Hyperspectral satellite data for water quality assessment: Lake Garda as a test site of a methodology developed for Australian coastal waters

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Ante Scriptum - It is with great sadness that we convey the news that our friend and collaborator Eugenio Zilioli passed away in the end of 2004. As a senior scientist and leader of CNR-IREA he excelled in the area of international co-operation in lake remote sensing. Whoever met Eugenio Zilioli could appreciate both his professional and scientific skills as well as his warm personality.

Introduction
Hyperion, mounted on the Earth Observing One (EO-1) satellite platform, is the first civilian hyperspectral satellite sensor in space: it is capable of resolving 220 spectral bands from 0.4 to 2.5 $\mu$m, with 30 m spatial resolution. We evaluated Hyperion’s capabilities for assessing the chlorophyll and tripton contents in Lake Garda, the largest Italian lake. The procedure used to map chlorophyll and tripton concentrations in the lake involved a direct inversion of a bio-optical model by means of a linear Matrix Inversion Method (MIM), as published by Brando and Dekker (2003). In their application, Hyperion data were analysed for mapping water quality parameters (chlorophyll, tripton, coloured dissolved organic matter, Secchi disk transparency and vertical attenuation of light) in the Deception Bay waters (Brisbane, Queensland, Australia).

The parameterisation and calibration of this bio-optical model for Lake Garda waters, and the subsequent water quality mapping were accomplished through collaboration of the Optical Remote Sensing Group of CNR-IREA (Milano, Italy), the Environmental Remote Sensing Group of CSIRO-Land and Water (Canberra, Australia) and the Dep. of Limnology of Uppsala University (Uppsala, Sweden). Since 2000 CNR-IREA and CSIRO-Land and Water have been collaborating in the research and applications area of aquatic remote sensing for water management purposes. This collaboration was initially supported by the Italian Embassy in Canberra and by the Italian Space Agency-Ninfà project (Giardino and Sasanelli, 2002). Currently the cooperation is financed by the CNR/CSIRO Agreement (Project 2004-2006) and by Regione Lombardia for supplying a 4-months young-scientist fellowship grant.

Area of study
Lake Garda, with a surface area of 368 km$^2$ and a water volume of 49 km$^3$ represents an extremely important environmental resource for a variety of purposes such as irrigation, navigation, water supply and drinking water. In the last few years however, the water quality, together with the growth of submerged vegetation, especially in the southern part of the basin, have become increasingly significant problems, particularly in the summer season. For these reasons the lake requires extensive and continuous water quality management, aimed at avoiding its progressive deterioration, which would affect its function for drinking and irrigation purposes.

Materials and methods
As already published in the Bollettino (Brando and Giardino, 2003), on 22nd July 2003, a 7.5 km by 40 km of Lake Garda surface was acquired by Hyperion. During the satellite overpass a field campaign was carried out to acquire data to validate the Hyperion imagery and the derived products, as well as to improve the bio-optical parameterisation.
The Hyperion image was previously convolved using a 5x5 low pass filter to increase the signal to noise ratio and then atmospherically corrected to subsurface irradiance reflectance $R(0-)$ using the Modtran-based c-WOMBAT-c algorithm (Brando and Dekker, 2003). c-WOMBAT-c was run with actual measurements of visibility range assessed using sun-photometer observations performed synchronously to the sensor overpass. The atmospherically corrected image was geo-located and $R(0-)$ values were compared with in situ measurements. The optical closure was good from 490 to 610 nm, while in the blue and near-infrared wavelengths the image data appears to be under- and over-estimated respectively when compared to measured values. The over-estimation may be due to glint contaminations on Hyperion radiances, while under-estimation in the blue region to a partial failure of the atmospheric correction due to Lake Garda being an Alpine lake at high elevation surrounded by mountains.

The bio-optical model used in this study was a Case-2 water model, e.g. (Pierson and Strömbeck, 2001), and it computes the spectral subsurface irradiance reflectance $R(0-)$ using a set of water quality input parameters in combination with optical parameters derived from the HYDROLIGHT model (Mobley and Sundman, 2001). The water quality parameters were the concentration of chlorophyll, concentration of tripton and the level of colored dissolved organic matter (or yellow substance) absorption at 440 nm. For the model parameterisation, the existing bio-optical parameterisation of the lake (Strömbeck et al., 2003) was integrated with the data set collected on 22nd July 2003, coincident with the Hyperion overpass. A data set consisting of 3 PR-650 measurements of $R(0-)$ and concentrations of chlorophyll and tripton was used to evaluate the performance of the bio-optical model. Because no data on colored dissolved organic matter was measured on 22nd July 2003, a constant value equal to 0.02 m$^{-1}$ was assumed based on earlier observations.

**Results**

Fig. 1 shows the Hyperion imagery of 22nd July 2003 and the two water quality derived products. The chlorophyll map shows lower values in the southern part of the lake and higher values in the north; vice versa tripton was higher in the south and lower in the northern part of the lake.

To validate these water quality map product ranges, a 20-km long transect of fluorescence and turbidity was measured. Fluorescence and turbidity data were collected using a flow-trough system, called Fluorescence And Turbidity Analyser (FATA, also mentioned in the Bollettino of March 2003, section "News", p. 124), mounted on a 20 feet motor boat cruising at speed about 12 knots. FATA data were converted into chlorophyll and tripton values using the chlorophyll and tripton concentrations derived from the water samples collected in 6 stops during the cruise. Flow-trough measurements were compared with Hyperion-derived chlorophyll and tripton concentrations. For their evaluation, 125 pairs of in situ and image data were used. The spatial variation of chlorophyll in the Hyperion-based map was in agreement (R2 of 0.84) with the trend of in situ measurements, even if image data seems to amplify spatial variation with respect to in situ observations. Hyperion-based tripton estimations were also in agreement with the transect data (R2 of 0.78) and similarly to chlorophyll data the remote sensing derived values seem to amplify spatial variation with respect to in situ observations.

For further details on materials, methods and results shortly presented in this paper, we refer to Giardino et al. (submitted).
Fig. 1 – From left to right: the study area and FATA transect performed on 22nd July 2003 surrounding Hyperion overpass, the MIM-retrieved product of chlorophyll, the MIM-retrieved product of tripton.

References
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