POLAR PORTAL
MONITORING ICE AND CLIMATE IN THE ARCTIC

Polar Portal Season Report 2013

All in all, 2013 has been a year with large melting from both the Greenland Ice Sheet and the Arctic sea ice – but not nearly as large as the record-setting year of 2012.

The most important Arctic monitoring results in 2013:

- The Greenland Ice Sheet contributed net 1.2 mm freshwater to global sea level.
- The surface mass balance was lower than normal with a gain of 166 Gt vs. an average since 1990 of 368 Gt.
- The sea ice extent was 21 % lower than normal (5.9 million km^2 vs. the 1981-2009 average of 7.5 million km^2).
- Record warmth in late July promoted strong ice sheet surface melting.
- The wind helped to maintain both ice sheet and sea ice.
- The glacier front positions had no strong deviations.

The Greenland Ice Sheet contributed 1.2 mm to global sea level

The ice sheet loses mass in three different ways: melting from the surface; melting from contact with sea water; and calving of icebergs into the sea. The ice sheet gains mass through snowfall after some snow is lost due to sublimation and evaporation. DTU Space has in a large international cooperation performed satellite observations of the ice sheet mass over the last decade. The observations show that the ice sheet is not in balance and that ice mass loss surpasses the surface mass balance where both snowfall and melting are included. The Greenland Ice Sheet has therefore been losing mass at a rate of about 200 Gt per year over the last decade. 1 Gt is one billion tons and corresponds to 1 cubic kilometer of water. A mass loss of 100 Gt translates to a sea level rise of 0.28 mm.

The ice sheet gained 166 Gt in 2012/2013 at the surface as the net result of snowfall minus melting. And the total mass loss – which includes both the loss through melting and calving of icebergs along with the gain from snowfall – is estimated to be about 430 Gt. One of the phenomena which may have reinforced the melting is the albedo feedback, through which the amount of solar energy reflected at the ice surface and in turn the melting are amplified by changes in the amounts of reflective snow. White and snow covered areas reflect more sunlight and thereby take up less energy from the Sun than dark, snow free areas.

Large parts of Greenland saw less early summer accumulation of snow this year than usual. When the melting began, the old and dark snow therefore more quickly became

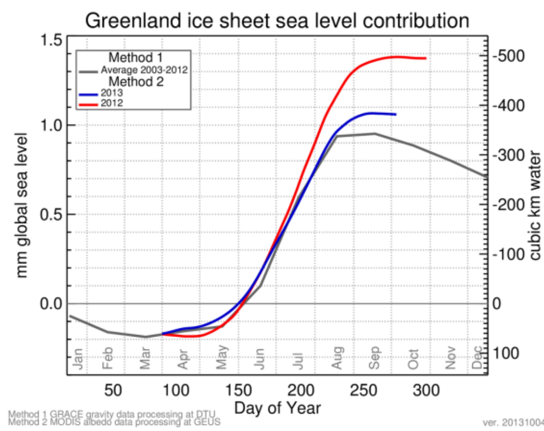

Figure 1: *Total estimate of the accumulated change in the amount of snow and ice (mass balance) over the year. The change is shown both as km^3 of water and as how much sea level change it would contribute with (in mm). The grey line shows the average for the period 2003-2012, the red line shows 2012 and the blue line shows 2013. See polarportal.org for details.*

visible. This may have caused the melting to rise dramatically, because the darker snow takes up more energy than the fresh, bright snow.

Another explanation for the large melting lies in the variations of the seasonal weather patterns in Greenland, influenced by the North Atlantic Oscillation (NAO). The NAO is a regional pattern of high and low pressure systems which let the western and southern areas of the island be alternately dominated by cold air from the north (the positive phase) and warm air from the south (the negative phase). In large parts of the record melt year of 2012, the NAO index was in its negative phase and created a situation with warmer air and clear skies. The negative phase has been less prevalent in 2013.

The annual melt season typically peaks in July or early August, and 2013 became a year with greater melt than normal – but lower than the melt of 2012. In the most sunlit period from April to September, the ice sheet lost mass corresponding to 1.6 mm of sea level. This is 24 % higher than the 2000-2013 average and 21 % lower than in 2012. The mass loss places 2013 as the fourth largest melt year of the last 14 years. When the average mass contribution from the winter period October-March is included, we estimate a total 2013 sea level contribution of 1.2 mm from the Greenland Ice Sheet. This is in spite of relatively cool conditions and a more persistent reflective snow cover in the low altitude areas where most melting occurs.

The changes in the ice sheet's total mass are calculated in two different ways. One method is based on satellite measurements of the changes in gravitational pull from the ice sheet which becomes weaker when ice is lost. It takes 2-3 months, however, to process these data. This has led GEUS scientists to develop a supplementary method which is fast but not quite as accurate as the gravity measurement. This method uses the albedo, that is, the reflection of sunlight from the ice sheet, since the researchers have found a statistical relationship between the albedo and the mass of the ice sheet. In this way, a fast but preliminary estimate of the ice sheet's mass loss is given here, while the more accurate data are being processed.

The surface mass balance was lower than normal

The surface mass balance is the isolated gain and melt of the ice sheet surface – that is, excluding that which is lost when glaciers calve off icebergs and melt when terminating in sea water. The surface mass balance has been declining since the mid-1990's resulting in a declining Greenland mass input year after year.

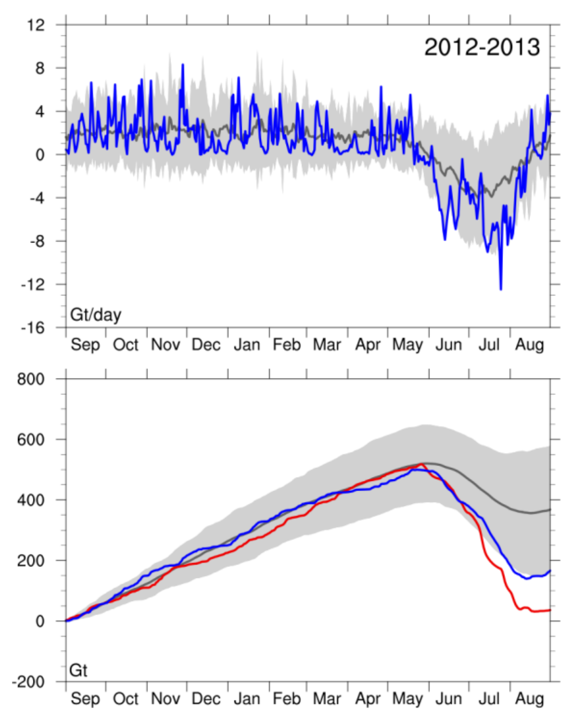

Figure 2: *Top: The total daily simulated contribution from the surface mass balance in all points on the ice sheet. Bottom: Here, the values are summed from Sep 1 and forward. The blue curves give the surface mass balance measured in Gt for the 2012-2013 season. The average curves for the 1990-2011 period are shown for comparison (grey). The red curve shows the 2011-2012 season.*

The melt season of 2013 began in late May after a month long snowy period. Mid-June saw a period with stronger than normal melt which ended late in the month. In the last weeks of July, warmer air blew from the south over Greenland. This promoted clear skies, more sunshine and widespread melting.

To monitor the surface mass balance, we perform both actual measurements and computer simulations.

The melting is measured directly at about 20 Programme for Monitoring of the Greenland Ice Sheet (PROMICE) weather stations operated by GEUS. The 2013 melting at the stations ranges from 2.9 to 4.8 m of ice in South and Southwest Greenland and from 0.3 to 3 m at the more northern stations below 500 m. For stations above 500 m elevation, the melting ranges between 0 and 2.5 m for the southern stations and between 0.4 and 2 m for the northerly stations.

In addition, DMI makes daily simulations of how much ice or water the ice sheet gains or loses. This provides an ice sheet wide number for the surface mass balance. Despite the melting in the period from May to August not reaching the levels of 2012 (334 Gt vs. 482 Gt), it still represents a loss of ice which contributes significantly to sea level. In total, over the year from September 2012 through August 2013, 166 Gt has been gained through the ice sheet surface (snowfall minus melting). This is somewhat lower than the average 368 Gt for the period 1990-2011, but not as low as in 2011-2012 where the net gain through the surface was only 36 Gt.

The highest melt rates in 2013 occurred on 25 July when the ice sheet surface lost a total of 12 Gt. The highest melt rate in 2012 was 20 Gt in one single day.

In 2012, extreme values were seen in melting, temperature, melt season duration, run-off and albedo. This is mainly due to a persistent high pressure over Greenland accompanied by warm air flowing up from southwest with few clouds and high solar radiation. There has been a general increase in melting over Greenland over the last six summers. This hints to a change in the general Arctic atmospheric circulation patterns.

The sea ice extent was lower than normal

2013 saw a relatively limited melt of sea ice and there has generally been a greater extent of sea ice after the maximum extent in March – when compared to the last 5-8 years. This is due to the low sea ice export through Fram Strait, the relatively normal spring temperatures and the late start of the melt season in the Arctic Ocean. The sea ice melt did, however, pick up pace in the first two weeks of July where the daily melt corresponded to an area three times that of Denmark. Thereafter the melt slowed down until August. The minimum extent reached 5.9 million km^2 which places it as the sixth lowest minimum extent in the post-1979 satellite record.

The Arctic sea ice extent was still considerably lower than 1981-2009 average (7.5 million km^2). The amount of sea ice is often referred to only in terms of its areal extent, but it is also important to factor in the thickness. Thick ice is more robust toward summer mel-

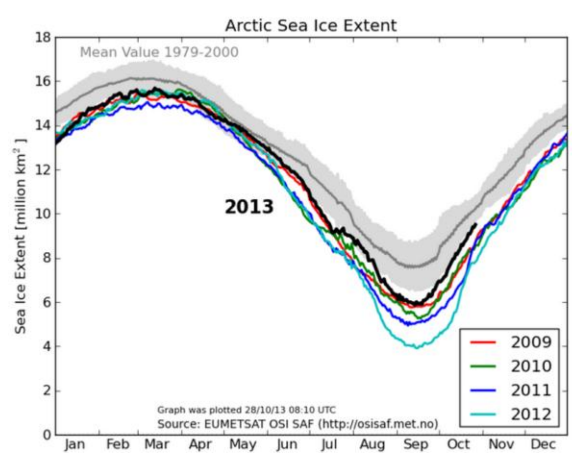

Figure 3: *Daily values for the total Northern Hemisphere sea ice extent.*

ting and model simulations show that the ice is still near record thin in 2013.

Three factors in particular determine whether Arctic sea ice extent is low in September:

- The sea ice thickness in spring
- The timing of the start of the melt season
- The weather during spring and summer

When the Arctic sea ice becomes thinner, the summer weather becomes more and more important for the final minimum extent in September. This implies that year to year variations have become greater than earlier and predictions of the minimum extent have become more difficult.

Large variations in melt rates were seen in July 2013. This indicates that sea ice extent to a large degree is controlled by the current weather. And this has to do with the sea ice being thin and fragile.

Particularly 2007 and 2012 stand out as extraordinary minimum sea ice extents but the minima over the last seven years are, in fact, the seven lowest on record. The 2013 extent resembles that of 2009.

Although the relatively cool summer of 2013 has helped maintain the sea ice extent, it has not been able to reestablish the Arctic sea ice thickness. This is evident from simulations with the American PIOMAS model (Pan-Arctic Ice-Ocean Modeling and Assimilation System). The total ice volume has stayed at the same low level as the last three years. Compared to the 1979-2011 average, the Arctic is missing some 7-8000 cubic kilometers of sea ice.

Record warmth in late July promoted strong ice sheet surface melting

Greenland temperatures were at a record high on 30 July, 2013 at 4 pm when 25.9 C was measured at the Maniitsoq/Sukkertoppen station a few hundred kilometers north of Nuuk on the southwest coast. This is the highest temperature measured since 1958 when systematic recordings began. The earlier record is from 1990 where a temperature of 25.5 C was measured on 27 July.

The reason for the high temperatures on 30 July is that a high pressure over Greenland combined with a low pressure over Baffin Island to produce southerly winds in the region and Föhn conditions associated with air warming due to downslope compression. Extreme high temperatures in Greenland are almost always associated with Föhn conditions. In addition, the Maniitsoq/ Sukkertoppen station is close to the sea and the Sun’s reflection in the sea surface during the afternoon may have contributed to the high temperatures.

The wind helped to maintain both ice sheet and sea ice

Not much sea ice was removed – or exported – through the Fram Strait in 2013. This was due to weak transpolar winds from Siberia towards Greenland and the Fram Strait during large portions of spring and summer. And this is, in turn, due to central Arctic winds being influenced by a relatively low surface pressure in June and a relatively high surface pressure in July.

The winds have also played an important role for the ice sheet. The regional pattern of high and low pressure systems alternately dominate Greenland with cold air from the north (positive NAO phase) and warm air from the south (negative NAO phase). In 2013, the warm, negative phase – which emerged in late July – has been less prevalent than in 2012, and this has led to less melting than in 2012.

The increased melting in Greenland can also arise as a consequence of a systematic and persistent change in the atmospheric circulation in early summer. This change can create so-called “blockings” which can favor melting. These are most pronounced in southern and western parts of Greenland.

Year 2013, however, was characterized by colder northerly air inflow along West Greenland. Summer 2013 displayed overall low pressure, more clouds and precipitation over West Greenland despite some intense melt episodes in early June and late July. While melt onset in 2013 began in late May as in 2012, the melt season was punctuated by snowfall a month earlier than in 2012 on 17 August.

The glacier front positions had no strong deviations

The 2013 melt season has not seen exceptional calving events such as the 2010 and 2012 massive events at Petermann Glacier. The late September position of Petermann’s tongue is close to the one at the end of summer 2012. The terminus of Kangerlussuaq Glacier rapidly lost about 1 km during the last week of September, but without reaching a new terminus position minimum. Overall, terminus fluctuations of the ten large marine terminating outlet glaciers included in Polar Portal broadly followed the usual annual cycle of advance during the cold season and retreat during the summer season.

Addendum January 2015:
A surprise in Greenland ice behavior, summer 2013

In 2013, the change in the land ice mass in Greenland derived from the Gravity Recovery and Climate Experiment (GRACE) showed a very different behavior to that which had been observed since the launch of the satellites in 2002. This was originally interpreted as related to a possible degradation of the GRACE data, and it was not clear until late 2014 that this anomaly should likely be interpreted as something real. The data shows that between June 2013 and June 2014, Greenland had very little ice loss. Compared to an average annual loss of more than 250 Gigatonnes in the previous ten years, this is quite unusual. It is possibly a consequence of the extreme 2012 melt, the largest on record.

The GRACE satellites provide monthly measurements of the mass change of Greenland's ice sheet and surrounding glaciers and in turn Greenland global sea level contribution. Because gaps in GRACE data have increased in recent years and because GRACE data typically have a 2 month processing delay, Polar Portal scientists have used an apparently strong statistical relationship between ice surface reflectivity (available near realtime from the MODIS sensor on the NASA Terra satellite) and ice mass changes from GRACE to a) fill gaps in the GRACE record and b) estimate Greenland ice mass change near-realtime.

The technique used to make near real-time estimates based on the reflectivity broke down in 2013, and yielded an inaccurately large ice loss result as reported in the Season Report. Polar Portal scientists are now busy assessing the physical processes underlying Greenland's surprisingly neutral mass balance summer 2013. In the meantime, we have suspended further reflectivity-based Greenland mass change estimates.

For more information, see polarportal.org or contact info@polarportal.dk