BALTEX

Baltic Sea Experiment

World Climate Research Programme / Global Energy and Water Cycle Experiment
WCRP GEWEX

Fourth Study Conference on BALTEX

Scala Cinema
Gudhjem, Bornholm, Denmark
24 - 28 May 2004

Conference Proceedings

Editor: Hans-Jörg Isemer

Jointly organised by
Risø National Laboratory
Technical University of Denmark
GKSS-Forschungszentrum Geesthacht GmbH

International BALTEX Secretariat
ISSN 1681-6471
Publication No. 29
May 2004

Calculation of Extreme Water Levels in the Eastern Gulf of Finland

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1. Introduction

Evaluation of extreme water level rises has very important practical meaning. For example, exploration of such objects as Leningrad Nuclear Power Station, located in the Koporskaya Bay of the Gulf of Finland (Fig.1), needs knowledge of extreme water levels with return period up to 10000 years. Water levels in Koporskay Bay (station Staroe Garkolovo) were measured in 1924-1940 and in 1957-1986. This time series is too short. Kronshtadt is the longest time series in this area (1806-1817, 1824, 1835-1871, 1873-present). Different statistical methods were applied to about 200 years long data in Kronshtadt to receive extreme values in the Koporskaya Bay (*Nudner et al.,* 1998). For 10000 years return period the values were in the range from 330 to 430 cm (in the Baltic Sea system). This difference is too high for making engineering solutions. Therefore hydrodynamical simulation of extreme storm surge in the Baltic Sea was applied to check these statistical results.

This work was sponsored by the Direction of the Leningrad Nuclear Power Station.

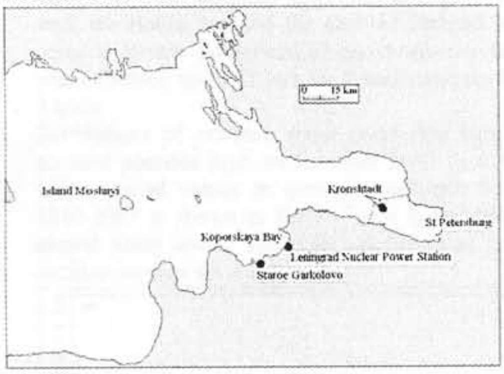

Figure 1. Map of the Eastern Gulf of Finland.

2. Numerical Model

Simulations were made with the CARDINAL modeling system *Klevanny K.A. et al.* (1994). This system allows to generate numerical models of arbitrary water objects using boundary-fitted curvilinear co-ordinates and to solve there 2D and 3D equations of water dynamics and transport of dissolved and suspended sediments. In the 2D case the shallow water equations are solved, while in the 3D case the Reynolds equations with the hydrostatic assumption and different schemes for turbulent stresses are used.

With this system 2D model of the Baltic Sea BSM3 was constructed. The model grid consists of 205 x 297 points. Sensitivity analysis proved that this resolution is enough for water level simulations. It was found that the model results are not very sensitive to values of the bottom friction and eddy viscosity coefficients. It can be found that the wind stress over the Baltic Sea is of major importance for water dynamics as compared with the atmospheric pressure gradients. Therefore in these simulations the atmospheric pressure gradients were ignored. The second order advection terms were also ignored. Of primary importance here is the correct estimation of the wind drag coefficient. Its value was found with the test runs for the storm surge of 15 October 1955. Wind was assigned from data of 72 weather stations along the Baltic Sea coast. The best result for St.Petersburg was received with the wind drag coefficient $C_D=(0.63+0.046|W|)\cdot 10^{-3}$.

3. Results

Weather maps, which correspond to the highest water level rises in St.Petersburg, were selected from the archive of the North-West Hydrometeorological Service of Russia (NWHMS). They include cases of 23 September 1924 (380 cm, #2 in the City history), 15 October 1955 (293 cm, #4), 29 September 1975 (281 cm, #5), 15 October 1929 (258 cm, #15). Flood #1 was in 1824 (about 421 cm) and #2 was in 1777 (321 cm). An example of weather map for the flood of 1924 is shown in Fig.2.

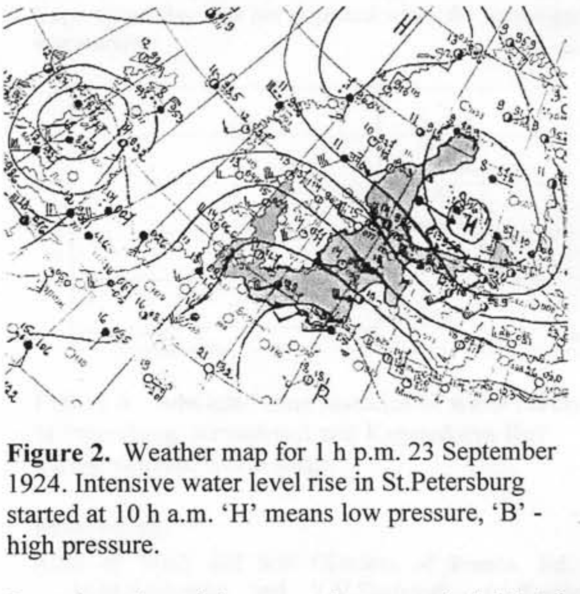

Figure 2. Weather map for 1 h p.m. 23 September 1924. Intensive water level rise in St.Petersburg started at 10 h a.m. 'H' means low pressure, 'B' - high pressure.

From the review of these maps it was concluded that for the Eastern Gulf of Finland the most dangerous wind field over the Baltic Sea is as shown in Fig.3. Wind over all the sea drags water into the Gulf of Finland. This situation is possible when the center of a cyclone is located over the southern part of Finland and there is a deep dish over the Baltic Proper. The run-up will be higher if such situation will stay for a longer time. Usually deep cyclones propagate quickly to the east and it prevents St.Petersburg from even more catastrophic floods. Of primary importance is extreme wind speeds over the shallow eastern extremity of the Gulf of Finland.

Extreme wind velocities were determined from *Atlas of wind...* (1997). According to it, maximum wind speed with 2 minutes averaging over the Gulf of Finland with 10000 years return period is 35-40 m/s. Wind in gusts can reach 40-60 m/s. The method, which was used in these estimations, is given in *Semenova* (1997). There is no information about duration and space distribution of such extreme winds. According to expert estimation of meteorologists of the NWHMS wind speed of 25 m/s over the Baltic Sea can continue up to 24 hours and wind speed of 35 m/s up to 3 hours. Data on wind during storm surge of 15 October 1955 shows that over the sea wind with velocity more than 20 m/s can continue up to 36 hours, and with velocity exceeding 30 m/s for up to 12 hours. These data also indicate that for a short period wind may be as high as 45 m/s.

Figure 3. Distribution of wind directions over the Baltic Sea, which corresponds to extreme storm surge in the Gulf of Finland.

Based on these estimations the following wind distribution was chosen for the extreme water level simulations. Wind directions were assigned according to Fig.3. Wind velocity over the Baltic Sea and the Gulf of Finland was assigned equal to 25 m/s. To the east of Island Moshnyi wind velocity was increased up to 35 m/s for 2 hours and up to 45 m/s for 1 hour.

Simulations of extreme water level rise should take into account possible high mean water level in the Baltic Sea. Mean annual values in station Kronshtadt for the period 1810-2001 is shown in Fig.4. There is no evident trend in annual water levels. Therefore, global trend in water level oscillations was set equal to zero.

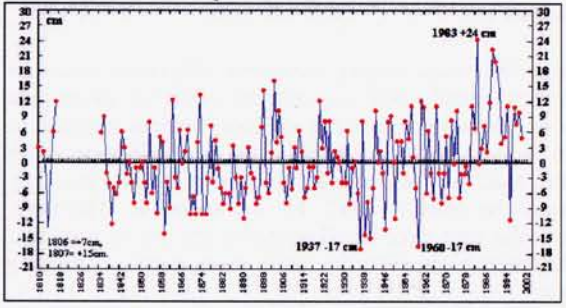

Figure 4. Mean annual water levels in Kronshtadt in 1810-2001.

The seasonal water level variations are significant. As it is noted in *Jensen et al.* (1998) mean water level in the Baltic reflects mean water level in the North Sea. Water exchange through the Danish Straits is the main reason of the seasonal variations of the Baltic water level. Maximum monthly mean water level in Kronshtadt in the 20th century was 77 cm in March 1990. Fig.5 shows time history of water levels in Kronshtadt in this year. Taking into account that due to prevailing western winds mean water level in the Eastern Gulf of Finland is higher than in the Baltic Proper, it is reasonable to assign 60 cm as mean water level in the Baltic Sea during extreme storm surge.

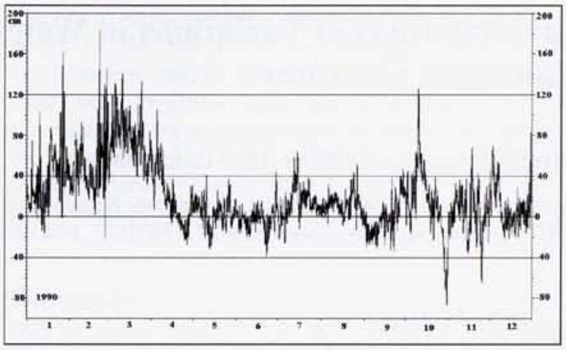

Figure 5. Water level in Kronshtadt in 1990.

Results of simulation of storm with the parameters defined above are shown in Fig.6. As it is seen from this figure simulated maximum water level rise in St.Petersburg equals to 606 cm, 520 cm in Kronshtadt and 434 cm in Staroe Garkolovo, near Leningrad Nuclear Power Station. This result is in very good agreement with the upper limit of different statistical evaluations. Namely, 430 cm was received for Staroe Garkolovo by Hydroproject Institute (*Nudner et al*, 1998). Such high water level for Koporskaya Bay was not expected when the investigation was started.

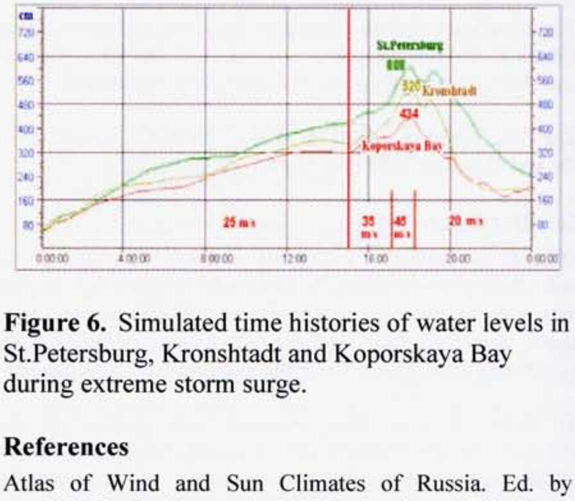

Figure 6. Simulated time histories of water levels in St.Petersburg, Kronshtadt and Koporskaya Bay during extreme storm surge.

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