Fluorescence Lidar Monitoring of the Arno River

H. Edner, J. Johansson, S. Svanberg, E. Wallinder

Department of Physics, Lund Institute of Technology
P.O. Box 118, S-221 00 Lund, Sweden

G. Cecchi and L. Pantani

CNR - Istituto di Ricerca sulle Onde Elettromagnetiche
Via Panciatichi 64, I - 50127 Firenze, Italy

ABSTRACT

A field test for monitoring water quality by fluorescence lidar technique was performed at the Arno River in Tuscany, Italy. A mobile fluorosensor system employing a frequency-tripled Nd:YAG laser, a 40 cm receiving telescope and an optical multichannel analyzer was used at three locations along the river. Yellow substance was found to increase downstream from Firenze to Bocca d'Arno, while algal fluorescence decreased.

INTRODUCTION

The protection of fresh-water resources and the marine environment from pollution is a matter of major importance.

In this context the development of powerful measurement techniques can contribute by providing an improved knowledge of the state of the environment. Remote sensing techniques provide non-intrusive measurements and coverage of large areas. Of the marine satellites the Nimbus 7 with its Coastal Zone Color Scanner (CZCS) has provided a vast amount of data. Recently the original data have been reevaluated providing improved global charting of yellow substance and chlorophyll (LEWIS 1989). The multi-spectral scanners (MSS) of satellites of this kind operate on reflected ambient light (passive remote sensing). By utilizing active techniques, illuminating the target area with e.g. laser light of well-known properties a more detailed assessment of the water properties can sometimes be obtained. Laser fluorosensor techniques have been used for oil spill detection and algal studies for quite some time. A review of this field of research has been given by HOGE (1988). Our own previous activities in environmental fluorescence monitoring are reviewed by Pantani and Cecchi (1990) and by Svanberg (1990).

In the present paper we describe remote measurements of the water of the Italian river Arno using a mobile fluorescence lidar system. Measurement were made at the river estuary at Bocca d'Arno and upstream in the river at Firenze. The campaign was performed within the framework followed by a description of the measurements and a comparison with the results from standard chemical sampling. Finally, the results are discussed and improvements to be implemented are suggested.

1. FLUORESCENCE CONSTRUCTION

The mobile fluorosensor set up for remote water monitoring is shown in Fig.1. The basic system is described by Ender *et Al.* (1987). The equipment is mounted in the laboratory compartment of a full size truck, which is also towing a 20 KVA power generator.

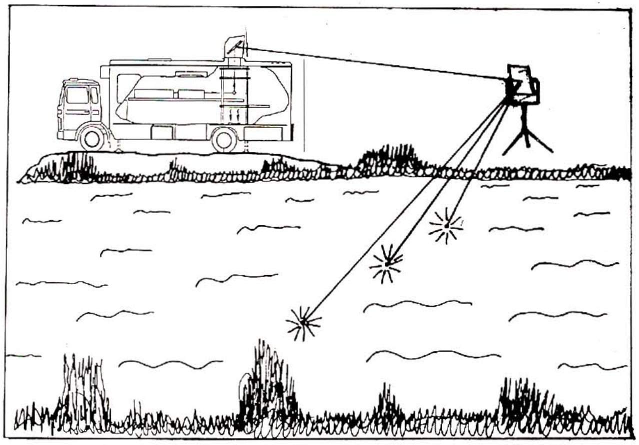

Fig. 1 - Schematic diagram of fluorescence lidar system set up for measurements at the Arno river.

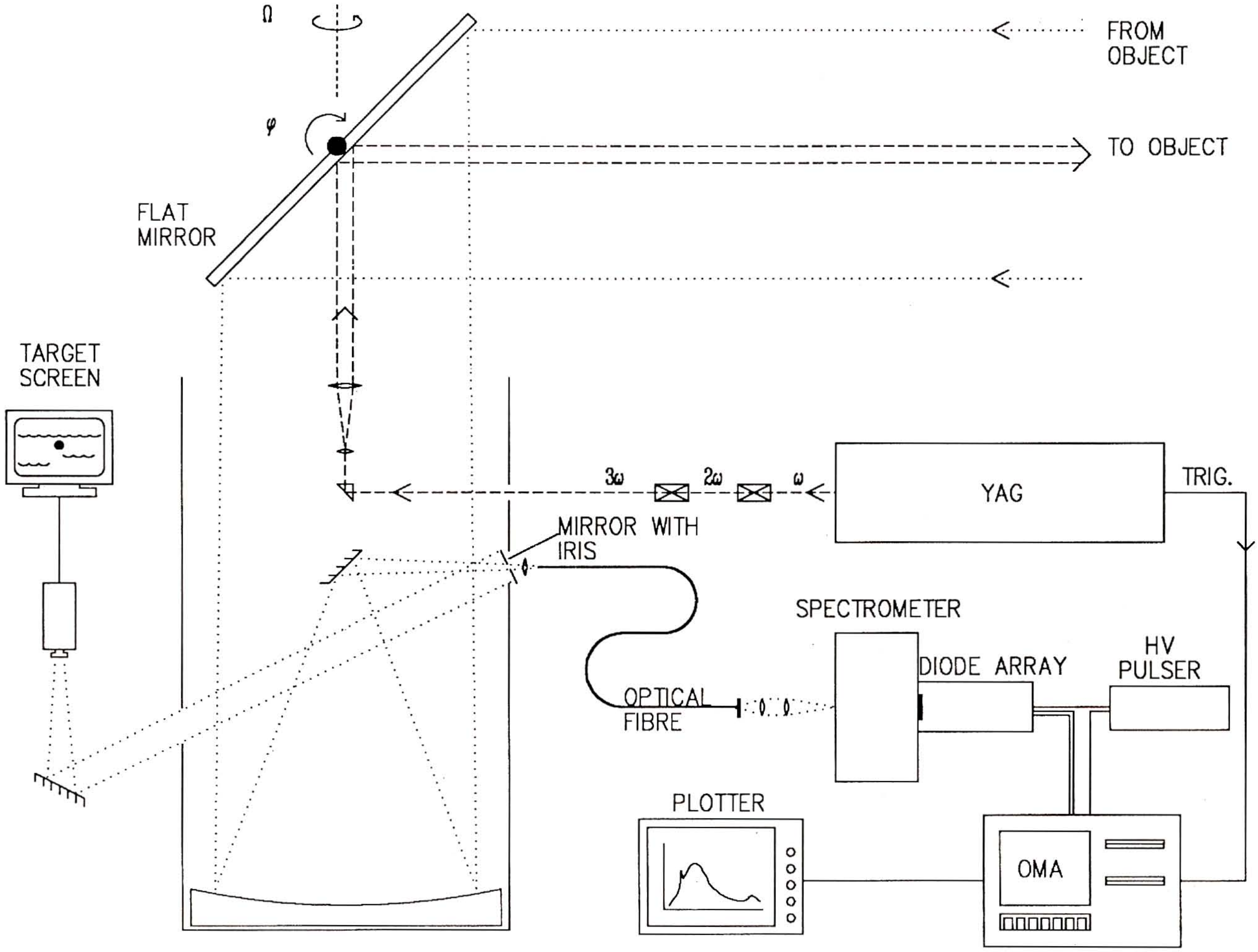

Fig. 2 - Schematic diagram of the fluorescence lidar system.

Although designed also for fluorosensing applications the system has previously mostly been used for atmospheric lidar work. The optical and electronic arrangements of the fluorosensor are shown in Fig.2.

A Continuum Model YG 682 Nd:YAG laser with a fundamental pulse energy of 1.2 J at a repetition frequency of 20 Hz was utilized. Pulses were frequency tripled to 355 nm, with output energies up to 250 mJ, before transmission via a beam expander and a large folding first surface aluminum mirror towards the water surface be studied. A further first surface mirror, mounted separated from the system on a heavy tripod was used to fold the light path tc achieve a larger angle of incidence (25-45°) on the river surface. For the distance telescope/water of about 40 meters chosen in the present experiments a laser output energy at 355 nm of about 25 or 60 mJ was used. Fluorescent light was guided back to a 40 cm diameter receiving telescope via the large folding mirrors. The light was focussed to the image plane of the telescope, where a polished streel plate reflected the light from the target area into a TV monitor. However, in the central part of the mirror a small hole was drilled to let the focussed fluorescence light pass into a 600m diameter quartz fibre, that was connected to an optical multichannel analyzer (OMA) system. The hole appears as a black spot on the TV monitor and is used for steering the system folding mirror under stepper motor control to the selected target. An input slit 400m wide was used in the spectrometer yielding a resolution of about 10 nm.

The system used for recording the fluoroscence is described by Andersson-Engels *et Al.* (1991). The quartz fibre is connected to the entrance slit of a Jarrel-Ash polychromator equipped with a 1024 elements EG&G PARC model 1421 intensified linear array detector. A Schott GG375 or GG40 coloured glass-filter was placed before the fibre to effectively suppress elastically scattered 355 nm light, that might otherwise have induced fluorescence in the fibre and /or overloaded the detector. Data recorded were read out to an EG&G model 1460 control unit and were stored on floppy disks. Spectral correction was provided using a spectrum of a calibrated reference tungsten lamp that was monitored at a distance through the same optical components. By gating the microchannel plate intensifier of the system to a 500 ns time window at the proper time delay, ambient light could be efficiently suppressed.

2. MEASUREMENTS

The Arno river is of vital importance for the whole area as a major source of water for drinking as well as irrigation. The river is regularly monitored by the Arno Basin Authority. Fluorescence lidar measurements were made at three locations along the Arno river is indicated in Fig. 3. Two sites were selected up and downstream of central Firenze (Varlungo and Isolotto), respectively. The third site was at the outlet of the river into the Tyrrhenian Sea at Bocca d'Arno.

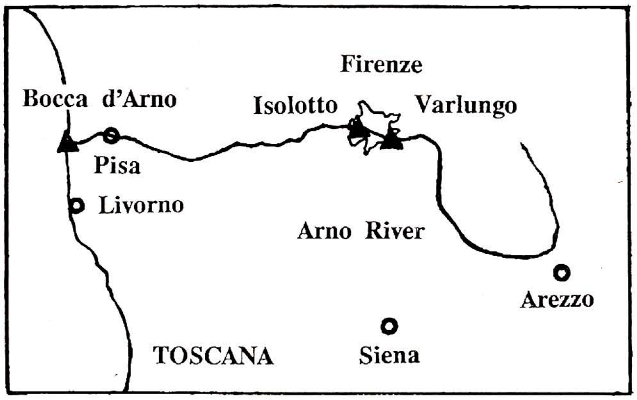

Fig. 3 - Map of part of Tuscany with Arno river and fluorescence lidar measuring sites indicated.

Remote fluorescence spectra were recorded by integrating the signal from typically 500 laser shots. Using the eparated folding mirror on the tripod target points at different distance from the river bank could be selected. Typical spectra from the three different locations are shown in Fig.4 The recording, that is spectrally corrected, shows three major features. In the blue-green region there is a broad, unstructured fluorescence distribution due to dispersed organic matter ("Gelbstoff") in the water. The signal provides a rough indicator of the degree of pollution in the water. Superimposed on this signal the O-H stretch Raman signal due to water can be seen at 404 nm matching the corresponding Raman shift of 3400 cm^{-1}. This signal provides a convenient built-in calibration, and provides a normalization to the volume of the water sampled by the laser pulse. In this way the influence of measurement distance, angle of incidence, pulse energy etc, is largely eliminated. Finally, a distinct peak at 690 nm can be seen originating from microscopic algae in the water mass.

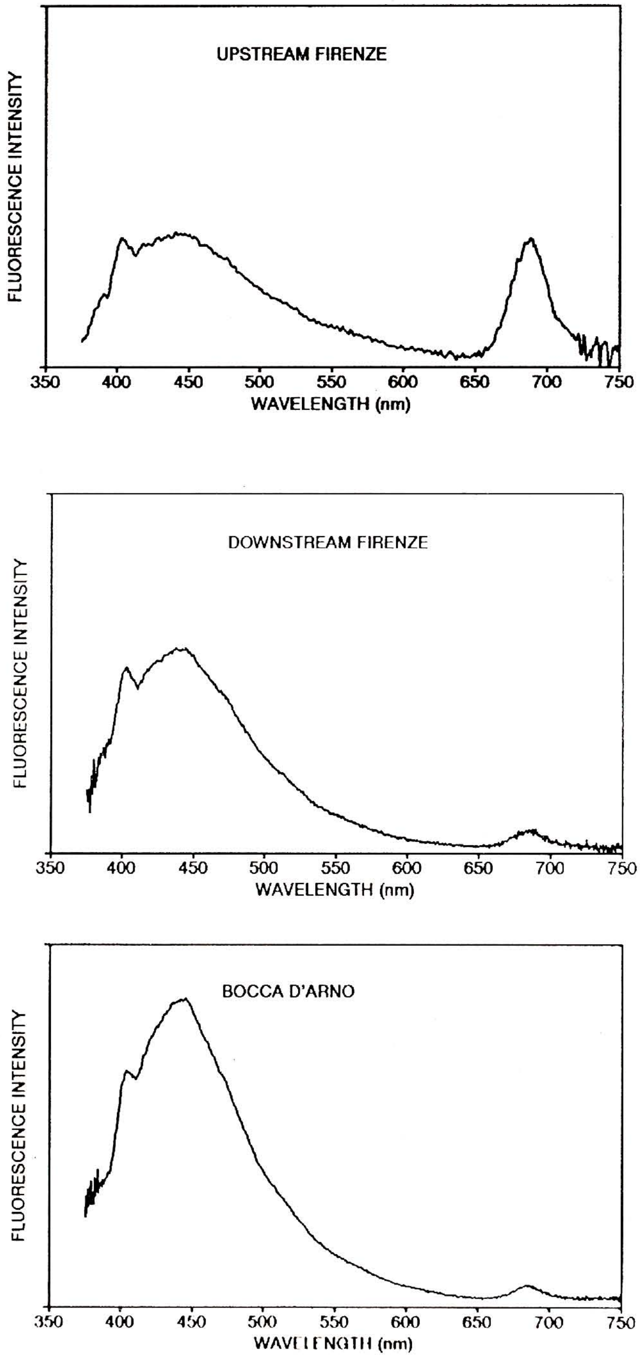

Fig. 4 - Typical fluorescence spectra of Arno river water at different locations measured at a distance of 40 m with the mobile system.

In the treatment of the data recorded at three different measurement sites the water Raman signal was first lifted off the gelbstoff fluorescence, and then the maximum Gelbstoff fluorescence intensity at about 445 nm and the background-free chlorophyll signal were normalized to the Raman signal. Data from the measurements are given in Fig.5 and Table I. The values are the mean ones from four spectra recorded at 3 different positions on the water surface. One standard deviation of the data is given.

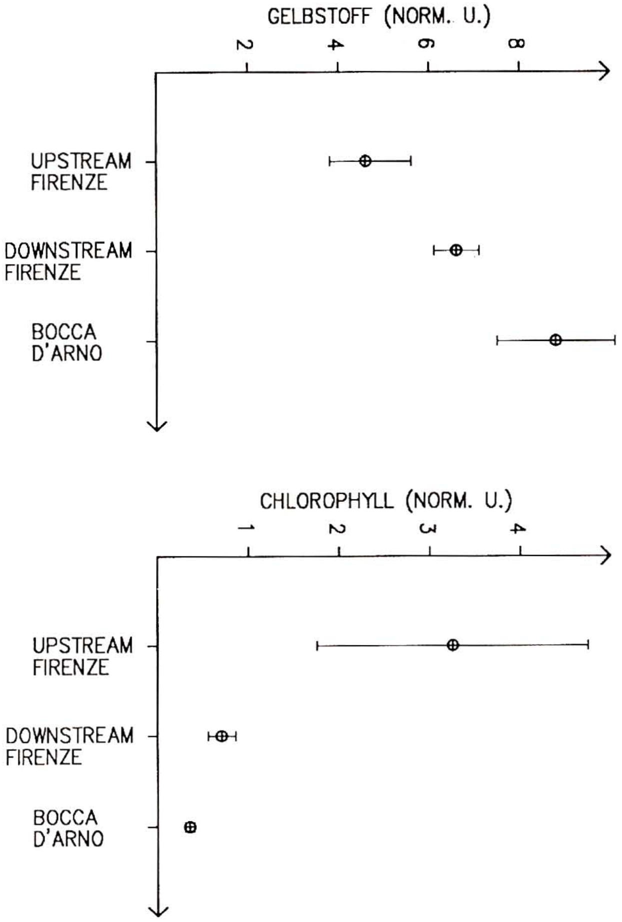

Fig. 5 - Diagram showing the fluorescence intensity of yellow substance and algal chlorophyll, both normalized on the water Raman signal, at the three different sites along the Arno river.

Table I. Ratios of fluorescence intensities evaluated from fluorescence lidar spectra recorded at three different locations along the Arno river. The selected wavelengths correspond to the O-H stretch Raman signal of H_2O (404 nm), Gelbstoff pollutants (445 nm) and algal chlorophyll (690 nm). Since the Raman signal is overlapping with the fluorescence background it is evaluated free-of-background for the ratio formation. The excitation wavelength was 355 nm.

Location	I(445 nm)/I(404 nm) (Gelbstoff, normalized)	I(690 nm)/I(404 nm) (Chlorophyll, norm.)
Upstream Firenze (Varlungo)	4.63(1.06)	3.24(1.52)
Downstream Firenze (Isolotto)	6.28(0.51)	0.672(0.127)
Estuary, Tyrrh. (Bocca d'Arno)	8.43(1.34)	0.377(0.066)

3. DISCUSSION

The present field test shows that useful remote fluorescence data from water can be obtained with the system described. The optical coupling between the receiving telescope and the detector system was presently made with a simple fibre, and could obviosly be improved by using a more elaborate optical system. The excitation wavelength used could be conveniently generated using solid-state laser technology. However, other excitation wavelengths could be considered. E.g., optimum excitation of the algal fluorescence would be at about 480 nm, that could easily be generated using the dye laser that is part of the mobile lidar system. Excitation with a XeCl laser at 308 nm (CECCHI *et Al.* 1989) is a further possibility, that like the tripled Nd:YAG provides eyesafe operation.

ACKNOWLEDGEMENTS

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