MACIEJ KAŁAS
Maritime Institute Gdańsk, Poland

BOGUMIŁ JAKUBIAK
Interdisciplinary Centre for Mathematical and Computational Modelling,
Warsaw University, Warszawa, Poland

ASSESSMENT OF NUMERICAL WIND FORECASTS FOR THE GDAŃSK BAY AREA DURING THE POLRODEX'97 EXPERIMENT

Abstract

The paper presents results of forecasts of wind field parameters over the Baltic Sea for the Gdańsk Bay area obtained using two atmosphere models: UMPL (ICM Warsaw University) and HIRLAM (SMHI Sweden). The obtained results are compared with field observations made on the open sea and at coastal stations during the POLRODEX'97 experiment. The agreement is quite good, although the influence of local weather conditions cannot be neglected.

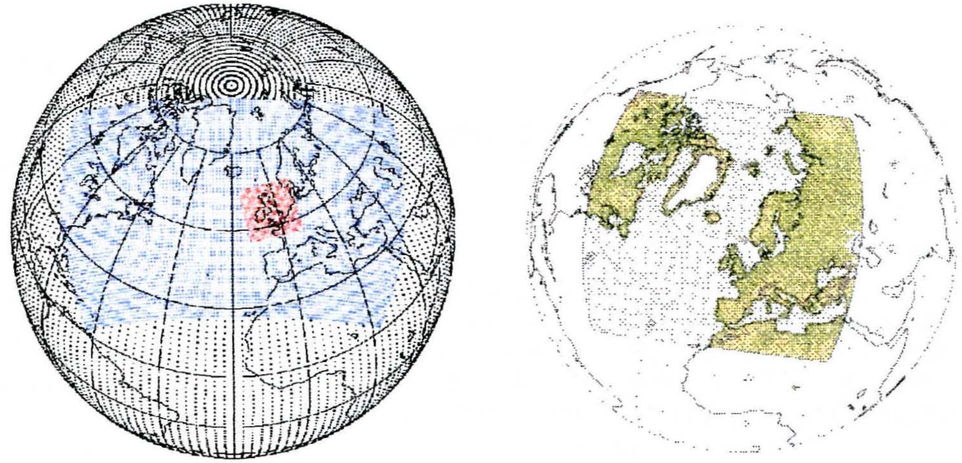
1. Introduction

The last years have seen a significant progress in the field of hydrophysical modelling for areas of different scale. A visible progress on weather conditions forecasting gives application in numerical computations of mesoscale models for atmosphere. However, all weather forecasting systems require continuous verification of the results of computations with the observations made in real conditions. In September 1997 a successive experiment on the open sea, called POLRODEX '97, was carried out. One of its goals was to obtain direct measurement data for different hydro-meteorological conditions at sea and in the coastal zone in order to calibrate and verify HIROMB – the hydrodynamic-numerical, operational model for the Baltic Sea, developed in co-operation by a number of research institutes from the Baltic countries, too. Wind field parameters are very important for this model, especially those observed over the open sea [2].

Data from two sites situated on the open sea: monitoring point ZN4 and drilling platform BETA, and from two coastal meteorological stations: Hel (Institute of Meteorology and Water Management - IMWM) and Gdańsk Port Północny (Institute of Hydroengineering – IH PAS) located in the Gulf of Gdańsk were used. The numerical forecasting information was taken from two mesoscale atmospheric models:

- UMPL mesoscale model - computed at the Interdisciplinary Centre for Mathematical and Computational Modelling of the Warsaw University (ICM) and based on boundary values of the Unified Model – Bracknell UK [4]. (In Fig. 1a the area of the Unified Model used in UK is shown; for the presented case it contains the whole area of the Baltic Sea and a greater part of Central Europe)
- High Resolution Limited Area Model - HIRLAM running in the Swedish Hydro-Meteorological Institute (SMHI) in Norrköping (Sweden) and based on boundary values taken from a global forecast model of ECMWF – Reading, England [1] (the area contained in this model is shown in Fig. 1b)

The location of observation points for wind parameters over the Gulf of Gdańsk during the POLRODEX'97 experiment and numerical grid points for the two forecasting models are shown in Fig.2. Fig. 2 shows also the area, where the rhodamin was released.



a) b)

Fig. 1 Two mesoscale atmospheric models: a) UMPL, b) HIRLAM

2. Mesoscale modelling for prediction of weather conditions

2.1 UMPL model

The system developed at the Warsaw University was implemented from UKMO Unified Model and contains a complete numerical weather prediction system used to perform meteorological forecasts for atmospheric perturbations below the synoptic scale of horizontal dimensions from tens to thousands kilometres. The main components of the system are: boundary data transmission from Bracknell to Warsaw, preliminary processing and quality control of observations, assimilation of new data into the model, hydrostatic, primitive equation numerical model, data visualisation tools and a system for distributing the results to users.

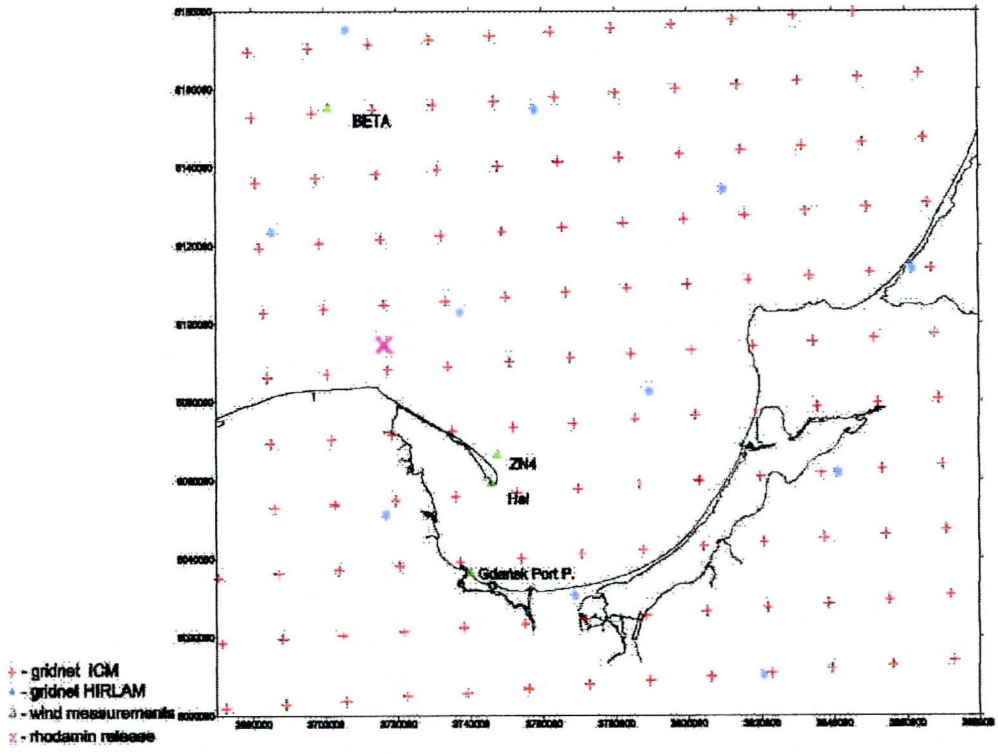


Fig. 2 Location of POLRODEX'97 measurements

An important part of the system is the quality control of the raw data from observations. Data are checked in order to detect possible random errors and to eliminate or correct erroneous observations. Such filtering of the observations is required because of the high sensitivity of the system, due to which an unrealistic forecast could be produced if it would be based on erroneous data. The quality check detects errors by performing several tests, in particular by comparing the observations with the forecast background and by comparing data from other, surrounding stations.

For an assimilation purpose the Analysis Correction method developed by Lorenc, [3] was applied. The method is variational, the optimum initial state is obtained basing on variational minimisation of a cost function. In a case of the meteorological data, the cost function is represented as a sum of two components: one measuring the fit with the observations and the other measuring the consistency with prior knowledge. In the system, the continuous data assimilation system is used. New information is coming every three hours, and all observations within a five-hour time window are assimilated into the model. Basically, data from over 1200 surface synoptic stations and 43 radiosondes are used. Satellite and aircraft observations are also used.

The forecasting model is based on hydrostatic primitive equations in the Eulerian form. The equations are presented in spherical coordinates in the horizontal domain and with a hybrid coordinate in the vertical domain. The resolution of the model is about 17 km, and model uses 144 by 116 points at each of the 31 levels. For the dynamic part of the model, an efficient split-explicate integration method is used with a longer advection step divided into several shorter adjustment steps. The model describes many physical processes, such as:

- Atmospheric radiation allowing for the effects of clouds, water vapour, ozone, carbon dioxide and a number of trace gases,
- Land surface processes including a multi-layer soil temperature and moisture prediction scheme,
- Vertical turbulent transport within the boundary layer,
- Large-scale precipitation determined from the water and ice content of a cloud,
- The convection effect through a scheme based on the initial buoyancy flux of a parcel of air. It includes entrainment, detrainment and the evaporation of falling precipitation. An explicit treatment of downdraughts is included.

2.2 HIRLAM model

The main aim of the HIRLAM forecasting system is to provide numerical short-term weather forecasts for operational purposes. The HIRLAM is a limited area, regional scale system and has three basic components: analysis of observations, prediction model and post-processing procedures. The analysis of some meteorological data is based on an optimum interpolation scheme, very similar to the one used at ECMWF, but adapted for use in a limited area model. A six hour data assimilation system is used. Since the system produces predictions over a limited area, it uses externally prescribed boundary values from a global model such as the ECMWF forecasting system. The co-ordinate system used is a rotated latitude-longitude grid in horizontal, and a hybrid p-sigma system in the vertical. The analysis is of the optimum interpolation type and intended for an intermittent system [1].

The forecasting model is a hydrostatic grid-point model based on classic dynamic and thermodynamic principles. Within a horizontally limited region the atmosphere is divided into boxes, typically of 55 by 20 km in horizontal and 0.5 km in vertical (16 to 31 levels). Through the governing equations the model state is integrated forward in time up to 36 or sometimes 48 hours. The model also includes effects of physical processes which occur in smaller scale such as clouds, radiative transfer, turbulence and ocean-land surface interaction. It contains a post-processing package for interpolation to pressure surfaces and for the output of results to the WMO standard GRIB files. After a forecast run the results are sent out at regular intervals for operational purposes.

The model is developed and maintained in co-operation with a number of north- and west-European meteorological Institutes. The forecast wind parameters used during the POLRODEX experiment were obtained from SMHI at Norrköping where the main model computations were carried out.

3. Measurements of wind during the POLRODEX'97 experiment

3.1 Location of wind measurements

During the field experiment the rhodamin was to be released at open sea, north of Cape Rozewie, near the drilling platforms of "PETROBALTIC'. Therefore, for the needs of the experiment, wind data during the period of the POLRODEX'97 were collected at two points on the open sea and at three coastal meteorological stations (Fig.2):

- derived from four-day measurements made every hour on board the naval hydrographical ship ORP "Arctowski", which was anchored at monitoring point ZN4 (54° 39.93' N, 18° 50.16' E), allowing to collect a homogeneous data series. The accuracy of the measurements was 0.1 m/s for wind velocity, and 5 deg. for wind direction,
- derived from simple meteorological observations using hand anemometer on the drilling platform BETA (54° 29' N, 18° 11' E). These measurements are usually made four or five times per day for own purposes of the "PETROBALTIC". The accuracy of wind measurements was worse than at point ZN4, and did not exceed 1-2 m/s for wind speed and 10 deg. for wind direction,
- derived from a digital anemometer situated on the coast guard observation tower in North Harbour in Gdańsk (54° 24' N, 18° 42' E) for the time of the experiment. This allowed obtaining wind data for each 10 minutes with an accuracy of 0.1 m/s for wind speed and 1 deg. for wind direction,
- derived from routinely working meteorological station of the Polish meteorological service (IMWM) situated near Harbour Master's building at the North Harbour in Gdańsk (54° 24' N, 18° 42' E). The obtained data have an accuracy of 0.1 m/s for wind speed and 10 deg. for wind direction,
- derived from routinely working meteorological station of the Polish meteorological service (IMWM) situated near the tip of the Hel Peninsula (54° 24' N, 18° 48' E). The data have an accuracy of 0.1 m/s for wind speed and 10 deg. for wind direction.

3.2 Synoptic situation in the period of 22-26 September 1997

During the first two days over almost the whole Europe dominated anticyclonic conditions. The mean sea level pressure of 1020 hPa in the vicinity of Gdańsk was accompanied by a weak and moderate westerly wind. The situation changed when the low-pressure centre over Lapland started moving to SE. The cold front associated with this centre moved quickly across the Baltic Sea, and at 0:00 UTC on September 24 the front reached the northern part of Poland (Pomeranian and Mazury region). Western and northern winds with gusts up to 15 m/s were observed during the whole day. During the next two days (25-26 September 1997) the synoptic situation returned to the initial state and over most of Northern Europe there was a high pressure area with weak and moderate western and northern winds (Fig.3).

3.3 Wind conditions over the Gdańsk Bay during the experiment

Wind variability recorded at several points in the Gdańsk Bay region during the main part of POLRODEX'97 is shown in Fig. 4 for speed (a) and for direction (b) respectively. As can be seen, the observed wind directions changed from SW – W at the beginning of the experiment to W - NW – N at later stages. The recorded wind speed at open sea and in the coastal zone varied significantly during the experiment from gentle and moderate breeze (3-8 m/s) to fresh and strong breeze (up to 12 m/s).

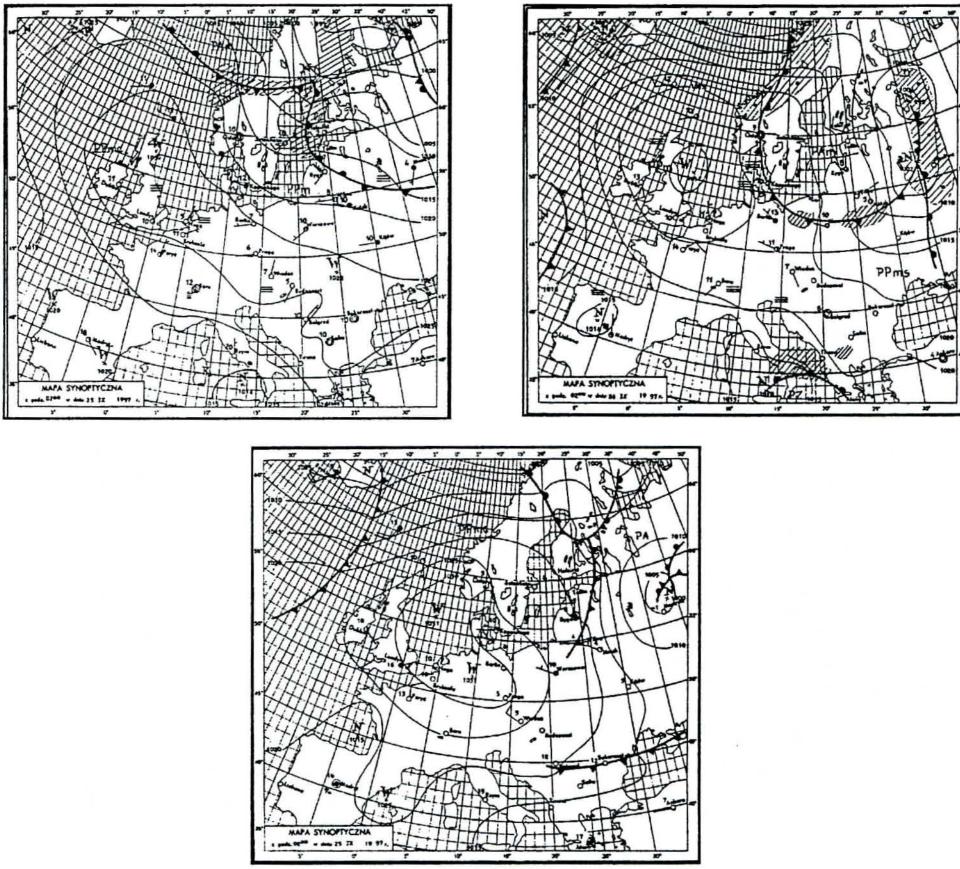


Fig. 3 Synoptic charts from the period of the POLRODEX'97 experiment

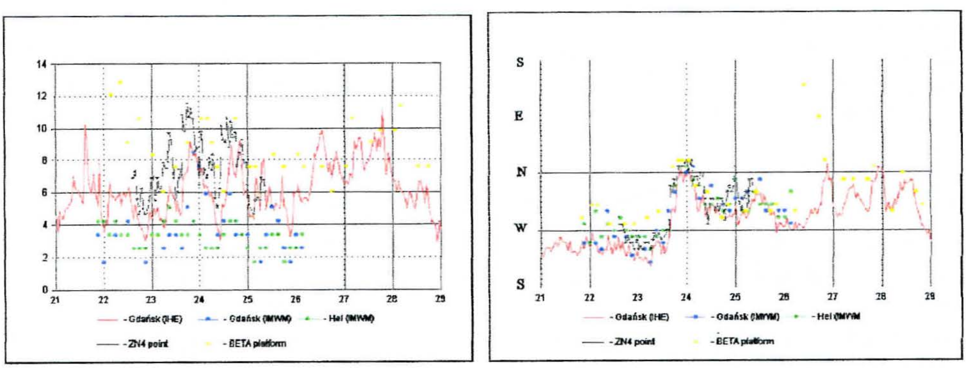


Fig. 4 Wind over the Gdańsk Bay observed during POLRODEX'97; a) speed, b) direction

A quite good agreement between open sea and coastal observations for wind direction can be seen. However in case of wind speed, the values measured at sea were visibly higher than those measured at the coastal stations.

4. Comparison of model computations and recorded wind data

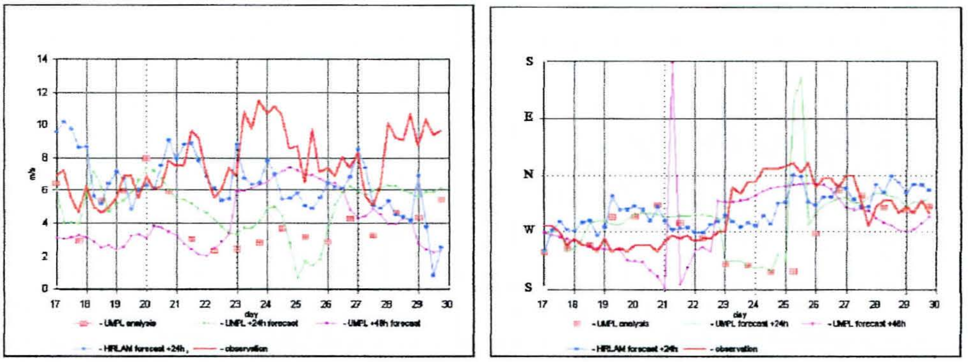
Wind data mentioned above were compared with the results of numerical computations, which were taken from two, described earlier, atmospheric models. In case of the UMPL model data were available not only for forecasts for one and two days ahead (up to 48 hrs) with 1 hour step, but also the analytical data, computed by the model at synoptic intervals (3 hour step). In case of wind data from the HIRLAM model, only forecast data up to 36 hrs, with a 6-hour step are available. This allows analysis of forecast wind data for only one day ahead.

For the comparison of recorded and predicted wind parameters, data from two representative sets of observations at open sea and two sets from the coastal stations were selected. Observed wind speed data were reduced to standard height – 10 m above sea level.

4.1 Wind conditions on the open sea near the Hel Peninsula

The data from point ZN4 give an illustration of wind conditions over the sea on the northern side of the Hel Peninsula. The period of observation was not long (about four days during the first part of the experiment) but it was possible to take hourly wind data from the open sea with good accuracy. The real observed wind parameters in comparison with the model data from two atmosphere models is shown in Fig. 5a (for wind direction) and Fig. 5b (for wind speed).

For the case of wind speed, significantly higher values were observed at sea than obtained from the UMPL model but the agreement of tendency was good. For the forecasts for two days ahead the agreement is worse. There is a better agreement between observations and HIRLAM model computations. For wind direction the agreement is quite good, though some greater differences are also visible.



a) b)

Fig. 5 Observed and modelled wind over the sea near Hel Peninsula (point ZN4) during POLRODEX'97; a) speed, b) direction

Short statistical analysis for the sets shown in Fig. 5 are presented in Tab.1, where: N is the number of analysed data, V_{mean}, V_{max}, V_{min} are mean, maximum and minimum values, D_{mean}, D_{max}, D_{min} are mean, maximum and minimum values for differences between observations and computations, MSD mean squarre deviation and R is the coefficient of correlation.

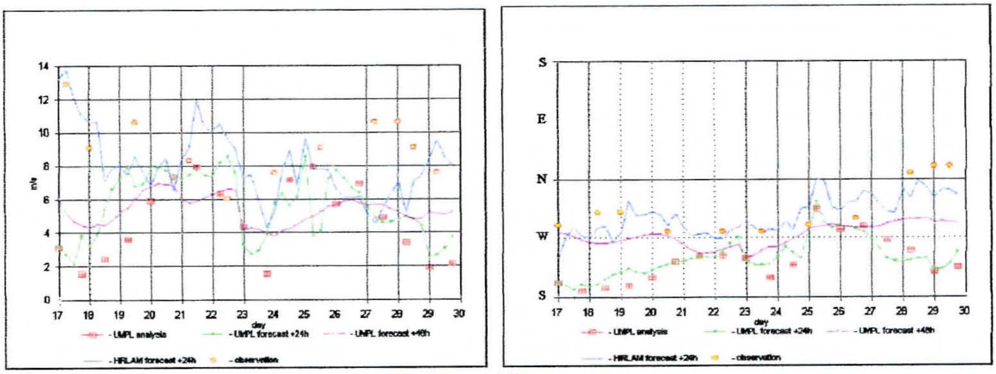
Table 1 Point ZN4. Observations of ORP "Arctowski" 22-25.09.1997

	Observations		Model UMPL						Model HIRLAM	
			analysis ICM		forecast +24h		forecast +48h		forecast +24h	
	v	d	v	d	v	d	v	d	v	d
N	67	67	23	23	67	67	67	67	11	11
V_{mean}	5.49	311.01	2.69	304.53	3.71	307.8	3.8	313.54	5.92	308.63
V_{max}	11.53		6.53		6.96		7.43		8.83	
V_{min}	4.61		0.59		0.63		2.04		5.36	
D_{mean}			3.89	31.22	3.09	36.45	30.6	46.19	1.78	30.79
D_{max}			8.23	74.82	8.98	143.08	7.08	109.17	4.77	62.79
D_{min}			0.97	5.3	0.02	1.78	0.09	0.27	0.01	2.79
MSD			4.46	37.15	3.66	43.78	3.76	56.44	2.34	36.42
R			0.57	0.71	0.52	0.45	0.36	0.18	0.47	0.25

The results compiled in Tab.1 confirm previous conclusions from Fig. 5. Visible differences between observed and computed parameters arise from a several-hour displacement between observed and computed values, but the agreement for tendency of changes is good. The best values of correlation coefficients are for analysis data and for the +24-hour forecast data from the UMPL model, however these values are not high.

4.2 Wind conditions at open sea near the BETA drilling platform

Wind conditions north of Cape Rozewie can be represented by meteorological data taken from the drilling platform BETA. Unfortunately, there is no automatic meteorological station, thus observations are irregular, taken from time to time during a day. But the point is so representative for sea



a) b)

Fig. 6 Observed and modelled wind parameters over the sea near the BETA drilling platform during POLRODEX'97; a) speed, b) direction conditions, that these data should not be omitted. It is planned to install an automatic meteorological station on the platform.

The period of observation covered the whole time of the experiment, but the data were available only four or five time a day and it is not correct to show them as a continuous curve. The courses of real observed wind parameters in comparison with model data are shown in Fig. 6a (wind direction) and Fig. 6b (wind speed).

Because observed wind data do not coincide with synoptic times, there was no possibility to make any direct comparisons between them and the analytical data from the ICM and HIRLAM models. Thus only short statistical computations for some forecast data for one and two days ahead could be made. The results of these computations do not seem to be sufficiently representative enough (Tab. 2).

Table 2 BETA drilling platform. Observations of 22-28.09.1997

	Observations		Model UMPL						Model HIRLAM	
			analysis ICM		forecast +24h		forecast +48h		forecast +24h	
	v	d	v	d	v	d	v	d	v	d
N	34	34	0	0	34	34	34	34	0	0
V_{mean}	6.25	327.83			4.39	322.02	4.94	318.98		
V_{max}	12.88				8.38		8.17			
V_{min}	3.79				0.89		2.70			
D_{mean}					3.22	38.38	3.12	40.51		
D_{max}					8.92	163.64	8.02	172.69		
D_{min}					0.31	2.95	0.01	1.21		
MSD					3.90	52.78	3.81	63.41		
R					0.49	0.42	0.29	0.05		

4.3 Wind conditions at synoptic station Hel

The synoptic station situated on the Hel Peninsula belongs to the Polish meteorological service (IMWM) and it is the important point in the Baltic weather observation network. It is located to NW of the town of Hel, in seaward part of the Hel Peninsula. The wind data

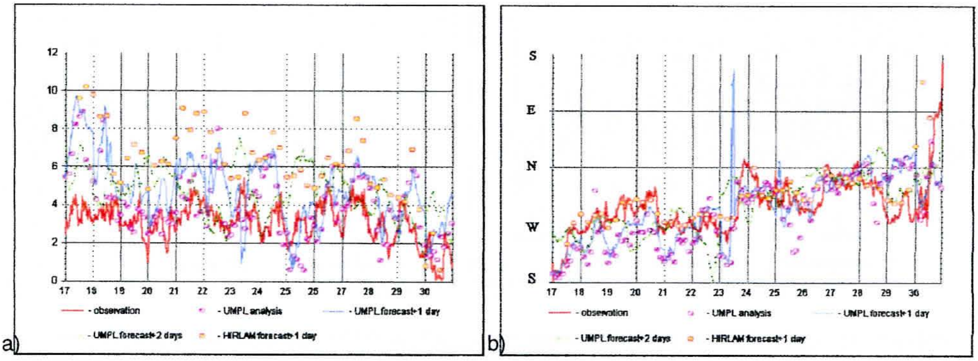


Fig. 7 Observed and modelled wind near Hel meteorological post during POLRODEX'97 experiment; a) speed, b) direction

from this place are not representative enough for sea conditions since it is located in a high forest, several hundred meters from the seacoast.

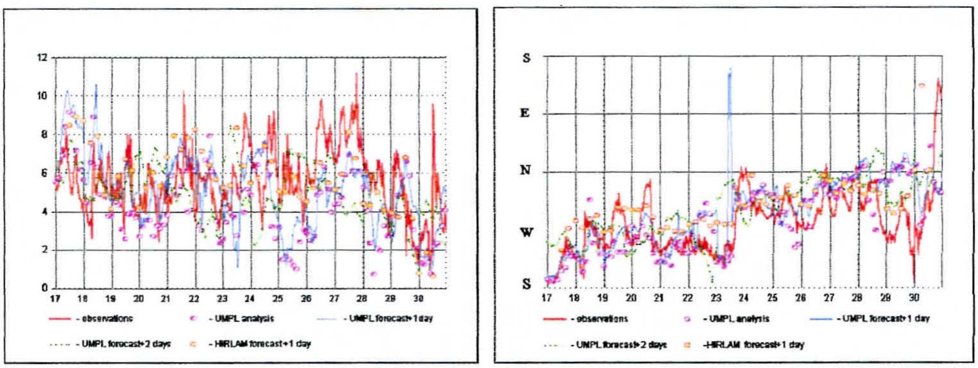
For the objectives of the experiment, there was a possibility to make an analysis of wind observations from a period of two weeks. Real and forecast values taken from both numerical atmosphere models are shown in Fig. 7 for speed (a) and for direction (b). A short statistical analysis for the sets is shown in Tab.3.

Table 3 Hel meteorological station. Observations of 17-30.09.1997

	Observations		Model UMPL						Model HIRLAM	
			analysis ICM		forecast +24h		forecast +48h		forecast +24h	
	v	d	v	d	v	d	v	d	v	d
N	336	336	112	112	336	336	336	336	53	53
V_{mean}	2.44	295.08	2.23	281.85	3.13	290.74	3.41	302.42	5.50	302.46
V_{max}	5.42		8.93		9.72		7.54		10.20	
V_{min}	0.09		0.58		0.69		1.18		0.60	
D_{mean}			1.42	35.97	2.03	31.53	1.68	33.89	3.28	20.98
D_{max}			5.43	136.17	6.48	177.31	5.73	124.90	6.72	149.83
D_{min}			0.03	1.27	0.02	0.10	0.01	0.13	0.06	1.20
MSD			1.84	44.15	2.42	41.21	1.09	43.06	3.61	32.16
R			0.65	0.51	0.60	0.63	0.53	0.50	0.71	0.63

4.4 Wind conditions near the North Harbour in Gdańsk

Wind information recorded at the North Harbour represents weather conditions of the southern part of the Gulf of Gdańsk. Two sets of wind data were available. The first is from the meteorological station belonging to the Polish weather observation network, and second – an automatic meteorological station - belonging to the Institute of Hydroengineering PAS,



a) b)

Fig. 8 Observed and modelled wind parameters near the North Harbour in Gdańsk during POLRODEX'97 a) speed, b) direction was situated during the experiment on a high tower several hundred meters to the East. For the analysis, the last mentioned data series was chosen since it contains continuous data, recorded every 10 minutes. Data from full hours were selected (Fig 8). Data from both numerical models are also shown in the figure. Results of computations of some statistical parameters are shown in Tab. 4.

As for the Hel station, it was possibile to use for the computations and for statistical analysis a two week period of wind observations. This allowed to compare wind data originated from these meteorological posts, and to check if they can be used as a driving force for hydrodynamic models for the sea.

Table 4. Gdańsk Port Północny. Observations of 17-30.09.1997

	Observations		Model UMPL						Model HIRLAM	
			analysis ICM		forecast +24h		forecast +48h		forecast +24h	
	v	d	v	d	v	d	v	d	v	d
N	336	336	112	112	336	336	336	336	53	53
V_{mean}	4.11	281.77	2.45	282.24	3.24	291.15	3.62	302.37	5.08	300.45
V_{max}	11.16		9.15		10.56		8.46		8.93	
V_{min}			0.92		0.74		0.86		0.90	
D_{mean}			2.02	36.51	1.85	35.50	1.78	40.89	1.71	35.54
D_{max}			7.31	167.30	7.79	177.93	7.20	154.75	8.95	159.99
D_{min}			0.07	0.26	0.01	0.24	0.02	0.13	0.08	1.28
MSD			2.45	48.27	2.27	47.92	2.21	50.82	2.31	44.15
R			0.65	0.45	0.59	0.52	0.52	0.37	0.29	0.24

If we take into account the wind speed, a better consistency between values observed and modelled for the North Harbour than for Hel is visible. The reason for this is, as was previously mentioned, that the Hel meteorological station is located in a forest, while in Gdańsk it is on a flat surface on a treeless beach. Thus for Gdańsk there is a better consistency between wind observed in the shore zone in comparison with wind registered at Hel. Even observed data from point ZN4, which is lying on the sea, have worse agreement with model results than the Gdańsk data. A good agreement is observed for forecast data one day ahead, but there are larger differences for the low values in the analysis of wind data from the UMPL model. Greater differences are also for a forecast data for two days ahead.

In the case of wind directions, there is a good agreement between measured and computed values for both meteorological coastal stations and for the open sea. The curves of forecast values have a similar shape to those for observational data.

For wind observations from coastal stations, longer sets of data are available than for observations from the open sea. Hence analyses of wind parameters for the coastal zone could be done more precisely than for the open sea.

The computed data from the HIRLAM model have smaller values for mean standard deviation (about 3.3 m/s for wind velocity and 36 deg for direction) The analytical and forecast data for one day ahead give a better coefficient of correlation (about 0.65 for speed and 0.55 for direction).

5. Conclusions regarding observed and modelled wind parameters over the Gulf of Gdańsk during the experiment

Wind parameters: speed and direction measured on the open sea as well as in the coastal zone, where the land-sea interaction is of significant importance, are one of the main and necessary sets of meteorological input data to run various hydrodynamic models for the sea. Thus the accuracy of the parameters determines the accuracy and reliability of sea forecasts obtained from model computations and the reliability of the whole forecasting system.

For the data presented above, there is a quite good agreement between observed and obtained from numerical models wind values, both for the open sea and the coastal zone. Visible differences are due to several reasons: the specific local conditions (topography, distance from dunes or coastline, presence of trees) at places where the observation stations were situated, the frequency and manner of measurements. It must be taken into account, that on the model result side, the density for the grid points is not sufficient, especially for sea areas lying near the coast, peninsulas, in lagoons etc. This determines the necessity to continue works aimed at developing operational models with a denser grid. Then it will become possibile to obtain detailed information for smaller scale areas in atmospheric models. An example is the HIRLAM system. It uses an operational model with a grid spacing of 44 km, and data of a model with a 22 km grid are available (SMHI), but models with higher horizontal resolution are used as nested for the basic model (16 km and 5.5 km in DMI--HIRLAM).

Forecast data for wind direction usually show quite satisfactory agreement with observations (MSD values are about 30–50 deg.), but low values of the coefficient of correlation are due to occasional shifting between two curves (the shapes of curves are very similar).

Wind speed shows a more complicated picture. There are visible, sometimes considerable, differences between real and forecast values, especially for the Hel and BETA data, but the reason of it may be accounted to the conditions of observations described above. There is a quite good conformity for the recorded data from ORP "Arctowski" (ZN4) and only little worse conformity for Gdańsk data, which last can be connected with a certain influence of the coastal zone. Values of MSD vary from about 1 to 4.5 m/s, and correlation coefficients have slightly bigger values than for directions.

In the future it is expected to attain an improved consistency of the modelled values by using atmospheric models with lower horizontal resolutions, especially non-hydrostatic models. For the verification of computations with such models a long series of good time resolution data measured in the open sea is necessary.

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