USING ACTIVE REMOTE SENSING TO ASSESS THE SEAWATER QUALITY

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Sistemele Lidar pot detecta compuşii fluorescenţi dintr-o coloană de apa, care sunt insesizabili utilizând alte metode. In acestă lucrare sunt prezentate primele rezultate obţinute în sondarea zonei costiere româneşti a Mării Negre utilizând un sitem bazat pe teledecţie activă. Sunt prezentate principiul de funcţionare si aplicaţiile unui sistem lidar de fluorescenţă destinat utilizării la bordul navelor de cercetare. Acurateţea datelor obţinute cu un astfel de sistem este dependentă atât de performanţele constructive cât şi de metodele de procesare. Pentru a identifica semnăturile spectrale specifice fiecărui compus organic sunt analizate mai multe tipuri de ape (apa de râu, apa de mare, apa curată, apa poluată).

*Laser remote sensing systems can detect the presence in water of fluorescent constituents that are not visible for other types of devices. The paper presents results obtained for the Romanian coastal zone of Black Sea for the first time using an active remote sensing system. The general principle of Lidar (**Li**ght **D**etection **a**nd **R**anging) detection and applications of a fluorescence ship borne system are discussed. The accuracy of the obtained information is dependent on the technical performances of the device and on the accuracy of the data processing method. Comparative analysis of the results obtained in the investigation of various water sources (river water, marine water, clean water, polluted water) is carried out in order to identify the specific fluorescence fingerprint.*

Keywords: fluorescence LIDAR, seawater pollution, chlorophyll detection

1. Introduction

A subject of great interest world-wide is the maintenance of environmental quality and, if possible, the rehabilitation of affected areas. Today, new technologies, which permit marine investigation from water surface to tens of meters depth, are available around the world [1, 2]. They can evidence and

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characterize pollutants and dissolved organic matters (DOM) which cause phenomena affecting the marine status. Laser remote sensing is one of these and is used in environmental monitoring for hydrological quality evaluation. The principal advantage of laser remote sensing is the possibility to obtain extensive information with high resolution from large water areas in real time. Up to now, studies using Lidar induced fluorescence were carried out in Italy, Russia, Estonia, in the Atlantic Ocean, the Pacific Ocean, the Adriatic Sea, the Baltic Sea, the Mediterranean Sea, and the North Sea [3-5]. These were focused on the distribution and temporal evaluation of phytoplankton, the pollution level estimation for marine waters and determination of hydrographical parameters.

The major goal of the paper is to reveal the contribution of LIDAR systems on water basins monitoring and to estimate the distribution of DOM and phytoplankton on Romanian Black Sea coastal zone during the spring of 2007 in order to assess the seawater quality in real time.

2. Black Sea campaign and Lidar data

The cruises were performed on April 2007 onboard the Istros vessel along Romanian Black Sea coast. Continuous LIDAR measurements were carried out on profiles 2 km long and physical-chemical water parameters as well as chlorophyll measurements on eight intermediate stations. The investigated area can be seen in fig. 1. Experimental data are divided in four areas having different human influences and degree of pollution:

- North Cap Midia – influenced by the Danube river and the northern seawater currents;
- Midia harbour – presumably a highly polluted zone and under river water influence;
- Mamaia gulf – considered as being influenced mainly by human activities;
- Constanta harbour presumably a highly polluted zone.

Physico-chemical parameters were evaluated for the surface waters for each profile at the sampling locations. Also standard chlorophyll concentration measurements were performed for each station in order to calibrate the LIDAR measurements.

The fluorescence Lidar system is a ship borne one, intended for remote online diagnostics of water and detection of a broad class of water pollutants: natural and anthropogenic, near surface and deep below surface, oil films on surface and emulsified oil water solutions, as well as the presence of phytoplankton. The operating principle is similar to radar, but instead of radio waves, laser light is used as sounding radiation. The optical field resulting from laser - medium interaction, which is the bearer of necessary information, is collected by means of a telescope and is analyzed [6]. The set up is sketched in fig. 2. It can remotely detect organic compounds, with a spatial resolution of 30 cm, using as sounding radiation the beam of an excimer laser (308 nm) and of a tunable dye laser (367, 460 nm). The short laser pulse is injected into the water after reflection on a mirror and the returned fluorescence radiation is brought back to the telescope via the same path. The system can provide rapid qualitative assessment of pollution presence in the studied area, without need to perform laboratory analysis of the samples. Without the mirror, the LIDAR can be used for direct remote probing of terrestrial targets at distances up to 50 m.

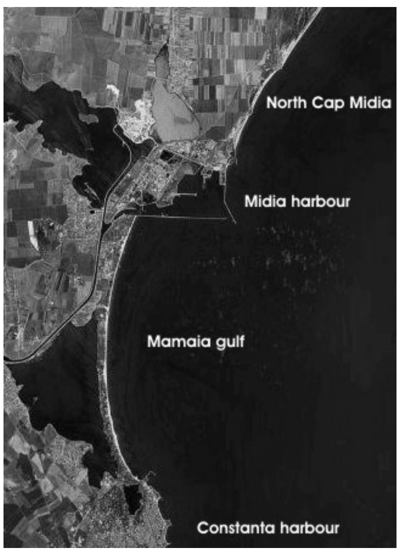

Fig. 1 Map of Romanian black sea cost – map of online monitoring

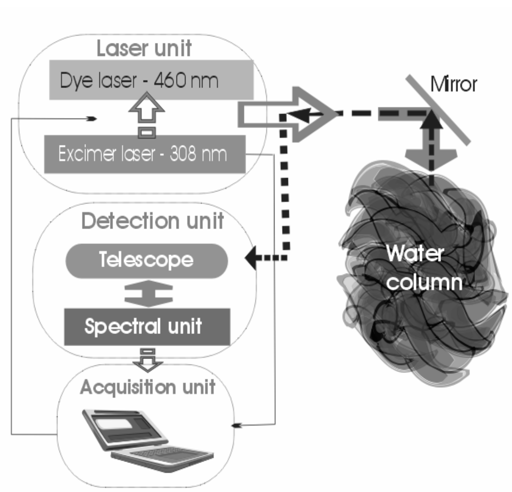

Fig. 2 Fluorescence LIDAR system the operating principle

Upon exposure to visible and UV laser radiation, Raman scattering of liquid water and fluorescence of phytoplankton chlorophyll, DOM and polluting anthropogenic components arise in the subsurface seawater layer. Though UV radiation excites quite efficiently the fluorescence its use is restricted because it cannot penetrate deeply into water. Visible radiation, mainly in the blue-green range, can penetrate into sea water to depths of a few tens of meters, however it excites less efficiently the chlorophyll fluorescence. This component of fluorescence cannot reach the surface from the water depth since its wavelength (about 680 nm) is very strongly absorbed by water. At the same time, it is well known that the chlorophyll (and phytoplankton) concentration changes with depth and most often has a maximum at a depth of 10–15 m.

3. Lidar equation

In the case of a pulsed, monostatic system, the intensity of the Lidar return signal [7, 8] is described by the Lidar equation:

$$\mathrm{d}I_{fl} = \mathrm{d}\Phi_{fl} R \frac{I_0}{x^2} e^{-(x-x')\left(\alpha_l + \alpha_{fl}\right)} \tag{1}$$

where $\mathrm{d}\Phi_{fl}$ represents the efficiency of the fluorescence process, R is a function which describes the system and medium characteristics, I_0 is the initial intensity, x-x' is the water depth where the signal has been excited, α is the attenuation coefficient and the subscripts l and fl describe the laser and the fluorescence wavelengths.

The efficiency of the fluorescence process is given by:

$$\mathrm{d}\Phi_{fl} = \mathrm{d}N_{fl}\sigma_{fl} = n_{fl}\sigma_{fl} S\mathrm{d}x \tag{2}$$

where $\mathrm{d}N_{fl}$ represents the fluorescent molecules number in a given water volume $V = S\mathrm{d}x$; n_{fl} is the concentration and σ_{fl} the fluorescence cross-section of the investigated molecules.

The fluorescence intensity corresponding to a water column between surface and depth z is given by:

$$I(z) = \int \mathrm{d}I = n_{fl} R I_0 \int_{x'}^{x'+z} \frac{1}{\left(x' + z\right)^2} e^{-\left(x - x'\right)\left(\alpha_l + \alpha_{fl}\right)} \mathrm{d}x \tag{3}$$

If we consider small z (a few cm) and $z \ll x'$ the fluorescence Lidar signal intensity can be calculated as [8]:

$$I(z) = n_{fl,z}\sigma_{fl,z} \frac{RI_0}{x'^2} \frac{1}{\alpha_l + \alpha_{fl}} \left(1 - e^{-z\left(\alpha_l + \alpha_{fl}\right)}\right) \tag{4}$$

In the case of a homogeneous water column, where the attenuation coefficient and fluorescence efficiency are constant, the intensity of the returned Lidar signal is considered proportional with concentration of the fluorescing molecule.

4. Results and discussion

LIDAR evaluation of water quality implies evaluation of the main water components by its spectral fluorescence fingerprint: phytoplankton, dissolved organic matter and petroleum products. A typical fluorescence signal for 308nm excitation contains three peaks: the peaks at 308 and 344 nm are due to elastic scattering and water Raman scattering while the intense band with maximum around 450 nm corresponds to the DOM presence (fig.3). The Raman scattering of water molecules presents a distinct peak shifted by a wave number interval of 3400 cm^{-1} with respect to the excitation line [9, 10]. In the case of oil products presence another less intense band below 400 nm or above 550 nm reveal the light oil and respectively the heavy oil presence. Fig. 3 presents a Lidar spectrum specific for 308 nm wavelength excitation for a clean seawater column.

The chlorophyll distribution can be evaluated using 460 nm excitation wavelength. Two fluorescence maxima are observed as shown in Fig.4: the Raman band mixed with blue-green fluorescence and the chlorophyll (at 685 nm). The water turbidity can be evaluated from the Raman signal. If the amount of particle in suspension on water column has important values the water transparency is very low. A bigger Raman signal corresponds to clean and transparent seawater.

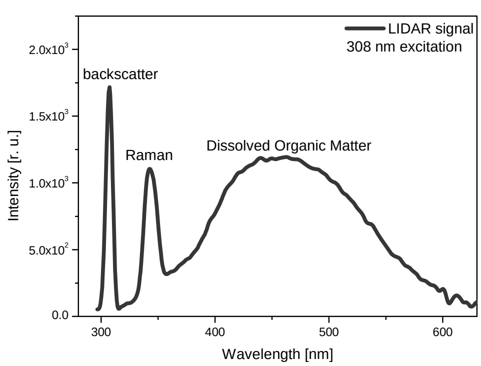

Fig. 3 Lidar signal for 308 nm excitation wavelength

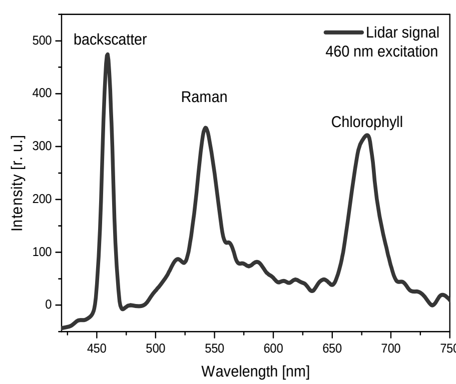

Fig. 4 Lidar signal for 460 nm excitation wavelength

The Lidar signal processing means to look at the fluorescence spectra and identify the various contributions. This is the simplest way of interpreting a fluorescence signal. A most complex evaluation of components includes an existing database and software designed to split the signals into the spectral components corresponding to signatures of each organic compound or maximum: scattering of laser line, Raman band, oil products, organic matter and second harmonics of laser etc (fig. 5). The split signals are considered standard and the new signals are compared with those revealing coefficients corresponding to relative concentrations.

Another approach in Lidar signal processing consists in computing the difference between two signals on the same spectral interval. The first signal is a well known one and the second is the measured one, which has unknown composition. Figure 6 shows such signals; the difference was performed in order to extract the petroleum products contributions. The polluted spectra represent the status of Constanta and Midia harbors in spring time.

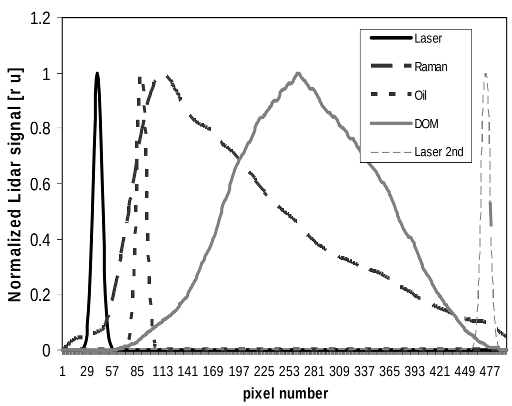

Fig. 5 LIDAR spectra decomposition

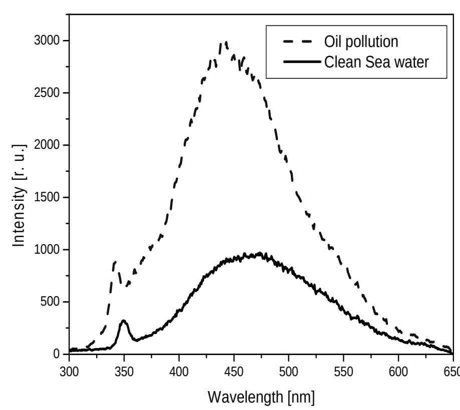

Fig. 6 Oil pollution Lidar spectra

Dissolved organic matter represents a complex mixture of organic molecules. The sources of DOM are extra cellular release of organic matter by algae, release by zooplankton, bacteria and algae cells decomposition and release from sediments [11]. The Lidar technique is a useful tool to identify the mixing of different types of water, an intuitive example is the mixing of the Danube river water with Black Sea water, in the North Midia proximity. As it can be seen in fig. 7 the shape of DOM fluorescence fingerprint have other features for the sea and the river. In the case of river water an intense and large maximum is expected, unlike the narrow maximum specific for clean open sea water.

The active remote sensing investigation on the Black Sea Romanian coast revealed an almost constant concentration of DOM, higher values were recorded in harbours due to the influence of river and wastewater discharges.

The phytoplankton blooming during the present measurement campaign was significant in harbours due to the absence of water currents and to the nutrients abundance. In the open sea the chlorophyll quantities are 10 times smaller than in the harbours. In the four selected areas differences between chlorophyll concentrations can be observed: the gulfs have the same behaviour with small quantities while Constanta and Midia zones presented very significant levels. The chlorophyll concentration, an indicator of phytoplankton presence, is proportional with the oxygen concentration and depends on the ph values.

The Lidar and laboratory measurements are in good agreement, the advantage of the remote evaluation consisting in the possibility to detect punctual fluctuations.

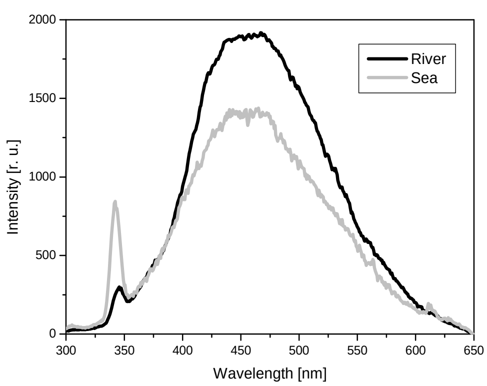

Fig. 7 DOM fingerprint for River and sea water

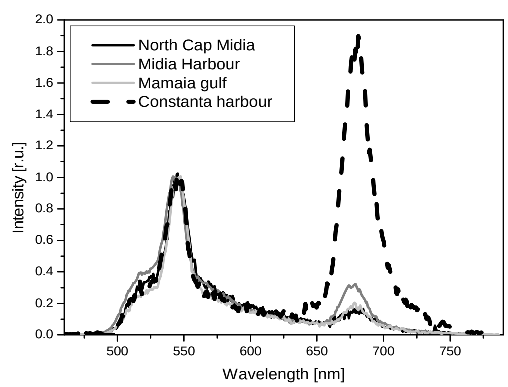

Fig. 8 Chlorophyll distributions on four areas

6. Conclusions

Lidar systems can be very useful in environmental investigations, especially of the open water basins, due to the large covered area and the real time response. The accuracy of obtained information is dependent on the technical performances of the device and on the sensitivity of the data processing method.

Lidar data on the parameters of seawater are in agreement with the results of laboratory measurements. The major quantity of phytoplankton was depicted in harbor locations. In the open sea the chlorophyll quantities are 10 times smaller than in the harbor.

In 2007 springtime the DOM distributions were constant along the Romanian Black sea coastal zone. As expected, significant DOM values were observed in areas under human influences.

Processed Lidar signals are useful in hydrocarbon pollution identification and the extent of spills areas.

The most important benefits of active remote sensing techniques are the possibility of sensing in the depth of water columns in real time and the possibility to determine the anthropogenic and rivers influences.

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