Measurements of Wave-Induced Fluctuations in Underwater Radiance under Various Surface Boundary Conditions

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LONG-TERM GOALS

This project is part of Radiance in a Dynamic Ocean (RaDyO) program which aims at developing a comprehensive understanding of variability in the underwater radiance distribution and its relation to dynamic processes within the ocean-atmosphere boundary layer.

OBJECTIVES

The principal objective of this project is to measure and quantitatively characterize the wave-induced fluctuations in underwater radiance under various sea-surface boundary conditions. The specific objectives include the characterization of radiance fluctuations as a function of various environmental and instrumental parameters such as wind/wave conditions, sky radiance distribution, direction of radiance observation relative to sun position and wind direction, depth of observation, and water optical properties. Because of the complexity of the problem and multiplicity of factors affecting the measured radiance field, we are aware that a full detailed characterization of all these effects is unrealistic within the timeframe of the RaDyO program. Therefore, we anticipate that our study will focus on selected specific objectives and environmental factors as the project progresses beyond the initial phase of experiments. One of the central questions will be to characterize fluctuations in radiance at shallow depths caused by surface wave focusing under clear skies. These are the most intense fluctuations in underwater light field and their temporal scales range from a fraction of a second to tens of seconds.

Specific objective for this reporting period was the development of a multi-sensor radiometer system for high-frequency measurements of underwater radiance distribution under a wind-disturbed sea surface.

APPROACH

The central idea of our project is to conduct in situ measurements of high-frequency fluctuations in underwater light field produced by surface waves under various boundary conditions. Our approach towards this objective builds largely on our past research experience in the area of wave-induced light fluctuations. This experience indicated a need for developing a suite of sensors whose design is optimized for measuring the high-frequency light fluctuations. In particular, the measurements of

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wave-induced fluctuations in the underwater light field performed in the past (Dera and Stramski, 1986; Stramski, 1986) showed that a radiometer capable of sampling the light field at frequencies as high as 0.5 - 1 kHz is required for accurate characterization of the phenomenon of interest to our project.

With regard to the development of the radiometer system, which was the main objective during the reporting period, our approach is based on the concept of multiple sensors mounted in a unique geometry to ensure measurements of radiance as a function of zenith angle θ within a given azimuthal plane Φ. The design includes more than twenty radiance sensors distributed within two azimuthal planes that are perpendicular to one another. The radiance sensors are based principally on a Gershun-tube design and have fast response enabling sampling of the underwater light field with a frequency of up to 1 kHz. This is a unique feature because typical radiometers used today in oceanographic research do not satisfy requirements for such high-frequency measurements. Each sensor is equipped with a collimating optics, an interference filter, and a custom-built photodiode detector with appropriate parameters for our purposes. In addition, the underwater unit is equipped with a depth sensor, temperature sensor, compass, and a rotator to control the spatial orientation of radiance sensors with respect to azimuthal direction.

The project is conducted in collaboration with the Institute of Oceanology, Polish Academy of Sciences (IOPAS) and the instrumentation is being developed at IOPAS. The key participants in the project from IOPAS are Dr. Miroslaw Darecki and an electro-optical engineer Mr. Maciej Sokolski.

WORK COMPLETED

We have completed the design of mechanical, optical, and electronic components of the multi-sensor underwater radiance system. The fabrication of the instrumentation is nearly completed. The general view of the system is given in Figures 1 and 2. Twenty-two upward-looking radiance sensors are positioned within two orthogonal azimuthal planes at several zenith angles. An upward-looking irradiance sensor with a plane cosine collector is also seen.

The single Gershun-tube radiance sensor is shown in Figure 3. One of the key components of the sensor is the silicon photodiode (Figure 4). This photodiode (p^+-ν-n^+ Type 37S) was developed specifically for our project by the Institute of Electron Technology, Silicon Microsystem and Nanostructure Technology Department in Warsaw, Poland. The photodiode is characterized by a combination of parameters that are unique and not normally available in typical commercial photodiodes. The new silicon material p^+-ν-n^+ is characterized by low dark current suitable for high precision measurements and the relatively large active area of the detector ensures high-speed response and high sensitivity. The key photodiode specification parameters include: sensitivity 0.35A/W (λ = 600 nm, U_R = 15V); maximum dark current $MaxI_D$ = 18.6 - 25 nA (U_R = 15V); and an active area of 1 cm^2 in circular shape (the sensitivity and the maximum dark current were estimated for the reverse voltage U_R). This combination of parameters is essential to our measurements with a sampling rate of up to 1 kHz. Each sensor of our system is equipped with such photodiode. The photodiode detector is mounted inside the Gershun tube that is 200 mm long. The field of view of the radiometer can be selected within a range from 4 to 12 degrees using an appropriate aperture. In the present version of the instrument, the narrow band interference filters centered at 532 nm (Edmund Optics, Inc.) are placed in the front of the photodiodes. The design of the Gershun tube allows to change the filter and aperture without difficulty.

The provide orientation (azimuth) stability during the underwater measurements, the system is equipped with a single axis rotator with position feedback (Figure 5). The rotator (R-10-FB, Remote Ocean Systems, Inc.) is controlled by the output from the EZ-Compass-3 (Advanced Orientation System, Inc.) that measures tilt, roll, and azimuth. We plan to combine the capabilities of the rotator with the action of natural ocean current to control the azimuthal orientation of radiance sensors during in situ deployments. In addition, the system is equipped with a pressure sensor TPS-05 (Zaklad Automatyki i Urzadzen Pomiarowych Arex, Poland) and temperature sensor for photodiode dark current control and correction.

The underwater control unit (Figure 6) is equipped with electronic components which provide various functions involved in controlling the measurements, data acquisition, and power supply. The logarithmic amplifiers used in our system ensure a dynamic range of about six orders of magnitude. The analog data from twenty two radiance sensors and one irradiance sensor are converted to digital format using a DI-720 data acquisition instrument (DATAQ Instruments, Inc.). The digital data are transmitted over the Ethernet underwater cable to the surface on-deck computer. This method of transmission ensures high accuracy and reliability of data acquisition. The DI-720 instrument includes 32 single-ended or 16 differential (software selectable per channel) input channels. The accuracy is ±0.25% of full-scale range of ±100 μV and the sample throughput rate (max samples/second; software selectable per channel) is 300,000 samples/second.

RESULTS

The primary outcome from our work during the reporting period is the fabrication of the instrumentation that is described in some detail above. Although the whole system has not yet been deployed at sea, the individual radiance sensors have been deployed and tested. Figure 7 shows example time series of wave-induced fluctuations in downward radiance that was measured recently at a depth of 1 m in the Baltic Sea during test experiments. These measurements were taken under sunny skies, weak wind, and low sea state with no breaking waves (Figure 8). The viewing angle of the radiance sensor was oriented approximately in the direction of the refracted solar rays underwater but this orientation was not maintained with high precision during the deployment. The example time series show a number of strong pulses of radiance produced by wave focusing during the presented period of 15 seconds. The pulses often exhibit short rise time and duration. These features underscore the need for high-frequency sampling of the light field, which has been achieved successfully with our newly developed instrumentation.

We plan to acquire similar data for different orientations of radiance sensors under various environmental conditions during RaDyO field experiments. Our results will characterize time-dependent underwater light field through the determination of statistical properties of light fluctuations and relationships between these statistical properties and environmental variables. The threshold analysis of time series is one of the statistical methods particularly well suited for characterizing the stochastic nature of relatively rare events of large-amplitude short-duration pulses (e.g., Dera and Stramski, 1986). In this analysis, we will focus on describing the frequency and duration statistics of radiance and irradiance pulses in relation to wind/wave conditions, sun position, sky conditions (i.e., diffuseness of surface irradiance), optical properties of the water column, and depth of observation.

IMPACT/APPLICATIONS

The major impact of this project will be to provide new data and understanding of wave-induced fluctuations in underwater radiance field. This phenomenon has been scantily investigated in the past.

RELATED PROJECTS

This effort is related to other projects funded through the RaDyO program.

REFERENCES

Dera, J., and D. Stramski. 1986. Maximum effects of sunlight focusing under a wind-disturbed sea surface. *Oceanologia*, 23, 15-42.

Stramski, D. 1986. Fluctuations of solar irradiance induced by surface waves in the Baltic. *Bulletin of the Polish Academy of Sciences, Earth Sciences*, 34, 333-344.

PUBLICATIONS

None.

PATENTS

None.

HONORS/AWARDS/PRIZES

None

Figure 1. A general view of the radiometer system.

Figure 2. A general view of the radiometer system from above. Twenty two Gershun-tube radiance sensors are positioned within two orthogonal azimuthal planes at several zenith angles. An upward-looking irradiance sensor with a plane cosine collector is also seen.

Figure 3. A Gershun-tube radiance sensor.

Figure 4. The custom-built fast response photodiode with a circular area for detecting light.

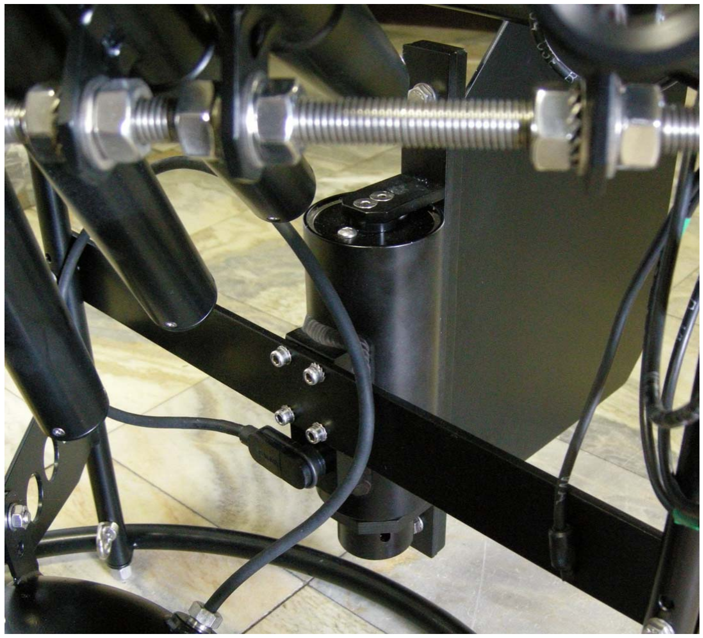

Figure 5. A close-up view of the rotator assembly.

Figure 6. A close-up view of the underwater control unit.

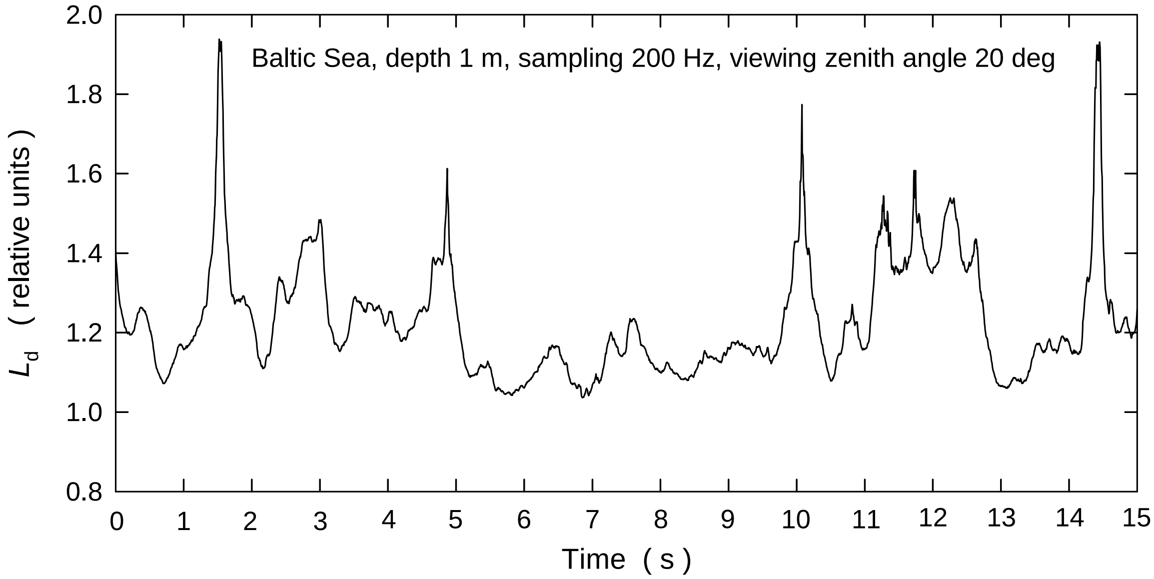

Figure 7. Example time series of wave-induced fluctuations in downwelling radiance measured at a depth of 1 m during test experiments in the Baltic Sea under sunny conditions (11 September 2007). The pulses of radiance intensity produced by wave focusing are seen.

Figure 8. Photograph of the sea surface taken during the measurement of radiance fluctuations shown in Figure 7.