Correlations of salinity, temperature and ocean colour variations from SMOS and MODIS satellite data in the Eastern Mediterranean for creating an inventory data base as to be compared to conservative radionuclides for remote recording under routine and case

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Abstract
A program concept has been developed to utilize sea surface salinity (SSS), sea surface temperature (SST) and ocean color parameters for the comparison to the inventory of artificial radionuclides, which are conservative and part of the sea salinity. As a pilot study, timeseries of SMOS and MODIS satellite measurements of ocean parameters are retrieved in order to investigate potential correlations to activity concentrations of 137Cs in the Aegean Sea (Greece) in order to develop an innovative tool for the remote radioactivity detection either for routine observations and emergency recordings. The presented first results are a part of this effort. Timeseries of SMOS sea surface salinity and temperatures as well as MODIS ocean colour parameters (e.g. SST and chlorophyll-a) spanning December 2011 to May 2014 are retrieved and correlated. The challenge of the study is the establishment of potential relations between satellite measurements of the marine environment and field readiological measurements resulting to a remote control tool for the radiological impact assessment under routine and event-case conditions. Results have shown that salinity retrievals currently present a high degree of noise and uncertainty due to high island density and RFI contamination. On the other hand, SST and chlorophyll distributions show inversely correlated seasonal patterns and a North to South gradients. Additionally, SST issued from SMOS and MODIS are highly correlated despite significant differences in spatial resolution and acquisition time in the day. Ongoing investigations for other spectral indicators of salinity changes from satellite measurements will provide additional information into establishing relations between satellite environmental monitoring and conservative radionuclide activity monitoring of the marine environment.

Keywords: Aegean Sea, SMOS, MODIS, SST, salinity, chlorophyll-a.

Introduction

The capability of ordinary Earth Observation satellites to record changes of ecological parameters in the environment is well documented. Nevertheless, radionuclide dispersion cannot be detected directly. However, the levels of radionuclides in the marine environment, especially for the soluble ones, are associated with physical and chemical parameters of the natural environment such as salinity, which is dependent on temperature, weathering processes and pollutant charge. Salinity controls water density and consequently is a major parameter for the marine radiological assessment. Even though the general relation between salinity and conservative radionuclide activities is well documented, investigations on global satellite data for sea surface salinity (SSS), sea surface temperature (SST) and other ocean color parameters (such as pigments and suspended matter) in space and time are very limited (Durrieu de Madron et al., 2011). Therefore, the investigation of the potential capability of EO satellites to document changes of salinity in the marine environment conjoint to field measurements processed and/or adapted to models of pollution dispersion, would be essential

in environmental monitoring and forecasting of potential impacts of accidental events. In this framework., the aim of the ongoing work is to adapt the integrated by space and time field measurements to satellite observations of sea surface salinity, sea surface temperature and chlorophyll-a variations, as to create a model applicable to the wide area of the Eastern Mediterranean and Black Sea for pollution evaluation and impact prediction (Florou et al., 2010; Evangeliou and Florou 2012). In particular, salinity is a critical parameter for weathering and anthropogenic influences in the marine environment such as rainfall, evaporation, river runoff, global fallout, accidental releases, interregional contamination through current circulation, which are potential impact sources for the marine environment.
Here we present the first results of the retrievals and correlations of timeseries spanning December 2011 - May 2014 of SMOS Sea Surface Salinity (SSS) and Sea Surface Temperature (SST) parameters and SST and chlorophyll concentrations issued from MODIS satellites in the Aegean Sea.

Materials and Methods

Study area

The Aegean Sea is an elongated embayment located at the northeastern part of the Mediterranean to the east of the Ionian Sea and to northwest of the Levantine Sea, bounded to the north and west by the Greek mainland, to the east by the Asian coasts and to the south by the islands of the Cretan Arc. In the north, it is connected to the Marmara Sea and Black Sea by the Dardanelles straits and Bosporus. The Aegean Sea displays a very irregular coastline and a very complicated topographic structure disclosing over 3000 greek islands and islets and an irregular sea floor. The most important water masses in the Aegean Sea are (i) the brackish and cold Black Sea Water (BSW) entering the northeastern part of the domain through the Dardanelles Straits, (ii) the very saline and warm waters of Levantine origin entering the southern Aegean through the Cretan Arc and (iii) the very dense deep waters that fill the bottom of the various sub-basins. Studies on water circulations, local sea surface salinity, chlorophyll variability patterns and temperature fields have been performed and presented in bibliography (Tsimplis et al, 2002, Skliris et al., 2011, Topouzelis et al., 2012, Velaoras et al., 2013, Borzelli et al., 2014).

Data processing

Sea surface salinity (SSS), sea surface temperature (SST) and chlorophyll-a (chla) measurements are retrieved over the Aegean and for the same dates from SMOS and MODIS Level 2 data for the period from December 2011 to May 2014.
Since SMOS resolves totally thirty nine pixels over the Aegean Sea, the parameter values are retrieved for the center coordinates of each pixel from both satellites. Once time series are created for each pixel, all pixels are grouped in five main geographic areas named North Aegean, Central Aegean, Eastern Crete, Western Crete and Central Crete (Fig. 1). Multiple curve analysis using linear averaging of monthly values is performed for the pixels included within the same geographic area. A new curve corresponding to the average curve for the parameter of each geographic area is then calculated. Finally, correlations are performed between SST values issued from SMOS and MODIS measurements and the corresponding coefficients of determination are presented for the best linear fit.

SMOS measurements

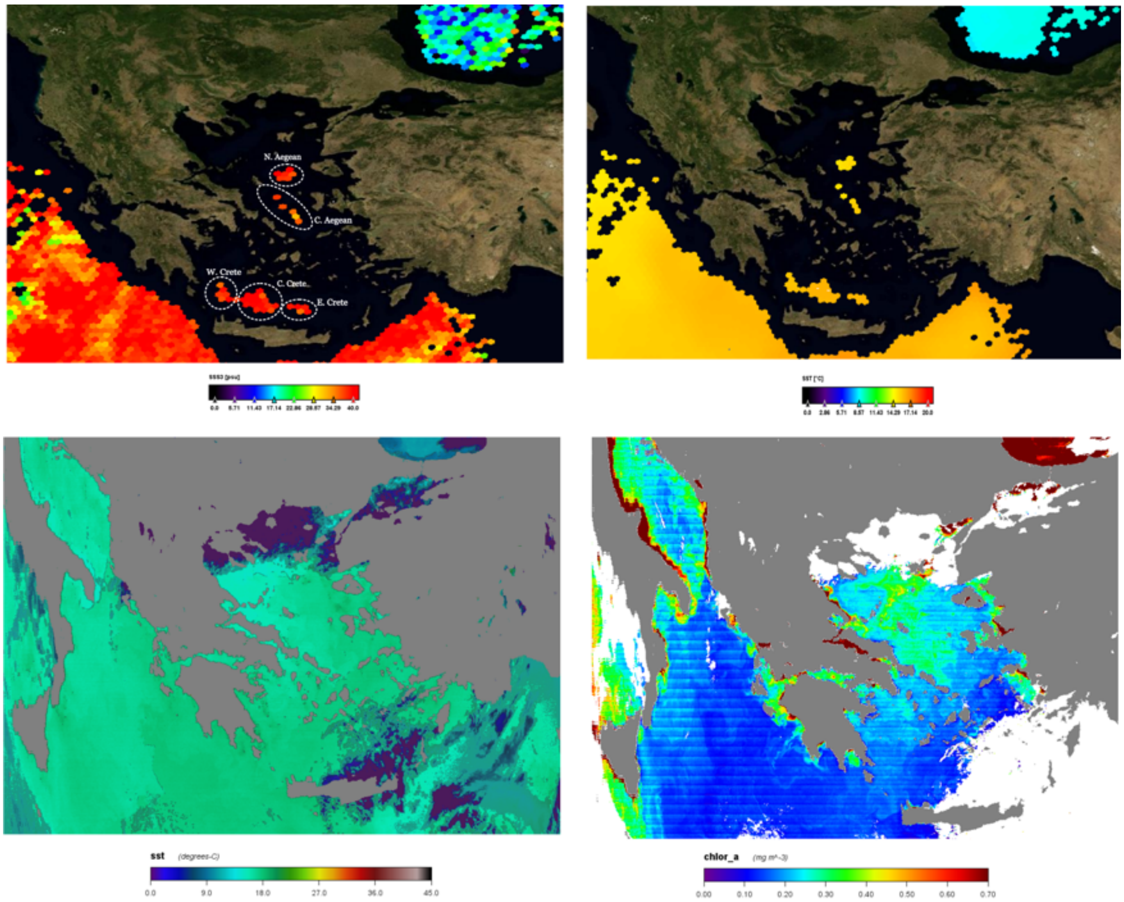
ESA's EarthExplorer satellite SMOS (Soil Moisture Ocean Salinity) is the first satellite to provide direct measurements of ocean salinity in a global scale in space and time. Sea surface salinity (SSS) and sea surface temperature (SST) are systematically monitored by SMOS in a quasi daily basis.
The L-band interferometric radiometer MIRAS onboard SMOS mission measures visibilities from which fully polarized brightness temperatures (Tb) are calculated. The measurements are affected by strong radiometric noise, however, during a satellite overpass, numerous

measurements are acquired at various incidence angles at the same location on the Earth's surface. The sea surface salinity (SSS) retrieval algorithm implemented in the Level 2 Salinity Prototype Processor (L2SPP) is based on an iterative inversion method that minimizes the differences between Tb measured at different incidence angles and Tb simulated by a full forward model. The L2OS processor generates SSS maps using three models: the surface roughness and foam model 1, the surface roughness model 2 based on the empirically modified small perturbation and small slope approximation method (SSA/SPM) and model 3 based on an empirical roughness estimation based on in situ campaign measurements (ESA SMOS L2 OS Algorithm Theoretical Baseline Document, 2010). Although initial results on salinity measurements obtained two years after launch are encouraging, they also indicate that further improvements at various data processing levels are needed and hence are currently still under investigation (Font et al., 2013).

The SST measured by SMOS corresponds to the temperature of the upper fraction of the ocean that contributes to L-band emission (approximately 1 cm). Global SST data are obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) operational system analysis, which is based on the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) system (Donlon et al., 2012). OSTIA uses satellite SST data provided by international agencies via the Group for High Resolution SST (GHRSST) Regional/Global Task Sharing (R/GTS) framework. GHRSST products include data from microwave and infrared satellite instruments with accompanying uncertainty estimates. The system also uses in situ SST data available over the Global Telecommunications System (GTS) and a sea-ice concentration product from the EUMETSAT Ocean and Sea Ice Satellite Applications Facility (OSI-SAF). The SST analysis is a multi-scale optimal interpolation that is designed for applications in numerical weather prediction and ocean forecasting systems. SMOS provides global SSS and SST maps at a spatial resolution of about 50 km, calculated at an average distance of 100 km from the coastline.

In this study, SSS (issued from the three estimation models) and SST are retrieved and attributed to the center coordinates of each one of the thirty nine pixels resolved over the Aegean Sea. Separate time series are then created from descending and ascending passes, each pass representing an acquisition frequency of approximately every three days for a 2.5-year period (about 200 acquisitions per pass). Two time series are then created that include all available measurements spanning December 2011 to May 2014, issued from descending and ascending passes. SSS values with a theoretical uncertainty exceeding the value of 3 are excluded from further processing as well as SSS values exceeding 40psu since they are considered unrealistic for the Aegean Sea. Example of SST and SSS images issued from SMOS acquisitions is shown in figure 1.

Figure 1. Example of different satellite daily acquisitions (March 17, 2014). Top left and top right: SST and salinity (using roughness model 3) respectively from SMOS descending pass. In the SST image, dotted lines delimit the five geographic areas of study. Low left and right: SST and Chla concentrations respectively issued from MODIS/Terra morning pass.



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MODIS measurements

In parallel, for the same coordinates and for the same acquisition dates, SST (measured both at 4μm and 11μm) and ocean color parameters from MODIS Level 2 Ocean products are retrieved. Measurements are issued from both TERRA and AQUA satellites, morning and night passes.

MODIS Ocean Level-2 archive products are produced and distributed by the NASA Goddard Space Flight Center's Ocean Data Processing System (ODPS). A MODIS Level-2 data product is generated from Level 1B corresponding product. The main data contents of the product are the geophysical values for each pixel, derived from the Level-1 radiance by applying the sensor calibration (for Level-1A), atmospheric corrections, and geophysical parameter algorithms. The Level 2 processing also makes use of meteorological and ozone information from ancillary resources. Each Level-2 product corresponds exactly in geographical coverage (scan-line and pixel extent) to that of its parent Level-1 product (NASA Ocean Level-2 Data Products, 2010). The Level-2 ocean color products provide nearly daily ocean color and SST measurements at 1km resolution with day/night ascending/descending coverage. Both short-wave and long-wave SST measurements are retrieved. The short-wave SST algorithm makes use of MODIS bands 22 and 23 at 3.959μm and 4.050μm respectively. The long-wave SST algorithm makes use of MODIS bands 31, 32 at 11μm and 12μm respectively. At night passes, the short-wave SST at 4μm (SST4) retrieval is considered more reliable. Finally, the operational algorithm for deriving near-surface chla concentrations (in mg/m^3) uses in situ data from the NOMAD_v2 global bio-optical data sets for a wide range of water types from coaster to offshore regions (O'Reilly et al., 2000). The algorithm corresponds to the polynomial best fit that relates log-transformed variable to a log-transformed ratio of satellite reflectances. An example SST and chla concentrations respectively issued from MODIS/Terra morning pass is shown in figure 1.

Results and Discussion

Timeseries of monthly averaged SMOS SSS for the five geographic areas are presented in figure 2. Salinity follows no distinct seasonal pattern and generally varies between 37-38 psu (Sykioti and Florou, 2014). The lowest mean values are observed in the C. Aegean (around 37.5 psu) and the highest ones in C. Crete and E. Crete (38.0-38.3 psu), indicating a general North-South increasing gradient. The highest salinity values are also observed in Crete. Finally, it is worth noting here that in most cases, salinity values issued from the descending pass are lower than those issued from the ascending pass, especially in the case E. Crete and W. Crete. This is due to problems in the calculation of brightness temperatures issued from land contamination, sun glint, sun direction and the varying position of the Sun with respect to the antennas throughout the year and between morning and evening passes (the descending pass is around 3am and the ascending one around 5pm). Such significant differences in retrieved salinity obtained using ascending and descending passes as well as latitudinal variation of the SSS bias as a strong function of season of season (strongest in Oct--Dec period) have already been reported by Jordi et al. (2013).

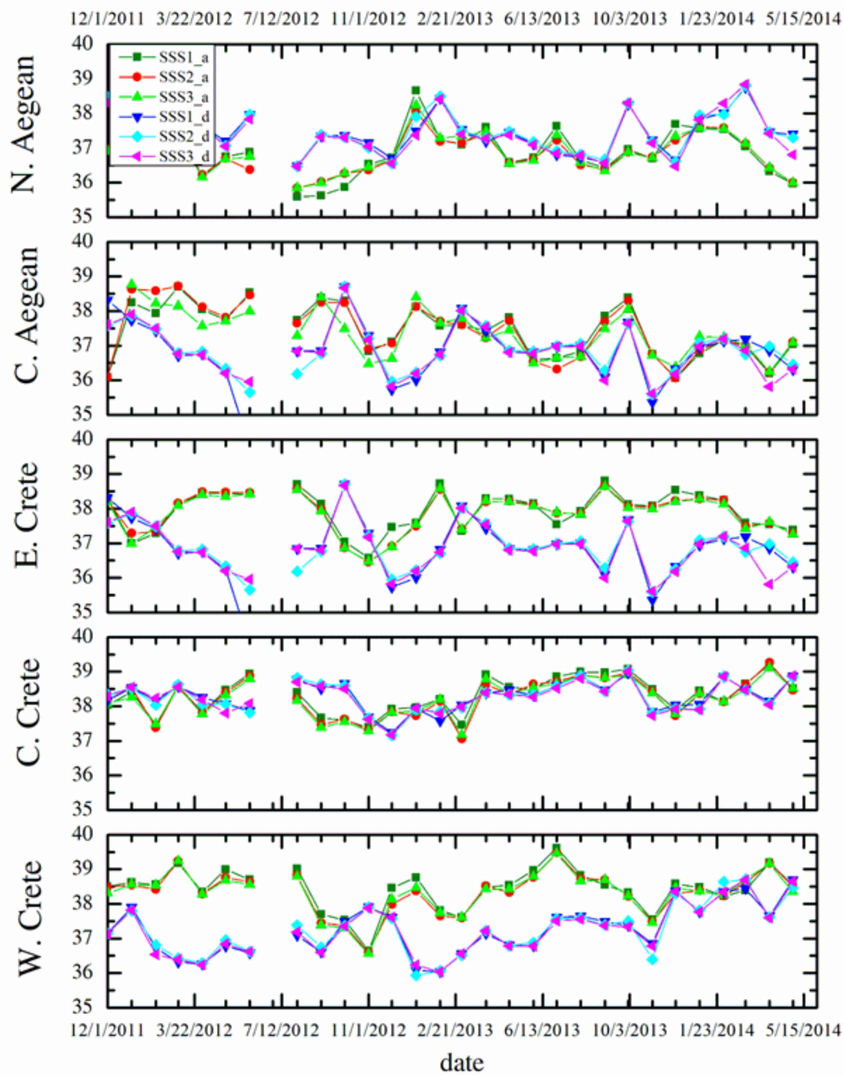

Figure 2. Linearly averaged monthly salinity values (issued from the three models) from both SMOS ascending and descending passes.

Furthermore, as aforementioned, there is a high degree of noise and uncertainty in salinity retrievals from SMOS. This is mostly due to land and RFI contamination near coastal regions (Mecklenburg et al., 2012). In particular concerning the Aegean Sea, the high island density is combined with radiofrequency interferences generated by illegal man-made emissions. The latter is a detected issue in specific areas worldwide, one of them being the Mediterranean Sea where emissions from the Southern European countries induce high levels of RFI interferences. Since the SMOS accuracy requirements are higher, a fraction of Kelvin error induces a non-negligible error in salinity (Boutin et al., 2012). Studies have shown that measurements seem to be generally underestimated in high salinity areas such as the Eastern Mediterranean (e.g. bias=-0.04psu, rms=0.54psu). Therefore, further analysis to salinity measurements and pattern includes high uncertainty. Furthermore, there are no salinity data from the AQUARIUS satellite over the Aegean Sea and therefore no intercomparisons are possible.

On the other hand, SST issued both from SMOS and MODIS follows a clear typical seasonal variation pattern with highest values observed in August and lowest ones around March (Fig. 3). Skliris et al. (2011) observed that generally the SST seasonal variability shows low temperatures in winter and spring (<0.15°C), high temperatures during summer (around 25°C) and values around 20°C in autumn. Indeed in this study, the temporal mean SST distribution shows a clear North to South increasing SST gradient whereas the highest min, max and mean values are observed in Crete and the lowest in the northern part of the Aegean Sea. The SST spatial mean shows a stable seasonal cycle, with a maximum value of about 24.5°C in the middle of August and a minimum value of about 14°C in the middle of February in the North and 19.5°C and 27°C respectively in the South. Similar SST observations in the Aegean from MODIS satellites between 2005 and 2008 have also shown that SST generally increases from North to South and monthly SST range from 15.1°C to 25.3°C with the coldest month of the year being February and the warmest one August (Topouzelis et al., 2012).

Separate correlations performed between SMOS descending/ascending pass and MODIS day or night passes (when data exist) show high correlations (Fig. 4). Despite the significant differences in satellite spatial resolution and acquisition time in the day, calculated coefficients of determination for a linear best fit are high (r^2 above 0.9) for all areas (Tab. 1).

Table 1. Coeffcients of determination (r^2) for a linear best fit between SST measuremetns from SMOS (ascending and descending pass) and MODIS passes within the same day

	N. AEGEAN	C. AEGEAN	E. CRETE	C. CRETE	W. CRETE
SMOS Ascending / MODIS_n	0.978	0.966	0.992	0.984	0.982
SMOS Ascending / MODIS_4μm	0.977	0.972	0.975	0.990	0.988
SMOS Ascending / MODIS_m	0.992	0.968	0.984	0.983	0.977
SMOS Descending / MODIS_n	0.981	0.978	0.987	0.990	0.981
SMOS Descending / MODIS_4μm	0.988	0.977	0.989	0.994	0.988
SMOS Descending / MODIS_m	0.953	0.940	0.976	0.960	0.953

n=measurement at 11μm from night pass

n4= measurement at 4μm from night pass
m=measurement in
morning pass

Mean surface chla concentrations present a spatial pattern that follows a strong seasonal cycle. Maximum values are observed in winter (December) and minimum ones in August-September (depending on the area) (Fig. 3). Concentrations reveal a rather oligotrophic environment for the major part of the Aegean with mean values between 0.12 and 0.15 mg/m^3 in all areas. The highest values are slightly above 0.3 mg/m^3 and are observed in the North and Central Aegean during winter.

SST and chlorophyll timeseries seem to be inversely correlated (Fig. 3) suggesting a close relationship between the two seasonal cycles. There is a two-month lag between the maximum chla concentrations (e.g. December) and the minimum SST (e.g. February). Similar observations using observations in previous years on SST and chla distributions have shown the same increasing North to South SST gradient (Pitta and Giannakopoulou, 2000; Gkanasos et al., 2009; Skliris et al. 2010, Volpe et al., 2012).

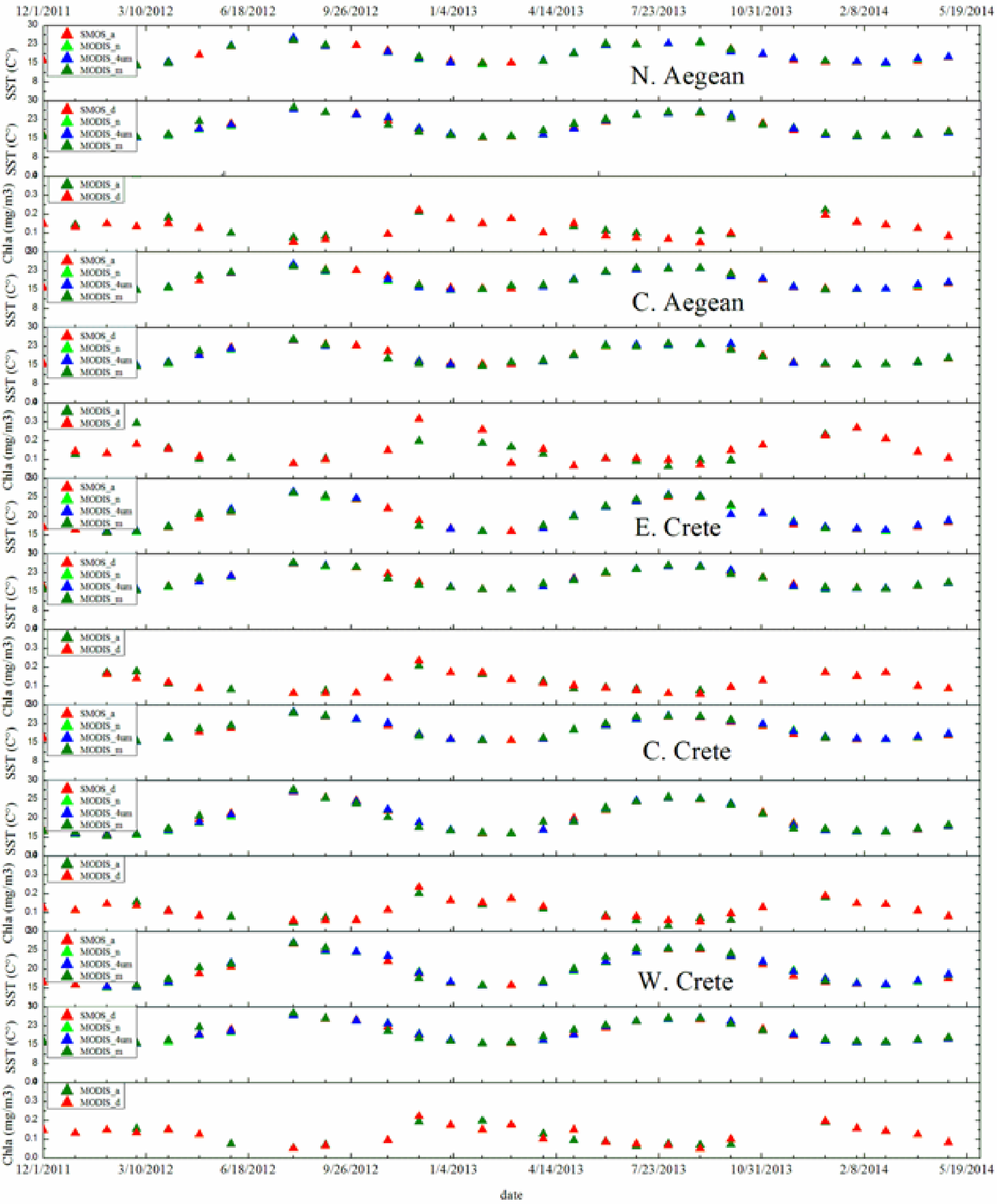

Figure 3. Averaged monthly time series of SST and Chla concentrations in the Aegean Sea from SMOS (ascending and descending pass) and MODIS morning and night pass (when data were available).

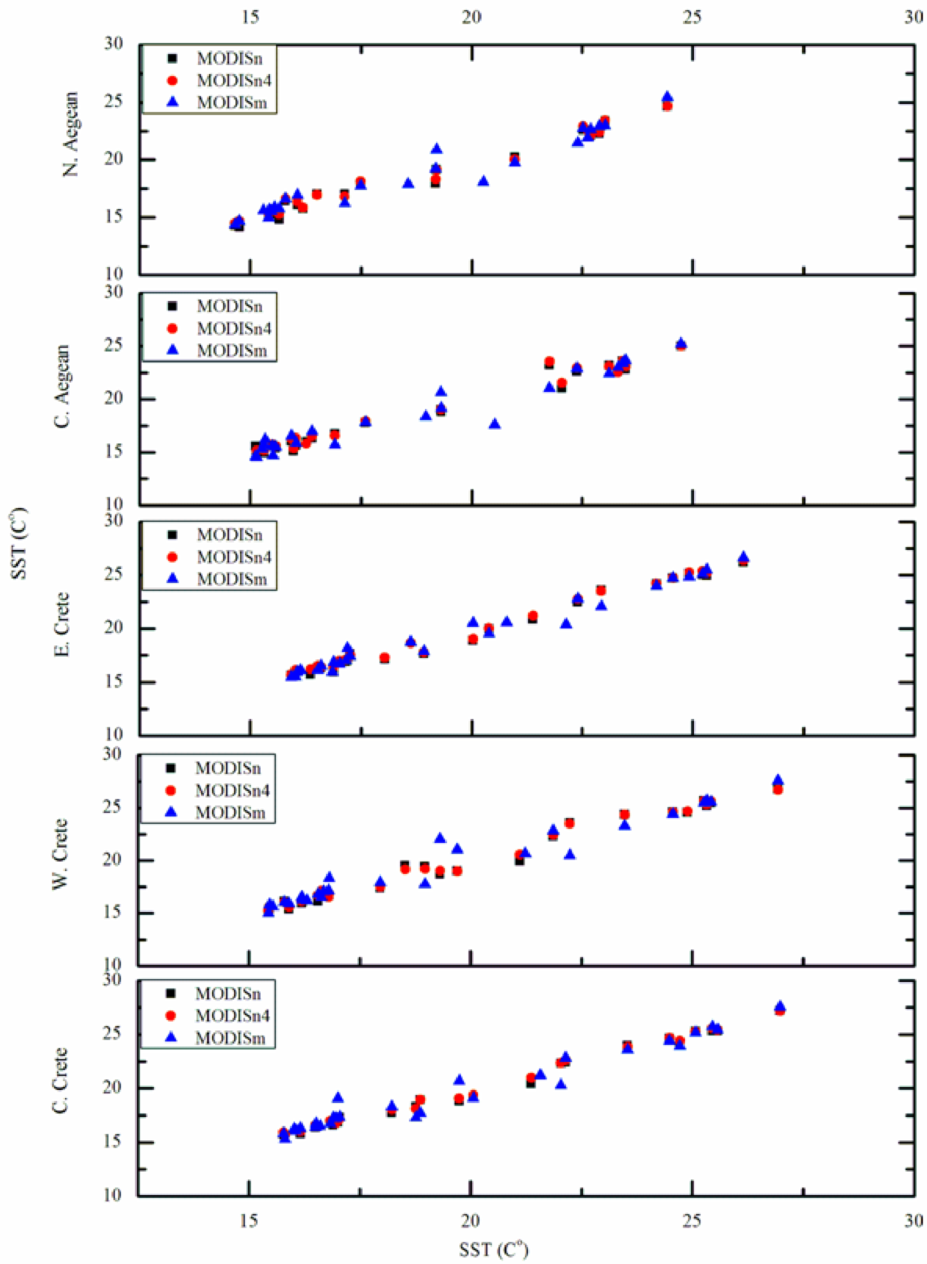

Figure 4. Correlations between SST measurements issued from SMOS descending pass and MODIS for the five study areas in the Aegean Sea. SSTn=MODIS night pass measured at 11μm. SST4= MODIS night pass measured at 4μm. SSTm=MODIS morning pass.

Conclusions

SMOS and MODIS marine parameters are retrieved for the Aegean Sea spanning the period December 2011 - May 2014.
Salinity follows no distinct seasonal pattern and generally varies between 37-38 psu following a general north-south increasing gradient. However, salinity retrievals actually present a high degree of noise and uncertainty due to high island density and RFI contamination.
SST distribution shows a clear North to South increasing gradient whereas maximum and minimum SST in the north are lower than in the south Aegean and a stable seasonal cycle, with highest values observed in August and the lowest ones in February. Additionally,

SMOS SST measurements are highly correlated to SST issued from MODIS despite significant differences in spatial resolution and acquisition time in the day. For this reason, considering that SMOS measurements are insensitive to cloud cover and despite the relatively low spatial resolution, they present a considerable advantage compared to optical systems providing reliable and constant monitoring capabilities.

Furthermore, mean surface chlorophyll distributions in the Aegean follow a strong seasonal cycle with maximum values observed in winter and minimum in August-September depending on the area. Concentrations reveal a rather oligotrophic environment for the major part of the Aegean with highest values slightly above 0.3 mg/m^3 observed only in the north during winter. SST and chlorophyll timeseries are inversely correlated suggesting a close relationship between the two seasonal cycles.

This is an ongoing study. Future work includes retrievals of ocean parameters from selected sited sites (e.g. the Black Sea, the Dardanelles Strait, Crete) and correlations to other field measurements. Further investigations for other spectral indicators of salinity changes from satellite measurements will contribute into establishing relations between satellite information and conservative radionuclide activity monitoring and radiological impact assessment under routine and event-case conditions

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