Wave climate in the Baltic Sea 2023

Baltic Marine Environment
Protection Commission

Hydrography

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Key message

The wave climate in 2023 showed rather typical monthly variation. October was rougher than usual in all the stations where observations were available, while December was calmer, especially in the northern parts of the Baltic Sea. Although long-term overall maxima were not exceeded, monthly record values of the significant wave height were observed at several stations.

Results and assessment

In 2023 waves were measured in 10 locations in the Baltic Sea and Skagerrak (Figure 1) using buoys or a directional radar gauge. These measurement systems provide real time information of the sea state for professional and free time navigation. The wave measurements are also important for wave related research and wave model development. As waves contribute to the mixing of the surface layer and their influence can extend to the bottom (resuspension) the information about the yearly wave activity adds to the understanding of the physical environment of the Baltic Sea.

The monthly mean values of significant wave height (see the definition of significant wave height in section Metadata) are plotted in Figures 2 and 3, and the highest values of significant wave height are shown in Figures 4 and 5. Figures 6 and 7 show the year-to-year variation of the mean significant wave height in June-July and October-November.

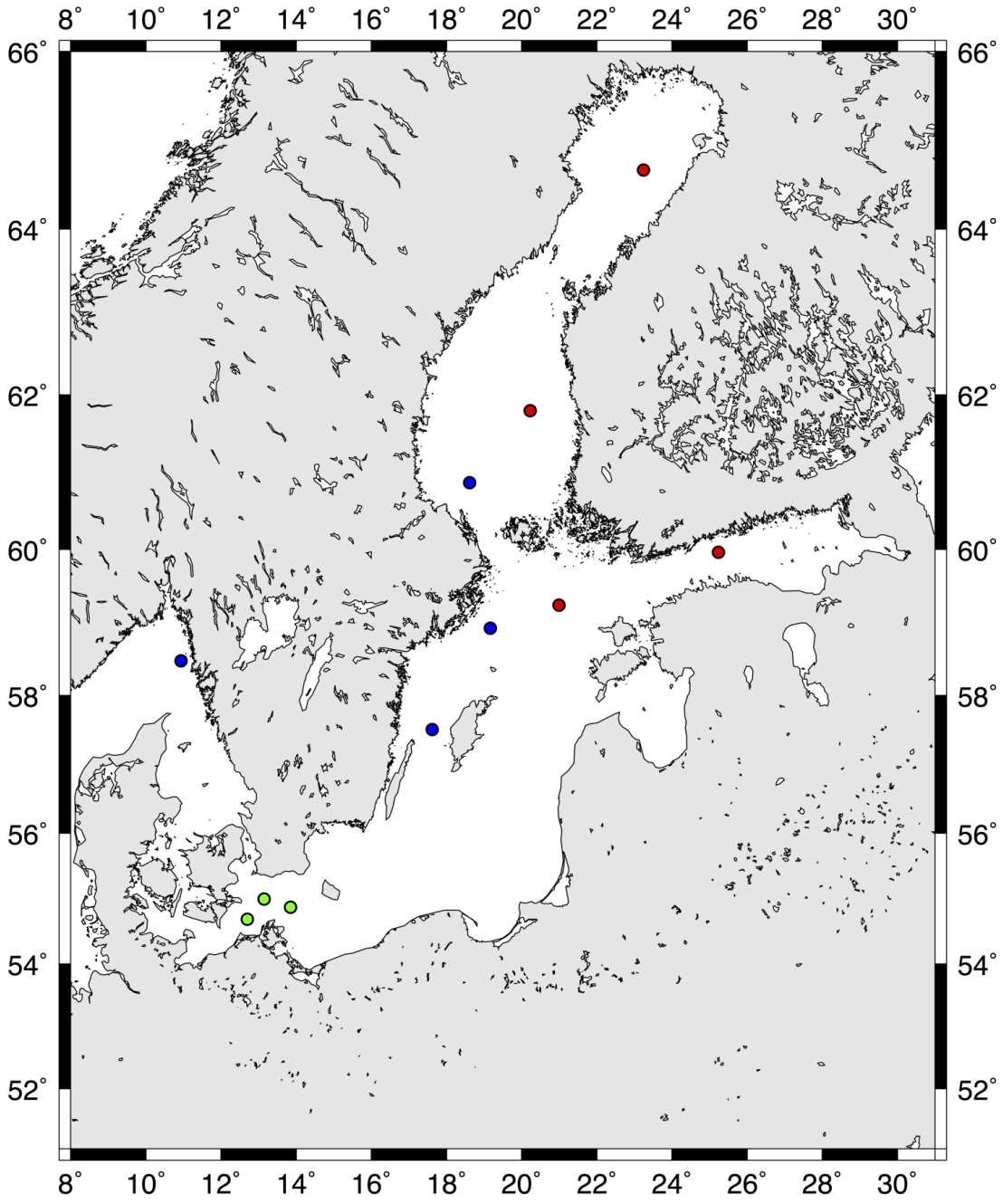

Figure 1. The positions of the wave monitoring stations in 2023. Red dots indicate FMI buoys in the Bay of Bothnia, in the Bothnian Sea, in the Northern Baltic Proper and in the Gulf of Finland (station Helsinki), blue dots SMHI buoys in the Southern Bothnian Sea (station Finngrundet), in the Baltic Proper (stations Huvudskär Ost and Knolls Grund) and in Skagerrak (station Väderöarna) and green dots the BSH stations in the Western Baltic Proper: Fino 2 (a directional radar gauge), off Cape Arkona and on the Darss Sill (buoys). See section Metadata for the exact coordinates of the locations.

The Gulf of Bothnia

The Bay of Bothnia

In 2023 the wave buoy in the Bay of Bothnia was deployed 5 June and recovered 11 December. The measurements are available until 3 December.

At the buoy location, the monthly mean significant wave heights in July and September- November were close to the long term mean values, while June and August were calmer than usual. The highest significant wave height during the six-month measuring period was 3.7 metres, measured both on 12 October (northwest winds) and on 28 November (northeast winds).

The Central Bothnian Sea

The wave buoy in the Central Bothnian Sea was operational throughout the year 2023.

At this station January, September and October were rougher than usual, while April, June and December were calmer. The mean value for December was 1.2 m, the lowest during the 13 years of measurements with a maximum significant wave height of 3.9 m (19 December). The maximum significant wave heights were close to the long-term maxima in March, October and November: the highest significant wave height for the whole period, 5.2 m, was observed 22 November during a south-southwest storm.

The Southern Bothnian Sea, station Finngrundet

The wave buoy at station Finngrundet was fully operational throughout the year 2023.

The monthly means of the significant wave height were very close to normal for as much as six months (Jan, Feb, May, Jul, Sep, Oct). One monthly record was noted.

April, June and August were slightly calmer than usual. The roughest month of the year was October followed by March and then November with a mean significant wave height of 1.3, 1.2 and 1.4 m respectively. Neither stands out as very rough although March, with a maximum significant wave height of 4 m reached the old monthly record, last noted in 2008.

The Gulf of Finland

The middle parts of the Gulf of Finland, station Helsinki

The wave buoy in the Gulf of Finland was recovered 29 January and redeployed 18 April. The buoy was operational to the end of the year 2023.

The monthly means of significant wave height were higher in July and October, and lower in January, June, November and December. Like in the Central Bothnian Sea and Northern Baltic Proper, December was the calmest December since the measurements started 23 years ago with a mean significant wave height of 0.9 m and a maximum value of 2.7 m (22 December). The maxima were below the long-term maxima, and the highest significant wave height, 4.2 m, in the measurement period in 2023 was observed 12 October during high southwestern winds.

The Baltic Proper

The Northern Baltic Proper, stations Northern Baltic Proper and Huvudskär Ost

The wave buoy at station Northern Baltic Proper was operational throughout 2023.

Like in the Gulf of Finland, June and October, as well as March, were rougher than usual. May, June, November and December were clearly calmer compared to the long-term statistics. Like in the Bothnian Sea and the Gulf of Finland, the mean significant wave height in December, 1.4 m, was the lowest observed in 28 years. The highest significant wave height for December was 3.7 m, measured on 22 December during the same wind event as in the Gulf of Finland.

Although the mean significant wave height in November was rather low, a record high significant wave height for November, and the highest value for the whole year, 7.8 m, was measured during the same southwestern storm on 22 November when the highest value in Central Baltic Sea was observed. Another monthly record, 5.6 m, was observed on 8 August during southern high winds. These high values are rare in the summer season.

The wave buoy at station Huvudskär Ost was operational March to November, although with periods of missing data in March, August, September and November. For January-February and December there is no data at all.

From the data available, the mean significant wave height for March, July and October were quite high, reaching or exceeding the highest mean values for previous years. May and June were calmer than usual, with a mean significant height of 0.5 and 0.4 m respectively, the lowest values since 2001.

In August, a new monthly record of the maximum significant wave height was noted with 4.2 m. Since 2001, a maximum significant wave height above 3 m for August have only been noted three other years, 2004, 2008 and 2021.

Central Baltic Proper, station Knolls Grund

The wave buoy at station Knolls Grund was fully operational the entire 2023.

The monthly mean significant wave height was very close to normal for as much as six months (Jan, Feb, Apr, Aug, Nov, Dec). One new monthly record was noted.

March was quite rough with a mean significant wave height of 1.2 m, which together with 2020 stands for the highest mean value for March. May, June and September were slightly calmer while July and October were a bit rougher than normal.

In August, during the storm mentioned in the section for the Western Baltic Proper, the maximum significant wave height of 3.5 m resulted in a new monthly record height. The old record value, 3.1 m was noted in the previous year, 2022.

Western Baltic Proper, stations Darss Sill, Arkona and Fino 2

Measurements were available from two measuring points this year. The Arkona buoy recorded data for nine months in 2023 (January to September). Unfortunately, no data was available from the buoy at the Darss Sill. This is due to technical problems with data transmission and storage. The radar gauge at FINO2 has continuously recorded data for the entire year 2023, so this data set covers 12 months.

Overall, the sea state parameters in 2023 were comparable to or slightly below the long-term average. However, there were also repeated very strong storms in 2023, which were also reflected in the prevailing sea state. In 2023, new monthly highs for significant wave heights were recorded throughout the year.

In the first half of 2023, the sea state climate was typical and unremarkable compared to the long-term average. There were various storm systems (Feb and May) with strong but short periods of high

winds, which are also visible in the sea state data. Especially at the FINO2 station (as the long-term average of the time series is still short in contrast to the other stations) strong peaks in the significant wave heights were recorded.

In August, an unusually strong summer storm caused heavy winds on the coasts of the Baltic Sea. Gusts of up to 70 kilometres per hour (wind force eight) swept across the western Baltic Sea, causing severe devastation. This short but strong event was also clearly visible in the sea state data. Both the Arkona buoy and the FINO2 station measured significant wave heights, which were clearly above the long-term average (FINO2: 3.5 m and Arkona: 4.1 m).

The storm surge on the night of October 20/21, 2023 was the most severe since the Baltic Sea storm surge of 1872. In line with the strong winds, maximum significant wave heights of up to 5.2 m were measured at FINO2.

Just before Christmas 2023, another strong low-pressure system storm struck the western Baltic Sea coast and caused extensive damage and gale-force winds from December 21 to December 22, 2023. The storm event is again clearly visible in the data, with a maximum significant wave height of up to 4 m at FINO2.

Overall, the sea state climate for 2023 can be summarized as follows: The frequent occurrence of storms was a notable characteristic while the overall sea state in 2023 was similar to previous years.

Skagerrak

Skagerrak, station Väderöarna

The wave buoy at station Väderöarna was fully operational during 2023. The mean significant wave height was over the year comparable to the long-term average. One monthly record was noted.

April and June were a bit calmer than usual, November stands out a little more as very calm. February, July and October were rougher than normal.

Especially July was unusually rough with a mean significant height of 1.3 m. Together with the year 2020 this is the highest July mean value since 2005. Low pressures were unusually active this July with mainly west to south-westerly winds. The maximum wave height in July reached 4.9 m, which is very high for being a July value. At the same occasion, another wave buoy located about 35 km southwest of Väderöarna station noted a significant wave of 6 m (station Brofjorden).

A monthly record of the significant wave height, 5.7 m was noted in mid-October when two lows passed northern Scandinavia; both lows with unusually low pressure, about 965-970 hPa. This record is shared with October in year 2008.

Data

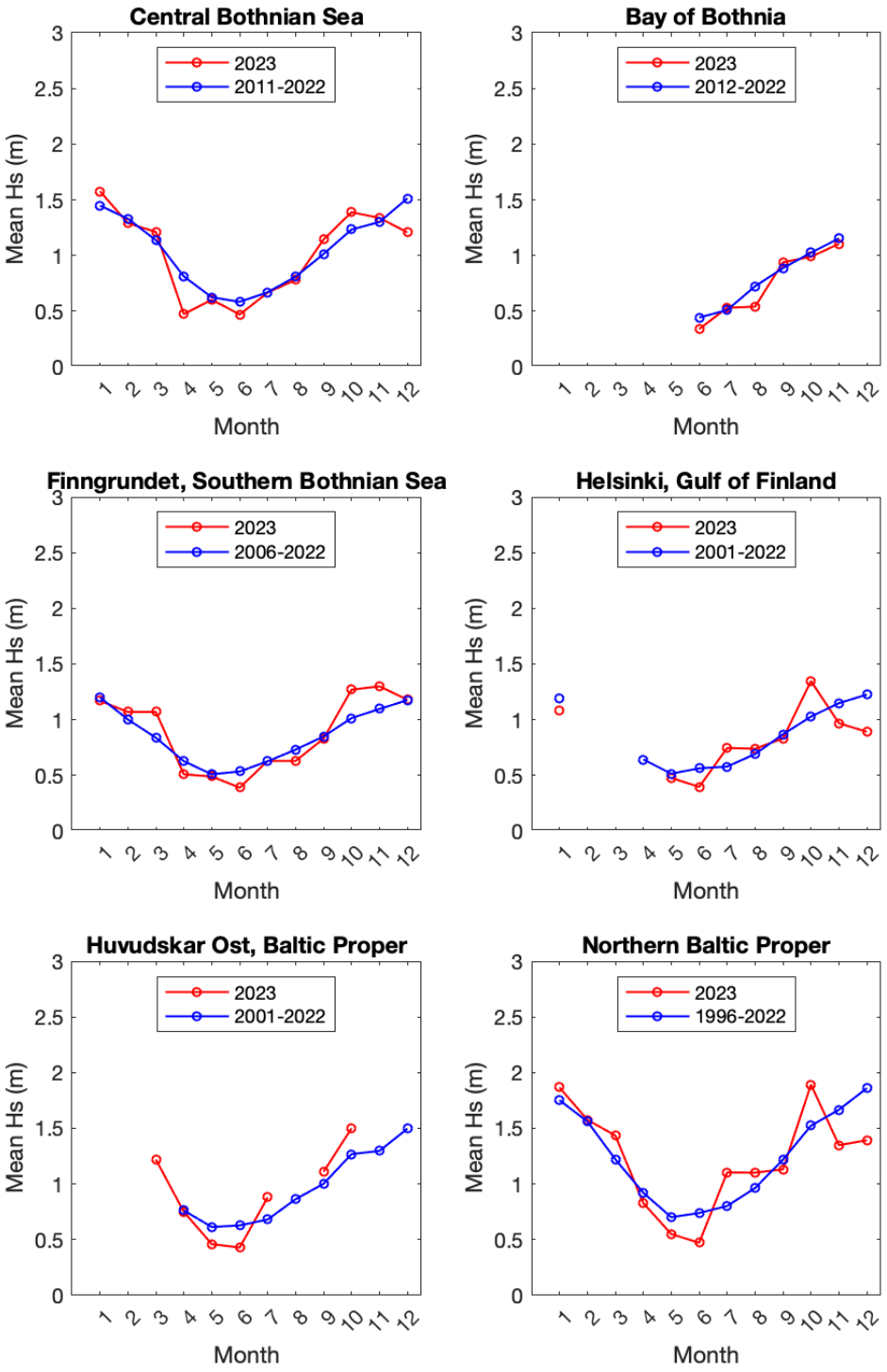

Figure 2. The monthly means of significant wave heights in the Bothnian Sea, the Gulf of Finland and the Northern and Central Baltic Proper. In some months the long-term statistics are calculated over fewer years (but at least over four years) than indicated in the legend.

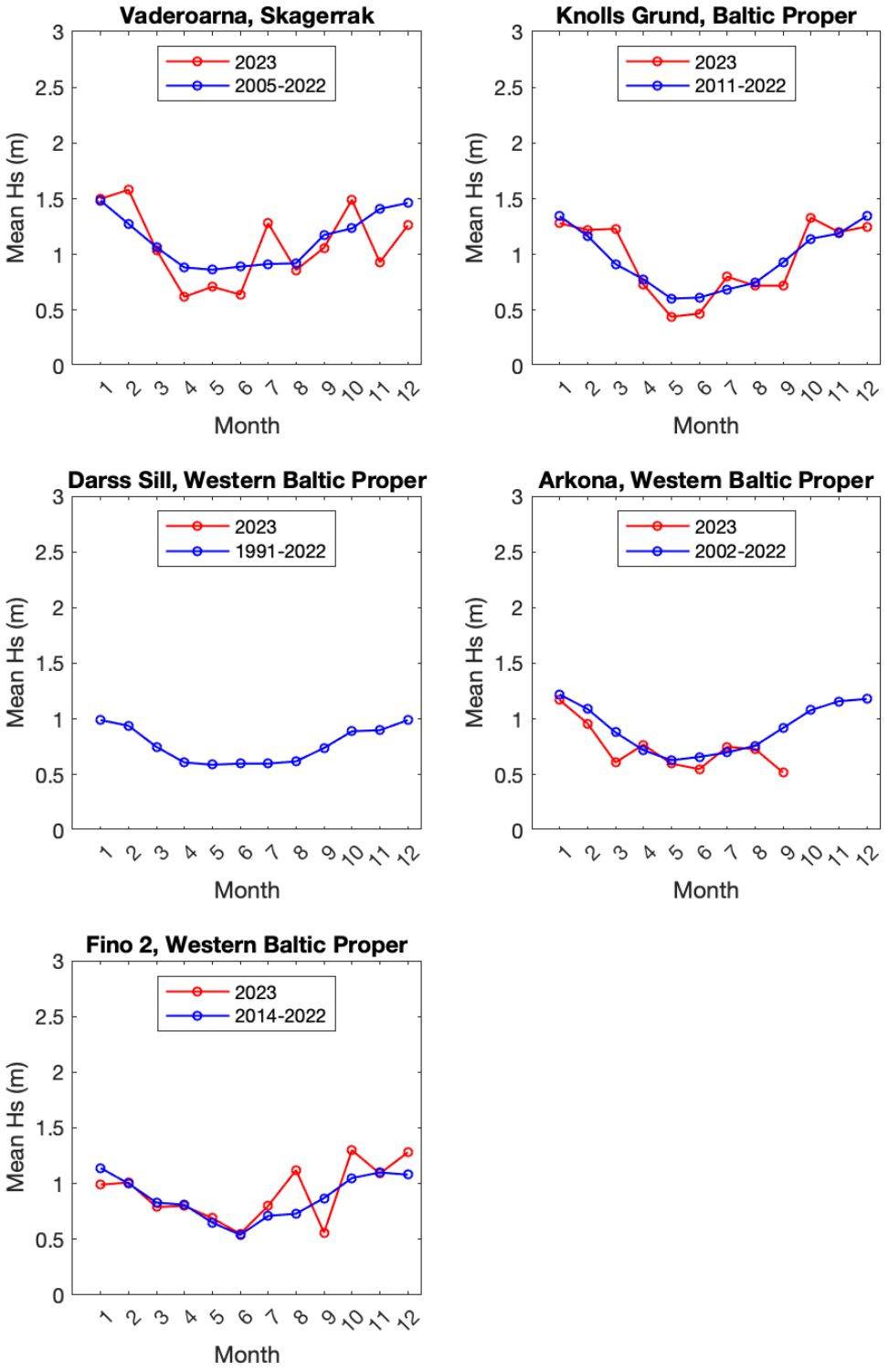

Figure 3. The monthly means of significant wave heights in Skagerrak, Central and Western Baltic Proper. In some months the long-term statistics are calculated over fewer years (but at least over four years) than indicated in the legend.

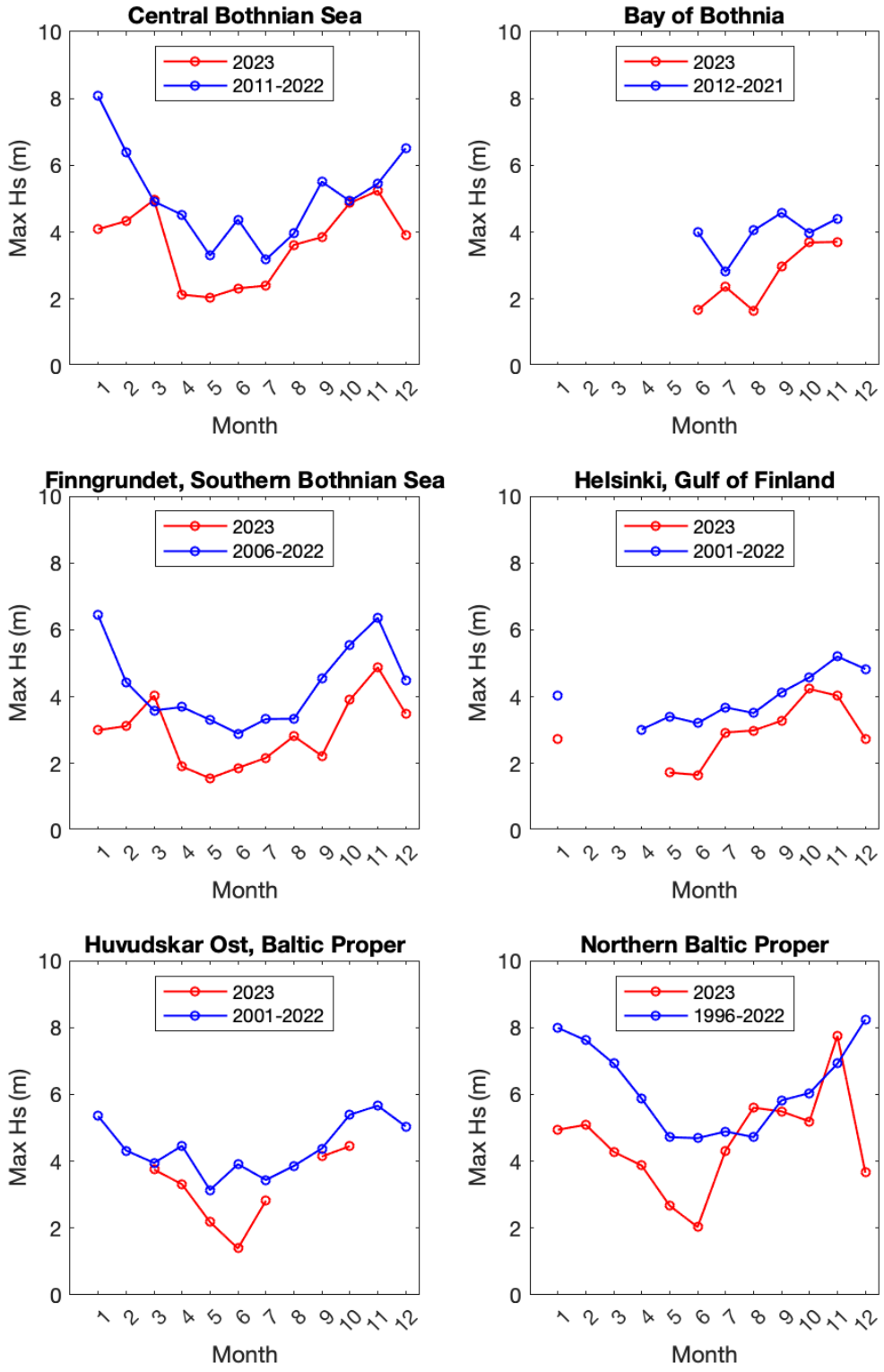

Figure 4. The monthly maxima of significant wave heights in the Gulf of Bothnia, the Gulf of Finland and the Northern Baltic Proper. Data gaps occur in some of the months.

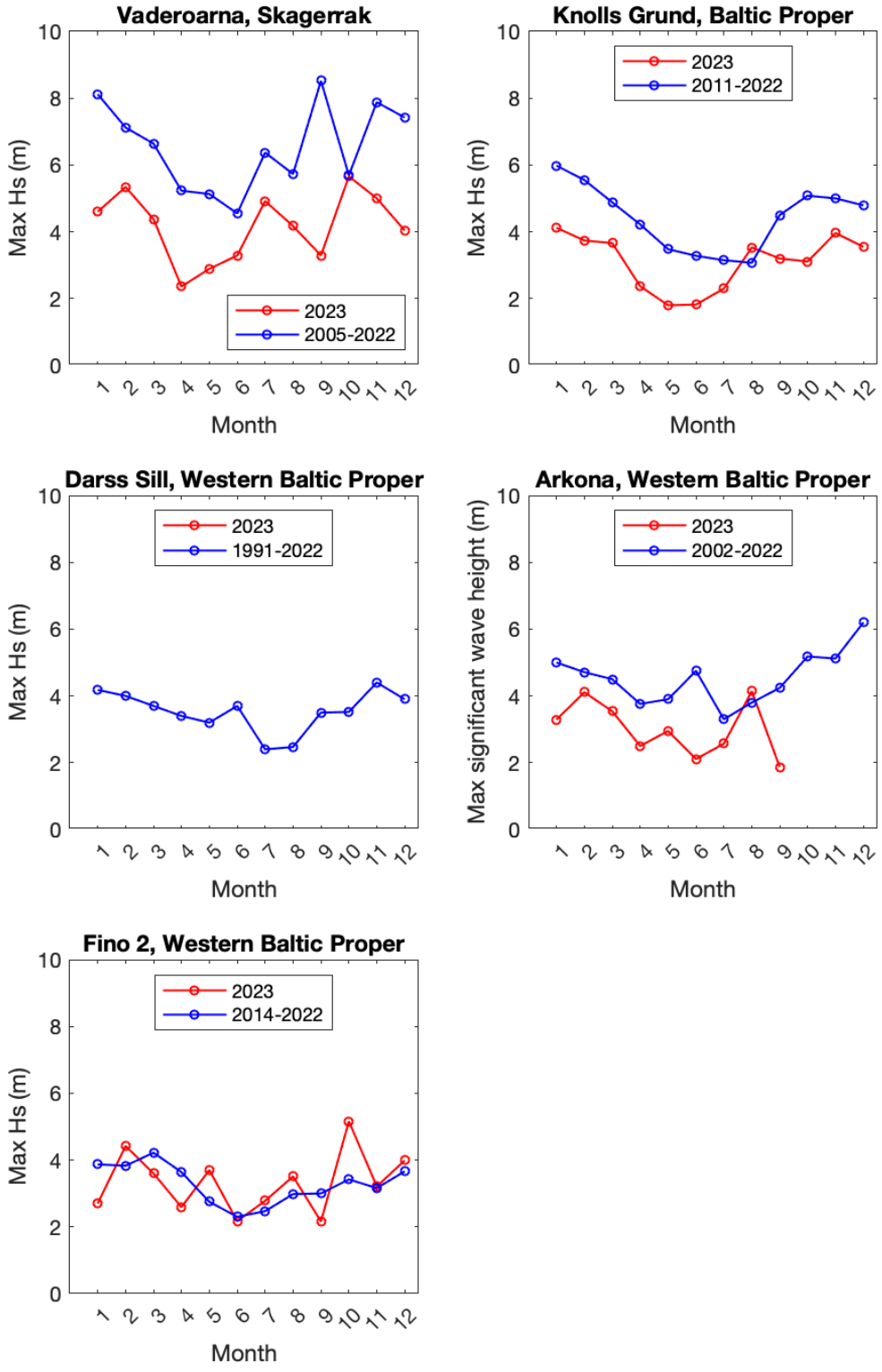

Figure 5. The monthly maxima of significant wave heights in Skagerrak, the Central and the Western Baltic Proper. Data gaps occur in some of the months.

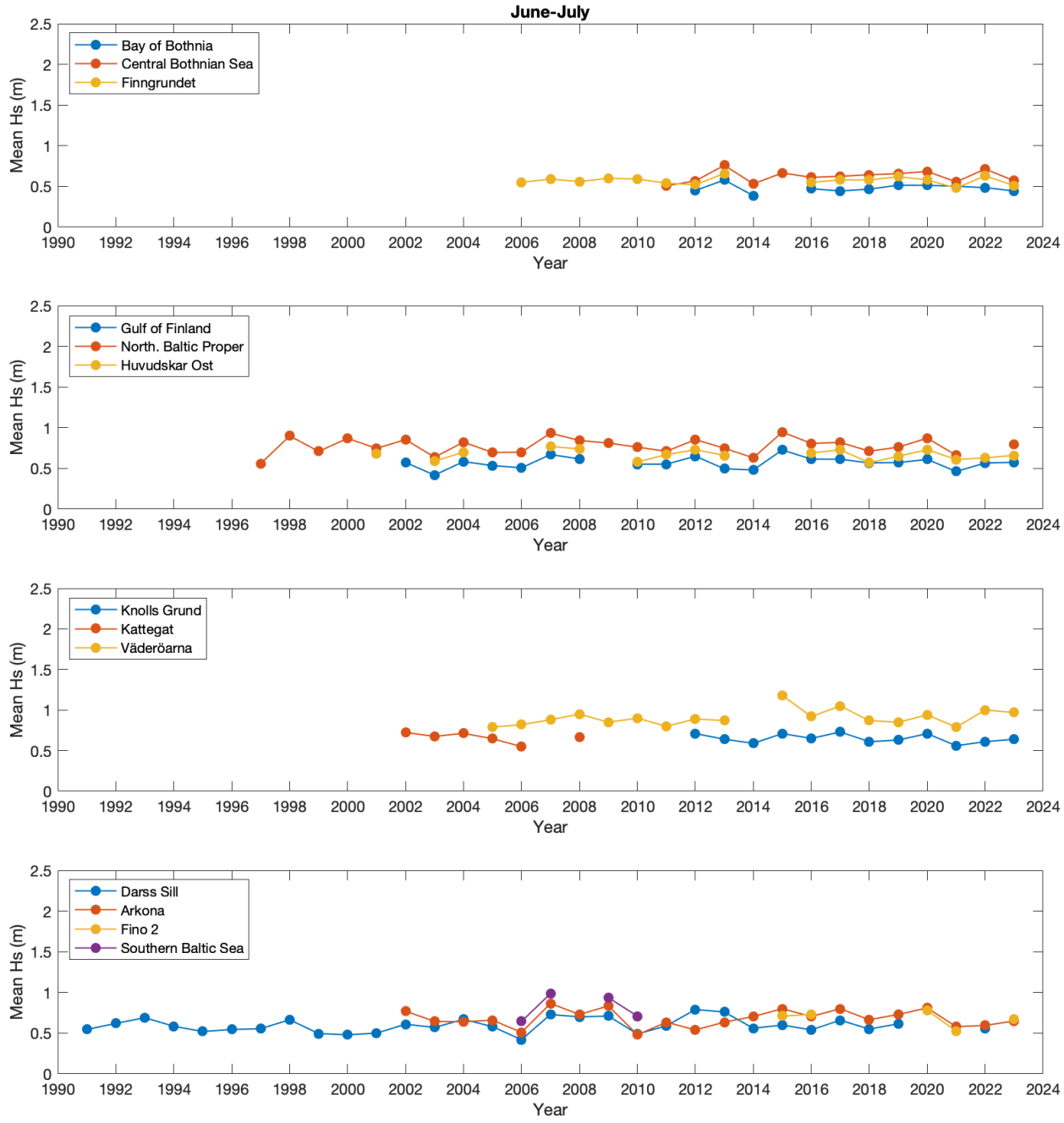

Figure 6. The yearly variation of the mean significant wave height Hs in the period of June-July. In some years the data do not fully cover the whole period.

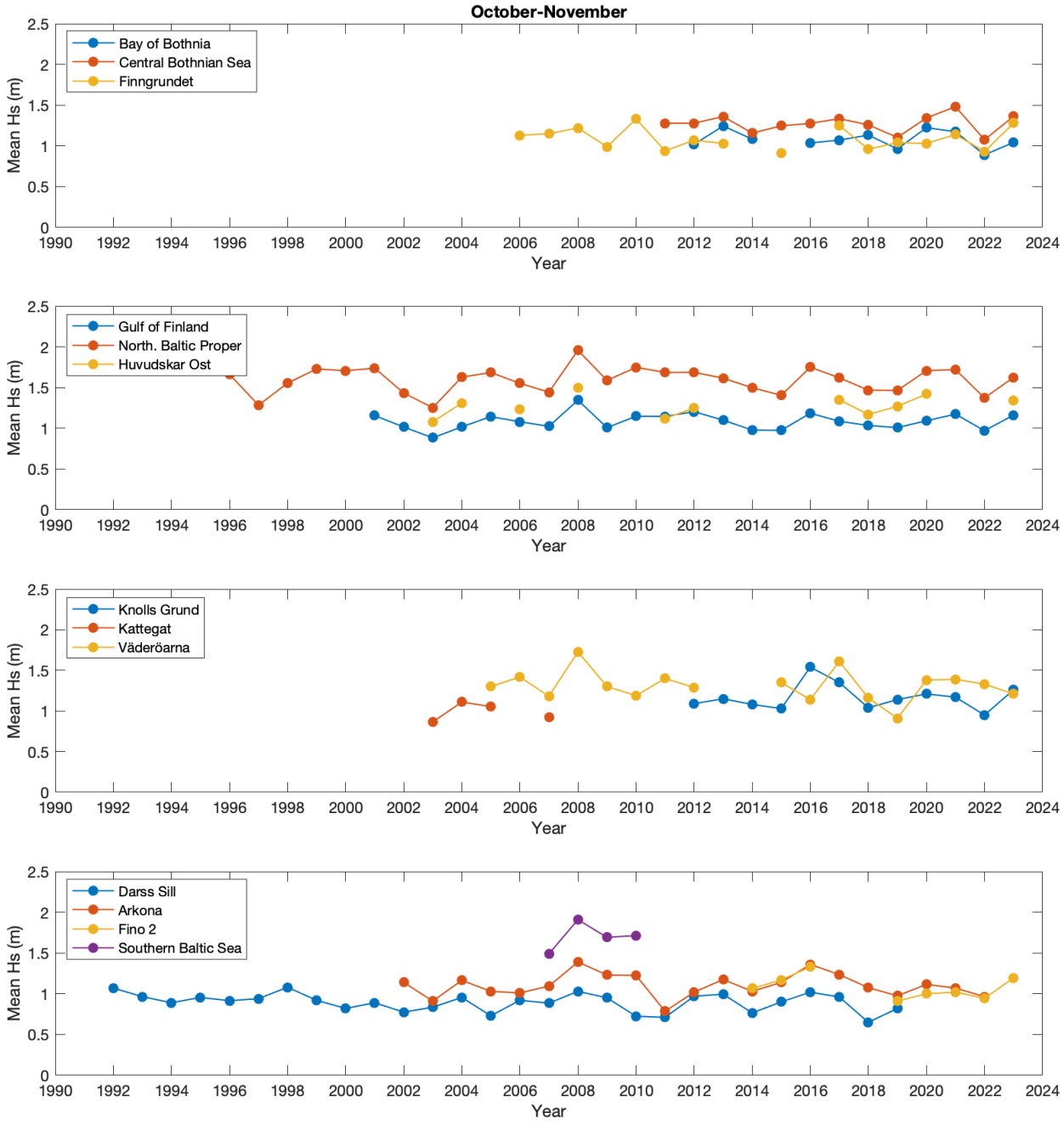

Figure 7. The yearly variation of the mean significant wave height Hs in the period of October-November. In some years the data do not fully cover the whole period. Especially at station Huvudskär Ost, the gaps in the data in years 2011 and 2012 might have left the mean value lower than it should be.

Metadata

In 2023 Finnish Meteorological Institute (FMI) made real time wave measurements at four locations in the Baltic Sea, in the Bay of Bothnia (station Bay of Bothnia, 64° 41.1' N, 23° 14.4' E), in the Central Bothnian Sea (station Bothnian Sea, 61° 48.0' N, 20° 14.0' E), in the Northern Baltic Proper (station Northern Baltic Proper, 59° 15.0' N, 21° 00.0' E) and in the Gulf of Finland (station Helsinki, 59° 57.9' N, 25° 14.1' E). The northern parts of the Baltic Sea freeze every year. The length of the measuring periods varies every year depending on the extent of the ice cover.

The Swedish Meteorological and Hydrological Institute (SMHI) made wave measurements at four locations, in the Southern Bothnian Sea (station Finngrundet, 60° 53' N, 18° 37' E), in the Northern Baltic Proper (station Huvudskär Ost, 58° 56' N, 19° 10' E), in the Central Baltic Proper (station Knolls Grund 57° 31' N, 17° 37' E) and in Skagerrak (station Väderöarna, 58° 29' N, 10° 56' E). To prevent the loss of both instruments and data due to trawling activities in the area the position of the buoy at Finngrundet has been adjusted twice since 2012. Today the position is still south of the eastern bank in waters of comparable depth but approximately 1 km further to the southwest of the previous position. The positions of the buoys operational in earlier years (shown in Figures 6 and 7) are: Kattegat 57° 11' N, 11° 32' E and Southern Baltic Proper 55° 55' N, 18° 47' E.

Since 1991, wave measurements in the western Baltic Sea have been carried out at a station located at 54° 41.9‘N, 12° 42.0‘E in the area of Darss Sill. Until November 26 2019 the Helmholtz-Zentrum Hereon was the operator of this buoy. Since November 26, 2019 the buoy is operated by the Federal Maritime and Hydrographic Agency of Germany (BSH). Beyond that, the BSH has performed measurements at a station northwest of Cape Arkona (54° 52.9‘N, 13° 51.5‘E) since 2002 and at the Fino 2 research platform located at 55° 00.5‘N, 13° 09.3‘E since 2014. For the latter position, mostly no long-term climatological wave data are available so far, as the buoy has been torn down very often. Finally, in October 2020, the classic wave buoy was replaced by a directional radar gauge. Up to now, measurement interruptions due to ice coverage or drift ice occurred only in the winter of 1995/1996 at the Darss Sill measuring station, and in February and March 2010 at the Arkona Basin station.

The significant wave height, usually denoted by H_s is, confusingly, defined in several ways. The most common way today is to calculate it from the variance of spectral density, also denoted by H_{m0}: $H_{m0} = 4\sqrt{\sigma^2}$, where $\sigma^2 = \int_0^\infty S(f)df$, $S(f)$ is the wave spectrum and f frequency. Another, older definition of H_s is the average height of the highest third of the waves, also denoted by $H_{1/3}$. In water that is deep for the waves (deeper than half of the wavelength) H_{m0} and $H_{1/3}$ are nearly equal. Both definitions are chosen to reflect how an experienced observer would visually estimate the sea state, which is the third, and probably the oldest definition of the significant wave height: a measure of the sea state that is significant to seafarers. The highest individual wave is approximately 1.6-2.0 times higher than the significant wave height.

The waves at each station except for Fino 2 are measured with surface following buoys, Seawatch, Watchmate (at Huvudskär Ost), Directional Waveriders, and Waveriders. Buoy measurements were collected 0.5 - 1 hour via Iridium, HF link, Argos-satellite, Orbcomm system and dataloggers with significant wave height calculated as H_{m0} on board the buoys over 1600 s or 1800 s time series of surface displacement. At Fino 2, the waves are measured by a radar gauge, which calculates H_{m0} every minute over the last 1200s time series of surface displacement. For the calculation of the statistics used in this report, values were taken every 20 minutes, so that each measured value of the surface displacement is reflected in exactly one value of significant wave height. The quality of the measurements was checked according to the routines at each of the responsible Institutes. All

measurement data referred to in the text are significant wave heights, namely monthly averages and maxima unless otherwise stated.

The lengths of the deployment periods in 2023 are indicated in the text. The length of the period at each station depends on the extent of the ice cover, maintenance and deployment logistics and possible instrument damages. As a consequence, measurements are not always available for 12 months per year for the long-term statistics. The years given in Figures 2-4 indicate the start of the measurements: in some months the statistics are over fewer years but only statistics over at least four years are plotted in the Figures. The monthly means are given when there are measurements over half of the month. Because of data gaps, the maximum values do not necessarily constitute the true monthly maximum, whereas the mean values are largely reliable. Due to the variation of the lengths of the time series in the statistics they should be used with caution.