POLAR PORTAL
MONITORING ICE AND CLIMATE IN THE ARCTIC

Polar Portal Season Report 2017

Unusual melting season in the Arctic

The 2016-17 season in the Arctic has in many ways been extraordinary. A snowy winter season and a comparably cold summer resulted in the Greenland Ice Sheet having benefitted from the season. The season has been less favourable with regard to sea ice, however, with ocean temperatures in some locations having been unusually high and more open water than normal for the period 1981-2010.

Greenland experienced heavy precipitation – both rain and snow – during the autumn and winter months, in addition to which the summer – and thus the melting season – was short. The large quantities of snow, in particular in Southeast Greenland, also resulted in a very high albedo, which has meant that the whiter than average surface has been able to reflect more of the sun's rays and thereby absorb less heat energy.

As a result, we have to go back to the 1980s and 1990s to find a comparable (slightly positive) surface mass balance, i.e., the mass balance of the ice sheet disregarding the effect of calving of icebergs. However, a single year must not be taken as evidence that the climate is on a more positive course with regard to the health of the Ice Sheet. The Ice Sheet remains the battleground for ongoing competition between precipitation and melting. And there is a clear trend during recent years, which indicates that melting is the crucial factor – even though there may be individual years in which levels of precipitation outweigh melting of the ice, as was the case in 2017. The 2017 sea ice minimum is in many ways similar to the minimum that was seen in 2016. In 2017, ocean temperatures have remained high, and there has been more open water than normal. This has resulted in slow increase of the sea ice during autumn 2017, which meant that the ice was thin as we headed into 2018.

In the following, we will look at the most important results monitored in the Arctic in 2017:

- High levels of precipitation, cool summer and weak and short melting season
- Unusually small degree of melting
- Final year with GRACE
- The Ice Sheet's albedo in 2017 was the third highest in 18 years
- Weakened state of the Arctic sea ice was helped by the cool summer in 2017

High levels of precipitation, cool summer and weak and short melting season

The season on the Ice Sheet (Sep. 2016 until Aug. 2017) has been characterised by large quantities of snow, mild weather during winter and spring, a cool summer and a weak and short melting season. In October 2016, the eastern part of Greenland, in particular around Tasiilaq, saw very high amounts of rain and snow, as the remnants of tropical cyclones Matthew and Nicole swept ashore. Following October's extreme precipitation, the rest of the winter was very average, and, in fact, parts of northwest Greenland expe-rienced less snowfall than normal.

We have defined two particular points in time used to assess when and how melting from the Ice Sheet takes place. The first is the onset of the melting season, which is the first of three days in a row with continuous melting on more than 5 % of the area of the Ice Sheet. The second is the onset of ablation, which is defined as the first of three days in a row in which the Ice Sheet loses more than one gigatonne of ice from its surface per day.

The melting season began as early as 5 May 2017, which is the third earliest start since 1981. However, soon after the start of the melting season, a period with cold weather and snow hit the region, which meant that the beginning of the period with high melting loss started later anyway.

The onset of ablation thus took place on 11 June, and this very average date is the 12th earliest since 1981 with respect to the start of ablation. The greatest degree of melting took place – in line with expectations – at the end of July.

On the other hand, the total mass loss was more unusual. For around one week from 27 June until 5 July, the surface mass balance remained at zero or even exhibited a slightly positive value, corresponding to a net increase in mass on the surface. This also reflected a period with very low temperatures for July, where at the Summit station (at an altitude of 3,216 metres) a record-low July temperature of -33 °C was measured on 4 July 2017. Somewhat unusually, later during the same month the highest ever July temperature was recorded – once again at Summit – with a temperature of +1.9 °C registered on 28 July 2017.

Unusually small degree of melting

The surface mass balance (SMB) for the 2016-2017 season (Sep. 2016 - Aug. 2017) occupies fifth place in terms of positive results since 1981. Surface mass balance is an expression of the isolated growth and melting of the Ice Sheet and is monitored by means of actual measurements and computer simulations.

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 that all temperatures in June, July and August were either close to or below average temperatures for the period 2008-2017. Along the western part of the melting area, the month of July was the coldest ever recorded in this period, whilst temperatures in June, July and August proved to be more than a standard deviation below average.

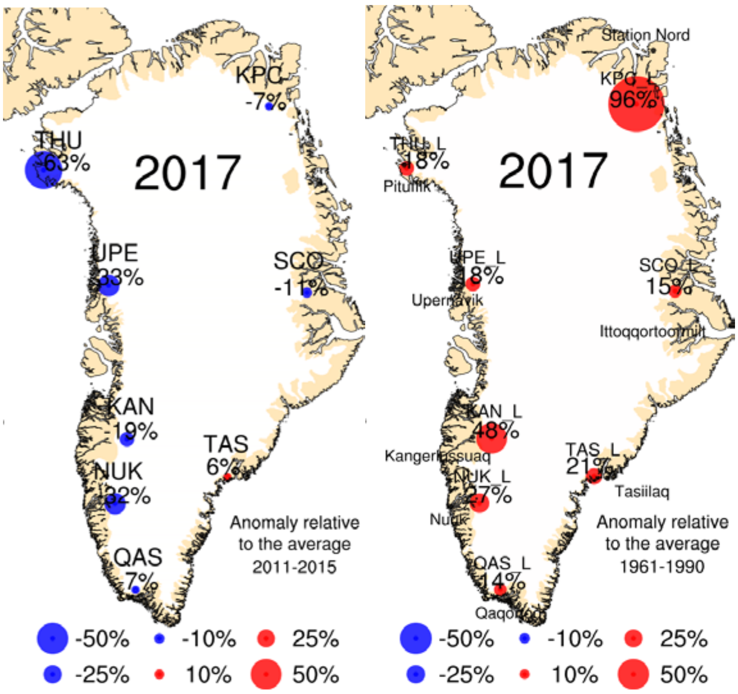

Figure 1: *The maps show the net melting anomalies for 2017 at low-lying PROMICE weather stations seen in relation to the periods 2011-2015 (left) and 1961-1990 (right) respectively.*

Similarly, the net extent of melting for the whole of 2017 was either close to or below average for 2011-2015 at all 20 measuring points. The largest anomalies were seen at the western edge of the Ice Sheet (Fig. 1, left). Following a simple re-calculation of the melting anomalies for 2017 in relation to the climate reference period 1961-1990 (Van As et al, 2016; Fig. 1, right), when the Ice Sheet is assumed to be in balance, we see that all melt anomalies are positive, with the weather station at Crown Prince Christian Land (KPC) exhibiting the highest positive anomaly.

The Danish Meteorological Institute (DMI) also performs daily simulations of how much ice or water the Ice Sheet loses or accumulates. Based on these simulations, an overall measure of how the surface mass balance develops across the entire Ice Sheet is obtained (Fig. 2). At the end of this year's season (31 Aug. 2017), the surface mass balance net result was 544 Gt, which means that 544 Gt more snow fell than the sum of snow and ice that melted and ran out into the sea (excluding loss of glaciers and icebergs).

The large quantities of snow in autumn 2016 and during the course of the winter, combined with the cool and short melting season, thus meant that the SMB exceeded the average value of 368 Gt for the period 1981-2010.

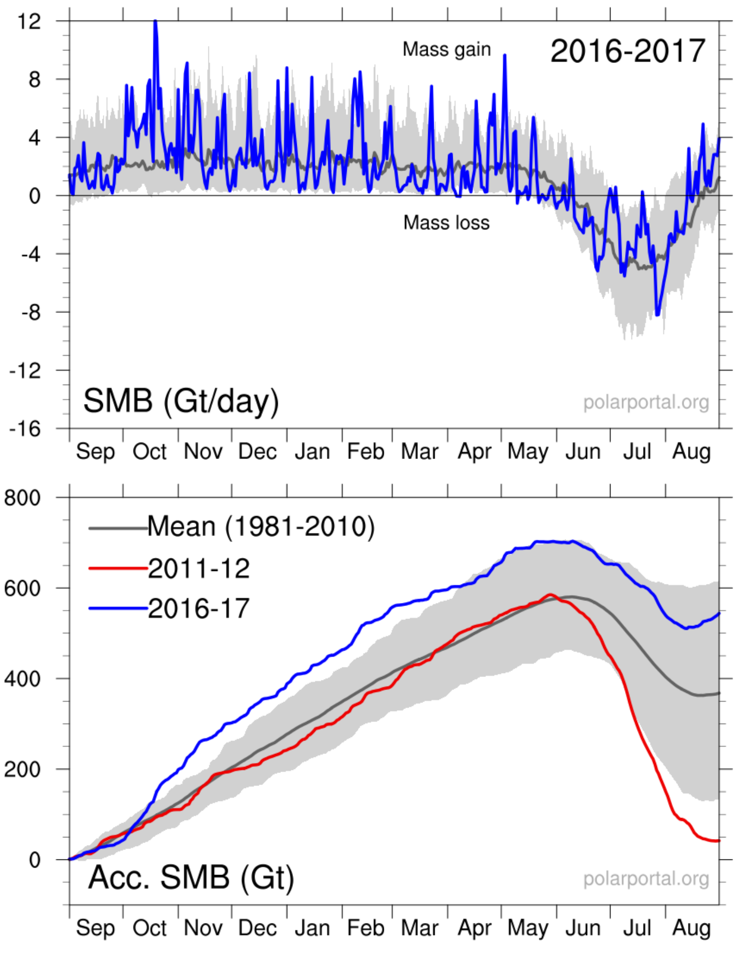

Figure 2: *The top graph shows the total daily simulated contribution to the surface mass balance from all points on the Ice Sheet. The bottom graph shows the total accumulated surface mass. The blue line represents the 2016-17 season, and it can be seen that by the end of the season the blue line is lying within the grey normal zone.*

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 at 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.

Final year with GRACE

Data for calculations of the Ice Sheet's contribution to rising sea levels has come from GRACE satellites since 2002. The GRACE mission has been a huge success, and after more than 15 years of data acquisition, the mission came to a conclusion in October 2017. In fact, the batteries on one of the satellites were no longer able to supply power, but in any case both satellites were by now flying at such low altitude that they would burn up in the atmosphere during the winter. The mission was originally planned to last only 5 years.

There will now be a gap in the acquisition of gravity data before the GRACE follow-on mission can deliver data to continue the valuable time series of changes of mass of Greenland's Ice Sheet. The GRACE follow-on mission is scheduled to be launched in 2018.

Since 2002, the total mass balance for Greenland's Ice Sheet has been negative, with losses typically amounting to around 200 to 300 Gt per year. These figures include both losses in the surface mass balance and losses in the form of glaciers and icebergs. In the 2016-17 season, however, the total mass account appears to have ended with a zero – or perhaps with a modest positive result. The average loss of ice when icebergs calve off into the sea is around 500 Gt. If you deduct this from 544 Gt, which is the result of the surface mass balance, the net result is that Greenland's Ice Sheet has gained a small amount of mass this year – around 44 Gt. However, this figure should be seen in the light of the total ice mass that the Ice Sheet has lost since 2002 – i.e. 3600 Gt. Unfortunately, 44 Gt is almost literally just a drop in the ocean. This is, however, only a provisional estimate based on previous average figures for calving.

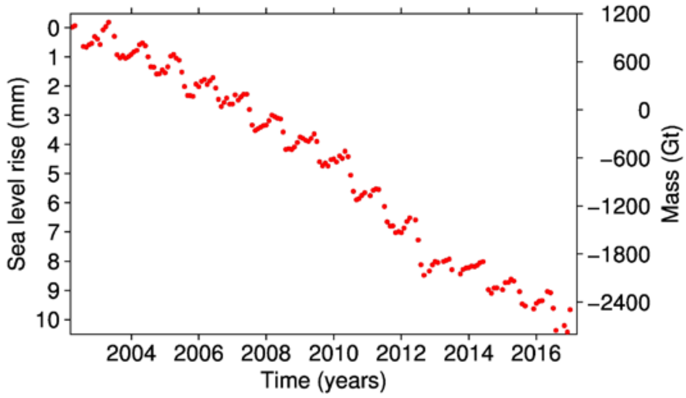

Figure 3: *The graph shows month-by-month development in the total mass change of the Ice Sheet measured in Gt (1 Gt is 1 billion tonnes or 1 km^3 of water. 1000 Gt corresponds to 2.8 mm global sea level). The measurements have been taken since 2002 up until January 2017. The changes in mass are shown in relation to 2002. It is important to underline that data from mid-2016 onwards is subject to considerably greater uncertainty than previous estimates due to problems with various instruments onboard the satellites. Therefore, the total changes of mass during the 2016-17 season cannot be calculated on the basis of data from GRACE.*

The Ice Sheet's albedo in 2017 was the third highest in 18 years

In 2017 the summer albedo from June to August was the third highest since 2000, topped only by the albedo in 2000 and in 2013. This was due primarily to the precipitation that resulted from former tropical cyclones Matthew and Nicole in October 2016. Because it was very wet and mild (although still below zero), there were heavy falls of snow that were able to keep the Ice Sheet under relatively good coverage of snow throughout the melting season in 2017. This snow cover meant that there was an unusually high reflection of sunlight (Fig. 4), and thereby heat energy, which helped to contribute to less melting. Albedo data comes from the MODIS satellite (Moderate-resolution Imaging Spectroradiometer), which since 2000 has observed the reflection of sunlight from the Earth. Albedo is an expression of the ability of a surface to reflect the sun's rays. The lighter the surface, the better it is at reflecting the rays of the sun. Dark surfaces, on the other hand, absorb large quantities of solar energy as heat.

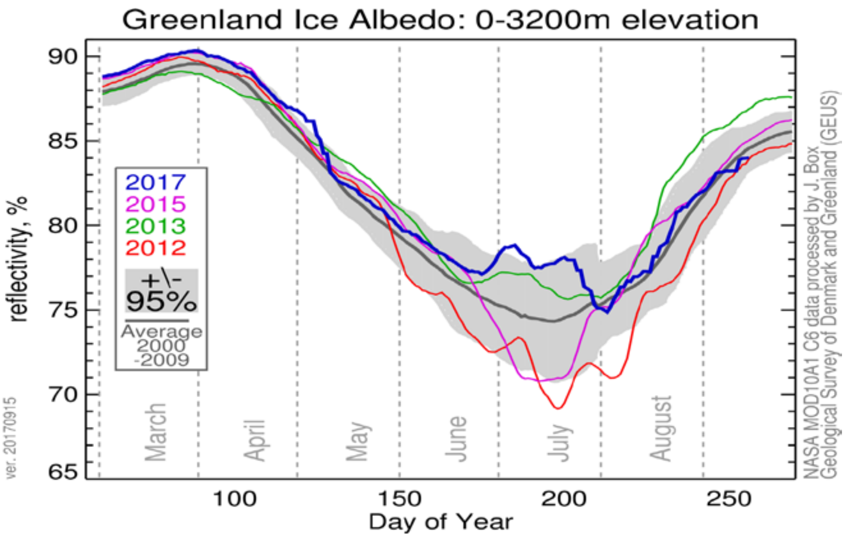

Figure 4: *The figure shows the daily average of albedo measurements for 2012, 2013, 2015 and 2017. The blue line represents 2017. It is clear that this line lies well above average during the summer months of June and July for the period 2000-2009 (grey).*

Weakened state of the Arctic sea ice was helped by the cool summer in 2017

The Arctic sea ice was in a poor state at the beginning of the melting season in 2017. Although the cool summer weather in the polar region slowed down the rate of melting of the ice in 2017, this did not mean that the sea ice had fully recovered by the time the melting season came to a close. In fact, the situation was very similar to that seen in 2016.

The conditions in September 2017, for example, were very similar to those in September 2016, with a great shortfall of ice in the Beaufort Sea and in the Chukchi Sea. In some places temperatures were up to 4°C warmer than average. High temperatures were in particular measured in Baffin Bay, Hudson Bay and in the East Siberian Sea. In the East Siberian Sea, the temperature was up to 10°C, which is exceptionally high. As a result, the turn of the year saw weakened and vulnerable sea ice in the Arctic.

Observations of the extent of coverage of the sea ice have revealed that the area of the Arctic summer sea ice has fallen by an average of approximately 94,000 km^2 a year since the 1970s. This corresponds to an area more than twice the size of Denmark.

The sea ice is crucial in terms of the climate because it is light and thus has a high albedo. The smaller the extent of the sea ice, the larger will be the dark surfaces in the Arctic, which absorb solar energy and thereby further contribute to warming and melting of the ice. The sun's energy also means greater warming of the sea, which in turn will delay freezing in the autumn. This means that the ice therefore has a shorter period in which to thicken during the course of the winter. This means – all else equal – that it will be thinner during the spring and thus break up even earlier.

March sea ice extent

Every year in March the extent of the sea ice in the Arctic is at its maximum. In 2017, however, this maximum was remarkably low following six months of unusually high temperatures in autumn 2016 and winter 2017. Every day during the first half of 2017 the area of the sea ice in the Arctic was, with only a few exceptions, at the lowest ever measured level for the time of year. This was also true of the year's maximum extent of coverage, which typically occurs in the middle of March. March sees the culmination of growth of the ice during autumn and winter, before melting during spring and summer becomes the dominant process.

The extent of coverage of the ice in March 2017 was at around the same level as in the winters of 2006, 2015 and 2016, which were the lowest recorded during the past 40 years with modern satellites. The low extent of coverage of ice in March 2017 was accompanied by a significant warm anomaly over the Kara Sea and Laptev Sea and relatively warm air blowing in over the Barents Sea. Indeed, it was in the Barents Sea, Kara Sea and the Sea of Okhotsk, situated north of Japan, that there was a shortfall of ice in March 2017 in relation to a normal year. During autumn 2016 the temperature in the North Pole region was as high as 15 °C above the normal temperature on several occasions. For a short period during the autumn it was no less than 20 °C warmer than normal. This meant poor growth conditions for the ice, which not only meant that the area of sea ice was low in March 2017, but also that the ice was thin. DMI's own ice model showed that the total volume of ice in March 2017 shared the negative record of 2016.

From the point at which freezing of the ice began in September 2016 until December 2016, there was a shortfall of around 1 million square kilometres of ice in relation to the average for the last 5 years – with this average already being low. If we take the period from 1978 until 2000 as our reference instead, no less than 2 million square kilometres of ice were missing, which corresponds to 46 times the land area of Denmark.

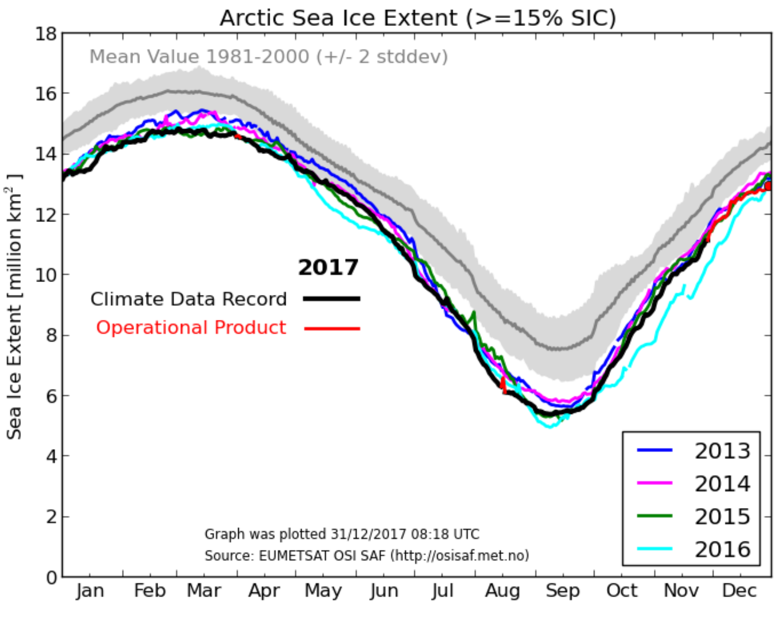

Figure 5: *DMI's graph of the extent of the sea ice. The picture is based on EUMETSAT's OSISAF ice concentration calculations and illustrates the extent of sea areas that have more than 15% ice cover. Graphics from Polar Portal.*

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 The Cryosphere scientific journal.

Melting season

Around Midsummer's Eve the daily solar energy input is higher in the area around the North Pole than anywhere else on Earth. This means that one of the planet's coldest regions experiences positive temperatures during the summer, thus rapidly accelerating melting of the sea ice. In 2017 the temperature in the North Pole region switched from frost to thaw on 13 June. This date was very close to the average transition date, which is 12 June.

The positive temperatures mean that the snow and ice change character, with melting ice, for example, absorbing more solar radiation than ice that has not yet reached its melting point. Positive temperatures also mean that new ice is not formed in cracks and fissures, and that precipitation falls as rain, and not snow. All these factors contribute to melting of the ice. Because positive temperatures accelerate melting of the ice, the date on which the temperature rises above the freezing point is crucial with regard to how much ice actually melts during the summer and thus how much ice remains at the annual minimum in September.

In 2017 the very average date of the onset of the melting season did not provide much of a clue as to the extent of the ice in September. In 2017 the weather conditions during the course of the summer were once again crucial to the extent of coverage and volume of the ice. In autumn 2016 it was clear that the Arctic sea ice would be in a weaker state when the melting season would begin in 2017. This was indeed the case, but cold summer weather in the Arctic region successfully slowed down the rate of melting during the summer of 2017.

The situation at the end of the summer in 2017 was therefore very similar to that in 2016 at the same time of year. The temperature of the water around the ice was high, and there was more open water than normal, which slowed down the development of ice during the autumn – in fact, it meant the lowest rate of growth seen for at least 8 years – the period in which it has been possible to follow the rate of growth with the European SMOS satellite.

This meant that the sea ice began 2018 with the lowest extent of coverage in relation to the time of year for at least 40 years.