Characteristics of extreme wind wave events in the Gulf of Gdańsk and associated atmospheric conditions over the Baltic Sea

Aleksandra Cupiał & Witold Cieślikiewicz
Institute of Oceanography, University of Gdańsk, Gdynia, Poland

Data sets – two hindcast datasets which are the result of an EU-funded project **HIPOCAS** (Cieślikiewicz & Paplińska-Swerpel 2008)

44-year long reanalysis of meteorological data produced with the **atmospheric model REMO** (REgional MOdel; Jacob and Podzun 1997)

Wave data (1958–2001) produced with wave model **WAM with the** subset of gridded REMO data as input wind data.

Calculations were carried out at the Academic Computer Centre (TASK) in Gdańsk

Fig. 1. Area of interest

Highlights

- Most severe storms in the Gulf are result of NW winds
- There seem to be two wind/storm regimes associated with cyclones' paths

The **aim** of this work is to obtain most characteristic features of extreme storms that had significant impact on **the Gulf of Gdańsk** during the last half-century and associated meteorological conditions.

Input data	Output data	Wind wave fields characteristics
1. Wind velocity fields U_{10} 2. Ice cover 3. Bathymetry (IOW)	1. Energy spectra 2. Integral wave parameters (used in thiswork: significant wave height (H_s) and mean wave period (T_z)	• Output data time step: 1 hour • Spatial resolution: 5’ × 5’ • Frequency resolution: $f_1 = 0{,}050545$ Hz, $f_n = 1{,}2\, f_{n-1} n = 2, \dots, 25$ • Coordinate system: Rectangular regular grid in rotated spherical coordinates

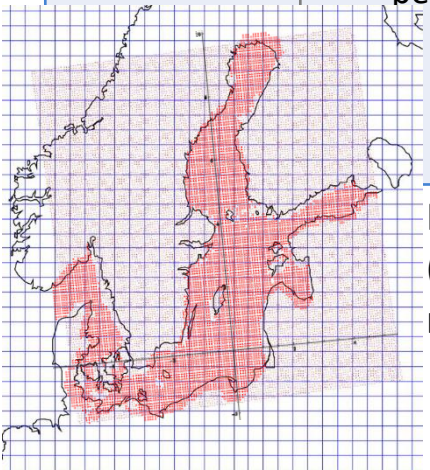


Fig. 2. WAM: 5209 sea points (red dots) overlaying REMO rectangular grid (blue net)

Meteorological data

The wind velocity hindcast covering the period 1958–2001 was performed in HZG (formerly GKSS), with the atmospheric REMO model. The REMO modelling area covers Europe and NE Atlantic with 0.5° × 0.5° resolution and gridded wind velocity fields have temporal resolution of 1 hour. (Jacob & Podzun 1997)

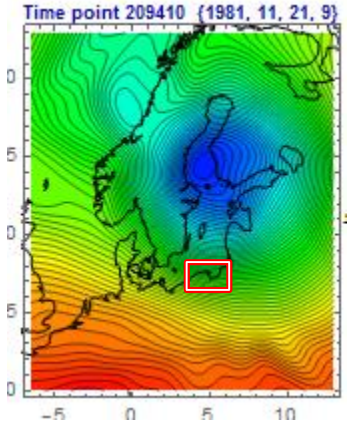


Fig. 3. Total area of interest for the meteorological data

For more comprehensive description of the data see Cieślikiewicz & Paplińska-Swerpel 2008 and the end of this presentation

Storm definition and selection

34 storms were selected for 5 points in the Gulf of Gdańsk, based on threshold values – set as values depending on location of given point.

Threshold for the H_s value ranges from 6.4 to 8.2 m in the open part of the Gulf (dark blue dot) and from 1.3 to 1.6 m in the sheltered Puck Bay (inner part of Gulf of Gdańsk – violet dot).

Overlapping events were classified as one storm event.

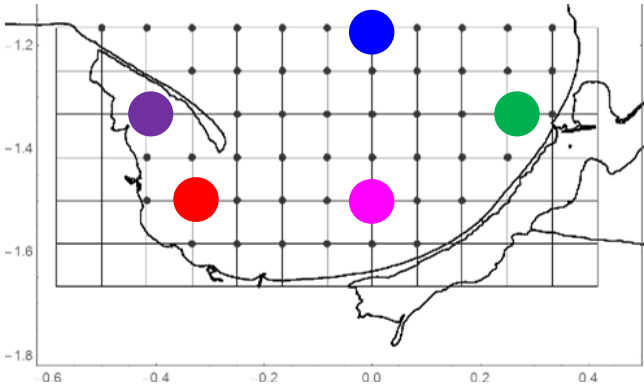


Fig. 4. Points of interest

@: aleksandra.cupial@phdstud.ug.edu.pl

Wave climate

Wave climate in Baltic is relatively mild, with most severe storms occurring in the winter period. In the open part of sub-basins one can expect H_s in the range 0.6–0.8 m. Modelled values of H_s during most severe storm events range usually between 6.0–9.0 m in the open sea.

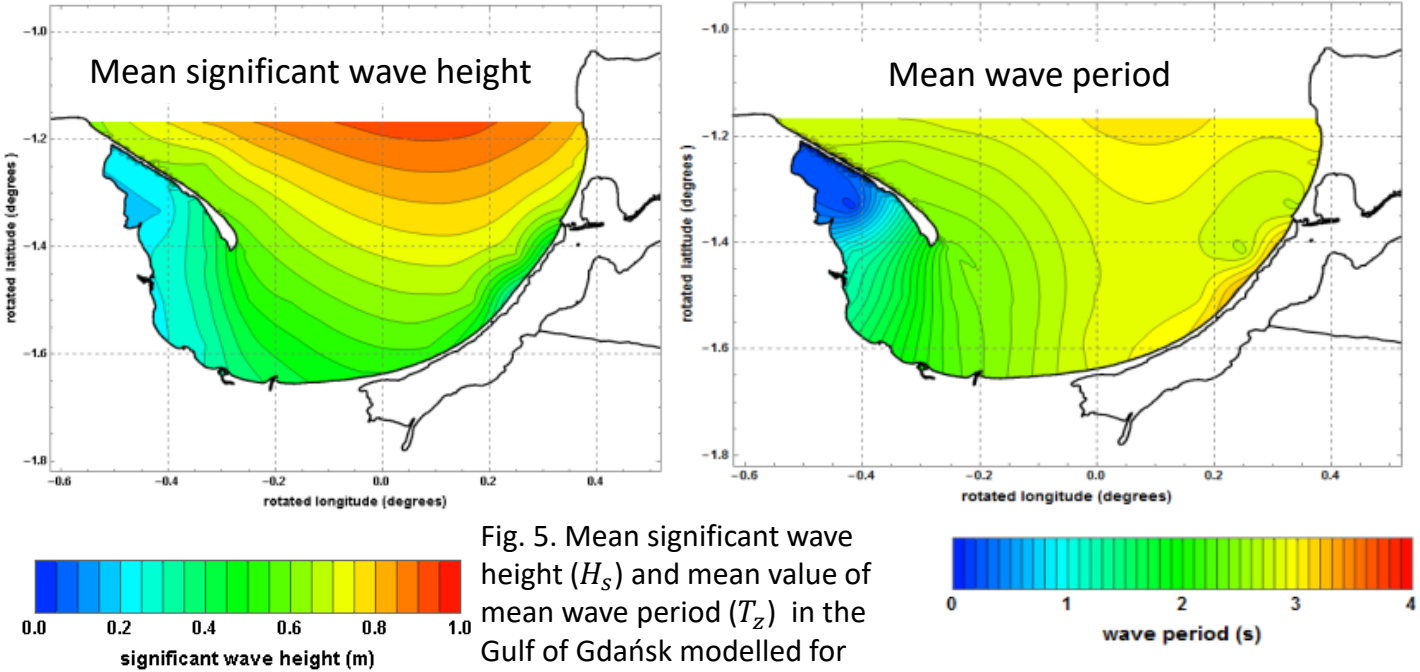


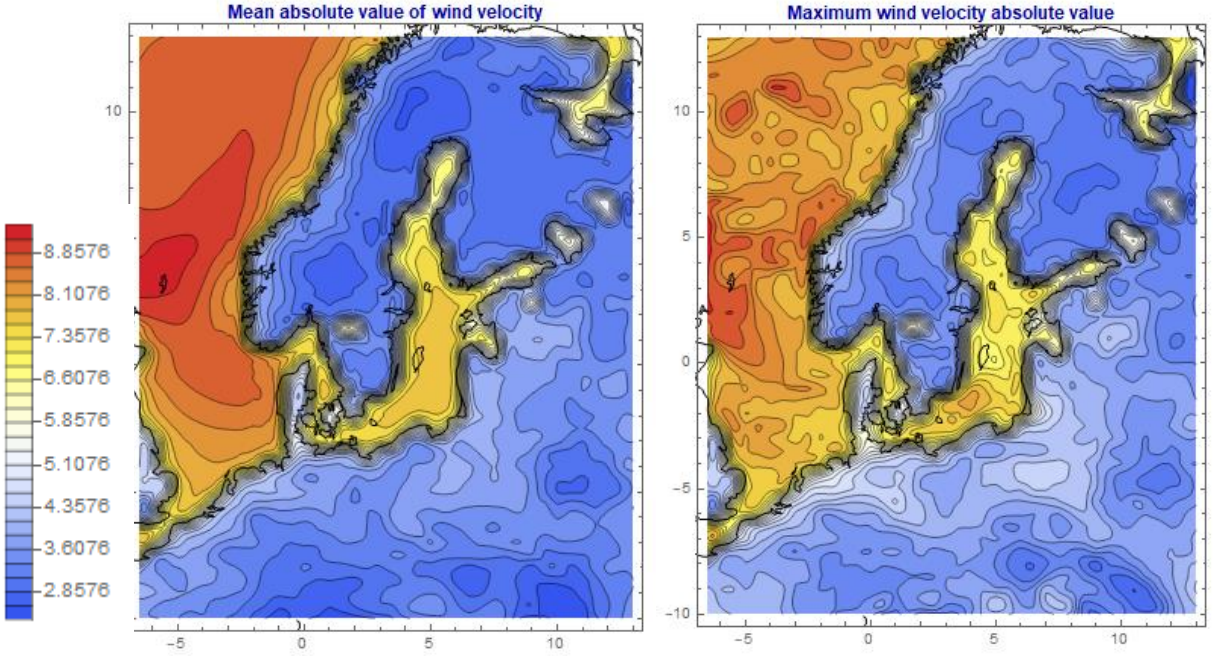
Fig. 5. Mean significant wave height (H_s) and mean value of mean wave period (T_z) in the Gulf of Gdańsk modelled for 1958–2001.

The most severe wave climate is in the southern part of the Baltic sea, with majority of highest wave events, as well as the most severe storms occurring in this area. As for the wave periods, they generally oscillate in 4–6 s in the open sea and in coastal areas are 2–4 s (Soomere & Räämet 2011, Björkqvist *et al*. 2018, Broman, 2006).

@: aleksandra.cupial@phdstud.ug.edu.pl

Wind climate

Dominant wind direction is SW-W. Average wind values at the centre of Baltic Proper range between 6–8 m/s depending on the month. The highest mean monthly wind speeds recorded in the coastal zone were 5–7 m/s. The strongest winds in Baltic occur in winter months, reaching over 25 m/s. Irregular shape of the Baltic and abundance of fetches and wind speeds lead to strong variability in wind climate (Zeidler *et al.* 1995, Räämet & Soomere 2010, Bierstedt *et al*. 2015).



Results

- All but two storms occurred during the winter period.
- Strongest storms (defined based on H_s) appeared to be caused by NW winds.
- At all points storm peaks occurred at roughly the same time, usually within one- two-hour window.
- The exception were two storms that instead of having a clear peak of H_s value had a sort of plateau at higher H_s (see fig. 7.).

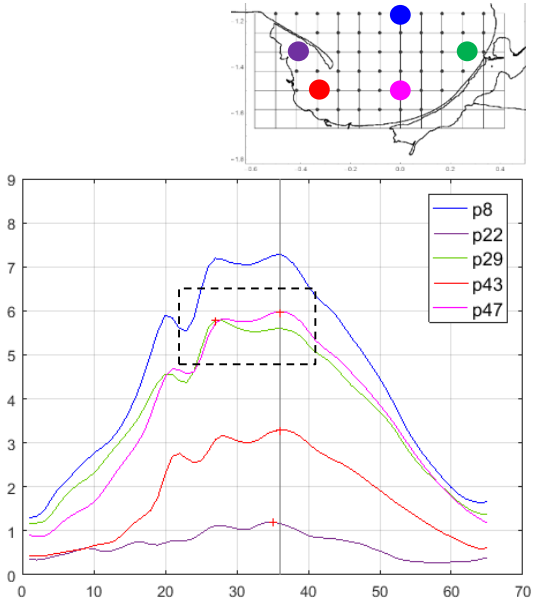


Fig. 7. Storm with 9-hour time lag between storm peaks. Peak is marked as red cross and grey line (for dark blue point); colors follow colors of selected points, horizontal axis: hours, vertical axis: H_s [m]

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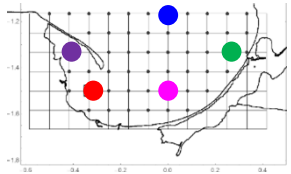
Results

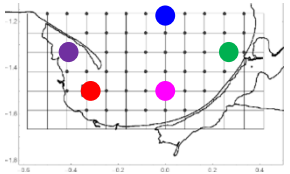


Events that were selected as storms based on H_S value in the most sheltered point (in the inner Puck Bay) are in all (but two) analysed cases not classified as storms according to other locations.

This means that maximum value of H_S fails to reach storm threshold set in those locations outside the Puck Bay. This, in turn, leads to the conclusion that the conditions generating maximum storms in the Puck Bay are much calmer over the majority of the area than during other events.

Keeping in mind that this observation strongly depends on our method of storm selection, we decided to look closer and see if there are distinct differences in storm's characteristics between those two groups of storm events.

@: aleksandra.cupial@phdstud.ug.edu.pl



Differences between storms

based on visual analysis – the following is true for **most** cases

Storms selected based on H_s value in Puck Bay

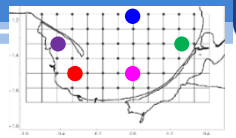
- During the storm peak, the centre of a low is located in the Baltic
  - over water
  - to the north of the Gulf of Gdańsk
- Westerly, south-westerly winds
- High pressure system is located mostly outside the total area of interest, in the south-west
- Path of a typical storm leads over the Baltic Sea along either the SW-NE or W-E direction

Storms selected based on H_s value outside Puck Bay

- During the storm peak, the cyclone's centre is located on land- to the east or south-east from the Baltic Proper
- North-westerly winds, some cases of NE winds
- Centre of high pressure system is present in the total area of interest, covering significant area in the west, north- or southwest
- Typical path of the storm leads either over the Baltic Sea along the NW-SE direction or over land area spanning from north to south on the eastern side of the Baltic Sea

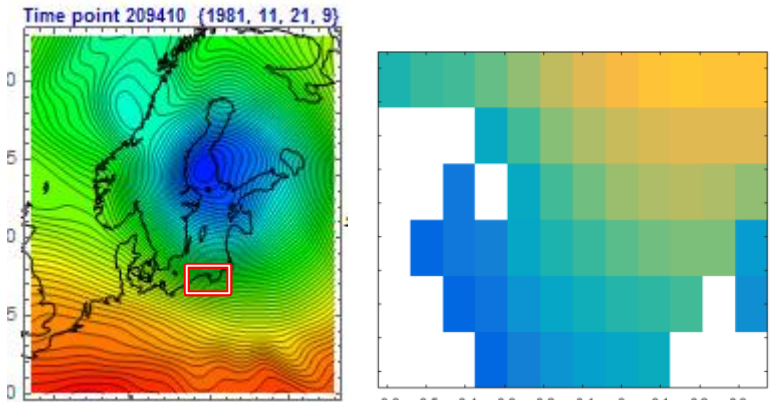
@: aleksandra.cupial@phdstud.ug.edu.pl

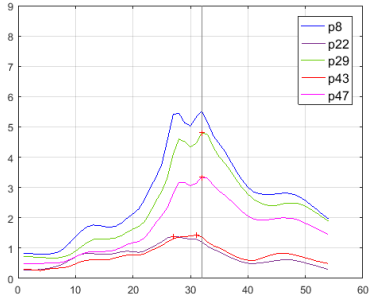
Comparison of storms selected based on different locations—examples



Storms selected based on H_S value in Puck Bay

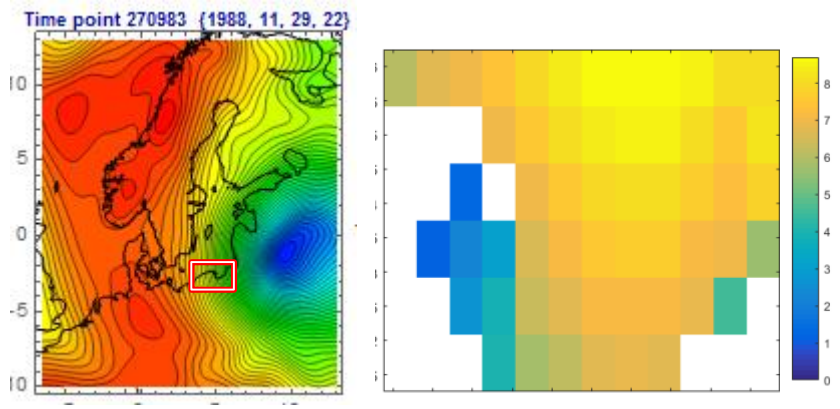
20.11.1981 – 22.11.1981





Storms selected based on H_S value outside Puck Bay

28.11.1988 – 1.12.1988



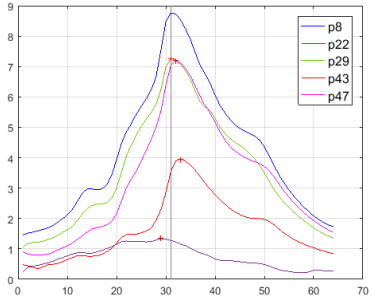


Fig. 8. From top left, clockwise: pressure pattern in the peak of storm, spatial distribution of H_S during the peak of storm, development of storm (horizontal axis: time [hours], vertical axis: H_S [m])

Main take away points

- In the hindcast of wave data spanning over 40 years, the 34 events were classified as storms in the Gulf of Gdańsk
- The most severe storms in the Gulf of Gdańsk are characterised by NW winds
- Apparently there are two wind regimes generating storms:
  1. associated with higher waves in the sheltered part of Gulf of Gdańsk, W-SW winds, and cyclones crossing Baltic along SW-NE or W-E direction
  2. characterised by extremely high waves in the main part of the Gulf and N-NW winds, with cyclones crossing Baltic along NW-SE direction or travelling to the east of the sea, along the meridian.

@: aleksandra.cupial@phdstud.ug.edu.pl

Thank you for your participation

Detailed description of model properties

	Wind velocity fields	Wind wave fields
Resolution in time domain	1 hour	1 hour (output data time step) 300 s (propagation and source terms time step)
Resolution in spatial domain	0,5°× 0,5°	5’ × 5’
Direction resolution and frequency resolution		frequency: $f_1 = 0{,}050545$ Hz, $f_n = 1{,}2\ f_{n-1}: n = 2, \ldots, 25$ angular resolution: 15°
Coordinate system	Rectangular regular grid in rotated spherical coordinates	
	„New” meridian set in the center of the modelling area	
Data provider	GKSS based on REMO (REgional MOdel) (Jacob and Podzun, 1997)	—

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