Remote radiological assessment in the marine environment: A pilot study based on Cs-137 measurements and satellite observations in the Aegean Sea

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Outline

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- Study Area
- Data Retrievals
- Methodology
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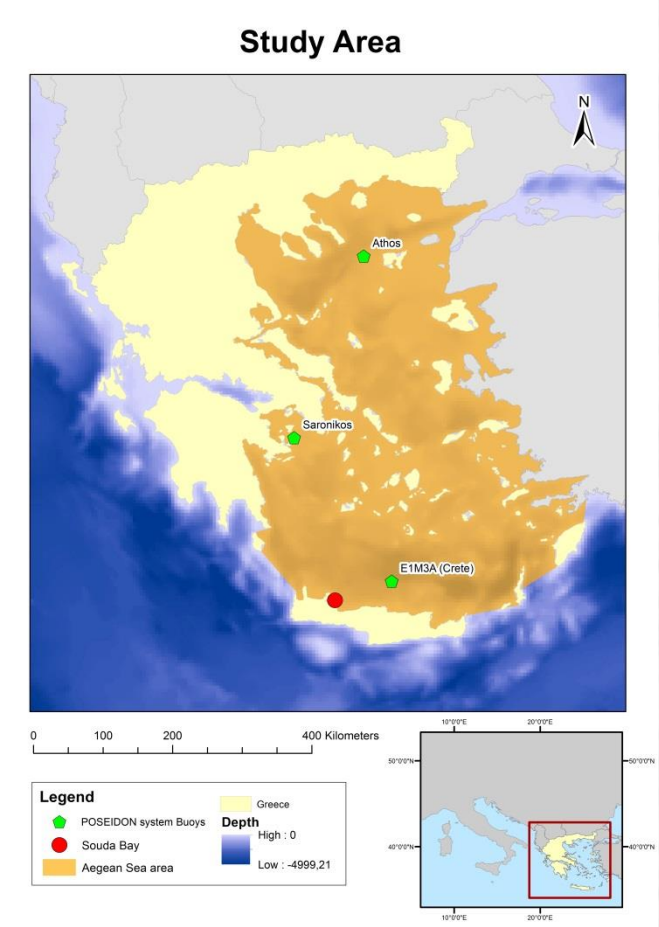
Introduction

- Satellite systems have a wide range of applications, with the most known application the environmental monitoring.
- However, the dispersion of radionuclides cannot be directly detected and monitored by satellite systems.
- Nevertheless, the levels of radionuclides in the marine environment, especially of the soluble ones like ^{137}Cs, are associated with physical, chemical and biological parameters of the natural environment such as sea surface temperature (SST), salinity, chlorophyll-A, weathering processes, pollutant charge, etc.
- Here, the first findings on the spatial correlations of ^{137}Cs measurements with MODIS L3 ocean data in the Aegean Sea are presented, whereas temporal correlations of ^{137}Cs measurements with MODIS L2 ocean and SMOS SST in Souda Bay area (island of Crete) are also shown. Time-series retrievals and correlations span the period between March 2012 and February 2015.

Study Area

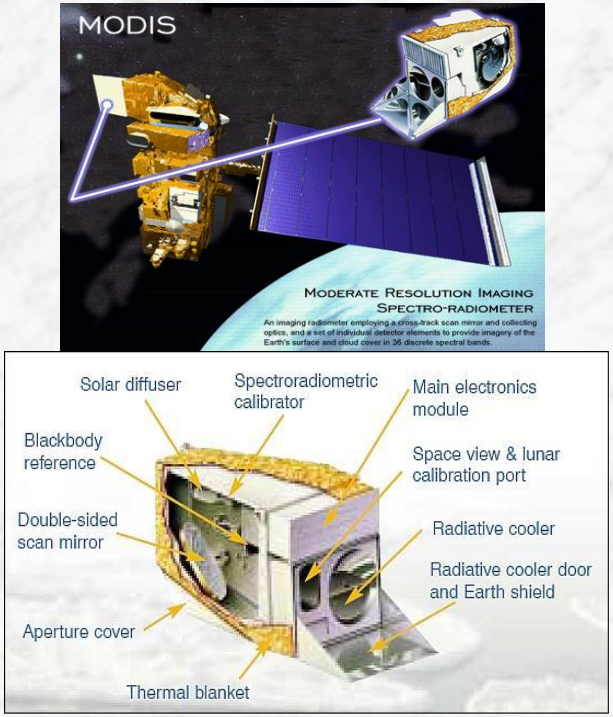


Map of the study area (Aegean Sea).

- Aegean Sea
- Souda Bay (Crete island).
- The Aegean Sea: located at the north-eastern part of the Mediterranean.
- Souda Bay: located in the Southern Aegean Sea, in the north-western part of the island of Crete. It was selected because, the most frequent measurements of ^{137}Cs activity concentration in sea water are provided by the Environmental Radioactivity Laboratory (ERL, NCSR“Demokritos”) database.
- POSEIDON database data are used for comparison.

Data Retrievals

Satellite data I

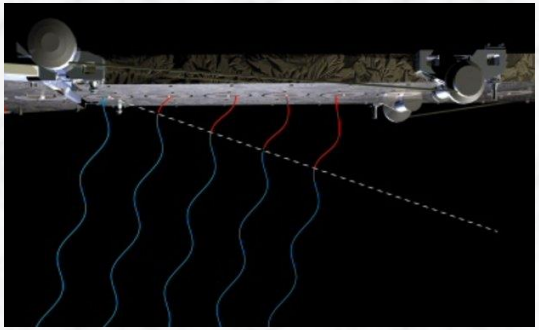


MODIS instrument on TERRA and AQUA satellites.
[*http://aqua.nasa.gov/about/images/modis.jpg* , *http://modis-sr.ltdri.org/rationale/sc2-modis.gif* , *https://directory.eoportal.org/web/eoportal/satellite-missions/t/terra*]

- MODIS (MODerate resolution Imaging Spectroradiometer) instrument
- Onboard NASA's TERRA and AQUA satellites.
- 36 spectral bands with wavelength from 0.4 μm to 14.4 mm.
- Spatial resolution varies from 250 m, 500 m and 1000 m depending on the spectral band.
- Worldwide coverage every 1-2 days.
- TERRA and AQUA satellites are a part of NASA's Earth Science program.

Data Retrievals

Satellite data II

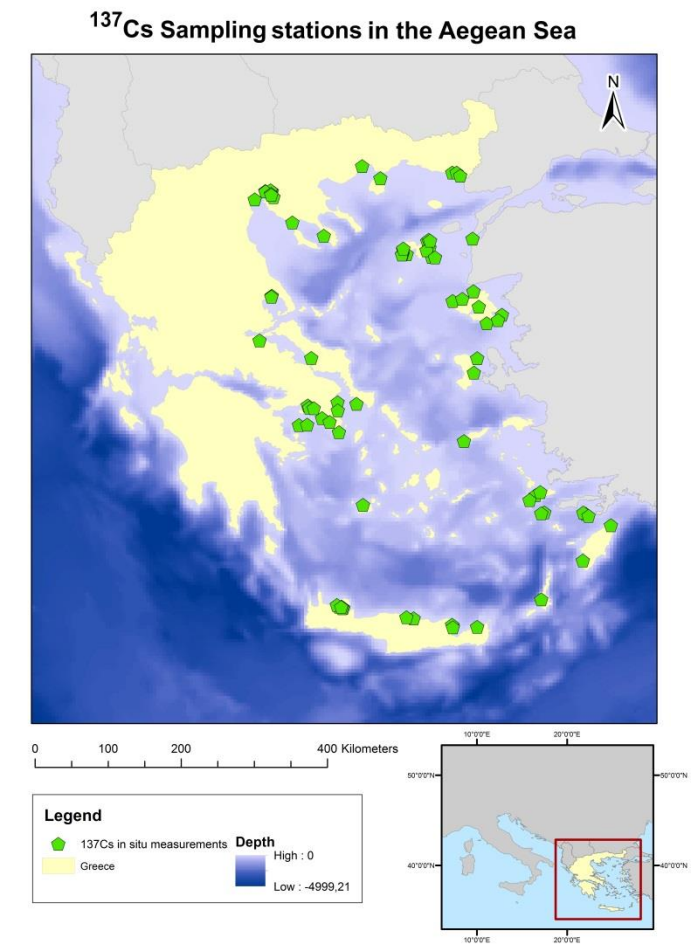


SMOS satellite and MIRAS instrument.
[http://due.esrin.esa.int/news/LogoImages/20130403145033.pjpeg , http://sciences.blogs.liberation.fr/.a/6a00e5500b4a6488330120a64ac053970b-pi , http://www.esa.int/var/esa/storage/images/esa_multimedia/images/2004/10/interferometry_principle/10267089-2-eng-GB/Interferometry_principle_large.jpg]

- SMOS (Soil Moisture and Ocean Salinity) satellite
- One of ESA's Earth Explorer missions.
- Launched on 02/11/2009.
- Data recording using the MIRAS (Microwave Imaging Radiometer using Aperture Synthesis) instrument.
- It records microwave emissions from the Earth's surface in L band (1.4 GHz, and wavelength of 21 cm).
- 69 receivers placed in a Y shaped antenna.
- Spatial limitations due to RFI (Radio Frequency Interference).

Data Retrievals

^{137}Cs data

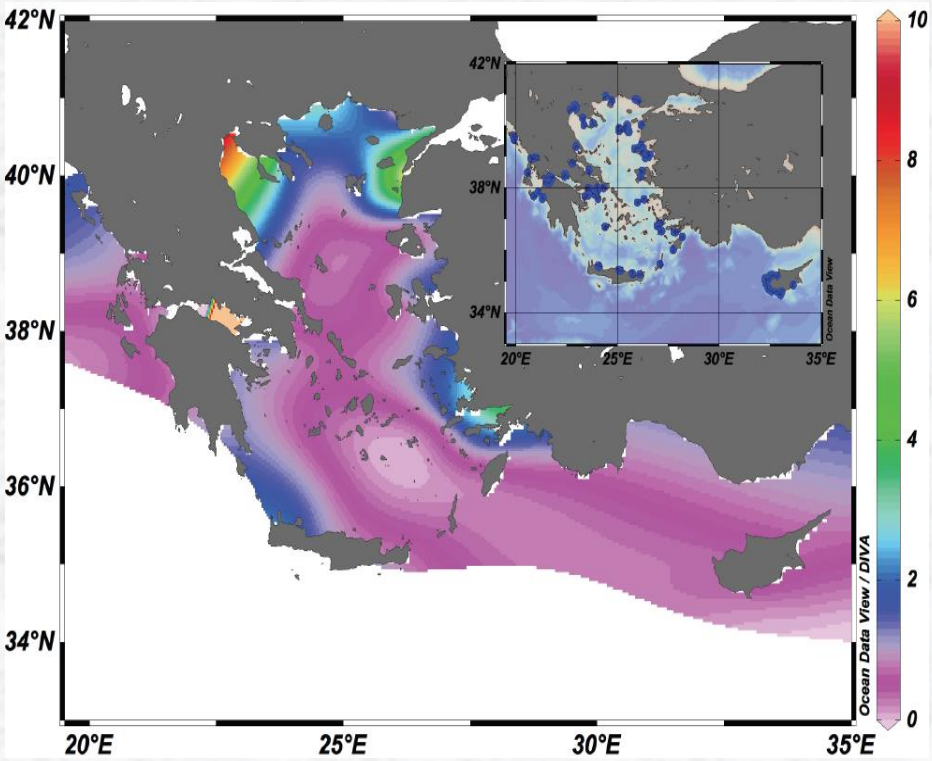


^{137}Cs sampling stations.

- Cesium is an alkali metal
- ^{133}Cs is the only stable isotope
- ^{137}Cs is a long lived radionuclide with a half-life = 30.2 years.
  - ✓ It is an atomic fission product of both uranium (U-) and plutonium (Pu-) reactors.
  - ✓ It is released to the environment as a result of global fallout, nuclear weapons testing, nuclear waste, nuclear accidents, nuclear powered vessels accidents (Florou, 2010).
  - ✓ It is an important indicator of radioactive pollution in aquatic environments (Ashraf, 2014).

Data Retrievals

^{137}Cs data

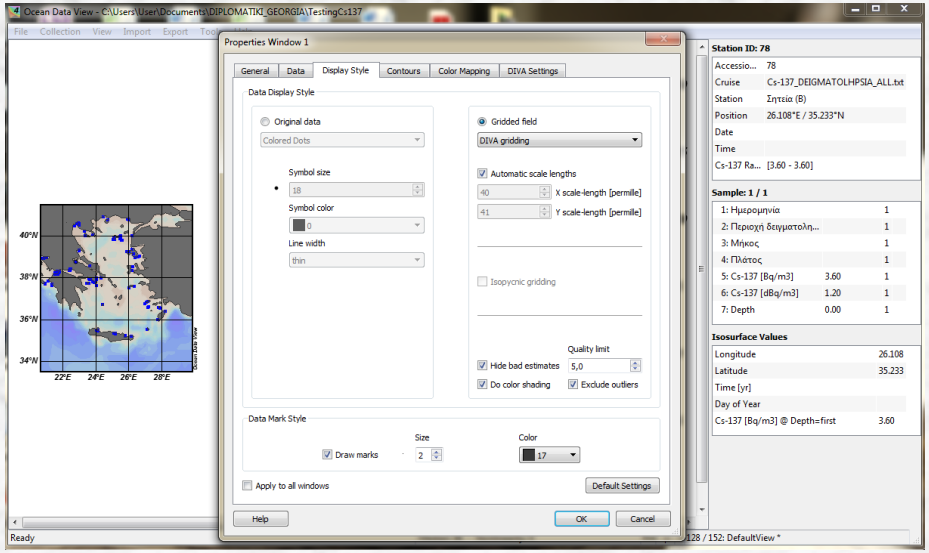


^{137}Cs activity concentrations (Bq m^{-3}) in the Aegean and Ionian Seas for 2014 corrected using the effective half-life reported by Florou et al., 2014 .

- The activity concentrations of ^{137}Cs used in this study were mainly retrieved from the ERL's database of ^{137}Cs.
- New sea water samplings and laboratory analyses were performed in order to retrieve additional measurements.
- In the Aegean Sea, a total of 85 sampling points were considered.
- The sea water samples were analysed for ^{137}Cs using an ammonium molybdophosphate (AMP) radioanalytical preconcentration method (Folsom et al., 1970).
- Subsequently the treated samples were measured in a gamma spectrometry system (described in methodology).
- All measured activity concentrations of ^{137}Cs were corrected using the effective half-life of 7.2 years (Florou et al., 2014).

Data Retrievals

Ocean Data View (ODV)

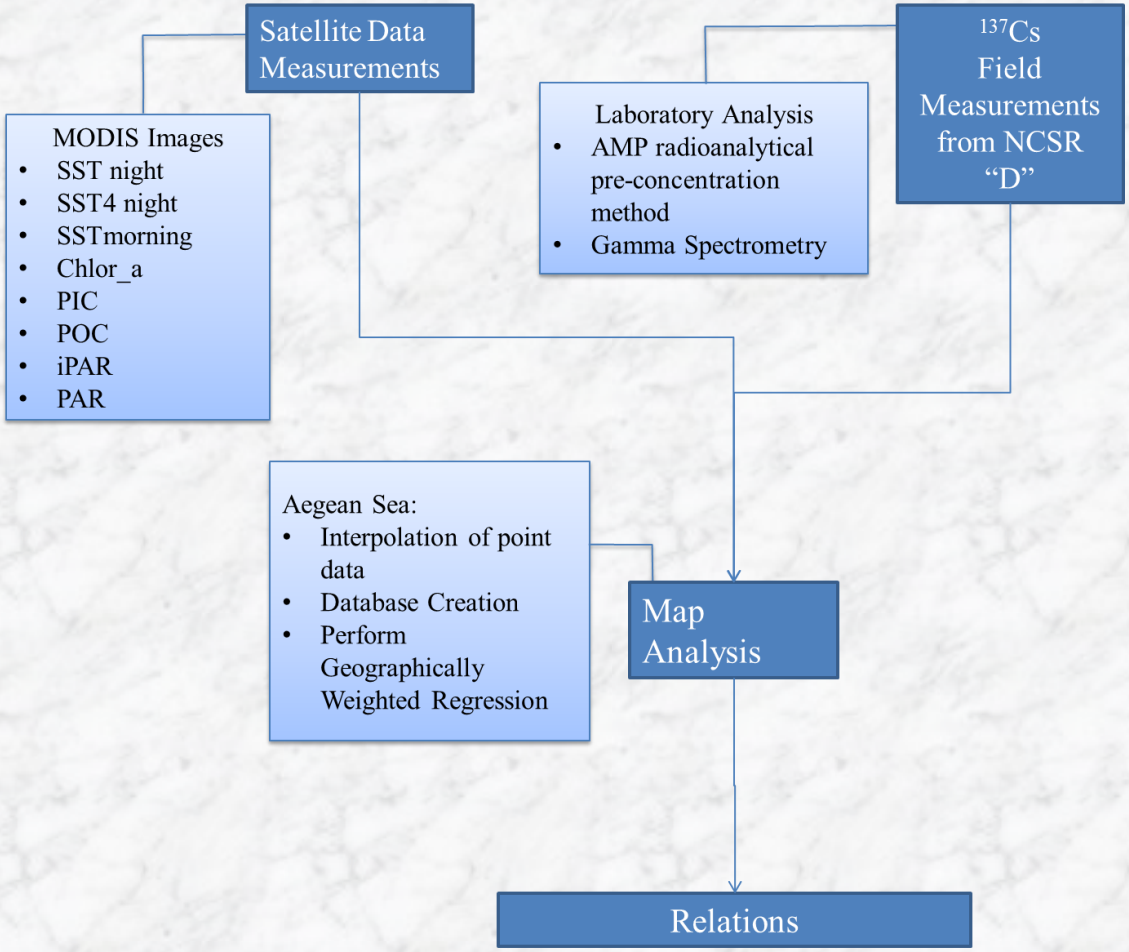


Ocean Data View (ODV) software.
(ODV, 2014. Available at: http://odv.awi.de.)

- Ocean Data View (ODV, 2014) was used for the mapping of ^{137}Cs by ERL for fig.9. Data-Interpolating Variational Analysis (DIVA, 2014) gridding method was used, which is more advanced and computationally more expensive than the other methods.
- DIVA software, used within ODV, has been developed at the University of Liege and offers a number of advantages over the weighted averaging methods built into ODV.
- DIVA allows analyzing and interpolating data in an optimal way, comparable to optimal interpolation (OI). Unlike OI, DIVA also takes into account coastlines and bathymetry features to structure and subdivide the domain on which estimation is performed. Calculations are performed on a finite element mesh adapted to the specific gridding domains.
- The necessary DIVA tools to generate the finite element mesh, optimize the parameters of the analysis and calculate the gridded field are included in the ODV installation package,and the DIVA gridding option is available by default with a Z-variable.
- ODV creates all necessary files for the operation of DIVA automatically, runs the DIVA mesh generation and field estimation steps, and reads the DIVA output for graphical display of the field by ODV.ins.

Methodology

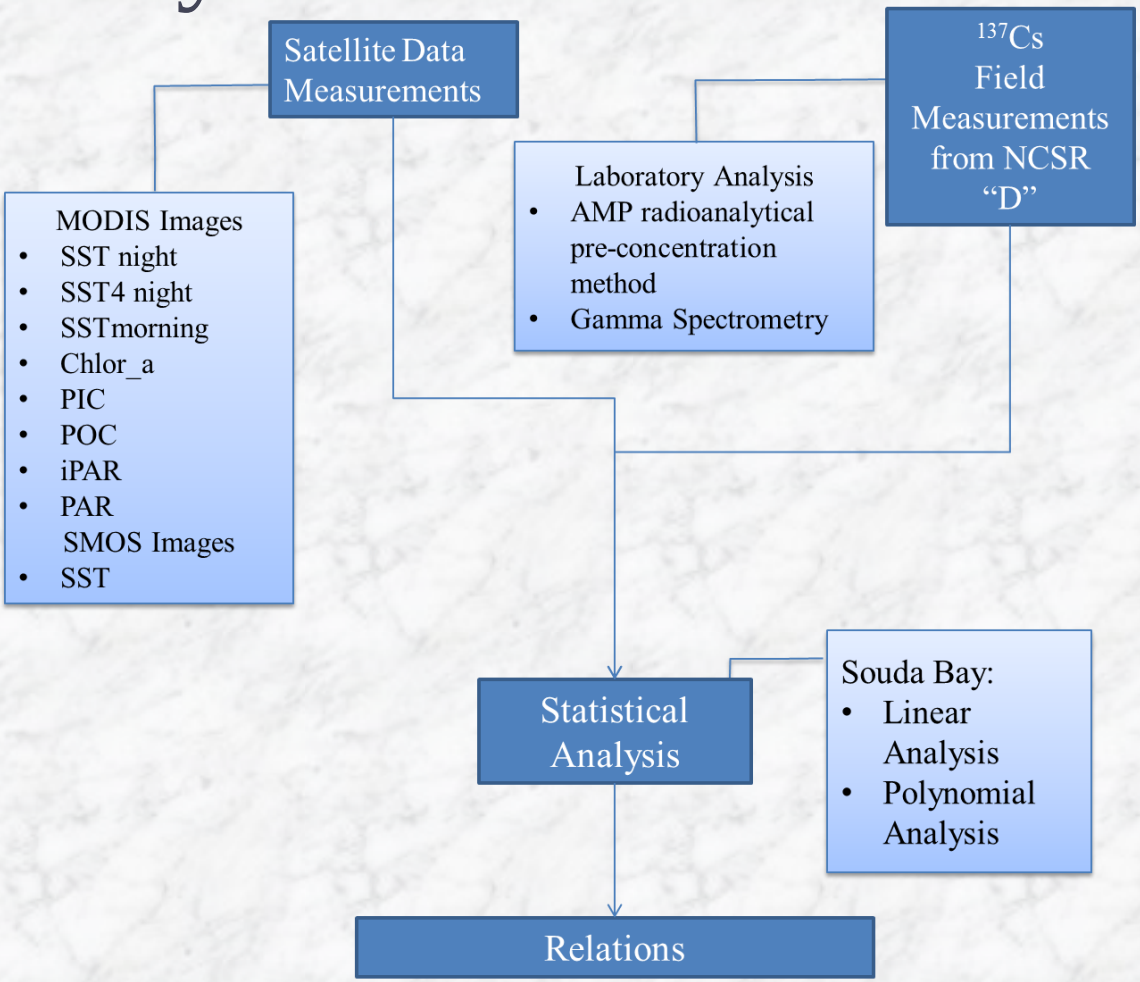
Aegean Sea



Flowchart of the methodology followed in the Aegean Sea.

Methodology

Souda Bay



Flowchart of the methodology followed in Souda Bay.

Methodology

Laboratory Analyses of samples

- AMP radioanalytical preconcentration method:
  - This method is based on the ion-exchange of dissolved ^{137}Cs with ammonium molybdophosphate $[(NH_4)_3P(Mo_3O_{10})_4]$ which is an insoluble yellow reagent.
  - 60-100 L of seawater is sampled.
  - Acidification of the sample to pH 1.5.
  - 0.5 Bq ^{134}Cs per litre of sample is added as carrier and yield tracer.
  - 400 mg microcrystalline AMP per litre of sample is added for co-sinking via ion exchange with Cs (Folsom et al., 1970; Florou et al., 1994).
  - The sample is continuously stirred for 15-30 min and then is allowed to precipitate for 48h.
  - The supernatant is pumped away and the AMP slurry is transferred to a 2 L beaker using 0.05 N HNO_3 rinsing it and is again allowed to precipitate.
  - After several transfers to decrease the volume of the sample, the slurry is finally placed in a calibrated measurement pot (radius 3.4 cm and height 2.0 cm) for gamma spectrometry and it is dried at 60 ^oC for 1h.
  - The yellow solid containing ^{137}Cs is then analysed using gamma spectrometry.

AMP method in the ERL laboratory.

Methodology

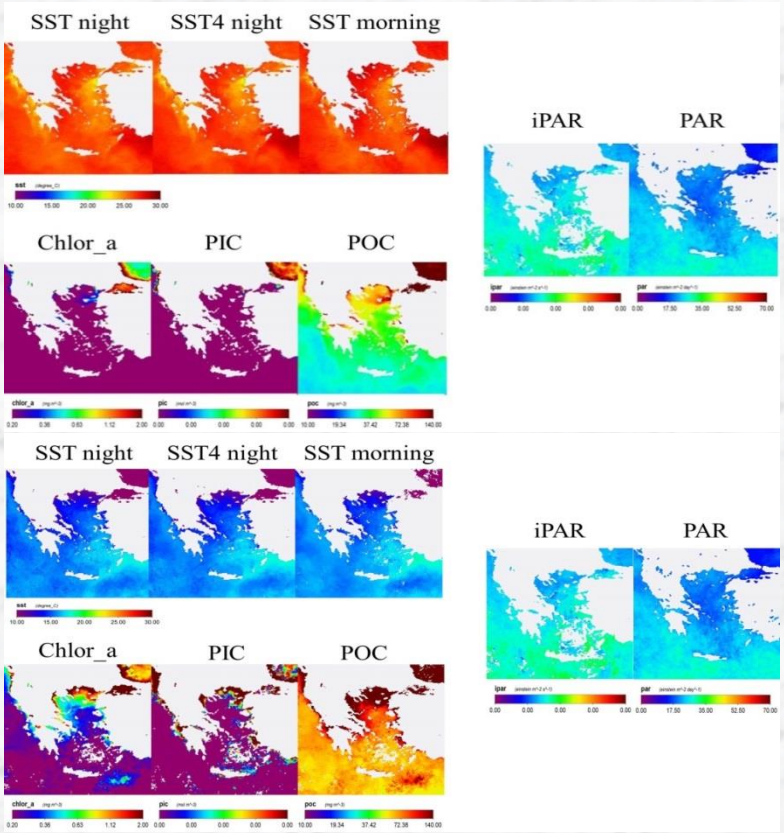
Gamma Spectroscopy measurements

- Gamma Spectrometry:
  - Gamma spectrometry was carried out using a Canberra system comprising of a High Purity Germanium (HPGe) Detector System.
  - This system has an efficiency of 90% (relative to a 3” x 3” Nal (Tl) crystal) and resolution of 2.1 keV at the 1.33 MeV photopeak of ^{60}Co.
  - The HPGe detector is connected to an 8k multi-channel analyzer operated with the Genie 2000 software.
  - The energy calibration has been performed using standard active sources of ^{22}Na, ^{54}Mn, ^{57}Co, ^{60}Co, ^{109}Cd, ^{133}Ba, ^{137}Cs, ^{241}Am covering an energy range up to 2000 keV, necessary for a range of different activities in the laboratory.
  - The efficiency of the detector was calculated using a standard active source of ^{226}Ra (240 Bq) under the same geometry with the pot used for the measurement of the samples.
  - The samples were measured for 70,000 s.

γ- spectrometry laboratory.

Methodology

MODIS Images

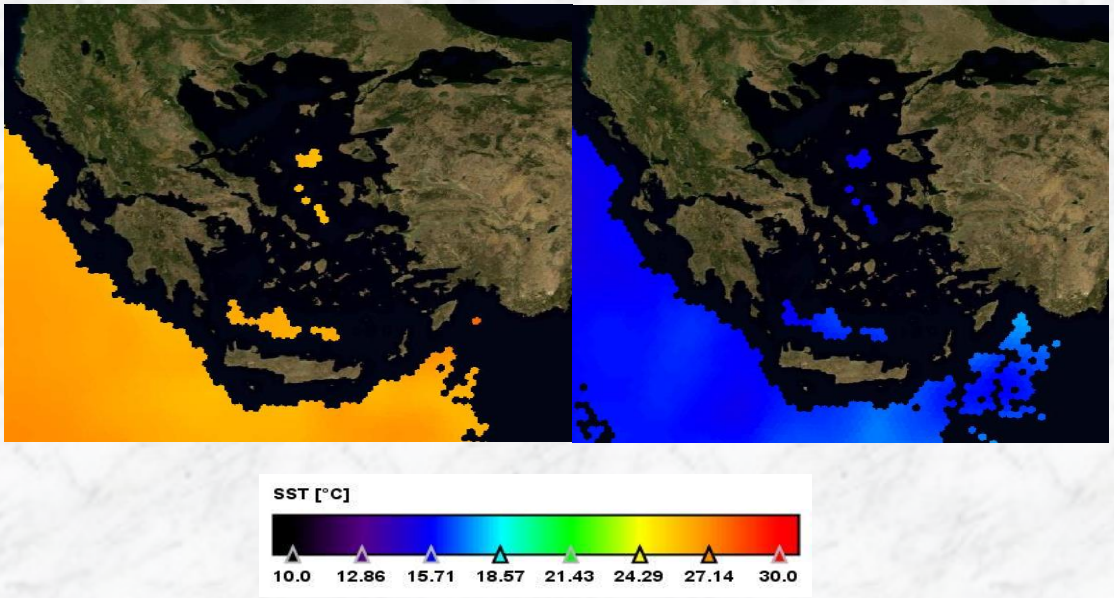


MODIS AQUA L3 SSTnight, SST4night, SSTmorning, Chlor_a, PIC,POC, iPAR and PAR images of August 2014 (above) and February 2015 (below).

- L2 and L3 MODIS ocean products were used to extract information on SST and ocean colour parameters.
- In particular, each SST product comprises short-wave and long-wave SST measurements, where the long-wave SST algorithm produces SST morning and SST night. The short-wave SST at 4μm (SST4 night) retrieval is complementary to the 11μm measurement SST night.
- The MODIS ocean colour products comprise derived chlorophyll-A (Chlor_a), particulate inorganic carbon (PIC), particulate organic carbon (POC) concentrations and instantaneous and daily photosynthetically available radiation (iPAR, PAR).

Methodology

SMOS images in Souda Bay

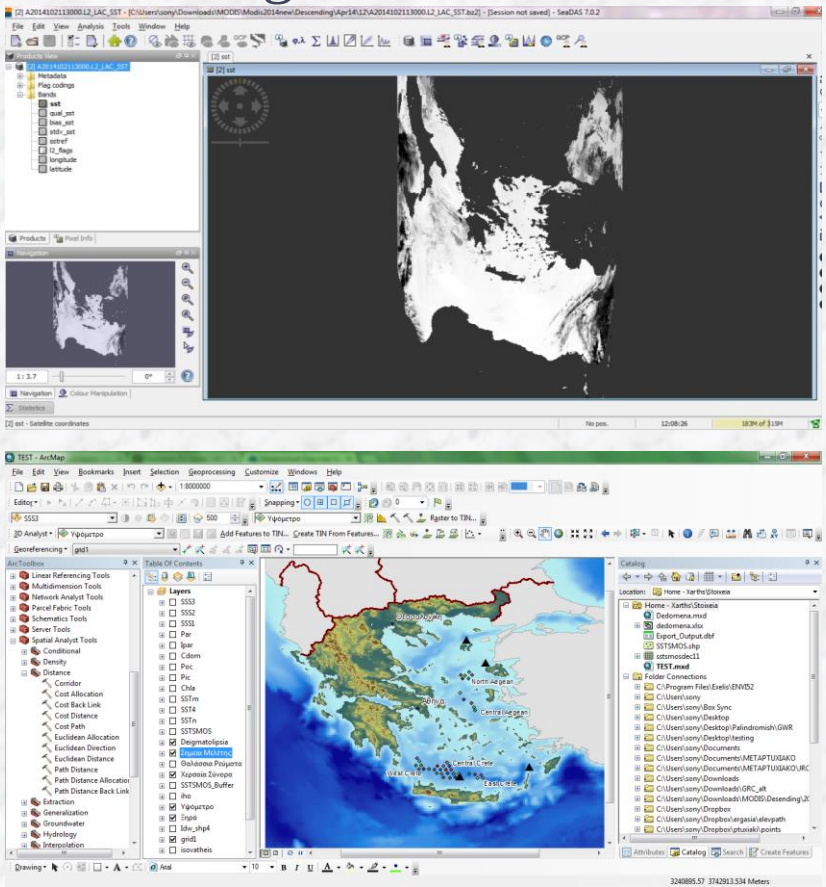


SMOS L2 SST images for 01/08/2014 (left) and 02/02/2015 (right).

- SMOS data are L2 Sea Surface Temperature (SST) images.
- Images were retrieved for the time period of March 2012 to February 2015.
- Images have a spatial resolution of 50 km.
- 39 points in the Aegean due to RFI spatial limitations.

Methodology

Satellite retrievals for Aegean Sea and Souda Bay / Map Analysis in the Aegean Sea



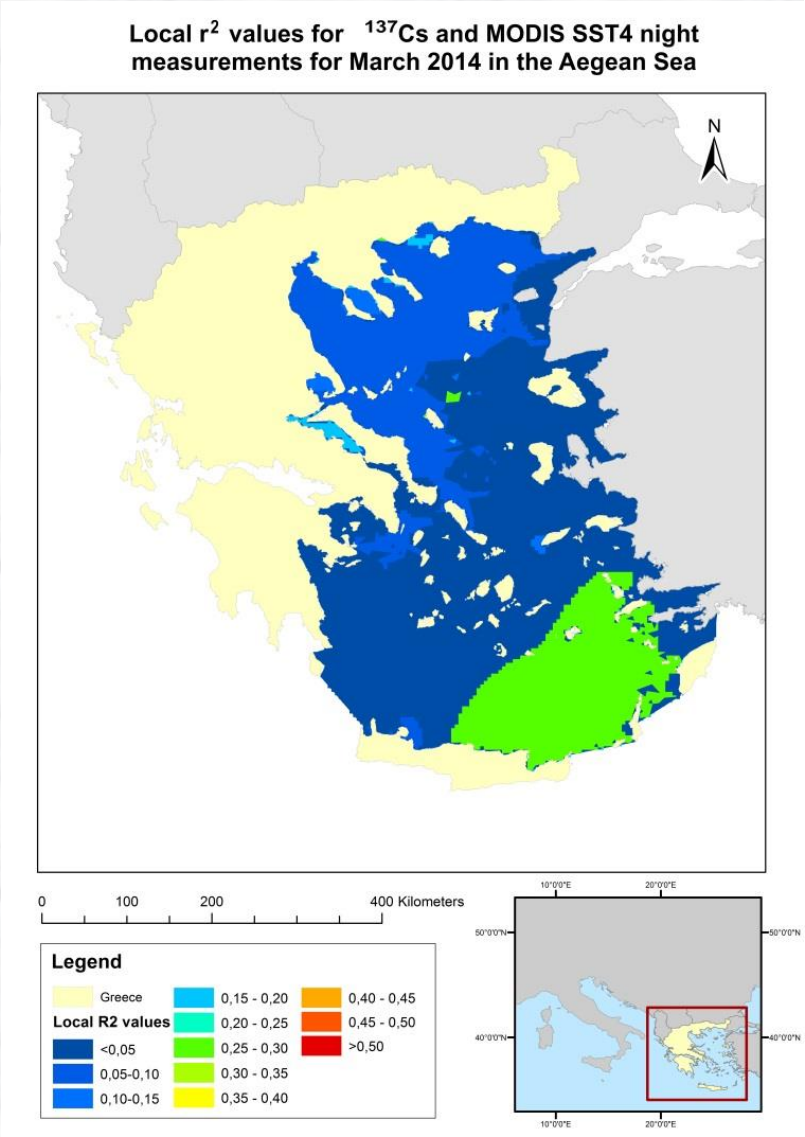
SeaDAS (above) and ArcMap (below) software.

- Data from satellite images were retrieved using SeaDAS and BEAM/VISAT software.
- Analysis into the GIS system consisted of creating a spatial database, interpolation of ^{137}Cs activity concentration data using the Inverse Distance Weighted (IDW) function and performing geographically weighted regression (GWR) in order to observe the relations between ^{137}Cs and satellite data.
- IDW uses a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each cell (Childs, 2004).
- GWR is a local form of linear regression that constructs a separate equation for every feature in the dataset (Brunsdon et al.,1998).

Results

Aegean Sea

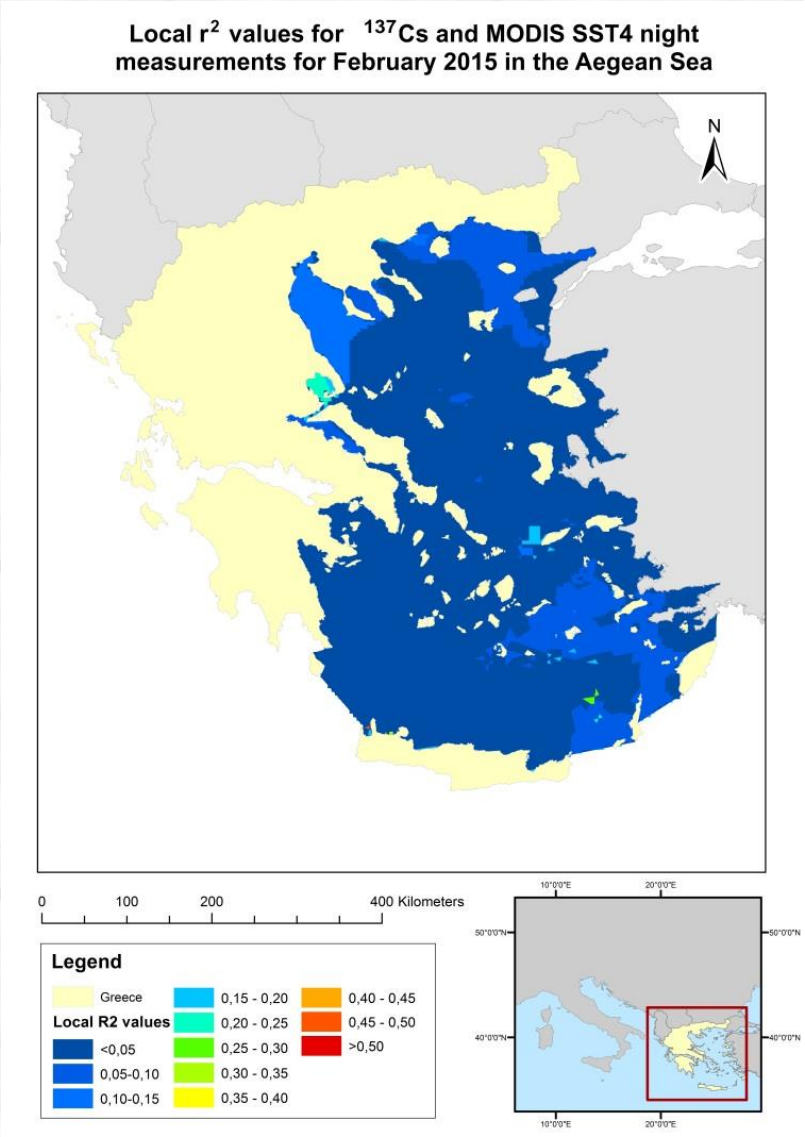
Local r^2 map for ^{137}Cs measurements and MODIS SST (4μm) night pass measurements for March 2014 .



Results

Aegean Sea

Local r^2 map for ^{137}Cs measurements and MODIS SST (4μm) night pass measurements for February 2015.



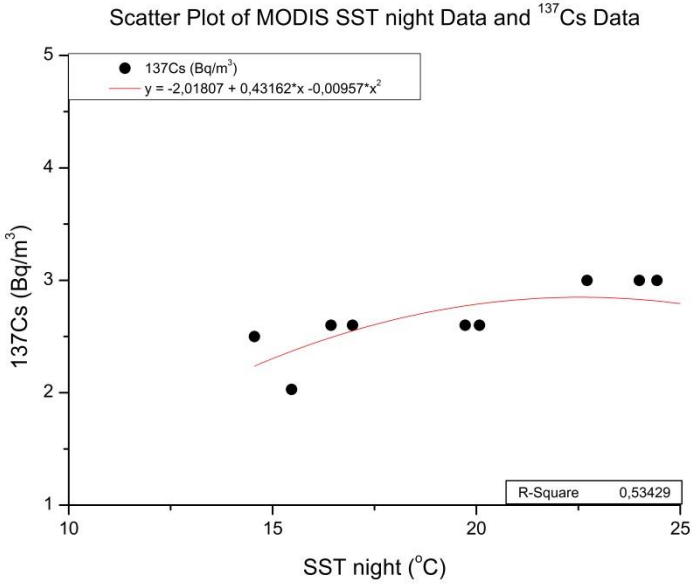
Results

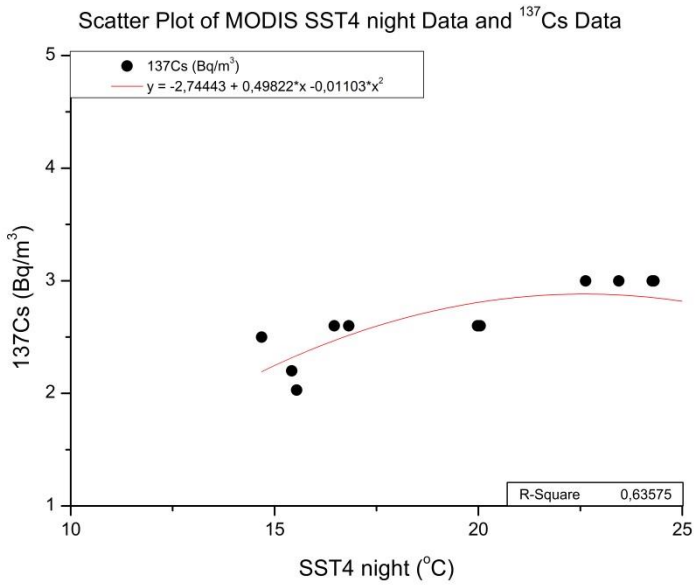
Aegean Sea

- Linear correlations between satellite and ^{137}Cs parameters:
  - $r^2 > 0.3$ observed mainly in the South Aegean area.
  - $r^2 > 0.3$ variable in time but with no evident seasonal pattern
  - highest r^2 values between ^{137}Cs and MODIS SST4 night ($r^2=0.51$)

Results

MODIS Souda Bay

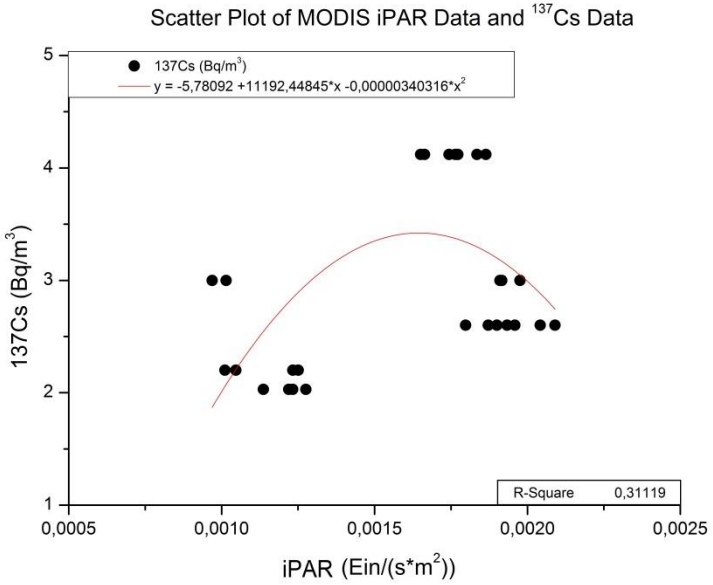


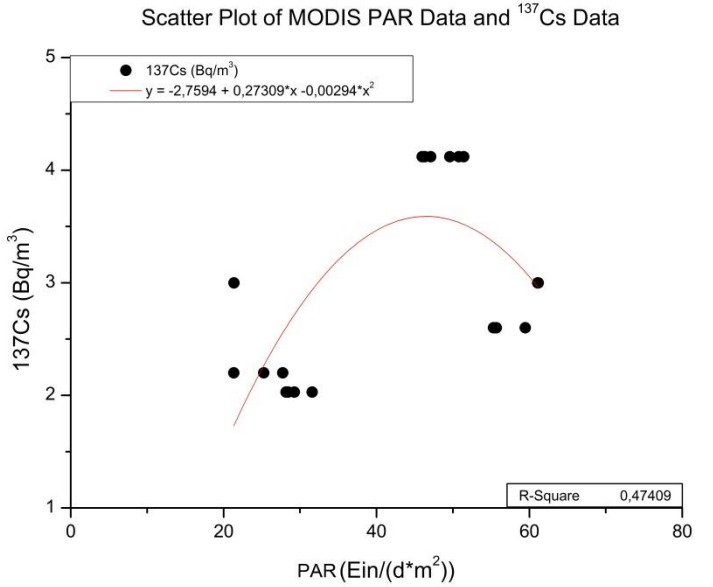


Graphs showing the second degree polynomial relation between ^{137}Cs concentrations and SST measurements: From left to right: MODIS SST night pass and SST4 night.

Results

MODIS Souda Bay

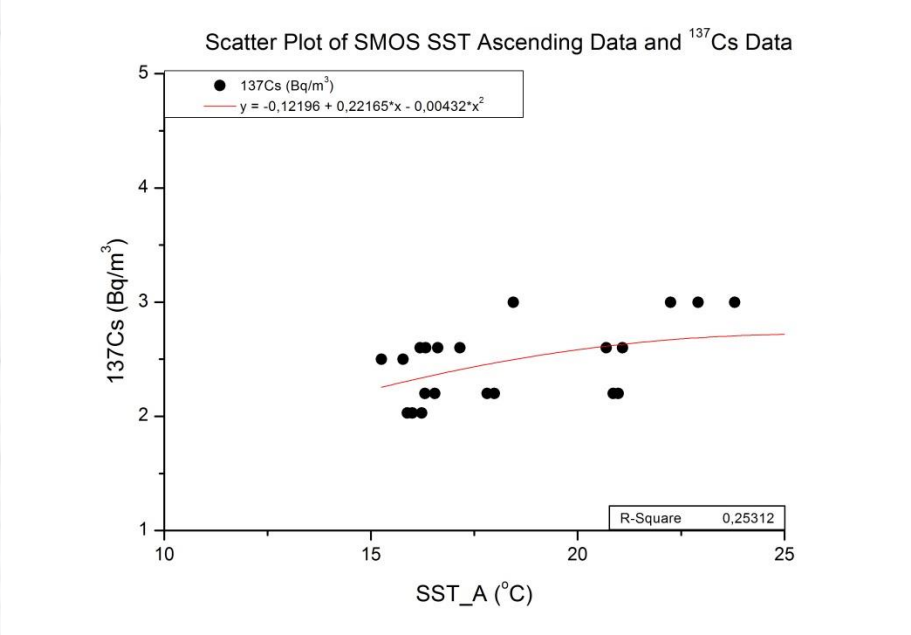




Graphs showing the second degree polynomial relation between ^{137}Cs concentrations and iPAR and PAR measurements: From left to right: MODIS iPAR and PAR.

Results

SMOS Souda Bay (40km away from sampling station)



Graph showing the second degree polynomial relation between ^{137}Cs concentrations and SMOS SST measurements.

Results

Souda Bay

- The statistical analysis shows that there is a significant difference between linear and polynomial regression results. Results show that:
  - The linear correlations of ^{137}Cs activity concentrations in Souda Bay with MODIS SST4 night parameter displays a r^2=0.34.
  - The best results of the second degree polynomial correlations of ^{137}Cs activity concentrations in Souda bay appear with the parameters of MODIS SST4 night (r^2= 0.64), SST night (r^2=0.53) and PAR (r^2=0.47).
  - Correlations of ^{137}Cs and MODIS ocean color parameters (i.e.: Chlor_a, PIC, POC) showed uncertain results, whereas SMOS SST data were aquired 40km far from Souda Bay sampling station, showed no statistical significance.
  - More detailed research is on going for real time measurements in order to justify and expand the findings.

Conclusions

- Polynomial regressions such as the second degree polynomial seem to describe better the relations between satellite derived sea parameters and ^{137}Cs activity concentrations than the linear regression. Thus, analysis using MATLAB in combination with GIS will be performed for point to point regression.
- Best non-linear correlations observed in Souda Bay with both MODIS night SST measurements and PAR (r^2 >0.5)
- This is an ongoing study
- Future work will include a more systematic and conjoined with simultaneous satellite passes, sea water sampling from the Aegean Sea, laboratory analyses and retrievals of ocean parameters from other satellite systems.
- An integrated GIS system including real time satellite data is expected to illustrate the remote radiological image ⇒ a toolbox including all the necessary parameters is under consideration.

Acknowledgements

- This ongoing study is being carried out in NOA and NCSR“D” in the frame of the coordinated Cat-1 Project SMOS.4681 of ESA which is acknowledged.
- NASA Goddard Space Flight Center, Ocean Biology Distributed Active Archive Center; 2010, L2 and L3 Ocean Data Products, Sea Surface Temperature and Ocean Color images for the time period 01/03/2012-28/02/2015.
- EC Student Grant recipient for attending the Living Planet Symposium 2016

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