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The purpose of the Conference was to transfer the current knowledge on hydrodynamic and physical aspects of coastal oceanography from senior scientists to young researchers and to provide an opportunity for all participants to share their scientific achievements and ideas to ensure further progress in understanding the physical fundamentals of nearshore and coastal dynamics. The Conference served as a school-seminar, and, therefore, two forms of presentations were used—invited lectures by leading experts and poster sessions for all participants.

The Conference continues the tradition of its first successful predecessor, held in Baltiysk (Russia) in June–July, 2008.

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Multiparametric in-situ observations in the Gulf of Finland

Urmas Lips, Inga Lips, Taavi Liblik, Villu Kikas, Kristi Altoja, Natalja Kuvaldina, Nelli Norit

Abstract

New observation tools, which enable to measure the fine structure of marine ecological state variables, are significantly improving the existing understanding of the ecosystem functioning and may be applied operationally. We present the multiparametric observations in the Gulf of Finland (Baltic Sea) using an autonomous system installed on board a ferry (autonomous measurement twice a day: time step 20 s, spatial resolution 150 m; weekly sampling), a moored water column profiler (vertical profiling of temperature, salinity and Chl *a* fluorescence with a time step of 3 h) and an ADCP deployed in the gulf, and measurements and water sampling on board a research vessel. An analysis of the collected data together with wind data from the area enabled us to characterise the structure and variability of hydrophysical fields, nutrients and phytoplankton and to relate the observed changes to the forcing and key processes.

Новые средства измерений, позволяющие измерять тонкую структуру параметров морской воды, существенно расширили существующие возможности в понимании функционирования морских экосистем. Они также могут использоваться и для операционных целей. Мы представляем многопараметрические наблюдения в Финском заливе (Балтийское море) с использованием автономных измерительных систем. Одна из них была установлена на борту парома, пересекающего акваторию два раза в день. Измерения проводились каждые 20 с, что соответствовало шагу по пространству порядка 150 м. С помощью заякоренной в стационарной точке буйковой системы проводилось регулярное (каждые 3 ч) вертикальное профилирование характеристик солености, хлорофилла, флюорисценции и измерение скорости течений с помощью ADCP. В ходе еженедельных

Urmas Lips, Inga Lips, Taavi Liblik, Villu Kikas, Kristi Altoja,
Natalja Kuvaldina, Nelli Norit (✉)
Marine Systems Institute, Tallinn University of Technology, Tallinn, Estonia
e-mail: urmas.lips@phys.sea.ee

рейсов научного судна проводились станционные наблюдения в точках вдоль трассы парома. Анализ собранных данных вместе с информацией о ветре позволил описать структуру и изменчивость гидрофизических полей, распределения биогенных элементов и фитопланктона, а также выявить ключевые процессы и отклики на внешние воздействия.

1. Introduction

New observation tools introduced within the last 10–20 years, which enable to measure the fine structure of marine ecological state variables, are significantly improving the existing understanding of the ecosystem functioning. Classical observations are performed with low frequency or episodically, the remote sensing methods do not reveal the vertical structure of the water column, i.e. essential phenomena and mechanisms may remain unnoticed. Thus, autonomous *in-situ* observation systems (among them autonomous vertical profilers) with near real-time data delivery play the key role in assessing the state and studying the pelagic ecosystem, especially meso-scale and fine-scale processes/features.

The Gulf of Finland is a stratified and wide estuary with a major fresh water inflow in the eastern end and relatively open water exchange with the Baltic Proper through the gulf's western boundary. Residual circulation in the surface layer consists of an outflow of gulf's waters in the northern part and an inflow of open Baltic Sea waters in the southern part of the gulf. Wind-driven circulation in the Gulf of Finland is highly variable and is characterized by intense meso-scale features—eddies, upwelling/downwelling, coastal and frontal jet currents which can cause significant vertical advection of water masses and substances, e.g. nutrients and phytoplankton.

Upwelling events have been reported to influence the phytoplankton dynamics in the upper layer in summer in the Baltic Sea, including the Gulf of Finland (Vahtera et al., 2005, Nausch et al., 2009, Lips & Lips, 2010). It has been shown both by modelling and direct measurements that the amount phosphate-phosphorus transported into the surface layer by a single coastal upwelling event may be approximately equal to the average total monthly riverine load of phosphorus to the Gulf of Finland (Zhurbas et al., 2008, Lips et al., 2009). One of the main factors influencing the cyanobacteria (especially *Aphanizomenon* spp.) bloom intensity in the Gulf of Finland is the intensity of pre-bloom upwelling events in May–June (Lips & Lips, 2008) and thus, near real time observations of upwelling events and their intensities are a pre-requisite for operational bloom forecasts (Laanemets et al., 2006).

The sub-surface maxima of phytoplankton biomass, among them the relatively deep maxima formed by dinoflagellate *Heterocapsa triquetra* (e.g. Pavelson et al., 1999, Kononen et al., 2003), have been observed in the Gulf of Finland in summer when the upper layer is depleted of nutrients but high reserves of nutrients are available below the seasonal thermocline. In July 2006 the sub-surface Chl *a* maximum layers with thickness varying between 1.5 and 9 m and intensity up to 7.6 μg l^{-1} were observed in the lower part of the seasonal thermocline within the depth range of 14.5 to 35 m (Lips et al., 2010). Nutrient analyses of water samples collected from the thermocline revealed the coincidence of the location of Chl *a* maxima and nutriclines.

However, no estimates of the role of sub-surface maxima in the total primary production during summer months are available yet for the Baltic Sea (Gulf of Finland).

The main aim of the present paper is to show how the high resolution *in-situ* observation systems can be applied to define the role of upwelling events for the development of surface blooms and to define the processes responsible for the formation and maintenance of sub-surface maxima of phytoplankton.

2. Material and methods

We present the results of multiparametric observations conducted in the Gulf of Finland (Baltic Sea) in July–August 2009. The measurement program was designed to map both, the horizontal and vertical distribution of ecological state variables with sufficient resolution, duration and extent. An autonomous measurement system (Ferrybox) installed on board a ferry travelling between Helsinki and Tallinn was used for measurements and sampling in the surface layer. Temperature, salinity and Chl *a* fluorescence were recorder along the ferry route (Fig. 1) twice a day with a time step of 20 s (corresponding approximately to spatial resolution of 150 m) and weekly water sampling at 17 locations was conducted. Water samples were analyzed for Chl *a* content and phytoplankton species composition and biomass.

In order to register the changes in the vertical distribution of temperature, salinity and Chl *a* fluorescence a moored water column profiler was deployed close to the ferry line (Fig. 1) from June 30 to August 28. While Ferrybox data were delivered once a day (after arrival of ferry to Tallinn) the vertical profiles acquired at the buoy station were transmitted after every profiling conducted with a time step of 3 h in the layer from 2 to 50(45) m. An acoustic Doppler current profiler (ADCP) was deployed near the autonomous buoy profiler to register the vertical flow structure in the whole water column (water depth 86 m) since July 23. CTD measurements and water sampling on board a re-

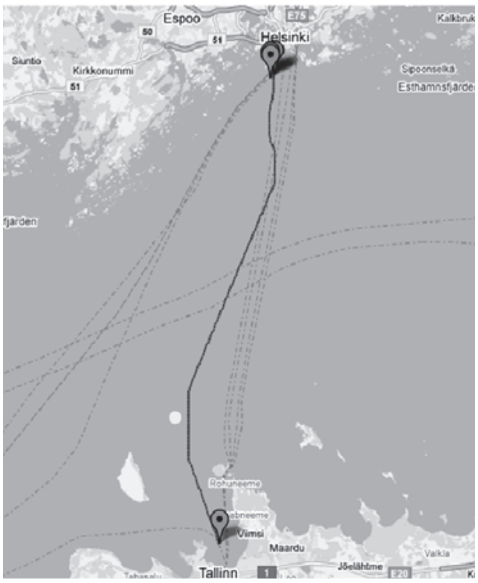

Fig. 1. Ferry route between Tallinn and Helsinki (blue/dark line) and location of autonomous buoy profiler (yellow/light circle) in the Gulf of Finland.

search vessel were performed on July 28 and 31, and August 11–12. Water samples were analyzed for nutrient (PO_4^{3-} and NO_2^-+NO_3^-) concentrations, Chl *a* content and phytoplankton species composition and biomass. Wind data used in the analysis were obtained from the Kalbådagrund meteorological station (Finnish Meteorological Institute).

3. Results

The observed changes in the horizontal and vertical distribution of temperature and salinity can be related to the changes in the atmospheric forcing. We specified four periods with different wind forcing and related changes in the vertical stratification (Fig. 2). South-easterly winds, which prevailed in the study area from 6 to 13 July, caused an upwelling near the Estonian coast. This event was registered also at the buoy station situated more than 20 km from the southern coast. Westerly-south-westerly winds (prevailing from July 16 until the end of July) caused deepening of the seasonal thermocline. This period was characterized by three-layer flow structure—an inflow was observed in the surface layer, a relatively weak outflow below the thermocline in the intermediate layer and a strong outflow in the near-bottom layer.

Period of weak winds in the beginning of August led to the formation of a warm and shallow surface layer. The flow structure returned to a typical

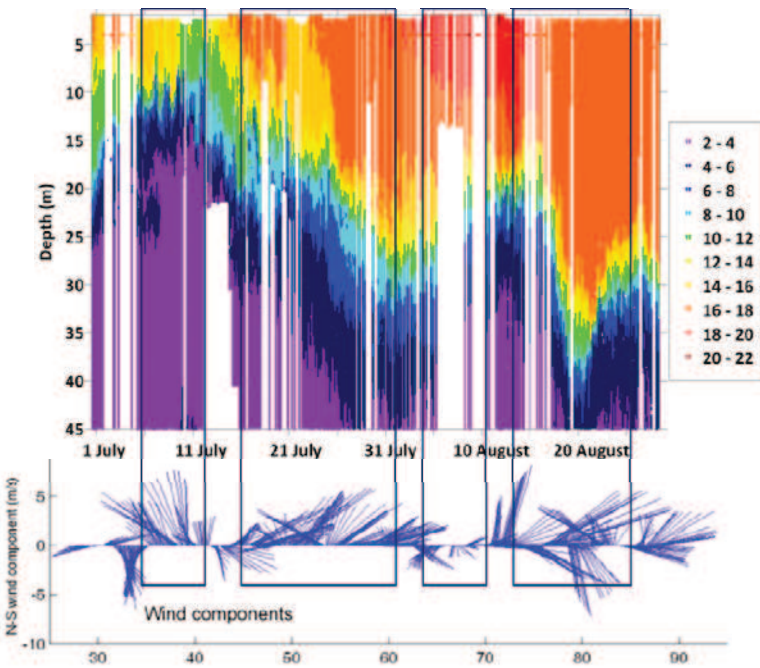

Fig. 2. Changes in the vertical structure of temperature field at the buoy station (upper panel, °C) and time series of wind vectors at the Kalbådagrund meteorological station (numbers on x-axis indicate days starting from June 1) from June 30 to August 28, 2009. Four periods with different wind characteristics are shown as rectangles. Dots at 4 m depth indicate simultaneous Ferrybox data at the closest point to the buoy station.

estuarine circulation pattern with an outflow in the surface and inter-mediate layers and an inflow in the deeper layers. Strong wind pulses observed in mid August caused barotropic current oscillations in the whole water mass. On August 16–20 a sharp deepening of the seasonal thermocline happened due to the strong winds from westerly directions. A clear two-layer flow structure was established.

In the described periods with different wind forcing and related hydrodynamic processes different phytoplankton groups dominated the community according to the water samples analyses collected in the surface layer. In the first period flagellates were dominating the phytoplankton community in the area of upwelling influence. When deepening of the seasonal thermocline and three layer flow structure were observed, dinoflagellate *Heterocapsa triquetra* became dominant. Warming of the surface layer (and development of stratification) created favourable conditions for cyanobacteria dominance.

In the periods of dominance of flagellates and especially dinoflagellate *H. triquetra* clear vertical migration of phytoplankton was revealed (Fig. 3). Speed of downward migration of the latter species up to 1 m h^{-1} could be estimated. According to the vertical distributions of Brunt-Väisälä frequency the phytoplankton cells did not stop in the layer with the strongest stratification but mostly just a few metres below it. As a rule the current shear was relatively low at the depths were the most intense sub-surface maxima were observed. Sampling on board the research vessel Salme revealed very high abundances of *H. triquetra* in these maxima—for instance on July 28 up to 2.5 million cells per litre were counted in a sample obtained from the 33 m depth.

It has to be noted that during the dominance of cyanobacteria in the beginning of August no remarkable vertical migration of phytoplankton was observed. However a high number of heterotrophic flagellates was often observed at the base (just below) the seasonal thermocline.

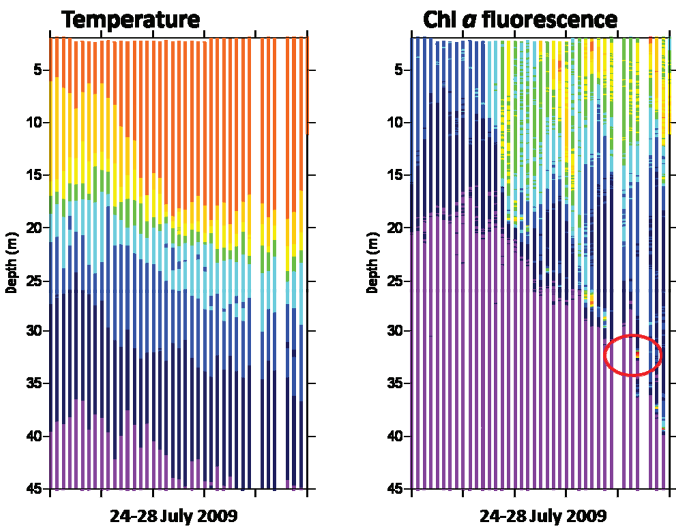

Fig. 3. Changes in the vertical distribution of temperature (left panel, °C) and Chl a fluorescence (right panel, arbitrary units) at the buoy station (July 24–28, 2009). Red oval indicates the maximum Chl a fluoresecence value measured on July 28 at 33 m depth.

4. Conclusions

We have observed pronounced hydrodynamic features and related changes in the horizontal and vertical distributions of temperature, salinity and Chl *a* in the Gulf of Finland in July–August 2009. Depending on the wind forcing a three-layer, two-layer or barotropic flow structure (oscillations) was observed. On the basis of high resolution Chl *a* fluorescence recordings different vertical migration patterns of phytoplankton were found. Phytoplankton behaviour depends on species composition (dominating species) but the species dominance seems to be controlled by the physical processes of various scales. High biomass of heterotrophic flagellates is commonly observed close to the base of the seasonal thermocline while very high biomass is formed there under certain conditions by mixotrophic dinoflagellate *Heterocapsa triquetra*.

In order to understand the mechanisms of the formation and maintenance of these layers of deep phytoplankton maxima and their role in the total primary production in the stratified estuaries further studies are needed.

References

Kononen, K., Huttunen, M., Hällfors, S. et al. (2003) Development of a deep chlorophyll maximum of *Heterocapsa triquetra* Ehrenb. At the entrance to the Gulf of Finland. *Limnol. Oceanogr.* **48**:594–607.

Laanemets, J., Lilover, M.-J., Raudsepp, U. et al. (2006) A fuzzy logic model to describe the cyanobacteria Nodularia spumigena blooms in the Gulf of Finland, Baltic Sea. *Hydrobiologia* **554**:31–45.

Lips, I. & Lips, U. (2008) Abiotic factors influencing cyanobacterial bloom development in the Gulf of Finland (Baltic Sea). *Hydrobiologia* **614**:133–140.

——— (2010) Phytoplankton dynamics affected by the coastal upwelling events in the Gulf of Finland in July–August 2006. *J. Plankton Res.,* doi:10.1093/plankt/fbq049.

Lips, I., Lips, U., Liblik, T. (2009) Consequences of coastal upwelling events on physical and chemical patterns in the central Gulf of Finland (Baltic Sea). *Cont. Shelf Res.* **29**:1836–1847.

Lips, U., Lips., I., Liblik, T., Kuvaldina, N. (2010) Processes responsible for the formation and maintenance of sub-surface chlorophyll maxima in the Gulf of Finland. *Estuar. Coast. Shelf Sci.*, doi:10.1016/j.ecss.2010.04.015

Nausch, M., Nausch, G., Lass, H. U. et al. (2009) Phosphorus input by upwelling in the eastern Gotland Basin (Baltic Sea) in summer and its effects on filamentous cyanobacteria. *Est. Coast. Shelf Sci.* **83**:434–442.

Pavelson, J., Kononen, K., Laanemets, J. (1999). Chlorophyll distribution patchiness caused by hydrodynamical processes: A case study in the Baltic Sea. *ICES J. Marine Sci.* **56(S)**:87–99.

Vahtera, E., Laanemets, J., Pavelson, J. et al. (2005) Effect of upwelling on the pelagic environment and bloom-forming cyanobacteria in the western Gulf of Finland, Baltic Sea. *J. Mar. Syst.* **58(1–2)**:67–82.

Zhurbas, V., Laanemets, J., Vahtera, E. (2008) Modeling of the mesoscale structure of coupled upwelling/downwelling events and related input of nutrients to the upper mixed layer in the Gulf of Finland, Baltic Sea. *J. Geophys. Res.* **113**, C05004, 1–8.