# Chl-*a* Trends in European Seas Estimated Using Ocean-Colour Products

**Giovanni Coppini[1], Vladyslav Lyubarstev[2], Nadia Pinardi[3], Simone Colella[4], Rosalia Santoleri[4], Trine Christiansen[5]**

[1] Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Italy

[2] Centro Euro Mediterraneo per i Cambiamenti Climatici, Italy

[3] Centro Interdipartimentale di Ricerca per le Scienze Ambientali, Università of Bologna, Ravenna, Italy

[4] Consiglio Nazionale delle Ricerche, Istituto per le Scienze dell'Atmosfera e del Clima, Rome, Italy

[5] European Environment Agency, Copenhagen, Denmark

Correspondence to: G. Coppini (giovanni.coppini@bo.ingv.it)

**Abstract**

Ocean-colour remote-sensing products have been used to estimate Chl-*a* trends in European seas, with the aim to develop a new indicator based on ocean-colour data for the European Environment Agency (EEA). The new indicator, called CSI023(+), produced from satellite ocean-colour products from the MyOcean Marine Core Service (www.myocean.eu) has been defined and calculated. In our analysis we have used 3 MyOcean satellite products: 2 global satellite products (SeaWiFS and a merged product) assessing the differences in estimating chl-a trends and one regional (adjusted to specific regional Mediterranean conditions) ocean-colour product. CSI023 (+) is intended to complement the EEA CSI023 indicator for eutrophication, which is based on chlorophyll-*a* (Chl-*a*) in-situ observations.

Analysis has revealed the potential of ocean colour as a CSI023(+) indicator to detect large-scale, and in some cases even local-scale, changes: decreasing Chl-*a* concentrations throughout the Black Sea, in the Eastern Mediterranean, in the southern part of the Western Mediterranean, in the English Channel and in the north part of the North Sea, whereas large areas with increasing trends are observed in the Bay of Biscay, in the North-East Atlantic regions of Ireland and the UK, in the northern part of the North Sea, in the Kattegat and in the

Giovanni Coppini 21/8/12 08:41
**Eliminato:** . This work aims

Giovanni Coppini 21/8/12 08:43
**Eliminato:** Validation of ocean-colour products has been carried out through comparison with observations of the Eionet EEA database, and we believe that such validation should continue in the future, perhaps with a dedicated data-collection exercise. Ocean colour has a much higher spatial and temporal resolution than the in-situ observations. The ocean-colour observations, however, are based on indirect measurements of the optical properties of the ocean, which are transformed to Chl-*a* using an appropriate algorithm. This algorithm can either be a global algorithm that reproduces the average global Chl-*a* concentrations well or one that is adjusted to specific regional conditions. In our analysis we have used both global and regional (adjusted to specific regional Mediterranean conditions) ocean-colour products, but the results highlight the fact that regional products produced with regional algorithms are recommended for the future.

Giovanni Coppini 21/8/12 08:43
**Eliminato:** This work proposes a methodology for analysing trends comparable to the method EEA uses for its CSI23 indicator.

Giovanni Coppini 21/8/12 08:46
**Eliminato:** :

Giovanni Coppini 21/8/12 08:46
**Eliminato:** appear to be captured by the satellite images even though in general the ocean-colour products underestimate the Chl-*a* values. CSI023(+) shows, in the period 1998-2009,

Baltic. Specific analysis has been performed in the Mediterranean coastal areas using regional products.

Validation of ocean-colour products has been carried out through comparison with observations of the Eionet EEA database. The validation results highlight the fact that regional products produced with regional algorithms are recommended for the future.

## 1 Introduction

A recent review (Ferreira et al. 2011) has presented an overview of eutrophication indicators for assessing environmental status within the European Marine Strategy Framework Directive (MSFD). Ferreira et al. 2011 arrived at the following definition of eutrophication as the basis for interpreting the MSFD descriptor: 'Eutrophication is a process driven by enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, leading to: increased growth, primary production and biomass of algae; changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services'. Among the biological indicators proposed to describe the status of eutrophication the report indicates Chl-*a*, which will increase due to increased nutrient availability. There is extensive literature on the use of phytoplankton as an indicator of eutrophication in inshore and offshore waters. All methods include Chl-*a* as an indicator of phytoplankton biomass, though the metrics differ. It is clear that Chl-*a* alone is not enough to estimate eutrophication processes and provide a complete picture of eutrophic conditions. Chl-*a* is one of the variables to be monitored and other characteristics should also be included in addition to Chl-*a*, such as changes in community composition, occurrence of nuisance and toxic species resulting from changes in nutrient ratios, and increased duration and frequency of blooms resulting from increases in nutrient loads (Ferreira et al. 2011).

Eutrophication in marine waters has been a management concern in Europe over recent decades. Legislative frameworks have been set up, including the Water Framework Directive (WFD) and the MSFD on transitional and marine waters. Moreover, several other EU Directives are aimed at reducing nutrient loads and impacts. These include the Nitrates Directive (91/676/EEC), the Urban Waste Water Treatment Directive (91/271/EEC) and the Integrated Pollution Prevention and Control Directive (96/61/EEC). Measures also arise from a number of other international initiatives and policies including the UN Global Programme

Giovanni Coppini 21/8/12 08:46
**Eliminato:** and the Black Sea

Giovanni Coppini 21/8/12 08:46
**Eliminato:** : we first defined *Chl*-a *areas* and then calculated the CSI023(+) for each of the *Chl*-a *areas*. This last analysis reveals that about 80% of *Chl*-a *areas* do not show significant trends; increasing significant Chl-*a* trends were detected in 3 *Chl*-a *areas* in the Black Sea and 32 *Chl*-a *areas* in the Mediterranean. Decreasing significant trends were detected in 6 *Chl*-a *areas* in the Mediterranean and 2 *Chl*-a *areas* in the Black Sea.

Giovanni Coppini 26/8/12 23:51
**Eliminato:** The WFD requires the achievement of good ecological status or good ecological potential of transitional and coastal waters across the EU by 2015, while the MSFD's aim is to achieve good environmental status of the EU's marine waters by 2020.

Giovanni Coppini 26/8/12 23:51
**Eliminato:** aimed at reducing nitrate pollution from agricultural land

Giovanni Coppini 26/8/12 23:51
**Eliminato:** aimed at reducing pollution from sewage treatment works and certain industries

Giovanni Coppini 26/8/12 23:39
**Eliminato:** ;

Giovanni Coppini 26/8/12 23:52
**Eliminato:** aimed at controlling and preventing pollution of water from industry

of Action for the Protection of the Marine Environment against Land-Based Activities; the 1975 Mediterranean Action Plan (MAP); the 1992 Helsinki Convention (HELCOM) on the Protection of the Marine Environment of the Baltic Sea Area; the 1998 OSPAR Convention for the Protection of the Marine Environment of the North East Atlantic and the 1994 Convention on the Protection of the Black Sea Against Pollution (Bucharest Convention).

In these European and international framework, EEA has set up an indicator based on in-situ Chl-*a* trends to monitor eutrophication in the European seas; this is referred to as CSI023 (Chlorophyll in transitional, coastal and marine waters) in the EEA system. For a complete overview of the indicator, please refer to the following web site:

Giovanni Coppini 26/8/12 23:40
**Eliminato:** The

Giovanni Coppini 26/8/12 23:40
**Eliminato:** uses

http://www.eea.europa.eu/data-and-maps/indicators/chlorophyll-in-transitional-coastal-and/chlorophyll-in-transitional-coastal-and-2.

The objective of the CSI023 indicator is to demonstrate the effects of policy measures taken to reduce loading of nitrogen and phosphates from rivers that affect primary production biomass in the coastal zones. CSI023 is calculated from Chl-*a* in-situ profiles estimated by fluorometer and averaged in the summer[1] and in the first 10 metres of depth. The CSI023 is defined as the significant increasing or decreasing temporal trend for each station.

Giovanni Coppini 3/8/12 07:15
**Eliminato:** i

The last EEA assessment was performed in July 2011, and its results are presented in terms of concentration of Chl-*a* in the European seas and CSI023 from 1985 to 2009.

The in-situ Chl-*a* estimates are provided to the EEA through the Eionet network (http://www.eionet.europa.eu/). Measurements using fluorometers are given at selected coastal stations, providing an accurate measure of Chl-*a*, although with a low temporal and spatial resolution. A second problem related to in situ Chl-*a* is poor coverage, especially in Southern European seas, and we have therefore identified the challenge of integrating the in-situ dataset with ocean-colour products to complement the former and provide EEA and Member States with valuable information for eutrophication assessment.

Giovanni Coppini 10/8/12 08:23
**Eliminato:** fluorimeters

Measurements using satellite radiometers of water-leaving radiance in the visible range (ocean colour) can today be used to determine Chl-*a* concentration, which is an indicator of

[1] Summer is defined as the months from June to September for stations north of 59 degrees in the Baltic Sea (Gulf of Bothnia and Gulf of Finland) and from May to September for all other stations.

algal photosynthetic activity and thus related to phytoplankton biomass. Chl-*a* can now be estimated from ocean-colour data at daily frequencies and 250m horizontal resolutions.

Ocean-colour satellite products are now available from SeaWiFS, MERIS-Envisat and MODIS-AQUA sensors. The future Sentinel-3 GMES satellite will also have an ocean-colour sensor ensuring continuous monitoring for the period 2015-2030. The first ocean-colour sensor, CZCS, was in operation from approximately 1980 to 1986, afterwards the MOS sensor was in operation from approximately 1997 to 2004 and OCTS from October 1996 to June 1997, finally, SeaWiFS, only started in 1997.

Giovanni Coppini 10/8/12 08:44
**Eliminato:** but the second

Estimation of Chl-*a* from ocean colour is an integral value over the e-folding scale of light in water. The optical properties of oceanic waters can be classed into Case 1 or Case 2 waters (Morel and Prieur, 1977; Gordon and Morel, 1983; Prieur and Sathyendranath, 1981). By definition, Case 1 waters are those in which phytoplankton (with their accompanying and co-varying retinue of other material of biological origin) are the principal agents responsible for variations in optical properties of the water. On the other hand, Case 2 waters are influenced not only by phytoplankton and related biological particles, but also by inorganic particulate and dissolved material. The water-leaving radiance of shelf and coastal waters is significantly influenced by suspended inorganic particulate and dissolved material, making the retrieval of Chl-*a* from a unique algorithm, from the open ocean to the coasts, less accurate. In conclusion, Case 1 optical properties can be modelled as a function of Chlorophyll-*a* concentration only, while the simplicity of single-variable models has to be abandoned when dealing with Case 2 waters. At least three relevant quantities (phytoplankton, suspended inorganic materials and yellow substances, and perhaps even bottom reflectance) can vary independently of each other, and specific algorithms related to optical water properties should be used. In shelf and coastal waters, Case 2 waters, suspended inorganic matter and yellow substances (colored organic dissolved matter, CDOM) significantly influence the water-leaving radiance, making the retrieval of Chl-*a* from satellites less accurate. However, the CDOM information is important and should be used in the future as a new indicator of river influence in coastal areas. In our analysis we used global and regional (adjusted to specific regional Mediterranean conditions) ocean-colour products, both developed for Case 1 waters because only these types of products were available.

Giovanni Coppini 10/8/12 08:53
**Eliminato:** The ocean-colour transformation algorithms have been calibrated with in-situ data at a global scale for the GSM product (Maritorena et al., 2010; Maritorena and Siegela, 2005) and with in-situ datasets acquired in the Mediterranean Sea for the MEDOC4 product (Volpe et al., 2007).

Giovanni Coppini 10/8/12 08:48
**Eliminato:** u

The analyses of derived apparent optical properties temporal variability in European seas are conducted in Vantrepotte and Melin 2010 on the SeaWiFS dataset (1997-2007) and the Chl-*a*

Giovanni Coppini 10/8/12 09:14
**Eliminato:** is

trends presented in our paper are consistent with the products such as reflectance band ratio trends as presented in Vantrepotte and Melin 2010. Moreover, inter-annual variations in the SeaWiFS global Chl-*a* concentration (1997–2007) are presented in Vantrepotte and Melin 2011 for the Global Ocean, but a direct comparison with our results cannot be presented because Vantrepotte and Melin 2011 present the results for the Global Ocean and study the full year trends, whereas we focus only on the summer period for consistency with existing EEA CSI023 and we focussed specifically on European Seas.

Giovanni Coppini 14/8/12 08:09
**Eliminato:** s

This paper aims to develop a methodology to complement the EEA CSI023 indicator with observations based on ocean colour from space. This is developed in this report, and named CSI023(+).

The purpose of the paper is to:

1. Analyse the ocean colour trends in European seas;
2. Compare ocean-colour Chl-*a* data and trends with in-situ ones;
3. Present the trends of Chl-*a* as CSI023 (+) in the European seas for the period 1998-2009.

The paper is organized as follows: Section 2 describes the satellite and in situ data sources, it defines the indicator and the Chl-*a areas* concept and the methods; Section 3 the validation of datasets; Section 4 the results; Section 5 concludes the paper.

Giovanni Coppini 21/8/12 08:57
**Eliminato:** ,

Giovanni Coppini 20/8/12 18:42
**Eliminato:** 3

Giovanni Coppini 20/8/12 18:42
**Eliminato:** Section 4 the validation of datasets;

## 2 Data and methods

### 2.1 Satellite and in-situ data sources

#### 2.1.1 Satellite data sources

In this work we used three different MyOcean ocean-colour datasets (Table 1): **Global Ocean GSM – MyOcean**'; '**Global Ocean SeaWiFS RAN – MyOcean**'; **Med Regional SeaWiFS RAN – MyOcean**'.

The first dataset '**Global Ocean GSM – MyOcean**', was developed within the framework of GlobColour (www.globcolour.info) and is regularly produced and distributed by the Global Monitoring for Environment and Security (GMES) MyOcean project. This product is a multi sensor merged products based on SeaWiFS, AQUA and MERIS data available from MyOcean at 4 km resolution. The **Global Ocean GSM – MyOcean** has been produced using

Giovanni Coppini 3/8/12 00:32
**Eliminato:** two

Giovanni Coppini 27/8/12 10:40
**Eliminato:** Table 1

Giovanni Coppini 14/8/12 07:11
**Eliminato:** .

Giovanni Coppini 14/8/12 07:12
**Eliminato:** Chl-*a* dataset

Giovanni Coppini 14/8/12 07:12
**Eliminato:** ,

Giovanni Coppini 14/8/12 07:13
**Eliminato:** ,

the bio-optical model-based merging procedure (Maritorena et al. (2002) and Maritorena and Siegel (2005)), which combines the normalized water-leaving radiances from different sensor data sets. Over each particular pixel of a geographical grid common to SeaWiFS, AQUA and MERIS, the spectral water-leaving radiance, NLw(λ) spectra from the available sensors at that pixel are selected and combined in a single, multi-source, spectrum which is then used in the inversion of the GSM01 semi-analytical ocean colour model (Maritorena et al., 2002). The use of these three sensors contributes to reduce data gaps increasing the coverage over ocean by a factor, which is nearly twice that of any single mission's observations (Maritorena et al., 2010). The **Global Ocean GSM – MyOcean** products  have been validated by Maritorena et al (2010) and by comparing them to the data sets obtained from individual missions. This product has been available since September 1997 and the time-series is constituted of daily products delivered by MyOcean with a one-month delay. Since this product is updated monthly and is based on  L2 input data proved by the space agencies therefore there is no guaranty that the configuration is unchanged. In particularly, the NASA MODIS L2 processing has been switched from R2009.1 to R2010.0 in June 2011 and the MERIS L2 processing switched from the 2nd to the 3rd MERIS reprocessing in autumn of 2012 (see MYO-OC-PUM-available on line at www.myocean.eu).

The second dataset is the '**Global Ocean SeaWiFS RAN – MyOcean**' Chl-*a*  dataset. The full SeaWiFS time series reprocessed  a consistent time series of L2 input data and using OC4-V4 algorithm for chlorophyll retrieval. This MyOcean product is associated with the latest reprocessing performed by NASA for SeaWiFS using SeaDAS 6.1 software.  Temporal characteristics: this dataset comprises of standard mapped image monthly mean global sea surface chlorophyll-a maps at 9km resolution (L3 product) and is distributed by the GMES MyOcean project. The quality of this product has been evaluated in the framework of MyOcean (Melin 2011).

The last satellite dataset is the '**Med Regional SeaWiFS RAN – MyOcean**' is the Mediterranean regional product based on SeaWiFS data and using the Mediterranean regional ocean colour algorithm for chlorophyll retrieval (MedOC4, Volpe et al., 2007). The  MedOC4 algorithm has been validated with a large in-situ bio-optical dataset for the Mediterranean area, and its performance has been compared with global algorithms such as OC4v4 for SeaWiFS, and the results show that MedOC4 is the best algorithm for satellite chlorophyll estimates in the Mediterranean (Volpe et al., 2007). The Med regional SeaWiFS RAN has been produced at once reprocessing the entire SeaWiFS L1 time series with a single software configuration and using the latest version of calibration and ancillary data using the SeaWiFS Data Analysis System (SeaDAS) software package version 6.1 available from NASA website (seadas.gsfc.nasa.gov). The complete description of MyOcean Mediterranean processing system and results on the product validation see Volpe et al (this issue). The product was obtained from MyOcean and CNR.

It is important to underline that the three MyOcean products are calibrated for open ocean waters and not specifically for coastal waters, and a lower performance in the coastal zone is therefore to be expected. . The complexity of optical properties of the European coastal zone requires the use of specialized local algorithm and processing system that are presently not available, therefore we used the MyOcean global and regional products to investigate trends in both open ocean and coastal areas of the European Seas. The availability of in situ coastal data will be use at posterior to check potential use of MyOcean ocean colour products to estimate trends also in the coastal waters.

The analysis of trends in ocean colour products has to consider the way these products have been created. For a series based on one sensor, this means making sure that the series has been created with one processing chain, including a consistent calibration table and calibration history (Sun et al 2008, Eplee et al., 2009, Meister et al. 2012). This applies to the **Med Regional SeaWiFS RAN – MyOcean** and to **Global Ocean SeaWiFS RAN – MyOcean.**

Potential problems of GSM product are: the use of L2 data provided by the space agencies at the time of the operation update of the dataset that does not ensure the complete consistency of the time series and the method does not account for a specific inter-bias calibration effort in the production of the merged datasets.

To evaluate the problem and the differences that the **Global Ocean GSM – MyOcean** products may show in the estimation of the Chl-a trends we have performed a specific analysis using SeaWiFS reprocessed dataset from 1998 to 2009. This analysis is presented in terms of summer chl-a trends for the European Seas calculated from the **Global Ocean GSM – MyOcean** and from the **Global Ocean SeaWiFS RAN – MyOcean** dataset.

The results of this analysis are presented in Figure 2 in the results section.

Giovanni Coppini 3/8/12 01:15
**Eliminato:** and '**Med Regional SeaWiFS – MyOcean and CNR**'

Giovanni Coppini 3/8/12 00:36
**Eliminato:** that is produced by MyOcean and the Consiglio Nazionale delle Ricerche (CNR), Istituto per le Scienze dell'Atmosfera e del Clima (ISAC), Italy.
The first dataset, **Global Ocean GSM – MyOcean**, is obtained using GSM algorithm (Maritorena et al., 2002; Maritorena and Siegel, 2005). One of the major characteristics of the product is that it combines normalized water-leaving radiances from different satellite-sensor datasets (Maritorena et al., 2010). Over each particular grid point of a geographical grid common to SeaWiFS, AQUA and MERIS the radiance of each sensor is combined and it is used to invert a semi-analytical model of Chl-*a* (Maritorena et al., 2002). This product has been available since September 1997 and the time-series is constituted of daily products delivered by MyOcean with a one-month delay. In this work we have performed analysis of ocean-colour data for the period 1998-2009.
The second dataset, **Med Regional SeaWiFS – MyOcean and CNR**, is the Mediterranean product produced with the regional algorithm MedOC4 (Volpe et al., 2007) from the SeaWiFS sensor only. The MedOC4 algorithm has been validated with a large in-situ bio-optical dataset for the Mediterranean area, and its performance has been compared with global algorithms such as OC4v4 for SeaWiFS, and the results show that MedOC4 is the best algorithm for satellite chlorophyll estimates in the Mediterranean (Volpe et al., 2007). This product was accessed in two consistent time series: the first covered the period January 1998-December 2004 and is delivered by MyOcean and is constituted by daily fields of Chl-*a*, while the second covers the period 2004-2007 and is delivered by CNR and is constituted by monthly mean of Chl-*a*. The SeaWiFS regional product for the period 2004-2007 was still covered by a commercial licence and was not distributed by MyOcean at the time we accessed the data. The MedOC4 algorithm is tested and valid up to values of 10 mg $m^{-3}$ of Chl-*a* and therefore we have decided to mask the Chl-*a* data that were higher than this value.

Giovanni Coppini 14/8/12 07:16
**Eliminato:** Mediterranean and global GSM

Giovanni Coppini 27/8/12 10:40
**Eliminato:** Figure 2

2.1.2 In-situ data sources

To validate the **Global Ocean GSM – MyOcean** and the **Med Regional SeaWiFS RAN – MyOcean** daily satellite products we used the in situ data collected in the framework of EEA-Eionet databank and distributed by ICES. The data consists of Chl-a profiles collected in European Seas. The in-situ dataset selected for this paper cover the period 1998-2009 and contains, after the removal of duplicates, 103170 profiles. For the comparison with the satellite dataset we have selected the in situ daily profiles that had a corresponding satellite data by regrinding the in situ data on the two satellites grid **Global Ocean GSM – MyOcean** and the **Med Regional SeaWiFS RAN – MyOcean**. The total corresponding in situ and **Global Ocean GSM – MyOcean** data are 8910.

In the case of the satellite regional product **Med Regional SeaWiFS RAN – MyOcean** in order to perform the comparison between point in-situ observations and ocean-colour data we decided to search in a surrounding area of 4 grid points around each single in situ observation. The MedOC4 algorithm is tested and valid up to values of 10mg $m^{-3}$ of Chl-a and therefore we have decided to mask the Chl-a data that were higher than this value.

The total corresponding in situ and **Med Regional SeaWiFS RAN – MyOcean** data are 13611.

Table 2 presents the principal information on the in-situ dataset used in the comparison with the two satellite products.

## 2.2 CSI023 (+) indicator definition

CSI023 (+) is computed from MyOcean ocean-colour gridded data as a temporal trend at each grid point starting from 1998. CSI023 (+) thus consists of significant Chl-*a* trends normalized by the Chl-*a* Standard Deviation (STD), and the units of CSI023 (+) are (mg $m^{-3}$ (mg $m^{-3}$)$^{-1}$ $y^{-1}$). In other words, CSI023 (+) represents Chl-*a* annual rate of change with respect to the Chl-*a* variability (STD) in the specific period.

CSI023 (+) is presented in the following two ways:

- '*CSI023 (+) Pan-European trend indicator*' calculated in European seas[2] based on a global ocean-colour dataset (**Global Ocean GSM – MyOcean[3] product**)
- '*CSI023 (+) Chl-*a *areas*[4] *trend indicator*' calculated in Mediterranean Sea based on a regional ocean-colour dataset (**Med Regional SeaWiFS RAN – MyOcean**[5] product)

## 2.3 Statistical analysis

This section describes the method used to calculate the trend and climatology (Figure 1 left panel) from ocean-colour data. For each grid point a yearly time series of summer mean Chl-*a* concentration was calculated for the period 1998-2009 (12 points maximum, some summer values can be missing at some grid points).

To calculate summer values first the monthly mean is calculated and then summer values are computed. A threshold on the minimum number of days required to create a valid monthly value is fixed at the level of 10 days.

Trend values ((mg $m^{-3}$) $yr^{-1}$)) are estimated using Sen's slope method (Sen, 1968; Gilbert, 1987; El-Shaarawi et al., 2001) for each grid point Chl-*a* time series.

For each grid point Sen's method calculates the slope of all data value pairs:

$$Q_m = \frac{X_i - X_j}{i - j} \quad \text{For all i and j where i>j} \qquad (1)$$

Where:

$X_i$ and $X_j$ are the summer mean Chl-*a* concentration for years *i* and *j*;

$Q_m$ is the linear slope between $X_i$ and $X_j$ summer values;

*m* is the index of slope estimates.

If there are *n* summer values $X_i$ in the time series we get as many as $M = \frac{n*(n-1)}{2}$ slope estimates $Q_m$ and $m = 1...M$.

---

[2] In each figure of the paper the Sea of Azov has been masked because it is very shallow (maximum 15 metres depth) and ocean-colour products would be strongly affected by bottom reflectance; the White Sea has been masked because it was out of our domain of interest.

[3] The Global Ocean GSM – MyOcean product is described in Section 2.1.1

[4] *Chl-*a *areas* are defined in Section 2.4.

[5] The Med Regional SeaWiFS RAN – MyOcean dataset is described in Section 2.1.1

Giovanni Coppini 20/8/12 18:43
**Eliminato:** from MyOcean at a resolution of approximately 4 km

Giovanni Coppini 20/8/12 18:43
**Eliminato:** Southern Europe

Giovanni Coppini 20/8/12 18:44
**Eliminato:** an s

Giovanni Coppini 20/8/12 18:44
**Eliminato:** s (the Mediterranean Sea and the Black Sea)

Giovanni Coppini 20/8/12 17:40
**Eliminato:** and CNR

Giovanni Coppini 20/8/12 18:43
**Eliminato:** from MyOcean and CNR at a resolution of 1 km.

Giovanni Coppini 27/8/12 10:40
**Eliminato:** Figure 1

Giovanni Coppini 14/8/12 08:33
**Eliminato:** ve

Giovanni Coppini 20/8/12 17:54
**Eliminato:** and CNR

Sen’s estimator of slope is the median of these M values of Q. For each grid point the M values of Q are ranked from the smallest to the largest and Sen’s estimator is:

$$\text{SLOPE}= Q_{[(M+1)/2]} \quad \text{if M is odd;}$$

$$\text{SLOPE}= ( Q_{[M/2]} + Q_{[(M+2)/2]})/2 \quad \text{if M is even;} \qquad (2)$$

A Mann-Kendal statistics check (Salmi et al., 2002; Gilbert, 1987) is applied to each Chl-*a* grid point to identify the statistically significant trends values at a 95% confidence level.

Chl-*a* standard deviation (*STD*) values are calculated using a non-parametric approach (68% confidence interval is considered as 2σ). Non-parametric Sen's slope (Sen, 1968; Gilbert, 1987; El-Shaarawi et al., 2001) is normalized by the non-parametric Chl-a STD values of each grid point, so that CSI023 (+) is then calculated as:

$$CSI023(+) = \frac{SLOPE}{STD} \qquad (3)$$

The units of CSI023 (+) are (mg m$^{-3}$ (mg m$^{-3}$)$^{-1}$ yr$^{-1}$) representing annual change of Chl-*a* over the specified period with respect to the Chl-*a* variability (STD).

Once CSI023 (+) values have been calculated at each ocean-colour data grid point they are presented in two different ways:

1) In a map over the European seas for values above the 95% confidence level (Figure 4 left panel).

2) Histograms of percentages of positive, negative and not significant values of CSI023 (+) in the Mediterranean *Chl*-a *areas* (

Figures 5).

Giovanni Coppini 27/8/12 01:27
**Eliminato:** SLOPE

Giovanni Coppini 27/8/12 01:30
**Eliminato:** for each grid point where SLOPE is significant as follows:

$$STD = \sqrt{\frac{1}{n}\sum_{i=1}^{N}(x_i - \bar{x})^2} \qquad (3)$$

Where:
n is the number of summers values at this grid point;
$X_i$ is the summer mean Chl-*a* concentration at year i;
$\bar{x}$ is the multi-year summer mean Chl-*a* concentration.

SLOPE is then normalized by the Chl-*a* STD values of each grid point so that CSI023 (+) is then calculated as:

Giovanni Coppini 27/8/12 01:31
**Eliminato:** 4

Giovanni Coppini 20/8/12 17:54
**Eliminato:** Figure 2

Giovanni Coppini 20/8/12 17:14
**Eliminato:** 6

Giovanni Coppini 20/8/12 17:52
**Eliminato:** and Black Sea

Giovanni Coppini 27/8/12 10:40
**Eliminato:** Figures 5Figures 3

## 2.4 Chl-*a* areas description.

In the Mediterranean Sea, where a regional ocean-colour product at high spatial resolution was available, a special application of CSI023 (+) was performed for the period 1998-2009. This application uses the concept of '*Chl*-a *areas*', defined on the basis of river basins and political borders, where Chl-*a* trends are calculated. This method makes use of the high spatial resolution of the colour images and thus produces a more robust trend estimate than the pan-European trend indicator.

*Chl*-a *areas* were defined in the Mediterranean (68 *Chl*-a *areas*), using information on the River Basin Districts (RBDs), and political borders when RBDs were not defined. Moreover, 18[7] open-ocean sub-basins were identified in the Mediterranean and used to design the *Chl*-a *areas*. When possible, within each *Chl*-a *area* two sub-areas are defined: a coastal one (IN), from the coast to a depth of 30 metres and an offshore one (OFF), from a depth of 30 to 200 metres. A name composed of 3 parts is associated with each single *Chl*-a *area* as following: 1) name of the RBD or name of the country; 2) name of the sub-basin; 3) 'IN' if it is the inshore part of the *Chla area* or 'OFF' if it is the offshore part of the *Chl*-a *area*.

For example, the offshore part of the Maltese *Chl*-a *area* in the Strait of Sicily will be named 'Malta-SSI-OFF'. In Annex 1 we present maps with the extensions and positions of Chl-a areas and a table with the list of their names.

## 3 Validation against in-situ data

The validation of the ocean-colour products used to calculated CSI023 (+) consists of the comparison of the ocean-colour products with in-situ values from the EEA-Eionet databank.

---

[7] North Adriatic Sea (NAD), South Adriatic Sea (SAD), Algerian Sea (ALG), Alboran Sea (ALS), Algero-Provençal Basin (APB), Gulf of Gabès (GGA), Gulf of Lion (GLI), Iberian Sea (Balearic Sea) (IBS), North Ionian Sea (NIO), South Ionian Sea (SIO), North Levantine Basin (NLB), South Levantine Basin (SLB), Ligurian Sea (LGS), Strait of Sicily (SSI), North Tyrrhenian Sea (NTY), South Tyrrhenian Sea (STY).

Giovanni Coppini 14/8/12 07:29
**Eliminato:** Black Sea and Sea of Marmara,

Giovanni Coppini 14/8/12 07:30
**Eliminato:** 7

Giovanni Coppini 20/8/12 17:11
**Eliminato:** 6

Giovanni Coppini 14/8/12 07:30
**Eliminato:** the Black Sea (5 *Chl*-a *areas*) and Sea of Marmara (1 *Chl*-a *area*)

Giovanni Coppini 20/8/12 17:11
**Eliminato:** Within

Giovanni Coppini 27/8/12 10:34
**Eliminato:** off-shore

Giovanni Coppini 20/8/12 17:13
**Eliminato:** -

Giovanni Coppini 27/8/12 10:34
**Eliminato:** off-shore

Giovanni Coppini 20/8/12 18:45
**Eliminato:**

Giovanni Coppini 19/8/12 11:03
**Eliminato:** is presented in Table 2

Giovanni Coppini 19/8/12 11:03
**Eliminato:** . The method consists of comparing

In-situ Eionet observations are re-gridded on the satellite products spatial grids (1/24° when using the **Global Ocean GSM – My-Ocean** and 1km*1km when using **Med Regional SeaWiFS RAN – MyOcean**).

In the comparison between **Global Ocean GSM – My-Ocean** and in-situ data we have proceed as following: for each in situ data of a specific day we check if there is a corresponding satellite daily data for that specific day. Then we build a datasets of daily mach-up in situ and satellite data. Finally summer and annual mean values are calculated by averaging all the corresponding (same day) in situ and satellite data for that summer and year respectively. Summer and yearly mean satellite values are then compared with the corresponding in situ values.

In the case of the **Med Regional SeaWiFS RAN – MyOcean** and in-situ data comparison we enlarged the space window in which we search for the corresponding satellite and in situ data because the coverage of the regional product is lower than the one of the Global merged product. In order to perform the comparison we decided to search in a surrounding area of 4 grid points around each single in situ observation. Then we build a datasets of daily mach-up in situ and satellite data. Finally summer and annual mean values are calculated by averaging all the corresponding daily in situ and satellite data for that summer and year respectively. Summer and yearly mean satellite values are then compared with the corresponding in situ values.

The MedOC4 algorithm is tested and valid up to values of 10mg $m^{-3}$ of Chl and no higher values are present in the satellite dataset. Therefore we have decided to remove from the comparison the in situ Chl-a data that were higher than this value.

The number of corresponding in-situ and ocean-colour daily values for the different satellite products is reported in Table 2.

The number of corresponding summer and annual mean values used in the comparison are reported in Table 3 together with the validation results.

We did not compare **Global Ocean SeaWiFS RAN– MyOcean**, because only monthly ocean-colour values were available.

In some locations the ocean-colour products differ greatly from the in-situ observations; one reason could be that in some cases in situ data quality could be low (i.e. problem with calibration of instruments is expected due to the large number of data providers; some

Giovanni Coppini 16/8/12 07:30
**Eliminato:** When using the **Global Ocean GSM – MyOcean** at a spatial resolution of 1/24 deg the in-situ Eionet observations are averaged to 1/24 * 1/24 deg. **Global Ocean GSM – MyOcean** data are compared with corresponding in-situ data collected on the same day. The number of corresponding in-situ and ocean-colour daily values for the **Global Ocean GSM – MyOcean** product in the summer period is 5470.

Giovanni Coppini 16/8/12 07:30
**Eliminato:** Corresponding daily in-situ and ocean-colour data are averaged in the summer and then compared.
When using the **Med Regional SeaWiFS – MyOcean**, validation was done using monthly Chl-*a* values, since only monthly ocean-colour values were available for the period 2004-2007. When using the **Med Regional SeaWiFS – MyOcean**, in order to perform the comparison between point in-situ observations and monthly ocean-colour data we decided to search, within the selected month, for in-situ data in a surrounding area of 5km * 5km around each single satellite observation; then the identified in-situ observations were averaged to 5km * 5km bins. The number of corresponding in-situ and ocean-colour monthly values for the **Med Regional SeaWiFS – MyOcean and CNR** product is 7822.
The data treatment of the **Global Ocean GSM – MyOcean** and **Med Regional SeaWiFS – MyOcean and CNR** differs because of the time and spatial resolution differences of the two datasets.

Giovanni Coppini 21/9/12 18:35
**Formattato:** Non Evidenziato

Giovanni Coppini 16/8/12 07:56
**Eliminato:** are

geographical coordinates of the single profiles were provided without precise rounding at the minutes value, and therefore with possible uncertainties on the geographical location of the sampling position) and this information is not provided with the Eionet datasets (i.e. data are not flagged for different quality levels). Moreover as explained in paragraph 2.1 ocean colour data used in this paper are based upon open ocean algorithms and therefore they are not as accurate as needed in the very coastal zone where part of the in situ data have been collected. For this reason we expect that the validation will be worse in some coastal regions.

**Global Ocean GSM – MyOcean** product validation results is presented in Figure 6 to 10, while **Med Regional SeaWiFS RAN– MyOcean** product validation is presented in Figure 9. The correlations were performed taking the logarithm on a decimal basis of the Chl-*a* values. The validation results are presented in Table 3.

The correlation between in-situ data and **Global Ocean GSM - MyOcean** ocean colour Chl-*a* concentration is relatively high ($r^2$=0,53) when analysis is carried out using all the data covering the entire European seas domain (Figure 6), Bias is equal to 1,10 (mg $m^{-3}$) and RMSD is 4,46 (mg $m^{-3}$). At the basin scales as expected correlation values are lower, for the Mediterranean (Figure 7) $r^2$ is equal to 0,31 in the summer analysis (0,34 in the annual analysis) with a low Bias (0,36 (mg $m^{-3}$)) and RMSD is equal to 1,95 (mg $m^{-3}$). In the annual analysis the Mediterranean Bias and RMSD increase to 0,42 (mg $m^{-3}$) and 2,15 (mg $m^{-3}$) respectively. In the Black Sea (Figure 7) we register the minimum number of data availability (46 for the full year and 23 for the summer period) and results show $r^2$ equal to 0,39 in the annual analysis and 0,38 in the summer analysis. Bias is equal to -0,62 (mg $m^{-3}$) in the summer analysis indicating an overestimation of the in situ data by the satellite ones, RMSD is equal to 1,00 (mg $m^{-3}$). In the annual analysis of Black Sea data Bias is positive and equal to 0,41 (mg $m^{-3}$) and RMSD is equal to 1,86 (mg $m^{-3}$). The North-east Atlantic (Figure 8) shows relative high $r^2$ equal to 0,45 in summer and 0,46 in the yearly analysis. The Bias is low in the annual analysis (0,02 (mg $m^{-3}$)) and in the summer period 0,23 (mg $m^{-3}$). RMSD for the North-east Atlantic is equal to 1,43 in the annual analysis and 1.44 in the summer analysis. In the North Sea (Figure 8) we found $r^2$ values similar to the other basins (0,40 in the annual analysis and 0,33 in the summer period analysis) while it shows the higher Bias RMSD equal to 2.12 (mg $m^{-3}$) in the annual analysis (2.03 (mg $m^{-3}$) in the summer analysis) and RMSD equal to 6,80 (mg $m^{-3}$) in the annual analysis (5,99 (mg $m^{-3}$) in the summer analysis). The Baltic Sea (Figure 8) the correlation drops noticeably ($r^2$ equal to 0,02 in the

Giovanni Coppini 19/8/12 10:19
**Eliminato:** without rounded at the minutes value

Giovanni Coppini 19/8/12 10:30
**Eliminato:** We therefore decided to eliminate the data from both in-situ and ocean-colour datasets when the difference among them was more than five times

Giovanni Coppini 19/8/12 10:31
**Eliminato:** . These values are eliminated from the dataset that is then used for the CSI023 (+) and climatology calculations and the validation. This filtering is possible because data are abundant enough and because

Giovanni Coppini 19/8/12 10:31
**Eliminato:** can only be done if the values are compatible

Giovanni Coppini 19/8/12 10:33
**Eliminato:** After this filtering, 4584 corresponding data remained for **Global Ocean GSM – MyOcean**. In the case of **Med Regional SeaWiFS – MyOcean and CNR**, dataset masking was applied to monthly values and after this filtering the remaining data were 6156.

Giovanni Coppini 19/8/12 11:04
**Eliminato:** Different validation tests were performed, and the results are presented in Figure 4 to Figure 15. Tests 1, 2 and 3 were performed using **Global Ocean GSM – MyOcean** products, while Test 4 was performed using **Med Regional SeaWiFS – MyOcean and CNR** products. The correlations for Tests 1 and 4 were performed taking the logarithm on a decimal basis of the Chl-*a* values.

Giovanni Coppini 21/8/12 16:24
**Eliminato:** (Test 1)

Giovanni Coppini 27/8/12 01:39
**Eliminato:** thigh

Giovanni Coppini 27/8/12 00:26
**Eliminato:** $R^2$

Giovanni Coppini 21/8/12 14:33
**Eliminato:** 8

Giovanni Coppini 21/8/12 14:35
**Eliminato:** Figure 4

Giovanni Coppini 21/8/12 16:25
**Eliminato:** a

Giovanni Coppini 21/8/12 14:36
**Eliminato:** Figure 5

Giovanni Coppini 21/9/12 19:01
**Eliminato:** Figure 8

Giovanni Coppini 21/9/12 19:01
**Eliminato:** Figure 8

Giovanni Coppini 21/8/12 16:42
**Eliminato:** $^2$ is equal to 0.6), while for the

Giovanni Coppini 21/8/12 17:11
**Eliminato:** (Figure 7)

Giovanni Coppini 21/8/12 14:32
**Formattato:** Nessuna sottolineatura, Non Apice/ Pedice

Giovanni Coppini 21/8/12 17:13
**Eliminato:** ($R^2$=0.3).

annual analysis and 0,15 in the summer analysis) and Bias is equal to 1,55 (mg $m^{-3}$) in the annual analysis and 1,26 (mg $m^{-3}$) in the summer analysis while RMSD is equal to 5,10 (mg $m^{-3}$) in the annual analysis and 4,74 (mg $m^{-3}$) in the summer analysis.

The comparison of **Med Regional SeaWiFS RAN – MyOcean** with in-situ data in the Mediterranean Sea shows a correlation $R^2$=0.41 in summer analysis (Table 3 and Figure 9) and 0,36 in the yearly analysis, which are higher than that observed with the **Global Ocean GSM – MyOcean** data (Figure 7 and Table 3; $R^2$=0,31 for the summer analysis and 0,34 for the yearly analysis). Bias of the Mediterranean regional products (-0,04 (mg $m^{-3}$) in the summer analysis and 0,15 (mg $m^{-3}$) in the yearly analysis) and RMSD (1,44 (mg $m^{-3}$) in the summer analysis and 1,36 (mg $m^{-3}$) in the yearly analysis) are lower than the ones of the Global product. The regional product **Med Regional SeaWiFS RAN – MyOcean** thus seems to be preferable with respect to **Global Ocean GSM – MyOcean** in comparison with in-situ data.

In addition to the comparison of in Chl-a concentrations presented above we also propose a comparison of in situ and satellite trends. To perform this comparison we identified locations at which there were at least 9 summer Chl-a mean values of corresponding in situ and satellite data. The identified time series are 48 in the case the **Global Ocean GSM – MyOcean** and in situ trends comparison. The results of this comparison are presented in a scatter plot in Figure 10 and in a map in Figure 11.

Results show that there are 16 locations in which both satellite and in situ products detect positive trends, 17 locations in which both satellite and in situ products detected negative trends, 6 locations in which in situ products detect positive trends while satellite products detect negative trends and 9 locations in which in situ products detected negative trends while satellite products detected positive trends. Position of the locations were trends are identified is shown in Figure 11 together with the trend slope and significance level. Even if the satellite products are able to capture the sign of the in situ trend in the majority of the stations (68%) the intensity of trends is not well capture by the satellite products.

The satellite and in-situ chl-a trends comparison is not performed at the level of Mediterranean Chl-a areas because only few corresponding time series are detectable and can not represent the different Chl-a areas.

Giovanni Coppini 26/8/12 20:55
**Eliminato:** good

Giovanni Coppini 26/8/12 20:55
**Eliminato:** (

Giovanni Coppini 26/8/12 20:56
**Eliminato:** 7)

Giovanni Coppini 26/8/12 21:38
**Eliminato:** Figure 15

Giovanni Coppini 26/8/12 21:40
**Eliminato:** is

Giovanni Coppini 26/8/12 21:41
**Eliminato:** Figure 4

Giovanni Coppini 26/8/12 21:02
**Eliminato:** 6

Giovanni Coppini 26/8/12 21:47
**Eliminato:** A

## 4 Results

The mean summer (May-September) spatial distribution of Chl-*a* concentration (mg m$^{-3}$) in coastal European seas for the period 1998-2009 calculated from both the **Global Ocean GSM – MyOcean** ocean-colour product (Figure 1 left panel) and in-situ data (Figure 1 right panel) is presented. CSI023(+) is presented in the two formats defined: a) CSI023(+) pan-European trend indicator and b) CSI023(+) *Chl*-a *areas* trend indicator in the Mediterranean Sea. Paragraphs 4.1 to 4.3 present the abovementioned results.

### 4.1 Spatial distribution of Chl-*a* concentration in coastal European seas (Chl-*a* summer climatology)

The European seas summer Chl-*a* mean (mg m$^{-3}$) over the period 1998-2009 (Figure 1 left panel) shows highest values in the Baltic Sea, in the southern North Sea and the Western Black Sea. The lowest values are reached in the Mediterranean Sea open-ocean areas. The Irish Sea, Bay of Biscay and Portuguese Atlantic areas also show high Chl-*a* values, although these are lower than the Baltic and North Sea. In the Mediterranean the low Chl-*a* values show a negative west-to-east gradient that is very well known for this area (Siokou-Frangou et al., 2010; D'Ortenzio and d'Alcalà 2009). The Black Sea shows highest values in the north-western part of the basin (Danube area). The in-situ climatology (Figure 1 right panel) reveals the sampling problem of the in-situ dataset. The two climatologies show similar values in most of the Baltic Sea with the exceptions of the Gulf of Finland and Gulf of Riga where ocean-colour products underestimate in-situ values. In the southern part of the North Sea in-situ and ocean colour show similar mean values, although there is still an evident underestimation of the values by the satellite products. In the northern part of the Adriatic Sea, the in-situ and ocean-colour products show similar values, while in the southern areas of the Adriatic ocean colour once again underestimates the in-situ values. In the Ligurian Sea too the ocean-colour products underestimate in-situ observations, as they also do in the Tyrrhenian Sea.

Giovanni Coppini 21/9/12 19:01
**Eliminato:** Figure 1
Giovanni Coppini 21/9/12 19:01
**Eliminato:** Figure 1
Giovanni Coppini 27/8/12 00:37
**Eliminato:** seas
Giovanni Coppini 27/8/12 00:37
**Eliminato:** 3
Giovanni Coppini 27/8/12 00:37
**Eliminato:** 3
Giovanni Coppini 27/8/12 10:40
**Eliminato:** Figure 1
Giovanni Coppini 27/8/12 10:34
**Eliminato:** theWestern
Giovanni Coppini 14/8/12 08:41
**Eliminato:** east-west
Giovanni Coppini 27/8/12 10:40
**Eliminato:** Figure 1
Giovanni Coppini 14/8/12 08:43
**Eliminato:** ocean colour

## 4.2 **Comparison of Global Ocean GSM – MyOcean, Global Ocean SeaWiFS RAN– MyOcean** and **Med Regional SeaWiFS RAN – MyOcean** trends.

Giovanni Coppini 6/8/12 12:28
**Eliminato:** <#>**CSI023 (+)**

Giovanni Coppini 22/8/12 07:58
**Formattati:** Elenchi puntati e numerati

To control the results of CSI023(+) obtained with **Global Ocean GSM – MyOcean** we have decide to perform a comparison between the Chl-a trends obtained with **Global Ocean GSM – MyOcean** and the ones obtained with **Global Ocean SeaWiFS RAN– MyOcean**.

In Figure 2 we show both significant and non-significant trends to allow a better comparison of the two trends. **Global Ocean GSM – MyOcean** and **Global Ocean SeaWiFS RAN– MyOcean** trends show similar patterns but in general the intensity of trends detected using **Global Ocean SeaWiFS RAN– MyOcean** time series are higher than the ones obtained using **Global Ocean GSM – MyOcean**. Both products show positive trends in the northern part of the North Sea and in the North East Atlantic, central and southern part of the Baltic Sea, Bay of Biscay, north-east Atlantic, Alboran Sea, Ligurian Sea and southern part of the Gulf of Lion, southern Adriatic Sea and north-east Ionian Sea. Moreover negative trends are detected by the two datasets in the Black Sea, in most of the Mediterranean Sea, in the English Channel and in the central part of the North Sea, in part of the northeast Atlantic. Main differences are found in the Gulf of Botnia, Gulf of Finland where **Global Ocean SeaWiFS RAN– MyOcean** shows negative trends while **Global Ocean GSM – MyOcean** shows positive trends. Moreover in the Skagerrak, Norwegian coasts and, in the English Channel, in the Po River mouth and in the western part of the Black Sea SeaWiFS shows similar in sign but stronger negative trends respect to GMS product. The trend in the central part of the Baltic Sea is found stronger in **Global Ocean SeaWiFS RAN– MyOcean** than in the **Global Ocean GSM – MyOcean** dataset.

The chl-a trend analysis is also performed in the Mediterranean Sea using the regional products **Med Regional SeaWiFS RAN – MyOcean** ocean-colour dataset for the period 1998-2009 and is presented in Figure 3. Results obtained with the regional product appear similar to the ones obtained using the global product **Global Ocean GSM – MyOcean** presented in Figure 2. In the western Mediterranean the global and regional satellite products show similar trend spatial patterns and trend intensity is also very similar. Some differences are detected in the Tyrrhenian Sea along the eastern coasts of Sardinia and Corse where the global product present positive trends not shown in the regional product. In the and in the southern part of the Tyrrhenian basin the regional product show positive trends areas that appear larger than the ones of the global product. The Adriatic Sea trends appear very similar in the two datasets. In the Ionian Sea the two products show similar trends with the exception of a positive trend area south of Sicily that appears larger in the regional product, the Gulf of Gabes in which the regional product show a negative trend and the Gulf of Sirte where the regional products highlight a positive trend that is not clearly present in the global products. In the central part of the Levantine Basin, in southern part of the Aegean Sea and in front of the Nile river mouth the regional product show stronger positive trends respect to what is shown by the global product.

The result of the regional product **Med Regional SeaWiFS RAN – MyOcean** are also compared with the ones obtained in the Mediterranean with the **Global Ocean SeaWiFS RAN– MyOcean**. Results appear very similar in the entire basin, small differences are detected in front of the Po River mouth where the regional product shows weaker negative trend values, while along the Italian Adriatic coast the negative trend appear stronger in the regional product. In the Gulf of Gabes the regional product show a negative trend that instead is detected as positive trend in the global SeaWiFS product. In front of the Nile river mouth the regional product detect a stronger positive trend with respect to the one shown in the global product.

### 4.3 CSI023 (+)

In this section we present CSI023 (+) analysis in terms of *pan-European* trends map (based on the **Global Ocean GSM – MyOcean** product) and *Chl*-a *area trends* in the Mediterranean Sea (based on **Med Regional SeaWiFS RAN – MyOcean product**).

#### 4.3.1 CSI023(+) pan-European trends

CSI023(+) over the period 1998-2009 is presented in Figure 4 (left panel). It is worth underlining that the STD of Chl-a (mg $m^{-3}$) is naturally high in regions of high Chl-a. Looking at relative changes, as we do in CSI023(+), provides a Pan-European picture that highlights the spatial variability of the trends and tries to minimize the natural Chl-a concentration differences among the European Seas. CSI023 (+) shows areas with decreasing Chl-*a* concentrations in the Black Sea, the Eastern Mediterranean, the southern part of the Western Mediterranean and the English Channel, whereas areas with increasing trends are observed in the northern Ionian Sea, the off-shore area of the Bay of Biscay, the North-East Atlantic, the North Sea, the Kattegat and the Baltic. Only points above the 95% confidence level are

Giovanni Coppini 14/8/12 08:52
**Eliminato:** Two different ways

Giovanni Coppini 14/8/12 08:52
**Eliminato:** of

Giovanni Coppini 14/8/12 08:52
**Eliminato:** ing

Giovanni Coppini 14/8/12 08:52
**Eliminato:** have been defined in Paragraph 2.2:
*Pan-European trends* of Chl-*a* based on the **Global Ocean GSM – MyOcean** ocean-colour dataset for the period 1998-2007. The methodology used to calculate pan-European trends is described in Paragraph 2.3).
Mediterranean and Black Sea trends for each *Chl*-a *area* for the period 1998-2007, based on high resolution (1km) **Med Regional SeaWiFS – MyOcean and CNR product**. *Chl*-a *areas* are described in Paragraph 2.4 The methodology used to calculate pan-European trends is described in Paragraph 2.3.
Below we present CSI023(+)

Giovanni Coppini 27/8/12 10:35
**Eliminato:** and

Giovanni Coppini 14/8/12 08:51
**Eliminato:** .

Giovanni Coppini 27/8/12 00:38
**Eliminato:** 1)

Giovanni Coppini 21/8/12 17:34
**Eliminato:** :

presented, and white areas in the map therefore correspond to grid points not showing any significant trend.

The Chl-*a* standard deviation over the period 1998-2009 presented in Figure 4 (right panel) shows that natural variability is high in the Baltic, the North Sea, the North-East Atlantic shelf areas and the northern regions of the Mediterranean and the Black Sea. Chl-*a* natural variability appears low in the Mediterranean, with a minimum in the Eastern Mediterranean basin.

### 4.3.2 CSI023(+) *Chl*-a *area* trends

In the Mediterranean when a regional ocean-colour product at high spatial resolution was available a special application of CSI023 (+) was performed for the period 1998-2009. CSI023 (+) is calculated for each *Chl*-a *area* and the way of presenting results for this special application of CSI023 (+) is based upon the classic CSI023 indicator mapping showing the percentage of decreasing, increasing and no-trend stations (

Figures 5). We show the number of colour- image grid points with decreasing, increasing and null trends. The CSI023 (+) *Chl*-a *areas* indicator for the Mediterranean Sea shows that about 52% of *Chl*-a *areas* do not show significant trends (i.e., significant trends found for less than 10% of the grid points in each area). Increasing Chl-*a* trends (i.e., found for equal or more than 10% of the grid points in each area) were detected in 9% (12) of the Chl-a areas (in Egypt, Greece, Tunisia, Malta and Turkey coast lines) see Figures 5 e and f.

Decreasing significant Chl-*a* trends (i.e., found for equal or more than 10% of the grid points in each area) were detected in the 39% (53) Ch-a areas (Italian coasts in the Adriatic, Slovenian coasts (Figures 5 d), Greek coasts in the northern Aegean Sea and in the northern Ionian Sea (Figures 5 e), Italian coast in the northern Tyrrhenian Sea and Ligurian Sea (Figures 5 c), Algerian coasts (Figures 5 e), Spanish coasts in the Ebro area, Catalan area and in the Alboran Sea (Figures 5 a), Maltese coasts (Figures 5 f), Turkish coasts in the northern Levantine and in the Aegean Sea (Figures 5 e), Sicily coasts in the Ionian Sea (Figures 5 c), Tunisian coasts (Figures 5 f), French coasts in the Rhone area (Figures 5 b), Syrian coasts (Figures 5 e), Libyan coasts (Figures 5 f) and Israeli coasts (Figures 5 e)).

Giovanni Coppini 21/8/12 17:34
**Eliminato:** Figure 2

Giovanni Coppini 21/8/12 08:58
**Formattato:** Tipo di carattere:Grassetto

Giovanni Coppini 27/8/12 00:38
**Eliminato:** 2)

Giovanni Coppini 21/8/12 17:35
**Eliminato:** , Black Sea and Sea of Marmara ... [1]

Giovanni Coppini 21/8/12 17:35
**Eliminato:** Figures 3…In this paper we discuss the results of all the *Chl*-a *areas*, but we selected only some of them (Black Sea *Chl*-a *areas* and 14 *Chl*-a *areas* in the Mediterranean), which that are presented in Figures 3…Southern European…seas 80…(higher than 10% ... [2]

Giovanni Coppini 21/8/12 18:03
**Eliminato:** following areas:
The Ukraine and Georgia areas (Georgia-BS-IN and -OFF and Ukraine-BS-IN);
The Turkish Aegean area Turkey (AEG-OFF);
<#>The Maltese area in the Strait of Sicily Strait (Malta-SSI-IN);
<#>The Greek areas (Crete-AEG-IN and –OFF, Epirus-NIO-IN and -OFF, Western-Sterea Ellada-NIO-IN and -OFF, Northern-Peloponnese-SIO-IN and -OFF, Western-Peloponnese-AEG-IN and -OFF, Eastern-Peloponnese-AEG-OFF, Attica-AEG-IN and Eastern-Sterea-Ellada-AEG-IN);
<#>The Egyptian area (Egypt-SLB-IN -OFF);
<#>The Tunisian areas (Tunisia-GGA-IN and Tunisia-SSI-IN and -OFF);
<#>The Italian Southern Apennines area (South.-Apennines-SAD-IN) and North Adriatic Sea area (Po-NAD-IN);
<#>The Croatian area in the North Adriatic Sea (Croatia-NAD-IN);
<#>The Albanian area (Albania-SAD-IN);
<#>The Italian areas in the Ligurian Sea (Serchio-LGS-IN and North.-Apennines-LGS-2-IN);
<#>The Italian Strait of Sicily area (Sicily-SSI-IN);
<#>The Balearic islands area (Balearic-APB-IN and Júcar-IBS-IN and -OFF areas);
<#>The Alboran Sea Spanish south-western areas (Cuencas-Med.-Andaluzas-IN and -OFF, Júcar-ALS-IN);
<#>The Moroccan area (Morocco-ALS-OFF).
(higher than 10% of the pixels) …the following…Figures 5…Figures 5…Figures 5…Figures 5…Figures 5…Figures 5…Figures 5…Figures 5…Figures 5…Figures 5…Siria…Figures 5…Figures 5…Figures 5 ... [3]

## 5 Conclusions

The CSI023 (+) indicator based on ocean colour products has been developed to contribute to the state-of-the-environment assessment and, in particular, the monitoring of eutrophication trends. The comparison of Chl-*a* concentrations and trends estimated through remote sensing with in-situ ones has been performed. The comparison presented shows that the global ocean-colour algorithm seems to underestimate Chl-*a* concentration (Figure 1). To evaluate the performance of satellite products to estimate Chl-a trends at Pan-European Scale we have compared different satellite products (i.e. **Global Ocean GSM – MyOcean** and **Global Ocean SeaWiFS RAN – MyOcean**) and we found that in general the intensity of trends of detected using SeaWiFS time series are higher with the GSM once, but GSM and SeaWiFS trends show similar patterns. The differences highlighted by this comparison in the northern Baltic Sea point out the lower confidence of the satellite products in detecting chl-a trends in this region. The comparison of the global products (i.e. **Global Ocean GSM – MyOcean**) with the regional product available in the Mediterranean Sea **Med Regional SeaWiFS RAN – MyOcean** show similarities in the general patterns and some specific differences have been highlighted. The comparison of **Global Ocean SeaWiFS RAN – MyOcean** and the corresponding regional product **Med Regional SeaWiFS RAN – MyOcean** show strong similarities but some local differences are discussed.

The CSI023 (+) indicator based on **Global Ocean GSM – MyOcean** shows the capability of detecting significant negative and positive terms for Chl-*a* trends in European seas, thereby allowing us to complement the in-situ CSI023 covering only part of the European coastal areas. The CSI023(+) indicator also shows a large area with decreasing Chlorophyll-*a* concentrations in the Black Sea, the Mediterranean, the English Channel and the northern part of the North Sea; whereas a large area with increasing trends is observed in the Bay of Biscay and the Baltic. Trends estimated by ocean colour products are compared with trends estimated by in-situ data (Figure 10 and Figure 11) showing clear differences but also the capability of ocean colour products to capture the sign of the in situ trend in the majority of the comparison locations. Moreover, the **Med Regional SeaWiFS** RAN**– MyOcean and CNR** regional daily dataset used in the Mediterranean Sea seems to show a good comparison with in-situ data (Table 3 and Figure 9), but further investigations need to be performed to compare the trends at the level of Chl-*a* *areas* as well when more coastal in situ chl-a time series will be available and when new satellite products produced with coastal algorithm will

Giovanni Coppini 21/8/12 18:14
**Eliminato:** :
The Slovenian area (Vodno-NAD);
The Turkish areas in the Black Sea (Turkey-BS-In and -OFF) and Northern Levantine Basin (Turkey-NLB-IN and -OFF)
The Syrian area (Syria-SLB-IN);
The Maltese areas (Malta-SSI-OFF and Malta-SIO).
<#>**Validation against in-situ data**
The validation of the ocean-colour products used to calculated CSI023 (+) is presented in Table 2. The method consists of comparing the ocean-colour products with in-situ values from the EEA-Eionet databank. When using the **Global Ocean GSM – MyOcean** at a spatial resolution of 1/24 deg the in-situ Eionet observations are averaged to 1/24 * 1/24 deg. **Global Ocean GSM – MyOcean** data are compared with corresponding in-situ data collected on the same day. The number of corresponding in-situ and ocean-colour daily values for the **Global Ocean GSM – MyOcean** product in the summer period is 5470. Corresponding daily in-situ and ocean-colour data are averaged in the summer and then compared.
When using the **Med Regional SeaWiFS – MyOcean and CNR**, validation was done using monthly Chl-*a* values, since only monthly ocean-colour values were available for the period 2004-2007. When using the **Med Regional SeaWiFS – MyOcean and CNR**, in order to perform the comparison between point in-situ observations and monthly ocean-colour data we decided to search, within the selected month, for in-situ data in a surrounding area of 5km * 5km around each single satellite observation; then the identified in-situ observations were averaged to 5km * 5km bins. The number of corresponding in-situ and ocean-colour monthly values for the **Med Regional SeaWiFS – MyOcean and CNR** product is 7822.
The data treatment of the **Global Ocean GSM – MyOcean** and **Med Regional SeaWiFS – MyOcean and CNR** differs because of the time and spatial resolution differences of the two datas ... [4]

Giovanni Coppini 3/8/12 06:23
**Formattati:** Elenchi puntati e numerati

Giovanni Coppini 21/9/12 19:01
**Eliminato:** Figure 1

Giovanni Coppini 22/8/12 08:02
**Formattato:** Tipo di carattere:(Predefinito) Times New Roman, 12 pt, Non Grassetto, Nessuna sottolineatura, Colore carattere:

Giovanni Coppini 21/8/12 19:06
**Eliminato:** show similar slope and sign if compared

Giovanni Coppini 21/9/12 19:01
**Formattato:** Colore carattere: Automatico

Giovanni Coppini 21/8/12 19:06
**Eliminato:** Figure 10

Giovanni Coppini 21/8/12 19:06
**Eliminato:** toFigure **14**

Giovanni Coppini 21/8/12 19:07
**Eliminato:** to

Giovanni Coppini 21/8/12 19:06
**Eliminato:** Figure

Giovanni Coppini 21/8/12 19:07
**Eliminato:** .

be available. Validation should continue in the future, perhaps with a dedicated data-collection exercise. *Chl*-a *area* analysis offers the user the possibility of synthesizing CSI023(+) information and focuses attention on coastal areas. The analysis has also revealed the need for regional ocean-colour products to be available to develop support of the EEA indicator, as well as the fact that there is potential in a long-term trend analysis based on ocean colour, as large-scale, and in some cases even regional-scale, changes appear to be captured by the satellite images. It is clear, however, that in order to build confidence in this analysis it needs to be based on the best possible regional products. As not all the used MyOcean products consist of complete reprocessed data, it is planned that as soon as new regional datasets are available they will be used to calculate CSI023 (+).

Although **Global Ocean GSM – MyOcean** and **Med Regional SeaWiFS RAN – MyOcean and CNR** were available as daily products, not all the information from ocean colour has been used yet because CSI023 (+) uses summer mean values in analogy with classical in-situ CSI023. However, for the future we plan to use full daily satellite Chl-*a* estimate resolution to evaluate changes in the statistical significance of the results.

Giovanni Coppini 27/8/12 00:58
**Eliminato:** the

Giovanni Coppini 27/8/12 00:58
**Eliminato:** donot

Giovanni Coppini 20/8/12 08:39
**Eliminato:** s

Giovanni Coppini 20/8/12 17:38
**Eliminato:** (for the period 1998-2004)

**Acknowledgements**

Work of this paper has been carried out within the framework of the European Topic Centre on Inland, Coastal and Marine Waters (ETC/ICM) (http://icm.eionet.europa.eu/), the European Topic Centre on Water (ETC/W) and MyOcean (www.myocean.eu.org) projects.

## References


D'Ortenzio F. and d'Alcalà M.R. (2009). On the trophic regimes of the Mediterranean Sea: a satellite analysis. Biogeosciences, 6 (2): 139-148

El-Shaarawi, Abdel H.; Piegorsch, Walter W. (2001), Encyclopedia of Environmetrics, Volume 1, John Wiley and Sons, p. 19, ISBN 978-0-471-89997-6.

Eplee, Jr., R. E., X. Xiong, J. Sun, G. Meister, and C. McClain, "The Cross Calibration of SeaWiFS and MODIS Using On-Orbit Observations of the Moon, Earth Observing Systems XIV", *Proc. SPIE*, vol. 7452, no. 74520X, 2009.

Ferreira João G., Jesper H. Andersen, Angel Borja, Suzanne B. Bricker, Jordi Camp, Margarida Cardoso da Silva, Esther Garcés, Anna-Stiina Heiskanen, Christoph Humborg, Lydia Ignatiades, Christiane Lancelot, Alain Menesguen, Paul Tett, Nicolas Hoepffnerm, Ulrich Claussen. (2011). Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuarine, Coastal and Shelf Science 93 (2011) 117-131

Gilbert R. O. (1987). Statistical Methods for Environmental Pollution Monitoring. John Wiley and Sons, 15/feb/1987. ISBN: 0-471-28878-0

Gordon Hr. and Morel Ay. (1983). Remote assessment of ocean colour for interpretation of satellite visible imagery: A review. Springer-Verlag (Lecture Notes on Coastal and Estuarine Studies. Volume 4), 1983, 118p

Maritorena S., O. H. Fanton d'Andonb, A. Manginb and D. A. Siegela, (2010). Merged satellite ocean colour data products using a bio-optical model: Characteristics, benefits and issues. Remote Sensing of Environment. Volume 114, Issue 8, 16 August 2010, Pages 1791-1804

Maritorena S., D. A. Siegela. (2005). Consistent merging of satellite ocean colour data sets using a bio-optical model. Remote Sensing of Environment 94 (2005) 429–440

Maritorena, S., Siegel, D. A., & Peterson, A. (2002). Optimization of a semi-analytical ocean colour model for global scale applications. Applied Optics, 41(15), 2705– 2714.

Meister, G., B. A. Franz, E. J. Kwiatkowska, and C. R. McClain, "Corrections to the Calibration of MODIS Aqua Ocean Colour Bands derived from SeaWiFS Data" IEEE Transactions on Geoscience and Remote Sensing, Vol. 50, No. 1, pp.310-319 (2012).

Morel, A. and Prieur, L. (1977). Analysis of variations in ocean-colour. *Limnol. Oceanogr*., 22: 709-722.

O'Reilly, J. E., and 24 co-authors, 2000, Ocean colour chlorophyll-a algorithms for SeaWiFS, OC2 and OC4: version 4. In SeaWiFS Post Launch Calibration and Validation Analyses, vol. 11, edited by S. B. Hooker and E. R. Firestone (Greenbelt, MD: NASA Goddard Space Flight Center), pp. 9–23.

Prieur L. and Sathyendranath S. (1981). An optical classification of coastal and oceanic waters based on the specific spectral absorption curves of phytoplankton pigments, dissolved organic matter and other particulate materials. Limnol. Oceanogr., 26(4): 671-689.

Salmi T., Määttä A., Anttila P., Ruoho-Airola T., Amnell T., Detecting Trends of annual values of Atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates- The excel template application Makesens


Giovanni Coppini 27/8/12 00:11
**Eliminato:** color

Giovanni Coppini 20/8/12 08:48
**Eliminato:** Lavender S. J., M. H. Pinkerton, J-M. Froidefond, J. Morales, J. Aiken and G. F. Moore (2004). SeaWiFS validation in European coastal waters using optical and bio-geochemical measurements, INT. J. Remote Sensing, 10–20 April, 2004, Vol. 25, No. 7–8, 1481–1488

Giovanni Coppini 27/8/12 00:11
**Eliminato:** color

Giovanni Coppini 27/8/12 00:11
**Eliminato:** color

Giovanni Coppini 27/8/12 00:11
**Eliminato:** color

Giovanni Coppini 27/8/12 00:11
**Eliminato:** Color

Giovanni Coppini 27/8/12 00:11
**Eliminato:** color

(2002). Ilmanlaadun julkaisuja Publikationer om luftkvalitet Publications on air quality No. 31. Ilmatieteen laitos, Meteorologiska Institutet, Finnish Meteorological Institute, Helsinki 2002

Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association. 63:1379-1389

Siokou-Frangou, I., Christaki U., Mazzocchi M.G., Montresor, M., d'Alcalà, M.R., Vaque, D., Zingone, A. (2010). Plankton in the open Mediterranean Sea: a review. Biogeosciences, 7 (5): 1543-1586

Sun J., R.E. Eplee, Jr., X. Xiong, T. Stone, G. Meister, and C.R. McClain, "MODIS and SeaWiFS on-orbit lunar calibration," in Earth Observing Systems XIII, J.J. Butler and J. Xiong, eds., Proc. SPIE7081, 70810Y, 2008.

Vantrepotte V., F. Melin (2010). Temporal variability in SeaWiFS derived apparent optical properties in

European seas. Continental Shelf Research 30 (2010) 319–334

Vantrepotte V., F. Melin (2011). Inter-annual variations in the SeaWiFS global chlorophyll a concentration (1997–2007). Deep-Sea Research I 58 (2011) 429–441.

Volpe, G., R. Santoleri, V. Vellucci, M. Ribera d'Alcalà, S. Marullo, F. D'Ortenzio (2007). The colour of the Mediterranean Sea: Global versus regional bio-optical algorithms evaluation and implication for satellite chlorophyll estimates. Remote Sensing of the Environment, 107, 625-638.

Giovanni Coppini 27/8/12 00:11
**Eliminato:** color

Table 1 Overview of ocean-colour data products used in the calculation of CSI023 (+).

| Dataset name/MyOcean Product Name | Domain | Spatial resolution | Time frame and resolution | Algorithm/merging method | Provider |
|---|---|---|---|---|---|
| Global Ocean GSM – MyOcean/OCEANCOLOUR_GLO_CHL_MERIS_MODIS_SEAWIFS_L3_L4_RAN | Global Ocean | 1/24° = 2.5′ (2.5′ latitude=4630m; 2.5′ longitude=3274m at Lat 45N) | 09/1997- 09/2009 daily | GSM | MyOcean |
| Global Ocean SeaWiFS RAN – MyOcean/OCEANCOLOUR_GLO_CHL_SEAWIFS_L3_RAN_OBSERVATIONS | Global Ocean | 1/12° | from 1997-09-01 to 2010-12-31 monthly | standard OC4-V4 algorithm for chla | MyOcean |
| Med Regional SeaWiFS RAN – MyOcean /OCEANCOLOUR_MED_CHL_SEAWIFS_L3_RAN_OBSERVATIONS | Mediterranean Sea | Approximately 1x1 km (Latitude step: 1131 m, Longitude step: 45N -> 1006 m 30N -> 1245 m) | from 1997-10-01 to 2009-12-31 daily | Mediterranean – MEDOC4 | MyOcean a CNR |

Giovanni Coppini 21/8/12 09:21
Eliminato: 1

Giovanni Coppini 21/8/12 08:58
Formattato ... [5]

Giovanni Coppini 21/8/12 08:58
Formattato ... [6]

Giovanni Coppini 21/8/12 08:58
Formattato: Tipo di carattere:10 pt

Giovanni Coppini 21/8/12 08:58
Formattato: Tipo di carattere:(Predefinito) Times New Roman, 10 pt, Nessuna sottolineatura

Giovanni Coppini 21/8/12 08:58
Formattato ... [7]

Giovanni Coppini 21/8/12 08:58
Formattato ... [8]

Giovanni Coppini 14/8/12 07:37
Eliminato: -

Giovanni Coppini 21/8/12 08:58
Formattato ... [9]

Giovanni Coppini 21/8/12 08:58
Formattato ... [10]

Giovanni Coppini 21/8/12 08:58
Formattato: Tipo di carattere:10 pt

Giovanni Coppini 21/8/12 08:58
Formattato ... [11]

Giovanni Coppini 21/8/12 08:58
Formattato ... [12]

Giovanni Coppini 27/8/12 01:46
Formattato: Tipo di carattere:10 pt, Colore carattere: Nero

Giovanni Coppini 16/8/12 07:09
Eliminato: and Black Sea

Giovanni Coppini 21/8/12 08:58
Formattato ... [13]

Giovanni Coppini 21/8/12 08:58
Formattato ... [14]

Giovanni Coppini 14/8/12 07:45
Eliminato: 05/1998-09/2004 daily ... [15]

Giovanni Coppini 27/8/12 01:32
Eliminato: for the period 1998-2004 and ... [16]

Giovanni Coppini 21/8/12 08:58
Formattato: Tipo di carattere:10 pt

Giovanni Coppini 21/8/12 08:58
Formattato ... [17]

Giovanni Coppini 21/8/12 08:58
Formattato: Tipo di carattere:10 pt

Giovanni Coppini 21/8/12 08:58
Formattato ... [18]

Giovanni Coppini 16/8/12 07:09
Eliminato: Test # and variables compar ... [19]

Giovanni Coppini 21/8/12 08:58
Formattato ... [20]

Table 2 Principal characteristics of the in situ EEA-EIONET dataset: number of points, coverage in time and space.

| Basins | number of daily profiles | coverage in time |
|---|---|---|
| All European Seas | 8910 | January 1998 – October 2009 |
| Mediterranean Sea[8] | 3861 | January 1998 – December 2008 |
| Black Sea | 78 | April 1998-September 2009 |
| North East-Atlantic | 647 | March 1998 - May 2009 |
| North Sea | 1844 | March 1998-October 2009 |
| Baltic Sea | 2480 | March 1998-October 2009 |
| Mediterranean Sea[9] | 13611 | January 1998 – December 2008 |

[8] in situ data after re-griding on the **Global Ocean GSM – MyOcean** satellite product grid

[9] in situ data after re-griding on the **Med Regional SeaWiFS RAN – MyOcean** satellite product grid

Table 3 Validation of the ocean-colour data products used in the calculation of CSI023 (+). Correlation coefficient (r2), Slope and intercept of the regression lines correspond to the one presented in figure 6, 7. 8 and 9. Numbers of summer/annual mean values compared are reported in the table for each of the seas and European Sea and for each of the aggregation period (summer or year). Root Mean Square Distance (RMSD) and BIAS are calculated for Chl-a absolute values (mg $m^{3}$), not logarithmic. The Mediterranean Sea results are reported for the **Global Ocean GSM – MyOcean** product (GSM) and **Med Regional SeaWiFS RAN – MyOcean** product (Med Reg).

| **Seas and period of analysis** | **$r^2$** | **Slope** | **Intercept** | **BIAS** | **RMSD** | **Num. Of points** |
|---|---|---|---|---|---|---|
| European Seas annual | 0,53 | 0,74 | -0,13 | 1,10 | 4,46 | 4176 |
| European Seas summer | 0,54 | 0,78 | -0,17 | 1,01 | 4,12 | 3107 |
| Baltic Sea annual | 0,02 | 0,41 | 0,15 | 1,55 | 5,10 | 1264 |
| Baltic Sea summer | 0,15 | 0,43 | 0,14 | 1,26 | 4,74 | 1103 |
| Mediterranean Sea annual (GSM) | 0,34 | 0,61 | -0,29 | 0,42 | 2,15 | 1570 |
| Mediterranean Sea summer (GSM) | 0,31 | 0,58 | -0,41 | 0,36 | 1,95 | 1133 |
| North Sea annual | 0,40 | 0,62 | -0,08 | 2,12 | 6,80 | 918 |
| North Sea summer | 0,33 | 0,55 | -0,08 | 2,03 | 5,99 | 637 |
| North-east Atlantic annual | 0,46 | 0,76 | -0,05 | 0,02 | 1,43 | 378 |
| North-east Atlantic summer | 0,45 | 0,59 | -0,01 | 0,23 | 1,44 | 211 |
| Black Sea annual | 0,39 | 0,61 | -0,06 | 0,41 | 1,86 | 46 |
| Black Sea summer | 0,38 | 0,87 | 0,25 | -0,62 | 1,00 | 23 |
| Mediterranean Sea Summer (Med Regional) | 0,41 | 0,55 | -0,22 | -0,04 | 1,44 | 1285 |
| Mediterranean Sea annual (Med Regional) | 0,37 | 0,72 | -0,13 | 0,15 | 1,36 | 1649 |

Giovanni Coppini 21/8/12 08:58
**Formattato** ... [21]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [22]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [23]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [24]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [25]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [26]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [27]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [28]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [29]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [30]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [31]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [32]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [33]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [34]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [35]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [36]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [37]
Giovanni Coppini 21/8/12 07:28
**Tabella formattata**
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [38]
Giovanni Coppini 21/8/12 16:26
**Formattato:** Centrato
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [39]

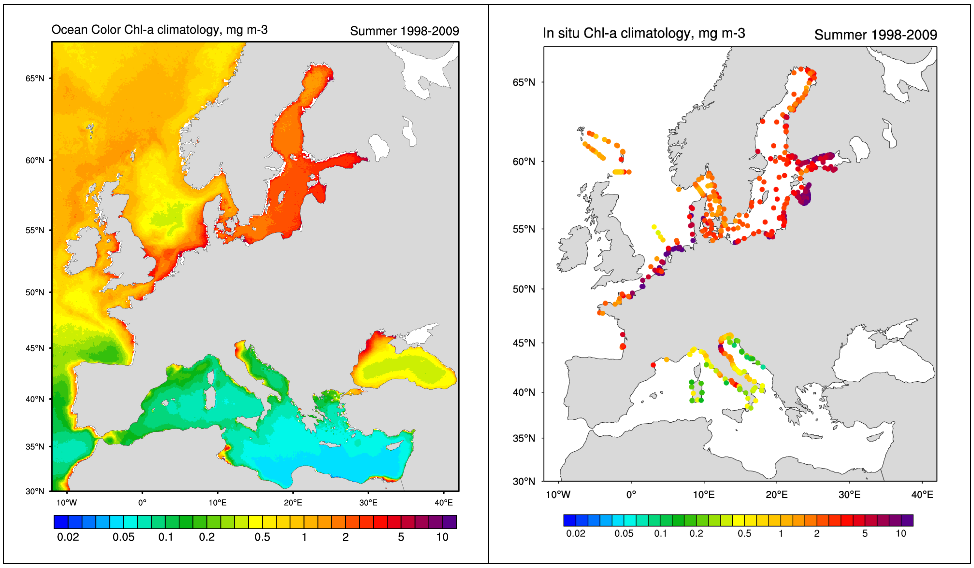



Figure 1. Summer (May-Sept) mean Chl-*a* concentration in European seas for the period 1998-2009 from the MyOcean ocean-colour global dataset (left panel) and the Eionet in-situ dataset (right panel).

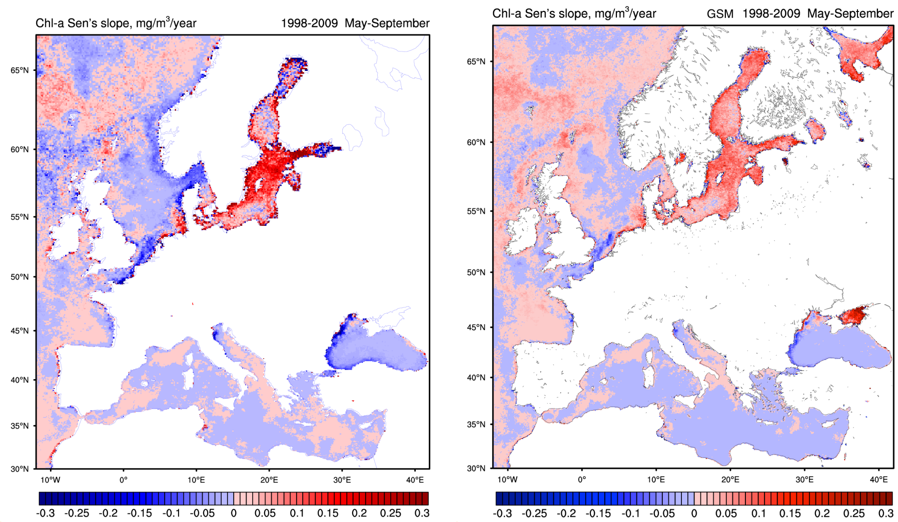
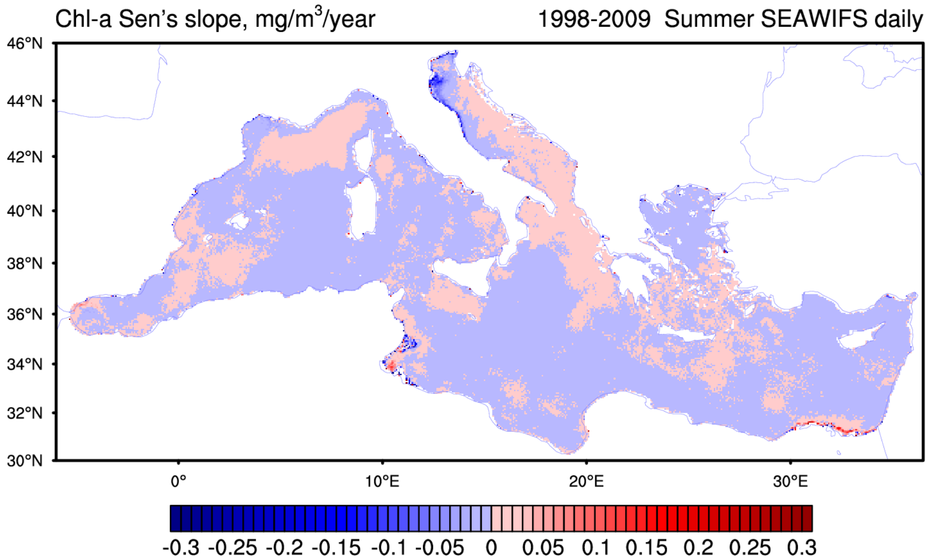



Figure 2. Pan-European Chl a trend values (mg m$^{-3}$ y$^{-1}$) (Sen's slope) from **Global Ocean SeaWiFS RAN – MyOcean** (left panel) and from **Global Ocean GSM – MyOcean** (right panel) for the period 1998-2009. Both significant and non-significant trends are displayed.

Unknown
**Formattato:** Tipo di carattere:Grassetto, Colore carattere: Colore personalizzato(RGB(79;129;189))

Unknown
**Formattato:** Tipo di carattere:Grassetto, Colore carattere: Colore personalizzato(RGB(79;129;189))




Unknown
**Formattato:** Tipo di carattere:Grassetto, Colore carattere: Colore personalizzato(RGB(79;129;189))

Figure 3. Mediterranean trend values (mg m$^{-3}$ y$^{-1}$) (Sen's slope) for the period 1998-2009 calculated using the regional product **Med Regional SeaWiFS RAN – MyOcean**. Both significant and non-significant trends are displayed.

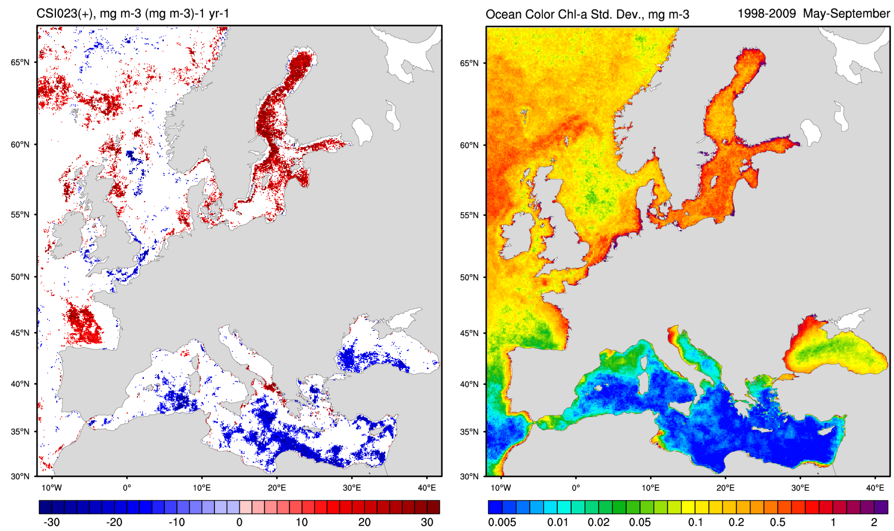
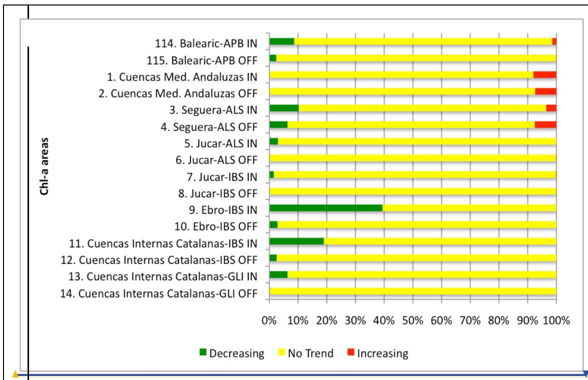



Figure 4. CSI023 (+) pan-European trend indicator values (mg m$^{-3}$ (mg m$^{-3}$)$^{-1}$ y$^{-1}$) (left panel) for the period 1998-2009. White areas indicate values that are not statistically significant. Chl-*a* standard deviation (mg m$^{-3}$) (right panel) for the period 1998-2009.

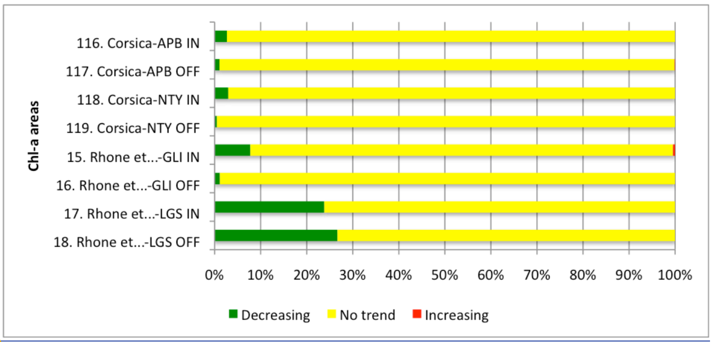
Giovanni Coppini 27/8/12 00:45
**Eliminato:**

Giovanni Coppini 27/8/12 00:01
**Eliminato:**

Giovanni Coppini 6/8/12 11:38
**Eliminato:** 2




a)




b)

Figures 5 a and b. CSI023 (+) *Chl*-a *area* trend indicators in the Western Mediterranean Spanish Coast (a) and Ligurian Sea, Gulf of Lions, Tyrrhenian Sea and Algero Provencal Basin (b) for the period 1998-2009. For each *Chl*-a *area* the red bars indicate the percentage of grid points with significant increasing trends, the green bars indicate the percentage of grid points with decreasing significant trends and the yellow bars indicate the percentage of grid points without significant trend.

Giovanni Coppini 20/8/12 21:44
**Eliminato:**

Unknown
**Formattato:** Tipo di carattere:10 pt, Grassetto, Colore carattere: Colore personalizzato(RGB(79;129;189))

Giovanni Coppini 27/8/12 02:37
**Eliminato:**
b)
... [40]

Unknown
**Formattato:** Colore carattere: Automatico

Giovanni Coppini 27/8/12 02:38
**Formattato:** Tipo di carattere:Non Grassetto, Colore carattere: Automatico

Giovanni Coppini 21/9/12 18:43
**Eliminato:**

Giovanni Coppini 20/8/12 17:53
**Eliminato:** 3

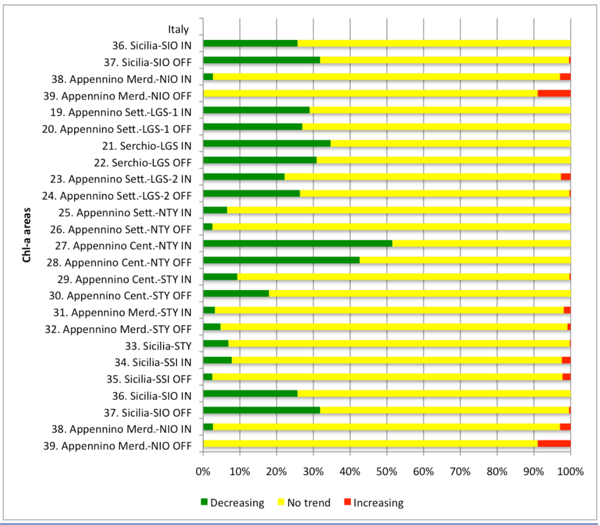
Giovanni Coppini 20/8/12 22:43
**Eliminato:** a and b

Giovanni Coppini 20/8/12 22:43
**Eliminato:** Black Sea

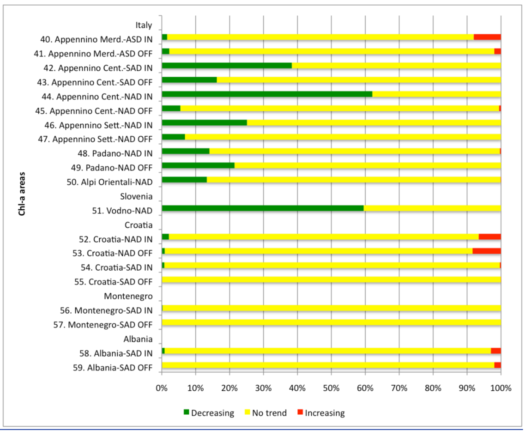
Giovanni Coppini 20/8/12 22:45
**Eliminato:** Aegean and Ionian Seas

Giovanni Coppini 20/8/12 22:45
**Eliminato:** 7

Giovanni Coppini 21/8/12 08:58
**Formattato:** Non Apice/ Pedice

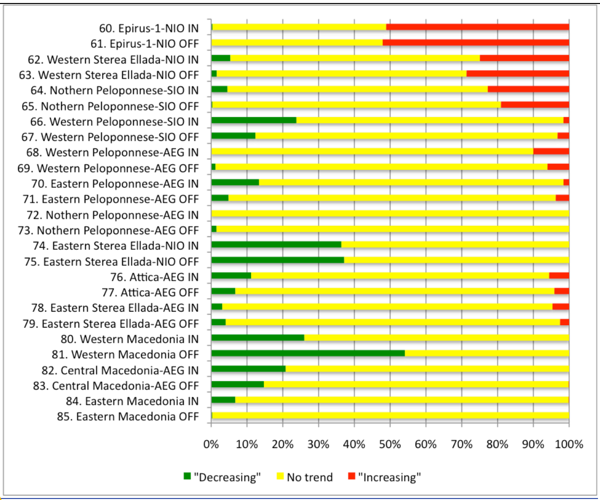



c)

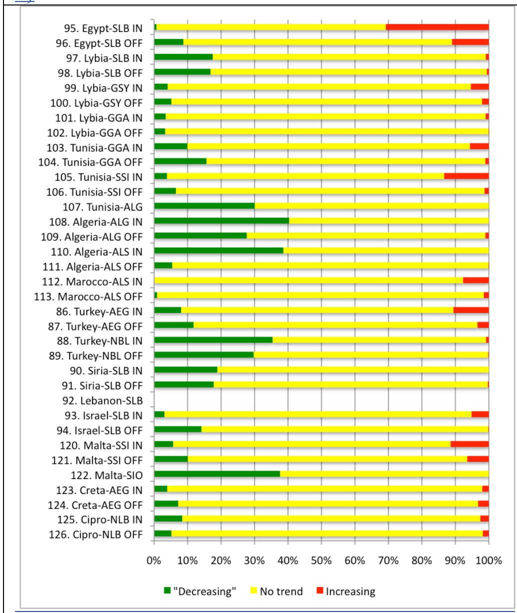



d)

Figures 5 c and d. CSI023 (+) *Chl*-a *area* trend indicators in the Ligurian, Tyrrhenian, Ionian Sea and Sicily Strait (c) and in the Adriatic Sea (d) for the period 1998-2009. For each *Chl*-a *area* the red bars indicate the percentage of grid points with significant increasing trends, the green bars indicate the percentage of grid points with decreasing significant trends and the yellow bars indicate the percentage of grid points without significant trend.




e)




f)

Figures 5 e and f. CSI023 (+) *Chl*-a *area* trend indicators in the Aegean Sea and Greek coasts (e) and in the Eastern Mediterranean and African Coasts (f) for the period 1998-2009. For each *Chl*-a *area* the red bars indicate the percentage of grid points with significant increasing trends, the green bars indicate the percentage of grid points with decreasing significant trends and the yellow bars indicate the percentage of grid points without significant trend.

Unknown
**Formattato:** Non Apice/ Pedice

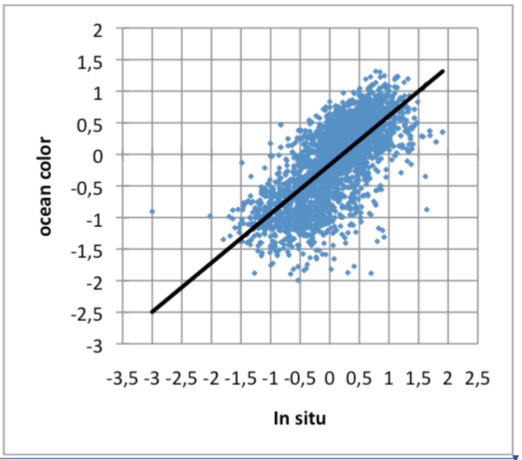



Figure 6. Summer Chl-*a* in-situ concentration and the ocean-colour **Global Ocean GSM – MyOcean** Chl-*a* concentration for all selected stations in the European seas (Log10 mg m-3). The black line is the best linear approximation between ocean colour (y) and in-situ values (x).

Unknown
**Formattato:** Sottolineato

Giovanni Coppini 19/8/12 11:29
**Eliminato:**

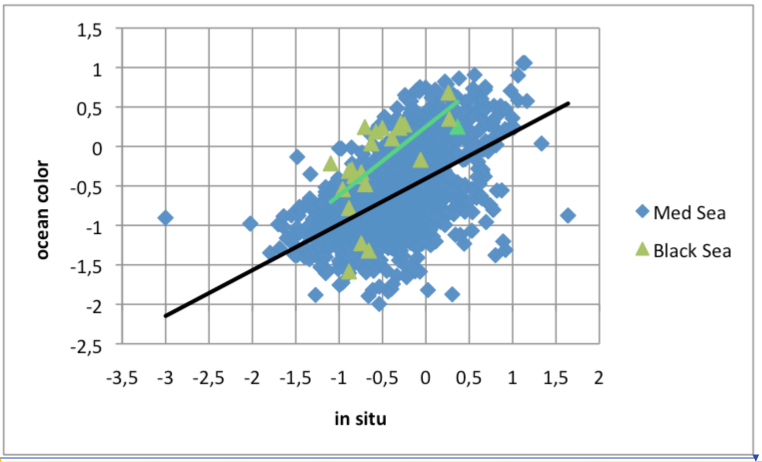



Figure 7. Summer Chl-*a* in-situ concentration and the ocean-colour **Global Ocean GSM – MyOcean** Chl-*a* concentration for all selected stations in the Mediterranean Sea (Log10 mg m-3). The black line is the best linear approximation between ocean colour (y) and in-situ values (x) in the Mediterranean Sea and the green line is the one for the Black Sea.

Unknown
**Formattato:** Sottolineato

Giovanni Coppini 19/8/12 11:29
**Eliminato:**

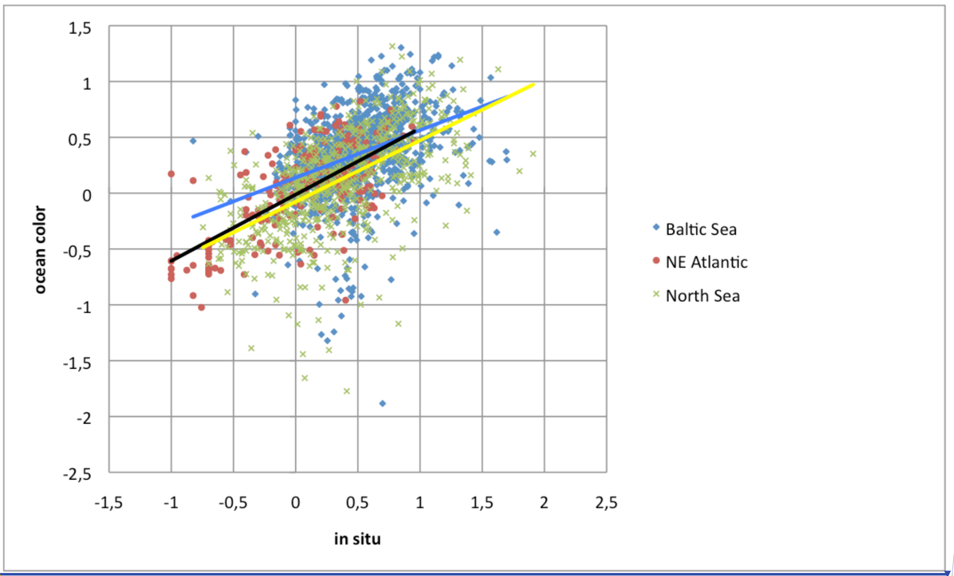



Figure 8. Summer Chl-*a* in-situ concentration and the ocean-colour **Global Ocean GSM – MyOcean** Chl-*a* concentration (Log10 mg m-3) for all selected stations in the Baltic Sea (blue diamond), North-east Atlantic (orange circle) and North Sea (green cross). The best linear approximation between ocean colour (y) and in-situ values (x) is in blue for the Baltic Sea, black for the North-east Atlantic and yellow for the North Sea.

Giovanni Coppini 19/8/12 11:29
**Eliminato:**

Unknown
**Formattato:** Tipo di carattere:Grassetto, Colore carattere: Colore personalizzato(RGB(79;129;189))

Giovanni Coppini 21/8/12 14:29
**Eliminato:** 6

Giovanni Coppini 21/8/12 08:31
**Eliminato:** (Log10 mg m-3)

Giovanni Coppini 21/8/12 08:32
**Eliminato:** black line is the

Giovanni Coppini 20/8/12 07:48
**Eliminato:** . The reference red line corresponds to the y=x approximation

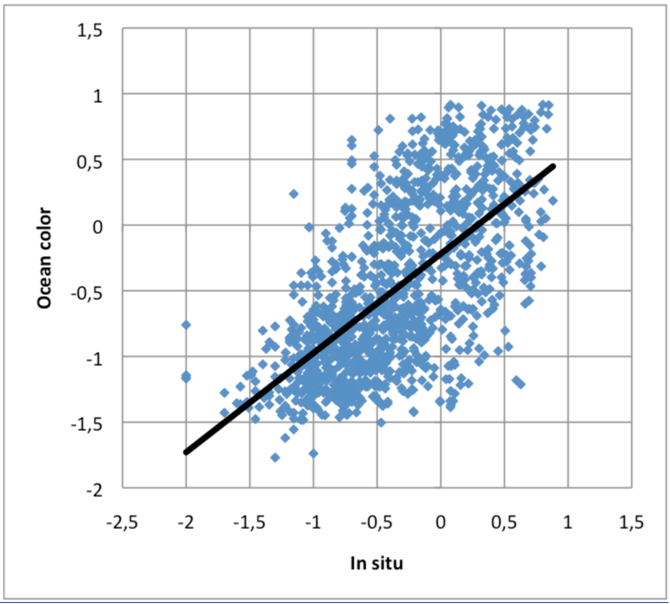



**Figure 9**. Summer log10 Chl-*a* in-situ concentration (x axis) compared with the ocean-colour Med Regional SeaWiFS RAN – MyOcean log10 Chl-*a* concentration (y axis). Log10 Chl-*a* values are expressed in mg $m^{-3}$. The black line is the best linear approximation between ocean colour (y) and in-situ values (x).

Giovanni Coppini 21/8/12 08:33
**Eliminato:**
a) ... [41]

Giovanni Coppini 19/8/12 11:28
**Eliminato: Figure 9. Chl-*a* concentration (mg $m^{-3}$) as estimated by ocean colour (a) and in-situ data (b) for the 2005 summer period.**

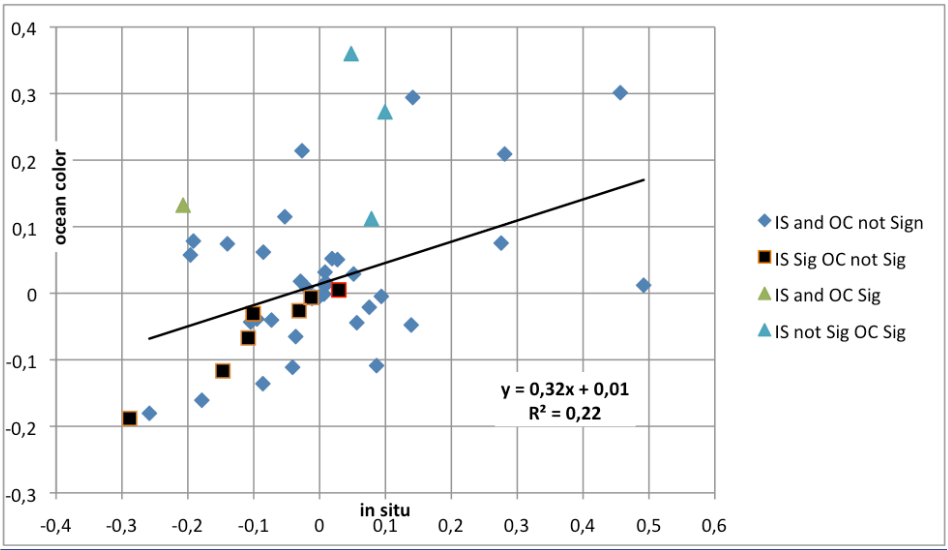



Figure 10. Summer Chl-*a* in-situ trends and the ocean-colour **Global Ocean GSM – MyOcean** Chl-*a* trends for all selected stations in the European Seas (mg $m^{-3}$ $y^{-1}$). The black line is the best linear approximation between ocean colour (y) trends and in-situ trend values (x). The significance of the trends is presented with different symbols: In situ (IS) and Ocean Colour (OC) not significant – blue diamond; IS significant (95%) and OC not significant – Black square; IS and OC both significant (95%) green triangle; IS not significant and OC significant (95%) blue triangle.

Unknown
**Formattato:** Tipo di carattere:12 pt, Non Grassetto

Giovanni Coppini 21/9/12 19:01
**Eliminato:** 10

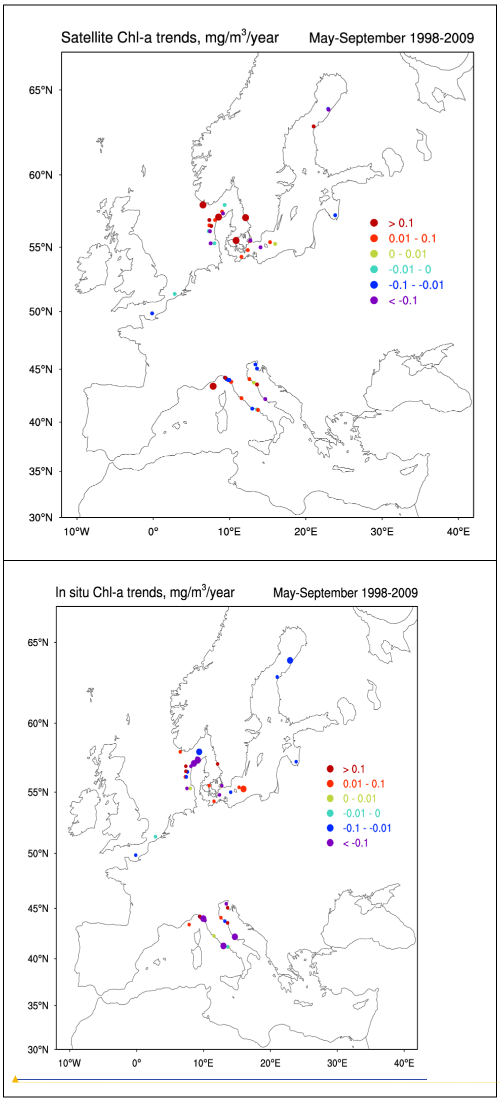



Figure 11. Comparison of Chl-a trends calculated estimated from ocean colour data **Global Ocean GSM – MyOcean** in the European seas for the period 1998-2009 (mg $m^3$ $y^{-1}$) and from the in situ dataset (right panel). Large circles correspond to significant (95% confidence level) trends while small circles correspond to non-significant trends. The palette indicates different trend's range (mg $m^{-3}$) with different colours.

Unknown
**Formattato:** Tipo di carattere:12 pt, Non Grassetto, Colore carattere: Colore personalizzato(RGB(79;129;189))

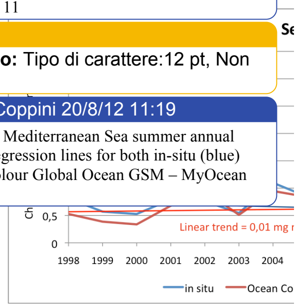
Giovanni Coppini 21/8/12 14:29
**Eliminato:** **Figura 1**

Giovanni Coppini 19/8/12 12:29
**Eliminato:**

Giovanni Coppini 21/8/12 14:29
**Eliminato:** 11

Unknown
**Formattato:** Tipo di carattere:12 pt, Non Grassetto

Giovanni Coppini 20/8/12 11:19
**Eliminato:** Mediterranean Sea summer annual means and regression lines for both in-situ (blue) and ocean-colour Global Ocean GSM – MyOcean (red) data



## Annex I *Chl*-a *areas* description

As explained in the paper in paragraph 2.4 *Chl*-a *areas* were defined in the Mediterranean Sea and they are 68. Chla areas are defined  using information on the River Basin Districts (RBDs), and political borders when RBDs were not defined. Moreover, 18 open-ocean sub-basins were identified in the Mediterranean and used to design the *Chl*-a *areas*. When possible, within each *Chl*-a *area* two sub-areas are defined: a coastal one (IN), from the coast to a depth of 30 metres and an offshore one (OFF), from a depth of 30 to 200 metres. A name composed of 3 parts is associated with each single *Chl*-a *area* as following: 1) name of the RBD or name of the country; 2) name of the sub-basin; 3) 'IN' if it is the inshore part of the *Chl*-a *area* or 'OFF' if it is the offshore part of the *Chl*-a *area*.

Chl-a areas are listed in table 1 and are presented in figures 1-4 of this Annex.

| **Chla Areas names** | **Chla Areas names** |
|---|---|
| Cuencas Med. Andaluzas | Western Peloponnese-SIO |
| Seguera-ALS | Western Peloponnese-AEG |
| Jucar-ALS | Eastern Peloponnese-AEG |
| Jucar-IBS | Nothern Peloponnese-AEG |
| Ebro-IBS | Eastern Sterea Ellada-NIO |
| Cuencas Internas Catalanas-IBS | Attica-AEG |
| Cuencas Internas Catalanas-GLI | Eastern Sterea Ellada-AEG |
| Rhone et...-GLI | Western Macedonia |
| Rhone et...-LGS | Central Macedonia-AEG |
| Appennino Sett.-LGS-1 | Eastern Macedonia |
| Serchio-LGS | Turkey-AEG |
| Appennino Sett.-LGS-2 | Turkey-NBL |
| Appennino Sett.-NTY | Siria-SLB |
| Appennino Cent.-NTY | Lebanon-SLB |
| Appennino Cent.-STY | Israel-SLB |
| Appennino Merd.-STY | Egypt-SLB |
| Sicilia-STY | Lybia-SLB |
| Sicilia-SSI | Lybia-GSY |
| Sicilia-SIO | Lybia-GGA |
| Appennino Merd.-NIO | Tunisia-GGA |
| Appennino Merd.-SAD | Tunisia-SSI |
| Appennino Cent.-SAD | Tunisia-ALG |



Eliminato: ... [42]
Unknown
Formattato ... [43]
Giovanni Coppini 21/8/12 08:58
Formattato ... [44]
Giovanni Coppini 3/8/12 06:38
Formattato ... [45]
Giovanni Coppini 21/8/12 08:58
Formattato ... [46]
Giovanni Coppini 21/8/12 08:58
Formattato ... [47]
Giovanni Coppini 21/8/12 06:39
Tabella formattata ... [48]
Giovanni Coppini 21/8/12 08:58
Formattato ... [49]
Giovanni Coppini 21/8/12 08:58
Formattato ... [50]
Giovanni Coppini 21/8/12 08:58
Formattato ... [51]
Giovanni Coppini 21/8/12 08:58
Formattato ... [52]
Giovanni Coppini 21/8/12 08:58
Formattato ... [53]
Giovanni Coppini 21/8/12 08:58
Formattato ... [54]
Giovanni Coppini 21/8/12 08:58
Formattato ... [55]
Giovanni Coppini 21/8/12 08:58
Formattato ... [56]
Giovanni Coppini 21/8/12 08:58
Formattato ... [57]
Giovanni Coppini 21/8/12 08:58
Formattato ... [58]
Giovanni Coppini 21/8/12 08:58
Formattato ... [59]
Giovanni Coppini 21/8/12 08:58
Formattato ... [60]
Giovanni Coppini 21/8/12 08:58
Formattato ... [61]
Giovanni Coppini 21/8/12 08:58
Formattato ... [62]
Giovanni Coppini 21/8/12 08:58
Formattato ... [63]
Giovanni Coppini 21/8/12 08:58
Formattato ... [64]
Giovanni Coppini 21/8/12 08:58
Formattato ... [65]
Giovanni Coppini 21/8/12 08:58
Formattato ... [66]
Giovanni Coppini 21/8/12 08:58
Formattato ... [67]
Giovanni Coppini 21/8/12 08:58
Formattato ... [68]
Giovanni Coppini 21/8/12 08:58
Formattato ... [69]
Giovanni Coppini 21/8/12 08:58
Formattato ... [70]

| | |
|---|---|
| Appennino Cent.-NAD | Algeria-ALG |
| Appennino Sett.-NAD | Algeria-ALS |
| Padano-NAD | Marocco-ALS |
| Alpi Orientali-NAD | Balearic-APB |
| Vodno-NAD | Corsica-APB |
| Croatia-NAD | Corsica-NTY |
| Croatia-SAD | Malta-SSI |
| Montenegro-SAD | Malta-SIO |
| Albania-SAD | Creta-AEG |
| Epirus-1-NIO | Cipro-NLB |
| Western Sterea Ellada-NIO | Sardegna-SAD |
| Nothern Peloponnese-SIO | Sardegna-STY |

Table 1. Names of the Chl-a areas

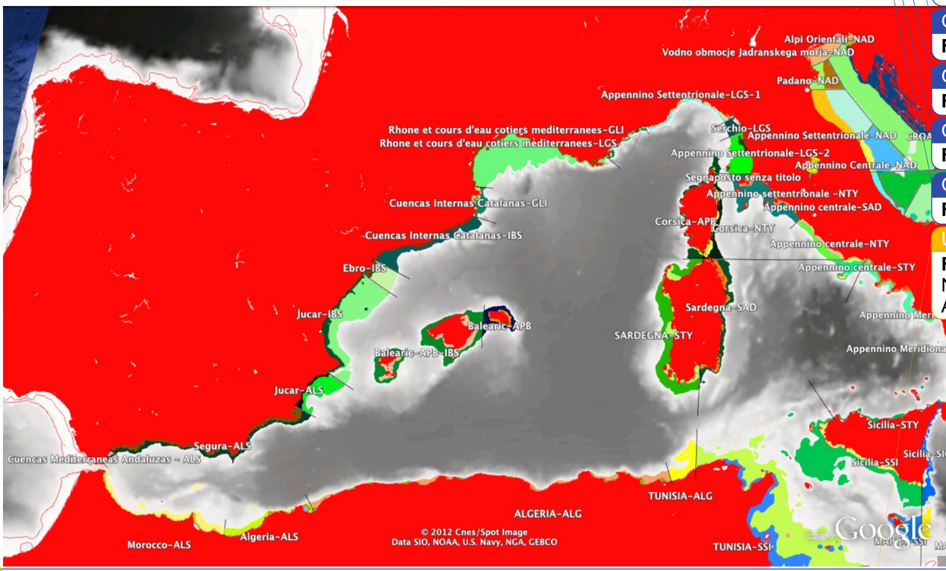



Figure 1: *Chla areas* in the Western Mediterranean Sea. Names of each *Chla area* are reported in the map. Each *Chl*a *area* is presented using specific different colour and within each *Chl*-a *areas* the –IN and OFF zones are presented using different colours. The black thin line perpendicular to the coastline represent the boundary of each Chla area. Land is coloured in red and bathymetry is represented in grey scale.

Giovanni Coppini 21/8/12 08:58
**Formattato** ... [71]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [72]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [73]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [74]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [75]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [76]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [77]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [78]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [79]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [80]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [81]
Giovanni Coppini 21/8/12 08:58
**Formattato** ... [82]
Unknown
**Formattato:** Tipo di carattere:(Predefinito) NimbusSanL-Regu, Colore carattere: Automatico

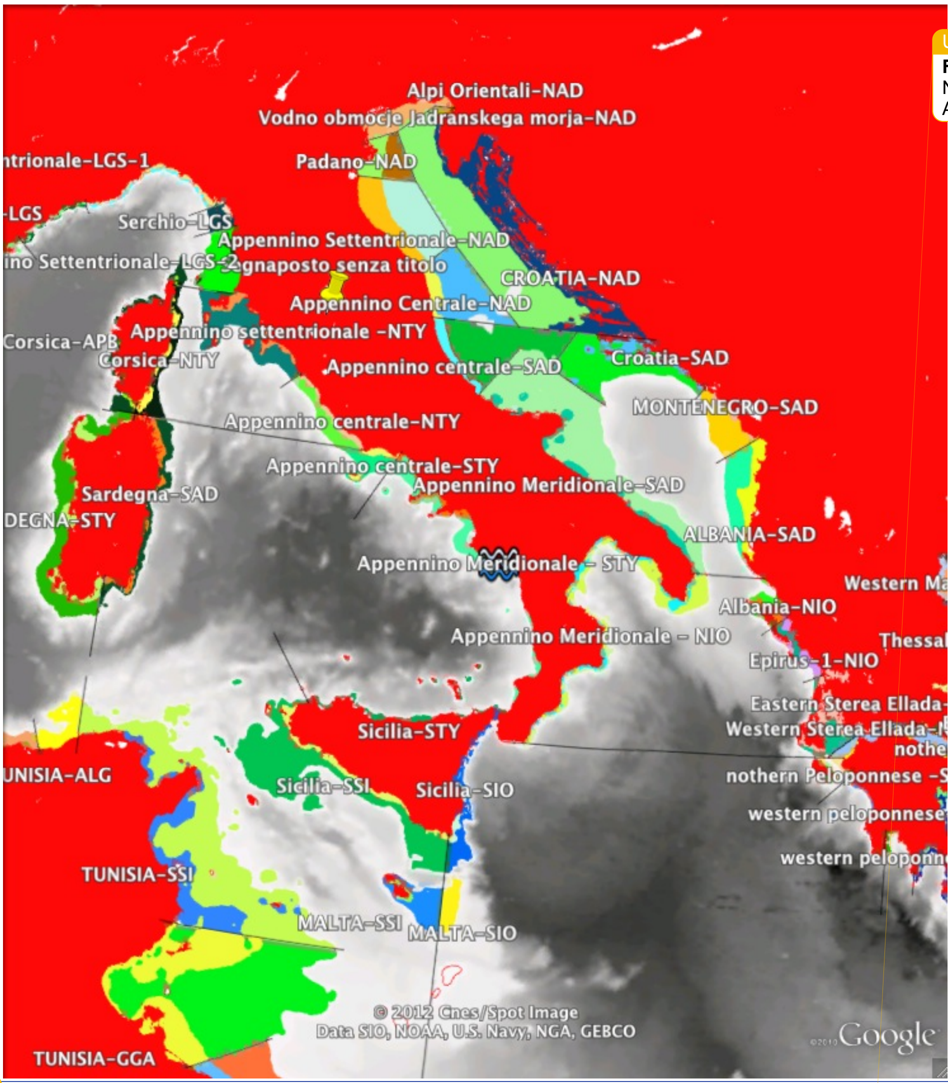



Figure 2: *Chla areas* in the Tyrrhenian Sea, Sicily Channel, Adriatic Sea and Ionian Sea. Names of each *Chla areas* are reported in the map. Each *Chla area* is presented using specific different colour and within each *Chl*-a *area* the –IN and OFF zones are presented using different colours. The black thin line perpendicular to the coastline represent the boundary of each Chla area. Land is coloured in red and bathymetry is represented in grey scale.

Unknown
**Formattato:** Tipo di carattere:(Predefinito) NimbusSanL-Regu, Colore carattere: Automatico

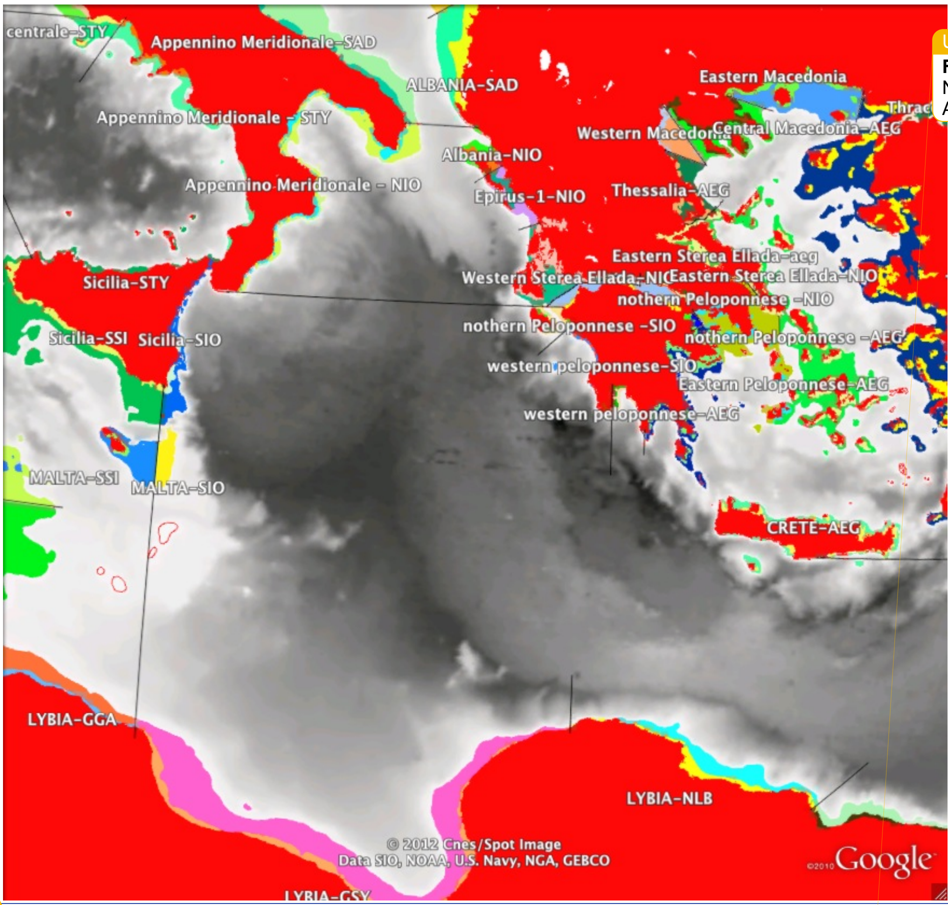



Figure 3: *Chla areas* in the Central Mediterranean Sea and Aegean Sea. Names of each *Chla area* are reported in the map. Each *Chla area* is presented using specific different colour and within each *Chl*-a *area* the –IN and OFF zones are presented using different colours. The black thin line perpendicular to the coastline represent the boundary of each *Chla area.* Land is coloured in red and bathymetry is represented in grey scale.

Unknown
**Formattato:** Tipo di carattere:(Predefinito) NimbusSanL-Regu, Colore carattere: Automatico

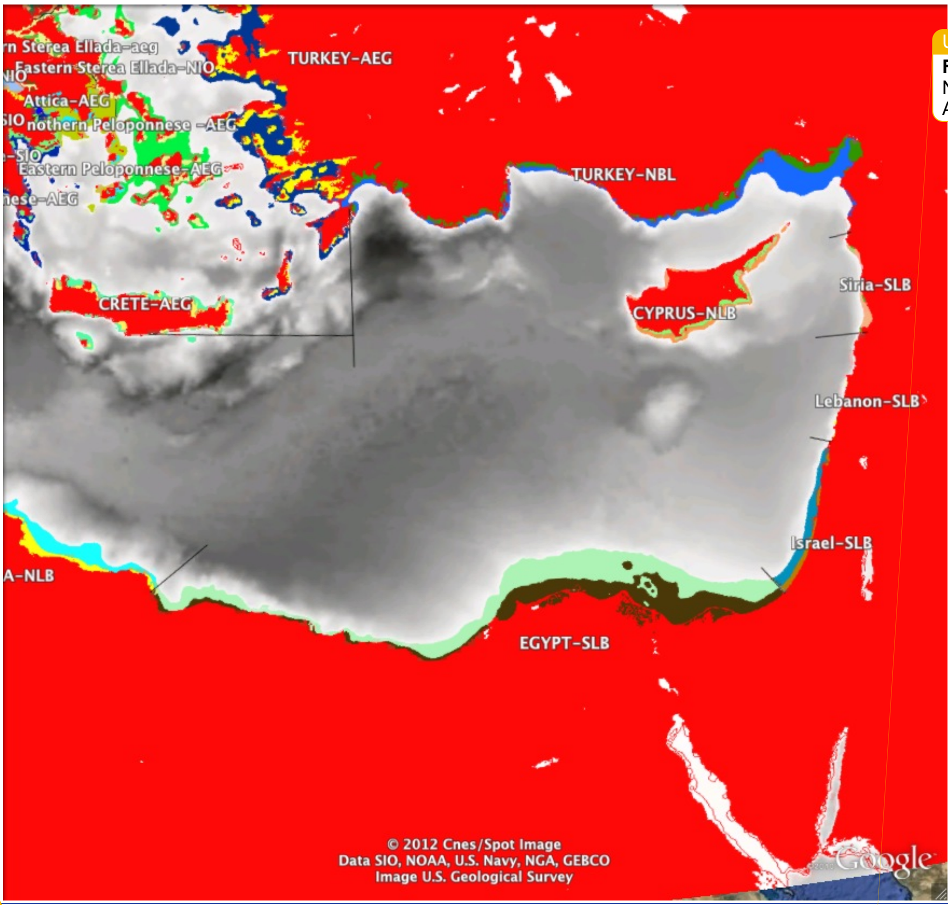



Figure 4: *Chla areas* in the Eastern Mediterranean Sea. Names of each *Chla area* are reported in the map. Each *Chla area* is presented using specific different colour and within each *Chl*-a *area* the –IN and OFF zones are presented using different colours. The black thin line perpendicular to the coastline represent the boundary of each *Chla area.* The black lines in the north-western part of the Levantine basin represent the idealized boundary between the Aegean Sea and the Levantine basin. Land is coloured in red and bathymetry is represented in grey scale.

Unknown
**Formattato:** Tipo di carattere:(Predefinito) NimbusSanL-Regu, Colore carattere: Automatico