Integration of Earth Observation Data to Improve the Knowledge of Upwelling Phenomenon in the Strait of Messina

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Abstract

The work focuses on the data Earth Observation (EO) integration with different spatial and temporal resolution according to the Group on EO Working Plan 2009-2011. In particular, the "Ecosystem observations will be better harmonized and shared, spatial and topical gaps will be filled, and *in situ* data will be better integrated with spacebased observations" (GEOSS Societal Benefit Areas) is the main challenge applied to the Strait of Messina. The area is a coastal site with a remarkable economic and environmental role addressable to the complex dynamic of the water body. The strait is located in the centre of the Mediterranean Sea with strong current and vortex due to the morphology of the site. In this area, the upwelling is a hydrological phenomenon that strongly impacts the marine ecosystem. The upwelling systems are characterized by increased 'biological richness'. The principal indicator of upwelling is low sea surface temperature (SST). Since 1994, SST and phytoplankton were measured by continuous underway surface measurements onboard dedicated research boats. During 1999-2002, these in-situ measurements have been integrated with remote sensing image acquired by MIVIS airborne sensor. The integration meets the requirements to validate the empirical algorithm applied to remotely data in order to retrieve the phytoplankton and, the remote sensing provides a synoptic view of upwelling phenomenon by mapping the SST and the phytoplankton into the water body of the strait.

1 Introduction

The Earth Observations system constitutes a critical input for advancing the understanding and monitoring the Earth system, such as climate, oceans, atmosphere, water, land, natural resources, natural and human-induced hazards and for protecting the global environment, reducing disaster losses and achieving sustainable development [1]. In order to ensure comprehensive and sustained Earth observations, a coordination of the efforts, articulated in the GEOSS 10-Year Implementation Plan, has been built on to add value to existing Earth observation systems, filling critical gaps and supporting their interoperability. Over the next decade, the global scientific community has been expected to join the pivotal GEOSS Plan. The GEOSS will provide an important scientific basis to clearly identify the planning and decision making in the complexity of the everyday life including public health, agriculture, transportation and numerous other areas to keep abreast of the rapid changes occurring in the society today. In less than two years, the number of participating countries has nearly doubled, and over 40 international organizations also support the emerging global network. The Messina monitoring projects take place at this strategic moment, when the Earth Observation has become an essential component of the global effort to deal with global challenges. The purpose of these projects is to promote capacity building in Earth observation, on existing local, regional and international initiatives and sector-specific needs, like GEOSS planned, in order to achieve comprehensive, coordinated and sustained *in situ*, airborne, and space-based observations of the Messina coastal area. The activities of these projects meet the need for timely, quality local scientific information as a basis for sound decision making, and will enhance delivery of benefits to society especially in the following initial areas, recognized in the GEOSS 10-Year Implementation Plan: "Improving the management and protection of terrestrial, coastal, and marine ecosystems" [2]. Hydrodynamical processes affect the spatial distribution and temporal development of phytoplankton biomass on the world's oceans and seas. Among the hydrological events, the divergent current bring nutrients into the upper layer of the water column and modulates the chlorophyll−a distribution [3]. Upwelling is a hydrological phenomenon that strongly impacts the marine ecosystem. In fact, upwelling systems belong to the most productive marine environments, and are characterized by increased 'biological richness' in all levels of the trophic chain. Low water temperature is one of the indicators of upwelling, and the difference of sea-surface temperatures between an upwelling zone and the surrounding waters is a parameter for defining upwelling intensity [4]. In these environments, phytoplankton growth is primarily regulated by the availability of allochthon nutrients, primarily nitrates, which stimulate the production of phytoplankton [5].

2 Study area

The Straits of Messina (Figure 1), at the center of the Mediterranean Sea, is an area where strong currents determine fast changes in the oceanographic conditions. This system, separating the Italian peninsula from Sicily, is an amphidromic point for the tides of the Tyrrhenian in the northwest and the Ionian seas in the southeast. Morphologically, the Strait resembles a funnel-shaped geometry with a northsouth length of 40 km and a west-east width ranging from 3 km near the Tyrrhenian edge, to about 25 km at the Ionian open boundary. The narrowest section (Ganzirri–Punta Pezzo), which coincides with the sill region, has a depth of about 80m and divides the area into northern and southern sectors. The sea bottom slopes steeply downward to a depth of 1000m at 19 km south of the sill. The northern sector has a gentler slope, and the 400m isobath is located 15 km north of the sill toward the Tyrrhenian Sea. The Straits exhibits strong tidal currents driven by both barotropic and baroclinic processes, due to strong bathymetric constraints exerted by the sill and coastal morphology [6]. Large gradients of tidal displacements are encountered in the Straits of Messina, because the predominantly semidiurnal north and south tides are approximately in phase opposition. Due to both

Figure 1: Study area.

phase opposition and topographic constrictions, the current velocities can attain values as high as 3.0ms^{-1} in the sill region, and are related to the position of the sun, the phase of the moon, the wind speed and direction, and the air pressure distribution [7]. Surface water turbulence in the Straits is mainly influenced by two types of circulation, a steady surface current and a turbulent mixing, both of which generate discontinuity of the thermo–haline distribution in the surface layer. The steady current has a maximum speed of 2m·s^{-1} and a prevalently north to south direction at the surface (0–30m). Water turbulence is caused both by internal waves and by tidal currents [8]. Internal waves are caused by differences in water mass densities of the two basins that are facing in the Straits. Tidal currents are caused by opposite tidal oscillations of the two basins (max 27 cm) with almost the same amplitude and period (about 6 1/4 h). These conditions lead to the upwelling of deeper water of Levantine Intermediate Water origin, which is colder, more salty and more nutrient-rich compared to the Tyrrhenian Surface Waters (Atlantic Water origin). Harmonic oscillations of the current flowing from the Tyrrhenian Sea waters into the Ionian Sea (high tide current), and from the Ionian water into the Tyrrhenian Sea (low tide current) are encountered, with a brief slack water interval (balancing flow). Because of these particular environmental features, the Straits have been studied by many researchers in order to define forcing factors that determine its current regimen [9]. Many hydrobiological studies have been conducted over the last few decades to describe the influence of complex hydrodynamic conditions on biological parameters [10, 11].

Figure 2: MIVIS surveys with superimposed the cruise tracks followed by the R/B "Delfo".

3 Instruments and methods

Since 1994, the IAMC-CNR (Institute for coastal marine environment) measures temperature, salinity, and phytoplankton by continuous underway surface measurements during the dedicated oceanographic cruises. During 1999-2002, remote sensing surveys were performed with MIVIS airborne sensor and specific in-situ measurements. Specific in-situ measurements meet the requirements to validate the empirical algorithm applied to remotely data in order to retrieve the phytoplankton and, the remote sensing provides a synoptic view of upwelling phenomenon by mapping the SST and the phytoplankton into the water body of the strait.

3.1 Oceanographic cruises

Spatial and temporal distribution patterns of physicochemical (temperature, salinity, and nutrient concentrations) and biological (chlorophyll−a measured by *in situ* fluorescence emission), data are presently available for the central-northern side of the Straits of Messina. Discrete water samples (nutrients, chlorophyll−a, etc.) based on conventional methods were collected during the surveys. The wind, air temperature and pressure were measured during each hydrographic cruise. Automatic real-time data were obtained by monthly surface tracking in the area between Capo Peloro (Sicily) to the north and Reggio Calabria to the south. This area was covered on the R/B "Delfo" using zigzag cruise tracks between the Calabrian and Sicilian coasts, adopting the lagrangian method in order to follow the wave of tide in the Strait. The location of the area and the track followed by the boat in each survey is displayed in Figure 2. It iswell known that the maximum intensity (> 3 $\mathrm{m{\cdot}s^{-1}}$) of the tidal currents occur during spring tides, corresponding to syzygy lunar phases. Measurements were carried out when the water slackens during the spring tide period to individuate the upwelling of deeper waters. Prior to taking measurements, the current forecast from "Tide tables of the Istituto Idrografico della Marina, Genova" was used in order to seize the quasi-stationary situations following the dynamic phases of high (high tide current, 3 h/cruise) and low (low tide current, 3 h/cruise) tides. Parameters taken into consideration in the present work are temperature and fluorescence, continuously (each 30 seconds) measured by means of a multiparameter probe (Meerestechnich Elekronik) and a fluorometer (Haardt-Mod1101LP).

3.2 Remote sensing surveys

3.2.1 Hyperspectral instrument

In situ: The ground-based acquisition have been performed by means of the Field-Spec Pro FR spectroradiometer (ASD). The ASD is a portable instrument covering the spectral domain between 350 nm and 2500 nm, sampled to 1 nm. Remote: The hyperspectral data have been acquired by the airborne MIVIS (Multispectral Infrared and Visibile Imaging Spectrometer) sensor. The MIVIS is a whiskbroom scanner composed of 4 spectrometers covering the spectral domain from 420 to 12700 nm by 102 channels. The scanner geometry is characterized by a Field of View of 90°.

3.2.2 Methods

In situ: During the remote sensing surveys, field measurements were collected to investigate spatial variability of physical, chemical and biological parameters, in particular in each station were collected water samples and performed Optical Measurement. The sampling stations were collocated between Sicily and Calabria coasts. Samples of water for the retrieve of CDOM, TSM (Total Suspended Matter) and chlorophyll-a at the surface and at 25 m depth were collected. At the same time the radiance upwelling from the sea surface and downwelling from the sky was recorded. All acquisition and elaboration procedures followed the Ocean Optics Protocols [12, 13]. The procedure for hyperspectral sea surface reflectance measurement is based on the acquisition of the upwelling and downwelling radiance according to SeaWifs Protocol [14]. Whereas, the reflectance measurements over land are directly the outputs of the instrument. The reflectance is obtained from the relative radiative measurements achieved by a fast double acquisition (target and reference panel) fixed in a nadir pointing configuration. During acquisition time some roles were respected in order to facilitate Rrs estimation and avoid other undesirable effects. At the same time of the remote sensing survey, reflectance spectra of some materials situated in land over Sicily and Calabria coastal areas, necessary for the atmospheric correction of the MIVIS images, were measured. Remote: The joint MIVIS (CNR LARA) and sailing vessel (CNR IST) campaign were carried out on 25th September 1999 at 2:00 p.m., on 2nd July 2000 at 12:00 a.m. and on 15th May 2002 at 11:30 a.m. in correspondence of the syzygy moon phase, when tidal currents reach maximum intensity. The MIVIS remote sensed 3 scenes with a NNE-SSW and SSW-NNE direction at the altitude of 4000 meters and a scanning speed of 16.5 Hz (Figure 2). A further scene was recorded over Messina at the altitude of 1500m (resolution at ground of about 3m). Preprocessing (sun glint effect): To assess the suspended and dissolved matter in water in the visible and near infrared spectral regions it is necessary to estimate with adequate accuracy the water leaving radiance [15]. Consequently radiance measured by a remote sensor has to be corrected from the atmospheric and the sea surface effects consisting in the path radiance and the sun and sky glitter radiance contributions. This paper describes the application of the sun glint correction scheme on to airborne hyperspectral MIVIS measurements acquired on the area of the Straits of Messina during the campaign in July 2000. In the Messina case study data have been corrected for the atmospheric effects and for the sun-glitter contribution evaluated following the method proposed by Cox and Munk [16]. Comparison between glitter contaminated and glitter free data has been made taking into account the radiance profiles relevant to selected scan lines and the spectra of different pixels belonging to the same scan line and located outside and inside the sun glitter area (Figure 3). The results show that spectra after correction have the same profile as the contaminated ones, although, at this stage, free glint data have not yet been used in water constituent retrieval and consequently the reliability of such correction cannot be completely evaluated [17].

4 Discussion and conclusions

The MIVIS has moreover stressed upwelling areas of the Straits of Messina, previously only hypothesised though never ascertained by the continuous traditional monitoring. As a matter of fact, because of the great space-time variability of the physical-chemical and biological parameters, the monitoring of the Straits by means of the vessel sailing was restricted both from time and space points of view. Therefore, monitoring techniques offered by the MIVIS hyperspectral data have provided for an instantaneous global view of the Straits integrating measures taken continuously by the sailing vessel. Then, the monitoring the Straits of Messina by means of the combined MIVIS and sailing vessel campaigns during the entire yearly cycle, could allow in the future a better vision of the sea circulation and its effects on the biological activity of the system during the seasonal variations.

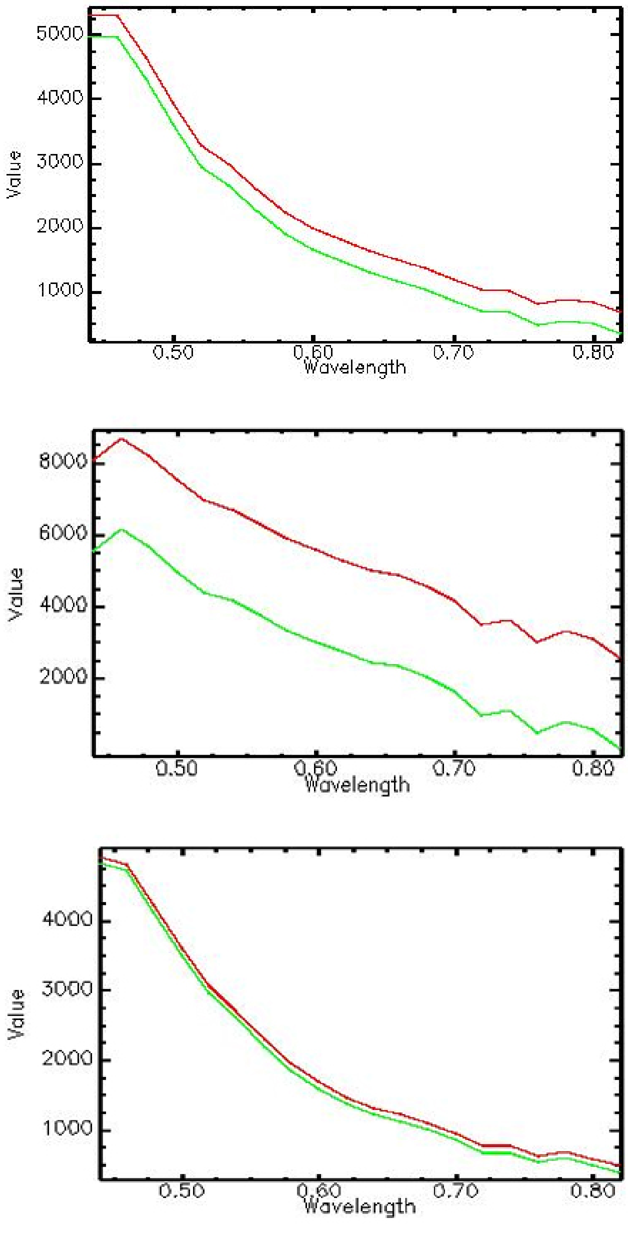

Figure 3: Comparison between spectra before (in red) and after (in green) the sun glint correction, relevant to three different pixels located outside (top and bottom) and inside (central graph) the sun glitter area.

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