Development of the Complex of Coordinated Models as a Basis for Operational Forecasting System for the Eastern Part of the Gulf of Finland

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***Abstract* - Paper describes the complex of hydrodynamic models that will serve as a basis for creating the operational forecast system for coastal zone of Russian part of the Gulf of Finland. The complex includes an atmospheric model, hydrodynamic models of the Baltic Sea as well as regional models with high spatial resolution. The test runs with SPBM (St.Petersburg Baltic Model) and NEVAM (Neva Bay model) showed their ability to simulate adequately circulation pattern in the Gulf of Finland and Neva Bay in different hydro-meteorological situations.**

I. Introduction

For the Baltic Sea area the forecasting atmospheric model HIRLAM with the special resolution of 18 km and three-dimensional sea model HIROMB with the special resolution of 5.5 km are used as parts of the integrated operational system. However, the resolution used in the sea model is not enough for the adequate description of coastal shallow water areas (the Eastern Fulf of Finland) and small water bodies (Neva bay, Luga bay, Vyborg bay, skerry areas, port areas, etc.). Thus, main idea is to create an integrated complex of coordinated hydrodynamic and ecosystem models as a basis for predicting the hydrodynamic and environmental state of the Gulf of Finland waters, including the prediction of catastrophic events (floods, oil spills, accidental wastewater discharges, eutrophication). This complex will be the fundamental basis for operational system for monitoring and forecast of the state of water bodies in the North-West of Russia, using the modern methods of weather forecast and hydrodynamic models for water bodies. A first step in this direction has been done within the national project of the Russian Foundation for Basic Research, grant 05-05-08018, where the prototype of the complex including the easternmost part of the Gulf of Finland, the Neva Bay and the Lake Ladoga has been developed [1]. In this paper the further development of this complex with special emphasis on the Gulf of Finland will be described.

II. Description of the Model Complex

The general structure of the regional complex of coordinated models is shown in Fig.1. This complex includes main models (in solid contour): atmospheric mesoscale model MM5, which is working operatively in Hydrometeorological Research Centre of Russian Federation and is used in operational practice in Saint-Petersburg Centre for Hydrometeorology and Environmental Monitoring, Gulf of Finland model (GOFM) [2] and Neva Bay model (NEVAM) with super-high spatial resolution of about 50m [3], wind model SWAN (Simulating WAves Nearshore), developed by the Technical University of Delft, Netherlands, as well as supplemental models (in dotted contour): HIROMB (HIgh Resolution Operational Model for the Baltic Sea) and SPBM (St.Petersburg Baltic Model) with the resolution of 4 km [2].

Apart from these models, the complex includes databases of input data (initial and boundary conditions), as well as blocks of information exchange between the models. Operational model of the Baltic Sea HIROMB was developed and is used by international consortium with the Swedish Meteorological and Hydrological Institute (SMHI) as a coordination centre. In the present study the results of this operational model forecasts will be used for setting the boundary conditions at the entrance to the Gulf of Finland. The SPBM is used for calculating the initial conditions in the Gulf of Finland.

The complex will be working in the following way. Atmospheric model MM5 is producing the forecast of atmosphere state for several days ahead using the ECMWF (European Centre for Medium-range Weather Forecasting) and NCAR (National Centre for Atmospheric Research, USA) results of re-analysis as initial and boundary conditions. Calculated fields of atmospheric characteristics (surface pressure, wind, temperature and air humidity, precipitation, cloud cover) together with the data on sea level, water temperature and salinity at the open boundary of the Gulf of Finland from HIROMB (or SPBM) and observations data on rivers' runoffs and temperatures are used by the GOFM for the forecast of hydrological characteristics in the Gulf. Forecast of hydrological characteristics in the Neva Bay on the high resolution grid is carried out by the NEVAM model using data on atmospheric characteristics from MM5, data on sea level, temperature and salinity on the open boundary of the model area located in the Eastern Gulf of Finland from GOFM, and observational data on Neva discharge and temperature. Wind wave parameters in the Gulf of Finland and Neva Bay are calculated by the SWAN model using information on surface wind from MM5 model and on surface

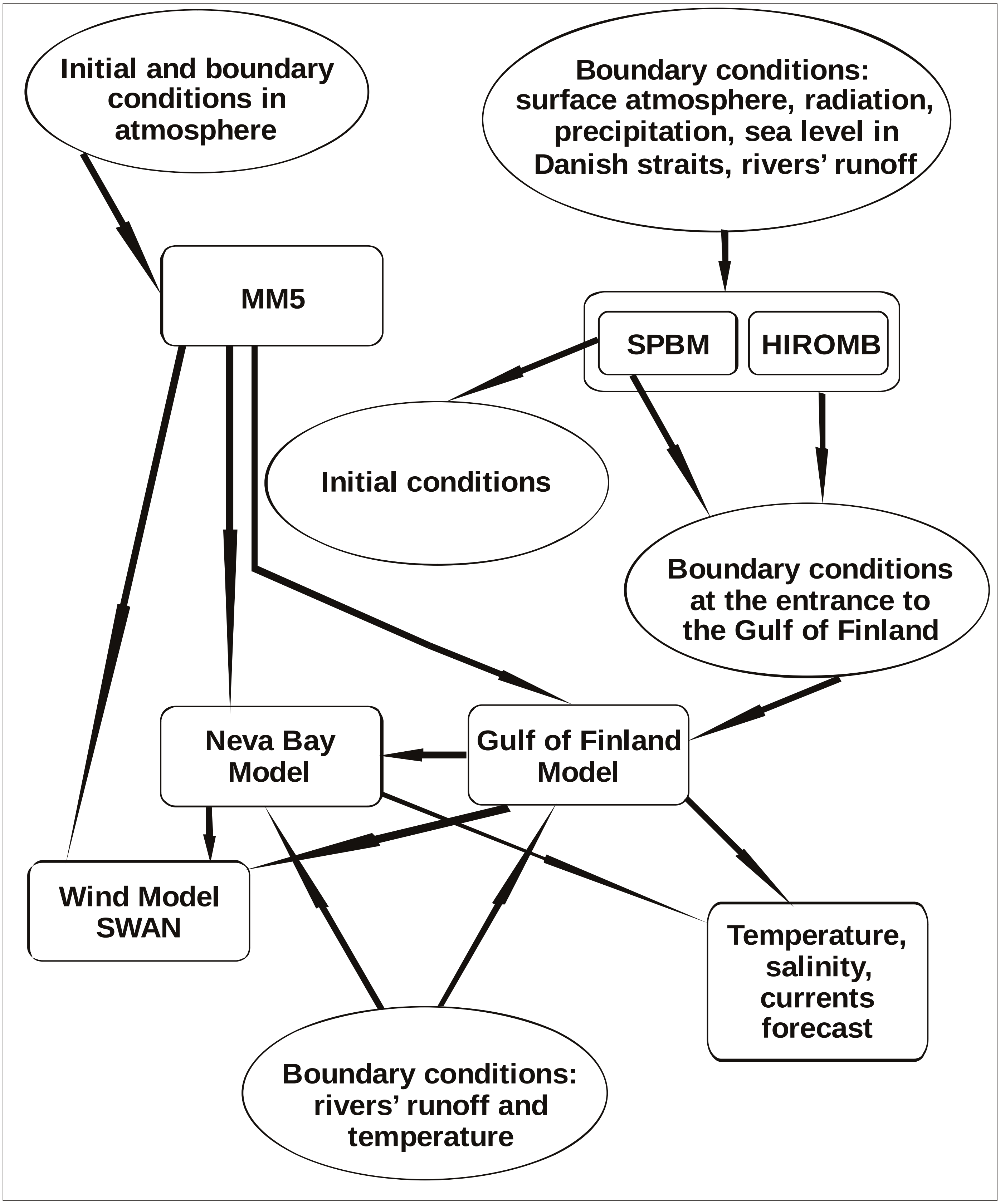

Fig.1 Block diagram of the model complex.

currents from GOFM and NEVAM. Initial conditions for calculation of hydrological characteristics in the Gulf of Finland will be produced by the SPBM.

III. Results

For testing of the model complex it is planned to carry out of hydrological characteristics for the period of several days in the Gulf of Finland and Neva Bay in the case of no strong storm surges as well as in the extreme conditions (cases of floods in Saint-Petersburg) for various seasons. To estimate the forecast quality, the following data will be used: data on changes of the sea level at gauge stations of St.Petersburg Hydrometeorological Research Centre located on the coast of Neva Bay and the Gulf of Finland; data on water temperature and salinity available from various sources; as well as unique data on long-term changes of current velocities in the Neva Bay collected by Institute of Limnology Russian Academy of Science during summer 2004 with the use of autonomous current meters. The selection of periods for calculations is governed by the availability of observational data for the comparison with model results, as well as by the availability of extreme conditions. Analysis of real meteorological information showed that over 10 floods were observed in St.Petersburg during 2002-2007. It is this period that was selected for the analysis. Some examples of testing of different components comprising the model complex will be given below.

For the calculation of initial conditions during the selected period the Baltic Sea model SPBM was used. Model was integrated on spherical grid 4′×2′ with 78 levels non-uniformly vertically arranged, with the resolution of 2m in the upper 30m layer. The 6-hour fields of cloud cover, precipitation, surface wind velocities, temperature and air humidity for the period of 2002-2007 taken from re-analysis of atmospheric circulation [4] were assigned as atmospheric forcing. Sea level, water temperature and salinity in the Danish straits were set on the basis of observations data. At the lateral boundaries of the area, mean monthly values of runoff of all major rivers running into the Baltic Sea were set whereas 'no heat flux' condition was used for water temperature.

Figs. 2 and 3 show the calculated distributions of surface currents velocity, ice cover thickness, surface temperature, and surface and bottom salinity in the Gulf of Finland in March and August, 2007. The results are in a good agreement with the existing ideas: 1) circulation in the Gulf during summer period is more intense than during winter with ice cover, and it has cyclonic character in August; 2) surface temperature distribution in August is almost uniform with the slight temperature increase in the coastal zone, in winter, surface temperature is close to the temperature of water freezing everywhere except small areas of thin ice and open water near the southern coast of the Gulf where it becomes 1-1.5 °C higher; 3) surface salinity distribution is characterized by its increase from 0‰ at the Neva mouth to 4-5 ‰ at the entrance to the Gulf and by its decrease on 1.5-2.0‰ from southern to northern coast, that is due to spreading of Neva freshwaters along the northern coast of the Gulf; 4) saline Baltic waters penetrate into the Gulf in the bottom layer along its central axis and according to the 6‰ isohaline reach up 27-27.5° E.

The evident disadvantage of the simulation is too low temperatures in the Neva estuary in August that is apparently due to the use of incorrect boundary condition for temperature (absence of heat exchange). It is planned in future to set Neva temperature according to observational data.

The NEVAM was used for forecasting the hydrological regime in the Neva Bay under atmospheric forcing prescribed from forecast of atmospheric parameters by model MM5. Three situations for different periods (initial time was respectively 00:00 GMT 22.06.2006, 00:00 GMT 19.07.2004, and 13:00 GMT 26.10.2006) were simulated. In the latter period, flood in St.Petersburg and Neva Bay was observed. Water level changes at the open western boundary of model domain were prescribed from the forecast performed on the basis of CARDINAL system [5]. The initial hydrological fields were given from NEVAM' simulation of Neva Bay in the period from April to October 2004 performed using, as external forcing, observations on atmospheric parameters and the discharge of the River Neva.

According to Fig.4, where calculated and observed water level at stations 'Institute of Miners' and 'Kronshtadt' for the situation of flood in St.Petersburg is shown, modeled changes of water level follow those prescribed at the western boundary lagging about 1 and 3 hours respectively for stations 'Kronshtadt' and 'Institute of Miners'. As an analysis of all above situations was shown, if prescribed water level at the western boundary fits its observed changes, the agreement between model and observations at the above stations turns out to be satisfactory (as, for example, it was for flood situation 26.10.2006).

Fig.5 shows calculated and observed current velocities in 3 locations in the Neva Bay for the period 22-24.06.2004. As seen, both direction and module of calculated current velocity fit observations rather well at stations 184 and 185 located far from the coastal zone. At the same time, at station 183, located near the end of dams of navigation canal, the module of model currents turned out to be underestimated in 1.4 times and their direction, to be unmatched the direction of observed currents. As a detailed analysis of modeled currents showed, currents in the vicinity of Station 183 is strongly variable because of the instability of strong current flowing out from the navigation canal bounded by dams in the Neva Bay.

IV. Conclusions

The GOFM is, in essence, a cut SPBM model realized on the grid of higher resolution. Thus, these calculations are a good test of GOFM adequacy. Although a comparison with observations was not performed, the results obtained do not contradict common ideas about the circulation pattern and thermohaline structure in the Gulf of Finland. Test runs performed with the NEVAM demonstrated its ability to simulate adequately water level and currents in the Neva Bay in different hydro-meteorological situations including events of flood. This as well as testing of other parts of the complex performed in [1] is encouraging prerequisites of future successful work of the complex to be developed.

The complex forecast system to be created should have a data assimilation capacity to achieve high quality of forecast. It is also important that the forecasting system for the Gulf of Finland and Neva Bay are planning to develop further in collaboration to the Baltic countries.

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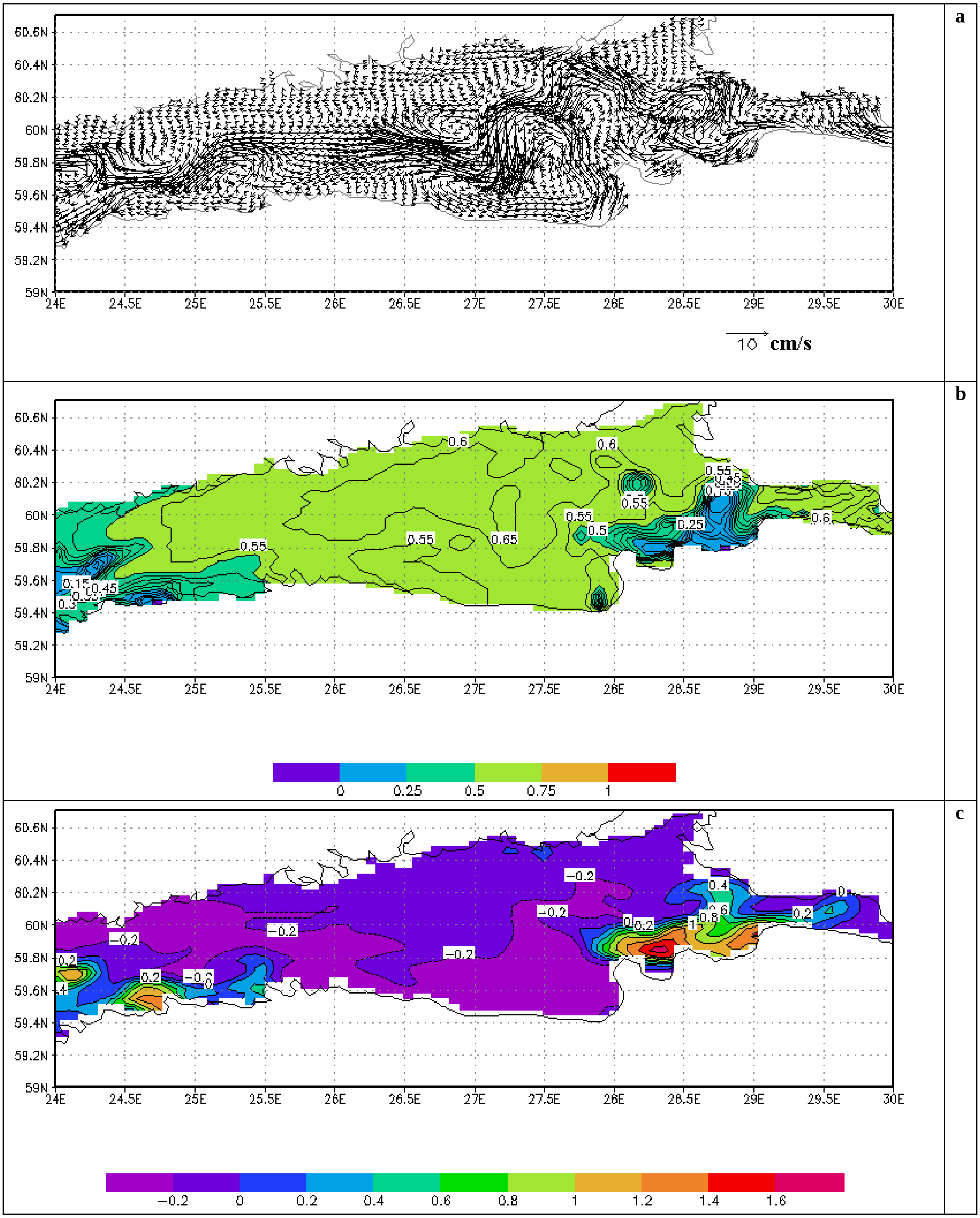
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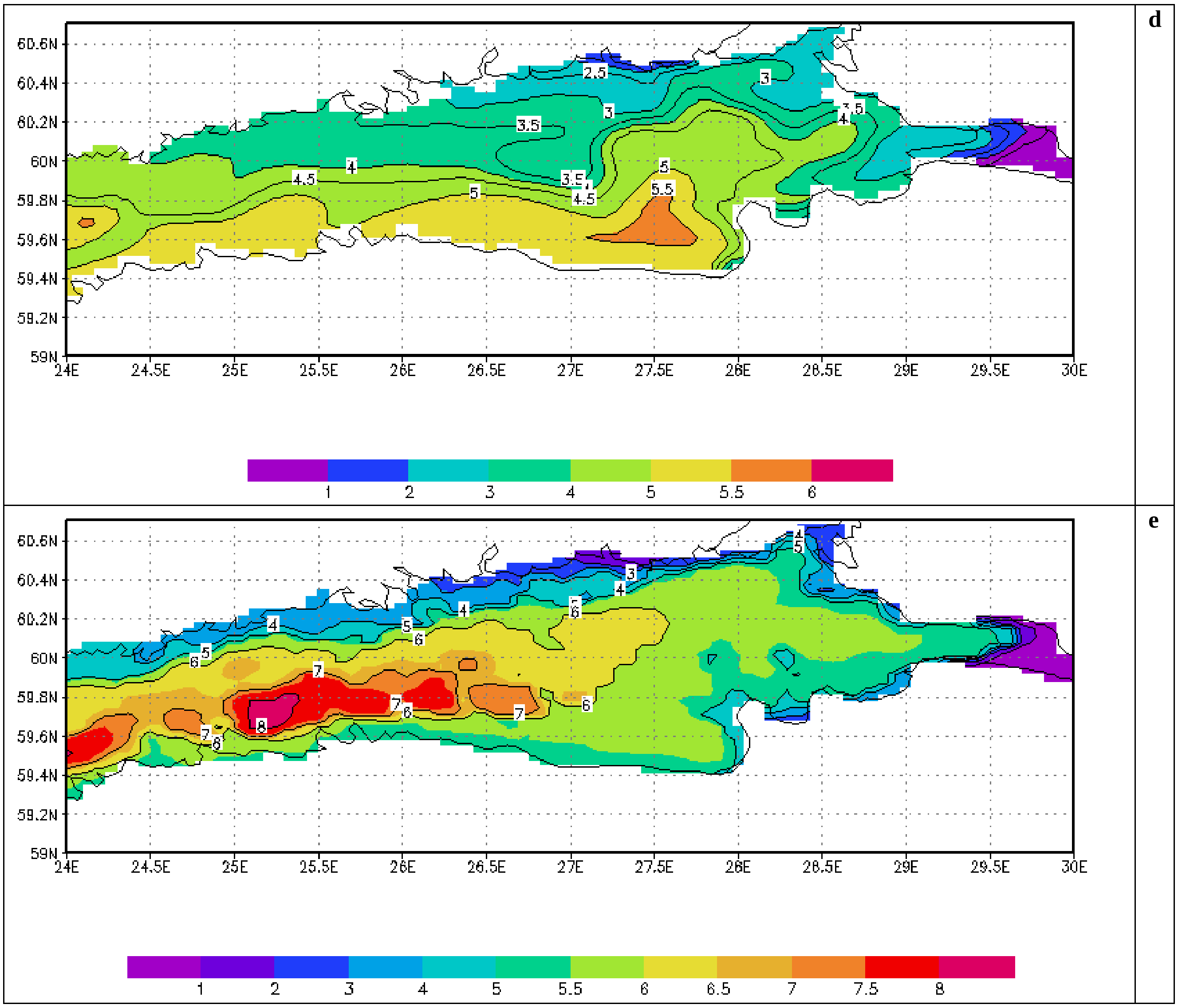
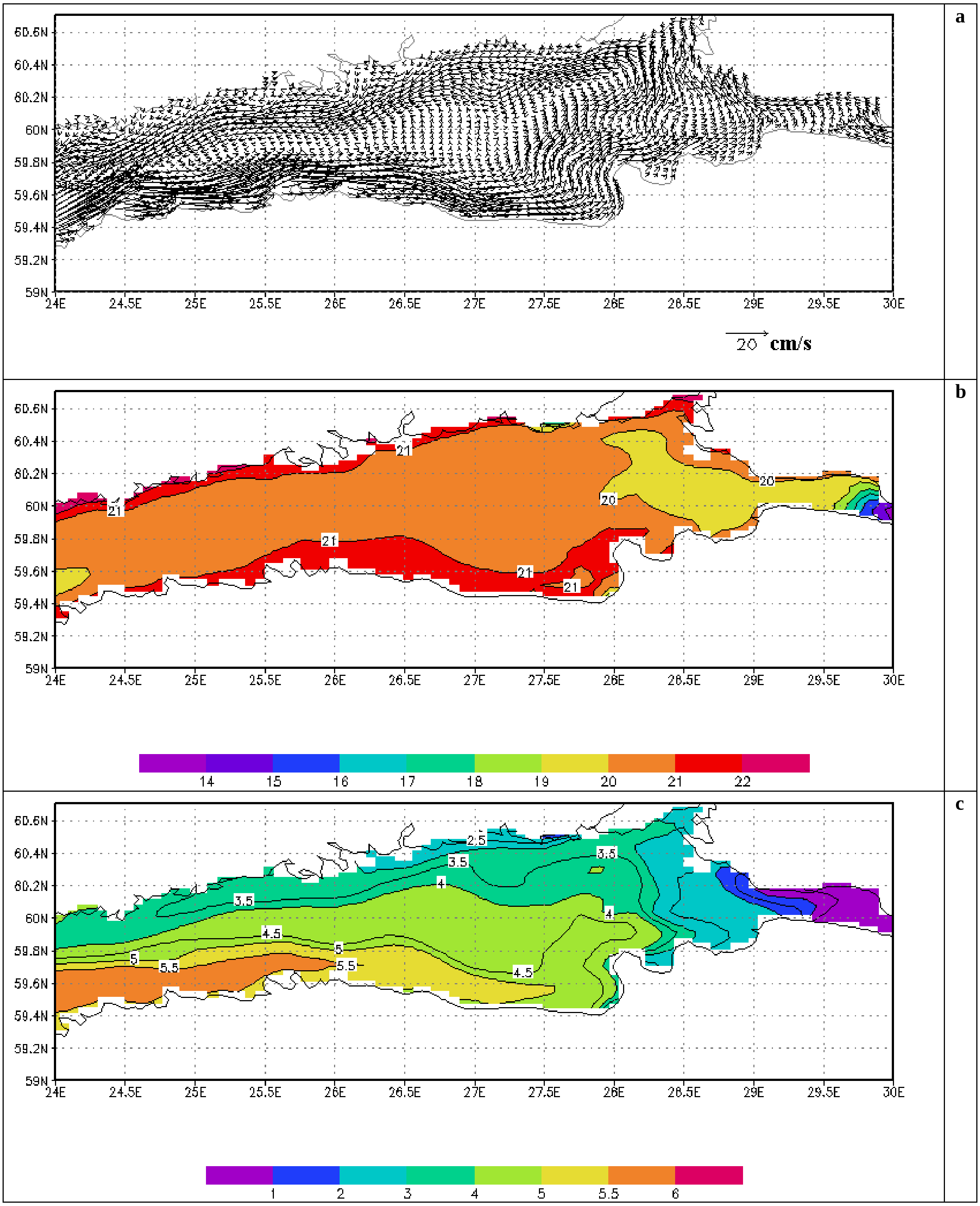


Fig.2 Calculated distributions of surface currents velocity, cm•c^{-1}(a); ice cover thickness, cm (b); surface temperature, °C (c); surface (d) and bottom (e) salinity, ‰ in the Gulf of Finland, averaged for the period 1-5 March, 2007.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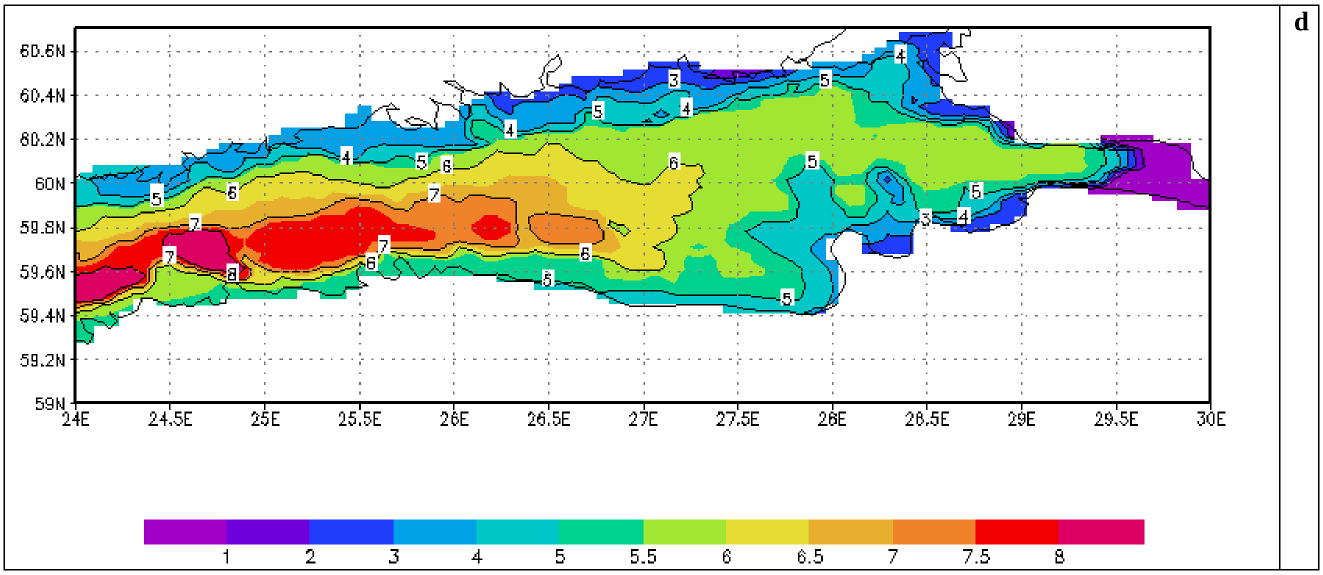

Fig.3 Calculated distributions of surface currents velocity, cm•c^{-1}(a); surface temperature, °C (b); surface (c) and bottom (d) salinity, ‰ in the Gulf of Finland, averaged for the period 1-5 August, 2007.

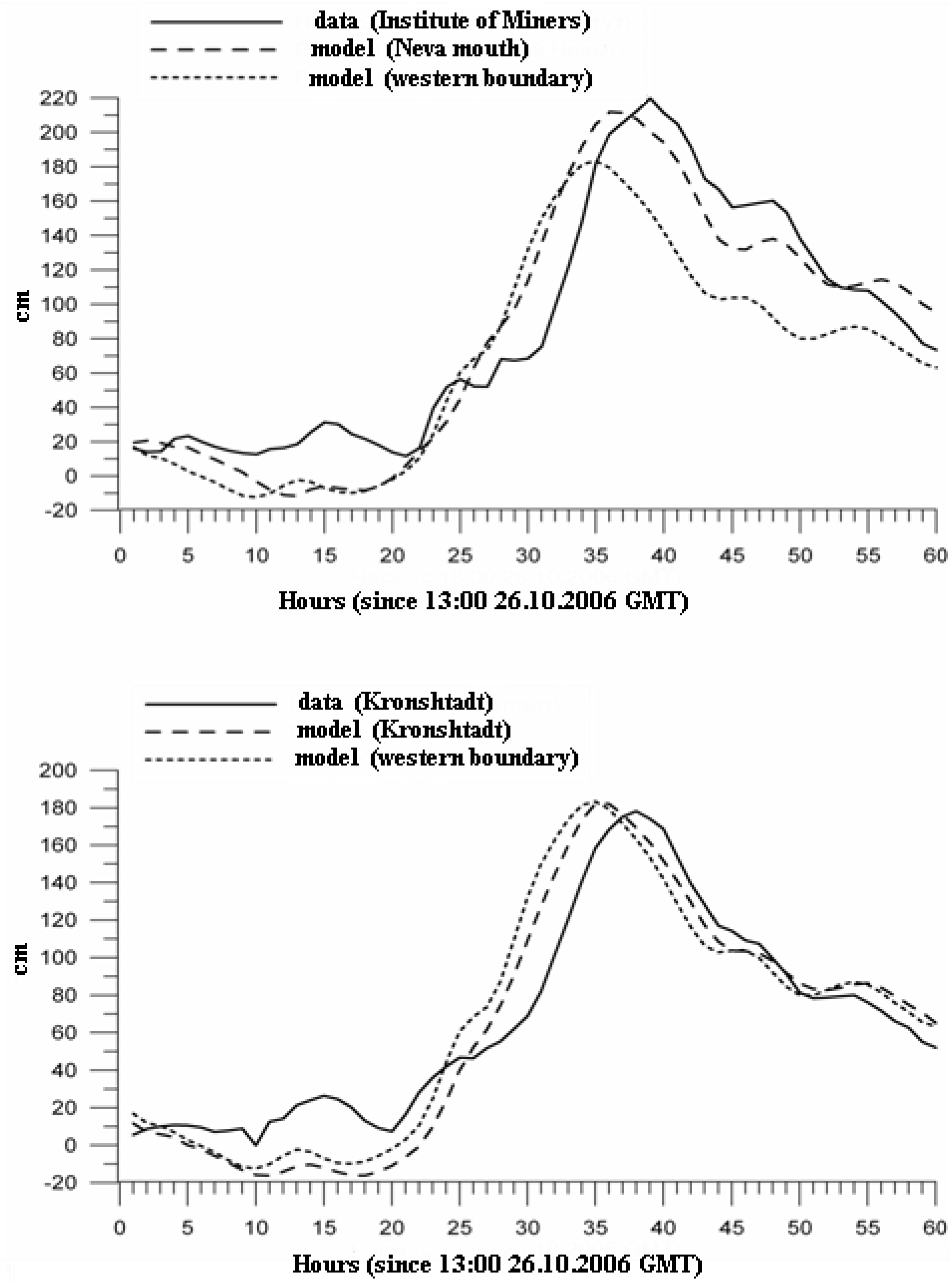

Fig.4. Model simulation of flood in St.Petersburg, the 28th October 2006: forecasted (large dashed lines) and observed (solid lines) water level at stations 'Institute of Miners' and 'Kronshtadt' in the period from October 26 to October 28 2006. The prescribed water level at the western boundary is shown by small dashed lines.

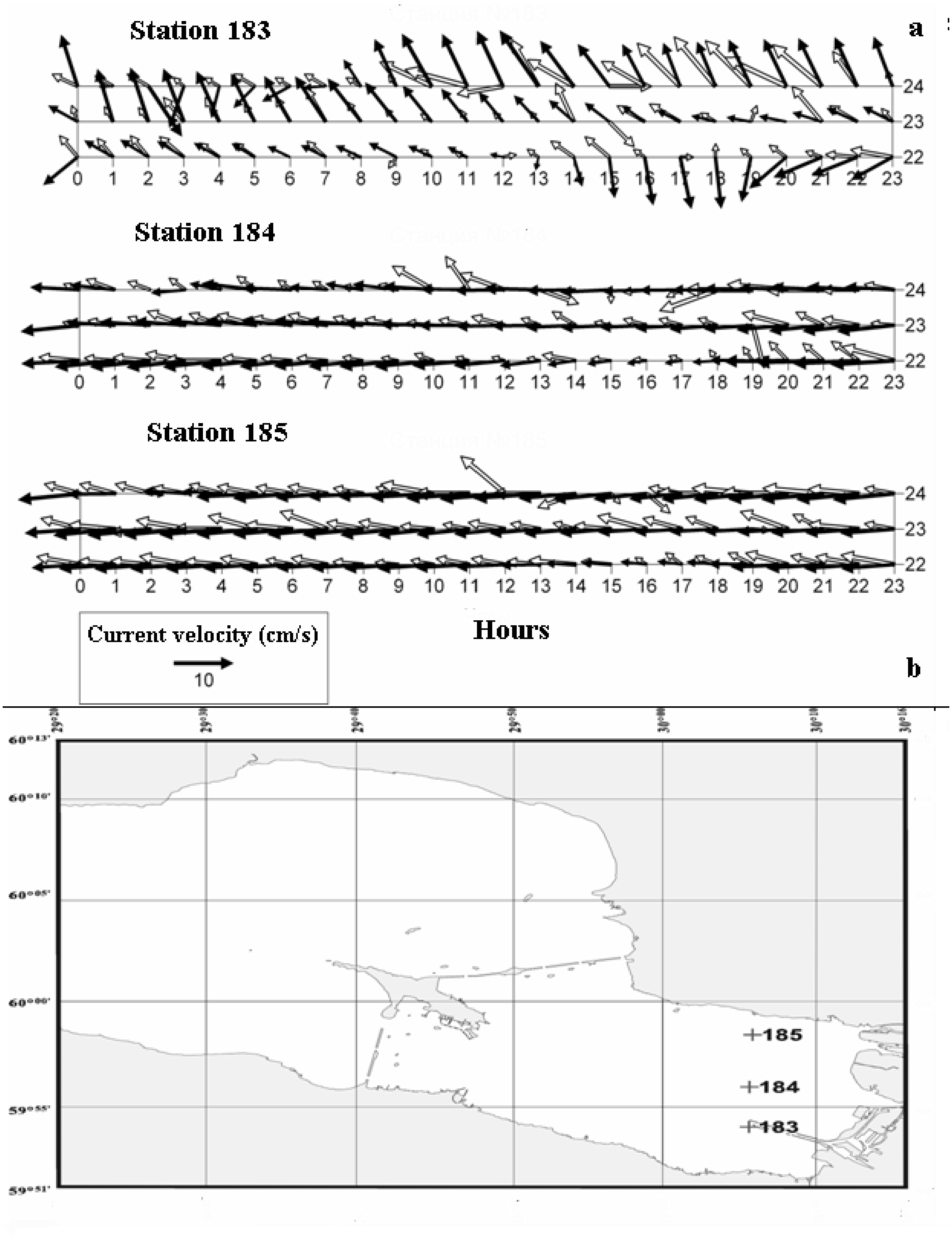

Fig.5. a- comparison of calculated (black arrows) and observed (white arrows) current velocities measured in the Neva Bay 22-24.06.2004 by the Institute of Limnology, Russian Academy of Sciences. Vectors of current velocity are hour instant values, b – the disposal of stations within the Neva Bay.