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# INVESTIGATIONS OF MESOSCALE HYDROPHYSICAL PROCESSES IN THE GULF OF FINLAND IN 1985—1990

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**Abstract.** Hydrophysical, hydrochemical, and hydrobiological comprehensive investigations carried out on board R/V *Arnold Veimer* in 1985—1990 established that the hydrophysical processes observed were of vital importance in the ecosystem of the Gulf of Finland. The direct current measurements showed the existence of a strong eastward surface current together with downwelling in the southern part of the Gulf of Finland. The distribution of the prevailing wind directions explains the generation of wind-induced upwelling near both coasts, whereas in summertime the upwellings are more frequent near the northern coast. West of Naissaar Island there exists a meandering quasi-permanent salinity front in the surface layer, which in summertime separates the water of the northern Baltic Proper and the water of the Gulf of Finland in the surface layer. The observed phenomena determine the distribution and variability of hydrochemical and hydrobiological fields in the Gulf of Finland.

**Key words:** Gulf of Finland, hydrophysical processes, currents, upwelling, downwelling, fronts.

## INTRODUCTION

The paper presents an overview of the main results of the experimental work carried out in the Gulf of Finland on board R/V *Arnold. Veimer* in 1985—1990. The aim of the investigations was to study the contribution of the mesoscale hydrophysical processes to the main circulation of the Gulf and their impact on the distribution of the hydrobiological parameters. These investigations were part of the research programme "The Baltic Sea". The project was led by the Department of the Baltic Sea of the Estonian Academy of Sciences; however, it was carried out with the participation of many scientists from different institutions of Estonia. An overview of the most expressive hydrophysical processes observed will be presented. Also the impact of hydrophysical processes on hydrobiology is shortly reported. The hydrophysical processes discussed are essential in understanding and modelling the sea ecosystem.

The time scale of the hydrophysical processes observed was from about half a day (inertial oscillations) to dozens of days. The characteristic space scale of these hydrophysical processes made their study in the entire Gulf of Finland impossible, so certain control areas (grids) had to be chosen.

## MATERIALS AND METHODS

The experimental investigations were performed in 1985, 1987, 1989, and 1990. Detailed investigations were carried out in two areas in different parts of the Gulf of Finland. One of these grids was situated in the western part of the Gulf of Finland, west of Naissaar Island near the Suurupi Peninsula (called the Suurupi grid), and the other in the central part of the Gulf of Finland, called the Lahemaa grid after the national park situated close to this region (Fig. 1). Both grids consisted of a certain number of transects perpendicular to the coastline. The distance between the neighbouring stations was 1.5—3.0 nautical miles. In all stations CTD-casts and water samples were collected. The following parameters were studied: temperature, salinity, chlorophyll *a* fluorescence, chlorophyll *a*, nitrite-nitrate, phosphate, total phosphorus, total nitrogen, primary production, phytoplankton, zooplankton, larvae, and bacteria. Most of these parameters were studied only on certain transects or even at a few stations as the amount of analyses required was great. Currents were measured by autonomous mooring stations.

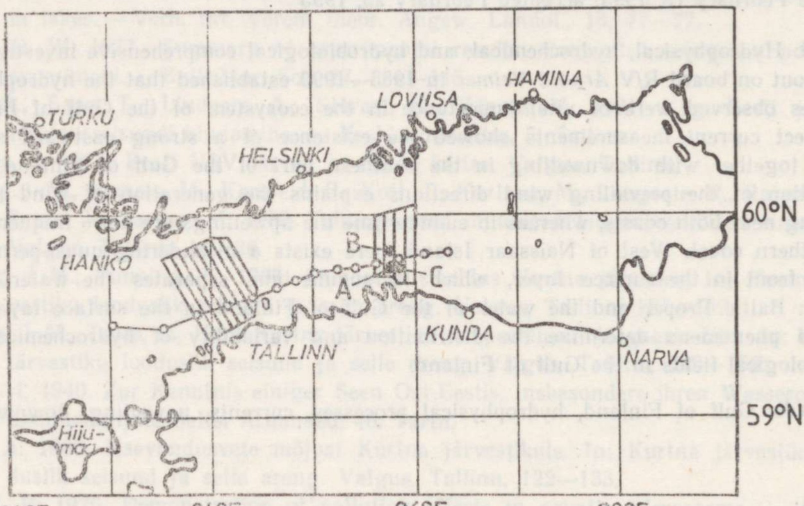


Fig. 1. Scheme of the Lahemaa and Suurupi grids and a separate transect in the central part of the Gulf of Finland. A, B, and C—mooring stations.

## RESULTS

**1. Wind data.** Wind stress was established to be the main source of energy for the hydrophysical processes observed in the Gulf of Finland. The local wind distribution was analysed using the data base of the Estonian Hydrometeorological Board. Fig. 2 presents the average wind distribution during the years 1977—1987 and in July 1977—1987 at the Kunda coastal station near the Lahemaa grid. Notice the dominance of southerly and south-westerly winds during both periods. Eastward wind-driven currents near the Estonian coast can be expected due to their influence. The occurrence of northerly winds is also remarkable.

**2. The September 1985 experiment.** The area under investigation was the Suurupi grid (Fig. 1) west of Naissaar. As a result of moderate (10—

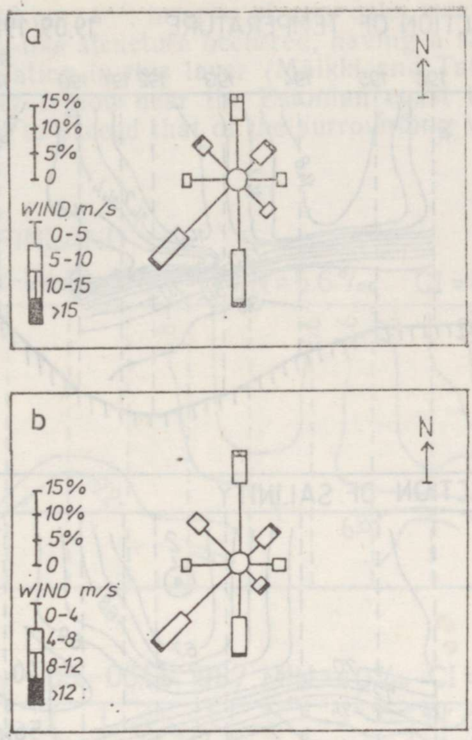


Fig. 2. Average annual winds (*a*) and average July winds (*b*) in Kunda Bay in 1977—1987.

14 m·s$^{-1}$) westerly winds, which were blowing for five days, an expressive downwelling near the southern coast with increased water level and an eastward current near the southern coast of the Gulf of Finland were observed. The downwelling caused the deepening of the pycnocline (the thermocline and the halocline coincided) southwards (Fig. 3). According to geostrophy the lateral shear was estimated to be up to 30 cm·s$^{-1}$ in relation to the near coastal current. This current shear caused a jet of warmer and fresher water upon the pycnocline slope. The absolute current was not measured but considering the widening of the fresher water region a small westward transport in the jet can be expected in the upper layer. Fig. 3. shows the temperature and salinity distribution through the jet. The downwelling near the Estonian coast is obvious. The arrow indicates the expected vertical water movement in the downwelling region (based on the analysis of biological and chemical parameters): downwelling occurs near the coast and weak upwelling near the front. A more detailed description of the hydrophysical processes observed during this experiment is given by Talpsepp (1987).

The nutrients concentration was low (near instrumental limits) in the surface layer. Southward from the front between the incoming saltier and warmer water and westward jet current water the potential primary production was six times higher than in the surrounding water. The phytoplankton and zooplankton concentrations (relying on particle counting results of that size) were higher in the incoming water. The 0-group herring was the most numerous in both frontal zones. The influence of hydrophysical processes on the distribution of hydrochemical and hydrophysical fields is discussed also in a paper by Nõmmann et al. (1987).

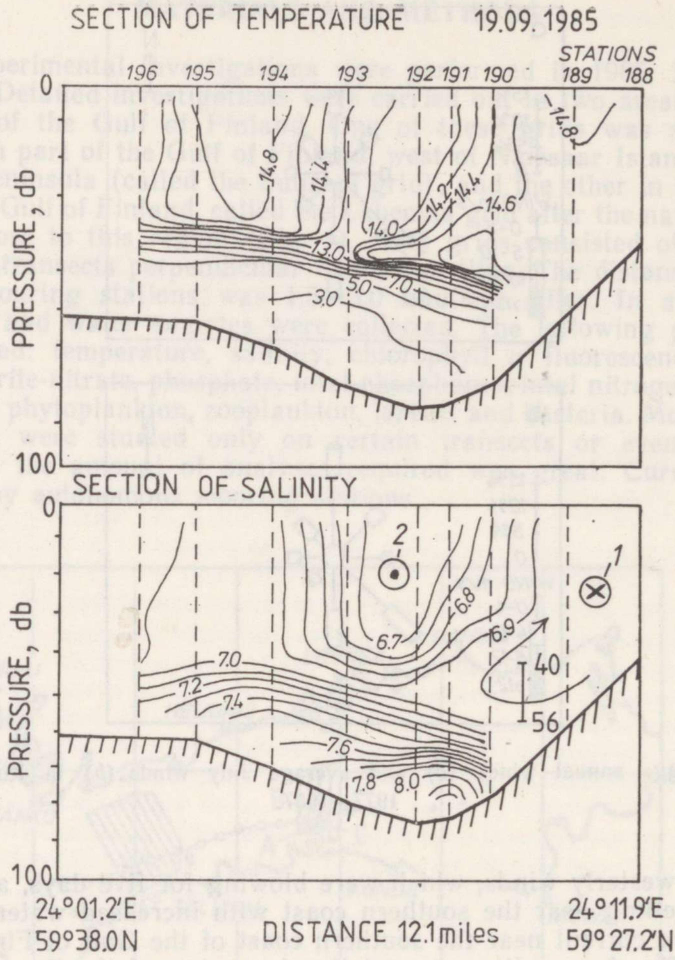


Fig. 3. Vertical distributions of temperature (*a*) and salinity (*b*) near the southern coast of the Gulf of Finland in autumn 1985. *1* — the eastward current and *2* — the expected westward current, the arrow indicates the vertical water movement in the downwelling region. (Reproduced from Talpsepp, 1987.)

**3. The spring 1987 experiment.** In 1987 two experiments were carried out. Most of the results of the joint two-ship work together with the Institute of Marine Research, Finland, performed in May 1987 were published by Mälkki and Talpsepp (1988). The experiment took place almost immediately after the ice cover disappeared at the beginning of May and so it was possible to compare the water salinity with that of late autumn 1986 before the ice cover was formed. We noticed (Fig. 4) the presence of saline water in the deeper layer that had been absent in late autumn. In the surface layer a fresh water stripe with a very sharp salinity front (up to 0.5 per three nautical miles) was observed on the Lahemaa grid near the Estonian coast. The salinity difference between the coastal zone and the open part of the Gulf was about 1 psu. This difference remained for some weeks though the surface water got saltier during this time period, obviously due to wind-induced mixing. During the experiment the penetration of a tongue-like fresh water mass to the northeast was observed. The speed of the current directed parallel to the front was estimated to be 10—12 cm · s$^{-1}$, in spite of very calm weather. In the near-bottom layer an eddy-like structure occurred, having a short life-time but influencing the circulation in this layer (Mälkki and Talpsepp, 1988).

In the fresh water region near the Estonian coast the chlorophyll *a* content was observed to exceed that of the surrounding water 2—3 times.

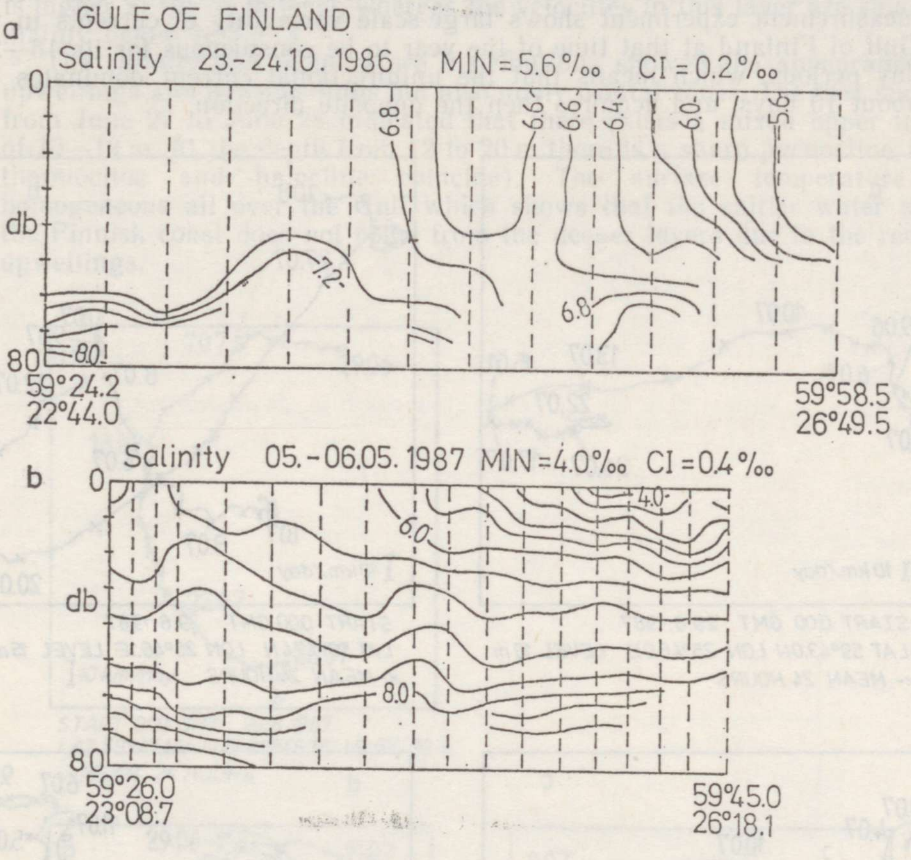


Fig. 4. Sections of salinity on the transect along the axis of the Gulf of Finland. *a* — two months before ice cover (23—24 October 1986); *b* — immediately after ice cover disappeared (5—6 May 1987). Sections are not shifted within the space scale.

**4. The summer 1987 experiment.** A more detailed experiment on board the *Arnold Veimer* was carried out in June-July 1987 on the Lahemaa grid. Most of the findings concerning the impact of hydrophysical phenomena on hydrobiological fields are presented in a joint paper by Talpsepp et al. (1993). Here we will refer to the hydrophysical situation during the experiment. Three mooring stations with three current meters in each were installed for the investigation of the currents. Seven repeated surveys of the temperature and salinity fields were carried out with different time intervals to study the temporal variability. As current measurements are rarely conducted, they are paid more attention to in this overview paper. The progressive vector diagrams of the currents in the surface layer are presented in Fig. 5 and in deeper layers in Fig. 6. Near the coast (Figs. 5*a* and 5*c*) the direction of the currents is quite similar at the levels of 10 and 25 m; the current velocities amount to 35 cm · s$^{-1}$ at the 10 m level, but only to 10 cm · s$^{-1}$ at the 25 m level. After low northward velocities at the beginning of the experiment, from July 6 to July 15, the eastward current dominates there. In the central part of the Gulf of Finland the north-eastward current with the daily mean velocities up to 20 cm · s$^{-1}$ was observed up to July 10 (Figs. 5*b* and 5*d*). After that the current turns south supplying the strong eastward near-coastal current with water. Fig. 5*d* depicts the velocities of a prolonged spiral to form at the 25 m level with distinct fluctuations of the near-inertial period being revealed. The current measurement experiment shows large-scale variability of currents in the Gulf of Finland at that time of the year to be conspicuous for its 18—20-day periods, which means that the unidirectional current dominates for about 10 days, and acquires then the opposite direction.

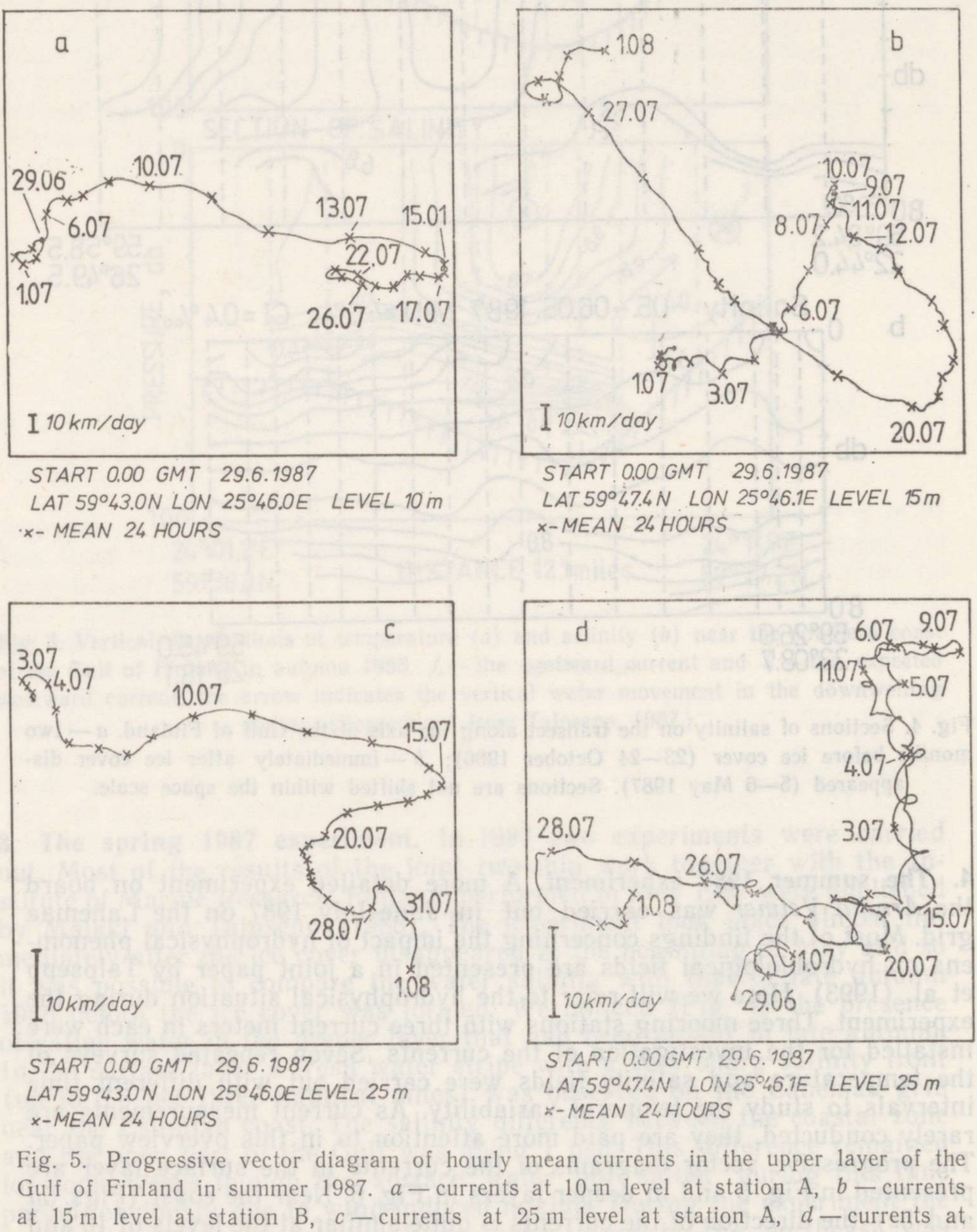


Fig. 5. Progressive vector diagram of hourly mean currents in the upper layer of the Gulf of Finland in summer 1987. *a* — currents at 10 m level at station A, *b* — currents at 15 m level at station B, *c* — currents at 25 m level at station A, *d* — currents at 25 m level at station B. See Fig. 1 for location of the stations.

The correlation of surface currents with wind was established, indicating the significance of wind-driven currents in the circulation of waters in the Gulf of Finland.

Fig. 6 presents progressive vector diagrams of currents in the deeper layer in July 1987. Large-scale circulation is as follows. In the course of 10 days at the beginning of the experiment a westward current dominates, which thereafter turns south, south-east, and east. Variability is higher at the 55 m level, whereas the velocities in this layer are smaller, mainly below 10 cm · $s^{-1}$.

The salinity and temperature distributions showed the appearance of upwellings and downwellings but also many frontal zones. The first survey from June 27 to June 28 indicated that there exists a mixed upper layer of 10—12 m. At the depth from 12 to 20 m there is a sharp pycnocline (the thermocline and halocline coincide). The surface temperature is homogeneous all over the Gulf which shows that the saltier water near the Finnish coast does not come from the deeper layers due to the recent upwellings.

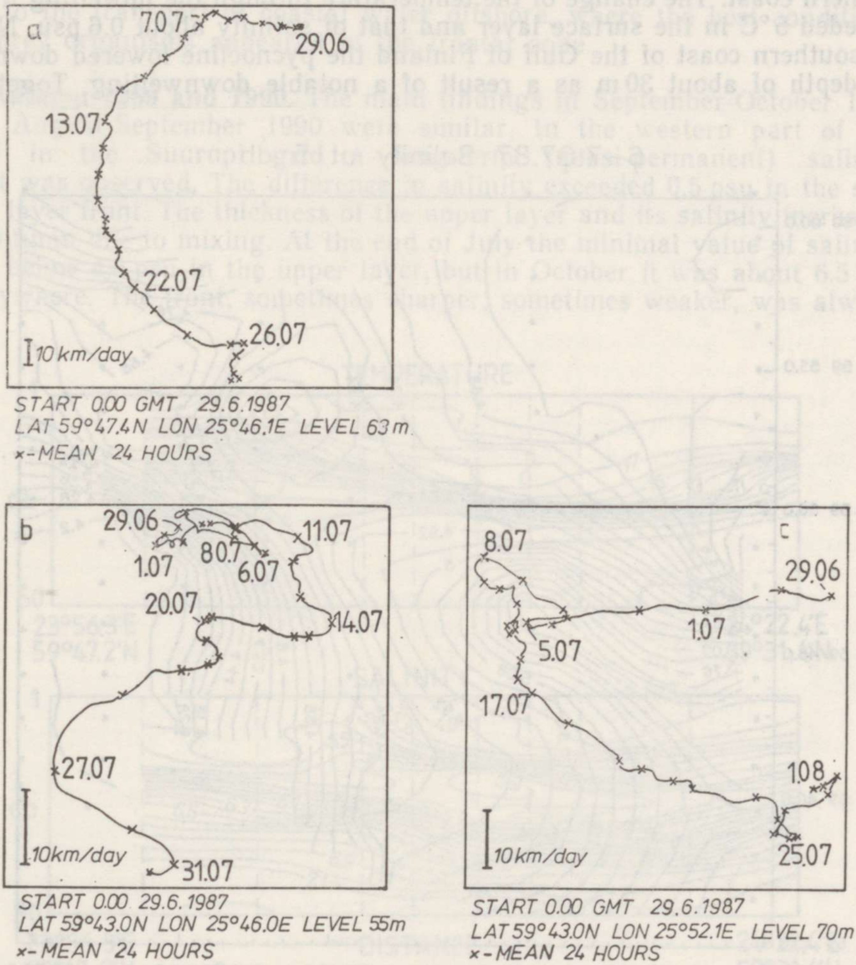


Fig. 6. Progressive vector diagram of the hourly mean currents in the near-bottom layers of the Gulf of Finland. *a* — currents at 63 m level at station B, *b* — currents at 55 m level at station A, *c* — currents at 70 m level at station C. See Fig. 1 for location of the stations.

The measurements on July 6—7 made evident the existence of salinity and temperature fronts in the middle of the grid area. The salinity and temperature distributions suggest that the frontal zone was the result of the penetration of a tongue-like fresher water mass from the southern coast to the north-east, like it was observed in May of the same year. The salinity distribution at the 5 m level is presented in Fig. 7, showing the fresher water tongue in the eastern part and that of the saltier water in the western part of the grid area. The currents in the frontal zone are directed parallel to the front to the north-east in the surface layer (Fig. 5*b*, offshore station, period June 5 to 8) carrying the coastal water offshore. Near the southern coast of the Gulf of Finland downwelling has taken place and thus the thickness of the upper mixed layer has increased up to 15—20 m. The rise of isopycnals in the 15—25 m layer near the coast and the fall in deeper layers implied to the formation of a coastal jet. In this period a distinct westward current is seen at the 70 m level, whereas in the upper layers an eastward current can be observed (Fig. 5).

The next survey on July 11—12 showed a well-developed upwelling in the northern part of the Gulf of Finland and a downwelling near the southern coast. The change of the temperature through the upwelling front exceeded 5 °C in the surface layer and that of salinity about 0.6 psu. Near the southern coast of the Gulf of Finland the pycnocline lowered down to the depth of about 30 m as a result of a notable downwelling. Together

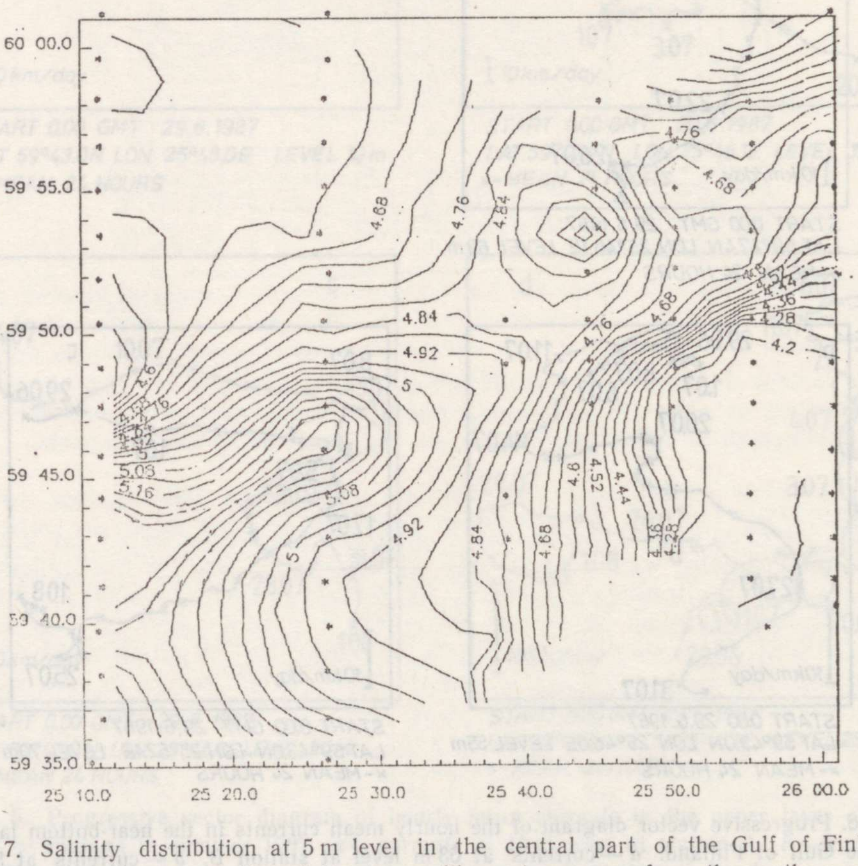


Fig. 7. Salinity distribution at 5 m level in the central part of the Gulf of Finland demonstrating the propagation of the tongue-like water masses from the southern coast to the north-east.

with the downwelling, a strong eastward jet current up to 35 $cm \cdot s^{-1}$ near the southern coast of the Gulf occurred. It was notable that the front of the coastal upwelling extended up to 35 km from the northern coast and about 25 km from the 20 db isobar. The submarine banks reaching up to 10 m, situated 15—20 km north-west of the observed upwelling front, are, however, more important than the coastline in the generation of upwelling in this region. The salinity and temperature front that was observed during the previous survey advected to the east.

The observed upwelling front and the front generated by the tongue-like transport of coastal water offshore had different impact on the hydrobiological fields during this period of the year. In the upwelling area an increase in mineral nitrogen but not in phosphorus was observed. The limiting factor phosphorus was very quickly consumed by phytoplankton and therefore its increase was not observable. In the upwelling front the primary productivity was much higher than in the surrounding areas due to the arrival of nutrients into the euphotic zone. In the coastal water front that appeared in the middle of the Gulf, mainly an increase in zooplankton and 0-group herring abundance was observed. The latter was obviously due to the transport of coastal water offshore, where the best conditions for prey organisms appeared in the frontal zone.

**5. Autumn 1989 and 1990.** The main findings in September-October 1989 and August-September 1990 were similar. In the western part of the Gulf in the Suurupi grid a long-term (quasi-permanent) salinity front was observed. The difference in salinity exceeded 0.5 psu in the surface layer front. The thickness of the upper layer and its salinity increased in autumn due to mixing. At the end of July the minimal value of salinity was below 4.5 psu in the upper layer, but in October it was about 6.5 psu everywhere. The front, sometimes sharper, sometimes weaker, was always

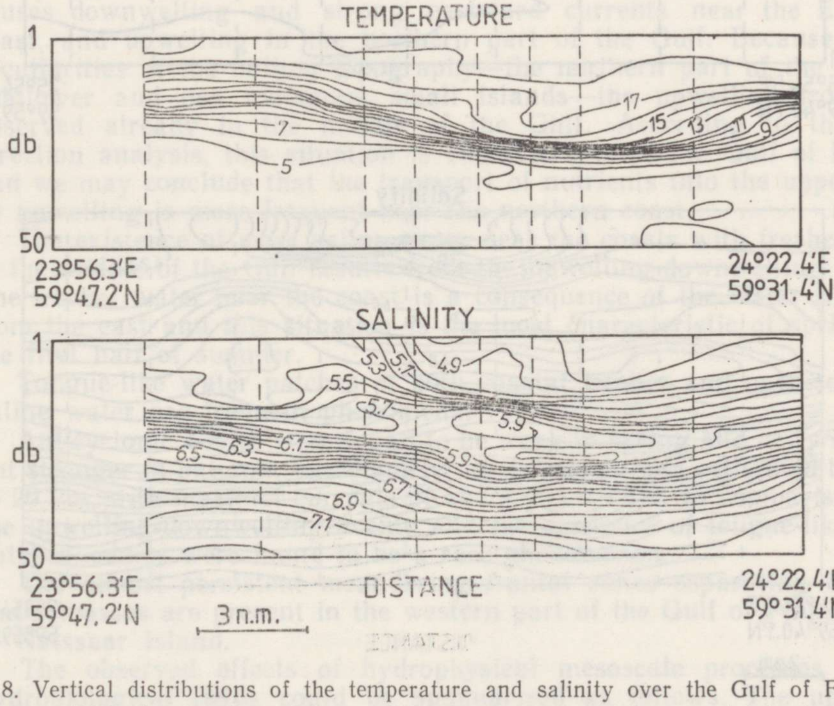


Fig. 8. Vertical distributions of the temperature and salinity over the Gulf of Finland in August 1990, showing the existence of the quasi-permanent front and intrusions near the frontal zone in the western part of the Gulf of Finland.

observable. The meandering and shifting of this salinity front was remarkable but it did not leave the investigation area south-west of Naissaar. In Fig. 8 sections of temperature and salinity are presented. We can observe a salinity front in the surface layer, but the temperature front is not well expressed. Like in autumn 1985 some stripes of anomalous water occur under the frontal zone; these are probably the result of great velocity gradients in this layer, transporting different water masses under one another.

The biological investigations showed also that this salinity front had existed for a long time because there were no remarkable changes in biological parameters.

During both experiments on the Lahemaa grid a fresh water stripe in the middle of the Gulf of Finland could be observed. One example of this is presented in Fig. 9. Such a fresh water stripe was observed many times during the second half of the year. That kind of water distribution may be the result of water transport from the east but it may also be due to upwelling events near the northern coast (induced by westerly winds)

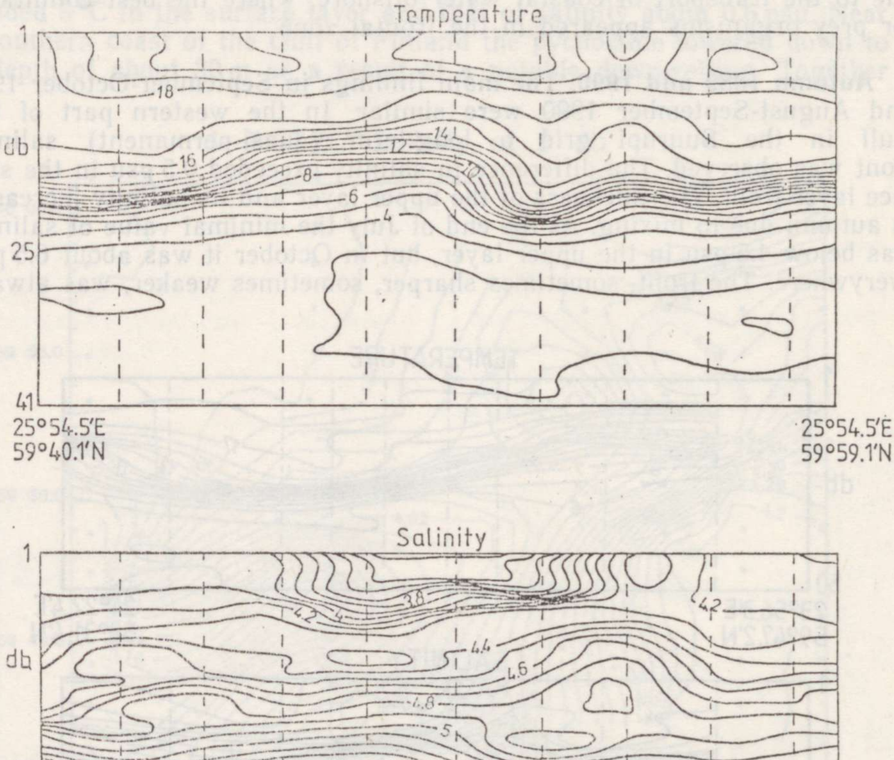


Fig. 9. Vertical distributions of temperature and salinity on Lahemaa grid in August 1990, demonstrating the fresh water stripe in the middle of the Gulf of Finland.

and near the southern coast (induced by easterly winds) during different periods. Most of the upwelled more saline colder water remains in the surface layer even in case of downwelling and warms up there. Thus, the upwellings induced by winds of opposite directions are the reason for the generation of fresher water stripes in the middle of the Gulf.

In October 1989 a strong cyclonic eddy with the diameter of about 18—20 km was observed west of Naissaar. The rise of isopycnals in the centre of the eddy generated an orbital geostrophic current whose velocity was estimated to be up to 25 $cm \cdot s^{-1}$.

The observed long-existing salinity fronts did not expose remarkable changes in biological parameters, evidently because there is no permanent transport of nutrients into the surface layer. The nutrients that had possibly been available after the generation of the front had been consumed too long ago to be expressed in the concentrations of the organisms of higher trophic levels. Some frontal areas were found to be in the destruction phase after enhanced productivity (deciding on increased number of saprophytic bacteria and their production).

## CONCLUSIONS

In winter the saline Baltic Sea water spreads under the ice cover in the deep layers to the eastern part of the Gulf of Finland as a result of the long-term thermohaline circulation. Thus, the wind-driven hydrophyisical processes do not effectively influence the main propagation of the saline water into the deep layers of the Gulf of Finland during winter-time. The water of the rivers forms a thin fresher water layer on the surface in consequence of which strong stratification can be observed in spring.

The hydrophysical processes in the central part of the Gulf of Finland are to a great extent controlled by wind stress. Strong westerly wind causes downwelling and strong eastward currents near the Estonian coast, and upwelling in the northern part of the Gulf. Because of the peculiarities of the bottom topography—the northern part of the Gulf is shallower and has numerous small islands—the upwelling front was observed already in the middle of the Gulf. According to the wind direction analysis, this situation is characteristic of the Gulf of Finland and we may conclude that the transport of nutrients into the upper layer by upwelling is more frequent near the northern coast.

The existence of more saline water near the coasts with fresher water in the middle of the Gulf results from the upwelling-downwelling system. The fresher water near the coast is a consequence of the water transport from the east and this situation is the most characteristic of spring and the first half of summer.

Tongue-like water patches of both coastal fresher and open-sea more saline water are frequent phenomena.

Anticyclonic eddies were found to be weak in spring and early summer but stronger in autumn. The diameter of the eddies was estimated to be up to 20 km, with maximal currents of about 25 $cm \cdot s^{-1}$. In comparison with the upwelling-downwelling events and the existence of tongue-like water patches, eddies were found to be a rare phenomenon.

The almost persistent meandering frontal zones separating different water masses are present in the western part of the Gulf of Finland west of Naissaar Island.

The observed effects of hydrophysical mesoscale processes on the hydrobiological fields could be summarized as follows. The upwelling area was always found to have high primary productivity, even in case of absence of higher concentrations of nutrients. Sometimes higher concentrations of only mineral nitrogen were found, convincing us of the high consuming rate of nutrients by phytoplankton and of the fact that phosphorus was the limiting factor in the Gulf of Finland. Higher primary productivity was also observed at the edge of the downwelling-induced coastal jet current (consequently there occurred vertical transport of nutrients with concentrations below instrumental sensitivity level). An increase in the abundance of zooplankton and 0-group herring was found in the frontal zones generated by coastal water offshore transport, probably due to better feeding conditions there. In the long-lived stagnant salinity fronts not higher productivity but enhanced destruction was observed.

## REFERENCES


Mälkki, P., Talpsepp, L. 1988. On the Soviet-Finnish experiment in the Gulf of Finland in May 1987: The results of hydrophysical measurements. In: CBO 16th Conference of Baltic Oceanographers. Kiel, 687—695.

Nõmmann, S., Kahru, M., Raid, T., Talpsepp, L., Vilbaste, K. 1987. Variability in the pelagic ecosystem of the Gulf of Finland: Effects of physical processes. In: CBO 15th Conference of the Baltic Oceanographers. Copenhagen, 436—445.

Talpsepp, L. 1987. On the jet current in the Gulf of Finland. In: CBO 15th Conference of Baltic Oceanographers. Copenhagen, 613—626.

Talpsepp, L., Nõges, T., Raid, T., Kõuts, T. 1993. Hydrophysical and hydrobiological processes in the Gulf of Finland in summer 1987: Characterization and relationship. — Cont. Shelf Res. In press.