POLAR PORTAL
MONITORING ICE AND CLIMATE IN THE ARCTIC

Polar Portal Season Report 2016

Less ice – both on land and at sea

This year's report is the fourth since the Polar Portal was launched, and as an introduction, we have chosen to take a look at the trends that have taken place in the Arctic, both at sea and on the Greenland Ice Sheet.

With respect to the Greenland Ice Sheet, melting has continued at approximately the same rate that has been seen since the turn of the millennium. Of course, there are warm and cold years, but the loss of mass has continued relentlessly. During the period 2003-2016 the ice sheet has on average lost some 268 Gt of ice per year, based on data acquired from the GRACE satellites. In terms of the sea ice, there has been a similar development. In this case, there are also years that have seen more or less ice, but when viewed over a longer period, the sea ice has continued to diminish. The period of the year in which the sea in the Arctic is covered by ice has shortened by between one and three months since the end of the 1970s. This is the conclusion of new calculations from DMI based on satellite data from 1978 to 2015. As the ice season is reduced, the so-called open water season increases in length accordingly, which in itself represents a threat to the sea ice. When the ice disappears, the Sun has a longer period to heat up the water during summer. This delays freezing in the autumn, and the ice thus has less time to thicken up during the winter. This results in the ice being thinner at the onset of spring and thus breaking up earlier.

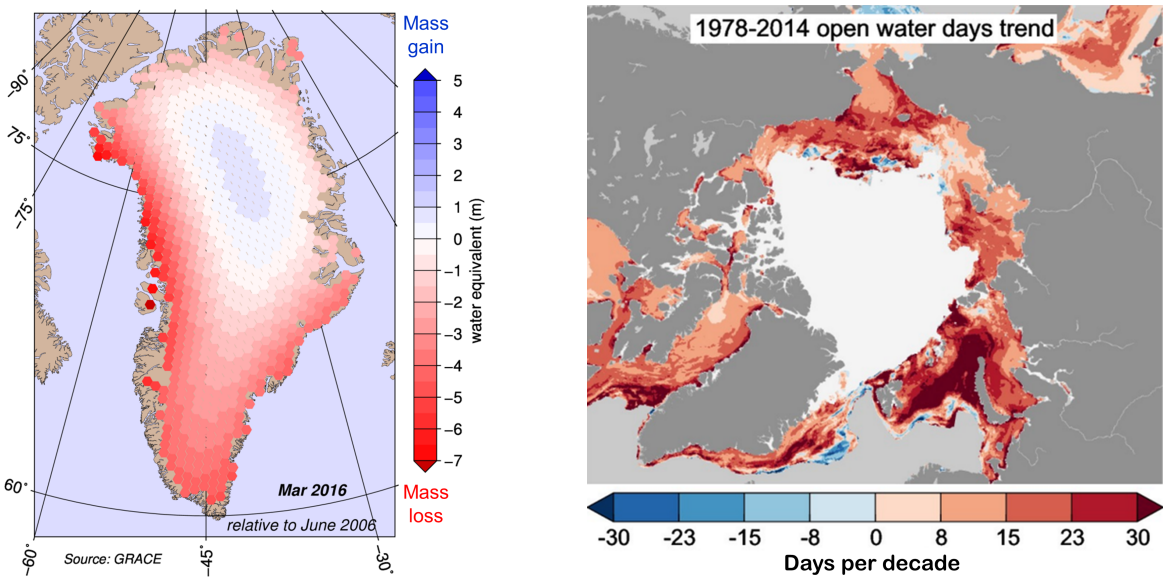

Figure 1. *Trends over a period of several years. The map on the left shows the total mass loss on the Greenland Ice Sheet up to and including March 2016 relative to June 2006, expressed in metres of water equivalent. The darker the shade of red, the greater the mass loss. In Northwest Greenland the ice sheet has lost 7 m of its thickness during the past decade. The map on the right shows the change in the number of days with open water in the Arctic per decade during the period 1978 to 2014. The darker the shade of red, the longer the open water season and thus the shorter the ice season. Between Svalbard and Nowaya Zemlya, the open water season is now three months longer than 37 years ago. Some areas appear to exhibit the opposite tendency. This is due in part to the fact that the analysis in these areas is based on relatively few observations, in addition to which the method of analysis is not suitable for new ice in very dynamic areas. The trends in the blue areas are not significant.*

There is thus a clear pattern in terms of the development of both the state of the Arctic sea ice and the ice sheet – both are diminishing. The warmer climate in the Arctic means, among other things, continued melting of glacier ice, which has consequences that are more far-reaching than simply rising sea levels. It may result in an increase in the addition of nutrients to the sea, as well as possibly reducing the ability of sea water to absorb CO_2. These are changes that may have great significance for the shipping industry, sealer and whaler communities, infrastructure, the Arctic food chain and fishing. Furthermore, they are changes that have already occurred and which continue to demand greater awareness of the link between the development of ice at sea and on land.

In the following, we will look at the most important results monitored in the Arctic in 2016:

- Early melting due to record high temperatures in Greenland
- Largest loss of glacier area since 2012
- High, but not record-high, melting season
- The albedo of the ice sheet in 2016 was the fifth lowest in 17 years
- Sea ice hit a low, but not record-low, level in 2016

Early melting due to record high temperatures in Greenland

In April, Greenland experienced very warm air masses from the southwest. This resulted in record temperatures, which in turn led to record early melting from the ice sheet. In the settlement of Kangerlussuaq, the previous record temperature of 16.0°C from 1996 was broken by a new record high of 17.8°C (11 April 2016). In Nuuk, the previous record temperature of 13.0°C from 1969 was surpassed by a new record of 16.6°C (11 April 2016). At the Summit research station, which lies at an elevation of around 3000 metres on top of the ice sheet, the previous record from 2007 of -8.2°C was surpassed by a temperature of -6.5°C (12 April 2016). Overall, these high temperatures meant that the Greenland Ice Sheet began melting unusually early in 2016.

In spite of the above, the criterion for the start of the melting season was not satisfied. Cold weather soon returned and it was not until 10-12 May 2016 that the ice sheet melted to such an extent that the melting season officially commenced. The start of the melting season is officially defined as the first day of a period of three consecutive days in which more than 5% of the area of the ice sheet is subject to melting.

The start of the season in 2016 was among the top 5 in terms of the earliest starts to the melting season since 1991, which was when calculations of the melting of the Greenland Ice Sheet began. The earliest start of the melting season since records began was 29 April in 1996, while in 2015 the melting season did not commence until 12 June.

Later during the summer, record high temperatures were once again recorded. The mean summer temperature was, for example, 8.2°C at Tasiilaq on the southeast coast, which is 2.3°C higher than the mean for 1981-2010, and thereby represents the highest recorded temperature since 1895, when records at the location began. Records were also broken in Narsarsuaq in southern Greenland and in Danmarkshavn in the northeast.

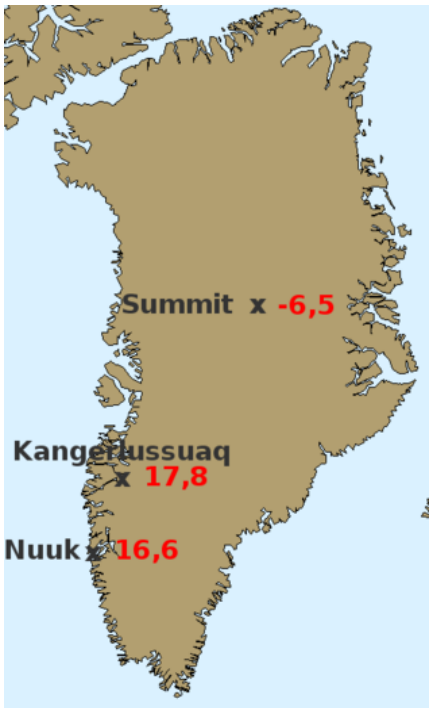

Figure 2: *The three locations that experienced record temperatures for April in 2016. Graphics Henning Gisselø.*

Record high temperatures were not the only notable events during the 2016 season. Records were also set for the lowest temperature and for the lowest precipitation. In July, Tasiilaq recorded just 0.1 mm precipitation, a figure that has not been so low since 1898, when the keeping of such records began. And despite the fact that Greenland's summer has generally been warm in 2016, a record low temperature was set on 1 August, when DMI's measuring station at Summit – on top of the ice sheet – registered -30.7°C. This is the lowest July temperature ever measured at the measuring station. Technically, this record belongs to July, since it is within the meteorological day, which ends on 1 August at 06 UTC. The previous record was -27.7°C in 1992.

Largest loss of glacier area since 2012

GEUS conducts annual studies of changes in the extent of 45 of the widest glaciers in Greenland (Box and Hansen, 2015). In 2016, 22 of these glaciers retreated (101 km^2 loss), 11 increased in size (41 km^2 increase) and 12 remained unchanged, such that the net loss was 60.6 km^2, which is the highest loss since the record-breaking year of 2012. These figures do not include the loss from the Spalte Glacier, however, where an area of ice of approximately 100 km^2 (nearly twice the size of Manhattan) almost, but not quite, broke off.

The warmer it is during the summer, the greater the amount of ice that melts. Some of the meltwater runs down into crevasses in the glacier, which are thereby opened further. This is a mechanism by which warm summers can lead to greater retreat of the glaciers. If an overall measure of glacier retreat is compared to the summer temperatures at 12 DMI weather stations at various points along the coast of Greenland, the correlation is seen at 8 of these 12 stations with more than 80% certainty and more than 95% certainty at the remaining 4.

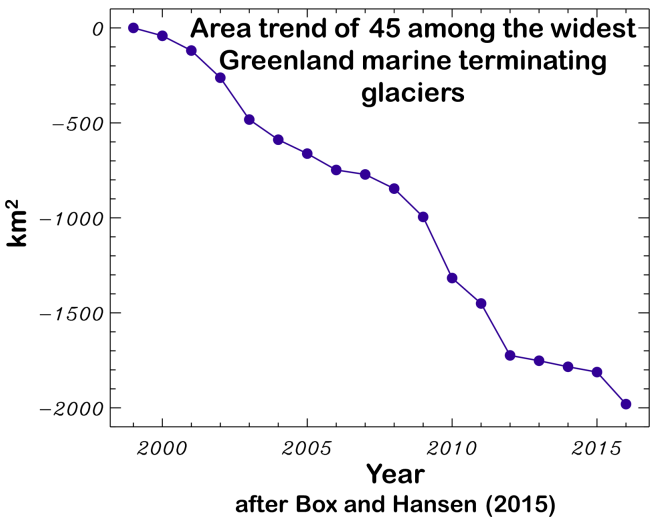

Figure 3: *Area change of 45 of the widest Greenlandic marine terminating glaciers, including Spalte Glacier, see text.*

Contribution of the Greenland Ice Sheet to sea level rise

(Data to calculate the total mass loss in 2016 not yet available)

As can be seen in Figure 4, the loss of mass from the Greenland Ice Sheet roughly follows the rate prior to the record-breaking year of 2012, which saw record-high surface melting and an unusually high mass loss, corresponding to a rise in sea level of 1.7 mm.

We cannot yet calculate the total mass change and the sea level change for the melt season 2016 because data is only available up to and including July 2016.

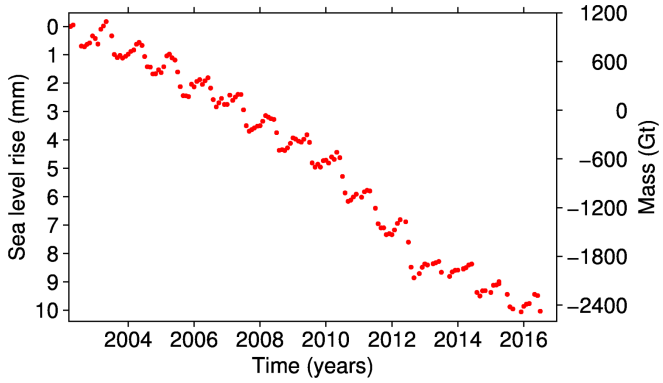

Figure 4: *The graph shows the development in the total mass balance month by month, measured in Gt (1 Gt is 1 billion tonnes or 1 km^3 of water). 100 Gt corresponds to 0.28 mm global sea level. All changes are in relation to June 2006.*

Mass loss and rise in sea level

Satellite observations with GRACE, available since 2002, indicate that the Greenland Ice Sheet has lost a mass of approximately 268 Gt per year during the period in which observations have been recorded, i.e. for more than a decade. One Gt is 1 billion tonnes and corresponds to 1 cubic kilometre of water. A mass loss of 100 Gt corresponds to a rise in sea level of 0.28 mm. Thus, a mass loss of 250 Gt per year corresponds to an annual rise in sea level of about 0.7 mm, and the total mass loss over the GRACE period (since 2002) corresponds to a contribution from Greenland to a rise in sea level of about 1 cm.

High, but not record-high, melting season

Just like in 2015, the degree of melting from the surface of the ice sheet in 2016 was greater than normal. The annual total for the ice sheet surface mass balance (SMB) amounted to 247 Gt.

The story of the surface mass balance for 2015-16 is one of unusual weather that by the end of the year produced an average result. Despite the large degree of melting early in April, the surface mass balance for 2016 amounted to 247 Gt (for the period September 2015 until August 2016), which is approximately 40 Gt below the average figure for the period 1991-2013 of 286 Gt.

The winter was characterised by large amounts of snow with an accumulation of 576 Gt during the period from September 2015 until the beginning of June 2016, which is 35 Gt above the average figure. However, the low surface mass balance is the result of a high melting sum of 328 Gt, which is approx. 75 Gt above the norm. The degree of melting was thus high, but not record high.

At the University of Liege, similar calculations of SMB are carried out, but with a different input of weather data and another snow/ice model. It is also seen here that the winter saw a lot of snowfall and the summer a considerable amount of melting, which resulted in the annual total being low.

Surface mass balance is an expression of the isolated growth and melting of the surface of the Greenland Ice Sheet. Precipitation contributes to an increase in the mass of the ice sheet, while melting causes the ice sheet to lose mass. The increase in mass typically takes place for nine months a year, while melting typically occurs during the three summer months of June, July and August. The term ablation season is used to describe the period in which the ice sheet loses more mass from melting than it gains via precipitation on its surface.

At the Polar Portal we define the onset of the ablation season as the first of three consecutive days in which the ice has lost more than 1 Gt from its surface to the sea. This occurred on 6 June this year, which is the sixth earliest start of the ablation season in the 27 years that such calculations have been carried out.

Melting from the ice sheet is measured directly at selected locations under the PROMICE project. Observations from the approximately 20 weather stations in the melting region of the ice sheet indicate air temperatures that were above average. This applies to 88% of all measurements from January to August. In April, in particular, record high temperatures were measured at more than half of the measuring stations. The months from May to August were also unusually warm at the edge of the ice sheet in the eastern part of the Scoresbysund region and to a lesser extent in the regions of Station Nord (northeast) and Thule (northwest).

The summer temperatures in June, July and August were close to the average for 2008-2016 along the rest of the edge of the ice sheet – apart from the southernmost parts of the Qassimiut and Nuuk regions, where temperatures were again very high.

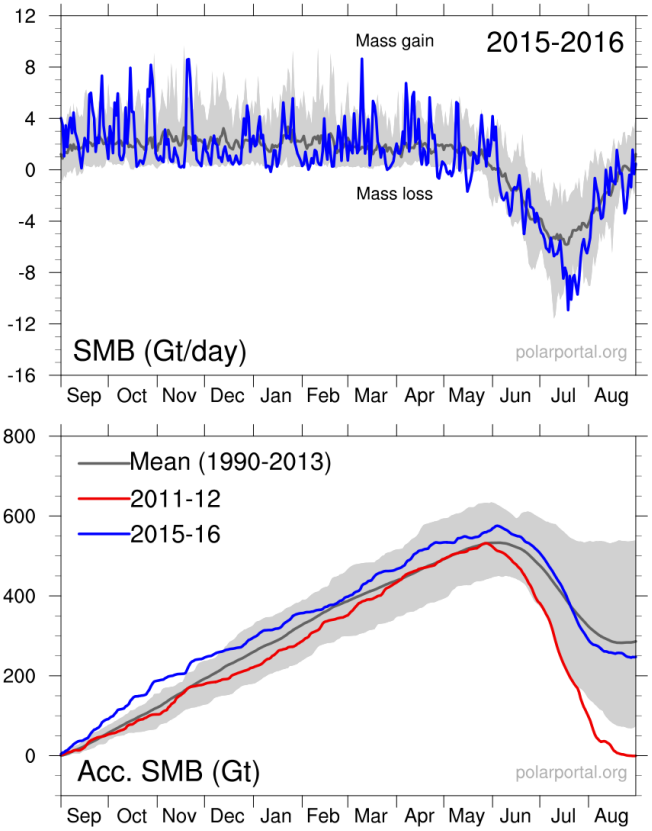

Figure 5: *The top graph shows the total daily simulated contribution to the surface mass balance from all points on the ice sheet. The bottom graph shows the total accumulated surface mass. The blue curve shows the 2015-16 season, and it can be seen that by the end of the season the blue curve ends up below the grey normal curve, but is not outside the normal range, as was the case in 2012 (red curve).*

Surface mass balance

Surface mass balance is an expression of the isolated growth and melting of the surface of the Greenland Ice Sheet. Precipitation contributes to an increase of the mass of the ice sheet, while melting causes the ice sheet to lose mass. In relation to the total mass balance, the surface mass balance gives the contribution at the surface of the ice sheet – i.e. excluding that which is lost when glaciers calve off icebergs and melt in direct contact with the warm seawater. Since the 1990s, the surface mass balance has been declining.

For eight selected melt measurements, values above the norm were found. The total net melting anomaly for the whole year is positive along the entire edge of the ice sheet. The biggest deviation in melting (124%) was seen in Pituffik (northwest), while the highest annual melting was found at QAS_L, with a total of 7.4 m ice melted away.

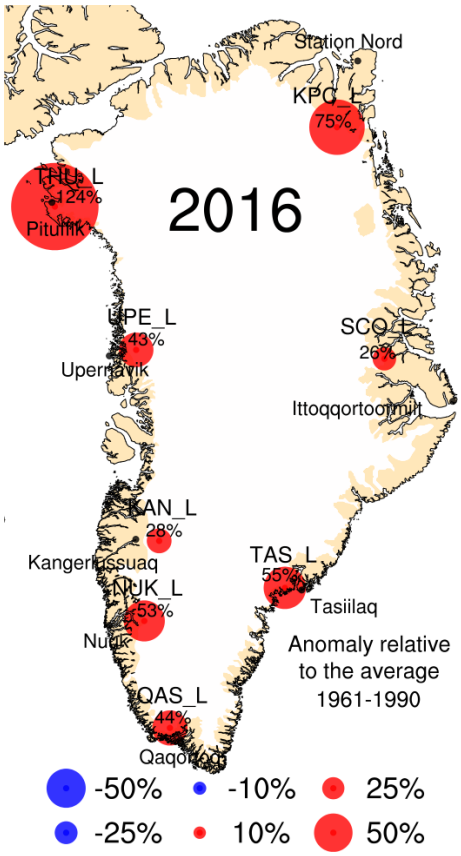

Figure 6: *The map shows the net anomalies for 2016 at the low-lying PROMICE weather stations in relation to the period 1961-1990. The diameter of the circles corresponds to the magnitude of the melt anomalies.*

The albedo of the ice sheet in 2016 was the fifth lowest in 17 years

Albedo is an expression of the ability of a surface to reflect sunlight. The lighter the surface is, the better it is at reflecting the light. Dark surfaces, on the other hand, absorb large quantities of solar energy as heat.

The albedo of the ice sheet in 2016 was the fifth lowest in the 17 years in which MODIS instruments on NASA satellites have been observing the Earth's reflection of sunlight. Measurements taken in June, July and August across the entire ice cap revealed that the total average albedo was 71.1%, which is around 4% lower – i.e. darker – than in 2000-2001. The average summer albedo in 2016 was higher than the record low albedo in 2012, however. The trend for the average albedo during the period 2000-2016 is -5.3 ±1.0% (for June, July and August) and -6.2 ±1.2% (for July alone). The highest albedo anomalies were found to be around -20 %. These were registered along the western dark area of the ice sheet, in agreement with albedo anomalies from previous years. Only the north-western part of the ice sheet had close to normal albedo values – at all other places on the ice sheet low albedo values dominated.

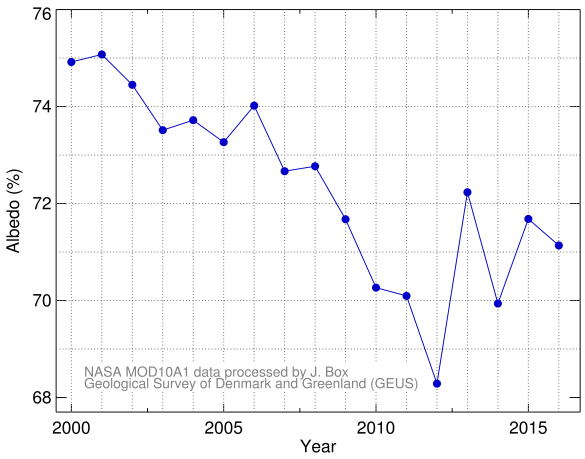

Figure 7: *The graph shows albedo anomalies over the Greenland Ice Sheet for June, July and August during the period 2000-2016.*

Sea ice hit a low, but not record-low, level in 2016

The extent of the sea ice in May and at the beginning of June 2016 was record-low, and the mean temperature in the area of the North Pole went from frost to thaw a few days earlier than normal. Both factors led to concern among ice researchers that the sea ice minimum would be even lower than in 2012, but massive melt of sea ice was prevented by the weather during the summer, in which June was cold enough to cause a slowdown in the rate of sea ice melt.

As the Arctic sea ice reached its summer minimum in September, the area was, however, at its second lowest level since systematic measurements by satellite began in the 1970s. The smallest extent of the ice in 2016 was measured on 10 September, where the sea ice in the Arctic covered an area of 5.1 million square kilometres.

In comparison, the September ice at the end of the 1970s and beginning of the 1980s covered between 8 and 8.5 million square kilometres. Since that time, the extent of the ice at its late summer minimum in September has fallen by an average of 94,000 square kilometres a year. This corresponds to the sea ice shrinking each year at a rate corresponding to twice the area of Denmark. The minimum for 2016 is very close to the level in 2007, which represented the record minimum until the disastrous year of 2012 when the ice recorded its hitherto lowest extent.

Since 2007 the extent of the Arctic ice in summer has been at a considerably lower level than in the 1970s, ´80s and ´90s. The lower level is a consequence of increasing temperatures in the Arctic and a general thinning of the sea ice. The trend began back in 2002, when the Beaufort Sea became a summer melting area. Due to the movement of the ice, this meant a considerable reduction in the amount of perennial and thick ice, which in turn reduced the chances of survival of the ice in the Arctic summer. Climate models predict that this tendency continues and we will begin to experience the first ice-free summers in the Arctic by as early as the middle of the 21st century.

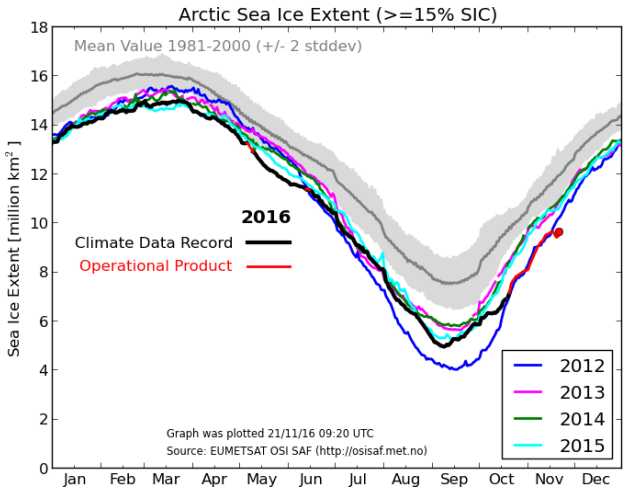

Figure 8: *DMI's graph of the extent of the sea ice shows that the minimum extent in 2016 occurred on 10 September. This picture is based on EUMETSAT's OSISAF ice concentration calculations, which illustrate the coverage of sea areas that have more than 15% ice cover. Graphics from Polar Portal.*

Extent of the Arctic sea ice

The extent of the Arctic sea ice is analysed by both the American NSIDC and the European EUMETSAT – 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 scientific journal The Cryosphere.