ABSTRACT

Since 1998 many areas inside the San Rossore Natural Park have been utilized as test sites during various remote sensing campaigns mainly devoted to calibration and validation activities and vegetation monitoring in coastal zones.

The Park which is located near Pisa (Italy) is limited on one side by the Tyrrhenian sea and is mainly covered by pine-forest (Pinus Pinaster Ait. and Pinus Pinea L.). The southern part of the park, which is confined by the Arno river mouth, is characterised by a wet area, a system of ponds directly connected to the dunes system, which is originated by the sediment deposition at the river estuary. The considerable amount of data collected during last years allow us to perform a multi-temporal analysis of the wetland spreading and land coverage as well as to assess many physical and biogeochemical parameters (like green biomass) from estimated Vegetation Index and reflectance maps.

Coastal wetlands are characterised by shallow waters, moor and dunes. These ecosystems are seasonally affected by waterlogging due to fresh and salt waters, and in general, even if relatively small, they are biogeochemically active due to their high productivity and redox gradients. Therefore the analysis of their ground texture and related features requires specifically developed optical sensors operating in a large number of visible and infrared spectral bands with high spatial and spectral resolution and radiometric accuracy. At the same time, the aforementioned analysis requires the calibration and validation of the collected data.

Since 2002 the CHRIS sensor, operating on board of PROBA-1 satellite, has been acquiring images of San Rossore test site in the framework of the Cat.1 LBR ESA EOP Project ID 2832. The cloud free images have been fully processed by us to obtain L1B (at-sensor radiance images) and L2 (spectral reflectance maps) data. These products are giving a valuable contribution to many in-situ measurements campaigns carried out in that area.

The monitoring of wetlands and floodplains areas are taking advantage from the PROBA acquisitions due to the CHRIS spectral and spatial resolution features as well as the multitemporal series of these data. Some outcomes from data processing will be introduced and discussed

1. INTRODUCTION

The wetland is an area where the water level is at or near the soil surface for a significant part of the growing season, and the soil is covered by active vegetation during the period of water saturation. Wetlands are biogeochemically active due to their vigorous productivity and redox rates. The frequency and the amplitude of flooding events are relevant to the monitoring of ecological processes occurring in the wetland area, and their modifications strongly affect the wetland hydrology.

Coastal wetlands are remarkable ecosystems in terms of environmental health (geomorphologic distinctive features, typical vegetation or faunal associations) and cultural heritage as evidence of human activities related to this singular environment.

Data collected by aerospace devices can be used to better classify wetlands and assess their spatial and temporal distribution. To take advantage from this technology, sensor response has to be accurately calibrated and mathematical and physical models should be developed [1], [2] to interpret the gathered data.

Many coastal wetlands in Tuscany are considered interesting environmental area but they are menaced by anthropogenic activities [3], [4]. The trend of the re-naturalization of some environments has brought about the re-formation of circumscribed wetlands. The Regional park of Migliarino, San Rossore, Massaciuccoli, is an important example of this trend.

The park is located on the seaside near Pisa (Italy) and is mainly covered by pine-forest. Its southernmost part is covered by the wet area of Lame di Fuori, a system of ponds and dunes affected by the sediment deposition occurring at the river estuary.

Due to the presence of different types of natural environments, since 1997 many areas inside the Park have been utilised as test site in many remote sensing
campaigns mainly devoted to the coastal zone monitoring. Since 2002 the CHRIS sensor, operating on board of PROBA-1 satellite, has been acquiring images of San Rossore test site. The monitoring of wetlands and floodplains areas are taking advantage from the PROBA acquisitions due to the CHRIS spectral and spatial resolution as well as the multitemporal series of these data [5]. Data gathered by the new airborne hyperspectral sensor HYPER-SIM GA during a CHRIS overpass on December 2005, have also been used to analyse the wetland characteristics and land coverage, and to assess biophysical parameters from Vegetation Indexes.

2. REMOTE SENSING OF WETLAND IN THE COASTAL ZONES OF SAN ROSSORE NATURAL PARK

2.1. Natural Park of Migliarino, San Rossore, Massaciuccoli

The Regional Park of Migliarino, San Rossore, Massaciuccoli (Latitude: 43.6° - 43.9° N; Longitude: 10.2° - 10.5° E; Altitude: 5 m a.s.l.) is depicted in figure 1 and consists of a coastal forest of about 40 km², a sandy shore and inland marshes, larger in the past, before they became subject to a land reclamation project. The richness of the flora in arboreal and herbaceous species is favoured by the local climatic conditions characterized by wet autumns, winters and springs, followed by very dry summers. The area closer to the sea is mainly covered by pine (Pinus Pinaster Ait. and Pinus Pinea L.) and ilex (Quercus Ilex L.) forest. The beach, consisting of mainly calcareous sand, is characterized by dunes where several herbaceous species grow: pioneer species along the shoreline, species building and fixing the sand, and species living in the back of the dunes. The presence of many classes of vertebrates is a remarkable aspect of the San Rossore Natural Park, where the populations of wild boars and fallow-deer are dominant in this area. The avifauna is the most representative faunistic group in the Park. The diversity of environments and their interpenetration give also the opportunity to observe the avifauna populations of the adjacent habitats. The most peculiar habitat of the Park is the wetland, which is mainly represented by the marshes located in the Natural Reserve Area of Lame di Fuori. This large wetland covers approximately 655 hectares and it is of fundamental importance as an over-wintering and stop-over site for avifauna. The complex of retrodunal pools of the Reserve is directly related to the winds and sea currents which started the formation of the dune system. Under favourable conditions, when dune begins to form, a consolidated sandbank builds up in front of the dunes. The new, growing beach tends to join the pre-existing shore and causes a sheet of water to accumulate between the new dune and the old coastline.
2.2. CHRIS Remote sensing campaigns at San Rossore Natural Park

CHRIS is a “push-broom” imaging spectrometer designed by SIRA Electro-Optics Ltd. (U.K.) to collect data for land and sea investigation, and aerosol measurement. CHRIS is the main instrument on board of ESA small satellite platform PROBA-1, launched on October 22, 2001.

The main scientific CHRIS-PROBA goal is the measurement of Earth surface directional reflectance in the visible and near-infrared spectral bands using the platform pointing capability [6].

CHRIS acquires a set of five images of the same scene at a Fly-by Zenith Angle (FZA) of +55º, +36º, 0º, -36º, and -55º during the same sun-synchronous polar orbit. Each image set has an associated “fly-by position” on the ground (roughly the image center) that corresponds to the Minimum Zenith Angle (MZA), defined as the off-nadir inclination of the sensor viewing direction in the plane perpendicular to the satellite orbit. The line of sight inclination in the along track direction (held in the orbit plane) is indicated by FZA. The geometrical composition of the aforementioned angles gives the true zenith angle of the sensor viewing direction.

The sensor can provide a 12-bit digital signal, spectrally dispersed at 18, 37 or 63 spectral bands with a spatial resolution of 18 or 36 m, and spectral coverage from 405 nm until 1050 nm, and a spectral width of 8.6 nm @ 550 nm.

Since June 2002 more than 30 hyperspectral images were collected by CHRIS over the San Rossore (Italy) forestry test site in the framework of Cat.1-LBR ESA-EOPI Project ID.2832 “Assimilation of biophysical and biochemical variables in biochemical and hydrological models at landscape scale”. This considerable amount of data allows us to continuously improve our understanding of different bio-geo-chemical phenomena such as those involved in the change of vegetation status as observed in areas that are strongly affected by anthropogenic activities [7].

The provided CHRIS data sets, like those from many other spaceborne imaging spectrometers, are still affected by various inaccuracies, mainly due to the sensor calibration. To mitigate this problem the received data have to be pre-processed [8].

In-field activities are extremely important in order to remove from the collected signal the atmospheric effects [9] and to validate/calibrate data retrieved from remotely sensed images. To better correct the atmospheric effects on the remotely sensed data, spectral measurements of atmospheric parameters [10] and land surface have been taken during the overpasses. A permanent test site has established and equipped with various scientific instruments in order to measure the following parameters: ground spectral reflectance, soil temperature, leaf area index, air temperature, pressure and relative humidity, wind speed and direction, rainfall, integrated and spectral solar irradiance, CO₂, SO₂ and NOₓ concentrations. An example of measured data is shown in figure 3.

![Fig. 3. Examples of in-field measurements at San Rossore test site: a) solar spectral irradiance, b) CO₂ and H₂O fluxes, c) spectral reflectance of different ground coverage.](image-url)
the Fraction of absorbed Photosynthetically Active Radiation (FPAR), the Water Index (WRI), and the Photo-chemical Reflectance Index (PRI) are relevant to vegetation and soil characterization. Using these quantities it is possible to assess biogeochemical parameters like: land cover, leaf area index (LAI), net primary production (NPP), Gross Primary Production (GPP), chlorophyll concentration, photosynthetic efficiency, leaf water content, carbon and water balances, foliar nitrogen, and biomass, which are used by various ecosystem process models to understand wetland ecosystems.

The classification method, traditionally utilized to process the remotely sensed data and based on assessment of dominant plant types, is not very useful because it does not reflect differences in biogeochemical cycles. Since wetlands have an important function in processing methane, carbon dioxide, nitrogen and sulphur, and in sequestering carbon, the parameters to characterize the role of wetlands in biogeochemical cycling of trace substances are: hydrology, temperature, primary production, vegetation type, soil type, salinity, chemical information, transport of organics and sediments, topography and geomorphology [11].

In the following a brief overview of the results obtained during different CHRIS acquisitions is introduced in order to point out the key parameters and relevant instrumental characteristics useful for wetlands description.

3. REMOTE SENSING CAMPAIGNS: OUTCOMES FROM DATA PROCESSING

3.1 CHRIS remote sensing campaigns

CHRIS long term series acquisitions allowed both multi-spectral and multi-temporal analysis continuously improving our understanding of different biogeochemical processes such as those involved in the change of vegetation status as observed in areas that are strongly affected by anthropogenic activities [7]. In particular CHRIS spatial and spectral resolution has allowed the estimation of narrow bands vegetation indexes like the Photo-chemical Reflectance Index (PRI).

In September 2004, preliminary estimates of canopy PRI and NDVI from CHRIS images were compared with leaf-level measurements from different plots corresponding to different vegetation types from among them some in wetlands [12]. LAI and hence NDVI is known to be correlated with fertility and light-use efficiency [13], and this could explain the relationship with PRI. To this aim the following relationship are utilized:

\[
PRI = \frac{(R_{531} - R_{570})}{(R_{531} + R_{570})}
\]

where \( R \) is the surface reflectance at the given wavelength (in nm) indicated by the suffix.

The preliminary analysis of one CHRIS image, acquired on 8th September 2004 at 0° along track pointing angle, demonstrates the feasibility of PRI measurement from space. A good relationship was observed (Figure 4) between PRI measured at the leaf level as ground truth and PRI estimated from CHRIS imagery \((R^2 = 0.45)\). The PRI ground vs PRICHRIS is maintained also for the images at +36° and –36° along track pointing angles giving a \( R^2 \) of 0.69 and 0.41, respectively.

Despite the noise of such a small signal, values are coherent across the image and differences among and within vegetation types are clearly visible, as displayed from a comparison of NDVI and PRI images in Figure 5 and 6, respectively.

In order to monitor seasonal changes in PRI and NDVI over the wet areas of Lame di Fuori Natural Reserve Area, CHRIS acquisitions on 27th March and 8th September 2004 are considered. The related results are displayed in Figure 5 and 6 for along track pointing angle of 0°, where changes in NDVI and PRI maps from early spring to late summer are reported.

Using a linear relationship [14], NDVI can be used to estimate the Fraction of Absorbed Photosynthetically Active Radiation fAPAR:

\[
fAPAR = a \cdot NDVI + b
\]

Gross Primary Production -GPP can be derived from this quantity through the following equation:

\[
GPP = \varepsilon \cdot \sum_i (fAPAR_i \cdot SR_i \cdot Tcor)
\]

where \( \varepsilon \) is the Light Use Efficiency (LUE, related to PRI), SR correspond to photosynthetic active solar radiation and Tcor is a coefficient related to the

![Fig. 4 Comparison of PRI measured in field the 8th September 2004 on 13 sampling areas and PRI retrieved from CHRIS image acquired the same day. Averages and standard deviations are reported for each area](image-url)
temperature. The sum is performed on the measurements taken in the period of interest.

Fig. 7 HYPR-SIM GA acquisition over “Lame di Fuori” on December 15, 2005: a) VNIR image (RGB: 621nm, 569 nm, 511nm); b) SWIR image (RGB: 1255nm, 973 nm, 1615nm); c) NDVI image; and d) PRI image

Images acquired over the wetland area of Lame di Fuori using VNIR and SWIR heads are shown in figures 7a and 7b. Due to the high spatial and spectral resolution of this new instrument, the reflectance spectra, extracted from both VNIR and SWIR images, are almost free from spectral mixing. Short wave infrared RGB image in figure 7b puts in evidence vegetation water content (green zones) and the presence of several pools (black zones) in “Lame di Fuori” area. High spatial resolution NDVI and PRI maps in figure 7c ad 7d point out fine differences in land cover and vegetation structures. In particular PRI map show a photosynthetic activity in some floodplains areas.

HYPER-SIM GA remote sensing campaign put in evidence the great potentiality of hyperspectral remote sensing techniques for wetland classification and monitoring of their resources. In particular, attention has to be paid to data calibration and validation for the complex heterogeneity of the observed ground surface and for the presence of water.

3.1 HYPER-SIM GA remote sensing campaign

On December 15th, 2005 the new push-broom imaging spectrometer HYPER-SIM GA flew over San Rossore for a validation/calibration remote sensing campaign planned during a CHRIS overpass. Two hyperspectral sensors, one operating in the Visible-Near InfraRed (VNIR) and the other in the Short Wave InfraRed (SWIR) instruments acquired images from 0.4 up to 2.5 micron with a spatial resolution of 1-2 m and spectral resolution of 2-5 nm.

Seasonal changes in PRI and NDVI maps shown in figure 5 and 6 put in evidence the changes in wetland land-use, and consecutively in the GPP of forest, pasture and marshes.

3.2 CONCLUSIONS

Remote sensing activities carried out at San Rossore National Park during CHRIS acquisitions have been revised and summarised. CHRIS data have been processed to analyse the wetland characteristics and land coverage, and to assess bio-physical parameters from Vegetation Indexes. This analysis has pointed out the need of using high spatial and spectral resolution sensors in order to better identify the wetlands areas and monitoring their resources.

Recently developed hyperspectral sensors have made necessary the calibration of their response and the
validation of the retrieved products that are relevant to the characterisation of wetland areas.

9. REFERENCES


