Polar Portal Season Report 2023

For the 27th year in a row, Greenland's Ice Sheet lost more mass during the course of the melting season than it gained during the winter, whilst the extent of the sea ice also continued to decline.

During the 2022-2023 season, there was a particularly high rate of melting in July, whilst the spring and early summer saw higher levels of precipitation in the form of both rain and snow. Although the Greenlandic summer was cold and wet – compared to North America and Europe – this was not enough to prevent Greenland's Ice Sheet from once again losing mass (196 billion tonnes) during the period from the beginning of September 2022 until the end of August 2023.

In the following, we will look at the most important results observed in the Arctic in 2023:

- Cool summer, but a high melting season and high temperatures at Summit
- The Ice Sheet's net loss for 2023 was the 15th highest in the last 43 years
- Late start for the melting season in 2023
- Greenland's Ice Sheet continues to loss mass
- The sea ice fell to its sixth lowest level in 2023

Cool summer, but a high melting season and high temperatures at Summit

Once again, the summer of 2023 was relatively cold in Greenland. A lot of snow fell from October to December 2022, but the late winter months were relatively dry. In June, the Ice Sheet continued to accumulate mass, and at the end of the month the surface mass balance of the Ice Sheet was 150 Gt above its mean value. In spite of this data and the fact that the melting season began late in 2023, the overall account for the Ice Sheet reveals a net loss of mass.

As in previous summers, we find the explanation for Greenland's rather wet and cold summers a long way from Greenland itself. In May and at the beginning of June, and then again at the end of August, a powerful and stable region of high pressure dominated the atmosphere over North America and Europe. These stable weather systems had a major impact on the weather in Greenland, in addition to causing the disastrous amounts of rainfall seen in Greece and Libya. Research suggests that these types of weather systems have become more prolonged and perhaps more powerful during recent years.

This year's melting season was more intense than the average melting season – even when compared to 2012 and 2019, which saw record-high melting seasons. Melting occurred on more than 50 % of the surface of the Ice Sheet for 29 consecutive days from 27 June until 25 July.

Record-high temperatures were also observed at the Summit monitoring station, which is located around 3000 metres above sea level. A new July record of -7.3°C was set here, which is almost 2 degrees warmer than the previous record of -9.2°C, which was set in 2012, and 4.4 degrees warmer than the long-term mean for 1991-2020 at Summit. Furthermore, August was also very warm with an average temperature of -11.3°C, which is 4.3 degrees warmer than the mean. As a consequence, the meteorological summer as a whole (June-July-August) broke records with an average temperature of -10.4°C, which is 3.4°C warmer than during the period 1991-2020.

The Ice Sheet's net loss for 2023 was the 15th highest in the last 43 years

Changes to the total mass of Greenland's Ice Sheet reflect the combined effects of the surface mass balance (SMB), which is defined as the difference between snowfall and run-off from the Ice Sheet – and which is always positive at the end of a year – and the loss of mass at the coast as a result of calving of icebergs and melting of glacier tongues that meet the sea.

The surface mass balance, which is an expression of the isolated growth and melting of the surface of the Ice Sheet, is monitored both via actual measurements at the surface (PROMICE and GCNet weather stations from GEUS) and computer models. The Danish Meteorological Institute (DMI) carries out daily forecasts of how much ice or water the Ice Sheet accumulates (through snowfall) or loses (through run-off). Based on these simulations, an overall measurement of how the surface mass balance develops across the entire Ice Sheet is obtained (Fig. 1).

The 2022-2023 season saw a net surface mass balance of 398 Gt for Greenland's Ice Sheet – i.e. somewhat lower than the figure for the previous season, which was 471 Gt. According to DMI's calculations, this ranks the season in 15th place overall, based on data from the last 43 years. This figure is very close to the average for the period 1981-2010. By way of comparison, the lowest calculated SMB was just 38 Gt in 2012.

If we look at the total mass balance, which is the sum of surface melting and calving of icebergs and melting of glacier tongues in contact with seawater, then Greenland's Ice Sheet lost around 196 billion tonnes during the course of the 12-month period that ended in August 2023. This means that 2022-2023 was the 27th year running in which Greenland's Ice Sheet has shrunk.

This places the loss for 2023 as 23rd overall, based on 37 years of data. The map in Figure 1 shows how the geographic distribution of SMB gain (blue) and SMB loss (red) for 2022-2023 can be compared to the long-term average (grey).

Surface mass balance

Surface mass balance is an expression of the isolated growth and melting of the surface of the Ice Sheet. Precipitation contributes to an increase of the mass of the Ice Sheet, whilst melting causes the Ice Sheet to lose mass. In relation to the total mass balance, the surface mass balance says something about the contribution on the surface of the Ice Sheet – i.e. excluding that which is lost when glaciers calve icebergs and melt as they meet the warm seawater. Since the 1990s, the surface mass balance has generally been declining.

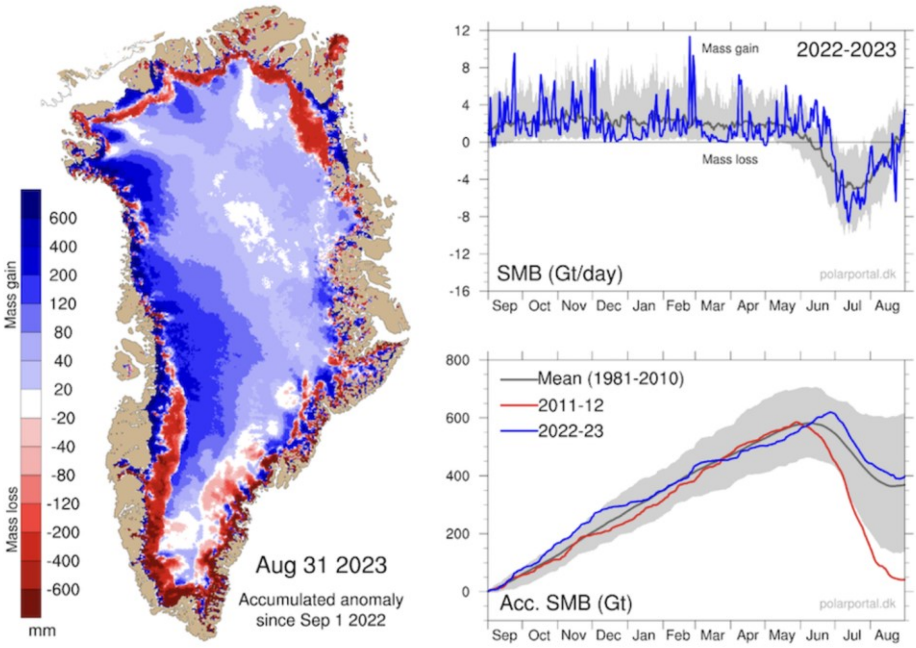

Figure 1: *Left: The map shows the difference between the annual SMB in 2022-23 in relation to the reference period 1981-2010 (expressed as mm ice melt). Blue indicates a larger accumulation of ice than average, and red shows a larger loss of ice than average. Right: Daily (top) and accumulated (bottom) SMB of Greenland's Ice Sheet, expressed in Gt (billion tonnes) per day, and Gt (billion tonnes) respectively – where 1 Gt corresponds to 1 cubic kilometre of ice. The blue line shows the "SMB year" 2022-23. The grey line shows the average for the period 1981-2010, whilst the grey areas show the second highest and second lowest values for each day of the year. The red line in the bottom diagram shows the record low SMB year of 2011-12. (Credit: Polar Portal).*

Late start to the melting season in 2023

Once again, summer came late to Greenland in 2023, and there were several heavy falls of snow in June, which contributed to a late start to the melting season. May 31 was the first of three days in a row in which melting took place on more than 5% of the surface of the Ice Sheet. This marked the onset of the melting season, and was five days later than the norm for the period 1981-2021.

The ablation season began on 29 June, which is extremely late – in fact, 16 days later than the norm measured in the period 1981-2021, which makes this year's onset of ablation the fifth latest during the 43 years in which data has been acquired. However, despite this cold start, there were periods with very high temperatures at the end of July; this led to a considerable loss of ice within just a few days.

Definitions of the onset of the melting season
At Polar Portal we work with two different definitions of the onset of the melting season:

Onset of the melting season: The first day of at least three days in a row in which more than 5% of the surface of the Ice Sheet undergoes melting of more than 1 mm/day.

Onset of the ablation season: The first day of at least three days in a row in which the Ice Sheet loses more than one gigatonne (Gt) of ice per day from the surface.

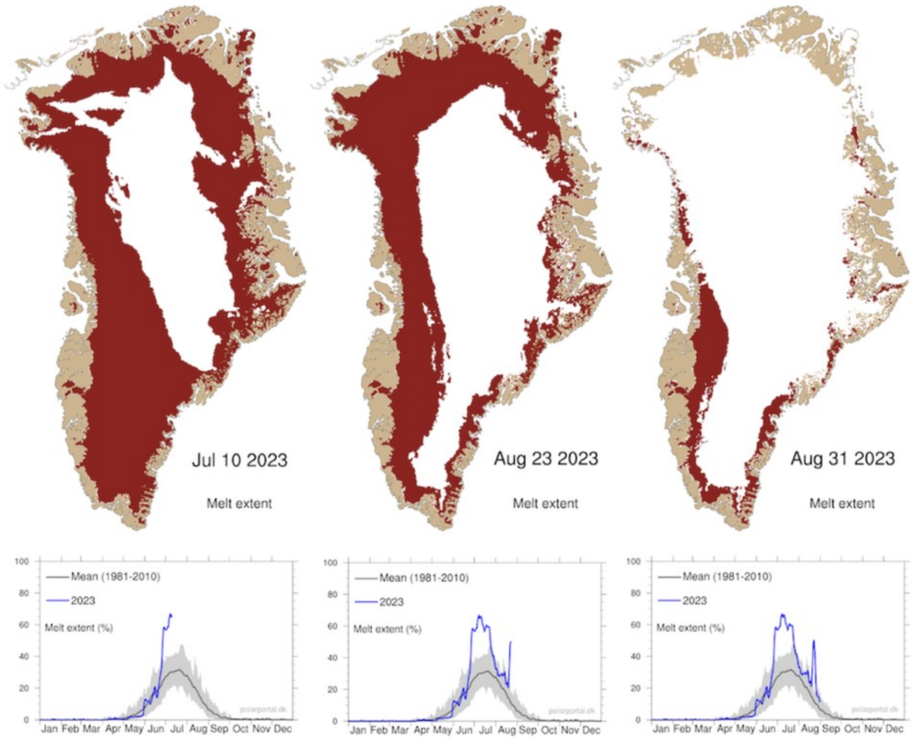

***Figure 2:** The map on the left shows the first peak of melting of the Ice Sheet, which took place on 10 July, when melting occurred on 67% of the surface of the Ice Sheet – shown in red. The map in the middle shows the second melting peak, which occurred on 23 August, with melting on 50% of the surface, whilst the map on the right shows the situation on 31 August. From 21 June, melting was above average throughout the rest of the melting season – and indeed also after the end of the melting season. The blue lines show the percentage of the surface that experienced melting. The grey line shows the average for the period 1981-2010. (Credit: DMI Polar Portal).*

In overall terms, the melting season values were within a deviation of 20% in relation to the average for 1991-2020 at the majority of the PROMICE project's automated weather monitoring stations on the Ice Sheet itself. This is shown by observations from eight of the monitoring stations. However, there were exceptions in the northwest region, where net melting of 2.2 metres was observed in Thule, which is 87% higher than average, whilst in Upernavik melting of 1.6 metres was observed, which is 32% lower than average. These overall summer values indicate the combined effects of a cooler June and warmer July and August. This resulted in approximately average melting in coastal areas.

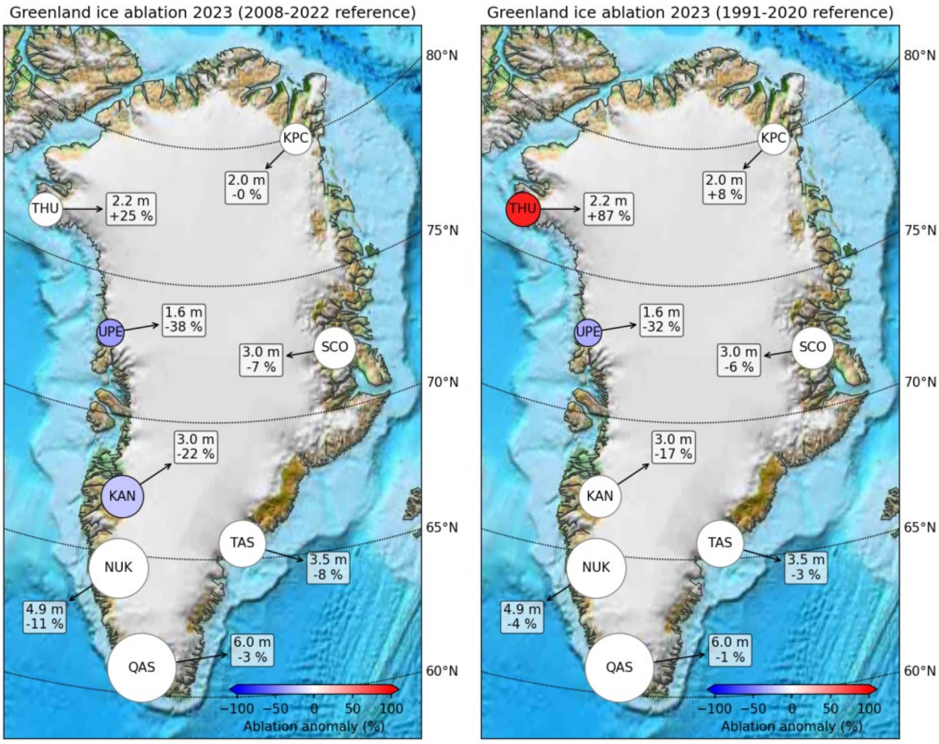

Figure 3: *The maps show the net melting anomalies for 2023 at lower altitude PROMICE weather stations compared to 2008-2022 (left) and 1991-2020 (right) (Credit: Van As et al. (2016), updated).*

Greenland's Ice Sheet continues to lose mass

Greenland's Ice Sheet can only gain more ice by having a positive surface mass balance (SMB). This occurs when more snow falls than melts. However, the Ice Sheet also loses ice via other processes, primarily "calving" of glaciers and melting of the glaciers' tongues where they meet the sea. The combination of these losses and the SMB results in a "total mass balance", TMB, for the year. Over the long term, this should average out at zero – i.e. no net gain or loss of ice – but this is not the case.

There are two methods of measuring the Ice Sheet's total mass balance: Modelling of calving and underwater melting (described in the article by Mankoff et al., 2021) and measurement of the mass of the ice via measurement of the Earth's gravitational field (GRACE). The two methods are completely independent of each other, although they have a common period of measurement: 1 April 2002 to 31 March 2023. And they arrive at relatively consistent values for loss on the Ice Sheet – 4,578 Gt (Mankoff et al.) and 4,745 Gt (GRACE) respectively.

Measurement of calving and underwater melting
Satellites can be used to measure the rate at which the ice flows through checkpoints along the edges of the Ice Sheet where we know the thickness and shape of the ice. By combining this data concerning the thickness of the ice, we can estimate the amount of ice that is lost through the process of calving and underwater melting.

GRACE satellites measure the Earth's gravitational field
GRACE-FO measure minor changes in the Earth's gravitational field that result from changes in the mass of the ice. This data enables changes in the mass of the Ice Sheet to be determined. According to measurements from GRACE and GRACE-FO, the Ice Sheet suffered a total loss of ice of around 4,745 Gt during the period from 1 April 2002 until 31 March 2023, corresponding to a rise in sea level

of 1.3 cm, which is enough to cover the entire land mass of the USA with half a metre of water.

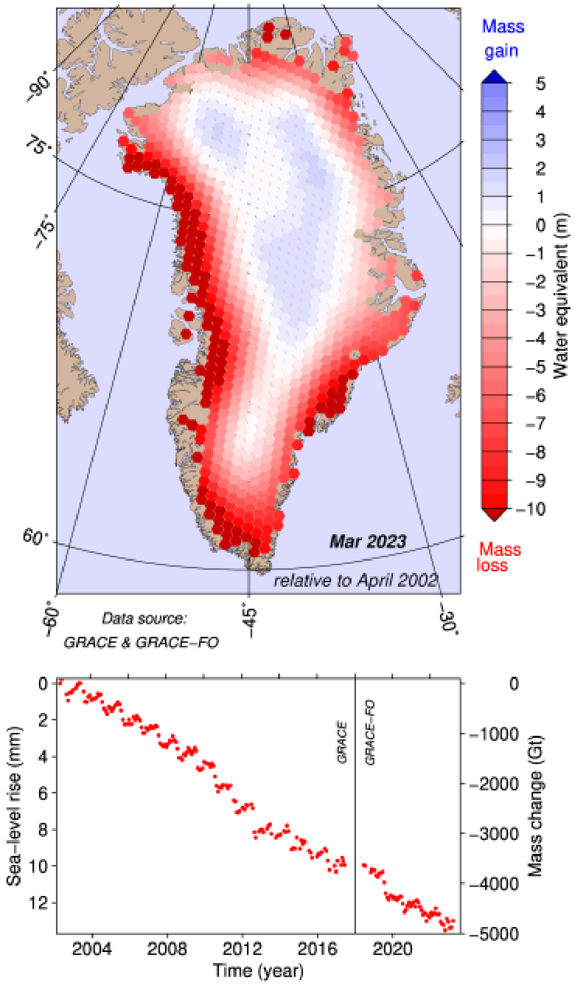

Figure 4: *The graph shows the month-by-month development in changes in the total mass of the Ice Sheet measured in Gt based on data from the GRACE and GRACE-FO missions. (1 Gt is 1 billion tonnes or 1 km*^{3} *of water. 100 Gt corresponds to a global rise in sea level of 0.28 mm). GRACE was launched in March 2002, with the mission ending in October 2017. GRACE-FO was launched in May 2018, and there is therefore a period between the two missions where data is missing. The latest data is from March 2023. (Credit: Polar Portal)*

The overall picture of the Ice Sheet

Data concerning the total mass balance of the Ice Sheet enables the overall Ice Sheet "account" for gains and losses to be monitored. The figures show that 2022-2023 once again saw a very high loss of ice in the form of calving and sea melting.

Greenland's Ice Sheet lost 196 Gt of ice, which makes 2023 the 17th consecutive year in which the Ice Sheet lost more ice than it gained (based on data from Mankoff et al.)

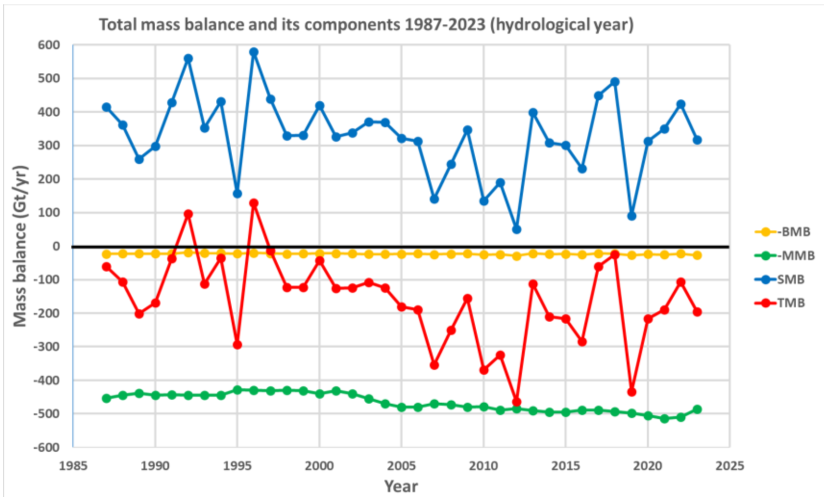

Figure 5: *The graphs provide an overview of overall melting from Greenland's Ice Sheet from 1987 until 2023. Surface mass balance (blue), marine mass balance (green), basal mass balance (yellow), total mass balance (red). The values are in Gt per year. (Credit: Martin Stendel, DMI)*

Sea ice fell to its sixth lowest level in 2023

The maximum extent of sea ice was reached on 2 March 2023, when the ice covered an area of 14.759 million km^2. The average extent for March 2023 was the fourth lowest since 1978, when satellite monitoring of the extent of the sea ice began. The result for the year thus tallies with observations from recent decades, where the maximum extent of sea ice in the Arctic has been very low. This underlines the fact that the extent of sea ice in the Arctic is under severe pressure from rising global temperatures.

The minimum extent of sea ice in the Arctic was observed on 16 September. On this day, 4.8 million km^2 of sea ice was observed. This means that the extent of the sea ice on this day in the Arctic was the sixth lowest since 1978, which was when satellite monitoring began.

Since 2000, the maximum and minimum extents of the sea ice in the Arctic have ranked in the top ten in terms of lowest figures. The trend for the extent of sea ice in the Arctic has been clearly negative since 1978, and has now become the new normal in the Arctic.

This downward trend is bad news for the Arctic climate, as sea ice plays a key role in the global climate system. Less sea ice leads to larger areas with dark surfaces, which thus absorb more energy from the sun's rays. And this drives a vicious circle which causes warming in the Arctic to accelerate.

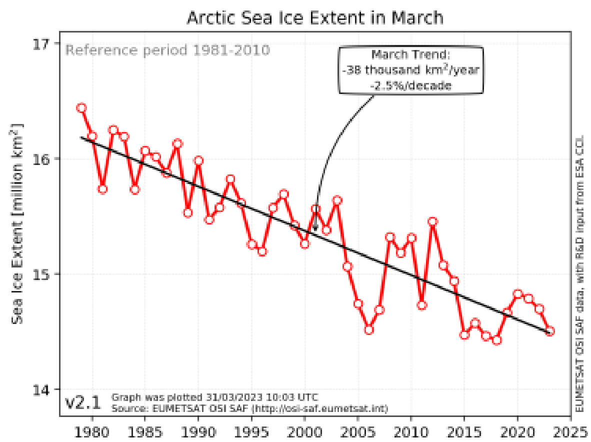

Figure 6: *Over the past 45 years the maximum extent of sea ice in the Arctic has shrunk by approx. 38,000 km^2/year in relation to the mean value in the period 1981-2010. (Credit: EUMETSAT's OSISAF).*

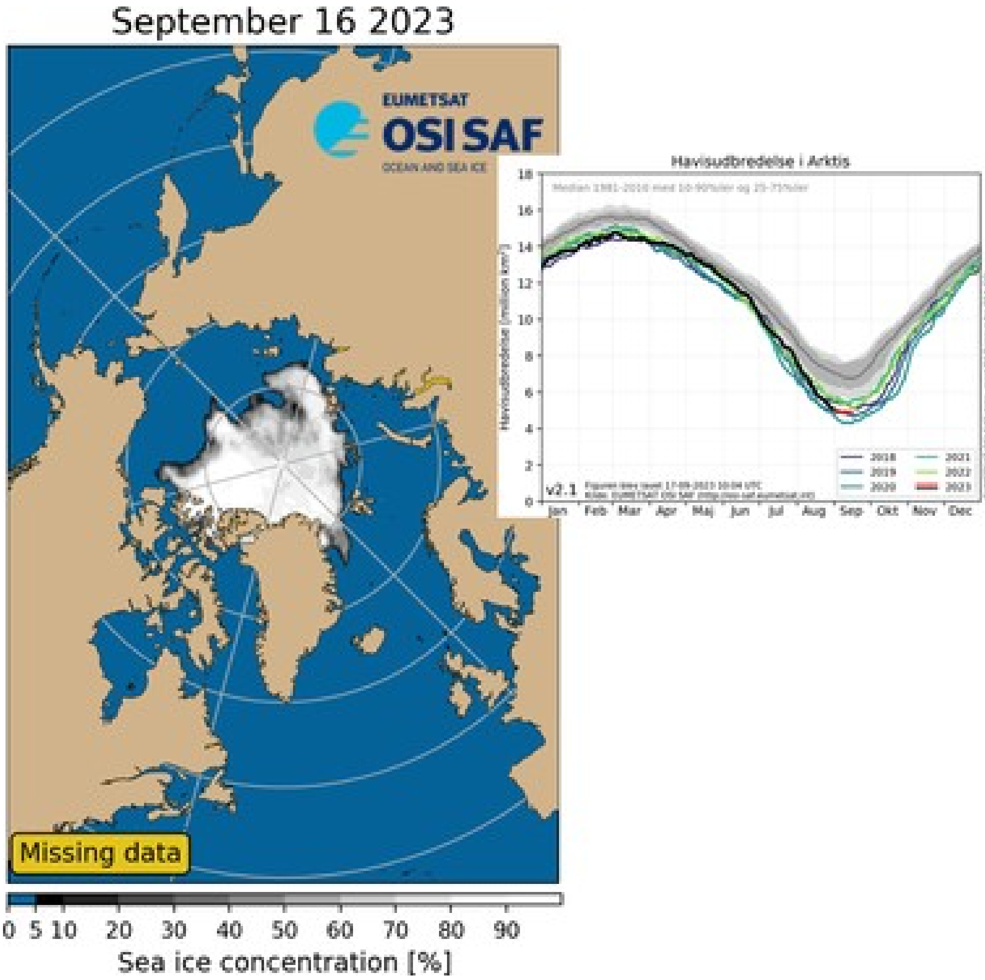

Figure 7: *DMI graph of extent of the sea ice on 16 September 2023, the day of the season's sea ice minimum. The map and graphics are based on EUMETSAT's OSI SAF ice concentration calculations, which show the area where the sea ice concentration exceeds 15% (Credit: Polar Portal).*

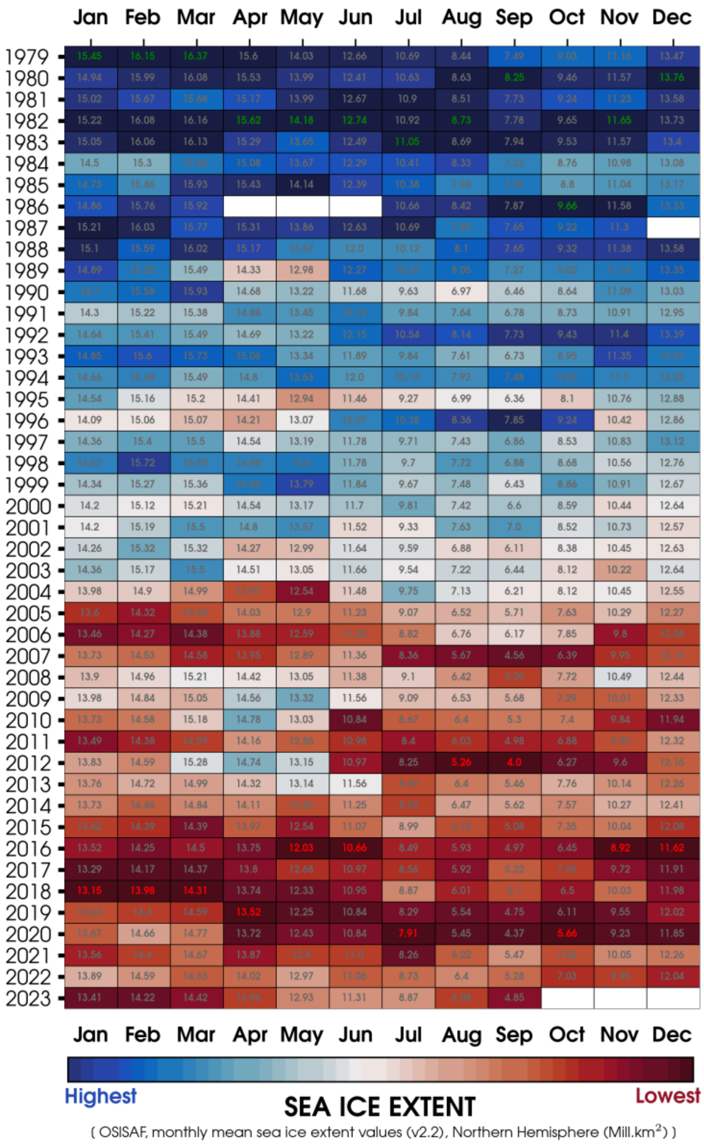

***Figure 8:** The figure shows the ranking of low extents of sea ice in the Arctic month-by-month since 1979. The figures in the box show the extent of sea ice ranked from the bottom (ocean.dmi.dk). The extent is calculated based on OSI SAF data (OSI 450), the temporary climate dataset ICDR, OSI-430-b and a Near Real Time (NRT) product. The monthly records for melting of ice are marked in red (Credit: http://ocean.dmi.dk/arctic/sie_monthmean.php)*

Extent of the Arctic sea ice

The extent of the Arctic sea ice is analysed by both the American NSIDC and the European EU-METSAT – and thus in turn by DMI. Both centres use the same satellite data, but they treat “noise” over open water and along the edges of the ice slightly differently. This means that the graphs for the extent of the sea ice are not quite identical. The European figures are compiled via data from DMI researchers and are published in The Cryosphere scientific journal.

Observations of the extent of the sea ice reveal that the area of the Arctic summer ice has fallen annually by an average of approx. 94,000 km^2 since the end of the 1970s. This corresponds to more than twice Denmark’s total land area.