

MODIS DATA PROCESSING FOR COASTAL AND MARINE ENVIRONMENT MONITORING: A STUDY ON ANOMALY DETECTION AND EVOLUTION IN GULF OF CAGLIARI (SARDINIA-ITALY)

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ABSTRACT:

In this paper, the authors demonstrate that MODIS sensor multispectral imagery may be used in marine and coastal environment monitoring and for anomaly detection and that MODIS imagery may represent an alternative to SAR techniques in oil spills mapping. Two MODIS dataset of the Gulf of Cagliari (Sardinia - Italy) have been analysed in order to study the sea signal among the visible and infrared wavelengths (bands 1 to 7) and to intercept a reported water anomaly. A simple spectral index is proposed to detect fluorescence anomalies due to oil spills. Using high multitemporal imagery, as MODIS sensor data, a monitoring system of sea surface may be built applying this index. Standard sea temperature elaborations have been used to verify the methodology.

1. INTRODUCTION

1.1 Background

Oil spill detection by remote sensing techniques (Fingas and Brown, 1997) includes passive (visible and infrared), microwave and radar (Synthetic Aperture Radar, SAR) methodologies. In the early '70s (Krishen, 1973) radar was considered the most efficient oil detection instrument in open sea.

The SAR technique detects the roughness difference between oil film and sea water, may work at any meteorological condition (penetrating cloud cover) and potentially may have high ground resolution.

However, SAR data may not have the daily availability, may depend on sea conditions (Liu et al., 2000) or may be affected by false alarms due to phytoplankton or to freshwater (Lin et al., 2002).

MODIS sensor, instead, may detect the oil spill on sea water by catching the radiometric signal, may have high temporal resolution, but, as optical sensor, is highly dependent on meteorological condition (cloud cover cannot be penetrated).

1.2 Objectives

In this paper, multispectral MODIS data are used for Sardinian coastal and marine environment monitoring and to detect anomaly on the sea surface.

On 4th September 2005 an extensive oil spill was reported around the southeastern coast of the Gulf of Cagliari (Sardinia – Italy). The TeleGis Laboratory has investigated the sea surface of that area using MODIS data captured by Terra and Aqua NASA satellites.

This work aims to demonstrate the great potential of coastal and marine environment monitoring using high temporal resolution

MODIS dataset, in particular to identify anomalies over the sea surface and to monitor their evolution in the time range of two consecutive data captures.

Two MODIS scenes captured on 4th September 2005 at 10:25 a.m. by TERRA satellite and at 12:05 p.m. by AQUA satellite have been studied to detect the oil anomaly and its evolution. Both the considered datasets acquired on 4th September 2005 by Terra and Aqua are almost centered on the investigated sector and clearly show an anomaly in the area of the Gulf of Cagliari: as sun-glint conditions emphasize the contrast against the surrounding marine water, applying simple contrast stretching techniques in the visible (MODIS bands 1, 3, 4) or in the NIR (e.g. bands 15, 16) range, it would be possible to easily detect in the sea a curved plum, darker than the surrounding seawater, expanding not far from the southeastern coast of Sardinia. This anomaly seems corresponding for geographical position and shape to the oil spill reported that day.

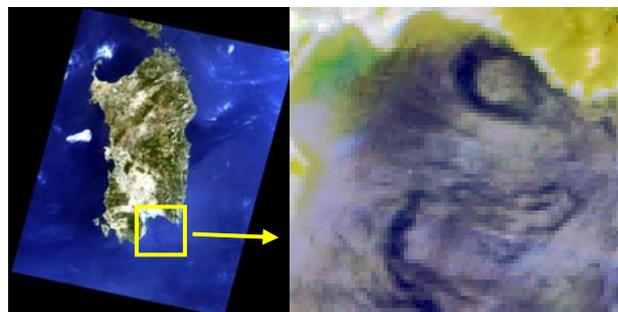


Figure 1. The anomaly in Gulf of Cagliari on September 2005.

2. METHODOLOGY

2.1 Data – MODIS data

MODIS is a sensor for multidisciplinary targets, fit to study the land, the sea and the atmosphere. (Esaias et alii 1998) In 1999 the first MODIS sensor has been put in orbit onboard the satellite Terra, followed in 2002 by its homologous launched onboard the Aqua satellite. The satellite Terra orbits around to the globe along an heliosynchronous descendant orbit, passing daily over the Equator at 10:30 a.m., while the Aqua satellite moves along an ascending orbit passing over the Equator at 1:30 p.m.. In this way the entire land surface is covered by Aqua and Terra every two days, acquiring environmental information in the wavelength range between 0.4 and 14.4 micron. The radiometric information is split in 36 bands from the visible to the near infrared and the thermal infrared. Data are captured according to 3 different spatial resolutions: 250 meters for bands (1-2), 500 meters for bands (3-19) and 1000 meters for bands (20-36). Data radiometric resolution is 12 bit: every pixel in every single band contains 4096 information. The MODIS Dataset used in this job have been acquired by TeleGis Laboratory - University of Cagliari - using the Terascan® X-Band LEO acquisition and processing system that collects data from satellites through the 2,4 meters diameter parabolic antenna, moving along three axes (Marini et alii, 2005). Captured data spatial coverage is centered on the antenna location in the middle of the Mediterranean basin and ranges up to the Northern Europe, Middle East and Northern Africa and Atlantic Ocean. The daily temporal resolution guarantees from satellites at least two daytime and two nighttime acquisitions.

2.2 Approach

Level 1b MODIS data at bands 1 to 7 from Terra and Aqua satellites have been analysed: an anomaly on sea surface is clearly evident in all these bands (250 and 500 meters ground resolution). In the visible range, the anomaly signal appears darker than the surrounding water, enforcing the hypothesis of the hydrocarbon spill.

The recent past literature (Fingas e Brown, 1997) considers oil spill reflectance, in visible range, greater than the seawater reflectance, but not enough to permit an easy distinction under natural irradiation. However, more recent study on optic models (Otremba e Piskosub, 2001 e 2003) demonstrate that acquisition angle, combined with a particular irradiation geometry, may enhance the reflectance contrast between oil and surrounding water.

Figure 2 and 3 show the reflectance trend along a W-E study transect crossing the Gulf of Cagliari in the Terra image at 10:25. In the first graphic the difference between land reflectance signal (higher values on the right) and sea water (almost lower flatten signal) is clearly exposed: red ellipse puts in evidence values corresponding to the anomaly, detailed in the second graphic, where the signal drop may be easier appreciated.

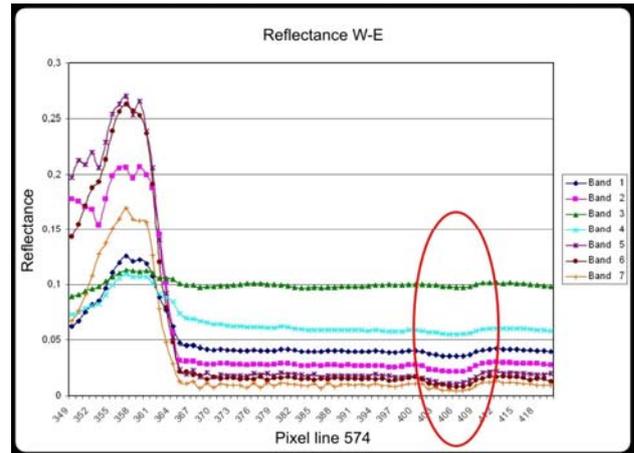


Figure 2. Reflectance trend along Gulf of Cagliari (see text)

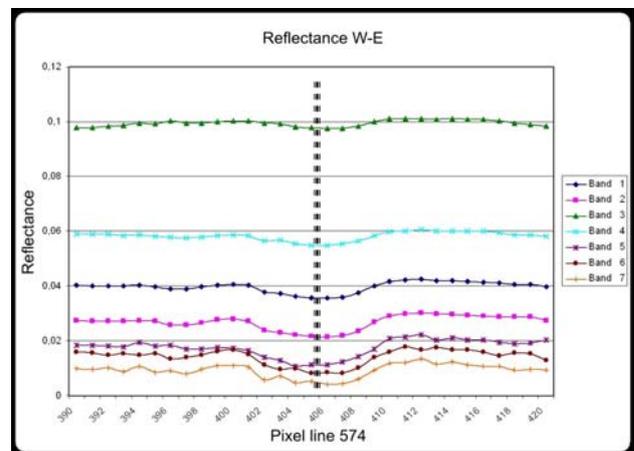


Figure 3. Reflectance trend along Gulf of Cagliari, detail

In order to highlight the anomaly signal and to understand its nature, further analysis has been carried out on MODIS spectral bands and on the possible causes related to suspected substances.

Hydrocarbon products are optically characterised by fluoresces proprieties, emitting light when hit by ultraviolet or some visible rays. On the electromagnetic point of view, these kinds of molecules react to a particular radiation releasing another higher wavelength radiation.

Oily substances generally have a greater reflectance in relation to the marine water, especially in the blue spectral range: this is due to fluorescence induced by $\lambda < 400$ nm sunlight rays.

Assuming that the observed anomaly may be caused by oil spill, a method to discriminate on MODIS imagery objects with fluorescent proprieties has been developed, elaborating data in order to enhance the blue range component.

A relative fluorescence index $F(1)$ has been defined as the following formula:

$$F = \frac{Blue - Red}{Blue + Red} \quad (1)$$

This algorithm is based on the relationship between blue and red ranges (respectively bands 3 and 1 in MODIS data), in which the higher is the value of the contribution of blue and the greater is F.

A new synthetic band has been produced applying the algorithm, enhancing the spatial development of F index, as shown in figures 4 and 5.

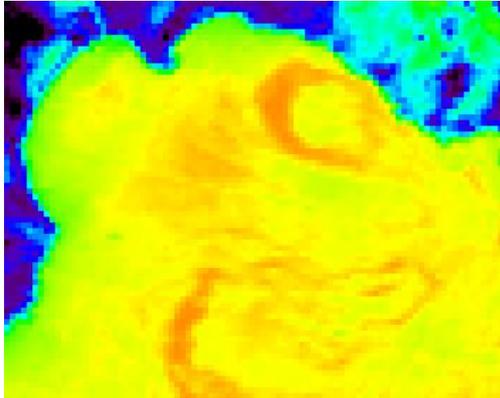


Figure 4. F index image

The elaboration, applied to both MODIS dataset considered in this study, allows a better enhancement of the anomaly in relation to a simple true colour composite, and the higher values of F index may let presume that the anomaly substance has hydrocarbon components.

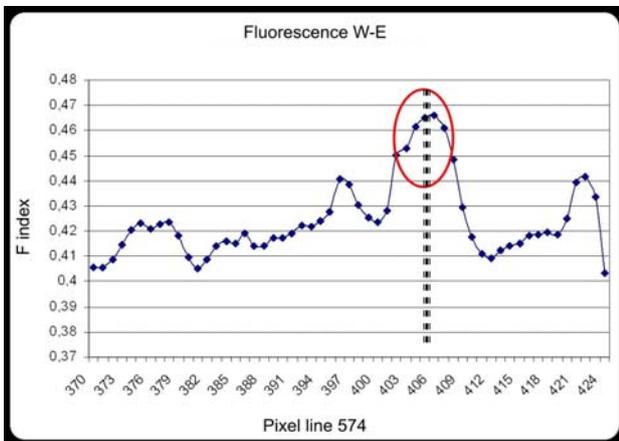


Figure 5. F index trend along the anomaly

In order to compare results, the processed datasets from Terra and Aqua have been geometrically rectified and geographically referenced using the WGS84-UTM system in order to allow the geographic comparison.

The comparison leads to the analysis of the evolution of the anomaly in the time range (about 2 hours) between the passage of the Terra and Aqua satellites over the Gulf of Cagliari, demonstrating the usefulness of MODIS high temporal resolution datasets for oil spill detection and evolution analysis.

Observing both datasets in true colour composite (TCC 1:4:3), it may be seen that the oily surface is particularly evident in

the Terra imagery for the sun glint conditions affecting the surrounding area during the acquisition: the resulting sunlight reflection of the seawater strongly enhance the darker signal of the oily substance. Aqua dataset, acquired about two hours later, does not present similar conditions and the anomaly may be detected after image contrast enhancement only.

The data comparison demonstrates how sun glint and acquisition geometry may have an important role in oil spill detection and mapping.

Applying the developed investigation methodology and elaborations to other MODIS imagery, a seawater monitoring system has been tested on the Gulf of Cagliari.

The 5th September 2006 imagery (figure 6) shows another anomaly in visible range, comparable with that previously described.

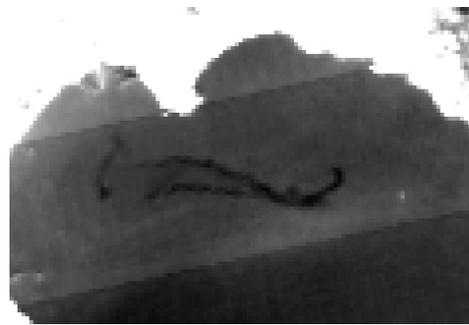


Figure 6. Another anomaly detected by MODIS Aqua on September 2006

In order to further develop the anomaly investigation, thermal bands have been analysed. Standard Sea Surface Temperature (SST) algorithms (Fu et alii, 1998) have been applied to correlate thermal variations to the observed anomaly.

The approach of this study was based on standard MODIS ocean product elaborations and atmospheric corrections. Standard algorithms for MODIS ocean products include standard atmospheric corrections that strongly depend on the aerosol contribution in radiance and that also sensibly flat the sun-glint effects (Vermote and Vermeulen, 1999). Applying these algorithms without an accurate estimation of aerosol in the investigated area may lead to false results and the sun-glint flattening effect makes anomalies very less evident in the scene.

This approach did not lead to important result for oil spill characterization, as it was not possible to associate any significant variation in temperature to the anomaly. The reason may be found in the processing applied for the atmospheric correction, as aerosol parameters were unknown.

Other reasons may be attributed to the standard temperature low-resolution (1 km) processing, or simply to the fact that the anomaly oily would be in thermal equilibrium with the surrounding water.

In conclusion, that approach demonstrates that standard MODIS ocean products are not particularly efficient for oil spill detection and characterization.

3. DISCUSSION AND CONCLUSION

The importance and complexity of the marine environment requires a continuous and multidisciplinary study.

Multispectral sensors like the MODIS radiometer (1985 Robinson - Robinson 2004) (ESA 2002) seems appropriate to investigate processes occurring at sea. In case of oil spill, MODIS sensor may easily highlight anomalies using higher resolution bands (250 and 500 m), especially in particular sun glint conditions.

The fluorescence index (F) developed in this study, using MODIS bands 3 and 1, may represent an interesting mean to identify and discriminate oily substances floating on the sea surface. By opposite, standard MODIS SST ocean product does not give appropriate results to detect these anomalies.

In conclusion, MODIS data may give a significant contribution for a marine and coastal monitoring system, also considering the availability of several daily acquisitions from Terra and Aqua satellites. A limitation of a MODIS data monitoring system is given by meteorological conditions, as cloud cover may prevent radiance penetration from sea surface.

A proper validation of the procedure and of the results described in this paper should be done by direct on ground measurements (e.g. of reflectance and chemical composition)

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