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ORIGINAL RESEARCH ARTICLE

Characteristics and inter-annual changes in temperature, salinity and density distribution in the Gulf of Riga

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Summary Available CTD profiles from the Gulf of Riga (May—August, 1993—2012) were analyzed to study inter-annual and long-term changes in temperature, salinity and density in relation to river runoff and atmospheric forcing (e.g. Baltic Sea Index). To describe temporal changes in vertical stratification, the upper mixed layer (UML) and deep layer (DL) parameters were estimated. On average the UML depth increases from 8.7 m in May to 9.0, 11.5 and 13.7 m in June, July and August, respectively, and the UML temperature increases from 8.0°C to 12.5, 18.7 and 18.6°C (May, June, July and August) while the UML salinity increases from 4.90 g kg^{-1} to 5.14, 5.28 and 5.38 g kg^{-1}, respectively. High correlation ($r = -0.82$) was found between the inter-annual changes in river runoff (spring) and mean salinity in the UML in August as well as between DL mean salinity ($r = 0.88$) and density ($r = 0.84$) in the Irbe Strait and DL mean salinity and density in the Gulf of Riga. Inter-annual changes in the UML depth as well as in DL salinity and density had a significant correlation with the changes in Baltic Sea Index. The strongest stratification (August) can be observed in the years with the highest UML temperature and the highest river run-off in spring. We suggest that the predicted increase in water temperature and changes in river run-off due to the climate change would result in faster development of the seasonal thermocline in spring and stronger vertical stratification in summer.

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1. Introduction

The Gulf of Riga (GoR) is a relatively closed basin in the eastern part of the Baltic Sea with surface area of 17,913 km^2 and volume 405 km^3 (Leppäranta and Myrberg, 2009). It has two openings — the Irbe Strait (sill depth of 25 m and cross-section of 0.4 km^2) in the western part and the Suur Strait (sill depth of 5 m and cross-section of 0.04 km^2) in the northern part of the gulf with 70—80% (Petrov, 1979) of the water exchange occurring through the Irbe Strait. The mean depth of the GoR is 26 m which is about two times less than in the Baltic Sea. The deepest regions of the gulf are situated to the east and southeast from Ruhnu Island where depth reaches about 56 m, although, the deepest spot in the whole GoR is Mersraga Trough (width about 50 m and length 4.5 km) with the depth of 66 m (Stiebrins and Väling, 1996) situated approximately 13 km to the north from the village of Mersrags.

The catchment area of the GoR consists of 134,000 km^2 with five major rivers discharging into the GoR — Daugava, Lielupe, Gauja, Pärnu and Salaca. First three are located in the southern part of the gulf where approximately 86% of all river run-off occurs (Berzinsh, 1995) and latter two in the eastern part. Annual mean run-off to the gulf in 1950—2012 has been stated as 1013.5 m^3 s^{-1} (Kronsell and Andersson, 2014) or approximately 32 km^3 which is about 7.9% of the volume of the gulf. It has been showed that river run-off together with the limited water exchange are the main reasons for the observed horizontal salinity difference in the surface layer — salinity decreases from the Irbe Strait to the southern part of the gulf (see e.g. Berzinsh, 1980, 1995; Stipa et al., 1999). The strongest difference can be observed in April and May when the influence of the river discharge is at its maximum and salinity decreases from about 6.0 PSU (Practical Salinity Scale) in the Irbe Strait to 2.0 PSU and less close to the mouths of Daugava and Lielupe. Slight surface salinity difference (about 1.0—1.5 PSU) can be observed also across the gulf from west to east during April (Stipa et al., 1999).

Water temperature in the GoR has a seasonal pattern — during November—February cooling of the whole water column occurs, March—April marks the start of the water column warming from surface layers which intensifies and reaches maximum during May—August and is again followed by a steady cooling during September—October. Data analysis during 1963—1990 revealed that mean temperature for the whole water column in winter, spring, summer and autumn was 0.0, 2.8, 12.0 and 9.0°C, respectively (Berzinsh, 1995). It was reported (Raudsepp, 2001) that seasonal changes in thermal stratification are consistent with the annual cycle of air-sea heat exchange. Due to these seasonal characteristics the whole water column in the GoR is thermally well mixed during December—March, whereas, seasonal thermocline starts to develop in April and the strongest stratification can be observed in August. More detailed analysis on stratification in the GoR is described in the research by Stipa et al. (1999).

According to the previous studies (Berzinsh, 1980, 1995) there have been two periods with opposite tendencies regarding salinity — from beginning of 1960s till 1977 average salinity increased (average rate of 0.035 PSU per year), whereas, from 1977 till early 1990s salinity decreased (0.041 PSU per year) which was mainly related to the dynamics of long-term river run-off. Similar decline of salinity was also observed within different layers (expressed as mean values at 0, 10, 20, 30, 40 and 50 m) of the GoR (Raudsepp, 2001). Remote sensing data for 1990—2008 has showed a strong increase of the sea surface temperature (SST) in the GoR — about 0.8—1.0°C per decade with similar or slightly higher values only in the Gulf of Finland and Bothnian Bay (BACC, 2015). Long-term changes in both, temperature and salinity, not only influence the physical characteristics of the GoR but they can have an impact to the whole ecosystem of the gulf. For example, Jurgensone et al. (2011) reported that the temperature increase would affect the phytoplankton community in the GoR suggesting a shift from dinoflagellates to chlorophytes in summer. Kotta et al. (2009) stated that the reduction in salinity had negative consequences for most of the benthic invertebrate species referring to their salinity tolerance. In general, the dynamics of zooplankton, zoobenthos and fish in the GoR primarily relies on climatic conditions.

The main goal of the present study was to describe the vertical characteristics of temperature, salinity and density fields and their inter-annual variability in the GoR based on the CTD data collected during 1993—2012 (May—August) as well as possible connection of revealed changes with different forcing factors. Previous studies have mainly focused on short-term analysis of temperature and salinity data (Kõuts and Håkansson, 1995; Stipa et al., 1999) and/or covered only the time period until 1995 (Raudsepp, 2001). In addition, present research aimed to estimate the baroclinic Rossby radius on the basis of the existing CTD profiles with a similar approach as used by Alenius et al. (2003) for the Gulf of Finland. Based on the results of this analysis and taking into account the latest climate change predictions we also suggest what could happen in the future.

2. Material and methods

Present paper analyzed the CTD data collected in 1993—2012 during various monitoring programmes and research projects conducted by Latvian Institute of Aquatic Ecology, Marine Systems Institute at Tallinn University of Technology and Institute of Food Safety, Animal Health and Environment (Latvia) and their predecessors. Vertical profiles of different parameters were acquired with following CTD profilers — AROP 500, SBE 19plus SeaCAT, SBE 19 SeaCAT, Neil Brown Mark III and Idronaut OS320plus.

In total 3558 CTD casts were processed and 863 CTD casts were used in the present study from the period of May—August, 1993—2012 with Gulf of Riga borders set along 58°N latitude and 22.6°E longitude (Fig. 1). CTD profiles were processed and analyzed with vertical resolution of 0.5 m (constant for all profiles) and only stations with depth over 20 m were used. Availability of CTD profiles differed widely between the years and months (Table 1).

Upper mixed layer (UML) depth was estimated using smoothed (2.5 m moving average) vertical profiles of density and the UML depth was defined at each vertical profile as the shallowest depth where the density difference between consecutive data points was equal or exceeded 0.05 kg m^{-3}. The latter value was derived empirically as a value which best reflects the start of pycnocline and, thus,