Seagrass mapping and monitoring along the coast of Crete, Greece

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MSc Thesis Defense

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Introduction

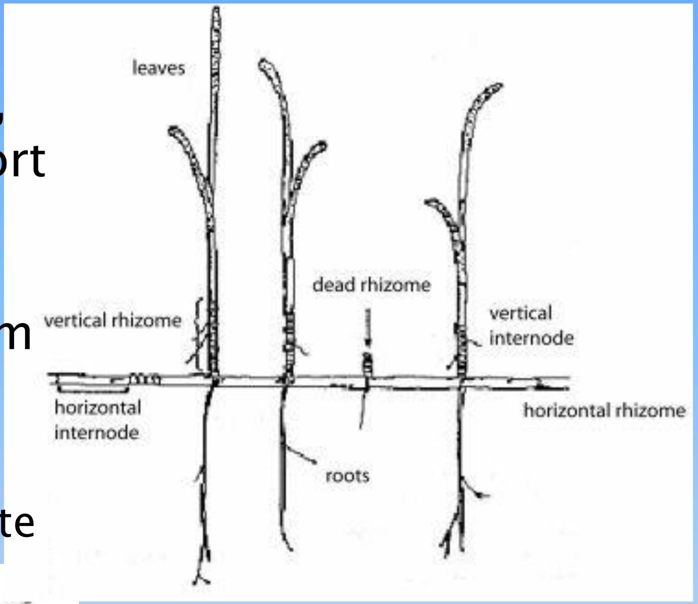
- Seagrasses – a unique group of aquatic plants growing submerged in the sea water
- Seagrasses play vital role in the marine ecosystems of the world Ocean (e.g. basis of the food web)
- Seagrasses create unique, complex, extremely diversified and productive ecosystems in the littoral coastal zones (0–50 meters) all over the world
- Globally, there are 58 recognized and described seagrass species
- In this work we focused on seagrass *P.oceanica*, an endemic species of the Mediterranean Sea
- The purpose of current study was to apply methods of remote sensing for mapping of seagrass *P.oceanica*

Research problem

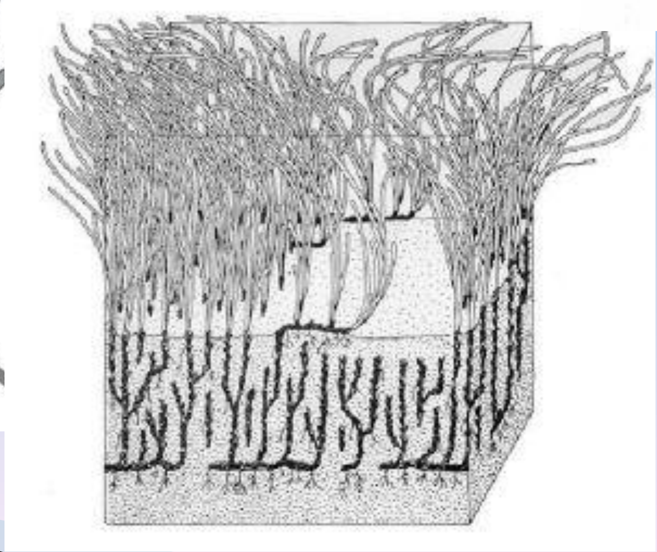
More than 50 % of the world population lives within one km of the coast, which results in continued anthropogenic pressure on the coastal regions.
Mapping and environmental assessment of coastal resources become increasingly important nowadays and is necessary for monitoring of the shelf zones
This research is a contribution to the development of the methodology of seagrass mapping which aims on the environmental monitoring.
The case study of this work is *P.oceanica* seagrass, an endemic Mediterranean seagrass species, dominating in marine landscapes and ecosystems along the coasts of Crete Island.

Most important facts about *P.oceanica*

P.Oceanica consists of long, 5-12 mm broad, hairy-like leaves, 3-4 mm thick roots and short rhizomes (0.5-2.0 mm).
The leaves of *P.oceanica* have length of 20-40 cm, in some cases they can reach up to 1 m



Growing *P.oceanica* make meadows which consist of smaller patches, called matte

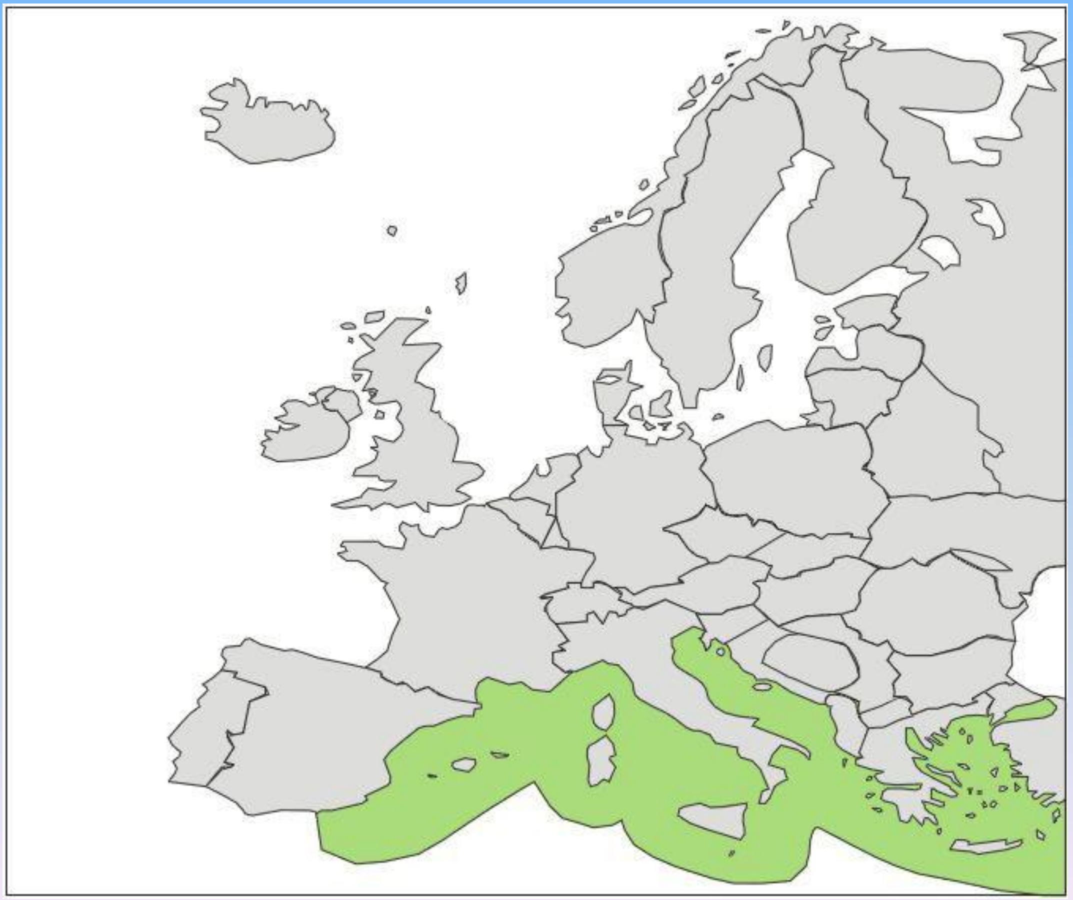


P.Oceanica creates one of the most productive Mediterranean ecosystems,
usually serves as a perfect biological indicator for the assessment of quality of water and environment

Geographic location of *P.oceanica*

P.oceanica is...

- Endemic species of the Mediterranean Sea
- Main species in the marine coastal Environment of Greece
- Creates dominant and most productive coastal ecosystem of the Mediterranean Sea



Distribution of *P.oceanica* is limited by the western part of the Mediterranean Sea, where cold Atlantic waters enter Gibraltar (as on picture)

Goal & general research objective

The main **goal** of this study is to analyse optical properties of the seagrass *P.oceanica* and other seafloor types (carbonate sand), and to apply remote sensing techniques for seagrass mapping in the selected locations of northern Crete

General objectives:
* Analysing spectral reflectance of the *P.oceanica* and other seafloor cover types by means of radiative transfer model tools (RTMs), using WASI.
* Mapping spatial distribution of the seagrass *P.oceanica* over selected locations along the northern coasts of Crete Island

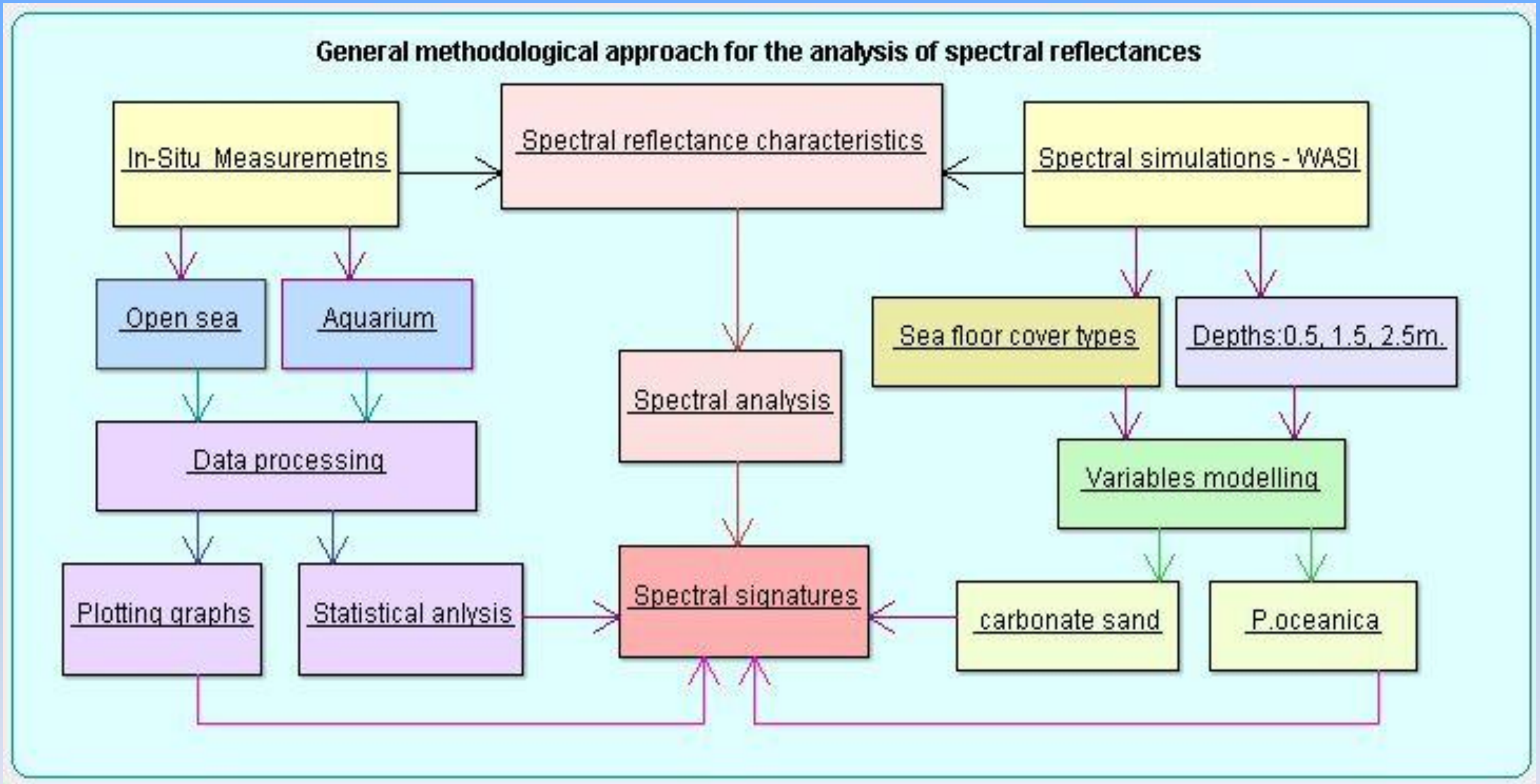
Specific objectives

1) To study narrow-band spectral reflectance properties of *P.oceanica* and other seafloor cover types (sand and silt) using WASI water colour simulation software
2) To use methods of the *in-situ* diving observations and underwater videometric measurements by Olympus ST camera in order to receive large-scale imagery of the *P.oceanica* mattes
3) To apply remote sensing data (Google Earth aerial images, Landsat scenes) for the monitoring of the seagrass meadows distribution
4) To perform images classification for the mapping of the *P.oceanica* distribution along the selected locations over the coasts of northern Crete.

Research questions

- Is *P.oceanica* spectrally distinct from carbonate sand with varying *in-situ* conditions ?
- Do broadband and hyperspectral sensors provide enough radiometric information for spectral discrimination of seagrass, and therefore, can be used for mapping of *P.oceanica* ?

Research Approach



Seagrass global monitoring: history and perspectives

- The methodology of the current work was guided by various reports and guidelines published by scientific organisation focusing on seagrass research, such as following.

- Global-scaled: *Global Seagrass Monitoring Network* and the *World Seagrass Association*;
- The *World Atlas of Seagrasses* is published by the UNEP.
- Australian *Seagrasswatch*
- European: the *Mediterranean association Seagrass-2000*, the *Mediterranean Institute for Advanced Studies* and *Seagrasses.org*
- US American seagrass recovery campaign by the *Seagrassgrow*, *Seagrass Ecosystems Research Laboratory*
- in South Florida*, Seagrass.LI* and *Florida Seagrass* organisation;
- Asian: *UNEP/GEF South China Sea Project*, *Marine Conservation Cambodia* and *Sosmalaysia.org*.

Application of the remote sensing towards seagrass mapping

Various methods and approaches have been applied towards studies of seagrass P.*oceanica,* based on following data:

- aerial Google Earth photographs,
- iPAQ data and GPS records
- non-destructive SCUBA based fieldwork sampling and seagrass observations
- videometric footage by means of Olympus waterproof camera
- multispectral imagery

Remote sensing techniques offer clear advantages for seagrass monitoring due to their following characteristics:

- ❖ weather-independence,
- ❖ cost-effectiveness,
- ❖ accuracy and
- ❖ spatial coverage

which enable periodic monitoring of the seagrass meadows and give access to the distant and unapproachable areas.

Measuring optical properties of benthic vegetation (continue)

- The optical properties of the sea water vary with different environmental conditions
- Optical properties (e.g. spectral reflectance, radiance, irradiance) reflect current chemical content and physical specifics of the water
- Shallow waters generally contain more dissolved substances and suspended particles
- Radiative Transfer Models (RTM) are used for simulation and study of optical properties;
- In current work we used WASI Water Colour Simulator

Measuring optical properties of benthic vegetation

Hyperspectral radiometers are used for measuring optical water and seafloor properties in *in-situ* conditions during the fieldwork

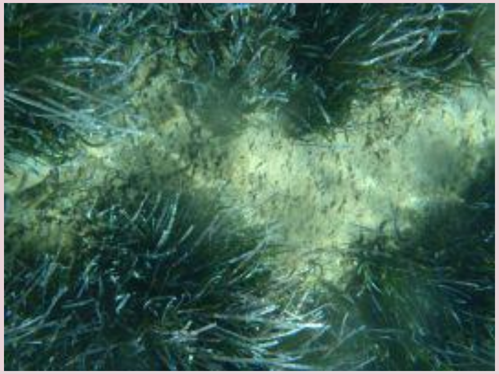
Trios-RAMSES-ARC – Hyperspectral UVVIS Radiance Sensor: 320-950 nm

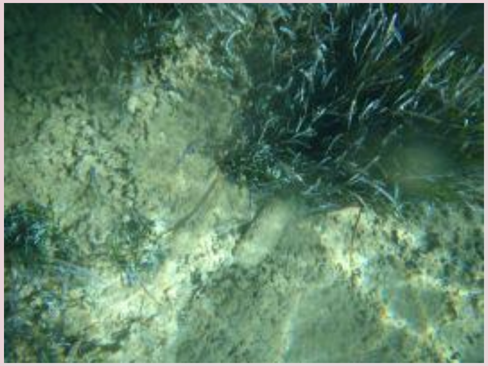
Trios-RAMSES-ACC-UV – Hyperspectral UVA/UVB Irradiance Sensor: 280-500 nm

In-situ observations of the seagrass

The method of *in-situ* seagrass sampling has been based on the standard scheme:

1. The seagrass is being sampled on the selected sites using transect lines, quadrant frame, single point markers, SCUBA gear diving equipment.
2. The geographic coordinates of measurement path are taken by means of GPS and iPAQ, from where data are stored in GIS in laptop.
3. The seagrass sampling is taken on the regular way to cover the research area





Materials

The research data include following materials:

✓ *Google Earth* **aerial images** and scenes from the *Landsat TM ETM+.* The imagery provides information of the recent distribution of *P.oceanica* within the coastal areas

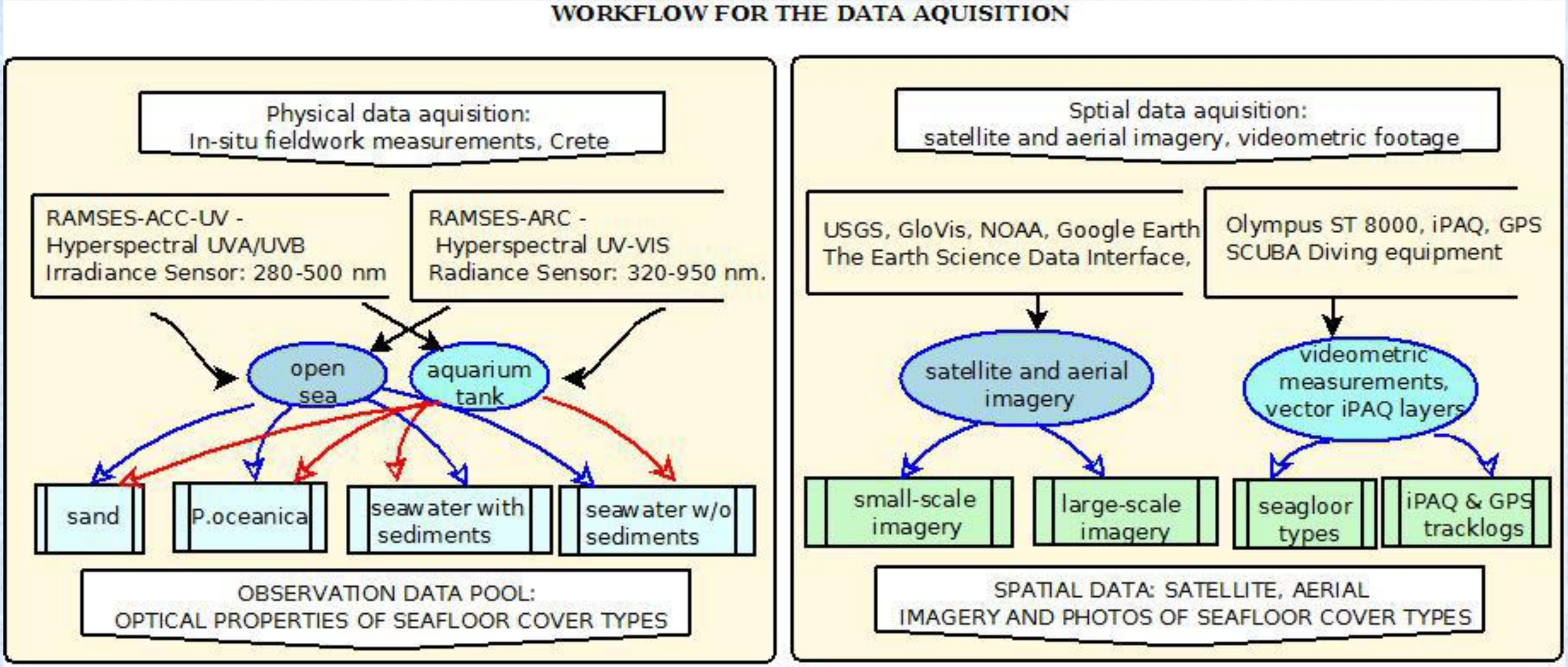
✓ Sampling of the *in-situ* **measurements** of the seagrass distribution. Sampling stations were located in northern coasts of Crete (Ligaria beach), as northern Crete is well suitable for the seagrass *P.oceanica* growth due to the favourable climatic (annual mean water tº C) and geological seafloor factors, i.e. substrate conditions and sediments.

✓ The **fieldwork** has been carried out during the September-October period 2010

✓ The results of the **videographic measurements** are used for the seafloor types detection, because seafloor types can be well distinguished and classified according to their optical characteristics

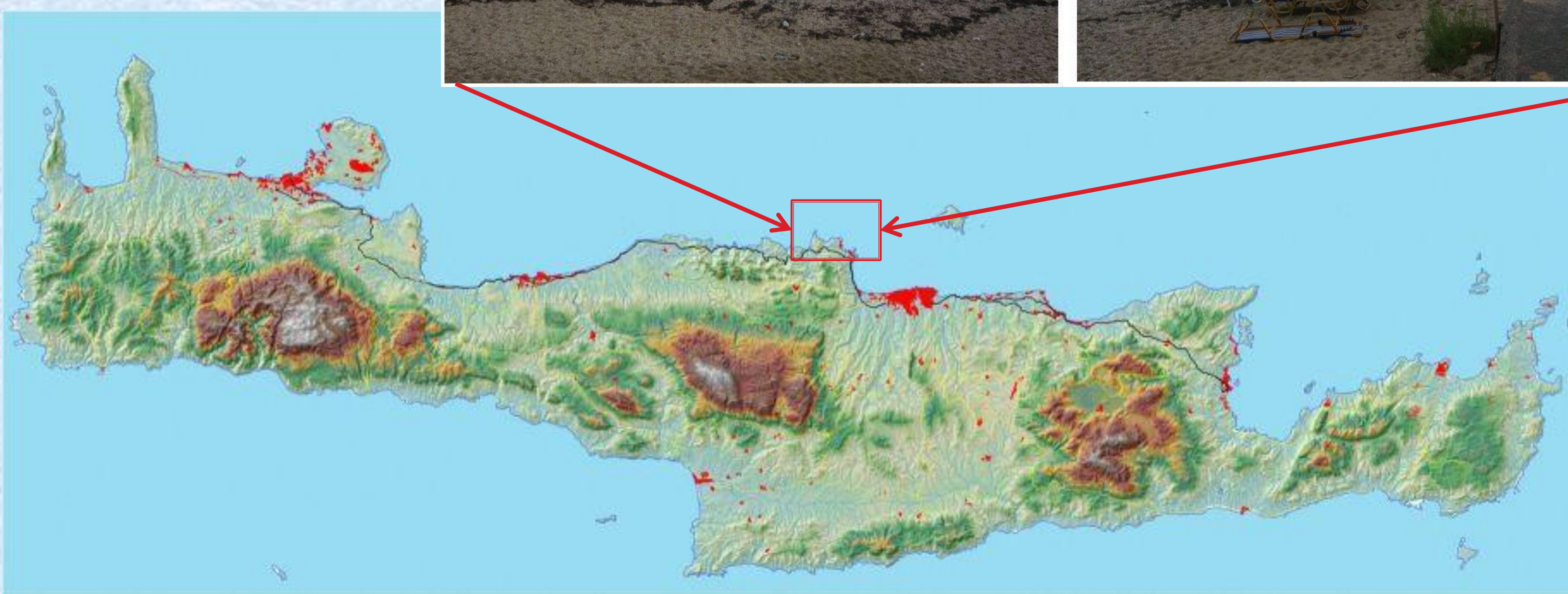
✓ The **optical measurements** of the irradiance and radiance of the sea water and bottom cover types of the seafloor have been received in 2009 by means of the optical sensors *Trios-RAMSES Hyperspectral UVA/UVB Irradiance* and *UV-VIS Radiance Sensors* by Ms. S. Noralez

Materials (continue): Flowchart for Data Capture

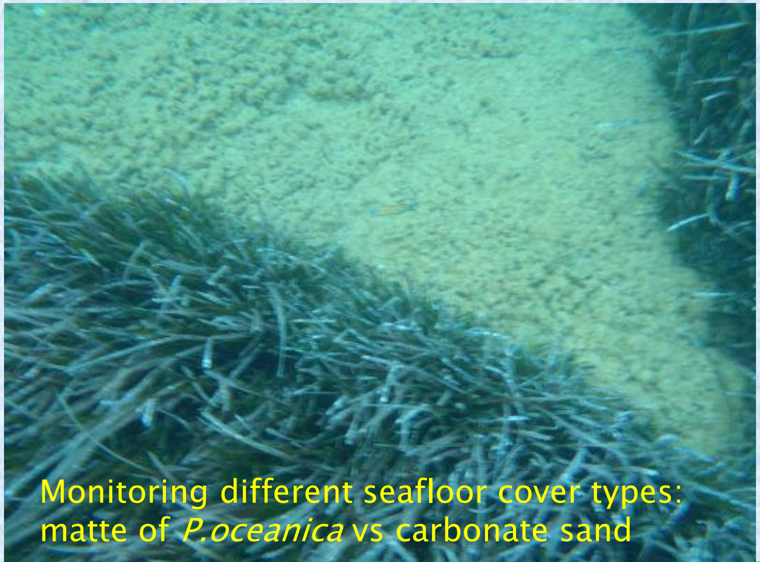


Fieldwork research area

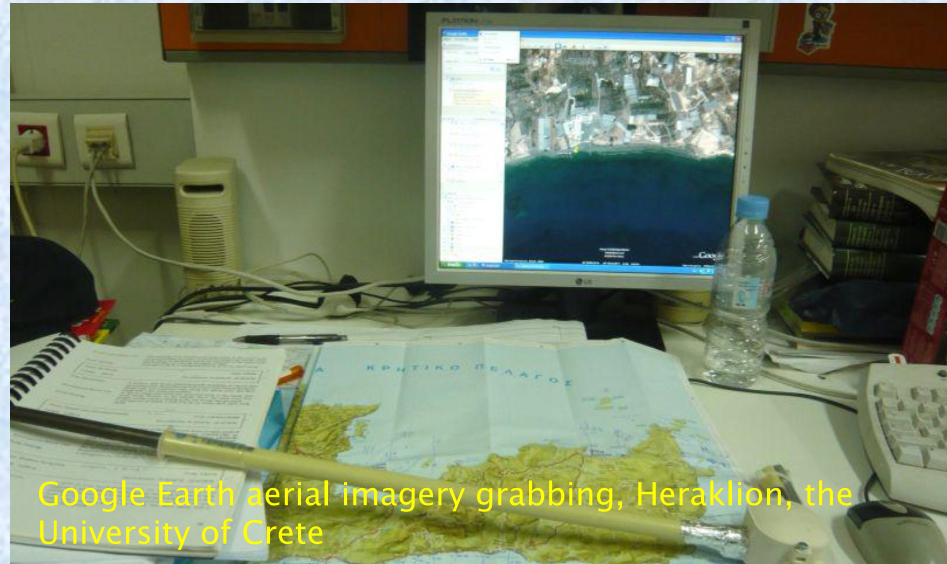
- Crete Island, Greece
- Ligaria Beach (36º20'N;22º59’E)
- Ligaria Beach – narrow, sandy and pebble beach



Fieldwork data collection

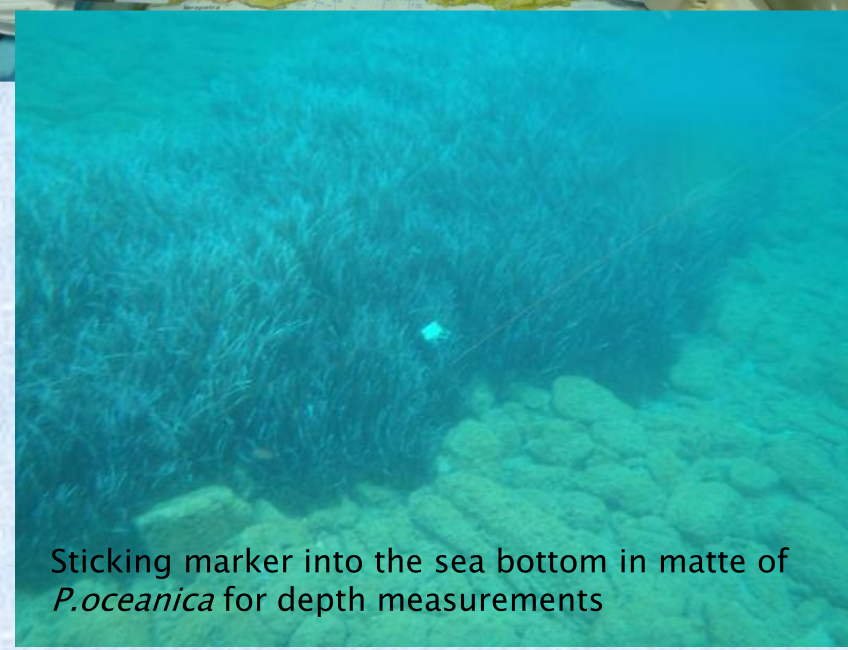


Monitoring different seafloor cover types: matte of *P.oceanica* vs carbonate sand



Google Earth aerial imagery grabbing, Heraklion, the University of Crete

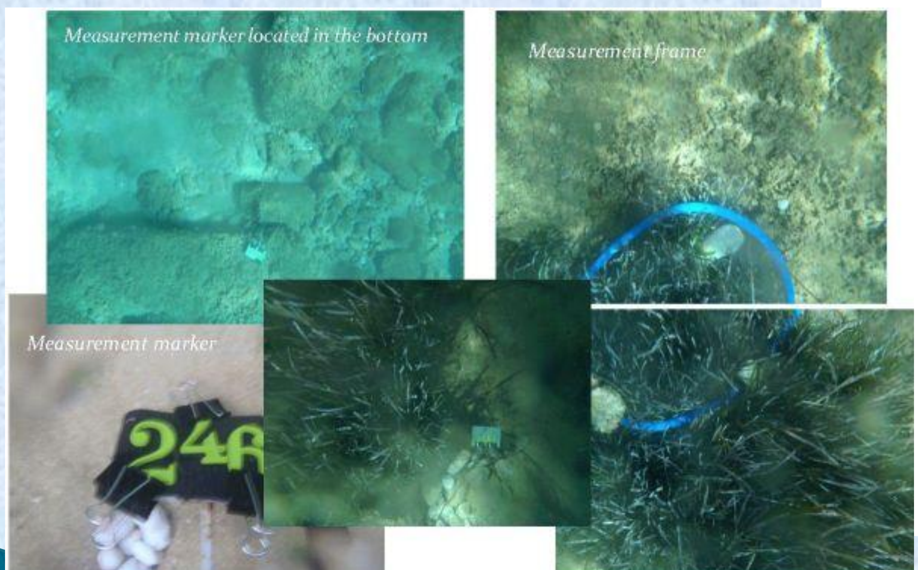
Placing the 0.5m circle and depth marker in the matte of *P.oceanica* for photo capture



Sticking marker into the sea bottom in matte of *P.oceanica* for depth measurements

Fieldwork equipment

1. Three iPAQs
2. Three GPS
3. Waterproof video cameras, Olympus ST 8000
4. Markers and cords for depths measurements



Fieldwork equipment

- Waterproof plastic Otterbox
- SCUBA diving equipment
- Boat

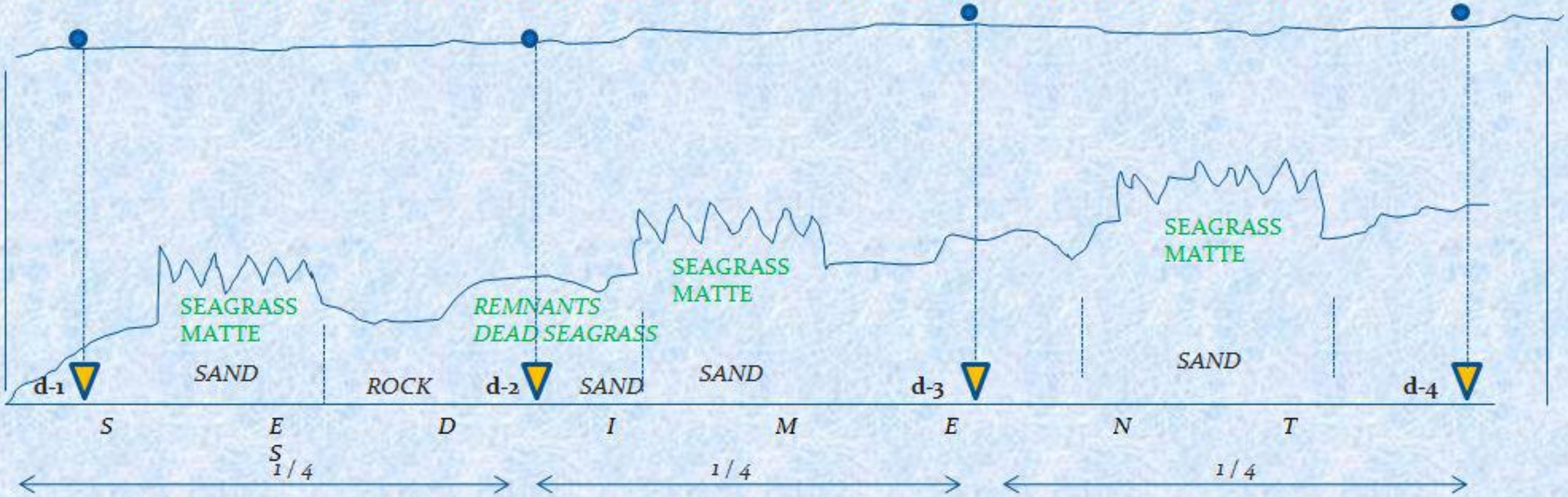
Sampling design

The sampling design of the fieldwork was aimed at surveying of the spatial distribution of the meadows of *P.oceanica* along northern coasts of Crete, at sampling place Ligaria beach

- The fieldwork included several routes of the boat in the Ligaria beach sampling site, in the directions parallel to the coastline, ca 180-200 m long each one
- The transect sampling method enables even and objective selection of sampling sites and covers area of growing seagrass

- The videometric measurements of the seafloor cover types were made using underwater video cameras *Olympus ST 8010*
- Transect sampling method, i.e. photographs were taken along the research path
- Camera were adjusted horizontally by a leveller and mounted under the bottom of the boat

SAMPLING DESIGN
DEPTHS MEASUREMENTS FOR THE SEAGRASS MONITORING



Scheme of the sampling design during the fieldwork.

▼ - *TRANSECT MARKER (d): 5 cm depth, 30 cm height*

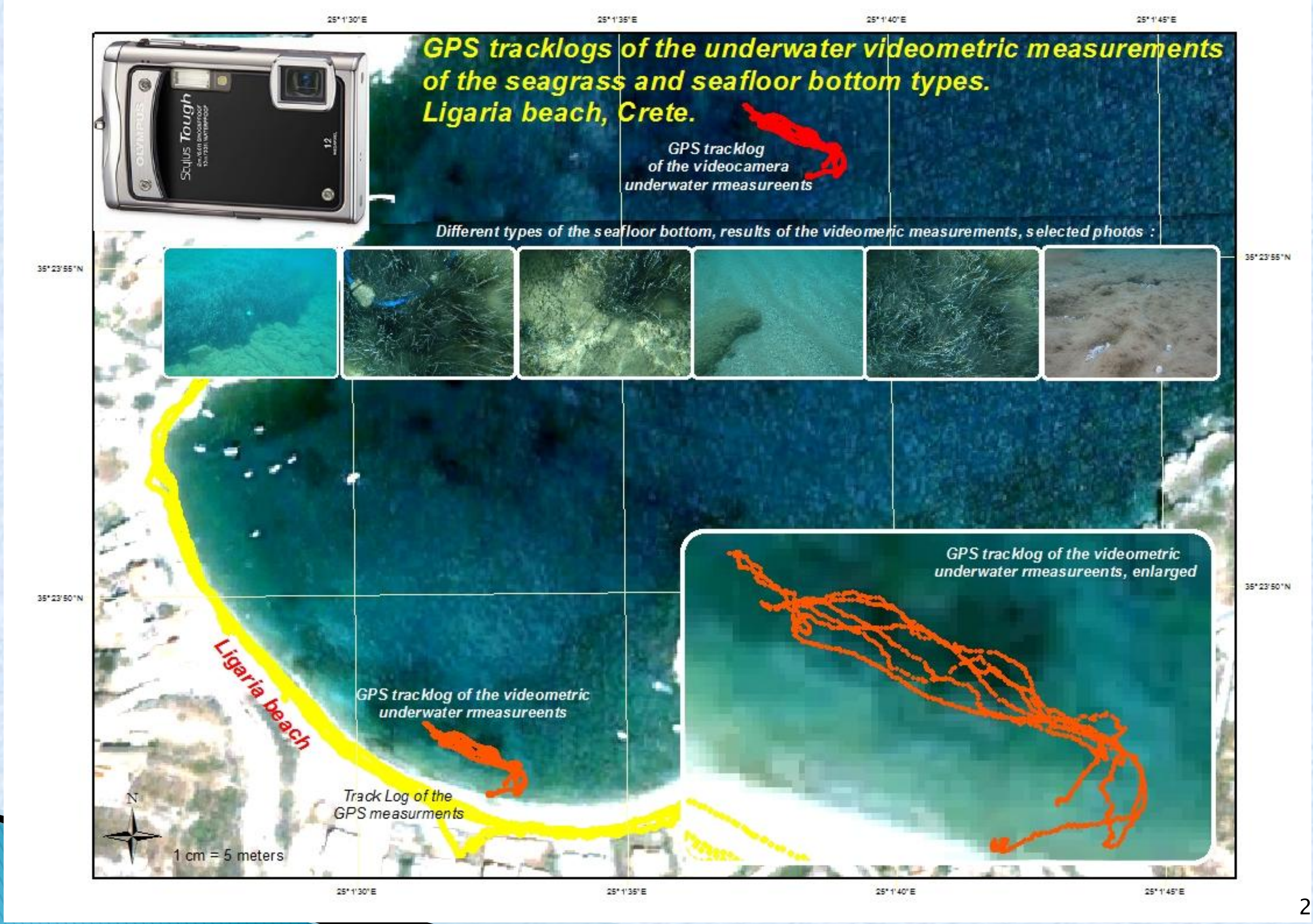
Using of markers:

1) Position of transect line
2) Depth of the sea floor
3) Depth of the marker (d)

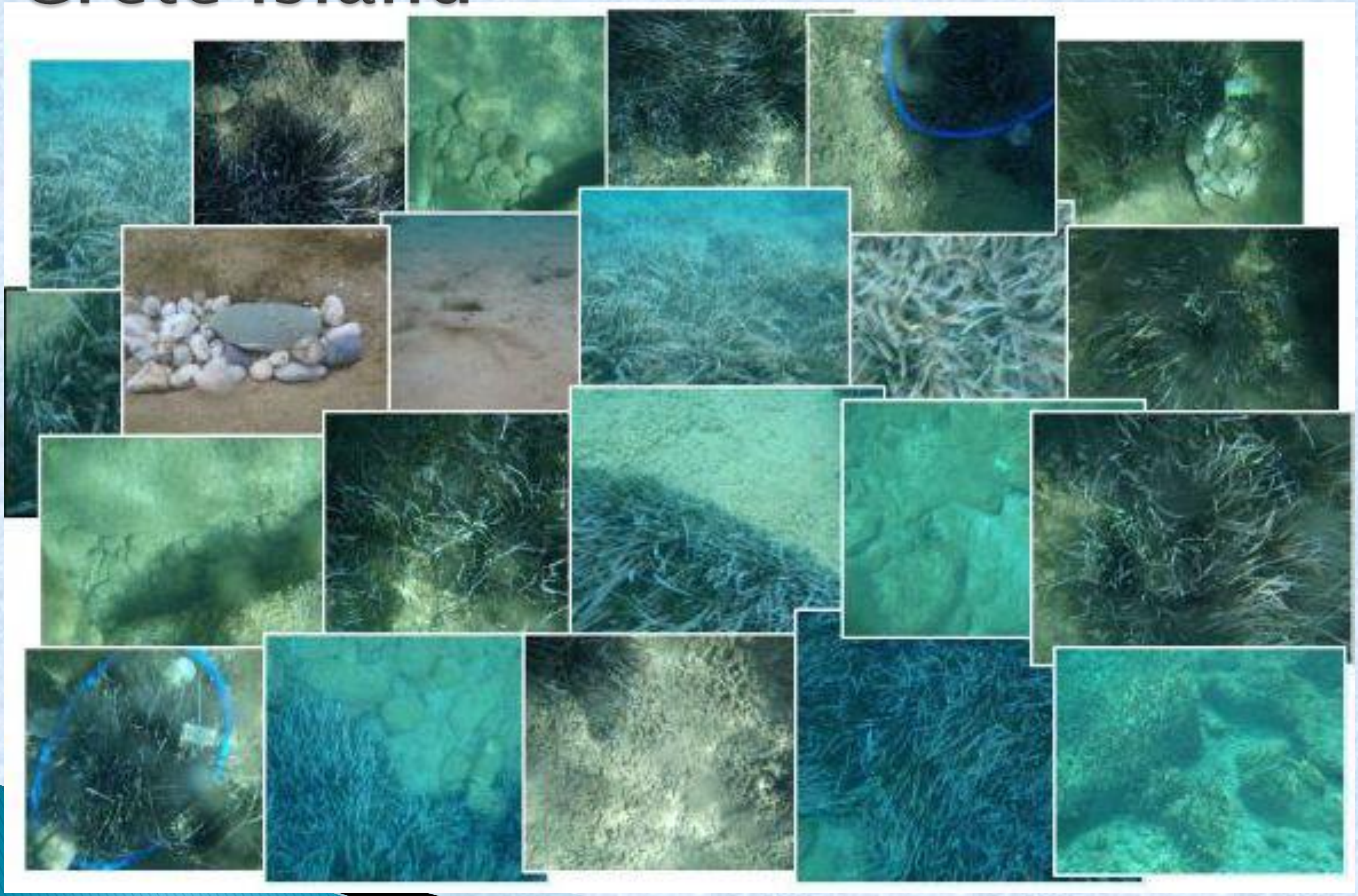
Measurement important points:

1. Photos of the seagrass meadow
2. Type of the sediment sand: coarse, fine vs middle-sized
3. Name of species (mostly *Posidonia*)
4. % cover of the seagrass

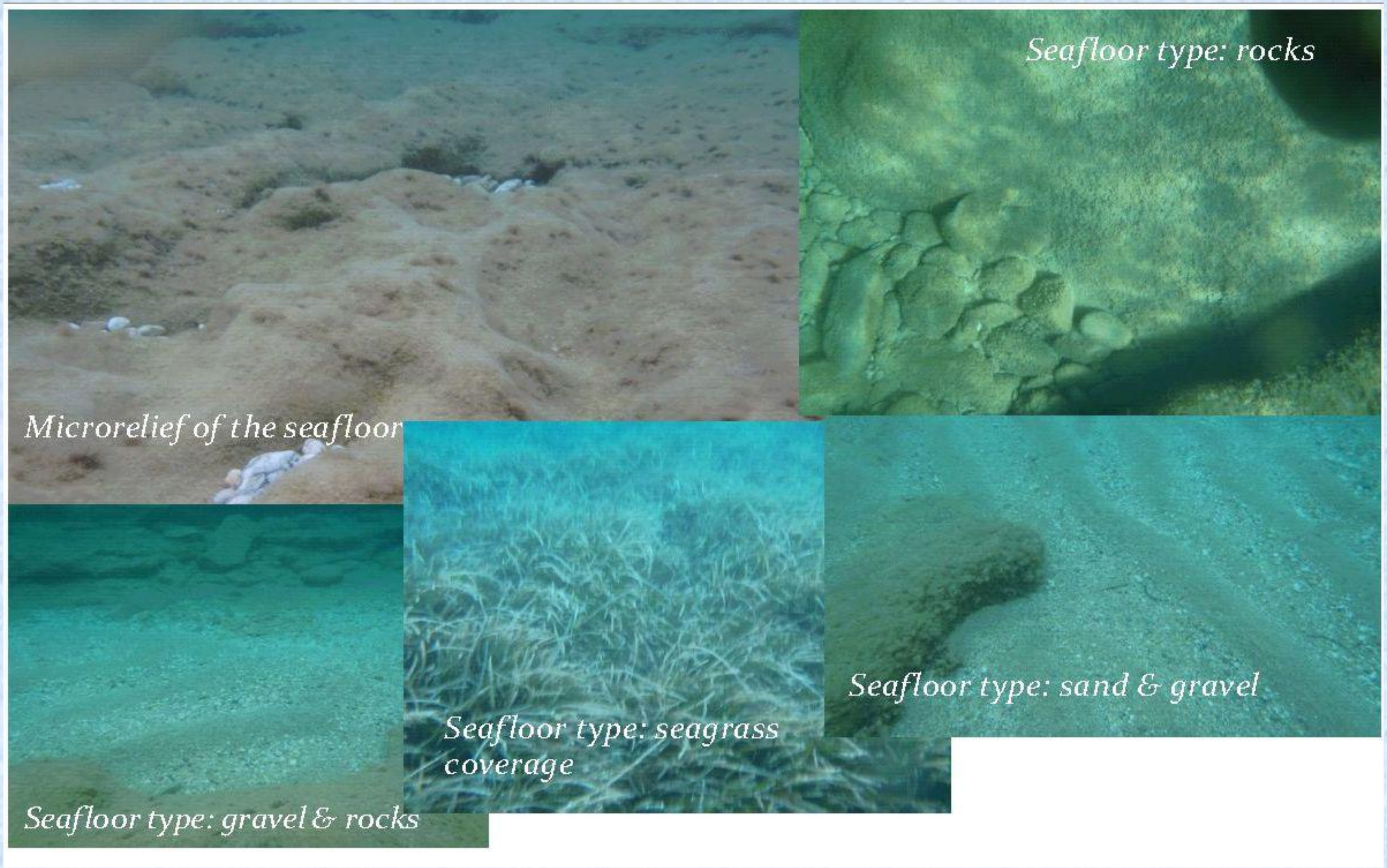
Locations of the videometric measurements and GPS tracklogs



Various seafloor cover types of on Crete Island



Various seafloor cover types (enlarged). Ligaria beach, Crete.



Review of the collected data

The collected data consist of the following types:

- ✓ Optical spectra of *P.oceanica*, carbonate sand, seawater with sediments and seawater measured in aquarium tank, without sediments, at different environmental conditions
- ✓ Aerial imagery from the *Google Earth*
- ✓ Satellite images from various open sources (Landsat)
- ✓ Results of underwater videometric measurements of the *Olympus ST* cameras made during the ship route

Optical measurements using Trios-RAMSES: spectral dataset from 2009

In this work we also used materials of previous measurements made by Ms. S. Noralez in 2009 using Trios-RAMSES hyperspectral radiometer

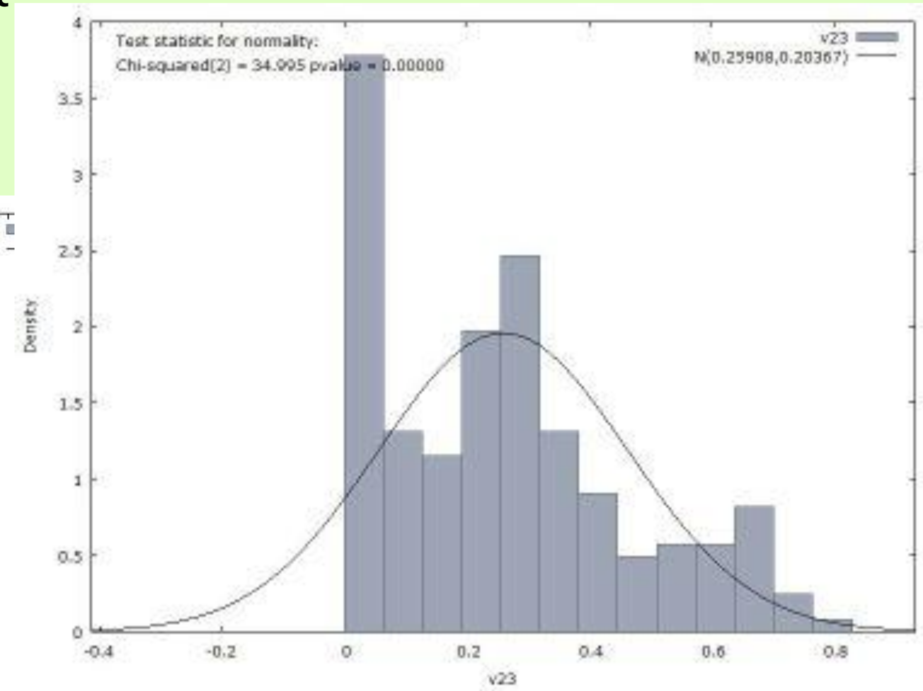
A data collection of visible spectra of two seafloor cover types - *P.oceanica* and carbonate sand - consist of data measured by means of RAMSES

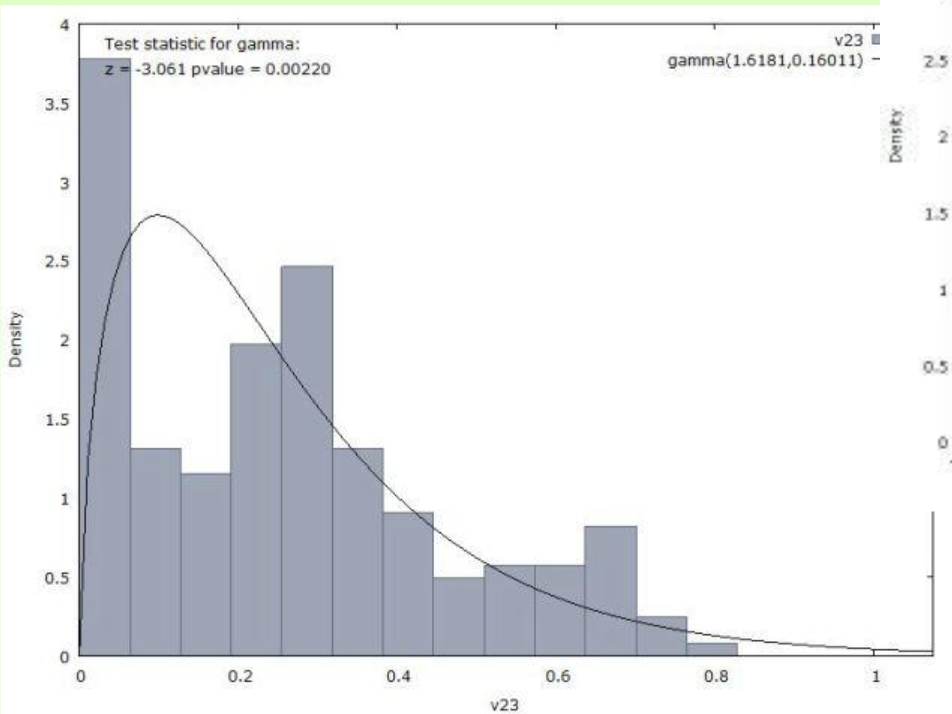
- 700 multiple measurement sets of *P.oceanica*;
- 106 for water without sediments, measured in aquarium tank;
- 27 for seawater with sediments measured in aquarium tank;
- 75 for carbonate sand

- ❑ The spectrometer Trios-RAMSES was adjusted for automatic measurements mode, with measurements taken as fast as possible.
- ❑ Trios-RAMSES head was held submerged, and the sampling was controlled by an operator on the surface boat.
- ❑ The head of the sensor was pointed downward at an angle of 0º (nadir) in order to capture the spatial discernibility in the radiance for the benthic cover types.
- ❑ The frame was held at 45° angle in order to keep sensor looking down at 0º (nadir view).
- ❑ A waterproof camera was attached to the platform to assist with the identification of the target object being measured

Normality testing

Frequency normality test against normal distribution: radiance of the seawater, measured in aquarium tank.

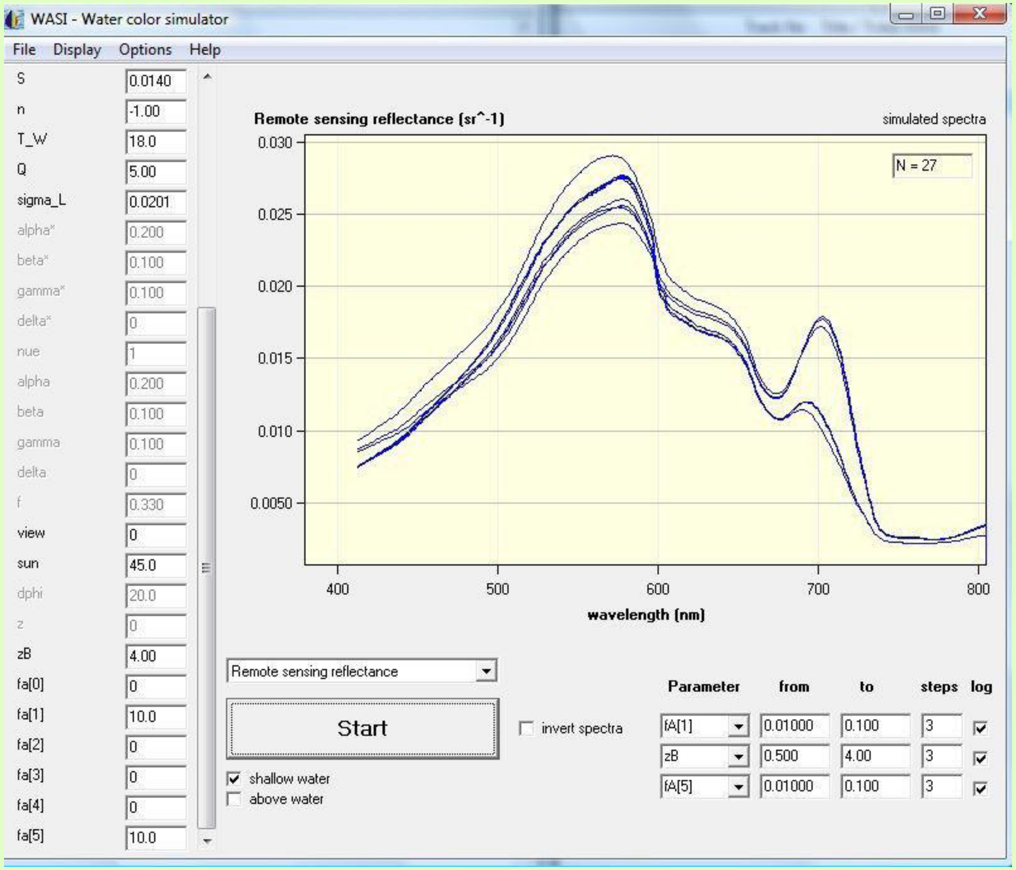




Frequency normality test against gamma distribution: radiance of the seawater, measured in aquarium tank

Spectral modelling method: *WASI* water colour simulator

- WASI is an RTM software used for artificial modelling of the seawater optical properties
- It enables simulation of radiance distribution within a water column and to understanding optical properties of seafloor cover types
- WASI has been chosen among other RTMs due to its
  - effectiveness,
  - adaptability for the Mediterranean environment,
  - open source availability,
  - coverage of necessary wavebands
  - clear, user friendly interface, enabling to adjust various environmental parameters.



Main interface of
Water Colour **Si**mulator (WASI) software

Spectral simulation of aquatic objects

- The main aim of spectral simulation using RTMS is to clarify if the bottom reflectance of two different seafloor types – mattes of seagrass *P.oceanica* and carbonate sand – differ and can be clearly discriminated during images interpretation for further mapping
- The remote sensing reflectance has been compared under the conditions of different water depths and cover fraction of the seafloor, in order to assess spectral signatures of the seagrass and carbonate sand as major seafloor types
- The ecological variables, specific to the field environmental conditions, were factored into the WASI-based simulation models. Through the WASI simulation process, imitating spectral properties of *P.oceanica* and carbonate sand for various broadband and narrowband sensors, models were created that accounted for not only atmospheric conditions (i.e. sun zenith angle), but also height of water column, thus approaching it to the Mediterranean conditions, and chemical content of the seawater

Assumptions.
WASI Modelling parameters: depth and bottom cover fraction

- We assumed constant values of the optical properties of the seawater, phytoplankton, total amount of suspended particles and solids, atmospheric conditions, as well as CDOM, which have been set up in modelling part of this work, during WASI simulations of various remote sensors.
- The specific parameters have been chosen for the simulation of the environmental conditions of Mediterranean Sea, endemic for P.oceanica seagrass
- Although seagrass *P.oceanica* can be found until depth limits down to 40 m depth, the most preferable limits of its distribution in the Mediterranean Sea, and most suitable for the research are shallow waters until 4 meters of depth.

Assumptions (continue)

- concentration of phytoplankton is accepted at the interval of 0,035 – 0,089mg-1
- viewing zenith angle is near to 90º
- reflection factor of sky radiance = 0.0201
- water temperature lies in the diapason17-25ºC
- The anisotropy factor of upwelling radiation or the quality (Q-) factor is taken as 5
- concentration of phytoplankton is accepted at the interval of 0,035-0,089mg-1
- Reference wavelength for *Coloured Dissolved Organic Matter* (CDOM) absorption is equal to 440
- The backscattering is accepted to be 0,00144m-1
- The coefficient of attenuation = 1.0546
- The concentration of non-chlorophyll particles (absorption at $\lambda 0$) and concentration of small suspended particles is equal to zero, so we do not count them in this work
- Exponent of CDOM (Gelbstoff) absorption is accepted as 0.0140
- The Bidirectional Reflectance Distribution Function (BRDF) of bottom reflectance (sand) is assumed to be 0.318 sr-1

Assumptions (continue)

Model-specific parameters of water colour simulator WASI, adjusted to simulate environmental conditions of the Mediterranean Sea along Crete.
For the spectral analysis we applied forward calculations, i.e. a computing and plotting of series of spectra according to specified parameter settings,
with exactly defined depths and cover fraction.

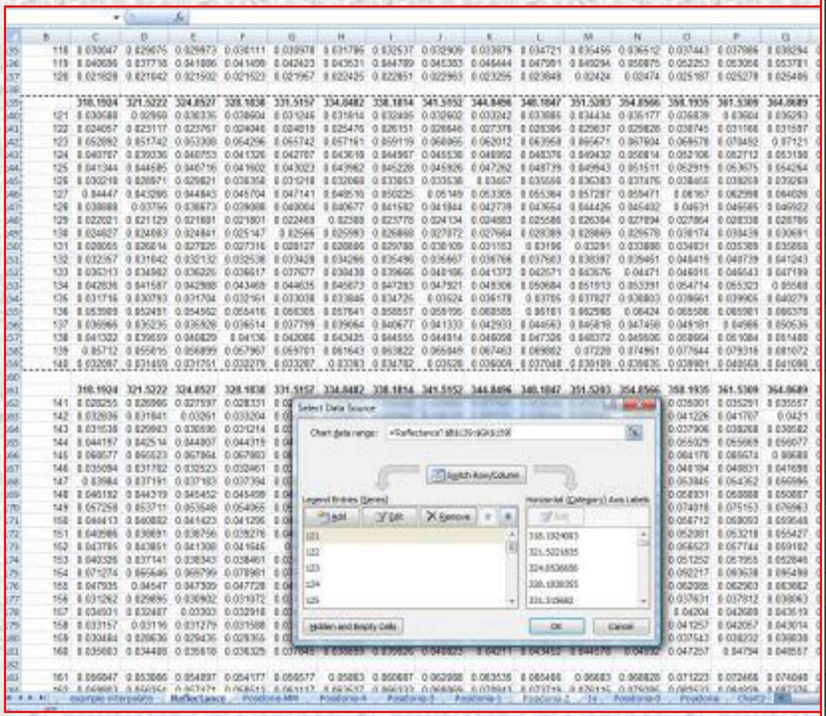
Parameter, WASI	Name and description	Values
C-L	Concentration of large suspended particles	8
C(i), i=0..5	Concentration of Phytoplankton	0.035 -0.089 ug -l
bbS	Specific backscattering for small particles	0.005 m2g-1
T-W	Temperature of water	17-25 C
n	Exponent of Backscattering by small particles	0.005 m2g-1
Q	Anisotropy factor of upwelling radiation ("Q-factor")	5.00
sigma-L	Reflection factor of sky radiance	0.0201
b1	Backscattering coefficient of saline waters	0.00144 m-1
0	Reference Wavelength for Gelbstoff absorption	440
sun	Sun zenith angle	45.0
zB	Bottom depth	4.00
f(i), i=0...5	Areal fraction of bottom surface type number n	01/10/10
K0	Coefficient of Attentuation	1.0546
view	Viewing angle (0 = nadir)	0
C-X	Concentration of non-chlorophyllous particles (absorption at 0)	0
S	Reference wavelength for scattering of small particles	500
C-S	Concentration of small suspended particles	0
S	Exponent of Gelbstoff absorption	0.0140
C-Y	Concentration of Gelbstoff (absorption at 0)	0.400
Bn	BDRF of bottom reflectance (sand)	0.318 sr -1

Results

- The finding of these studies showed that the relationship between the spectral reflectance of various seafloor cover types was tied to depth, i.e. water column height.
- The results of the *in-situ* fieldwork measurements revealed that spectral reflectance of *P.oceanica* undergo alterations at depths of 0.5, 2.0 and 3.5m and differ from carbonate sand
- Studies of the broadband and narrowband sensors demonstrate that simulated spectra of the seagrass, made using WASI modeller, have the best results at CZCS scanner, especially devoted to the measurement of ocean color.
- Other remote sensors (MODIS, SeaWiFS) may also be used for the seagrass mapping, because their technical characteristics enable to spectrally discriminate P.oceanica seagrass from other seafloor cover types particularly carbonate sand, as tested in the current work.

Data pre-processing: raw observations

Right: preliminary statistical analysis of spectral reflectance of *P.oceanica*



Above:
fragment of the spreadsheet with observed data: transposing columns to rows.

Wavelength, nm	mean	Q1	min	Q3	max	median
318.23354	0.030467	0.038907	0.029764	0.069762	0.116100	0.048984
338.29900	0.033560	0.043030	0.032847	0.076252	0.128290	0.054334
358.37932	0.039897	0.051320	0.039131	0.091143	0.154409	0.066354
378.47247	0.045786	0.058849	0.045039	0.105993	0.177150	0.078339
398.57640	0.052346	0.066859	0.051625	0.122328	0.201038	0.091905
418.68905	0.058942	0.074842	0.058240	0.138984	0.226028	0.106207
438.80838	0.070690	0.089761	0.069999	0.167825	0.267712	0.130580
458.93235	0.080107	0.102089	0.079392	0.191424	0.304933	0.149762
479.05891	0.086278	0.110348	0.085546	0.207940	0.332934	0.162881
499.18600	0.098498	0.126592	0.097689	0.239161	0.380603	0.188192
519.31159	0.110222	0.143976	0.109022	0.265948	0.421370	0.210237
539.43363	0.125694	0.166156	0.124310	0.302678	0.475842	0.240492
559.55006	0.131844	0.175865	0.130257	0.319385	0.503907	0.253726
579.65885	0.121915	0.166084	0.120186	0.302078	0.485661	0.237873
599.75794	0.077236	0.111113	0.075669	0.200557	0.343876	0.154016
619.84529	0.057038	0.085386	0.055588	0.154781	0.281737	0.117003
639.91885	0.050841	0.077438	0.049432	0.141810	0.265181	0.106188
659.97657	0.038118	0.059971	0.036997	0.110774	0.223366	0.082411
680.01641	0.032892	0.052265	0.032012	0.095789	0.198389	0.071686
700.03633	0.034756	0.058426	0.033643	0.101504	0.215413	0.075789
720.03426	0.026287	0.047084	0.025162	0.082940	0.193535	0.061184
740.00817	0.009740	0.022355	0.010145	0.042861	0.132244	0.029414
759.95601	0.008651	0.020234	0.009191	0.039371	0.128165	0.026558
779.87573	0.006019	0.014157	0.006397	0.028320	0.100314	0.019322
799.76528	0.008607	0.020030	0.009050	0.037323	0.118123	0.026535
819.62263	0.008777	0.020295	0.009288	0.037598	0.118055	0.026799
839.44571	0.002562	0.008010	0.002864	0.017472	0.076515	0.011432
859.23249	0.002653	0.006921	0.002897	0.016121	0.070377	0.009889
878.98091	0.002327	0.008080	0.002821	0.018625	0.082462	0.011617
898.68893	0.004077	0.013098	0.004709	0.031217	0.101146	0.019767
918.35451	0.006215	0.020162	0.007229	0.045213	0.199711	0.029950
937.97559	0.005783	0.026132	0.007307	0.065475	0.195072	0.040848

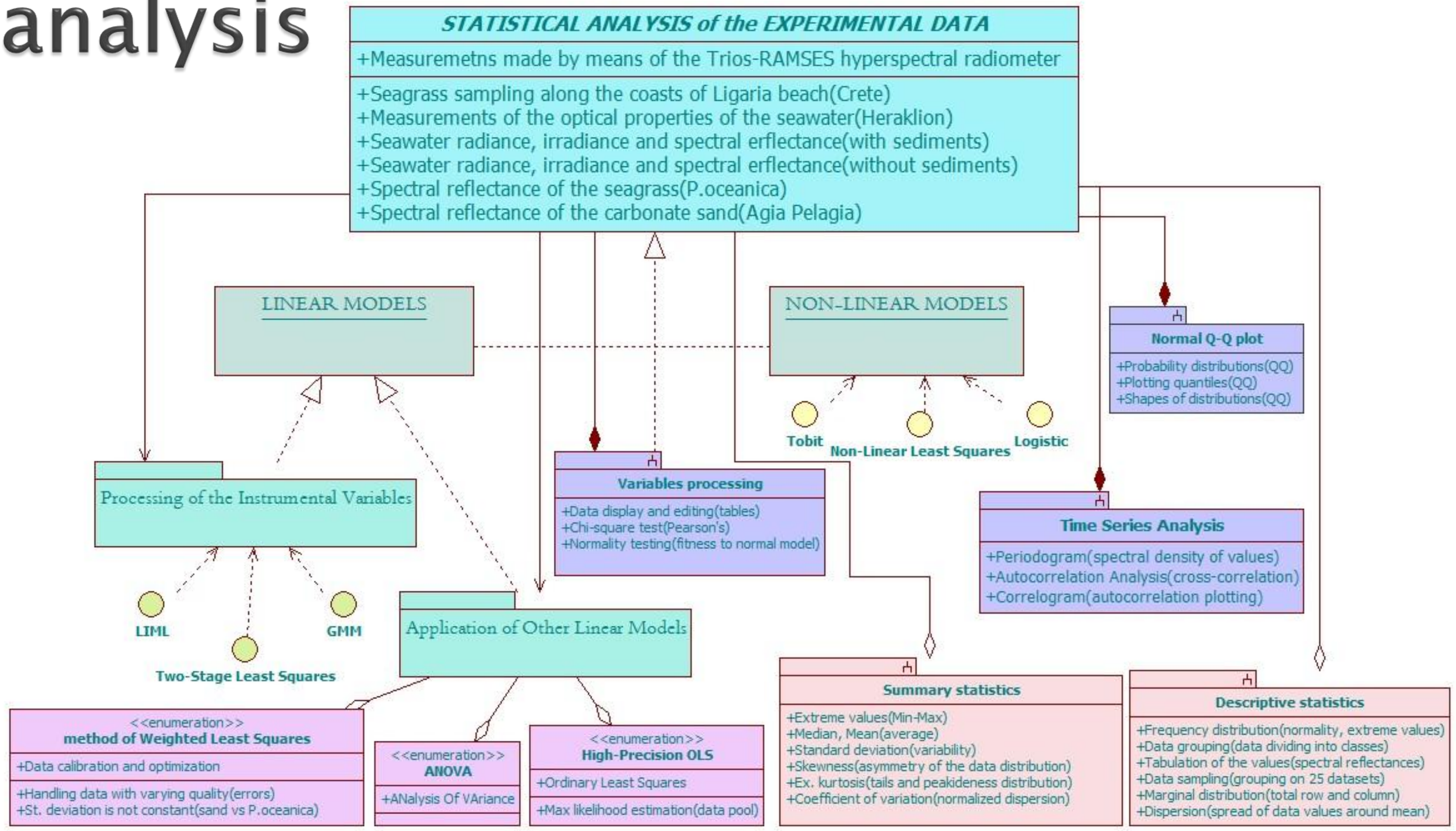
Statistical analysis of the observational data

The total amount of measured data was large and included following datasets made using hyperspectral radiometer Trios-Ramses in 2009:

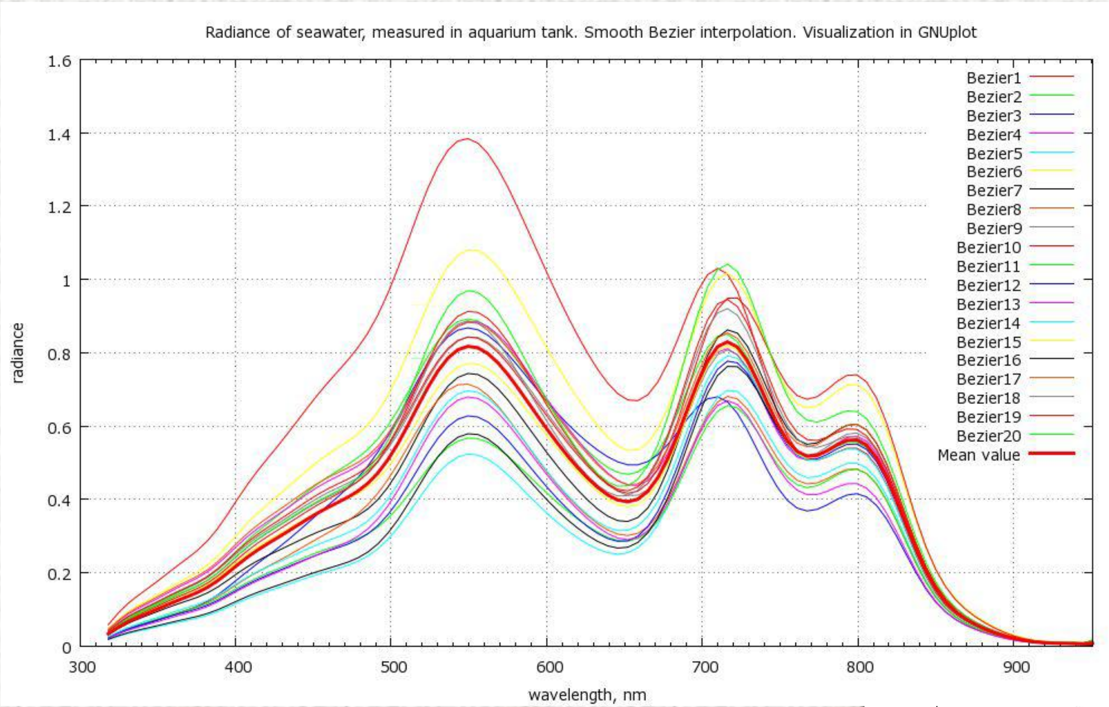
- 350 measurement sets of *P.oceanica* reflectance for 14th Oct,
- 400 sets of *P.oceanica* reflectance for 15th Oct,
- 84 datasets for seawater reflectance with sediments,
- 105 datasets for seawater reflectance without sediments,
- 87 sets for spectral reflectance of carbonate sand

A statistical approach was used for proper processing of such amounts of data.

Implementation of statistical analysis



Radiance and irradiance of the seawater with sediments

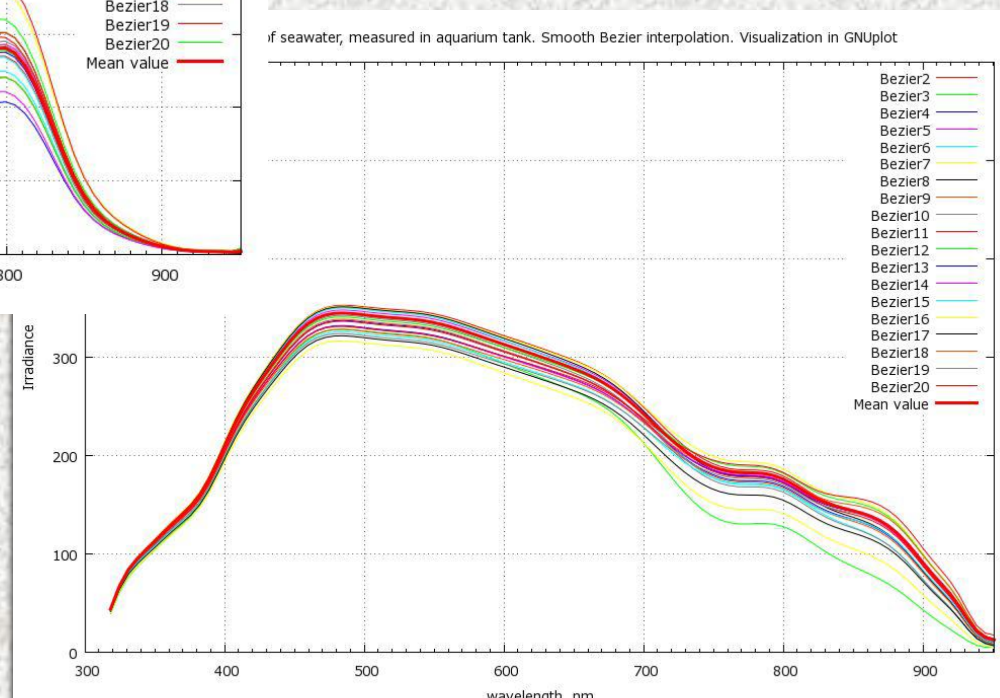


Model 6: LAD, using observations 1:01–8:23 (T = 1

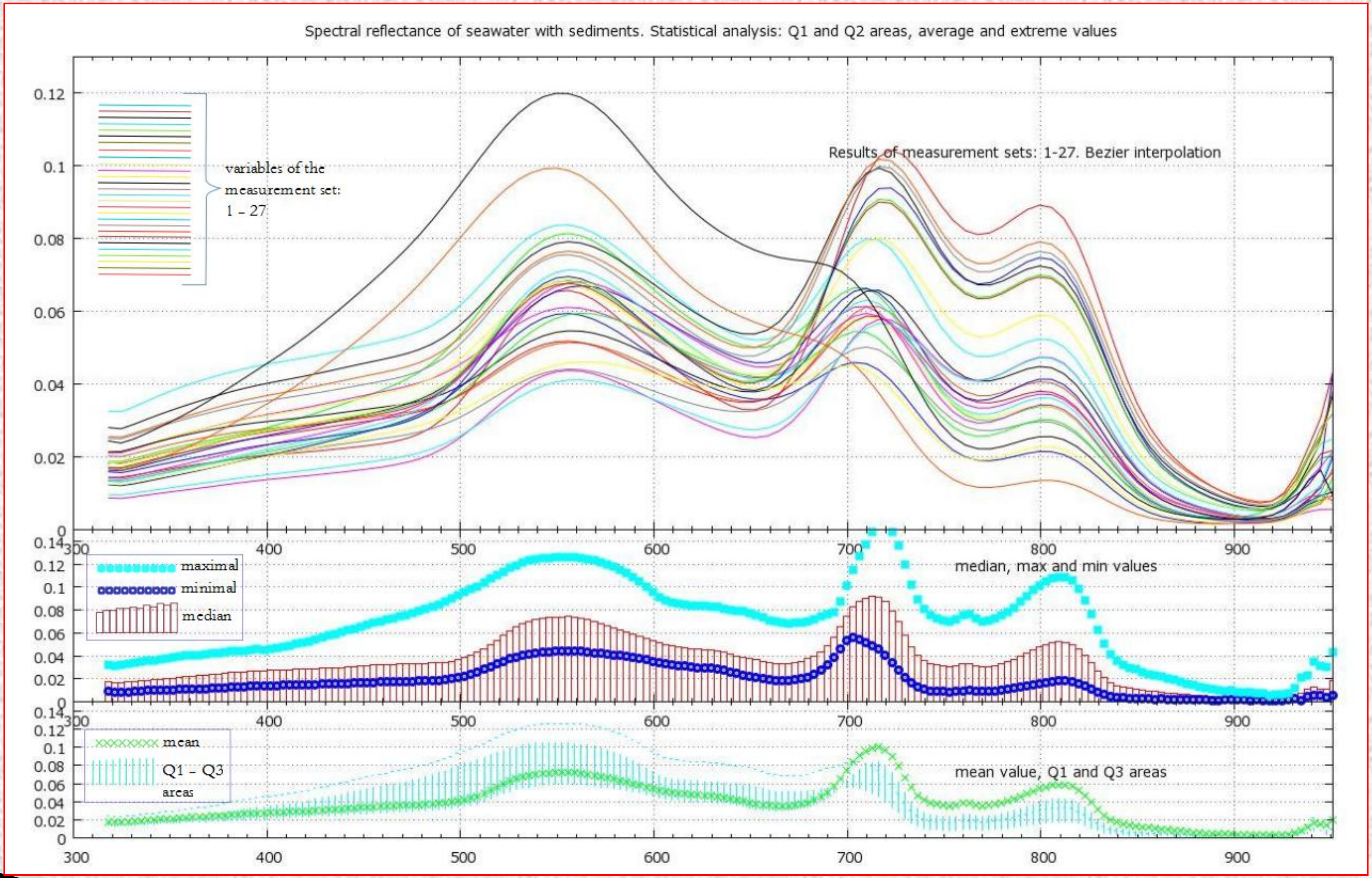
Dependent variable: v16

	Coefficient	Std. Error	t-ratio	p
const	0.738911	0.0862011	8.5719	0
v1	−0.000775186	0.000114010	−6.7993	0

Median depend. var	0.227857	S.D. dependent var	
Sum absolute resid	30.22342	Sum squared resid	
Log-likelihood	28.74727	Akaike criterion	-
Schwarz criterion	−46.99000	Hannan–Quinn	-

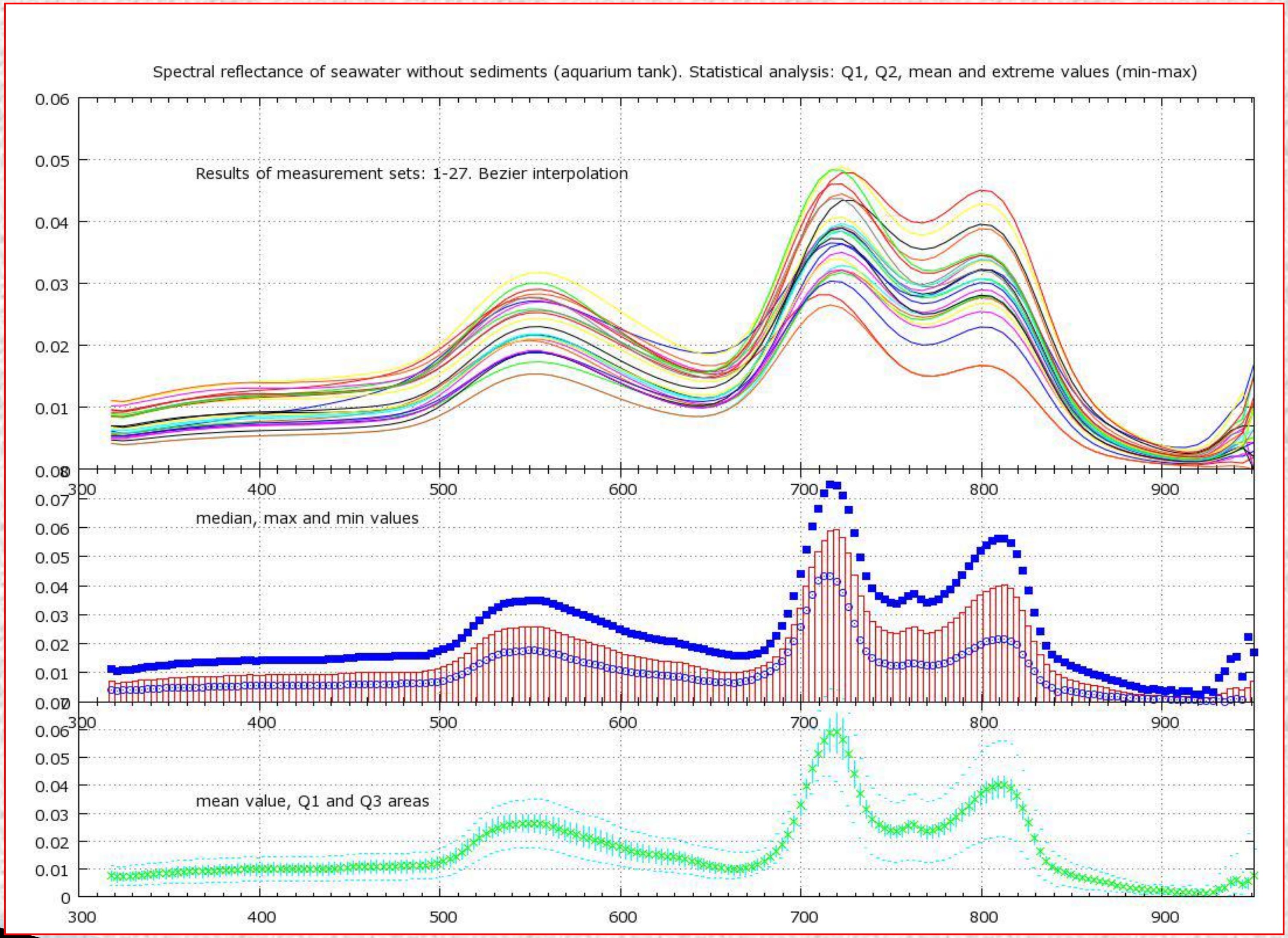


Spectral reflectance of the seawater with sediments



measured in aquarium tank, HCMR, Crete

Spectral reflectance of the seawater without sediments

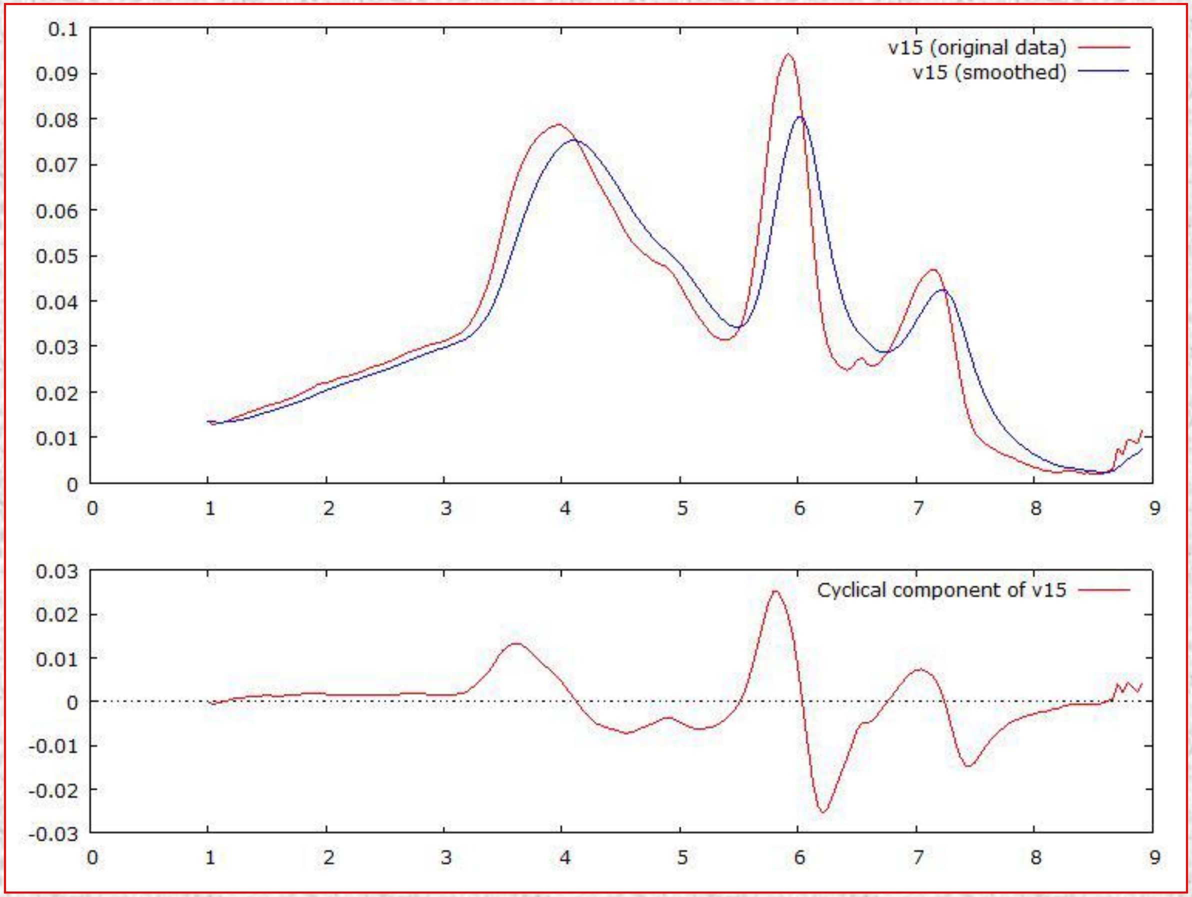


Optical properties of the seawater with sediments

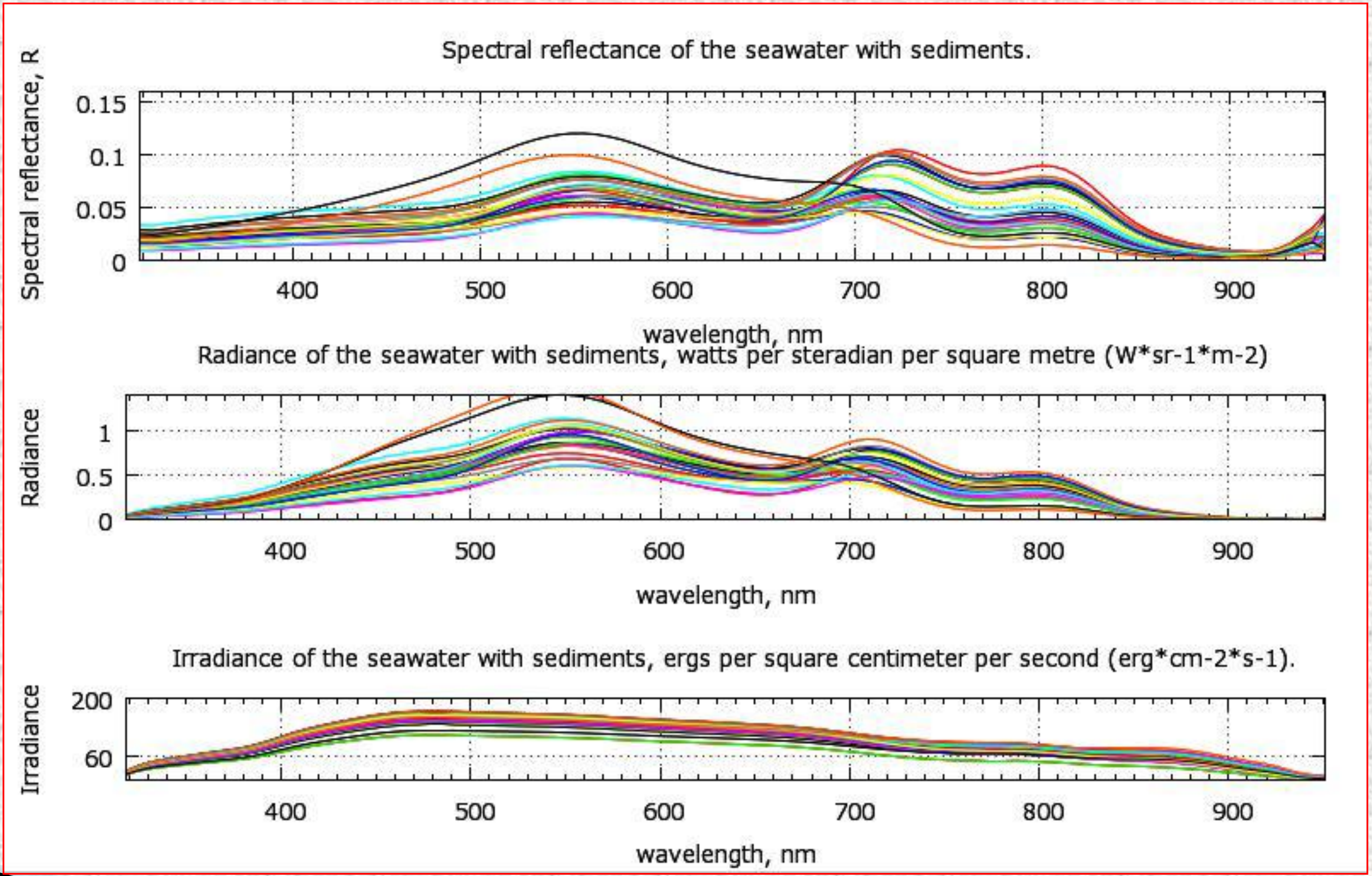
- The graphs showing optical properties of seawater with and without sediments focused on spectral variability of the water with changed physical and chemical content.
- The alterations in the individual spectral signatures of single measurements reflect individual health properties of leaves: different nitrogen and chlorophyll content causing diverse colour pigmentation and light absorption, water content in leaves and plant physiological conditions, which vary across seagrass meadow, shoot morphology, etc.
- The differences in spectral reflectance values of the measurements taken on various days might have been caused by the impact of atmospheric conditions, such as solar radiation and sun illumination by different zenith angle.

Statistical evaluation of data (continue): seawater with sediments measured in aquarium

Exponential moving average
of spectral reflectance
of seawater with
sediments.
Ligaria Beach, Crete.
Example for
measured variable
V15



Optical properties of the seawater with sediments, measured in aquarium tank

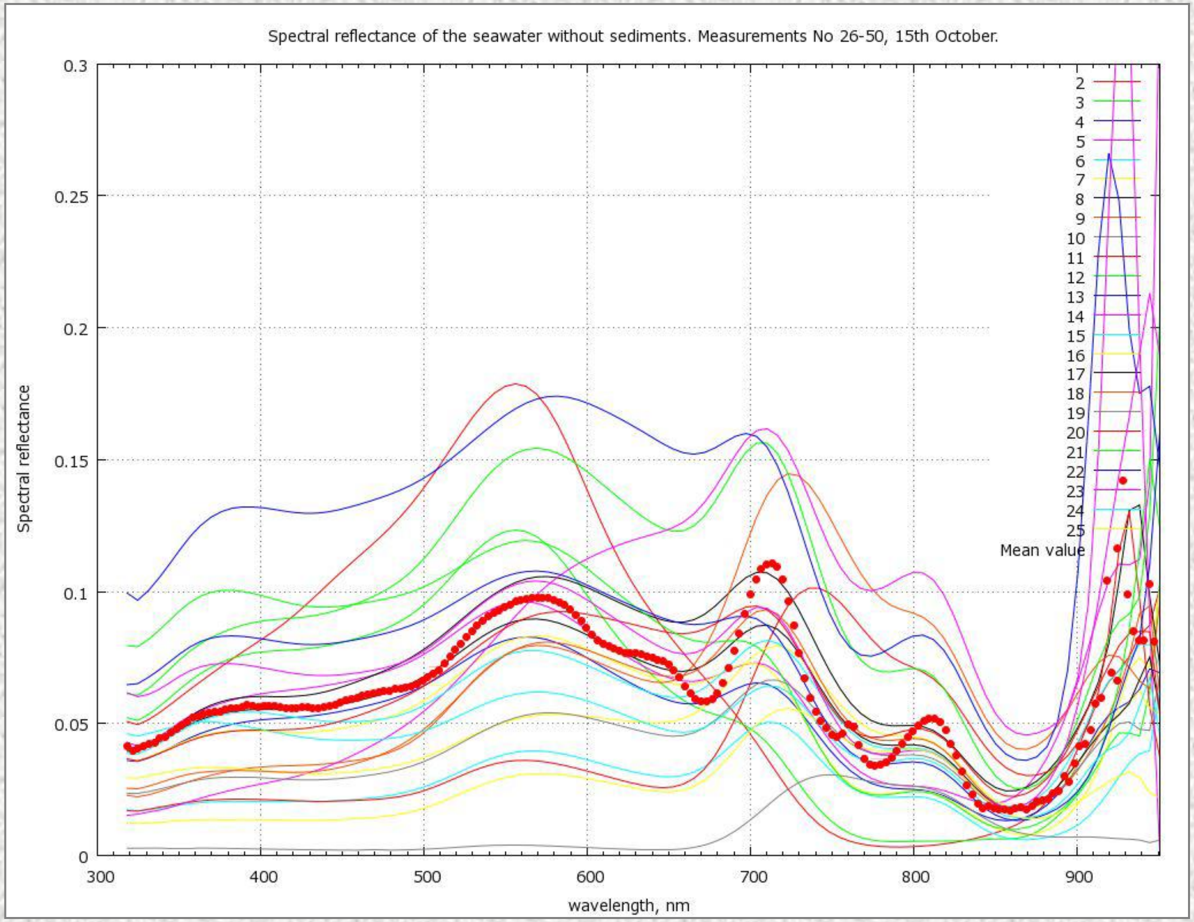


measured in aquarium tank, HCMR, Crete

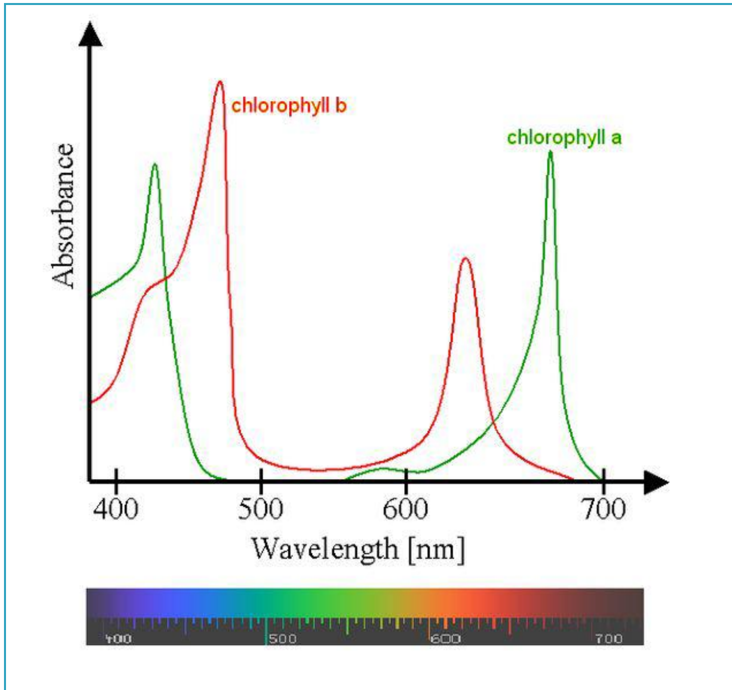
Statistical evaluation of spectral measurements of *P.oceanica* reflectance

The reflectance spectra of *P.oceanica* show a values maxi mum between 450 nm and 600 nm,

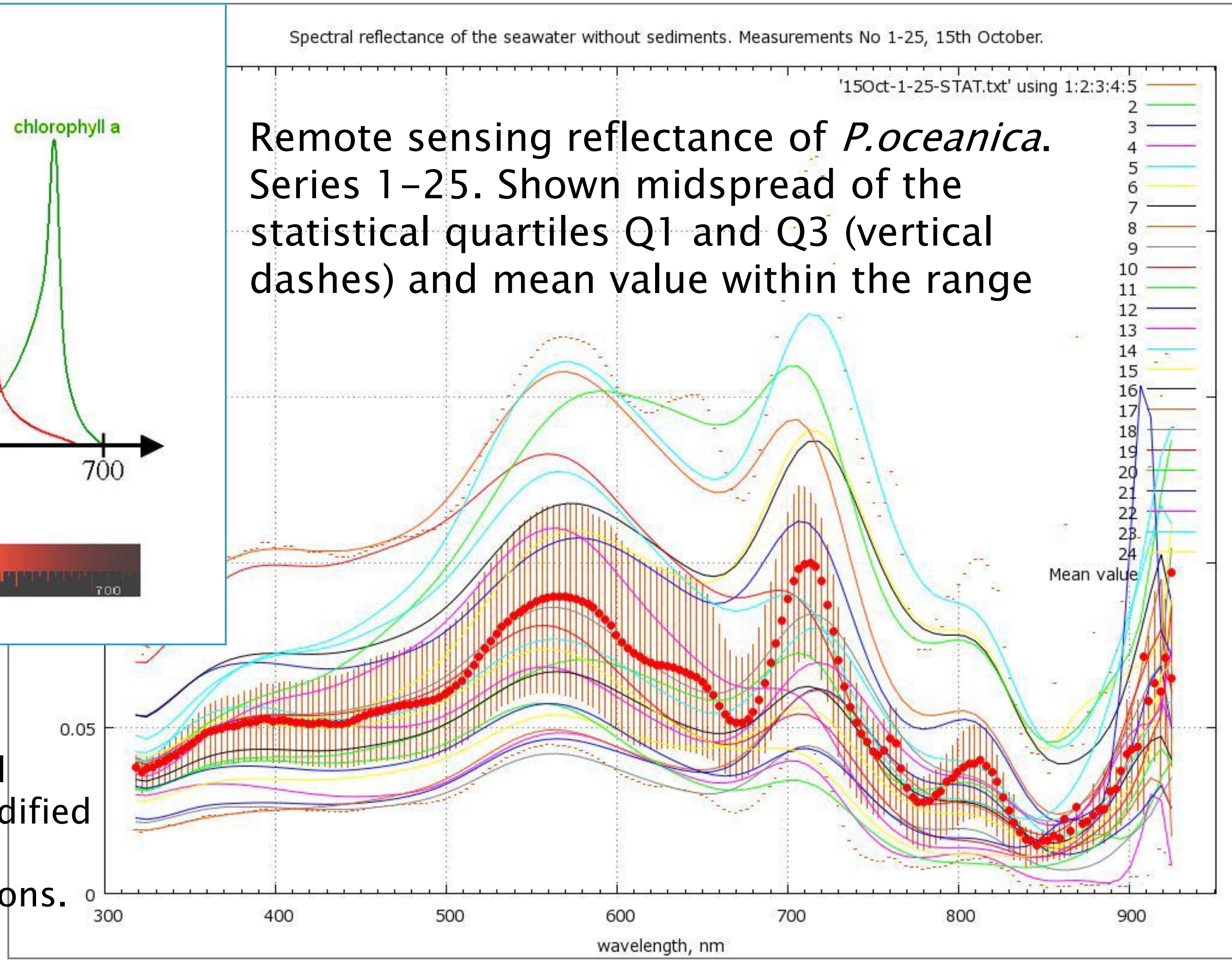
1. first, because of the chlorophyll absorption peak at 465 and 665nm
2. secondly, because of the weakening of CDOM (or Gelbstoff) in the blue part of the VIS spectrum, as it most strongly absorbs short wavelength light in blue to ultraviolet range,
3. and finally, because the absorption of the seawater increases in the red part of the VIS spectra.



Statistical evaluation of spectral measurements of *P.oceanica* reflectance



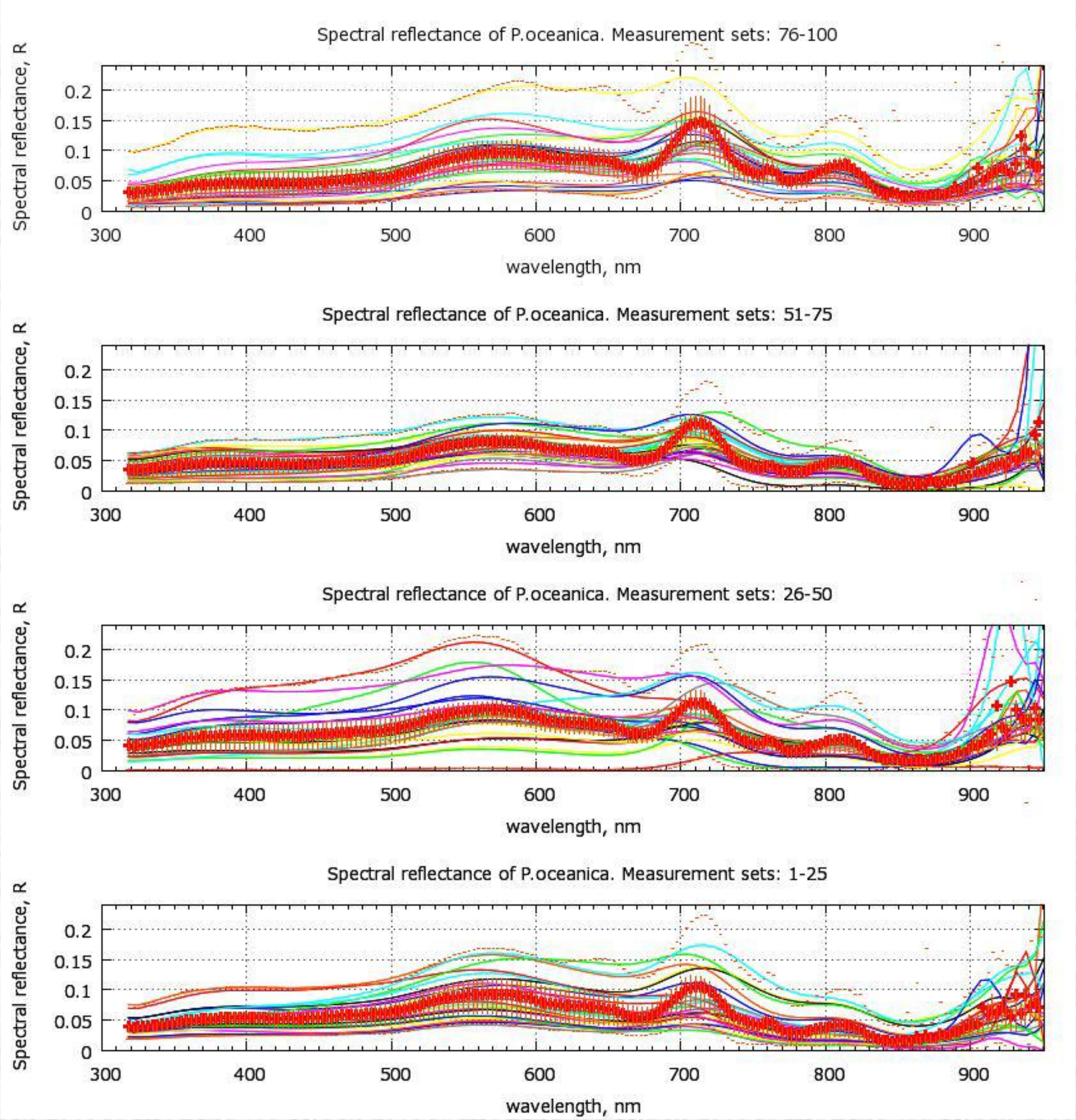
Absorbance spectra of chlorophyll in a solvent. The spectra of chlorophyll molecules are slightly modified depending on specific pigment-protein interactions. Source of picture above: Wikipedia.org



Remote sensing reflectance of *P.oceanica*. Series 1-25. Shown midspread of the statistical quartiles Q1 and Q3 (vertical dashes) and mean value within the range

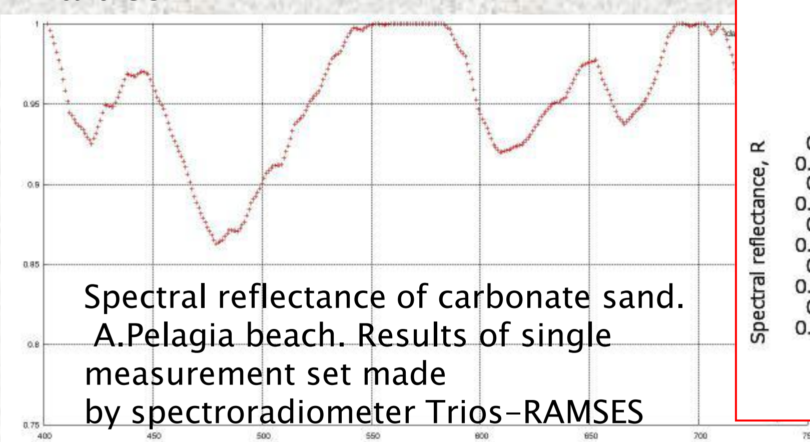
Spectral reflectance of *P.oceanica*

The analysis of spectra shows that the appropriate wavebands for seagrass mapping lay between 500 and 600 nm, and has also peaks at around 700 nm, ca between 680 and 710 nm.
The highest values of the bottom reflectance are at spectra of 500–600 nm.
The most appropriate depths at which the spectral signatures of the seagrass could be discriminated are lesser than 2.5 meters.

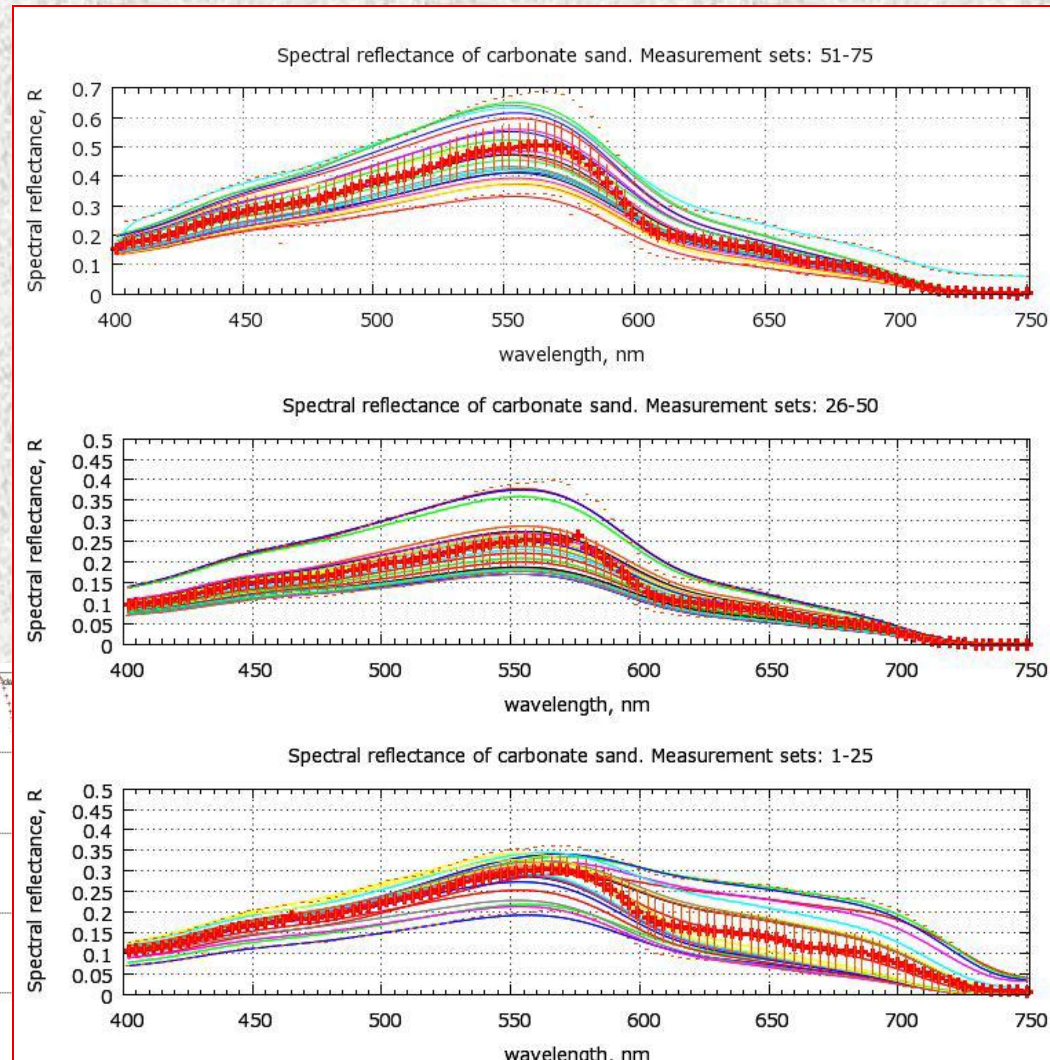


Spectral reflectance of carbonate sand

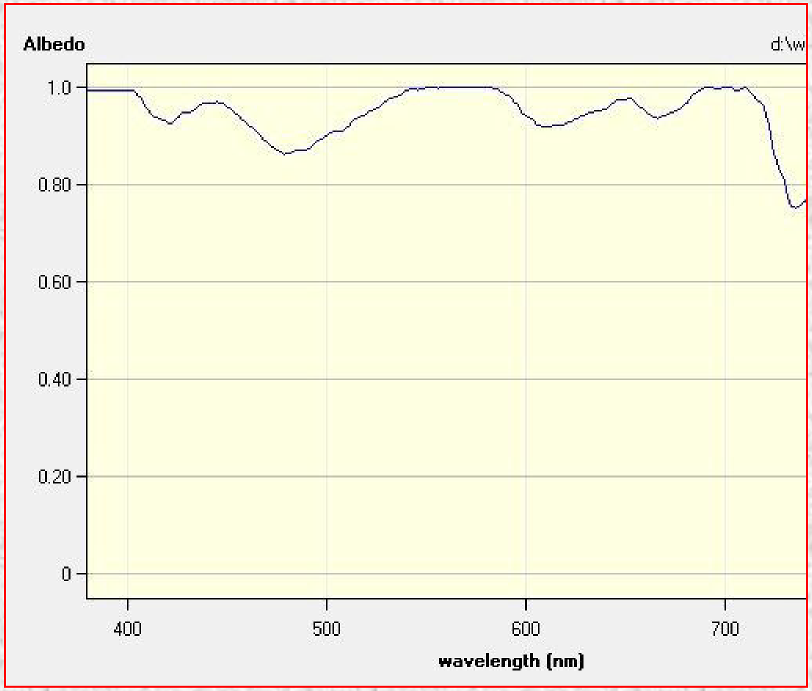
The analysis of the spectral signatures of the seagrass *P.oceanica* and carbonate sand clearly shows that **seagrass** has spectral reflectance much lesser than that of a **carbonate sand**, in general not increasing values of 10% reflectance in spectra of 500-600 nm, while **carbonate sand** has spectral reflectance approaching 63% in its highest values.



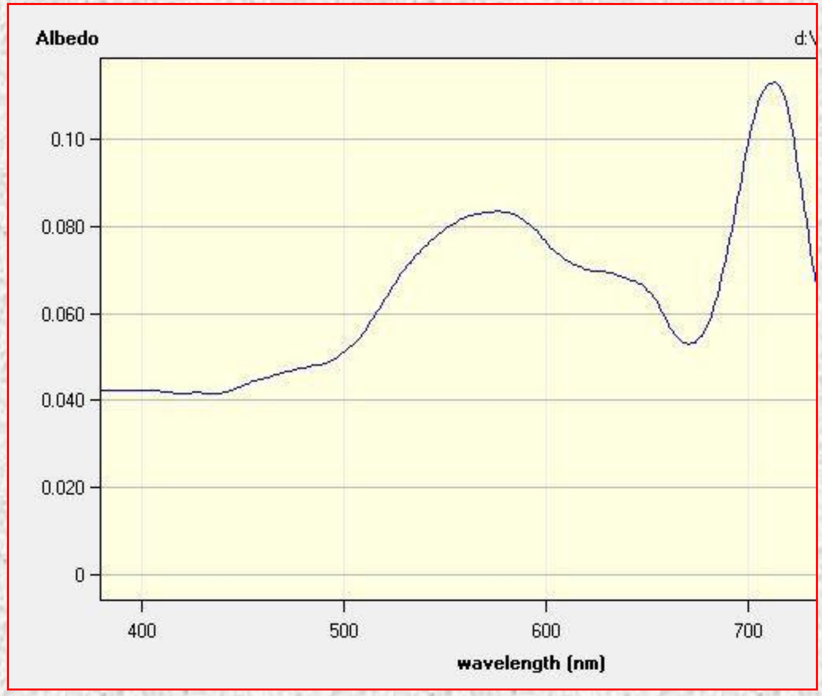
Spectral reflectance of carbonate sand.
A.Pelagia beach. Results of single measurement set made
by spectroradiometer Trios-RAMSES



Bottom albedo of carbonate sand and seagrass *P.oceanica*. Agia Pelagia, Crete.



(a) Sand



(b) *P.oceanica*

Hypothesis

For the Research Question 1 the *Hypothesis Ho* claims: seagrass types are not spectrally distinct from other seafloor types with varying in-situ conditions, which means
Ho : $\mu 1 = \mu 2 = \mu 3 = \ldots = \mu n$.
The alternative *Hypothesis Ha* claims the opposite statement: seagrass is spectrally distinct with varying in-situ conditions, *Ho* : $\mu 1 \neq \mu 2 \neq \mu 3 \neq \ldots \neq \mu n$.

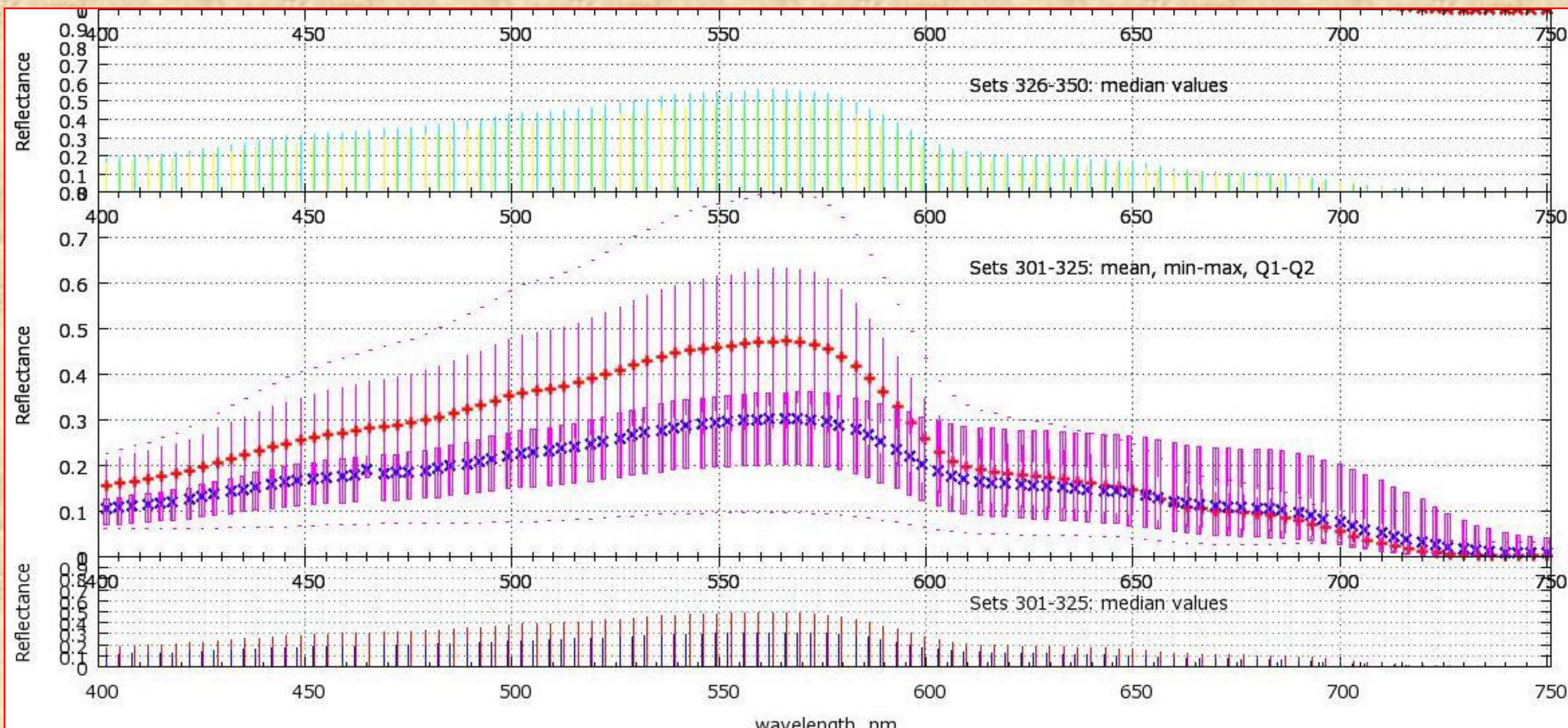
SPSS statistical analysis and hypothesis testing:

ANOVA one-way analysis: results of the single factor (depth) testing of spectral reflectance of *P.oceanica* at various depths: 0.5, 1.5 and 2.5 m

Source of Variation	SS	df	MS	F	P value	F crit
Between Groups	373841.7048	2	186920.8524	407.85359	1.11677	3.01153
Within Groups	261233.1668	570	458.3038014			
Total	635074.8716	572				

P more than .05, which means that there is a significant difference in radiance of *P.oceanica* at three different depth (0.5, 1.5 and 2.5).

Answering *Research Question 1:* comparative analysis of spectral signatures of *P.oceanica* and carbonate sand



Comparison of spectral reflectance of seagrass *P.oceanica* and carbonate sand (evaluated in GRETL)

Answering *Research Question 1:*
comparative analysis of spectral signatures of *P.oceanica* and carbonate sand

These results indicate that seagrass *P.oceanica* can be detected and discriminated from other seafloor cover types (carbonate sand) with varying environmental conditions, i.e. water column height, by hyperspectral spectroradiometers (Trios-RAMSES), which positively answers the first research question of this thesis ("Is *P.oceanica* spectrally distinct from carbonate sand with varying *in-situ* conditions ?").

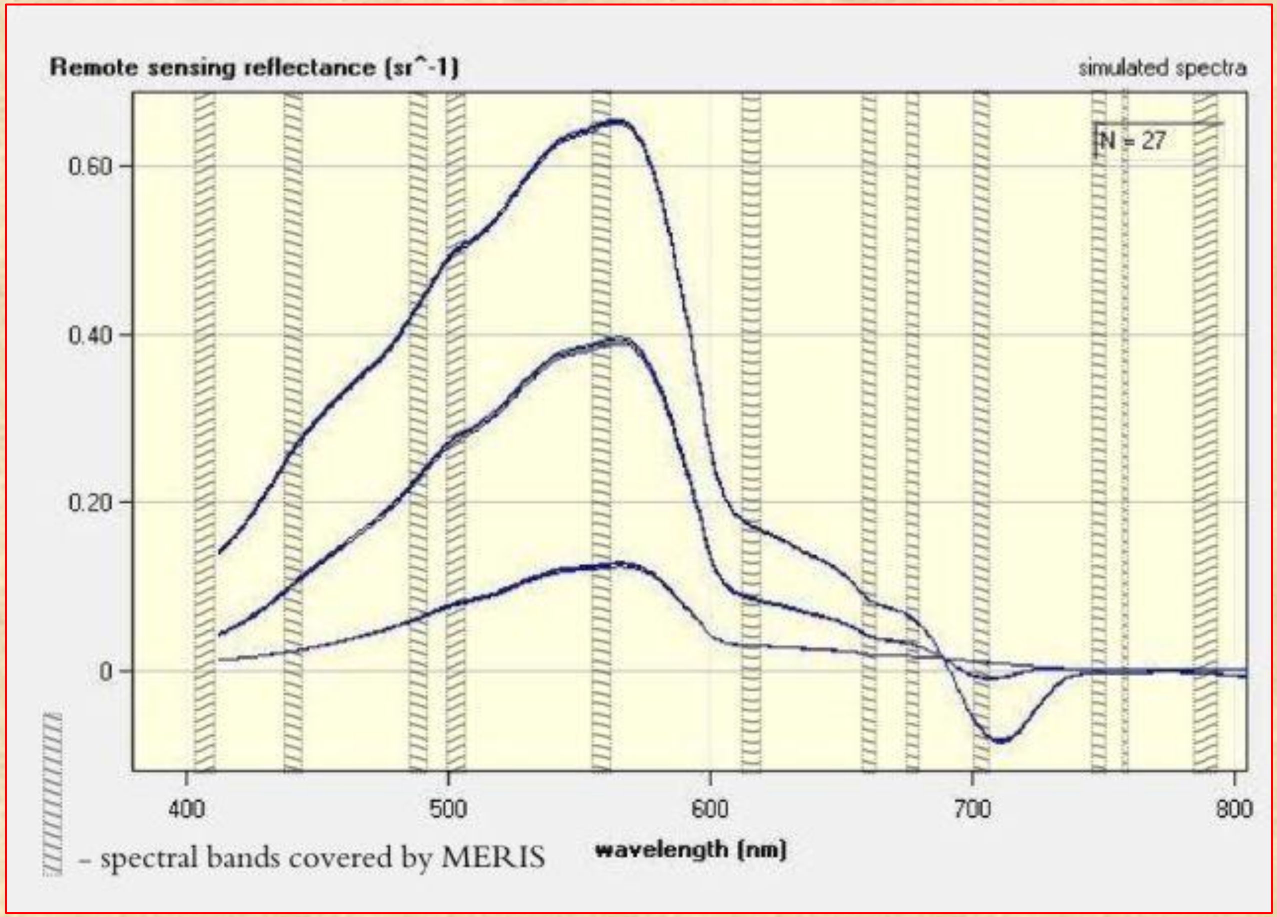
Answering *Research Question 1 (continue):* distinguishability of spectral signatures of *P.oceanica* and carbonate sand

The results of spectral measurements at various depths shown:

P.oceanica is spectrally distinct from other sea floor types (carbonate sand), based on differences in their spectral signatures,

with changing environmental conditions:

increasing water column height, i.e. depths.

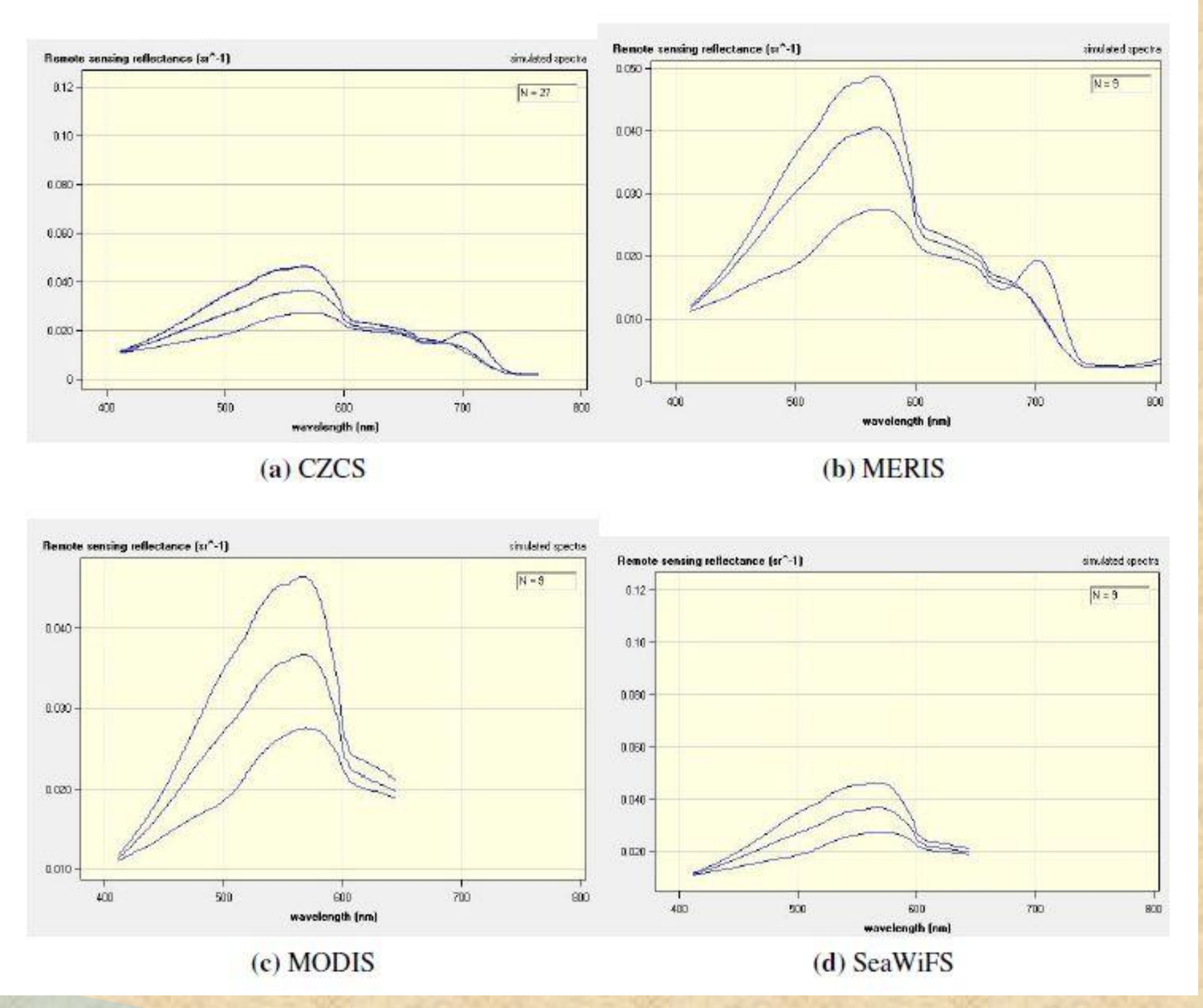


Simulated remote sensing reflectance of *P.oceanica* at various depths: 0.5, 2.0 and 3.5 m

Answering *Research Question 2*

Do broadband and hyperspectral sensors provide enough radiometric information for spectral discrimination of seagrass, and therefore, can be used for mapping of seagrass *P.oceanica* ?

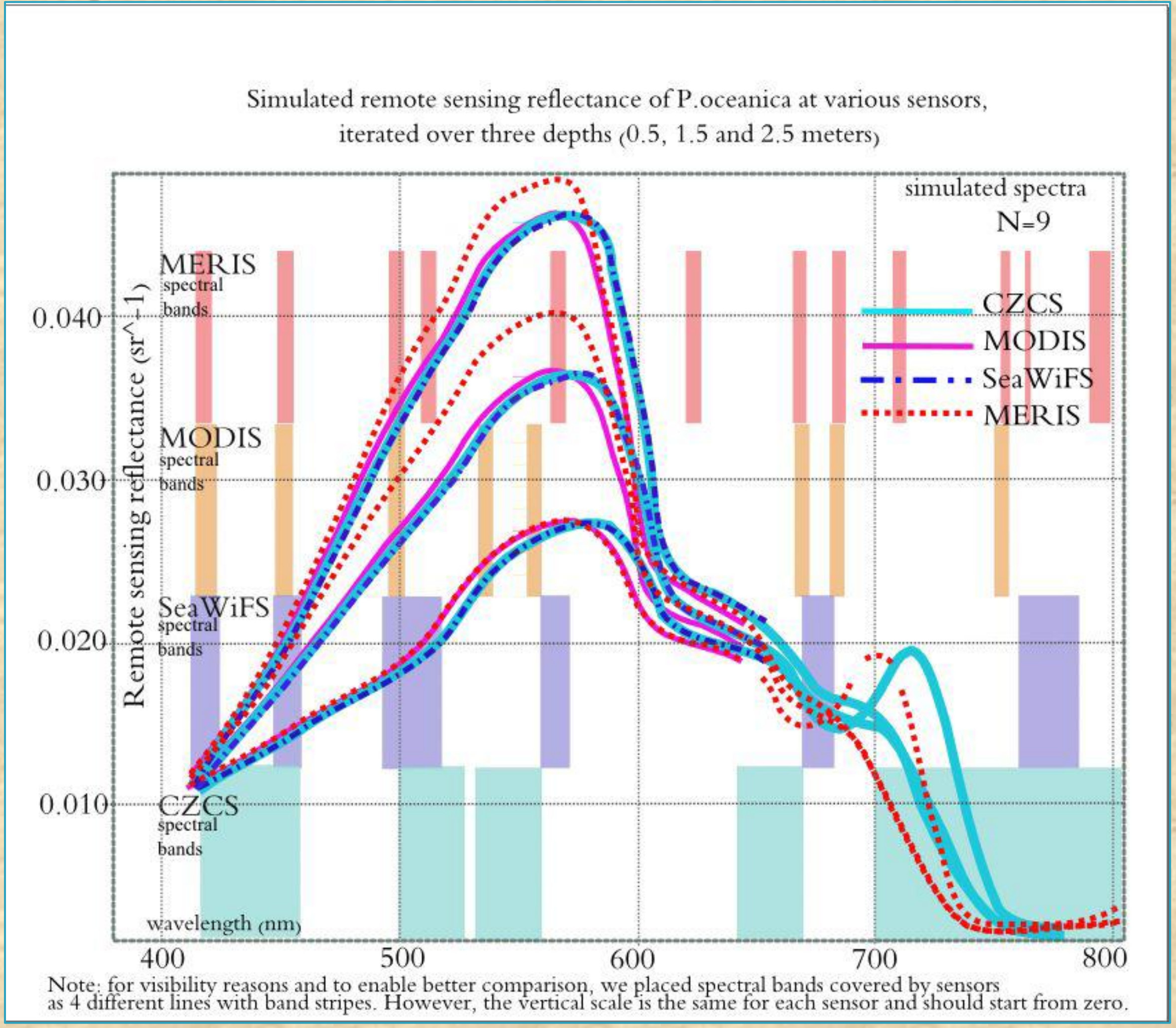
Separated plots of simulated remote sensing reflectance of seagrass *P.oceanica* at various sensors: *MODIS*, *MERIS*, *SeaWiFS* and *CZCS*, iterated over three depths



(a) CZCS (b) MERIS (c) MODIS (d) SeaWiFS

Answering *Research Question 2* (continue: comparison of various sensors)

Combined plots of simulated remote sensing reflectance of seagrass *P.oceanica* at various sensors: *MODIS*, *MERIS*, *SeaWiFS and CZCS*, iterated over three depths, as stripes shown spectral bands covered by these sensors



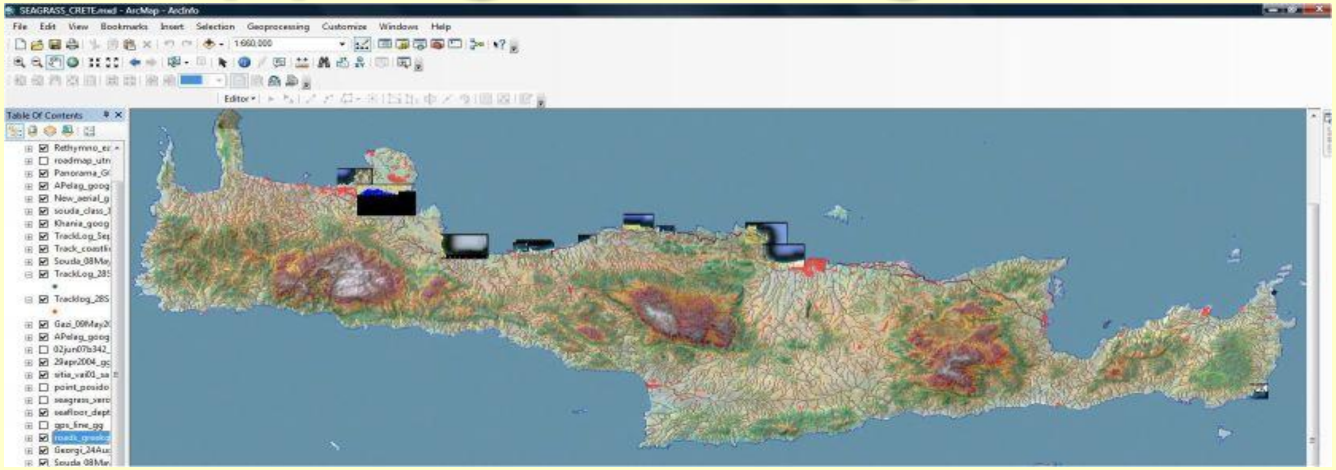
Answering *Research Question 2* (continue)

- Studies of simulated spectra of the seagrass, made using WASI modeller, demonstrated best results at CZCS scanner, especially devoted to the measurement of ocean color. The spectrum of *P.oceanica* reflectance, simulated for CZCS, covers the wavelength interval of 400–800 nm, and is distinctive for various depths.

The second research question of this MSc thesis ("Do broadband and hyperspectral sensors provide enough radiometric information for spectral discrimination of seagrass, and therefore, can be used for mapping of P.oceanica ?") is therefore answered with "yes",

and the most suitable sensor is the Coastal Zone Color Scanner CZCS

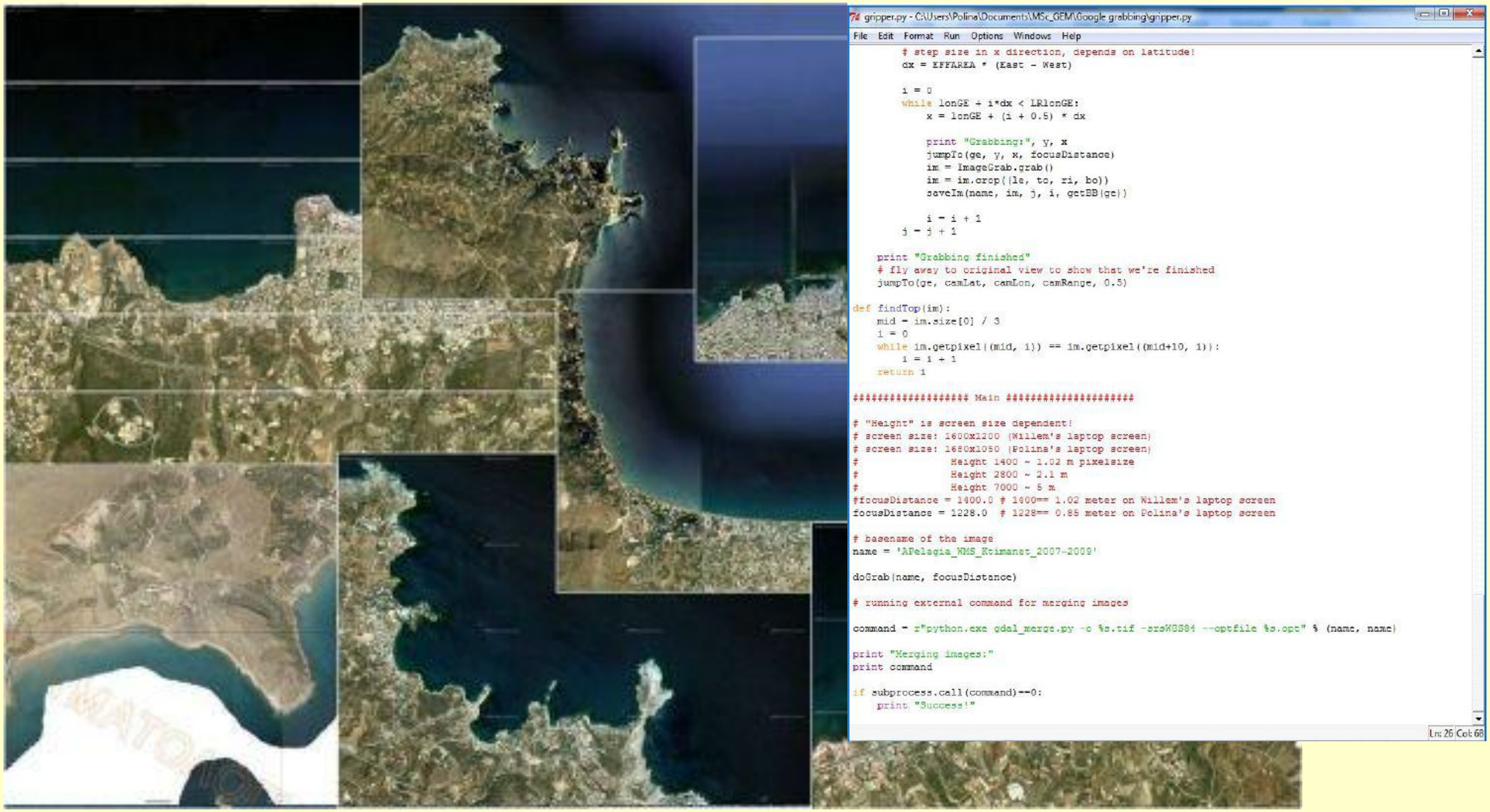
GIS mapping of seagrass



- Arc GIS 10.0 has been used for data incorporation, storage, analyses, visualizing and mapping.
- Data integration: the integrated approach used in this research work has high potential as a means to monitor changes in seagrass landscape occurring in shallow waters over Crete area.
- Current work integrated data from various sources: high resolution aerial color *Google Earth* images, spaceborne satellite imagery, assessment of spectral signatures using WASI software and their statistical analysis, image processing by means of Erdas Imagine and Arc GIS based mapping.
- The final mapping has been supported in ArcGIS through the data exporting, conversion and integration in one GIS-project

Google Earth aerial imagery for the seagrass mapping

Capturing aerial imagery from the Google Earth




```
        # step size in x direction, depends on latitude!
        dx = EFFAREA * (East - West)

        i = 0
        while lonGE + i*dx < LRlonGE:
            x = lonGE + (i + 0.5) * dx

            print "Grabbing:", y, x
            jumpTo(ge, y, x, focusDistance)
            im = ImageGrab.grab()
            im = im.crop((le, to, ri, bo))
            saveIm(name, im, j, i, getBB(ge))

            i = i + 1
        j = j + 1

    print "Grabbing finished"
    # fly away to original view to show that we're finished
    jumpTo(ge, camLat, camLon, camRange, 0.5)

def findTop(im):
    mid = im.size[0] / 3
    i = 0
    while im.getpixel((mid, i)) == im.getpixel((mid+10, i)):
        i = i + 1
    return i

################### Main #####################

# "Height" is screen size dependent!
# screen size: 1600x1200 (Willem's laptop screen)
# screen size: 1680x1050 (Polina's laptop screen)
#                Height 1400 ~ 1.02 m pixelsize
#                Height 2800 ~ 2.1 m
#                Height 7000 ~ 5 m
#focusDistance = 1400.0 # 1400== 1.02 meter on Willem's laptop screen
focusDistance = 1228.0  # 1228== 0.85 meter on Polina's laptop screen

# basename of the image
name = 'APelagia_WMS_Ktimanet_2007-2009'

doGrab(name, focusDistance)

# running external command for merging images

command = r"python.exe gdal_merge.py -o %s.tif -srsWGS84 --optfile %s.opt" % (name, name)

print "Merging images:"
print command

if subprocess.call(command)==0:
    print "Success!"
```

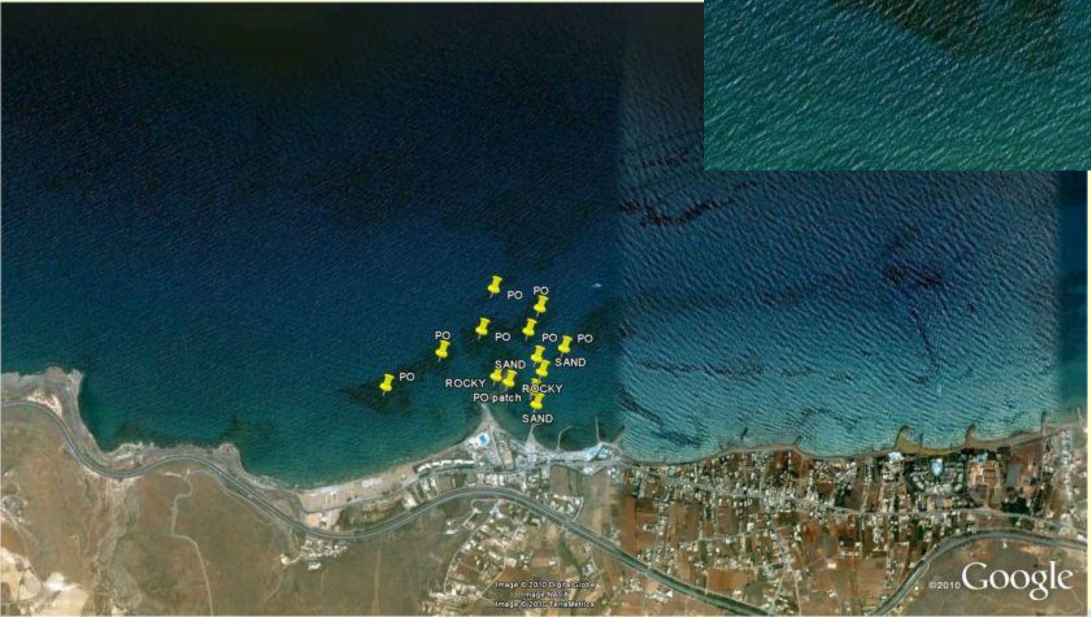
Image processing using Erdas Imagine

The *in-situ* field large-scale matte-level level of seafloor monitoring was then upscaled to airborne *Google Earth* aerial imagery interpretation, to provide a meadow-level view of seagrass landscapes.

enables to analyze environmental changes within seagrass landscapes based on data from various sources: aerial and satellite images, geographically referenced maps of Crete island and results of images classification showing areas of seagrass distribution.

Seafloor classification on Google Earth imagery

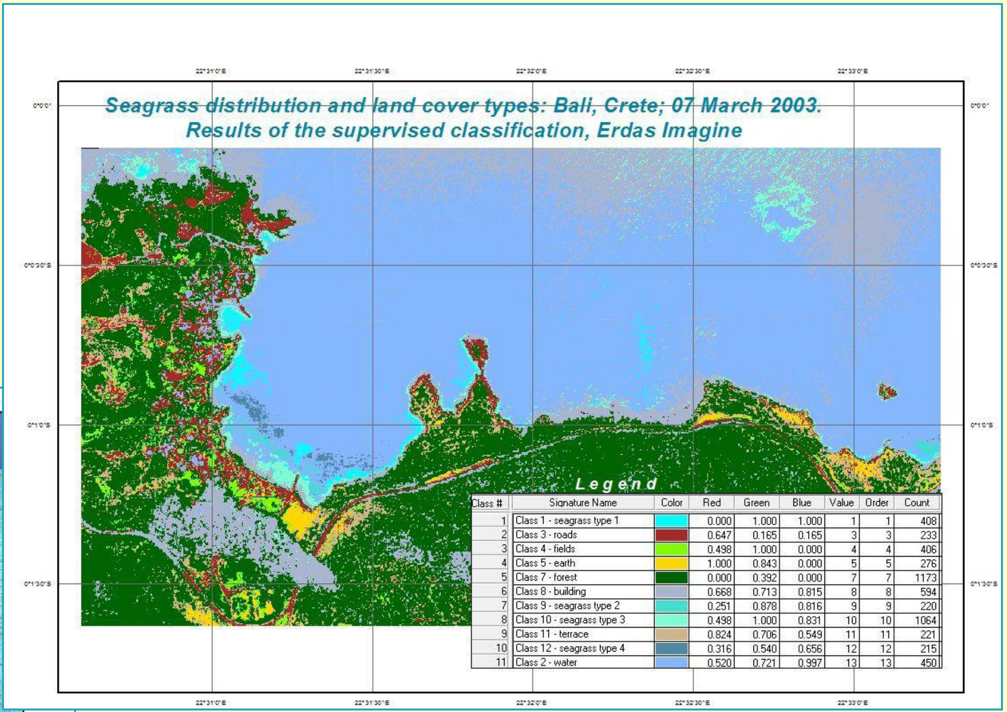
Supervised classification is based on training sites of seafloor cover types. Spectral properties were used for classification of seafloor types: carbonate sand, patches and meadows of seagrass *P.oceanica* and rocks.



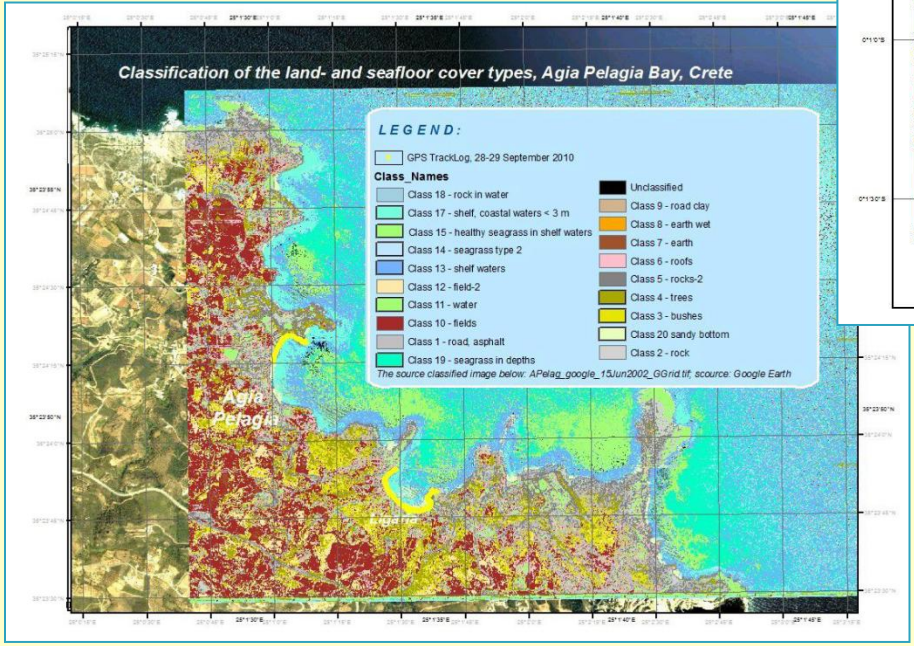
The classification is based on the properties of seafloor cover types, incl. *P.oceanica* seagrass: brightness, colour, texture and structure of the seagrass mattes.

Image processing using Erdas Imagine

The analysis of the imagery of the Cretan coasts is based on the images classification and is aimed to investigate the distribution of the seagrass *P.oceanica* within the research area.



Supervised classification



Unsupervised classification

Accuracy assessment for unsupervised classification

Overall Kappa (k) accuracy is calculated using the formula: $\Sigma A = N$, where A is number of correctly mapped points (172) and N is the total number of points (270). Thus, according to the results the overall accuracy= 172/270= 0.6370, which is 64%.

Overall accuracy for unsupervised classification =64%.

Users accuracy (Reliability of classes) varies between 0.22 and 0.94 depending on class, which proves that supervised classification has better results for seagrass mapping than the unsupervised classification.

Producer accuracy lies in interval between 0.52-0.77, according to class.

Correctly classified	Rocky bottom	Shelf, < 3m	Healthy seagrass	Seagrass *P.oceanica*	Carbonate sand	Shelf waters, 0-3m	Shelf waters, 3-7m	Deep waters, > 7m	Field: corn, greens	Roads: asphalt+ground	Seagrass, other> 3m	Ground	Buildings (roofs)	Trees	Bushes	Total	κ producer accuracy
Rocky bottom	**14**	2	0	0	3	0	0	0	0	1	0	2	0	1	1	24	0.58
Shelf, < 3m	0	**12**	0	3	1	2	0	0	1	0	0	0	1	0	0	20	0.60
Healthy seagrass	0	1	**10**	3	2	0	0	0	1	0	2	0	0	0	0	19	0.52
Seagrass *P.oceanica*	0	1	1	**13**	0	1	0	0	1	0	2	0	0	1	1	21	0.62
Carbonate sand	2	0	0	0	**16**	0	0	0	0	0	0	2	0	0	0	20	0.80
Shelf waters, 0-3m	0	3	0	0	0	**9**	2	0	0	0	0	0	0	0	0	14	0.64
Shelf waters, 3-7m	1	2	0	0	0	3	**8**	1	0	0	0	0	0	0	0	15	0.53
Deep waters, > 7m	1	1	0	0	1	2	3	**16**	0	0	1	0	0	0	0	25	0.64
Fields: corn, greens	0	0	0	0	0	0	0	0	**14**	0	0	0	0	3	4	21	0.66
Roads: asphalt+ground	1	0	0	0	1	0	0	0	0	**5**	2	0	0	0	0	9	0.55
Seagrass, other> 3m	0	0	0	3	0	0	0	0	0	0	**24**	2	0	1	1	31	0.77
Ground	1	0	0	0	0	0	0	0	0	0	0	**11**	3	1	1	17	0.65
Buildings (roofs)	0	0	0	0	2	0	0	0	0	0	0	0	**9**	2	3	16	0.56
Trees	0	0	2	0	0	0	0	0	0	0	0	0	0	**7**	3	12	0.58
Bushes	0	0	0	0	0	0	0	0	0	0	0	0	0	2	**4**	6	0.66
Total	20	22	13	22	26	17	13	17	17	6	31	17	13	18	18	270	
κ user's accuracy	0.70	0.55	0.77	0.59	0.62	0.53	0.62	0.94	0.82	0.83	0.77	0.65	0.69	0.39	0.22	-	**0.64**

Accuracy assessment for supervised classification

Correctly classified	Seagrass-1	Roads	Fields	Earth	Forest	Buildings	Seagrass-2	Seagrass-3	Terrace	Seagrass-4	Water	Total	κ producer accuracy
Seagrass *P.oceanica*	**22**	0	0	0	0	0	2	1	0	1	1	27	0.81
Roads	0	**18**	0	3	1	2	0	0	0	0	0	24	0.75
Fields	0	1	**10**	0	3	0	0	0	1	0	0	15	0.66
Earth	0	1	1	**13**	0	1	0	0	1	0	0	17	0.76
Forest	0	1	1	1	**9**	0	0	0	1	0	0	13	0.69
Buildings	0	0	2	0	1	**24**	0	0	1	0	0	28	0.85
Seagrass-2	3	0	0	0	0	0	**33**	2	0	2	2	42	0.78
Seagrass-3	1	0	0	0	0	0	1	**27**	0	1	1	31	0.87
Terrace	0	2	3	1	0	1	0	0	**19**	0	0	26	0.73
Seagrass-4	1	0	0	0	0	0	2	2	0	**37**	1	43	0.86
Water	2	0	0	0	0	0	1	1	0	1	**14**	19	0.74
Total	29	23	17	18	14	28	39	33	23	42	19	285	-
κ user's accuracy	0.76	0.78	0.59	0.72	0.64	0.86	0.85	0.82	0.83	0.88	0.74	-	**0.72**

Overall Kappa (k) accuracy is calculated using the formula: Σ A=N, where A is number of correctly mapped points (226) and N is the total number of points (285).

Overall k accuracy for supervised classification= 72%.

Users accuracy (Reliability of classes) varies between 0.59 and 0.88 depending on class. Producer accuracy lies in interval between 0.66-0.87 according to class as well.

Discussion

- An approach of the seagrass spectral analysis, monitoring and mapping has been taken in this work, which integrates various research techniques and tools, combining remote sensing methods of spectral analysis of the seafloor cover types, and knowledge of the ecology of *P.oceanica*, with the aim to develop a method of seagrass spectral optical discrimination for the seagrass mapping based on the aerial imagery classification
- The relationship between the optical properties (spectral reflectance) of the seafloor cover types and hydrological parameters of the environment has been studied in order to analyse limitations and capabilities of broadband and narrowband sensors under the conditions of altering environmental parameters
- For further development of the remote sensing based monitoring and mapping of the seagrass and other seafloor cover types it is desirable to consider upscale mapping with concern to bathymetry
- Landscape fragmentation and patchiness in seagrass meadows is caused, besides natural reasons, by the anthropogenic disturbances (e.g. ocean trawling).

Remote sensing for seagrass mapping

- Application of the remote sensing towards seagrass mapping in this work is based on the assumption that various types of the seafloor bottom have different characteristics of the reflectivity, which is visually expressed in distinct colours of the objects (seagrass *P.oceanica* and carbonate sand).
- In its turn, reflectivity of the sediments is affected by the water optical properties and content (suspended particles, microalgae, etc)
- Measuring optical properties of the seawater allows to calculate spectra of the objects and to discriminate them on the aerial and satellite images which enables spectral discrimination of submerged vegetation and other seafloor cover types

Upscale mapping of the seagrass landscapes

The general principles of the hierarchy within the seagrass landscapes are based upon the quantitative analysis of the spatial patterns, consisted by components and separate elements.

1) Bunches of individual shoots construct **patches** of seagrass
2) Patches are arranged into discrete clumps of **mattes** (at a scale of several *cm-meters*).
3) Mattes create **beds** with *l-100m* in diameter.
4) Seagrass beds are arranged into homogeneous, continuous seagrass **meadows** that may reach in size from tens up to hundreds *meters* and even extend over kilometre-wide areas.

Meadows are sometimes defined as landscapes.

Conclusion

- The goal of this MSc research was to explore the perspectives, advantages and limitations of the narrowband and broadband sensors for the environmental mapping and monitoring of *P.oceanica* seagrass along the coasts of Crete Island.
- The methodology of the spectral discrimination of seafloor cover types is..
  - designed in the frame of this research
  - based on the application of the remote sensing RTM techniques,
  - uses data from broadband sensors, hyperspectral radiometers for measurements of optical properties of the seawater,
  - applies categorical and continuous statistical analysis for the data processing and
  - uses GIS raster based software for images visualization, classification and analysis

Research outcome

- The results of this work demonstrated that
- the application of the remote sensing data from the broadband sensors is highly advantageous for the seagrass mapping,
- the spectral discrimination of *P.oceanica* from other seafloor cover types is possible at diverse and changing environmental conditions (water column height),
- *P.oceanica* is spectrally distinct from other seafloor types (carbonate sand) at varying environmental conditions, as well as from other seagrass species (*Thalassia testudinum*)
- The RTM software is a powerful means for analyzing spectral signatures of various seafloor types and enabling simulations of data received from broadband and narrowband remote sensors.

Future Directions & Recommendations

- To extend the research area towards the whole Crete Island
- To extend the temporal period of the imagery coverage, once the data are available
- To apply various classifications methods for the available imagery in order to compare accuracy and precision of results
- To consider various factors determining the effect of the ecology, health and spatial distribution of *P.oceanica* (besides bathymetry and chemical content of seawater)
- In upscaling to the small-scale mapping level further environmental variables need to be considered: health conditions of the seagrass, hydrology, geomorphology
- Other RTM software may be tested and the modelling outcomes compared
- Application of various open source GIS could be very useful for analysis of accuracy of the results

Major Influences for this work (most important works from Bibliography)

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Thank you for attention.

Questions ?