POLAR PORTAL
MONITORING ICE AND CLIMATE IN THE ARCTIC

Polar Portal Season Report 2014

Year 2014 comes in above average for the amount of melting from the Greenland Ice Sheet in the period since 2002. On the other hand, Arctic sea ice was strengthened in 2014.

The most important results of climate monitoring in the Arctic in 2014 are:

- The Greenland Ice Sheet contributed approximately 1.2 mm to sea-level rise;
- Below average reflection of sunlight is associated with increased melting from the Greenland Ice Sheet in 2014;
- The surface mass balance of the Greenland Ice Sheet was lower than normal, but not record low;
- Arctic sea ice strengthened in 2014;
- A new temperature record was established in west Greenland in June 2014;
- There were no exceptional changes in the movements of glacier fronts in Greenland.

The Greenland Ice Sheet contributed approximately 1.2 mm to sea-level rise

Satellite observations since 2002 show that the Greenland Ice Sheet is not in balance and that the loss of ice from calving of icebergs and surface melting exceeds the overall mass input from snowfall. The Greenland Ice Sheet has lost about 250 Gt/year of mass over the past decade. One Gt is 1 billion tonnes and is equivalent to 1 cubic kilometer of water. A loss of mass of 100 Gt of ice corresponds to a sea-level rise of 0.28 mm.

Satellite measurements from 2003 to 2012 thus show an average mass loss from the ice sheet equivalent to a sea-level rise of about 0.7 mm per year. Initial calculations for 2014 (see Box 2 on page 3) indicate an amount of melting that results in a sea-level rise of up to 1.2 mm. However, 2012 remains the record year, with a mass loss that is equivalent to a sea-level rise of 1.3 mm.

The annual melting season is normally at its peak in July or at the beginning of August, and 2014 was a year with greater melting than normal—although less than the highest level so far from 2012. According to our reflectivity-based estimate, the ice sheet lost mass equivalent to approximately 1.7 mm sea-level rise during the period of greatest sunlight from May to September 2014. This is about 50% more than the average for the years 2002 to 2013 and only about 5% less than the loss of mass in the record year 2012. This loss of mass puts the year 2014 in third place in relation to melting since 2002. Second place is year 2010.

When the average addition of mass equivalent to 0.4 mm during the winter period from October to March is considered, it is estimated that in 2014 the Greenland Ice Sheet contributed about 1.2 mm to sea-level rise over the entire period.

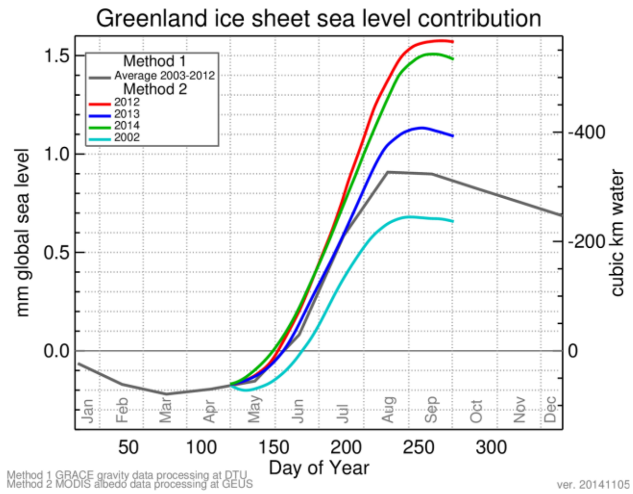


Figure 1. *Overall results of the cumulative change in the amount of ice over the sunlit period of the year. The changes are given in km^3 of water and calculations have been made of the contribution of this amount of water to global sea level (measured in mm). The light blue line illustrates the lowest estimated melting season since 2002. Method 1 is based on satellite measurements of changes in gravity of the ice sheet since 2003. Method 2 is based on the statistical relationship between the reflection of sunlight from the ice sheet and contribution to sea-level rise.*

Low reflection of sunlight is associated with increased melting from the Greenland Ice Sheet in 2014

The increased melting may be a result of the decreased amount and decreased whiteness of the snow on Greenland. This has an effect on the amount of snow that melts because darker snow absorbs more energy from the sun. This is termed the 'albedo effect'.

In recent decades, researchers at the Geological Survey of Denmark and Greenland (GEUS) have recorded a general decrease in albedo of the ice sheet, in which 2014 was so far the second 'darkest year' after 2012. The melting of the ice sheet increased correspondingly. A below average albedo was measured already in May before widespread melting and corresponds with the observation of earlier melting of the snow cover so that the dark earth was uncovered over a large area. It is thought that soil and dirt are blown up onto the ice sheet and have made it even darker, which again contributed to a lower albedo. At the end of August 2014 there was also a week with very strong melting and that would have reinforced the overall low albedo in that period. Furthermore, 2014 was a year with relatively little precipitation on the ice sheet, and old snow is darker than new snow.

The albedo in 2014 was thus the second lowest since the year 2000. The low albedo level was most widespread in the month of August and especially high up on the ice sheet where the levels were record low. This unusually low albedo high up on the ice results in increased melting, but does not necessarily contribute to sea-level rise because the meltwater can refreeze in the snow instead of running off. This means that the calculated contribution to the

Box 1: New and more precise estimates

The values for the total mass balance of the ice sheet in this season report cannot be directly compared with figures from last year's report. The 2014 estimate of sea-level rise is more certain than previous estimates, which suffered from an error in the total calculation. In addition, there has been a modification in the figures because they are now based on the period May to September instead of April to September.

sea-level rise based on the reflection of sunlight can be slightly overestimated in 2014.

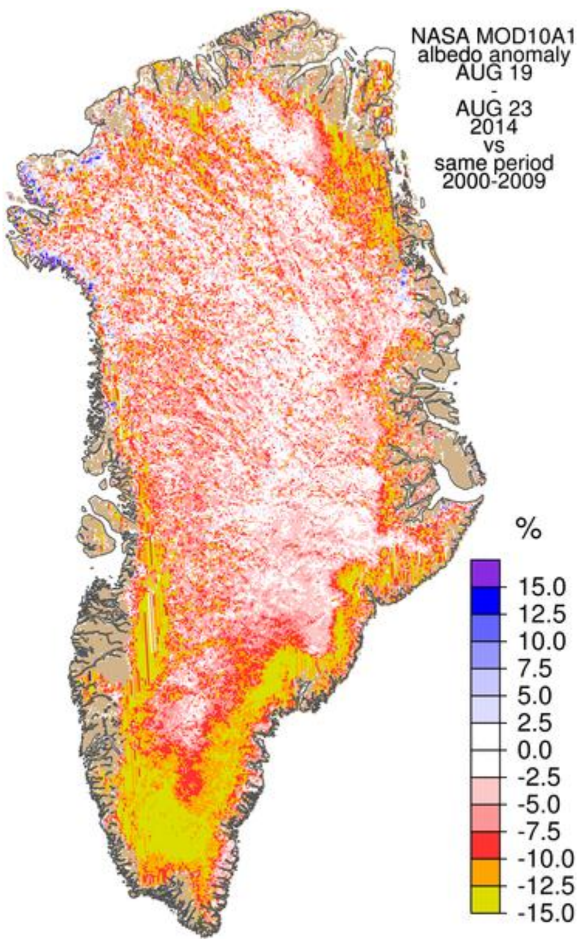


Figure 2. *The map illustrates the albedo anomaly measured in the period 19 to 23 August, 2014 when the temperature was high and there was strong radiation from the sun. It can thus be seen where the ice has reflected greater or lesser amounts of sunlight than normal.*

Box 2: The total mass balance of the ice sheet is calculated using satellite measurements of both albedo and force of gravity

Changes in the overall mass of the ice sheet are determined by two different methods. One method builds on measurements from the GRACE satellite of changes in the gravitational pull of the ice sheet, which decreases when there is less ice. However, it takes up to two to three months to analyze these data and GRACE data are unavailable mid-2014 due to satellite power problems. Therefore, researchers from GEUS have developed a supplementary method that is faster but not quite as precise as measurements of the gravity. This method is based on measurements of the albedo effect, that is, the reflection of sunlight from the ice sheet. This can be used because a statistical relationship has been found between the albedo effect and the gravity of the ice sheet. In this way a rapid, but provisional assessment can be made of the loss of mass from the ice sheet, while the more precise data are being analyzed.

The mass balance of the surface of the Greenland Ice Sheet was lower than normal, but not at a record low

The mass balance of the surface of the ice sheet relates to the isolated growth and melting of the surface. This does not include the loss when icebergs are calved from glaciers and melt when they meet the warm seawater. Since the middle of the 1990s, the surface mass balance has been decreasing.

Both specific measurements and simulations are made to monitor the surface mass balance of the ice sheet. Direct measurements of surface melting are taken under the PROMICE (Programme for Monitoring of the Greenland Ice Sheet) project of GEUS and DTU.

The measurements show that 2014 has not been a year with record melting. However, the temperature and melting were nonetheless considerably higher than in 2013, yet lower than in 2010 and 2012.

In 2014, melting in South and Southwest Greenland ranged between 3.5 and 6 m, while ice melting near the northerly stations at elevations lower than 500 m ranged between 1.7 and 3.1 m. At higher elevation stations, melting was from 0.0 to 3.2 m in the south and from 0.0 to 1.9 m for the northerly stations. These values are from the PROMICE surface stations.

DMI also prepares daily simulations of how much ice or water is released from or accumulated on the ice sheet. From these simulations, an overall measure can be obtained for how the surface mass balance is developing through time across the island.

According to DMI's results, in 2014 the melt season on the Greenland ice sheet began on 19 May. This is neither early nor late.

The melting in the period May to August 2014 was around 265 Gt, and this is not as high as the 415 Gt in 2012. Nonetheless, it represents an ice loss that contributes to ongoing global sea-level rise.

Collectively, over the year from September 2013 to August 2014 an amount of 275 Gt was added to the ice sheet through the surface (snowfall minus meltwater runoff). This is somewhat lower than the normal amount of approximately 400 Gt in the period 1990-2011, but not as low as in the 2012 season, when the ice surface gained only 127 Gt. A large accumulation of mass especially in Southeast Greenland outweighed to an extent a large loss

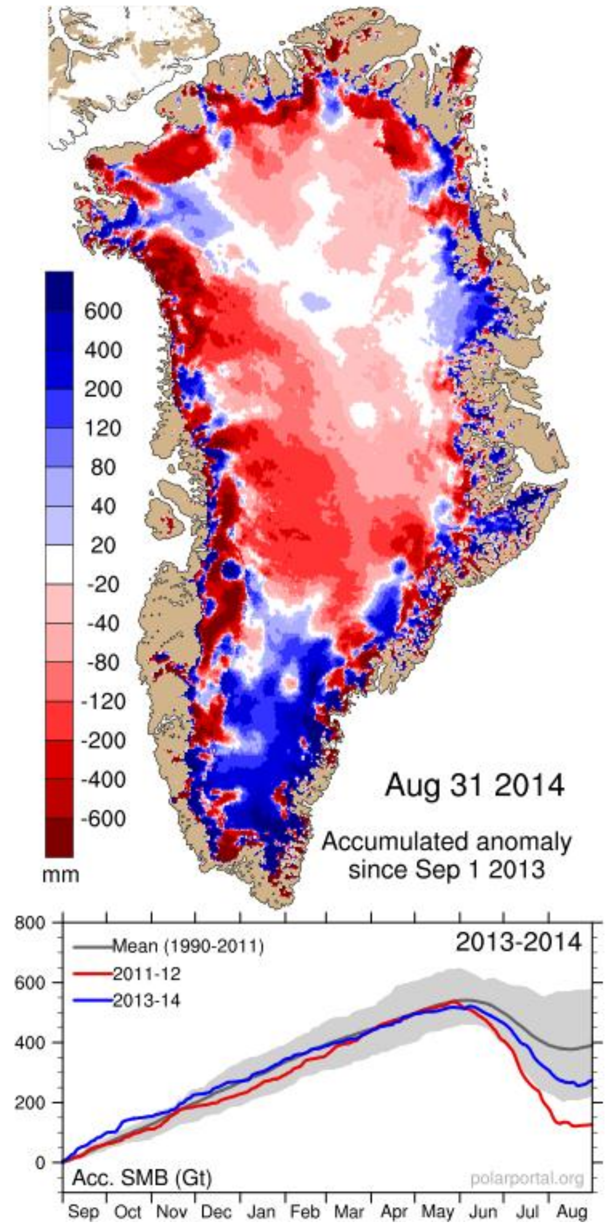


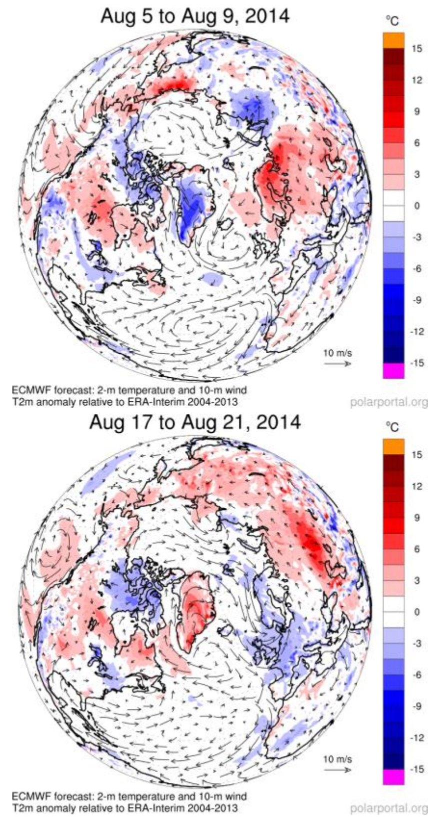
Figure 3. *The map illustrates the cumulative surface mass balance anomaly from 1 September 2013 until 31 August 2014. The blue colour illustrates areas where greater mass than normal has accumulated compared to the period 1990 to 2011, while the red colour illustrates areas where less mass than normal has accumulated. The graph illustrates the overall cumulative surface mass. The blue line illustrates the 2013/2014 season and it can be seen that this season is far down in the grey-shaded normal zone but not below it, as was the case in 2012.*

of mass from melting. Yet, this contribution of mass was not large enough to compensate for the loss from iceberg calving, so the ice sheet overall lost mass, as reported above.

The wind and the temperature of the air are important in relation to the amount that melts from the surface of the ice, and the large melting is associated with the variations in Greenland's special seasonal weather patterns. They are influenced by the North Atlantic Oscillation (NAO), which is a regional variation in high and low pressure systems. The result is that Greenland alternates between a dominance of cold air from the north (positive NAO) or warm air from the south (negative NAO). In 2012, the NAO index was negative for much of the year and this gave warmer air and clearer skies. Conversely, in 2014 the NAO index had only a weak tendency to be in the negative phase. This resulted in a melting in 2014 that was higher than average, but not as high as in 2012.

Box 3: New "engine" in the model to calculate surface mass balance

There has been a further development in the underlying "engine" in the program that calculates the surface mass balance. The values that are presented in the season report for 2013 were based on the previous version of this model. Therefore, there are several inconsistencies between the values in the season report for 2013 and those that are presented in this report. The year 2013 appears to be a relatively extreme year in the season report for 2013. However, the new and more precise model indicates that 2013 was average. All the values and graphs shown on Polar Portal are now calculated using the new model.



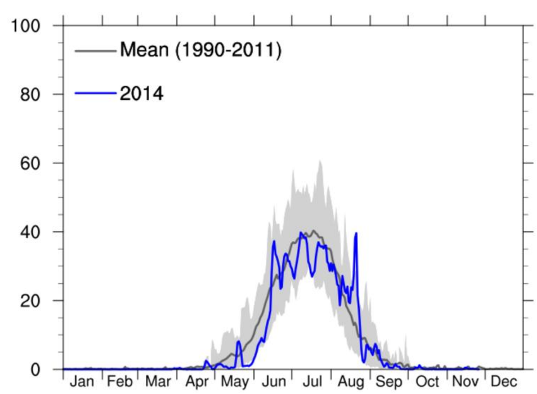


Figure 4. *The two weather maps illustrate the "seesaw" in weather between Greenland and Scandinavia. When Scandinavia has warm weather, it is usually cold on Greenland, and vice versa. The temperature anomaly and wind map for the period 5 to 9 August illustrates that the temperatures were higher than normal in Scandinavia and lower than normal in Greenland in comparison with this period in 2004-2013. On the other hand, the map for 17 to 21 August illustrates that Scandinavia had cooler weather and Greenland warmer weather in comparison with 2004-2013 after the marked shift that occurred in August owing to wind from the south that brought warm air northwards.*

Arctic sea ice strengthened in 2014

To evaluate the state of sea ice, both the thickness and the extent must be considered. The Arctic sea ice became stronger at the end of 2014 even though the warm winter of 2013/2014 slowed down the formation of new sea ice with a temperature that remained 5°C over normal the entire winter. The overall result is that sea ice at the end of 2014 both has a larger extent and is thicker than at the end of 2013.

The freeze-up of sea ice in the autumn of 2013 actually began earlier than normal in autumn. However, the high temperatures in winter resulted in a slower development and a slower rate of freezing especially at the end of winter.

The average extent of sea ice in September 2014, at the end of the melting season, was about 6.3 million km^2, that is, only 0.1 million km^2 larger than at the same time in 2013 and a full 2.2 million km^2 larger than in 2012, when the sea-ice extent was down to around 4.1 million km^2. In comparison, the area of Denmark is around 0.043 million km^2.

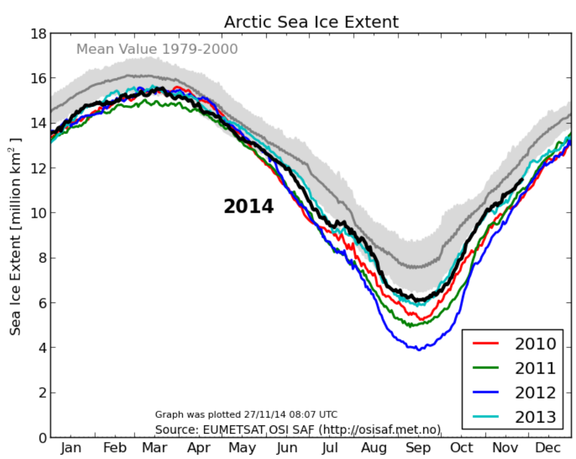


Figure 5. *Daily values for the total area of sea ice in the northern hemisphere. The black line is for 2014.*

In spite of the lower freeze-up of sea ice in the winter of 2013/2014, the Arctic sea ice was 30% to 40% thicker at the end of September than at the same time in the past four years. That has made the sea ice more robust. The sea ice in the Arctic is now at the level of the average thickness from ten years ago. But it is still far from the thickness that the ice had 20 or 30 years ago. Nonetheless, the increased thickness of the ice is very important. The thickness of the ice is an indication of how well the floating ice cap over the Arctic Ocean is equipped to resist storms and the very warm summers that occur in some years.

In 2014, the melt season for sea ice in the central Arctic began on 17 June, which was one week later than normal and two full weeks later than in 2012, when the sea-ice extent diminished to the smallest area yet measured. In evaluating the satellite measurements of sea ice over the past 35 years, a clear relationship can be seen between the beginning date of the melt season in June and the area of the year's smallest sea-ice extent in September. For when melting has first begun, it accelerates on its own. This is because frozen snow reflects more sunlight, and thus more energy, than snow that melts.

A new temperature record was set in Greenland in June 2014

West Greenland had a warm summer in 2014, and June-August was the warmest ever recorded in Kangerlussuaq. On 15 June, a temperature of 23.3°C was measured in Kangerlussuaq. This is a new daily maximum record for June temperatures, 0.2°C higher than previously measured.

There were few large changes in the movements of glacier fronts in Greenland

Variations in most of the 20 largest outlet glaciers followed the usual seasonal cycle, with growth during winter and retreat in the course of the summer. There were no dramatic glacier front retreats during the melt season of 2014, as was the case, for example, with the Petermann Glacier in 2010 and 2012. But there were large variations for several of the glaciers which seemed natural.

Zachariae Glacier is one of the 20 largest glaciers that changed the most during the 2014 melt season. Already in April several km^2 had broken off the terminus, but were nonetheless partially rebuilt by the glacier flow from the ice sheet. However, between July and August an additional roughly 20 km^2 of the glacier's terminus was broken off to form floating icebergs. This especially affected the central and northern parts of the glacier, which lost 4 km between June and September.

Even though there were no major changes in the terminus of 79N Glacier, there were both more and larger meltwater lakes on the surface of the glacier in the middle of August in comparison with the same period in 2013.

At Nunatakassaap Sermia southwest Greenland the glacier terminus changed markedly in the southern part in 2014 and shifted several hundred meters back in comparison with 2013.

Some glaciers also grew. After the very large calvings from Petermann Glacier in 2010 and 2012, there have been no additional major events in 2013 and 2014. This means that the glacier has been able to advance about 2 km in the course of 2013 and 2014.

An area of Ryder Glacier also continued to increase its advance in 2014 and reached a more advanced position than in year 2000. However, the remaining portion of the Ryder Glacier lost a 1.2 x 3 km large iceberg. This means that it is now 3 km behind the terminus front in the year 2000 and there is a possibility that it will lose another large iceberg.

In East Greenland, the summer retreat of Kangerlussuaq Glacier and Helheim Glacier was 2.5 km and 4.0 km, respectively, which is 2.1 km and 1.5 km, respectively, more than in 2013.

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.dk or contact info@polarportal.dk