*Original Research*

# Remotely Operated Ship Used for Measurements in Coastal Waters

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**Abstract**

A remotely operated model ship has been constructed to provide a mobile platform for measurements in the coastal waters. On board both dissolved oxygen and water temperature microcomputer probes as well as data loggers along with a water pump were deployed. This set-up allowed us to cross the coastal breaking wave zone and trace both oxygen and water temperature with a frequency of 1-15 seconds, as well as to collect samples of subsurface water. The constructed model was successfully used under conditions of high wind speed and during the winter, when measurements in coastal waters are most difficult and dangerous. Data on dissolved oxygen distribution showed enhanced oxygen evasion taking place within the breaking wave paths along the coastal barriers. Results indicate that breaking waves control the dissolved oxygen and other gaseous content in the coastal surface waters as well as their water-to-air fluxes.

**Keywords:** remotely operated model ship; coastal measurements, dissolved oxygen

## Introduction

It has long been recognized that coastal waters are most important areas of biological, chemical and physical processes that are more complex and dynamic than open maritime waters [1]. While the oceanographic and atmospheric data on the open ocean are recorded routinely e.g. [2-4] and other authors) the published data from the coastal waters and in particular from the surf zone are rather sparse. Even coastal laboratories located at the southern Baltic Sea coast *(i.e.* Kap Arkona, Zingst (Germany), Lubiatowo, Hel (Poland) or Preila (Lithuania)) do not monitor coastal water properties on a routine basis.

Since environmental studies depend upon the development of new measuring techniques that include not only analytical methods but also devices for conducting measurements [5], a continuous effort in testing and exploring new sampling methods are needed. In particular, coastal measurements require a specific, usually heavy installation that provides data for immediate and local environmental assessment. To enhance the coastal environment measurements a search for a portable, remotely operated vehicle has been undertaken. As a result, a radio-operated model ship, able to perform simultaneously three measuring tasks, was constructed and tested in the breaking wave coastal waters. To investigate important processes that are associated with the usually nutrient-rich southern Baltic Sea coastal waters, changes in dissolved oxygen distribution were chosen.

The dissolved oxygen saturation in the water depends on plankton-related oxygen production, thermal balance at the air water interface as well as on biodegradation of suspended and dissolved organic matter [6, 7]. Since during the warm seasons oxygen production is enhanced and dominates over the oxidation processes, dissolved oxygen usually supersaturates surface waters. That implies domination of water-to-air oxygen evasion that may be

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enhanced within coastal waters. Additional coastal upwelling movements, currents or breaking waves usually provide extra loads of suspended organic compounds dispersed in the water column, enhancing both oxidation and decomposition processes, thus decreasing overall oxygen content in the water.

## Remotely Operated Ship

A 'model ship' of 1 m length, able to carry small measuring equipment of about 2-3 kilograms weight was constructed. She has been equipped with 12 V battery motor as well as a steering module, operated by radio-control. A ship's speed ranged between 0.2-0.4 m/s and was slightly adjustable in accord to the wave shapes to allow it best crossing over the crests. Before measurements about 10 to 15 minutes accommodation of oxygen and temperature probes in current water temperatures was undertaken. After accommodation a typical time required to record one set of data in a typical distance of 50 m was about 3-5 minutes.

Inside the ship a vacuum water pump was installed. On board a nest for water bottles of 1 l volume and/or a water resistant box for the protection of electronic equipment was mounted. In order to make the ship's position visible, a flag or electric torch for night measurements was fixed to the top of a mast.

The first version of the ship was equipped with fixed standard ballast. However, several preliminary missions conducted in open Baltic Sea coastal waters showed difficulties in passage over shallow banks, where the ship was often grounded and tilted. Because of that a new, more flexible and more elevated ballast was installed (see Photo 1). That significantly improved the ability of the ship to penetrate even shallow waters of a few centimetres depth. Most important, however, was its ability to cross typically steep coastal waves and their breakers.

During its first mission she was used for coastal measurements of dissolved oxygen and water temperature.


Photo 1. Radio-operated ship with deployed oxygen and water temperature probes.

Both parameters were traced with a frequency of 2 seconds in offshore sections by sensors submerged at 10 cm depth. In addition, a frequent sampling of subsurface water from chosen places was done. The maximum tested distance of the action radius of the ship was about 300 m offshore.

## Measurements

To show the complexity of interactions between biological, physical and chemical processes which simultaneously occur in the coastal zone, the dissolved oxygen content of sea water was investigated. In addition, water temperature was measured as a primary physical parameter that controls solubility of atmospheric gases in the water. Both measuring units were carried on board the model ship. The constructed ship's model was able to follow closely the shape of the waves, therefore the obtained results refer to the depth of 10 cm, just below the sea surface.

In order to minimize the time resolution of collected data, electronic oxygen and temperature probes were used. Data presented in this study were obtained by two microcomputer oxygen membrane electrodes (CX-315 and CO-315) as well as water temperature probes, both manufactured by Elmetron. For oxygen measurements the compensation of water temperature was an automatic function of the used microcomputer mode, while the compensations of atmospheric pressure and water salinity were done before each set of measurements. Both oxygen concentration and water temperature were recorded by separate data loggers. After each mission data were downloaded to computer files.

All electric parts of the oxygen and temperature meters along with a 12 V battery supply and data loggers were kept in a watertight box (see Photo 1). The oxygen and temperature probes were kept at 10 cm depth, in about 10 cm distance from the ship's board, just outside the immediately disturbed water.

The oxygen electrodes are immersed in an electrolyte, that is separated from the test solution by a selective membrane [8]. Since accurate measurements require continuous and rather steady passage of the water, both requirements have been achieved by movement of the vehicle with a speed exceeding about 0.2 m/s, thus providing sufficient flow of water near the submerged oxygen and thermometer probes.

In contrast to the traditional Winkler method, which requires sampling of water and laboratory processing [9], the electrode methods combined with electronic data loggers are applicable for online and fast records [8].

The remotely operated water sampling system consisted of a battery-operated 12 V water pump and a water line, allowing sampling from the subsurface layer to 1 m depth. The water was slowly pumped from the chosen depth into the nested bottles of 1 litre volume. During sampling the ship was set to drift for about 5-10 minutes, depending

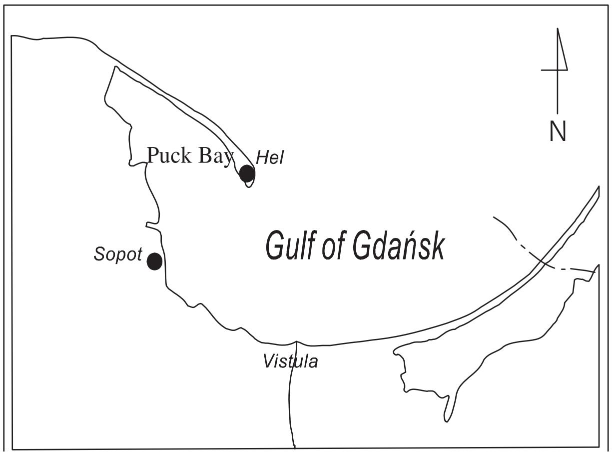


Fig. 1. Locations of the coastal measurements in the Gulf of Gdańsk.

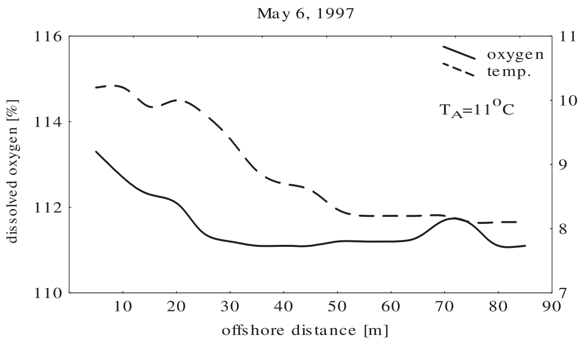


Fig. 2. Dissolved oxygen saturation and water temperature recorded in coastal waters off Sopot (Gulf of Gdańsk) May 6, 1997.

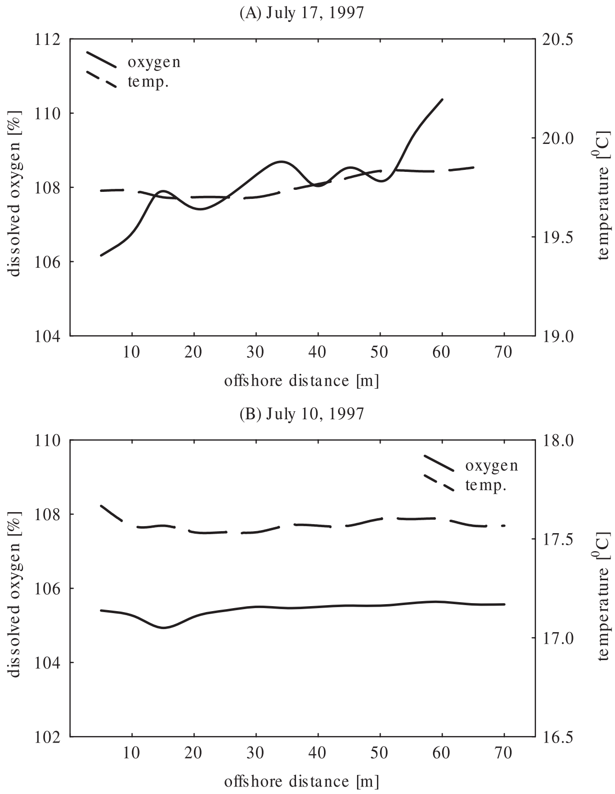


Fig. 3. Coastal cross-sections of dissolved oxygen saturation measured in the surface water under breaking wave (A) and without breaking wave action (B) in Hel.

on the needed volume of water. Collected water samples were used to estimate the accuracy of the used oxygen meters that ranged within 1.5% as compare to the data obtained by Winkler Titration back in the home laboratory.

To show the effect of thermal processes that are an important part of variability of oxygen concentration in the coastal zone record of data collected under pronounced solar warming was chosen. Data were collected in Sopot, during springtime conditions of typical solar warming on May 6, 1997.

During the measurements the air temperature was 11°C and the coastal water was directly exposed to strong solar heating. Results showed that dissolved oxygen and water temperature records increased at a distance of 50 m offshore. Within that distance, from offshore towards the coast, the water temperature increased from 8°C to about 10°C, while the dissolved oxygen rose from 111% to 113.5%, with most pronounced increase within a distance of 25 m offshore (see Fig. 2). The data show a typical record of springtime warming of the shallow surface waters which caused thermal increase of dissolved oxygen saturation. In other words the access and accumulation of solar energy that warmed the shallow water caused a rise of water temperature that decreased gas solubility and finally resulted in an increase of the dissolved oxygen supersaturation. It indicates also that all other dissolved gases may reach supersaturation and may be available for sea-to-air gas transfer.

To study the influence of wave action on the water-to-air oxygen flux, two coastal cross-sections, collected with and without breaking waves under almost the same wind speed of 3-4 m/s, are plotted in Fig. 3. The first set of data was collected in Hel from the Puck Bay side on July 17, 1997. Under wind from E-ESE the waves formed three breaking paths along the coast. It resulted in decrease of dissolved oxygen content that dropped from 111.5% to 106% when approaching the shore. The observed three paths of offshore breakers corresponded with three minima of oxygen content formed at the distances of about 50 m, 40 m and 20 m offshore. A final minimum was formed just at the shore (see panel A, Fig. 3). In contrast, panel B, Fig. 3, shows a typical non-breaking wave record traced under the offshore wind direction. In this case no release of dissolved oxygen from supersaturated water was noted and oxygen saturation of 105-105.5% remained almost stable along the 60-m distance, although the supersaturation was lower (see both panels in Fig. 3).

In this case, data were collected under the similar wind speed conditions as on July 10, 1997. The comparison of both data sets demonstrates that the presence of the breaking waves enhances transfer of the dissolved oxygen from supersaturated sea surface waters. Without breaking waves water may tend to remain almost constantly supersaturated. Similar results on breaking wave-related enhanced bubble and aerosol production in laboratory-controlled experiments were reported by [10].

The presented study showed that within the breaking waves paths that are typical for coastal waters, the air-sea gas exchange is significantly enhanced. Therefore, in cases of oxygen supersaturation, the direct sea-to-air transfer has to be regarded as an important mechanism that provides a significant share of atmospheric oxygen. Furthermore, it may contribute to the transfer of energy in the coastal water column and aerosols across the air-sea interface. The constructed model ship may provide a new experimental tool to investigate coastal breaking wave areas that may allow more accurate estimates of the role of coastal gas exchange processes.

## Conclusions

A remotely operated, portable ship was constructed and successfully tested as a measuring platform in the breaking wave coastal zone. This set-up allowed us to carry a small box with equipment and/or a bottle for water sampling. It allowed us to cross the coastal waters from the shore to a distance of about 300 m. The ship closely followed the wave shapes, thus the submerged measuring probes and water sampling could be performed at precise depths. Several missions confirmed the good performance of the ship in collecting data and sampling water in the breaking wave zones. Successfully conducted measurements in tracing dissolved oxygen saturation and water temperature changes, confirmed applicability of the constructed model to perform even complex electrode-based measurements.

The obtained dissolved oxygen data show that southern Baltic Sea coastal waters rich in nutrients are dynamic areas of enhanced oxygen production and are of importance for related water to air oxygen fluxes.

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