The ice winter of 2012/13 on the German North and Baltic Sea coasts and a brief description of ice conditions in the entire Baltic Sea region

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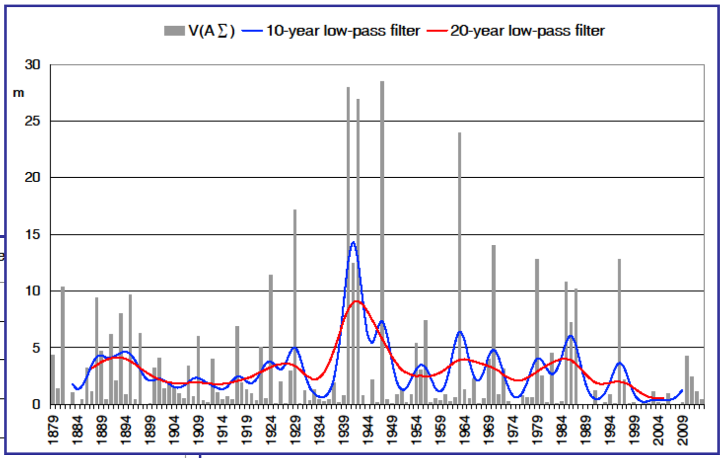


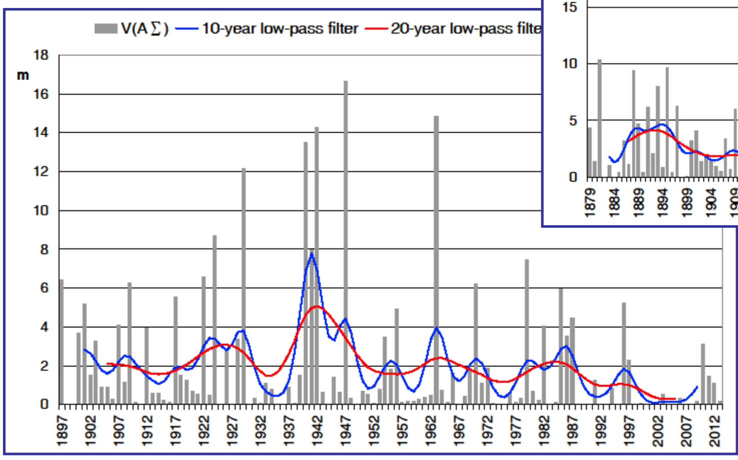


Fig. 1. Distribution of accumulated areal ice volume on the German North Sea coast in the period between 1897 and 2013, and on the German Baltic Sea coast in the period between 1879 and 2013

Contents

General 2

Weather conditions in the German coastal areas during the winter months 3

Ice conditions and navigation on the German North Sea coast 4

Ice conditions and navigation on the German Baltic Sea coast
- Quality of ice observation data 4
- Cold sum dependence of ice thickness growth (T. Düskau) 5
- Warm sum dependence of ice thickness reduction 7
- Ice thickness calculation for the ice winter of 2012/13 9
- Description of ice and navigational conditions 10

Ice conditions in the Kattegat, Skagerrak, and in the Danish and Swedish waters of the western Baltic Sea 11

Ice conditions in the southern Baltic Sea 12

Ice conditions in the northern Baltic Sea (north of 56°N) 12

Appendix

Table A1. Ice conditions on the German North Sea coast in the winter of 2012/13 13
Table A2. Navigational conditions on the German North Sea coast in the winter of 2012/13 14
Table A3. Ice conditions on the German Baltic Sea coast in the winter of 2012/13 15
Table A4. Navigational conditions on the German Baltic Sea coast in the winter of 2012/13 17
Fig. A1. Daily ice occurrence on the German North and Baltic Sea coasts in the ice winter of 2012/13 19

General

In the ice winter of 2012/13, the accumulated areal ice volume used for assessing the intensity of ice winters on German coasts, cf. http://www.bsh.de/de/Meeresdaten/Beobachtungen/Eis/Kuesten.jsp, is **0.20 m** for the North Sea and **0.38 m** for the Baltic Sea **(**cf. Figs. 1 and 2). This classifies the ice winter of 2012/13 as a weak ice winter on both German coasts.
As in most winters, the greatest degree of ice production was observed on the coast of Mecklenburg-Vorpommern. The accumulated areal ice volume on this part of the German Baltic Sea coast is *0.63 m* (a moderate ice winter), on the coast of Schleswig-Holstein *0.08 m* (a very mild ice winter).

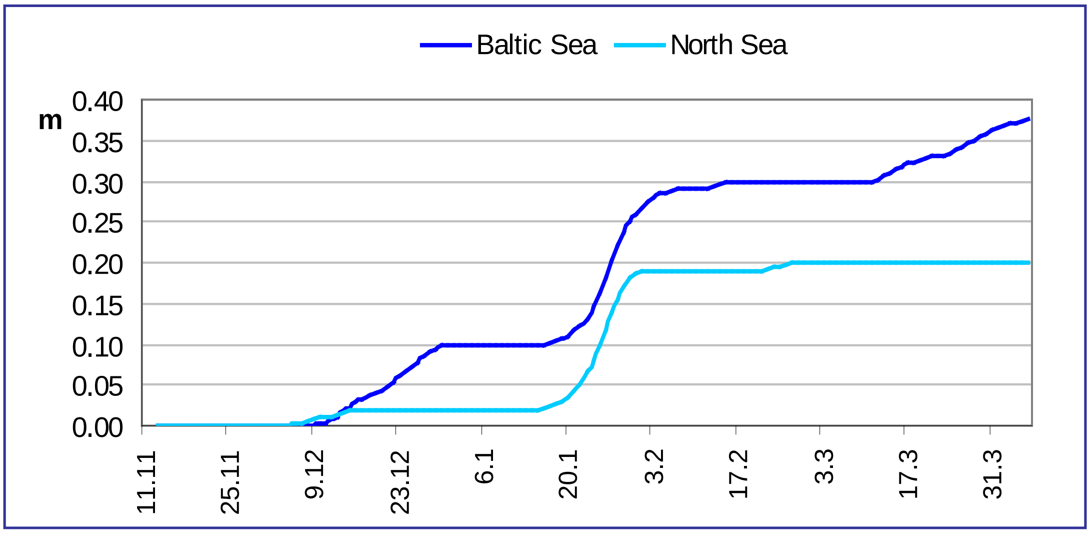


Fig. 2. Accumulated areal ice volume on the German coasts in the winter of 2012/13

In the northern Baltic Sea region, the highest degree of ice formation in the winter of 2012/13 was recorded end of March. Based on the maximum ice extent in the entire Baltic Sea, which was approx. 187,000 km^2 on 25 March, the winter of 2012/13 is classified as a **moderate** ice winter for the Baltic Sea. The maximum ice volume in the Baltic Sea was reached on 2 April and corresponds to **34.9** $\mathbf{km^3}$. This value is likewise indicative of a moderate ice winter.
Ice volume is a more objective measure for describing the intensity of an ice winter, since it takes into consideration not only ice extent, but also ice thickness. The results of researching ice volume in the Baltic Sea over the past 40 years will be published separately.

The BSH reported on ice conditions and expected ice development in the entire Baltic Sea region and German coastal waters in the ice winter **2012/13** by way of

117 ice reports (official reports issued Monday – Friday),
33 German Ice Reports (international exchange, issued when ice forms in German shipping lanes),
about 100 NAVTEX reports (in German and English for the German North and Baltic Sea coasts),
57 ice reports “German Baltic Sea coast“ (detailed description of ice situation for German users),
13 ice reports “German North Sea coast“ (detailed description of ice situation for German users),
26 weekly reports (information for the Federal Ministry of Transport, Building and Urban Development and for MURSYS)
31 general ice charts (once a week, as a reference ice chart for the entire Baltic Sea)
15 ice charts for the western Baltic Sea, Kattegat, and Skagerrak,
27 special ice charts (German Baltic Sea coast).

The current ice reports and ice charts of the BSH are available free of charge online under http://www.bsh.de/de/Meeresdaten/Beobachtungen/Eis/. The archive with all ice charts heretofore issued is available at ftp://ftp.bsh.de/outgoing/Eisbericht/.
In addition, the ice charts were distributed on board ship via the ICEMAR system (www.icemar.eu).

GIS-compatible data in Shape format comprising all ice parameters available can be provided on request.

Weather conditions in the German coastal regions during the ice winter months

Table 1. Monthly mean air temperatures (℃) in the winter of 2012/13 and their deviation from the 1961 – 1990 (K) climate means (courtesy of Deutscher Wetterdienst, www.dwd.de*)*

Station	November		December		January		February		March	
	℃	K	℃	K	℃	K	℃	K	℃	K
Greifswald	5.8	1.2	-0.0	-1.1	0.8	1.4	0.2	0.2	-0.6	-3.3
Rostock-Warnemünde	6.3	1.0	1.0	-0.9	1.3	1.1	0.6	-0.1	-0.2	-3.3
Schleswig	5.7	0.8	0.6	-1.1	0.9	0.6	-0.0	-0.6	-0.4	-3.2
Norderney	6.8	0.5	3.5	0.3	1.5	-0.1	1.3	-0.5	0.8	-3.2
Cuxhaven	6.5	0.7	2.6	-0.0	1.7	0.6	0.8	-0.7	0.3	-3.5

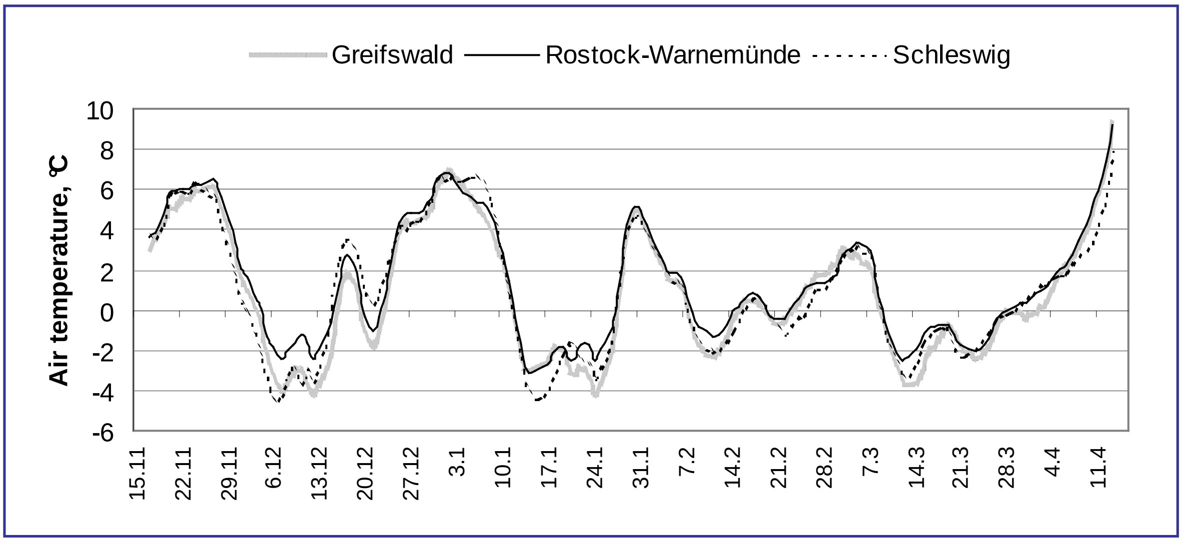


Fig. 2. 5-day running mean of air temperatures in the winter of 2012/13 (courtesy of Deutscher Wetterdienst, www.dwd.de*)*

In the coastal regions between November 2012 and April 2013, frost and thaw periods alternated in almost regular intervals. In total, compared to the values of the reference period 1961 to 1990, the months of November and January were too warm, December was too cold and February was almost normal (cf. Table 1, Fig. 2). During the cold periods there was plenty of snowfall; in the mild phases plentiful rainfall was observed to some extent. With extremely meager sunshine, the winter months, especially January and February, were uncommonly dim (http://www.dwd.de). In the sheltered shallow areas, the water was in freezing condition already during the first ten days of December, in the inner fairways as of middle of December. In the coastal area of the Pomeranian Bight and the German Bight, the water temperature briefly fell to freezing point in the second half of January (Fig. 3). In other sections of the outer coast and in the offshore waters, the water temperature was continuously above 0℃. In ea rly March, Northern Germany was affected by the southern flank of a strong high above Northern Europe with influx of very cold Arctic air. This weather phase brought frosty nights, occasional snowfall and plenty of sunshine, lasted for about three weeks and ended in the first days of April. Particularly low air temperatures were recorded on 13 March (06:00 Uhr UTC, Lübeck -15.6℃ , Arkona -6.6℃) and on 24 March (Ueckermünde -10℃, Hamburg -6.4℃). In total , March was about 3 K too cold. Towards the end of the month, the water temperature in many areas likewise dropped to near freezing point.

Corresponding to the weather trend, the winter of 2012/13 featured four separate ice periods. The first period lasted from 6 December 2012 to early January 2013, the second from middle to end of January 2013, the third from 10 to 20 February 2013 and the fourth from middle of March to early April 2013.

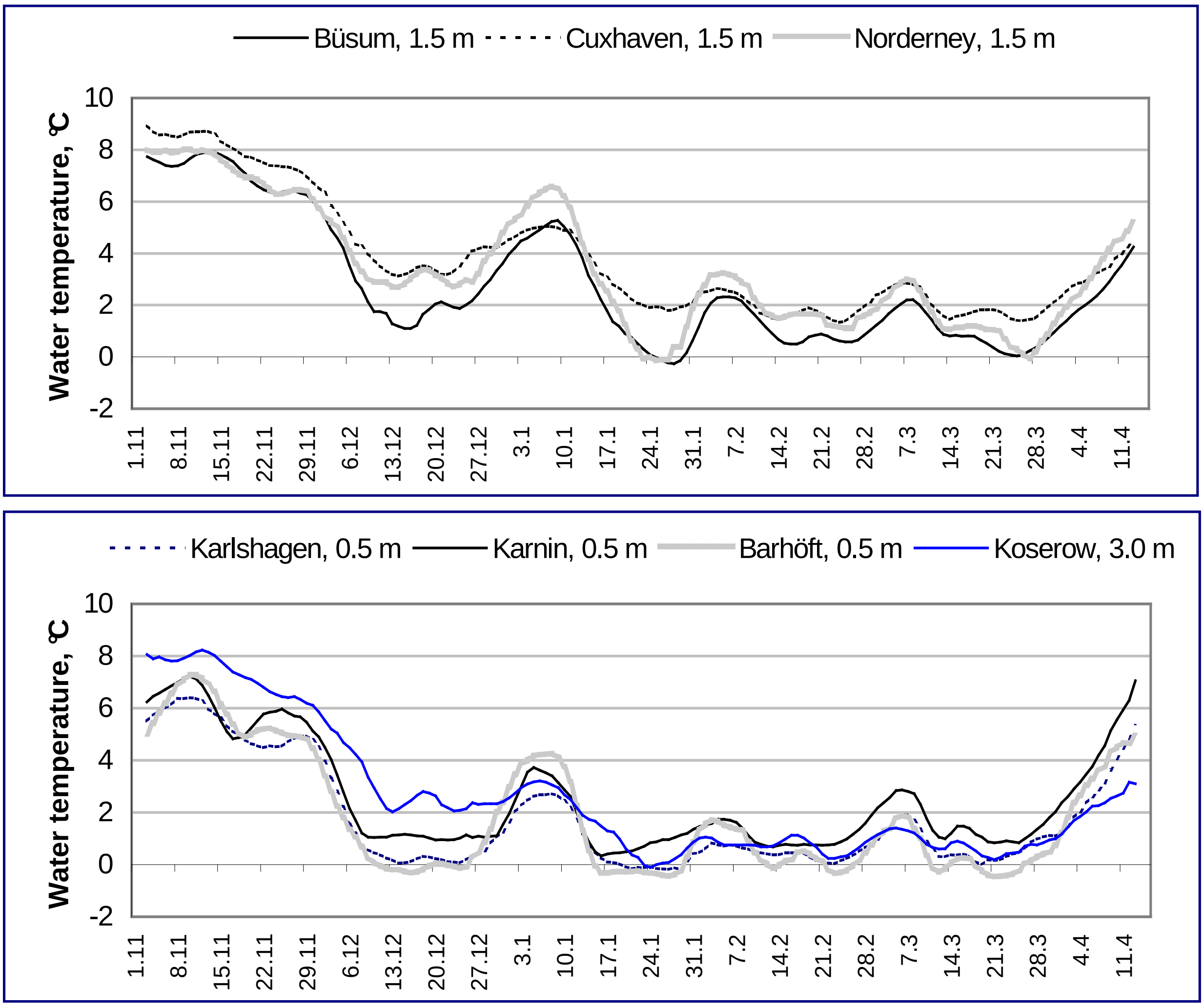


Fig. 3. Water temperatures in the coastal waters of the southern Baltic Sea and of the German Bight
Source of measurement data: Koserow, StALU Mittleres Mecklenburg, Dienststelle Rostock; Karlshagen, Karnin and Barhöft, WSA Stralsund, Brunsbüttel, WSA Brunsbüttel; Norderney and Cuxhaven, DWD; Büsum, sluice (Schleuse) Büsum

Ice conditions and navigation on the German North Sea coast

(Cf. Annex, Tables A1 and A2, and Fig. A1)

With an accumulated areal ice volume of 0.20 m, the ice winter of 2012/13 on the German North Sea coast resulted in a mild ice season. Ice formed exclusively in coastal areas of the German Bight mostly during the second ice period and only on the North Frisian coast during the first and third ice periods. In the ports of Tönning, Husum and Büsum and at Eiderdamm, ice was present for a total of about three to four weeks; in other areas, the ice season lasted only a few days. Ice thickness reached 5 to 15 cm during the second ice period in January. Major shipping remained normal also during the ice winter of 2012/13; obstructions occurred in January for smaller vessels, in particular in the North Frisian Wadden Sea and partly on the Lower Elbe.

Ice conditions and navigation on the German Baltic Sea coast

(Cf. Annex, Tables A1 and A2, and Fig. A1)

<u>Quality of ice observation data</u>

Most ice observers provided reliably good data also for the ice winter of 2012/13. Observations did not take place on individual days with bad visibility or in the event of illness. In such cases, the data is reconstructed without major difficulty on the basis of weather conditions and data submitted by neighbouring ice stations; the rate of potentially occurring errors is low. During this ice season, reports from ice observers were in higher demand, since in April last year the environmental satellite "ENVISAT"

broke down, resulting in the unavailability of SAR satellite data. The images from weather satellites are impaired by clouds and the dull weather in December, January and February allowed for only very few usable images. Unfortunately, in the winter of 2012/13, no reliable data was available specifically for fairways with frequent ice formation, namely access to Stralsund, Wolgast and Rostock. About 70% of all reports from these areas carried the comment "no information" or "unknown"; the quality of reported data was more than questionable on several days. For maintaining the daily reports during the ice season, images of the webcams installed along the coast were evaluated in addition to weather conditions and reports from neighbouring stations.
Description and classification of an ice winter requires uninterrupted data sets. Based on the methodology developed by the Ice Service and described below, it is possible to determine the date of the first and the last occurrence of ice in a given area and to calculate the increasing or decreasing ice thickness. The Ice Service has been using this method for several years for calculating missing ice thickness data; it works particularly well in secluded waters. It is not suitable for determining the ice concentration or the topography of the ice.
Theoretically obtained data is not exact and therefore must be regarded only as orientation values. For the closed (Szczecin Lagoon, Dänische Wiek, Vierendehlrinne) and semi-open (Greifswald Lagoon, Lower Warnow) areas, the error margin for dates of first ice formation is estimated to be ± 5 days. The standard deviation for calculated ice thickness is ± 3 cm in the event of uninterrupted growth, for example, in the Szczecin Lagoon, and ± 10 cm in more open areas, for example, in the fairway section Palmer Ort – Freesendorfer Haken.

Cold sum (CS) dependence of ice thickness growth
This research was conducted in the context of a student internship by T. Düskau (University of Marburg). The aim of the study was to find or, rather, to update a method for prognostic forecasting of ice thickness and beginning of ice formation in various areas of the German Baltic Sea coast.

As is well known, ice formation occurs when water cools down to freezing point. Theoretically, ice thickness can be derived from the equation describing heat flow through the ice. The mathematical calculation of ice formation and ice growth uses the Stefan Method (root law). Stefan (Stefan, 1861) showed that ice thickness increase primarily depends on the root value of the cold sum (CS, sum of negative daily mean air temperatures). For thin ice (up to 10 cm), a linear function provides better results (Ashton, 1989). For calculating ice thickness in a given area, numerous physical values are necessary, which in practice are not available. With some simplification and limitations, ice thickness increase (h) can be described by the empiric equation $h=a+b*CS^{1/2}$. The coefficients a and b are specific for each individual area and are obtained by application of the known data.

The study is based on daily mean air temperatures (DWD data) and the measured or estimated ice thickness at the respective ice observation stations. The measured data from the stations Greifswald, Schleswig, Rostock-Warnemünde and Arkona provided the air temperatures; the ice observation stations Kamminke, Dänische Wiek, Palmer Ort – Freesendorfer Haken, Vierendehlrinne, Wismar – Walfisch, Lübeck, Westermarkelsdorf, Kiel-Leuchtturm and Arkona provided measurement data for ice thickness.

In normal winters, the theoretical equation captures ice thickness increase up to the maximum values in one winter. In severe ice winters, the validity of the root law is limited to description of those ice thickness values, which were reached up until the first longer thaw period. Thaw periods during winter are typical of our latitudes. They can last several days to several weeks and cause stagnation in the ice increase process or even reduction of ice thickness. Ice development continues during the subsequent frost period, but ice thickness increase can no longer be described by the basic equation.

It can happen, especially in the case of sea stations, that no single ice thickness was measured directly. In these cases, ice thickness was entered manually, using the code numbers of the Baltic Sea Ice Code. This was done using two methods: for a start, corresponding to the code number, a mean value of ice thickness was entered (e.g. code number 2 (10-15 cm) mean value: 12.5). Yet since this does not take into account the increasing cold sum or previous ice thickness, another method was employed for supplementing ice thickness values. Again, ice thickness was entered according to code number, but under observation of increasing cold sums, so that ice thickness steadily increased.

Finally, the results of the individual measurement stations were illustrated in a graph. Here, the y-axis represents ice thickness and the x-axis represents the root of the cold sum. The square root is the best way to visualise the problem.

Here, too, various methods of illustration apply. One graph shows only the actually measured ice thickness values. Other graphs include both the measured and the averaged values. The third graph gives the measured values and the manually added ice thickness values (cf. examples in Fig. 4).

Ultimately, the correlation coefficient for each of the individual illustration methods was calculated in order to arrive at a more precise estimation of accuracy and distribution of measured data.

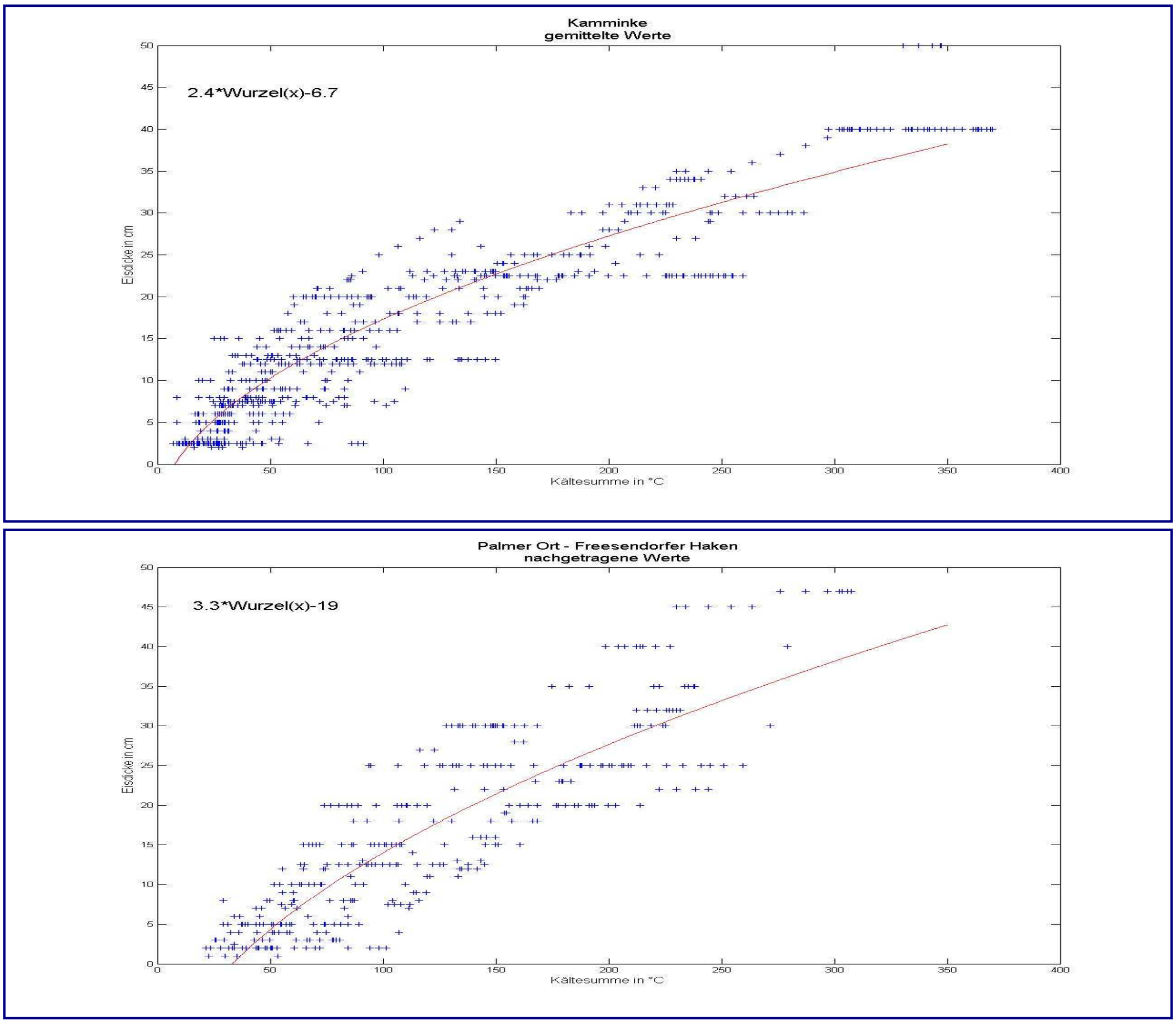


Fig. 4. Ice thickness as a function of cold sum in Szczecin Lagoon and the Greifswald Lagoon

Principally, it can be said that prediction of ice thickness is far more difficult for sea stations than for stations located in sheltered areas. In particular, sea stations reveal a strong scattering of measured data, especially since only very sparse data is available here. It thus can happen that ice thickness decreases in spite of an increasing cold sum, which can be traced back also to changing wind conditions. In this context it must be mentioned also that this study exclusively focused on the correlation between ice thickness and cold sum or, rather, air temperature; other influences such as wind or snow coverage were not taken into consideration. Sheltered areas definitely display linear correlation and applicable results. Here, the upward curve is very steep initially and then the gradient slows down with increasing cold sums.

Because of very good measured data and frequently occurring ice, scattering is not very high here. The cold sum values needed for ice formation are much lower here than in the case of sea stations. However, shipping traffic in harbour stations can necessitate higher cold sums for ice formation to occur than in areas free of shipping traffic. Moreover, it can be stated that the graph gradient is stronger the later ice forms. This fact can be observed in particular at sea stations. Also, the western regions remain ice-free for longer, which can be traced back to the influence of warmer and saltier water from the North Sea.

During evaluation of the various illustration methods, it was noted that, in the presence of sufficient measurement data, hardly any or no deviation at all can be discerned between strictly measured data and subsequently added data. This is not so in the case of sea stations with little measurement data. Here, there is deviation between measured, averaged and manually added values. However, deviation between measured and manually supplemented values is not quite as large as deviation between measured and averaged values.

Table 2. Coefficients of the empirically found equation for determinating ice thickness (h) as a function of the cold sum (CS)
$h = a + b * \sqrt{(CS)}$

	Kam	DänWiek	Vierendehl	PO bis FH	Wis-Walfisch	Lü-Trav	Arkona	Kiel-LT	WMD
a	-5.2	-7.4	-11	-19	-14	-20	-21	-24	-24
b	2.3	2.4	2.5	3.3	2.8	3.3	3.3	3.2	3.1
CorrCoeff	0.92	0.91	0.84	0.88	0.82	0.89	0.75	0.77	0.62

Warm sum (WS) dependence of ice thickness reduction

Dependence of ice thickness on air temperature during the thaw period was analysed for nine areas of the German Baltic Sea coast. These areas comprise inner, sheltered waters (Szczecin Lagoon, Dänische Wiek) and inner fairway sections (Palmer Ort to Freesendorfer Haken, Wismar to Walfisch, Lübeck to Travemünde) as well as the open sea at Arkona, Kiel and Westermarkelsdorf. The data series contain the measured or estimated ice thickness values during the period 1981 to 2012 and the mean daily temperatures at the stations Arkona, Greifswald, Warnemünde and Fehmarn during the same period.

Sources of error

1. Data quality:

Measured ice thickness values are available only for inner, sheltered waters (Szczecin Lagoon, Dänische Wiek). In the other areas, ice thickness is estimated on the basis of the Baltic Sea Ice Code in intervals of < 5 cm, 5-10 cm, 10-15 cm, 15-30 cm, 30-50 cm.

Air temperatures were not measured exactly at each of the analysed ice observation stations. Only the temperature series from the Arkona station was used for adapting the ice data for the sea off Arkona. The temperature series from the Greifswald station was used for the areas of Szczecin Lagoon and Greifswald Lagoon; the temperature series from the Rostock-Warnemünde station was used for the areas in the Wismar Bight and in the Bay of Lübeck; the temperature series from the Fehmarn station was used for the areas Westermarkelsdorf and Kiel-Leuchtturm.

2. Data selection:

Corresponding to the meteorological character of winters in our latitudes with several cold spells and thaw periods, an ice winter can consist of several ice periods, which can alternate with ice-free periods. Data from mild ice winters was not included in the analysis, because these ice winters feature more periods without ice than ice-related data. For inner waters, the data from moderate and severe to extremely severe ice winters was analysed. In doing so, only the thaw phase of the longest ice period was taken into consideration. On the open sea, ice forms only in very severe and extremely severe ice winters. The ice is in constant motion, predominantly dependent on wind, currents and wave motion. This fact and the small number of data allow for only a very rough estimate of ice thickness dependence on air temperature as regards the open sea regions. The ice in the observation area rarely remains on site until total thawing by temperature increase; it usually disappears by breaking up and subsequent drift away from the observation area or thawing is accelerated by rain, fluctuations in the water level and stronger mixing of the water column. Therefore, the data pairs 'warm sum – ice thickness = 0 cm' were not included in the analysis.

3. Results

The aim was to investigate the thermally caused decrease of ice thickness. Since dynamic processes play a significant part in the disappearance of ice, especially in open sea regions, it was not possible to say from the outset which equation would best describe the thawing process. Six different equations were tested: $h = a + b*(WS)$, $h = a + b*\sqrt{(WS)}$, $h = a + b*(WS)+c*(WS)^2$, $h = a + b*(WS)^c$, $h = a*\exp(b*WS)$, $h = a + b*\mathrm{Ln}(WS)$.

In spite of improved standard deviations of the other tested equations, only the linear function is suitable in our case. Experience has shown that the ice melts more slowly at the beginning of the thawing period than at the end, when it is already rotten and porous. In a linear trend, ice thickness decreases evenly, whereas in other equations the melting process slows down.

Table 3. Coefficients of the empirically found equation for determining ice thickness (h) as a function of the warm sum (WS)
$h = a + b * \sqrt{(WS)}$

	Kam	DänWiek	Vierendehl	PO bis FH	Wis-Walfisch	Lü-Trav	Arkona	Kiel-LT	WMD
a	26.46	27.5	25.65	34.37	22.06	21	25.26	18.5	21.94
b	-0.25	-0.3	-0.417	-0.567	-0.364	-0.693	-0.918	-1.91	-1.81
CorrCoeff	0.71	0.66	0.71	0.81	0.63	0.68	0.71	0.60	0.66

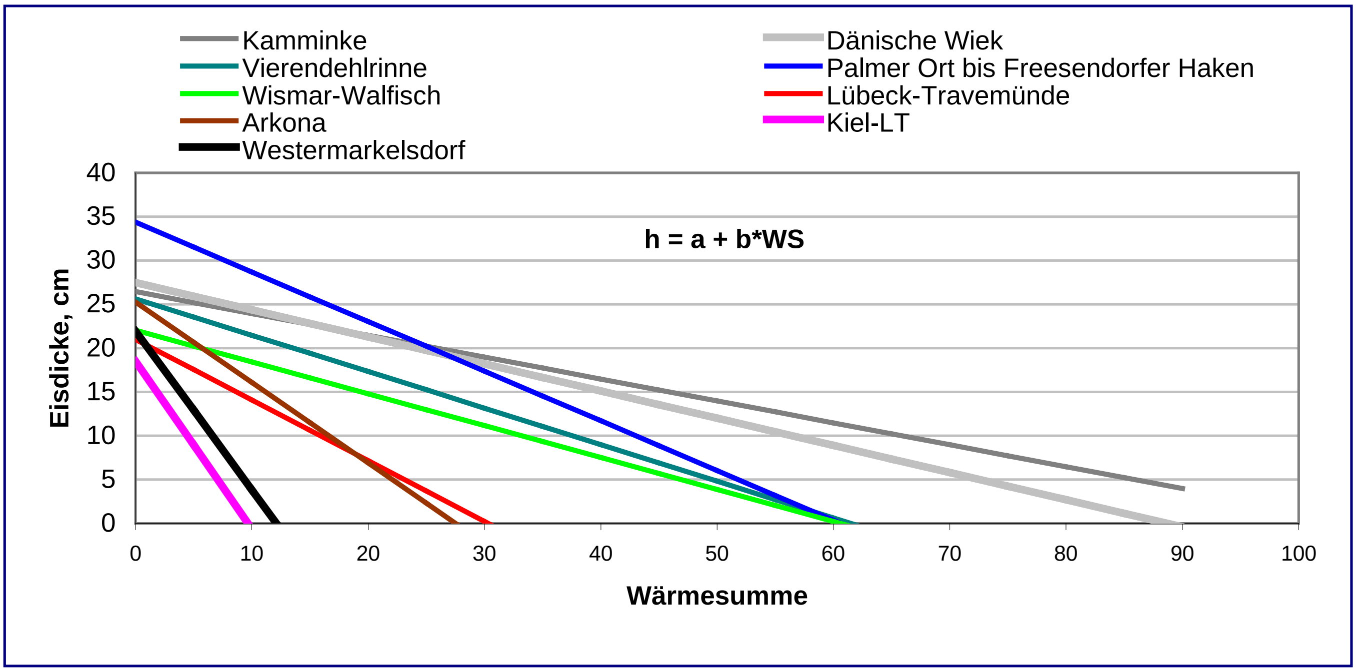


Fig. 5. Comparison of ice thickness as a linear function of the warm sum for nine stations at the German Baltic Sea coast

In the inner, secluded waters, the disappearance of ice is slower than in the inner fairway sections, where ice is crushed up by shipping traffic and is subjected to greater motion. In the areas Palmer Ort to Freesendorfer Haken, Vierendehlrinne and Wismar to Walfisch, the ice melts equally fast (regression tendency almost identical), even though warmth introduced to the more western areas is less. The most favourable melting conditions are given in the fairway Lübeck – Travemünde. At sea, the east – west divide is even more marked (cf. the coefficients of the equations for Arkona, Westermarkelsdorf and Kiel - Leuchtturm). In the West, the ice disappears much faster at a much smaller warm sum than in the East. To introduce the thawing process, the sea off Arkona needs the same amount of warmth as do the more western inner Wismar Bight and the Lower Trave; the influence of cold mainland air from the East remains palpable well into February and March.

Ice thickness calculation for the ice winter of 2012/13

Corresponding to the four cold spells, four distinct ice periods were observed in the regions of the German Baltic Sea coast (cf. Fig. 6). During the thaw periods in between, the ice disappeared completely over longer periods of time, so that each ice period could be treated as an independent phase.

Fig. 7 shows the results of ice thickness calculations for the ice winter of 2012/13 and the available measured values.

The reported ice data for the Stralsund and Wolgast areas were further supplemented by the calculated values. During the winter of 2012/13, no ice was observed in the fairways Lübeck – Travemünde and Wismar – Timmendorf and theoretical calculations likewise revealed that ice formation was impossible in these areas throughout the winter.

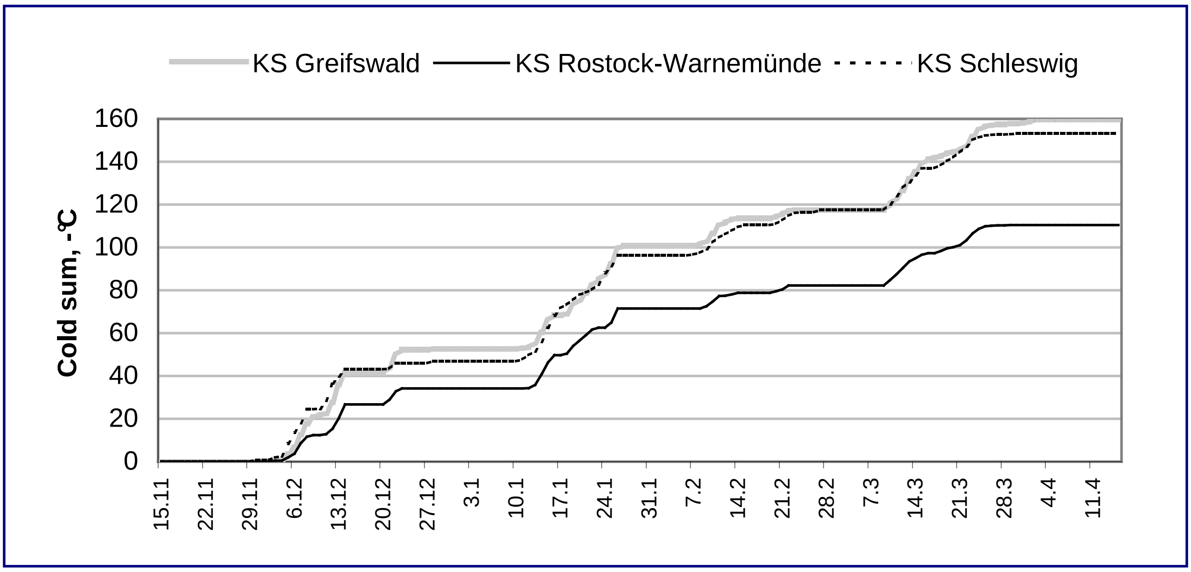


Fig. 6. Cold sum trend (sum of negative daily mean air temperatures) in Greifswald, Rostock-Warnemünde and Schleswig

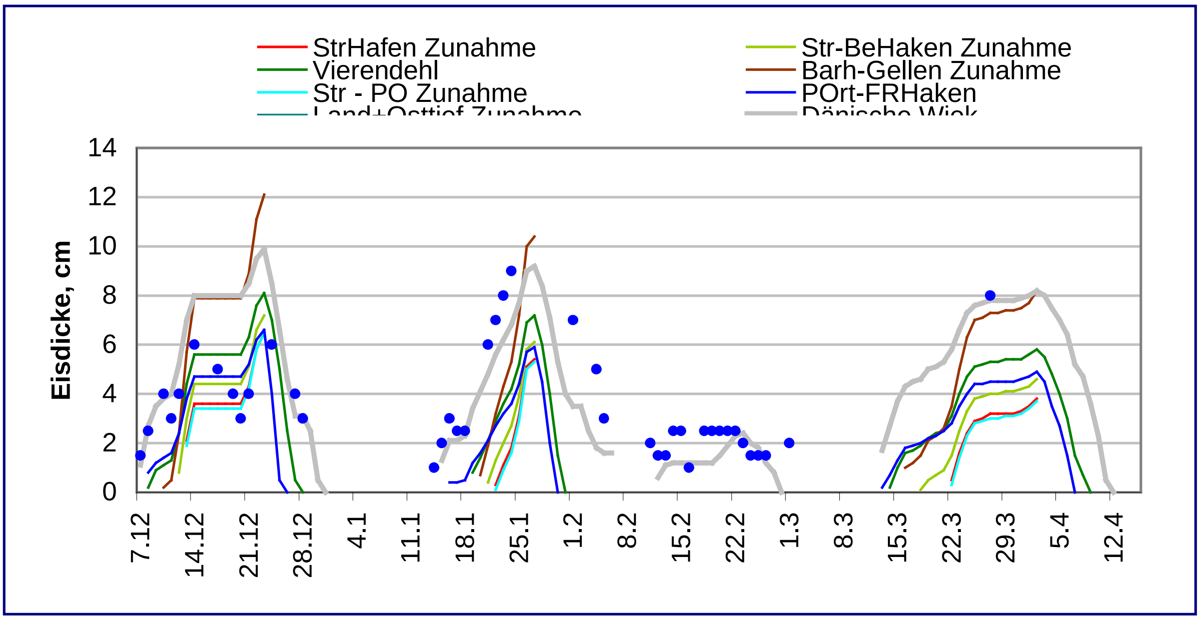


Fig. 7. Distribution of calculated ice thickness in some areas of the German Baltic Sea coast in the ice winter of 2012/13 and comparison with the values measured in the Dänische Wiek

<u>Description of ice and navigational conditions</u>

Although ice formation in the inner waters of the German Baltic Sea coast began already during the first days of December, the further course of the winter brought with it no extensive ice production. At the coast of Schleswig-Holstein, ice occurred in some harbours and in the Flensburg Inner Fjord only on very few days during the second ice period in January; the exception is the inner Schlei (91 days) with ice formation in all four periods. Ice thickness reached values of 5 to 10 cm. At the Mecklenburg coast, ice occurred in the Wismar harbour on 54 days, in the Rostock city harbour and on the Lower Warnow on about 30 days. Small amounts of new ice were recorded in January in the overseas port and in the Warnemünde ship canal. Shipping was not obstructed.

In the bodden waters south of Darß and Zingst, ice formed in all four periods, on a total of 60-80 days. At the time of maximum ice formation, ice thickness reached values between 5 and 15 cm in each period.

New ice or thin ice occurred on about 60 days in the fairways to Stralsund and in the bodden waters between Rügen and Hiddensee. The ice remained for a particularly long time during the fourth ice period, accumulated on the western coastlines by freshened easterly winds. In cooler weather, ice decrease was very slow and the waters became fully ice-free only as late as on 8 April.

In the Greifswald Lagoon, ice formed in the near-shore areas during all four periods. In the sheltered Dänische Wiek, ice was present for a total of 97 days and in the Greifswald-Ladebow harbour for 74 days. In the outer regions, new ice occurred only sporadically and usually in January.

On the southern Peenestrom, the Achterwasser and in the Kleine Haff of the Szczecin Lagoon, ice was observed during the first three cold spells. It remained in place for a total of about two months between early December and mid-March; the thermally grown ice thickness reached values between 10 and 15 cm. In the fourth cold spell, ice formed during the frosty nights, but disappeared almost completely during the day because of longer hours of sunshine and fresh easterly winds.

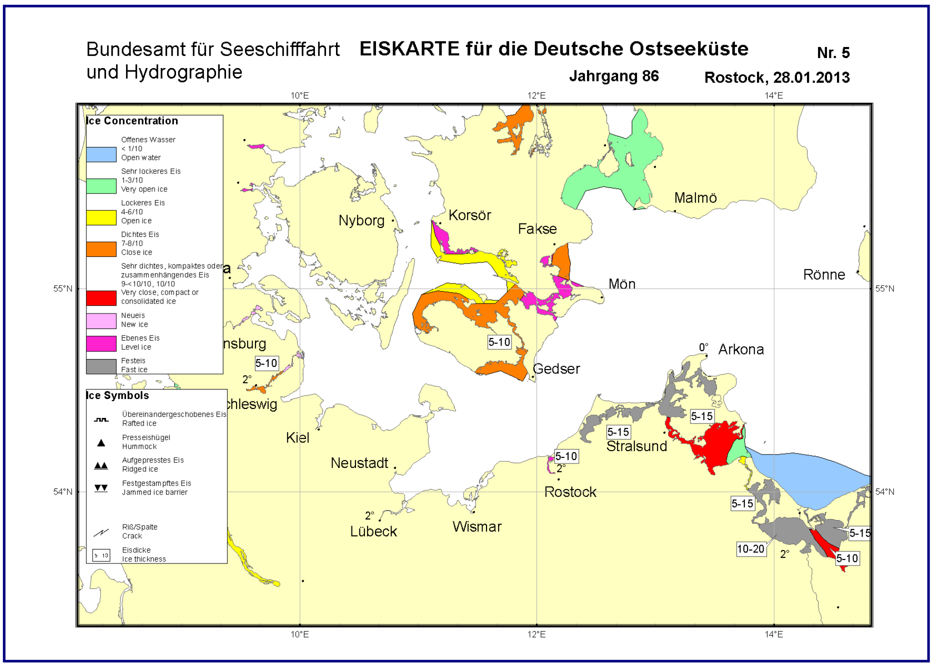


Fig. 8. Ice situation on the German Baltic Sea coast on 28 January 2013

Larger, strongly built ships were not obstructed in the waters of Vorpommern; however, in the period 24 January to 7 February, the northern approach to Stralsund (including western bodden waters), the southern Peenestrom and the Kleine Haff remained closed to shipping (WSA Stralsund).

On the German outer coast, new ice occurred in the near-shore areas of the Pomeranian Bight on 2 to 4 days; the coldness of the 2012/13 winter was not sufficient for ice formation in other sections of the outer coast and in the open sea regions.

Ice conditions in the German Bight, Kattegat, Skagerrak, and in the Danish and Swedish waters of the western Baltic Sea

In the Wadden Sea south of the West Frisian Islands on the Dutch *North Sea coast*, ice occurred between 21 and 27 January. Ice concentration on these days varied from very open to close; ice thickness reached values between 5 and 10 cm; for a short while the ice was pushed together in some places to more than 30 cm in height. In the *Limfjord* on the Danish coast, smaller bays were covered with thin ice or new ice as early as on 22 January. Over the course of January, in some sheltered areas of the Limfjord, the ice grew to a thickness of 5 to 15 cm. The ice cover in the Limfjord changed persistently up until the end of March, but shipping was not seriously obstructed at any point in time.

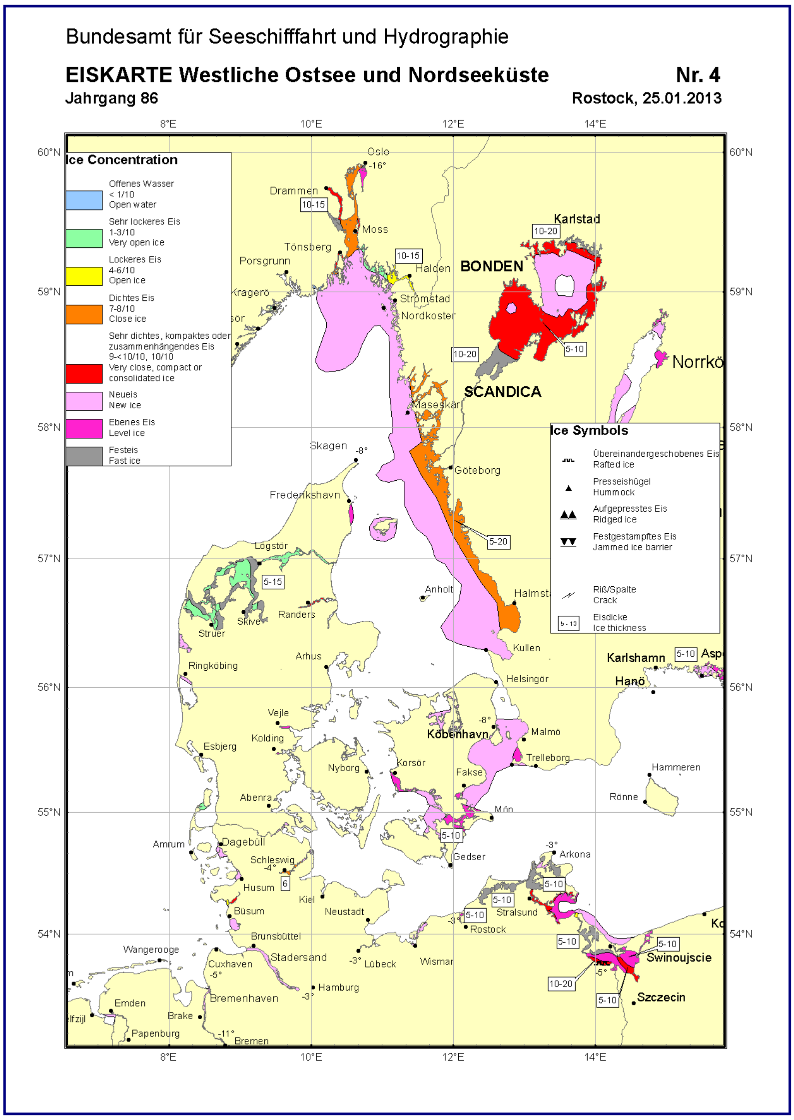


Fig. 9. Ice situation in the German Bight, Skagerrak, Kattegat, and in the Danish and Swedish waters of the western Baltic Sea on 25 January 2013

In the *Skagerrak*, 30-50 cm thick fast ice persisted in some harbours and smaller fjords on the Norwegian coast from early December to early April. At sea, large expanses of new ice formed on 24 and 25 January (cf. Fig. 9). In the Oslo harbours and the Oslofjord, close to very close ice of 5-15 cm thickness occurred at the end of January, February and March brought mostly new ice.

The inner bays and the Danish and Swedish coasts of the *Kattegat* were covered with fast ice or level ice in the third ten days of January; ice thickness reached values of 5 to 15 cm. Between 24 and 28 January, new ice was observed also at sea and in the *Sound*. The ice disappeared completely in the Kattegat by mid-February. The *Belts* remained free of ice in the ice winter of 2012/13.

On *Lake Vänern* and on *Lake Mälaren*, the ice season lasted from early December to end of April. At the time of maximum ice development end of March, the skerries on the northern coast of Lake Vänern as well as at Vänerborgsviken and Kinneviken were covered by 20-40 cm of fast ice, Lake Mälaren was covered by 20-35 cm of fast ice.

In the bays and sheltered waters of the Danish and Swedish coast in the western Baltic Sea, thin, level ice or new ice occurred in the second half of January. Offshore waters remained ice-free also in the winter of 2012/13.

Ice conditions in the Polish and Lithuanian coastal waters in the southern Baltic Sea

On the Polish coast, ice occurred only in the lagoons and in the Puck Bay. The fast ice thickness grew to a maximum of 20 cm in the Vistula Lagoon at the end of March. The Szczecin Lagoon was completely covered by very close ice of 5-20 cm thickness at the end of January. Until mid-February, the ice cover continuously decreased; formation of new ice was observed only on some days between middle and end of March. In the Curonian Lagoon, fast ice persisted from mid-December to mid-April and the thickness reached values of 20 to 30 cm by the end of March.

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

The first ice of the 2012/13 winter formed in the northern innermost skerries of the Bay of Bothnia during the second ten days of November and in the eastern Gulf of Finland about two weeks later. This corresponds largely to the long-term mean dates. Usually, the Gulf of Finland becomes completely ice-free by 1 May and the Bay of Bothnia by end of May. The last ice of the 2012/13 winter was observed in the Gulf of Finland on 3 May and in the Bay of Bothnia in the final week of May. In total, the ice development of the past winter corresponds to the development of a moderate ice winter. At the time of maximum ice extent between 25 and 29 March, the Gulf of Bothnia, the Gulf of Finland and the Gulf of

Riga were completely covered by ice; in the skerries and bays of the northern Baltic Sea, fast ice or level ice was present southwards as far as Karlskrona (cf. Fig. 10).

In early April, the fast ice thickness in the skerries of the Bay of Bothnia reached 35-80 cm, in the skerries of the Sea of Bothnia 20-50 cm and in the Archipelago Sea 20-40 cm. The skerries on the Finnish coast of the Gulf of Finland were covered by 15-60 cm of fast ice, the Kronstadt Bay and the Vyborg Bay by 35-65 cm, the Pärnu Bay by 35-70 cm. As in every winter, shipping in the northern Baltic Sea was supported by several icebreakers. Ice conditions were particularly difficult in the eastern half of the Bay of Bothnia in March and April, featuring strongly ridged ice and rough hummocks.

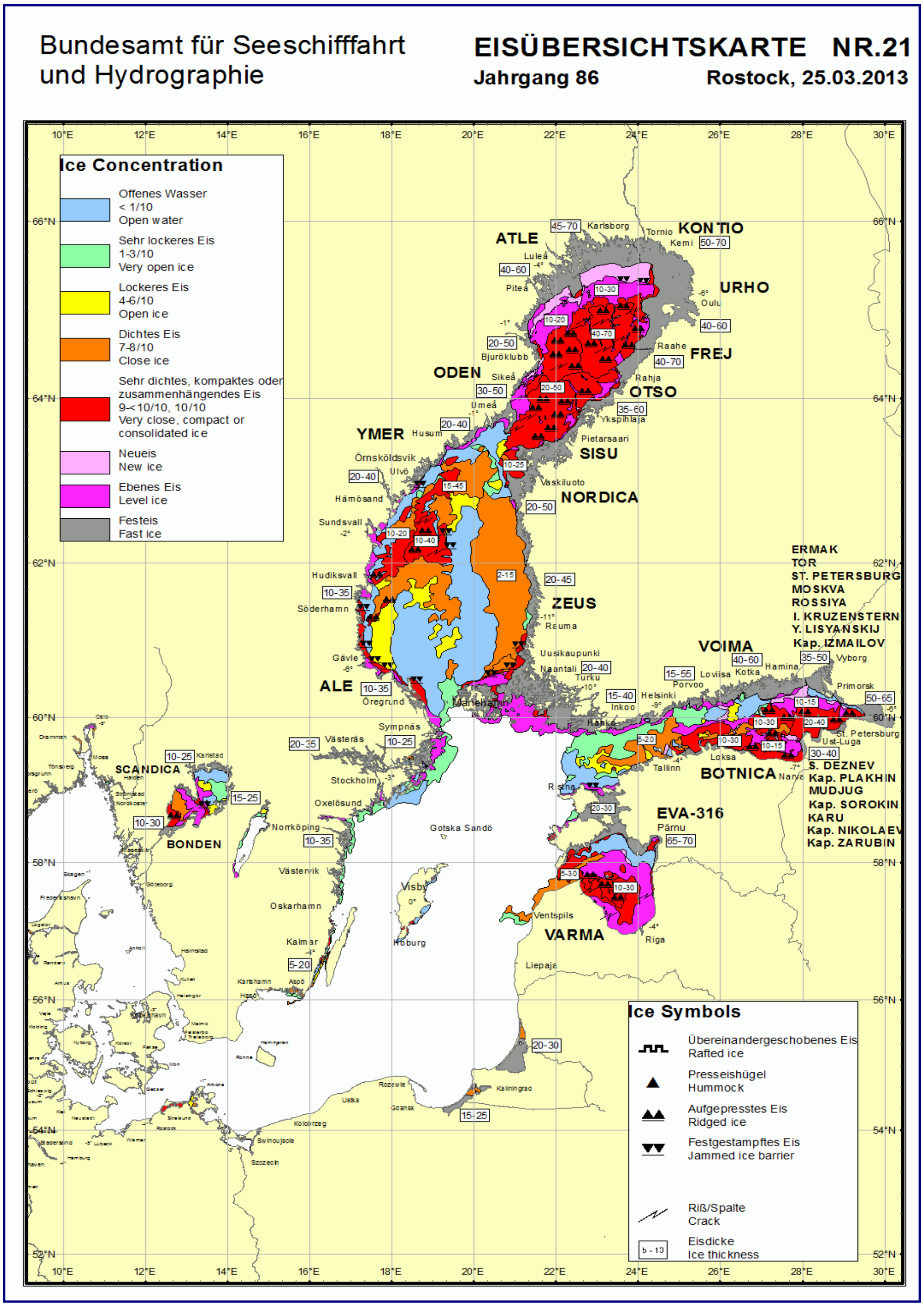


Fig. 10. General ice chart of 25 March showing maximum ice coverage in the northern Baltic Sea region in the winter of 2012/2013

Annex

Table A1. Ice conditions on the German North Sea coast in the winter of 2012/13

Observation station	Beginning of ice occurrence	End of ice occurrence	Number of days with ice	Max. thickness of level ice, cm
German Bight				
Ellenbogen (Sylt), List Deep	06.12.2012	24.03.2013	22	5
Dagebüll, harbour	24.01.2013	12.03.2013	5	< 5
Dagebüll, fairway	24.01.2013	27.01.2013	4	< 5
Wyk on Föhr, harbour	24.01.2013	29.01.2013	6	5-10
Wyk on Föhr, Norderaue			0	
Amrum, Wittdün harbour			0	
Amrum, Vortrapp Deep			0	
Amrum, Schmal Deep			0	
Husum, harbour	08.12.2012	29.01.2013	19	5-10
Husum, Au	08.12.2012	29.01.2013	12	< 5
Nordstrand, Hever			0	
Tönning, harbour	08.12.2012	25.02.2013	26	5-15
Eiderdamm, sea area	08.12.2012	24.02.2013	30	10
Büsum, harbour	08.12.2012	30.01.2013	19	5
Büsum, Norderpiep	20.01.2013	30.01.2013	10	< 5
Büsum, Süderpiep	20.01.2013	30.01.2013	10	< 5
Harburg, Elbe	22.01.2013	29.01.2013	8	5
Hamburg, Landing Pier - Kehrwieder	22.01.2013	29.01.2013	8	5
Hamburg – Landing Pier, Elbe	22.01.2013	29.01.2013	8	5
Altona, Elbe	22.01.2013	29.01.2013	8	5
Stadersand, Elbe	24.01.2013	28.01.2013	5	5-15
Glückstadt, harbour and entrance	24.01.2013	29.01.2013	6	5-15
Glückstadt, Elbe	25.01.2013	29.01.2013	5	5-15
Brunsbüttel, Elbe	25.01.2013	29.01.2013	5	5-15
Cuxhaven, harbour and entries	28.01.2013	28.01.2013	1	< 5
Cuxhaven, Elbe			0	
Cuxhaven – Neuwerk			0	
Neuwerk, Elbe	28.01.2013	28.01.2013	1	< 5
Bremen, Weser	25.01.2013	26.01.2013	2	< 5
Brake, Weser			0	
Bremerhaven, Weser	23.01.2013	27.01.2013	5	< 5
Wilhelmshaven, harbour entries			0	
Wilhelmshaven, tanker unloading pier			0	
Schillig, Jade area			0	
Wangerooge, fairway			0	
Wangerooge, Watten			0	
Wangerooge, Harle			0	
Norderney	No observations			
Papenburg – Emden	23.01.2013	30.01.2013	8	10
Emden, new inner harbour	25.01.2013	30.01.2013	6	5
Emden, Ems and outer harbour	25.01.2013	30.01.2013	5	5-10
Ems, Emden – Randzelgat	21.01.2013	30.01.2013	9	5-15
Borkum, Randzelgat	20.01.2013	21.01.2013	2	< 5
Borkum, Westerems			0	

Table A2. Navigational conditions on the German North Sea coast in the winter of 2012/13

Observation station	Days with K_B=2*	Days with K_B=3,5,6*	Days with K_B=8,9*
German Bight			
Ellenbogen (Sylt), List Deep	3		
Dagebüll, harbour			
Dagebüll, fairway			
Wyk on Föhr, harbour			
Wyk on Föhr, Norderaue			
Amrum, Wittdün harbour			
Amrum, Vortrapp Deep			
Amrum, Schmal Deep			
Husum, harbour			
Husum, Au			
Nordstrand, Hever			
Tönning, harbour	10		
Eiderdamm, sea area	11	3	
Büsum, harbour			
Büsum, Norderpiep			
Büsum, Süderpiep			
Harburg, Elbe			
Hamburg, Landing Pier - Kehrwieder			
Hamburg – Landing Pier, Elbe			
Altona, Elbe			
Stadersand, Elbe	1		
Glückstadt, harbour and entrance	1		
Glückstadt, Elbe	1		
Brunsbüttel, Elbe			
Cuxhaven, harbour and entries			
Cuxhaven, Elbe			
Cuxhaven – Neuwerk			
Neuwerk, Elbe			
Bremen, Weser			
Brake, Weser			
Bremerhaven, Weser			
Wilhelmshaven, harbour entries			
Wilhelmshaven, tanker unloading pier			
Schillig, Jade area			
Wangerooge, fairway			
Wangerooge, Wadden			
Wangerooge, Harle			
Papenburg – Emden			
Emden, new inner harbour			
Emden, Ems and outer harbour			
Ems, Emden – Randzelgat	1		
Borkum, Randzelgat			
Borkum, Westerems			

* According to the Baltic Sea ice code

K_B = 2	Navigation difficult for unstrengthened or low-powered vessels built of iron or steel. Navigation for wooden vessels even with ice sheathing not advisable.
K_B = 3,5,6	Navigation without icebreaker assistance possible only for high-powered vessels of strong construction and suitable for navigation in ice (with or without icebreaker assistance)
K_B = 8,9	Navigation temporarily closed or ceased

Table A3. Ice conditions on the German Baltic Sea coast in the winter of 2012/13

Observation station	Beginning of ice occurrence	End of ice occurrence	Number of days with ice	Max. thickness of level ice, cm
Kamminke, harbour and environment	11.12.2012	15.03.2013	55	11
Ueckermünde, harbour	13.12.2012	15.02.2013	25	10
Ueckermünde, harbour to Uecker mouth	23.01.2013	30.01.2013	8	10
Ueckermünde, Szczecin Lagoon	12.12.2012	28.02.2013	47	10-15
Karnin, Szczecin Lagoon	08.12.2012	01.02.2013	34	5-10
Karnin, Peenestrom	08.12.2012	01.02.2013	34	5-10
Anklam, harbour	08.12.2012	01.02.2013	29	7
Anklam, harbour – Peenestrom	08.12.2012	01.02.2013	30	7
Bridge Zecherin, Peenestrom	08.12.2012	01.02.2013	36	10-15
Rankwitz, Peenestrom	06.12.2012	17.03.2013	69	12
Warthe, Peenestrom	07.12.2012	26.03.2013	60	13
** Wolgast – Peenemünde*	*08.12.2012*	*04.04.2013*	*58*	*5-15*
** Peenemünde – Ruden*	*15.12.2012*	*17.03.2013*	*24*	*5-10*
Koserow, sea area	15.12.2012	27.01.2013	4	5-10
** Stralsund, harbour*	*13.12.2012*	*04.04.2013*	*58*	*5-15*
** Stralsund – Palmer Ort*	*11.12.2012*	*04.04.2013*	*55*	*5-15*
** Palmer Ort – Freesendorfer Haken*	*14.12.2012*	*17.03.2013*	*38*	*5-15*
Greifswald-Wieck, harbour	10.12.2012	02.04.2013	60	5-15
Dänische Wiek	06.12.2012	03.04.2013	97	5-15
Greifswald-Ladebow, harbour	08.12.2012	05.04.2013	74	10-15
** Osttief*	*17.12.2012*	*17.03.2013*	*17*	*5-10*
** Landtief channel*	*28.12.2012*	*14.03.2013*	*15*	*5-15*
Thiessow, bodden area	14.12.2012	26.03.2013	28	5-10
Thiessow, sea area	25.12.2012	24.03.2013	17	5-10
Lauterbach, harbour and vicinity	13.12.2012	22.03.2013	41	10
Greifswalder Oie, eastern sea area	26.01.2013	27.01.2013	2	< 5
Sassnitz ferry harbour and vicinity			0	
Sassnitz ferry harbour, sea area			0	
Sassnitz, harbour and environment	26.01.2013	18.03.2013	16	5-10
Sassnitz, sea area	14.03.2013	17.03.2013	4	< 5
Arkona, sea area			0	
** Stralsund – Bessiner Haken*	*13.12.2012*	*08.04.2013*	*57*	*5-10*
** Vierendehlrinne*	*12.12.2012*	*08.04.2013*	*64*	*5-10*
** Barhöft – Gellen, fairway*	*11.12.2012*	*04.04.2013*	*65*	*5-10*
Neuendorf, harbour and vicinity	07.12.2012	08.04.2013	89	10-15
Neuendorf, sea area	26.01.2013	23.03.2013	6	< 5
Kloster, sea area			0	
Kloster, bodden area	08.12.2012	05.04.2013	74	10
Schaprode – Hiddensee, fairway	15.01.2013	04.02.2013	21	5-10
Dranske, Libben fairway			0	
Dranske, bodden area	11.12.2012	30.03.2013	61	5-10
Wittow, ferry	11.12.2012	31.01.2013	36	10
Althagen, harbour and vicinity	13.12.2012	04.04.2013	63	5-15
Zingst, Zingster Strom	07.12.2012	25.03.2013	38	6
Zingst, sea area			0	
Barth, Harbour and vicinity	07.12.2012	05.04.2013	82	5-15
Rostock, city harbour	09.12.2012	22.03.2013	36	5-15
Rostock – Warnemünde	10.12.2012	14.03.2013	31	5-15
** Rostock overseas port*	*08.12.2012*	*13.03.2013*	*10*	*5*

Table A3, contd.

** Warnemünde, sea canal*	*25.01.2013*	*13.03.2013*	*5*	*< 5*
** Warnemünde, sea area*	*13.03.2013*	*13.03.2013*	*1*	*< 5*
Rostock, approach buoy			0	
Wismar, Harbour	06.12.2012	03.04.2013	54	5
Wismar – Walfisch			0	
Walfisch – Timmendorf			0	
Timmendorf –Wismar, approach buoy			0	
Lübeck – Travemünde			0	
Travemünde, harbour			0	
Travemünde, sea area			0	
Neustadt, harbour	15.01.2013	15.03.2013	14	5
Neustadt, sea area			0	
Dahmeshöved, sea area			0	
Fehmarn Sound			0	
Kiel, inner harbour	12.12.2012	15.03.2013	8	< 5
Holtenau – Laboe			0	
Bülk, sea area			0	
Kiel lighthouse, sea area NE			0	
Kiel lighthouse, sea area NE			0	
Heiligenhafen, harbour	26.01.2013	16.03.2013	8	
Fehmarn Sound, western entrance			0	
Westermarkelsdorf, sea area			0	
Marienleuchte, sea area			0	
Fehmarn Belt, eastern entrance	23.12.2012	24.03.2013	4	< 5
Eckernförde, harbour	16.01.2013	12.03.2013	17	< 5
Eckernförde, bay			0	
Schlei, Schleswig – Kappeln	06.12.2012	03.04.2013	91	5-10
Schlei, Kappeln – Schleimünde	24.01.2013	29.01.2013	6	5
Flensburg – Holnis	12.12.2012	15.03.2013	10	< 5
Holnis – Neukirchen			0	
Neukirchen – Kalkgrund lighthouse			0	
Falshöft, sea area			0	

* Orientation values, Information from reconstructed data

Table A4. Navigational conditions on the German Baltic Sea coast in the winter of 2012/13

Observation station	Days with K_B=2*	Days with K_B=3,5,6*	Days with K_B=8,9*
Kamminke, harbour and environment	15		13
Ueckermünde, harbour			
Ueckermünde, harbour to Uecker mouth			
Ueckermünde, Szczecin Lagoon	5	1	8
Karnin, Szczecin Lagoon	6		9
Karnin, Peenestrom	6		9
Anklam, harbour	6		
Anklam, harbour – Peenestrom	6		9
Bridge Zecherin, Peenestrom	2		9
Rankwitz, Peenestrom	1		14
Warthe, Peenestrom	17	1	12
Wolgast – Peenemünde	5		
Peenemünde – Ruden			
Koserow, sea area			
Stralsund, harbour	*6*		
Stralsund – Palmer Ort	7		
Palmer Ort – Freesendorfer Haken	7		
Greifswald-Wieck, harbour	5		
Dänische Wiek	8		
Greifswald-Ladebow, harbour	26	6	
Osttief			
Landtief channel			
Thiessow, bodden area	5	1	
Thiessow, sea area	1		
Lauterbach, harbour and vicinity	7		
Greifswalder Oie, eastern sea area			
Sassnitz ferry harbour and vicinity			
Sassnitz ferry harbour, sea area			
Sassnitz, harbour and environment			
Sassnitz, sea area			
Arkona, sea area			
Stralsund – Bessiner Haken	4		13
Vierendehlrinne	5		15
Barhöft – Gellen, fairway			14
Neuendorf, harbour and vicinity	36	12	
Neuendorf, sea area			
Kloster, sea area			
Kloster, bodden area	33		
Schaprode – Hiddensee, fairway	8		
Dranske, Libben fairway			
Dranske, bodden area	26	11	
Wittow, ferry	6		
Althagen, harbour and vicinity	1		10
Zingst, Zingster Strom	6		
Zingst, sea area			
Barth, Harbour and vicinity	20	1	9
Rostock, city harbour	3		
Rostock – Warnemünde	8		
Rostock overseas port			

Table A3, contd.

Warnemünde, sea canal			
Warnemünde, sea area			
Rostock, approach buoy			
Wismar, Harbour			
Wismar – Walfisch			
Walfisch – Timmendorf			
Timmendorf –Wismar, approach buoy			
Lübeck – Travemünde			
Travemünde, harbour			
Travemünde, sea area			
Neustadt, harbour			
Neustadt, sea area			
Dahmeshöved, sea area			
Fehmarn Sound			
Kiel, inner harbour			
Holtenau – Laboe			
Bülk, sea area			
Kiel lighthouse, sea area NE			
Kiel lighthouse, sea area NE			
Heiligenhafen, harbour			
Fehmarn Sound, western entrance			
Westermarkelsdorf, sea area			
Marienleuchte, sea area			
Fehmarn Belt, eastern entrance			
Eckernförde, harbour			
Eckernförde, bay			
Schlei, Schleswig – Kappeln	29		
Schlei, Kappeln – Schleimünde			
Flensburg – Holnis			
Holnis – Neukirchen			
Neukirchen – Kalkgrund lighthouse			
Falshöft, sea area			

* According to the Baltic Sea ice code

$K_B = 2$ Navigation difficult for unstrengthened or low-powered vessels built of iron or steel. Navigation for wooden vessels even with ice sheathing not advisable.
$K_B = 3,5,6$ Navigation without icebreaker assistance possible only for high-powered vessels of strong construction and suitable for navigation in ice (with or without icebreaker assistance)
$K_B = 8,9$ Navigation temporarily closed or ceased

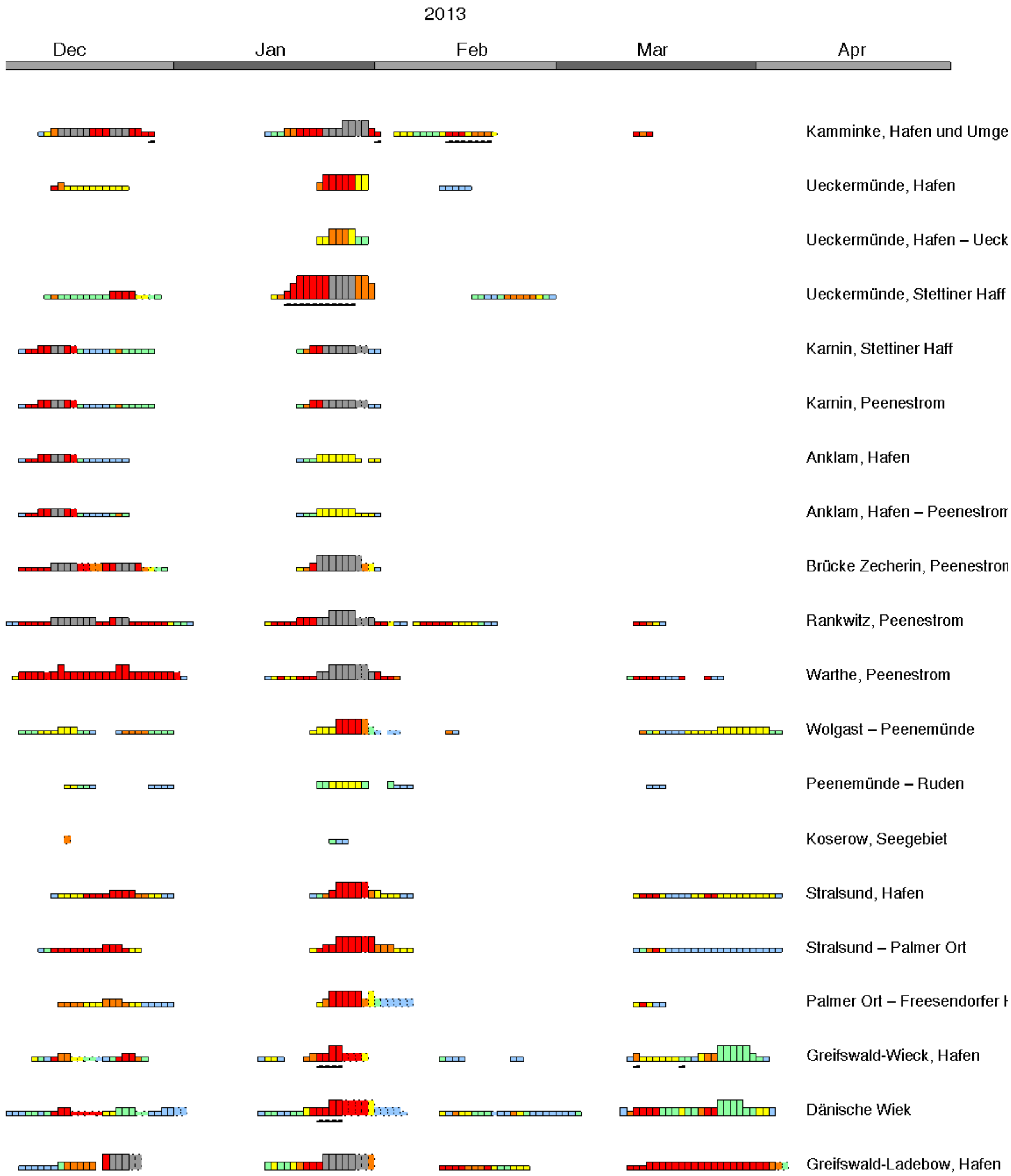
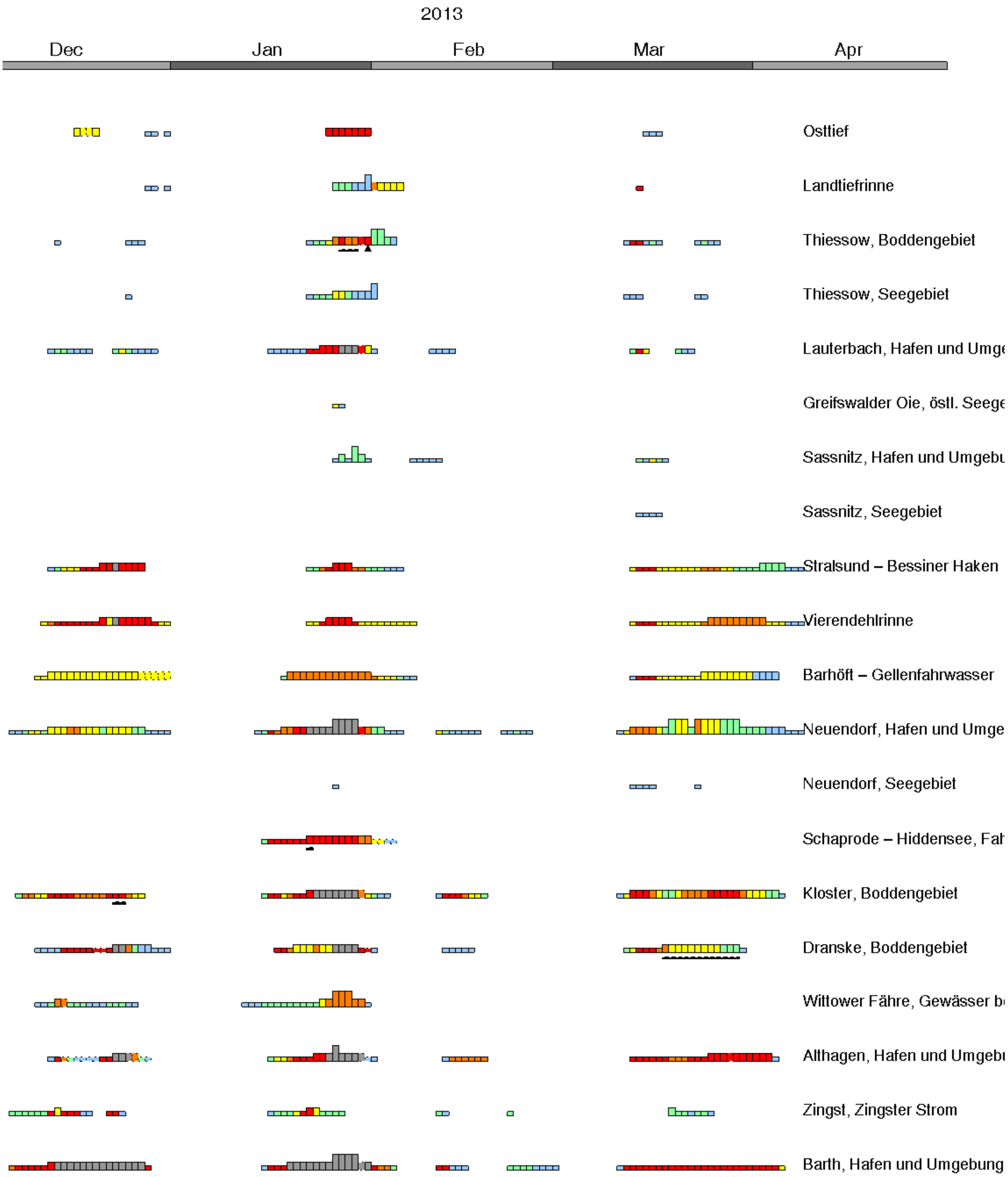


Fig. A1. Daily ice occurrence on the German North and Baltic Sea coasts in the ice winter of 2012/13

Fig. A1, contd.



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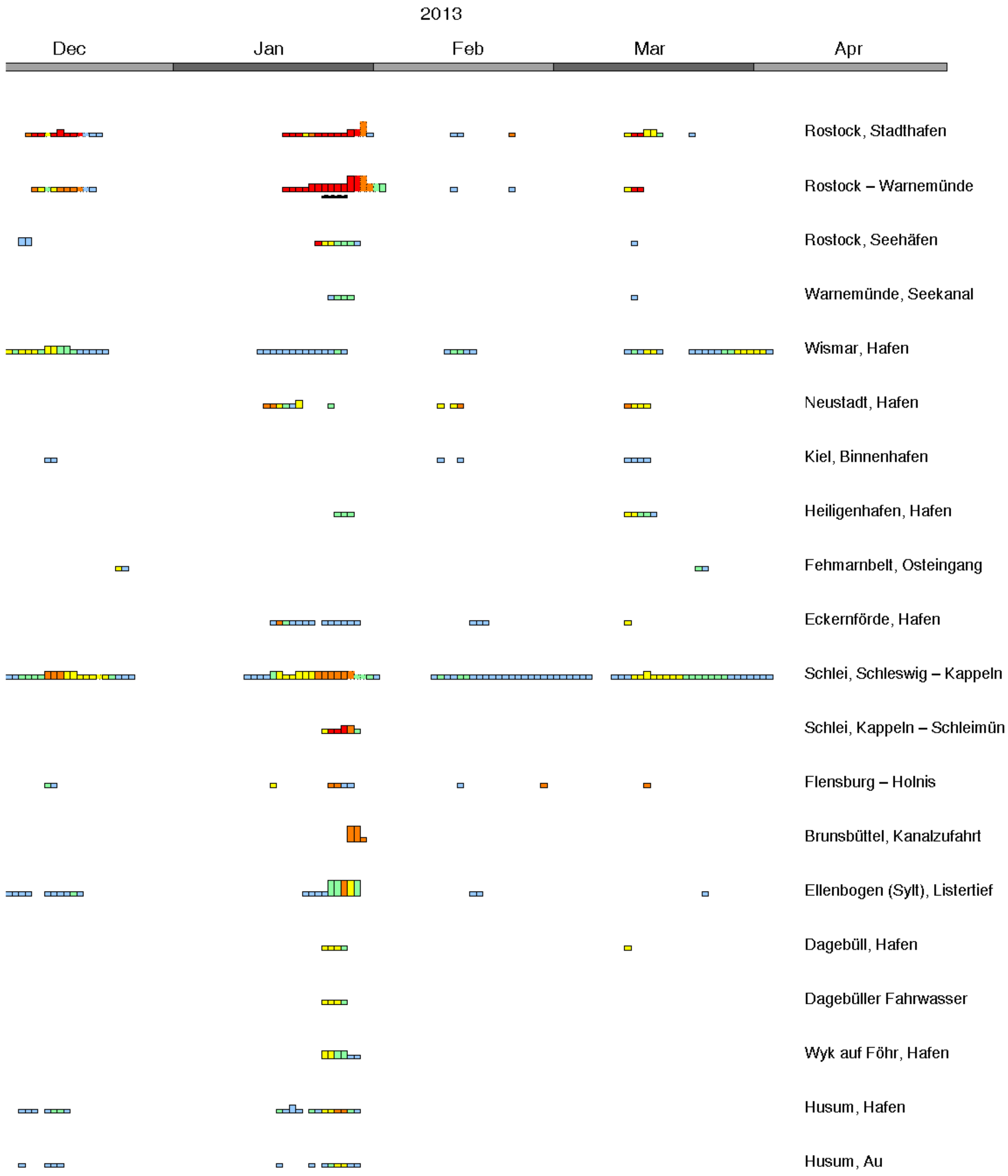
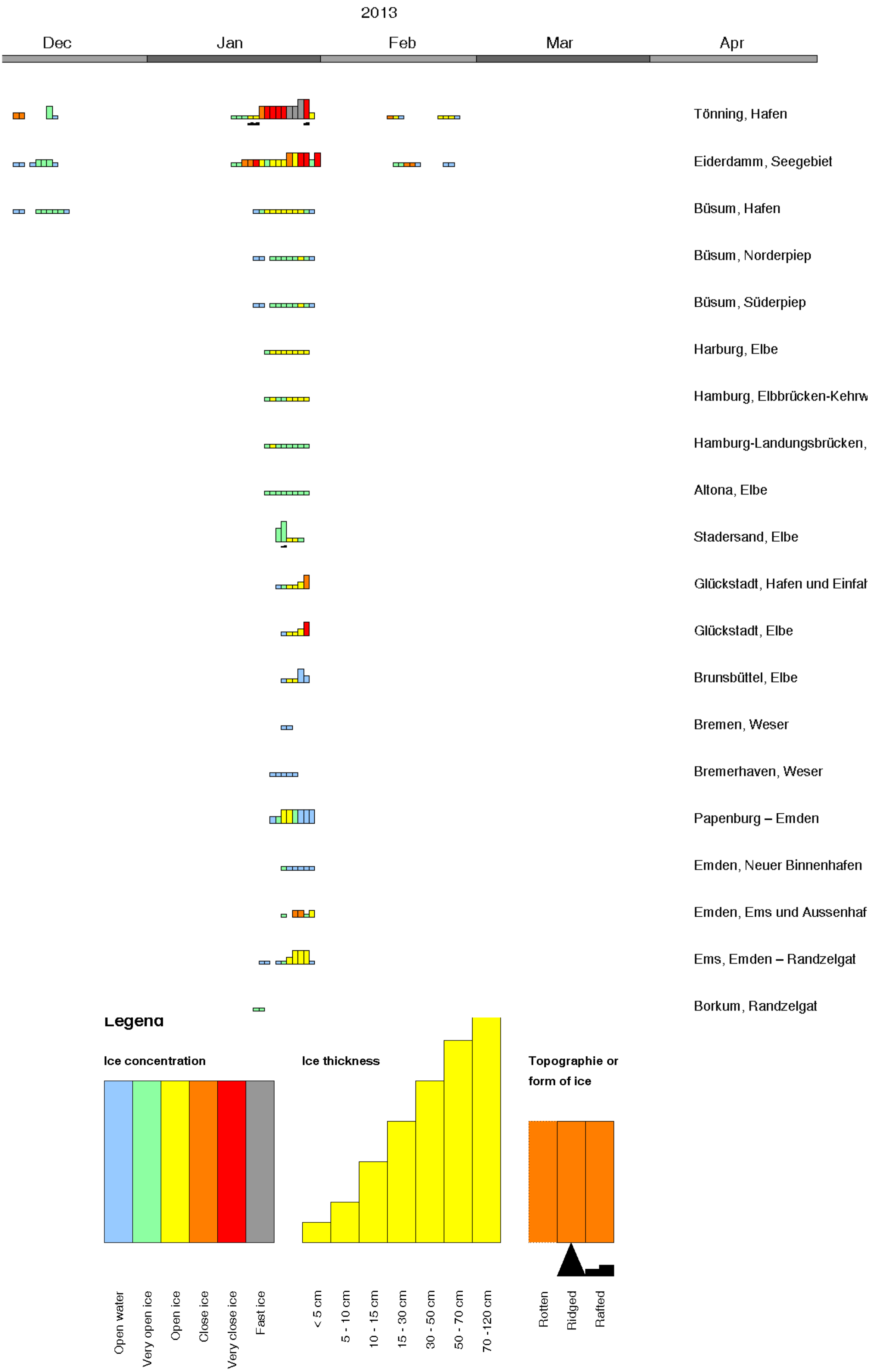

2013
Dec
Jan
Feb
Mar
Apr
Rostock, Stadthafen
Rostock – Warnemünde
Rostock, Seehäfen
Warnemünde, Seekanal
Wismar, Hafen
Neustadt, Hafen
Kiel, Binnenhafen
Heiligenhafen, Hafen
Fehmarnbelt, Osteingang
Eckernförde, Hafen
Schlei, Schleswig – Kappeln
Schlei, Kappeln – Schleimün
Flensburg – Holnis
Brunsbüttel, Kanalzufahrt
Ellenbogen (Sylt), Listertief
Dagebüll, Hafen
Dagebüller Fahrwasser
Wyk auf Föhr, Hafen
Husum, Hafen
Husum, Au

Fig. A1, contd.


2013
Dec
Jan
Feb
Mar
Apr
Tönning, Hafen
Eiderdamm, Seegebiet
Büsum, Hafen
Büsum, Norderpiep
Büsum, Süderpiep
Harburg, Elbe
Hamburg, Elbbrücken-Kehrw
Hamburg-Landungsbrücken,
Altona, Elbe
Stadersand, Elbe
Glückstadt, Hafen und Einfal
Glückstadt, Elbe
Brunsbüttel, Elbe
Bremen, Weser
Bremerhaven, Weser
Papenburg – Emden
Emden, Neuer Binnenhafen
Emden, Ems und Aussenhaf
Ems, Emden – Randzelgat
Borkum, Randzelgat
Legend
Ice concentration
Open water
Very open ice
Open ice
Close ice
Very close ice
Fast ice
Ice thickness
< 5 cm
5 - 10 cm
10 - 15 cm
15 - 30 cm
30 - 50 cm
50 - 70 cm
70 -120 cm
Topographie or form of ice
Rotten
Ridged
Rafted