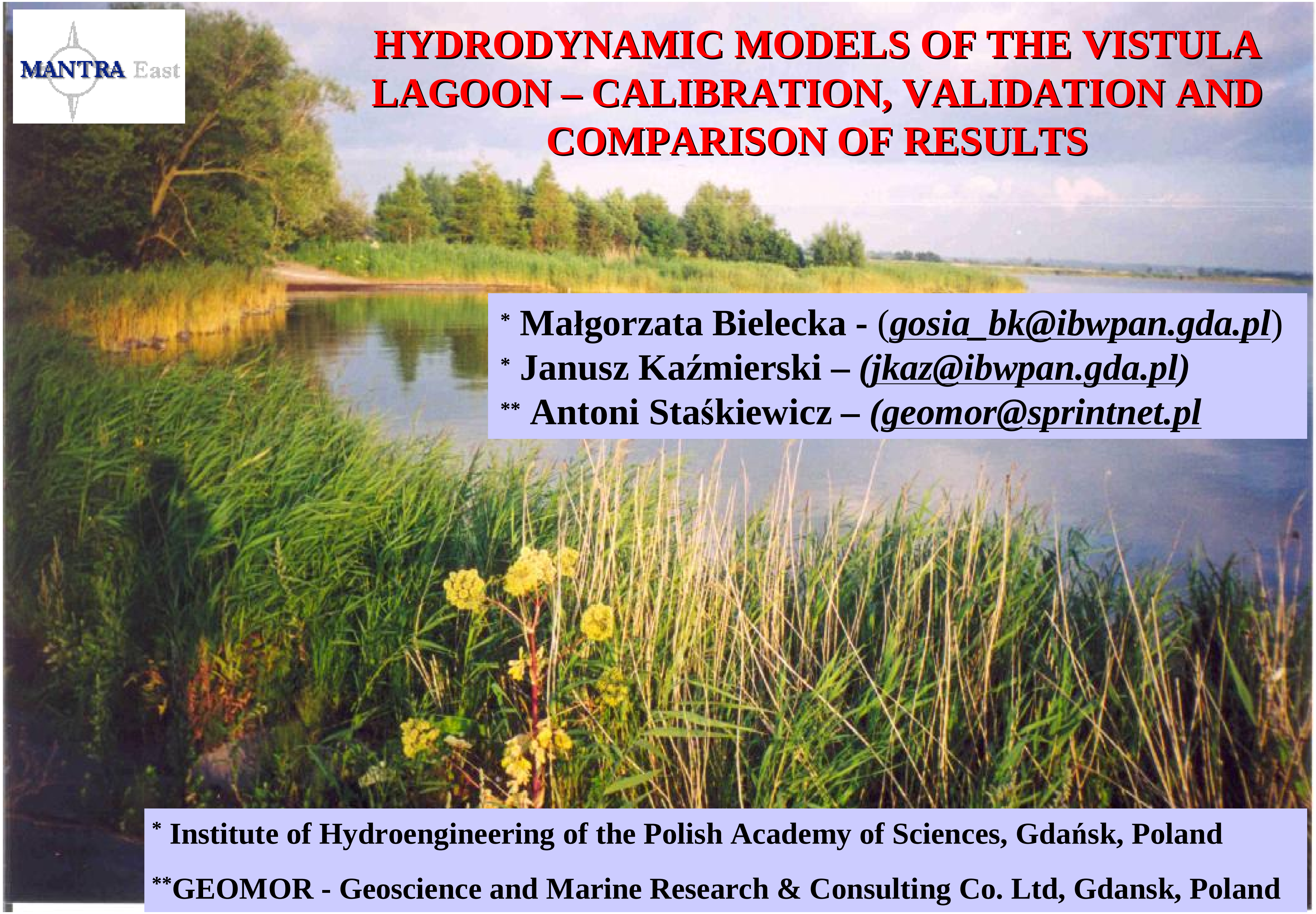

MANTRA East

HYDRODYNAMIC MODELS OF THE VISTULA LAGOON – CALIBRATION, VALIDATION AND COMPARISON OF RESULTS

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INTRODUCTION

- Delft3D Flow and 2D Mike 21 hydrodynamic models have been elaborated for the Vistula Lagoon within the MANTRA-East project
- The hydrodynamic models are a base for water quality Delft3D WAQ and Mike 21 models
- Water quality models are used to assess water quality status of the Lagoon and potential of WQ improvement in future
- Calibration and validation results and salinity distributions for years 1998 - 2000 will be presented
- Accuracy of simulation results with use of 3D and 2D models will be assessed

THE VISTULA LAGOON AND ITS DRAINAGE BASIN

•**Area**: 838 km^2 (Russia 56%, Poland 44%)

•**Length**: 90 km

•**Width**: 10-19 km

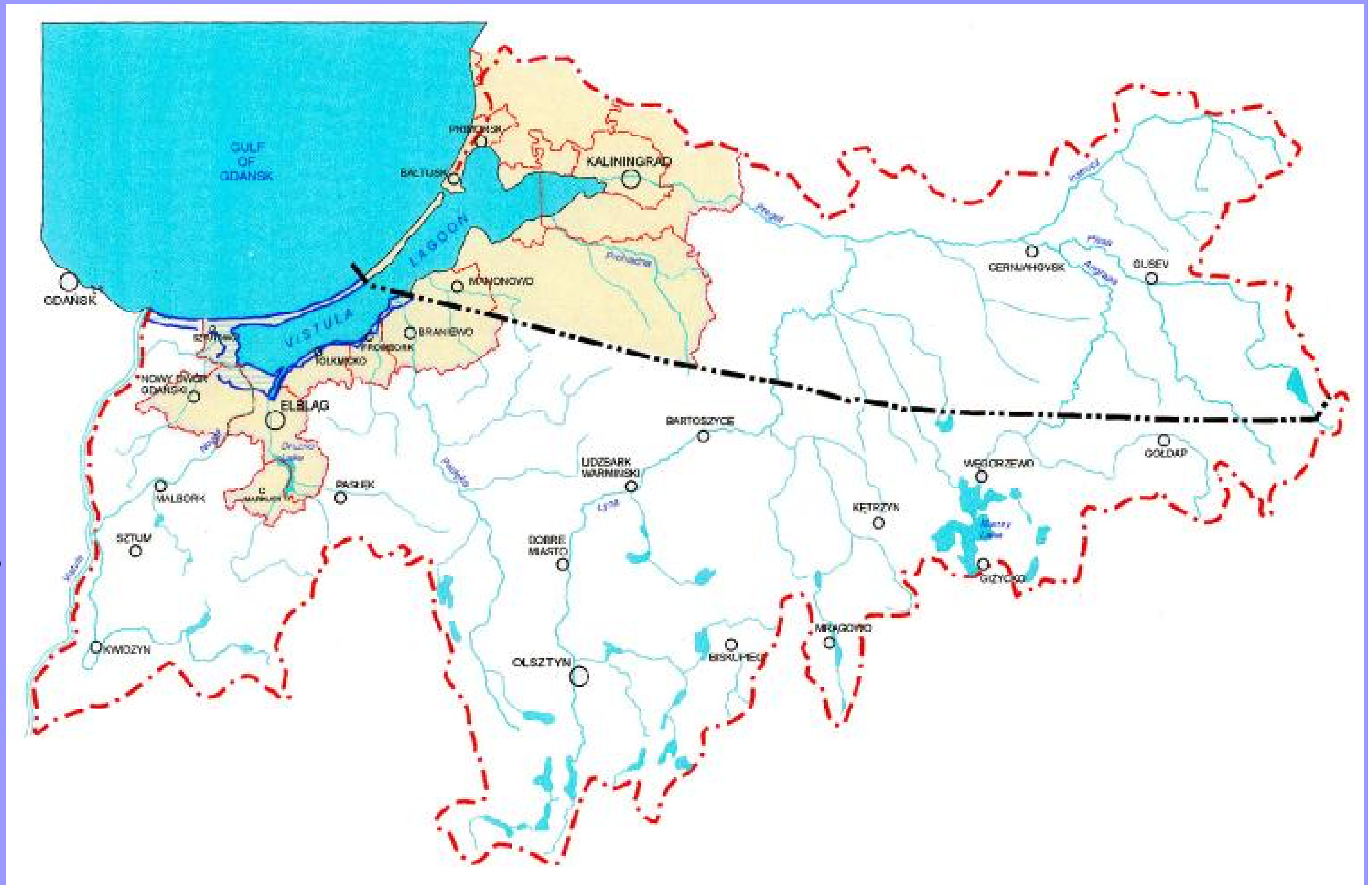
•**Avr. depth**: 2.7 m

•**Total drainage area**: 23,871 km^2

•**Salinity**: 0.1 - 4.5 PSU

•**Water volume**: 2.3 km^3

•**Avr. retention time**: 6 months



•**Largest rivers** within the drainage area: Pregola, Prokhladnaya, Elbląg, Pasłęka, Nogat, Bauda

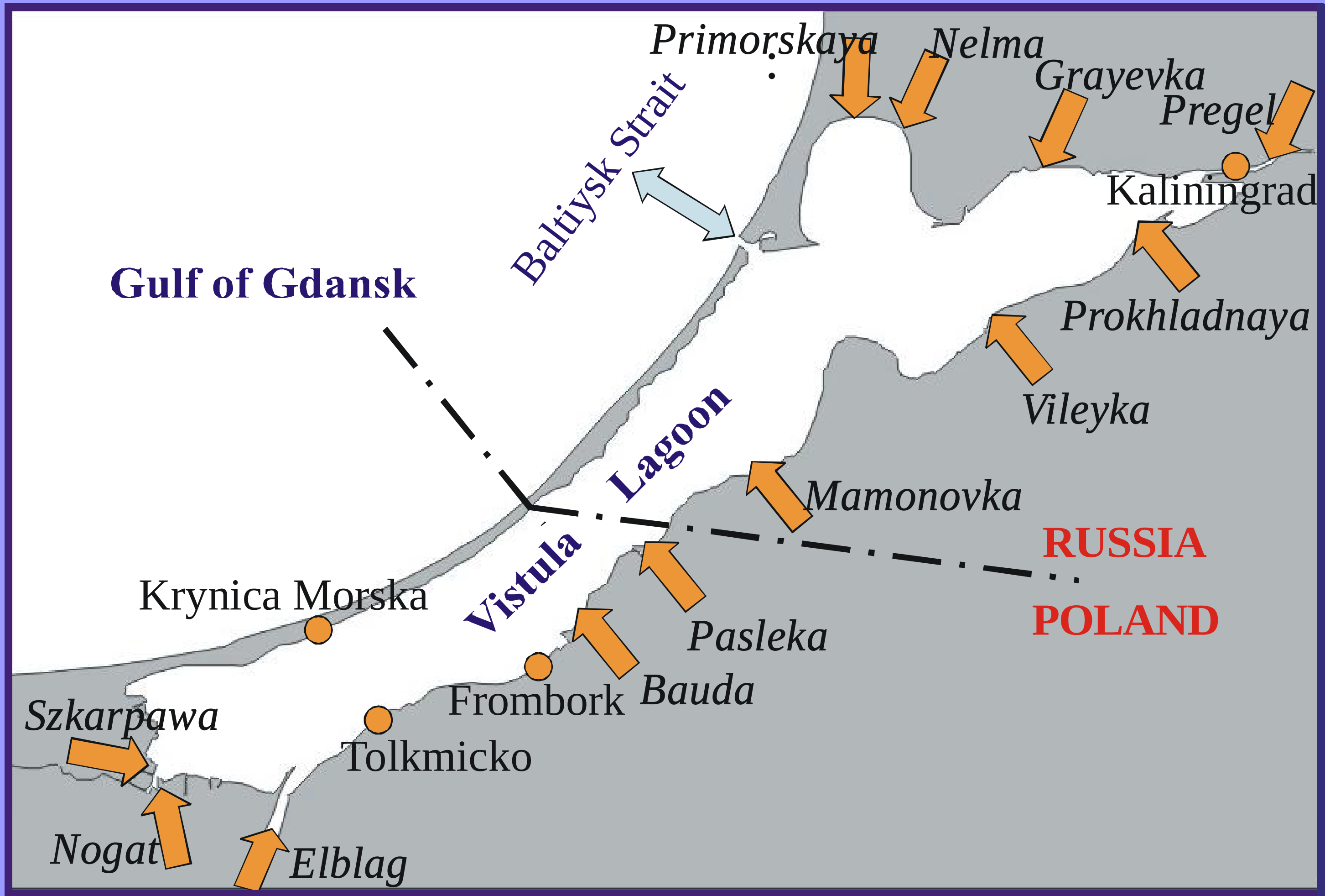
•**Connection with the Gulf of Gdańsk**: narrow, dredged channel near Baltiysk (Russia)

WATER BALANCE OF THE VISTULA LAGOON

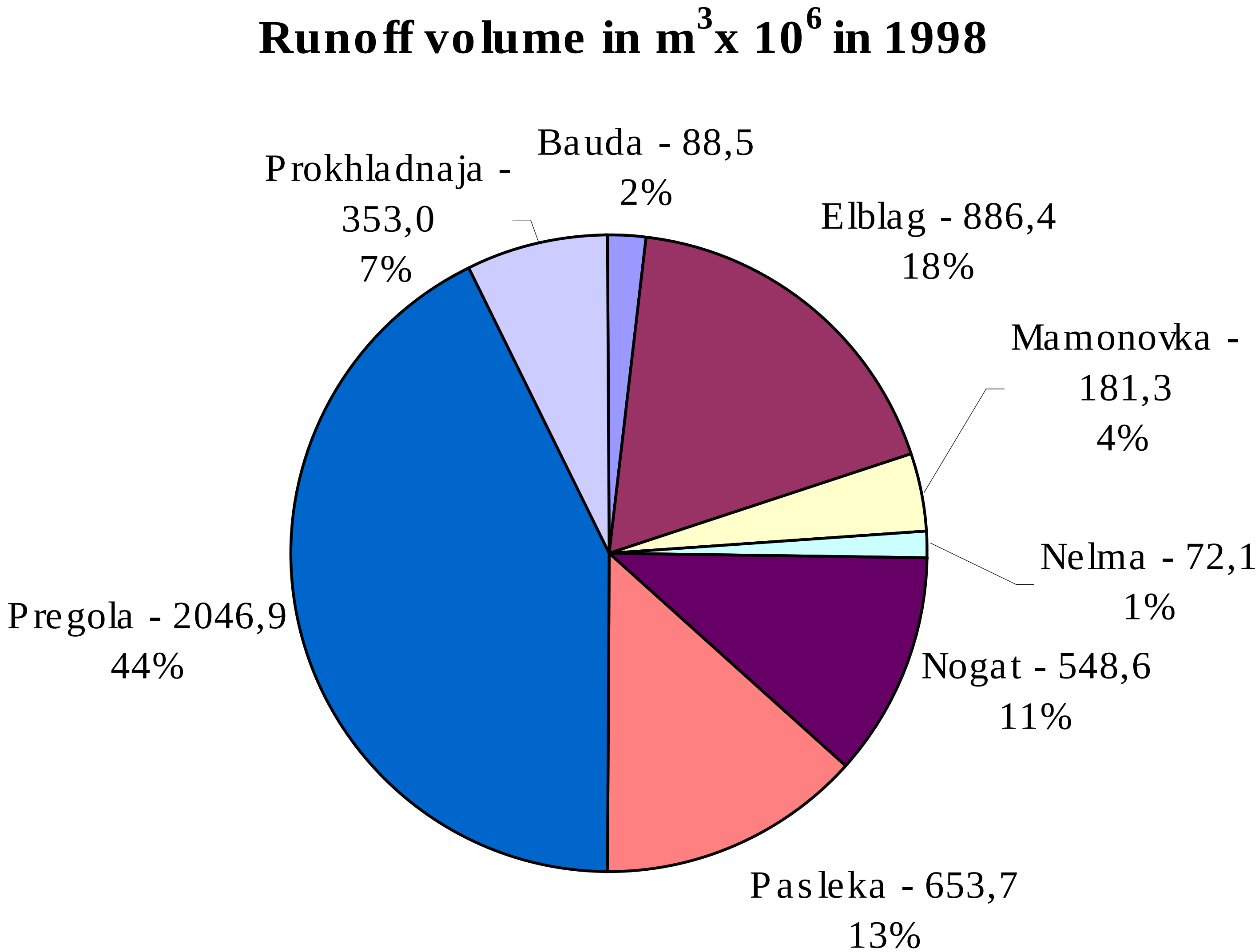
	Ingoing (km^3)	%
Water from the rivers	3.62	**17.1**
Marine inflow	17.00	**80.2**
Precipitation	0.50	2.4
Ground water	0.07	0.3
Total	21.19	100.0
	Outgoing (km^3)	**%**
Flowing to the sea	20.48	**96.9**
Evaporation	0.65	3.1
Total	21.13	100.0

Water balance of Vistula Lagoon 1951-1965 (Silicz, 1975)

WATER DISCHARGES TO THE VISTULA LAGOON



WATER DISCHARGES TO THE VISTULA LAGOON



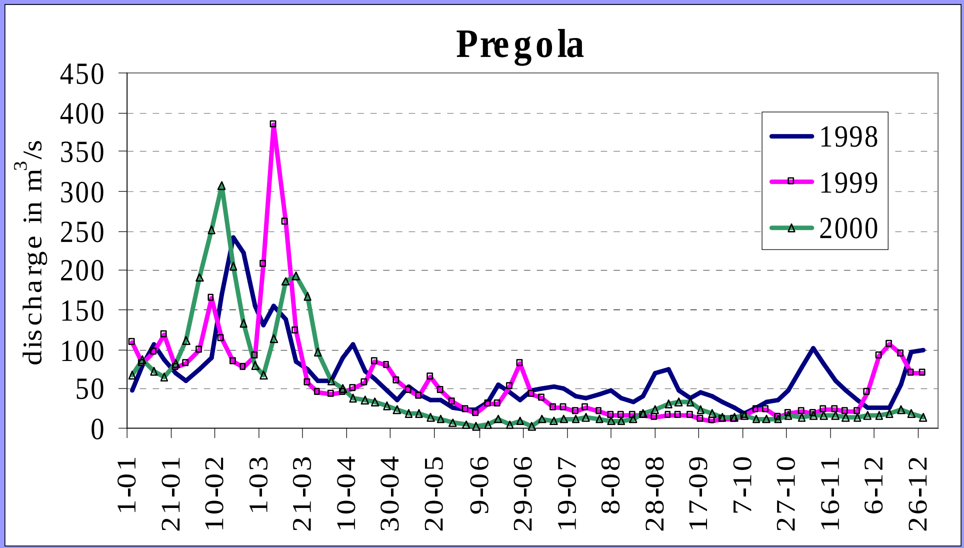
WATER DISCHARGES TO THE VISTULA LAGOON

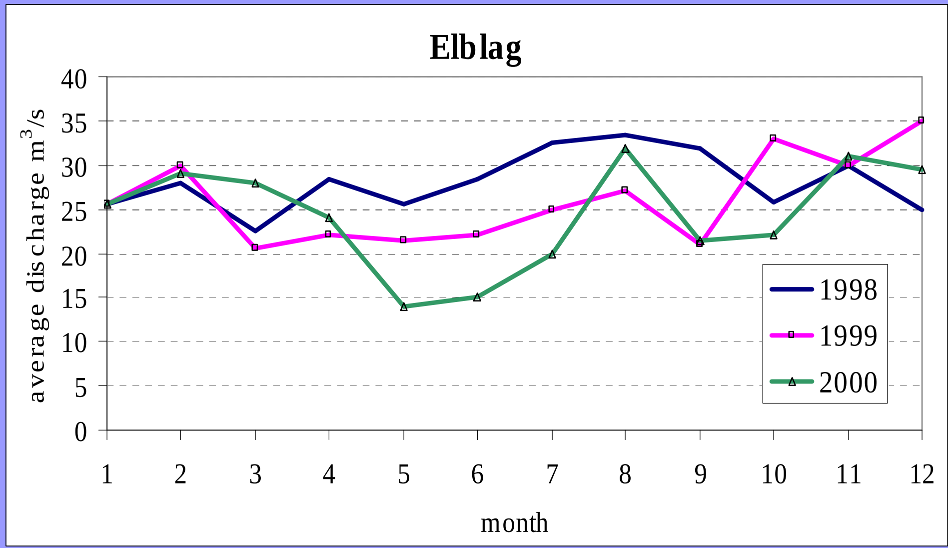
Discharges from main Polish and Russian rivers (m^3/s) in years 1998 – 2000 based on information from Institute of Meteorology and Water Management (IMWM), Regional Water Management Board - Poland and Hydromet - Russia

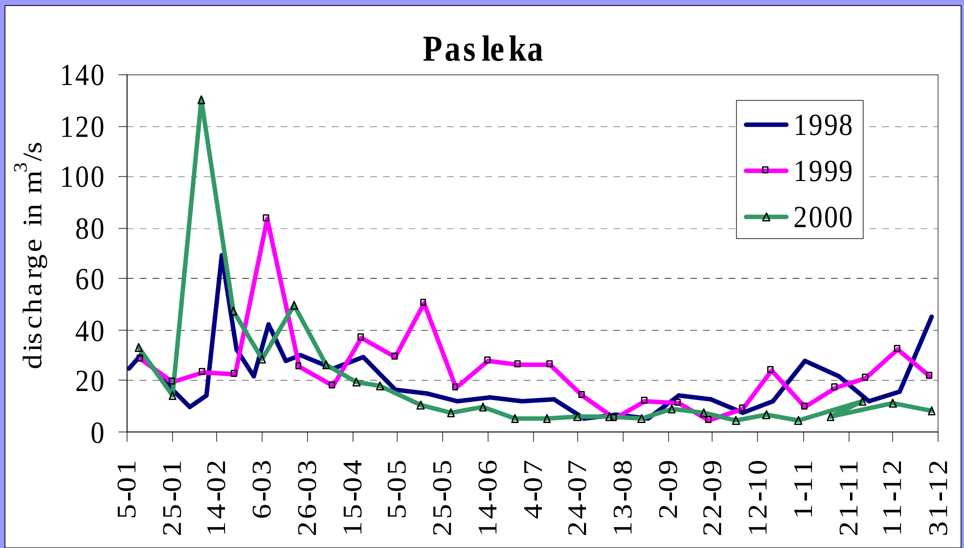
RIVER	Year 1998	Year 1999	Year 2000	Average from years 1998 - 2000
Polish Rivers				
Pasleka	20,7	23,7	18,9	21,1
Elblag	28,8	26,0	24,3	30,9
Nogat	16,5	18,6	10,9	15,6
Bauda	3,1	2,9	2,2	2,7
Sum Rivers	**69,1**	**71,2**	**56,3**	**70,3**
Russian Rivers				
Pregola	65,5	59,3	48,0	57,6
Mamonovka	5,7	5,4	5,4	5,5
Prokhladnaya*	11,2	12,81	10,2	11,4
Nelma	2,3	2,2	1,7	2,1
Sum Rivers	**84,7**	**79,7**	**65,3**	**76,6**

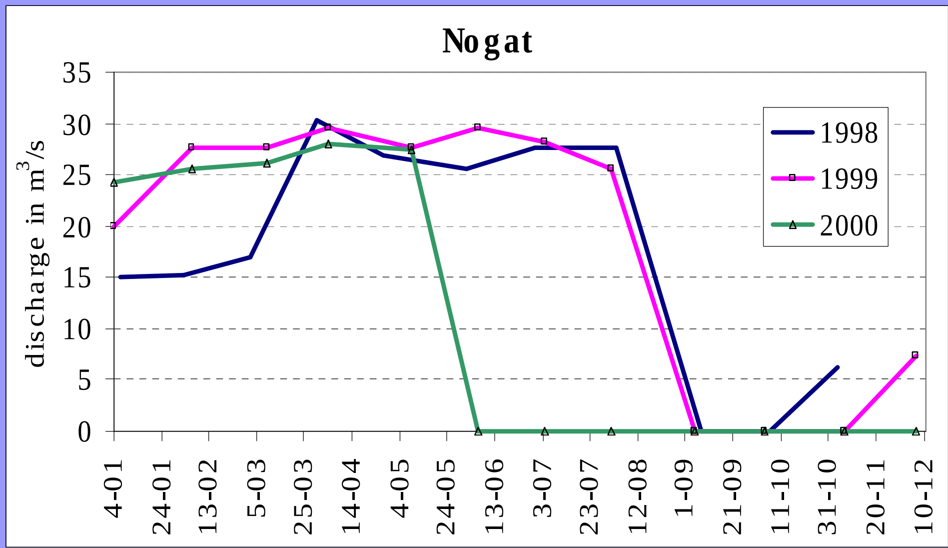
•- *estimated discharge due to missing data for years 1998 – 2000*

YEARLY VARIATIONS OF MAIN RIVER DISCHARGES







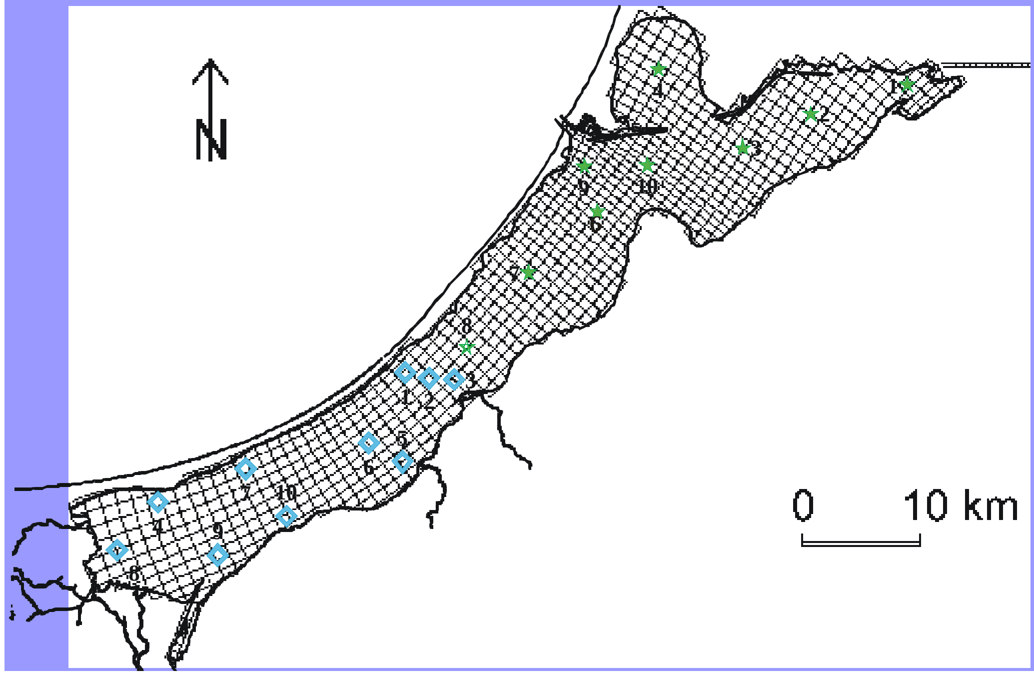


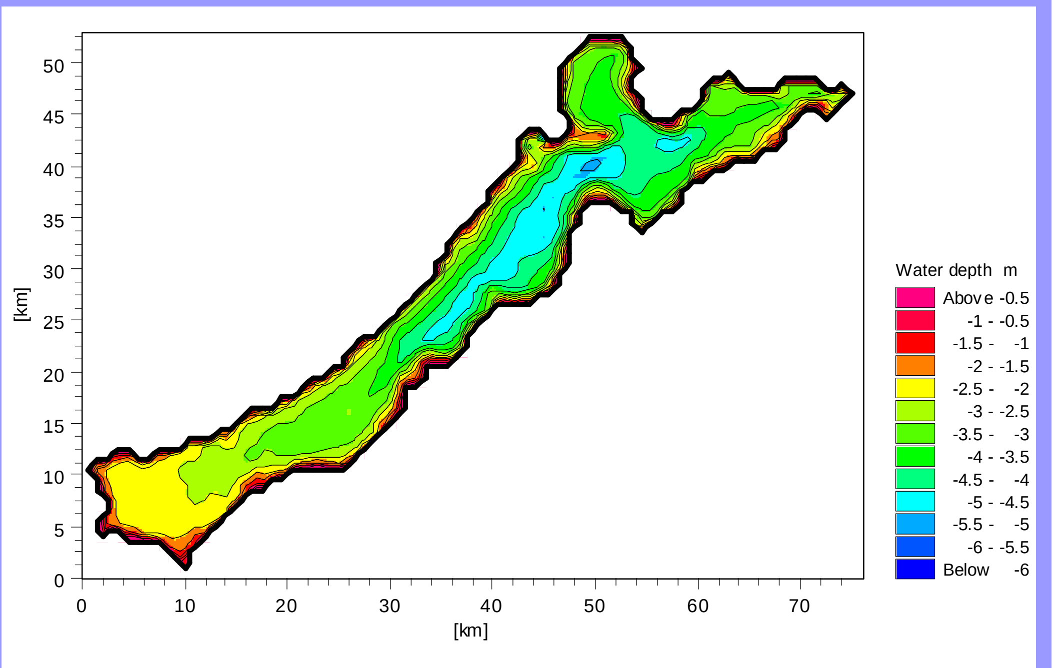
NUMERICAL ASSUMPTIONS OF THE VISTULA LAGOON 3D AND 2D MODELS

- **Computational horizontal grid** of 3D type (900 horizontal cells in curvilinear orthogonal system varying from 200 to 1300 m, and 11 layers in Sigma coordinate system)

- **Computational horizontal grid** of 2D type (horizontal cells in regular orthogonal system of 200 and 1000 m)

Computational horizontal grid of the Vistula Lagoon 3D hydrodynamic model with monitoring points, and bathymetry used in models.





NUMERICAL ASSUMPTIONS AND BOUNDARY CONDITIONS OF THE VISTULA LAGOON MODELS

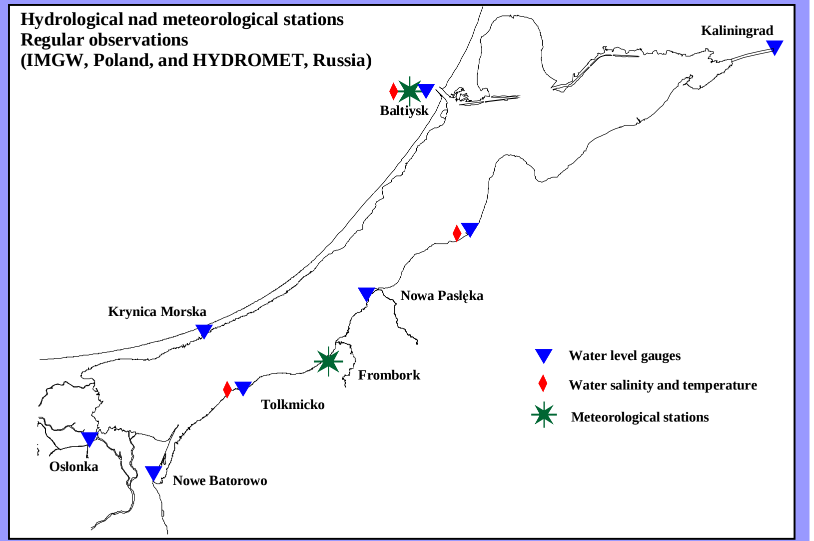
Numerical parameters applied in the hydrodynamic models

Model	Grid cell dimensions [m]	Bottom friction Manning coefficient – variable in the lagoon			Horizontal eddy viscosity – constant in the lagoon [m^2/s]	Horizontal eddy diffusivity - constant in the lagoon [m^2/s]	Time step [s]
		Lagoon area	Baltiysk Strait and navigation channel	Along shore line			
3D	200 - 1300	0.018	0.015	0.025	0.1	0.8	60
2D	200	0.016	0.016	0.016	0.1	5.0	18
2D	1000	0.015 *	0.015	0.015	0.1	0.8	120

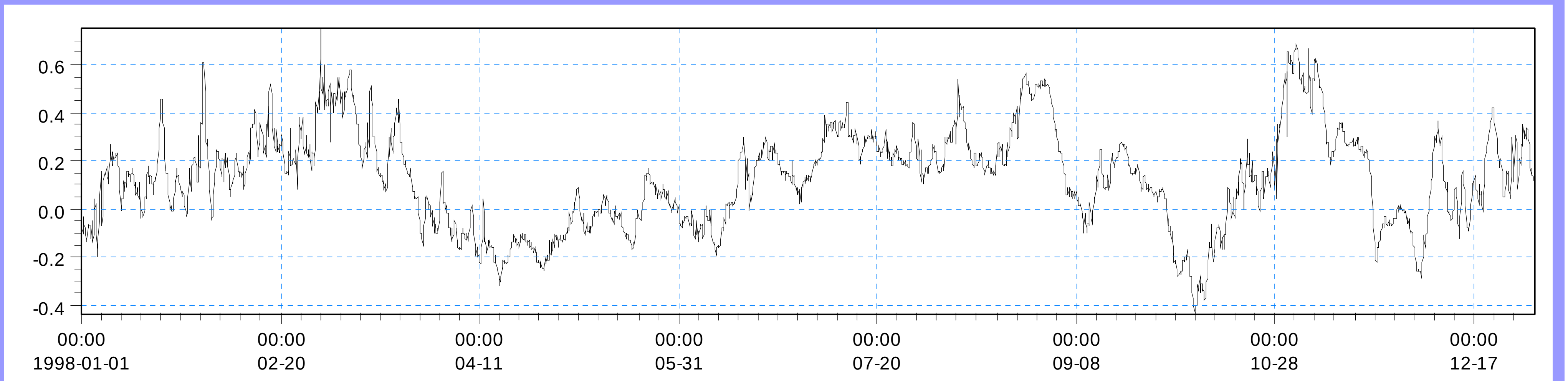
- **Inflowing rivers assumed as sources of water (discharges)**

- **Initial conditions – constant water level (from measurements) and variable salinity (1.8 – 4.5 psu)**

NUMERICAL ASSUMPTIONS AND BOUNDARY CONDITIONS OF THE VISTULA LAGOON MODELS



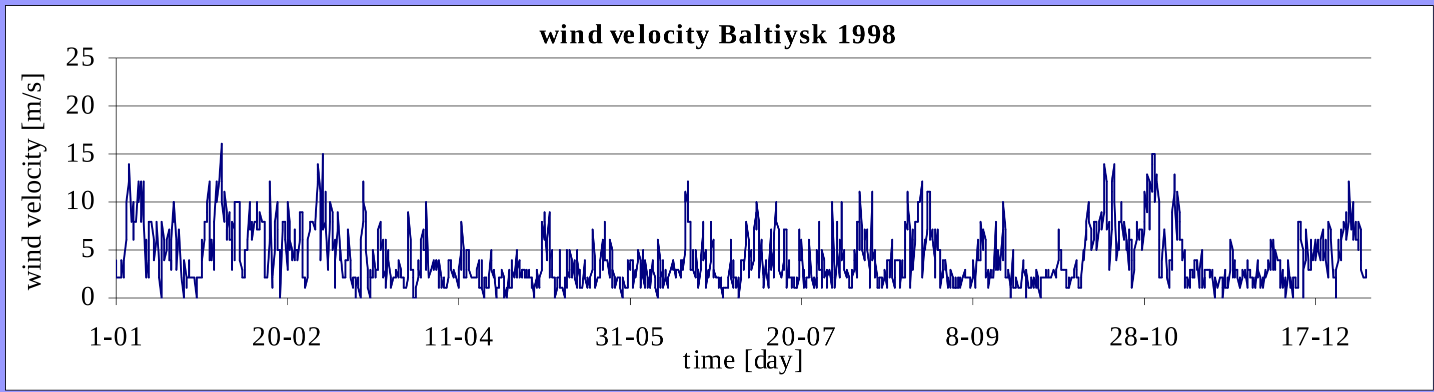
- **Boundary condition – water level in Baltiysk Strait every 6 hours, salinity - once a day**

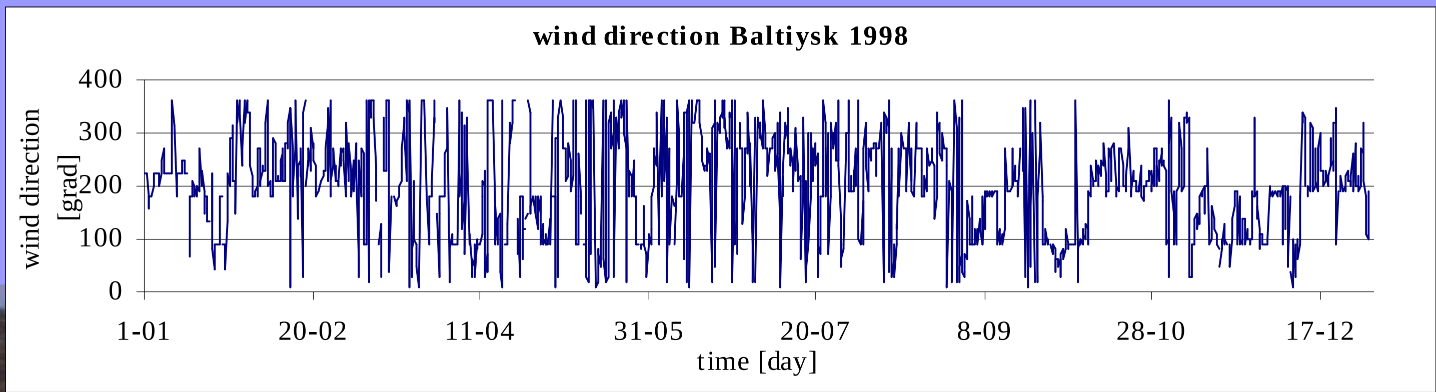


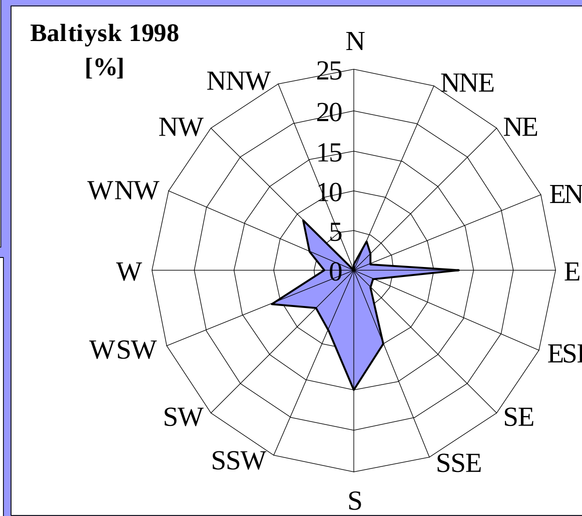
Open boundary condition - water level (m) records in Baltiysk

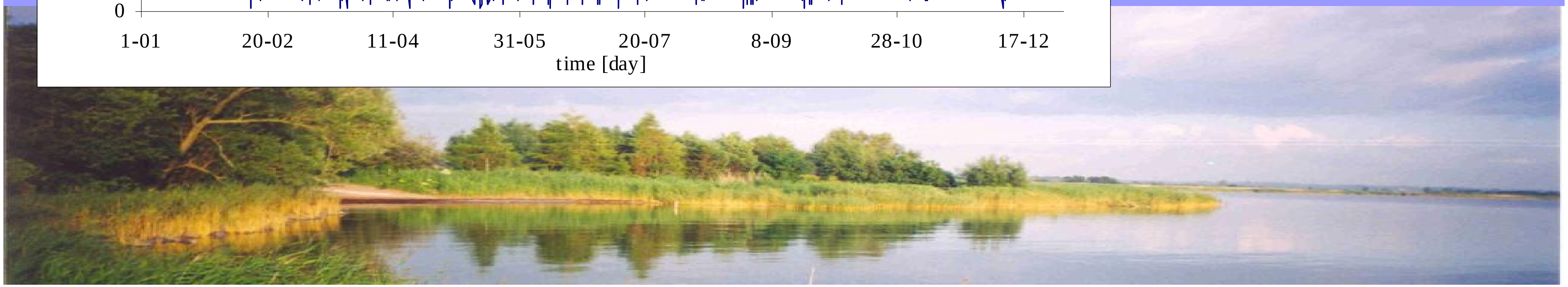
NUMERICAL ASSUMPTIONS AND BOUNDARY CONDITIONS OF THE VISTULA LAGOON MODELS

- **Wind velocity – from Baltiysk weather station every 6 hours**









RESULTS OF THE 2D MODEL CALIBRATION FOR THE 200 M GRID AND POSSIBILITY OF DATA FROM OPERATIONAL MODELS USAGE

- **The Vistula Lagoon is a transboundary basin shared by two countries: Poland and Russia.**
- **To calibrate and run the models data are needed from both countries.**

...but

There is no common data base. Data exchange is difficult and not always possible.

How to deal with these problems?

How to deal with these problems?

A

cooperate and
build common data base

use the same modelling system

B

if there is no cooperation

use own data and
use operational modelling system
to fill in the gaps

use the same modelling system
or different

Assessment of WQ status of the Lagoon
Scenarios of WQ changes

OPTION B

- **2D Mike21 modelling system applied to VL: HD + WQ modules**

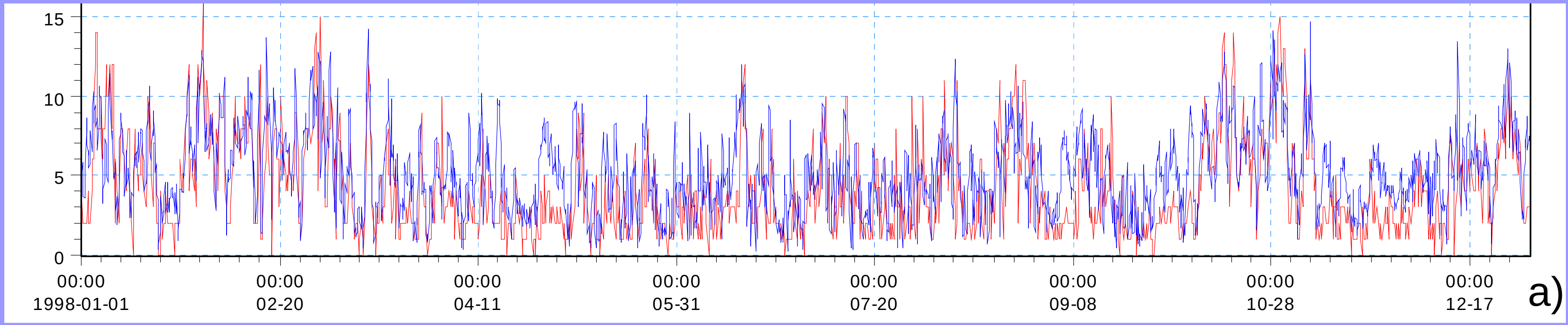
- **Required data from both sides for boundary and initial conditions:**
  - **water levels, especially from Baltiysk,**
  - **meteo PL/RU,**
  - **discharges PL/RU + WQ parameters in Lagoon and discharges.**

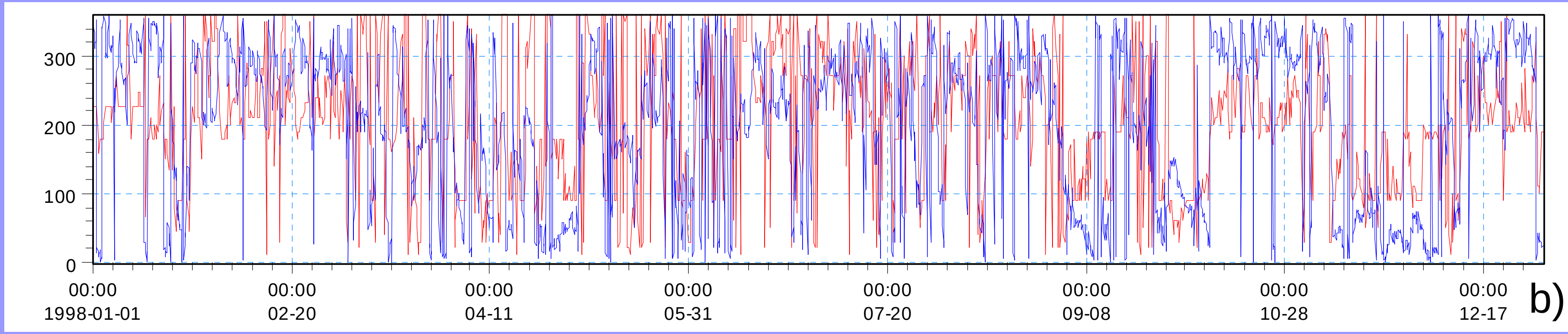
- **Available data from Poland:**
  - **water levels from PL only, no data from Baltiysk,**
  - **meteo PL,**
  - **discharges PL (RU from historical data and estimates) + WQ parameters in Lagoon and discharges.**

- **2 operational models may be used to fill in the gaps: HIROMB for HD conditions and HIRLAM for meteo**

Boundary conditions of the Vistula Lagoon model for year 1998 – operational models

Wind velocity from the atmosphere model UMPL (UK Unified Model for Poland area, covering all Central Europe and the Baltic Sea) run operationally in the University of Warsaw; the wind analysis data from UMPL were available every 3 hr with the horizontal resolution of 17 km

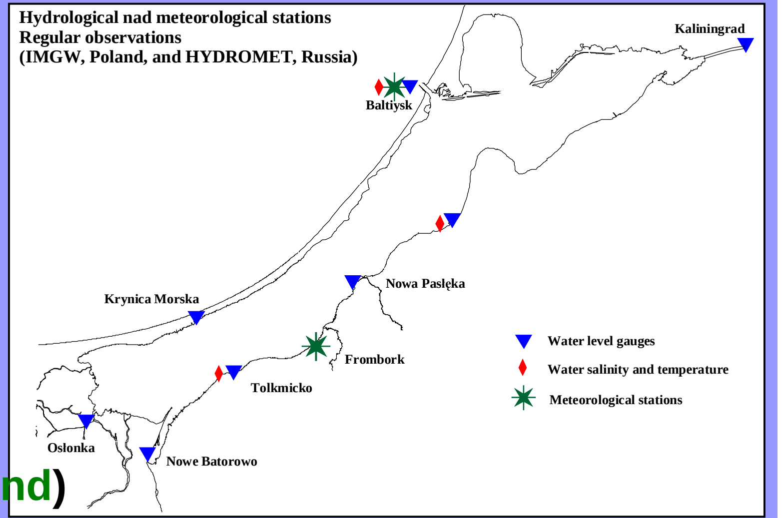




red line – observations in Baltiysk, every 6 hours; blue line – synoptic wind (UMPL analysis), every 3 hours

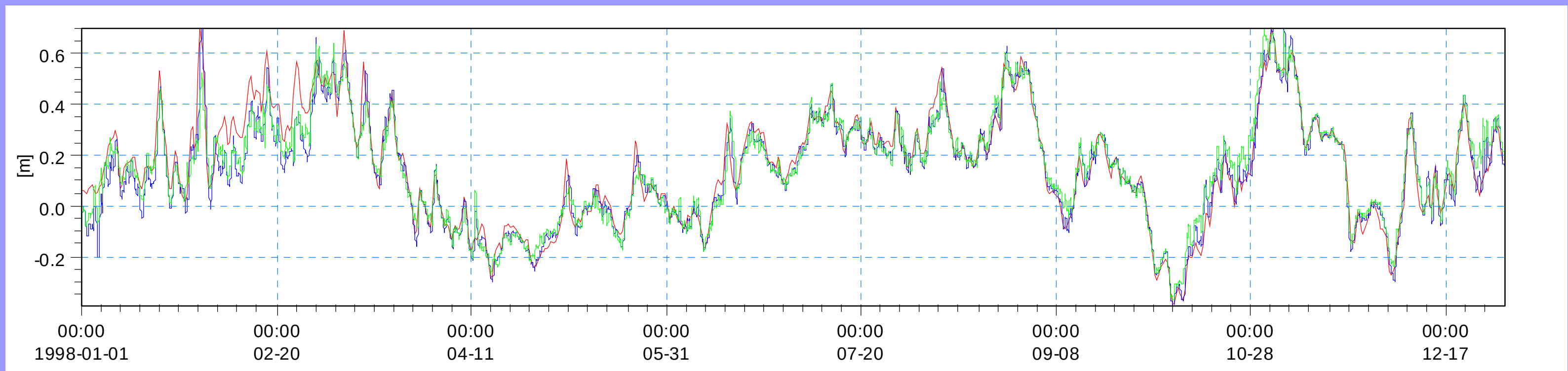
Wind forcing in the model: a) wind velocity, b) wind direction

CALIBRATION RESULTS FOR YEAR 1998

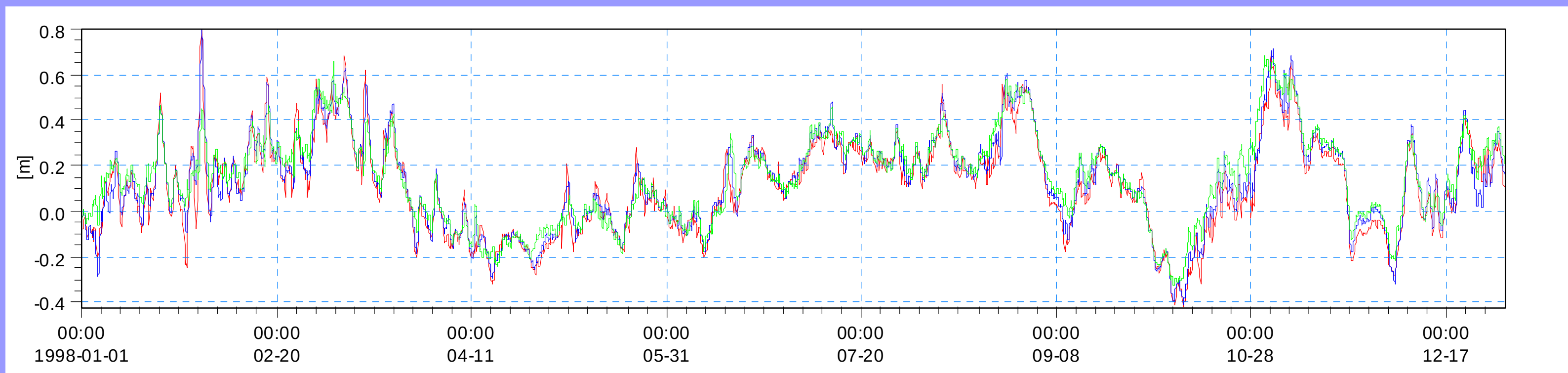


Water level, observed and simulated

(red – measurements, blue – wind Baltiysk, green – synoptic wind)

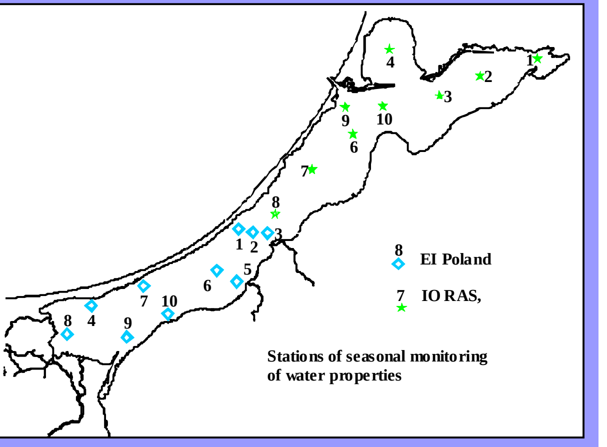


Krasnoflotskoye



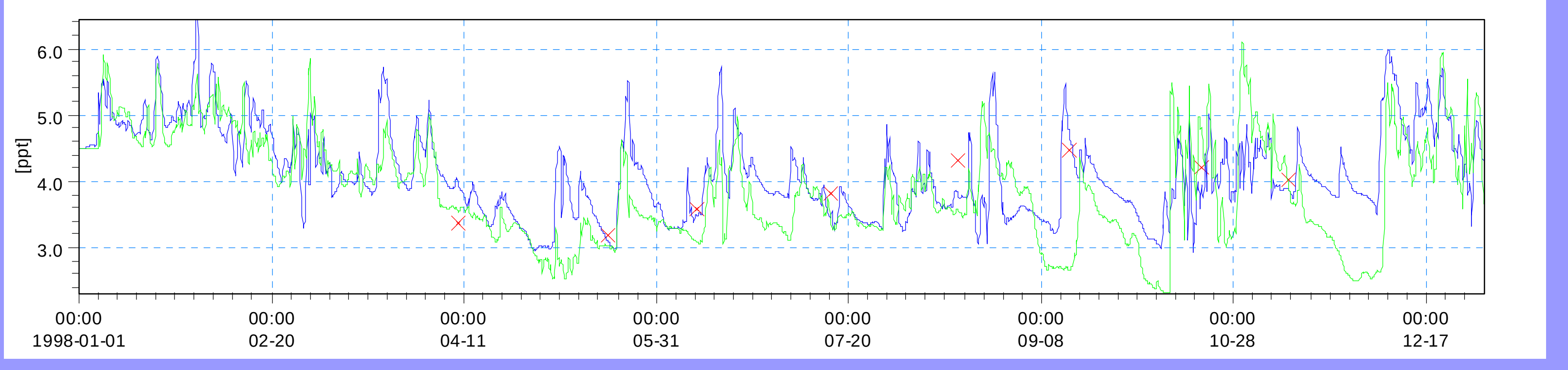
Nowa Pasleka

CALIBRATION RESULTS FOR YEAR 1998

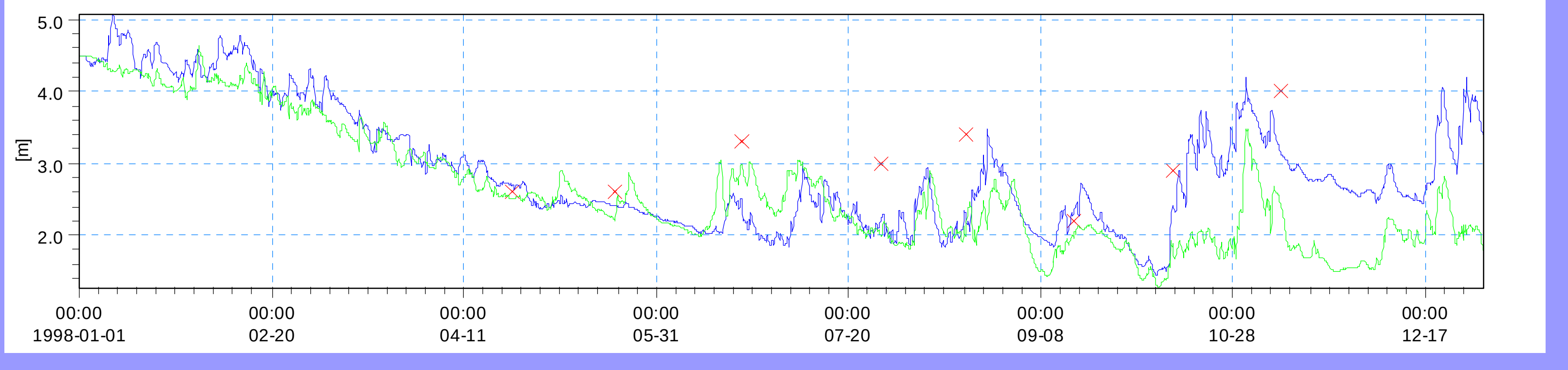


Salinity

(red – measurements, blue – wind Baltiysk, green – synoptic wind)

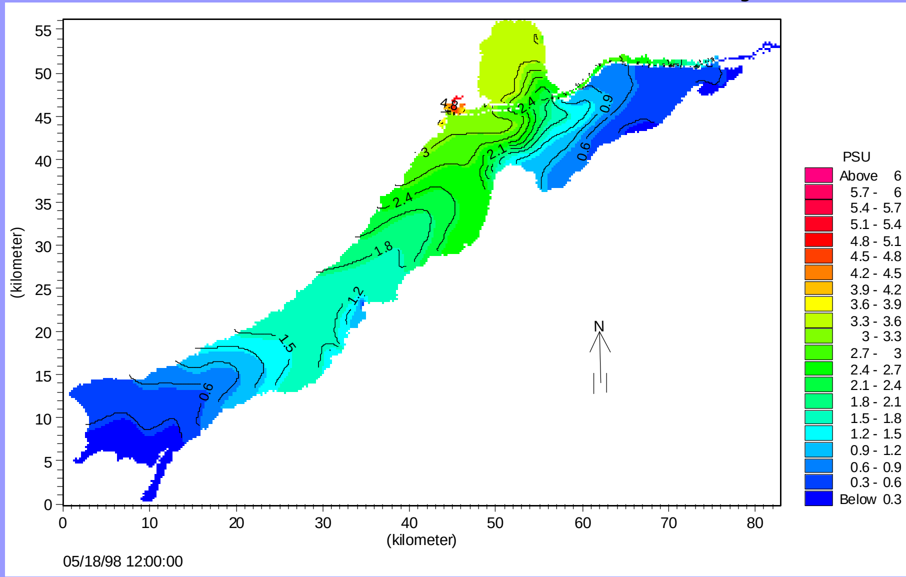


Monitoring station R6

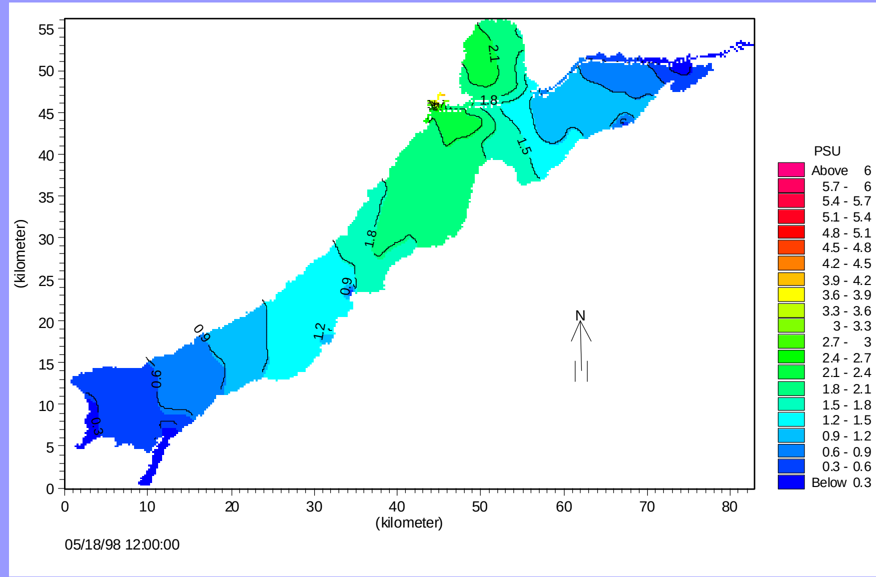


Monitoring station P1

Salinity distribution, 18-05-1998

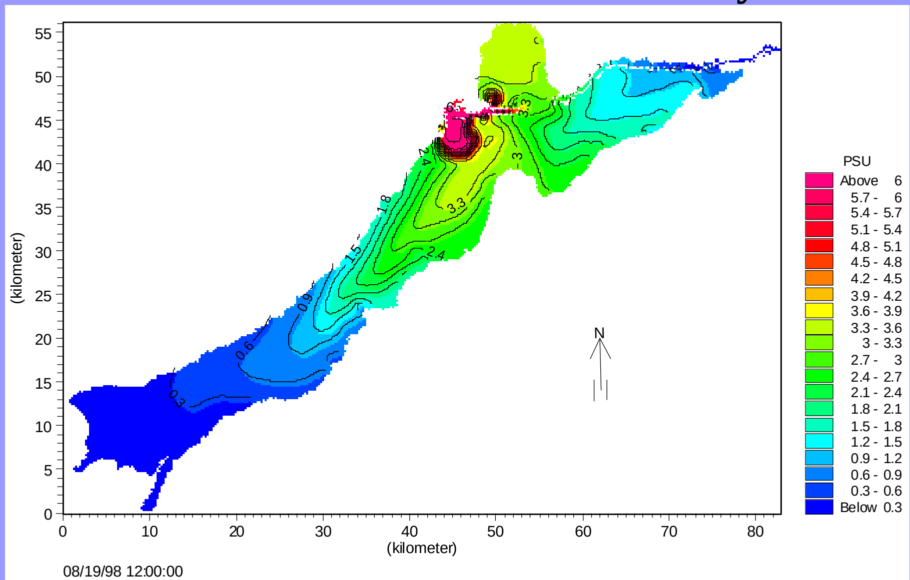


with measured wind data

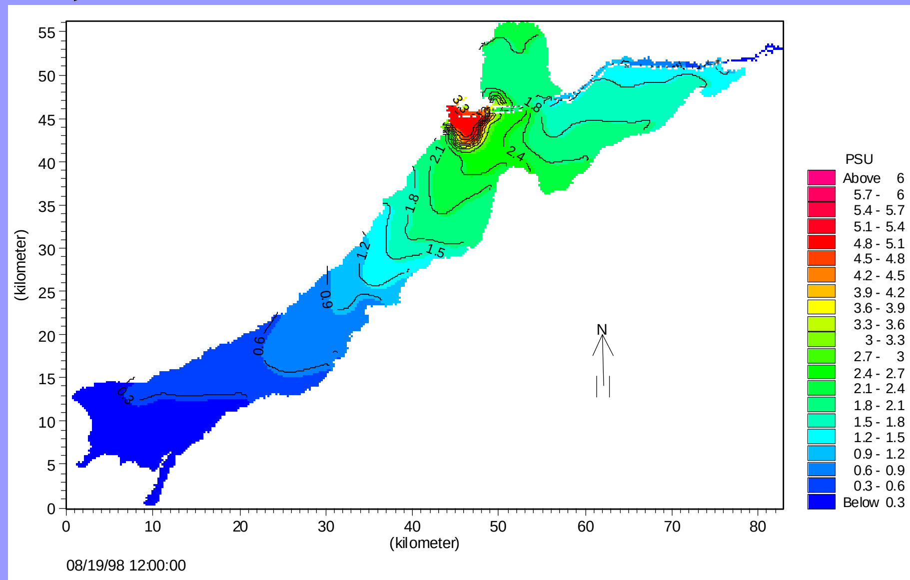


with synoptic wind data

Salinity distribution, 19-08-1998



with measured wind data



with synoptic wind data

CONCLUSIONS

- The Vistula Lagoon is a transboundary basin and it is a very frequent problem that the data necessary for running the models are not always freely available. To avoid this problem it is recommended to build an operational modelling system, that will predict driving forces and boundary conditions for the models.

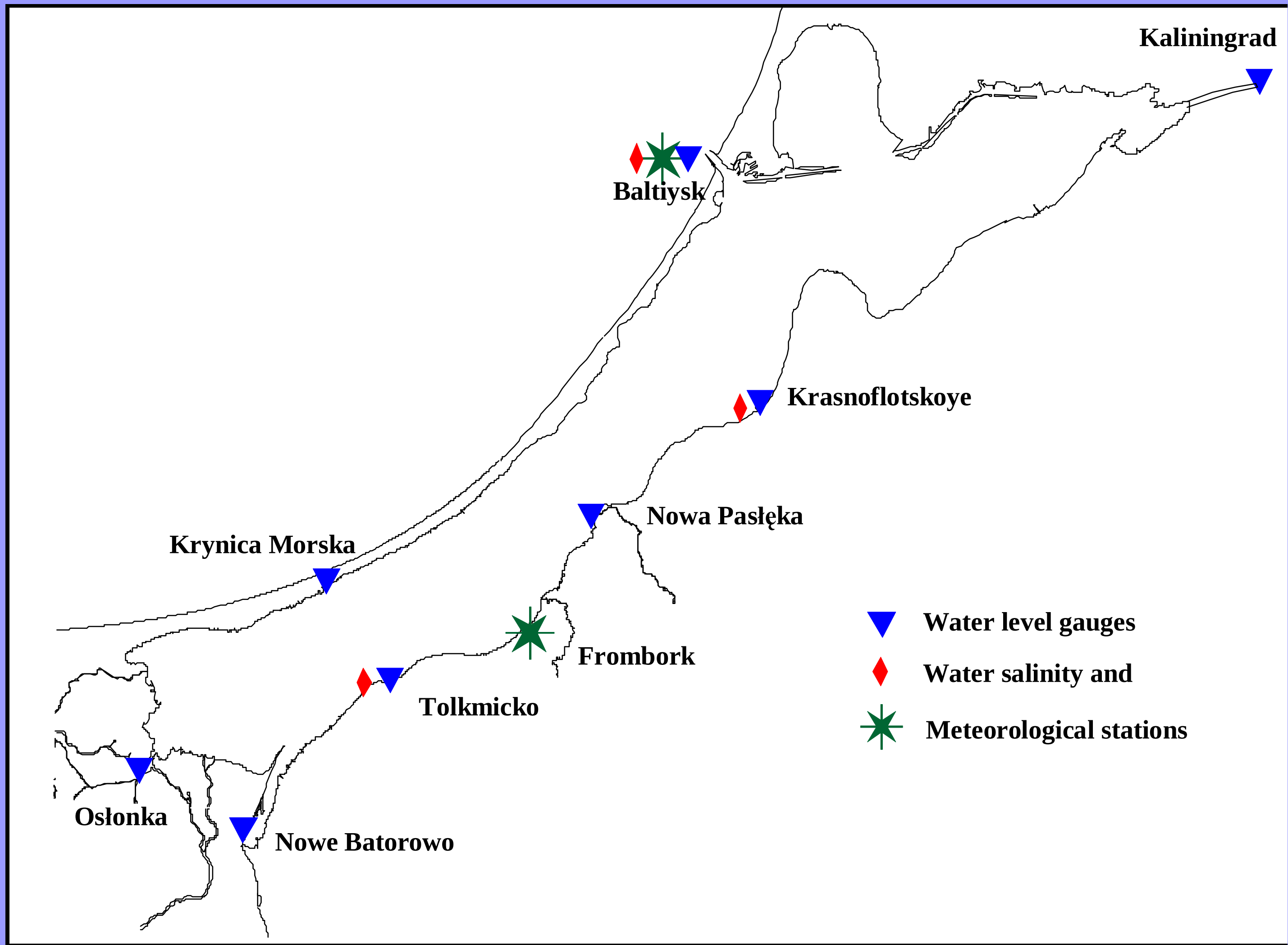
- To simplify the task, only prediction of wind data was considered with use of an operational atmosphere model UMPL which is run in the University of Warsaw.

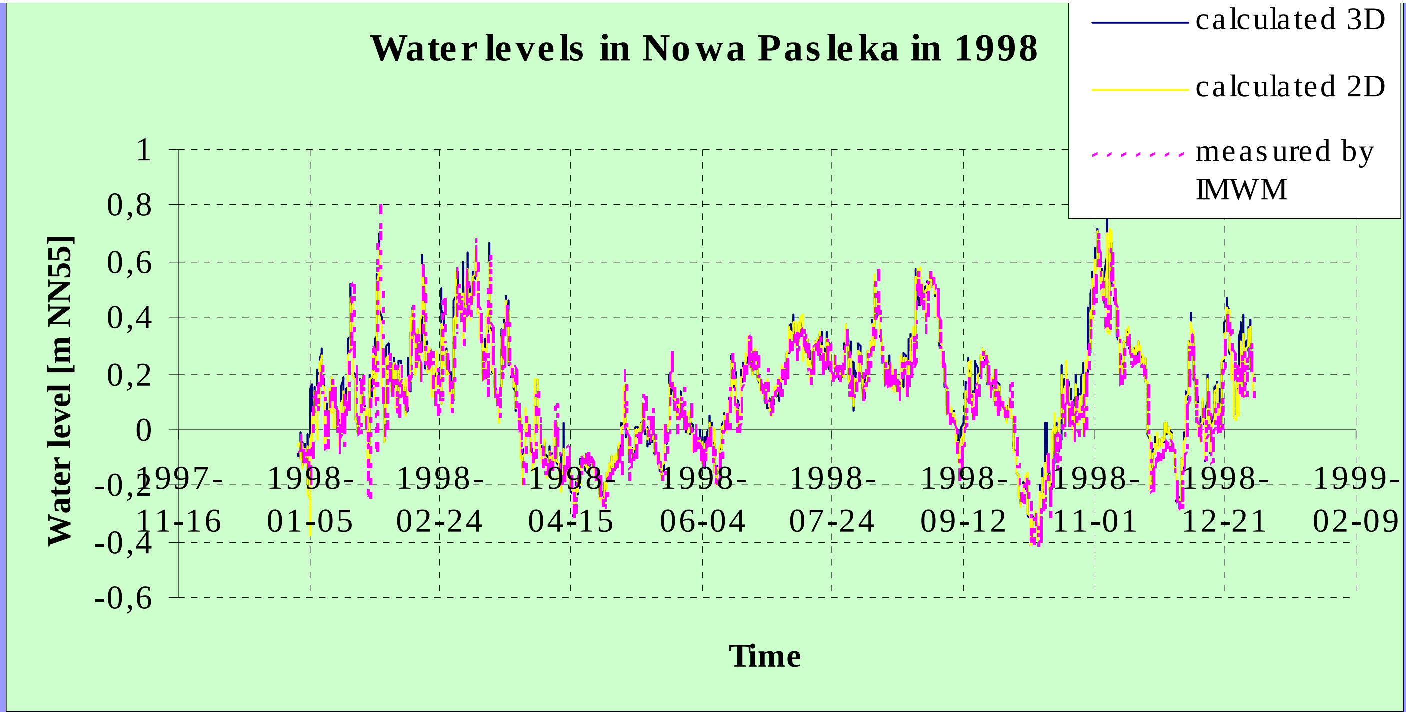
- Results of calibration of the hydrodynamic model, ran with the measured and UMPL data, proved that in both cases water levels and salinity are predicted with very similar accuracy.

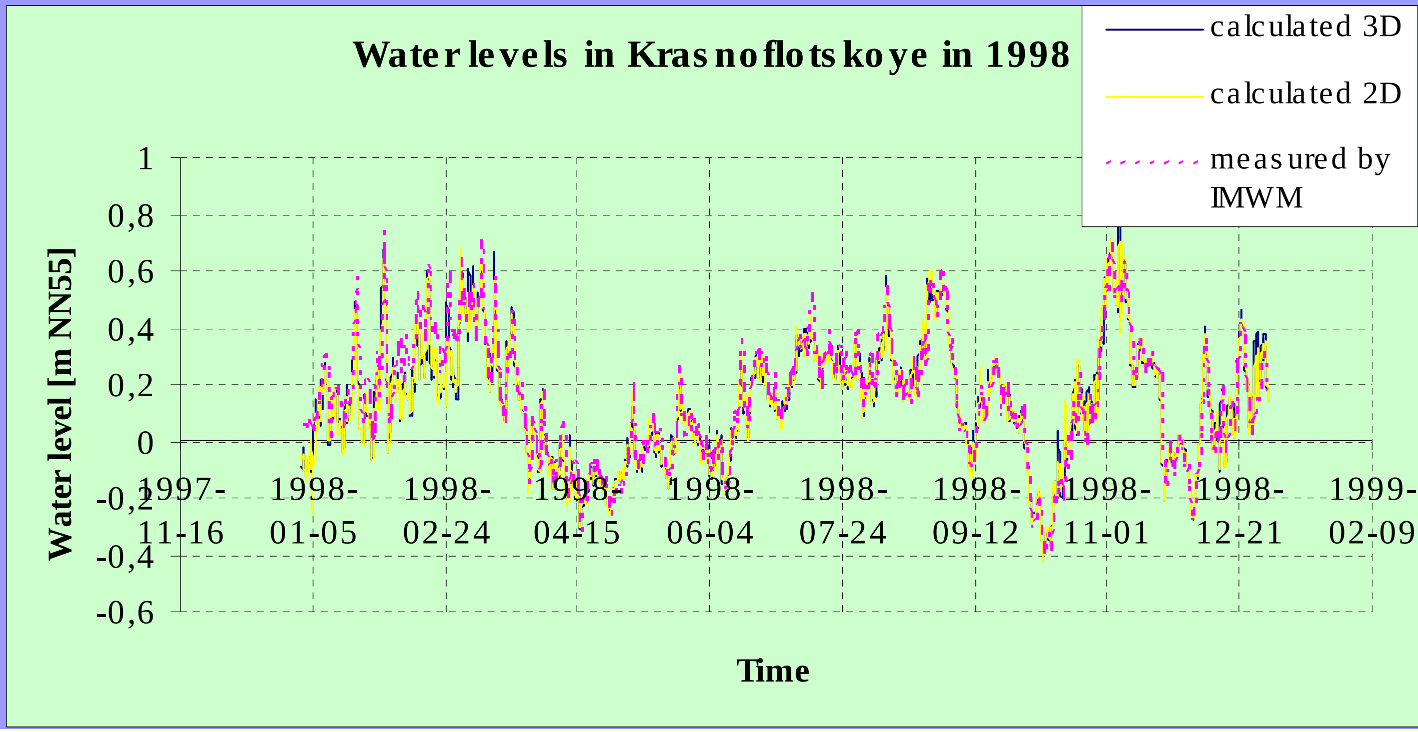
- Therefore usage of operational model, instead of actually measured data may be recommended in this situation.

- Both countries have access to HIROMB and HIRLAM operational models, therefore they are proposed to be used in case data from one country is not available to the other country.

CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS.
WATER LEVELS




Water levels in Nowa Pasleka in 1998
calculated 3D
calculated 2D
measured by IMWM
Water level [m NN55]
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
1997-11-16
1998-01-05
1998-02-24
1998-04-15
1998-06-04
1998-07-24
1998-09-12
1998-11-01
1998-12-21
1999-02-09
Time


Water levels in Krasnoflotskoye in 1998
calculated 3D
calculated 2D
measured by IMWM
Water level [m NN55]
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
1997-11-16
1998-01-05
1998-02-24
1998-04-15
1998-06-04
1998-07-24
1998-09-12
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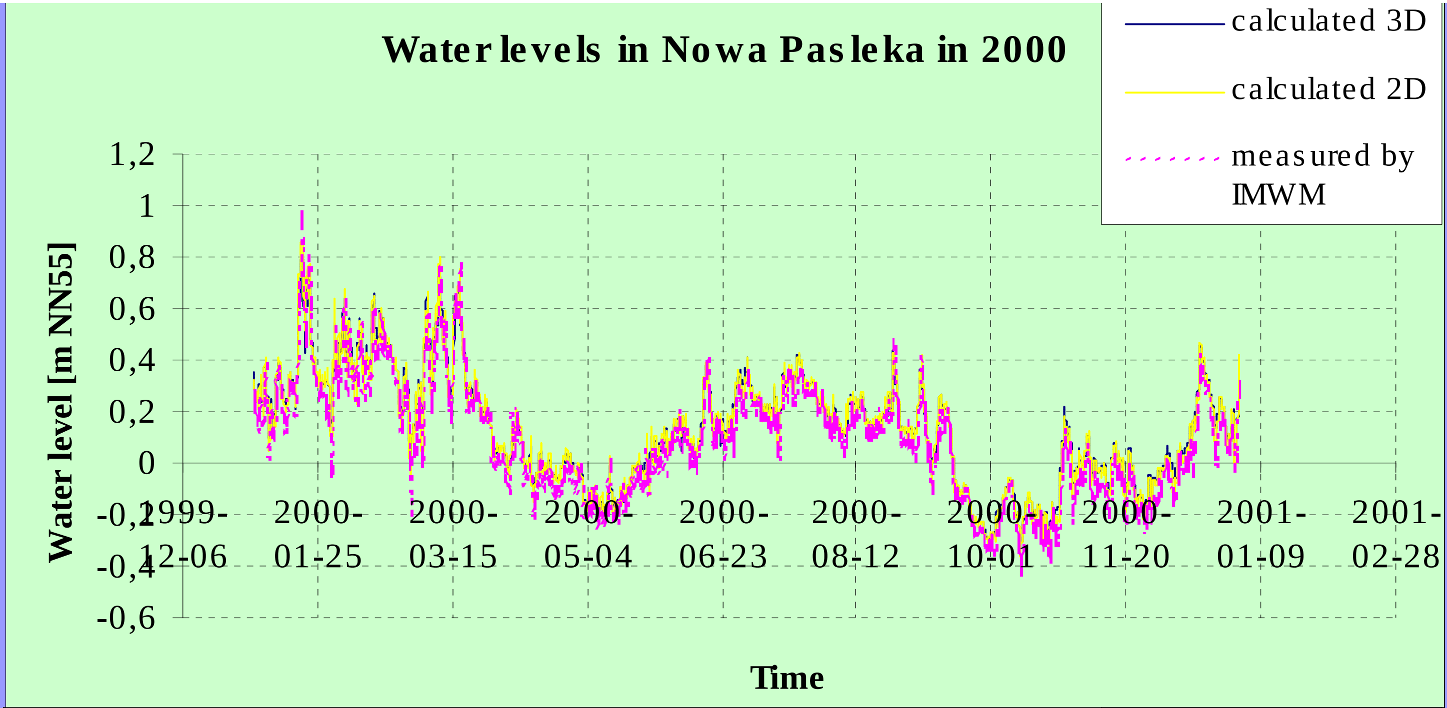
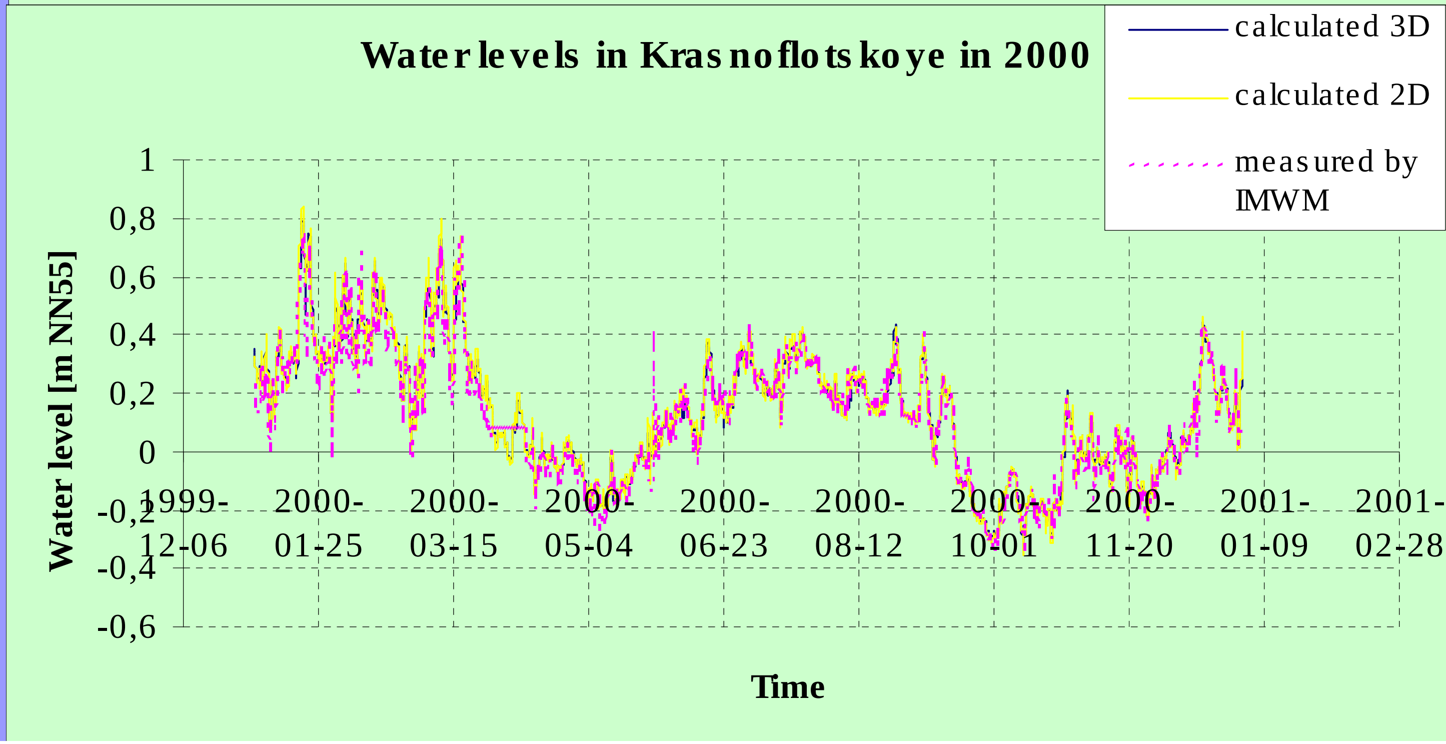
1998-12-21
1999-02-09
Time

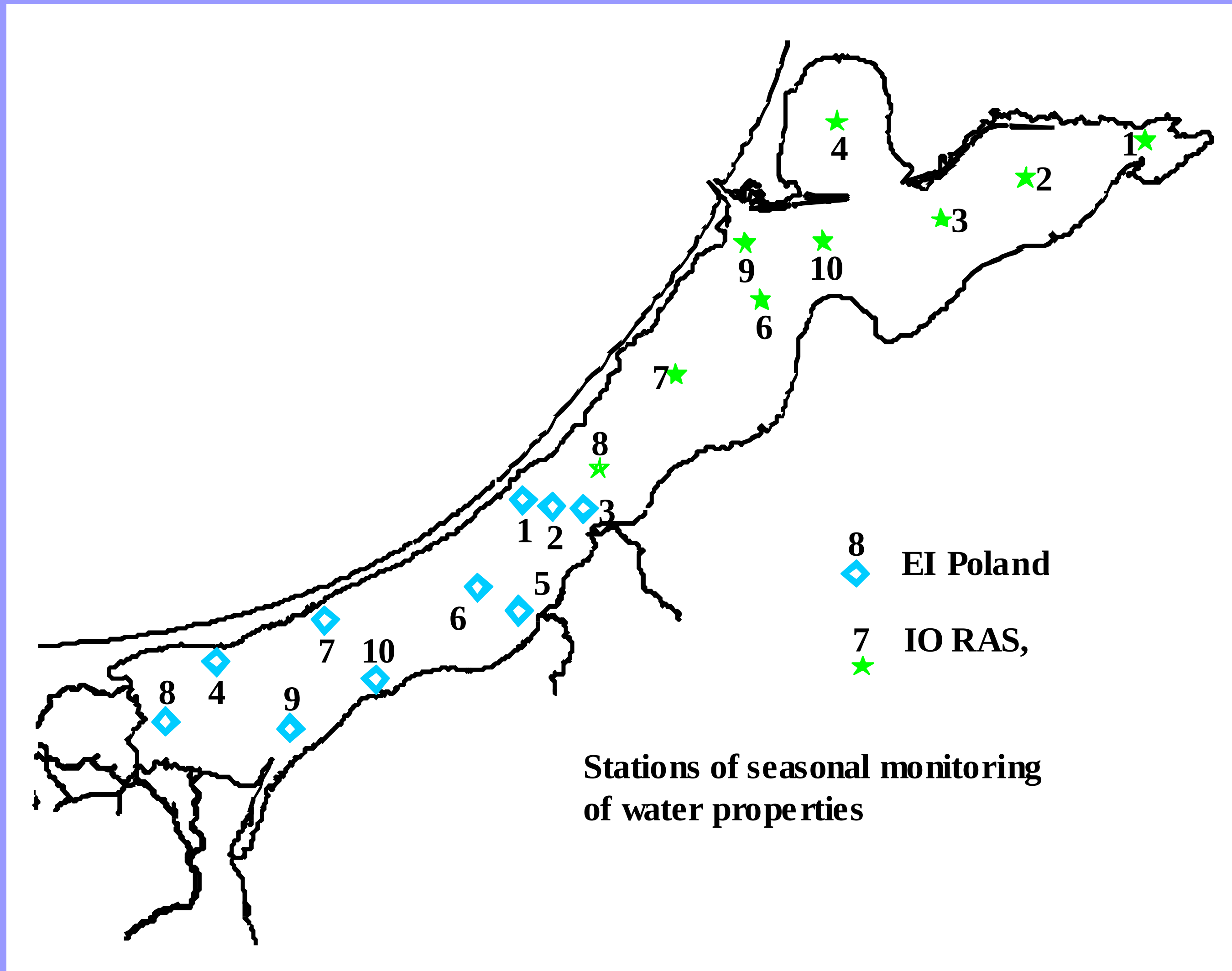


Water levels in Nowa Pasleka in 2000
calculated 3D
calculated 2D
measured by IMWM
Water level [m NN55]
1,2
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
1999-12-06
2000-01-25
2000-03-15
2000-05-04
2000-06-23
2000-08-12
2000-10-01
2000-11-20
2001-01-09
2001-02-28
Time

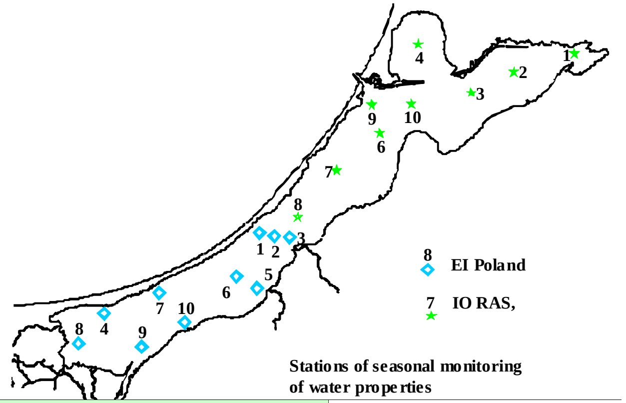


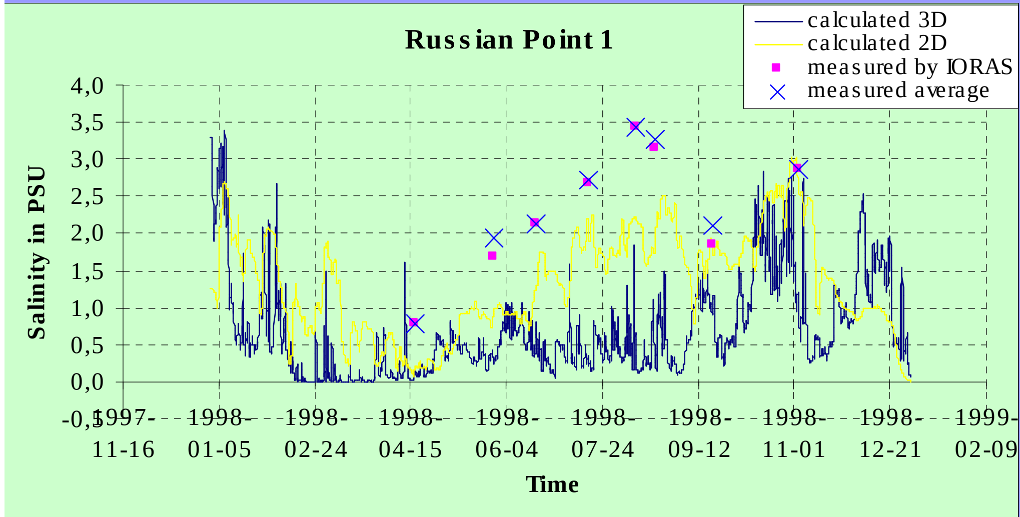
Water levels in Krasnoflotskoye in 2000
calculated 3D
calculated 2D
measured by IMWM
Water level [m NN55]
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
1999-12-06
2000-01-25
2000-03-15
2000-05-04
2000-06-23
2000-08-12
2000-10-01
2000-11-20
2001-01-09
2001-02-28
Time

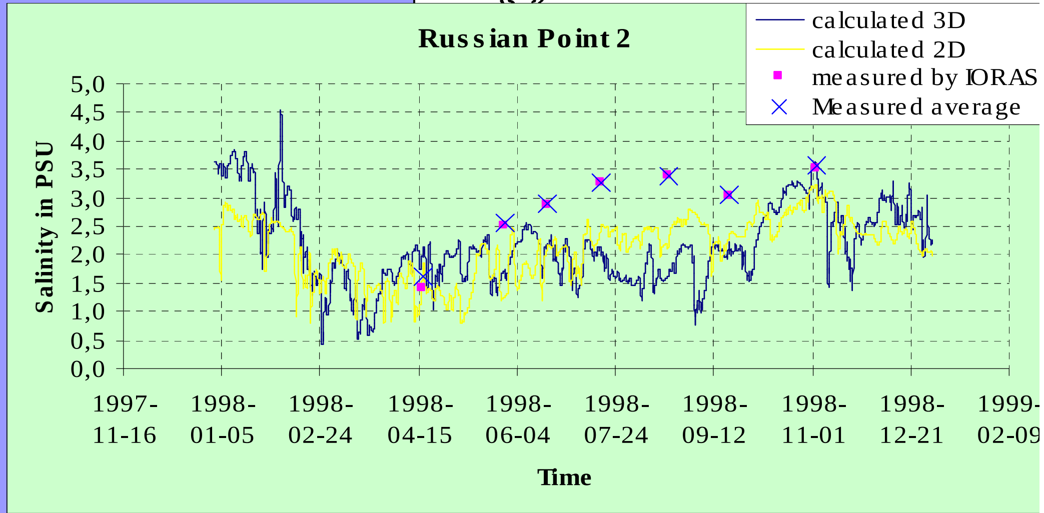
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS. SALINITY

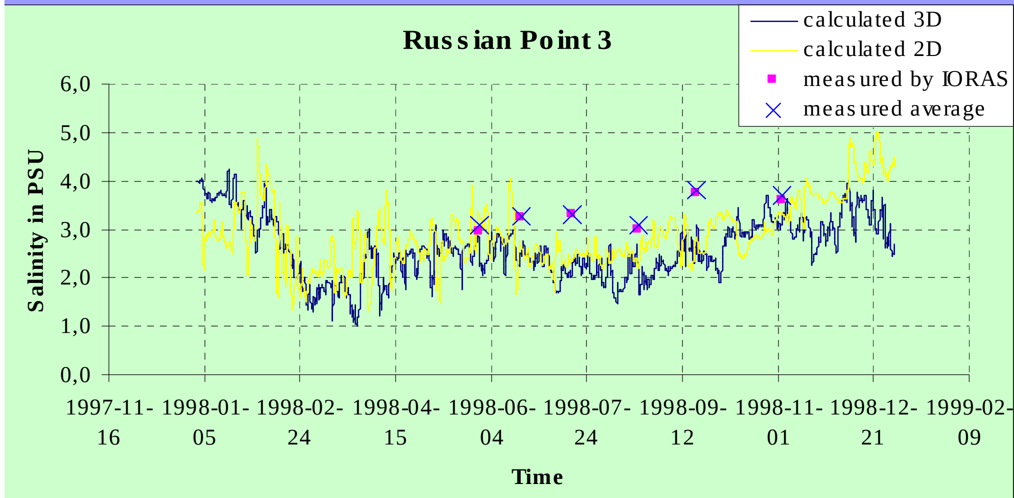


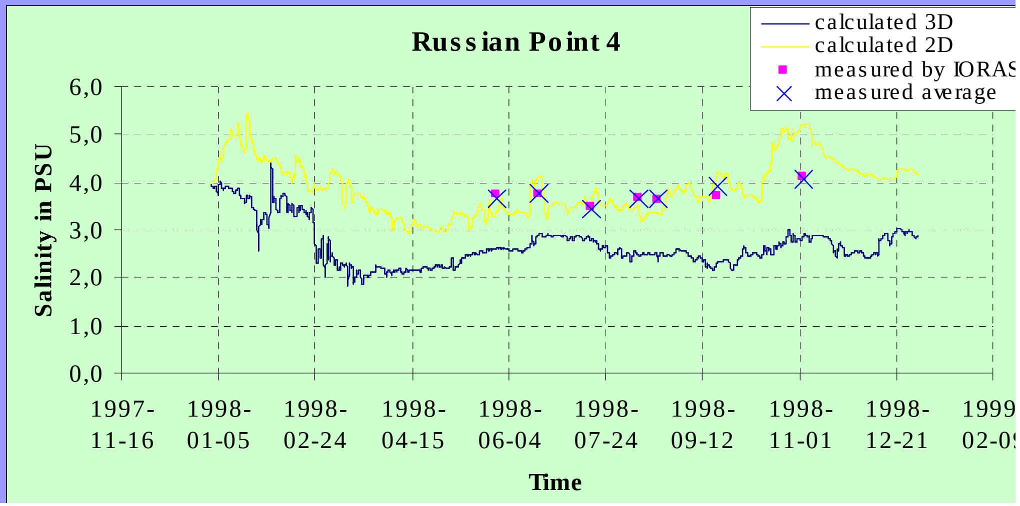
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS. SALINITY – Russia - 1998



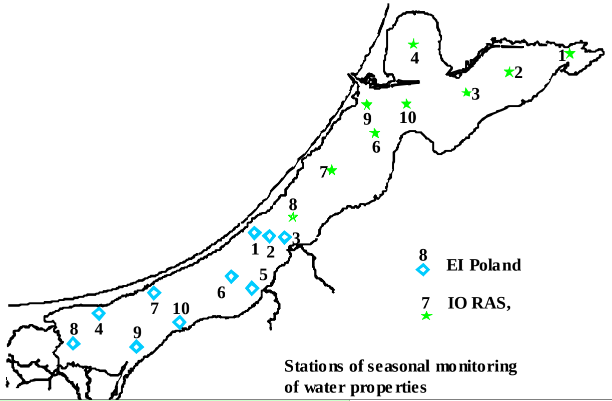


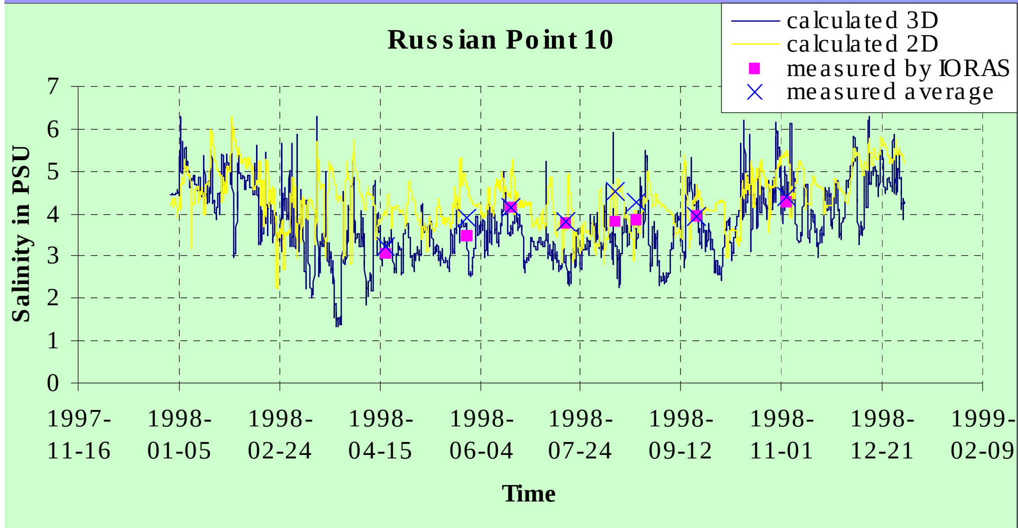


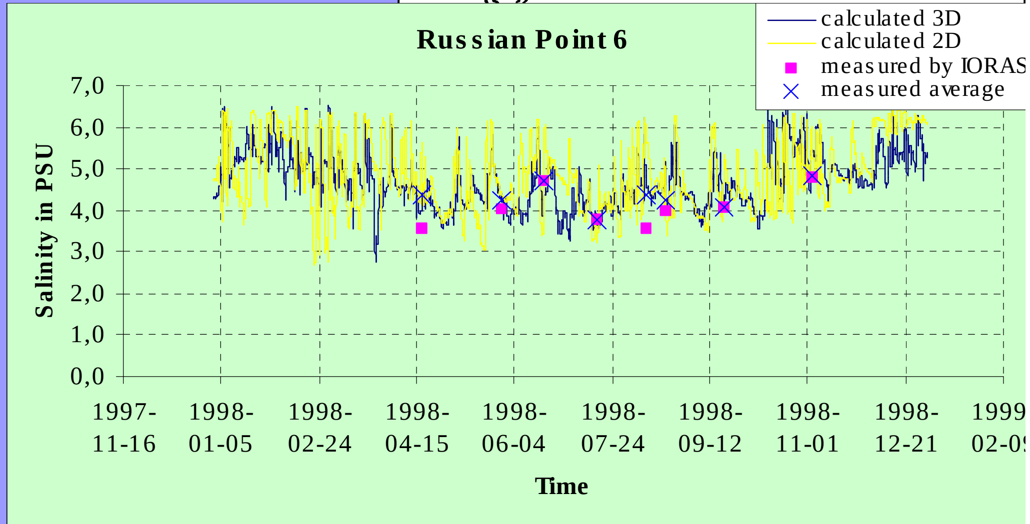


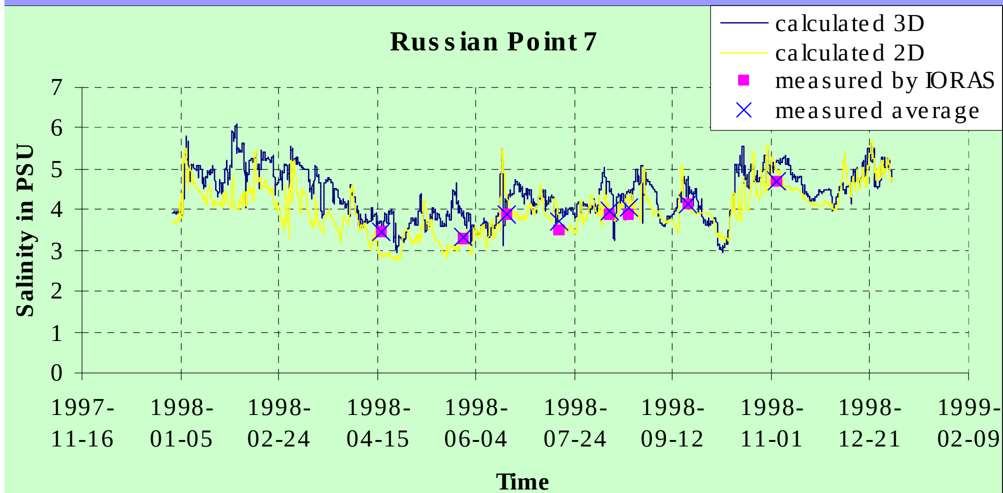


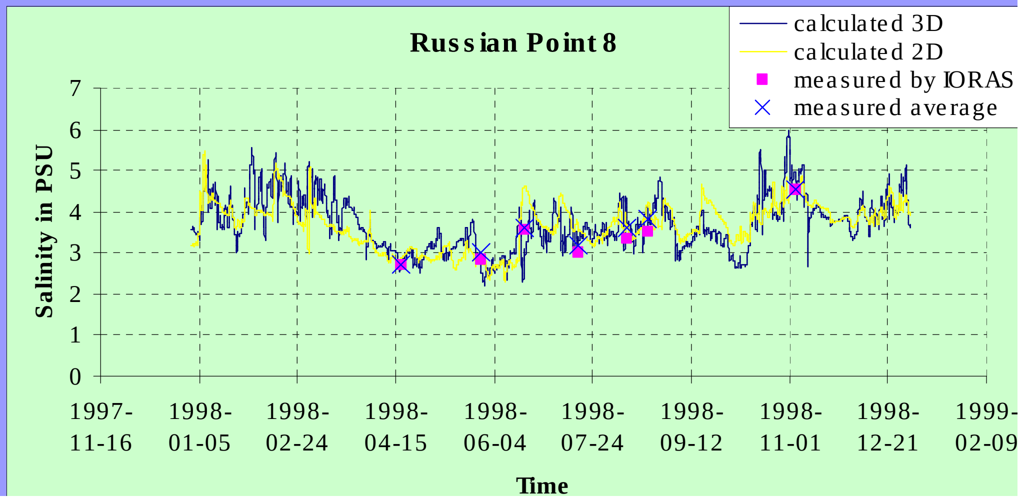
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS. SALINITY – Russia - 1998





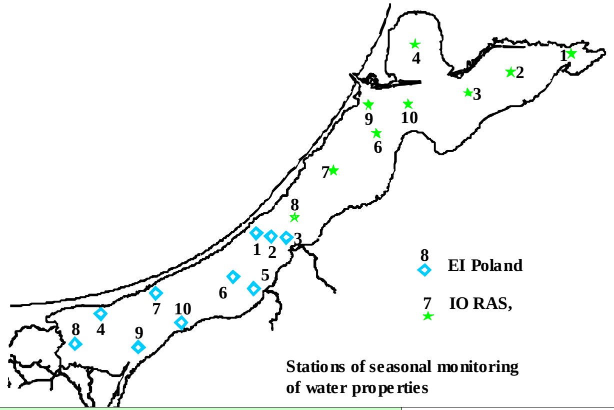


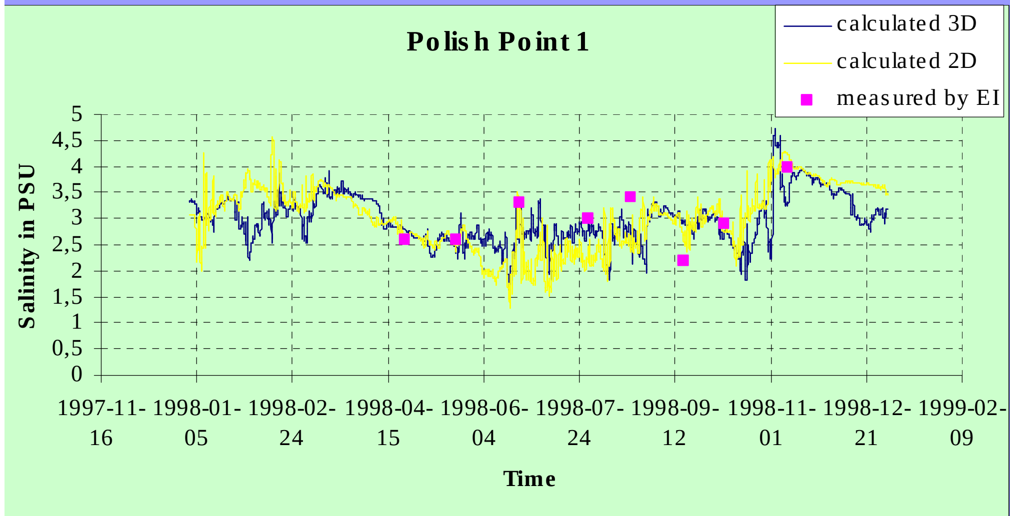


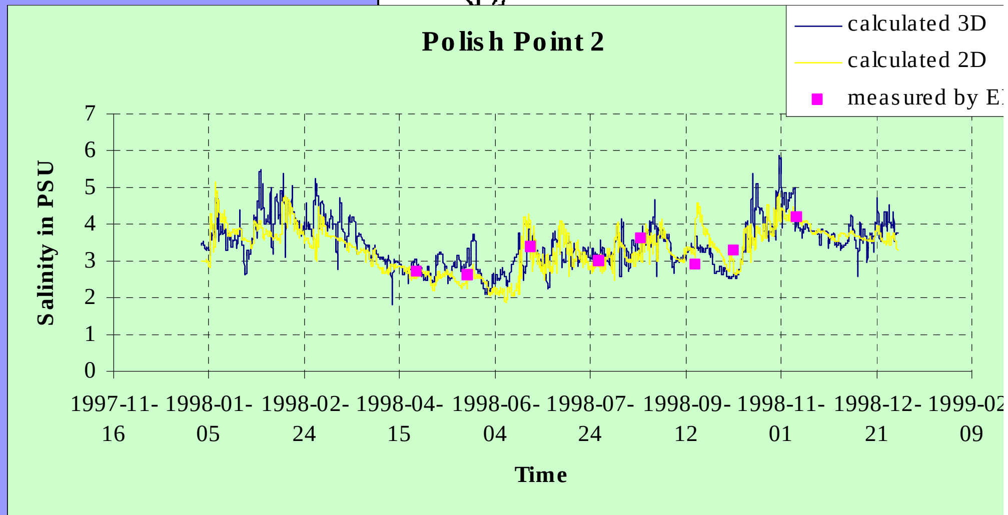


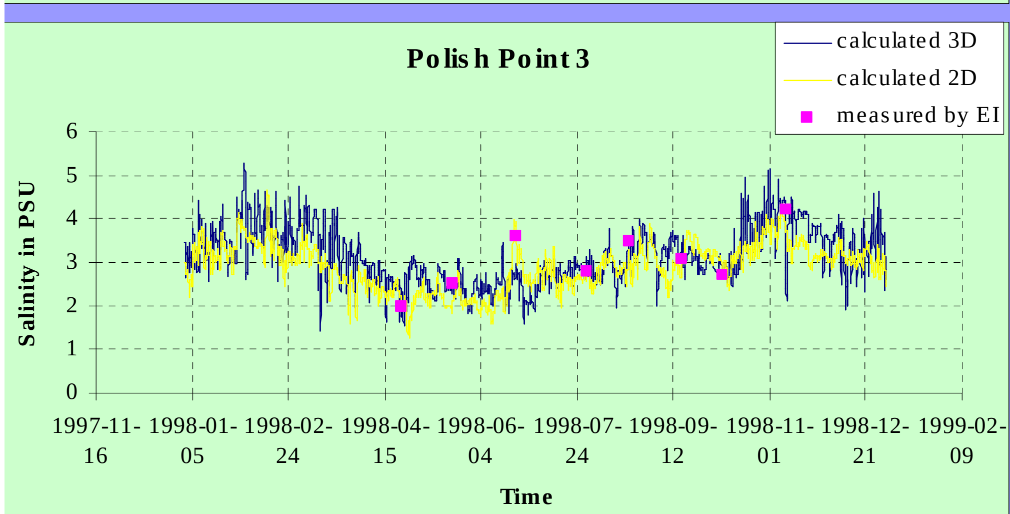
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS.

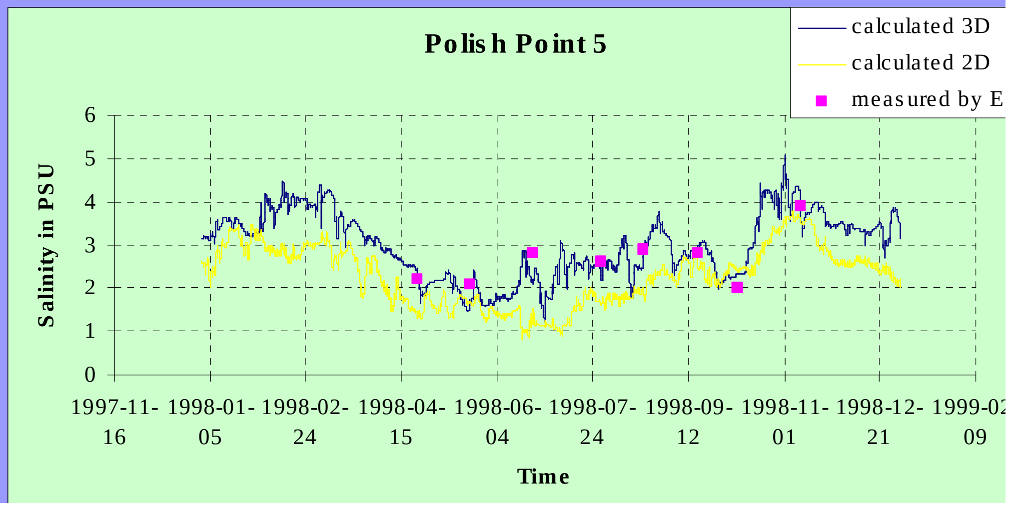
SALINITY – Poland - 1998



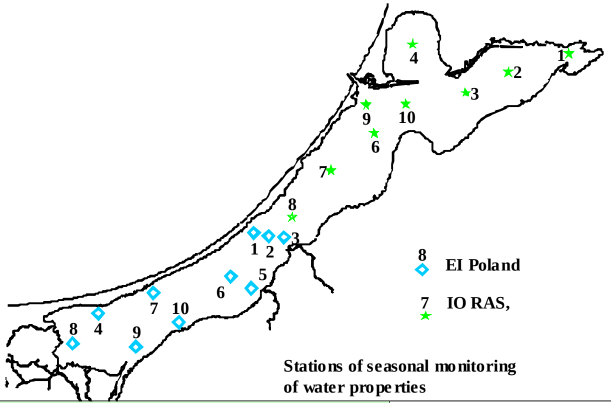


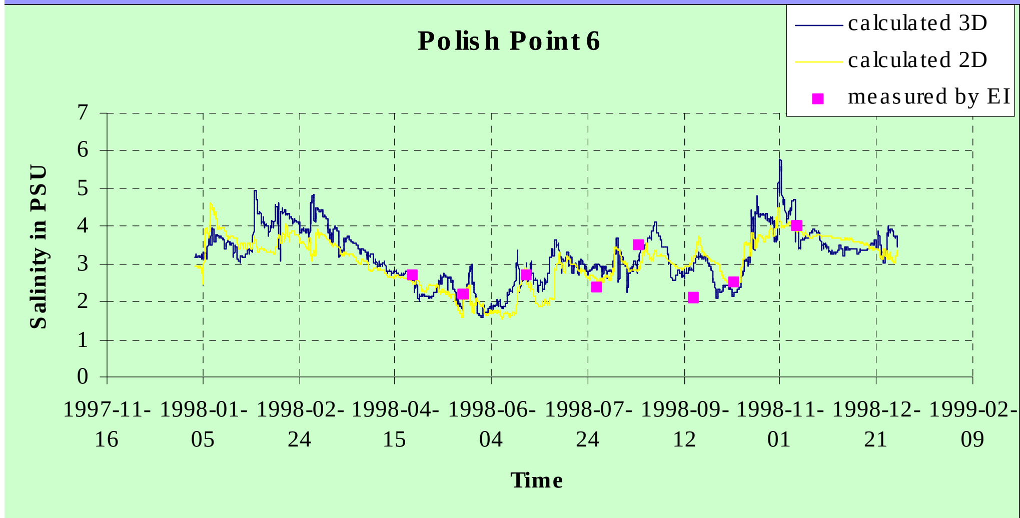


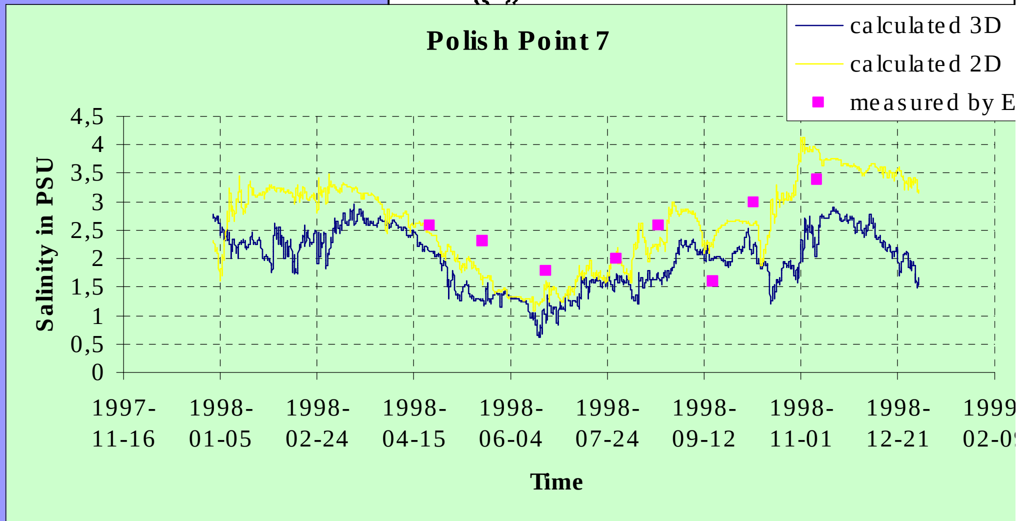


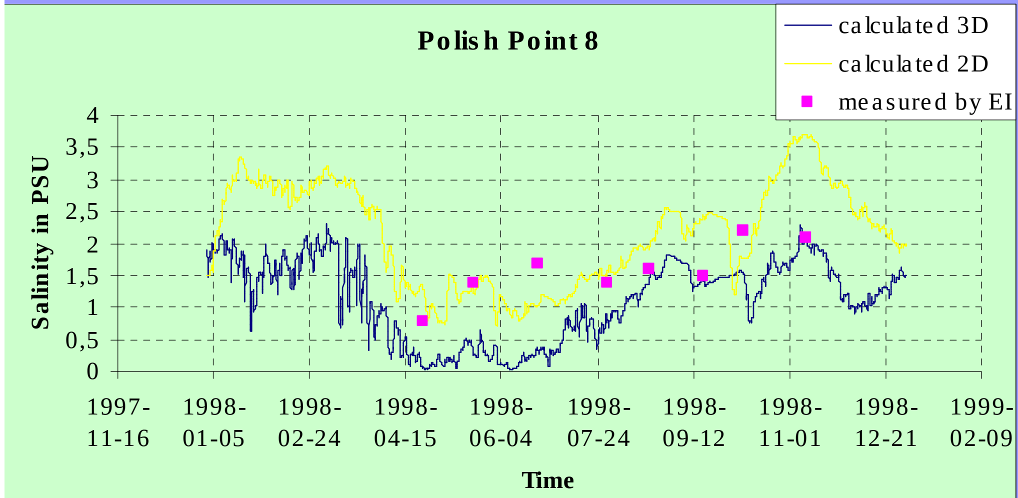


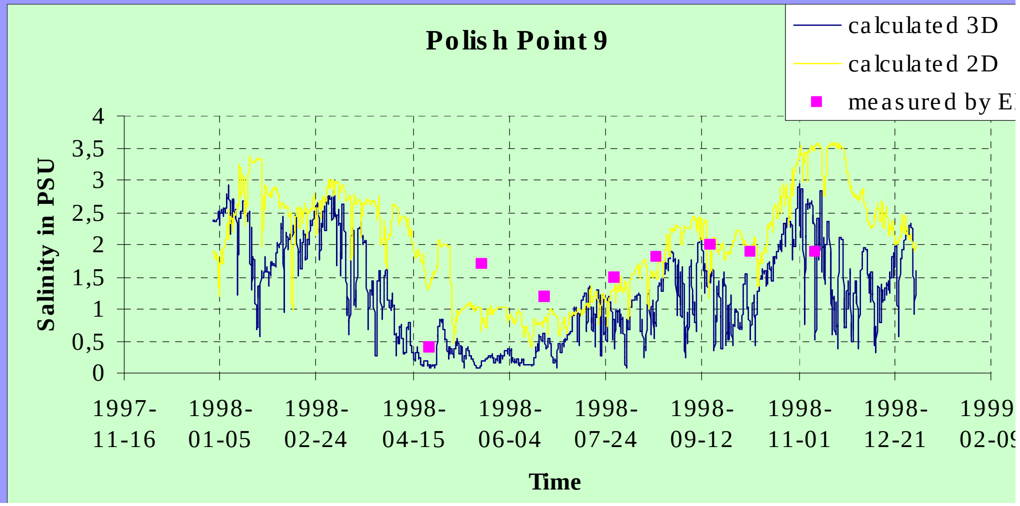
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS. SALINITY – Poland - 1998



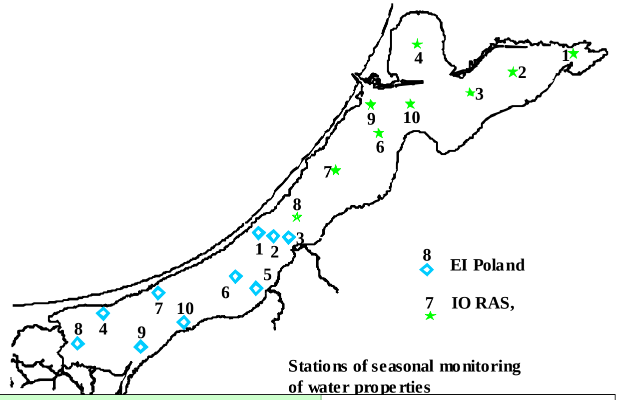


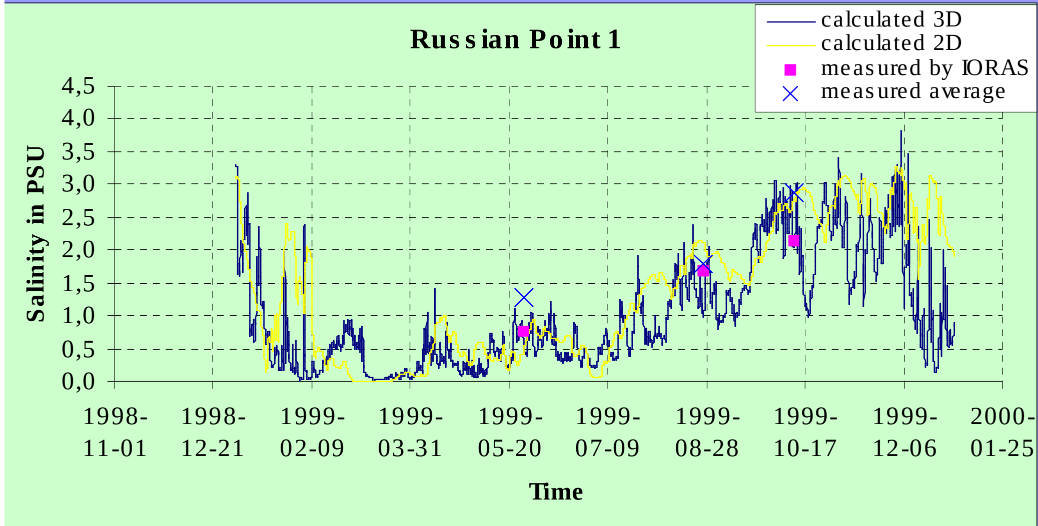


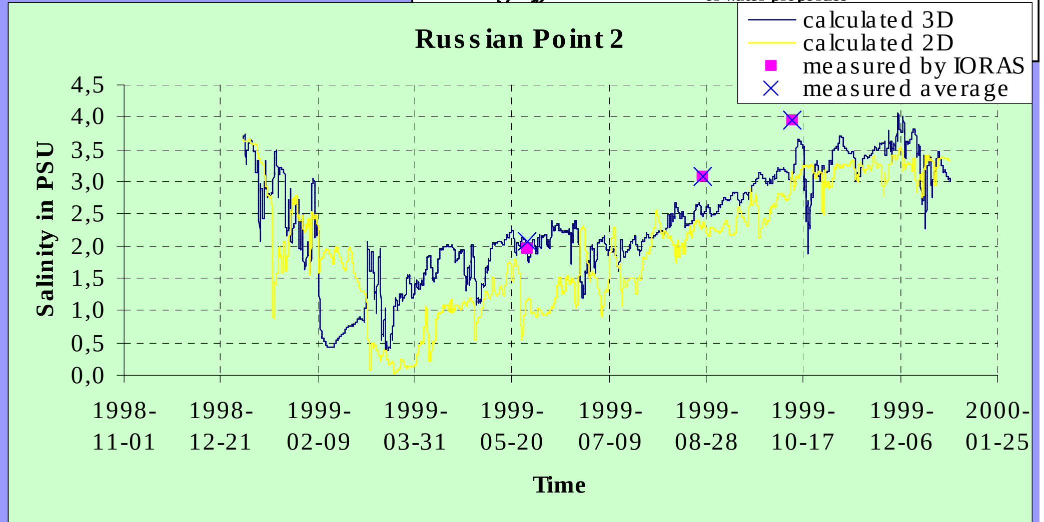


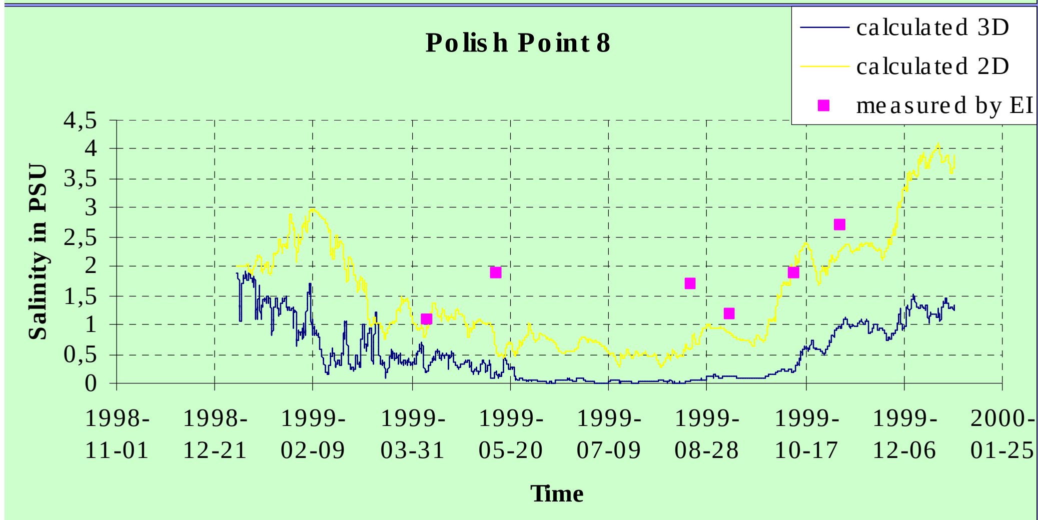


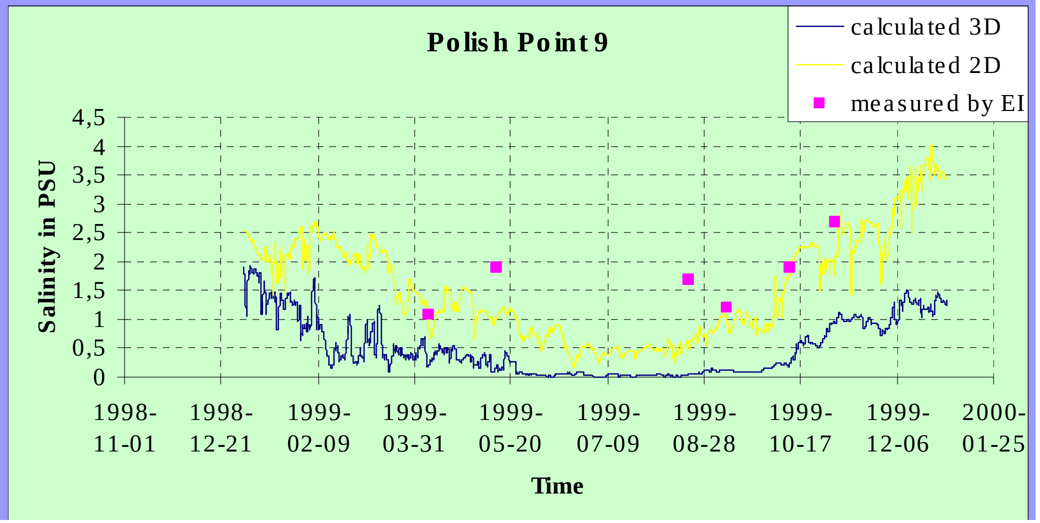
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS. SALINITY – Russia and Poland - 1999



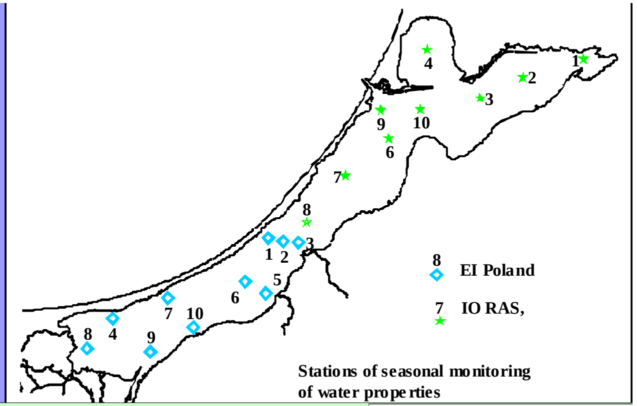


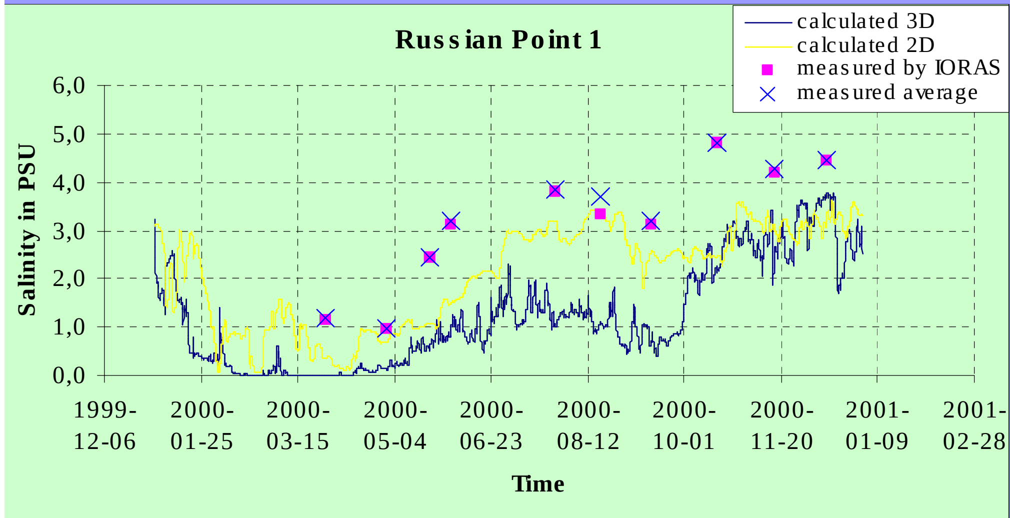


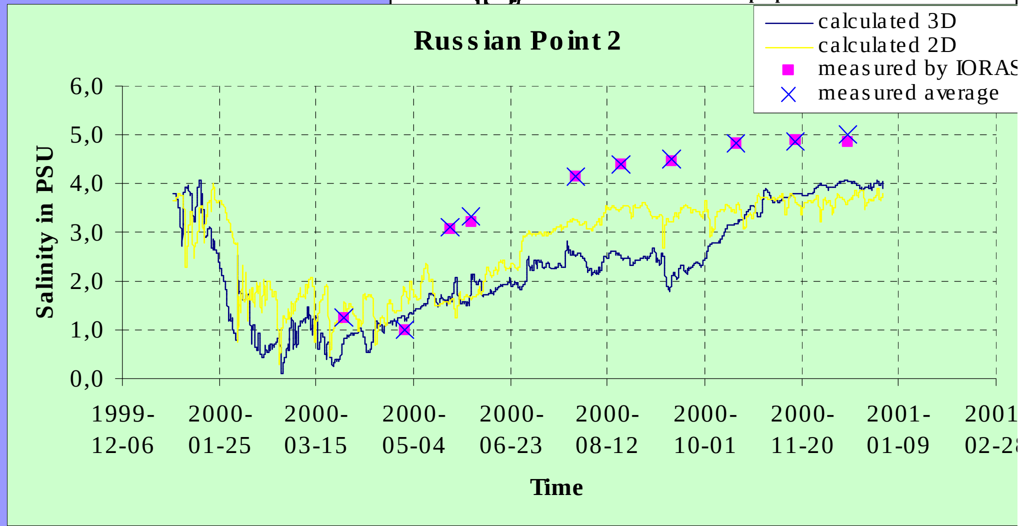


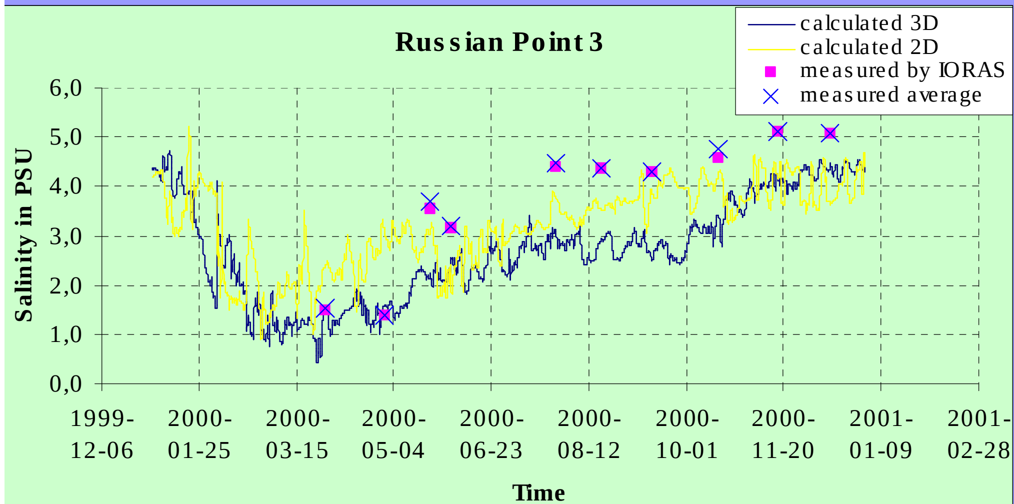


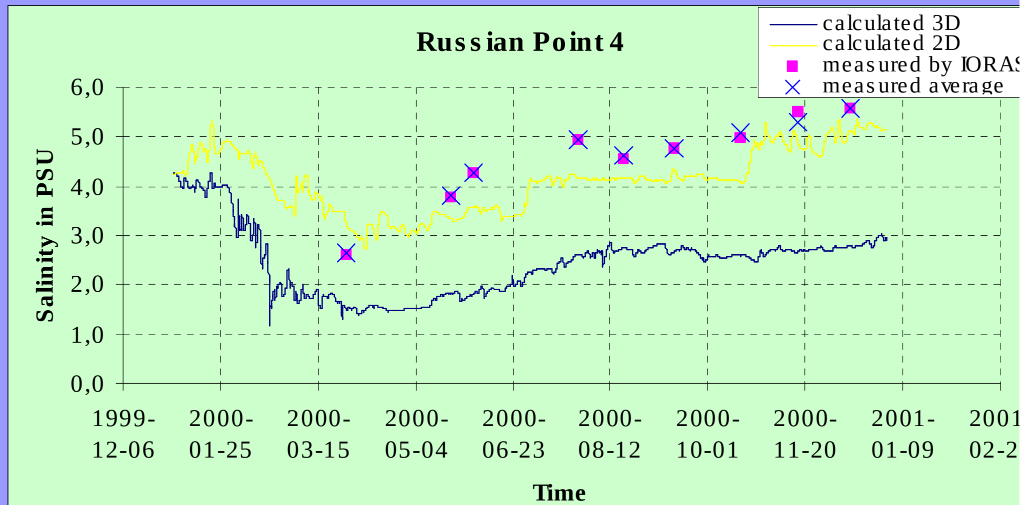
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS. SALINITY – Russia - 2000



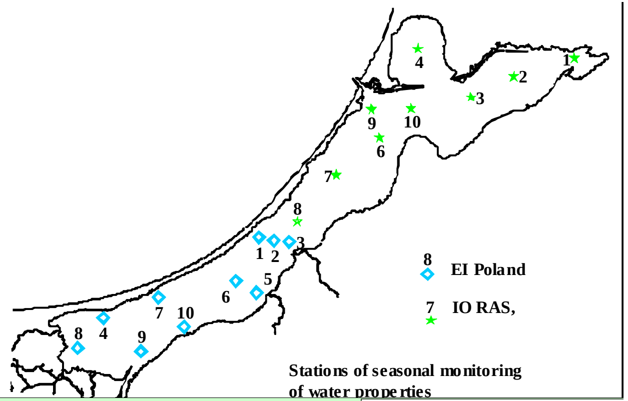


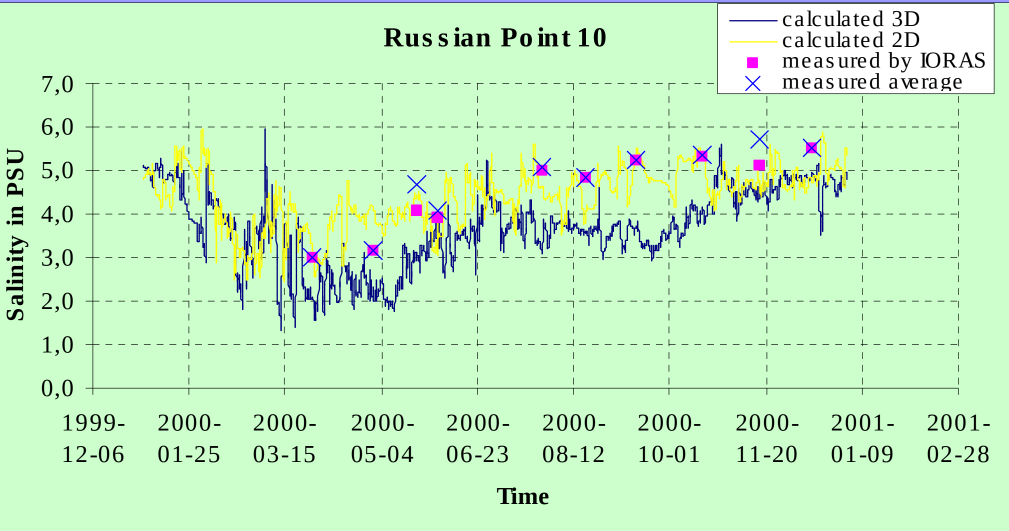


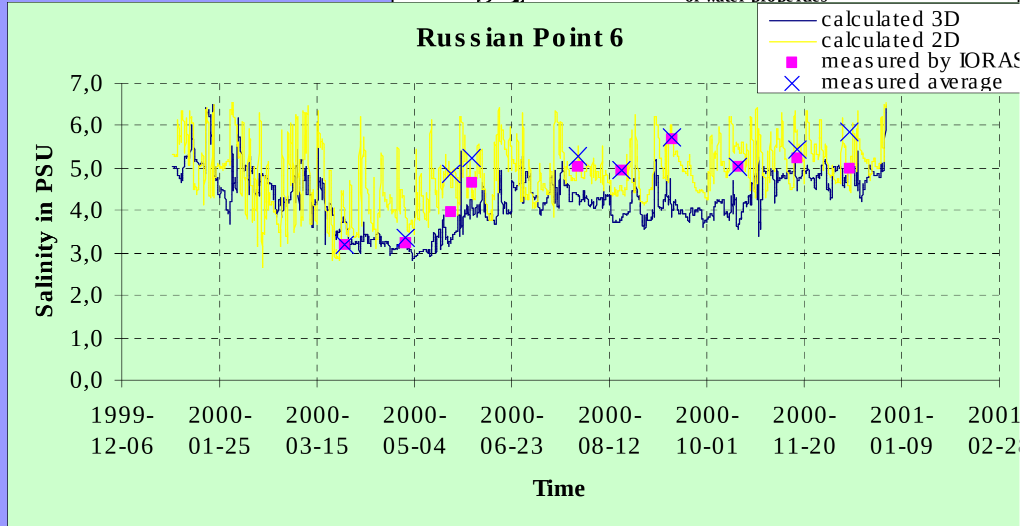


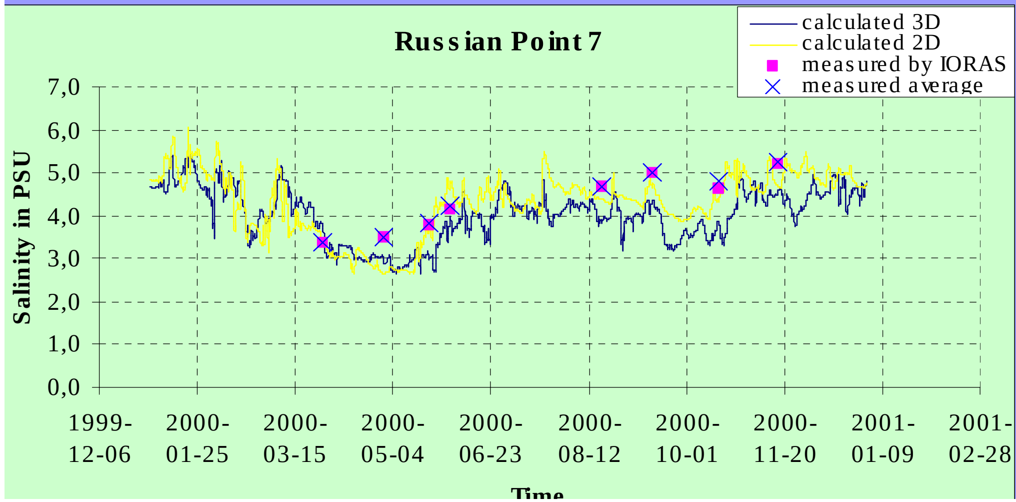


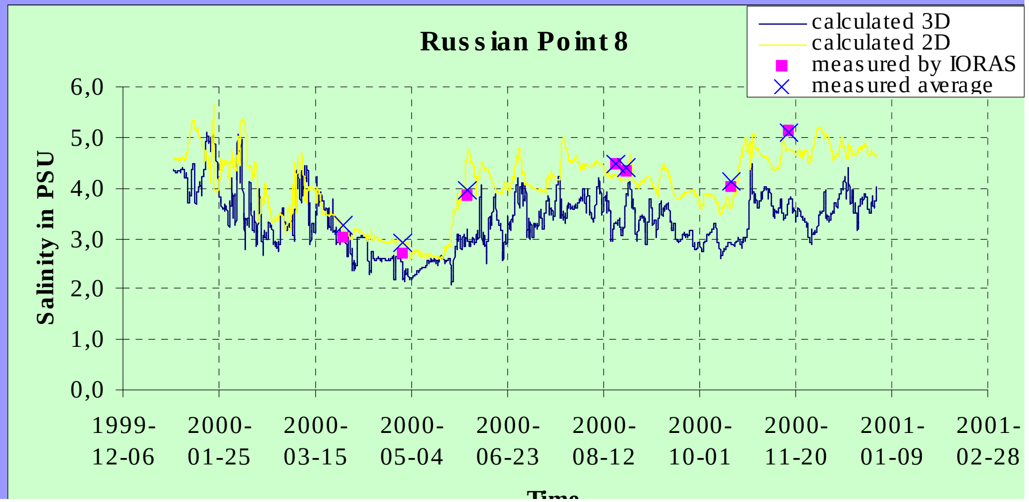
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS. SALINITY – Russia - 2000



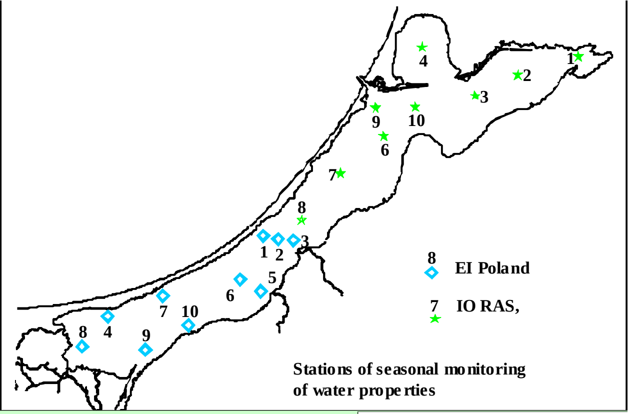


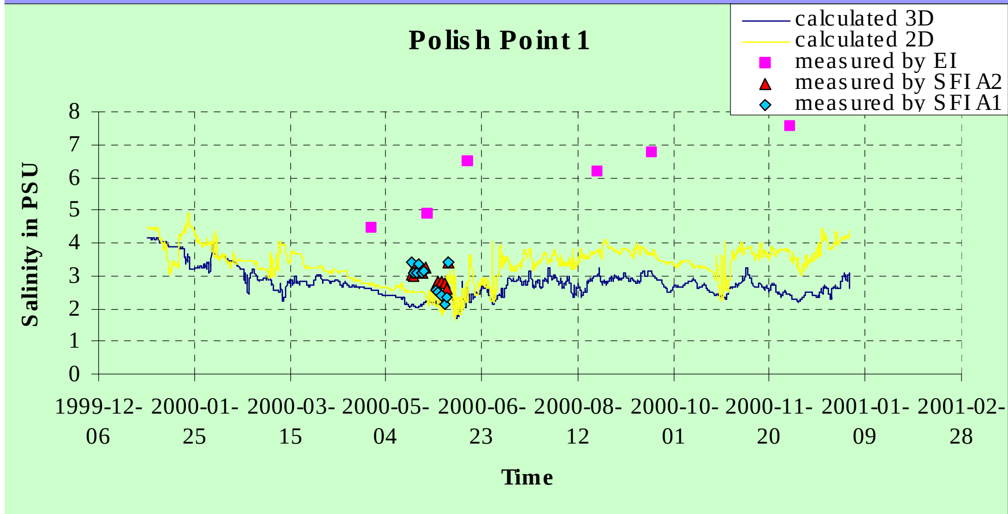


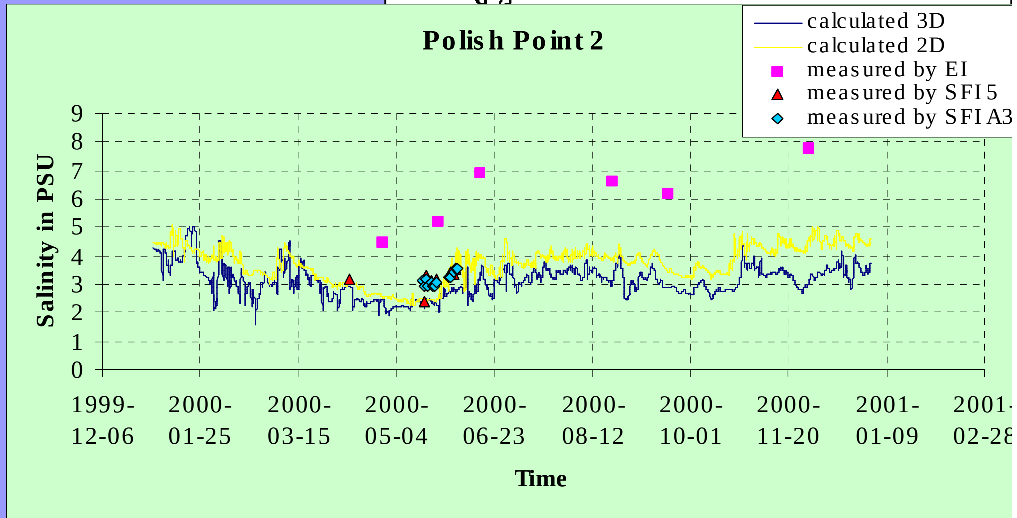


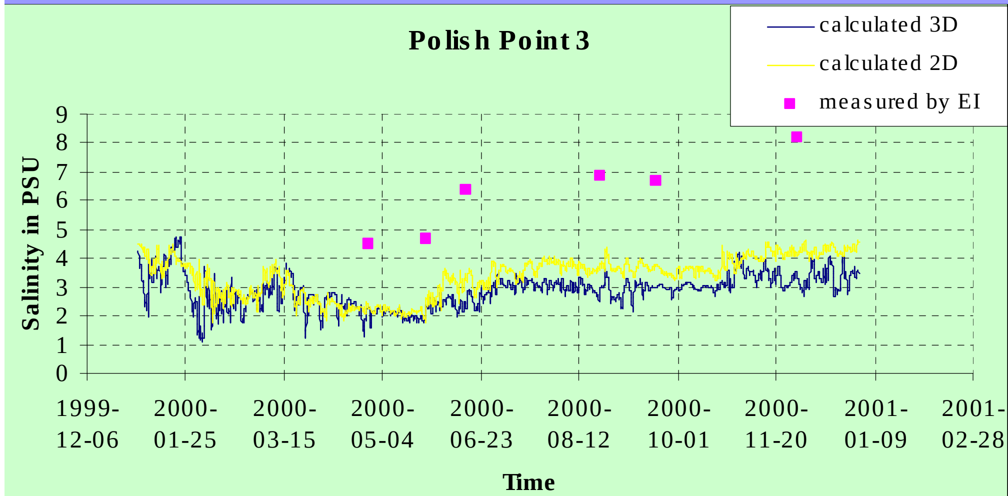


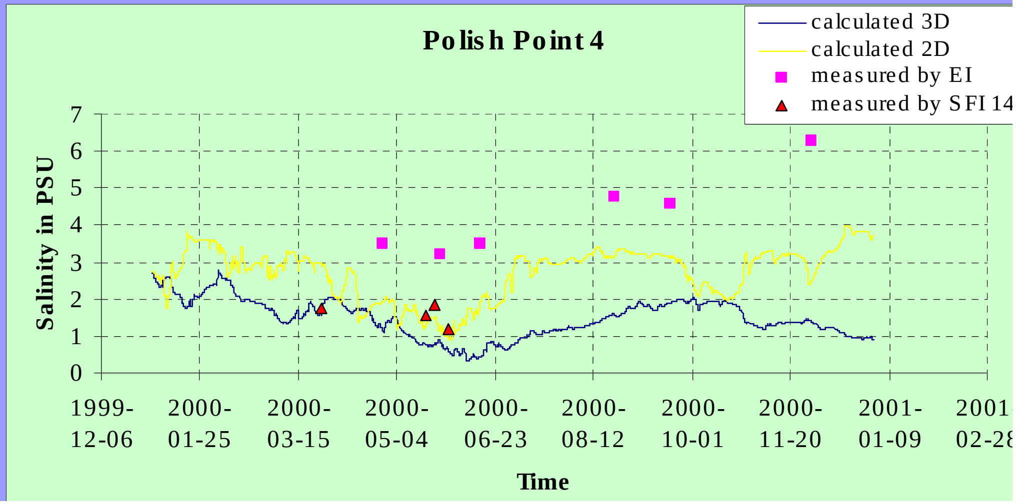
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS. SALINITY – Poland - 2000



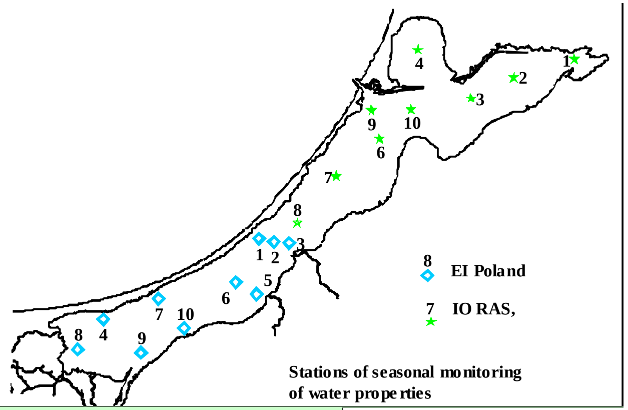


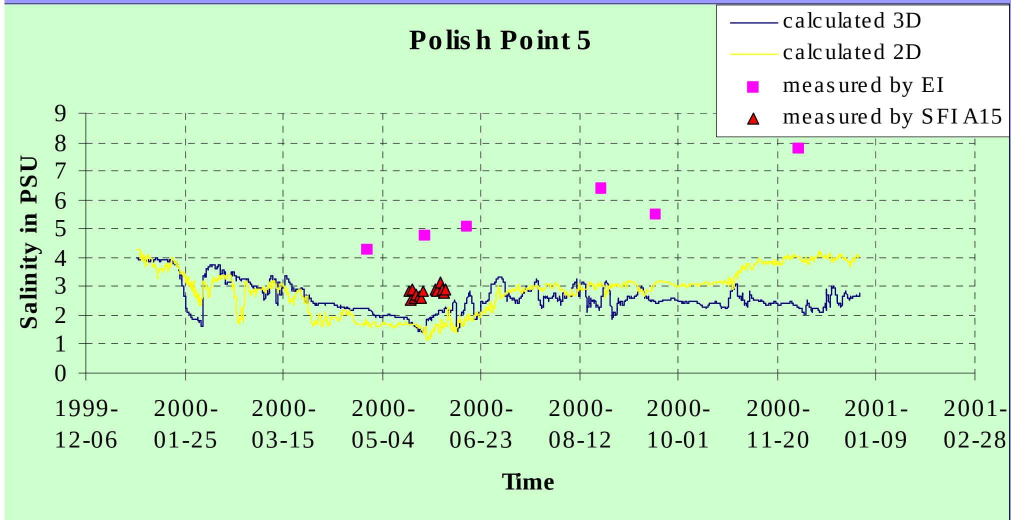


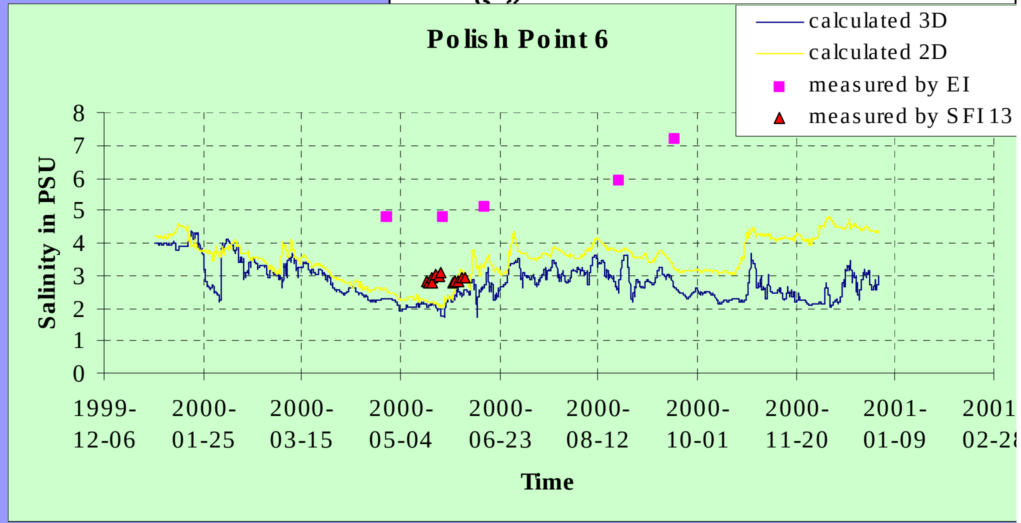


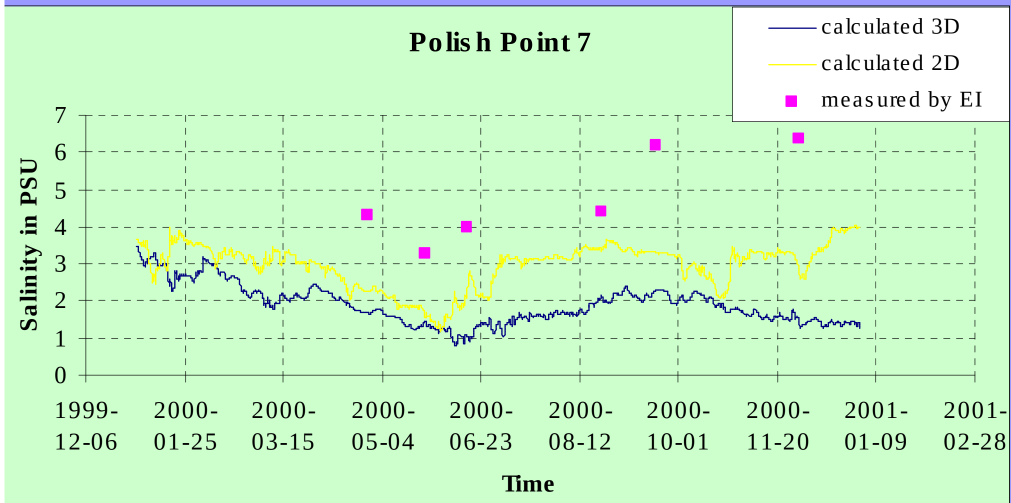


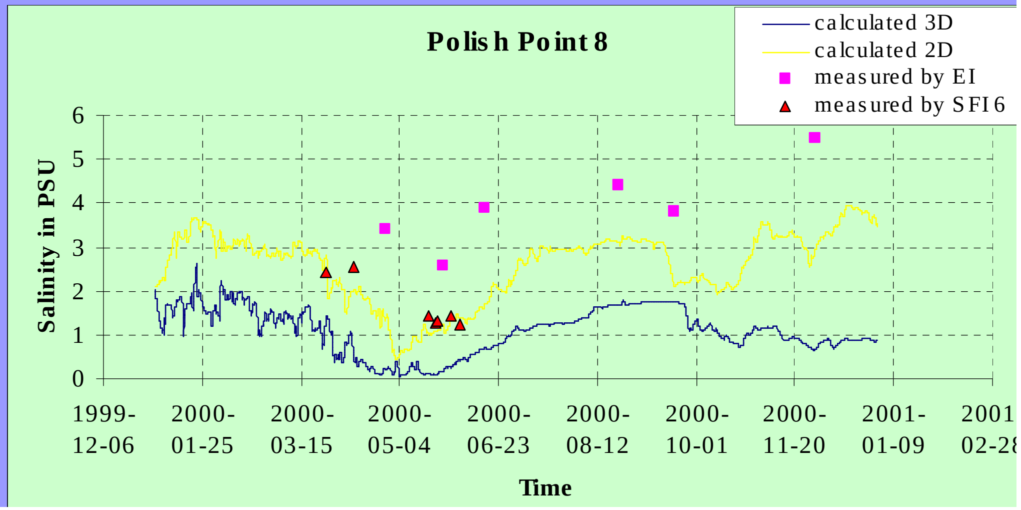
CALIBRATION AND VALIDATION OF 3D AND 2D HYDRODYNAMIC MODELS. SALINITY – Poland - 2000



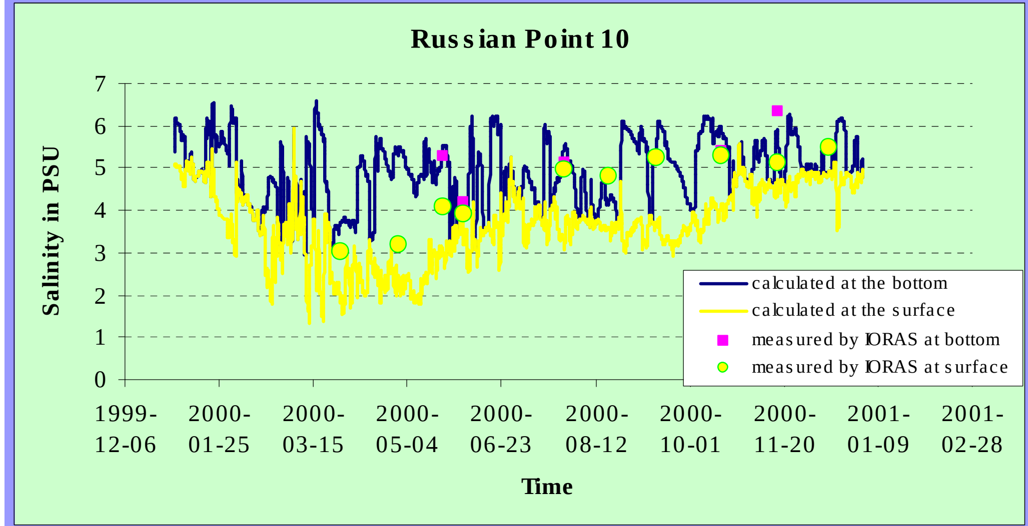


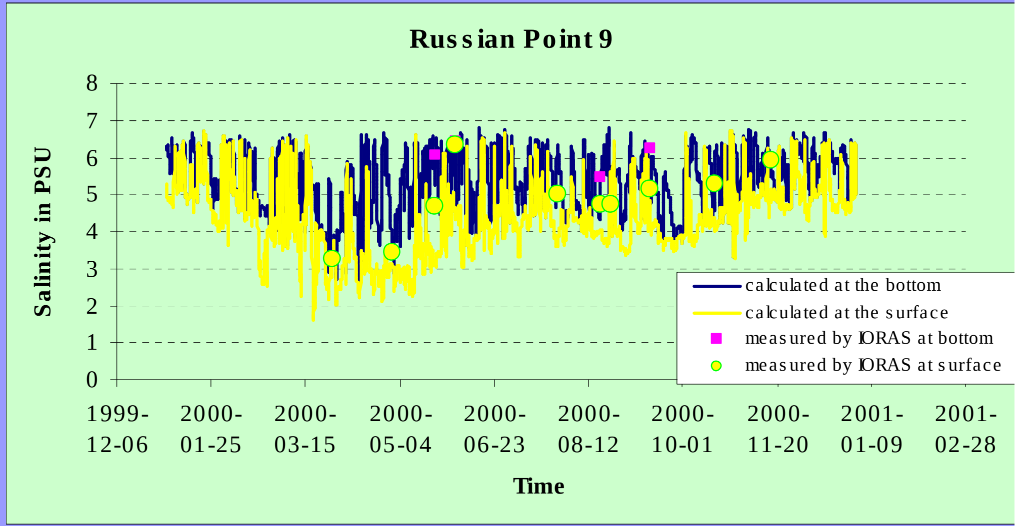


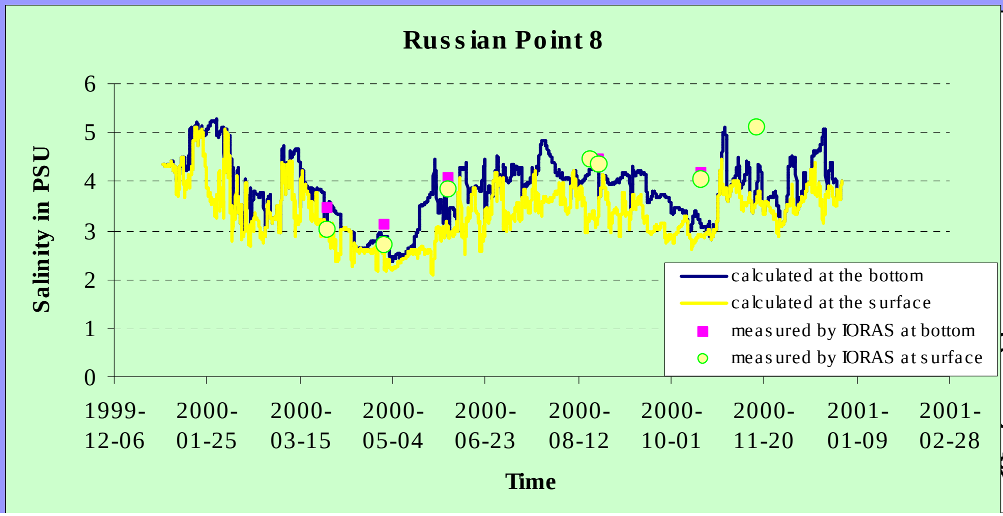


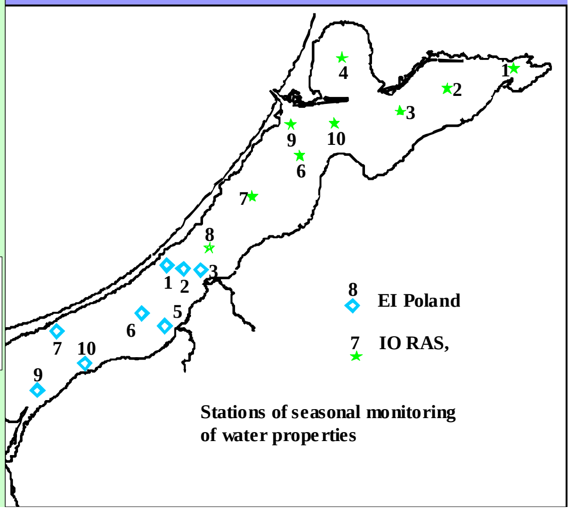


MEASURED AND CALCULATED WITH THE 3D MODEL SALINITY DISTRIBUTIONS IN UPPER AND BOTTOM LAYERS, IN RUSSIAN MONITORING POINTS IN 2000.

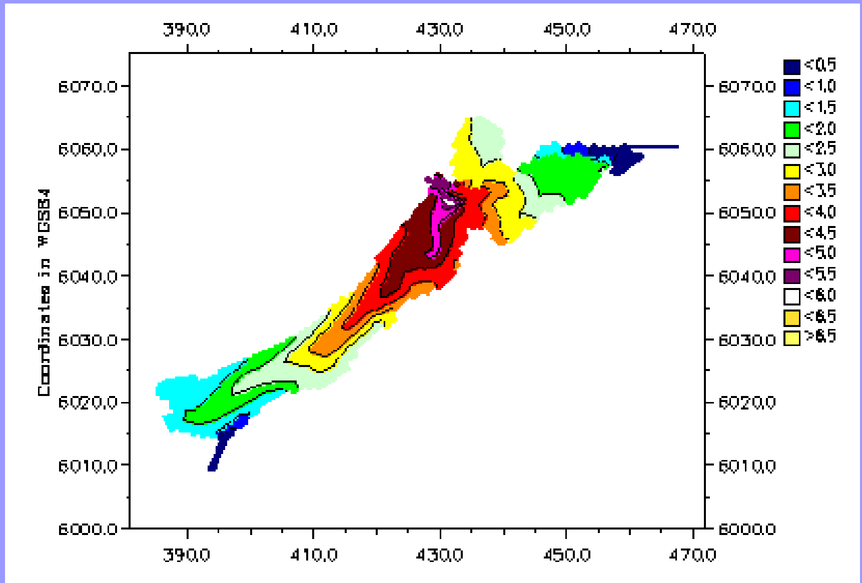


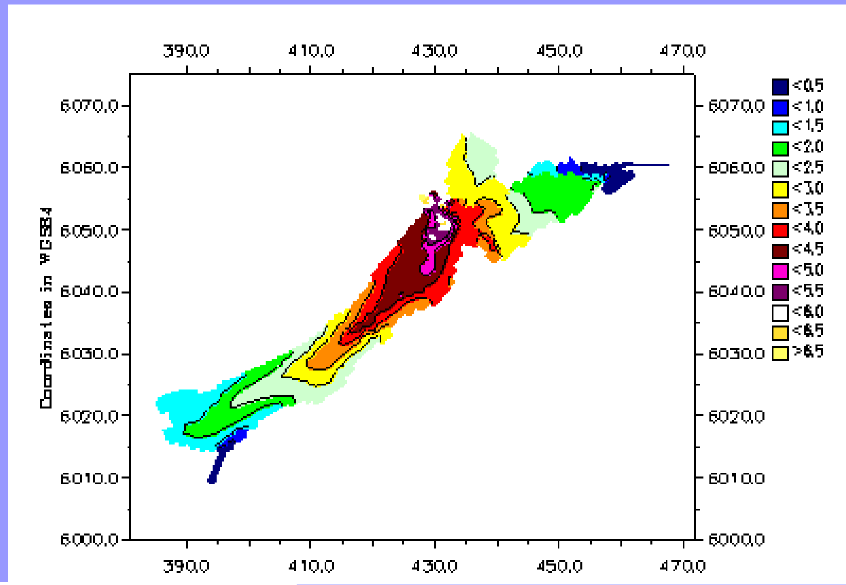


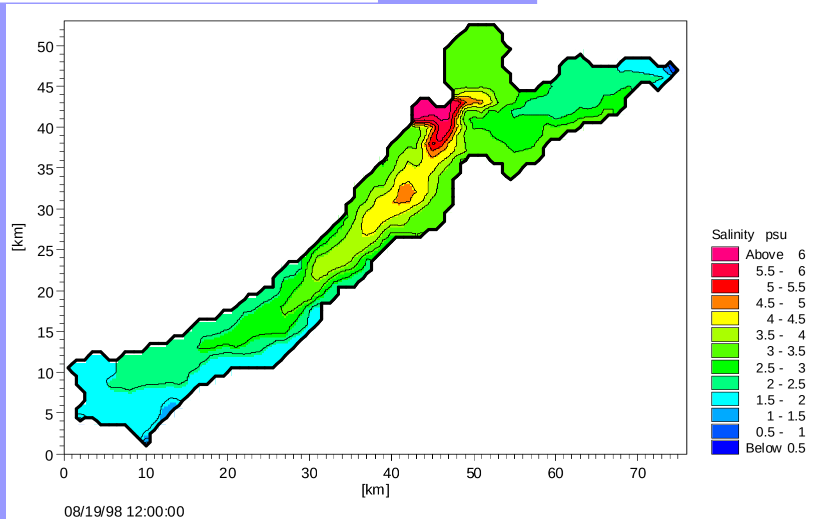




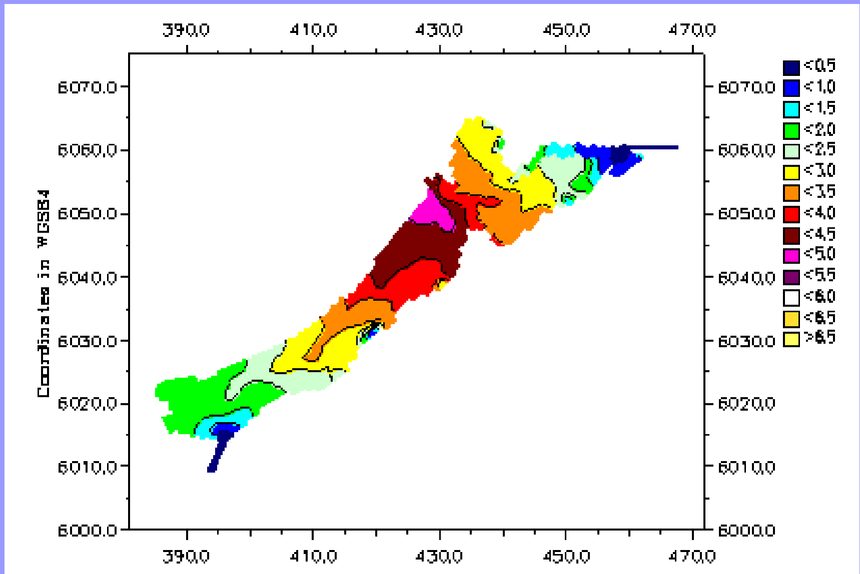
CALCULATED SALINITY DISTRIBUTIONS ON 19-08-1998 IN SURFACE (LEFT PLOT) AND BOTTOM LAYERS (RIGHT PLOT) WITH 3D MODEL AND 2D MODEL (BOTTOM PLOT) – SITUATION WITH NO STRATIFICATION.

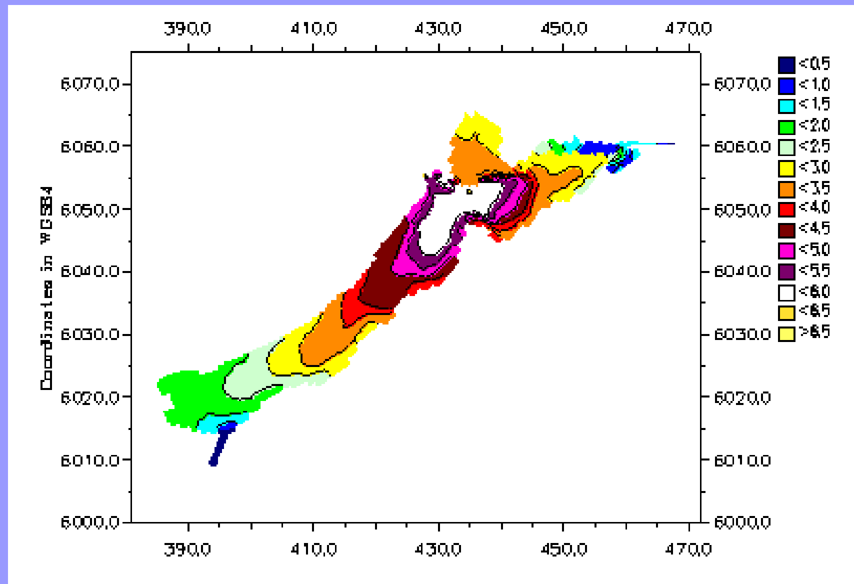


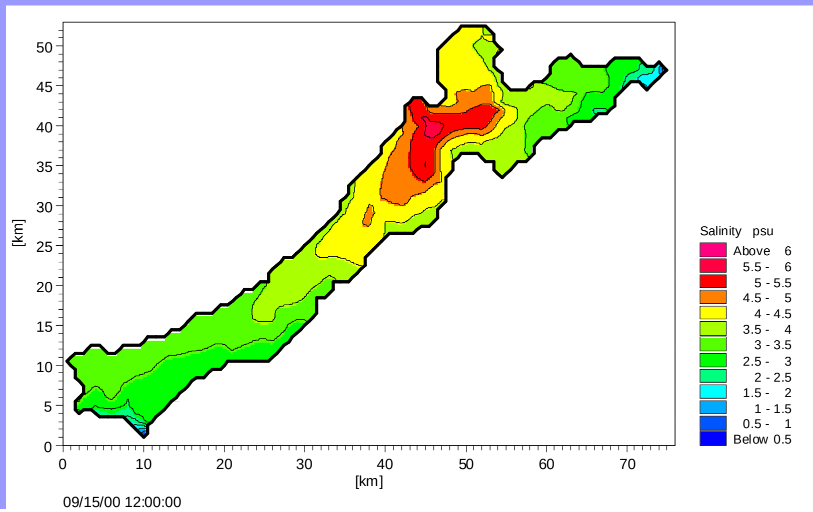




CALCULATED SALINITY DISTRIBUTIONS ON 15-09-2000 IN SURFACE (LEFT PLOT) AND BOTTOM LAYERS (RIGHT PLOT) WITH 3D MODEL AND 2D MODEL (BOTTOM PLOT) – SITUATION WITH STRATIFICATION.







CONCLUDING

- **Comparison of calculation results with use of 2D and 3D models against monitoring data indicates that both models reproduce water levels and salinity distributions in the lagoon quite accurately.**

- **There is no distinctive indication that there are areas where usage of 3D model would be more justified.**

- **For solving large scale problems in the lagoon 2D model is absolutely satisfactory.**

- **However, for analysis of small scale hydrodynamic and transport processes in Baltiysk Strait and navigation channel areas, the application of the 3D model would be more justified.**

Basing on existing monitoring data and calculation results, errors of salinity calculation using 2D and 3D models were determined

- The average errors in all monitoring points where determined according to the following formula:

$$E_A = \frac{1}{N}\sum_{i+1}^{N}\left|\left(1-\frac{S_c(M)}{S_m(M)}\right)\right| * 100\%$$

where:

E_A – is an average error in all monitoring points,
N – is a number of monitoring points,
M – is a monitoring point identificator (M = 1, 10),
S_c – is a calculated value of salinity,
S_m – is a measured value of salinity.

Average error for the 3D model varied from 20.7 to 27 % and for the 2D model – from 12.9 to 16.8 %

Average errors (E_A) of calculated salinity in the Vistula Lagoon monitoring points

Error of calculated salinity in the monitoring points [%]			
Year	**1998**	**1999**	**2000**
3D model – Polish points	17,9	39,4	30,7
3D model – Russian points	23,4	14,7	18,2
3D model – average for PL and RU points	**20,7**	**27,05**	**24,45**
2D model – Polish points	11,8	18	21,2
2D model – Russian points	14,0	15,6	10,9
2D model – average for PL and RU points	**12,9**	**16,8**	**16,05**

- **The 2D model showed better accuracy. Both models were most accurate in 1998 and least - in 1999, however these were not significant differences.**

DISTRIBUTION OF SIMULATION ERRORS FOR EACH OF THE MONITORING POINTS IN YEARS 1998 – 2000

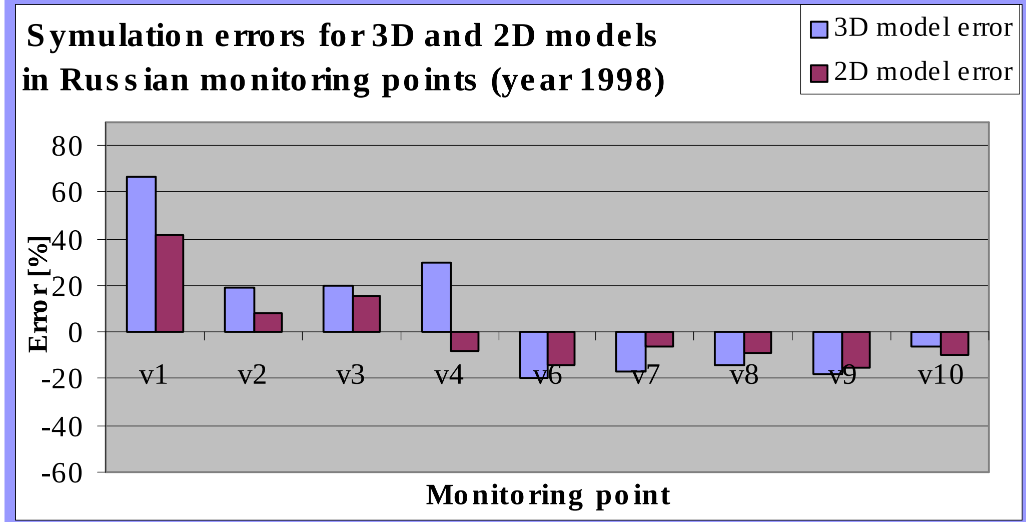
- **Calculated according to the following formula:**

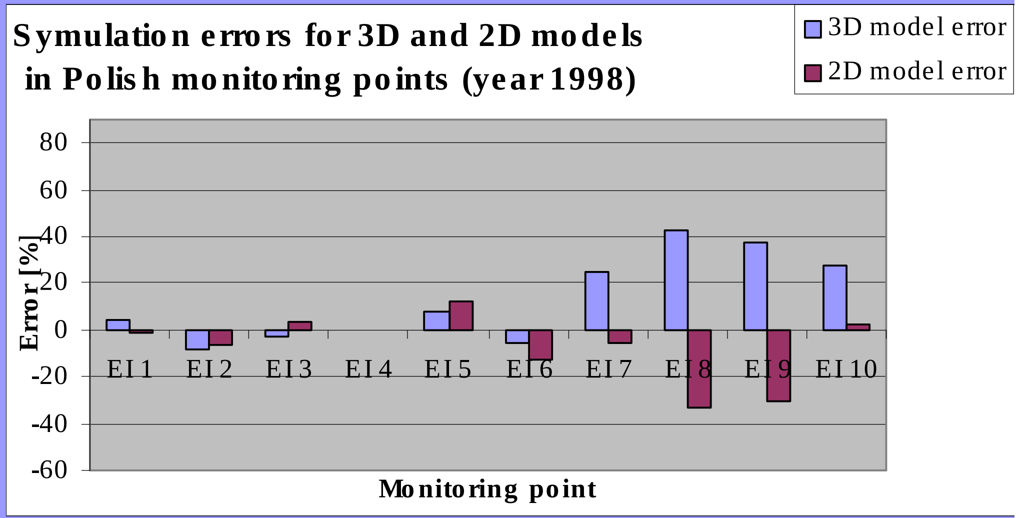
$$E_M = \left(1 - \frac{S_c(M)}{S_m(M)}\right) * 100\ \%$$

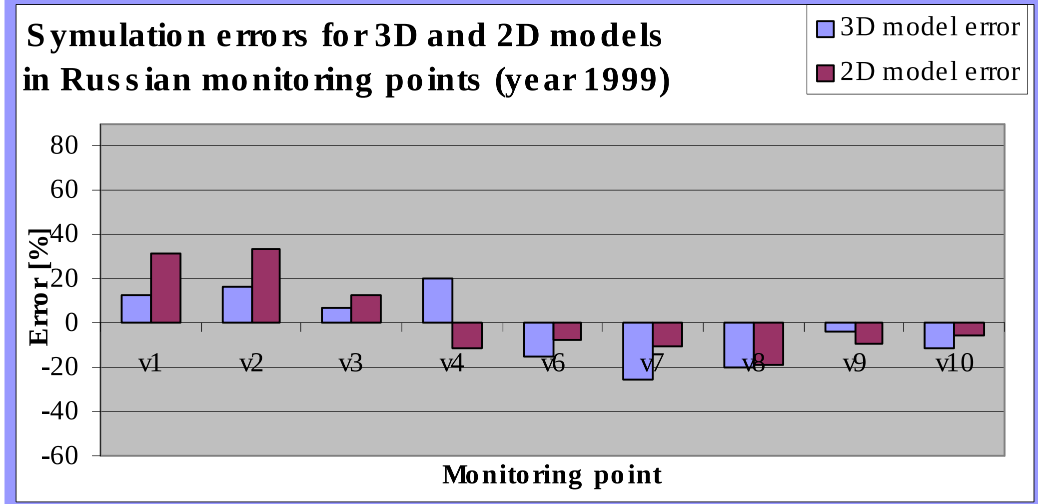
where:

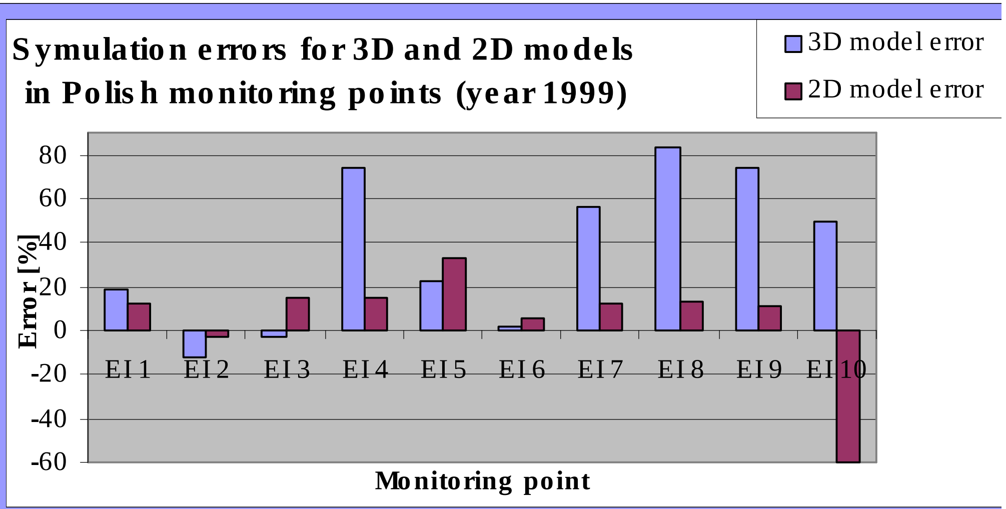
E_M **– is an average error in each of the monitoring points**

DISTRIBUTION OF SIMULATION ERRORS (E_M) FOR ALL MONITORING POINTS IN THE VISTULA LAGOON IN YEARS 1998 – 2000

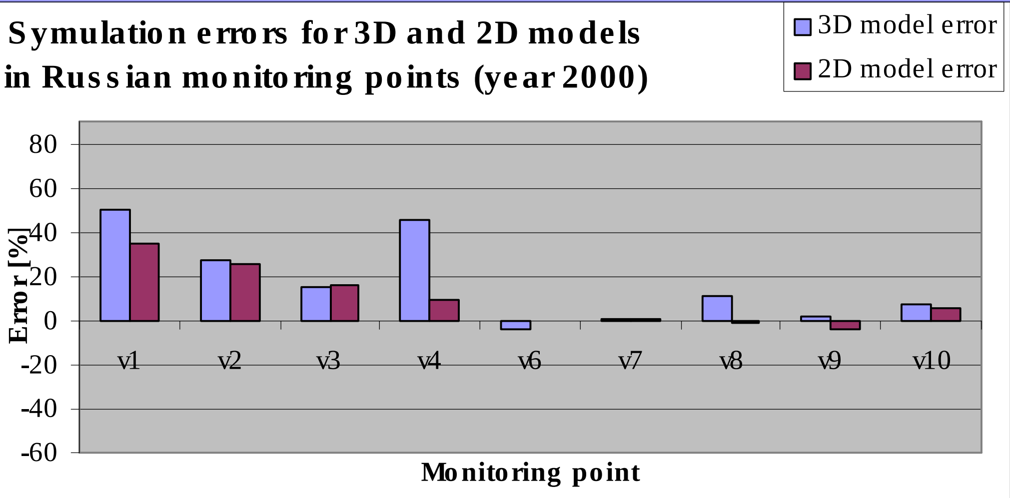


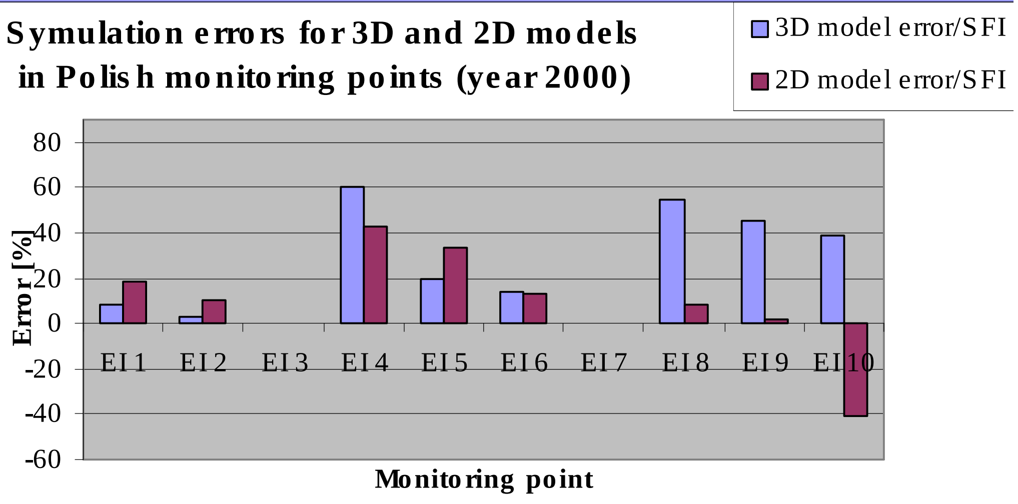






DISTRIBUTION OF SIMULATION ERRORS (E_M) FOR ALL MONITORING POINTS IN THE VISTULA LAGOON IN YEARS 1998 – 2000





- **The highest errors were observed in vicinity of river mouths, both on Russian (Pregola River – points v1, v2, v3) and Polish side (Elblag and Nogat rivers – points EI9 and EI8).**
- **Generally in those points the 3D model was less accurate than the 2D model, especially with regard to Polish monitoring points.**
- **Both models produced much more accurate results in the central parts of the Lagoon – monitoring points EI1, EI2, EI3, EI6 and v6 – v10.**

CONCLUSIONS

- The Mike 21 and Delft 3D modelling systems are intended to be used to evaluate a potential to improve the environmental situation of the Vistula Lagoon by reducing nutrient discharges from the major Polish and Russian rivers. The impact of planned abatement actions in both countries, in respect to the environmental situation, will be evaluated. In order to perform water quality calculations it is necessary to determine flow fields in the Lagoon with the use of hydrodynamic model. Next the water quality calculations may be conducted. Therefore first it is necessary to calibrate hydrodynamic then water quality models before they are used for forecast purposes.

- The Vistula Lagoon is a transboundary basin and it is a very frequent problem that the data necessary for running the models are not always freely available. To avoid this problem it is recommended to build an operational modelling system that will predict driving forces and boundary conditions for the models. Such situation was tested with use of Mike 21 on basis of the year 1998. To simplify the task, only prediction of wind data was considered with use of an operational atmosphere model UMPL, which is run in the University of Warsaw.

CONCLUSIONS

- Results of calibration of the hydrodynamic model ran with the measured and UMPL data, proved that in both cases water levels and salinity are predicted with very similar accuracy. Therefore usage of operational model, instead of actually measured data may be recommended in this situation. Since both Poland and Russia have access to HIROMB and HIRLAM operational models, therefore they are proposed to be used in case data from one country are not available to the other country.
- The Delft3D FLOW and Mike 21 models were calibrated using water level and salinity data from year 1998. Next they were validated with use of 1999 and 2000 data.
- Results of calibration and verification show that the models reproduce water level variations very accurately.
- On average the 2D model showed better agreement with the monitoring data than the 3D model.
- In general calculation results obtained from 2D and 3D models are comparable. This indicates that in case of a shallow lagoon it is enough to use 2D model in order to produce relatively accurate salinity distributions in the lagoon.

CONCLUSIONS

- Better results can be achieved by better description of conditions at open boundaries. The most important are the conditions in the Baltiysk Strait, where more frequent observations of water levels and salinity are necessary. This would improve the description of salinity balance in the Lagoon. The Delft3D FLOW and Mike 21 models were calibrated using water level and salinity data from year 1998. Next they were validated with use of 1999 and 2000 data.
- Equally important is accurate information on river discharges, which in this case based on very scarce measurements. Analysis of the present and historical data indicated that possible errors in discharges assumed for calculations.
- There are also indications of significant measurement inaccuracies of salinity concentrations in the Polish part of the Lagoon in year 2000.
- Results of measurements as well as calculations with Delft3D FLOW model indicate that vertical salinity stratification appears most frequently in Russian part of the Lagoon, close to the Baltiysk Strait. In the Polish part of the Lagoon such stratification nearly does not exist at all. It should also be indicated that even though some stratification occurs in the Russian part, it does not last long and waters are quickly mixed.

CONCLUSIONS

It is STRONGLY RECOMMENDED to set up a COMMON POLISH/RUSSIAN MONITORING PROGRAM of the Vistula Lagoon and discharging rivers, as well as conduct frequent intercalibrations of measurements !!!


THANK YOU !
MANTRA East

ACKNOWLEDGMENTS

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