INTEGRATED USE OF MERIS AND OTHER EO DATA FOR WATER QUALITY AND RED TIDE MONITORING ALONG UNITED ARAB EMIRATES COASTS

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ABSTRACT

Coastal zones host a large percentage of global population and economical and productive activities and are in need of a constant monitoring. The C-wams project is focused at implementing a suite EO services targeting two growing sectors: Waste Water Treatment and Desalination plants. The coast of the United Arab Emirates (UAE) hosts some of the largest desalination plants in the world and their operation can affect and be affected by the status of the WQ near the coast: the local phenomenon known as Red Tide caused increasing damages in the last 4 years. Some actors are involved in this respect in the Persian gulf, among them the Environment Agency of Abu Dhabi (EAD). In UAE an historical study-case is being performed aimed at identifying Red Tide events using MERIS images, integrating them with other medium and higher resolution data. The present work describes its scenario and the preliminary results obtained.

1. INTRODUCTION

Coastal zones mark the transition from land to ocean. A large percentage of global population resides within, or with easy access to, these areas. Moreover most of the economical and productive activities are located from the coastal area (100km from the coast). They include transport, shipping, oil and gas, mineral extraction, fisheries and tourism to name a few sectors. A large amount of these sectors depend on the coastal ecosystem being healthy, so they need to be constantly monitored. Monitoring of coastal water ranges from the direct measurement of bio-physical parameters (e.g. chlorophyll, sea surface temperature, turbidity, salinity, oxygen) to the use of models to detect and forecast the variation of some key parameters. Currently the most accurate method to monitor Water Quality (WQ) is by means of on-site measurements. However this method has some drawbacks mainly linked to the capability of sparse sampling – in respect to space and time – to be representative of wide areas and of large periods of time. Together with this traditional means the use of EO techniques has been recently increased. A number of space-related projects have dealt with the realization of EO based WQ monitoring systems.

A growing sector, which can have several impacts on the coastal zones are the one linked to the production of drinkable waters from sea water by means of Desalination plants (DP).
The coast of the United Arab Emirates (UAE) in the Persian Gulf and Oman Sea, hosts some of the largest desalination plants in the world (in 2011 it was the second producer of desalinates sea water, after Saudi Arabia) and their operation is linked in two ways to the status of the water quality near the coast: from one side the water they release could have an impact on the coastal ecosystem and from the other side they can be strongly affected by harmful and not-harmful algae bloom [1]. In particular the local phenomenon known as Red Tide in the last 4 years had a relevant impact to desalination plants operation, causing severe damages and stopping the operations for many weeks.
The term Red Tide often is used for indicating a harmful algal bloom (HAB), a phenomenon which occurs when colonies of algae – simple ocean plants that live in the sea – grow out of control while producing toxic or harmful effects on people and environment. Scientists prefer to use the term Red Tide for particular kind of HABs which are caused by a few species of phytoplankton and dinoflagellate able to discolour the water giving to it a red or brown colour. In the present paper the latter terminology is adopted.

2. THE C-WAMS PROJECT

The Coastal Water Attribute Monitoring using Satellite data (C-wams) project – funded by ESA under the Value Added Element (VAE) of the EO Envelope Programme – is focused at implementing a suite of EO products and data services specifically targeting two growing sectors: Waste Water Treatment plants and Desalination plants.
The main objectives of the C-wams projects are:

a) To start from existing assets, define and setup – together with the user(s) – realistic and feasible service and products for supporting their activities in waste waters and desalination plants;
b) To implement and demonstrate those products and services over two test areas chosen together with the user(s);
c) To assess the service performance and the service utility, getting the user(s) feedback for identify issues/solutions and improvements;
d) To elaborate a plan for a wide service uptake within the framework of the international (e.g. European

Marine Directive) obligations.

To fulfil its scope the C-wams project, building on existing prototype EO products, aims in implementing and demonstrating a monitoring service able to derive Near Real Time (NRT) WQ parameter and HAB detection from medium resolution sensors like MERIS and MODIS and to detect.

The consortium developing the C-wams project is composed of TechWorks (Prime, Irl) and Planetek Hellas (Gr), which leads the study case about Desalination Plants in the UAE.

The project kick-off was the 1st August 2012. The first phase of the project was concluded in July 2013. The user requirements have been consolidated, together with a first market analysis. From that a service portfolio has been agreed with the users and ESA. Following that, four service trials have been defined in detail. Among them the Water Quality and Red Tide Service Demonstration in the United Arab Emirate, conducted by Planetek Hellas. Finally the service chain has been implemented and tested on a simulated scenario to demonstrate the readiness for starting the real service demonstration.
The second phase of the project started in August 2013 and it will deliver the service trial, which will be followed by the technical assessment and the service utility evaluated with the users.

3. UAE SERVICE TRIAL

3.1. Objective

The study case in UAE is aimed at identifying HAB (in particular Red Tide) events by detecting anomalous values in some water parameters using MERIS data, with the further support of higher resolution images (i.e. MODIS first bands and RapidEye) to empirically retrieve Chlorophyll concentration (Chl) and Total Suspended Matter (TSM). Moreover when a HAB alarm is issued, the use of a very high resolution sensor (like DubaiSat-1 or Pleiades) is considered to be used for a precise determination of the HAB extent, giving a concrete support in preventing and forecasting its effects.

The service trial involves the EAD as user and its objective is to demonstrate the capability of EO derived products to support users' current practices concerning environmental protection by efficaciously monitoring WQ parameters (in particular) with the aim of detecting, in near real time, the occurrence of HABs events, like the Red Tide.

3.2. EAD current practices and needs

The EAD is a governmental agency committed to protect and manage biodiversity, to provide a clean environment and to promote sustainable development in the Emirate of Abu Dhabi. In particular EAD is designated as the competent authority charged with the assessment and management of the environment and living coastal and marine resources in the Emirate of Abu Dhabi. In this role it provides a direction for Government, business and the community to build environmental considerations into the way they plan and live without compromising Abu Dhabi development.

EAD is involved in the DP topic basically in two ways:

- as responsible for the water quality of the coastal areas, EAD provides advice to government and other entities at UAE level on the environmental implications of new policies and, as required, support the implementation of federal policies. Furthermore EAD performs regular marine WQ survey on some sites in Abu Dhabi, mainly located near the main beaches along the Abu Dhabi coasts, which gives a limited view of the coastal area status. In this respect, the detection HAB and in particular the Red Tide common in that areas, has a great importance for the health of the sea environment and of the people [2].
- As a regulator, EAD's role is to ensure that industry and other entities minimise their impact on the environment. EAD sets the environmental parameters to be abided by industrial projects, both governmental and private. These parameters are enforced by the Regulation Supervision Bureau (RSB), in charge of releasing licenses for building and operating industrial plants according to the guidelines and regulations defined by EAD. The duties of the RSB of Abu Dhabi concern the water, wastewater and electricity sector.
  So, in the case of DP, EAD defines the guidelines for the installation of new plants. Then the private industry operator submits an EIA to the RSB for approval. The EIA should include an assessment to justify the choice of the DP site and a proposal for the monitoring of the WQ during the building and of the operation of the plant. The monitoring from the DP owner is commonly performed measuring some WQ parameters at the water inlet and outlet of the DP, lacking a more synoptic view of the chosen coastal area.

According to that, EAD main requirement is to have a methodology of proven efficiency for monitoring WQ and detecting HAB, to be adopted for its duties and as recommended practices to the DP operators. This methodology should allow to perform a monitoring over the whole coastal areas and also at open sea, of parameters like Chl and TSM and to allow an alert system for HAB and Red Tide approaching beaches and industrial plants.

A final consideration to be done is that EAD can be considered a representative actor and a precursor in respect of WQ and concerning the operation of DP in the region of Middle East and eastern North Africa. In fact, in the wider area of the Persian Gulf the UAE – represented by EAD – is, along with other Gulf states, a signatory to the Kuwait Action Plan, drawn up by the Regional Organisation for Protection of the Marine Environment (ROPME) concerning the critical areas of environmental management, in particular pollution, but also WQ. Within this framework many countries in the area and in the (eastern) North Africa are adopting legislation and practices inspired by the ones implemented by EAD.

3.3. Description of the UAE scenario

Since the purpose of C-wams is the demonstration of the EO capabilities and not the realisation of an operational service, the service trial will consist of an historical case study, in particular to be able to use both MERIS Full Resolution (FR) and MODIS images.
This choice will allow:

- Exploitation of the MERIS FR higher resolution
- Exploitation of the high pass frequency of MODIS
- Demonstration of the utility of a service that will become technologically sustainable with the start of the Sentinel3 mission.

NRT processing will be simulated to assess the capability of the service provider to provide NRT HAB detection.

The area of interest (AOI) is the UAE coastal area both in the Persian Gulf and in the Oman Sea, as shown in Fig. 1.

Figure 1. Area of interest for the UAE Service Trial

The service trial is initially planned to be performed considering data covering the following temporal periods:

- November 2008 – May 2009
- July 2009
- a third period by crossing user provided data and availability of MERIS data

The choice of the first two periods is related to a series of very large Red Tide events that occurred between August 2008 and July 2009 within the Persian Gulf and the Oman Sea along the UAE coasts [3] [10].

The final products for the user will be mainly related to HAB/Red Tide detection over specific historical periods when one or more Red Tide events in the area of interest occurred. Since HAB/Red Tide products are derived from WQ products the latter will also be generated during the trial and supplied to the EAD for evaluation, see Tab. 1.

Table 1. UAE service trial's Products and EO data used

Theme	Product	EO data used
Water Quality	Chlorophyll	MERIS FR MODIS
	TSM and Turbidity	
	High resolution TSM and Turbidity (2 - 6m)	RapidEye Pléiades
Environment	Sea Surface Temperature	MODIS
HAB & Red Tide	HAB detection map	MERIS FR MODIS
	HAB spatial extent	DubaiSat-1

EAD will act as a representative user to assess the project's services and provide feedback on their utility, benefit and impact: it will give feedback on the products and services delivered within the trial, provide information on the usability of these products with respect to its current practices and assess the resulting positive impact and benefits.

3.4. HAB detection Service Trial concept

In Fig. 2 is illustrated the concept for the HAB monitoring and detection Service Trial to be demonstrated in the UAE scenario.

A Regular Monitoring is started using MERIS FR data, which allows to measure WQ parameters and perform HAB detection covering the AOI every 2-3 days.
If an alert condition – agreed with the user – occurs (e.g. high Chl concentration, HAB detected) then an Enhanced Daily Monitoring Service is activated for detecting HAB, integrating MODIS data and also eventual in situ measurements carried out by the user in the area (e.g. a survey in response to the alert). At the same time an alert report is done regularly to the user.

The Enhanced Daily Monitoring continues until the alert condition ceases or until the HAB evolves up to become a risk to a sensitive area (e.g. a beach, a DP, an aquaculture site, etc.). In the latter situation a further Enhanced Monitoring at High Resolution Service is activated using higher resolution EO data which allow a fast acquisition time like RapidEye and DubaiSat-1. It will trigger further measurements at sea from the user, which in turn will be integrated into the service.

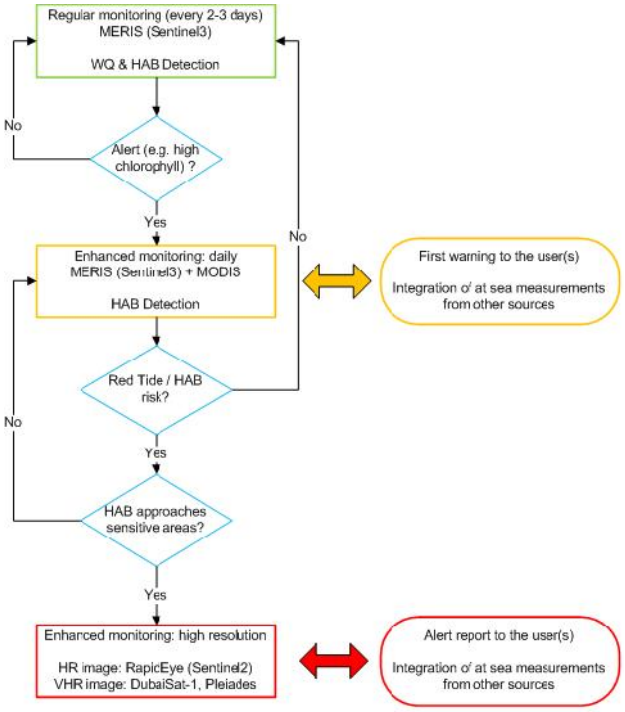

Figure 2. Flowchart describing the UAE Service Trial concept for HAB/Red Tide monitoring and alert

The Enhanced Monitoring at High Resolution will provide to the user regular warning reports, including high resolution maps of the HAB extent, allowing for mitigation actions and forecasting of the phenomenon. This service will continue until the HAB risk decreases.

3.5. EO and ancillary data

Following Tab. 1 the input data for the Service Trial in UAE will be optical at medium and high resolution, with the support of in-situ data from EAD.

MERIS FR L1 images will be considered as main source for the WQ monitoring, exploiting its higher radiometric quality and the capability to reach 300m resolution for all bands. MERIS data are procured within a Category 1 (Cat.1) from ESA.
MODIS L2 data will be considered trying to exploit its higher resolution bands for TSM and also for testing NRT capabilities of the service. MODIS data sets are freely available from the OceanColour NASA repository.
Such approach will be also useful for demonstration purposes in preparation for the Sentinel-3 mission.

High/Very High Resolution satellite images will be used for the precise delineation of the Red Tide borders and also as an input for the improved WQ products related to suspended matter. They will include:

- DubaiSat-1 data, to be provided by the Emirates Institution for Advanced Science and Technology (EIAST) in cooperation with the end user.
- Pléiades-HR1A data provided within an announcement of opportunity from Pléiades User Group (ASTRIUM) - project study number 107
- RapidEye data procured within a Cat.1 from ESA as Third Party Mission (TPM). This in particular will constitute a test bench in preparation for the Sentinel-2 mission.

In-situ data provided by the user will be fundamental for the quantitative validation of the products and, if possible, for the initial calibration of the algorithms. A preliminary agreement with the EAD user has been done, to provide WQ measurements from surveys and from the fixed stations. Furthermore some information about location and date of some HAB events has been retrieved by the EAD Geoportal.

3.6. Algorithms and Methods

WQ parameters

The processing of MERIS L1 data is performed within the BEAM toolbox [4] using the Case2Regional (C2R) processor [5], based on a neural network approach, which performs the atmospheric correction and retrieves the inherent optical properties and calculations, among other parameters, Chl, TSM and Turbidity. The retrieval algorithm is the same adopted by ESA for the MERIS 3rd data reprocessing [6].
Concerning the MODIS processing, the Chl and Sea Surface Temperature (SST) are directly extracted from the L2 data. The TSM is obtained using an algorithm defined by the Doron et al. [7].

Finally empirical algorithms will be adopted to obtain higher resolution TSM and Chl products from RapidEye and Pléiades data, calibrated by means of temporal and spatial matching against MERIS products and/or using in situ measurements provided by the user.

HAB detection

Starting from the MERIS FR water leaving reflectances obtained by the C2R, the following parameters are calculated: Fluorescence Line Height (FLH), Maximum Chlorophyll Index (MCI) [8] and a Red tide Index (RI) defined by the following formula [9]:

$$RI = \frac{[\,Lw(510) / Lw(555) - Lw(443)\,]}{[\,Lw(510) / Lw(555) + Lw(443)\,]} \quad (1)$$

where Lw() are the water leaving reflectances at 510, 555 and 443nm.
The same algorithms are applied, adapted to the wavelengths of the MODIS bands.

Using information on the spatial and temporal occurrence of HAB/Red Tide events along the UAE coasts, the RI behaviour will be analysed considering scenes with and without an HAB event to define a set of

thresholds leading to an alert or warning status [9]. This led to the definition of a first method to HAB detection, as described in the First Outcomes section.
The method will then be refined analysing also the behaviour of Chl and TSM parameters as well as the FLH and MCI indexes, to define further conditions (main based on thresholds) to improve the detection efficiency, reducing false alarms.

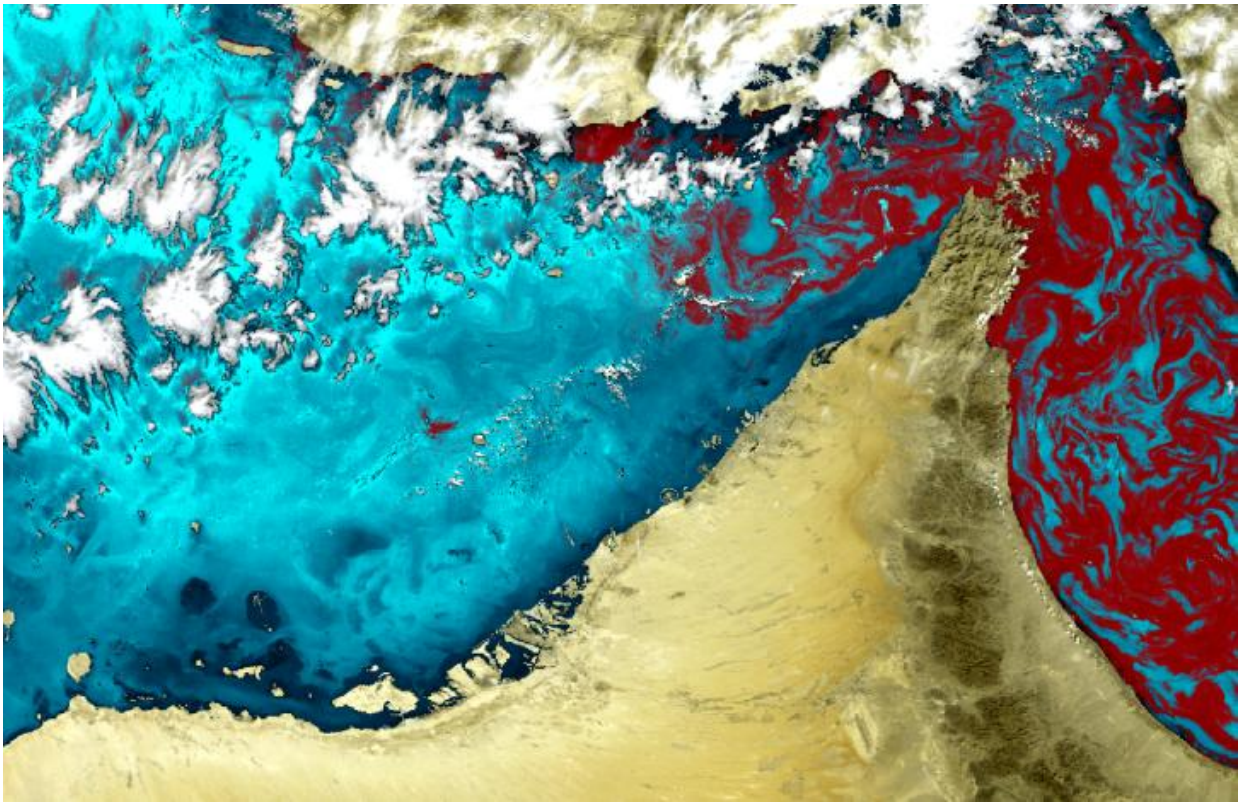

Figure 3. Large Red Tide in the Oman sea and Persian Gulf. Composite image resulting from the processing of a MERIS data acquired 22/11/2008. The land is obtained using the Tristimulus algorithm (L1 data). The sea image is obtained using the following band combination: Red=Red tide Index, Green=band ratio 490/555nm, Blue=band ratio 510/555nm. The image can be interpreted as follow: Red colour - HABs (Red Tide), Brown colour - non-HABs, Dark blue colour - high suspended sediments and dissolved materials, Cyan colour - relatively clear waters. Clouds are in white color

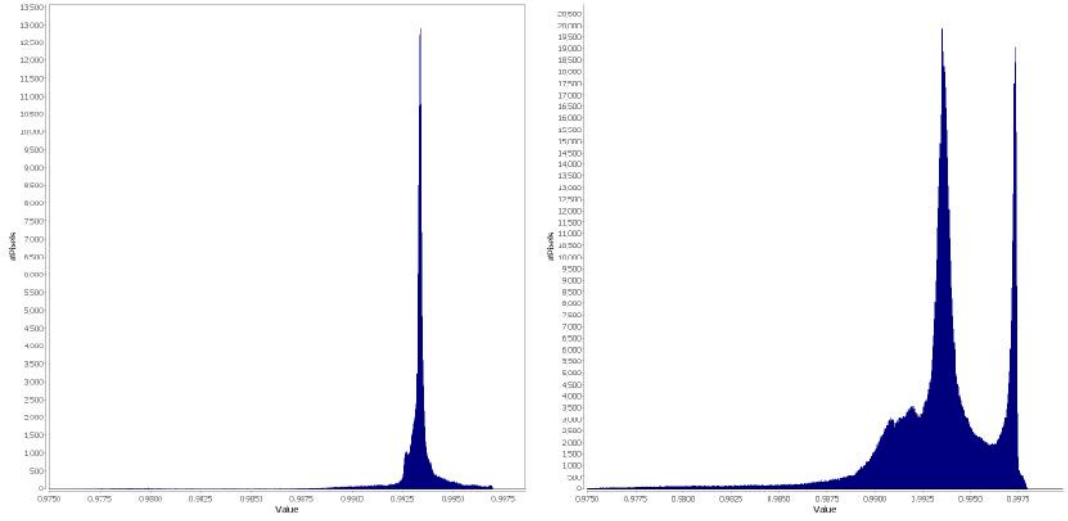

Figure 4. Histograms of the Red tide Index (RI) for two MERIS images dated 13/05/2009 with no alga bloom (left) and 22/11/2012 when a large Red Tide interested both Oman sea and Persian Gulf (right). Both histograms show a peak around 0.994, while the right one shows a second peak after 0.997 common to other scenes with a Red Tide occurring.

4. FIRST OUTCOMES

59 MERIS FR L1 scenes have been selected (i.e. cloud free) and fully processed over the area of interest, covering the period 1st November 2008 – 16th May 2009. During that period almost continuous HABs and Red Tides events occurred in the Oman Sea and periodically also in the Persian Gulf.

A first series of analysis have been done on the basis of the RI and of the Chl maps generated and focusing on the reported periods in which a HABs was detected along the UAE coasts.
In Fig. 3 an example of a Red Tide appearance is illustrated, during a large event. According to the available reports, during the considered period a Red Tide was almost always occurring in the Oman sea, decreasing and again increasing with time and frequently spreading in the Persian gulf, also approaching the UAE western coasts [11].

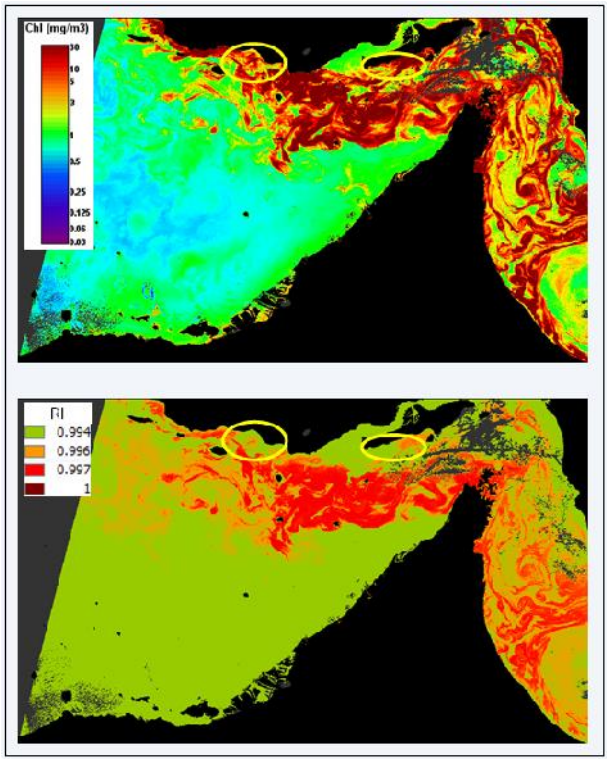

Figure 5. Chlorophyll map (top) ad HAB detection map (bottom) from a MERIS scene acquired the 30/12/2012. The HAB map was obtained applying three threshold values to the RI: red=high probability, green=no HAB. The yellow circles evidence different behaviours of the two parameters.

From the analysis of the RI histograms its range of values shows a maximum around 0.998 and a minimum varying from 0.96 in winter and 0.92 in other seasons. The minimum value was larger than the one theoretically expected [9], but is also strongly sea dependent. Furthermore all the images shows a peak around the 0.994 value, while when a HAB is present a new peak appears around 0.997. An example is illustrated in Fig. 4. From the characteristics of these peaks an initial set of thresholds have been defined to determine three level of HAB alert, obtaining the HAB detection map as showed in Fig. 5.
In Fig. 5 is also shown the corresponding Chl map. Comparing the two maps, it can be noted that almost always very high values of Chl corresponds to high HAB risk, but in few cases it doesn't happen. Investigations are ongoing, also considering FLH maps and local information. From the first results it seems that the RI depicts better the real Red Tide extension.

5. SOME CONCLUSIONS

The C-wams Service Trial over UAE was started and as a first step all the MERIS FR images selected for the period 01/11/2008 – 16/05/2009 have been processed, in particular generating maps of Chl, TSM, RI, FLH and MCI.
From a first analysis of the use of the RI for HAB/Red Tide detection the following conclusions can be derived:

- the use of RI, combined with a set of thresholds, appears to be a useful parameter to detect HAB/Red Tides
- RI proved to be a robust tool, in respect to Chl alone
- preliminary results show that integrating FLH and/or MCI can improve the detection

From these outcomes, an outline of the next steps to be performed has been made:

- to investigate the use of other parameters like FLH, MCI, SST and TSM to detect false HAB alarms
- to perform and evaluate the integration of daily MODIS data
- use of in situ data to be received by the user

Furthermore high resolution products would be implemented and applied to the HAB detection.

The prosecution of the Service Trial will then foresee:

1. Delivering of the full product dataset to EAD
2. Assessment of the performance of the service delivery
3. Evaluation with EAD of the products content and of the fulfilment of the requirements
4. Assessment of the service utility with EAD

The last three elements will be an important input to the final project evaluation of the technical and economical sustainability, in particular considering the evolution to the Sentinel 3 and 2 missions respectively from the results obtained with the MERIS and RapidEye images.

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