Papers

A water Raman extinction lidar system for detecting thin oil spills: preliminary results of field tests*

OCEANOLOGIA, 40 (1), 1998.
pp. 3–10.

KEYWORDS
Lidar
Remote sensing
Oil spills

Jacek Piskozub,
Violetta Drozdowska,
Mirosław Irczuk
Institute of Oceanology,
Polish Academy of Sciences,
Sopot

Manuscript received January 23, 1998, in final form February 26, 1998.

Abstract

A new FLS–UV lidar system using the extinction of the laser-induced water Raman signal for detecting thin oil slicks on the sea surface was employed. The system uses a solid state laser with frequency multiplication and an array of photomultipliers to measure oil film thicknesses in the 0.5–10 μm range. The system was tested during two cruises of r/v 'Oceania' in the southern Baltic in May and September 1997. The first experimental results are presented and the system's possibilities and limitations are discussed.

1. Introduction

The detection of oil and oil product spills on a water surface is a subject of great importance for the environmental protection of coastal sea basins as well as navigable rivers and lakes. During the last 20 years several methods of oil slick detection have been developed. While the classical optical ones employ still and video photography, more advanced versions use spectral filters and the Brewster angle to increase the contrast (Fingas *et al.*,

* This work was funded by the Polish State Committee for Scientific Research, grant No. PB 983/PO4/95/08.

1994). However, oil spreading over a water surface has no specific spectral characteristics in the visible range of the spectrum to distinguish it from the seawater (Hoge and Swift, 1983). The signal received from an irradiated sea surface is due both to the oil layer and to the substances dissolved in the seawater. This means that oil spills are visible mostly because of the difference in capillary wave amplitude caused by the difference in surface tension. This condition sets limits to the method, rendering it susceptible to error due to the reflection of sunlight, local wind variations, seaweed and shallow water. Since capillary waves are also subject to damping, radar methods are only applicable at wind speeds between 1.5 and 6 m s^{-1} (Fingas and Brown, 1997).

A more promising oil film detection technique is the use of infrared sensors. This method is based on the different absorption and emission properties of oil and water in the IR range. It can be employed during the day or at night except during short periods after sunrise and sunset when the temperatures of an oil spill and the surrounding water are identical. However, this method has the drawback that it can only detect spills at least 10–70 μm thick (Fingas *et al.*, 1994). Another interesting technique of detecting an oil film on water and measuring its thickness is the laser acoustic method (Brown *et al.*, 1994), in which the oil layer is heated by an IR laser. In this process, acoustic waves are produced which can be detected by using another laser and an interferometer. The thickness of the oil film can be calculated from the frequency of the standing wave in the oil layer. However, this technique is inherently complicated and no operational system based on this principle has yet been developed (Fingas and Brown, 1997).

Some of the most promising methods of oil spill detection are lidar methods. A technique that not only enables the remote detection of oil spills but also the differentiation of oil types is laser fluorosensing (Hengstermann and Reuter, 1990; Brown *et al.*, 1996). This method employs a laser source inducing fluorescence in the oil (usually at 300–340 nm) and a spectral receiver (most frequently CCD) recording the oil fluorescence emission bands in the 400–650 nm region (Camagni *et al.*, 1991).

All the methods described above permit the detection of oil slicks at least a few micrometres thick. However, the only method that allows the oil film thickness to be estimated below this range is the Raman band attenuation method. This technique uses the suppression of the Raman seawater backscatter signal in the oil film. The calculation of the film thickness requires a knowledge of the attenuation coefficients of seawater at the laser and Raman wavelengths. Also required are the extinction coefficients of the oil at the laser and Raman wavelengths. This is important as 'no reliable methods (of measuring oil spill thickness) exist, even in the laboratory' (Fingas and

Brown, 1997). Any such reliable method, such as the proposed laser acoustic one, can at present only be a theoretical proposition. Moreover, the Raman band attenuation lidar has been suggested in the literature several times (Hoge and Swift, 1980; Burlamacchi *et al.*, 1983), but up till now no devices of exactly this kind have been built. This paper presents our first results of field tests of an operational lidar system using the Raman band attenuation technique for very thin oil films.

2. Materials and methods

An FL–UV lidar system built by Laser Diagnostic Instruments Ltd., Tallinn, Estonia, was used in this study. The device[1] is a prototype built for the Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland. The technical data and operating formulae used to calculate the oil film thickness have already been presented by Piskozub *et al.* (1997).

The system measures the thickness of an oil slick by the extinction of the laser-induced Raman scattering light of the water column below the oil slick. The laser wavelength chosen (299 nm) was the most suitable for measuring thin oil films (Piskozub *et al.*, 1997). This wavelength is generated using a 299–YAG laser (the fourth harmonic of 1062 nm, equal to 266 nm, was converted to 299 nm with a Raman gas vessel with H_2 at 100 atm. pressure, 1 mJ energy per pulse). The output energy of the laser is measured for every pulse, as is the backscattered signal at the peak of the Raman band and at two wavelengths off the peak. These data, together with the distance from the lidar to the sea surface, enable the Raman band intensity to be calculated. Therefore, by applying the Beer–Lambert law it is possible to calculate the oil film thickness if the extinction coefficients of the oily substance on the sea surface at the laser and Raman band wavelengths are known. If not, as is often the case, the system yields only the relative thickness of the oil slick. The distance to the sea surface is assumed constant when the lidar is used from a ship. This allows for the auto-calibration of the 0 μm value of the oil film thickness on the assumption that the smallest measured value represents the clean water response, *i.e.* with no oil on the surface. Typical values of absorption coefficients of oils in the 300–350 nm spectral region lie within the 0.2–0.8 μm^{-1} range. The measuring range of the oil film thickness is about 0–10 μm (thicker slicks would virtually block the returning UV radiation). Films in this thickness range are measured *in situ* by this technique. In the measurements described in this paper, a value

[1] The purchase was funded by the Polish State Committee for Scientific Research, grant No. PB 983/PO4/95/08.

of 0.5 μm^{-1}, typical of crude oils, was used as the average value of absorption coefficients for the laser and Raman wavelengths.

The FL–UV lidar system was tested during two cruises of r/v 'Oceania' in the Gulf of Gdańsk and the adjacent southern Baltic on 19–26 May and 10–19 September 1997. The system was mounted 3 m above the sea surface on a 2 m boom overhanging the ship's side about 10 m forward of the stern. The backscattering signal was transmitted to the receiving unit in the ship's laboratory via an optical fibre. The data were recorded by a PC computer controlling the measurement process.

3. Results and discussion

The first tests of the lidar–UV at sea have shown that the system is sensitive to the presence of foam on the sea surface. This means that it cannot be used in rough seas. Moreover, on both cruises the lidar was attached to a temporary boom so that it would be suspended over the water. This location was chosen in view of the proximity of a dry laboratory; this helped to protect the optical fibre from accidental damage. However, as it was exposed to high waves, the system could work only when the ship's speed did not exceed 3 knots. Therefore, most of the measurements were done at measurement stations when the ship was drifting or at anchor. Extreme care was taken to ensure that no ship producing traces of oil entered the field of visibility of the system and that there was no foam present in the vicinity.

Fig. 1 shows the measurements made at a station close to the Hel Peninsula at the entrance to Puck Bay (54°35′N, 18°44′E) on 14 September 1997. The ship was anchored within a current leaving the bay which, besides accommodating the commercial port of Gdynia, is also an area of heavy shipping and fishing activity. Every measurement consisted of about 40–50 pulses in order to minimise the statistical error. Tests showed that further increasing the number of pulses did not reduce the statistical error. It may be seen from the graph that the average value was usually not significantly larger than one standard deviation. The authors believe this was due to the extreme patchiness of the oil film: every series contained a large number of readings close to zero film thickness. The readings taken at this station show clear trends in the average thickness of the film: there were local maxima of the measured value around 10:00, 12:00 and 18:00 hrs. All that day no large slicks could be observed with the naked eye.

The results presented here ought to be considered qualitatively. The actual film absorption coefficients at the wavelengths used were not known – it is very difficult to take samples of films that thin. This makes these values unreliable by a factor of about 30%; moreover, they can vary during the day. If the source of the pollution was known, laboratory measurements

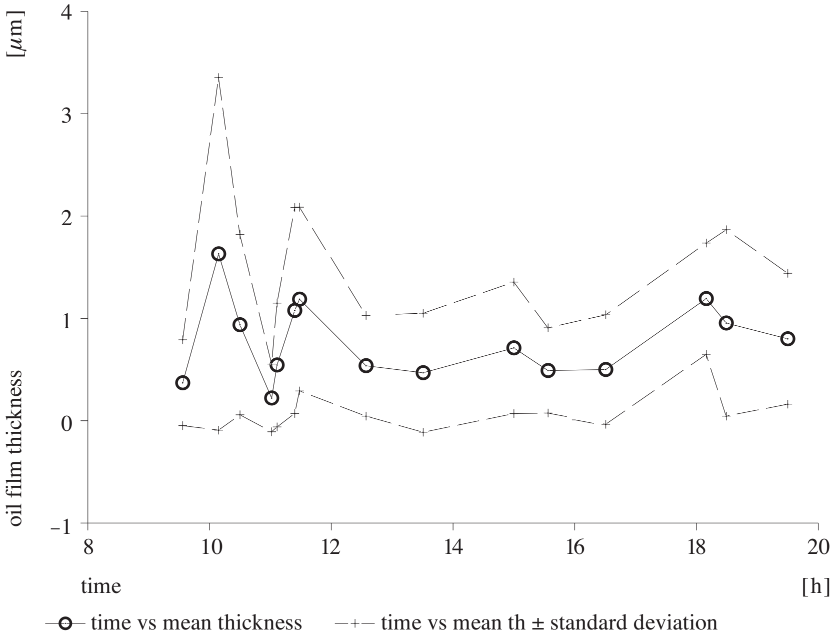

Fig. 1. Time series of oil film thickness measurements (with standard deviations shown) at an anchored station (54°35′N, 18°44′E) on 14 September 1997

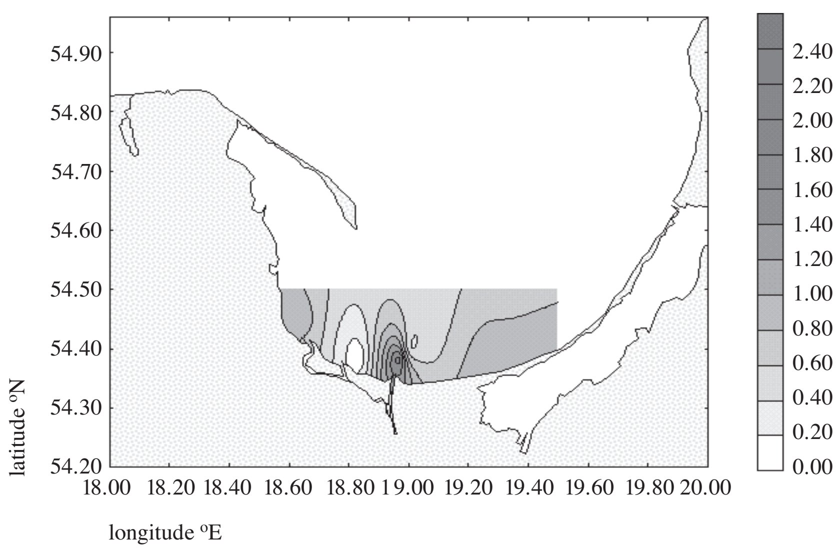

Fig. 2. A map of oil film thicknesses [μm] in the southern Gulf of Gdańsk off the mouth of the river Vistula measured on 22–25 May 1997

would permit the absorption to be determined. As mentioned above, there are no systems capable of accurately measuring the thickness of thin films on the sea surface if the type of oil is unknown. Secondly, accurate calibration of the system is impossible at the present time. The best available approximation was to calibrate the lidar in the laboratory with accurate hand-made films made from small amounts of oils dissolved in acetone (Piskozub *et al.*, 1997).

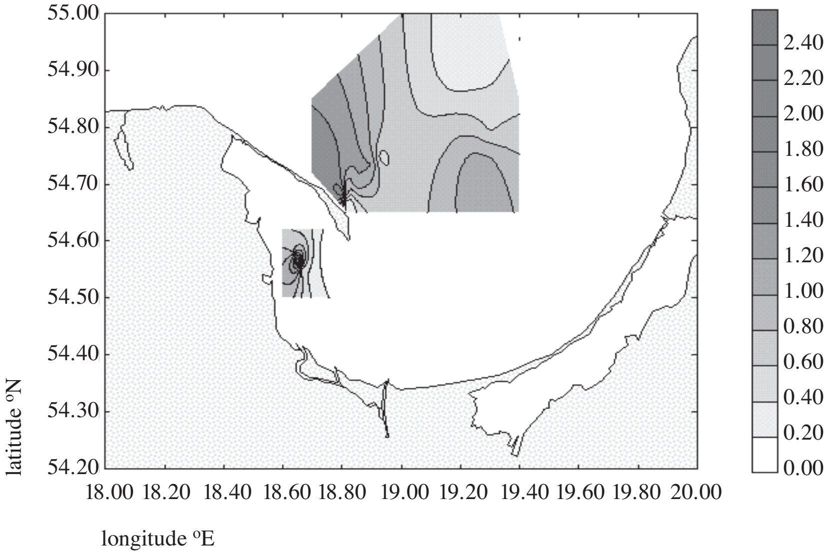

Fig. 3. A map of oil film thicknesses [μm] in parts of the Gulf of Gdańsk and Puck Bay measured on 14–16 September 1997

The map in Fig. 2 gives the readings taken near the mouth of the river Vistula on 22–25 May 1997. They clearly show the effect of the river water carrying some oil pollution into the Gulf of Gdańsk. Similarly, Fig. 3 gives the readings taken on either side of the Hel Peninsula on 14–16 September. The distinct difference in values between Puck Bay south of the peninsula and the open water north of it is clear: the values tend to fall, the further away from Puck Bay and the shipping lanes along the Hel Peninsula they were measured.

4. Conclusions

The FL–V lidar system is capable of detecting thin oil films in the 0.5–10 μm thickness range. The problem lies in the precise calibration of the system, because samples of the polluting substance are not available for laboratory measurements.

The lidar system could be more useful if continuous measurements were possible. This would require some changes in its design (a faster pulse frequency) and placing it on a long boom overhanging the ship's bows or making measurements from a helicopter flying high enough not to disturb the foam on the sea surface. But in either case, precise measurement of altitude over the sea surface would be necessary.

Initial results show that most of the coastal waters in and near the Gulf of Gdańsk are covered with a thin film of oil. This is probably very patchy, possibly because it is constantly being broken up by the wind and surface waves. The film becomes thicker in the vicinity of ports and shipping routes, and at the mouth of the Vistula, which are pointers to the probable origin of the pollution. More comprehensive results, however, will be possible only with more research: in particular, measurements need to be made at different seasons and with various wind directions.

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