# Polar Portal Season Report 2022

## Once again, Greenland's Ice Sheet lost more mass during the course of the melting season than it gained during the winter in 2022, whilst the extent of the sea ice also continued to decline.

**While record levels of heat were observed in large areas of Europe and North America, it was relatively cool and wet in Greenland. The melting season started late and was already over by the middle of August, which saw heavy falls of snow. The total mass balance reveals, however, that the Ice Sheet nevertheless lost 84 billion tonnes. 2021/22 is thus the 26th season in a row with a negative mass balance. We have to go all the way back to 1996 to find a growth in the mass of the ice. Furthermore, the end of the season was immediately followed by several periods characterised by very high temperatures and more rain.**

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**In the following, we will look at the most important results observed in the Arctic in 2022:**

- Cool summer, followed by record-high temperatures and rain at high altitudes
- Relatively normal season for the Ice Sheet – although still with net loss
- Late start for the melting season in 2022
- Overall loss – total mass balance
- Sea ice fell to its ninth lowest level in 2022

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## Cool summer, followed by record-high temperatures and rain at high altitudes

The summer of 2022 was relatively cold in Greenland. This can be explained with the atmospheric circulation over the Northern Hemisphere: when North America (as in 2021) or Europe (as in 2022) are dominated by high pressure, the temperature in Greenland will typically be relatively low. This is due to the jet stream, which leads to low pressure and cool temperatures over Greenland.

Autumn, on the other hand, saw several records being broken. At seven out of DMI's 20 weather monitoring stations along the west coast, record temperatures were registered in September. The highest deviation from the average was observed at the Summit station at an altitude of 3,260 m, which recorded a mean temperature of -14.2°C (9.4°C above the 1991-2020 mean). As both October and November were also considerably warmer than normal, autumn 2022 at Summit ended with a deviation of 7.5°C compared to the 1991-2020 average. Furthermore, record temperatures were observed at three DMI stations in Southeast Greenland. In all three cases, southerly winds carried the unusually warm air to Greenland; this led to extensive melting in the southwest of Greenland, which is very unusual for this time of year.

**Rain at high altitudes on the Ice Sheet**

Rain was once again an issue in 2022, particularly in the summer season. In 2021, rain was registered for the first time since the beginning of observations in 1989 at Station Summit at a height of 3,216 metres. Rain was registered once again at high altitudes in 2022, more specifically at South Dome in southeastern Greenland at a height of 2,892 m. Rain means that temperatures are close to or above freezing point, which at these altitudes is very rare.

In addition, several record-highs in terms of precipitation were registered: at Station North in January and June, at Ittoqqortoormiit in March, in Nuuk in June and in Kangerlussuaq in October. Furthermore, a precipitation record was registered in August in Pituffik (more than six times the average precipitation) and in September in Aasiaat (more than four times the average precipitation). This resulted in a record-wet spring in Nuuk, a record-wet summer in Pituffik and a record-wet autumn in Aasiaat and Kangerlussuaq. In Nuuk and Aasiaat, 2022 also saw the highest-ever levels of precipitation overall.

## Relatively normal season for the Ice Sheet – although still with net loss

Changes in the total mass of the Greenland Ice Sheet reflect the combined effects of surface mass balance (SMB), which is defined as the difference between snowfall and runoff from the Ice Sheet – which is always positive at the end of a year – and the loss of mass along the coasts as a result of calving of icebergs and melting of glacier tongues in contact with sea water.

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

The 2021-2022 season saw a net surface mass balance of 471 billion tonnes (Gt) for the Greenland Ice Sheet. According to DMI calculations, this ranks the season in 10th place overall, based on data from the last 42 years.

As a 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 sea water, the Greenland Ice Sheet lost about 84 billion tonnes over the 12-month period that ended in August 2022. This means that 2021/2022 is now the 26th year running a a mass loss on the Greenland Ice Sheet.

This ranks the loss for 2022 as 27th overall, based on 36 years of data. In other words, the 2021/2022 season was relatively normal for Greenland's Ice Sheet, although the Ice Sheet still ended up exhibiting a net loss. The map in Figure 1 shows how the geographic distribution of SMB gain (blue) and SMB loss (red) for 2021-2022 can be compared to the long-term average (grey).

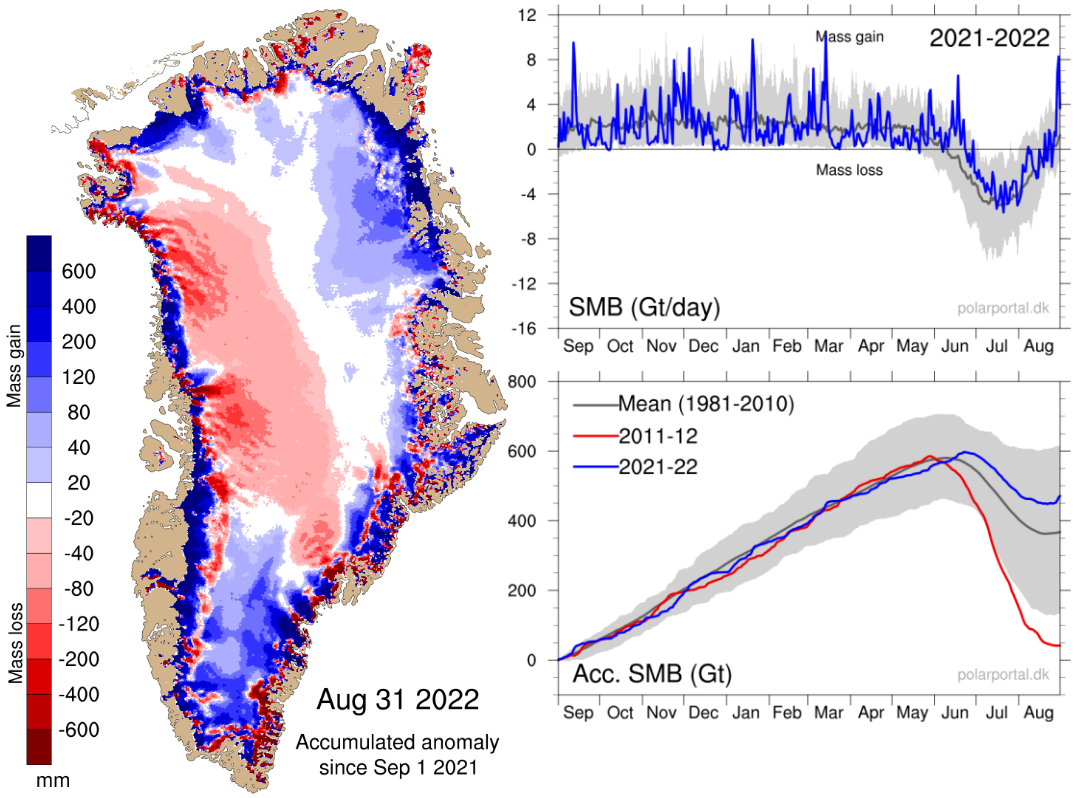


***Figure 1:*** *Left: The map shows the difference between the annual SMB in 2021/2022 in relation to the reference period 1981-2010 (expressed as mm ice melt). Blue indicates a larger accumulation of ice than average, and red shows a larger loss of ice than average. Right: Daily (top) and accumulated (bottom) SMB of Greenland's Ice Sheet, expressed in Gt (billion tonnes) per day, and Gt (billion tonnes) respectively. The blue lines show the "SMB year" 2021/2022. The grey lines show 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 lower diagram shows the record low SMB year of 2011-2012. (Credit: Polar Portal).*

**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 tells us about the contribution on the surface of the Ice Sheet – i.e. excluding loss by calving icebergs and melt when glacier tongues meet warm sea water. Since the 1990s, the surface mass balance has generally been declining.

## Late start to the melting season in 2022

Summer came late to Greenland in 2022, and there were several heavy falls of snow in June, which contributed to a late start to the melting season. May 28th was the first of three days in a row during which melting took place on more than 5% of the surface of the Ice Sheet. This marks the onset of the melting season, which is two days later than the norm for the period 1981-2021.

The ablation season began on 30th June, which is very late – in fact, 17 days later than the norm measured in the period 1981-2021, which makes this year's onset of ablation the fourth latest during the period of 42 years over which data has been acquired. Although melting took place on more than 30% of the surface of the Ice Sheet, there was also heavy snowfall in southern Greenland in comparison to 2021.

The automatic weather stations on the Ice Sheet in the PROMICE project measured temperatures in June that were less than -1 standard deviation for the entire Ice Sheet. In June and August the measurements were within +/-1 standard deviation (see Figure 2).

Throughout the entire ablation season, PROMICE's weather monitoring stations measured melting that was close to the average for the period 2008-2022. However, the northwest of Greenland underwent above average melting, whilst the northeast of Greenland experienced melting that was below average (see left panel of Figure 2).

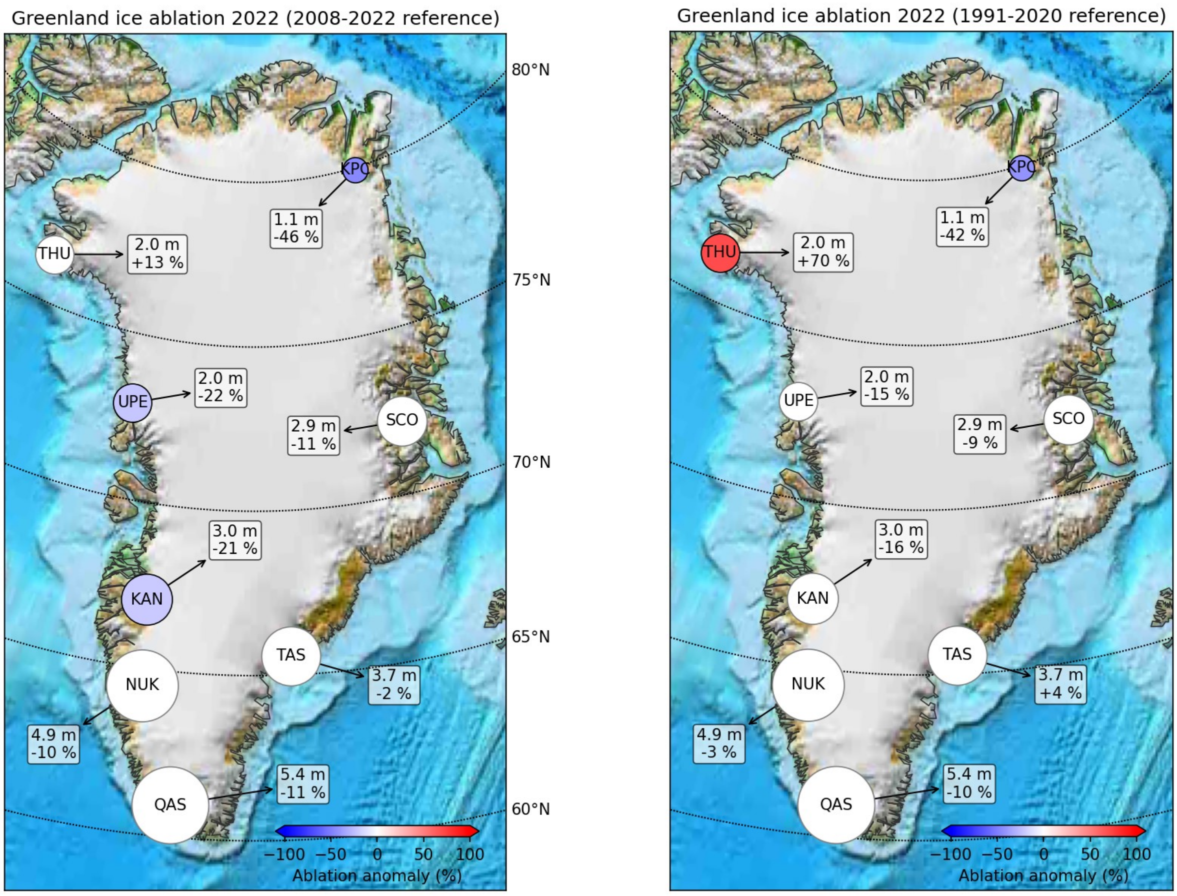


***Figure 2:*** *The maps show the net melting anomalies for 2022 at the lower elevation PROMICE weather stations compared to 2008-2022 (left) and 1991-2020 (right) (Credit: Van As et al. (2016), updated).*

### 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.

On 2nd September, warm, moist air from the central North Atlantic flowed up along the western side of the Ice Sheet. On the following day – 3rd September – this air then moved east across the Ice Sheet, and PROMICE and the GC-Net (Greenland Climate Network) weather station registered rainfall at South Dome, which lies at an altitude of 2,900 metres above sea level. At one of the weather stations, heavy rainfall of 32 mm within a 24-hour period was measured along the western part of the Ice Sheet.

At the beginning of September, record-high temperatures were also observed in Kangerlussuaq, Nuuk, Paamiut, Narsarsuaq and Qaqortoq along the west coast. The temperature in Nuuk, for example, reached 20°C, with the wind increasing in strength to storm. This figure is remarkable because the highest temperature at any time during the summer in Nuuk was only 17°C.
There were further two warm periods in September. In connection with the latter, high temperatures were also observed along the east coast, and in Tasiilaq, a Piteraq with wind gusts of 53 m/s or 191 km/h were observed. A Piteraq is a katabatic wind from the Ice Sheet, whereby accumulations of cold air can descend like avalanches over coastal terrain.

## Overall loss – total mass balance

The Greenland Ice Sheet can only gain ice via 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" for the year. Over the long term, this should average out to zero – i.e. there would be no net gain or loss of ice, but this is not the case.

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.

This data makes it possible to monitor the overall budget of the Ice Sheet. The figures reveal that 2021-2022 once again had a very high loss of ice in the form of calving and underwater melting, although the figure was lower than the year before.

Although Greenland did not experience a record-high loss of ice in 2022, it was still the 26th year in succession that the Ice Sheet lost more ice than it gained.

Based on these figures, it can be calculated that from 1st September 1986 until 31st August 2022 Greenland's Ice Sheet has lost approximately 5,500 Gt of ice. This corresponds to a contribution of 1.5 cm to the average global rise in sea levels of approximately 12 cm – note that this is only due to loss of mass from Greenland's Ice Sheet. For the 20-year period 1st September 2002 until 31st August 2021, which is covered by GRACE data (see below), the loss is 4,352 Gt, corresponding to a 1.2 cm rise in sea level.

## Satellites continue to register a loss in total mass balance and the height of the Ice Sheet

**GRACE satellites and their successors measure the Earth's gravitational field**

GRACE-FO measure small changes in the Earth's gravitational field which are the result of changes in the mass of ice. This data enables changes in the mass of the Ice Sheet to be determined.

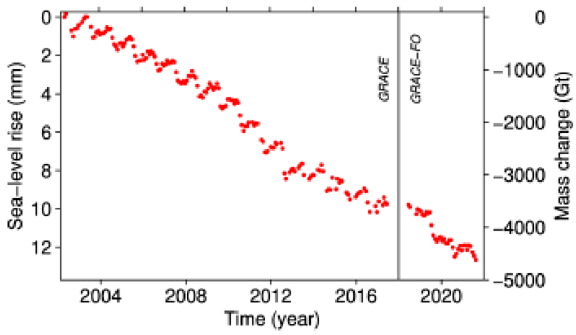


*Figure 3: The graph shows month-by-month development in the total mass change of the Ice Sheet measured in Gt based on data from the GRACE and GRACE-FO missions. (1 Gt is 1 billion tonnes or 1 km$^3$ of water. 100 Gt correspond to a global sea level rise of 0.28 mm). GRACE was launched in March 2002, and the mission ended in October 2017. GRACE-FO was launched in May 2018. Therefore a gap exists between both missions.*

According to measurements from GRACE and GRACE-FO, the Ice Sheet suffered a total loss of ice of around 4,470 Gt during the period from April 2002 until August 2021, corresponding to a rise in sea level of 1.2 cm, which is enough to cover the entire land mass of the USA with half a metre of water. This provides good agreement with the mass balance data described above. Note that these methods are independent of each other.

## Sea ice fell to its ninth lowest level in 2022

The minimum extent of the sea ice in the Arctic in 2022 occurred on 17$^{th}$ September. On this day, 5,137 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 ninth lowest since 1978, when satellite monitoring began.

The average extent of the sea ice in September was the eleventh lowest, with 5,390 million km$^2$.

In light of the fact that we got used to many record-low degrees of coverage during the last 15 years or so, it can be considered positive that the sea ice extent both this and last year has generally been some way off setting any new records. However, the trend concerning the sea ice in the Arctic since 1978 is clearly negative.

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.

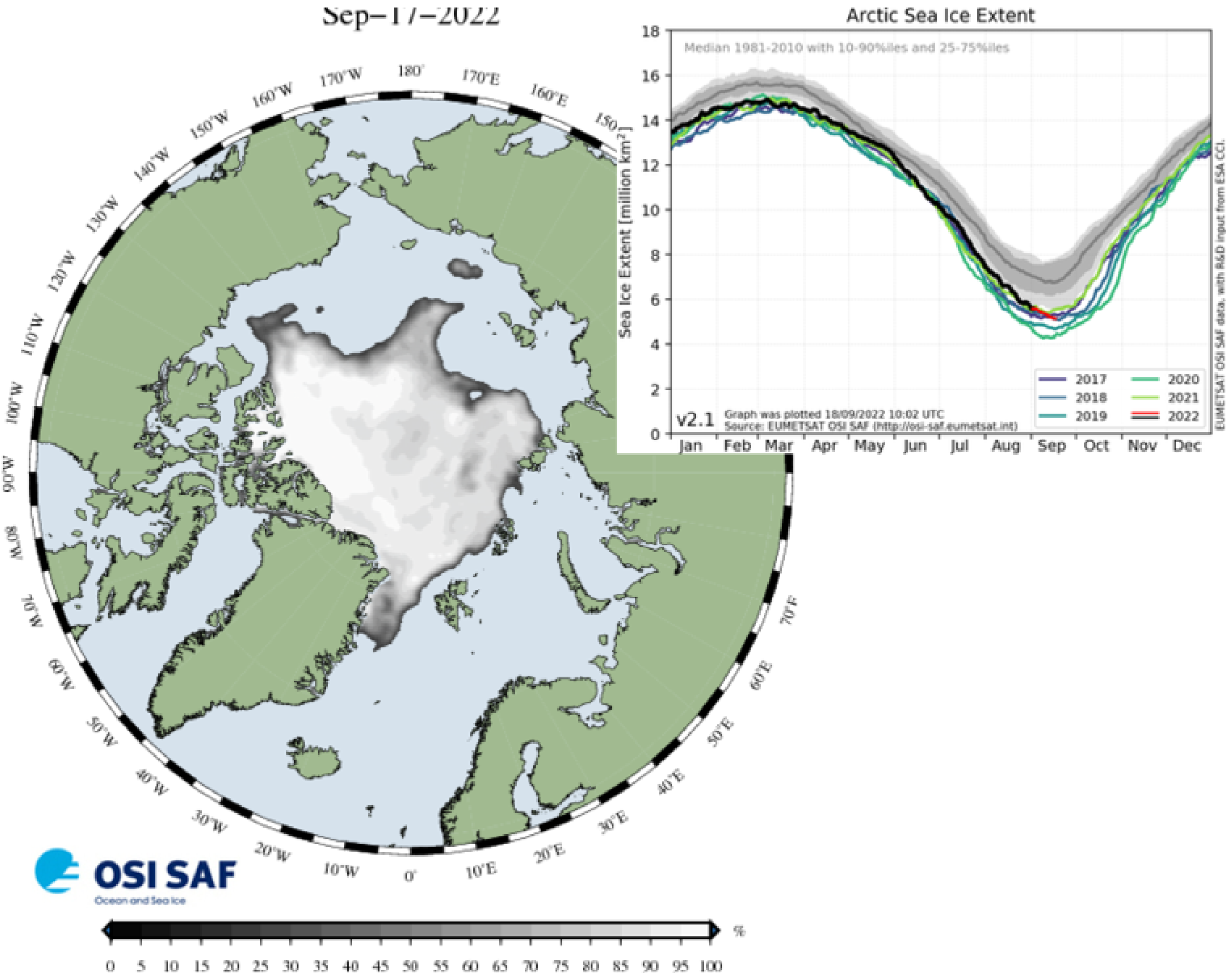


***Figure 4:*** *DMI graph of extent of the sea ice on 17th September 2022, the day of the annual sea ice minimum. The map and graphics are based on EUMETSAT's OSI SAF ice concentration calculations. They show where the sea ice concentration exceeds 15% (Credit: Polar Portal).*

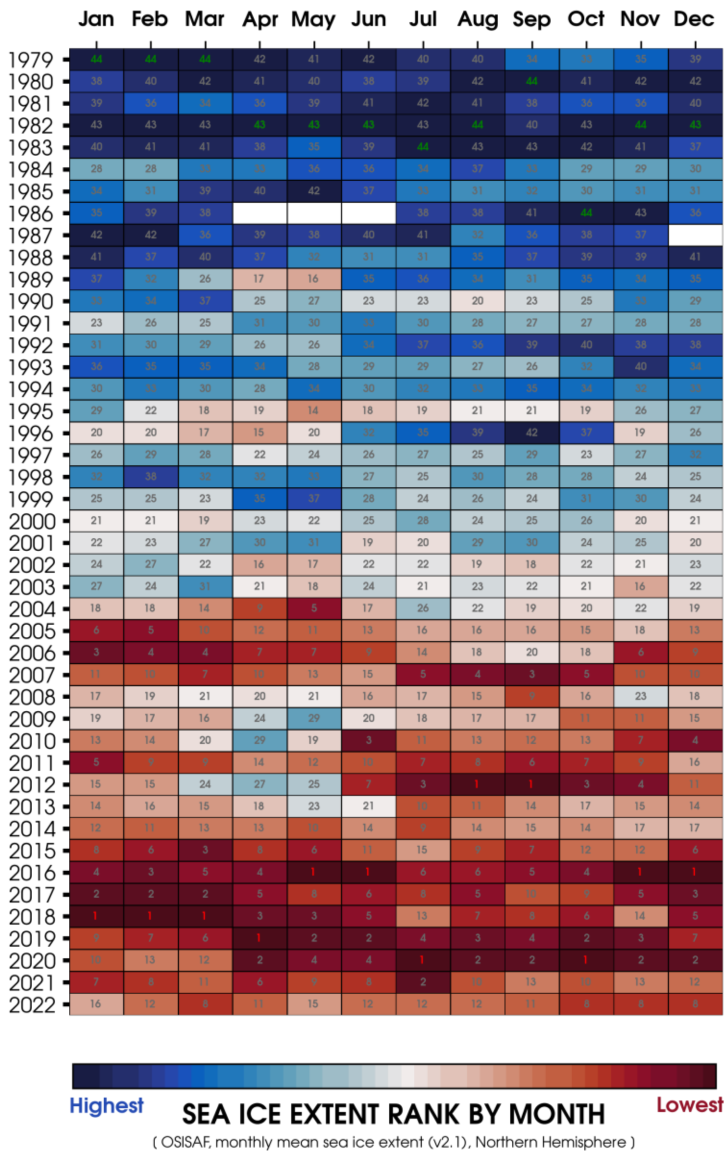


***Figure 5:*** *The figure shows the ranking of low extents of sea ice in the Arctic month-by-month since 1979. The figures in the box show the extent of sea ice ranked from the bottom (ocean.dmi.dk). The extent is calculated based on OSI SAF data (OSI 450), the temporary climate dataset ICDR, OSI-430-b 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 scientific journal The Cryosphere.

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.