Polar Portal Season Report 2021

2021 is the 25th year in a row in which Greenland's Ice Sheet lost more mass during the course of the melting season than it gained during the winter. The early part of the summer was cold and wet with unusually heavy and late snowfall in June, which delayed the onset of the melting season, whilst a heatwave at the end of July led to a considerable loss of ice.

The Greenlandic Ice Sheet ended the 2020-2021 season with a net surface mass balance of approximately 396 billion tonnes (Gt). According to calculations performed by the Danish Meteorological Institute (DMI), this makes the current season the 28th lowest in the 41-year time series. Seen from a current perspective, this can be regarded as a somewhat average year. However, it is thought-provoking to realise how our perspective changes in line with climate change: at the end of the 1990s, for example, the same figure would have been regarded as a year with a very low surface mass balance in the climate picture at that time.

2021 was notable for several reasons. It was the year in which precipitation at Summit Station, which is located at the "top" of the Ice Sheet at an altitude of 3,200 metres above sea level, was registered in the form of rain. Furthermore, 2021 saw an acceleration of the loss of ice at the Sermeq Kujalleq glacier – or Ilulissat glacier – where the rate of loss had otherwise been stagnant for several years. Turning to the total mass balance, which is the sum of surface melting and calving of icebergs, in addition to melting of glacier tongues in contact with seawater, Greenland's Ice Sheet lost around 166 billion tonnes of ice during the 12-month period ending in August 2021. This means that 2021 is the 25th year in succession in which Greenland's Ice Sheet has shrunk. Winter snowfall in 2020-2021 was close to average for the period 1981-2010, which was good news for the Ice Sheet. A combination of low winter snowfall and a warm summer can result in very large losses of ice, as was the case in 2019.

Incidentally, the cause of the cold and wet early part of the summer across the Ice Sheet is found a long way away – over southwest Canada and northwest USA. Over the western part of Canada and the USA an enormous "blocking" high pressure system was formed. Shaped like the Greek capital letter Omega (Ω), this flow pattern actually occurs regularly in the troposphere, and not just over North America, but this blocking anticyclone has never been observed with such strength before. An analysis by World Weather Attribution demonstrates that such a circulation pattern can only be explained as a result of atmospheric warming caused by human activity.

In the following, we will look at the most important results observed in the Arctic in 2021:

- Unusual weather during the Arctic summer 2021
- Close to average melting of the surface of the Ice Sheet in 2021
- Extreme melting periods despite average temperatures
- The overall loss – the total mass balance
- Smaller growth in the period 2018-2021
- The extent of the sea ice fell to its second-lowest level in July 2021

Unusual weather in the Arctic summer 2021

The Arctic weather in the summer of 2021 was out of the ordinary. In spite of the cool early part of the summer, the end of July saw a period with very high temperatures at the onset of the melting season. This resulted in a considerable degree of melting around the Ice Sheet – and a very high loss of ice within just a couple of days.

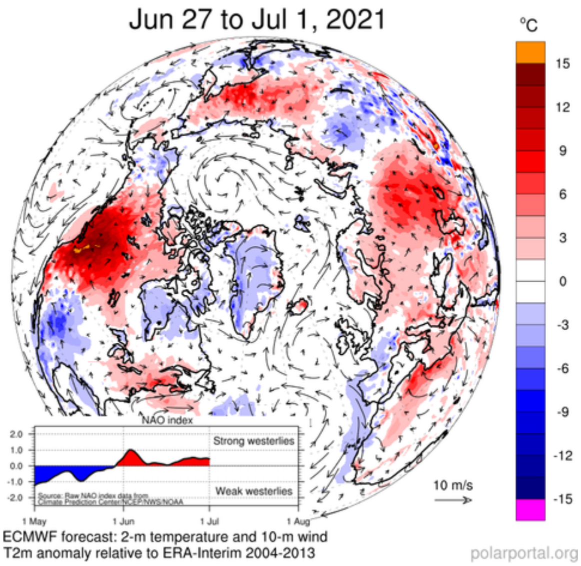

Fig. 1: *The map shows cool, moist summer weather over Greenland (in the middle of the map) and the extreme heat over North America. Colours indicate temperatures warmer (red) or colder (blue) than the average temperature. The arrows show the atmospheric circulation patterns (credit: Polar Portal).*

The map in Figure 2 shows the area of melting ice on 28th July (red area), whilst the table below confirms that melting took place on more than 60 % of the surface of the Ice Sheet on this particular day.

The East Greenlandic airport community, Nerlerit, close to Ittoqqortoormiit, registered a new record-high temperature of 23.4°C at the time.

Rain was also a constant theme in the early part of the summer in 2020-2021. In Qaqortoq in southern Greenland a new precipitation record of 145 mm was set on the summer solstice, while there were reports of flooding in the town of Qaanaaq in northwest Greenland.

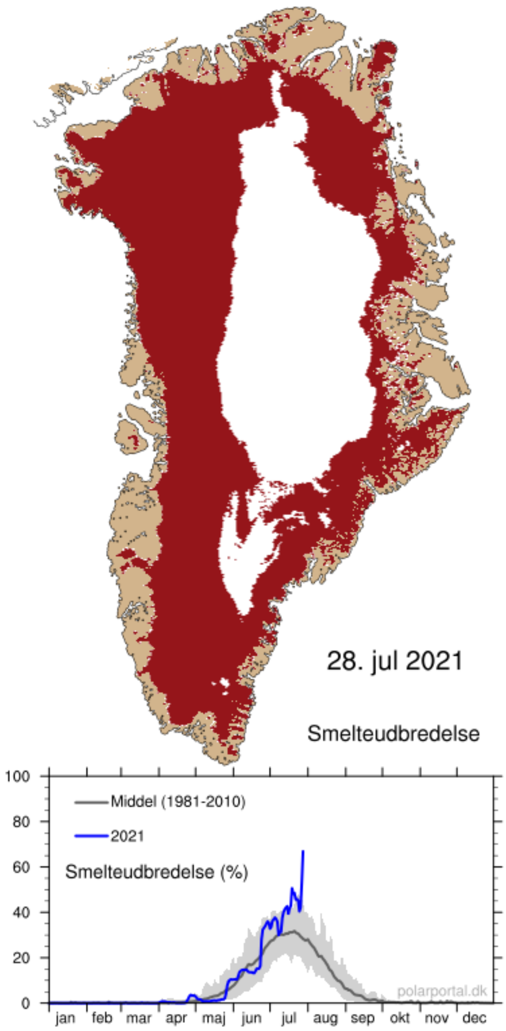

Fig. 2: *Top: Map of Greenland showing regions with surface melting over Greenland on 28 July 2021 (red). Bottom: Percentage of the area of the inland ice with melting conditions in 2021 (blue line ending on 28 July). The grey line shows the 1981-2010 average (credit: Polar Portal).*

The second unusual event occurred on 14th August 2021, when it rained at Greenland's highest-lying weather station, literally at the top of Greenland. The weather station has a very remote location some 3,216 metres above sea level and has an average annual temperature of -30°C.

Rain occurs at temperatures close to or above freezing point, with melting at this altitude being extremely rare. It is thus the first time since observations began in 2008 that employees at the station had observed rain.

Records from Summit Station only go back to the 1990s, so we cannot say much about rainfall at Summit Station. However, if we look at data from the GISP2 ice core which has been drilled out here, thin layers of ice can be identified that reveal that there must have been thawing and that rain possibly fell, as meltwater and/or rain could refreeze in the snow. As summer and winter snow look different in such a core, the years can be counted back and a year in which melting took place can be identified.

During the course of the last 2000 years a melt layer has only been observed nine times (Alley et al. 1995); in 2021, 2019 and 2012, a melt layer was also observed directly by the personnel at the station. If we go further back in time, we find further layers of ice during the course of the last 2000 years – in 1889, 1094, 992, 758, 753 and 244. Unfortunately, we cannot go any further back in time because the ice and snow becomes more compacted the deeper we go. At a depth of between 400 and 500 m you can no longer see individual layers of ice. Melting and/or rain is thus an extremely rare occurrence at Summit. Incidentally, the highest temperature ever observed at the top of Greenland was 2.2°C on 13th July 2012.

Close to average melting of the surface of the Ice Sheet in 2021

In 2021, the onset of the melting season was delayed by record-high snowfall at the beginning of June. As new snow is brighter in terms of whiteness and reflects sunlight better than the old dark glacier ice below, melting was low at the beginning of the melting season. The weather was also rather cold and wet in June and at the beginning of July.

Changes to the 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 – 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 via actual measurements (PROMICE 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 run-off). Based on these simulations, an overall measurement of how the surface mass balance develops across the entire Ice Sheet is obtained (Fig. 2).

According to DMI's calculations, the net result of the surface mass balance for Greenland's Ice Sheet in 2021 was 396 billion tonnes (Gt). This is not far off the average for 1981-2020 of 341 Gt. The period from September 2020 until August 2021 ranks as the 28th lowest out of the 41-year time series. In the current climate, this would be regarded as a rather average year. At the end of the 1990s, the same result would have been seen as a very low year. As a comparison, the lowest calculated SMB was just 38 Gt in 2012.

The map in Figure 3 shows how the geographic distribution of SMB gain (blue) and SMB loss (red) for 2020-2021 can be compared to the long-term average (grey).

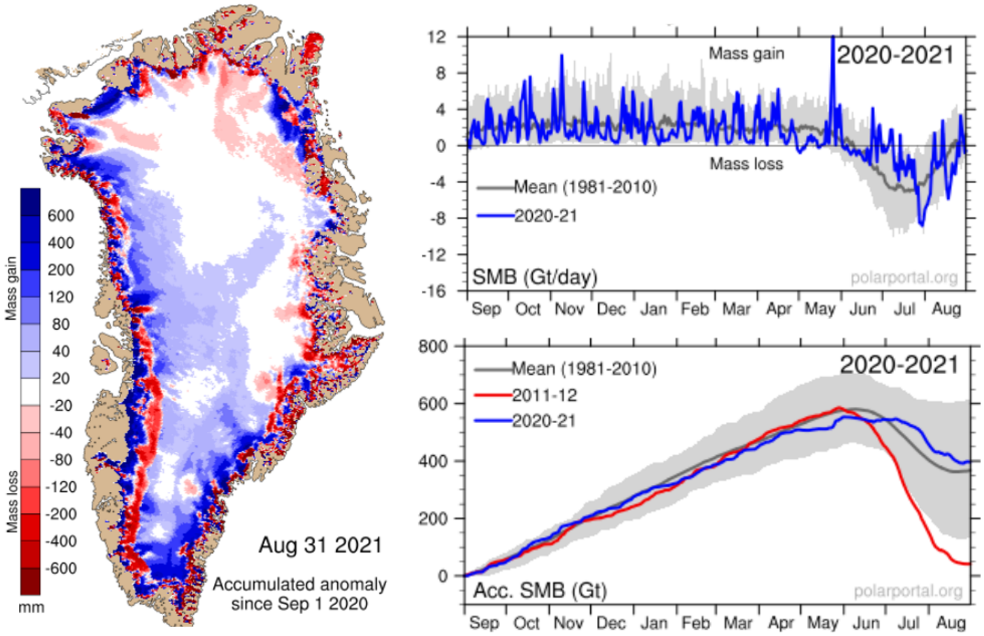

Fig. 3: *Left: Difference between the annual SMB for the periods 2010-2021 and 1981-2010 (expressed as mm ice melt). Blue indicates a larger accumulation than average, and red shows a larger ice melt than average. Right: Daily (top) and accumulated (bottom) SMB over the Greenland Ice Sheet, expressed in Gt (billion tonnes) per day, and Gt (billion tonnes) respectively. Blue lines show the SMB in 2020-2021. The grey lines show the average for the period 1981-2010. The red line in the lower diagram shows the record low SMB in 2011-2012.*

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.

Extreme melting periods despite average temperatures

The automated weather stations that are part of the PROMICE project measured temperatures in June and July 2021 that were within +/- 1 standard deviation. At the end of July and August, however, there were three occurrences of extreme melting. The first of these took place on 19th July. Melting was observed over an area of 702,000 km^2 of the surface of the Ice Sheet. This corresponds to 43 % of the total surface area of the Ice Sheet. The second extreme event occurred on 28th July, when melting was observed on 54 % of the surface of the Ice Sheet. The third such event took place on 14th August, with a melting area of 53 % of the Ice Sheet. This final melting period was also the event in which melting was registered highest up on the Ice Sheet, i.e. at National Science Foundation's (NSF) Summit Station at an altitude of 3,216 metres.

At all the weather stations along the edge of the Ice Sheet, temperatures were measured that were above average during all three of the extreme melting events mentioned above.

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 undergoes melting of more than 1 mm/day.

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

Throughout the entire ablation season the PROMICE weather monitoring stations located along the edge of the Ice Sheet have registered melting that was significantly higher than average along central western and eastern coasts.

The melting season on the Ice Sheet in 2020-2021 began on 27th May. The ablation season began on 17th June, which is 4 days later than the average for 1981-2020.

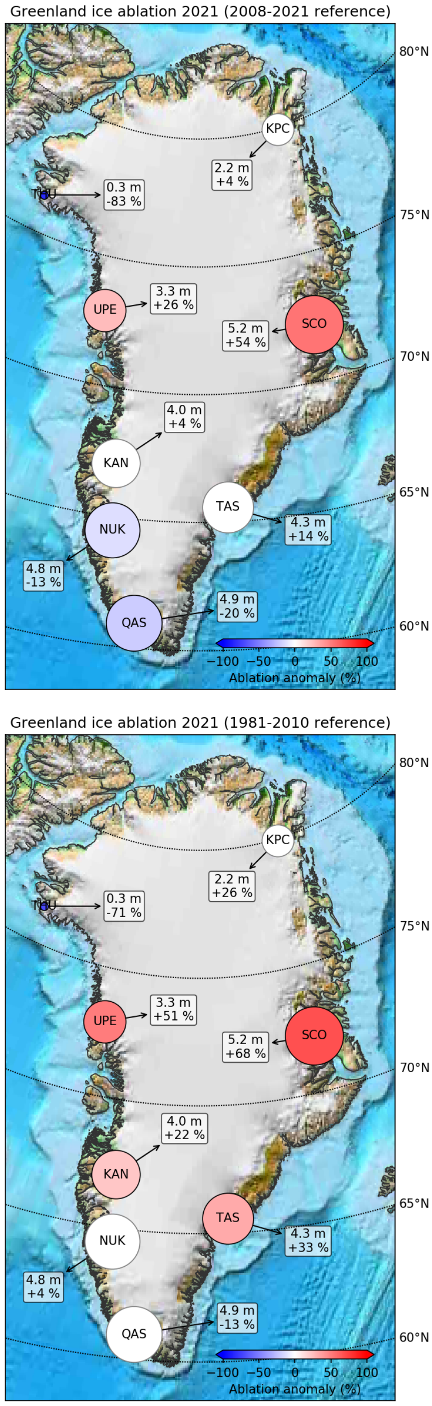

***Fig. 4:** The maps show the net melt anomalies for the lower elevation PROMICE stations compared to 2008-2021 (left) and 1981-2010 (right) (credit: van As (2016), updated).*

The total loss – total mass balance

Greenland's Ice Sheet can only gain more ice by having a so-called "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 at zero – i.e. there is 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 "account" of the Ice Sheet. The figures reveal that 2020-2021 had the highest loss of ice in the form of calving and underwater melting since 1986, when satellite registrations began. Furthermore, the fastest-moving glacier in the world, Sermeq Kujalleq (also known as the Ilulissat glacier) began accelerating again in 2020-2021 after a couple of relatively "quiet" years. At the same time, the glacier produced a huge quantity of icebergs, and calculations reveal that it lost around 45 Gt of ice in 2021. Indeed, this is more than 10 % of the total figure for the annual surface mass, which thus has a considerable impact on the year's overall ice account.

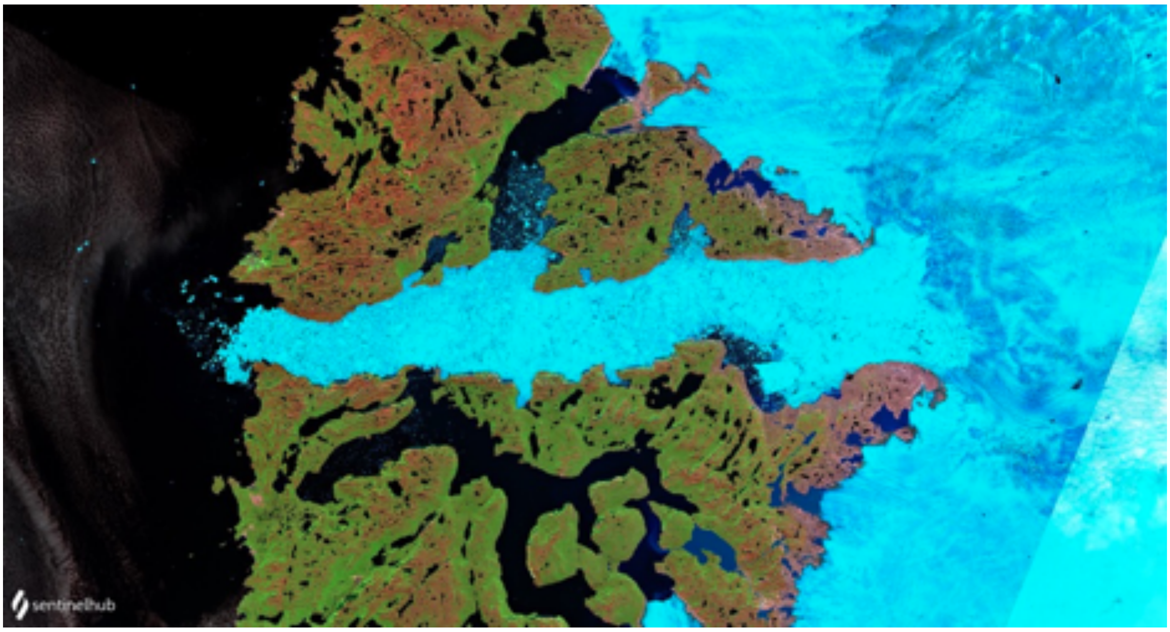

Fig. 5: *The satellite images show the Sermeq Kujalleq glacier on 22 August 2021, as seen from the ERA Sentinel-2 satellite. The glacier accelerated considerably in 2020-2021 compared to previous years and lost approximately 45 Gt of ice (credit: ESA/Sentinel-2).*

Although Greenland did not experience a record high loss of ice – including calving – during the 2020-2021 season, it was still the 25th year in succession that the Ice Sheet lost more ice than it gained.

The total mass balance for 2020-2021 shows a loss of around 166 Gt of ice from Greenland. This figure is close to the average annual loss of ice for the period 1987-2021. Based on these figures, it can be calculated that from 1st September 1986 until 31st August 2021 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 is only due to loss of mass from Greenland's Ice Sheet. For the 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.

Lower growth during the period 2018-2021

The GRACE satellites and their successors, GRACE-FO, measure small changes in the Earth's gravitational field, such that changes in the mass of the Ice Sheet can be determined.

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

The maps in Figure 6 illustrate how the Ice Sheet has become thinner or thicker respectively during the period from January 2017 until December 2020. The map on the left shows the three-year period from January 2017 until December 2019, whilst the map on the right shows how it has changed during the period from January 2018 until December 2020. The data originates from the Sentinel-3A satellite, which is a so-called radar altimeter mission. The satellite emits a radar signal which is reflected from the surface of the Earth back up to the satellite.

The ice has become thinner even at the centre of the Ice Sheet. This has never been the case before, where the major reduction in thickness was associated with the large marine terminating glaciers. The image confirms a relatively small loss of ice from the Ice Sheet from 2017-18, followed by a high degree of melting in 2019 and 2020. It can also be seen how the heavy snowfall in southeast Greenland has helped put a brake on the rate of melting. This area is one of the only areas on the map from 2018-2020 where we can see that the ice has become thicker.

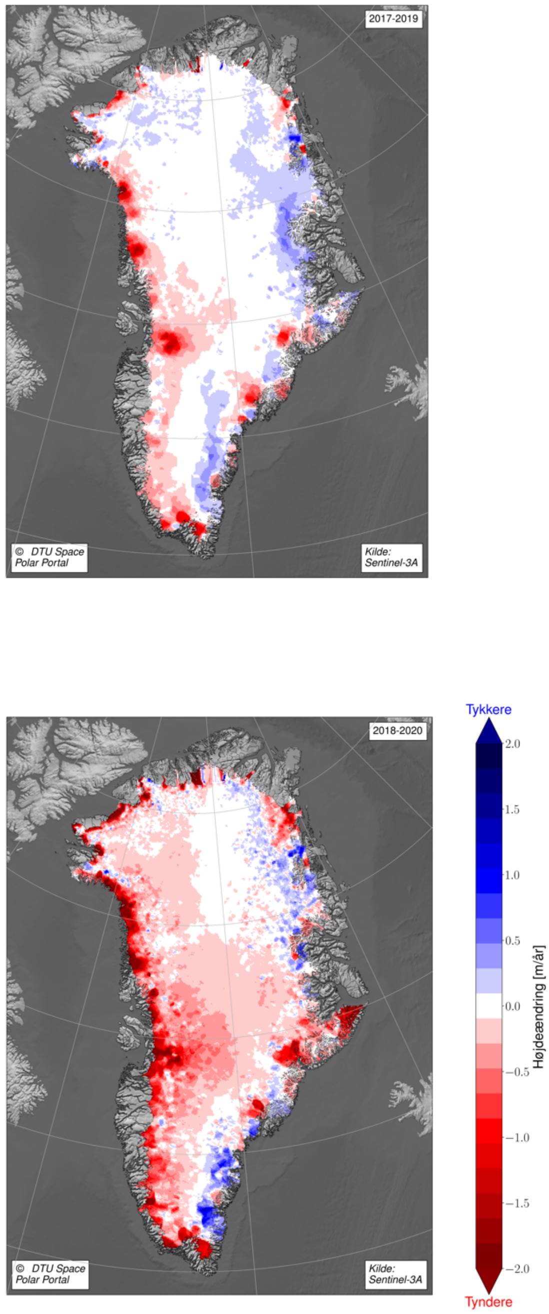

Fig. 6: *The map shows data from the satellite Sentinel-3A. Red tones show areas where the ice has become thinner, whilst blue indicates regions with an increase in ice thickness. The figure confirms a relatively small mass loss in 2017-2018 followed by a large mass loss in 2020. It can also be seen how heavy snowfall events decelerate melting. This is the only region with an increase of ice mass (credit: DTU Space. Data source: ESA/Sentinel-3A).*

The sea ice fell to its second-lowest level in July 2021

July 2021 saw the second-lowest extent of sea ice being measured since 1979. In August and September, however, melting was not as high, and when the extent of sea ice reached its annual minimum on 12th September, its overall extent was just outside the top 10 of years with the lowest extent of sea ice since 1979.

In 2021, the date of the annual minimum of extent of the sea ice was two days later than the average for 1981-2010 (10th September). Refreezing of the sea ice thus also commenced a little later than normal. Many of the lowest extents of sea ice have been measured within the last 20 years, and the downward trend is bad news for the climate in the Arctic, as sea ice plays a major role in the global climate system. This is due, among other things, to the fact that the reduction of sea ice drives a vicious circle in which warming in the Arctic accelerates.

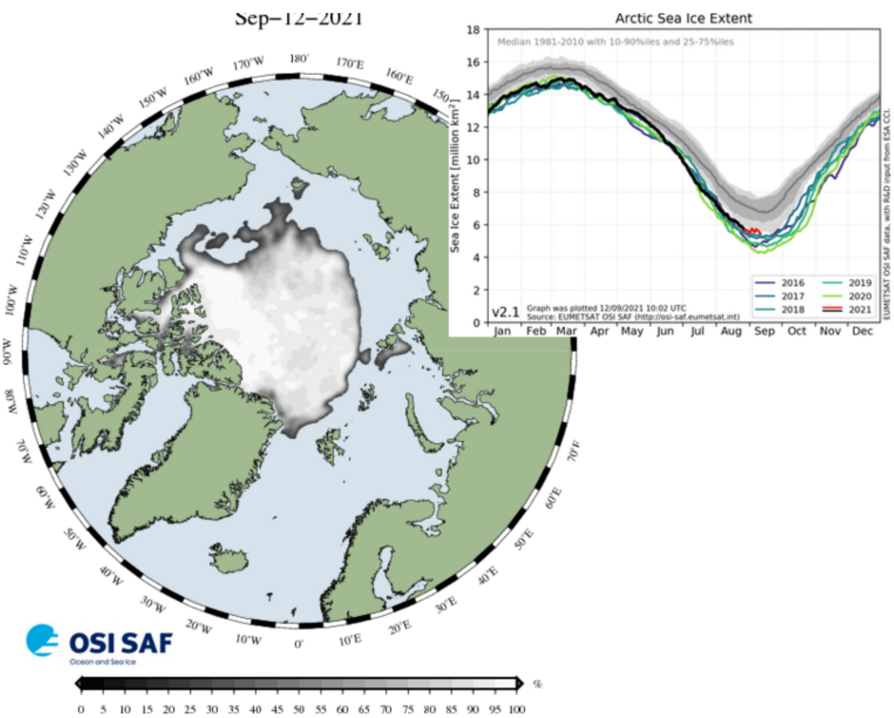

Fig. 7: *DMI graph of extent of the sea ice on 12 September 2020, the day of the annual sea ice minimum. The map and graphics are based on EUMETSAT's OSISAF ice concentration calculations. They show where the sea ice concentration exceeds 15% (credit: Polar Portal).*

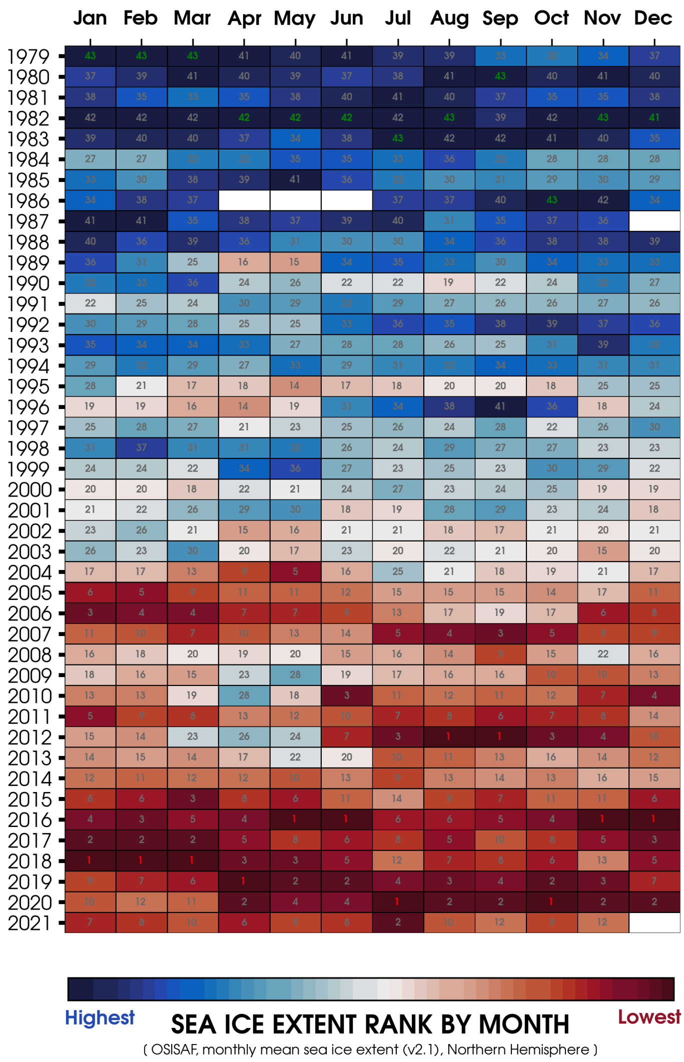

Fig. 8: *The figure shows the ranking of sea ice extents over the years, from low to high. The extent is calculated based on OSISAF data (OSI 450), the temporary climate dataset ICDR, OSI-430-b and a Near Real Time (NRT) product. The monthly record low ice extents are marked in red.*
(credit: http://ocean.dmi.dk/arctic/sie_monthmean.php).

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.