The ice winter of 2016/17 on the German North and Baltic Sea coasts with a brief description of ice conditions in the entire Baltic Sea region

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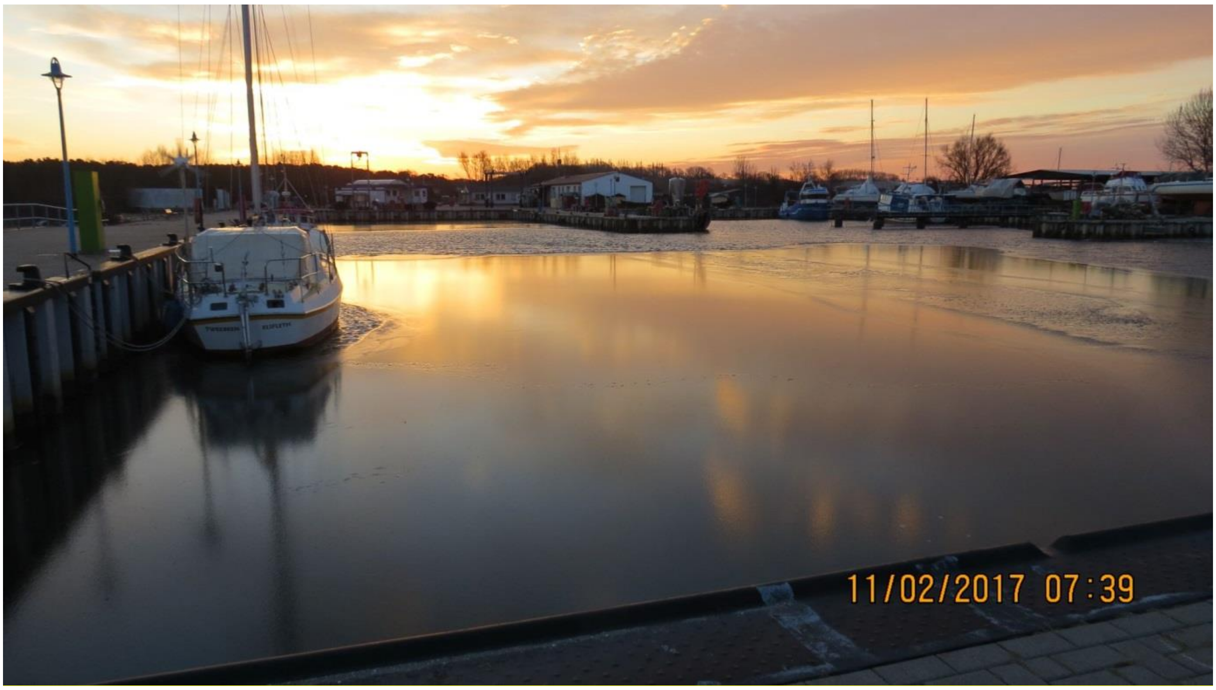
Content

New-ice cover in the port of Thiessow (Bay of Greifswald) on 11.02.2017 Courtesy of Frank Sakuth



Progression of the ice winter on the German North and Baltic Sea coasts

Weather conditions on the German coastal areas

In the winter 2016/2017, November was comparatively cold at the German coasts. Locally, temperatures dropped down to or slightly below the freezing point in the mid of the month. With monthly averages between 4°C and 6°C, air temperatures were well below the values for the usually used reference period 1961 – 1990 (Ch. Lefebvre, 2013) and even a bit lower for the current reference period (1981-2010, see reference periods in Tab. 1). In December air temperatures were, on the contrary, up to 2-3°C higher than the reference values (Tab. 2). The seasonal cooling of the air proceeded very slowly in December. Although light frost occurred occasionally, temperatures rose also up to 10°C. Northern Germany was influenced predominantly by high pressure systems by that time; mostly westerly to north-westerly winds transported mild air masses into the coastal regions. In the beginning of January, north-easterly winds brought a frost period - parallel to the big storm surges in the North and Baltic Seas - which lasted for few days. Afterwards the weather situation was unstable for the rest of the month with occasionally occurring frost periods (see Fig. 1).

Table 1: Climatological mean of air temperatures (°C) in winter months on the German Baltic cost for the period 1961-1990 (P1) and 1981-2010 (P2) exemplarily for Greifswald, Rostock-Warnemünde, Schleswig and Norderney (Data source: Deutscher Wetterdienst, www.dwd.de).

Station	November		December		January		February		March	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Greifswald	4,6	4,7	1,1	1,5	-0,6	0,7	0,0	1,1	2,7	3,7
Rostock-Warnemünde	5,3	5,5	1,9	2,3	0,2	1,4	0,7	1,7	3,1	4,1
Schleswig	4,9	5,0	1,7	2,0	0,3	1,3	0,6	1,4	2,8	3,7
Norderney	6,3	6,6	3,2	3,5	1,6	2,6	1,8	2,6	4,0	4,9

Table 2: Monthly mean air temperatures (°C) and their deviations from the reference period P2 (1981 – 2010) in °C for the winter 2016/2017 (Data source: Deutscher Wetterdienst, www.dwd.de).

Station	November		December		January		February		March	
	T_{air}	ΔT_{air}	T_{air}	ΔT_{air}	T_{air}	ΔT_{air}	T_{air}	ΔT_{air}	T_{air}	ΔT_{air}
Greifswald	4,0	-0,7	3,8	2,3	-0,2	-0,9	1,7	0,6	6,3	2,6
Rostock-Warnemünde	5,0	-0,5	4,8	2,5	1,1	-0,3	2,3	0,6	6,3	2,2
Schleswig	4,0	-1,0	4,7	2,7	1,1	-0,2	2,5	1,1	6,1	2,4
Norderney	5,8	-0,8	5,5	2,0	2,3	-0,3	3,1	1,3	7,2	2,3

In total, January was nevertheless a bit colder than normal. The first persistent frost period occurred only in February when the wind changed to easterly directions. Although February was warmer than normal, daily averaged air temperatures dropped below the freezing point permanently between the 7th and 14th of February. On the 15th of February the wind changed to westerly directions and the air became milder again. Afterwards, temperatures stayed above the freezing point for the rest of the season.

Summarized, the winter of 2016/2017 consisted of one weak cold period from the beginning of January up to mid-February. Temperatures were not permanently below the freezing point during this period but varied around 0°C by few degree Celsius. The lowest values of the daily averaged temperatures lay between -3°C at the North Sea and up to -10°C at the German Baltic Sea (Fig. 2).

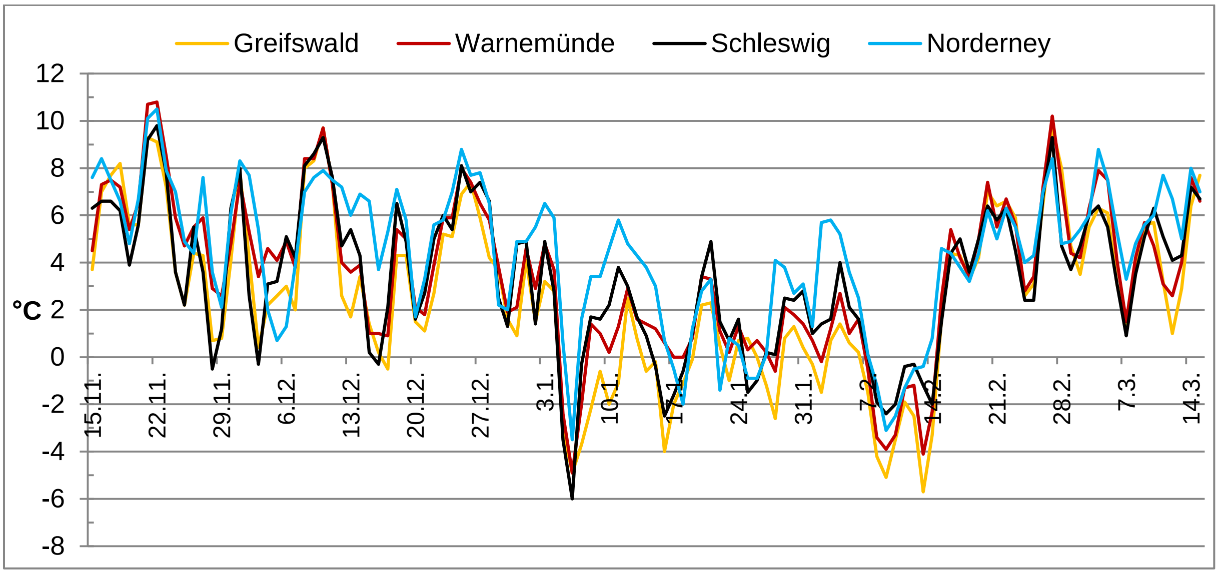


Figure 1: Daily averages of air temperatures in the winter 2016/17 (Data source: Deutscher Wetter-dienst, www.dwd.de/) exemplarily for Greifswald, Rostock-Warnemünde, Schleswig und Norderney.

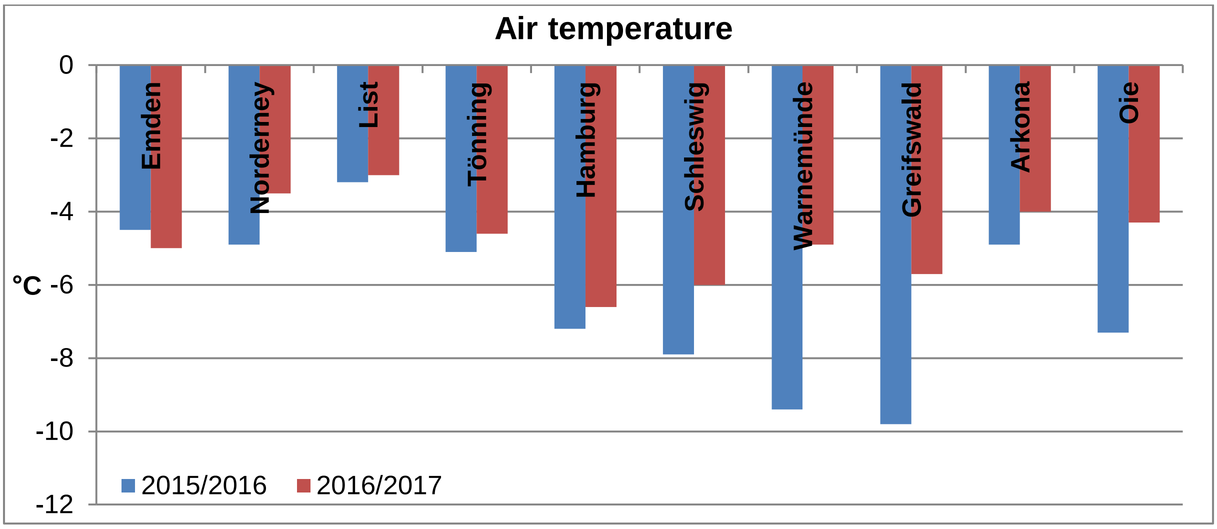


Figure 2: Lowest air temperatures along the German coasts, from the west to the east.

Water temperatures dropped below the freezing point in the beginning of January in the inner waters of the German Baltic Sea coast except for the Schlei, where ice growth could already be observed mid-November for a few days. At the outer coastal part of the North and Baltic Seas, temperatures stayed above 0°C over the entire winter (see Fig. 3).

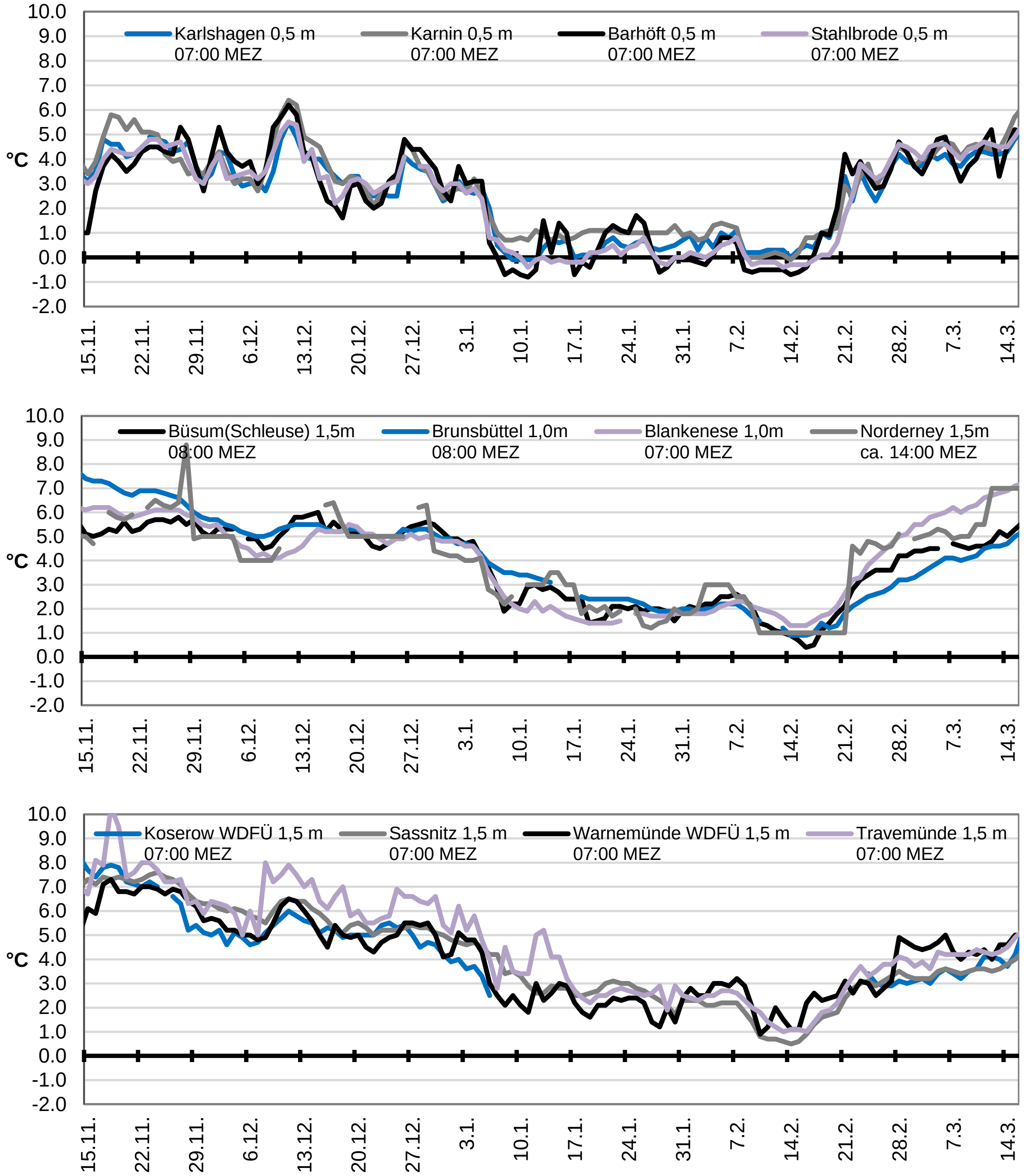


Figure 3: Water temperatures of the German coastal waters. Data sources: Karlshagen, Karnin, Barhöft, Stahlbrode, Koserow, Sassnitz and Warnemünde – WSA Stralsund; Travemünde – WSA Lübeck; Büsum – Schleuse Büsum; Blankenese - Institut für Hygiene und Umwelt; Norderney – Deutscher Wetterdienst; Brunsbüttel – WSA Brunsbüttel.

Ice conditions on the German North and Baltic Sea coasts

The ice winter of 2016/17 consisted of three ice periods at the German North Sea coast: the first ice occurred in the beginning of January. Afterwards, there was a short ice period in mid-January and a further one in February. At the German Baltic Sea coast, ice growth took place for three times between mid-November and beginning of December, but only for few days in each period. In the beginning of January, a permanent ice cover formed regionally between 5th of January and 24th of February. The evolution of the ice winter 2016/2017 is shown in Figure A1 in the appendix. Table A1 and A2 of the appendix summarize the most important ice parameters for the season.

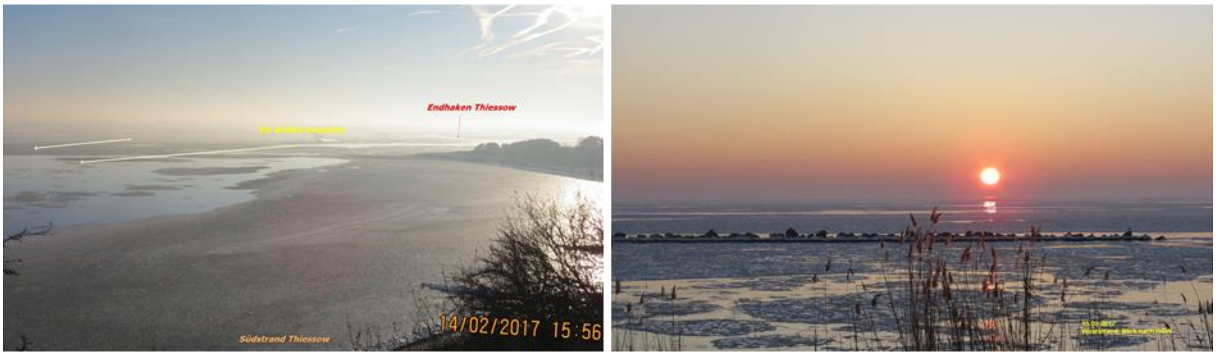


Figure 4: Ice conditions in Thiessow at the time of maximum ice extent on the German Baltic Sea coast. Courtesy of Frank Sakuth.

The initial ice formation started on the 12th November on the river Schlei. In fact, this was the earliest seasonal ice formation since 1984, when the first ice was discovered in Warthe on the 1st of November. The former earliest ice formation on the river Schlei took place on the 17th November 1993.

At the North Sea, ice had initially formed in Emden on the 3rd January and in Tönning on the 5th January. In Tönning ice could be found temporarily until the 16th February. At the Baltic Sea, ice persisted locally until the 24th February. At the time of the maximum ice development, which was the 16th February 2017 (Fig. 5), the North Sea was already ice free. Ice thicknesses reached values of 5 to 10 cm at the North Sea and up to 30 cm at the German Baltic Sea coast. On the river Schlei, predominantly very open up to 10 cm thick ice or open water occurred and in the Bay of Wismar, thin new ice has formed in the harbour for a short time. Further east, the river Warnow was covered by new ice and the bays of the Zingst-Darßer Bodden Chain and those around Rügen up to the Szczecin Lagoon were partly covered by very close ice and fast ice. Ice thicknesses varied between less than 5 cm in the areas where only little new ice had formed up to 30 cm in sheltered areas where ice had already formed in the beginning of January.

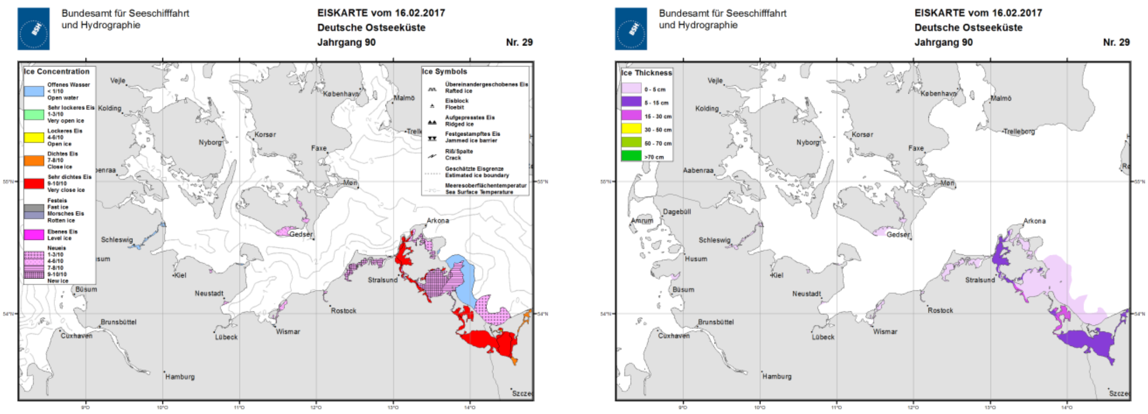


Figure 5: Sea ice extent and sea ice thickness in the German waters off the North and Baltic Sea coasts at the time of maximum ice formation (16th February) in the ice winter 2016/17.

Mid-February, mild air masses where transported in the coastal regions by westerly wind and initiated the ice retreat for that winter. The number of days with ice varied in the ice winter 2016/17 again significantly (see Tab. A1 and A2): In the sheltered areas of the Bay of Greifswald and the Szczecin Lagoon ice was present on up to 48 days and also in the Zingst-Darßer Bodden chain ice persisted up to 37 days. In the sea area next to Thiessow ice was observed for 8 days. In the Bay of Wismar, only the harbours of Wismar and Neustadt were covered by thin new ice for 13 and 10 days, respectively. For one day, ice drifted also into the sea area off Neustadt. Although the first ice on the river Schlei had already formed mid-November, ice occurred only on 29 days between Schleswig and Kappeln. Between Kappeln and Schleimünde, ice was observed on two days. Further west, on the river Elbe, no ice had formed in the winter of 2016/2017 but on the river Weser new ice formed locally on two days. The river Ems was covered by new ice for 13 days in the inner harbour of Emden and for 11 days in its outer harbour. The sea area off the German coast stayed ice free during the winter 2016/2017.

Navigational conditions on the German Baltic Sea coast

At the German North Sea coast, ship traffic was barely affected by sea ice in the winter 2016/2017. In the western inner fairways at the German Baltic Sea coast, the southern Peenestrom, the Achterwasser and the Kleine Haff were closed for ship traffic due to sea ice occurrence from the 7^{th} to the 24^{th} of February 2017. On the 14^{th} February 2017, navigation was additionally prohibited during night for the northern ship route to Stralsund (including the Bodden waters west), for the eastern ship route to Stralsund from the buoy „Landtief B" up to the ports of the Greifswalder Bodden and Stralsund as well as for the northern Peenestrom (WSA Stralsund, 2017). This prohibition persisted through the 28^{th} February 2017.

Figure 6: Tow near the Südperd in the Bay of Greifswald on 6^{th} February. The Bay was not covered completely by ice at this time. . Courtesy of Frank Sakuth

Ice winter intensity

The ice winter 2016/17 was a weak one for both the North Sea and the Baltic Sea – the 5^{th} weak winter in succession. The indices for the ice winter strength are calculated out of observational data from the 13 climatological stations at the Baltic Sea coast and the 13 climatological stations at the North Sea coast and are expressed in terms of the reduced ice sum, or as the accumulated areal ice volume ($V_{A\Sigma}$), respectively. An explanation of the terminology is available on
http://www.bsh.de/de/Meeresdaten/Beobachtungen/Eis/Kuesten.jsp. The calculated indices for the ice winter 2016/17 are summarized in Table 3. For the Baltic Sea, the ice winter strength was also calculated for the coasts of Mecklenburg-West Pomerania and Schleswig-Holstein separately. Like it is common, the ice production at the coast of Mecklenburg-West

Pomerania was stronger than the production at the coast of Schleswig-Holstein, which can be explained by the stronger impact of the continental climate in Mecklenburg-Western-Pomerania. But also the general icier Mecklenburg-West Pomerania had an ice volume sum that indicates a weak winter for that region in 2016/2017.

Table 3: Reduced ice sum and accumulated areal ice volume at the German coasts in the winter of 2016/17.

Area	Reduced ice sum	Accumulated areal ice volume
North Sea coast	1.4	**0.04**
Baltic Sea Coast	6.4	**0.16**
Coast of Mecklenburg- West Pomerania	7.4	0.22
Coast of Schleswig-Holstein	5.2	0.09

Figure 7 shows the evolution of the ice formation by means of the daily areal sea ice volume for both German coastal areas and Figure 8 illustrates the respective daily accumulated areal ice volume over the climate stations. At the Baltic Sea coast, there were three short periods with ice formation between mid-November and beginning of December. Afterwards, weather conditions were too mild for any ice formation for some weeks. In the beginning of January, ice formed again, not only in the Baltic Sea but also at the North Sea coast. In the course of January, ice formation took place ever and anon, with some warmer phases without ice formation or even ice melt in between. In some parts, however, the ice coverage persisted up to mid-February. In the second half of February, the maximum ice volume sums of 0.04 m at the North Sea and 0.16 m in the Baltic Sea were reached. Afterwards, the ice melted within few days completely.

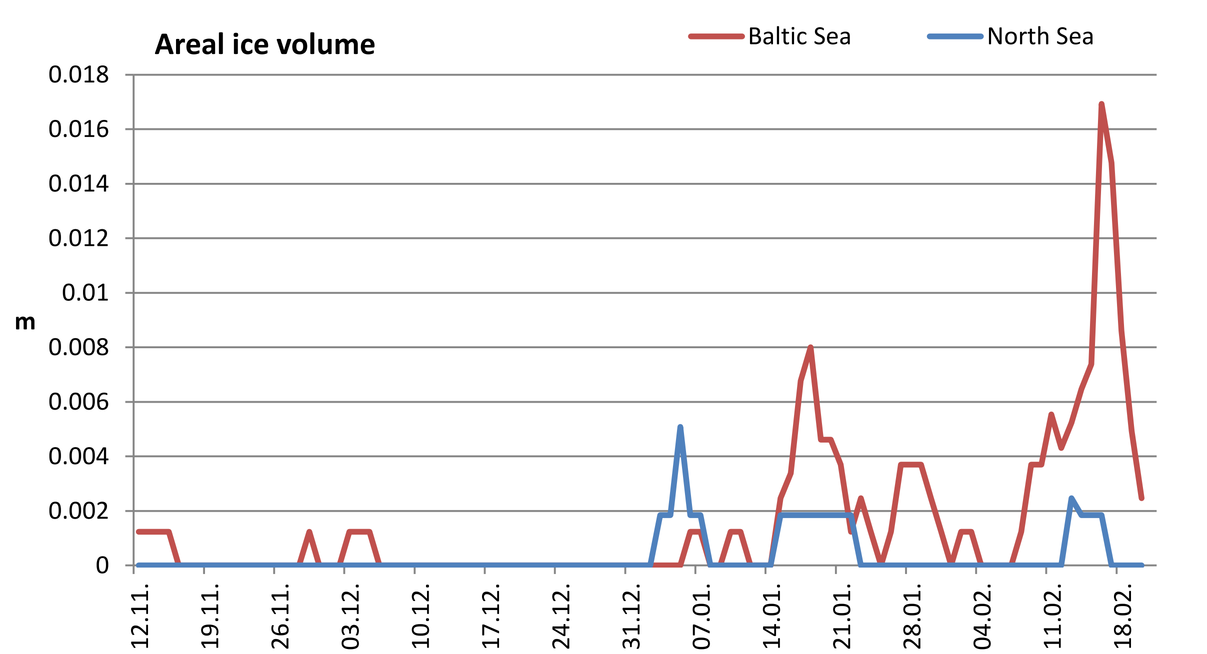


Figure 7: Areal ice volume at the German coasts in the winter of 2016/17.

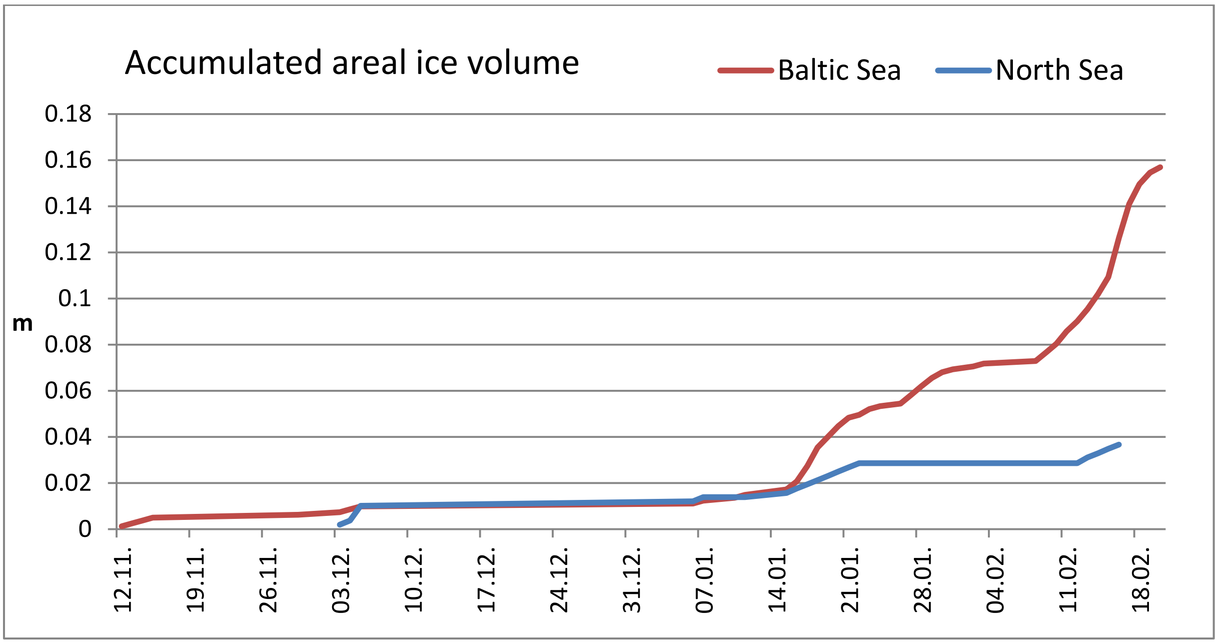


Figure 8: Accumulated areal ice volume at the German coasts in the winter of 2016/17.

The BSH reported on ice conditions and expected ice development in the entire Baltic Sea region and German coastal waters in the ice winter **2016/17** by the following reports and ice charts:

140 ice reports (official reports issued Mondays to Fridays),
32 German Ice Reports (international exchange, issued when ice forms in German fairways),
about 32 NAVTEX - reports (in German and English for the German North and Baltic Sea coasts),
32 ice reports “German Baltic Sea coast” (detailed description of ice situation for German users),
3 ice reports “German North Sea coast” (detailed description of ice situation for German users),
29 weekly reports (information for the BMVBW and the public),
29 general ice charts (once per week as reference for the entire Baltic Sea),
35 special ice charts (German Baltic Sea coast).

The current ice reports and ice charts of the BSH are available online and free of charge under http://www.bsh.de/de/Meeresdaten/Beobachtungen/Eis/1975.jsp. The archive with all ice charts issued so far is available at ftp://ftp.bsh.de/outgoing/Eisbericht/.

The strength of the ice winter 2016/2017 - compared to former years - is shown in Figure 9 and Figure 10. Since 1896/97 (121 Years) 29 winters have been less strong than the winter 2016/2017 at the German North Sea coast and 30 at the German Baltic Sea – hence ¼ of all winters were weaker or of the same strength than the ice season 2016/17. In total, the ice winter 2016/2017 was the 5th weak winter in a row. Considering the entire time series, there is a statistical significant trend[1] of -0.18 m per decade for the ice volume sum at the German North Sea, i.e. the ice volume sum is decrease with a certainty of 95%. For the period from 1961 to 2017, the decrease even amounts to 0.41 m per decade. This decrease was already visible in the comparison of the periods 1961-1990 and 1981-2010 within the climatological ice atlas of Schmelzer et al. (2015). Although this does not mean that we do not expect any strong ice winter again, the probability to get such a winter and the frequency of having those winters has decreased. In the Baltic Sea we have also observed a tendency to less strong

[1] The significance of the trend was tested with the double-sided t-test, as threshold the 95% quantile of the student’s t-distribution was used in dependence of the number of degrees of freedom (i.e. number of years).

winter strengths over the 121 years, but this decrease is statistically not significant, i.e. the interannual variability of the ice winter strength is still larger than the observed trend.

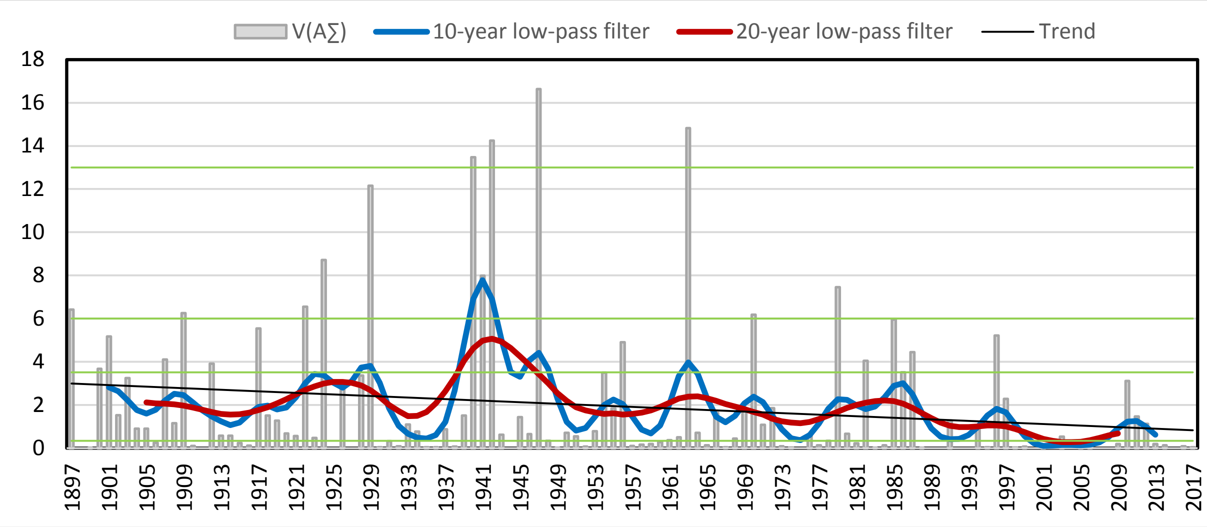


Figure 9: Distribution of the areal ice volume sum for the German North Sea coast with 10-year (blue) and 20-year (red) low-pass filter as well as the long-term trend (black).

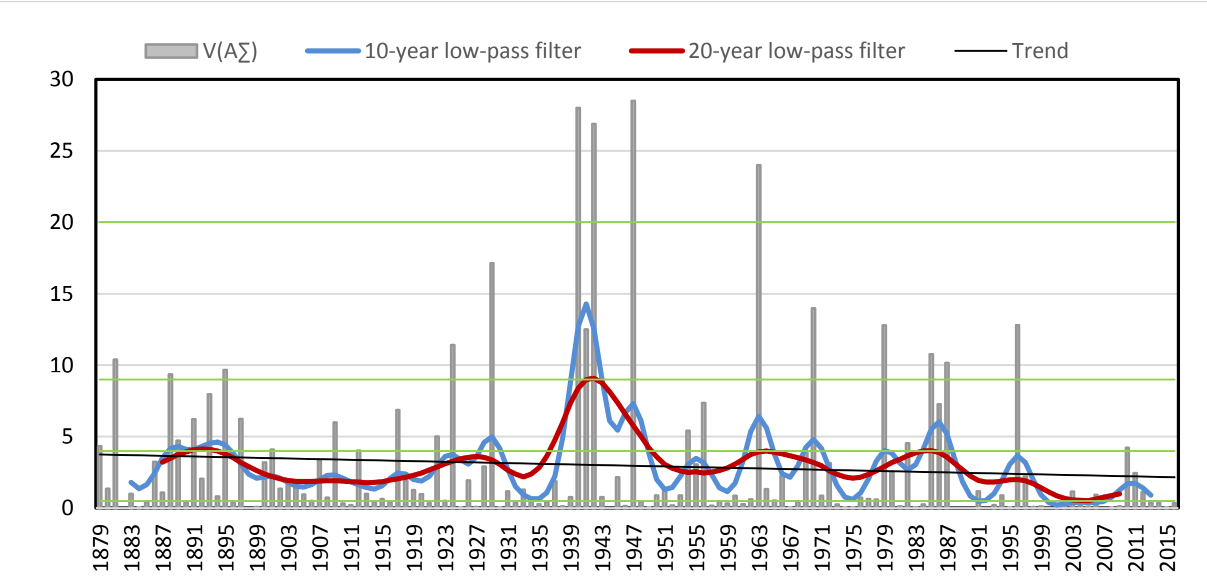


Figure 10: Distribution of the areal ice volume sum for the German Baltic Sea coast with 10-year (blue) and 20-year (red) low-pass filter as well as the long-term trend (black).

Ice conditions in the western and southern Baltic Sea

In the Danish waters of the western Baltic Sea, new ice formed for some days in smaller harbours and shallow and sheltered coastal sections between the 15th January and 22nd February. However, the major shipping was not affected.

In the southern Baltic Sea, the first pack ice occurred in the Curonian Lagoon on the 8th January followed by ice in the Vistula Lagoon on the 9th January and two days later also in the Szczecin Lagoon. In the Bay of Puck, ice formation started at the same time. The ice thicknesses reached 5-20 cm in the Szczecin Lagoon by mid-February and up to 25 cm in the Vistula Lagoon at the same time. Afterwards, ice melt started. On the 24th February, the Szczecin Lagoon and the Bay of Puck were virtually ice free, in the Curonian and the Vistula Lagoons there was regionally some ice up to the 15th March.

Ice conditions in the northern Baltic Sea (north of 56°N)

In the winter 2016/2017, ice formation started comparatively early in the Bay of Bothnia. In the week around the 8th November, the inner archipelagos along the Finnish Coast were already covered by new ice up to Vaasa. Until end of January, the ice formation proceeded slowly and was restricted to shallow waters. Afterwards, there was a quick increase in ice coverage up to mid-February, when the maximum ice extent was reached for that winter. According to the Finnish ice service, the maximum ice extent occurred on the 11th February with 88000 km^2. The Gulf of Bothnia was covered by ice up to 63°N by that time. Further south, ice occurred in places along the coast up to the south-western Baltic Sea. According to the ice charts of the German ice service, the maximum ice extent on the 11th February was 103714 km^2. Therefore, the ice winter 2016/2017 was a weak winter following the Finnish ice winter strength classification (Seinä und Palosuo, 1996).

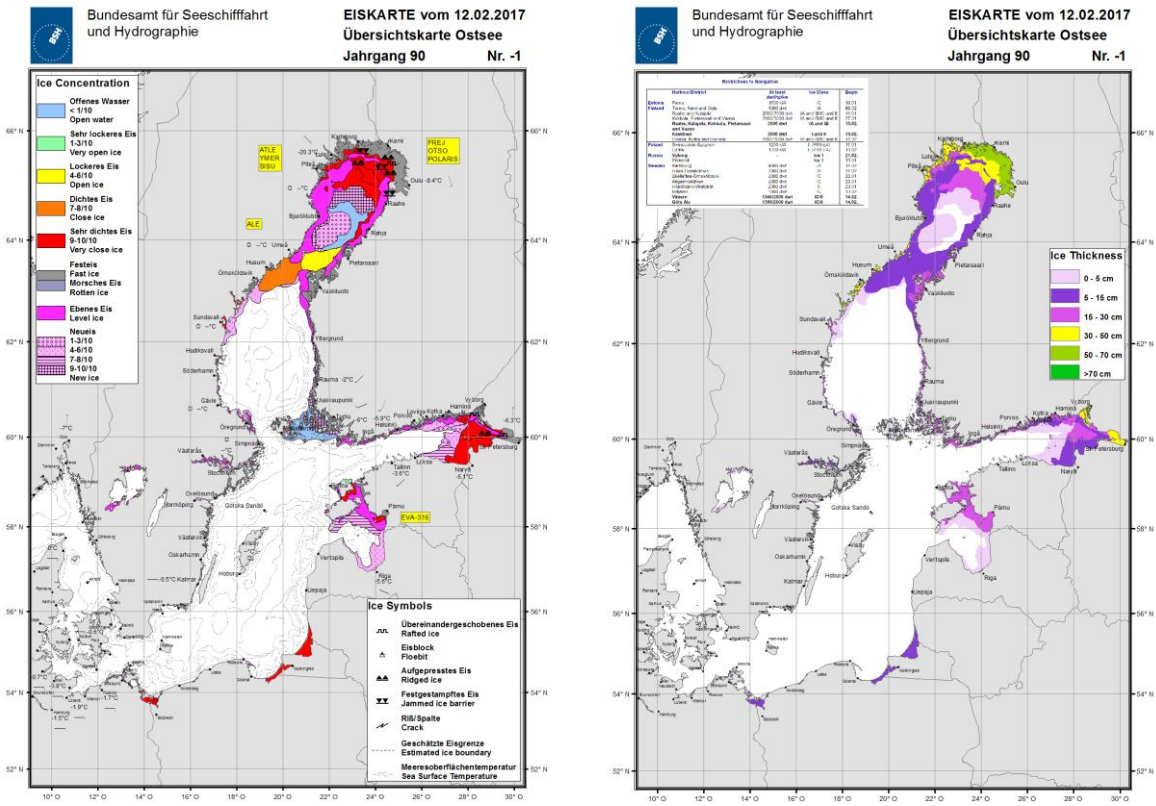


Figure 11: Ice chart for the entire Baltic Sea at the day of maximum sea ice extent in this winter (12. February 2017). Left: Ice coverage (coloured), form of the ice (symbol), temperature and wind at individual stations, water temperature and icebreaker operation for shipping assistance. Right: Ice thickness distribution and shipping restrictions.

While the ice extent was influenced by mild weather in the southern regions afterwards, so that the ice coverage decreased, ice in the Bay of Bothnia and in the Gulf of Finland still grew. In the second week of March, the entire Bay of Bothnia and the eastern part of the Gulf of Finland were covered by sea ice. The total ice coverage was close to the maximum in February with 83800 km^2, the ice volume reached its maximum for the season 2016/2017 with 16.4 km^3 around the 7th March. According to the ice volume, the winter was an extremely weak one. However, it is noticeable that the sea ice extent was about 20% lower in the winter 2016/2017 compared to the former winter but the sea ice volume was 17% higher in 2016/2017.
After the ice volume maximum in March, the sea ice disappeared only slowly. The last ice of the season situated in the Bay of Bothnia melted in the beginning of June 2017.

The maximum ice thicknesses varied between 45-80 cm for the northern fast ice, 30-60 cm for the pack ice in the Bay of Bothnia, 20-50 cm for the fast ice and 5-20 cm for the pack ice in the Gulf of Finland, and 10-30 cm for ice on the Gulf of Riga in the ice winter 2016/2017.

Although the winter is classified as a weak one ship traffic was affected. In the Gulfs of Bothnia, Finland and Riga restrictions regarding ice class, ship size and deadweight were announced and several icebreakers were deployed for shipping assistance. The Lake Saimaa and Saimaa Canal were closed for ship traffic from the 15th January up to the 29th April 2017. The traffic separation scheme in the Quark was out of use between the 18th February and the 31st March.

Maximum sea ice extent and maximum sea ice volume in the Baltic Sea

The Finnish ice service uses for the classification of the ice winter strength the reconstructed or the calculated data of the yearly maximum sea ice extent of the Baltic Sea (Seinä und Palosuo, 1996). The German ice service calculates the maximum yearly sea ice extent and the sea ice volume for the entire Baltic Sea based on the ice charts, which instead are based on information from satellite data as well as on ice observations.

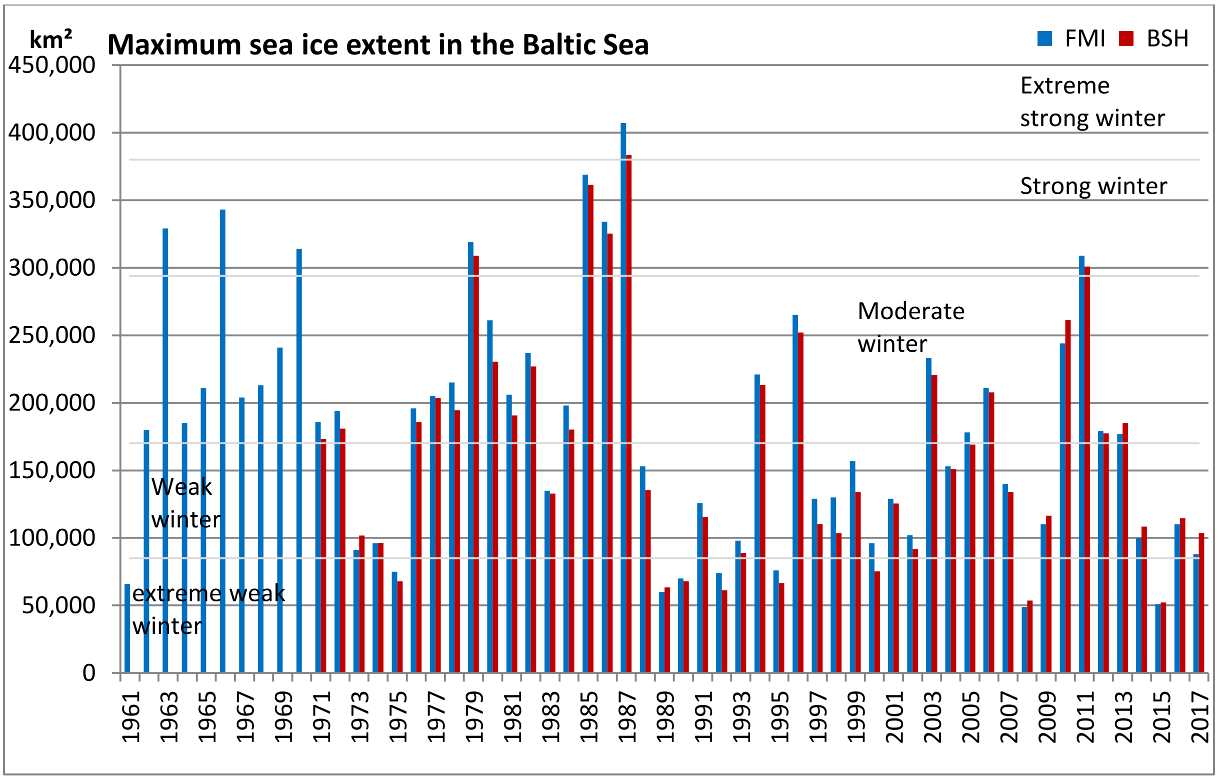


Figure 12: Yearly maximum sea ice extent in the Baltic Sea for the period 1961 – 2017 (Data source: FMI and BSH).

Figure 12 shows the maximum sea ice extent of each winter calculated from the Finnish and German ice service, respectively, compared to each other, as well as the class boundaries for the ice winter strength according to Nusser (1948). As in every year, there is a slight difference between the Finnish and the German maximum ice extent for the ice winter 2016/2017, since the interpretation of satellite data may slightly differ and different land masks are used in both services. However, the difference does generally not influence the classification of the ice winter strength. As mentioned before, the winter 2016/2017 can be classified as a weak winter with respect to the ice extent. It is the 18th weak winter since 1961. For 56 years now, this ice winter class has been the 2nd frequent one, slightly more often, moderate winters occur. The frequency of extreme weak and strong to extreme strong winters is nearly the same, and they occur only less than half as often as weak and moderate winters do. However, the frequency of strong and very strong winters has decreased since end of the 1980s whereas the frequency of extreme weak winters has increased.

Table 4: Class boundaries for different ice winter types.

Max. Area	Min. Area		Max. Volume	Min. Volume
1000*km^2	1000*km^2		km^3	km^3
405 (1987)	> 380	Extreme strong ice winter	**99.4** (1987)	> 89
380	295	Strong ice winter	89	65
294	171	Moderate ice winter	64	30
170	85	Weak ice winter	29	17
< 85	**49** (2008)	Extreme weak ice winter	< 17	**7.6** (1992)

Figure 13 shows the maximum sea ice volume from the BSH data set since 1971. As the maximum yearly sea ice volume comprises the ice extent as well as the sea ice thickness, it is a much better measure for the description of the ice winter strength. Although the ice volume of the winter 2016/2017 is a little bit higher than in the former year, it is still classified as an extreme weak winter – the 4th in a row. In total, a decrease in sea ice volume has been observed since 1971. Per decade, sea ice volume decreases by 4.2 km^3. The statistical significance was also here tested by a two-sided t-test and the negative trend has a confidence of 90%.

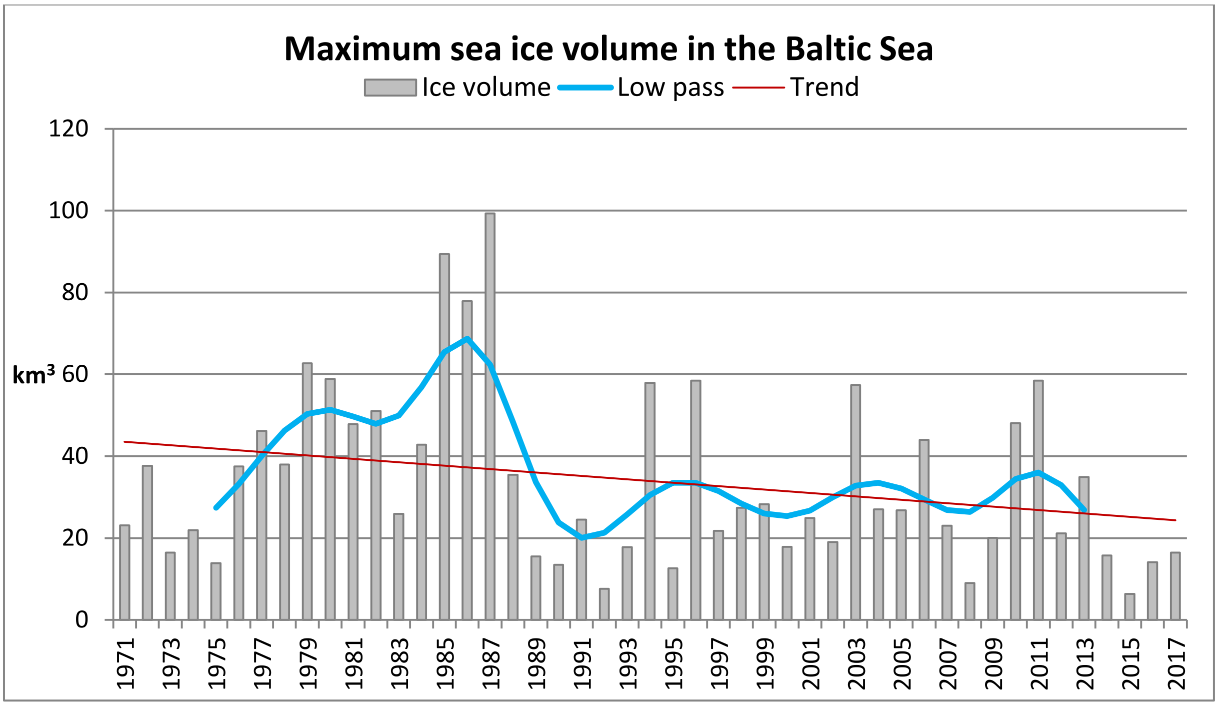


Figure 13: Yearly maximum sea ice volume of the Baltic Sea for the period 1971 – 2017.

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Appendix

Table A 1: Ice conditions at the German North Sea coast in the winter of 2016/17.

Observation station	Begin of ice occurrence	End of ice occurrence	Days with sea ice	Sea ice thickness
Tönning, Habour	05.01.	16.02.	7	10 cm
Eiderdamm, Sea area	07.01.	15.02.	6	5 cm
Bremen, Weser	17.01.	18.01.	2	5 cm
Emden, New inner harbour	02.01.	23.01.	13	5 cm
Emden, Ems and outer habour	03.01.	22.01.	11	5 cm

Table A 2: Ice conditions at the German Baltic Sea coast in the winter of 2016/17.

Observation area	Begin of ice occurrence	End of ice occurrence	Days with sea ice	Max. ice thickness
Kamminke, Harbour and vicinity	08.01.	24.02.	48	15 cm
Ueckermünde, Habour	10.01.	19.02.	27	10 cm
Ueckermünde, Harbour to Uecker	10.01.	19.02.	27	10 cm
Ueckermünde, Szczecin Lagoon	10.01.	20.02.	42	22 cm
Anklam, Habour	16.01.	18.02.	14	10 cm
Anklam, Habour – Peenestrom	16.01.	19.02.	15	10 cm
Brücke Zecherin, Peenestrom	11.01.	24.01.	14	15-30 cm
Rankwitz, Peenestrom	07.01.	20.02.	45	10 cm
Warthe, Peenestrom	07.01.	21.01.	46	17-30 cm
Wolgast – Peenemünde	11.01.	21.02.	18	5 cm
Peenemünde – Ruden	12.01.	19.02.	12*	5 cm
Stralsund, Habour	15.01.	19.02.	20*	15 cm
Stralsund – Palmer Ort	17.01.	19.02.	25*	15 cm
Palmer Ort – Freesendorfer Haken	15.01.	19.02.	16*	10 cm
Greifswald-Wieck, Habour	06.01.	19.02.	39	15 cm
Dänische Wiek	06.01.	21.02.	43	15 cm
Greifswald-Ladebow, Habour	08.01.	20.02.	15	17-30 cm
Osttief	09.02.	19.02.	11	5 cm
Landtiefrinne	17.01.	19.02.	16	10-15 cm
Thiessow, Bodden area	18.01.	20.02.	18	10 cm
Thiessow, Sea area	12.02.	20.02.	8	5 cm
Lauterbach, Harbour and vicinity	10.02.	20.02.	11	15 cm
Sassnitz, Harbour and vicinity	27.01.	16.02.	6	5 cm
Stralsund – Bessiner Haken	15.01.	20.02.	21*	15 cm
Vierendehlrinne	10.01.	20.02.	32*	10-15 cm
Barhöft – Gellenfahrwasser	15.01.	20.02.	22*	15 cm
Neuendorf, Harbour and vicinity	05.01.	20.02.	36	15 cm
Kloster, Bodden area	06.01.	19.02.	15	15 cm
Dranske, Bodden area	10.02.	20.02.	11	10 cm
Wittower Ferry	07.01.	18.02.	19	10 cm
Althagen, Harbour and vicinity	09.01.	20.02.	37	5 cm
Zingst, Zingster Strom	07.01.	16.02.	9	10 cm
Barth, Harbour and vicinity	09.01.	19.02.	25	10 cm
Rostock, City harbour	06.01.	16.02.	11	5 cm
Rostock, Warnemünde	18.01.	21.01.	4	5 cm
Rostock, Sea harbour	16.02.	19.02.	4	5 cm
Wismar, Habour	17.01.	17.01.	13	5 cm
Neustadt, Habour	16.01.	16.02.	10	5 cm
Neustadt, Sea area	16.01.	16.01.	1	5 cm
Heiligenhafen, Habour	15.02.	16.02.	2	5 cm
Schlei, Schleswig – Kappeln	12.11.	17.02.	29	10 cm
Schlei, Kappeln – Schleimünde	15.02.	16.02.	2	5 cm
Flensburg-Holnis	17.01.	18.01.	2	5 cm

* Exact number of days not known due to missing observations.

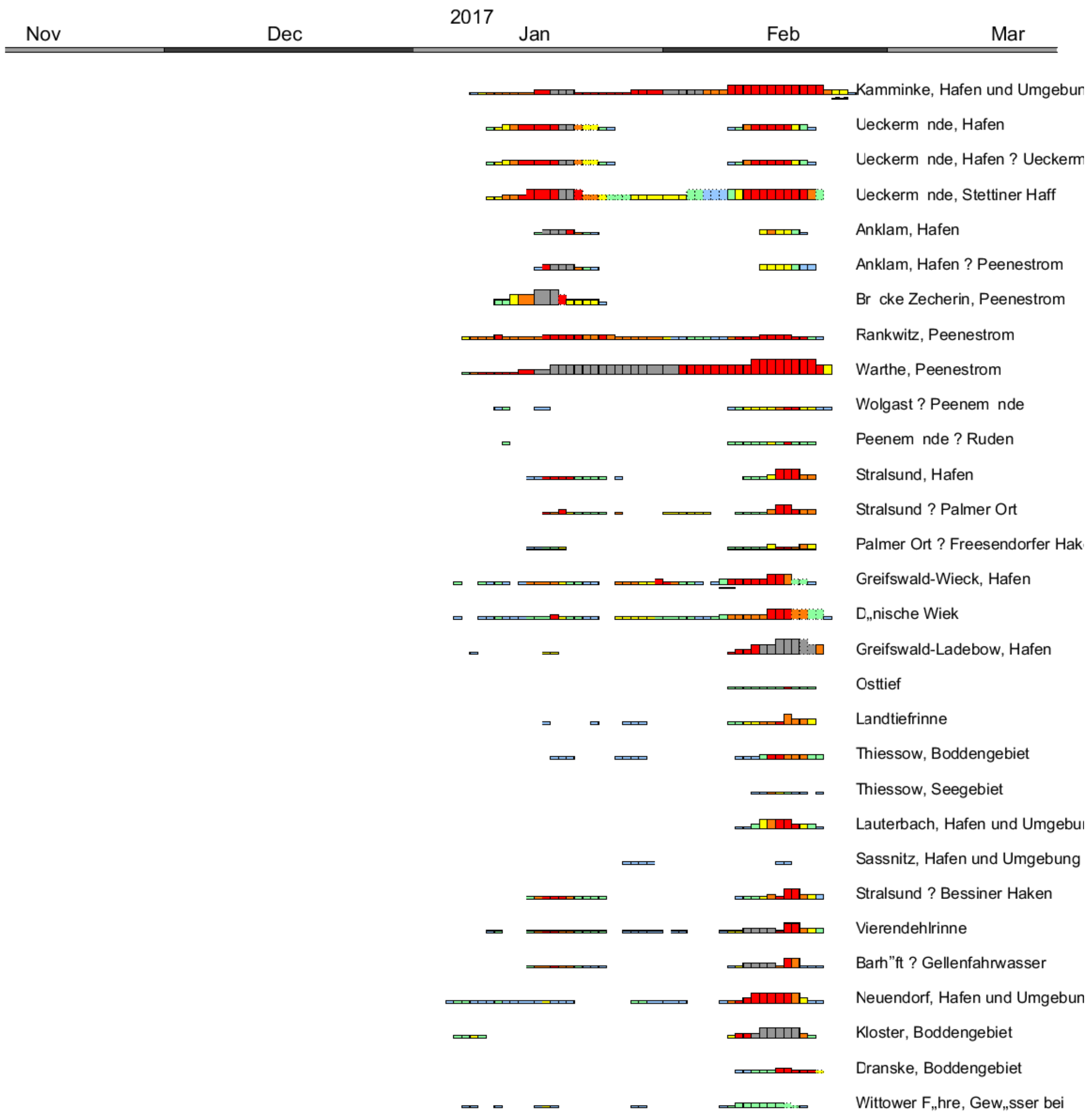

Figure A 1: Daily ice occurrence at the German North and Baltic Sea coast in the winter of 2016/17.

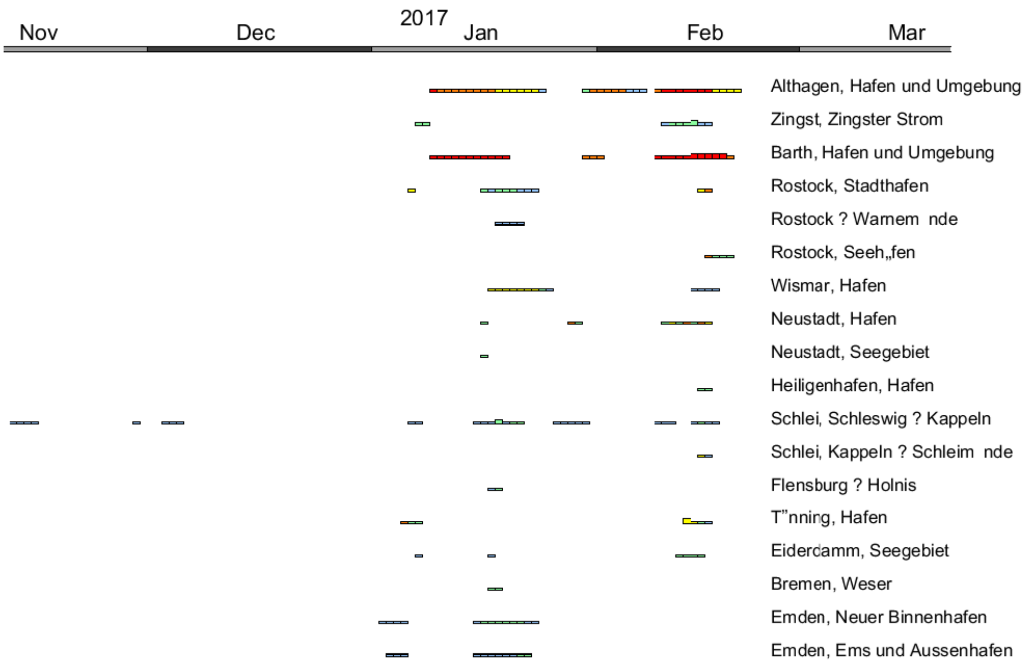

Figure A1: Continuation