The ice winter of 2010/11 on the German North and Baltic Sea coasts and a brief description of the ice conditions in the entire Baltic Sea region

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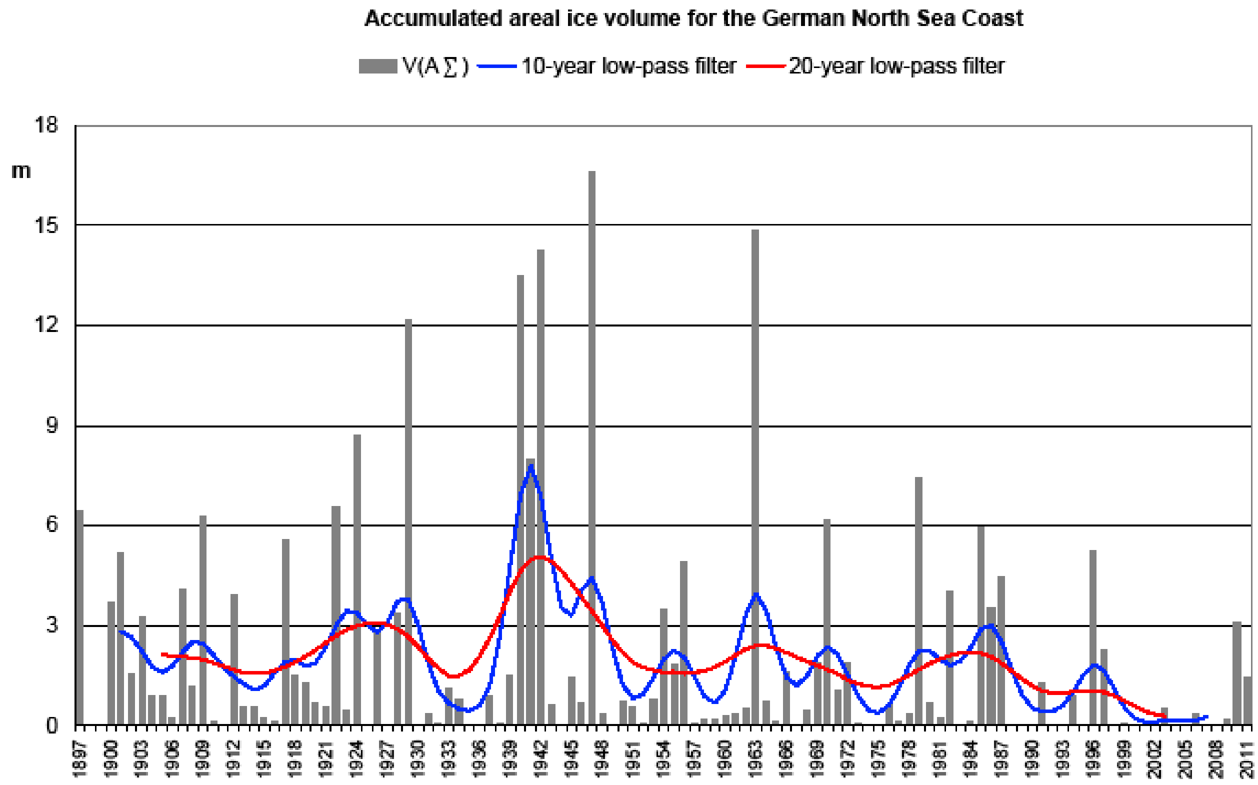


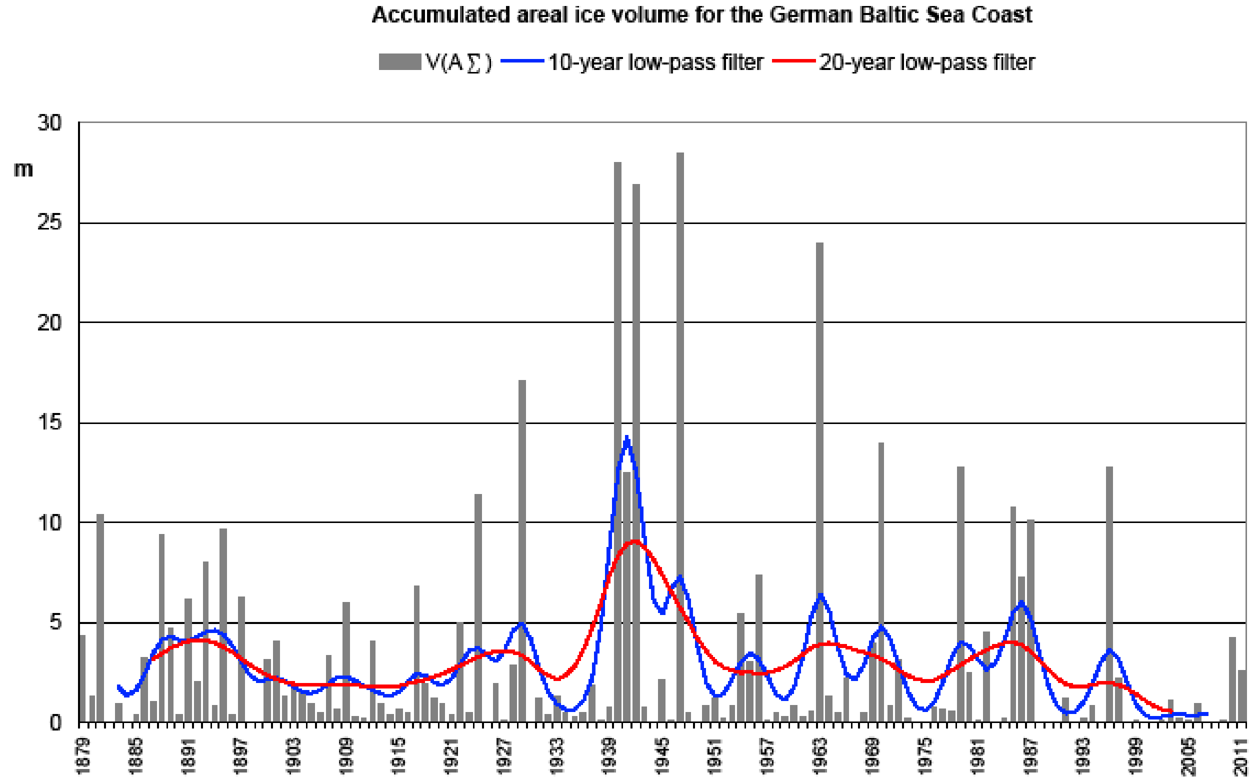


Figure 1. Distribution of accumulated areal ice volume on the German North Sea coast in the period from 1897 to 2011 and on the German Baltic Sea coast in the period from 1879 to 2011

General

In terms of ice volume and duration of the ice cover in the German coastal waters, the winter of 2010/11 was a **moderate** ice season.

In the ice winter of 2010/11, the accumulated areal ice volume expressing the severity of ice winters on the German coast, http://www.bsh.de/de/Meeresdaten/Beobachtungen/Eis/Kuesten.jsp, is **1.47 m** for the North Sea, and **2.45 m** for the Baltic Sea**,** cf. Fig. 1. The frequency of moderate ice winters in the past 50 years (1961 – 2010) is 34% on the North Sea coast, and 32% on the Baltic Sea coast.

From late November to early January, the entire Baltic Sea region was under the influence of cold polar air from northerly, northeasterly or easterly directions. This cold spell was interrupted by several short periods during which warmer air masses flowed into the area from the west or south, mostly with precipitation in the form of snow. The ice cover of the Baltic Sea in early January corresponded to conditions which normally prevail at the end of January / early February. Fig. 2 shows the maximum ice extent in the ice winter of 2007/08, known as the weakest ice winter in 300 years, compared to the ice extent on 5 January 2011. At this early date, the winter of 2010/11 in the western and southern Baltic Sea already met the criteria for a moderate ice winter. Based on maximum ice coverage in the entire Baltic Sea, which was 309 000 km^2 around 25 February (information from the ice service of Finland), cf. Figs. 3 and 4, the winter of 2010/11 has been classified as a **severe** ice winter.

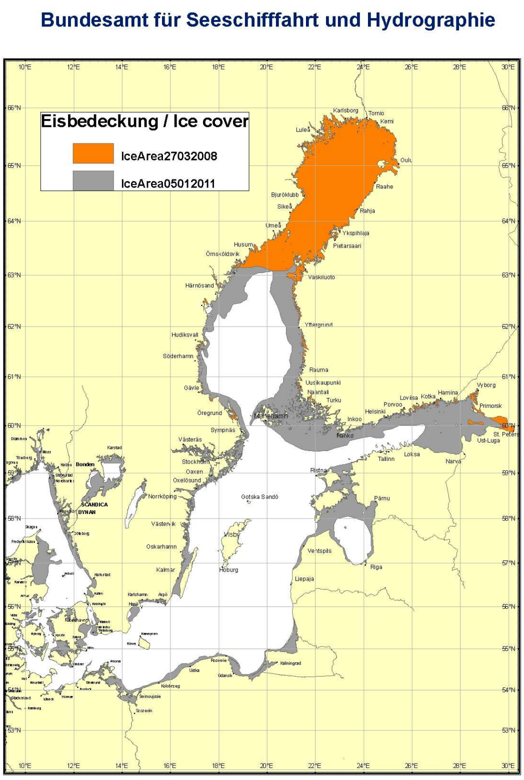


Figure 2. Comparison of maximum ice extent (26./27.03.) in the very weak ice winter of 2007/08 with the ice situation on 05.01.2011

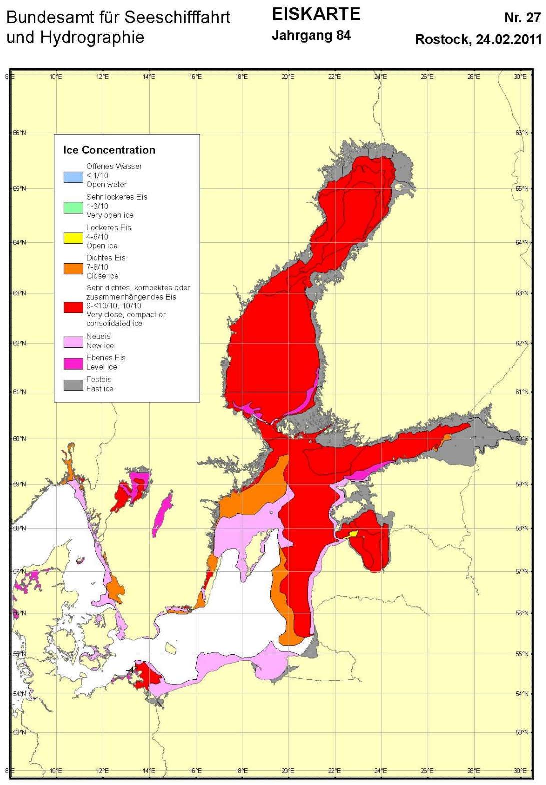


Figure 3. Maximum ice extent in the entire Baltic Sea on 24 February 2011

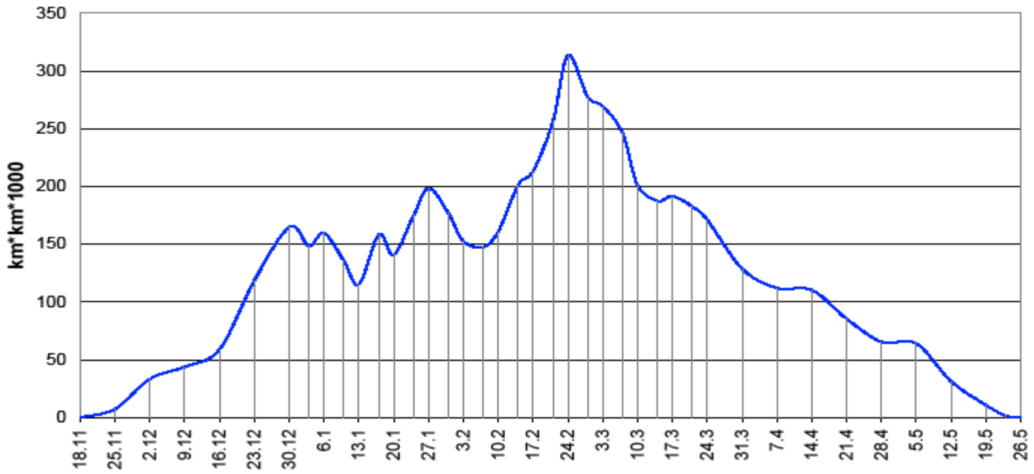


Figure 4. Daily ice extent in the entire Baltic Sea in the winter of 2010/11

During the ice winter of **2010/11**, the BSH issued the following information about the ice situation and expected ice development in the entire Baltic Sea and the German coastal waters:

- 127 ice reports (official reports issued Mo – Fr),
- 52 general ice charts (twice weekly, as annex to the ice reports),
- 87 German Ice Reports (international exchange, issued when ice forms on German shipping lanes)
- about 300 NAVTEX reports (in German and English for the German North and Baltic Sea coasts)
- 70 ice reports "German Baltic Sea coast" (detailed description of ice situation for German users)
- 34 ice reports “German North Sea coast” (detailed description of ice situation for German users)
- 60 Ice Charts for the western Baltic Sea, Kattegat and Skagerrak
- 33 Ice Charts (Radiofax-Charts for the western Baltic Sea, Kattegat and Skagerrak)
- 108 special ice charts (German Baltic Sea coast and Baltic Proper)
- 26 weekly reports (information for the Federal Ministry of Transport, Building and Urban Affairs, and to MURSYS)
- information provided to individual users.

About 80 users received the BSH’s ice reports and ice charts via E-mail. Several libraries and scientific institutions receive products of the Ice Service by post in exchange for other printed material. All current reports and charts are additionally published on the Internet, free of charge, at http://www.bsh.de/de/Meeresdaten/Beobachtungen/Eis/, ftp://ftp.bsh.de/outgoing/eisbericht.

The Table below shows the number of views of Ice Service products on the BSH’s homepage:

		Current Ice Report	**Current General Ice Chart**	**Current Western Baltic Sea Ice Chart**
December	2010	2500	2558	29060
January	2011	1878	1867	23042
February	2011	2143	3043	13609
March	2011	2042	2142	6110
April	2011	889	926	0
May	2011	681	554	0

Weather conditions in the German coastal areas during winter

November 2010 was slightly too warm on the eastern coasts, and too cold in the west, see Table 1. In the first half of the month, the coasts were under the influence of mild air from the southwest and west, causing daily temperatures in the Baltic Sea area to rise up to 15℃. Gradual cooling due to cold air flowing in from Scandinavia did not set in until the third decade of the month. At the end of November, an inflow of cold air from Siberia affected the entire North and Baltic Sea region, causing continuous frost (S. Haeseler, 2010), cf. Fig. 5. Occasional strong snow showers accelerated cooling of the inner coastal waters, Fig. 6.

Table 1. Monthly mean air temperatures (℃) in the winter of 2010/11, and deviations from the 1961 – 1990 climate means (K) (data from Deutscher Wetterdienst, www.dwd.de)

Station	November		December		January		February		March	
	℃	K	℃	K	℃	K	℃	K	℃	K
Greifswald	5.0	0.4	-4.2	-5.3	1.0	1.6	-0.2	-0.2	3.6	0.9
Rostock-Warnemünde	5.4	0.1	-3.3	-5.2	1.4	1.2	0.4	-0.3	3.5	0.4
Schleswig	3.8	-1.1	-4.1	-5.8	0.6	0.3	0.6	0.0	3.6	0.8
Helgoland	6.4	-1.2	0.1	-4.3	2.6	0.1	1.9	-0.2	3.9	1.8

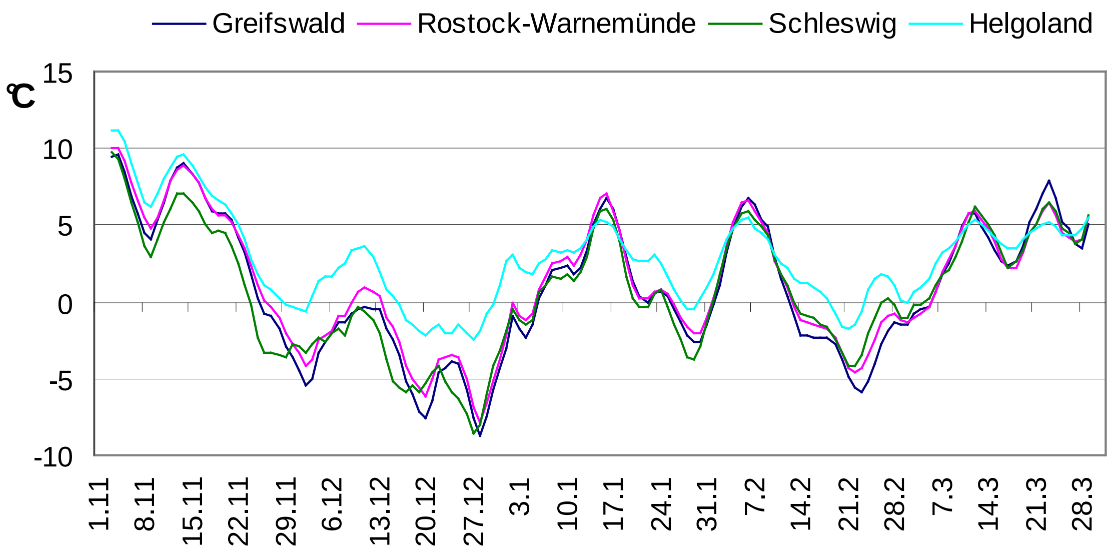
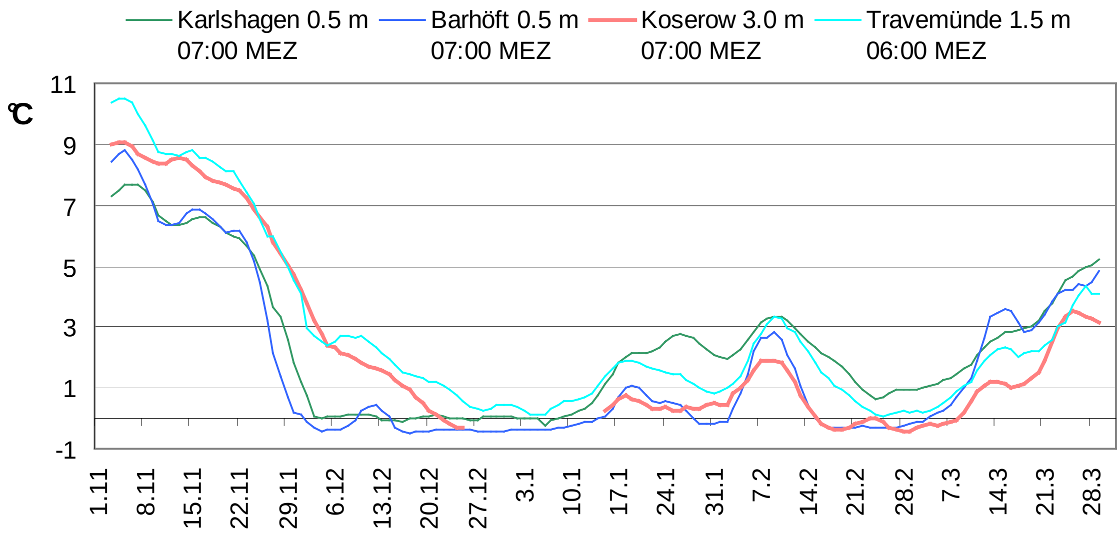
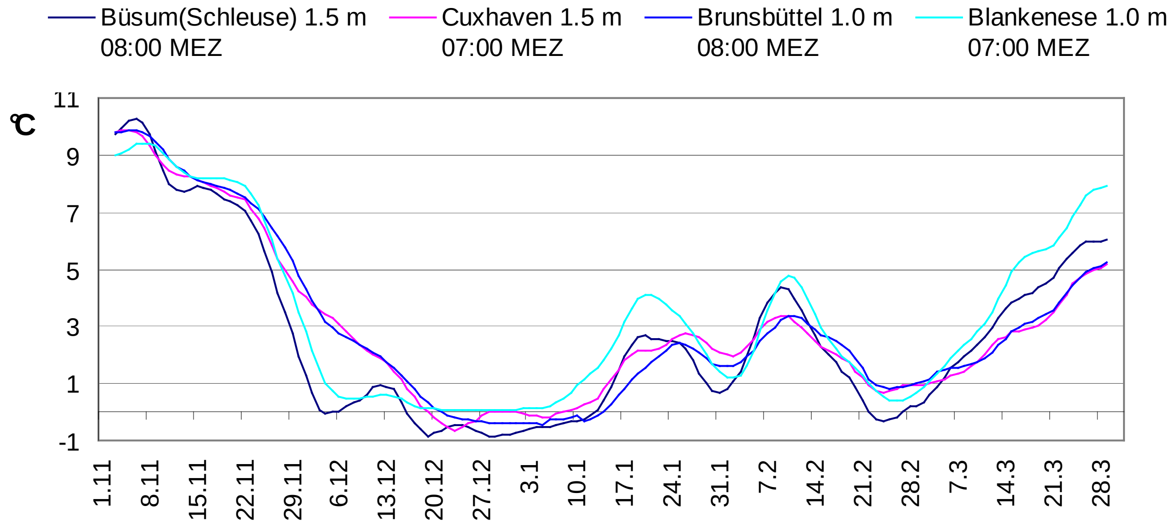


Fig. 5. 5-day daily running mean of air temperatures in the winter of 2010/11 (data from Deutscher Wetterdienst, www.dwd.de)

December 2010 was the coldest month of the winter of 2010/11 and had the most snow. Monthly mean temperatures in the coastal areas deviated -4 to -6 K from the long-term means. The thickness of the snow cover in the north and east reached 20 to 40 cm, and near the Baltic coast up to 50 cm. The continuous frost in this area was caused by repeated inflows of very cold Arctic air, which northerly to northeasterly winds transported south as far as the western Baltic, and westward to the German Bight. In the German inner coastal waters, the water was close to freezing at the beginning of the month, and also on the outer coasts water temperatures reached freezing point in the third decade of December. January and February, the typical winter months, were mild in comparison with December. At the beginning of the year, southwesterly winds caused an inflow of mild maritime air on the front side of the low over Norway, marking the beginning of a warm spell. The thawing period lasted until mid-February, interrupted only briefly for a few days at the end of January. In the second decade of February, a high-pressure zone developed over Scandinavia which grew stronger as it slowly moved east. This anticyclone influenced weather in the coastal region until early March, with mostly calm, cold winter weather. The Baltic Sea region remained longer under the influence of the cold air masses than the North Sea coast, with the line of separation between cold and warm air running diagonally across Germany from northwest to





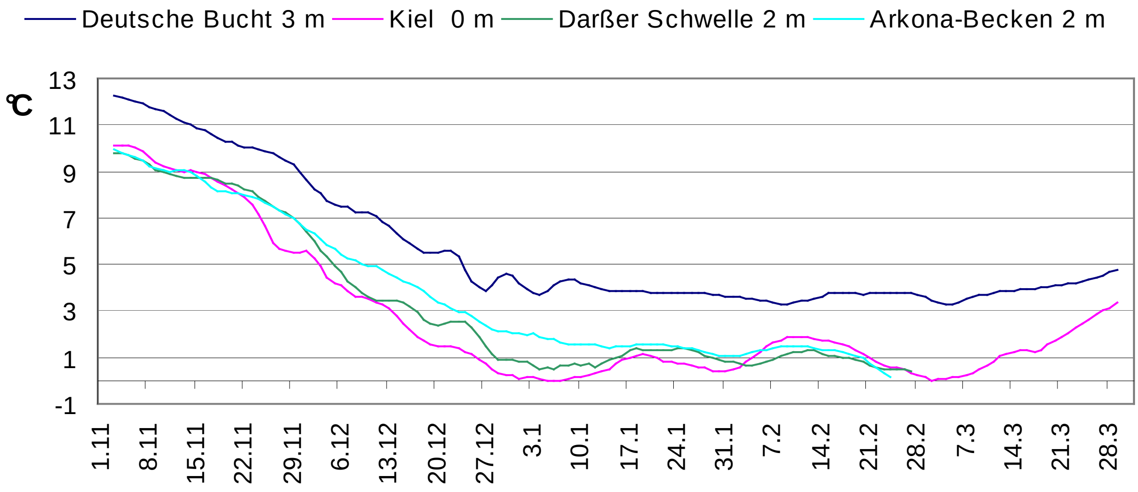


Figure 6. Water temperature in the western Baltic Sea and in the German Bight

Quellen der Messungen: Karlshagen und Barhöft, WSA Stralsund; Koserow, StALU Mittleres Mecklenburg, Dienststelle Rostock; Travemünde, WSA Lübeck; Brunsbüttel, WSA Brunsbüttel; Büsum, Schleuse Büsum; Cuxhaven, DWD; Blankenese, Institut für Hygiene und Umwelt, Hamburg; MARNET - Messnetz, Bundesamt für Seeschifffahrt und Hydrographie (BSH), Leibniz-Institut für Ostseeforschung Warnemünde (IOW) southeast. The water surface cooled quickly, not only in the sheltered inner coastal waters but also offshore, especially in the Pomeranian Bight. The predominantly easterly winds freshened only on a few days. Daily mean temperatures in January generally were 1-2 K above the long-term means, and February had average temperatures. Calm anti-cyclonic conditions also determined the coastal weather during most of March. During the first, and parts of the last, decade of the month, air temperatures at night were below freezing. By day, longer insolation caused a marked temperature rise. March temperatures in the coastal region were 0.5 to 2 K too warm.

Ice conditions on the German North Sea coast

Ice production on the German North Sea coast this winter was about half of that produced in the ice winter of 2009/10, cf. Fig. 7. In spite of that, both winters have been classified as moderate ice winters, whose frequency of occurrence in the North Sea region has been 34% in the 50-year period from 1961 to 2010.

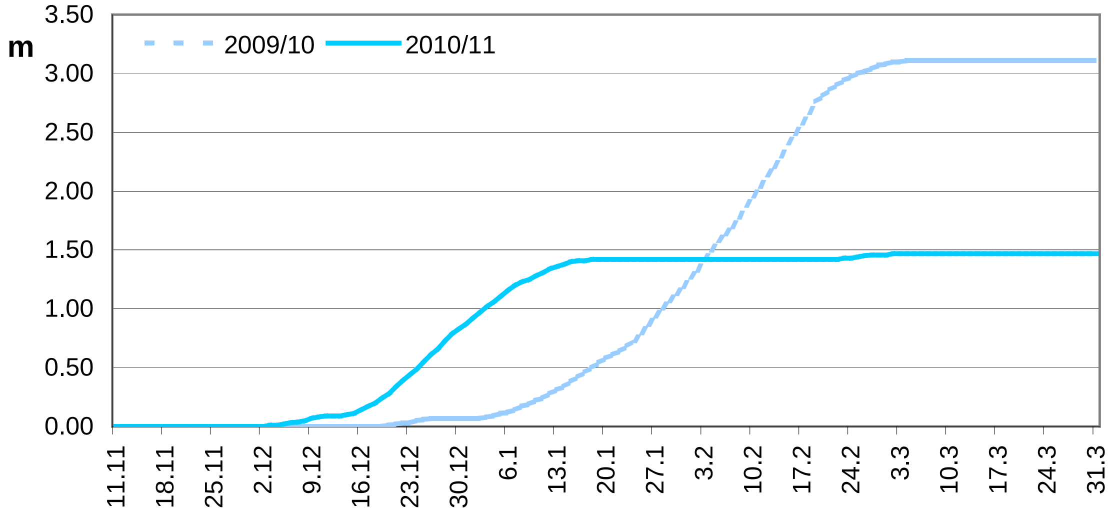
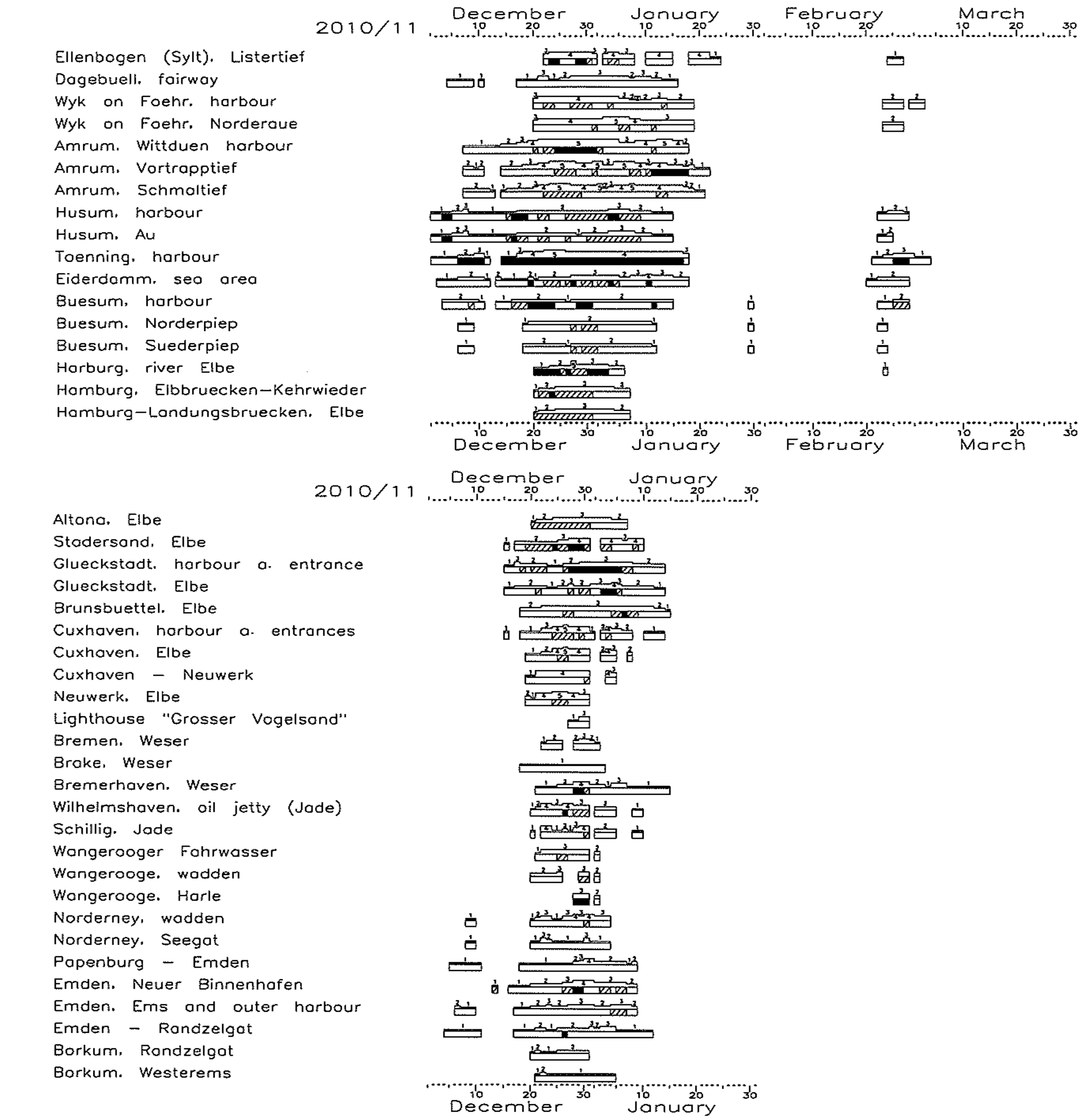
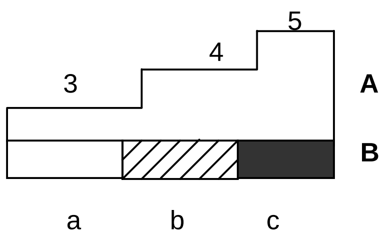


Figure 7. Accumulated areal ice volume on the German North Sea coast in the winters of 2009/10 and 2010/11

Meteorological conditions on the German North Sea coast in the winter of 2010/11 led to two periods of ice formation. The largest volume of ice was produced during the first cold spell from late November to early January. During the second half of February, the second period of ice formation, the volume of ice produced on the North Sea coast was so small that the North Sea tributaries and the East Frisian coasts remained completely free of ice, cf. Fig. 8 and the coloured plot diagrams in Fig. A1 in the Annex.

First ice formed in several harbours and inner waters of the East and North Frisian coasts in early December 2010 (Table A1 in the Annex). Ice formation continued steadily and reached its maximum on the last days of December, cf. ice chart in Fig. 9. At this point, the tidal flats and inner areas of the rivers Ems, Weser, and Elbe were covered with very open to very close ice. The ice reached thicknesses of 5 to 15 cm in some southern parts of the coast, and 10 to 30 cm on the North Frisian coast. Tidal forcing and temporarily freshening onshore winds caused ice ridging of 50 – 80 cm height in some coastal sections. On the whole, ice on the East Frisian coast and in the North Sea tributaries lasted up to 4 weeks, and along the North Frisian coast 30 to 60 days. Low-powered vessels were obstructed by ice on a few days, and the harbour of Tönning was closed to shipping for 26 days, cf. Table A2 in the Annex.





A – Eisdicke / Ice thickness
1: < 5 cm 2: 5-10 cm
3: 11-15 cm 4: 16-30 cm
5: 31-50 cm

B – Bedeckungsgrad / Ice concentration
a: < 7/10 b: 7/10-8/10
c: 9/10-10/10

Figure 8. Daily ice occurrence on the German North Sea coast in the ice winter of 2010/11

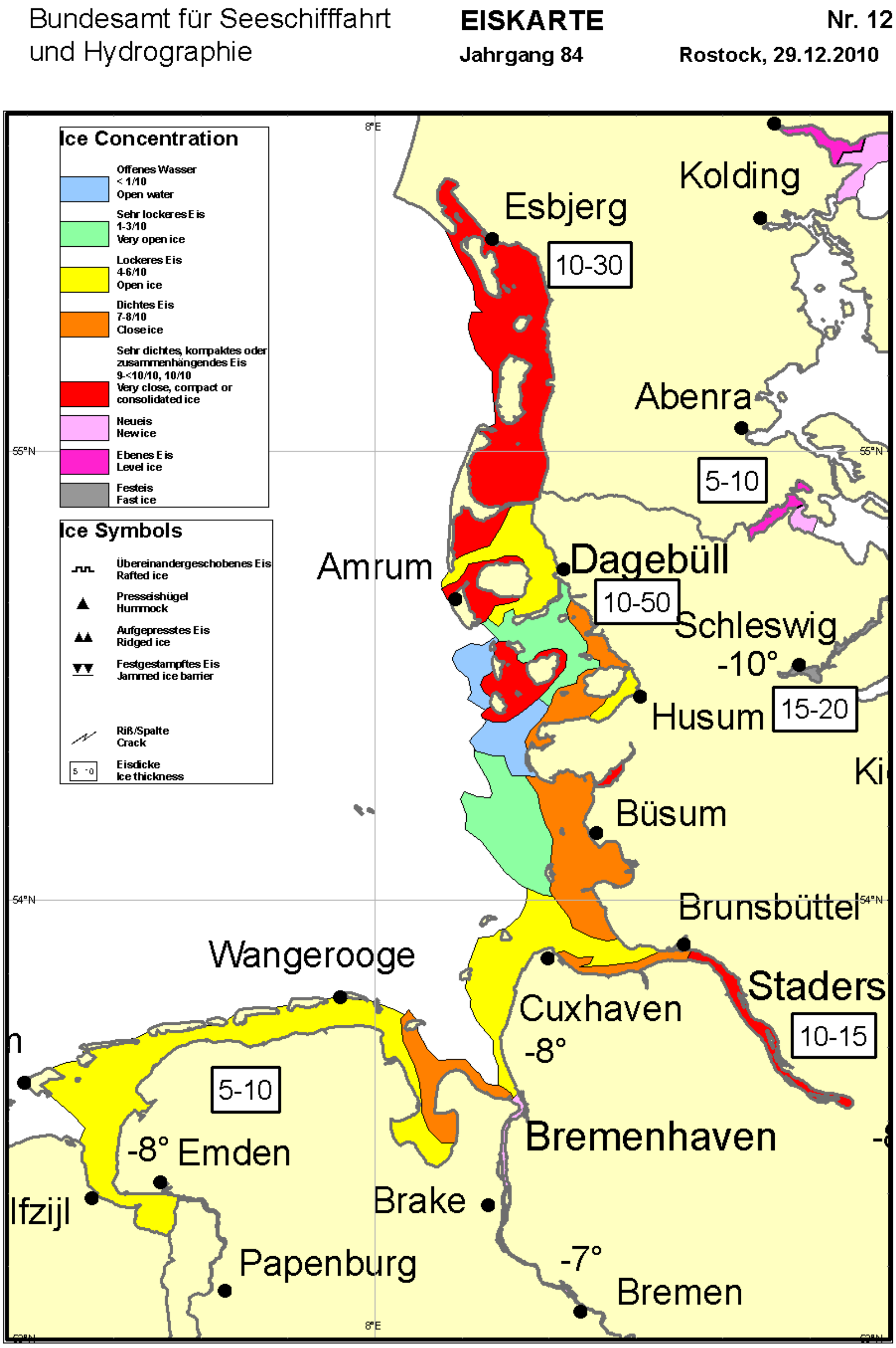


Figure 9. Ice conditions on the German North Sea coast in the winter of 2010/11 at the time of maximum ice development

On 16 December, first ice formed near Brunsbüttel in the approaches to Kiel Canal, and last ice in this area melted on 14 January. In Kiel Canal, ice occurred between Holtenau and Brunsbüttel on about 20 days, with ice thicknesses of 10 to 15 cm. Coastal navigation was impeded by ice on a few days only, cf. Fig. 10.

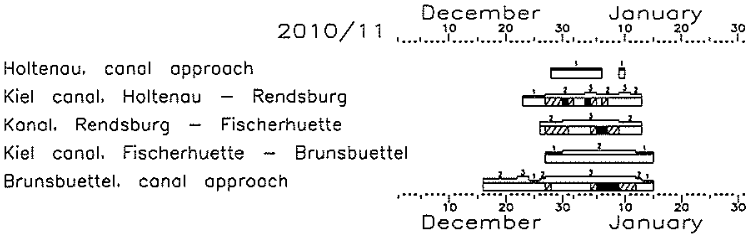


Figure 10. Daily ice occurrence on the Kiel Canal in the ice winter of 2010/11

Ice conditions on the German Baltic Sea coast

The ice winter of 2010/11 on the German Baltic Sea coast was of shorter duration and produced less ice (n = 35.5 days, $V_{A\Sigma}$ = 2.45 m) than the year before (n = 45.8 days, $V_{A\Sigma}$ = 4.22 m), cf. Fig. 11). It was classified as a moderate ice winter, whose relative frequency in the western Baltic Sea is 32%.

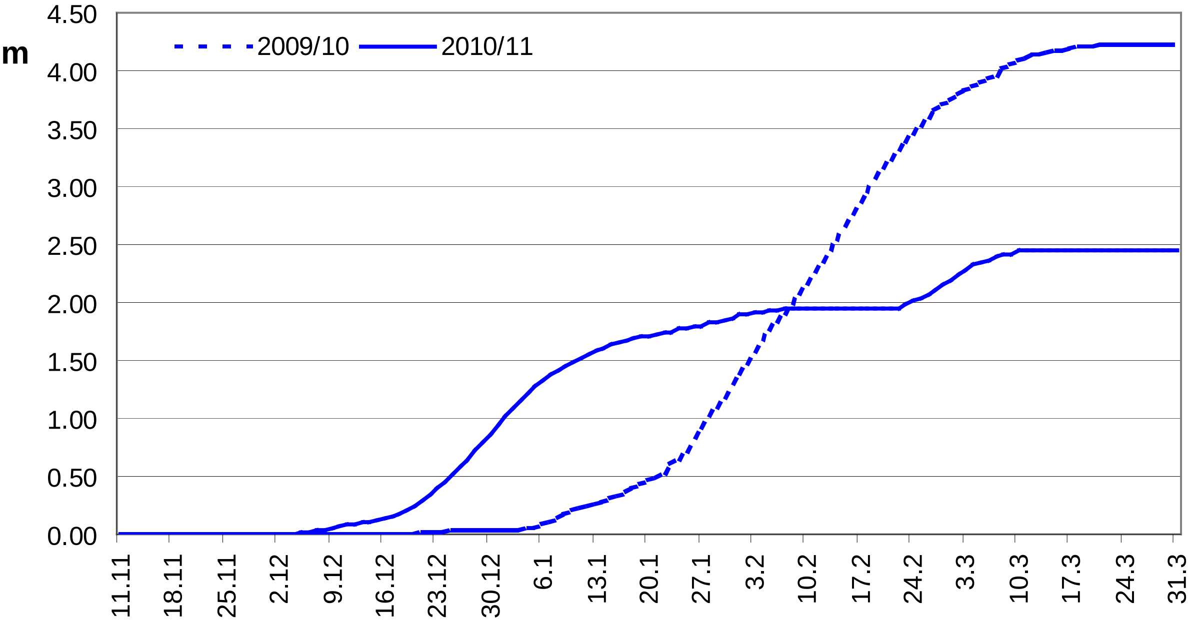
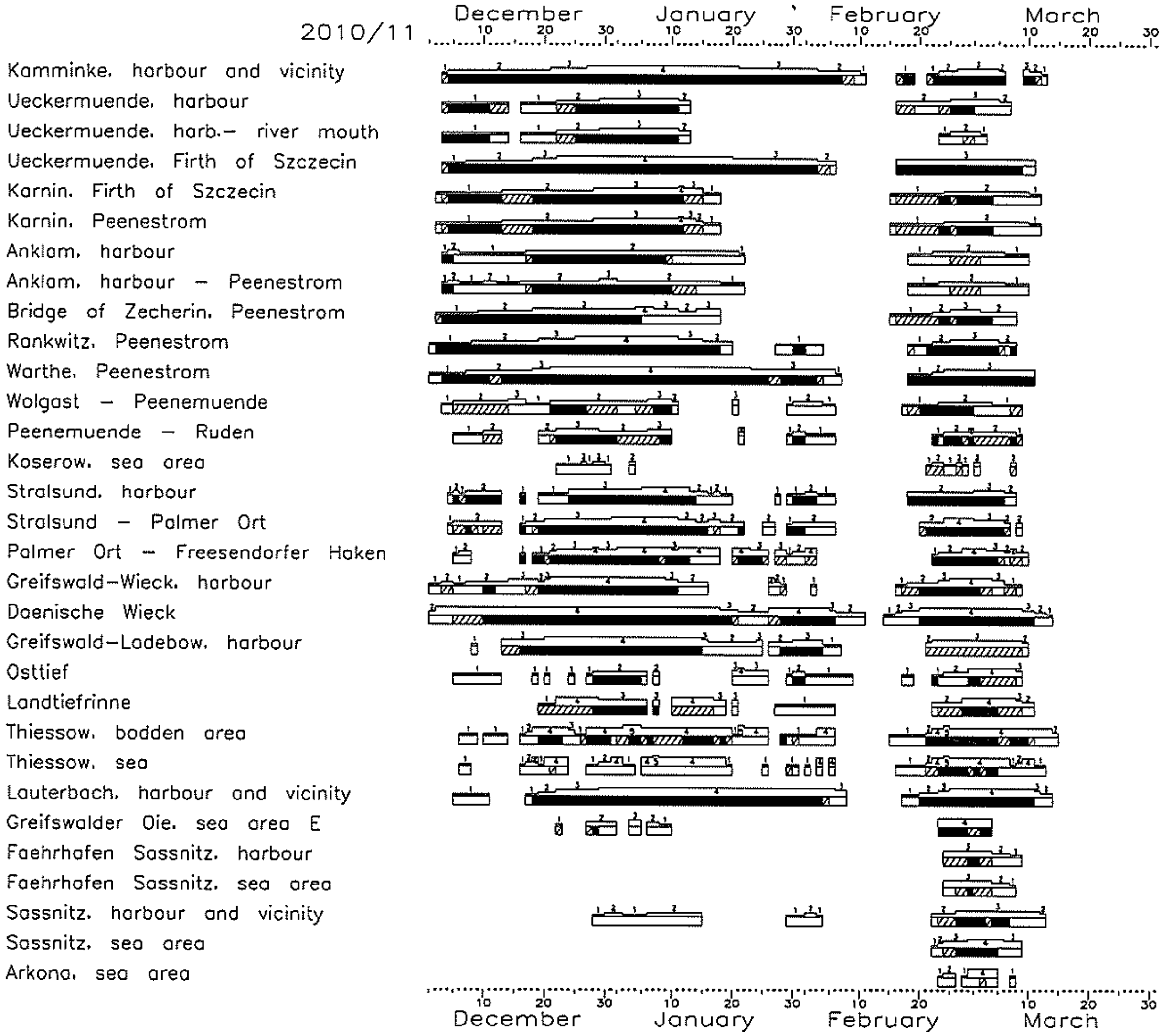
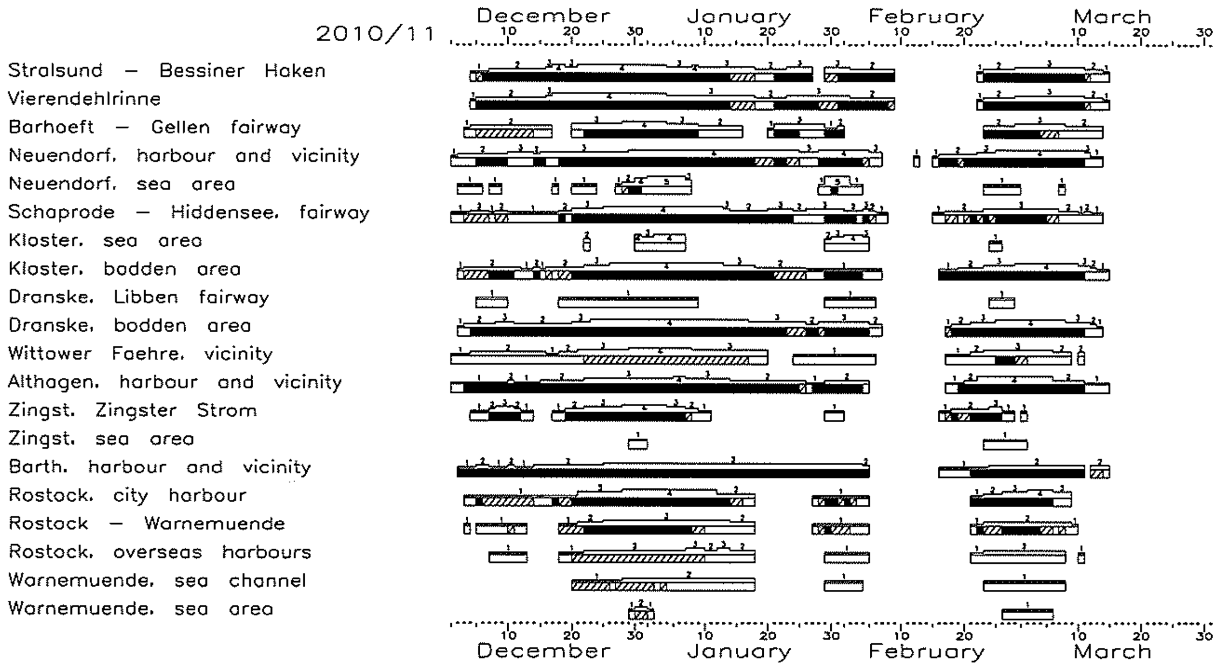


Figure 11. Accumulated areal ice volume on the German Baltic Sea coast in the ice winters of 20009/10 and 2010/11





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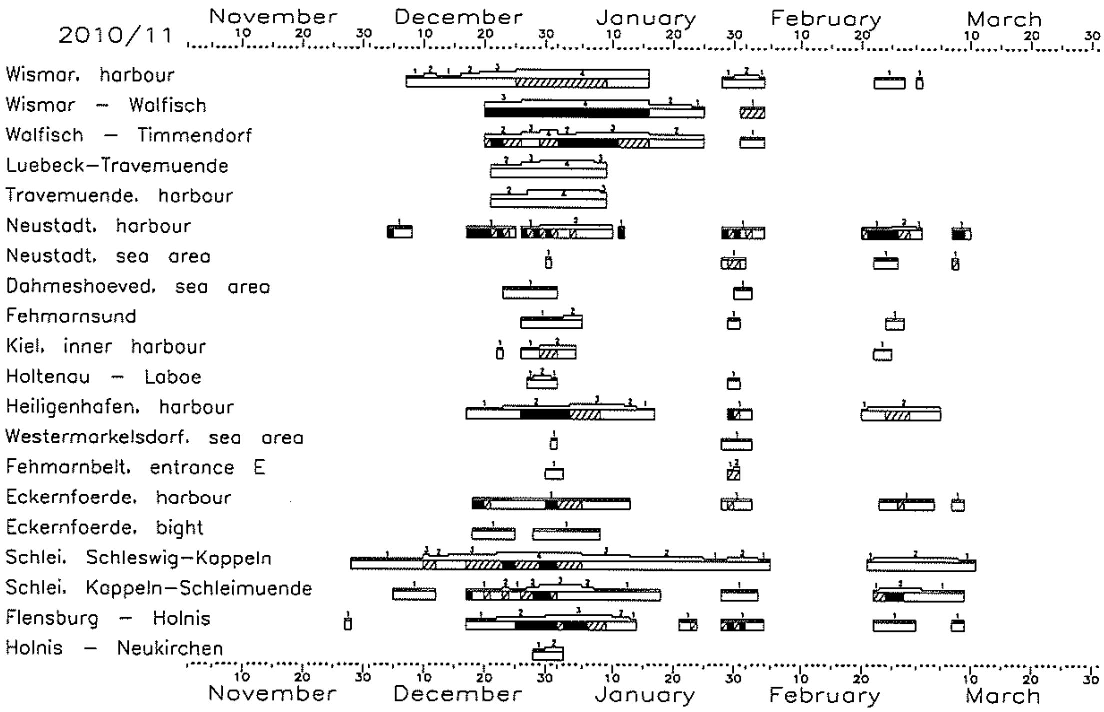

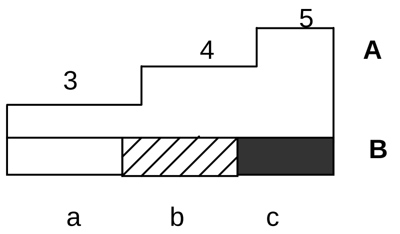

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1: < 5 cm   2: 5-10 cm
3: 11-15 cm   4: 16-30 cm
5: 31-50 cm

B – Bedeckungsgrad / Ice concentration
a: < 7/10   b: 7/10-8/10
c: 9/10-10/10

Figure 12. Daily ice occurrence on the German Baltic Sea coast in the winter of 2010/11

The daily development of ice conditions on the German Baltic Sea coast is shown in Fig. 12 and Fig. A1 in the Annex.

In the winter of 2010/11, two separate periods of ice formation occurred also on the German Baltic Sea coast. Ice formation in the sheltered areas (bodden waters, Schlei) began during the last days of November or first days of December, 3 - 4 weeks earlier than normal. Normally, first ice in the bodden waters forms around 20 December, and in the waters around Stralsund in late December. In the 52nd week (27.12.2010 – 02.01.2011), ice also formed on the outer coasts and temporarily in the offshore waters of the Kiel and Mecklenburg Bights. After just a few days, the ice had largely disappeared due to water level fluctuations and wind forcing. The maximum of ice development was reached during the first cold spell, on 30/31 December 2010, cf. Fig. 13. Ice conditions at that time were as follows:

Offshore waters and outer coast

Ice fields of 10 – 20 cm thickness occurred in the southern Pomeranian Bight. Thin drifting ice floes occurred sporadically east of Greifswalder Oie. Compact ice of about 15 cm thickness occurred on the west coast of the island Hiddensee. Offshore, new ice was observed off Warnemünde, on the outer coasts of the Darss peninsula and along the coasts of the Bay of Lübeck. In the Fehmarn Belt, pancake ice and some new ice occurred close to the shores.

Main fairways
Fairway to Flensburg: The harbour was covered with very close, 10-15 cm thick ice, the inner fjord with 5-10 cm thick ice. Very open thin ice occurred in the outer fjord.
Fairway to Schleswig: The inner Schlei was covered completely with 20 cm thick ice. Between Kappeln and Schleimünde, the ice was 10 cm thick.
Fairway to Eckernförde: Very close new ice covered the harbour waters, very open new ice floated in the Bight.
Kiel Bight: Close thin ice occurred in the inner harbour of Kiel, open water in the inner fjord. The harbour of Heiligenhafen was covered with 5-10 cm thick ice through which a fairway had been cut; brash ice floated in the fairway. Thin ice on the margins, slush, and new ice occurred in the western approaches to Fehmarn Sound.
Bay of Lübeck: On the river Trave, open ice of 10-20 cm thickness was observed in the navigation fairway. The ice in the harbour of Travemünde was very open and 10-20 cm thick. Open, thin drift ice was observed in the harbour of Neustadt. Off Dahmeshöved, a narrow belt of ice sludge drifted seaward.
Fairway to Wismar: Ice in the harbour was 15-20 cm thick; fast ice of about 20 cm thickness occurred as far as buoys 22 and 24, with a navigation fairway cut through it, and new ice was observed beyond Timmendorf.
Fairway to Rostock: An ice cover of 10-20 cm thickness had formed in the city harbour and on the Lower Warnow; thin to compact, 10-15 cm thick ice occurred in the sea ports, and close thin ice in the sea fairway and offshore waters.
Fairway to Stralsund: In the harbour of Stralsund and as far as Freesendorfer Haken, a fairway had been cut through an ice cover of 10-20 cm thickness. In the Landtief and Osttief, a fairway had been cut through consolidated ice of 5 – 15 cm thickness.
Fairway to Sassnitz: Open thin ice and new ice floated in the harbour of Sassnitz.
Fairway to Wolgast: Close to compact 5-10 cm thick ice occurred from Wolgast to Ruden; a navigation fairway had been cut.

Bodden waters:
Bodden south of Darss und Zingst peninsula: Covered with 15-20 cm thick ice. Consolidated, 20-25 cm thick ice occurred in the Zingster Strom.
Bodden between Rügen and Hiddensee: Covered with 15-25 cm thick fast ice. Near the Wittow ferry, close ice was 15-20 cm thick.
Greifswalder Bodden: In the harbour of Greifswald-Wieck and in Dänische Wiek, there was a closed ice cover of about 16 cm thickness, close to shore about 25 cm. On the north coast, fast ice reached 10-20 cm thickness. In the other areas, consolidated ice of 10-20 cm thickness prevailed. In the outer waters, single thin ice floes drifted eastward.
River Peene: Covered with about 10 cm thick ice.
Peenestrom: Covered with 10-25 cm thick fast ice from Wolgast southward.
Szczecin Lagoon: 10-25 cm thick fast ice.

The general ice situation and growing ice cover caused the Stralsund Waterways and Shipping Board to impose the following navigation restrictions for all areas under its responsibility:

09.12.2010: Navigation at night is prohibited in the pilotage areas of Stralsund and Wolgast, in the approaches to the harbours along Greifswalder Bodden and Kleines Haff, and on the river Peene.

15.12.2010: The pilotage areas of Kleines Haff and southern Peenestrom, the river Peene and, from the end of the year, the northern approach to Stralsund including the western bodden waters are closed to navigation. Use of icebreakers is discontinued.

01.01.2011: Icebreaker assistance in the approaches to the north and south harbours of Stralsund, in the harbours along the southern coast of Greifswalder Bodden (Lubmin, Vierow, Ladebow), and in the harbour of Wolgast is only provided to ice-strengthened vessels having an ice class (1C or higher). The engine output of such vessels must be at least 1000 KW.

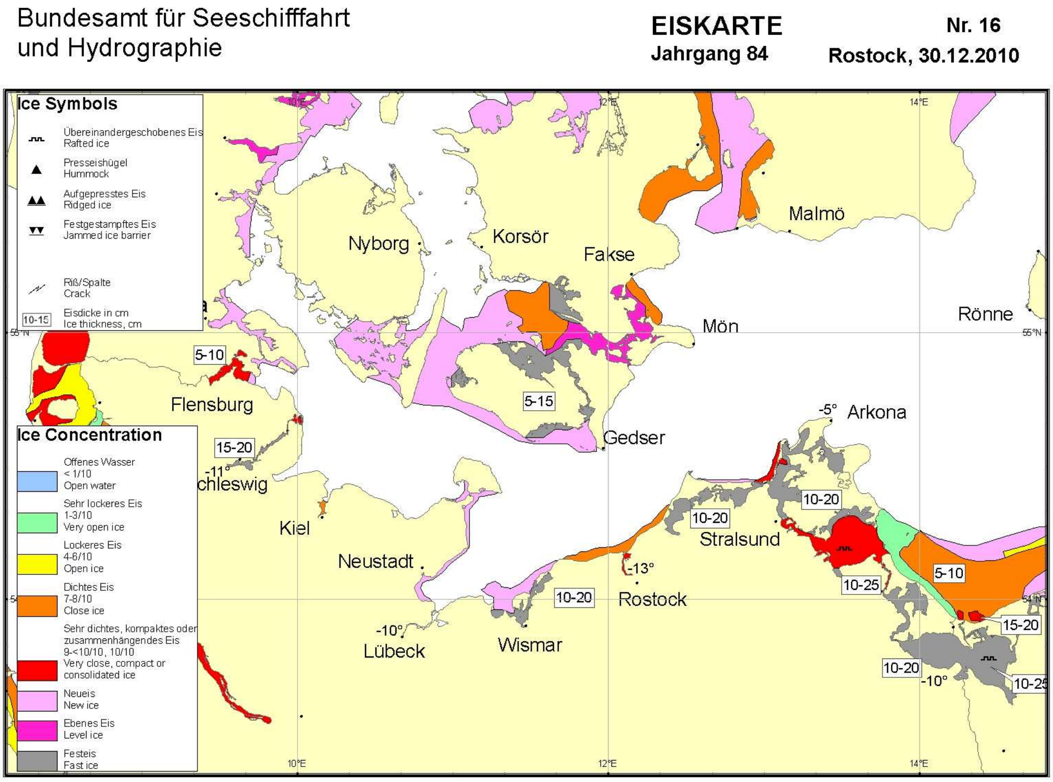

Figure 13. Ice situation in the western Baltic Sea on 30 December 2010

During the next five weeks, the development of ice was slow, with an initially weak decreasing trend followed by a faster melt-down of ice. Between 8 and 16 February, also the inner coastal waters of Vorpommern were completely free of ice. This was due to two successive warm spells with temperatures of up to 9℃, temporary rain, and fresh westerly to southwesterly winds. In mid-February, the weather situation changed once more: on the south side of a high-pressure zone over northern Scandinavia, southeasterly to easterly winds brough moderately cold air into the German coastal areas. New ice began to form in the inner coastal waters along the eastern Baltic coast. Decreasing wind and falling temperatures during the next few days led to increasing ice formation, also in the inner coastal waters of the western part of the coast. However, the strongest ice formation was recorded on the eastern coast, where the inner waters soon were covered completely with ice. Pancake ice which had newly formed in the Pomeranian Bight quickly formed a closed ice cover. The second maximum of ice development was reached on 27/28 February, cf. Fig. 14. Ice thicknesses between 5 and 20 cm were measured, with the larger values recorded in areas where ice rafting occurred. The ice forming during the second cold spell disappeared as quickly as it had developed: by mid-March, all German Baltic Sea waters were free of ice.

Conclusions

Early ice formation does not necessarily imply that a severe or very severe ice winter is imminent. In the waters around Stralsund, ice normally begins to form at the end of December, the earliest date on record being 20 November (winter of 1965/66). The average date of beginning ice formation in the bodden waters is 20 December, and the earliest date is mid-November (e.g. 15 Nov. 1965, and 16 Nov. 1984 in Kleines Haff). The winter of 1965/66 was a moderate ice winter, that of 1984/85 a very severe ice winter. Also the ice season of 2010/11 has been classified as a moderate ice winter despite its early beginning.

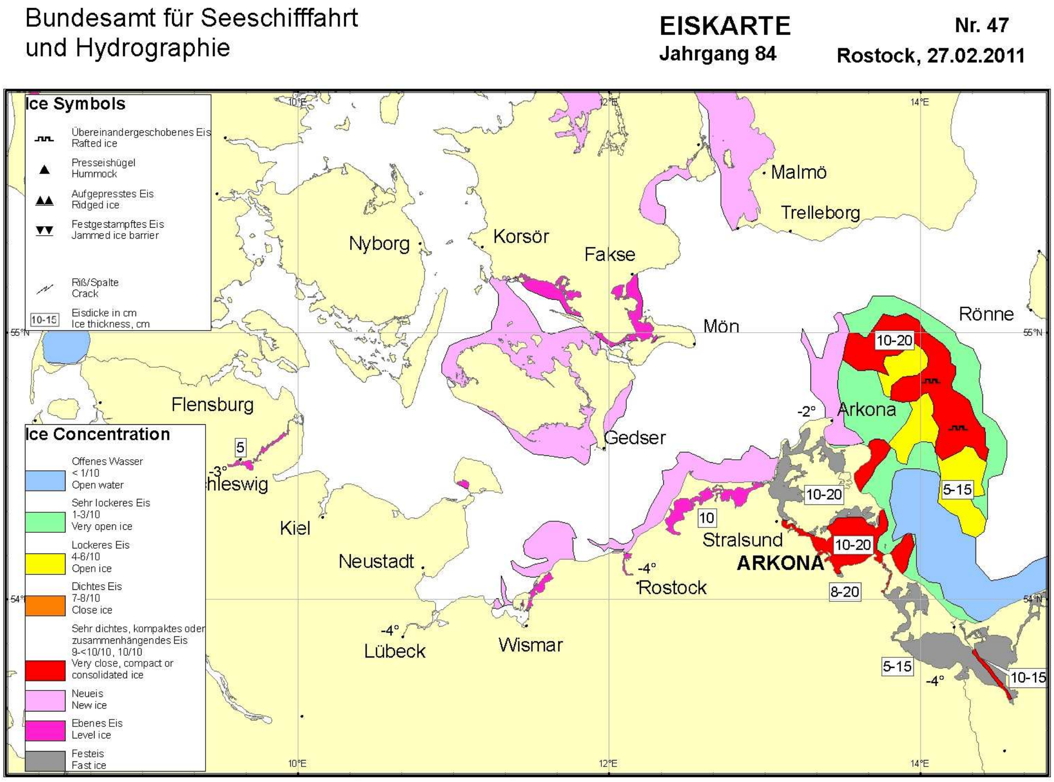

Figure 14. Ice situation in the western Baltic Sea on 27 February 2011

Relationship between accumulated areal ice volume and winter severity index

In the ice winters of 2009/10 and 2010/11, sufficient ice was produced to allow a verification of the relationship between the accumulated areal ice volume ($V_{A\Sigma}$) and the modified winter severity index (W_z*). The accumulated areal ice volume indicates the severity of an ice winter, and the winter severity index stands for the meteorological characteristics of a winter. The relationship between the two quantities was found empirically and has been described in the paper by G. Koslowski "Die flächenbezogene Eisvolumensumme, eine neue Maßzahl für die Bewertung des Eiswinters an der Ostseeküste Schleswig-Holsteins und ihr Zusammenhang mit dem Charakter des meteorologischen Winters" published in the "Deutsche Hydrographische Zeitschrift", vol. 42, p. 61-80.

Figs. 15 and 16 show the relationship between $V_{A\Sigma}$ and W_z* and the accumulated areal ice volume figures of the last 6 ice winters which were strong or moderate on the coast of Schleswig-Holstein (coefficient of determination $R^2 = 0.9853$). The large deviations of the $V_{A\Sigma}$ values measured on the coasts of Schleswig-Holstein from the $V_{A\Sigma}$ part of the regression equation, by 2 m, are clearly minimised by taking into account the influence of relative humidity, cf. Fig. 17. The „dry" ice winters of 1995/96 and 1996/97 are better described by the equation for winters with a „low" relative humidity, and the „wet" ice winters of 2002/03, 2005/06, 2009/10, and 2010/11 by the equation for winters with a „high" relative humidity (around 90% on average). The relationship between $V_{A\Sigma}$ and W_z* on the coast of Mecklenburg-Vorpommern is dealt with separately. Differences in the prevailing meteorological conditions and coastal morphology often lead to differences in ice production, mostly with more ice produced in the east. Good examples are the past two winter seasons: $V_{A\Sigma}$(SH, 2010) = 2.93 m , $V_{A\Sigma}$(MV, 2010) = 5.33 m, $V_{A\Sigma}$(SH, 2011) = 1.39 m, $V_{A\Sigma}$(MV, 2011) = 3.35 m. Averaged values in this case are not likely to produce a good match with meteorological characteristics.

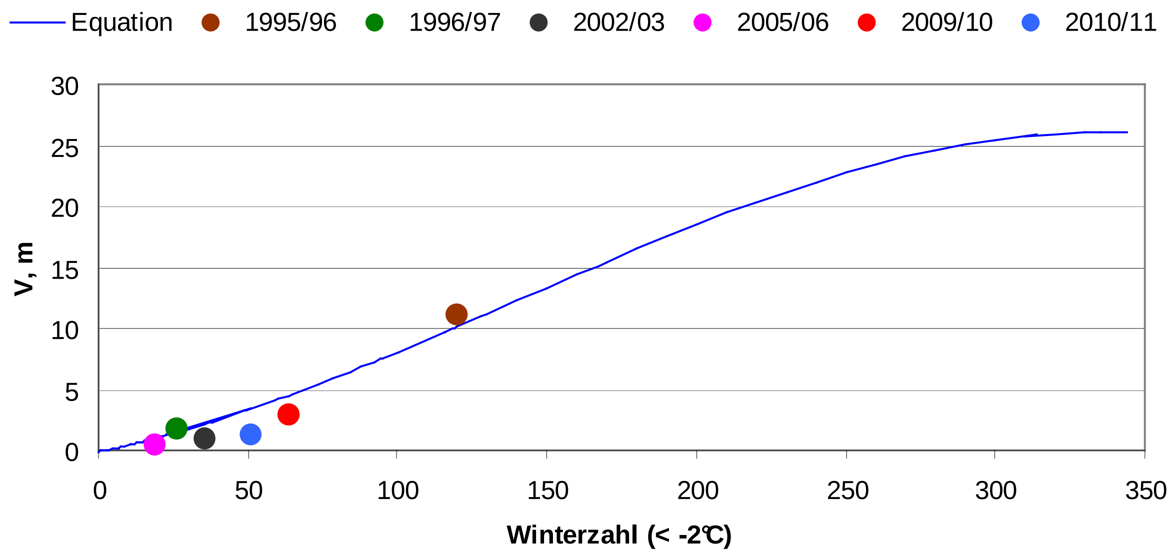

Figure 15. Regression curve for the accumulated areal ice volume on the coast of Schleswig-Holstein and winter severity index W_z^* (Tm < -2.0℃) for Schleswig

Equation: $V_{A\Sigma} = -0.1017 + 0.0506\, W_z^* + 0.4033 \cdot 10^{-3}\, W_z^{*2} - 0.9588 \cdot 10^{-6}\, W_z^{*3}$

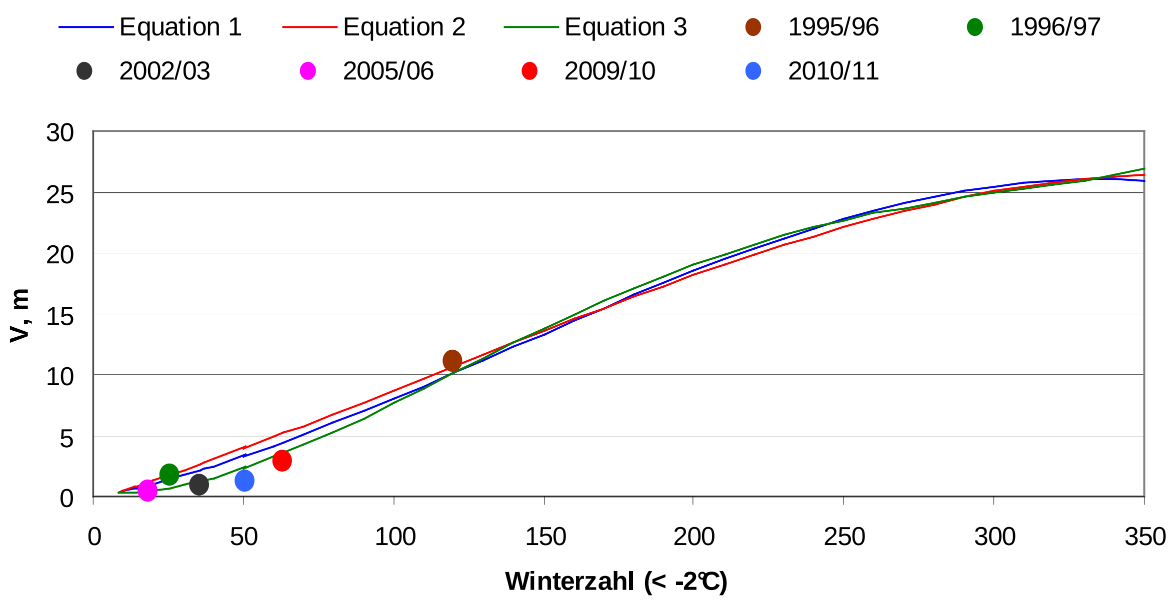

Figure 16. Regression curves for the accumulated areal ice volume on the coast of Schleswig-Holstein and winter severity index W_z^* (Tm < -2.0℃) for Schleswig

Equation 1: for all winters

$V_{A\Sigma} = -0.1017 + 0.0506\, W_z^* + 0.4033 \cdot 10^{-3}\, W_z^{*2} - 0.9588 \cdot 10^{-6}\, W_z^{*3}$

Equation 2: for winters with “low“ relative humidity

$V_{A\Sigma} = -0.2958 + 0.07705\, W_z^* + 0.1802 \cdot 10^{-3}\, W_z^{*2} - 0.5196 \cdot 10^{-6}\, W_z^{*3}$

Equation 3: for winters with “high“ relative humidity

$V_{A\Sigma} = 0.3061 - 0.01539\, W_z^* + 0.1361 \cdot 10^{-2}\, W_z^{*2} - 0.5324 \cdot 10^{-5}\, W_z^{*3} + 0.6229 \cdot 10^{-8}\, W_z^{*4}$

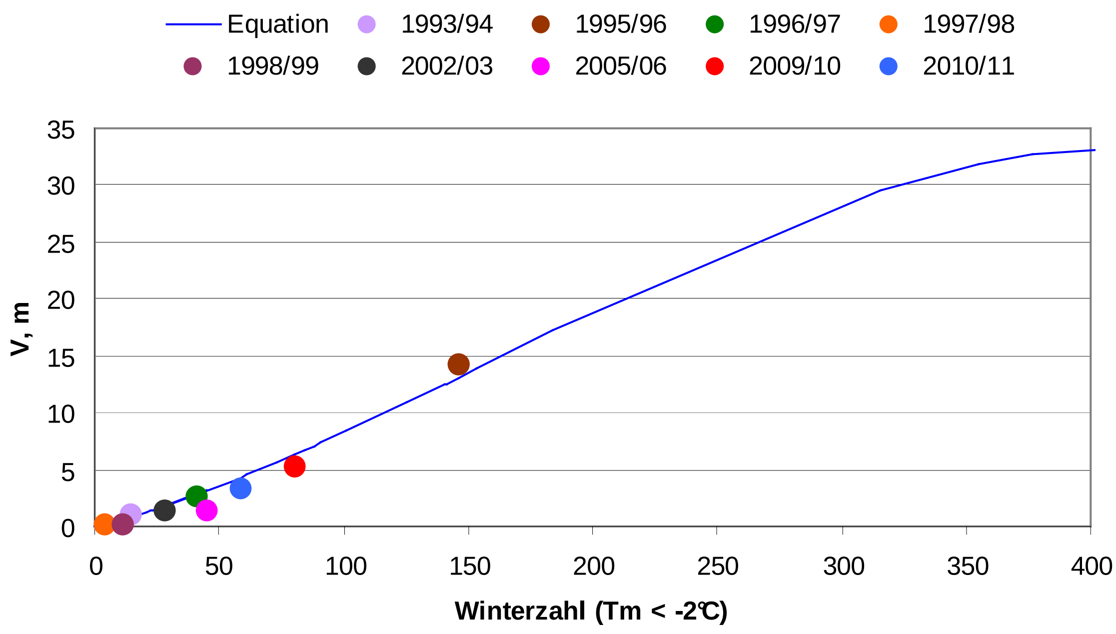

Figure 17. Regression curve for the accumulated areal ice volume on the coast of Mecklenburg-Vorpommern and winter severity index W_z^* *(Tm < -2.0℃) for Greifswald*

Equation: $V_{A\Sigma} = -0.0655 + 0.059\, W_z^* + 0.3 \cdot 10^{-3}\, W_z^{*2} - 0.6 \cdot 10^{-6}\, W_z^{*3}$

The regression equation for the coast of Mecklenburg-Vorpommern was derived from data covering the period from 1940 to 2011 (coefficient of determination $R^2 = 0.9803$). Fig. 17 shows the relationship between $V_{A\Sigma}$ and W_z^* .

Whether relative humidity also plays an important role on the coast of Mecklenburg-Vorpommern, where the influence of dry continental air from easterly directions is stronger than in the western coastal region, will have to be examined. The statistical relevance of this relationship and its possible use in the computation of unknown quantities in historical data series remains to be investigated.

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

On the Dutch *North Sea coast,* very open to open thin ice occurred south of West Frisian Islands in the third decade of December and on a few days in early January. Ice was observed on a total of 6 – 18 days. In the Limfjord waters on the Danish coast, ice began to form in sheltered areas in early December. At the beginning of January, the ice formed a consolidated layer of up to 50 cm thickness, cf. Fig. 18, which lasted until mid-February. Small, low-powered vessels were warned of navigation in these waters. In the period between late February and mid-March, the waters of Limfjord were covered with thin ice or new ice.

In the *Skagerrak,* some smaller fjords on the Norwegian coast were covered completely with ice from late November to late March. The ice cover increased steadily to a thickness of 50 cm. In the fairway to Oslo, close to very close thin ice occurred from mid-February to mid-March, cf. Fig. 19.

In the *Kattegat*, ice occurred only during the first cold spell in December and January in some smaller harbours and fjords on the coast of Denmark. The skerries and sheltered bays along the Swedish coast were covered continuously with ice of different concentrations from late December to mid-March. Ice thicknesses reached 10 - 30 cm. In offshore waters and in the *Belts* and *Sounds*, major quantities of ice occurred only at the end of December, cf. Fig. 18.

Lake Vänern was covered completely with ice from late December to early April: the maximum thickness of fast ice in the skerries reached 50 cm in March, and compact 30-50 cm thick ice occurred in offshore waters.

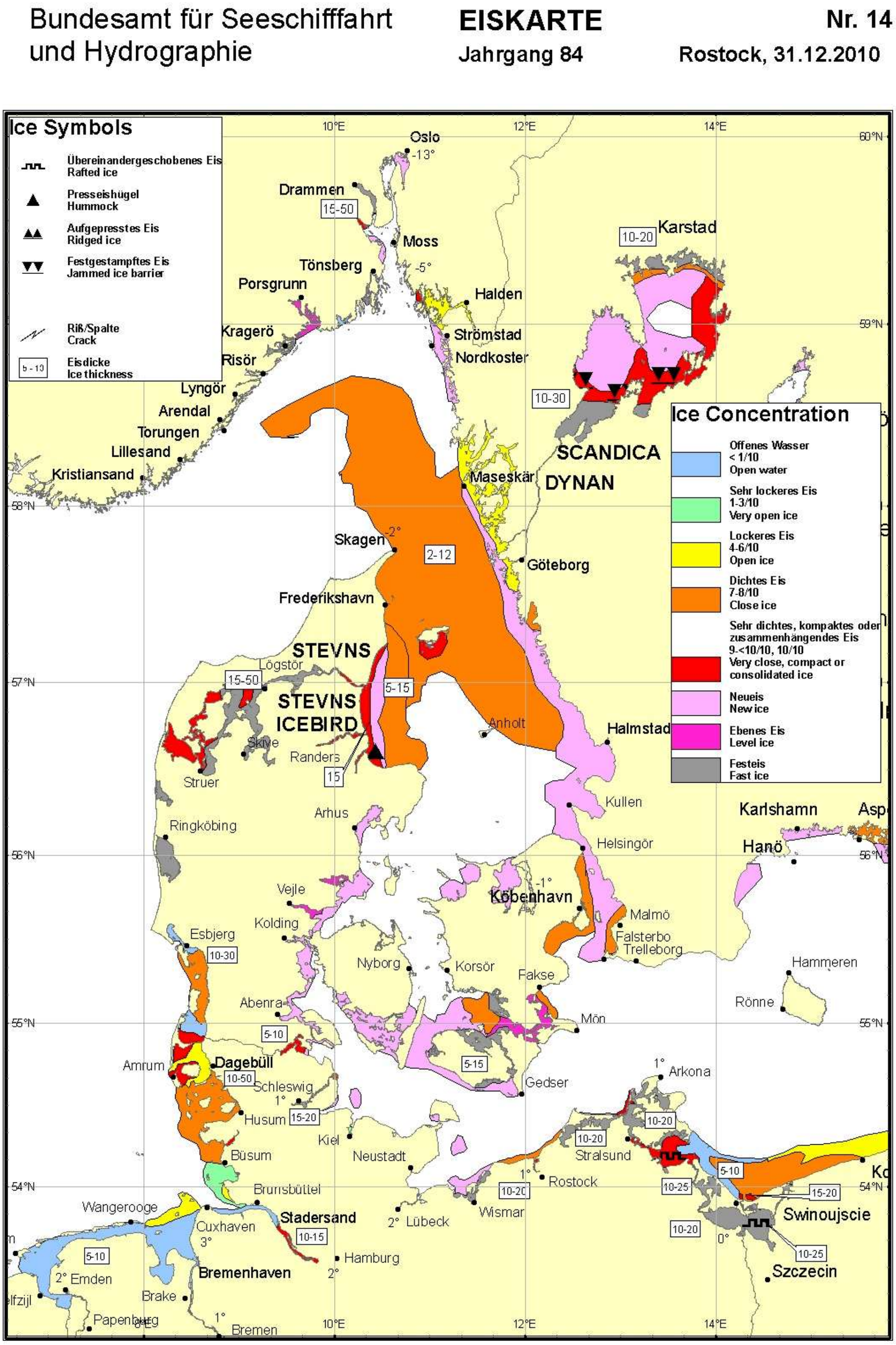

Figure 18. Ice situation in the western Baltic, Skagerrak and Kattegat on 31 December 2010

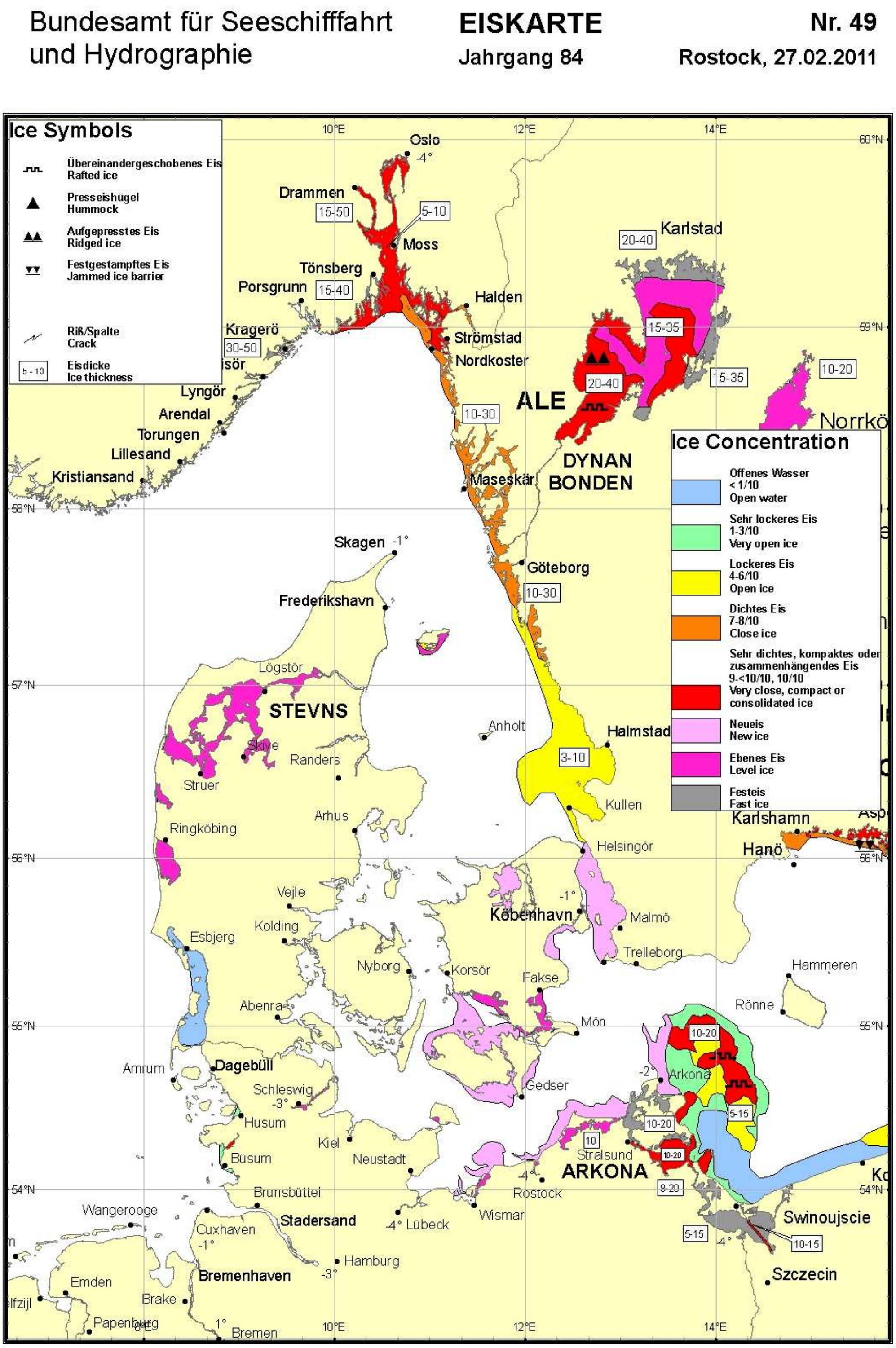

Figure 19. Ice situation in the western Baltic, Skagerrak and Kattegat on 27 February 2011

Ice conditions in the southern Baltic Sea region

The maximum of ice development was reached in the third decade of February. At that time, fast ice of 10-15 cm thickness covered Szczecin Lagoon on the coast of Poland, and close to very close, up to 20 thick ice or new ice was observed in the harbours along the coast. In the Pomeranian Bight and on the outer Baltic coasts, a belt of locally close 5-12 cm thick ice extended eastward. Ice of 10-20 cm thickness occurred off the coasts of the Gulf of Gdansk.

Vistula Lagoon and Curonian Lagoon were covered with 20-54 cm thick fast ice. The offshore waters east of 19°E were covered with close to very close 5-15 cm thick drift ice, cf. Fig. 20.

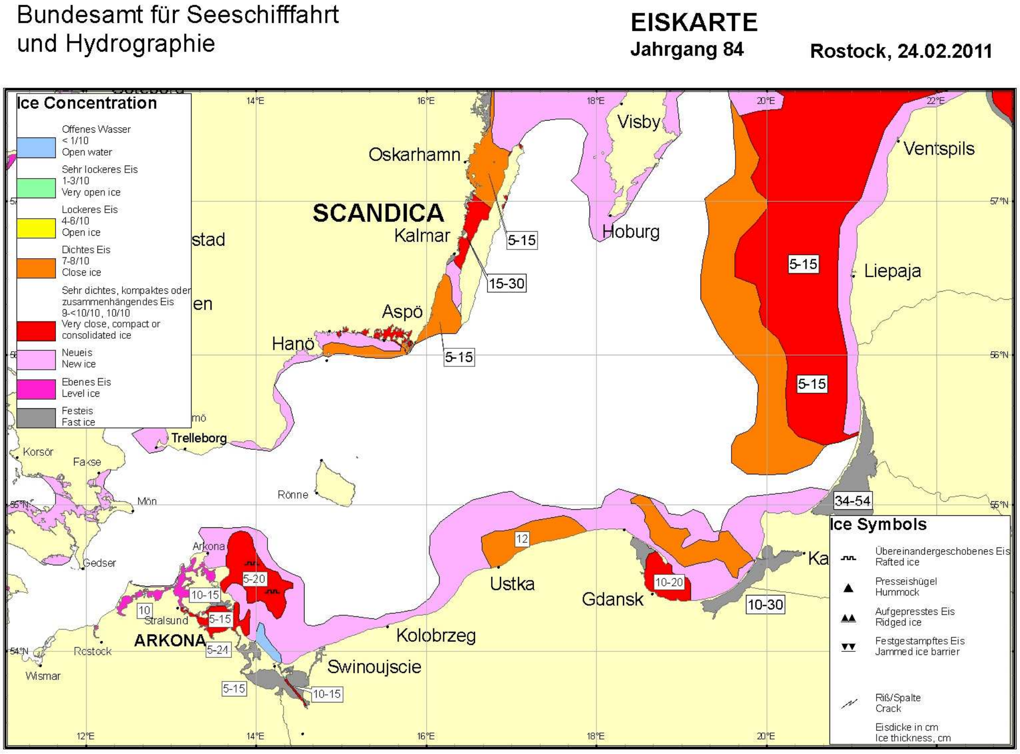

Figure 20. Ice situation in the southern Baltic Sea on 24 February 2011

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

First ice formed in the northernmost inner skerries of the Bay of Bothnia in early November. In the eastern part of the Gulf of Finland, ice formation began on 25 November, which is about the normal time. Until mid-December, ice development was slow. Short phases of intensive ice formation were interrupted by warm spells bringing mild southerly air into the region. Around 20 December, the northern Baltic Sea region came under the influence of a high-pressure zone over Greenland. Weather in the Baltic was determined by high reaching cold air flowing in from the east and north. Moderate to severe frost caused both ice thickness and extent in the northern Baltic region to increase further. In early January, the Gulf of Bothnia north of 63°N, the Gulf of Finland east of 27°E, and the Archipelago Sea were covered completely with ice. At the beginning of February, very cold northerly air at the back of two low-pressure zones tracking east to southeastward across northern Scandinavia flowed into the northern Baltic Sea region and came under the influence of an anti-cyclonic zone. The stable high-pressure zone over northern Scandinavia determined weather conditions in the northern Baltic from mid-February to the end of February. Intensive ice formation continued, and both thickness and extent of ice increased in all areas, with air temperatures ranging from -15°C to -30°C. The southern ice limit extended from the northern spit of Öland to Gotland, then from the northern spit of Gotland eastward to about 19°30'E, and along this line to the waters south of Klaipeda. The maximum of ice formation in the northern Baltic region was reached around 25 February, cf. ice chart in Fig. 21. Fast ice in the skerries of the Bay of Bothnia at this time was 35 – 75 cm thick, in the Sea of Bothnia 30 – 70 cm, in the eastern part of the Gulf of Finland 40 – 65 cm, in the western Gulf of Finland and Archipelago Sea 20 – 55 cm, in the Gulf of Riga 20 – 70 cm, and in the skerries of the northern Baltic Sea 15 – 30 cm thick. In the offshore waters, level ice reached thicknesses of 20 – 65 cm in the Bay of Bothnia, 10 – 30 cm in the Åland Sea,10 – 50 cm in the Gulfs of Finland and Riga, and 5 – 15 cm in the offshore waters of the northern Baltic Sea.

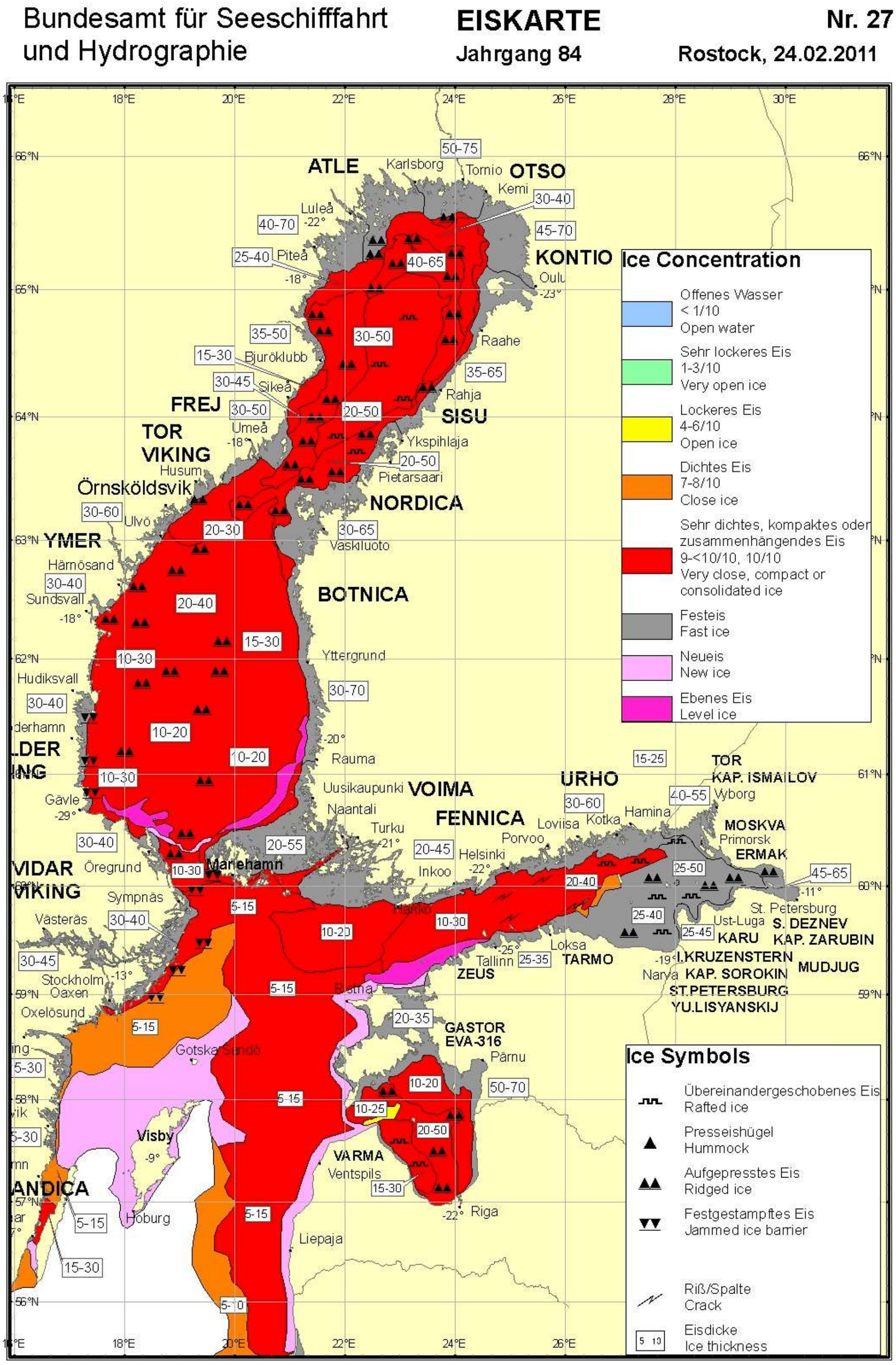

Figure 21. General ice chart of 24 February 2011 with maximum ice extent

Navigation in all offshore waters was obstructed by ice ridges and ice rafting on the windward coasts and on the ice edges. Conditions were particularly difficult in the waters of the Gulf of Bothnia off the coast of Finland, and in the eastern part of the Gulf of Finland during March and April, caused by temporarily freshening winds mainly from westerly directions. At the beginning of March, wind-induced changes in the ice situation prevailed in the northern Baltic: ice in the Gulf of Bothnia drifted in northeasterly to easterly directions, and a wide channel opened along the coast of Sweden. The thin ice in the central and northern parts of the Baltic Sea also drifted eastward and decreased, with the southern ice limit moving a considerable distance north. The seasonal ice melt set in at the end of March, beginning in the south. Last drift ice in the central offshore area of the Bay of Bothnia melted at the end of May, which is the normal time.

Annex

Figure A1. Daily ice occurrence on the German North and Baltic Sea coasts in the ice winter of 2010/11

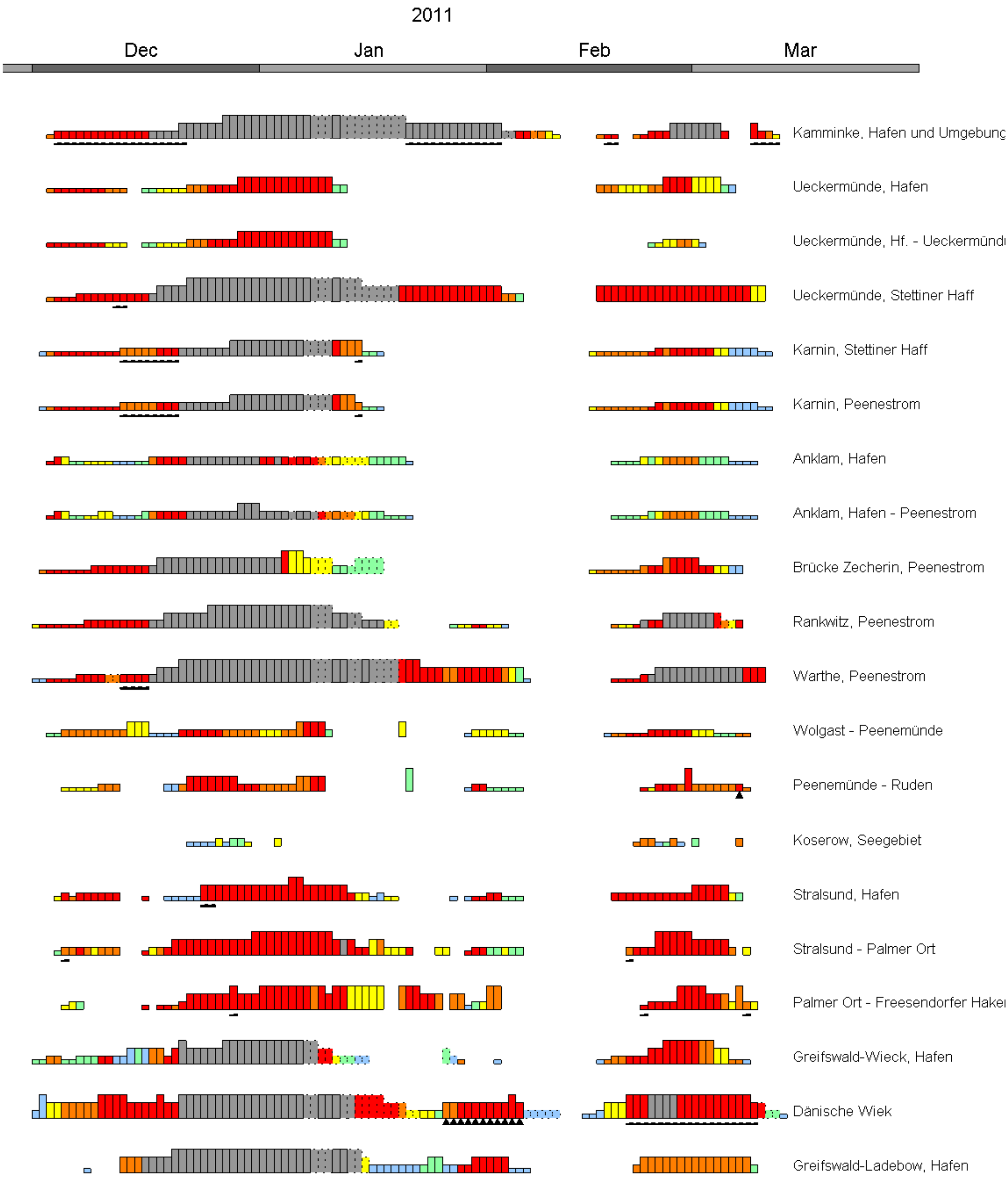

Figure A1 continued

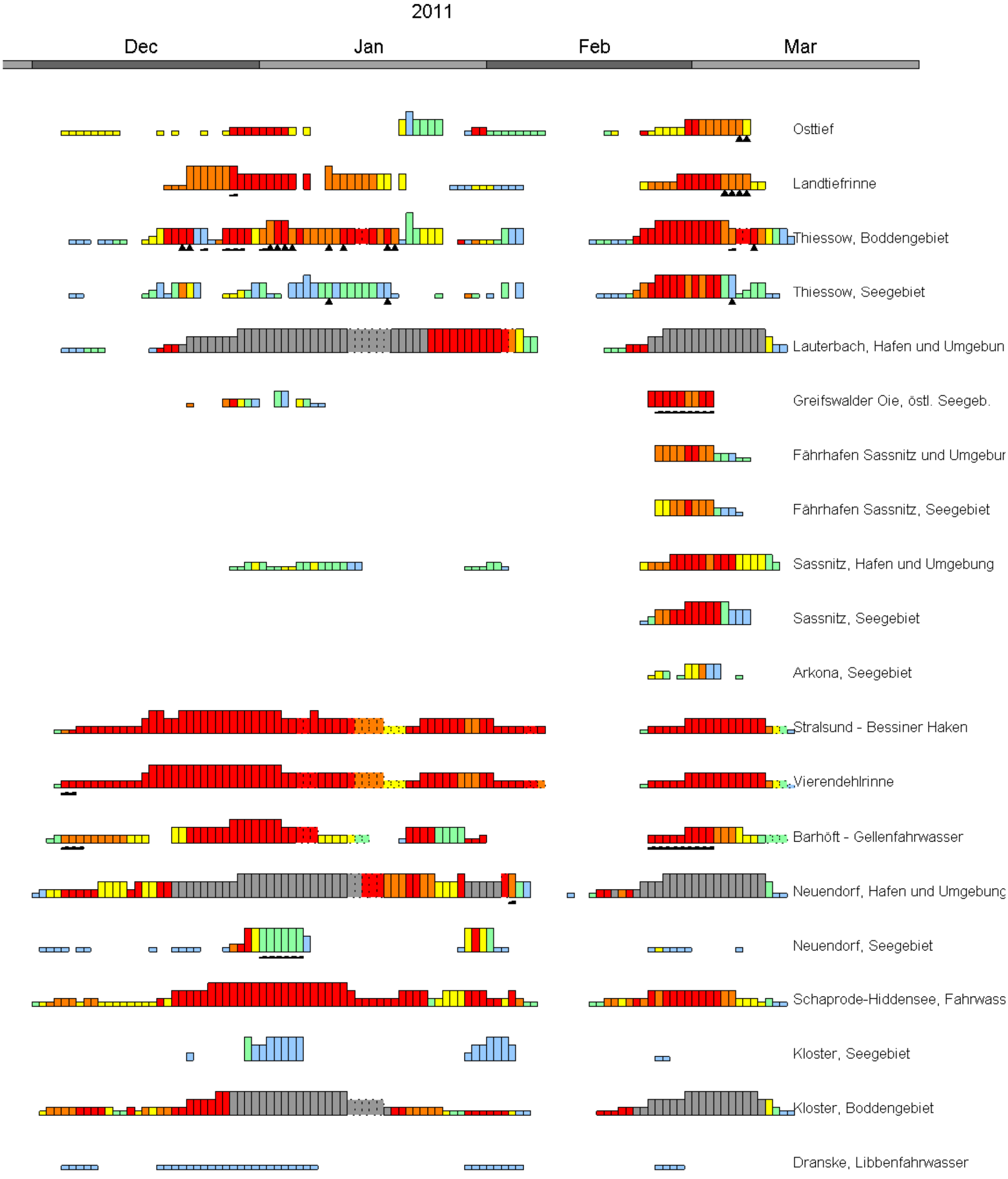

Figure A1 continued

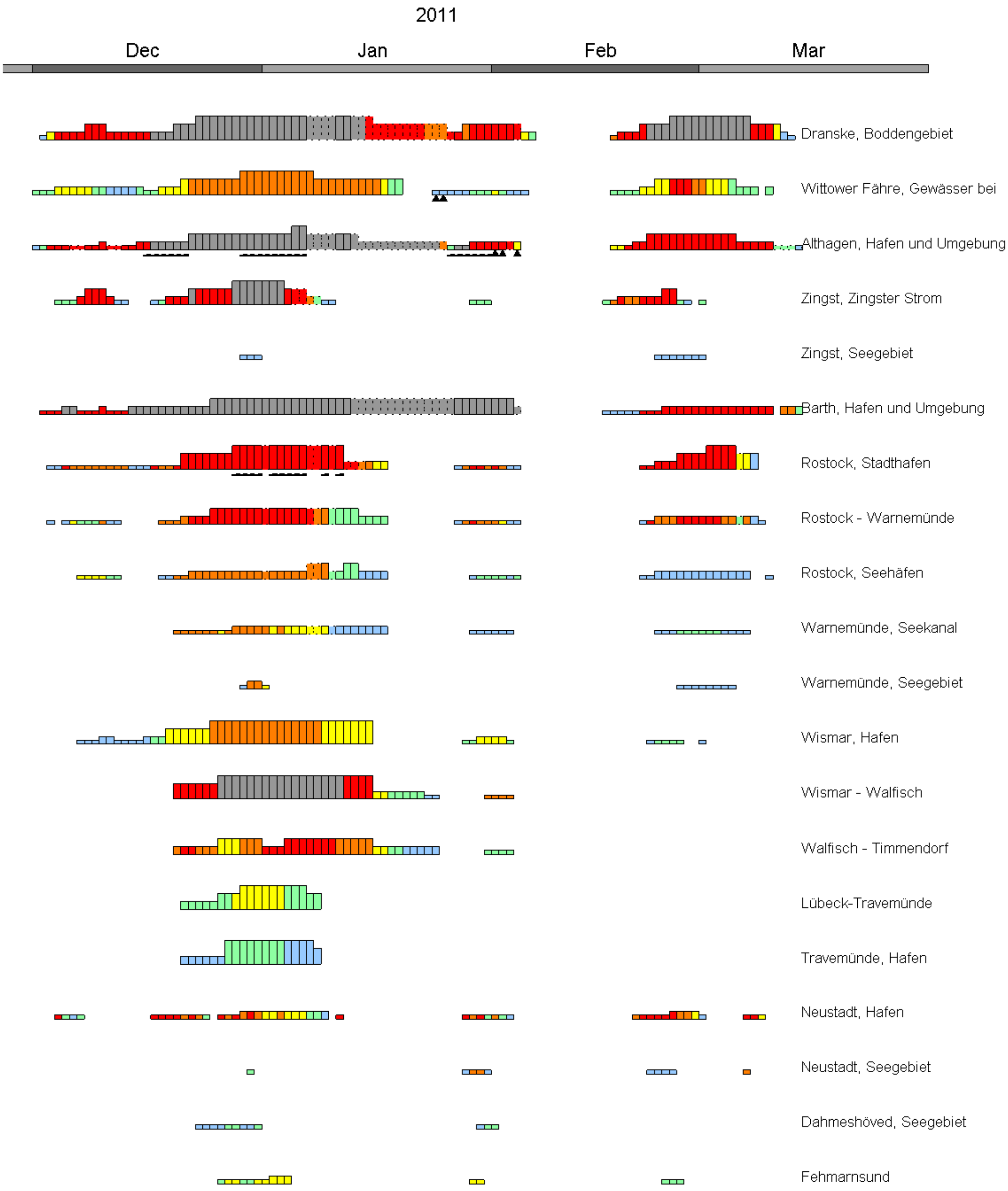

Figure A1 continued

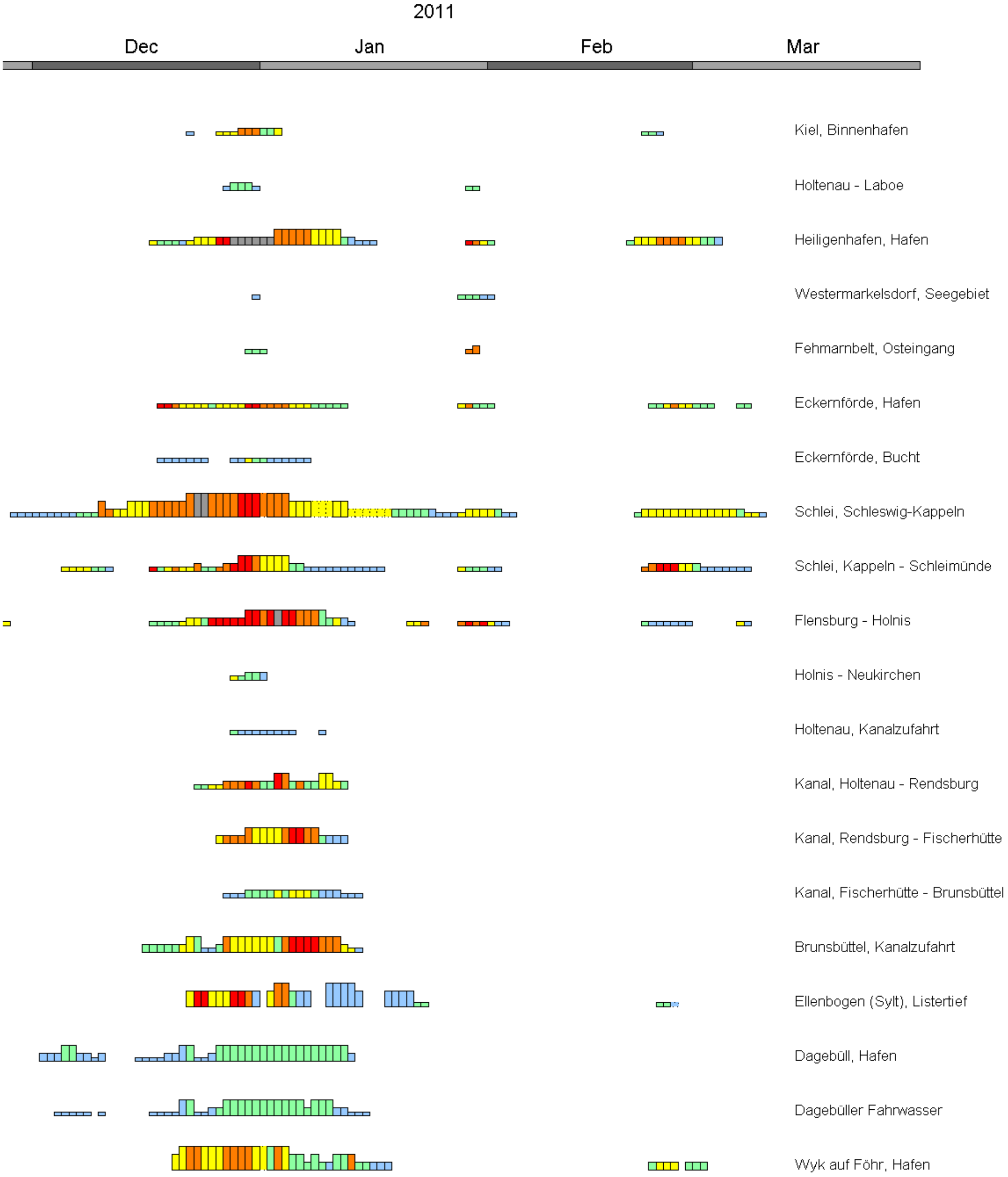

Figure A1 continued

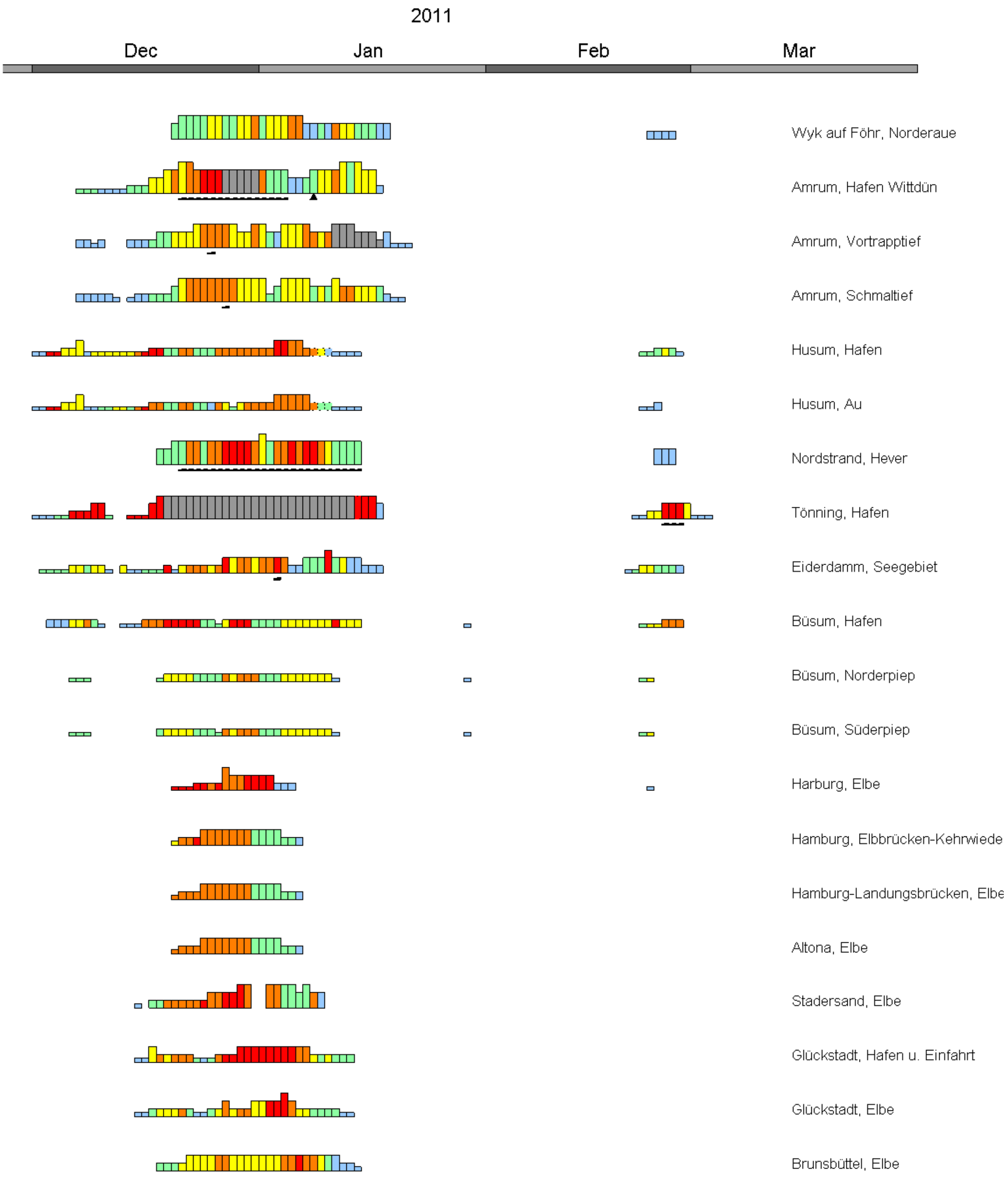

Figure A1 continued

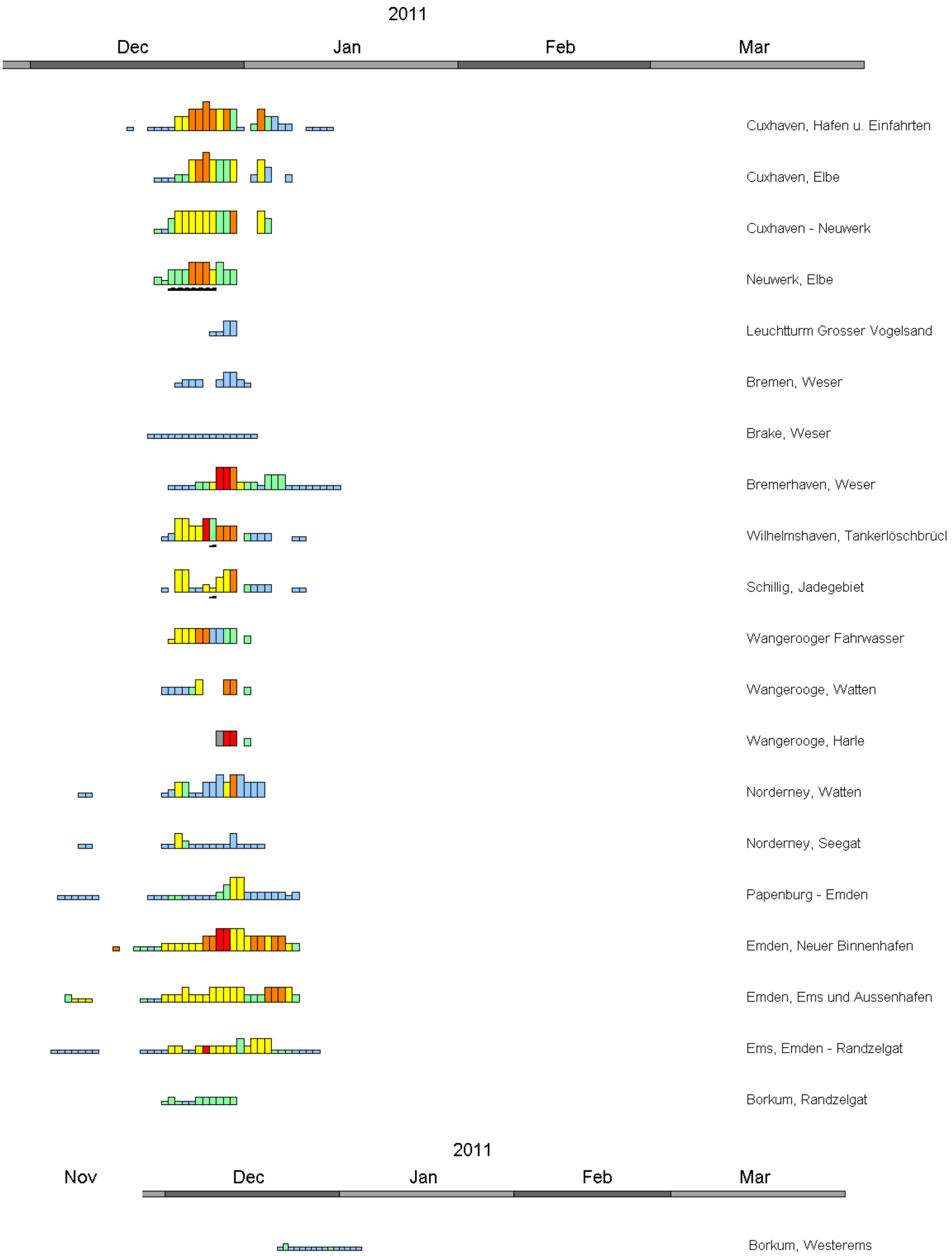

Figure A1 continued

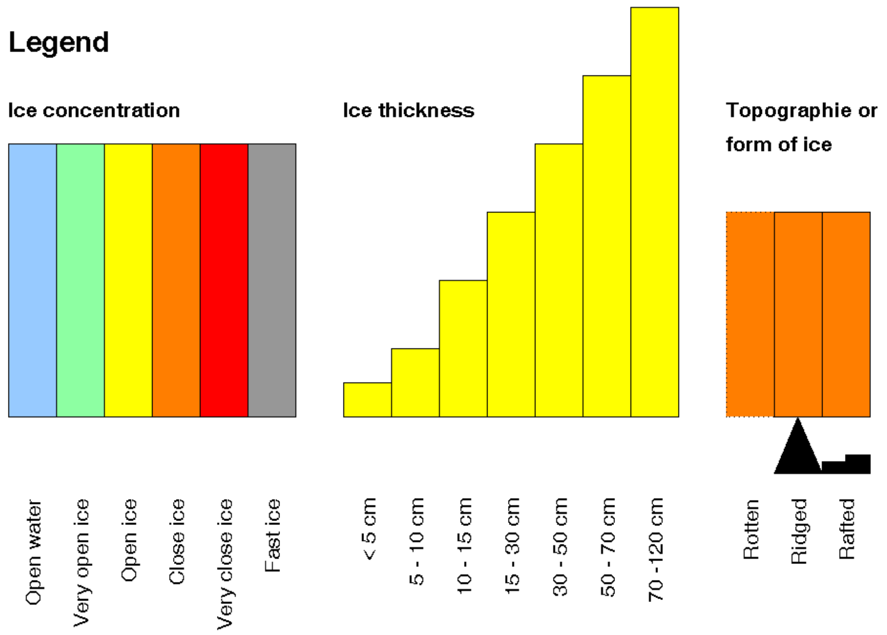

Table A1. Ice conditions in the German North Sea coastal waters and Kiel Canal in the winter of 2010/11

Observations stations	Beginning of ice occurrence	End of ice occurrence	Number of days with ice	Max. ice thickness, cm
Holtenau, Canal approach	28.12.10	09.01.11	10	< 5
Kiel Canal, Holtenau – Rendsburg	23.12.10	12.01.11	21	10-15
Kiel Canal, Rendsburg – Fischerhütte	26.12.10	12.01.11	18	10-15
Kiel Canal, Fischerhütte – Brunsbüttel	27.12.10	14.01.11	19	10-15
Brunsbüttel, Canal approach	16.12.10	14.01.11	30	10-15
Ellenbogen (Sylt), Listertief	22.12.10	26.02.11	30	17
Dagebüll, harbour	02.12.10	13.01.11	39	10-15
Dagebüll, fairway	04.12.10	15.01.11	36	10-15
Wyk on Föhr, harbour	20.12.10	02.03.11	37	15-30
Wyk on Föhr, Norderaue	20.12.10	26.02.11	34	15-30
Amrum, harbour Wittdün	07.12.10	17.01.11	42	30
Amrum, Vortrapptief	07.12.10	21.01.11	43	30
Amrum, Schmaltief	07.12.10	20.01.11	44	30
Husum, harbour	01.12.10	27.02.11	51	10-15
Husum, Au	01.12.10	24.02.11	48	10-15
Nordstrand, Hever	18.12.10	26.02.11	31	18
Tönning, harbour	01.12.10	03.03.11	57	15-30
Eiderdamm, sea area	02.12.10	27.02.11	54	15
Büsum, harbour	03.12.10	27.02.11	48	5-10
Büsum, Norderpiep	06.12.10	23.02.11	31	5-10
Büsum, Süderpiep	06.12.10	23.02.11	31	5-10
Harburg, river Elbe	20.12.10	23.02.11	18	10-15
Hamburg, Elbbrücken – Kehrwieder	20.12.10	06.01.11	18	10-15
Hamburg-Landungsbrücken, Elbe	20.12.10	06.01.11	18	10
Altona, Elbe	20.12.10	06.01.11	18	10
Stadersand, Elbe	15.12.10	09.01.11	23	15-30
Glückstadt, harbour and entrance	15.12.10	13.01.11	30	10-15
Glückstadt, Elbe	15.12.10	13.01.11	30	10-15
Brunsbüttel, Elbe	18.12.10	14.01.11	28	10-15
Cuxhaven, harbour and entrances	15.12.10	13.01.11	25	30
Cuxhaven, Elbe	19.12.10	07.01.11	16	30
Cuxhaven – Neuwerk	19.12.10	04.01.11	14	15
Neuwerk, Elbe	19.12.10	30.12.10	12	15
Lighthouse “Grosser Vogelsand”	27.12.10	30.12.10	4	10
Approach buoy “Elbe”			0	
Helgoland, harbour and entrances			0	
Bremen, Weser	22.12.10	01.01.11	9	10
Brake, Weser	18.12.10	02.01.11	16	< 5
Bremerhaven, Weser	21.12.10	14.01.11	25	10-15
Lighthouse “Hohe Weg”, channel			0	
Alte Weser, channel			0	
Neue Weser, channel			0	
Wilhelmshaven, harbour entrances			Not observed	
Wilhelmshaven, oil jetty (Jade)	20.12.10	09.01.11	17	10-15
Schillig, Jade	20.12.10	09.01.11	16	10-15
Wangerooge, fairway	21.12.10	01.01.11	11	10-15
Wangerooge, Wadden	20.12.10	01.01.11	9	10-15
Wangerooge, Harle	28.12.10	01.01.11	4	10-15
Norderney, Wadden	08.12.10	03.01.11	17	15

Table A1 continued

Norderney, Seegat	08.12.10	03.01.11	17	10-15
Papenburg – Emden	05.12.10	08.01.11	28	10-15
Emden, new inner harbour	13.12.10	08.01.11	25	15-20
Emden, Ems and outer harbour	06.12.10	08.01.11	27	10-15
Ems, Emden – Randzelgat	04.12.10	11.01.11	33	10-15
Borkum, Randzelgat	20.12.10	30.12.10	11	5-10
Borkum, Westerems	21.12.10	04.01.11	15	5-10

Table A2. Navigation conditions in the German North Sea coastal waters and Kiel Canal in the winter of 2010/11

Observation stations	**Days with K_B=2***	**Days with K_B=3,5,6***	**Days with K_B=8,9***
Holtenau, Canal approach			
Kiel Canal, Holtenau – Rendsburg			
Kiel Canal, Rendsburg – Fischerhütte	3		
Kiel Canal, Fischerhütte – Brunsbüttel			
Brunsbüttel, Canal approach	7		
Ellenbogen (Sylt), Listertief	11		
Dagebüll, harbour			
Dagebüll, fairway			
Wyk on Föhr, harbour			
Wyk on Föhr, Norderaue	13		
Amrum, harbour Wittdün	9	9	
Amrum, Vortrapptief	19	5	
Amrum, Schmaltief	18	4	
Husum, harbour	4		
Husum, Au	2		
Nordstrand, Hever	9	8	
Tönning, harbour	10	2	26
Eiderdamm, sea area	9		
Büsum, harbour	7		
Büsum, Norderpiep			
Büsum, Süderpiep			
Harburg, river Elbe	14		
Hamburg, Elbbrücken – Kehrwieder	10		
Hamburg-Landungsbrücken, Elbe	10		
Altona, Elbe	10		
Stadersand, Elbe	10		
Glückstadt, harbour and entrance	7	13	
Glückstadt, Elbe	14	4	
Brunsbüttel, Elbe	4		
Cuxhaven, harbour and entrances	3		
Cuxhaven, Elbe	1		
Cuxhaven – Neuwerk	1		
Neuwerk, Elbe			
Lighthouse “Grosser Vogelsand”			
Approach buoy “Elbe”			
Helgoland, harbour and entrances			
Bremen, Weser			
Brake, Weser			
Bremerhaven, Weser	1		
Lighthouse “Hohe Weg”, channel			
Alte Weser, channel			
Neue Weser, channel			
Wilhelmshaven, harbour entrances			
Wilhelmshaven, oil jetty (Jade)	6	1	
Schillig, Jade	5		
Wangerooge, fairway			
Wangerooge, Wadden	2		
Wangerooge, Harle	3		
Norderney, Wadden	3		

Table A2 continued

Norderney, Seegat	1		
Papenburg – Emden	3		
Emden, new inner harbour	12		
Emden, Ems and outer harbour	7		
Ems, Emden – Randzelgat	1		
Borkum, Randzelgat			
Borkum, Westerems			

* Code numbers according to the Baltic Sea Ice Code

K_B = 2 Navigation difficult for low-powered vessels, for wooden vessels not advisable

K_B = 3,5,6 Navigation is possible only for high-powered vessels of strong construction and suitable for navigation in ice (without or with ice breaker assistance)

K_B = 8,9 Navigation is temporarily closed or has ceased

Table A3. Ice conditions in the German Baltic Sea coastal waters in the winter of 2010/11

Observations stations	**Beginning of ice occurrence**	**End of ice occurrence**	**Number of days with ice**	**Max. ice thickness, cm**
Kamminke, harbour and vicinity	03.12.10	12.03.11	90	15-30
Ueckermünde, harbour	03.12.10	06.03.11	58	10-15
Ueckermünde, harbour – river mouth	03.12.10	02.03.11	47	10-15
Ueckermünde, Firth of Szczecin	03.12.10	10.03.11	88	15-30
Karnin, Firth of Szczecin	02.12.10	11.03.11	72	10-15
Karnin, Peenestrom	02.12.10	11.03.11	72	10-15
Anklam, harbour	03.12.10	09.03.11	70	5-10
Anklam, harbour – Peenestrom	03.12.10	09.03.11	70	10-15
Bridge of Zecherin, Peenestrom	02.12.10	07.03.11	68	15-20
Rankwitz, Peenestrom	01.12.10	07.03.11	76	27
Warthe, Peenestrom	01.12.10	10.03.11	89	26
Wolgast – Peenemünde	03.12.10	08.03.11	68	10-15
Peenemünde – Ruden	05.12.10	08.03.11	54	15-30
Koserow, sea area	22.12.10	07.03.11	19	5-10
Stralsund, harbour	04.12.10	08.03.11	69	10-20
Stralsund – Palmer Ort	04.12.10	08.03.11	72	15-30
Palmer Ort – Freesendorfer Haken	05.12.10	09.03.11	64	15-30
Greifswald-Wieck, harbour	01.12.10	08.03.11	71	20
Dänische Wiek	01.12.10	13.03.11	100	26
Greifswald-Ladebow, harbour	08.12.10	14.03.11	74	15-30
Osttief	05.12.10	11.03.11	56	10-20
Landtiefrinne	19.12.10	10.03.11	56	10-20
Thiessow, bodden area	06.12.10	14.03.11	85	40
Thiessow, sea area	06.12.10	12.03.11	64	40
Lauterbach, harbour and vicinity	05.12.10	13.03.11	84	30
Greifswalder Oie, sea area E	22.12.10	03.03.11	21	15-20
Fährhafen Sassnitz, port and vicinity	24.02.11	08.03.11	13	10-15
Fährhafen Sassnitz, sea area	24.02.11	07.03.11	12	10-15
Sassnitz, harbour and vicinity	28.12.10	12.03.11	43	10-15
Sassnitz, sea area	22.02.11	08.03.11	15	10-30
Arkona, sea area	23.02.11	07.03.11	10	10-30
Stralsund – Bessiner Haken	04.12.10	14.03.11	88	25
Vierendehlrinne	04.12.10	14.03.11	88	27
Barhöft – Gellen, fairway	03.12.10	13.03.11	72	25
Neuendorf, harbour and vicinity	01.12.10	13.03.11	96	15-30
Neuendorf, sea area	04.12.10	07.03.11	37	20
Schaprode – Hiddensee, fairway	01.12.10	13.03.11	96	20
Kloster, sea area	22.12.10	25.02.11	18	20
Kloster, bodden area	02.12.10	14.03.11	94	20
Dranske, Libben fairway	05.12.10	28.02.11	39	5
Dranske, bodden area	02.12.10	13.03.11	92	30
Wittower Fähre, vicinity	09.12.10	10.03.11	84	15
Althagen, harbour and vicinity	01.12.10	14.03.11	92	15
Zingst, Zingster Strom	04.12.10	01.03.11	51	20-25
Zingst, sea area	29.12.10	01.03.11	10	5
Barth, harbour and vicinity	02.12.10	14.03.11	91	15
Rostock, city harbour	03.12.10	08.03.11	71	15-30
Rostock – Warnemünde	03.12.10	09.03.11	66	12-15
Rostock, overseas harbours	07.12.10	10.03.11	60	10-15

Table A3 continued

Warnemünde, sea channel	20.12.10	07.03.11	48	5
Warnemünde, sea area	29.12.10	05.03.11	12	5
Approach buoy Rostock			0	
Wismar, harbour	07.12.10	01.03.11	53	20
Wismar – Walfisch	20.12.10	03.02.11	40	25
Walfisch – Timmendorf	20.12.10	03.02.11	40	12
Timmendorf – approach buoy Wismar			0	
Lübeck–Travemünde	21.12.10	08.01.11	19	30
Travemünde, harbour	21.12.10	08.01.11	19	30
Travemünde, sea area			0	
Neustadt, harbour	04.12.10	09.03.11	48	6
Neustadt, sea area	30.12.10	07.03.11	10	< 5
Dahmeshöved, sea area	23.12.10	01.02.11	12	< 5
Fehmarnsund	26.12.10	26.02.11	15	5-10
Kiel, inner harbour	22.12.10	24.02.11	13	5-10
Holtenau – Laboe	27.12.10	30.01.11	7	5-10
Bülk, sea area			0	
Lighthouse Kiel, sea area NE			0	
Lighthouse Kiel, sea area E			0	
Heiligenhafen, harbour	17.12.10	04.03.11	48	12
Fehmarnsund, western entrance			0	
Westermarkelsdorf, sea area	31.12.10	01.02.11	6	< 5
Marienleuchte, sea area			0	
Fehmarnbelt, entrance E	30.12.10	30.01.11	5	5-10
Eckernförde, harbour	18.12.10	08.03.11	42	< 5
Eckernförde, Bight	18.12.10	07.01.11	18	< 5
Schlei, Schleswig – Kappeln	28.11.10	10.03.11	87	20
Schlei, Kappeln – Schleimünde	05.12.10	08.03.11	60	10
Flensburg – Holnis	27.11.10	08.03.11	48	10
Holnis – Neukirchen	28.12.10	01.01.11	5	5-10
Neukirchen-Kalkgrund, lighthouse			0	
Falshöft, sea area			0	

Table A4. Navigation conditions in the German Baltic Sea coastal waters in the winter of 2010/11

Observation stations	**Days with K_B=2***	**Days with K_B=3,5,6***	**Days with K_B=8,9***
Kamminke, harbour and vicinity	14	10	57
Ueckermünde, harbour	20		5
Ueckermünde, harbour – river mouth	13		5
Ueckermünde, Firth of Szczecin	27		51
Karnin, Firth of Szczecin	9	2	27
Karnin, Peenestrom	9	2	27
Anklam, harbour	15		25
Anklam, harbour – Peenestrom	13		24
Bridge of Zecherin, Peenestrom	10		33
Rankwitz, Peenestrom	13		41
Warthe, Peenestrom	4	23	49
Wolgast – Peenemünde	13	12	
Peenemünde – Ruden	12	13	
Koserow, sea area	1		
Stralsund, harbour	9	32	
Stralsund – Palmer Ort	21	25	
Palmer Ort – Freesendorfer Haken	10	35	
Greifswald-Wieck, harbour	28	5	
Dänische Wiek	38	30	
Greifswald-Ladebow, harbour	19	46	
Osttief	15	10	
Landtiefrinne	17	17	
Thiessow, bodden area	14	41	
Thiessow, sea area	11	16	
Lauterbach, harbour and vicinity	4	63	
Greifswalder Oie, sea area E	4	7	
Fährhafen Sassnitz, port and vicinity	7	1	
Fährhafen Sassnitz, sea area	8		
Sassnitz, harbour and vicinity	7	2	
Sassnitz, sea area	4	3	
Arkona, sea area			
Stralsund – Bessiner Haken	11	37	24
Vierendehlrinne	9	43	22
Barhöft – Gellen, fairway	14	29	12
Neuendorf, harbour and vicinity	19	5	62
Neuendorf, sea area	9	5	
Schaprode – Hiddensee, fairway	42	16	
Kloster, sea area			
Kloster, bodden area	14	8	68
Dranske, Libben fairway			
Dranske, bodden area	52	30	1
Wittower Fähre, vicinity	30	21	
Althagen, harbour and vicinity	15	22	33
Zingst, Zingster Strom	14	15	
Zingst, sea area			
Barth, harbour and vicinity	37	12	24
Rostock, city harbour	11	22	
Rostock – Warnemünde	16		
Rostock, overseas harbours			
Warnemünde, sea channel			

Table A4 continued

Warnemünde, sea area			
Approach buoy Rostock			
Wismar, harbour	21	6	
Wismar – Walfisch	19	3	
Walfisch – Timmendorf			
Timmendorf – approach buoy Wismar			
Lübeck – Travemünde			
Travemünde, harbour			
Travemünde, sea area			
Neustadt, harbour			
Neustadt, sea area			
Dahmeshöved, sea area			
Fehmarnsund			
Kiel, inner harbour			
Holtenau – Laboe			
Bülk, sea area			
Lighthouse Kiel, sea area NE			
Lighthouse Kiel, sea area E			
Heiligenhafen, harbour	8		
Fehmarnsund, western entrance			
Westermarkelsdorf, sea area			
Marienleuchte, sea area			
Fehmarnbelt, entrance E			
Eckernförde, harbour			
Eckernförde, Bight			
Schlei, Schleswig – Kappeln	20	41	
Schlei, Kappeln – Schleimünde	14	2	
Flensburg – Holnis	13		
Holnis – Neukirchen			
Neukirchen-Kalkgrund, lighthouse			
Falshöft, sea area			

* Code numbers according to the Baltic Sea Ice Code

$K_B = 2$ Navigation difficult for low-powered vessels, for wooden vessels not advisable
$K_B = 3,5,6$ Navigation is possible only for high-powered vessels of strong construction and suitable for navigation in ice (without or with ice breaker assistance)
$K_B = 8,9$ Navigation is temporarily closed or has ceased