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# Critical storm thresholds for the generation of significant dune erosion at Dziwnow Spit, Poland

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ABSTRACT

Storm influence on the southern Baltic coast was examined for a 14-km long section of the Polish coast along the Dziwnow Spit based on 30 years of post-storm dune erosion observations. In this study, we assumed that a significant storm causes noticeable sand dune erosion. Significant changes of the coast after each major storm were analysed based on reports from 1978 to 2008 provided by the Maritime Office, Szczecin. Thirty-two storms that caused dune losses were chosen for analysis. Correlation and hierarchical cluster analysis allowed us to distinguish three groups of storms that caused varying amounts of dune erosion: G1 (small), G2 (medium), and G3 (large). Sea level is the main parameter that influences the amount of dune erosion caused by storms on the southern Baltic coast. Factors such as maximum significant wave height, mean wave direction, storm energy and duration can also, but less significantly, influence dune erosion. The study area was divided into two sections: Dziwnow, where there are many protection measures in place, and Miedzywodzie, which has no protection measures in place. In both areas, we observed differences in the impact of sea level and significant wave height and storm groupings. Approximate minimum sea level and significant wave height thresholds were defined for particular storm groups.



## 1. Introduction

The most valuable defences against storms on a dune coast are well-developed bar systems and a wide beach with a high and wide dune system. Sea-level rise during storms moves the location of high wave action landwards. As a result, large amounts of upper beach and dune erosion, overtopping and even total dune damage can be observed. These topographical changes are especially dangerous when property and people occupy the coast area just behind or on the dunes. It is necessary to study the process of dune erosion during storms and the effectiveness of protection measures. The key influence of storms on the beach is changeability of a cross-shore profile, which tends to achieve an equilibrium state. Numerous models that describe changeability of the shape of a cross-shore profile have been developed. They can be divided into two groups. The first approach consists of wave steepness and grain size (Rector, 1954; Sward, 1974, 1976; Vellinga, 1986). The second approach considers wave energy dissipation (Bruun, 1954; Dean, 1976; Larson and Kraus, 1989; Dean, 1991). The first group describes the final dune shape as a result of wave and water level conditions, whereas the second group describes the transport process of sediments away from the dune, resulting from the direct wave hits. In non-tidal seas, such as the Baltic Sea, it is essential to recognise the value of sea-level change during storm surges. Sea-level changes during storm surges cause variation in the influencing conditions between waves and the bottom, and speed of the changes (Musielak, 1978). In this paper, we investigate the influence of significant storm parameters on the dune erosion volume.

Each storm was characterised by five parameters: sea level, storm duration, maximum height of a significant wave, mean wave direction and storm energy calculated based on previous parameters. Each parameter influenced the dune erosion value. Because all the parameters influence dune erosion, it is difficult to describe this influence with a single function. We, therefore, applied Ward's method (Ward, 1963) to group storm events described by many parameters. The aim was to group storms according to size effects to determine dune erosion.

We try to define "thresholds" of dune erosion volume calculated based on the classification tree method. Then we prepare a classification of the significant storms and analyse for correlations between the storm parameters. Analyses were done for protected and natural sections of the coast to observe the importance of particular storm parameters with reference to the dune erosion volume.

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## 2. Area of investigation

The Baltic is a non-tidal sea, and the maximum tidal range is limited to centimetres (Sztobryn et al., 2005); therefore, tides have minimal impact on coast erosion. However, a temporary rise in sea level can be observed in the southern Baltic Sea when a long-lasting low-pressure zone over the Danish Strait causes large volumes of water to flow into the Baltic Sea. This type of event is locally called “filling up” of the southern Baltic Sea. Surges of up to 0.7 m (570 cm) above mean sea level can result from local atmospheric pressure changes (Wiśniewska, 1981). When combined with a temporary sea-level rise, low significant wave heights can cause significant erosion and storm floods along the coast of the southern Baltic Sea. The largest known historic storm flood events occurred on November 13, 1872, and December 28, 1913 (Majewski et al., 1983).

The Dziwnow Spit is located on the western part of the Polish coast, separating Pomeranian Bay and Kamienski Lagoon (Fig. 1). It is a sandy spit about 0.3 km to 0.5 km wide and 14 km long. The coast has dunes 3 m to 12 m high and 50 m to 150 m wide, whereas the back-barrier is flat and low-lying (Furmańczyk and Dudzińska-Nowak, 2009). The Dziwna inlet is at the middle of the spit. Increasing erosion was observed since the beginning of 20th century, when an artificial channel was constructed (1892–1900) (Racinowski and Seul, 1999; Dudzińska-Nowak, 2006). Since then, different kinds of protection measures, such as seawalls, groynes, jetties and recently beach nourishment, were implemented. A historical diagram showing the development of the coastal protection methods is presented in Fig. 2 (Dudzińska-Nowak, 2006).

The study area is known for strong morphodynamic processes and strong erosion tendency. An analysis of the long-term coastal changes of the Dziwnow Spit, for time periods 1938–51, 1951–73 and 1973–96, shows that the protection methods had a significant impact on the coastline near Miedzywodzie. Groynes accumulated material carried by longshore drift and abrasion nearly stopped. However, the erosion problem moved to the west and can be identified as a linked side effect. Protection measures used in the town of Dziwnow increased the danger of erosion along the whole spit. Although protection methods were used, the coast became more stable because annual erosion rate decreased from 2 m/year to 1 m/year. The area and length of eroded sections increased whilst the area and length of accumulation sections dramatically decreased (Dudzińska-Nowak, 2006).

The whole area is an important tourist destination, with 22,000 people visiting during the summer (permanent population 2001–4437) (Furmańczyk et al., 2003). Three municipalities are located on the spit: Dziwnow town, Miedzywodzie and Dziwnowek. Dziwnow town is located on the narrowest part of the spit at the eastern side of the inlet. In some parts of Dziwnow town, buildings are located directly on the dunes close to the open sea, and are protected by a concrete seawall (Fig. 1). However, the concrete seawall caused increased erosion on adjacent sections of the coast (Dudzińska-Nowak, 2006).

Winds of the southern Baltic are affected by atmospheric circulation and the moderate latitude, and they are modified by the pseudo-monsoon exchange of air masses with those from the Atlantic Ocean and the European continent. The superposition of air masses causes the predominance of South-Westerly (SW) and Westerly (W) wind directions throughout the year, except in the spring. Three zones are characterised by different wind speeds: open sea, shore and land. The mean annual wind speed over the open sea exceeds 6 $ms^{-1}$ (4 Bft — degree in Beaufort scale), but this average decreases near the shore and on land. Wind speeds above 6 Bft occur most frequently in the period from October to March, and represent 15–20% of the time in each month.

The highest mean monthly wind speeds in the coastal zone, 5–7 $ms^{-1}$ (4 Bft), occur in autumn and winter. The lowest, 2.5 to 3.5 $ms^{-1}$ (2 Bft), are recorded from May to August when there are weak pressure gradients over the Baltic Sea basin. The greatest number of days with strong winds occurs during the autumn and winter seasons. Stronger winds occur more frequently in coastal waters than on land and reach a frequency of 20–25%. The frequency of stormy weather (above 8 Bft) can vary from 2 to 5%, depending on the month and area (Zeidler et al., 1995).

In the International Glossary of Hydrology (WMO, 1992), a storm surge is defined as an elevation of the sea level caused by the passage of a low-pressure centre. In Poland, a storm is officially declared when the wind force exceeds 8 Bft and a storm surge occurs when the sea level is at least 70 cm above mean sea level, i.e., exceeds 570 cm

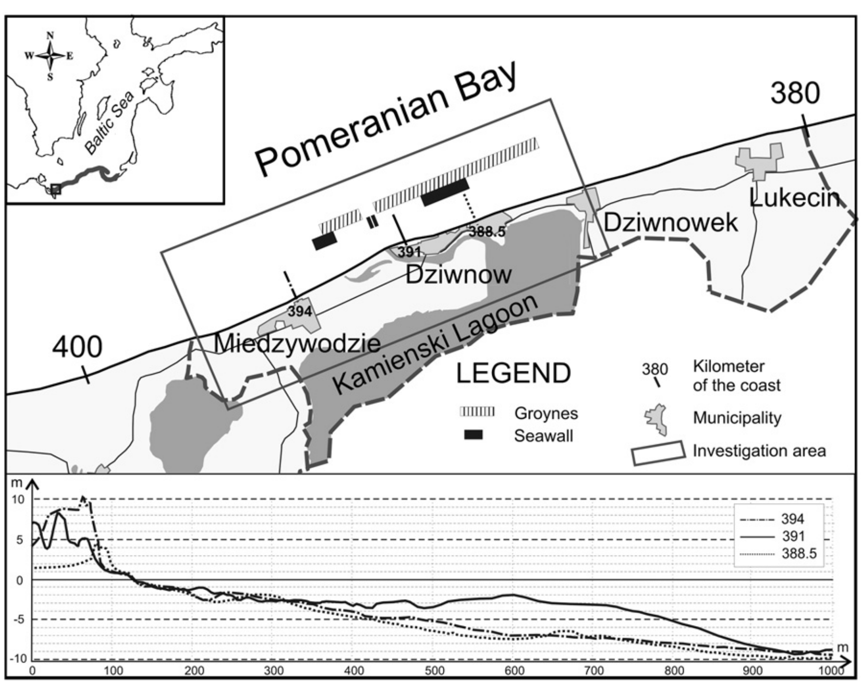


**Fig. 1.** Area of investigation with three typical coastal profiles.