Elimination of the surface background in contactless sea investigations

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Remote sensing

JERZY OLSZEWSKI, MACIEJ SOKÓLSKI
Institute of Oceanology,
Polish Academy of Sciences,
Sopot

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Abstract

A method of surface background elimination in contactless optical investigations of the marine environment has been developed and checked under natural conditions. The method utilizes the properties of the time course of upward radiance changes over a waving sea surface, enabling momentary cutting off of the surface reflected radiance with a black screen. It has been established that the method is very efficient and enables the determination of the radiance from below the surface during a normal motion of a vessel under moderate hydrometeorological conditions.

1. Introduction

The necessity of elimination of the background formed by the surface reflected radiance constitutes a serious problem in remote passive detection of the optical properties of the marine environment. Majority of methods of such an elimination consists in a theoretical evaluation of the background, which requires the knowledge of the characteristics of the field of light falling onto the sea surface and of the state of the surface (Olszewski, 1981). The mentioned characteristics are usually obtained also by theoretical modelling, possibly aided empirically. In the case of the investigations carried out from large altitudes, *e.g.* from satellites or planes, the described procedure seems to be the only practical method of the background elimination.

New possibilities arise when the determination is performed from a low altitude, *e.g.* from the board of a sailing vessel or from a low-flying

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helicopter. Presented below are such possibilities, resulting from the analysis of the time course of the process of interaction of the light field with a waving sea surface (Lommatzsch, 1989).

2. General assumptions of the proposed method

It has already been mentioned that new possibilities of the surface background reduction arise when the determination of the upward radiance flux over the sea is carried out from altitudes comparable with the length of the surface waves. Using a suitably designed instrumentation it is possible in this case to observe the time variations of the state of the observed fragment of the sea surface and to carry out the measurements in moments favouring the elimination of the background. At a sufficiently low sight angle of the upward radiance meter, limiting the field of view of the water surface to the dimensions much smaller than the wavelength, this will be the moments in which the observed fragment has an almost horizontal position. In such a situation both the sky region from which the reflected radiance origins, *i.e.* the surroundings of the zenith, and the incidence and reflection angles of this radiance, close to 0^o, can be very accurately determined.

Natural properties of water surface, for which the equilibrium state is the horizontal position, as well as all the statistical distributions used for the description of the state of the surface indicate that the mentioned position must occur much more frequently and last for a longer time than any other orientation of the surface elements. Small deviations of the most probable orientations from the level can occur only under steady conditions of a heavy wind, yet these deviations never exceed a few degrees (Cox and Munk, 1954). Therefore it is sufficient to synchronously record the radiance from the small cone round the zenith reaching the surface to achieve a much greater accuracy of the calculations of the reflected radiance than in any other situation.

Now they are the purely technical problems that have to be solved. The most difficult ones are the achievement of the suitable sight angles of the upward and downward radiance meters, the assurance or signalling of the vertical orientation of their optical axes, minimization of the dimensions of the meter observing the surface so that it does not intercept the incident light, and the development of a data recording system recognizing the moments when the surface is level, *e.g.* by their longer duration.

Most of these technical difficulties can be overcome by applying a modified version of this method.

3. Practical solution of the background elimination problem

The general principle of the proposed method consists in total elimination of the downward radiance falling from the cone around the optical axis of the upward radiance meter by means of a black screen connected to the meter.. This yields several significant advantages:

1. A direct, almost complete reduction of the surface reflected radiance is achieved;
2. The necessity of the synchronous measurement of the downward radiance is eliminated;
3. Maintenance of the vertical position of the optical axis is less critical – it is only important that this axis is from time to time perpendicular to a possibly flat, and not necessarily level fragment of the water surface;
4. The moments of the total background elimination are found through the observation of the minima of the time course of the upward radiance.

The principle of the method is illustrated in Figure 1. The analysis of the presented geometry of the measurement allows to establish the following dependence between the diameter of the screen d, its distance from the water surface h, sight angle of the meter v and the maximum allowable wave slope γ:

$$d = 2h[tg(2\gamma + v) + tgv]. \qquad (1)$$

At the assumed boundary slope of the water surface during the measurment and at the fixed sight angle of the meter, the diameter of the screen and its distance from the water surface are proportional to each other.

Figure 1 and equation (1) do not directly reveal one more important parameter, *viz.* the area of the observed water surface. This is due to an idealization of the state of the surface in Figure 1, corresponding to a lack of capillary waves. Under the real wind conditions the centimeter capillary waves visible as tiny ripples are superimposed on longer waves.

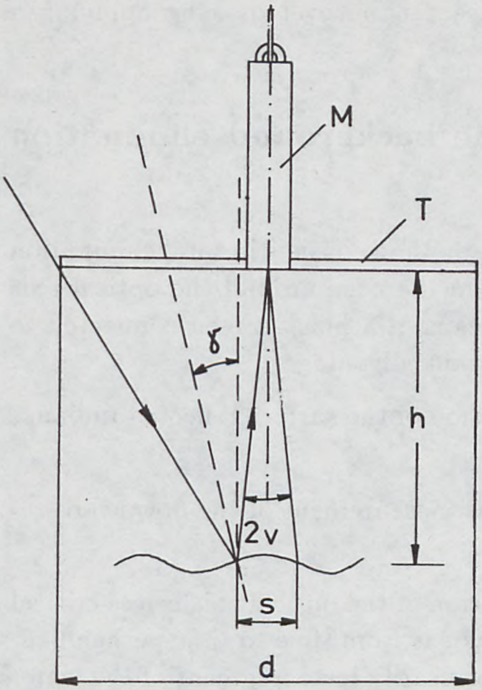

Figure 1: An outline of the geometry of upward radiance measurement above the sea surface: M – radiance meter, T – black screen, h – distance between the screen and the water surface, s – diameter of the observed fragment of the water surface, v – sight angle of the meter, γ – slope of the wave

The slopes of the capillary waves can be large with quite a high probability. In practice during such a measurement the meter sees simultaneously a number of capillary wave slopes of different inclination. It has been experimentally established that in order to keep all the visible slopes within the acceptable limits the field of view of the radiance meter should not be greater than a few cm^2 of the water surface.

Experiments have been carried out in order to confirm the above presented assumptions. Two types of radiance meters constructed in the Institute of Oceanology of the Polish Academy of Sciences have been used in the experiments:

- a two-channel meter of the sight angle $v = 5^o$, measuring the upward radiance in the 450 and 520 nm bands;
- an eight-channel meter of the sight angle $v = 0.3^o$, measuring the

radiance succesively in 8 spectral bands: 400, 425, 465, 520, 535, 580, 620 and 680 nm.

Both the meters were characterized by a short time constant on the order of 10 ms.

The two-channel meter was equipped with a black screen of the diameter $d = 0.6$ m fastened at the level of the optical diaphragm and was hung at a distance $h = 0.7$ m from the water surface. Upward radiance was recorded simultaneously in both the spectral channels and normalized with respect to the downward irradiance measured simultaneously in the same spectral ranges. The experiments have been carried out aboard an anchored vessel on a cloudless day, the sun being ca 40^0 above the horizon and the state of the sea being 1–2. A measurement without the screen has been also performed under the same conditions. For this purpose the meter was immersed in such a way that its optical diaphragm was immersed from time to time directly below the water surface. The aim of the experiment was to prove that the results obtained with a meter equipped with the screen and kept above the water surface are similar to that obtained from measurements directly below the surface. The optical parameter known as the colour index (Jerlov, 1974) has been chosen for the comparisons. This parameter is defined as the ratio of the upward 450 and 520 nm radiance. The results are illustrated in Figure 2. The upper part of the Figure presents the time course of the 450 nm upward radiance recorded with the screen. Two distinct minima are clearly seen in this course. The minima of the 520 nm radiance occurred in the same moments, as well as the minima of the colour index, which is illustrated in the middle part of the Figure. The value of the colour index in these moments is 0.76 and is similar to the value obtained in the moments when the meter without the screen was immersed in water. This is illustrated in the lower part of the Figure, where the time course of the colour index obtained without the screen is superimposed on the course obtained with the screen.

Even more convincing effects have been obtained with the eight-channel, narrow-angle radiance meter. The measurements have been carried out from the bow of an anchored vessel, using a screen of the diameter $d = 2$ m hung at a distance $h = 3$ m above the surface. The state of the sea was 3, the sky was partly covered with clouds, and the sun was obscured by clouds. The course of the upward radiance was recorded

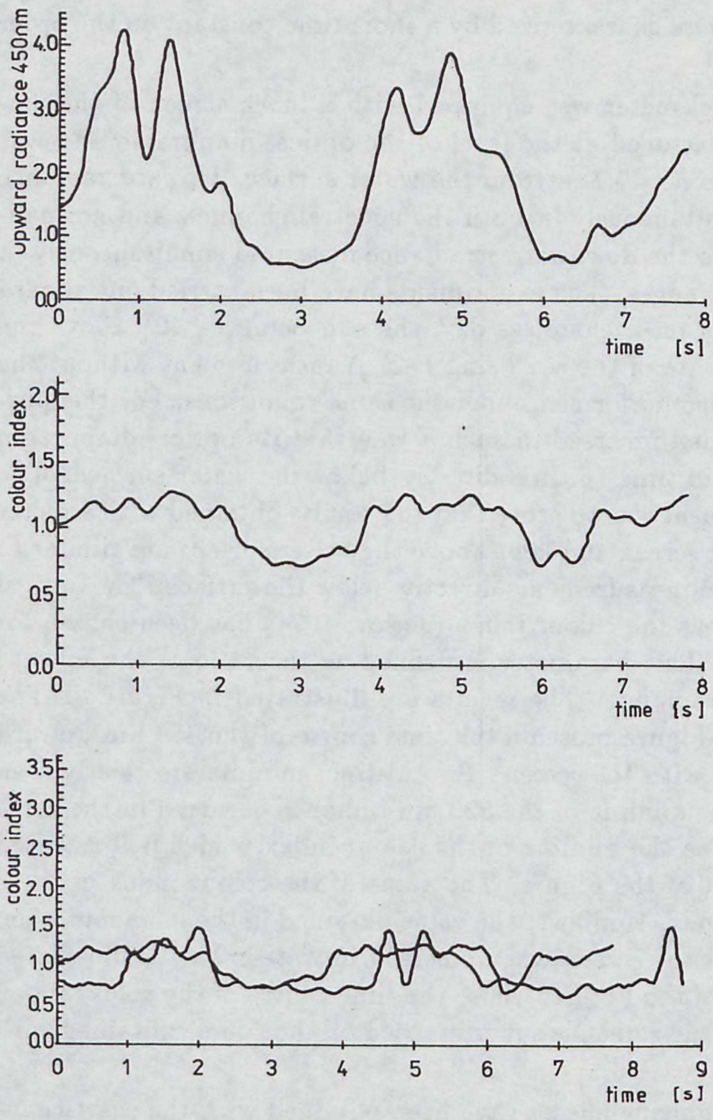

Figure 2: Example of the time course of the upward radiance: Baltic Sea, 54°57.3'N, 18°24.9'E, 1989.05.10, 0820 GMT; $v = 5°$, $d = 0.6\ m$, $h = 0.7\ m$. Upper part: upward radiance LU in the 450 nm band above the sea surface (in relative units). Middle part: colour index [LU(450 nm)/LU(520 nm)] above the water surface. Lower part: colour index above and directly below the surface

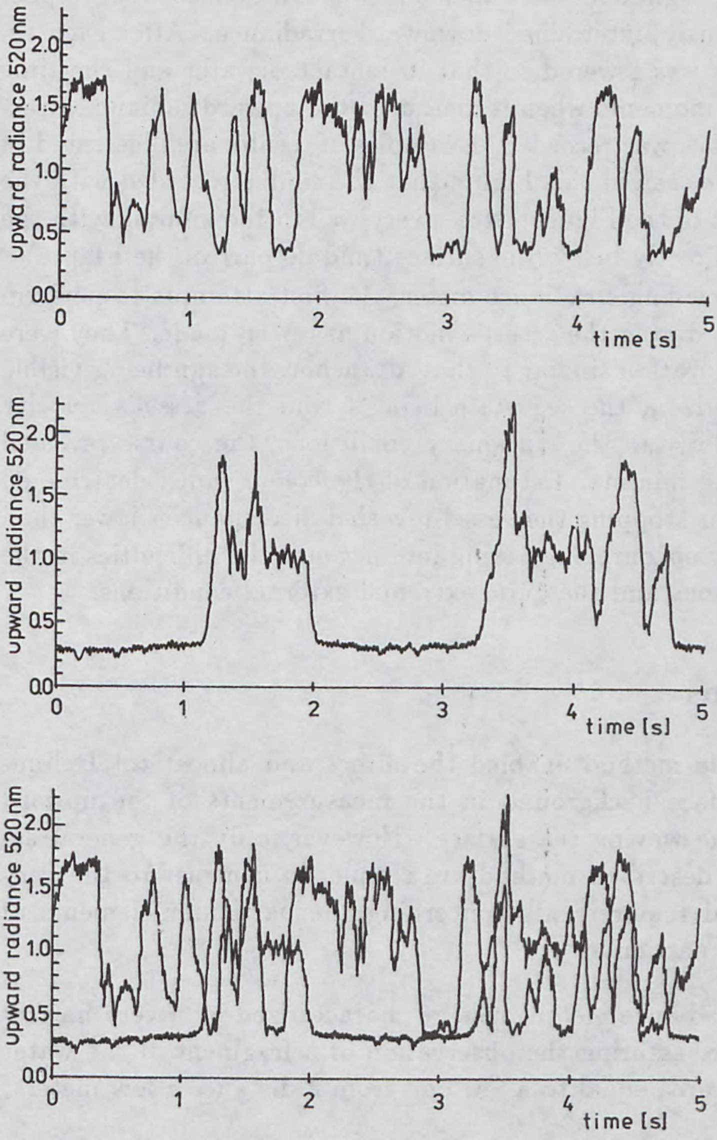

Figure 3: Example of the time course of the upward radiance: Baltic Sea, 54°35.0'N, 18°40.0'E, 1989.06.20, 1330 GMT; $v = 0.3°$, $d = 2\ m$, $h = 3\ m$. Upper part: upward radiance LU (520 nm) above the sea surface. Middle part: upward radiance LU (520 nm) directly below the surface. Lower part: the course of both the radiances (all the diagrams in the same relative units)

successively in the eight spectral bands and was normalized with respect to the simultaneously determined downward irradiance. After each recording the meter was lowered so that it contacted water and the time course containing moments when it measured the upward radiance directly below the surface was recorded. Examples of results are illustrated in Figure 3. It can be seen in this Figure that the course recorded with the screen (upper part of the Figure) agrees very well in the minima with the results obtained directly below the surface (middle part of the Figure).

Using the narrow angle radiance meter, the first attempts to perform the measurements during the vessel's motion has been made. They were carried in a configuration similar to that at anchor, the sun being visible 40^{o} above the horizon, the sea state being 5 and the vessel's velocity ca 8 knots. Similarly to the stationary conditions, the course revealed distinct and strong minima. Estimation of the colour index determined in motion and after stopping the vessel revealed discrepancies lower than 35%, which is very encouraging taking into account the difficulties in the accurate comparisons and the quite extremal external conditions.

4. Conclusions

A relatively simple method enabled the direct and almost total elimination of the surface background in the measurements of the upward radiance above the waving sea surface. However, only the general assumptions of the described method are simple, in contrast to the very stringent technical requirements concerning the particular elements of the apparatus. In particular:

- the upward radiance meter must be characterized by a very narrow opening angle, assuring the observation of a fragment of the water surface of an area equal to a few cm^2 from a distance a few meters;
- due to the strict limitation of the sight angle the applied detector must be very sensitive; till now, only the photomultipliers coupled with highclass electronics meet this requirement;
- the electronic circuit of signal acquisition and recording must be very fast, of the time constant on the order a few ms, since only in this case there is a possibility of utilizing every moment promoting the proper measurement even at relatively high speeds of the vessel;

- the screen eliminating the background should be placed in front of the vessel's bow and should have a diameter on the order of 2/3 of the distance from the water surface. At the same time it should not create any danger to the measuring set even under difficult hydrometeorological conditions;
- the measurement should be carried out in at least two wavelenght ranges, best of all simultaneously, since monochromatic measurements basically have no practical value;
- simultaneous recording of the downward irradiance is necessary in order to allow for the variability of the external illumination conditions.

Meeting these requirements enables a contactless "entry" below the water surface during a normal motion of the vessel, except for the extreme hydrometeorological conditions, endangering the apparatus. It is also possible to perform the measurements from a helicopter flying at a low altitude. The fuselage of the helicopter could serve as quite a large screen.

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