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Identification of climate related hazards at the Baltic Sea area

Keywords

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Abstract

The article is created to identify the climate related hazards at the Baltic Sea area and their extreme event parameters exposure for maritime ferry analysis. As a result, there are distinguished possible natural hazards coming from climate/weather change: strong winds, sea water level, precipitation, ice, fog, large waves, water temperature and air temperature.

1. Introduction

Critical infrastructures, which refer to transportation systems, are very susceptible to all sorts of hazards and threats. The impact of hazards related to climate and weather conditions changes on the operation of critical infrastructures is significant. The aim of this article is to identify possible climate hazards that occur in the Baltic Sea area (i.e sea water level in the coasts of the Baltic Sea, precipitation, ice conditions, fog formation, large waves and winds, water and air temperature).

2. Identification of climate related hazards at the Baltic Sea area

The climate-weather change influence on the Baltic port critical infrastructure network is presented in [6]. The climate of the Baltic Sea basin is characterized by large seasonal contrasts, owing to its geographical location, variable topography, and land-sea contrasts. It is influenced by air pressure systems, particularly the North Atlantic Oscillation during wintertime, which affects the atmospheric circulation and precipitation in the Baltic Sea basin [7].

The following major hazards affecting critical infrastructures at the Baltic Sea area are distinguished below.

<u>Sea water level in the coasts of the Baltic Sea</u> [2]-[3]
In contrast to tide-dominated basins, extreme sea levels in the Baltic Sea are mainly due to wind, which affect sea level in two main ways. First, they may build up a sea level slope within the sea, resulting in the strongest deviations at the ends of the Baltic Sea. Second, water can be transported into or out of the Baltic Sea (which result in raising or lowering sea level in the basin). However, the amplitude of such events is normally less than 50cm. All over the sea, both extreme high and low sea level events tend to occur in the meteorologically more variable winter months.
In Kronstadt, Russia, there is a tide-gauge (also known as mareograph), which measures the change in water sea level relative to a datum. The Kronstadt sea-gauge with the pavilion is the zero level of the Baltic system of depths and heights. The reference system Kronstadt 86 operate on the basis of the regulations from the year 2012. According to its measurements, it is possible to derive the mean water level maximal amplitude in the Baltic Sea illustrated in *Figure 1*.

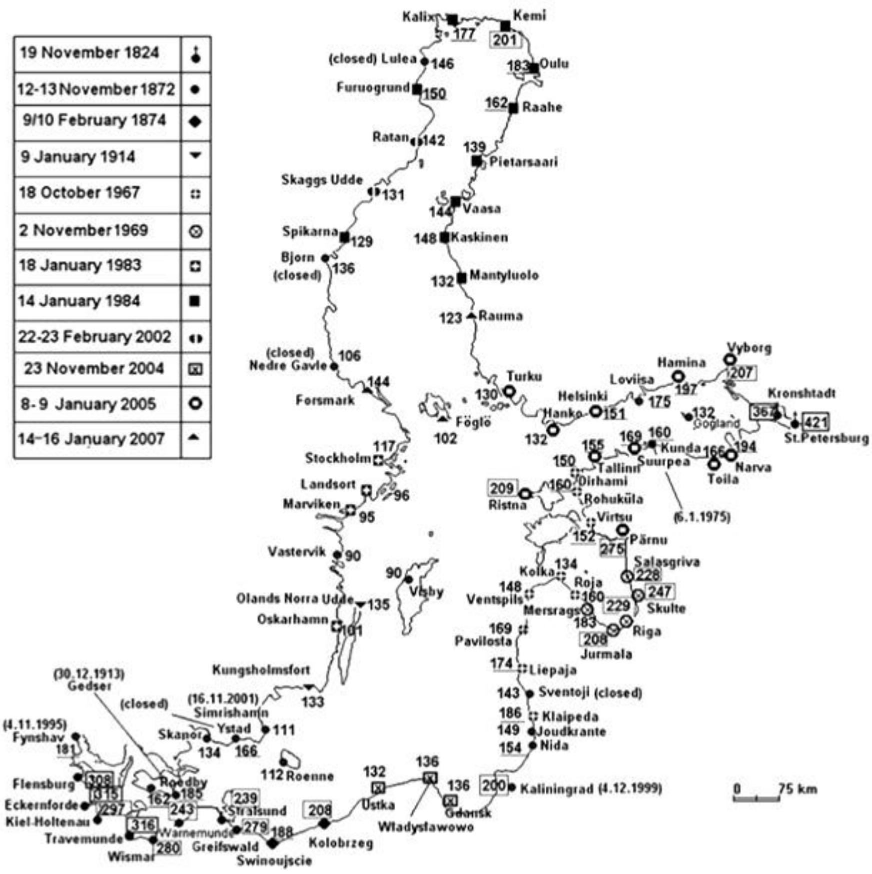

Figure 1. Historical water level maximal amplitude (cm) in the Baltic Sea.

<u>Precipitation</u> [6], [10]

In the 30 years considered annual amount of precipitation was greatest in the extreme southwest of the area and reached 927 mm at Schleswig. These amounts decreased sharply towards the Belts and the Sound, being as low as 473 mm at Rosnaes or 490 mm at Falsterbo. On the southern coast precipitation amount increased when moving east. Stations in the western part of the subregion, from Boltenhagen to Kołobrzeg, experienced predominantly less than 600 mm of precipitation. Further east, starting with Koszalin, sums were much higher, over 700 mm at those places lying more inland (Kaliningrad - 791 mm). The eastern coast is precipitation-rich area with annual totals between 600-700 mm. Moving northwards along the coast of the Gulf of Bothnia annual sums of precipitation declined to a minimum of 433 mm at Oulu. Of all stations located in the Gulf, only two, Turku and Soderhamn, had annual precipitation amounts exceeding 600 mm. All the area of the open sea characterised by the data from the islands, was poor in precipitation with annual totals lower than or close to 500 mm with the smallest values at Ólands Sodra Udde (431 mm) and Landsort (433 mm). It is noteworthy that the stations on the western coast of the central Baltic received much less rainfall than those located on the eastern coast, probably due to the leeward effect of the Scandinavian Mountains.

Annual distribution of monthly values was of approximately uniform character: the highest monthly sums occurred in summer with a secondary maximum in late autumn. On the southern coast the maximum was usually recorded in July, whilst it was August on the eastern and northern coasts. On the islands in the open sea highest monthly precipitation occurred in September. In some areas the secondary maximum in autumn (November) could become the main one (e.g. the eastern coast from Klajpeda to Ventspils, south-eastern coast of Sweden and further south, including Bornholm, some places in the Belts and the coast around Schleswig).

Minimum monthly precipitation in February prevailed; however, it occurred in March or April in a few places, especially in the far north (April) and at some island stations in the central Baltic Sea.

The distribution of the monthly totals is reflected in the seasonal characteristics. The ratio of seasonal precipitation amount to annual precipitation amount computed for the whole Baltic region reveals that almost two-thirds of the total precipitation was recorded in summer and autumn (30% and 31%, respectively). The driest season seemed to be winter with 18% of annual precipitation.

In summer the ratio computed for particular stations was greatest on the southern coast, in the southern and eastern part of the Gulf of Finland, along the eastern coast of the Gulf of Bothnia as well as on the inland stations in Sweden (Stockholm, Norrkoping). On the islands in the central part of the region this ratio did not exceed 28%. In autumn the maximum seasonal portion of precipitation was recorded in the Kattegat, at majority of the stations along the eastern and northern coast and over the open sea. As in autumn, islands in the central part of the Baltic recorded high value of the ratio also in winter Only 15 to 23% of the annual precipitation fell in spring, the highest portions in the south-western areas, the smallest portions (15-17%) on the coast from Kaliningrad to Haparaada.

Days with precipitation > 0.1 mm were most frequent from November to January when cyclonic circulation and invasions of moist air prevailed. The greatest number of such days exceeding 20 was recorded at Schleswig (21 days per month from November to January) and along the eastern coast as far north as Kemi, where 24 days with precipitation were observed in January. South of Haparanda, along the Swedish coast maximum monthly number of days with precipitation > 0.1 mm decreased so that it did not exceed 18 days per month on the central islands. Over the course of the year the frequency of precipitation days was lowest in May and June when 11-14 days with fall were recorded at the coastal stations and 8-9 days on the majority of the islands.

The ratio of seasonal number of days with precipitation to their annual sum was highest in winter and autumn, with values for the whole region of 29% and 28%, respectively. Low number of days with fall was encountered in spring when precipitation was recorded only on one out of five days (21 %). Taking into account ratio values for individual stations, it appears that they did not differ significantly from each other within successive seasons as differences did not exceed 4% in spring and 7% in winter.

The precipitation in the Baltic Sea region varies between seasons and regions. The mean annual precipitation equals 750 mm/year for the entire Baltic Sea basin (including both land area and sea area). The largest precipitation amounts occur in Scandinavia and some Poland regions, while the lowest amounts occur in the northern and northeastern part of the basin as well as over the central Baltic Sea. Mean monthly precipitation is the highest during July and August, with up to 80 mm in August, and lowest from February to April, with less than 45 mm on average.

Ice conditions [6]-[7]

Both, the salinity and the air temperature have influence on the Baltic Sea annual ice occurrence. The ice impairs shipping as well as has influence on marine wildlife. The ice cover during normal and mild winters occupies 15-50% of the sea area in the north-eastern part of the basin, but may be extended to the entire sea during infrequent severe winters. In general the Bothnian Bay is ice-covered every winter, while the Baltic Proper is usually ice-free. The latest winters with the Baltic Sea totally frozen were in 1941/1942 and probably also in 1946/1947. The maximum ice coverage is typically reached in February or March, but sometimes already in January, and finally sea ice remains in the Bothnian Sea usually until mild-May. In the Bothnian Bay, the ice thickness is commonly 65-80 cm, while 10-50 cm in coastal areas of Poland and Germany.

Figure 2 illustrates the annual maximum ice extent in the Baltic Sea. In extremely mild winters, the maximum ice extent is at least the area marked by the lightest blue and at most that plus the area marked by the next-lightest blue. The maximum ice extent in mild, average, severe, and extremely severe winters is marked analogously, with darker colours for the more severe ice winters.

Figure 2. Annual maximum ice extent in the Baltic Sea area.

Fog formation [1], [4], [10]-[11]

The south-western part of the Baltic Sea is relatively mild, although there can be very unsettled periods with strong winds and rough sea. Fog is a very local phenomenon, not very frequent over the open sea but is most common in winter and spring in narrow channels and inlets. Visibility is often good and exceptional visibility occurs with northern or northwestern winds. Over the open sea the lowest frequency of fog is in the summer with less than 2% of occasions. Fog over the open sea is most frequent encountered in the spring, in April and May, while the water is still cold but the air temperature is rising. In March and April, fog frequencies are around 25% near the Southeast of Sweden and near the South of Gotland and 10% elsewhere. During July and August the frequencies are around 10% and 2% respectively. The frequency steadily increases throughout the autumn to reach a maximum in winter and spring of between 6% and 10% and with the highest incidence in the south of the area. Winter fogs are often the results of radiation fog which forms over cold inland areas at night and then drifts out to the sea.

All visibilities less than 1 km were counted as fog, disregarding the reason of origin of this low visibility. In winter, snowfall sometimes is the reason for bad visibility, in summer heavy showers occasionally may reduce the visibility to less than 1000 meters.

The main centre of fog occurrence is found over the Danish Isles, minor ones over the northern and central parts of the Bothnian Bay and in the Gulf of Finland. Minimum fog frequencies are observed along the Swedish coast and north of Gotland. Generally, the months of March and April present the maximum, August the minimum fog frequencies within the seasonal cycle. But there are regional differences: the Danish maximum has its greatest strength during February and its least occurrence (nearly zero) in July; in the northern part of the Bothnian Bay the respective months are April and November/December. Within the central parts of the Baltic Sea (south of Gotland), the yearly cycle is much weaker with maximum values in April, minimum ones in August.

<u>Large waves and winds</u> [6], [9]-[10]

The Baltic Sea region is dominated by south-west winds. Highest wind speeds occur in the central open Baltic Sea with a maximum east of the island of Rùgen. Also high wind speeds are found in Skagerrak and Kattegat. Lower mean wind speeds are found near the coastlines, between the Danish and Estonian isles and at the end of the Finnish and Bothnian Bay.

November is the month with the highest wind speeds, May presents the lowest ones. For the central Baltic Sea, the yearly cycle of wind speed ranges from 11 to 19 knots. Normally, southwesterly winds prevail during winter and westerlies during summer. But there are some exceptions: in February southerly winds prevail many sea areas but they are relatively unstable: there are more periods with easterly wind than in other winter months. Those easterlies dominate in some sea areas, especially near the Swedish coast.

The two spring months April and May show relatively weak and unstable winds, in May the northerly and easterly directions dominate over great parts of the Baltic Sea.

The centres of maximum strong breeze and storm frequency are found east of the island of Rugen south of the island of Bornholm. Here, the percentage of strong winds is more than two times, the amount of storms more than three times higher than near most parts of the coast. This windy region is similar to the Skagerrak.

Compared with the North Sea, frequencies of strong winds are similar, but storm frequencies are lower: averaged over the whole Baltic Sea and for the year, storm frequencies amount to about 2% compared with 4-5% in the southern North Sea and 5 to 6.5 % in the central and northern parts of the North Sea.

November is the month with most strong breezes and storms, May is the quietest one. *Table 1* shows the yearly cycle of strong winds without storms (11-16 m/s) and of storms (> 17 m/s) for the "Baltic storm centre" south of Bornholm.

Table 1. Frequency (percent) of strong winds (11-16 m/s) and storms (≥17m/s) for the "Baltic storm centre" (about 54.5°N, 15°E).

Month	I	II	III	IV	V	VI	VII
strong wind	22	19	21	14	12	12	16
storm	3.8	2.8	2.7	1.8	0.7	1.3	1.6

Month	VIII	IX	X	XI	XII	**Year**
strong wind	17	23	30	32	31	**20.7**
storm	2.5	4.5	7.8	8.7	7.4	**3.8**

There is a strong increase of strong wind and storm frequency between August and October and a marked decrease between December and January, another one between March and April. During March, the centre of strong wind and storm activity shifts to the western Baltic Sea, during August and September it extends from the area east of Rugen to the central Baltic Sea.

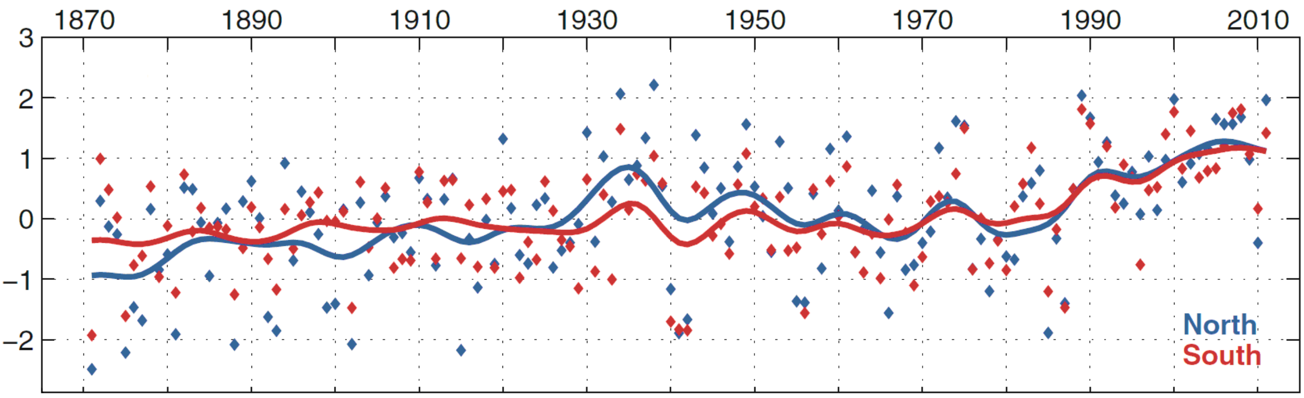

Figure 3. The annual mean surface air temperature anomalies for the Baltic Sea Basin from 1871 to 2011.

In the long term average, maximum wave heights are observed in November or December, the minimum occurs in May or June. Relatively high waves are found in the central Baltic Sea, while enclosed or semi-enclosed areas (Fehmarn Belt) show lower ones.

In most areas, waves generally approach from southwesterly directions. During summer, there is a veering to more westerly or even northwesterly directions. During spring (April, May) the wind and also the wave direction are very unstable and therefore different directions may occur even for adjacent areas. In most parts of the Baltic Sea, low waves (0,0 - 0,75 m) dominant throughout the year: in some central open areas moderate waves (0,75 - 1,75 m) are more frequent than low ones. Wave ranges of 3,25 - 4,75 m are relatively rare and occur mostly in winter. In the central Baltic Sea waves may reach heights of about 8 meters, in very rare occasions event 10 meters.

The Baltic is the stormy sea (in average 3□B/year) and waves are short and steep. The highest waves are about 10 meters but typically they reach about 5 meters. Prevailing winds come from west, thus air pollutants are usually transported from west to east. On the other hand the Baltic surface water constantly and anti-clockwise circulates thus, the marine pollutants from the south can pass the east and the north coastal areas to return to the south. Moreover winds blowing at the speed of 15 m/s are strong enough to disrupt ferry and other ships, bring down electricity cables and other structural damages as well as whip up large waves at the coast to cause localized flooding.

<u>Water and air temperature</u> [6], [8], [10]

Temperatures of the Baltic water ranges from -0.5 to +20°C. Moreover, the bottom water temperature is constant independently of the season (about 2-4°C) whereas the wind-mixed surface water temperature is variable according to the season. Thus, the layer between the seasonally changes of water temperature and deeper water with constant temperature at water depth of about 20-70 m (called thermocline) is observed.

Throughout the year, the highest temperatures of the Baltic Sea are found over the southern waters, between the Danish Isles and over the Kattegat and Skagerrak. The coldest part is the northernmost tip of the Bothnian Bay. Generally, the coasts and the continents are colder than the sea. This is normal for the climate north of latitude of 40°N.

Especially during autumn and winter, temperatures over the continents are much lower than over the sea (October to February). During March and August they are similar on land and at sea; in spring and early summer (April - July) the adjacent land is warmer than the sea, especially in May. During this month, temperatures at sea are lower than in October. February is the coldest, and July to mid-August the warmest time of the year.

The climate around the Baltic Sea is different in the north and south because of long north-south extension (about 3000 km) of the basin. The mean annual air temperature is 0°C in the north, whereas it is 8° - 12°C in the south. The surface air temperature has increased since 1871. The changes of temperature are resulting in changes in the season: the length of the warm season has increased, while the length of the cold season has decreased. In the *Figure 3*, , the annual mean surface air temperature anomalies (compared to the 1960-1991 period) for the Baltic Sea Basin from 1871 to2011, calculated from 5° by 5° latitude, longitude box average taken from the CRUTEM3v dataset [5] based on land stations. The blue colour relates to the Baltic Sea Basin to the north of 60°N and red colour to the south of that latitude. The dots represent individual years, and the smoothed curves highlight variability on time scales longer than ten years.

According to the detailed analysis considered in this article and in [6], climate change might have various impacts on port operations and infrastructure, especially on those located in vulnerable to sea level rise and storm surges areas. Baltic Sea critical infrastructures can be affected by climate change also in various other ways, such as rising temperatures or changing precipitation and storm patterns. Large spatial and/or temporal variations of temperature, manifested through frequent freeze and thaw cycles during winter time or heat waves during summer, may damage infrastructure, equipment and cargo. Climate change can result in more extreme events at many seaports and might impact their operations causing interruptions and bottlenecks in the flow of products through ports. Climate changes, such as decreasing sea ice cover and rising sea level, affect ports depending on their geographic location, type and adaptive capacities.

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