Marine Water Quality Information Services
AQUAMAR
FP7-SPACE-2009-1 / Collaborative project N° 241759

AQUAMAR context

The AquaMar project focused on downstream services turning Marine Core Services products into water quality end-user services. While the current MarCoast 2 project (Marine & Coastal Environmental Information Services), funded by ESA under the GMES Services Element programme, does not include any R&D activities, AquaMar aimed at developing new service lines that can potentially be included into operational services.
Water quality is a key topic for monitoring agencies and the public, and it is subject of several European Directives: Water Framework Directive(WFD), Bathing Water Directive, Marine Strategy Framework Directive (MSFD), Environmental Impact Assessment (EIA) Directive; and regional conventions: Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR), Helsinki Convention (HELCOM), Barcelona Commission (BARCOM). Marine Water Quality is the physical, chemical and biological characteristics of water in relationship to a set of Standards which vary significantly due to different environmental conditions, ecosystems, and intended human uses. Some measurements can be made on-site in direct contact with the water source in question. More complex measurements require a water sample to be collected, preserved, and analysed in the laboratory. Taking these complex measurements can be expensive. In the past, remote sensing has proven to provide a contribution to water quality measurements, which is limited in terms of number of measurable parameters, but significant in terms of spatial span of the observed parameters and in terms of cost / benefit.
Optical remote sensing techniques provide measurements of apparent optical properties of water (water leaving reflectances) which can be converted into basic biological and physical parameters (transparency, chlorophyll-a concentration, suspended matter concentration), or through statistical analysis and integration with in-situ measurements into higher level indicators (e.g. Percentile 90). Assimilation of remotely sensed quantities into numerical models enlarges the suite of derived parameters (nutrients, algal species composition).
The basic products delivered from optical remote sensing are serving only part of the users' requirements. The near coastal area, which is the main focus of the WFD, is not properly addressed.

The AquaMar developments were done under guidance by the users, through the User and Customer Executive Board (UCEB), in order to make sure that user requirements were constantly and properly met and in order to establish customer retention to the service network.

The AquaMar project concept was based on three central R&D elements:

(1) scientific development of new methods for innovative products. The results of this element are scientific/technical descriptions of new algorithms.
(2) technological implementation of the methodological results, raised up to a pre-operational status; robust and applicable to all relevant water types and times; properly documented and implemented in various instances; tested with users in a quasi-operational environment.
(3) validation methodology developed for both development lines, taking the specific objectives into account.

These three activities were supported by cross cutting activities, such as development of generic remote sensing methods.

Achieved results

AquaMar developed novel products and methods, to be integrated into MarCoast services as to improve the quality and spectrum of the products delivered to the end-users concerning Water Quality. The service portfolio of products developed in AquaMar includes: (1) indicators for the reporting requirement of the Water Framework Directive and the European Marine Strategy, (2) algal bloom detection of different species, (3) support to large scale marine infrastructures projects, (4) services supporting the Bathing Water directive monitoring, (5) aquaculture precision farming.
For each of the five innovative service/products lines two trials were performed, allowing for assessing their accuracy and value towards the user requirements and practices and identifying further elements to be developed, with existing technology gaps.
Furthermore some of the outcomes have been successfully implemented into MarCoast2 operational services.

Concerning the validation of water quality products, AquaMar defined a validation protocol tested within the service trial and implemented in the last year on operational services in MarCoast2 and other European projects. Fruitful cooperation with other project contributed to the further improvement of the products validation processes and information dissemination, as for example the adaptation of the Marcoast/AquaMar Validation protocol for FP7 projects Freshmon and Cobios. Furthermore a Service Validation Information System has been developed allowing service providers, users and validation reviewers to use a single interface to access the validation information and provide feedback at all levels.

Concerning the User community, AquaMar put efforts for the dissemination of best practices to the service provider's community started through interactions and cooperation between providers to ensure the promotion of ocean colour services within users. Two User Training and Validation Workshops have been held – in conjunction with the last two MarCoast2 Service Validation Workshops – involving many users and discussion the outcomes of the R&D and trial activities.

AquaMar has contributed to the users' uptake to support the following legislation:
Marine Strategy Framework Directive (MSFD)

- Introduction of MarCoast Chl and Total Suspended Matter into initial state assessment for MSFD in France (France)
- Presentation to and discussion with national board for phytoplankton monitoring (BLMP subgroup, responsible for WFD & MSFD) (Germany)

Water Framework Directive (WFD)

- Improved Chl-P90 products for DG-ENV Belgium requirements (Belgium)
- Integration of MarCoast products into time series (statistics) for WFD areas (Norway)
- Experimental usage of MarCoast products for WFD assessment in 2 case studies (Italy)

Contribution to the support to Water Framework Directive (WFD)

This activity improved the quality of satellite data products near the coast (within 1 nautical mile) in order to provide better products to support monitoring requirements of the WFD. Four activities demonstrated significant results.

- Improvements on the pre-processing of coastal water ocean colour data have been achieved: a cloud detection refined; new flags for differentiating mixed pixels and floating vegetation added; a more accurate land-water mask.
- The validation on chlorophyll concentration with in-situ data as well as error estimation of P90 calculation has been performed and validated. An indicator build on the P90 has been developed following the Belgium implementation of the WFD and time series of chlorophyll_a are also being used as an indicator (searching for algal bloom characteristics like starting date, duration, etc.).
- An ocean front product has been validated qualitatively and quantitatively with very good results with a potential use for Marine Protected Area delineation and monitoring, as thermal/chl_a fronts can be used as a proxy for pelagic productivity.
- Finally, research on the improvement of the chlorophyll detection is carried out by the implementation of the OC5 algorithm and the use of vicarious calibration approaches.

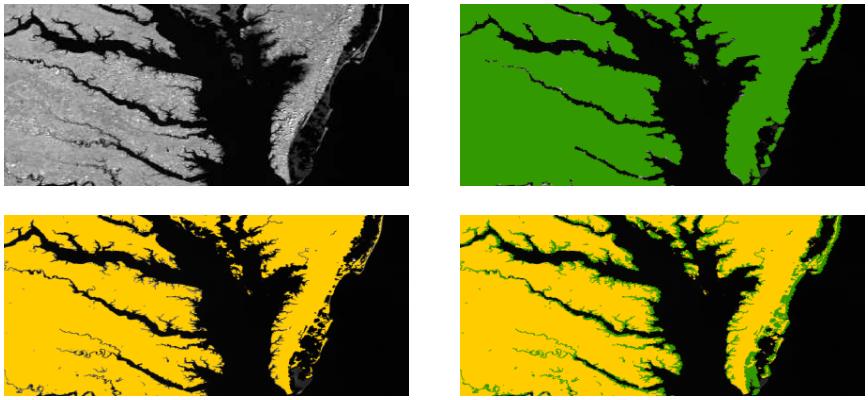

Figure 1: (a) Original image; (b) standard land/water mask; (c) new land/water mask; (d) Difference L1b standard mask/new water mask (source: Brockmann Consult)

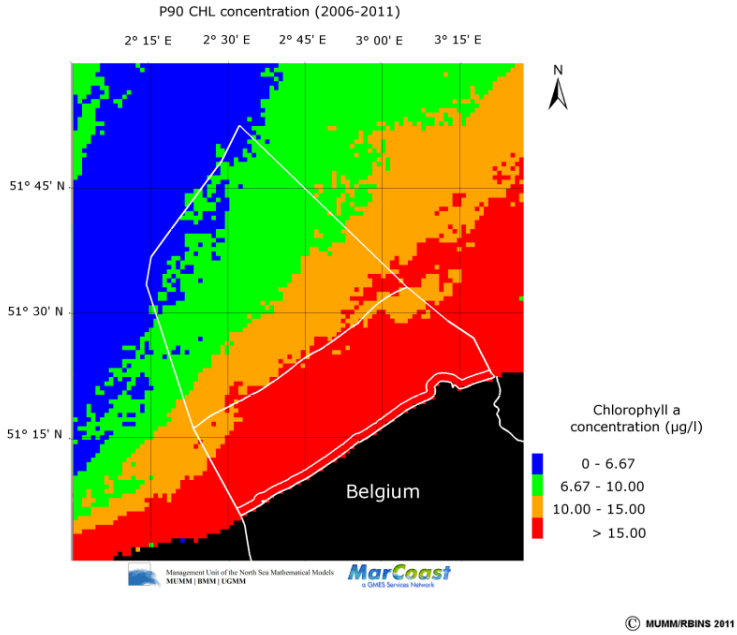

Figure 2: Example of the chlorophyll P90 products as stated in the Belgian Law used to monitor the eutrophication state the Belgian part of the North Sea. The chlorophyll P90 values are classified according to the stated requirements for the 6-year periods 2006-2011.

Satellite discrimination of harmful algal blooms in European coastal waters

Monitoring water quality in European oceanic and coastal waters is a task of high importance for monitoring agencies and a focus of public interest in recent years. Development of efficient monitoring service is demanded for the needs of fisheries, aquaculture and tourism. Harmful algal blooms (HABs) are one of the main factors of water quality degradation in European coastal area. In high concentrations harmful algae may cause respiratory irritation for humans, shellfish neurotoxic poisoning, fish mortality and can lead to significant economic losses by damaging fish farms and degrading coastal tourism sites.
The methodology developed at Plymouth Marine Laboratory within the EC *AquaMar* project uses satellite ocean colour data provided by MODIS and MERIS sensor for automatic detection and discrimination of HABs. It is applicable to HAB species that form dense monospecific blooms and may cause a characteristic colouring of the water. The methodology has been thoroughly validated for two high biomass HAB species: *Karenia mikimotoi* off the English and Scottish coasts and *Phaeocystis globosa* in the southern North Sea, by comparison with *in situ* measurements of cell concentrations. Accurate results were achieved using both MODIS and MERIS satellite data, correctly identifying 89% of *Phaeocystis* and 88% of *Karenia* blooms in these regions. Tests confirmed that the classifier discriminated HABs more effectively than just using Chl-a.

Information about HABs is available as a service in near-real time and can be evaluated on the MultiView website (http://www.neodaas.ac.uk/multiview). HAB risk maps are coloured red where the ocean colour indicates higher risk of a “harmful bloom”. The “harmless bloom” and “no bloom” waters are given in green and blue.

An example of Phaeocystis HAB risk map of the southern North Sea region is shown in Figure 1. The weekly composites of HAB risk maps can be useful during cloudy days, are also made available to the users.

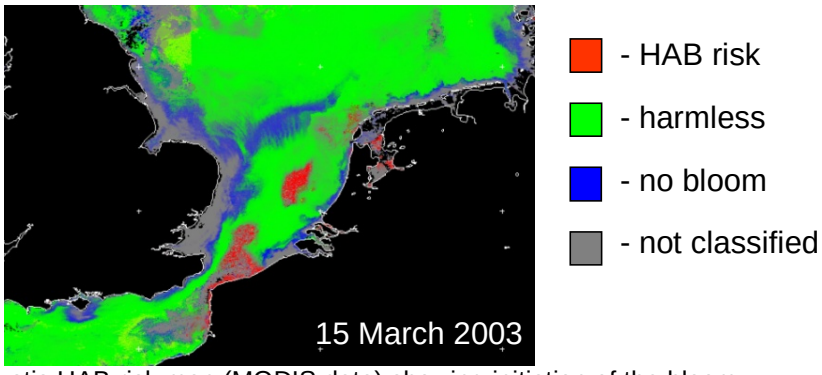

Figure 1. Phaeocystis HAB risk map (MODIS data) showing initiation of the bloom during the second week of March off the Dutch coast and at the Channel entrance

Contribution to the bathing water monitoring: assessing potential proliferation of cyanobacteria

Cyanobacteria, also called blue-green algae, are photosynthetic micro-organisms. They can be found as unicellular individuals (Microcystis, Woronichinia, oelosphaerium, Aphanocapsa, Merismopedia, Snowella) or colonies (like filamentous Aphanizomenon, Anabaena, Planktothrix, Oscillatoria, Limnothrix, Phormidium). These species develop in inland waters or fresh, brackish or saline waters with poor renewal, producing bright green, yellow-brown and red blooms. Three methods have been evaluated to detect cyanobacteria in coastal waters showing that the study of the reflectance at 620 nm is probably the most suitable (cyanobacteria characteristic pigments show peeks of absorption at 550nm (PE) and at 620 nm (PC)). An operational algorithm has been developed that makes use of this absorption band (available on MERIS). Figure 4 shows for the Baltic Sea the comparison between ACRI-ST method with the model outputs provided by the SMHI on the Baltic Sea (which is used here as a reference). The brown area on the top image indicates anomaly in Absorption of PhycoCyanin (APC). It corresponds rather well to zoning performed by using SMHI algorithm (based on a threshold detection which has been tuned on Baltic waters). The method developed and validated in AquaMar could then be directly used to other marine and continental waters.

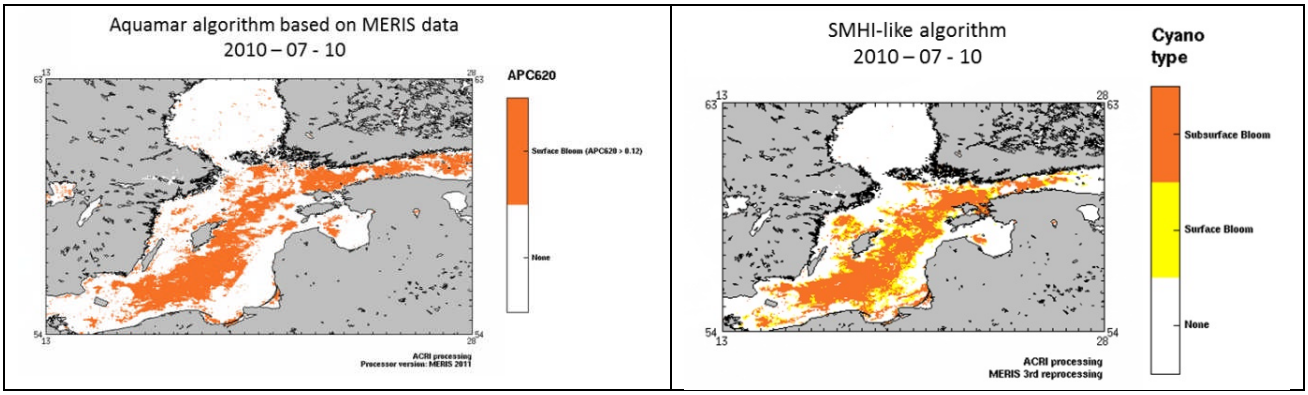

Figure 3: a) ACRI-ST zoning of positive phycocyanin absorption,
b) Threshold classification (SMHI)

A daily chl-a analysis at 4 km resolution

A daily chl-a analysis at 4 km resolution, i.e. cloudless daily fields of chl-a has been developed. The method is based on geostatistical interpolation and cluster analysis to basically use the best algorithm for a specific water type (oligotrophic, chl-a dominated waters and coastal waters). The final purpose is to provide to the user community cloudless continuous fields of chl-a. The method will be published soon and the resulting product is the first global, multi-sensors and multi-algorithms, Chl-a analysis in the World. Following hot topics in science should benefit of time series of the chl-a analysis:

- Climate change studies: the estimated trends from the analysis are less biased than trends estimated from the monthly means usually used.
- High frequency monitoring for coastal areas for the WFD directives: the analysed data is directly comparable in term of frequency to the buoy measurements. The continuous distribution in time of the chl-a fields ensures an unbiased estimation of the P90 of the chl-a used to estimate the eutrophication status.
- Direct comparison with bio-geochimical model outputs for validation (or for assimilation as forcing condition).

The Figure 5 shows a comparison between the daily simple chl-a merge of MODIS-MERIS for the 20040420 and the corresponding chl-a analysis. 15 MODIS images and 15 MERIS images are used to estimate the daily chl-a analysis. The increase of coverage is about from 25 % for the simple merge of MERIS and MODIS to 97% of the water pixels for the chl-a analysis. The Chl-a analysis is now a MyOcean II official product and available using MyOcean II facilities http://www.myocean.eu/.

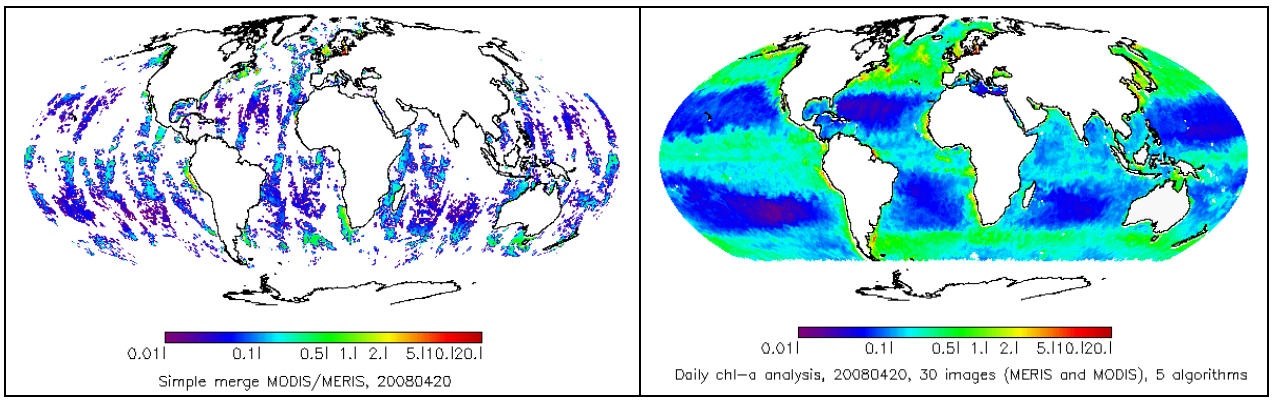

Figure 4: Comparison between the daily merge of chl-a (MODIS & MERIS) and the analysis for the 20080420 (© ACRI-ST).

Trends and level shifts detection in multiple geophysical time series.

An advanced methodology to estimate trends using multiple geophysical datasets in presence of autocorrelation noises has been developed within the Aquamar project. The methodology allows also to optimize the observation networks, in terms of needed time overlap between successive satellite or in-situ time series in order to reduce the uncertainty on the detection of long-term trends. The methodology is in publication process at JGR : « Detection of linear trends in multi-sensor time series in presence of auto-correlated noise: application to the chlorophyll-a SeaWiFS and MERIS datasets and extrapolation to the incoming Sentinel 3 - OLCI mission “

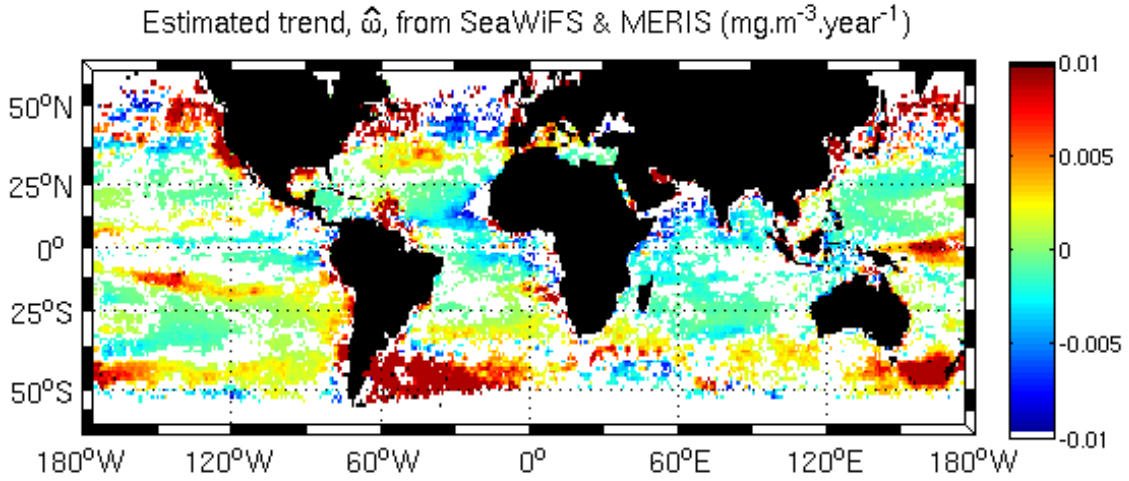

Figure 4 : Estimated Significant linear trends, $\hat{\omega}$, with respect to a 95% confidence level for the multi-sensor model using the SeaWiFS and the MERIS dataset (1998-2011).

Tools and recommendations

Cross-cutting developments contributed to other scientific topics:

- Creation of the first Chl-a daily global analysis at 4km resolution in the world relevant for the following topics: Climate change studies, High frequency monitoring for coastal areas, Validation of bio-geochemical models (or assimilation as forcing condition)
- Implementation and improvement of tools for satellite data processing (e.g. BEAM processor)
- Online web based tools for data processing and service validation processes
- Recommendations for future satellite missions and sensors needed for Marine & Coastal Water Quality long term service evolution
- Strategies for marketing, data policy and business model

Figure 5: AquaMar/MarCoast Information system portal

Website: www.marcoast.eu