Keywords: meteotsunami hazard; wave height; thunderstorm; sea level variations; Baltic Sea

Title:

Meteotsunamis - Sea bears - in the Southernwestern and Southern Baltic Sea – German and Polish coast

Short title:

Meteotsunamis in the Southwestern and Southern Baltic Sea

Authors:

Bärbel Weidig[1], Ines Perlet[1], Grzegorz Pietrucha[2], Jürgen Holfort[1], Ida Stanisławczyk[2], Sandra Schwegmann[1]

Affiliation:

[1]Bundesamt für Seeschifffahrt und Hydrographie, Rostock

[2]Instytut Meteorologii I Gospodarki Wodnej, Gdynia

***Corresponding author:**

Bärbel Weidig, Bundesamt für Seeschifffahrt und Hydrographie, Neptunallee 5, 18057 Rostock, baerbel.weidig@bsh.de

Abstract

The german term "Seebär" – sea bear - is more generally referred to as meteotsunami. The notion sea bear is mainly used in the North Sea and Baltic Sea. A meteotsunami is a fast, rapidly, unforeseen, mostly local, larger sea level variation up to 1 m. They often occur in small harbors and narrow bays. In contrast to the tsunamis known from the press, meteotsunamis are not caused by earthquakes or landslides, but they have meteorological reasons. These are mainly atmospheric phenomena, such as short-period atmospheric pressure variations, thunderstorm gusts or front passages. With today's weather forecasting models, these atmospheric phenomena are very difficult to predict, especially because of their small-scale location and time of formation.

Available sea level data on the German and Polish Baltic Sea coast were examined for signals from meteotsunamis. A simple search for faster and / or larger sea level variations resulted in many, mostly wrong cases, a criterion regarding energy in a certain frequency range (1 to 10 minute values of sea level) was added. This functionality works only with the newer minute data. Only very few signals from meteotsunamis were found although the hourly water level data, which go back to the 1950's.

Determining the meteorological factors which are responsible for the appearance of the meteotsunamis was very difficult. Often, meteotsunamis and their causes are very local and thus the meteorological factors are not recorded correctly by the great distance of the stations. For some events, for example, instead of fronts, the speed and direction of the movement of convergence zones played a greater role. However, these zones are not included in many of the weather maps used, especially the older one.

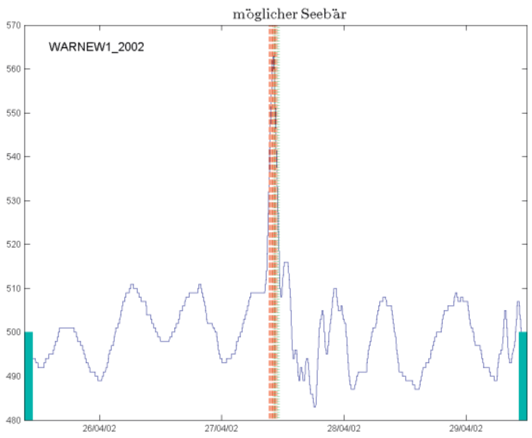
From the found meteotsunamis some selected events are presented, together with the description of the hydrological situation and the analysis of the connected meteorological weather conditions.

1. Introduction and general description

Meteotsunamis or meteorological tsunamis are long waves in the tsunami frequency band caused by mesoscale atmospheric disturbances, such as thunderstorms, squall lines, and other air pressure anomalies, moving above the sea at a resonant speed (Monserrat et al. 2006). Meteotsunamis are known and described worldwide, for example the catastrophic meteotsunami at Nagasaki Bay (Japan) on the 31th of March 1979. The physical causes of the occurrence of meteotunamis are described in detail at Monserrat et al. 2006. The prediction of meteotsunamis is difficult to not possible due to the very small-scale and local atmospheric phenomena. However, an operational meteotsunami forecasting system has already been developed for the Adriatic Sea and the coast (Denamiel et al., 2019). Meteotsunamis often occur in small harbors and narrow bays. The prevailing bathymetry of the Baltic Sea (narrow shallow coastline) favors the formation of meteotsunamis. The literature already describes historical meteotsunamis in the Baltic Sea (e.g. Credner 1889, Doss 1907, Defant 1961, Hupfer 1984 and 2003, Majewski 1989). In German the term "sea bear" is used for a meteotsunami. Originally the term comes from the Low German word “boeren”, which means "to lift". On the Swedish and Finnish coasts, this locally and suddenly occurring large wave with rapid increase in level is known as “sjösprång” (sea jump).

2. Method of identification

The water level data available on the German and Polish coasts were examined with a program for signals from meteotsunamis. At 1-10 minute water level, the search worked well, but such high-resolution water levels did not appear until the 1990's. Figure 1 shows the automatic detection of a meteotsunami in April 2002 for the Warnemünde gauge, and Figure 2 shows the evaluated gauge stations. The hourly values dating back to the 1950s were also examined, but very few possible signals for a meteotsunami have been found. These signals were additionally checked manually using the analogue level records.



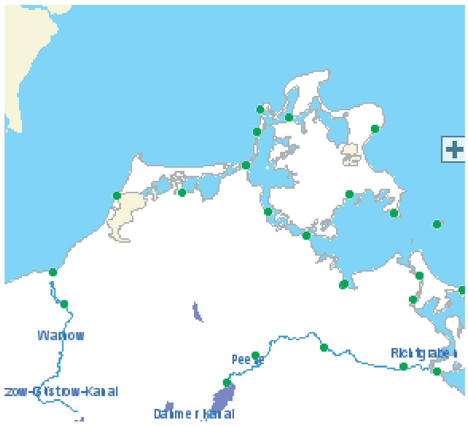


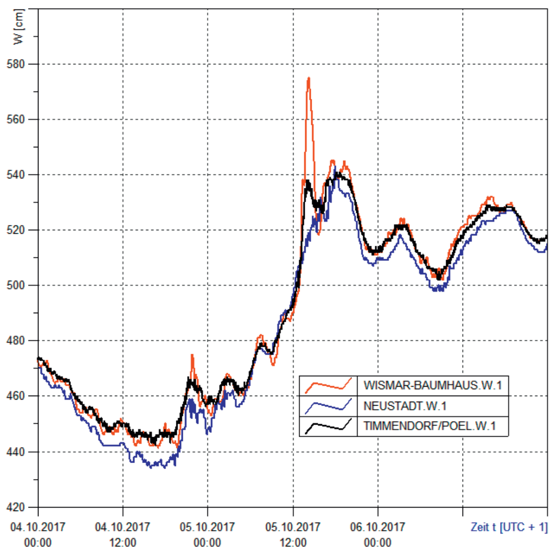
Fig. 1: Example of automatic detection for a meteotsunami on 27th April 2002

Fig. 2: Investigated water level stations of the Federal Waterways and Shipping Administration

3. Description of selected examples of meteotsunamis

3.1 Example for a meteotsunami caused by a local wind field

An example for the formation of a meteotsunami by the passage of a local wind field is the water level rise on 05th October 2017. Along the whole German coast, the water levels were on 04th October 2017 fell by a half meter through the fresh to strong wind from westsouthwest. In the night of 05th October 2017, the wind had decreased and the water levels started to rise. A secondary depression moved from the German Bight along the German Baltic Sea coast. On the morning of 05th October 2017 the wind blew from southeast with 2 Bft in Boltenhagen, at 12 UTC the wind turned south and reached maximum speeds of 7 Bft. An hour later, the speeds increased to 9 Bft (average 8 Bft). The wind turned to the north. Within 3 hours, an air pressure change of 14 hPa was measured in the observed area. Changes in air pressure on the sea surface cause the water level to be raised or lowered; 1 hPa corresponds to a water column of 1 cm. In this case, the water level increased up 14 cm. This strong air pressure change and the prevailing weather situation was the cause of a special water level congestion in the Wismar Bay. Within 2 ½ hours the water level in Wismar increased from 13 cm below to 75 cm above the mean sea level, which corresponds to a difference of 88 cm. Thereafter, the water level dropped quickly by 56 cm. This meteotsunami occurred unforeseen and locally only in Wismar.



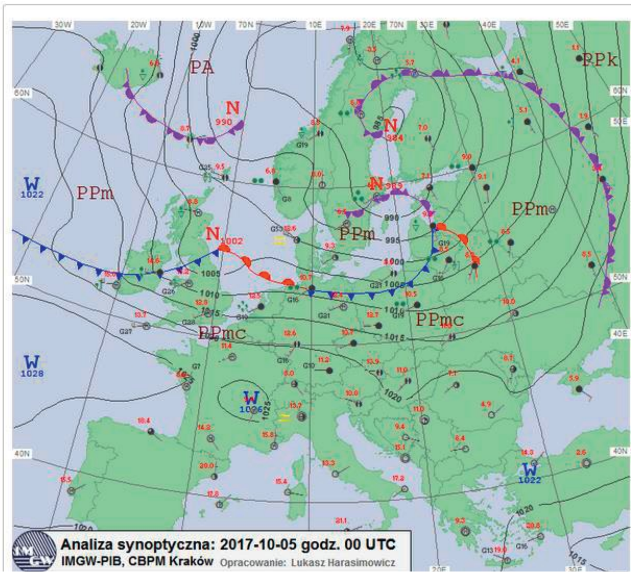


Fig. 3: Water level from 4th - 6th October 2017 for the gauges Wismar, Neustadt and Timmendorf

Fig. 4: Synoptic analysis (a pressure pattern over Europe) from 00.00 UTC on 5th October 2017 (IMGW-PIB, Weather Forecast Office in Cracow)

3.2 Example for a typical summer meteotsunami

Typical summer meteotsunamis are created in particular by moving convergence zones. In the convergence zone large vertical temperature differences occur, which usually result in strong thunderstorms and winds. At the meteotsunami on 3th August 2014, the convergence zone was associated with a rapid drop in temperature of up to 15 ° C in a few minutes, a sudden wind turn of about 150-170 ° with wind speeds around storm strength and a drop in air pressure up to 2.5 hPa in one hour. There it took place quite dangerous phenomenon of thunderstorm with intense rain and hail and sudden wind gusts of up to 9 Bft. The radar images in Figure 5 show the movement of the convergence zone. The days before the meteotsunami the water gauges show typical curves for calm summer days. The water levels were around the mean sea level. There was a light to weak breeze from different directions. At 17 UTC, wind from northwest was measured in Göhren. About 2 hours later, the wind jumped to the southwest and within a few minutes to the south-southeast. Due to the refreshing high wind, the water level in Karnin (Little Lagoon) began to rise at 6 pm from 12 cm above the mean sea level and after 45 minutes reached a value of 41 cm above the mean sea level. In the same time thereafter, the water level dropped by 30 cm. An hour later, a similar short wave reached in Sassnitz. The level rose by 30 cm within 41 minutes and after half an hour it fell by 45 cm.

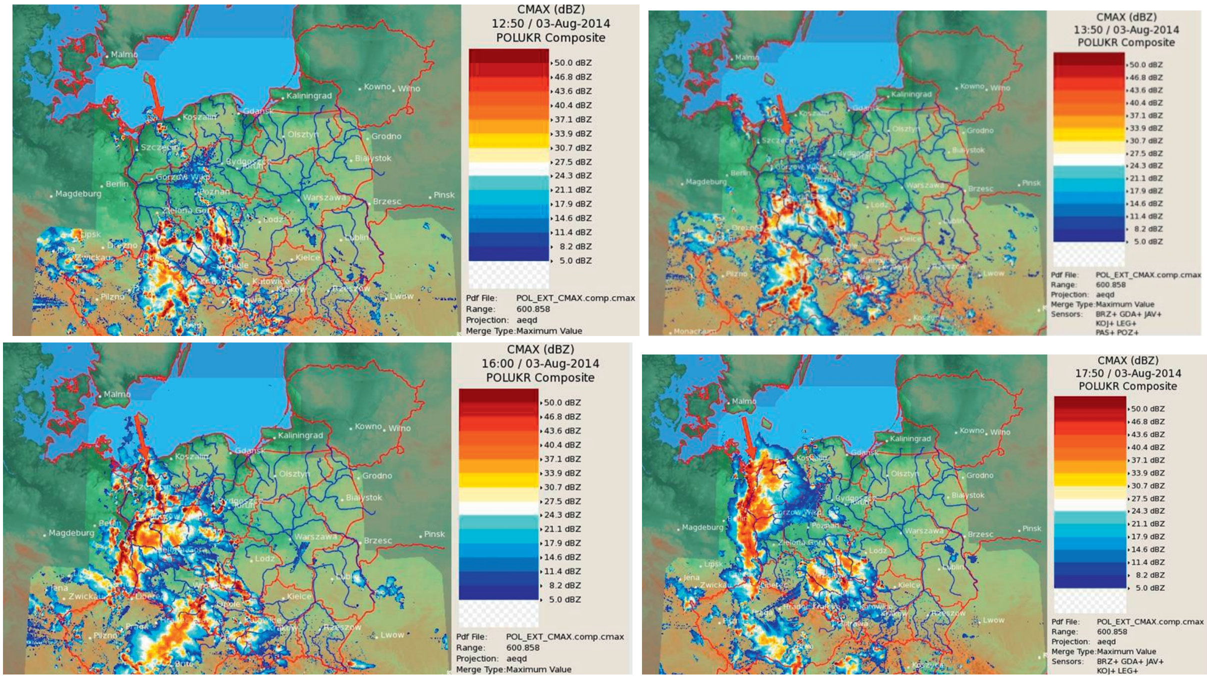


Fig. 5: Radar images showing the movement of the convergence zone. Source: IMGW

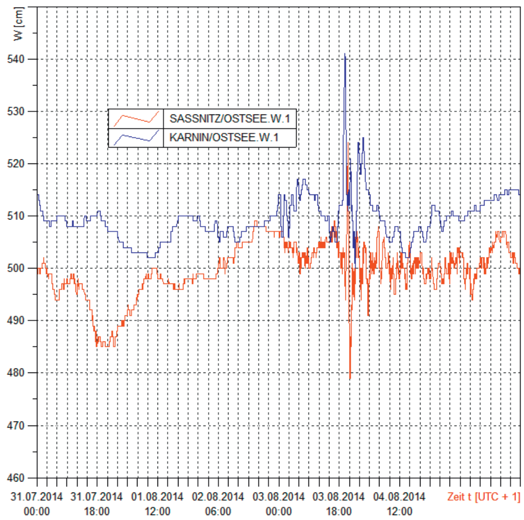
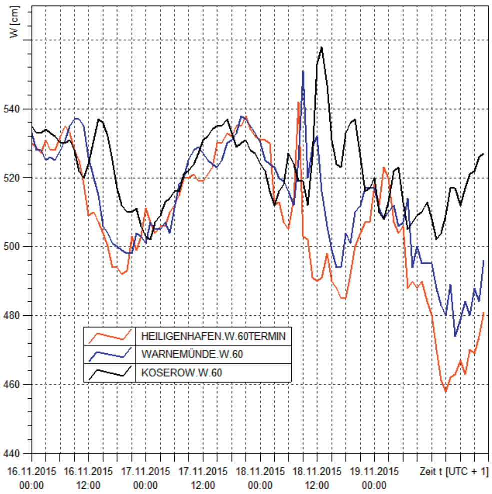


Fig. 6: Water level from 31st July – 4th August 2014 for the gauges Sassnitz and Karnin

3.3 Example for a typical winter meteotsunami

A typical winter meteotsunami was recorded on 18th November 2015, caused by the rapid passage of a small but strong deep (Figure 8). The crossing fronts in the area of our observation area produced strong, very fast wind increases and large drops in air pressure. On the Polish coast, pressure drops about 6 hPa were recorded in 3 hours and the wind increased rapidly to 9-10 Bft for 2-4 hours. The recorded water level in Figure 7 clearly shows the time sequence of a wave, which was not noticeable in the water level forecast models. Within 2.5 hours, the water level of the gauge Heiligenhafen rose at 4:25 pm from 4 cm to 42 cm above the mean sea level. An hour later, the water level fell again by 40 cm. At 6:00 clock the gauge in Warnemünde increased by 40 cm and fell again by 36 cm. 3 hours later, a wave in Koserow rose by 40 cm and dropped again by 36 cm.



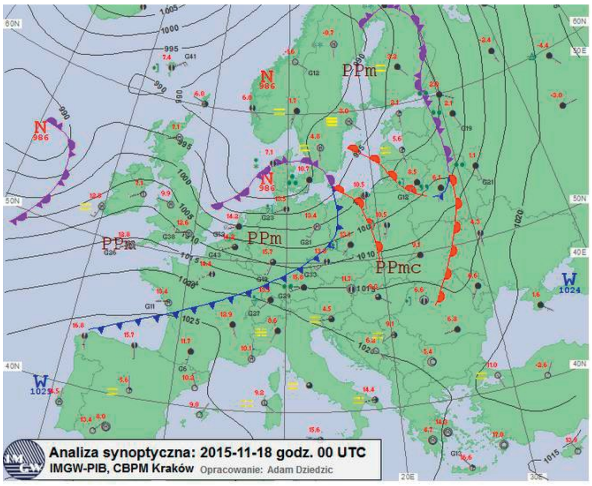


Fig. 7: Water level from 16th - 20th November 2015 for the gauges Heiligenhafen, Warnemünde and Koserow

Fig. 8: Synoptic analysis (a pressure pattern over Europe) from 00.00 UTC 18th November 2015 (IMGW-PIB, Cracow)

4. Physical interpretation and remarks

Meteotsunamis are mainly triggered by pressure fluctuations of small-scale atmospheric phenomena. The processes are thus interlinked in the atmosphere and the ocean, which is why this phenomenon is treated in conjunction with meteorology and oceanography (Etling, D., 2015). Precisely because of these small-scale phenomena, a prediction of the meteotunamis is very difficult. In the existing water level models at the BSH and the IMGW these short-term water level changes could not yet be displayed because they are dependent on the weather models of the responsible weather services and such a timely recalculation of the models is not yet possible. The path of the fronts, storm fronts and local wind fields are difficult to predict. Our approach is to subsequently reproduce the weather and water conditions of a meteotsunami using the detected meteotsunamis to filter out certain weather conditions where a great probability of a meteotsunami and to put them into the forecasting routine.

5. References

Cléa Denamiel, Jadranka Šepić, Damir Ivanković, Ivica Vilibić: The Adriatic Sea and Coast modelling suite: Evaluation of the meteotsunami forecast component, Ocean Modelling, Volume 135, 2019, Pages 71-93, ISSN 1463-5003

Credner, R.: Über den "Seebär" der westlichen Ostsee vom 16/17. Mai 1888. In: III Jahresbericht der geographischen Gesellschaft zu Greifswald 1886–1889, pp 57–96

Doss, B.:1907," Über ostbaltische Seebären", Beiträge zur Geophysik VIII. Band, 367-399

Defant, A: 1961 Physical oceanography, vol 2. Pergamon Press, Oxford

Etling, D.: Tsunami und Meteotsunami. In: Mitteilungen DMG 1/2015, S. 2-6

Hupfer, P.: 2010, "Die Ostsee - kleines Meer mit großen Problemen", Gebrüder Borntraeger, 115

Hupfer, P., Harff, J., Sterr, H., Stigge, H-J.: 2003, "Die Wasserstände an der Ostseeküste", Die Küste Heft 66, 181-185

Kühnen: "Das Mittelwasser der Ostsee bei Travemünde Marienleuchte Wismar Warnemünde Arkona Swinemünde Pillau Memel", Veröffentlichung des Königl. Preuszischen Geodätischen Institutes Nr.70, 207, 1916

Majewski, A.: 1989, "Ungewöhnliche kurzzeitige Anstiege des Meeres an den Süd- und Ostküsten der Ostsee", Übersetzung aus dem Polnischen. Przeglad Geofizyczny 34, 191-199

Monserrat, S., Vilibić, I., and Rabinovich, A. B.: Meteotsunamis: atmospherically induced destructive ocean waves in the tsunami frequency band, Nat. Hazards Earth Syst. Sci., 6, 1035-1051, https://doi.org/10.5194/nhess-6-1035-2006, 2006

Proudman, J.: The effects on the sea of changes in atmospheric pressure. Geophys. Suppl. Mon. Notices R. Astron. Soc. 2 (4), 197-209, 1929