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CHANGES OF WATER PHYSICAL FEATURES AS INDICATORS OF THE CONVECTION MOVEMENTS IN THE COASTAL ZONE OF THE POMERANIAN BAY

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Abstract

In the study water temperature and salinity changes under different meteorological conditions were analysed to recognise convection movements of waters in the coastal zone of the Pomeranian Bay (near the Wolin Island). The summer period (1971-1990) was considered. The study revealed that a rapid up to 5.0°C drop of sea surface temperature, which cannot be explained by the air temperature fall, may indicate the outflow of subsurface waters to the surface or along shore movement of waters coming from eastern upwelling regions. The contribution of easterly winds during such events reached 54% (Świnoujście). On the other hand a sea temperature increase can be the result of the movement of waters (mainly the Oder waters) caused by westerly winds. However since the Pomeranian Bay is shallow and exposed to enhanced dynamics it can't be perceived as a typical upwelling or downwelling region.

Key words: water temperature, salinity, air temperature, wind conditions, the Pomeranian Bay

INTRODUCTION

Vertical water motions in processes called *upwelling* and *downwelling* are generated by wind blowing over water. In the Northern Hemisphere the surface water does not move directly in front of the wind but moves about 45 degrees toward the right of the wind's motion. This process, called Ekman transport, is a result of the Coriolis effect. Where winds cause the surface water to move away from a coastline or to diverge from another surface water mass, deeper water will move up to the ocean surface, creating an upwelling current. Where winds cause the surface water to move toward a coastline or to converge with another water mass, the surface water will try to move downward to create a downwelling current. Upwelling currents bring deeper, colder and more salty water to the surface. As surface waters are usually depleted of nutrients such as phosphates and nitrates that are critical to plant growth, deeper waters have high concentrations of these nutrients. Upwelling replenishes the surface layers with the nutritional components necessary for biological productivity. So regions of upwelling are among the richest biological areas of the world (Bowden, 1998).

At the southern coasts of the Baltic Sea the most important factor responsible for upwelling phenomenon, in accordance with the Ekman theory, is wind from eastern sector. Sometimes the outflow of subsurface waters to the surface occurs also under winds not consistent with the Ekman theory but consistent with bottom bathymetry. As in summer months subsurface waters are colder than surface waters thus during upwelling phenomenon a rapid drop of sea surface temperature is observed. Together with the fall of water temperature there are recorded often changes of other physical, chemical and biological features (like increase of salinity). At the Polish coast upwelling appears irregularly and is of small time and space scales. So far it has been distinguished in Kołobrzeg, Łeba and Hel regions (Urbański, 1995). Since the Pomeranian Bay is shallow and exposed to enhanced dynamics it wasn't perceived as a typical upwelling region (Urbański, 1995, Kowalewski, 1997). However some researches think that upwelling occurs at all the Baltic coastal stations (Klimkiewicz, 1966).

At the southern coasts of the Pomeranian Bay under appropriate weather conditions there are recorded rapid and significant changes of sea surface temperature during day. They are the result of air temperature changes as well as advection movements of waters coming from regions with different water physical features or may indicate convection movements. During summer period under eastern and southern winds sea surface temperature fall can indicate outflow of subsurface waters to the surface (upwelling phenomenon) or along shore movement of waters coming from eastern upwelling regions. Often salinity increase is recorded then. On the other hand in case air masses are coming from west or north, sea surface temperature increase and salinity decrease can point out movement of the warmer and fresh Oder waters onshore and than its fall down (downwelling event). But the increase of salinity under such wind conditions can be the result of along shore movement of more salty waters coming from the Arkona Basin and the Western Baltic Sea (Kowalewska-Kalkowska, 2000).

Different methods of investigating of upwelling and downwelling processes are in use. Direct measurements of velocities of vertical fluxes are very difficult. Very often researches analyse effects of those processes like changes of water temperature and salinity as well as content of nutrients. Examining upwelling remote sensing techniques are applied successfully (Gidhagen, 1987, Krężel, 1997, Urbański, 1995). But the registration is limited only to cloudless days and with significant temperature differences between surface and subsurface waters, so to the summer period. Coastal downwelling is very difficult to detect and it hasn't been examined widely so far. So more and more often numerical modelling is applied to get to know convection movements in the Baltic Sea (Jankowski, 1998, Kowalewski, 1997, Kowalewski, Ostrowski, 2002).

In the study water temperature and salinity changes under different meteorological conditions were analysed to recognise convection movements of waters in the coastal zone of the Pomeranian Bay (near the Wolin Island).

DESCRIPTION OF THE STUDY

To investigate the problem mean daily data sets of near shore water temperature (Tw) and salinity (S) at Międzyzdroje (1) as well as air temperature (Ta) at Świnoujście (2) were considered (fig.1). Air circulation over Central Europe in a 9-degree scale (eight basic directions and no advection) and routine local winds as measured at Świnoujście and Kołobrzeg (3) were analysed too. The months April – October in the years 1971-1990 were taken into consideration. The data were obtained from IMGW.

Firstly we analysed situations with water temperature drop that could indicate upwelling phenomenon. Sincerely situations with daily water temperature drop more than 2.0°C were found, we have excluded daily changes of water temperature caused by daily sunshine or nightly heat emission as the only acting factors. For those 79 situations the analysis of meteorological conditions was carried out. Additionally changes of salinity were checked as well. In case the air temperature was constant or its rise was recorded as well as air masses were coming from east or south, sea surface temperature fall was more than 2.0°C and salinity was constant or its increase was recorded, these conditions were treated as an identifier of upwelling phenomenon. Finally several situations indicating the outflow of subsurface waters to the surface (upwelling phenomenon) or along shore movement of waters coming from eastern upwelling regions were found. For those events further statistical analysis was carried out in order to find typical features for upwelling.

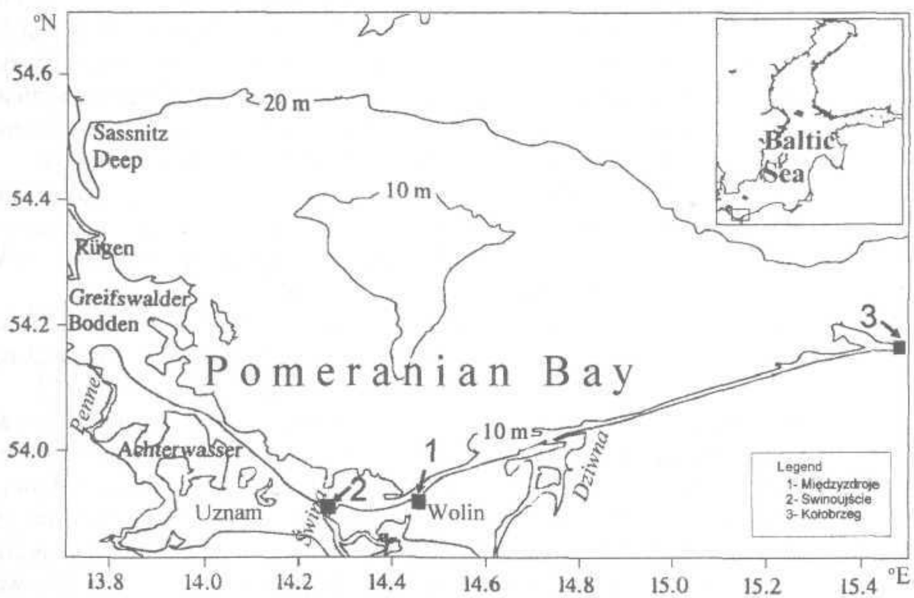

Fig. 1. The Pomeranian Bay

Next we examined situations with water temperature rise of more than 1.5°C that could point out downwelling phenomenon. Similarly we performed the statistical analysis of 18 situations with water temperature increase under different meteorological conditions. In case the air masses were coming from western sector and the air temperature influence could be excluded, sea surface temperature rise was more than 1.5°C as well as salinity fall were recorded, these conditions were treated as an identifier of movement of the warmer and fresh Oder waters onshore and than its fall down. On the other hand the increase of salinity under such wind conditions indicated onshore movement of more salty open waters coming from the Western Baltic Sea.

RESULTS AND DISCUSSION

Some situations indicating the outflow of subsurface waters to the surface

In May 1983 when offshore south air circulation was prevailing for several days on 21st May there was observed a rapid fall of water temperature (4.9°C) and a rise of salinity (1.21 PSU). Local winds as measured at Świnoujście and Kołobrzeg were mainly from SE. As air temperature increased (4.1°C) such conditions could indicate the outflow of subsurface waters to the surface. Next day when conditions changed there was observed a gradual rise of Tw and a drop of salinity (fig.2).

In July 1984 when air masses were coming from south on 9th July there was observed a rapid fall of water temperature (1.5°C) and a rise of salinity (1.28 PSU). Next day Tw decreased till 13.0°C and salinity increased up to 8.03 PSU. In three days (8th to 10th July) local winds at Świnoujście were mainly from south and at Kołobrzeg from SE. Those days air temperature increased (4.1°C) so water physical changes could be explained by appearance of offshore movement of waters north and replacing them by colder and more salty waters from below. Next days wind conditions changed and a fast rise of Tw and a drop of salinity were observed (fig.3).

On 30th May 1973 there was observed a rapid drop of water temperature (3.5°C) although air temperature increased (1.3°C). It happened after some days of air circulation from NE and its change to S. When air circulation changed to SW a gradual increase of Tw was recorded (fig.4).

In June 1979 after some days with air circulation from NE to S on 22nd June a fall of water temperature (2.2°C) and a slight rise of salinity (0.79 PSU and next day 0.35 PSU) were recorded (fig.5). Air temperature increased slightly (1.1°C).

During examined two decades the small amount of cases with rapid water temperature drop indicating upwelling, certifies that in the coastal zone of the Pomeranian Bay the outflow of subsurface waters to the surface occurs very seldom. It appears irregularly and is of small time and space scales. The most often the phenomenon was recorded in July, May and June. However the Pomeranian Bay is shallow and exposed to enhanced dynamics so it can't be perceived as a typical upwelling region.

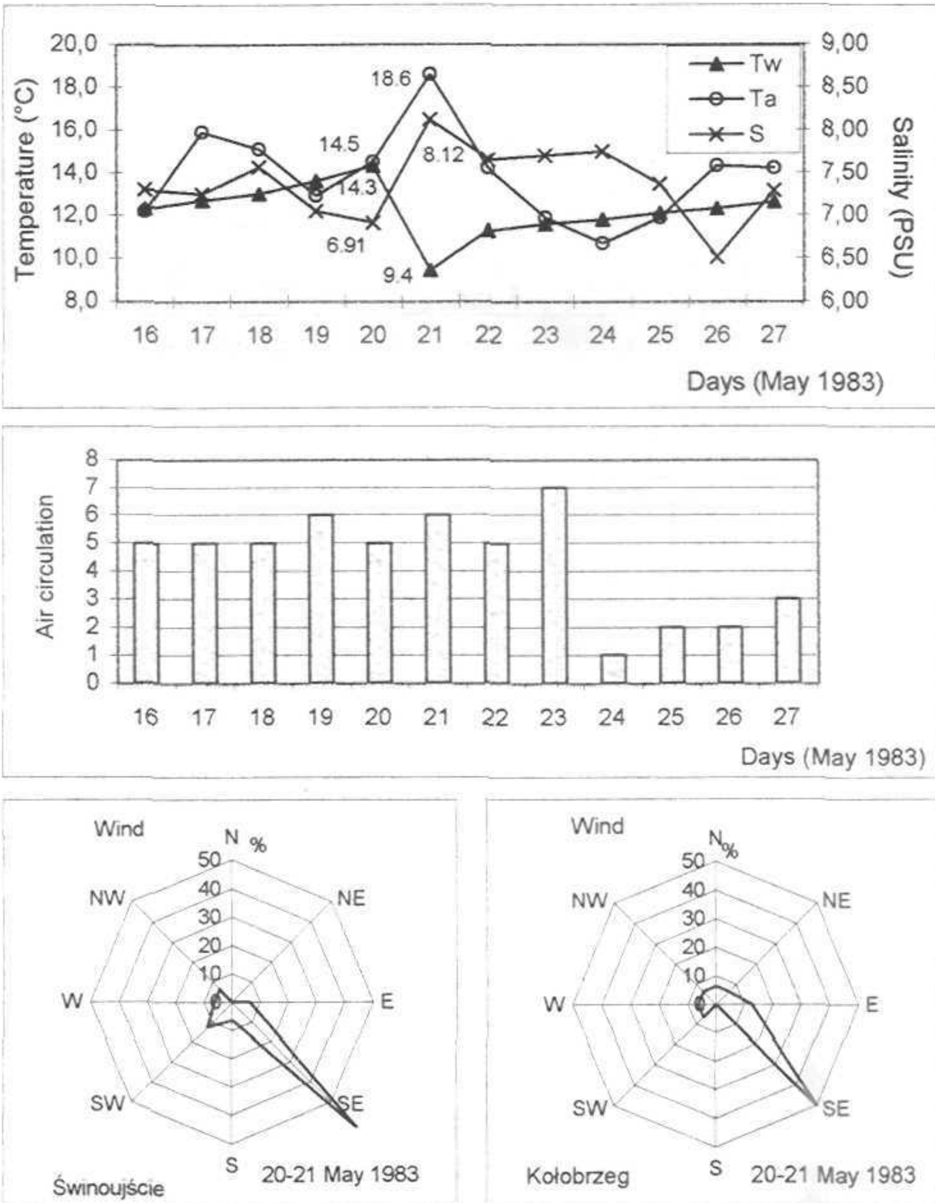

Fig. 2. Hydrometeorological situation in May 1983.
Legend: Air circulation types:
0 – no advection, 1 – N, 2 – NE, 3 – E, 4 – SE, 5 – S, 6 – SW, 7 – W, 8 – NW.

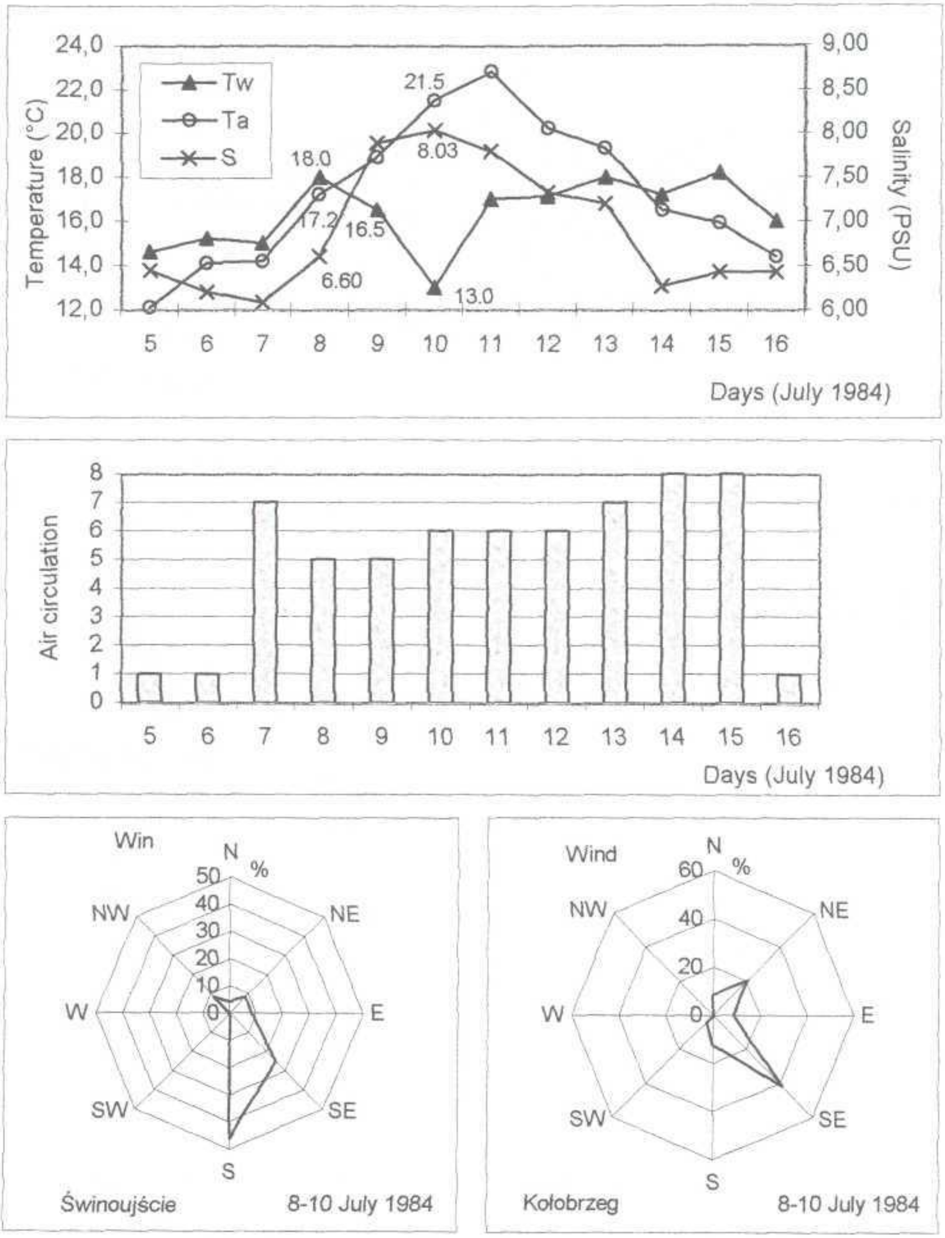

Fig. 3. Hydrometeorological situation in July 1984.
Legend: Air circulation types:
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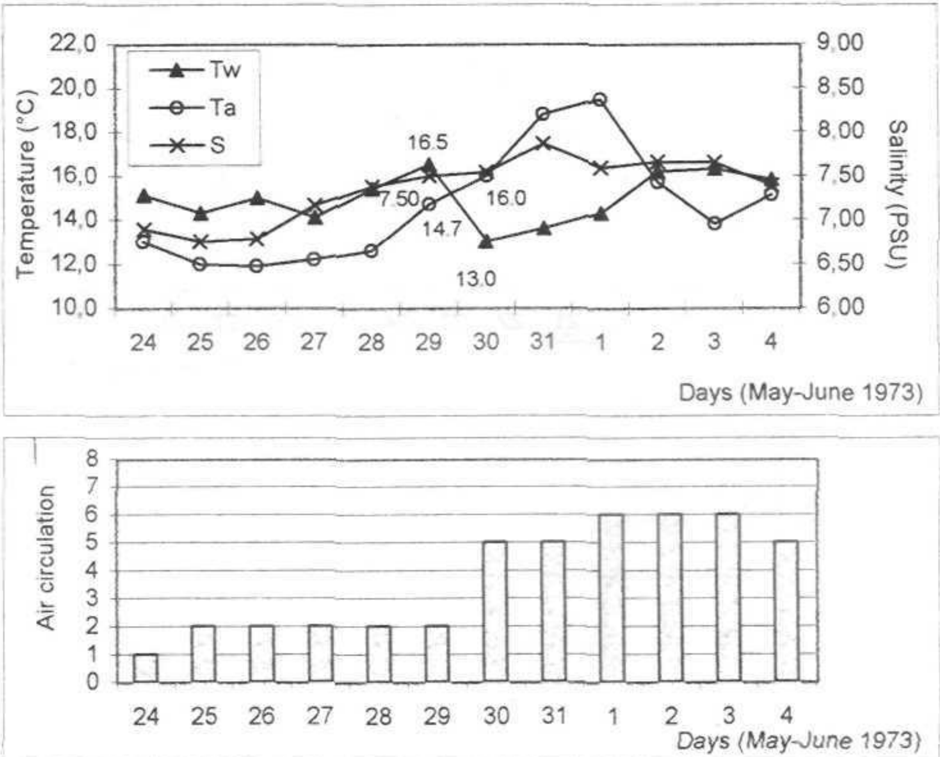

Fig. 4. Hydrometeorological situation in May/June 1973.
Legend: Air circulation types:
0 – no advection, 1 – N, 2 – NE, 3 – E, 4 – SE, 5 – S, 6 – SW, 7 – W, 8 – NW.

In the examined region the most important factor responsible for upwelling phenomenon, in accordance with the Ekman theory, is wind from eastern sector. During such events the contribution of easterly winds (NE – SE) reached 54%[1] (fig.6). Appearance of upwelling followed even after some hours with appropriate wind conditions. A significant contribution of northern wind is a result of typical weather conditions appearing in summer period.

[1] The frequency was calculated for winds blowing during the day with water temperature fall and the day before.

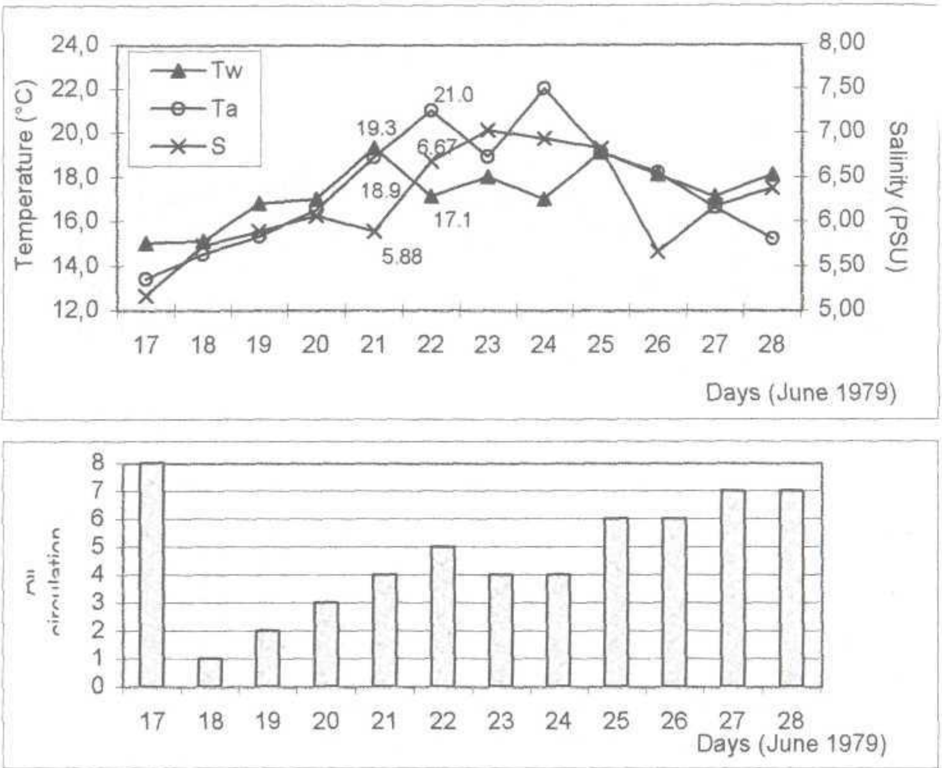

Fig. 5. Hydrometeorological situation in June 1979.
Legend: Air circulation types:
0 – no advection, 1 – N, 2 – NE, 3 – E, 4 – SE, 5 – S, 6 – SW, 7 – W, 8 – NW.

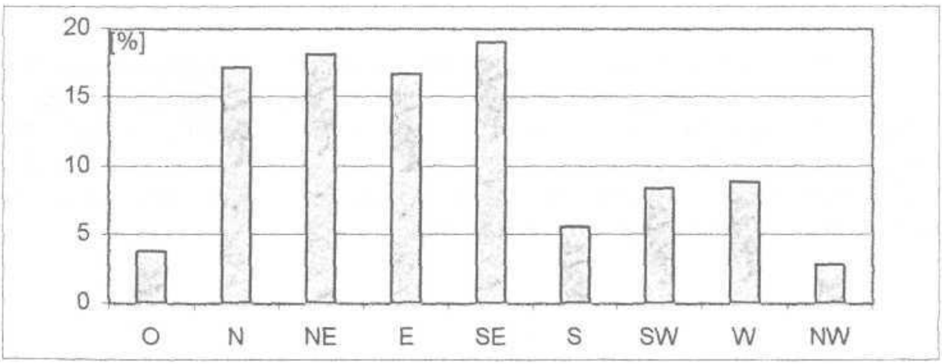

Fig. 6. The frequency of wind direction occurrence.

The occurrence of upwelling seems not to depend on wind speed. Although the measured values of wind speed were usually between 2 and 4 m/s, stronger winds were recorded as well (fig.7). The results are in accordance with results obtained for the Polish coast by other researches (Urbański, 1995, Krężel, 1997). It should be mentioned that speeds between 2 and 4 m/s are typical for the examined region and appearance of upwelling seems to be mainly a result of weaker long lasting winds.

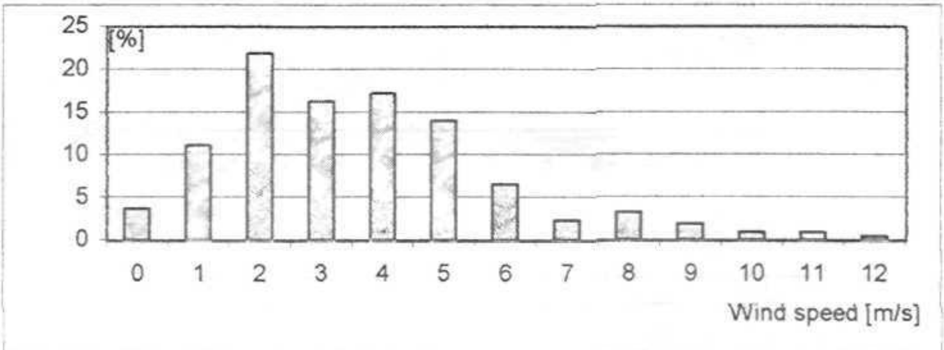

Fig. 7. The frequency of wind speed occurrence.

Disappearance of water temperature anomalies followed usually very fast (even after one day), especially after rapid change of wind direction. The longest falls of sea temperature lasted 3 days. Occurrence of western winds caused quicker disappearance of anomalies. That indicates rather small range of cold water spreading out on the surface.

Some situations indicating the movement of surface waters onshore

On 8th July 1987 under strong western air circulation and winds coming almost from west sector there were recorded simultaneously a rise of sea surface temperature from 17.8°C to 20.8°C and a little fall of salinity from 5.95 to 5.32 PSU pointing out the inflow of the warmer waters from the Szczecin Lagoon (fig.8). Next two days under the same wind conditions there were recorded a rise of salinity (1.39 PSU) and a little drop of sea temperature (1.8°C) indicating the inflow of more salty open waters. During these three days air temperature decreased from 22.7°C until 13.5°C.

In July 1990 when air masses were coming from western sector for several days in three days 7th to 9th a significant increase of water temperature of 2.2°C and a rapid decrease of salinity of 1.55 PSU were observed. Local winds were mainly from SW and W. As during those days air temperature was colder than water temperature that situation pointed out the inflow of the warmer and fresh Oder waters to Międzyzdroje (fig. 9). Such wind conditions were prevailing for next days pushing waters of different physical features onshore (notable changes of salinity).

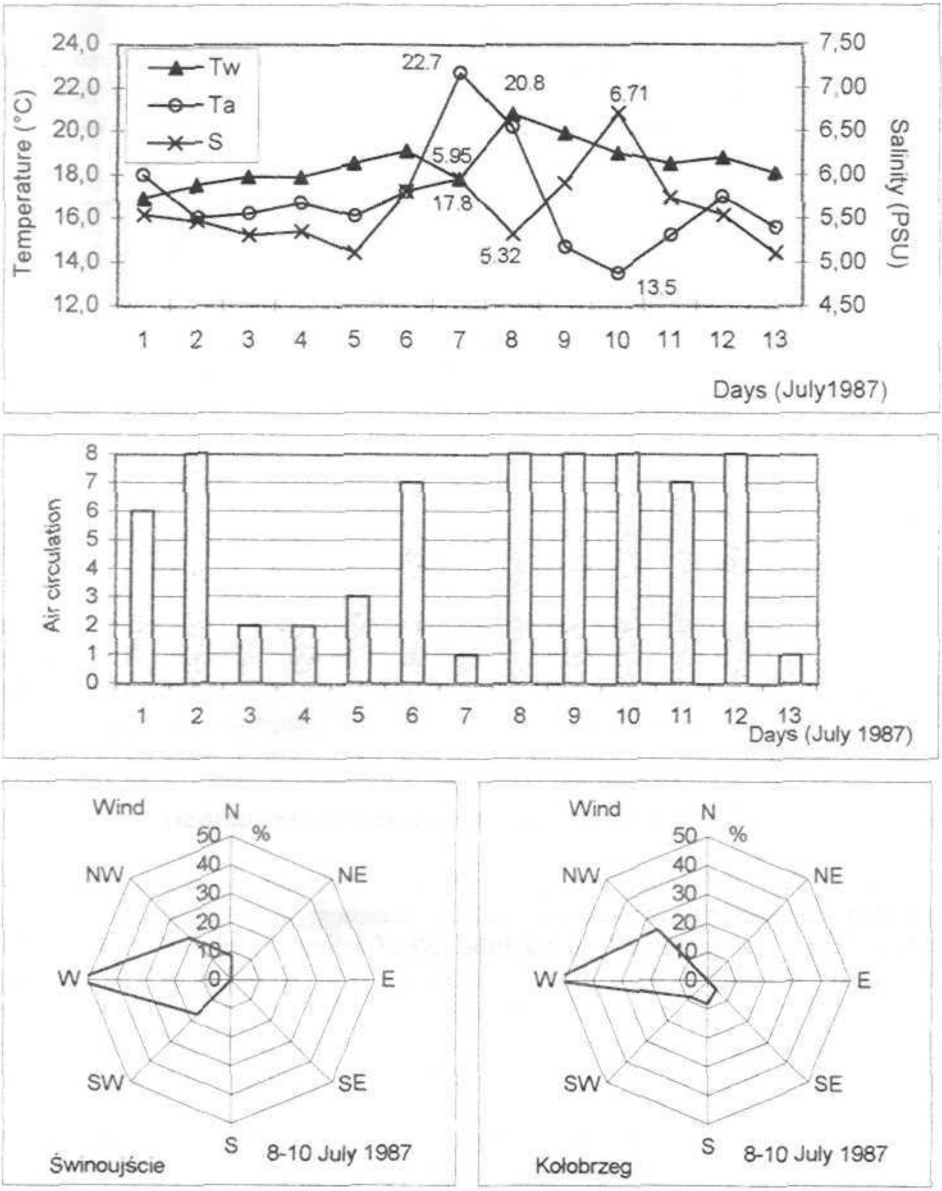

Fig. 8. Hydrometeorological situation in July 1987.
Legend: Air circulation types:
0 – no advection, 1 – N, 2 – NE, 3 – E, 4 – SE, 5 – S, 6 – SW, 7 – W, 8 – NW.

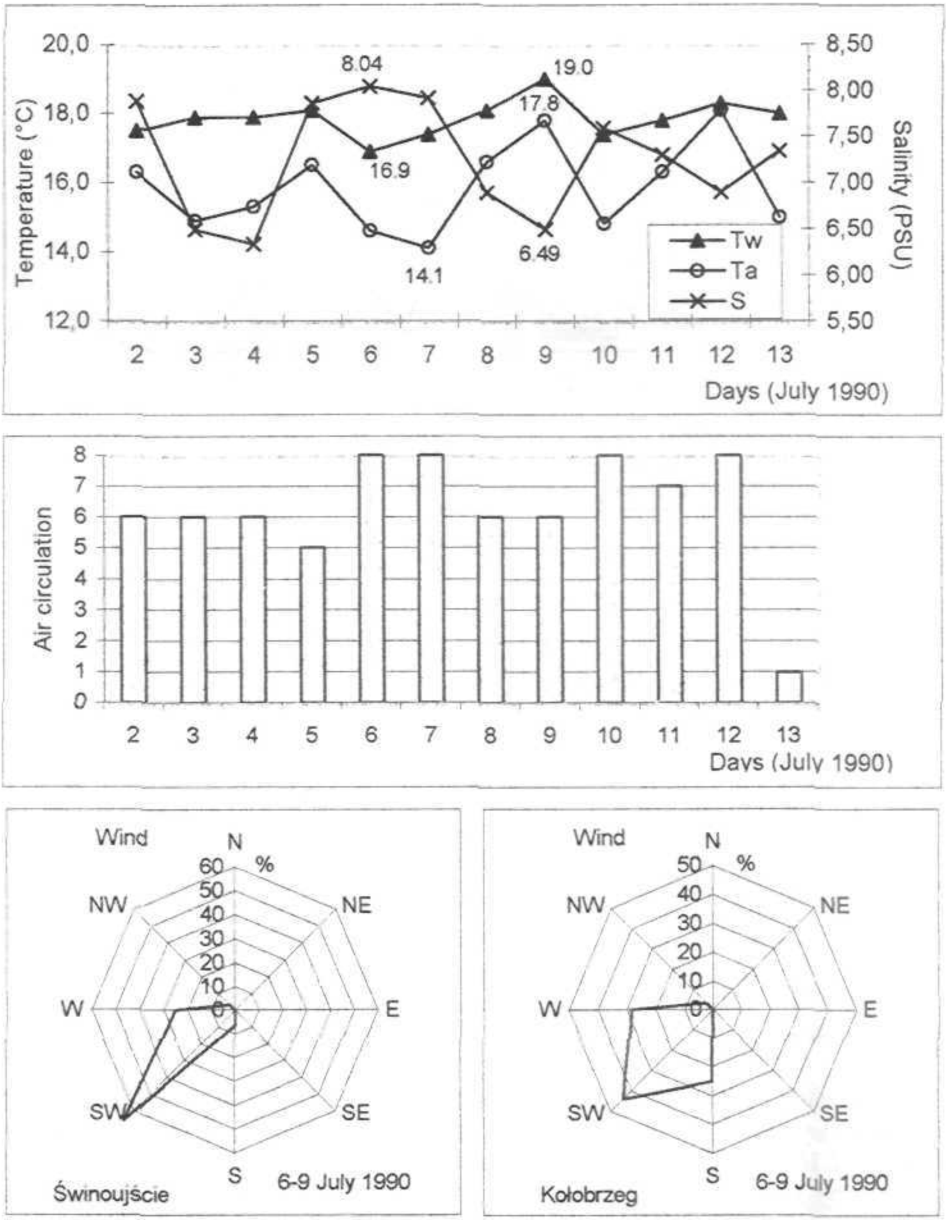

Fig. 9. Hydrometeorological situation in July 1990.
Legend: Air circulation types:
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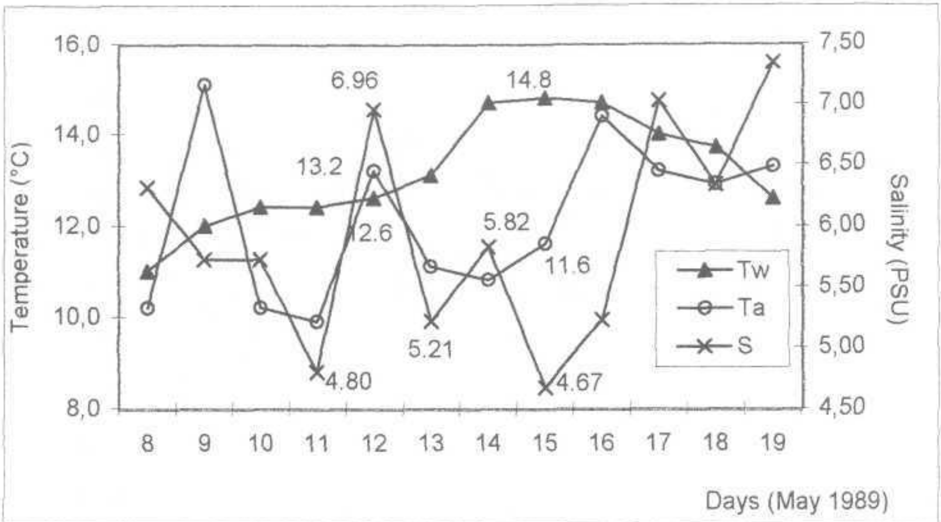

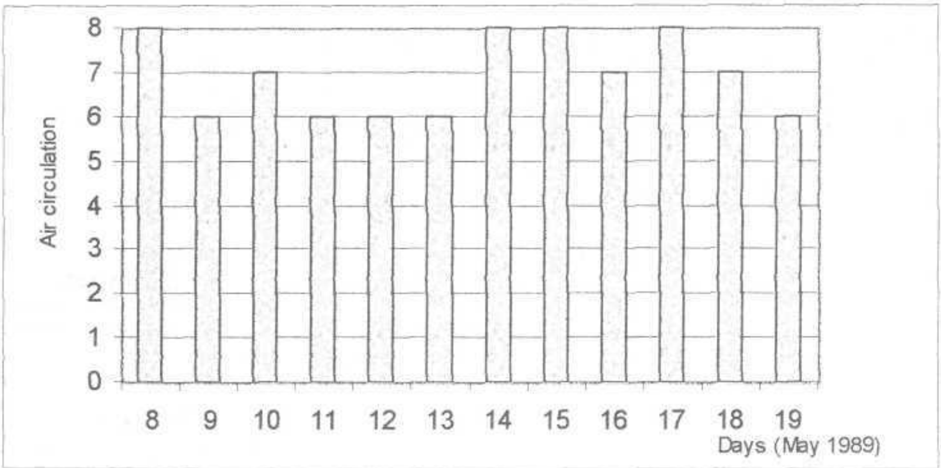

Fig. 10. Hydrometeorological situation in May 1989
Legend: Air circulation types:
0 – no advection, 1 – N, 2 – NE, 3 – E, 4 – SE, 5 – S, 6 – SW, 7 – W, 8 – NW.

Significant changes of salinity under SW to NW inflows of air masses were recorded in May 1989 (fig. 10). First on 12th May there was observed a high increase of salinity of 2.16 PSU but next days salinity decreased until 4.67 PSU. Water temperature was growing slightly and was higher than air temperature. Local winds were blowing mainly from western sector. That situation indicated the inflow of waters with different physical features onshore.

In the end of May 1989, when air circulation as well as local winds from SW to NW where prevailing, a decrease of salinity of 1.72 PSU pointed out the movement of fresh waters from the Szczecin Lagoon to the region of Międzyzdroje. From 29th to 31st May water temperature was almost constant but higher than air temperature (fig.11).

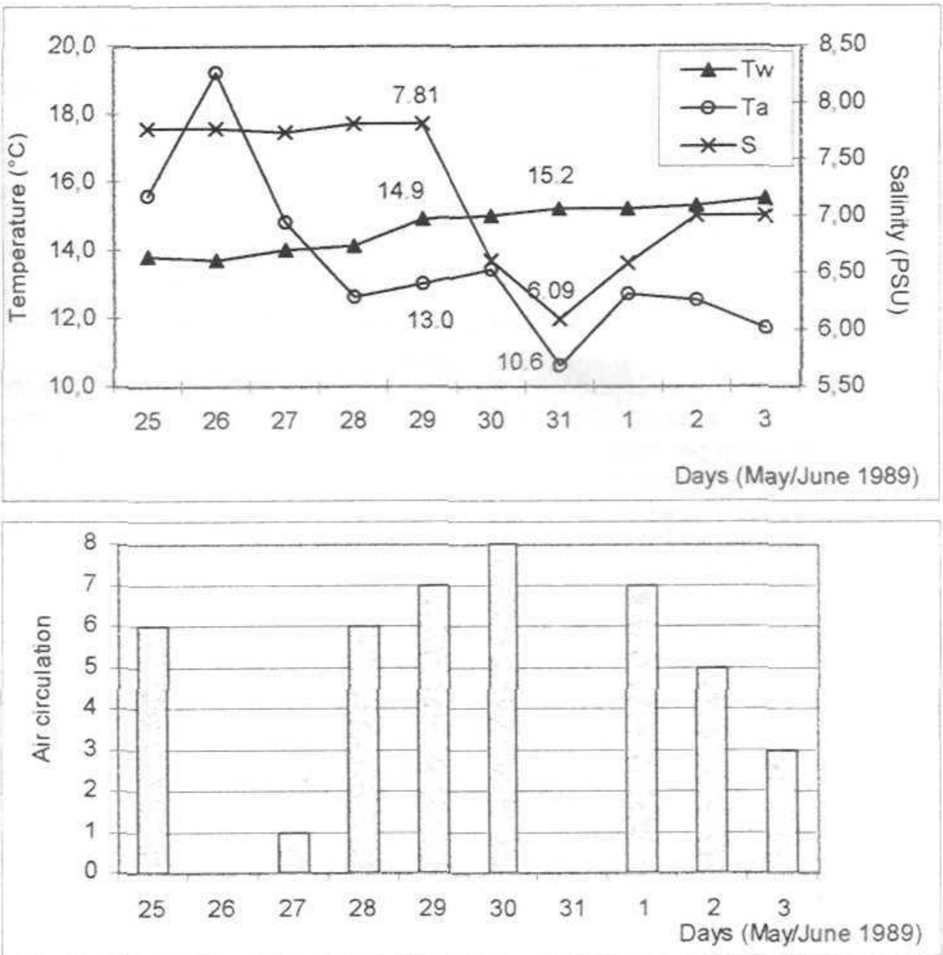

Fig.11. Hydrometeorological situation in May/ June 1989.
Legend: Air circulation types:
0 – no advection, 1 – N, 2 – NE, 3 – E, 4 – SE, 5 – S, 6 – SW, 7 – W, 8 – NW.

CONCLUSIONS

The analysis revealed that:

⇒ At the southern coasts of the Pomeranian Bay (the Wolin Island) during summer period when air masses from E, NE, SE and S were advected a rapid up to 5.0°C drop of sea surface temperature was observed. The increase of salinity up to 2.80 PSU was often recorded as well. Such change of water temperature, which cannot be explained by the fall of air temperature, may indicate the outflow of subsurface waters to the surface (upwelling phenomenon) or along shore movement of waters coming from eastern upwelling regions. The contribution of easterly winds during such events reached 54%. The occurrence of upwelling seems not to depend on wind speed. Although the measured values of wind speed were usually between 2 and 4 m/s, stronger winds were recorded as well.

⇒ On the other hand in case air masses were coming from west or north, sea surface temperature increase and salinity fall even of 2.3 PSU was recorded such conditions could point out the inflow of the warmer and fresh Oder waters onshore and than its fall down (downwelling event). But the increase of salinity even more than 2.2 PSU under such wind conditions could be the result of along shore movement of more salty waters coming from the Western Baltic Sea.

⇒ In the coastal zone of the Pomeranian Bay, where river and sea waters mix together, great variability of water physical feature is recorded. Hence recognising convection processes there, it is important to investigate both changes of water temperature and salinity. However as the Pomeranian Bay is shallow and exposed to enhanced dynamics it can't be perceived as a typical upwelling or downwelling region.

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ZMIANY CECH FIZYCZNYCH WÓD JAKO WSKAŹNIKI RUCHÓW KONWEKCYJNYH W STREFIE BRZEGOWEJ ZATOKI POMORSKIEJ

Streszczenie

W pracy podjęto próbę identyfikacji ruchów konwekcyjnych wód u południowych wybrzeży Zatoki Pomorskiej, w rejonie Wyspy Wolin, analizując zmiany temperatury i zasolenia wody przy różnych warunkach pogodowych. Wykorzystano średnie dobowe zasolenie i temperaturę wody w Międzyzdrojach, średnią dobową temperatura powietrza w Świnoujściu, a także terminowe pomiary prędkości i kierunku wiatru w Świnoujściu i Kołobrzegu oraz średnie dobowe kierunki napływu mas powietrza z lat 1971-1990 otrzymane z IMGW. Pod uwagę wzięto okresy od kwietnia do października.

Jako główne identyfikatory zjawiska upwellingu lub downwellingu potraktowano zmiany temperatury i zasolenia wody powierzchniowej przy uwzględnieniu ich relacji z cyrkulacją dobową, kierunkiem i siłą wiatru oraz z temperaturą powietrza.

Analiza wyników pozwoliła na sformułowanie następujących wniosków:

⇒ U południowych wybrzeży Zatoki Pomorskiej /Wyspa Wolin/ w półroczu letnim, przy napływie mas powietrza z E, NE i SE oraz S, zachodzą nagłe i duże dobowe spadki temperatury wody powierzchniowej nawet do 5,0°C. Często towarzyszy im wzrost zasolenia wody powierzchniowej, nawet do 2,80 PSU. Takie spadki T_W, nie mające związku z ochłodzeniem powietrza, mogą świadczyć o wypływie podpowierzchniowych wód na powierzchnię (zjawisko upwellingu) lub o wzdłuż-brzegowym przemieszczaniu się w okolicach Międzyzdrojów chłodniejszych wód pochodzących z sąsiednich, wschodnich rejonów określanych mianem upwellingowych. Udział wiatrów wschodnich w tych sytuacjach sięga 54%. Czas inercji upwellingu nie zależy w dużym stopniu od prędkości wiatru. Zanotowane prędkości mieściły się najczęściej w przedziale 2 - 4 m/s, ale występowały również wiatry o większej sile.

⇒ Z drugiej strony przy napływie mas powietrza z sektora zachodniego lub z północy wzrost temperatury powierzchniowej wody przy jednoczesnym spadku zasolenia nawet o 2,30 PSU wskazuje na dopływ w kierunku Międzyzdrojów wysłodzonych i cieplejszych wód rzecznych wypływających z Zalewu Szczecińskiego przez Cieśninę Świny. Natomiast wzrost zasolenia nawet o

2,20 PSU przy tych warunkach cyrkulacyjnych wskazujący na występowanie w zatoce prądów wzdłuż-brzegowych i dotarcie wód bardziej słonych z zachodniej części Bałtyku.

⇒ W rejonie Zatoki Pomorskiej, miejscu styku wód śródlądowych i morskich występuje bardzo duża zmienność cech fizycznych wód. Stąd przy badaniu procesów konwekcyjnych ważna jest analiza zmian zarówno temperatury jak i zasolenia wody. Jednak ze względu na silną dynamikę wód i niewielkie głębokości Zatoka Pomorska nie może być postrzegana jako rejon typowo upwellingowy lub downwellingowy.