CONCEPTION OF PRODUCTS AND SERVICES FOR COASTAL APPLICATIONS

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ABSTRACT

The scope of this study is the exploitation of MERIS data to provide repetitive information on natural resources in coastal zones. Five different sites have been chosen to identify the most frequent problems encountered in coastal zones and to find the most adapted MERIS products. This approach takes advantage of the temporal, spatial and spectral resolution of the MERIS sensor. Special emphasis is put on advanced data processing methods such as fusion of MERIS and TM, to provide a product with the best resolution and taking advantage of the repeat cycles of the two sensors.

Keywords: Coastal applications, MeRIS, fusion, eutrophication

INTRODUCTION

Human activities have various kinds of severe impacts on the environment. This is mainly due to highly populated coastal regions (70% of the global population) and tourism involving temporary overpopulation in some areas. The objective of this study is to develop products and services dedicated to coastal zone management needs based on MERIS images. Like MODIS/Terra & Aqua, the Medium Resolution Imaging Spectrometer (MERIS), launched on ENVISAT in 2002 proposes a spectral resolution but also a spatial resolution more spectrally adapted to coastal zone studies than other sensors such as CZCS/nimbus, SeaWiFS/SeaStar, GLI/ADEOS II (1). Alcatel , the Institut de Recherche pour le Développement and the Ecole des Mines de Paris are all involved in the GMES programme and the results of this study will be proposed within this context.

Compared to other projects like the COASTWATCH project of ESA, we list all problems on the five sites and we try to identify the most adapted MERIS products. The five different sites were chosen in various geographic areas (the Gulf of Lion, the French Atlantic coast, French Guyana, the Reunion Island and New Caledonia) in order to identify frequent problems in coastal areas where partners had a good knowledge of local conditions. This choice takes advantage of the rich diversity of French coastal areas, representing typical littoral types among the chosen sites, both from the biological, physical and human points of view. For each site, the marine, coastal, and economic contexts have been studied for a better understanding of the various problems. The transversal aspect of this study allows to sort these by order of occurrence.

According to these problems and to MERIS spectral, spatial and temporal resolutions, five applications have been identified to suit the needs of coastal zone managers. Table 1 lists the test sites versus these problems and shows that the selected sites cover the most important of these.

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Table 1: List of problems versus the test sites

	Golf of Lion	French Atlantic coast	Reunion Island	French Guyana	New Caledonia
Water Pollution	X	X	X	X	X
Chemical pollutants diffusion	X	X	X	X	X
Oil pollution risk	X	X	X		
Flood risk		X		X	
Chronic Water Pollution (outfall, eutrophication)	X	X	X	X	X
Coastal erosion and sedimentation	X	X	X	X	X
Poor knowledge of seabed cover	X		X		X
Over fishing	X	X		X	
Water resource threat	X	X			
Poor knowledge of watershed land use	X	X	X	X	X
Maritime traffic	X	X		X	
Ecological damage (lagoons, coral reefs)	X	X	X		X
Bathymetry variability		X		X	X

MERIS DATA

MERIS is a spectrometric imager developed by Alcatel Space Industries, spaceborne on ENVISAT, launched in March 2002. Its 300m spatial resolution provides a new perception of the Earth, better adapted to coastal zone studies than previous wide field sensors (AVHRR/NOAA, CZCS, SeaWiFS…). MERIS provides 15 programmable spectral bands between 390 and 1050 nm. The same site is imaged at least once every 3 days at the Equator. It allows algorithms to take into account the temporal dimension.

Level 1b data products (Figure 1) are resampled considering the acquisition geometry and with an absolute registration accuracy of 2 km. Images are in radiance units measured by the sensor.

Level 2 data products provide 20 layers containing 13 bands in reflectance and 17 geophysical products (algal pigment, suspended matter and yellow substance concentrations, atmospheric parameters and vegetation index).

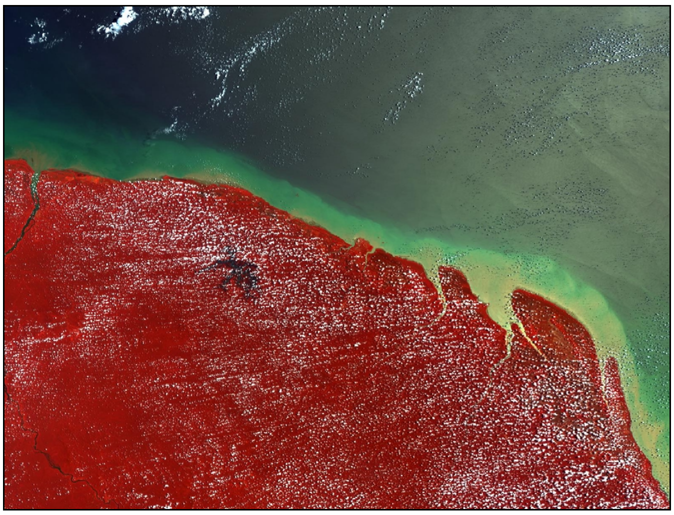


Figure 1: Level 1b MERIS Image on French Guyana- 6 September 2002

Some applications (e.g. bathymetry, watershed mapping) on small study areas require a resolution better than 300 m. We have already demonstrated that the resolution of MERIS can be improved by merging MERIS and TM/Landsat data (2). The method is based on the classification of the TM image and the estimation of spectral profiles of each TM class in the mixed MERIS pixels. The best characteristics of the two images (spatial, spectral, temporal) are then preserved in the resulting image, see Figure 2.

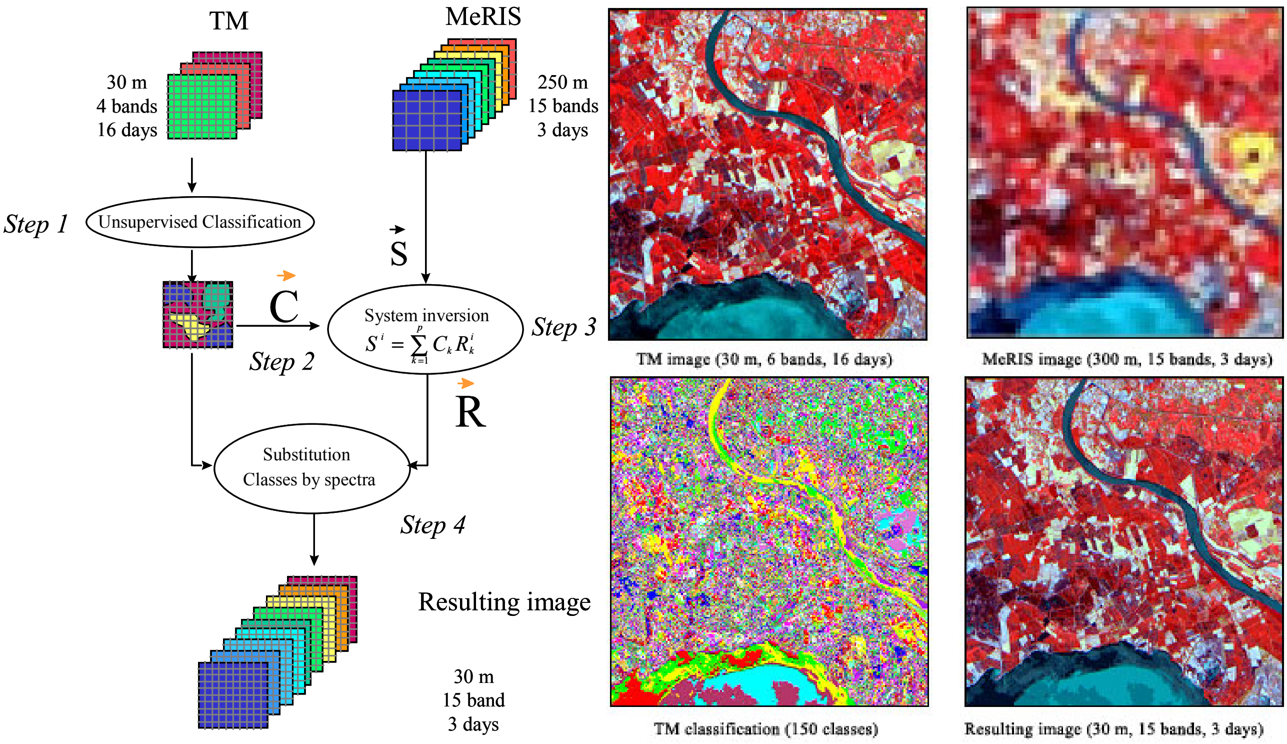


Figure 2: Synopsis, Inputs and outputs of fusion algorithm (site of Camargue, France)

CONTEXT AND PROBLEMS ON FRENCH SELECTED SITES

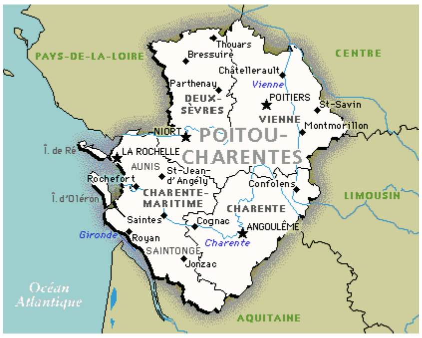
Information about context and problems were provided by institutions and actors from the European Commission to local managers.

Gulf of Lion

The water quality is threatened by wastes from industrial, agricultural and urban activities. Industrial (metals, chlorine, hydrocarbon) and agricultural pollutants are transported by the Rhône and other rivers and by the Ligurian current along the Gulf coast from East to West. The coastal areas are highly urbanised but treatment plants are often not adapted to temporary overpopulation in some tourist areas. Fertilizers (nitrates and phosphates) and organic matters contribute to eutrophication in the Gulf and in numerous lagoons from the Rhône delta to the Spanish border. This phenomenon leads to the asphyxia of local organisms caused by excessive algae proliferation (2).

Erosion occurs also in the Gulf brought about by a deficit of sedimentary transport due to the construction of river dams and a subduction phenomenon. There are two geographic consequences : variation of the coastal line and the bathymetry.

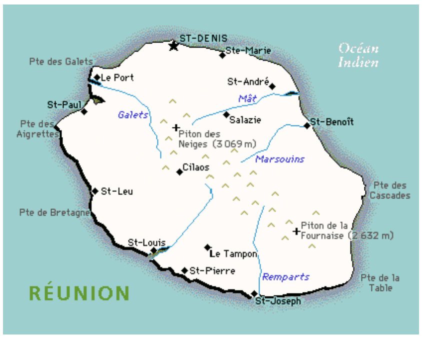
Atlantic Coast, Pertuis Charentais



Around the Pertuis Charentais (west coast of France), the continental shelf reaches a maximum of 20 m depth. The current is principally generated by tides of 5 m maximum amplitude. The Charente rivers drains a 1375 km² watershed occupied by numerous cultivated marshes. An old plant upstream has poured mercury and cadmium for many years into the Charente river. Population density is low on the coast except in summer.

Conflicts between shell-fish farming, fishing, tourism and farming on the marshes lead to problems of coastal management. The water pollution caused by bacterial waste in summer, fertilizers, cadmium and mercury threaten the shell-fish and fishing activities.

Réunion Island



Located in the Indian Ocean 1000 km east of Madagascar, this volcanic island presents a high relief (max. 3000 m). The population lives along the coast (85% of population, 237 inhabitant/km²). Sugar cane exploitations (both crops and plants) provoke water pollution from runoff, infiltration and waste discharge. The coralline lagoon situated at the west of the Island is seriously threatened by eutrophication.

French Guyana

Situated on the Atlantic coast, in the north of Brazil, the French Guyana littoral receives sediments from rivers, mainly from the Amazon river. These sediments are carried by strong SE-NW currents. Suspended matter concentration which can reach 400g/m^3 along the coast causes very high turbidity. The variation in coastline (2 km appeared or disappeared in 10 years, in some places) provokes land property questions, and variation in bathymetry leads to navigation difficulties. The economic activities are centred around the space centre, gold extraction and shrimp fishing. Harbours and estuaries need regular dredging.

New Caledonia

The New Caledonia Islands are situated in the Pacific Ocean, 1500 km from the eastern Australian coast. The main island “Grande Terre”, is elongated, protected on both sides by 600 km of barrier reef. The high relief (max. 1600m) concentrates population on the coast especially around the main city Nouméa (50% of population). New Caledonia is the third nickel producing region in the world. This exploitation, however, involves the transport and erosion of 300m^3/an of mud and strong sedimentation on coastal areas.

Both of these coastal landscapes are subject to degradation processes with consequences in all relevant domains (biological, physical and economical). For each type of situation, punctual studies have shown the potential offered by remote sensing data. The aim of this work is to identify both the major needs and how new technologies and available sensors allow to define advanced tools, regardless of the geographical location. The ESA Envisat satellite has been launched with a payload adapted to these applications: the MERIS Instrument.

SELECTION OF PROBLEMS

Our methodology developed on these five sites leads to an exhaustive list of problems encountered in coastal zones. A transversal study allows to sort these problems in order of occurrence: water pollution, erosion and sedimentation, poor knowledge of watershed land use, ecological damage (lagoons, coral reefs), landscape damage, eutrophication, marine oil pollution risk, coastline and bathymetric variation, maritime traffic, over fishing, poor knowledge of seabed cover, water resources threatened, flood risk, ...

In order to develop applications from MERIS images for coastal zones management, we studied the relevance of MERIS data based of 5 criteria:

Criteria 1: Interest of coastal manager, public opinion, and political body for the problem

Criteria 2: Spatial benefit compared to other means of surveying (ground measurements) to study the problem

Criteria 3: Compatibility between the problem observation scale and MERIS spatial resolution (with or without fusion with TM images)

Criteria 4: MERIS spectral ability to detect and follow the evolution of the problem

Criteria 5: Compatibility between frequency and duration of the problem with the sensor repeat cycle.

Because selection of a problem on qualitative criteria is not easy, relevant criteria have been quantified between 1 and 4 to give a total maximum sum of 20 when the problems fulfil all criteria.

This evaluation has been obtained thanks to bibliography (2) and to the experience of remote sensing users.

Table 2: Relevance of MERIS data based of 5 criteria described above.

	Criteria 1	**Criteria 2**	**Criteria 3**	**Criteria 4**	**Criteria 5**	**Sum**
Punctual or accidental problems						
Water pollution	4	2	1	4	2	**13**
Chemical pollutants diffusion	4	2	1	0	2	**9**
Oil pollution risk	4	3	1	3	2	**13**
Flood crisis management	4	3	1	2	2	**12**
Chronic or long term problems						
Chronic water pollution (outfall, eutrophication)	4	3	4	3	4	**18**
Flood risk (prevention)	4	3	3	3	3	**16**
Poor knowledge of seabed cover	2	4	3	4	4	**17**
Over fishing	4	4	1	3	1	**13**
Water resources threat	4	2	3	3	3	**15**
Poor knowledge of watershed land use	4	4	3	4	4	**19**
Maritime traffic	4	4	1	2	1	**12**
Ecological damage (lagoons, coral reefs)	3	4	3	4	3	**17**
Bathymetric variability	3	4	3	3	4	**17**
Coastal erosion, sedimentation	4	4	3	3	4	**18**

We can note that MERIS data is more adapted to chronic and long term problems than to temporal and accidental ones.

We chose the first six problems most relevant regarding MERIS data (raw or merged with TM/Landsat image):

- Poor knowledge of watershed land use (with fusion)
- Chronic water pollution (with fusion or not)
- Coastal erosion and sedimentation (with fusion or not),
- Bathymetric variability (with fusion),
- Poor knowledge of seabed cover (with fusion),
- Ecological and landscape damage (with fusion).

According to this classification of problems, we propose applications in order to provide relevant information for their management. This selection results also from bibliographic studies and users reflections.

SELECTION OF APPLICATIONS

Eutrophication index

Some pollutions, like bacterial, chemical or those due to heavy metals cannot be detected by remote sensing, but by abnormal vegetal production which has an impact on water reflectance (Figure 3). This production can be directly related to eutrophication induced by excessive fertilizer (natural or chemical) and its contribution can be measured by spectro-radiometers.

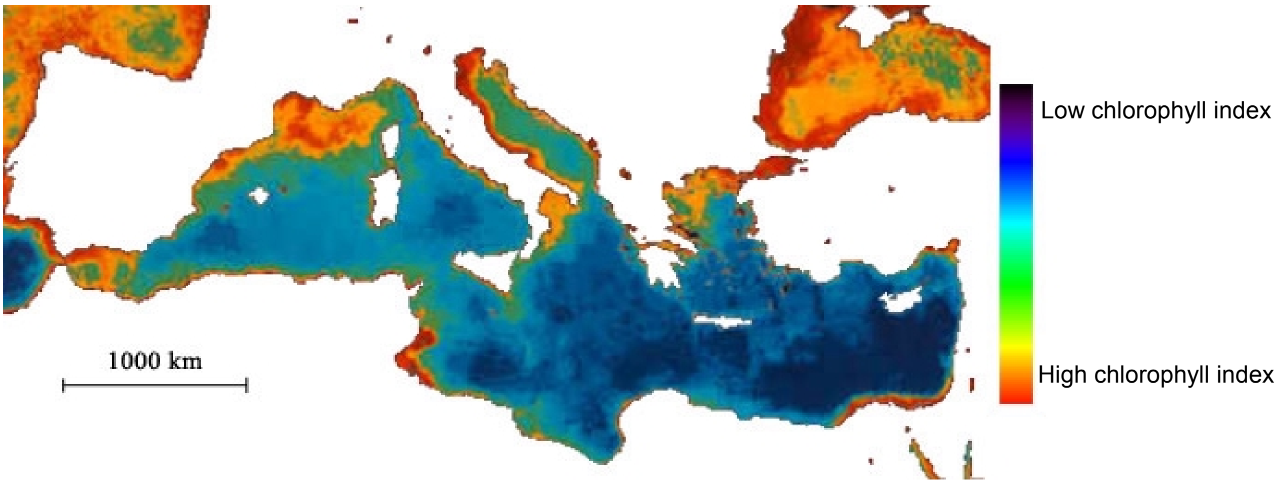


Figure 3: Chlorophyll Index on Mediterranean from CZCS

MERIS Level 2 products indicate pigment concentration. The eutrophication threshold has been fixed at 20µg/l of chlorophyll in (3). This value allows obtaining a eutrophication index.

As an example, this index will be useful for the lagoons of Languedoc-Roussillon (Gulf of Lion) in France because 56% of the lagoons are considered as “bad” in terms of eutrophication. This is reported by 350 ground measurements made once a year. Because of economical and environmental management improvement in this area, one of the objectives is to bring 90% of measurements to a good eutrophication level. The satellite could provide the measurements several times a year, especially during summer.

Sedimentation index

In a similar way to algae, sediments modify water reflectance (4). Suspended matter concentration can be estimated with the MERIS sensor and this product is included in MERIS level 2 products.

When the sediment concentration increases, silting occurs. Fixing a threshold for suspended concentration will provide a sedimentation index (Figure 4). In French Guyana, harbour activities are strongly affected by sedimentation and repeated dredging has to be scheduled. A repetitive calculation of the sedimentation index should help to optimise harbour dredging.

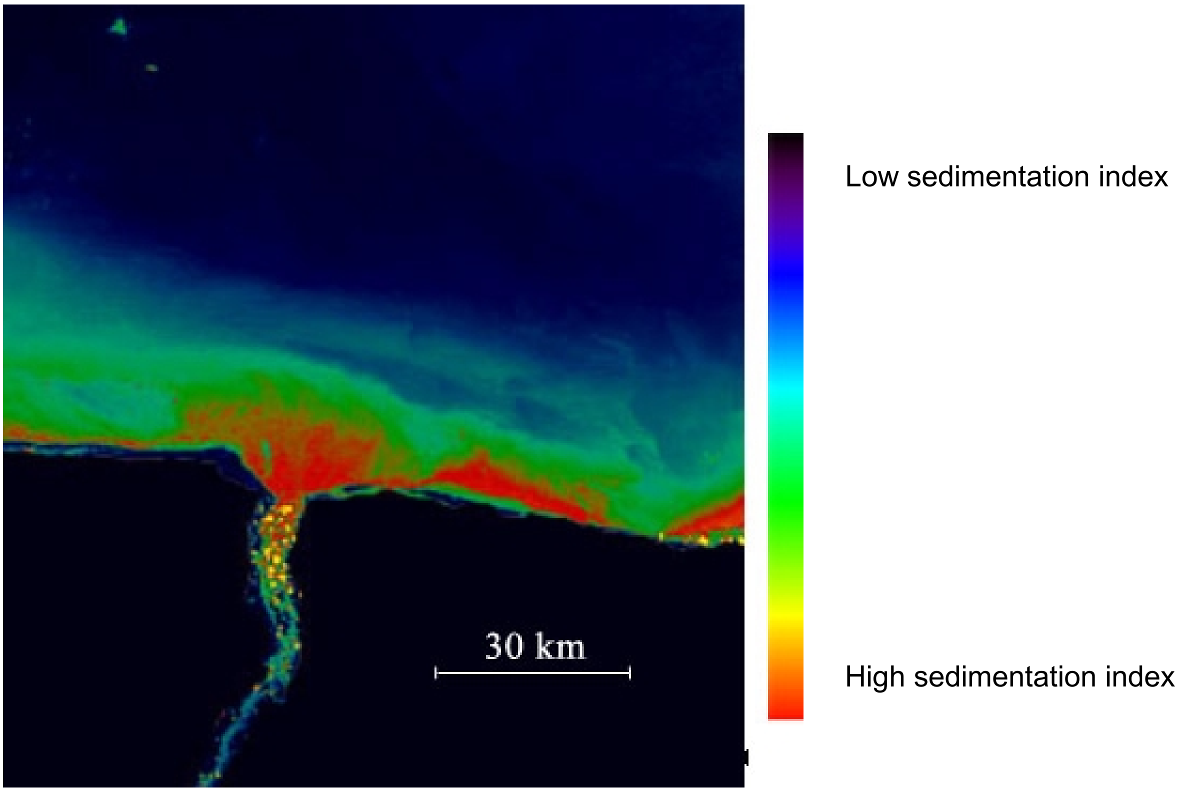


Figure 4: Sedimentation index on Maroni river mouth, French Guyana; MERIS, 6 September 2002

Change detection

A change detection tool is very helpful for coastal managers, in order to detect coastline change due to erosion or sedimentation processes, environmental damages or bathymetric variations.

Many algorithms have been developed which show different kinds of changes (5) (*e.g.* geometric or radiometric). Algorithms have to be chosen according to changes that need to be identified.

Bathymetric model

In the marine domain, only one (multispectral) image is needed to provide a digital bathymetric model (in opposition with land digital elevation model) provided that water is clear enough. Whatever the seabed cover, its reflectance is similarly modified by the water column and then by depth. This method described in (6) is based on a combination of two spectral bands that provide two new bands including one linearly dependent on bathymetry. Then, some depth values allow the definition of the model and provide the bathymetric mode. Figure 5 presents one example of the bathymetric model obtained from CASI images on Porquerolles Island, eastern Gulf of Lion. The grey colour corresponds to land or to areas out of image.

This method is restricted by water attenuation which limits the maximal depth estimation. The sensor resolution also limits the application in some areas. Knowing MERIS resolution (300 m), depth estimation will be difficult for weak bathymetry. For these geographical areas, fusion with better resolution sensors can be used but a hyperspectral sensor like Hyperion (EO-1, 30m resolution) or the airborne sensor CASI (1-5m) can be preferred.

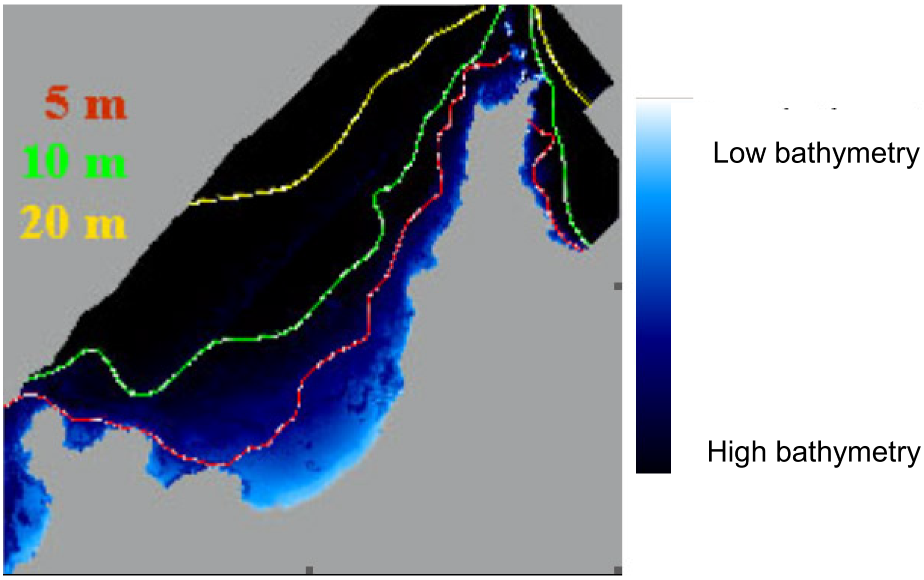


Figure 5: Bathymetric model obtained from airborne CASI images, Porquerolles Island, France

Watershed or seabed mapping

Many algorithms of classification (supervised or not) have been developed. Depending on available ground data (land use information, spectral database, etc.) the choice of classification method has to be chosen (7). For seabed mapping, sunglint and water column effects have to be removed because they affect the seabed reflectance.

Sun glint can be removed from the imagery by determining the linear relationship between near infrared and visible radiance over an area of water too deep for the seabed to be of influence.

The water column affects seabed reflectance as a function of depth. Bathymetry needs then to be estimated. Reflectance of the seafloor can be calculated for every pixel in the imagery, see Figure 6.

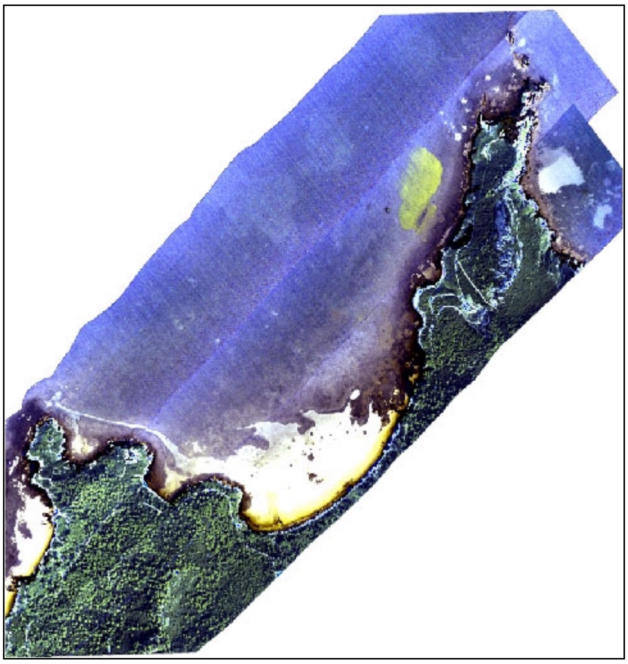


Figure 6: Result of water column effect correction on CASI images, reflectance of the seafloor, Porquerolles Island, France

When the water effect on the seabed reflectance has been removed, classification can be applied in order to map the seabed.

CONCLUSION

We have developed in this article the methodology used to select relevant applications from MERIS images for coastal managers. According to the real problems encountered and to MERIS characteristics, we selected 6 applications: eutrophication and sedimentation indexes, change detection between multitemporal images, bathymetric model and the watershed and seabed mapping.

For all applications, a reflection on the operational use of products and services will be carried out according to the user group expectations (delay in reception of images, pre-processing algorithm, available algorithms to show the phenomenon, available means of validation, delay to obtain the final product, the required level of automation, cost…).

The fluidity of the sensor-users MERIS chain and the image quality will be analysed in order to evaluate the difficulty level for potential users to access the proposed data and services.

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