Reduced Arctic Sea Ice Extent - Background

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http://ccdatacenter.org/documents/ReducedArcticSeaIceExtentBackground.pdf

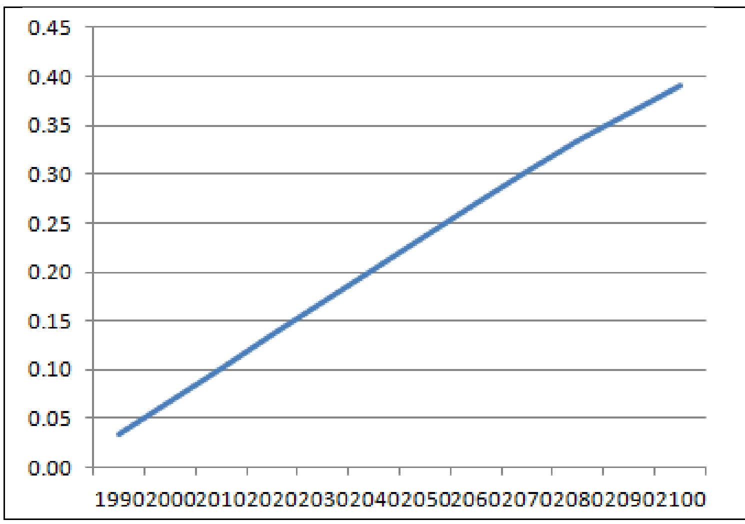
Abstract

"The annual sea-ice minimum, based on a five-day average, is seen as an important indicator of climate change. Overall, the Arctic has lost 40% of its sea-ice cover since 1980, and 75% of its volume. Most scientists believe the ocean at the north pole could be entirely ice-free in the summer by the middle of the century – if not sooner." (http://www.theguardian.com/environment/2013/sep/20/arctic-sea-ice-decline-melting-summer)

The area of the Arctic Ocean covered by ice in the summer fluctuated in a fairly narrow range for most of the last 1400 years (see Figure 1) but after about 1990 began to decline rapidly. Since the reduced summer-time extent of the ice in the Arctic Ocean is decreasing the albedo of the Arctic region, it could have a modest effect on the expected temperature change both for the Arctic region and the Earth as a whole in this century. This "discussion paper" provides some background information on various aspects of the decline in the ice in the Arctic Ocean.

There is not much agreement as to how fast the ice in the Arctic Ocean is melting or how much warming the melting will cause (e.g., see "8. Ice-free Arctic Ocean" below). One analysis (see"2. Proceedings of the National Academy of Sciences below") estimated that the radiative heating from 1979 to 2011 for the Arctic is equivalent to 0.18 W/m^2 of radiative forcing for the Earth as a whole, which is over 1/2 the amount that Hudson (see "1. Hudson" below) predicted for four weeks of summer-time free Arctic Ocean, at which time the September sea ice extent will have declined by about three times as much as it had in 2011.

If Hudson's estimate for radiative forcing is correct and if the Arctic Ocean is ice-free for four weeks on 2070, the total radiative forcing from the Arctic Ocean ice melt could approach .4 W/m-2, adding about .20°C to the Earth's average temperature (which is equivalent to about 125 GTC of carbon dioxide, 12 years of current emissions, and about 1/2 of the IPCC's "carbon budget").

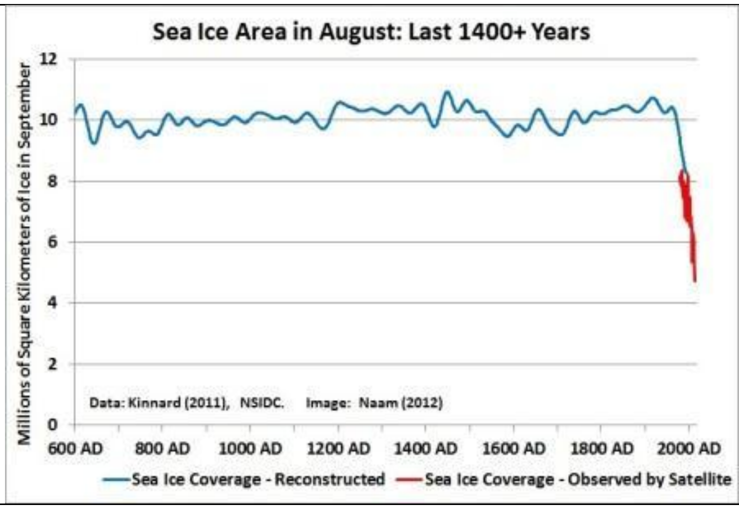


Radiative Forcing (W/m-2) For the Expected Albedo Change from 1990 for a Linear Decrease in Arctic Ice extent

Based on .3 W/m-2 for 4 weeks of an ice-free Arctic Ocean in 2070

(Source: http://ccdatacenter.org/documents/ProjectingTheDeclineOfArcticSeaIce.pdf, page 11)

Useful Figures



Arctic sea ice coverage, as reconstructed from 69 sites around the area, fluctuated in a fairly narrow range for more than 1400 years. In the last few decades, it has plunged abruptly.

http://blogs.scientificamerican.com/guest-blog/2012/09/21/arctic-sea-ice-what-why-and-what-next/

Figure 1 – Arctic Sea Ice Area for last 1400 Years

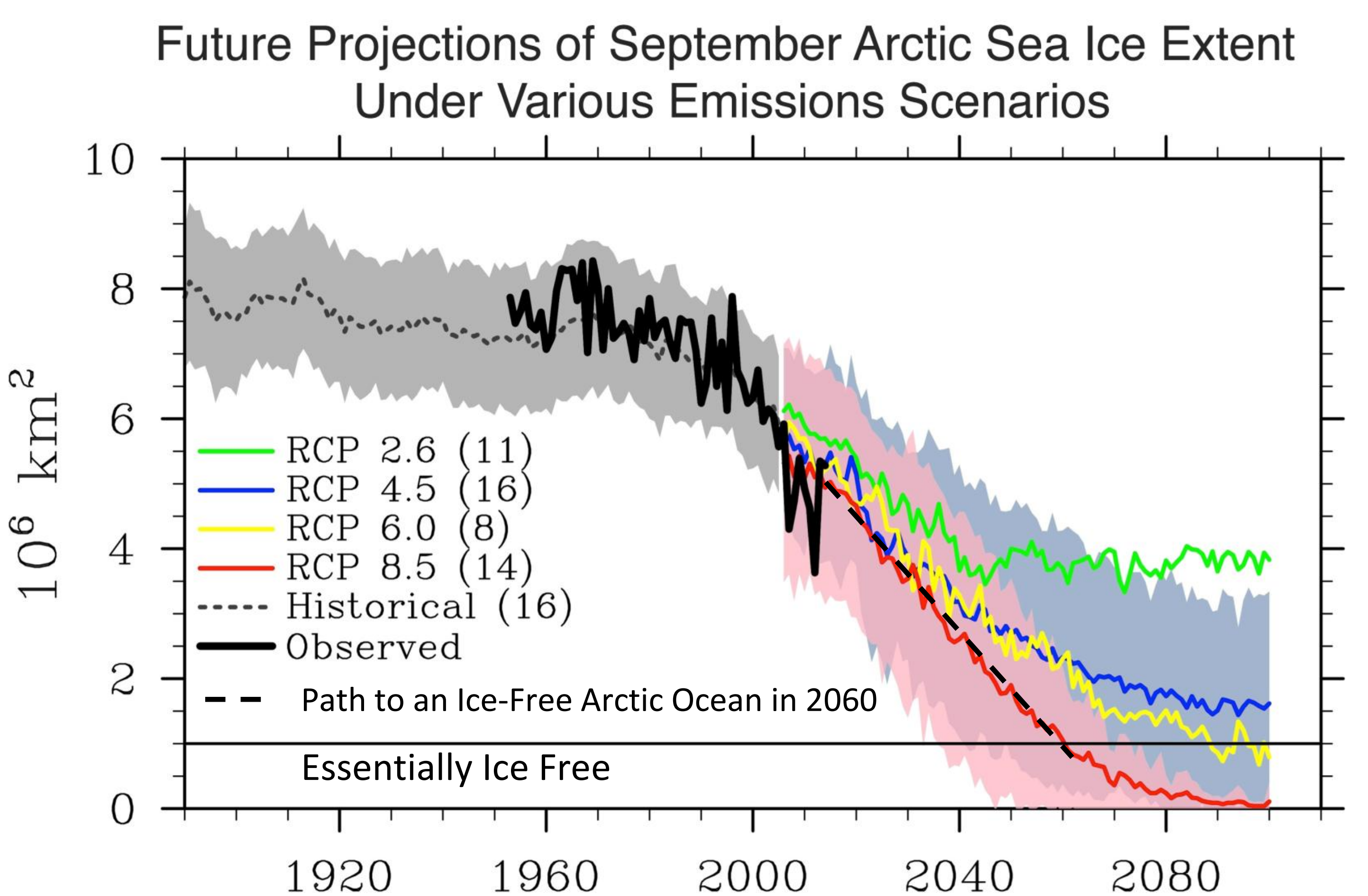


Figure 2.29. Model simulations of Arctic sea ice extent for September (1900-2100) based on observed concentrations of heat-trapping gases and particles (through 2005) and four scenarios. Colored lines for RCP scenarios are model averages (CMIP5) and lighter shades of the line colors denote ranges among models for each scenario. Dotted gray line and gray shading denotes average and range of the historical simulations through 2005. The thick black line shows observed data for 1953-2012. These newer model (CMIP5) simulations project more rapid sea ice loss compared to the previous

generation of models (CMIP3) under similar forcing scenarios, although the simulated September ice losses under all scenarios still lag the observed loss of the past decade. Extrapolation of the present observed trend suggests an essentially ice-free Arctic in summer before mid-century.**139** The Arctic is considered essentially ice-free when the areal extent of ice is less than one million square kilometers. (Figure source: adapted from Stroeve et al. 2012**136**).
Note: The IPCC has really underestimated when the summer-time Arctic ocean will likely become ice free, so it's temperature estimates are likely low

Figure 2 – Future Projections of September Arctic Sea ice extent (http://nsidc.org/arcticseaicenews/ + add'l notes)

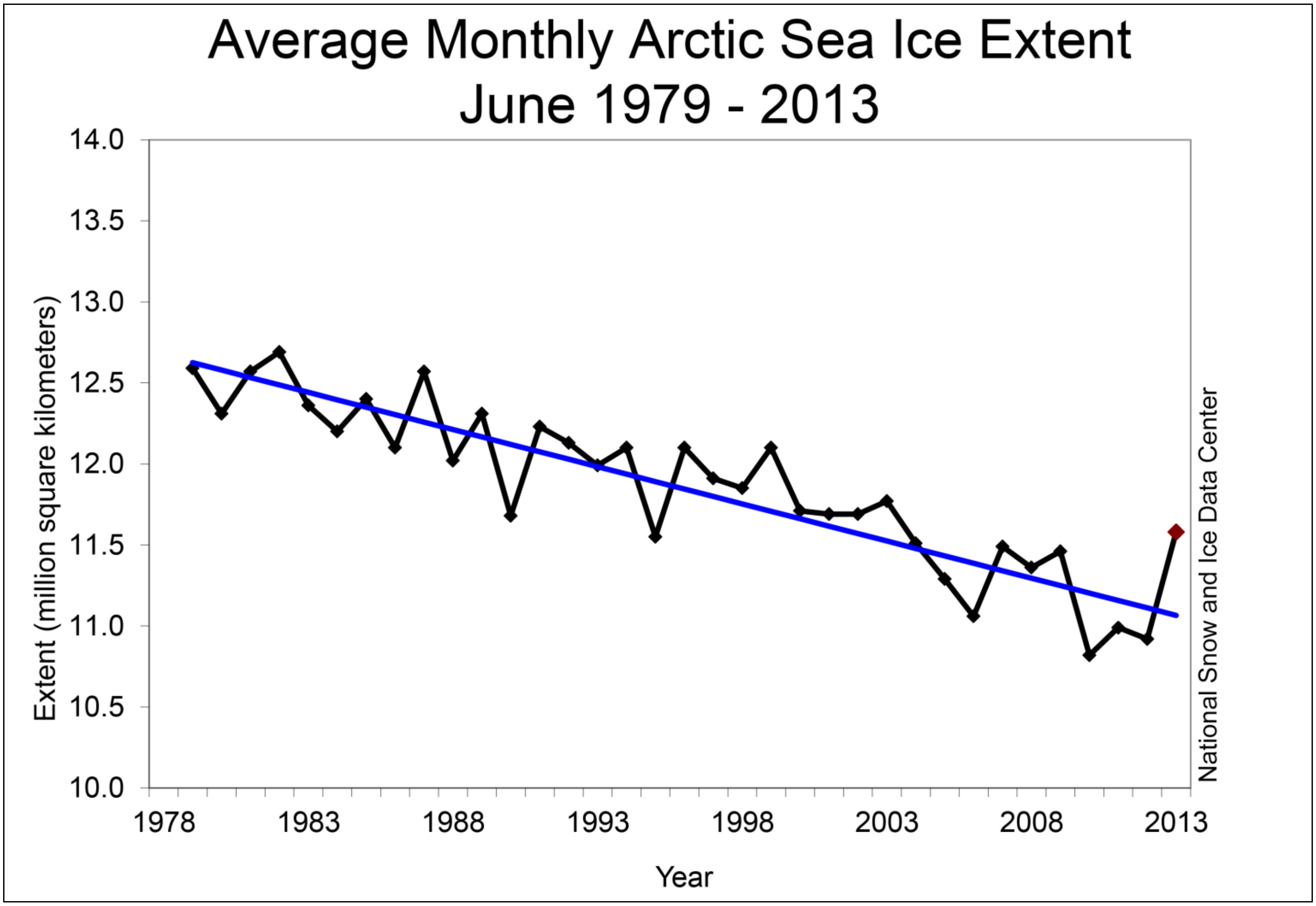


Figure 3 – Average Monthly Arctic Sea Ice Extent – June 1979-2013

What is most important for global warming is when the Arctic is ice-free in June, as this is when the sun is directly overhead and will cause the oceans to warm up the most. At the current rate it will take about 100 years for the Arctic to become ice free in June.

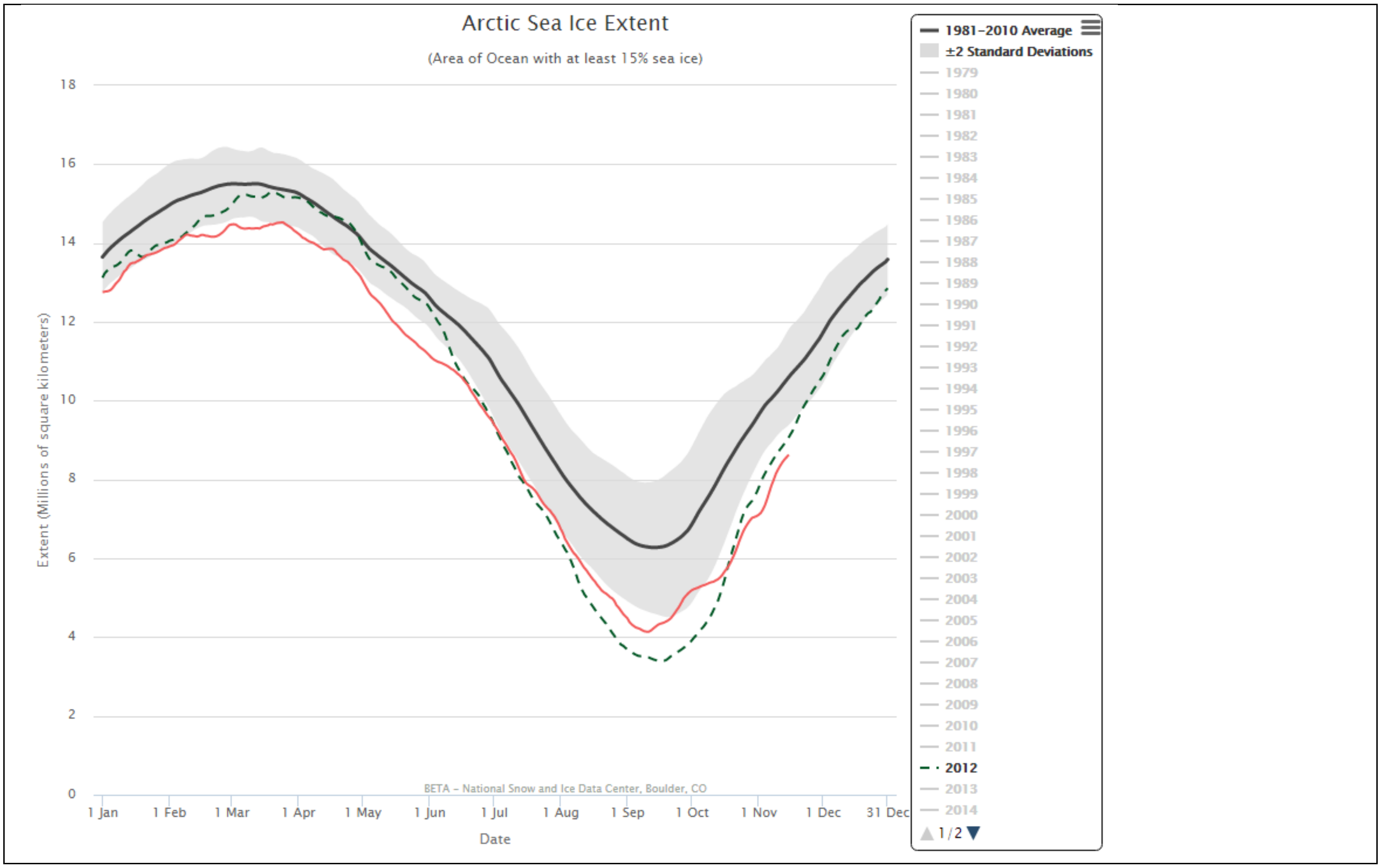


Figure 4 - Arctic Sea ice extent on 15 November 2016 (http://nsidc.org/arcticseaicenews/charctic-interactive-sea-ice-graph/)

http://blogs.scientificamerican.com/guest-blog/2012/09/21/arctic-sea-ice-what-why-and-what-next/

If the pace of the last decade were to continue on this recent pace – and didn't keep on accelerating – June ice would be gone by 2026…

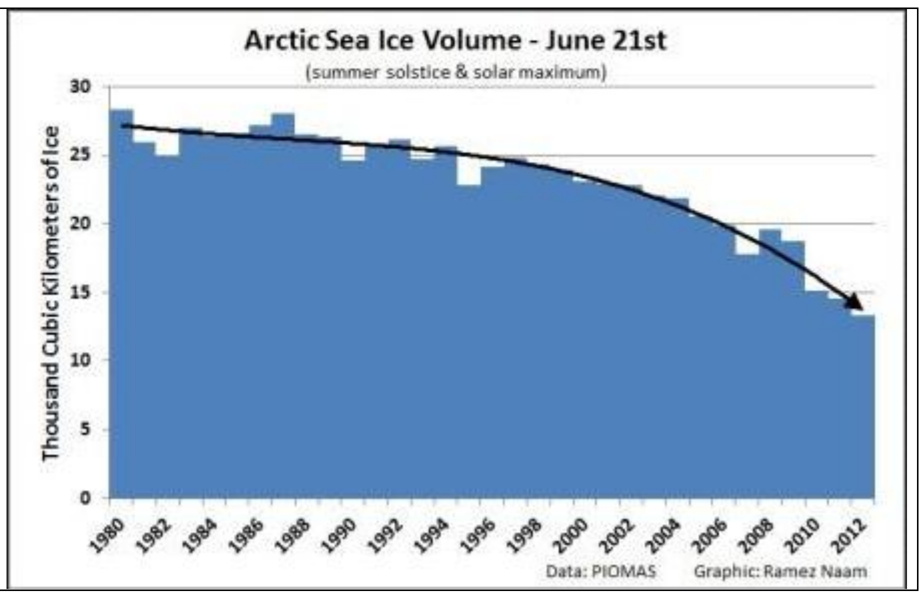


Figure 5 – Arctic Sea Ice volume on June 21st for 1980-2012

The volume of Arctic ice has been declining steadily since 1990, and the Arctic is expected to be ice-free in the summer sometime in the next 20-30 years. An ice-free Arctic will absorb a substantial amount of heat from the sun – equivalent to the warming caused by the CO_2 which has been emitted since 1870. This will likely increase the rate at which the Earth warms.

Estimates of albedo/radiative forcing changes

1. Hudson

One estimate of the radiative forcing from a summer-time ice-free Arctic Ocean is about 0.3 W/m^2.

Estimating the Global Radiative Impact of the Sea-Ice-Albedo Feedback in the Arctic
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D16102, DOI:10.1029/2011JD015804, 2011
Stephen R. Hudson Norwegian Polar Institute, Tromsø, Norway Submitted 11 February 2011; revised 18 April 2011; accepted 10 May 2011; published 16 August 2011_
Abstract. A simple method for estimating the global radiative forcing caused by the sea-ice-albedo feedback in the Arctic is presented. It is based on observations of cloud cover, sea-ice concentration, and top-of-atmosphere broadband albedo. The method does not rely on any sort of climate model, making the assumptions and approximations clearly visible and understandable, and allowing them to be easily changed. Results show that the globally and annually averaged radiative forcing caused by the observed loss of sea ice in the Arctic between 1979 and 2007 is approximately 0.1 W m−2 ; a complete removal of Arctic sea ice results in a forcing of about 0.7 W m−2 , while a more realistic ice-free-summer scenario (no ice for one month, decreased ice at all other times of the year) results in a forcing of about 0.3 W m−2 , similar to present-day anthropogenic forcing caused by halocarbons. The potential for changes in cloud cover as a result of the changes in sea ice makes the evaluation of the actual forcing that may be realized quite uncertain, since such changes could overwhelm the forcing caused by the sea-ice loss itself, if the cloudiness increases in the summertime.
http://www.npolar.no/npcms/export/sites/np/en/people/stephen.hudson/Hudson11_AlbedoFeedback.pdf

2. Proceedings of the National Academy of Sciences

However, recent observations determined that the change in radiative forcing from 1979-2011 (6.4 W/m^2) was about 0.18 W/m^2 for the Earth as a whole, and the ice melt in that time frame represents only a small fraction of the ice that is expected to have melted by 2100. (Proceedings of the National Academy of Sciences)

Arctic Albedo Observational determination of albedo decrease caused by vanishing Arctic sea ice Sept 2013 http://www.pnas.org/content/111/9/3322.full Significance The Arctic sea ice retreat has been one of the most dramatic climate changes in recent decades. Nearly 50 y ago it was predicted that a darkening of the Arctic associated with disappearing ice would be a consequence of global warming. Using satellite measurements, this analysis directly quantifies how much the Arctic as viewed from space has darkened in response to the recent sea ice retreat. We find that this decline has caused 6.4 ± 0.9 W/m^2 of radiative heating since 1979, considerably larger than expectations from models and recent less direct estimates. Averaged globally, this albedo change is equivalent to 25% of the direct forcing from CO_2 during the past 30 y. *Note: The albedo from Arctic ice extent change 1979-2011 is the equivalent of about 14 PPM CO2e. (=278*POWER(2.718,((6.4*14/510)+1.99)/5.35)-403), which is equivalent to emissions of about 240 GTCO2*

3. NASA Satellites Measurements

And another recent study shows that the increase in absorbed radiation from 2000 to 2014 was about 0.27 W/m^2, or about the same as Hudson and projected for the year 2100.

NASA Satellites Measure Increase of Sun's Energy Absorbed in the Arctic (Dec. 17, 2014)
Since the year 2000, the rate of absorbed solar radiation in the Arctic in June, July and August has increased by five percent… When averaged over the entire Arctic Ocean, the increase in the rate of absorbed solar radiation is about 10 Watts per square meter *(about .27 Watts per square meter globally).*
http://www.nasa.gov/press/goddard/2014/december/nasa-satellites-measure-increase-of-sun-s-energy-absorbed-in-the-arctic/#.VOdX7ubF9bI

4. Scientific American Blog

And another calculation shows results almost identical to this analysis – an ice-free Arctic Ocean in the summer time would "have an additional heating effect just as large as the heating effect of all human CO2 and other greenhouse gasses to date" (but that does not include the effects of cloud cover). Given that the current radiative forcing is about 2.3 W/m-2 and that cloud cover is 60% in the summer, the radiative forcing would be about .92 W/m-2, almost the same radiative forcing projected by this analysis - .93 W/m-2

Arctic Sea Ice: What, Why, and What Next
By Ramez Naam on September 21, 2012
Scientific American blog
The sunniest time of year in the northern hemisphere is the summer solstice, in late June, and the weeks preceding and following it. For several weeks the sun's rays are at their most intense and the Arctic receives 24/7 sunlight, giving it a double whammy of heating. In fact, in June, July, and the latter half of May, the Arctic receives *more total solar energy per day* than regions at the equator do at any time of year. Thus, every patch of dark ocean water revealed by melting ice in June, or May, or July, has a warming effect much larger – as much as five or six times larger – than the same change in ice coverage in September, when the ice hits its minimum today. The loss of ice in September is one thing. Loss of ice in June would have a far bigger impact on the region and the planet. If the pace of the last decade were to continue on this recent pace – and didn't keep on accelerating – June ice would be gone by 2026, exposing the dark waters of the Arctic Ocean to the year's most intense influx of solar energy, which would then be captured as heat. Peter Wadhams of the Global Oceans Physics Program at Cambridge calculates that the loss of the Arctic ice throughout the summer would have a warming effect roughly equivalent to all human activity to date. That is to say, with the ice gone in summer, the planet would have an additional heating effect just as large as the heating effect of all human CO2 and other greenhouse gasses to date. In other words, the complete meltdown of the Arctic could roughly double the rate of warming of the planet as a whole. There are important caveats and uncertainties to that analysis. First, Wadhams doesn't take into account the effect of clouds. Darker waters absorb more energy from sunlight only if the sunlight reaches them. Cloud cover in the Arctic – something which may increase as rising temperatures enable Arctic air to carry more moisture – may reflect sunlight back into space before it ever touches the water, thus reducing the warming effect of ice melt.
http://blogs.scientificamerican.com/guest-blog/arctic-sea-ice-what-why-and-what-next/

5. Nature. 2010

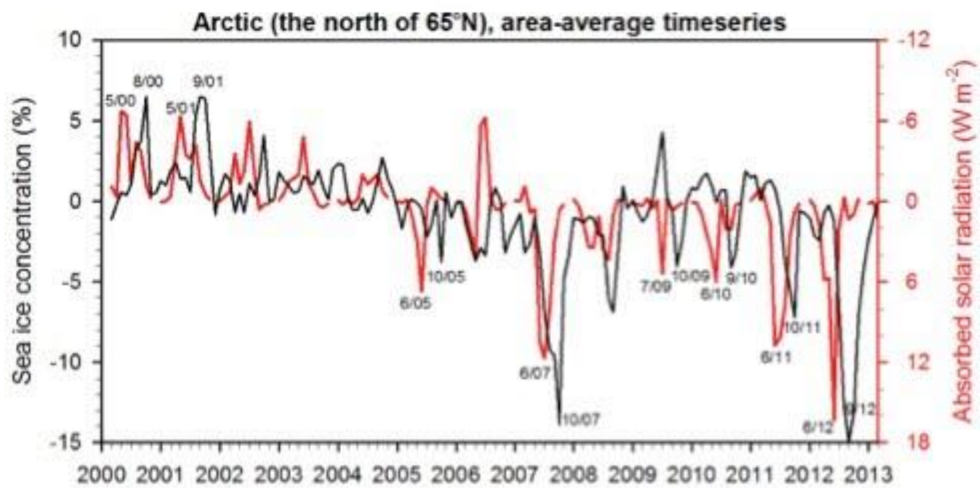
The central role of diminishing sea ice in recent Arctic temperature amplification
James A. Screen & Ian Simmonds
Nature. 2010 Apr 29 (http://www.nature.com/nature/journal/v464/n7293/full/nature09051.html)

Abstract

The rise in Arctic near-surface air temperatures has been almost twice as large as the global average in recent decades-a feature known as 'Arctic amplification'. Increased concentrations of atmospheric greenhouse gases have driven Arctic and global average warming; however, the underlying causes of Arctic amplification remain uncertain. The roles of reductions in snow and sea ice cover and changes in atmospheric and oceanic circulation, cloud cover and water vapour are still matters of debate. A better understanding of the processes responsible for the recent amplified warming is essential for assessing the likelihood, and impacts, of future rapid Arctic warming and sea ice loss. Here we show that the Arctic warming is strongest at the surface during most of the year and is primarily consistent with reductions in sea ice cover. Changes in cloud cover, in contrast, have not contributed strongly to recent warming. Increases in atmospheric water vapour content, partly in response to reduced sea ice cover, may have enhanced warming in the lower part of the atmosphere during summer and early autumn. We conclude that diminishing sea ice has had a leading role in recent Arctic temperature amplification. The findings reinforce suggestions that strong positive ice-temperature feedbacks have emerged in the Arctic, increasing the chances of further rapid warming and sea ice loss, and will probably affect polar ecosystems, ice-sheet mass balance and human activities in the Arctic.

(Uses data for 1989-2008)

6. Clouds and Arctic Sea Ice



Absorbed solar radiation at the top of the atmosphere (red) versus sea ice concentration (black) for the Arctic region between 2000 and 2013. Courtesy: Climate System Laboratory, Seoul, Korea

The record low in Arctic sea ice recorded in September 2012 when the sea ice extent dropped to just 3.41 million square kilometers was related to anomalously low cloud cover over the Arctic region in the early summer, according to new research.
Researchers have found that the low amounts of cloud in the early summer lead to low concentrations of sea ice in the late summer. This relationship between cloud cover and sea ice is so strong that it can explain up to 80 per cent of the variation in sea ice over as much as 60 per cent of the sea ice area.
Furthermore, computer climate models fail to capture the role of clouds in mediating the relationship between solar radiation absorbed at the top of the atmosphere in the early summer and Arctic sea ice concentrations in the late summer, according to the research published in the Journal of Geophysical Research Atmospheres.

http://www.reportingclimatescience.com/news-stories/article/high-cloud-levels-drive-low-arctic-sea-ice.html

Low cloud cover in winter can lead to more summer ice

This process is known as the cloud radiative effect, or cloud forcing. It is because of this effect, Key said, that clouds warm the Earth's surface at night, and, likewise, "if you don't have clouds, most of that longwave radiation just escapes to space and the surface of the Earth cools."

Liu and Key were not dealing with a small change in cloud cover, but up to 20 percent less cloud cover than average. "That's a big difference, especially in the coldest part of the winter," said Key. "That turns into a lot of cooling, and more ice growth."

The scientists estimated that in an area of 20 percent less cloud cover, ice could grow 45 centimeters more in two months. - See more at: http://www.ssec.wisc.edu/news/articles/6621#sthash.hxZOykeg.dpuf

http://www.ssec.wisc.edu/news/articles/6621

7. Aerosols and Arctic Warming

http://www.carbonbrief.org/blog/2015/02/aerosols-dampen-pace-of-arctic-warming-for-now-say-scientists/

Aerosols dampen pace of Arctic warming for now, say scientists

As the Earth warms under increasing greenhouse gas emissions, temperatures have risen more quickly in the Arctic than the rest of the world. But particles emitted as fossil fuels are burned mask a lot of that warming. Without them, the temperature rise in the Arctic would be more than double what we've seen in the past century, a new study finds.

8. "Ice-free" Arctic Ocean

An "ice-free" Arctic Ocean is often defined as "having less than 1 million square kilometers of sea ice", because it is very difficult to melt the thick ice around the Canadian Arctic Archipelago.[10][11][12] The IPCC AR5 defines "nearly ice-free conditions" as sea ice extent less than 10^6 km^2 for at least five consecutive years.[3]

Many scientists have attempted to estimate when the Arctic will be "ice-free". They have noted that climate model predictions have tended to be overly conservative regarding sea ice decline.[2][13] A 2013 paper suggested that models commonly underestimate the solar radiation absorption characteristics of wildfire soot.[14] A 2006 paper predicted "near ice-free September conditions by 2040".[15] Overland & Wang (2009) predicted that there would be an ice-free Arctic in the summer by 2037.[16] The same year Boé et al. found that the Arctic will probably be ice-free in September before the end of the 21st century.[17] A follow-up study concluded with the possibility of major sea ice loss within a decade or two.[18] The IPCC AR5 (for at least one scenario) estimates an ice-free summer might occur around 2050.[3] The Third U.S. National Climate Assessment (NCA), released May 6, 2014, reports that the Arctic Ocean is expected to be ice free in summer before mid-century. Models that best match historical trends project a nearly ice-free Arctic in the summer by the 2030s.[19] However, these models do tend to underestimate the rate of sea ice loss since 2007. A 2010 study suggested that the Arctic Ocean will be ice-free sooner than global climate models predict. They chart the summer of 2016 as ice-free, but show a possible date range out to 2020.[20] This assessment was reported in the press as "US Navy predicts summer ice free Arctic by 2016" [21] In a study from 2016, the prediction uncertainty of an ice-free Arctic was quantified to be at around two decades, based on model simulations [22]

https://en.wikipedia.org/wiki/Arctic_sea_ice_decline