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## CHARACTERISTICS OF WIND CONDITIONS IN THE ODRA ESTUARY

### Abstract

*In this paper a statistical analysis of wind conditions occurring in the Odra estuary has been presented. The measurements of wind directions and velocities from years 1970-1995 for four meteorological stations of IMGW: Świnoujście, Dziwnów, Trzebież and Szczecin-Dąbie have been analysed.*

### Introduction

The analysis of wind conditions in the Odra estuary is necessary to determine the safety conditions of shipping, shipyards work, riverbanks protection and flood control of this region. Wind constitutes one of the basic factors determining hydrodynamics of the Lower Odra. Small river slopes, which appear in the Odra mouth, cause the range of wind effect on water stages and flows to be considerable in this region - storm surge can be noticed even upstream to Gozdowice cross-section. Particularly strong northern and north-western winds (opposite to the Odra flow direction), which arise during passing of strong depressions over the Baltic Sea and often create the phenomenon of wind backwater [1], are of a substantial importance. A great swelling of water level is then observed in the whole Lower Odra river net as well as surface backward tides - opposite to the direction of the main flow.

Figure 1 shows the propagation of the storm surge that appeared in November 1995. There was one of the greatest surges observed lately. The maximum water stage at Świnoujście cross-section - equal to 669 cm - was the highest over the last 50 years. The wind velocity noted in Świnoujście during this surge reached 30 m/s. The amplitude of the storm surge was equal to 1.70 m in Świnoujście and moving upstream the Odra - 1.10 m in Szczecin and Widuchowa cross-sections.

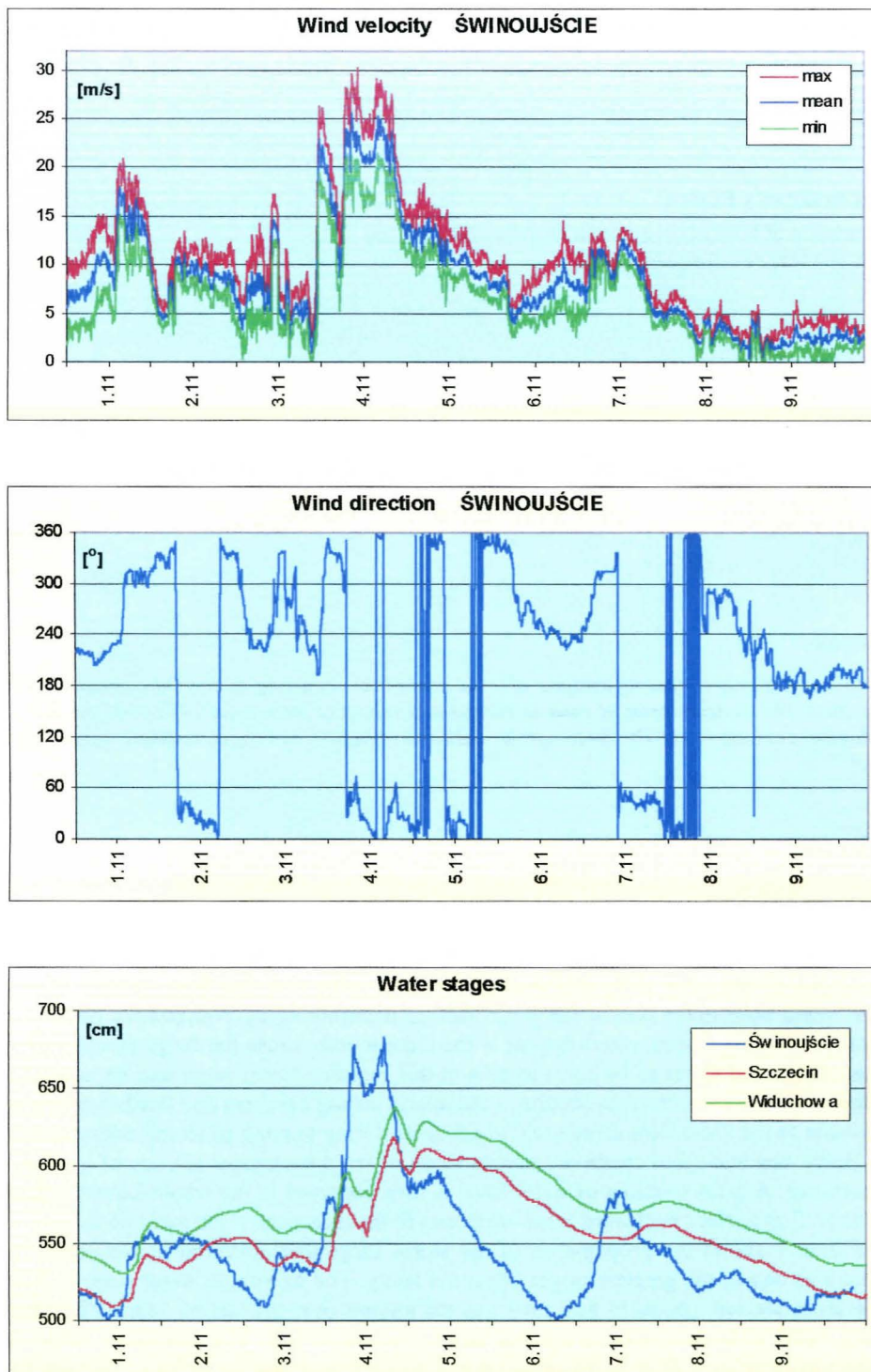


Fig. 1. Storm surge in November 1995

### Wind measuring stations in the Odra estuary

In the region of the Odra mouth there are now three meteorological stations of Institute of Meteorology and Water Economy (IMGW), which make measurements of wind direction and velocity (Fig. 2): at Świnoujście, Dziwnów and Szczecin-Dąbie (at the airfield). Two stations were closed: in 1974 station Szczecin-Łabędzia located in the left-sided part of the city and in 1991 meteorological station in Trzebież - the only one within the Szczecin Bay. There are no wind measuring stations of IMGW south of Szczecin cross-section (up-stream the Odra).

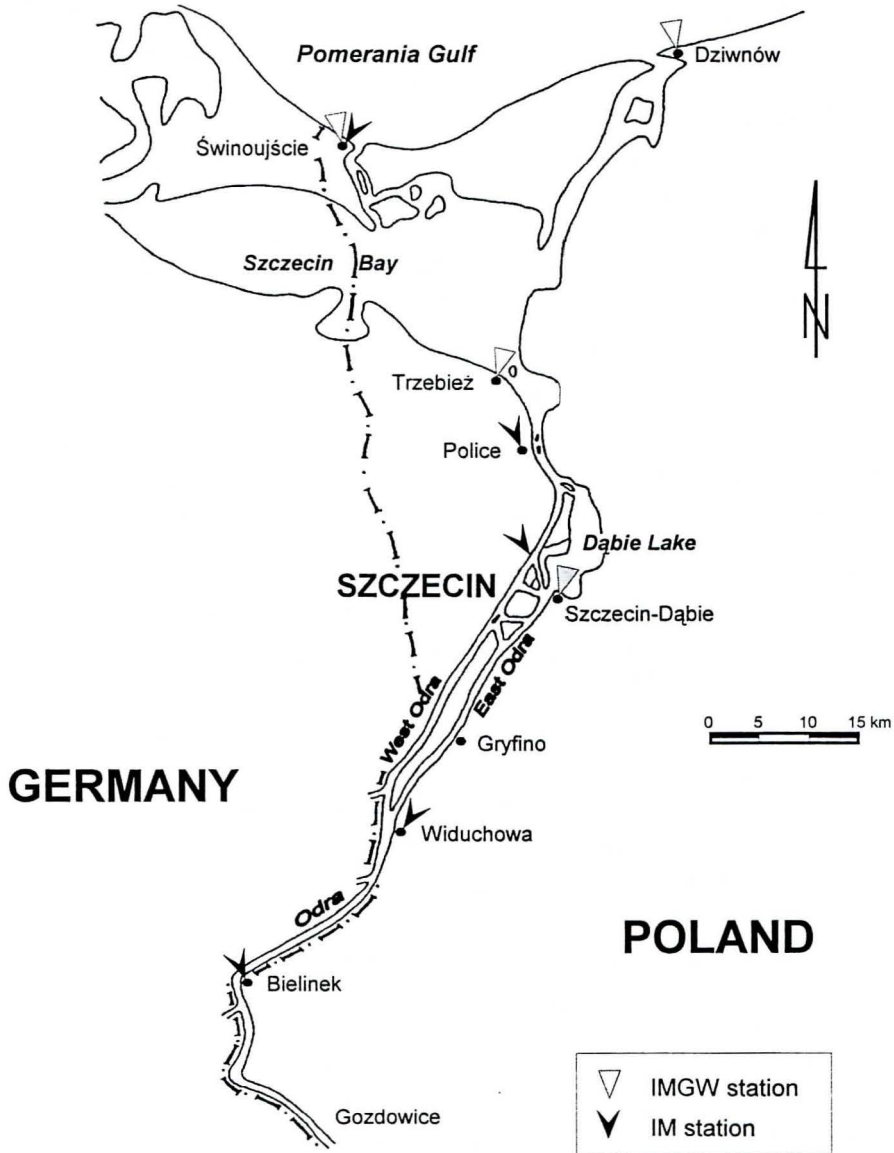


Fig. 2. Location of wind measuring stations in the Odra estuary

In this region, apart from the measuring stations operated by IMGW, the measurements are carried out by Port Authorities at: Świnoujście, Dziwnów, Trzebież, Nowe Warpno and Szczecin. Besides, since 1992 Maritime Research Institute (IM), Szczecin Branch has started 5 automatic stations, which register wind observations at Świnoujście, Police, Szczecin, Widuchowa and Bielinek (Fig. 2). Wind measurements are carried out by IM Szczecin Branch in co-operation with Maritime Office of Szczecin (stations in Świnoujście, Police and Szczecin) and Provincial Office in Szczecin (stations in Widuchowa and Bielinek).

In this paper the analysis of wind phenomena for four meteorological stations of IMGW located in area of the Odra river mouth is presented:

- 1) Świnoujście – the station is equipped with anemometer M-63, located 11 m over ground level; the altitude of this measuring station is 6 m relating to NN<sub>55</sub>,
- 2) Dziwnów – the station is equipped with anemometer ARM, located 12 m over ground level; the altitude of this measuring station is 7 m relating to NN<sub>55</sub>,
- 3) Trzebież – the station is equipped with Wild's anemometer, located 16 m over ground level; the altitude of this measuring station is 1 m relating to NN<sub>55</sub>; the measurements were finished 31.12.1990;
- 4) Szczecin-Dąbie – the station is equipped with Fuess' anemometer, located 23 m over ground level; the altitude of the measuring station is 1m relating to NN<sub>55</sub>.

### Data for analysis

Wind conditions in the Odra estuary are determined on the basis of wind direction and velocity measurements for meteorological stations IMGW: Świnoujście, Dziwnów, Trzebież and Szczecin-Dąbie. Data for analysis were taken from unpublished materials of IMGW, which include everyday records:

- for Świnoujście - observation period 1970-1995:
  - 7<sup>00</sup>, 13<sup>00</sup> and 19<sup>00</sup> for periods 01.01.1970 – 31.12.1982, 01.01.1984 – 30.06.1984,
  - 1<sup>00</sup>, 4<sup>00</sup>, 7<sup>00</sup>, 10<sup>00</sup>, 13<sup>00</sup>, 16<sup>00</sup>, 19<sup>00</sup>, 22<sup>00</sup> for periods 01.01.1983 – 31.12.1983, 01.01.1989 – 31.12.1995,
  - 1<sup>00</sup>, 5<sup>00</sup>, 9<sup>00</sup>, 13<sup>00</sup>, 17<sup>00</sup>, 21<sup>00</sup> for periods 01.07.1984 – 31.12.1988,
- for Dziwnów - observation period 1970-1979, 1983-1985:
  - 7<sup>00</sup>, 13<sup>00</sup> and 19<sup>00</sup> for periods 01.01.1970 – 31.12.1979, 01.01.1983 – 31.12.1985,
- for Trzebież - observation period 1970-1988:
  - 7<sup>00</sup>, 13<sup>00</sup> and 19<sup>00</sup> for periods 01.01.1970 – 31.12.1988,
- for Szczecin-Dąbie - observation period 1970-1995:
  - 7<sup>00</sup>, 13<sup>00</sup> and 19<sup>00</sup> for periods 01.01.1970 – 31.12.1982, 01.01.1984 – 30.06.1984,
  - 1<sup>00</sup>, 4<sup>00</sup>, 7<sup>00</sup>, 10<sup>00</sup>, 13<sup>00</sup>, 16<sup>00</sup>, 19<sup>00</sup>, 22<sup>00</sup> for periods 01.01.1983 – 31.12.1983, 01.01.1989 – 31.12.1995,
  - 1<sup>00</sup>, 5<sup>00</sup>, 9<sup>00</sup>, 13<sup>00</sup>, 17<sup>00</sup>, 21<sup>00</sup> for periods 01.07.1984 – 31.12.1988.

The hours of the measurements are given in the Central European Time (CSE). The measurements of wind velocity were carried out with precision to 1 m/s and the measurements of wind direction - to 10°. Both the observation period and quantity of data, which were chosen for the analysis, were acknowledged to be sufficient in respect of statistics.

### Characteristics of wind conditions in the Odra estuary

The statistical analysis of the wind conditions for IMGW stations has been prepared in form of characteristics of an average year from the analysed perennial period comprising:

- frequency of wind directions and velocities,
- average velocities and length of time of winds for the particular directions.

The same characteristics has been worked out for the particular months of the average year.

The carried out statistical analysis of wind occurrence in the area of the Odra river mouth for the stations: Świnoujście, Dziwnów, Trzebież and Szczecin-Dąbie indicates that the analysed area is characterised by different anemometric conditions. What determine this, are the following factors: changing topography of the area, and especially the location of measuring stations near big water reservoirs: Szczecin Bay and Baltic Sea, that enables air masses to translocate naturally. High riverbanks in the Lower Odra cause canalising of wind direction along the Odra river valley to be observed in the analysed area.

The region of the Odra river mouth is characterised by distinct changeability of wind occurrence in the particular year seasons (Figs. 3a, 3b, 3c, 3d). In the spring-summer time winds from the northern sectors (NE, N and NW) are often observed, and in the autumn-winter time winds from the southern directions (especially SW and S) dominate. The seasonality of wind is connected with the influence of the Baltic Sea, and especially with differentiation of temperatures between the land and the sea. Therefore, in spring and summer the circulation towards the land dominates, and in autumn and winter – circulation from the land.

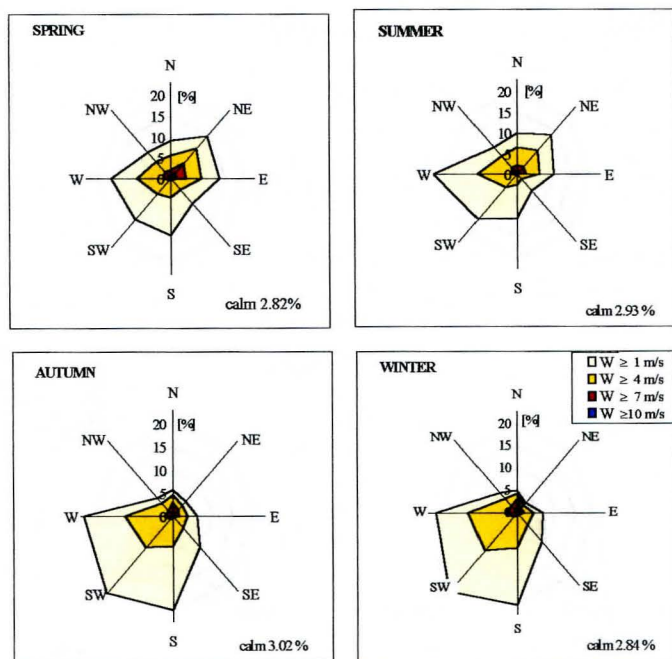


Fig. 3a. Frequency of wind velocities and directions at ŚWINOUJŚCIE in the average year from 1970-1995

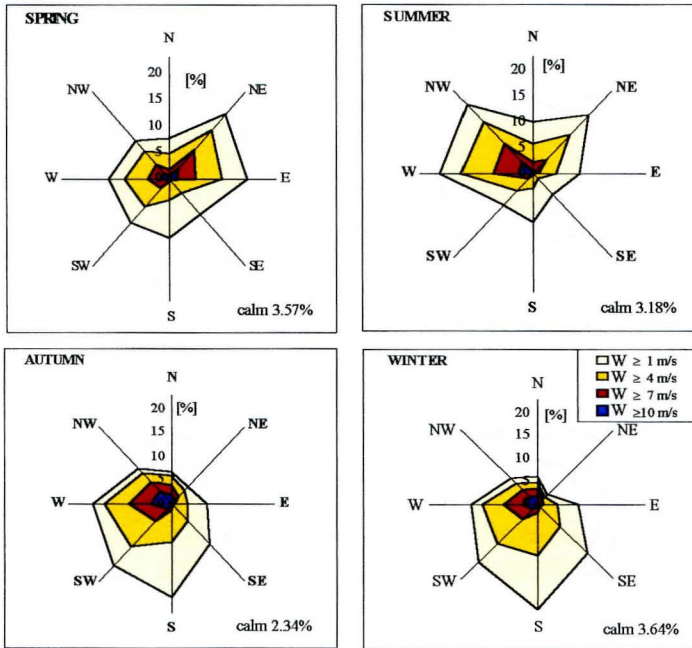


Fig. 3b. Frequency of wind velocities and directions at DZIWNÓW in the average year from 1970-1985

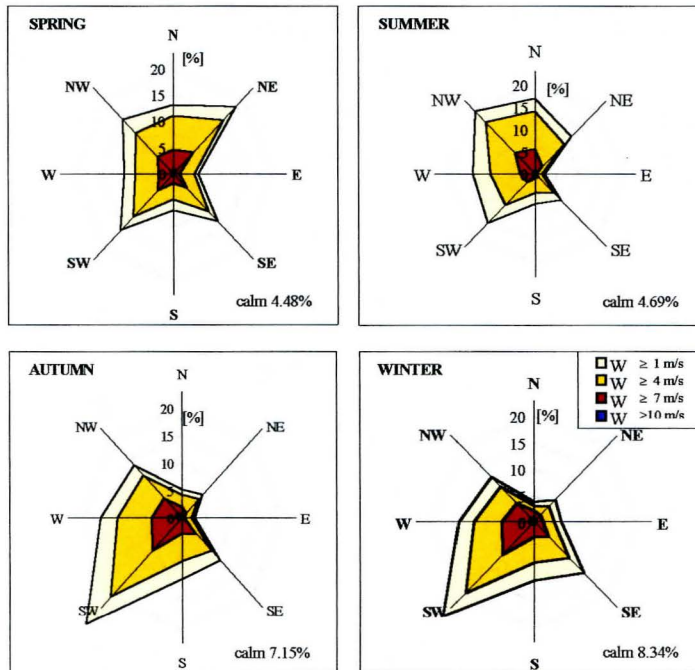


Fig. 3c. Frequency of wind velocities and directions at TRZEBIEŻ in the average year from 1970-1988

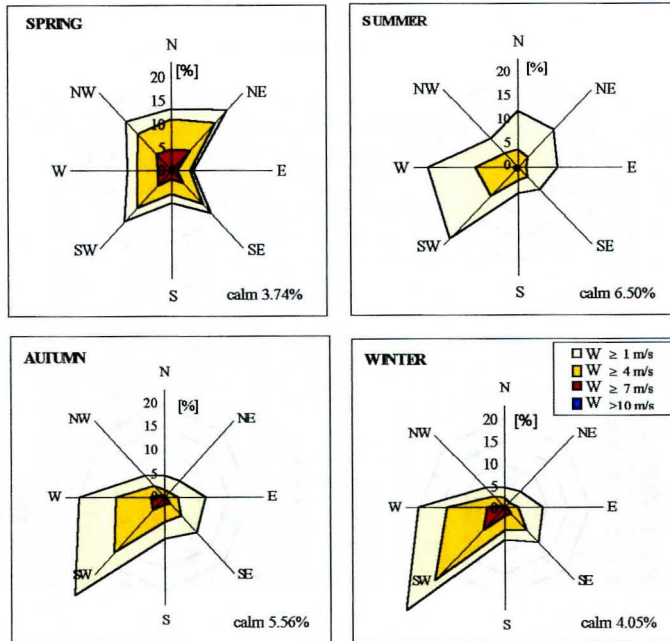


Fig. 3d. Frequency of wind velocities and directions at SZCZECIN in the average year from 1970-1995

The calm appears most often in Trzebież - on the average 22.5 days a year, making 6% of all the observations and in Szczecin - 18 days a year. In Świnoujście and Dziwnów there is twice as fewer calms as in Trzebież - accordingly 10.6 and 11.6 days in the average year. The analysis of calm appearance frequency in particular months of the average year from perennial period (Fig. 4) points out that most calms are observed in Trzebież in January (3.2 days), February (3.1 days) and October (2.8 days) and in Szczecin in August (2.6 days).

The strongest winds appear at Dziwnów - the average year velocity is 5.0 m/s, and at Trzebież - 4.7 m/s. At Świnoujście the average wind velocity is smaller and equals 3.9 m/s, and in Szczecin - 3.7 m/s. The analysis of wind velocities in the particular months of the average year (Fig. 5) indicates that highest average velocities are typical for winds in November: 5.7 m/s in Dziwnów and 5.3 m/s in Trzebież, and in December: 5.5 m/s in Dziwnów and 5.2 m/s in Trzebież.

The frequency of wind occurrence from SW and W directions are biggest in Szczecin (accordingly 25.6 and 19.1% of all the observations) and in Świnoujście (19.3 and 20.6%), a little smaller at Trzebież (20.8 and 13.9%) and Dziwnów (14.0 and 15.8%). There is the least quantity of winds from the eastern direction at Trzebież (3.8%), from the southern direction in Szczecin (6.9%), from north-western direction at Świnoujście (7.4%) and from northern direction at Dziwnów (7.7%).

The winds from the north-western sector are characterised by the highest average velocities, amounting to: at Dziwnów 6.8 m/s from NW direction and 6.6 m/s from W direction, at Trzebież 5.6 m/s (N) and 5.4 m/s (NW) and at Świnoujście 5.6 m/s (N). In Szczecin-Dąbie the southern (4.5 m/s) and the south-eastern winds (4.4 m/s) are the strongest ones.

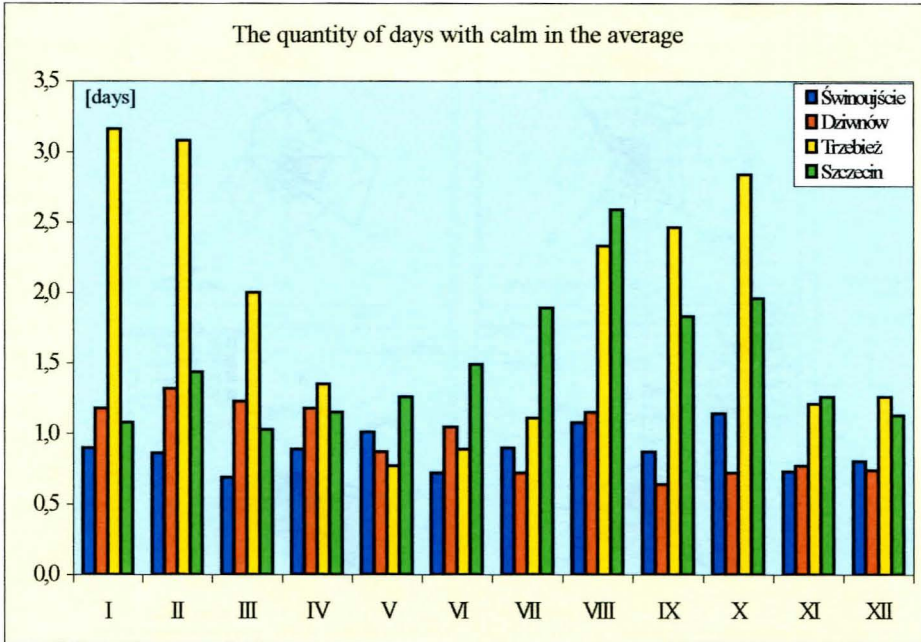


Fig. 4. Frequency of calms appearing in the particular months of the average year

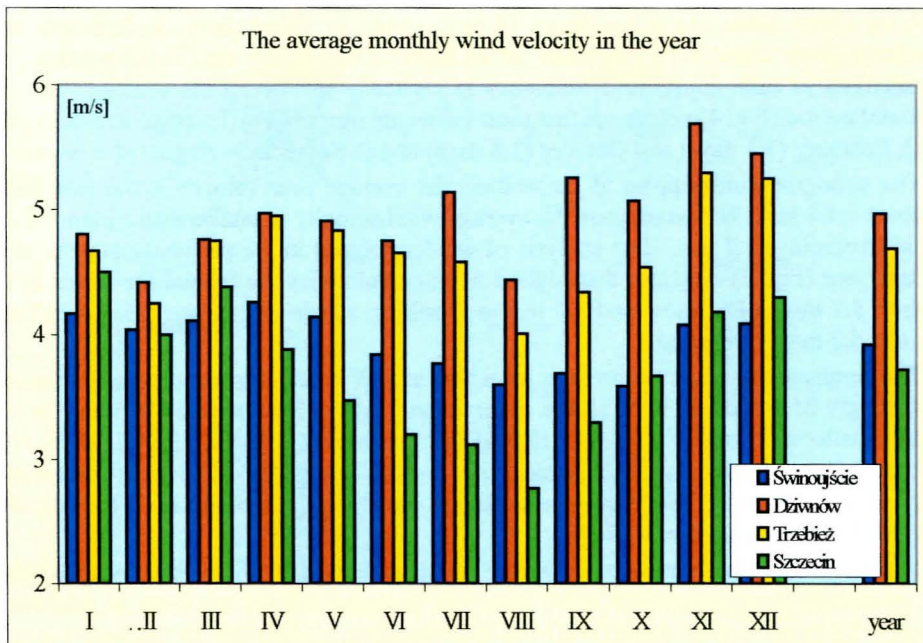


Fig. 5. The average monthly wind velocity in the average year



The frequency of wind occurrence and average wind velocities from the particular directions for the considered wind stations are presented in Tables 1, 2 and in Figs. 6, 7.

Table 1. The frequency [%] of wind occurrence from the particular directions in the average year

Direction	Świnoujście	Dziwnów	Trzebież	Szczecin
N	7.39	7.68	9.69	7.61
NE	8.82	10.42	10.42	8.78
E	9.11	10.79	3.79	10.13
SE	8.18	10.49	11.37	10.04
S	16.27	15.73	8.99	6.87
SW	19.29	14.00	20.81	25.60
W	20.61	15.83	13.86	19.07
NW	7.42	11.89	14.90	6.91

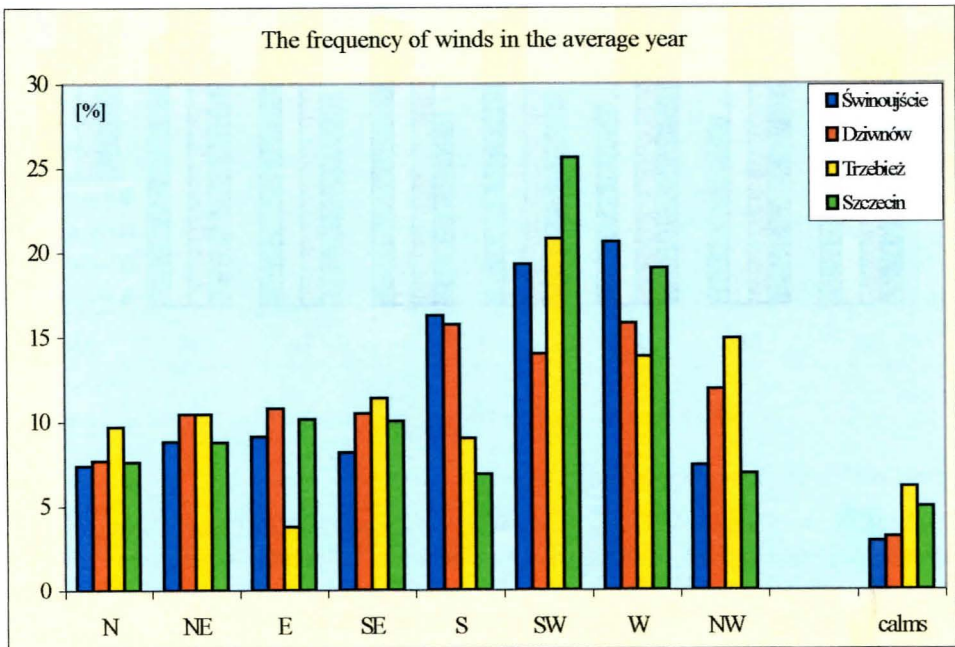


Fig. 6. The frequency of wind occurrence from the particular directions in the average year

Table 2. The average wind velocity [m/s] from the particular directions in the average year

Direction	Świnoujście	Dziwnów	Trzebież	Szczecin
N	5.6	5.8	5.6	3.2
NE	5.4	5.7	5.0	2.9
E	5.0	4.6	4.7	3.1
SE	3.3	3.3	4.8	4.4
S	3.0	3.5	4.4	4.5
SW	3.3	4.9	4.7	4.2
W	3.9	6.6	5.2	4.2
NW	5.1	6.8	5.4	4.0

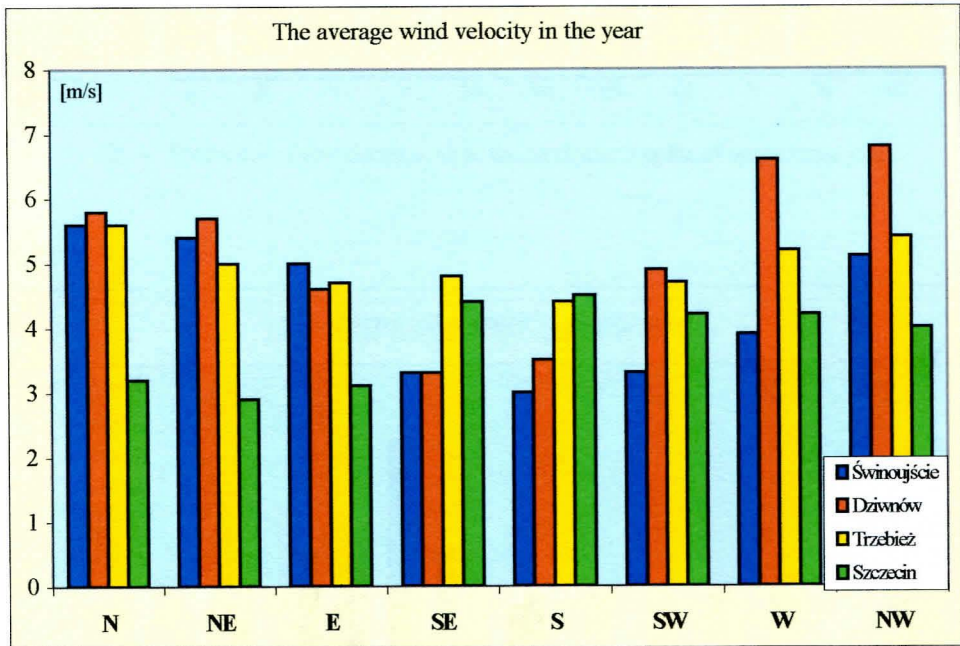


Fig. 7. The average wind velocity from the particular directions in the average year

### Strong and very strong winds

The analysis of strong and very strong winds in the area of the Odra river mouth is particularly important in view of the safety of shipping in Świnoujście - Szczecin fairway and in the incoming fairway to Świnoujście. The storm surges, which are caused by the sea, create water stages in the whole Odra estuary in the significant way.

The occurrence of strong winds in the analysed area is connected with translocation of strong depression over the Baltic Sea. Then arising winds of huge velocities (even over 20

m/s), mainly from northern and north-western directions, cause the rapid swelling of the water level in the sea. Because of very small river slopes in the Odra estuary, the sea surges increase the water level in the Lower Odra river net as they are passing upward the river. The range of the sea influence is significant, especially at the low flows in the Odra river, so that they can reach even Gozdowice (150 km up-stream the river).

In the area of the Odra river mouth strong winds (of velocities  $W \geq 10$  m/s) occur most often at Dziwnów - on the average for over 25 days a year. Both at Trzebież and at Świnoujście, there are twice fewer winds of velocities  $W \geq 10$  m/s: at Trzebież they are observed for 11 days in the average year, at Świnoujście - for 10 days, while in Szczecin - for only 4 days in year. Very strong winds (of velocity  $W \geq 16$  m/s) appear for 2.9 days in year at Dziwnów, 0.74 day at Trzebież and 0.45 day at Świnoujście. Such strong winds have not been noticed in the analysed period of time in the meteorological station in Szczecin-Dąbie.

The maximal observed wind velocities were equal: at Dziwnów - 25 m/s from W, at Świnoujście - 22 m/s from W and at Trzebież - 20 m/s from north-western sector (NW, N and W). In the analysis of the strong winds occurrence - due to lack of data - the extremal values, i.e. wind gusts, have not been considered, but only velocities measured at the specified hours.

The frequency of strong and very strong winds occurrence in the average year for the four considered wind stations at Świnoujście, Dziwnów, Trzebież and Szczecin-Dąbie has been presented in Table 3 and Fig. 8.

Table 3. The quantity of days in the average year with strong and very strong wind

Wind velocity	Świnoujście	Dziwnów	Trzebież	Szczecin
$W = (10-12)$ m/s	10.06	25.27	11.29	4.42
$W = (13-15)$ m/s	2.43	5.74	0.47	0.40
$W = (16-18)$ m/s	0.45	2.90	0.74	0.00
$W > 18$ m/s	0.06	0.61	0.21	0.00

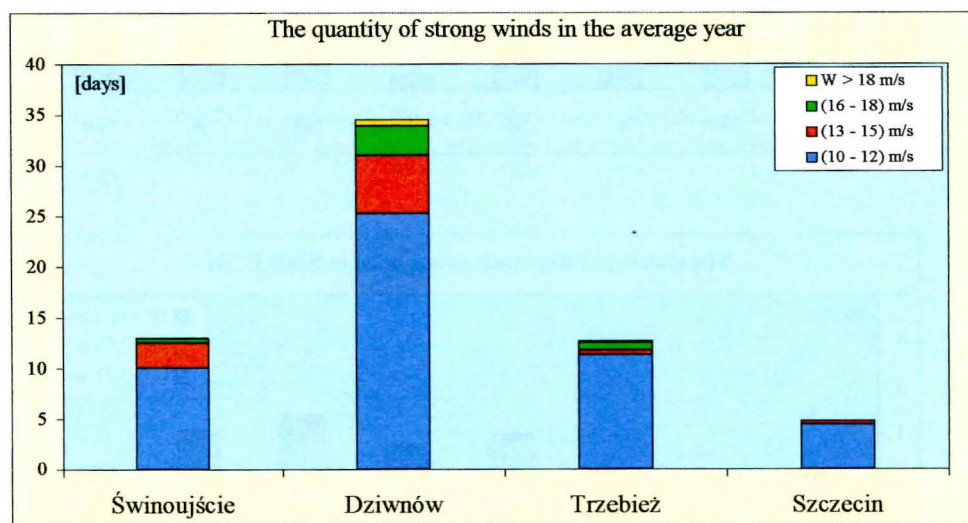


Fig. 8. The frequency of strong winds occurrence in the average year

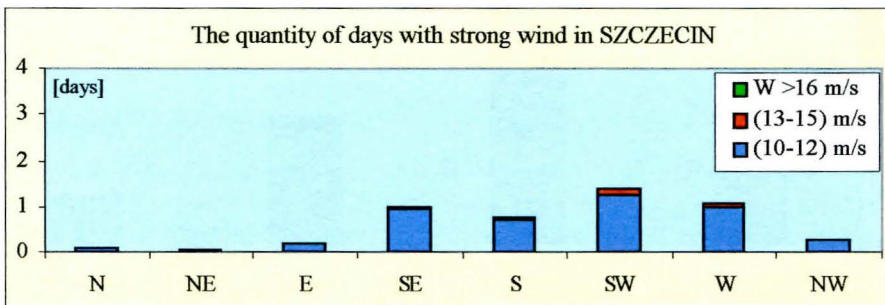
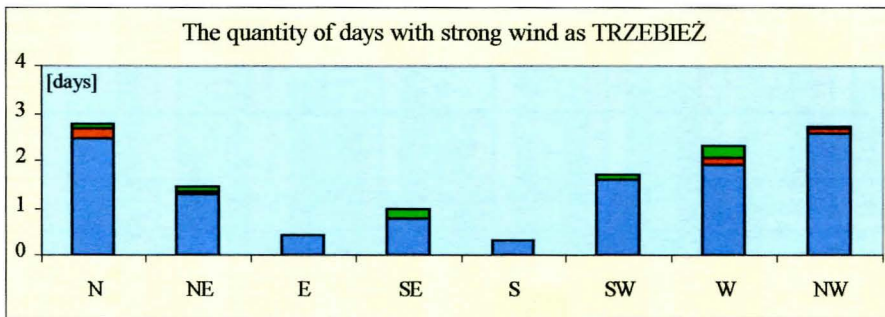
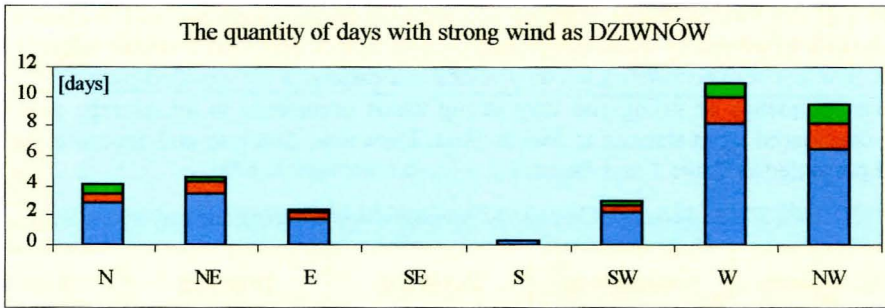
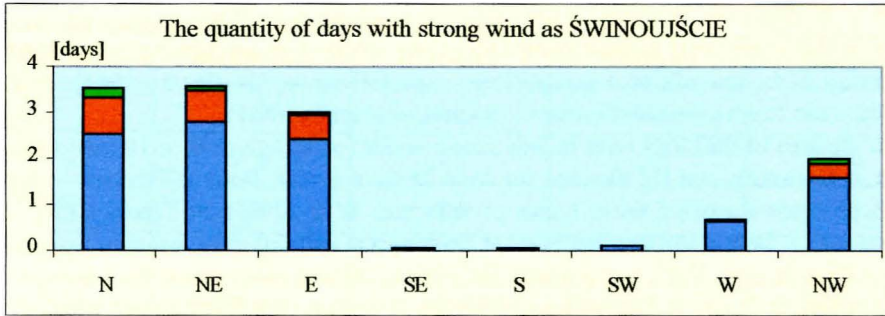


Fig. 9. The quantity of days in the average year with strong wind

Analysing the distribution of occurrence of strong winds from the particular direction (Fig. 9) we can say that the winds of velocity  $W \geq 10$  m/s blow most often in:

- Świnoujście from directions: NE (2.77 days), N (2.53 days), E (2.42 days),
- Dziwnów from directions: W (8.15 days), NW (6.53 days),
- Trzebież from directions: N (2.58 days), NW (2.47 days), W (1.88 days),
- Szczecin-Dąbie from directions: SW (1.25 days), W (1.0 day).

### Summary

- 1) In this paper a statistical analysis of wind conditions occurring in the Odra estuary has been presented. The measurements of wind directions and velocities from years 1970-1995 for four meteorological stations of IMGW: Świnoujście, Dziwnów, Trzebież and Szczecin-Dąbie have been analysed.
- 2) The carried out analysis indicates that the region of the Lower Odra is characterised by the differentiated wind conditions. It is due to both the influence of measuring stations' location near the Szczecin Bay and the Baltic Sea and the influence of canalising of winds' direction along the Odra river valley.
- 3) The winds in the area of the Odra river mouth are characterised by the seasonal occurrence - in spring-summer time winds from the northern sector are often observed, which is connected with air masses circulation toward the land. In autumn-winter time the southern winds dominate, which is connected with circulation from the land.
- 4) The strongest winds appear in autumn-winter time, mainly in November and December - they are generally from the north-western sector. These winds are the reason for storm surges arising in the sea, which propagate up-stream the Odra river and thus, cause the wind backwater.

### References

- [1] Buchholz W., 1989, *Influence of wind on flow in river outlets*. Prace Instytutu Morskiego No. 703, Gdańsk. (In Polish).
- [2] Pluta M., 2000, *Wind conditions in the outlet part of Odra*. [In:] *Scientific – technical conference on the occasion of 50<sup>th</sup> anniversary*. Materiały Instytutu Morskiego No 897. Gdańsk. (In Polish).