Assessment of current and future multi- and hyperspectral sensors for the retrieval of soil variables

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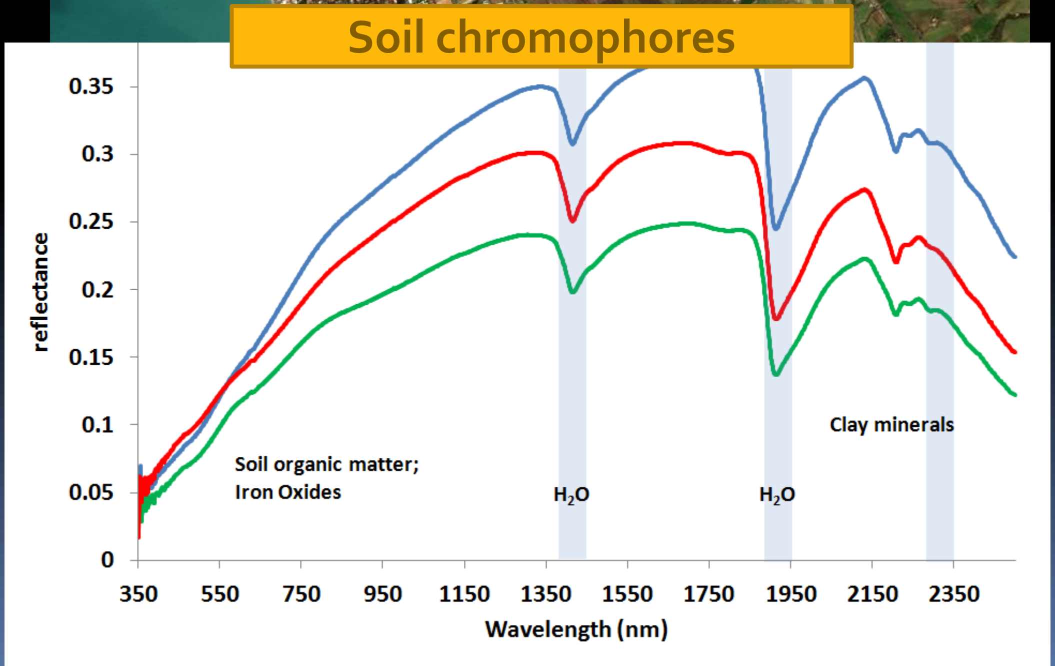
S A P 4 P R I S M A

Sviluppo di Algoritmi e Prodotti per applicazioni in agricoltura ed il monitoraggio del territorio a supporto della missione PRISMA

Bare soils are typically observed in arable croplands

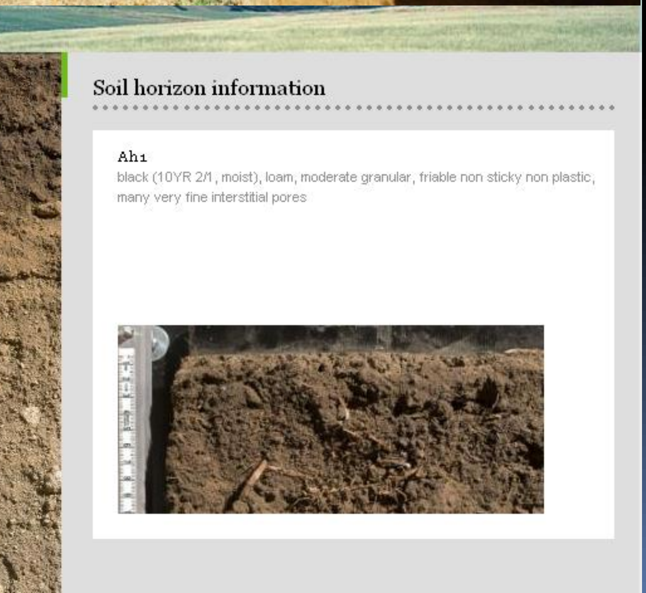
Can we retrieve quantitative information from optical data of bare soils ?

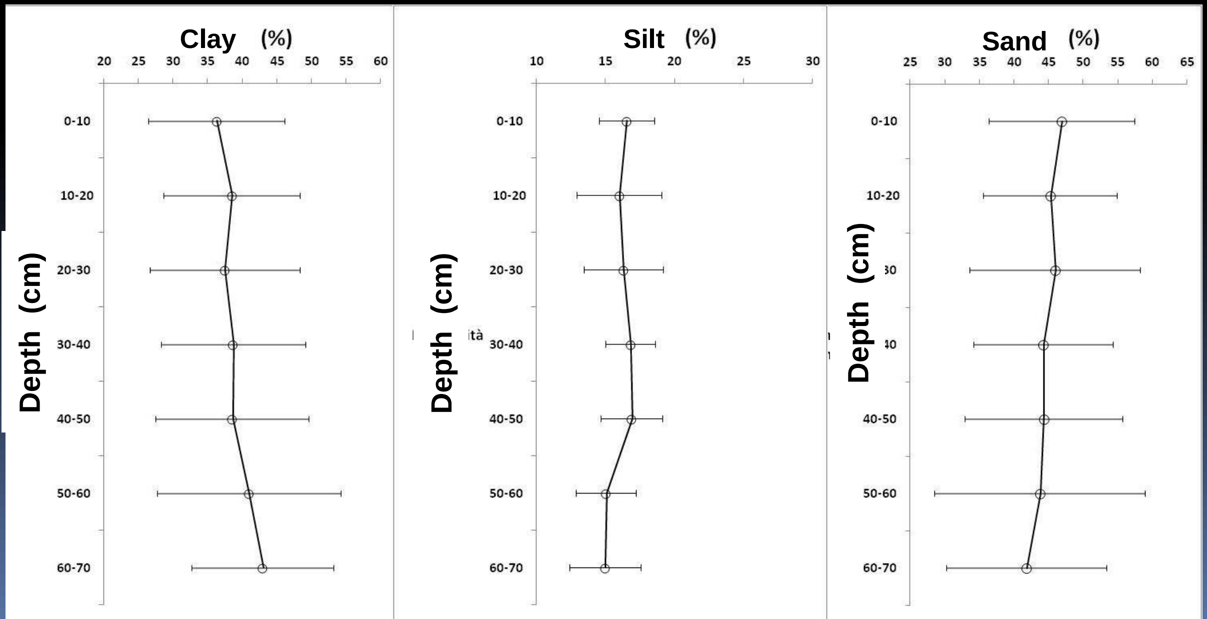


….soil reflectance conveys information from the topsoil surface only

Natural soil profile : variation with depth

Soil tillage: roughly similar properties within cultivated layer





Objective: evaluate the performance of current and forthcoming multispectral and hyperspectral imagers for the quantitative retrieval of soil texture (clay, sand and silt) and Soil Organic Carbon (SOC)

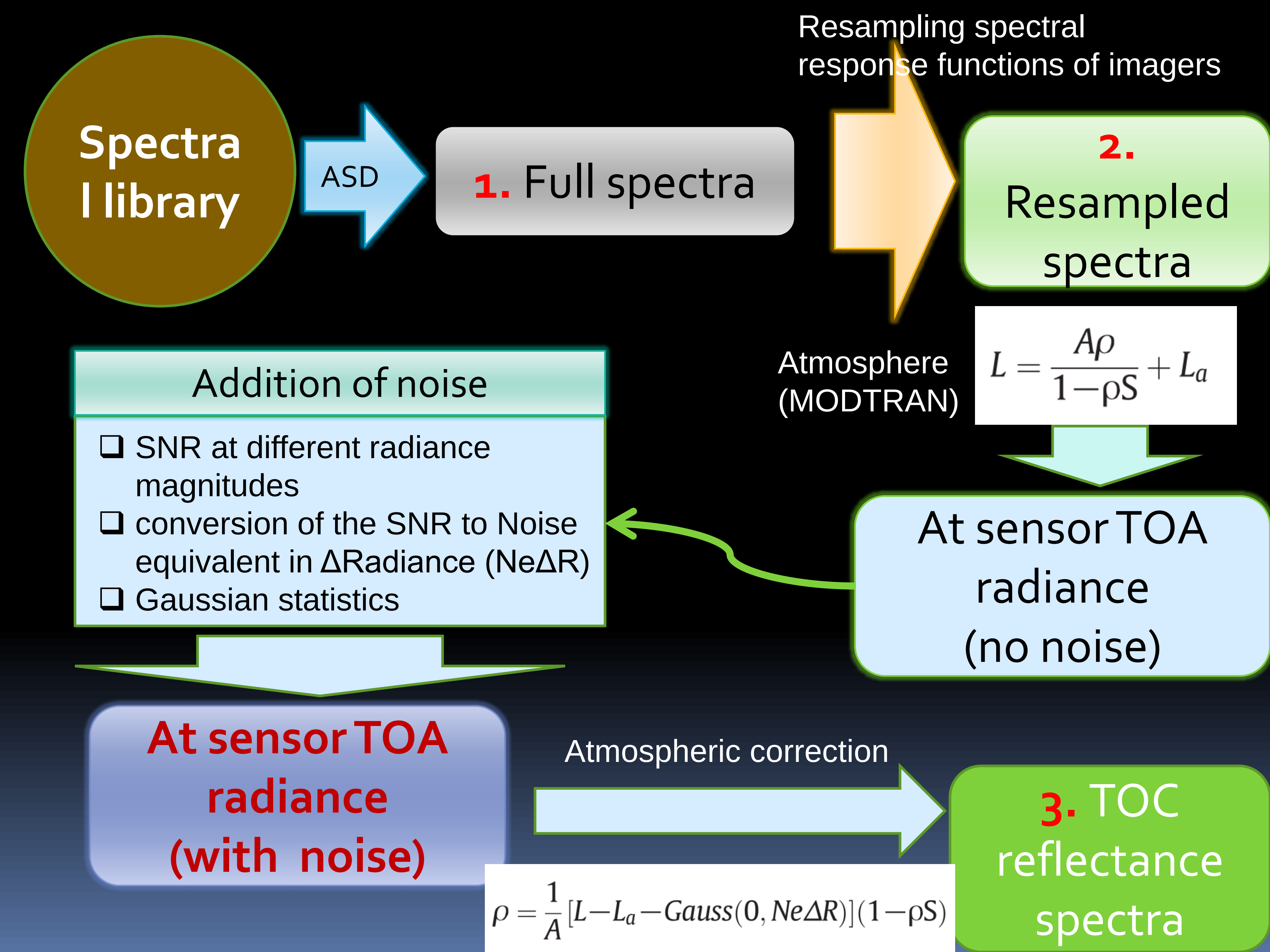
Spectral libraries

Library	Soil variable	n	Min	Max	Mean	sd	CV	Skewness	Transformation	Removed outliers
LUCAS_C	Clay / %	713	3	78	29.72	13.54	0.46	0.51	Sqrt	9
	Sand / %	713	1	92	26.18	18.59	0.71	1.08	Sqrt	20
	Silt / %	713	3	79	44.01	13.89	0.32	-0.23	None	1
	SOC / %	713	0.1	16	1.65	1.18	0.72	4.67	Sqrt	50
PONMAC	Clay / %	163	3.95	56.08	34.77	9.75	0.28	0.09	None	1
	Sand / %	163	15.01	60.59	36.84	9.73	0.26	0.33	None	0
	Silt / %	163	8.42	63.93	28.38	9.41	0.33	0.45	None	1
	SOC / %	166	0.55	2.32	1.25	0.46	0.37	0.64	Log	0

Soil samples were placed in Petri dishes and their spectral signatures were measured in a dark lab in the visible-near infrared (VNIR) to SWIR optical domain (350-2500 nm, spectral sampling of 1 nm) using an ASD Field Spec Fr Pro spectroradiometer

Main technical characteristics of the imagers considered in this study

Imager	Spectral bands	Spectral range	FWHM (nm)	SNR	SNR condition
EO-1 ALI	7	4 VNIR 3 SWIR	20-200	572 @550 nm 1040 @1550 nm 912 @2080 nm	17,08 mW/cm^2 sr µm 2,15 mW/cm^2 sr µm 0,68 mW/cm^2 sr µm
LANDSAT 8 OLI	7	5 VNIR 2 SWIR	20-200	100 @562 nm 100 @1610 nm 100 @2200 nm	30 W/m^2 sr µm 4,0 W/m^2 sr µm 1,7 W/m^2 sr µm
Sentinel-2 MSI	12	9 VNIR 3 SWIR	10-60	168 @560 nm 100 @1610 nm 100 @2190 nm	128 W/m^2 sr µm 4,0 W/m^2 sr µm 1,5 W/m^2 sr µm
Hyperion	220	400-2500	10	161 @550 nm 147 @700 nm 110 @1125 nm 40 @2125 nm	nadir looking 60° sun-zenith angle 0.3 earth albedo
EnMAP	242	420-2450	10	> 500 @495 nm > 150 @2200 nm	nadir looking 30° sun-zenith angle 0.3 earth albedo
PRISMA	247	400-2500	7÷11	600 @ 0.65 µm > 400 @ 1.55 µm > 200 @ 2.1 µm	nadir looking 30° sun-zenith angle 0.3 earth albedo
HyspIRI	214	380-2510	10	560 @500 nm 356 @1500nm 236 @2200 nm	nadir looking 23,5° sun-zenith angle 0.25 earth albedo


Spectra l library
ASD
1. Full spectra
Resampling spectral response functions of imagers
2. Resampled spectra
Atmosphere (MODTRAN)
$L = \frac{A\rho}{1-\rho S} + L_a$
Addition of noise
❑ SNR at different radiance magnitudes
❑ conversion of the SNR to Noise equivalent in ΔRadiance (NeΔR)
❑ Gaussian statistics
At sensor TOA radiance (no noise)
At sensor TOA radiance (with noise)
Atmospheric correction
$\rho = \frac{1}{A}[L - L_a - Gauss(0, Ne\Delta R)](1-\rho S)$
3. TOC reflectance spectra

Partial Least Squares Regression (PLSR)

- ✓ Pre-treatment: elimination of outliers (outside mean +/- 1.5 IQR) ; transformation of non normal soil data; removal of noisy bands falling into the absorption ranges of the atmospheric gases.
- ✓ estimate soil variables from three types of data: **(1)** full laboratory spectra **(2)** resampled spectra **(3)** simulated spectra including sensors' noise + atmospheric effects
- ✓ to detect main spectral regions that affect soil variables estimation, **variance importance in projection (VIP)** values are calculate. VIP = weighted sum of squares of the PLS weights.
- ✓ Multiple jack-knifing validation: 100 times random selection of calibration (70%) and validation (30%) sets
- ✓ statistics and ANOVA of 100 reps of RPIQ:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(y_o - y_p\right)^2}{n}}$$

$$RPD = \frac{sd}{RMSE}$$

$$RPIQ = \frac{IQ}{RMSE}$$

RPD>2	accurate models
RPD between 1.4 and 2	intermediate
RPD<1.4	no predictive ability

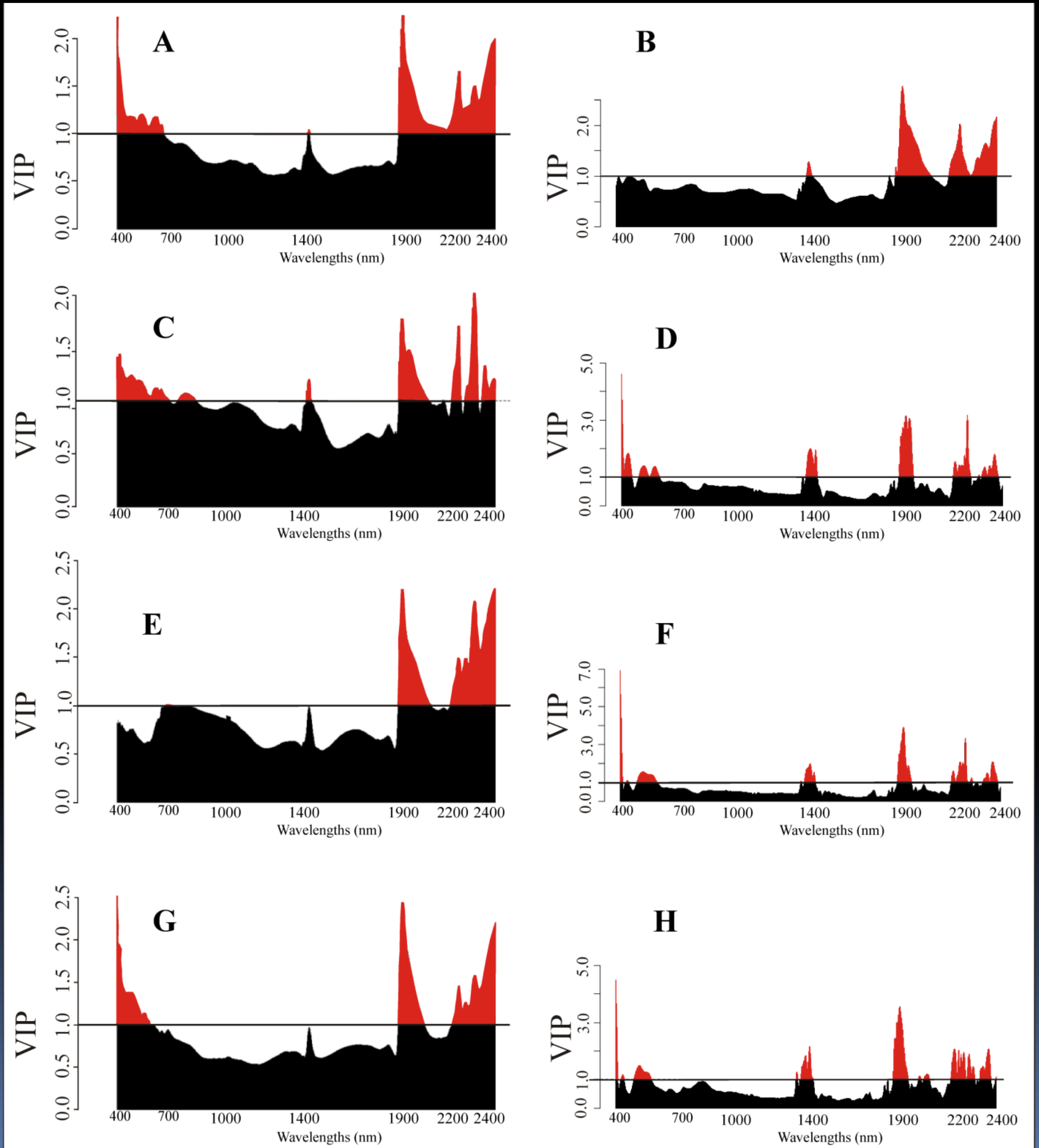
PONMAC LUCAS

CLAY

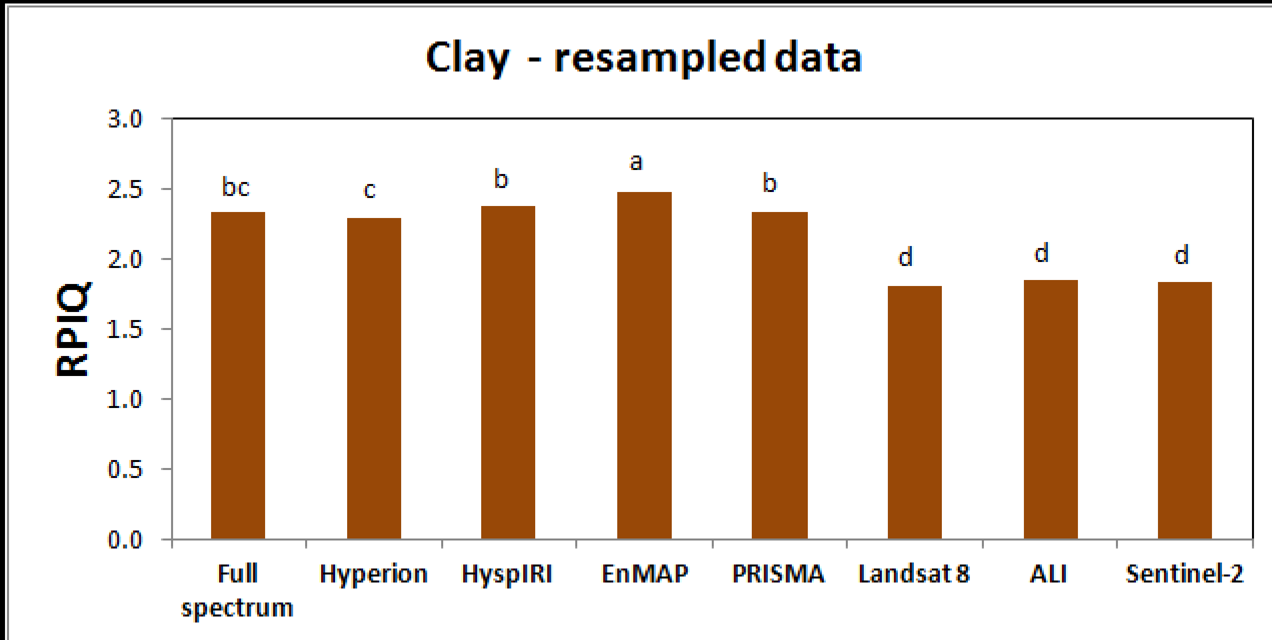
SAND

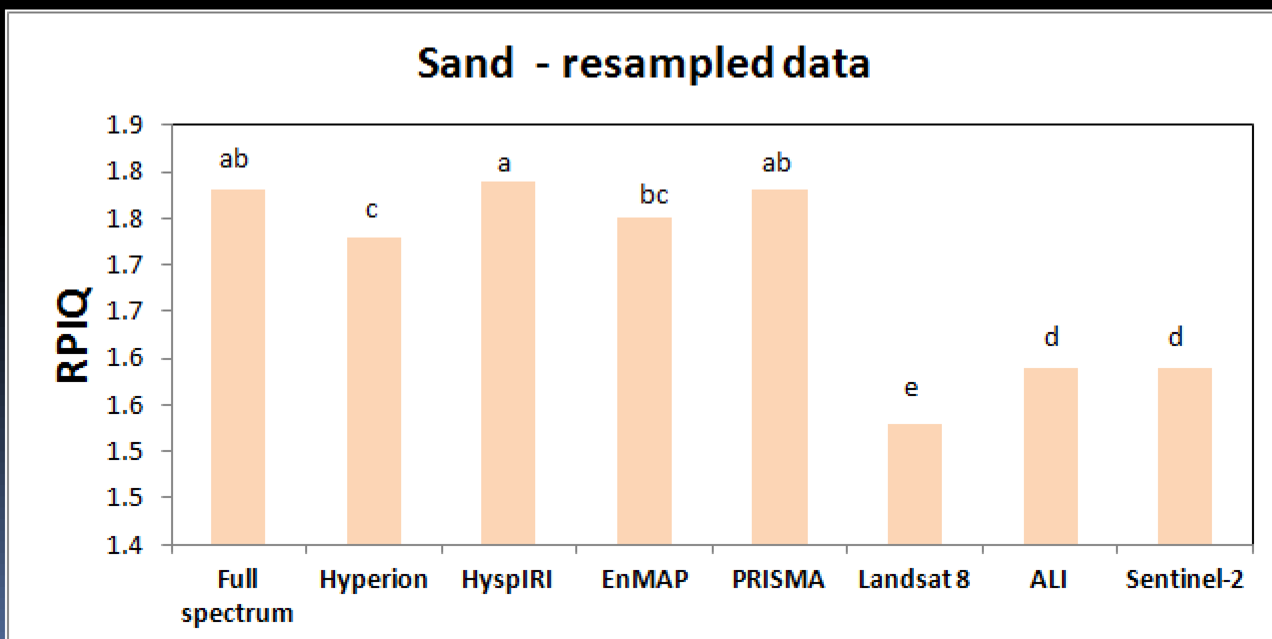
SILT

SOC



LUCAS Spectral library





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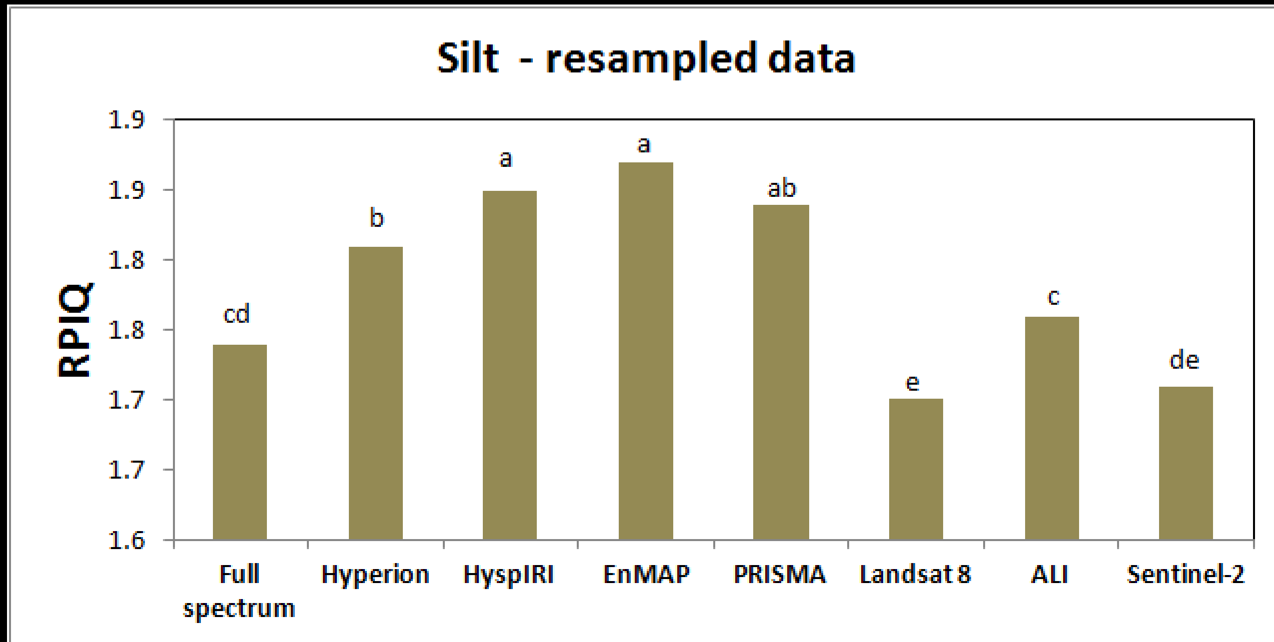
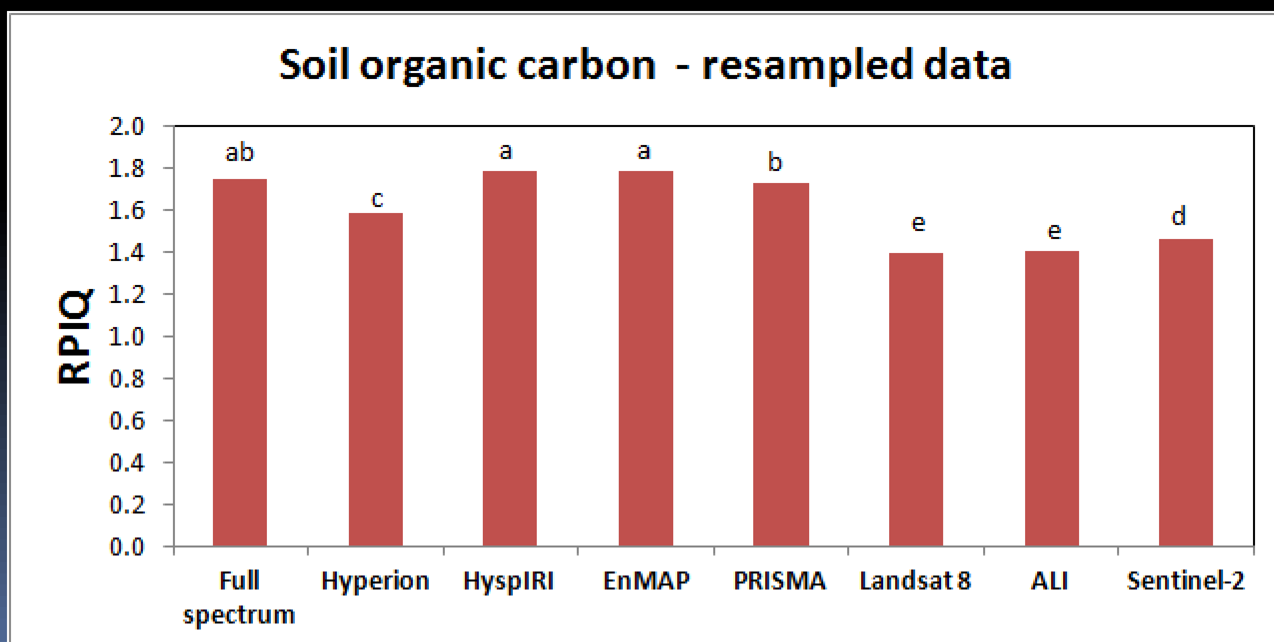
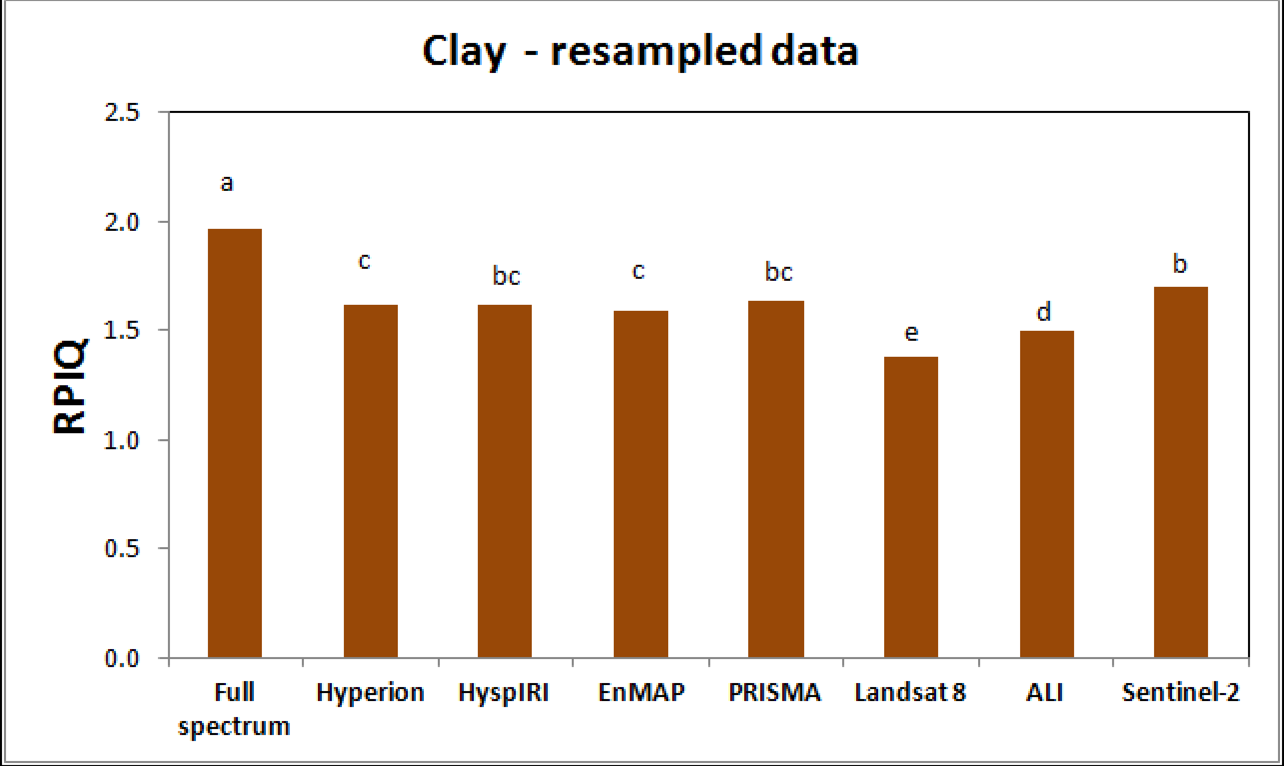
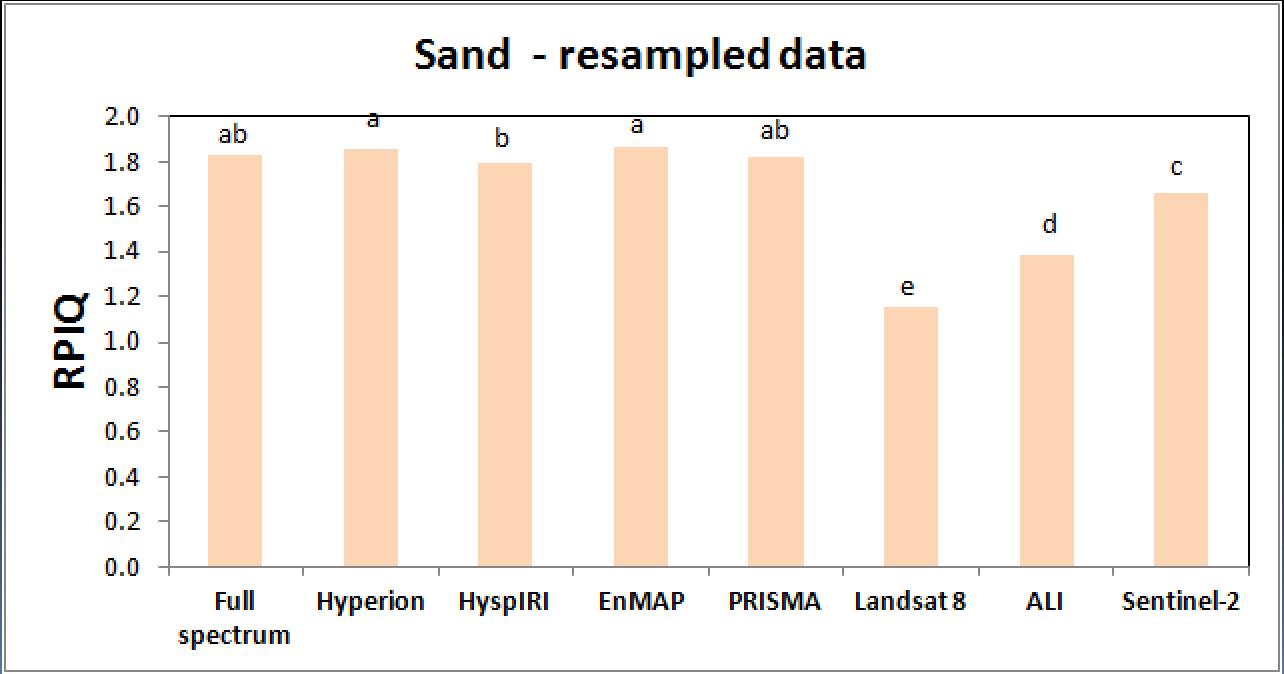




PONMAC Spectral library





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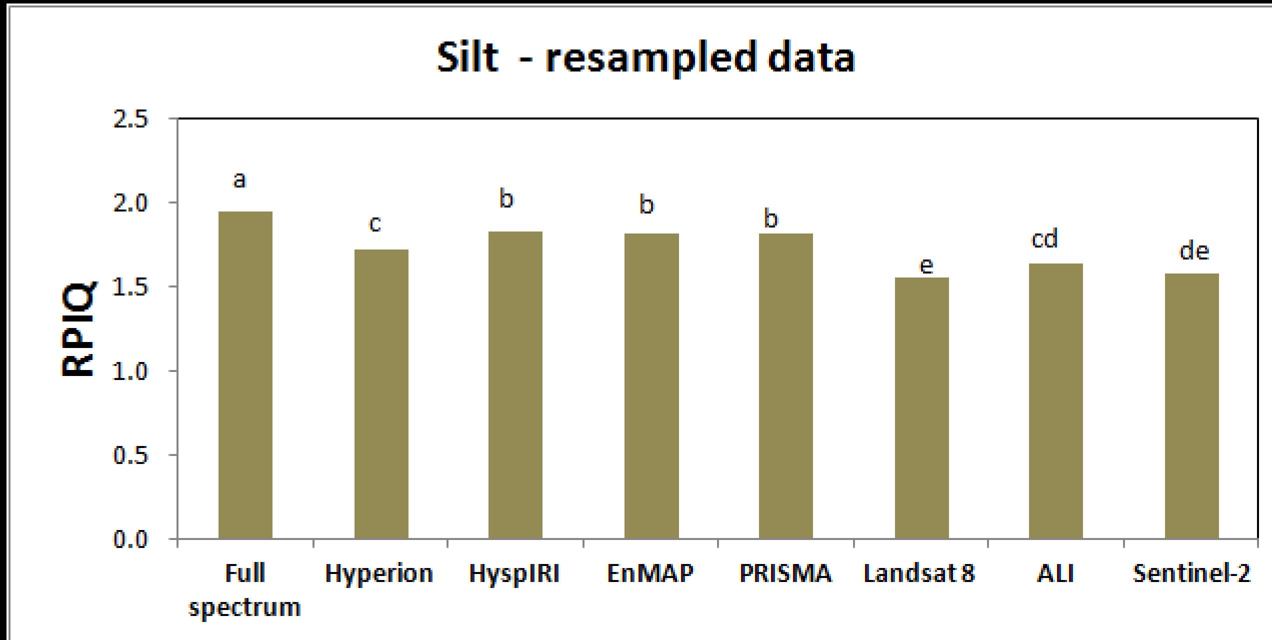

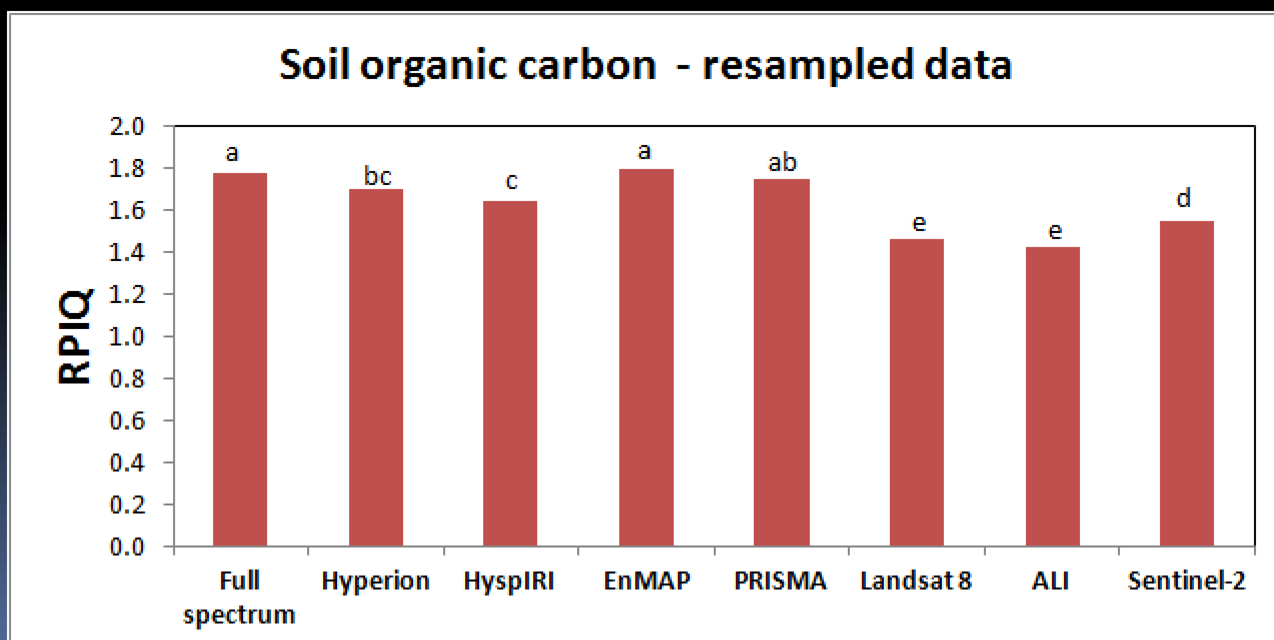

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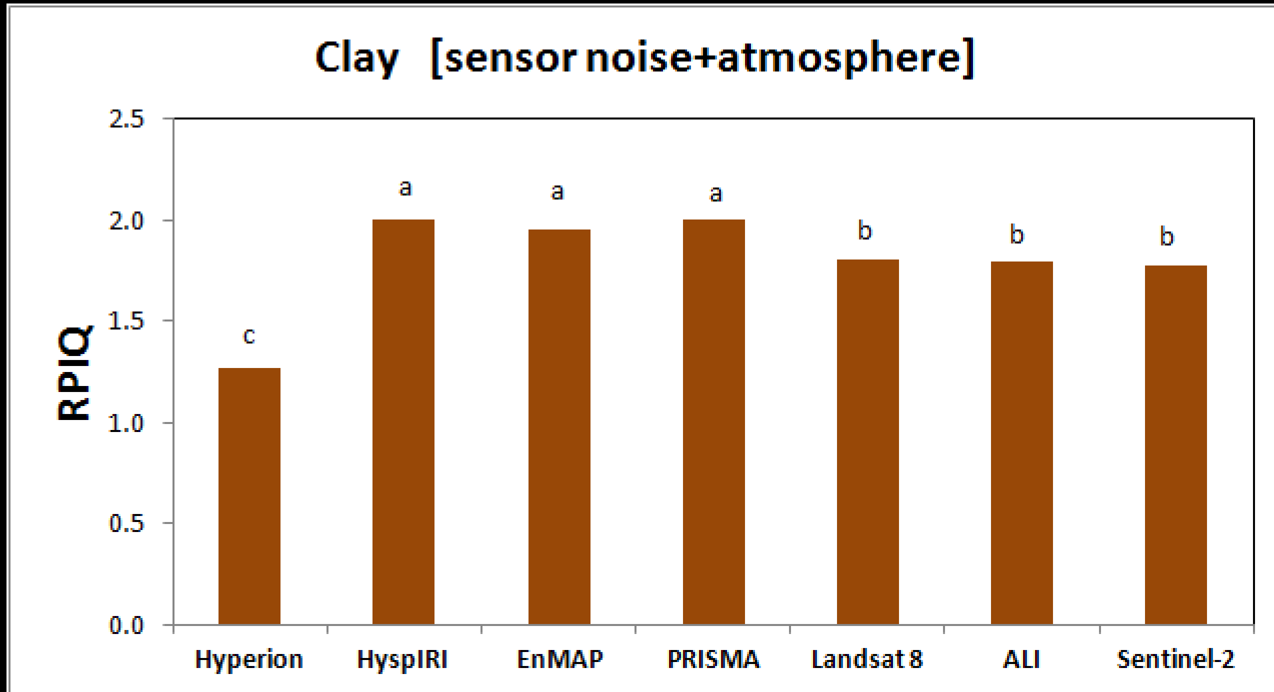

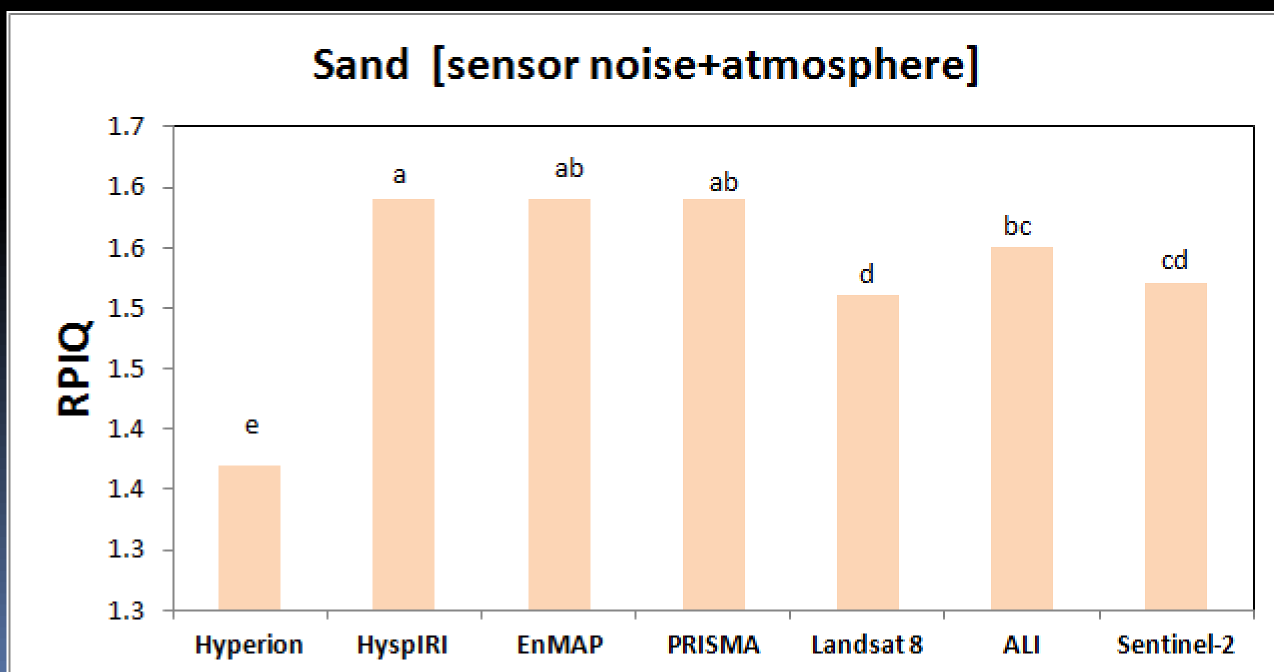

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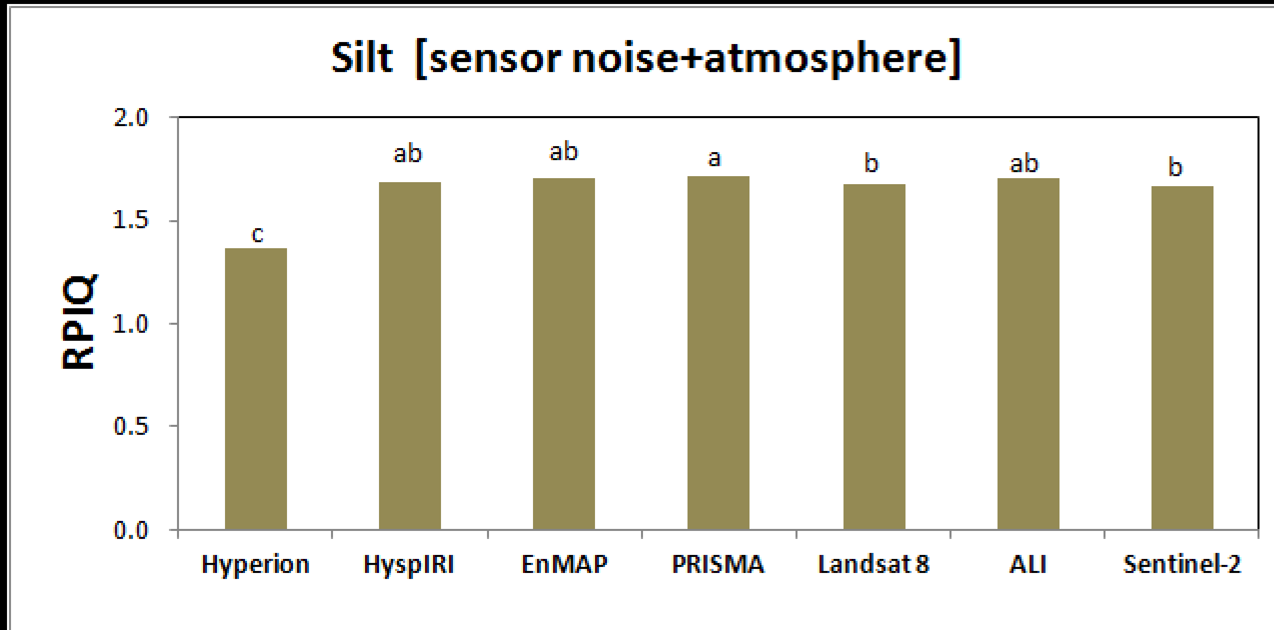

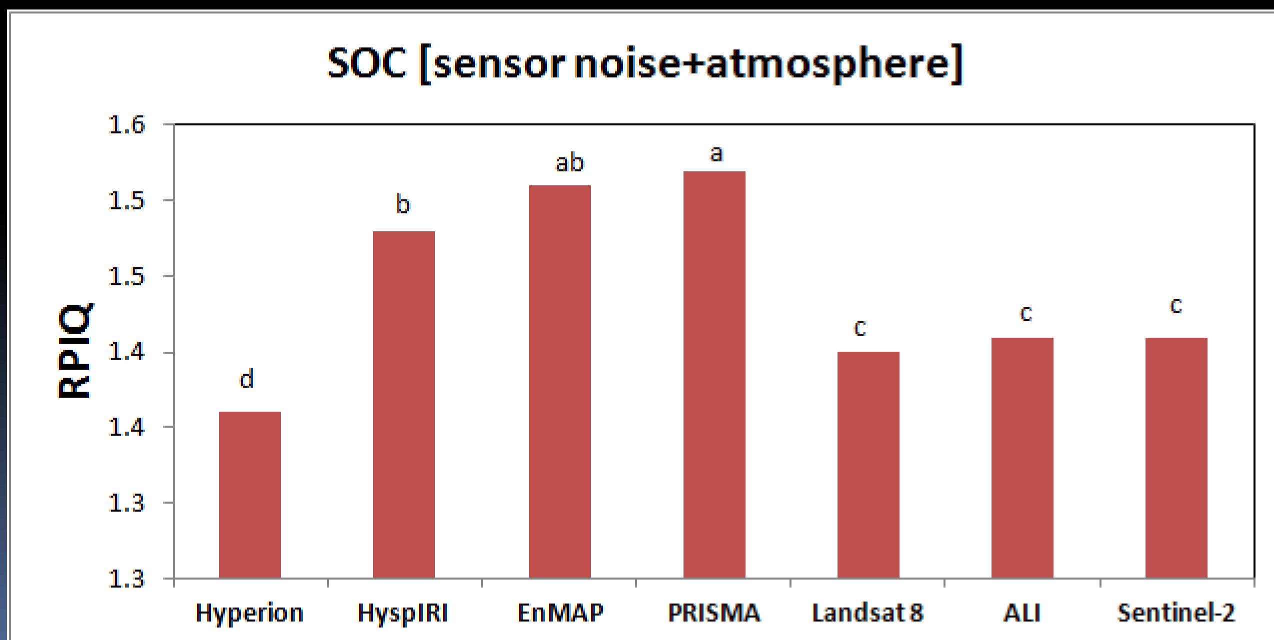

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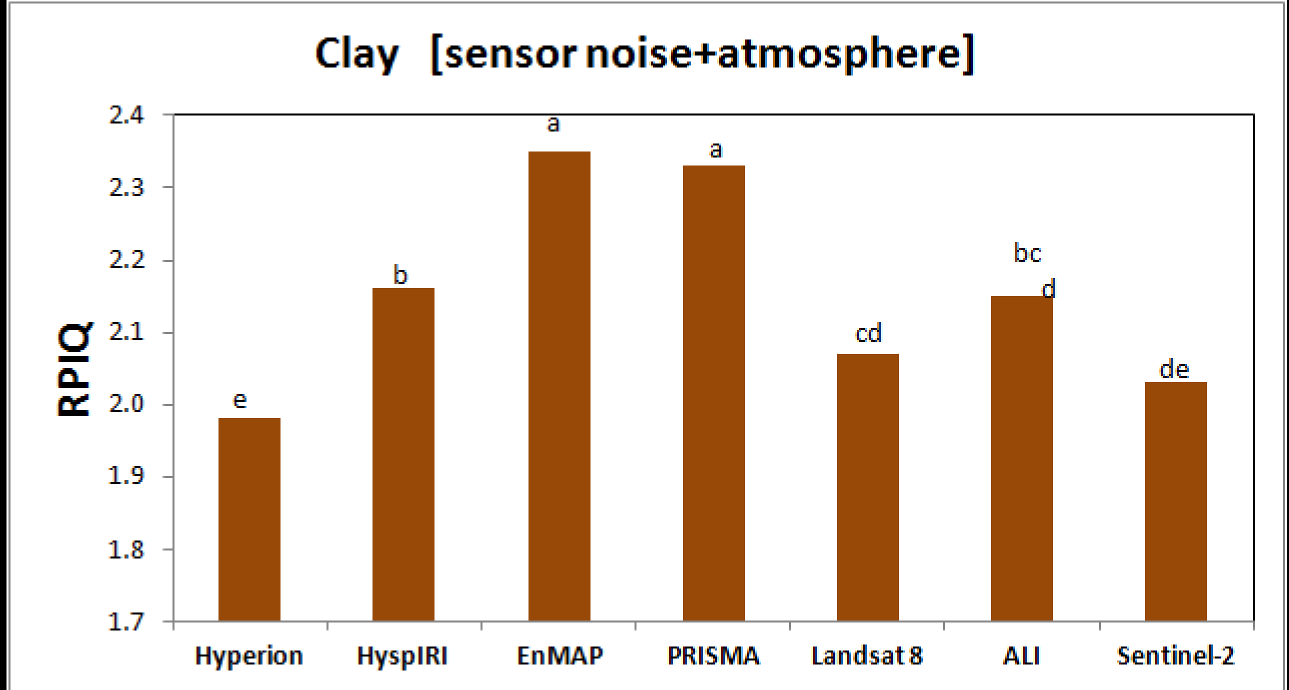

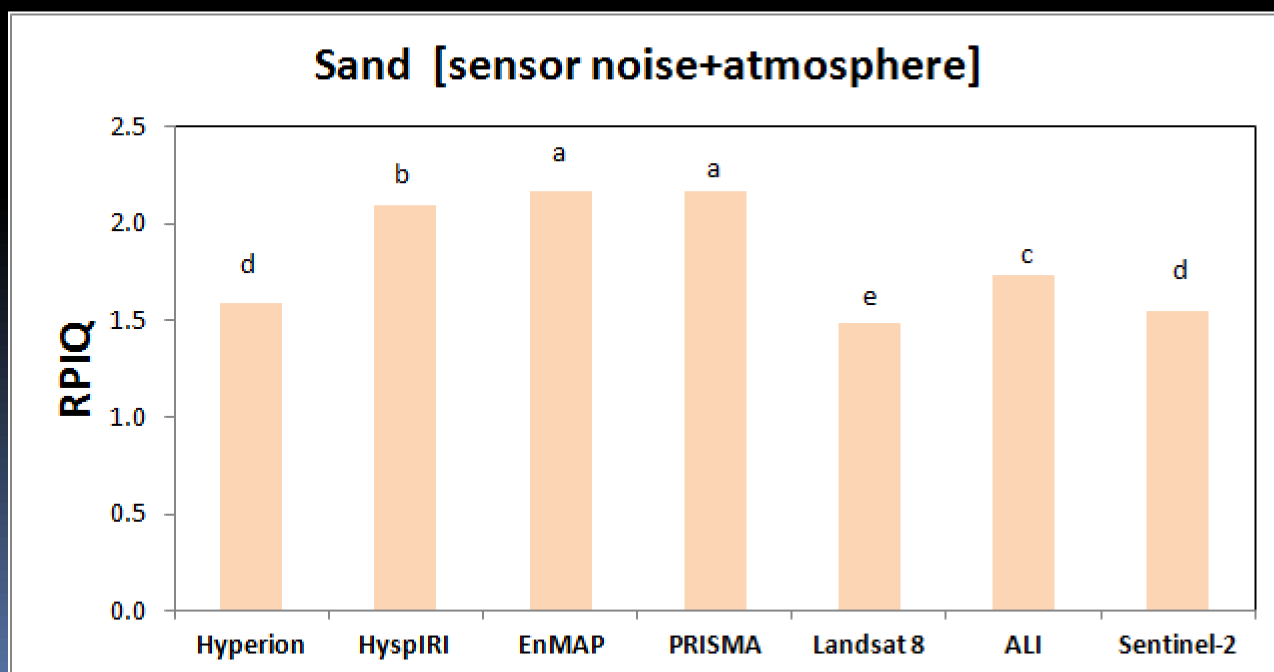

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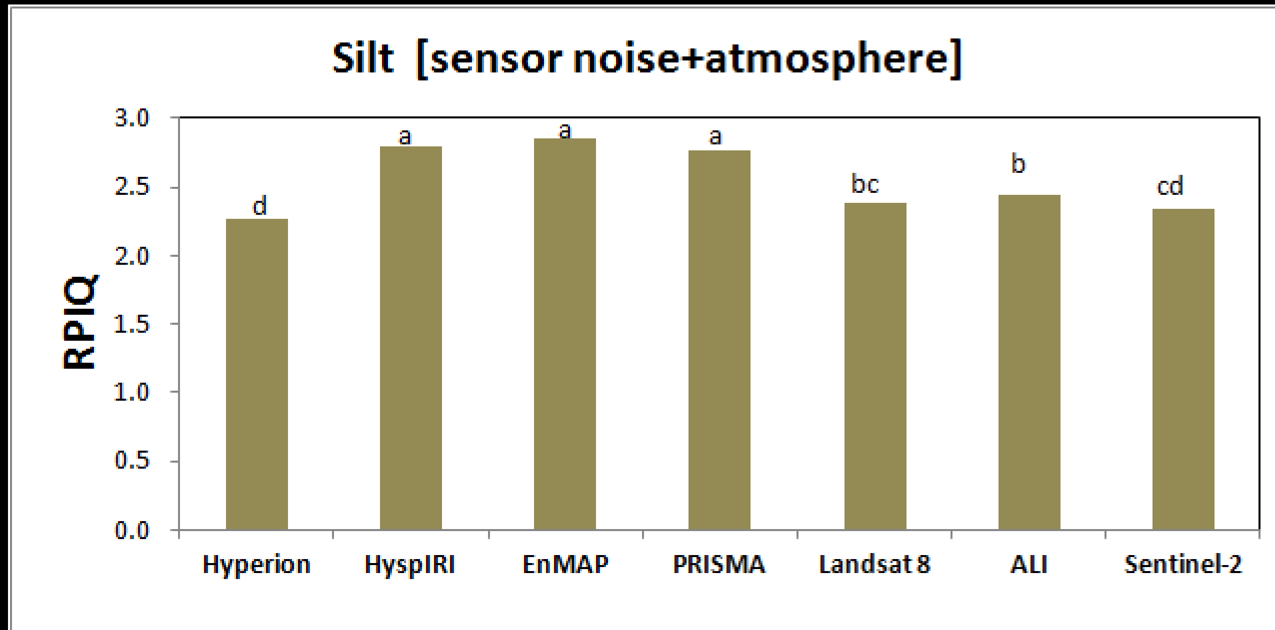
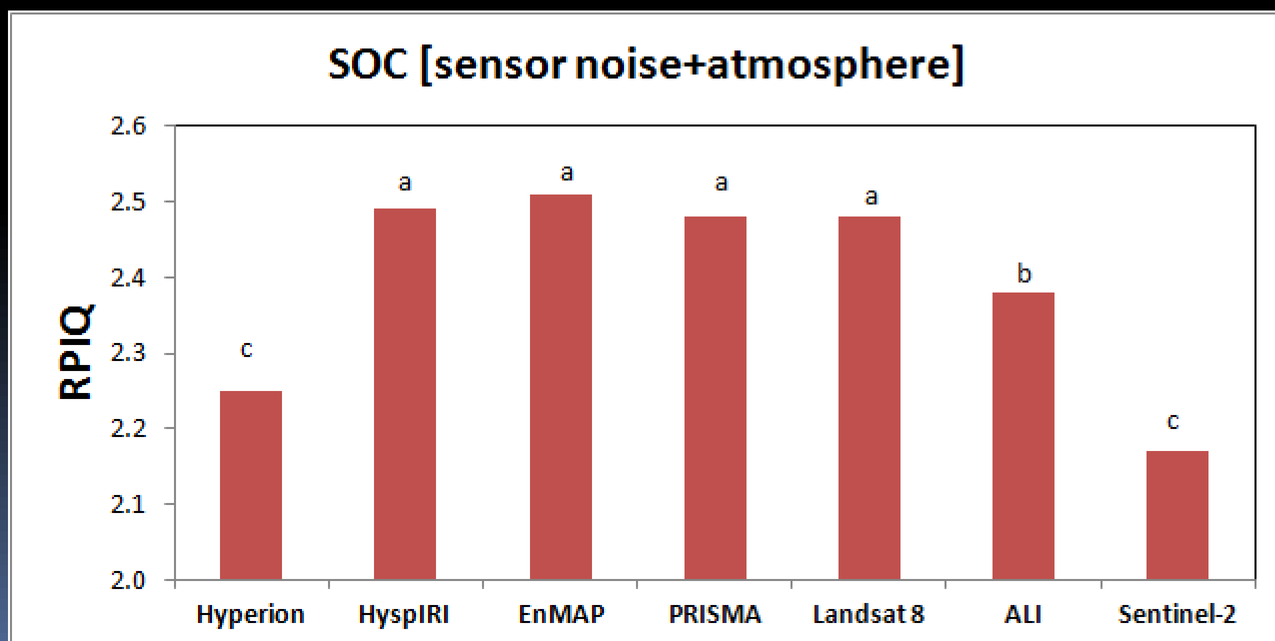




Issues when moving to real data

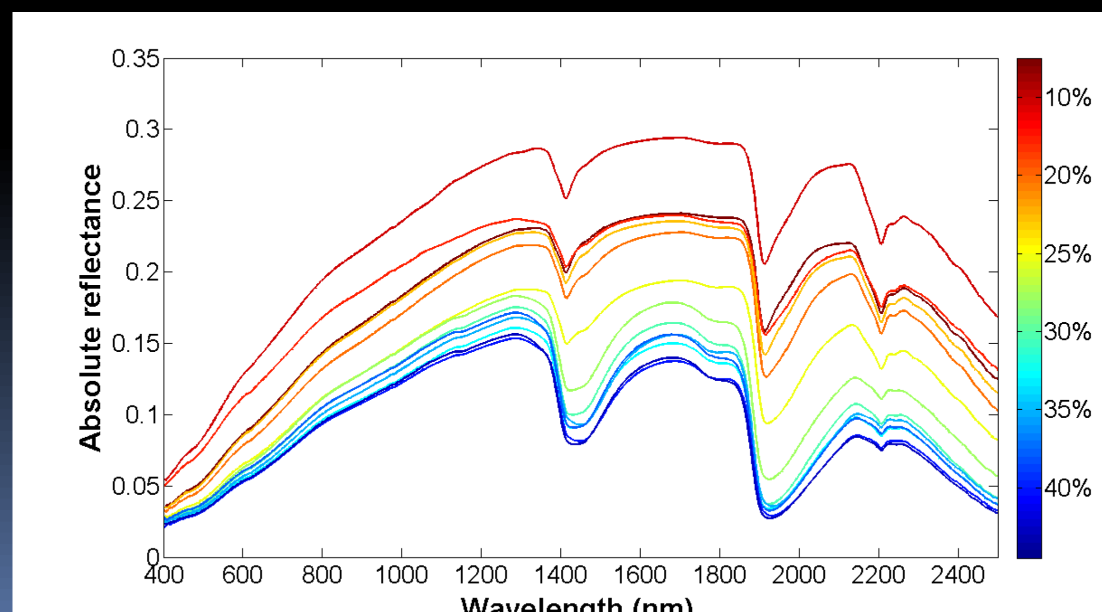
Satellite imaging spectroscopy

- **Multivariate or hybrid techniques (e.g. PLSR or RK)**
- **Hyperspectral indices**

Model generalization ??

Obstacles : *spectral resolution, signal quality, geometric and atmospheric correction, availability of bare soil image, roughness, crop residues,* ***soil moisture****….*

Soil Moisture generally reduces the reflectance over the entire spectrum, but this decrease is not linear and its magnitude varies depending on the spectral region and the soil type.



CONCLUSIONS

- forthcoming hyperspectral imagers enhance the accuracy of soil variables estimation as compared to current generation sensors, with RMSE between 5.2 and 6.7% for texture, 0.25 for SOC
- advancement of the new generation hyperspectral imagers (e.g. as compared to Hyperion), due to the improvement of the SNR in the SWIR region (especially 2000-2400 nm)
- EnMAP, PRISMA and HyspIRI imagers provided significantly better estimation accuracy than ALI, Landsat 8 and Sentinel-2
- improvement is mainly due to a higher spectral resolution coupled to a better SNR
- satisfactory quantitative estimation results from hyperspectral imagers is still hampered by a too low SNR in the SWIR spectral region

Castaldi, F., Palombo, A., Santini, F., Pascucci, S., Pignatti, S., Casa, R.., 2016. Evaluation of the potential of the current and forthcoming multispectral and hyperspectral imagers to estimate soil texture and organic carbon. Remote Sensing of Environment, 179, 54-65.