 2018 PRISMA & ENMAP hyperspectral 30m/pixel images will be available to the community (free data policy?);

- ✓ The advent of HYS will allow the mapping of the physical and chemical characteristics of agricultural soils (in the first 30 cm of soil) like:
  - Texture (% of clay, silt and sand)
  - % of soil organic carbon - SOC
  - Soil moisture
  - Soil contamination (?)

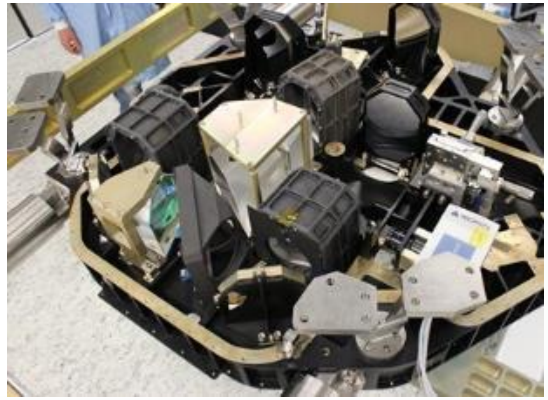
- ✓ The availability of new HYS imagery will impact on the retrieval accuracy of:
  - parameters pertaining to the agronomical management ;
  - agronomical proxi variables (e.g. yield, nitrogen content in grain, nitrate nitrogen in the soil at the end of crop cycle etc.) related to food security issues

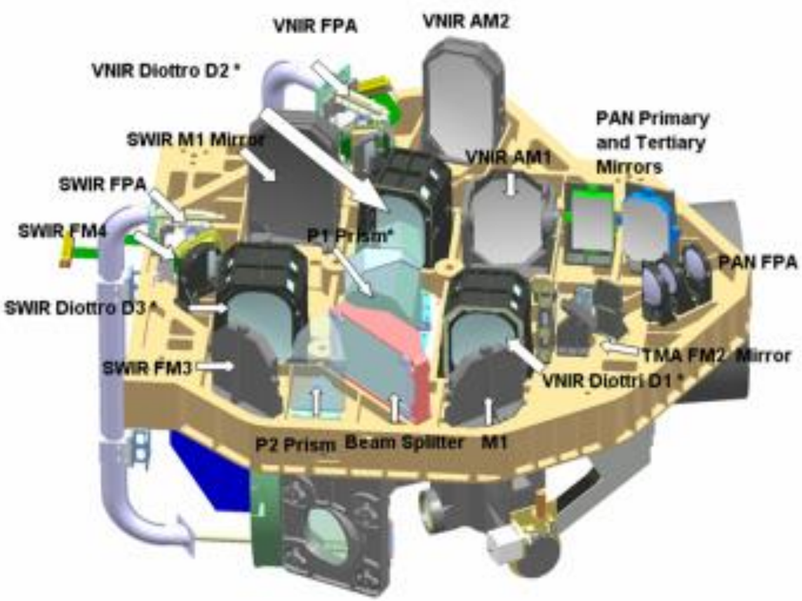
Conclusion II

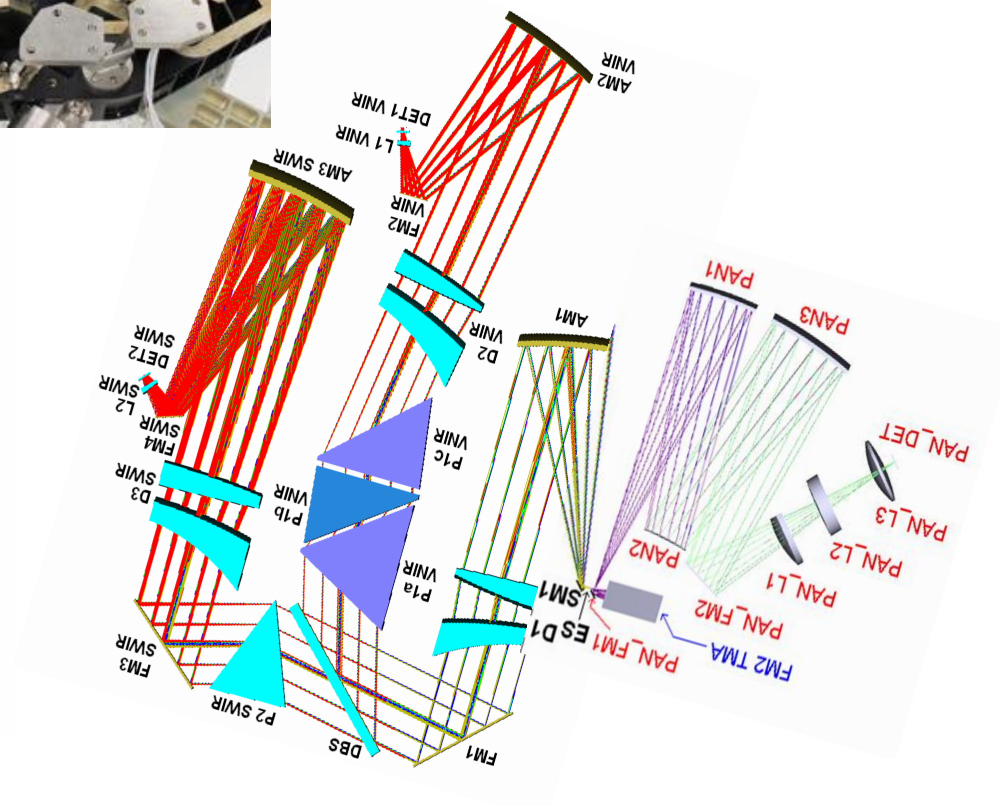
- ✓ The future HYS missions should assure an higher spatial resolution, and a wider swath to fulfill the tight requirements of the precision agriculture applications;

- ✓ HyspIRI and SHALOM will start to fill these gaps providing high spatial resolution and a full spectral coverage covering from the VSWIR to the LWIR

- ✓ Synergy with the Sentinels (wide swath and temporal frequency) is still an important issue




VNIR FPA
VNIR AM2
VNIR Diottro D2 *
SWIR M1 Mirror
PAN Primary
and Tertiary
Mirrors
VNIR AM1
SWIR FPA
SWIR FM4
P1 Prism*
PAN FPA
SWIR Diottro D3 *
TMA FM2 Mirror
SWIR FM3
VNIR Diottri D1 *
P2 Prism
Beam Splitter
M1


AM2 VNIR
DET1 VNIR
L1 VNIR
AM3 SWIR
FM2 VNIR
D2 VNIR
AM1
PAN1
PAN3
DET2 SWIR
L2 SWIR
FM4 SWIR
P1c VNIR
PAN_DET
D3 SWIR
P1b VNIR
PAN_L3
PAN2
PAN_L2
P1a VNIR
SM1
PAN_L1
ES D1
PAN_FM2
PAN_FM1
FM2 TMA
FM3 SWIR
P2 SWIR
DBS
FM1