Amplifying Feedbacks in the Arctic

Bruce Parker

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

There is increasing doubt that our society will take the steps needed to limit the temperature increase to 2°C by 2100[1]. And the amplifying feedbacks[2] in the Arctic region not only make that effort even more unlikely but they also could very possibly drive the temperature to catastrophic levels in the centuries ahead[3] regardless of any actions that we are likely to take to reduce greenhouse gas emissions or remove carbon dioxide from the atmosphere.

Since about 1990 the rate of warming in the Arctic region warming (roughly 0.6°C per decade[4]) has been about three times that of the rest of the Earth (roughly 0.2°C per decade[4]) for one main reason: the surface albedo is decreasing as part of an amplifying feedback loop as warmer temperatures reduce the extent of both the sea ice and snow cover, which results in more warming, etc. In addition, not only is the permafrost is beginning to thaw[5] but the Arctic soils are turning from a carbon sink to a carbon source[6], both of which release greenhouses gases in another amplifying feedback loop. Since it is very unlikely that we will be able to limit the temperature increase to 2°C by 2100[1], these amplifying feedbacks have the potential to overwhelm our mitigation and sequestration efforts and eventually result in catastrophic global warming[3]. The most pressing climate change questions then become (1) Given a relatively aggressive greenhouse gas mitigation effort, how much additional warming will these feedbacks likely cause in the next several centuries? (2) What is a reasonable, high estimate of the amount of CO2 that our society would be willing to capture and sequester in the next 50 years (BECCS, CCS, and CDR)? and (3) If a high estimate of what can be sequestered is not sufficient to prevent eventual catastrophic climate change, should solar radiation management be undertaken?

Answering the following questions would provide a framework for addressing the first two questions above and help to evaluate the seriousness of the global warming problem:

1. For a relatively aggressive greenhouse gas mitigation effort, by mid century and by 2100
    a. What would the greenhouse gas emissions be?
    b. How much will the radiative forcing of aerosols change?
2. How much CO2 can realistically be sequestered by natural means (afforestation, soils, etc.)?
3. How much CO2 will be released by natural means (forests, soils, etc.)?
4. How much additional warming will the Arctic feedbacks cause?
    a. In climate models, what percent of radiative forcing is attributable to surface albedo changes in the Arctic region[7]?
    b. What will be the surface albedo changes for various amounts of Arctic sea ice extent and snow cover extent[8]?
    c. What are the projections of the actual change to surface albedo in the Arctic region through mid-century[9]?
    d. How much radiative forcing beyond that forecast by climate models is expected[10]?
    e. What are the projections for greenhouse gas emissions from the thawing permafrost[5]?
    f. What are the projections for greenhouse gas emissions from Arctic soils?
5. Will clouds cause much more warming than the models predict?[11]
6. What is the expected costs of the various carbon sequestration techniques through mid century?
7. How much would society be willing to pay per year for carbon sequestration?

Additional Thoughts

- Since we have been relying primarily on "market forces" to reduce greenhouse emissions and since severe climate change is inevitable (possibly by mid-century), we should be focused on ways to both reduce future suffering and to make our societies more resilient, rather than paying for mitigation and carbon sequestration which have no real economic value
- Our major technological effort should be focused on removing CO2 from the atmosphere with the hope that someday it will be inexpensive enough to remove many hundreds gigatons in order to reduce atmospheric CO2 to around 300 PPM.

Footnotes/Notes

1. **The Growing Case for Geoengineering**

Without some kind of drastic action, climate change could be killing an estimated half-million people annually by the middle of this century, through famine, flooding, heat stress, and human conflict. Preventing temperatures from rising 2 °C above preindustrial levels, long considered the danger zone that should be avoided at all cost, now looks nearly impossible. It would mean cutting greenhouse-gas emissions by as much as 70 percent by 2050, and it may well require developing technologies that could suck megatons of carbon dioxide out of the atmosphere, according to the U.N.'s Intergovernmental Panel on Climate Change. But a growing body of research suggests that we probably will not have the time or technology to pull this off. Notably, even if every nation sticks to the commitments it's made under the politically ambitious Paris climate accords, global temperatures could still soar more than 5 °C by 2100.

"Everyone is looking at two degrees, but to me it's a pipe dream," says Daniel Schrag, director of the Harvard University Center for the Environment, who was one of President Obama's top advisors on climate change. "I fear we'll be lucky to escape four, and I want to make sure nobody ever sees six."

https://www.technologyreview.com/s/604081/the-growing-case-for-geoengineering/

2. **The Arctic Amplification**

A dangerous spiral already seems well established in the Arctic, with warming of the Arctic causing further warming.

The Arctic warms, the Arctic ice retreats, and the ocean absorbs more of the sun's rays, so the Arctic warms further.

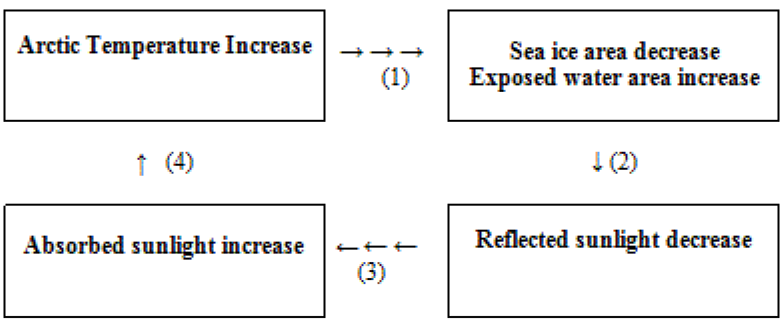


Diagram: The Arctic Ice Feedback Cycle

This is an amplifying feedback cycle in which: (1) an increase in temperature melts ice, decreasing the area covered by sea ice and so increasing the area of exposed ocean. (2) This decreases the reflection of sunlight as ice is far more reflective than the newly exposed ocean. (3) This reduced reflection increases the sunlight that is absorbed by the ocean. (4) This increases the temperature, amplifying the original increase in temperature and melting more ice so the cycle tends to repeat.

http://www.feedbackreigns.net/dangers/feedbacks/

3A If one looks at the warming that anthropogenic emissions (at least 2.5°C) and the "Arctic amplification" (at least 1.5°C) are likely to cause, along with the relatively high cost of "carbon dioxide removal", then with even an aggressive greenhouse gas mitigation effort there is little chance that global temperatures can be kept below a 4°C increase (particularly in the "long run").

As the temperature continues to rise, increasing amounts greenhouse gases will be emitted from the various organic stores of carbon on the Earth's surface   Climate scientists cannot accurately predict the greenhouse gas emissions from these sources as a function of temperature, but given that at least a 5.4 degree F rise in temperature can be expected (and more in the Arctic, where most of the carbon stores reside), these emissions could easily surpass human-caused emissions.

The table below lists some the "carbon stores" and "albedo feedbacks". The "likely temp changes" are very rough but are "directionally correct". (I would really like to see the table filled out based on peer-reviewed articles, but they are very hard to find and interpret.)

GHG Source	Carbon Store (GTC)	Estimates	Likely Temp Change by 2100 (°C)	Likely Temp Change by 2200 (°C)
Anthropogenic - Likely Emissions thru 2100	1000	Average of 12 GTC/year for 80 years?? (MIT study estimated average of 16 GTC through at least 2050 (640 GTC by 2050))	2.5 – 3.5	3.5 - 4?
Feedbacks - Albedo				
Arctic Sea Ice		Already .27 W/M^{2}, with pollution reducing the amount .3 W/M^{2}-1.3 W/M^{2} (perhaps .2 W/M^{2} used in models???)	.25	.5
Snow Cover		1.3 W/M^{2}	.5	1.0
Vegetation				
Feedbacks - GHGs				
Permafrost	1,600	.25-1°C by 2100 80PPM Up to 250 GtC or more	.5	1.5
Methyl Hydrates[12]	5,000 to 20,000			
Peat[13]	270 to 370	40% loss by 2100 (100 GTC) 80% loss by 2200 (220 GTC)	.2	.5
Other Soils				
Amazon	86			
Temperate Forests[14]				
Other Carbon Stores				
Atmosphere	820			
Fossil Fuels	810-3,500			
IPCC Post 2011 Budget	485			

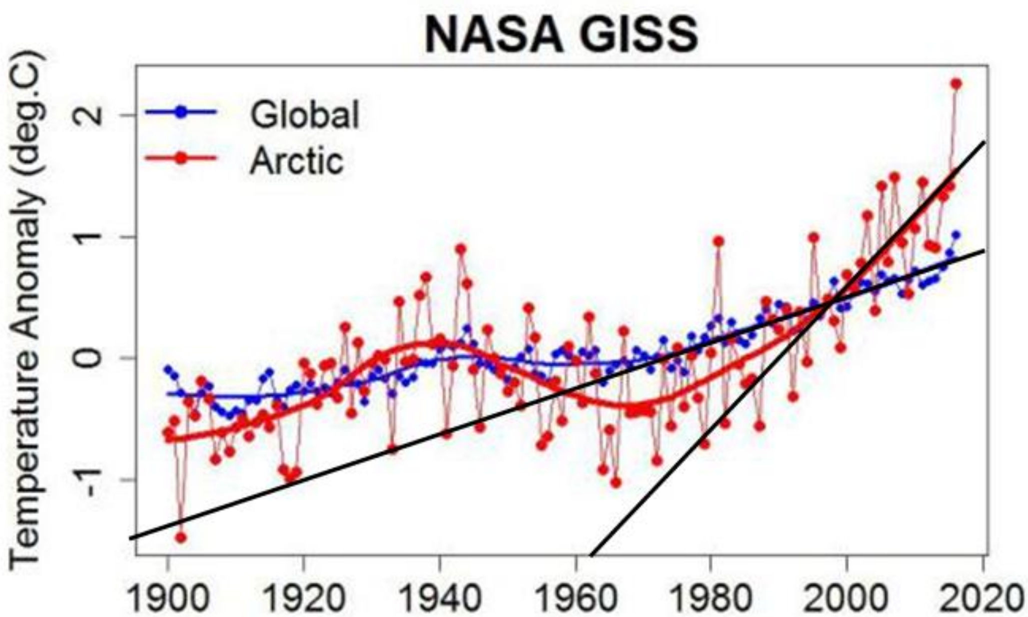
3B

Why even this bleak prospect may be optimistic

Alert readers may have already noticed that this article has not yet used the word "methane". When organic matter in the permafrost is thawed and decomposes it produces mostly CO_2 but also small amounts of methane, particularly so in the wetlands that are prevalent in areas of thawing permafrost. Schuur and Abbott (2011) polled 41 experts on permafrost decay who estimated that about 3% of the carbon released from the permafrost will be in the form of methane. Methane has a restricted lifetime in the atmosphere, measured in decades, but while present in the air it has a greenhouse effect some 25 times that of CO_2 over a 100-year period and higher values over shorter periods. According to Schuur and Abbott, the small amount of methane is responsible for approximately half of the warming effect from the permafrost emissions.

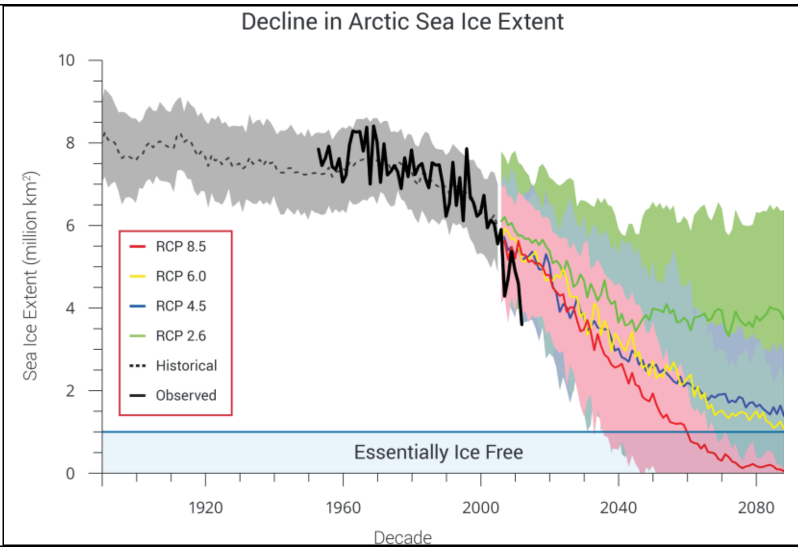
The UVic model does not simulate methanogenesis. That is to say that it does not model the generation of methane—all of the permafrost carbon that goes into the atmosphere in the model is in the form of CO_2. This is a significantly conservative simplification over the time period studied.

Also, their model assumes only purely thermal degradation of the permafrost. Physical erosion, for example at coastlines, is not considered. Their model accounts only for permafrost down to a depth of 3.5 metres and there is

	plenty of carbon stored below those depths that was excluded from their modelling. Finally, this study does not consider any contribution of methane from methane hydrates, either from under permafrost or under ice sheets, nor from fossil methane currently trapped under an impermeable seal of continuous permafrost. http://www.skepticalscience.com/Macdougall.html
3C	AAAS http://whatweknow.aaas.org/wp-content/uploads/2014/07/whatweknow_website.pdf Destabilizing of Sea Floor Methane Frozen methane in the shallow shelves of the Arctic Ocean represents an unlikely but potentially strong feedback loop in a warming climate. Methane is a short-lived but potent greenhouse gas. Although the release of these deposits due to global warming is likely to be slow and mitigated by dissolution into the sea, the deposits are large and vulnerable to warming expected on the higher emission pathway.[76] The release of Arctic methane hydrates into the atmosphere would further increase—perhaps substantially—the rate of global warming.[77]
4.	
5A	The worrying news, no matter how you dice the de-icing permafrost findings "There's so much carbon stored in northern permafrost soils that even if, say, 10 percent of that carbon is released through the processes we studied, it would still have a big impact," Cory said. She calculated that "conservative" scenario would raise atmospheric carbon dioxide levels by 75 to 80 parts per million — over and above the effects of continued fossil fuel burning and other causes. And that, she said, would lead to "a lot of warming." http://www.climatecentral.org/news/good-news-bad-news-on-carbon-from-melting-permafrost-18001

5B	AAAS Permafrost Melt The release of CO_2 and methane from thawing Arctic permafrost represents another critical feedback loop triggered by global warming. The amount of carbon stored in the permafrost is the largest reservoir of readily accessible organic carbon on land.[78] However, the positive feedback warming due to the loss of carbon from frozen soils is generally missing from the major climate change models.[79] Not surprisingly, methane and carbon dioxide emissions from thawing permafrost are thus regarded as a key uncertainty in climate change projections. Disturbingly, there is low confidence in the estimates of expected emissions from thawing permafrost.[80] Although an abrupt release on the timescale of a few decades is judged unlikely, this conclusion is based on immature science and sparse monitoring capabilities.[81] The high end of the best estimate range for the total carbon released from thawed permafrost by 2100 is 250 GtC on the higher pathway. Other individual estimates are far higher.[82] http://whatweknow.aaas.org/wp-content/uploads/2014/07/whatweknow_website.pdf
5C	**Summing-up** Thawing permafrost will release carbon to the atmosphere that will have an appreciable additional effect on climate change, adding at least one quarter of a degree Celsius by the end of the century and perhaps as much as one degree. (In comparison, Swart and Weaver (2012) calculated that combustion of the in-place resources of the Alberta oil sands would increase temperatures by 0.24-0.50°C.) The temperature effect of the coming permafrost feedback is not sensitive to the emission pathway that we choose to follow. The permafrost feedback response to our historic emissions, even in the absence of future human emissions, is likely to be self-sustaining and will cancel out future natural carbon sinks in the oceans and biosphere over the next two centuries. Unfortunately, there are several good reasons to consider the outlook in MacDougall et al. as rosy; as the authors themselves make clear. http://www.skepticalscience.com/Macdougall.html
6A.	**Tundra May Be Shifting Alaska to Put Out More Carbon Than It Stores, Study Says** A new study suggests that Alaska, with its huge stretches of tundra and forest, may be shifting from a net sink, or storehouse, of carbon to a net source. The study focused on one possible cause: warmer temperatures that keep the Arctic tundra from freezing until later in the fall, allowing plant respiration and microbial decomposition — processes that release carbon dioxide — to continue longer . https://www.nytimes.com/2017/05/08/climate/alaska-carbon-dioxide-co2-tundra.html
6B.	**Slow-Freezing Alaska Soil Driving Surge in CO_2 Emissions** Alaska's soils are taking far longer to freeze over as winter approaches than in previous decades, resulting in a surge in carbon dioxide emissions that could portend a much faster rate of global warming than scientists had previously estimated, according to new research. Measurements of carbon dioxide levels taken from aircraft, satellites and on the ground show that the amount of CO_2 emitted from Alaska's frigid northern tundra increased by 70% between 1975 and 2015, in the period between October and December each year. Researchers said warming temperatures and thawing soils were the likely cause of the increase in CO_2 at a time of year when the upper layers of soil usually start freezing over as winter sets in. http://www.climatecentral.org/news/slow-freezing-alaska-soil-co2-emissions-21444

7A

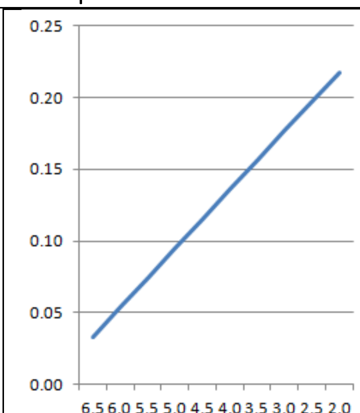


"The annual sea-ice minimum, based on a five-day average, is seen as an important indicator of climate change. Overall, the Arctic has lost 40% of its sea-ice cover since 1980, and 75% of its volume [as of 2013]. Most scientists believe the ocean at the north pole could be entirely ice-free in the summer by the middle of the century [, which is - much sooner than the IPCC estimated] "[5].

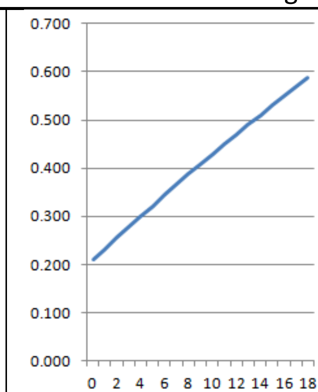
7B

Brian J. Soden and Isaac M. Held ("An Assessment of Climate Feedbacks in Coupled Ocean–Atmosphere Models", 2006; http://journals.ametsoc.org/doi/full/10.1175/JCLI3799.1) estimated that the radiative forcing of the models they reviewed (roughly doubling in equivalent CO_2 between 2000 and 2100) was 4.3 W m^{-2} and, "[o]n average, the strongest positive feedback is due to water vapor (1.8 W m^{-2} K^{-1}), followed by clouds (0.68 W m^{-2} K^{-1}), and surface albedo (0.26 W m^{-2} K^{-1}), thus surface albedo changes (primarily Arctic sea ice and Northern Hemisphere snow cover extent) contribute about 6% of the total radiative forcing at the global tropopause.

8A.



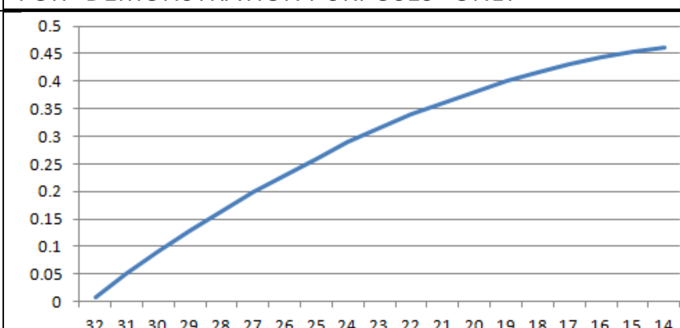
Change in Radiative forcing vs. September Sea Ice Extent



Change in Radiative forcing vs. Number of Ice Free Weeks

FOR "DEMONSTRATION PURPOSES" ONLY

8B.



Change in Radiative forcing vs. Average Snow Cover Extent March 4 - May 26

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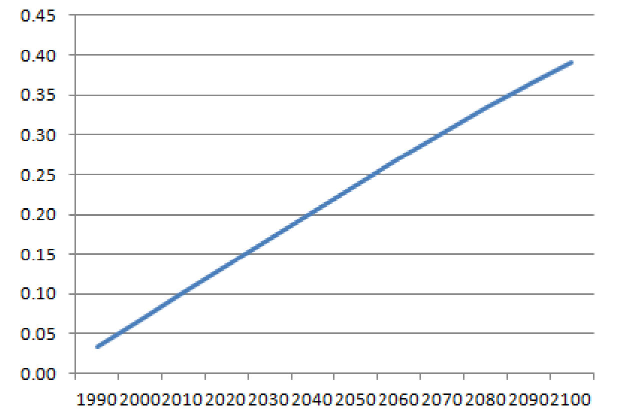
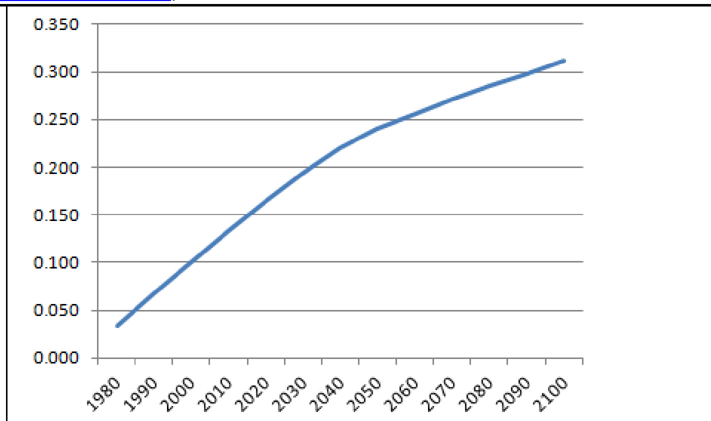
9.

In "Radiative forcing and albedo feedback from the Northern Hemisphere cryosphere between 1979 and 2008", Flanner, et. al., concluded that "cyrospheric cooling declined by 0.45 W m−2 from 1979 to 2008, with nearly equal contributions from changes in land snow cover and sea ice. On the basis of these observations, we conclude that the albedo feedback from the Northern Hemisphere cryosphere falls between 0.3 and 1.1 W m−2 K −1,

	substantially larger than comparable estimates obtained from 18 climate models. " http://data.engin.umich.edu/faculty/flanner/content/ppr/FlS11.pdf)
10	 Change in Radiative Forcing by Year from Arctic Sea Ice Extent FOR "DEMONSTRATION PURPOSES" ONLY  Change in Radiative Forcing by Year from Decrease In Northern Hemisphere Snow Cover Extent FOR "DEMONSTRATION PURPOSES" ONLY
11.	**Global warming may be far worse than thought, cloud analysis suggests** Climate change projections have vastly underestimated the role that clouds play, meaning future warming could be far worse than is currently projected, according to new research. Researchers said that a doubling of carbon dioxide in the Earth's atmosphere compared with pre-industrial times could result in a global temperature increase of up to 5.3C – far warmer than the 4.6C older models predict. https://www.theguardian.com/environment/2016/apr/07/clouds-climate-change-analysis-liquid-ice-global-warming
12.	http://www.killerinourmidst.com/methane and MHs2.html
13A	A 2008 Nature Geoscience study — "High sensitivity of peat decomposition to climate change through water-table feedback" — projected that "a warming of 4°C causes a 40% loss of soil organic carbon from the shallow peat and 86% from the deep peat" of Northern peatlands. On our current emissions path, the world is set to warm well beyond 4°C (7°F). According to the 2008 study, "We conclude that peatlands will quickly respond to the expected warming in this century by losing labile soil organic carbon during dry periods." http://thinkprogress.org/climate/2015/01/13/3610618/peat-wetlands-global-warming/
13B	globalcarbonproject.org/global/pdf/pep/Limpens.2008.Peatlands& Carbon.BiogeosciencesDiscus.pdf
14	The US Forest Service now expects the US forests to shift from their current status of net sequesters of CO_2 to become a significant emissions source in all future scenarios