

## Global Warming Feedbacks

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<http://ccdatacenter.org/documents/GlobalWarmingFeedbacks.pdf>

The significance of the magnitudes of the positive feedbacks from global warming are not widely appreciated. This is most likely because (1) modeling their expected magnitudes through the end of the century is very difficult and likely understates the actual magnitudes<sup>0</sup>; (2) most analyses of the feedbacks look only at what has happened so far; and (3) the feedbacks are usually looked at individually. By doing some simple analyses of four of the primary feedbacks (albedo changes from melting Arctic sea ice and Northern Hemisphere snow cover; and greenhouse gas emissions from permafrost and peat) and estimating their magnitudes through 2100, a startling picture emerges:

1. The warming potential in 2100 from the four feedbacks are roughly equivalent to about ½ of current CO2 emissions
2. By 2100 this will result in a warming potential (99 PPM CO2e), about equivalent to that of all fossil fuel emissions since pre-industrial times, and capable of adding about 0.82° C to the Earth's average temperature.
3. The "CO2 emissions equivalent" of these feedbacks through 2100 is about twice the UNFCCC's carbon budget.

The results of the simple analysis are shown in Table 1.

Feedback	Maximum Potential Radiative Forcing	RF Change Thru 2014	Likely Change 2015 - 2100				Likely Change 1870 - 2100			
			Rad. Forcing	Total Equiv. Emiss	Atmos. CO2e Change (PPM )	Temp Incr.	Rad. Forcing	Total Equiv. Emiss	Atmos. CO2e Change (PPM )	Temp Incr.
Albedo Changes										
Arctic Ocean <sup>1</sup>	0.76	.10	0.29	340	19.6	0.15	0.39	452	26.1	0.20
Retreating snowline <sup>2</sup>	0.69	.14	0.17	240	13.9	0.10	0.31	409	23.6	0.16
Tundra greening <sup>3</sup>										
Land use changes <sup>3</sup>										
Other? <sup>3</sup>										
GHG Emissions	Carbon Store Size	Emiss. Thru 2014								
Permafrost <sup>2a</sup>	6,230–6,780 <sup>4</sup> 3,660 <sup>5</sup>	N/A	0.33	440	25.5*	0.19	.33	440*	25.5	0.19
Peatlands and Peat Bogs <sup>6</sup>	2000 <sup>7,8</sup>	60	.26	360	20.8*	0.16	.30	400*	23.1	0.17
Methane Hydrates <sup>3</sup>	5000 to 36000 <sup>4</sup>									
Reservoirs				60	3.5	0.10	0.05	60	3.5	0.10
Other Soils <sup>3</sup>										
Amazon <sup>3</sup>	315									
Temperate Forests <sup>3</sup>										
Other? <sup>3</sup>										
Total		0.24	1.02	1440	83	0.70	1.38	1761	101.8	0.84*

\* Assumes a 45% airborne fraction

# Temperature increases are not "additive", so the total temperature increase is based on the total radiative forcing

Table 1 – Feedback Estimates - Equivalent CO2 Emissions In GTCO2e; Radiative forcing in W/m<sup>2</sup>; Temperature increase for a climate sensitivity of 3.0°C for a doubling of atmospheric CO2

Notes:

The analysis for the albedo changes are based on data from the National Snow and Ice Data Center (Arctic sea Ice extent) and from the “Snow Lab” at Rutgers University (Northern Hemisphere snow cover extent). The estimate for the permafrost is based on the “mean” estimate for total emissions from permafrost (120 GTC) reported by Kevin Schaefer of the National Snow and Ice Data Center. The estimate for peatlands and peat bogs assumes that the emissions will remain at the current rate (4 GTCO<sub>2</sub>/year) through 2100.

The conversion of radiative forcing (W/m<sup>2</sup>) to the “equivalent CO<sub>2</sub>e PPM” involves an exponential function which uses the radiative forcing ( $e$  raised to the power of the radiative forcing, where  $e$  is about 2.178), so it takes more atmospheric CO<sub>2</sub> to increase the radiative forcing a specific amount as the atmospheric CO<sub>2</sub> increases. For example, the table below shows the radiative forcing and equivalent atmospheric CO<sub>2</sub> PPM from a chart in Nature Climate Change (see <http://ccdatacenter.org/documents/AlbedoCO2TempCalcs.pdf>). Hence adding radiative forcing and the equivalent atmospheric concentration of CO<sub>2</sub> for multiple components is problematic. In the above chart, the combined radiative forcing of the four components is about 1.28 W/m<sup>2</sup>, which, by itself, would be equivalent to 113 PPM (or .82°C). But when the corresponding concentrations of CO<sub>2</sub> increases for the individual components are added together, the result is 99 PPM (or .74°C). For example:

RF	Equivalent Atmospheric CO <sub>2</sub> PPM
2.0	403
2.5	443
3.0	487
3.5	535
4.0	587

The current CO<sub>2</sub> equivalents from the global warming feedbacks are sufficient to add about 0.22° C to the Earth’s average temperature (0.12° C from the snowline retreat, about 0.08° C from Arctic Ocean ice melt, and about 0.02° C from peat bogs).

There are multiple other feedbacks in the Arctic which could lead to much more warming than is calculated above – see “E. Arctic Amplification” below.

Other Relevant Numbers	GTCO <sub>2</sub> e
IPCC Post 2011 Budget for CO <sub>2</sub> (Table 2.2 of <a href="#">IPCC AR5 synthesis report</a> )	1000
IPCC Post 2015 Budget for CO <sub>2</sub> (38 GTCO <sub>2</sub> emissions/year)	850
Atmosphere	2670 <sup>4</sup>
All living vegetation	2380 <sup>4</sup>
2011 CO <sub>2</sub> emissions from fossil fuels	34.6 <sup>10</sup>
Proven and economically recoverable fossil fuel reserves	2800 <sup>9</sup>
Fossil Fuels in the ground	5500-18000 <sup>4</sup>

Table 2 – Other Relevant Numbers

## Footnotes

0	<p><b>Radiative forcing and albedo feedback from the Northern Hemisphere cryosphere between 1979 and 2008</b></p> <p>We find that cyrospheric cooling declined by <math>0.45 \text{ W m}^{-2}</math> 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 <math>1.1 \text{ W m}^{-2} \text{ K}^{-1}</math>, <b>substantially larger than comparable estimates obtained from 18 climate models.</b></p> <p><a href="http://www.nature.com/ngeo/journal/v4/n3/pdf/ngeo1062.pdf">http://www.nature.com/ngeo/journal/v4/n3/pdf/ngeo1062.pdf</a></p>
1	<p>See “A. Arctic Ocean Albedo Change” below            Details: <a href="http://ccdatacenter.org/documents/FeedbackFromArcticSealceMelt.pdf">http://ccdatacenter.org/documents/FeedbackFromArcticSealceMelt.pdf</a>            Data: <a href="http://ccdatacenter.org/documents/FeedbackFromArcticSealceMelt.xlsx">http://ccdatacenter.org/documents/FeedbackFromArcticSealceMelt.xlsx</a></p>
2	<p>See “B. Snowline Retreat” below            Details: <a href="http://ccdatacenter.org/documents/FeedbackNHSnowCover.pdf">http://ccdatacenter.org/documents/FeedbackNHSnowCover.pdf</a>            Data: <a href="http://ccdatacenter.org/documents/FeedbackNHSnowCover.xlsx">http://ccdatacenter.org/documents/FeedbackNHSnowCover.xlsx</a></p>
2a	<p>See “C. Permafrost” below            Details: <a href="http://ccdatacenter.org/documents/FeedbackPermafrost.pdf">http://ccdatacenter.org/documents/FeedbackPermafrost.pdf</a></p>
3	<p>No data available – included for completeness)            Temperate Forests - US forests will change from a sink to a source later this century</p>
4	<p><a href="http://www.nap.edu/read/18373/chapter/4#82">http://www.nap.edu/read/18373/chapter/4#82</a>            Abrupt Impacts of Climate Change: Anticipating Surprises (2013)</p>
5	<p><a href="https://www.washingtonpost.com/news/energy-environment/wp/2015/04/01/the-arctic-climate-threat-that-nobodys-even-talking-about-yet/">https://www.washingtonpost.com/news/energy-environment/wp/2015/04/01/the-arctic-climate-threat-that-nobodys-even-talking-about-yet/</a></p>
6	<p>See “D. Peatlands and Peat Bogs” below</p>
7	<p><a href="http://www.imcg.net/media/download_gallery/climate/couwenberg_2009b.pdf">http://www.imcg.net/media/download_gallery/climate/couwenberg_2009b.pdf</a></p>
8	<p><a href="http://www.wetlands.org/Whatarewetlands/Peatlands/Carbonemissionsfrompeatlands/tabid/2738/Default.aspx">http://www.wetlands.org/Whatarewetlands/Peatlands/Carbonemissionsfrompeatlands/tabid/2738/Default.aspx</a></p>
9	<p><a href="http://www.climatecentral.org/news/ipcc-climate-change-report-contains-grave-carbon-budget-message-16569">http://www.climatecentral.org/news/ipcc-climate-change-report-contains-grave-carbon-budget-message-16569</a></p>
10	<p><a href="http://cdiac.ornl.gov/ftp/ndp030/global.1751_2011.ems">http://cdiac.ornl.gov/ftp/ndp030/global.1751_2011.ems</a> (Global CO2 emissions 1751-2011)</p>

### A. Arctic Ocean Albedo Change

The models used by the IPCC have underestimated the speed with which the summer-time ice in the Arctic Ocean has been melting (See Figure 1), so the resulting temperature forecasts for 2100 and likely low. To get a better idea of what to expect, a simple approach can be used to estimate the albedo change from 2015 to 2100: linearly extrapolate the 1979-2014 weekly sea ice extent to 2100, determine the decrease of sea ice extent for each week from 2015 to 2100, estimate the albedo change for each week, then factor in the cloud cover. For any given week, the albedo change for that week can be approximated by estimating both the average latitude of the southern edge of the sea ice extent on that date and then estimating the average solar radiation for that latitude and date. The results for 2100 are a change in albedo of about 0.0032, which would result in a temperature increase of about 0.20°C. *(Note that an exponential decrease in sea ice is more likely, which would result in a greater temperature increase.)* Based in the linear extrapolation the following time periods would have the indicated radiative forcing changes:

Time Period	Increase in Radiative Forcing (W/m-2)
1990-2011	0.10
1990-2016	0.12
1990-2060	0.27
1990-2100	0.39
1990-3000	0.76
2016-2060	0.15
2016-2100	0.27

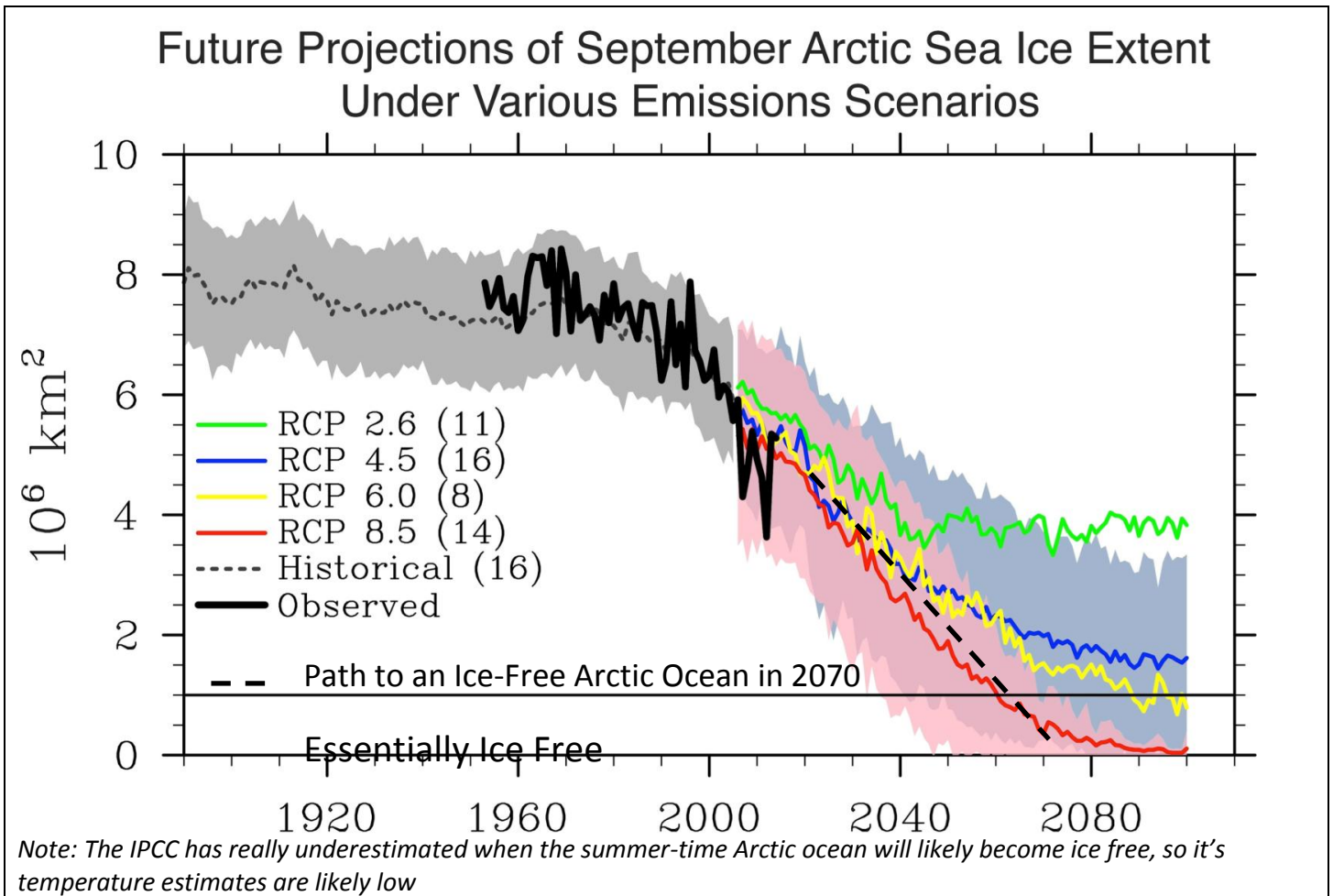


Figure 1 – September Arctic Sea Ice Extent 1953-2012 - with data added for 2013-2015

Details: <http://ccdatacenter.org/documents/ProjectingTheDeclineOfArcticSealce.pdf>

Data: <http://ccdatacenter.org/documents/FeedbackFromArcticSealceMelt.xlsx>

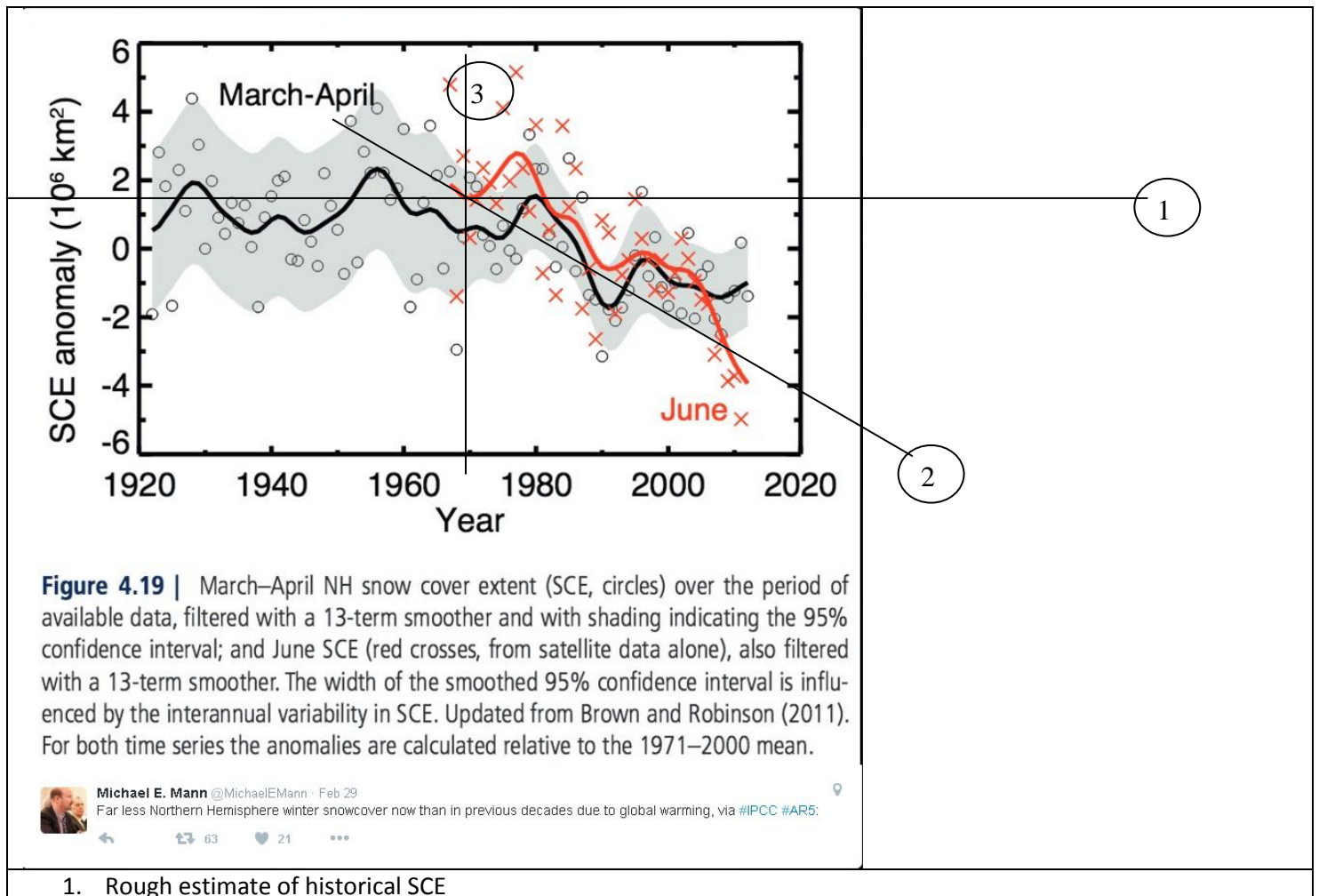
See also: <http://ccdatacenter.org/documents/ReducedArcticSealceExtentBackground.pdf>

## B. Snowline retreat

The Northern Hemisphere snow cover extent has been declining since about 1979 (see Figure 2), and this is decreasing the springtime albedo of the Arctic region. A “back-of-the-envelope” calculation was done to estimate the magnitude of the both the current albedo change (about -0.0014) and the expected change by the year 2100 (about -0.003).

Assuming a 70% cloud cover and a climate sensitivity of 3.1, the current albedo change will eventually add about 0.09° C to the Earth’s average temperature, and the albedo change by 2100 will increase the Earth’s temperature by about 0.18° C.

Time Period	Change in Radiative Forcing (W/m <sup>2</sup> )	Equivalent Emissions (GTCO <sub>2</sub> e)	Atmospheric CO <sub>2</sub> e Change (PPM )	Temperature Increase for a Climate Sensitivity of 3.0
1870-2100	0.31	409	23.6	0.18
2011-2100	0.18	240	13.9	0.10
2015-2100	0.16	220	12.7	0.10
1870-3000	0.69	946	54.6	0.41



2. Rough estimate of SCE decline
3. Rough estimate of when the SCE decline started (also indicates that 1970 is a reasonable “historical” year)

Figure 2 – Changes in the snow cover extent since 1920<sup>4</sup>

Details: <http://ccdatacenter.org/documents/FeedbackNHSnowCover.pdf>

Data: <http://ccdatacenter.org/documents/FeedbackNHSnowCover.xlsx>

### C. Permafrost Thawing

The permafrost alone contains almost twice as much carbon as that atmosphere, so even if only a small percentage (even a few tenths of one percent) of the carbon is released each year the quantities could dwarf the anthropogenic emission reduction efforts.

Carbon released from permafrost soils will likely have a very significant impact on future temperatures (perhaps 0.13 to 0.3 degrees C by 2100, and certainly more by 2200). “It [(permafrost melt)] was first proposed in 2005. And the first estimates came out in 2011.” Indeed, the problem is so new that it has not yet made its way into major climate projections, Schaefer says.” ...”None of the climate projections in the last IPCC report account for permafrost,” says Schaefer. “So all of them underestimate, or are biased low.” ... “It’s certainly not much of a stretch of the imagination to think that over the coming decades, we could lose a couple of gigatons per year from thawing permafrost,” says Holmes.... But by 2100, the “mean” estimate for total emissions from permafrost right now is 120 gigatons, say Schaefer. <http://www.washingtonpost.com/news/energy-environment/wp/2015/04/01/the-arctic-climate-threat-that-nobodys-even-talking-about-yet>

Time Period	Change in Radiative Forcing (W/m <sup>2</sup> )	Equivalent Emissions (GTCO <sub>2</sub> e)	Atmospheric CO <sub>2</sub> e Change (PPM )	Temperature Increase for a Climate Sensitivity of 3.0
1870-2100	.33	440	25.5	0.19
2011-2100	.33	440	25.5	0.19
2015-2100	.33	440	25.5	0.19
1870-3000	0.69	6100	54.6	0.41

(Although there are current greenhouse gas emissions from permafrost thawing, no source could be found which estimated the current annual or historical amounts)

Details: <http://ccdatacenter.org/documents/FeedbackFromPermafrost.pdf>

**Some suggest** the arctic tundra could go from being a carbon sink to a carbon source by the mid-2020s.

Researchers at the National Snow and Ice Data Center **estimate** that by 2200, 60% of the Northern Hemisphere's permafrost will probably be melted, which could release around 190 billion tons of carbon into the atmosphere. This amount is about half of all the carbon released in the industrial age. The affect this will have on the rate of atmospheric warming could be irreversible. At the very least, these estimates mean fossil fuel emissions will have to be reduced more than currently suggested to account for the amount of carbon expected to discharge from melting permafrost.

[https://www.wunderground.com/resources/climate/melting\\_permafrost.asp](https://www.wunderground.com/resources/climate/melting_permafrost.asp)

A 2017 study estimated that if global temperatures rise 1.5°C above 1861 levels, thawing permafrost could release 68 to 508 gigatons of carbon. Without factoring in human activity, this carbon alone would increase global temperatures 0.13 to 1.69°C by 2300. Since we may have already locked in 1.5°C of warming above pre-industrial levels, this amount of additional warming could result in catastrophic impacts of **climate change**.

Many scientists are concerned that thawing permafrost could be a tipping point that triggers an irreversible

cycle: When permafrost releases its carbon as CO<sub>2</sub> or methane, it will accelerate warming, which will then precipitate more permafrost thaw, and so on. There will be nothing humans can do to stop it.

Read more at: <https://phys.org/news/2018-01-permafrost.html#jCp>

#### D. Peatlands and Peat Bogs

Since I could not find any estimates for future emissions from peatlands and peat bogs, I assumed that the current annual emissions of about 4GTCO<sub>2</sub>e would continue until 2100. To see if this is in the right “ballpark”, if carbon from 40% of shallow peat and 86% of deep bogs will be emitted over several centuries, perhaps 70% of the carbon will be emitted over four centuries, which would be about 3.6 GTCO<sub>2</sub>e/year.

“Our modeling suggests that higher temperatures could cause water tables to drop substantially, causing more peat to dry and decompose,” says Paul R. Moorcroft, professor of organismic and evolutionary biology in Harvard’s Faculty of Arts and Sciences. “Over several centuries, some 40 percent of carbon could be lost from shallow peat bogs, while the losses could total as much as 86 percent in deep bogs.”

Typically found at northerly latitudes, peat bogs are swampy areas whose cold, wet environment preserves organic matter, preventing it from decaying. This new work shows how peat bogs’ stability could be upset by the warming of the Earth, which has disproportionately affected the higher latitudes where the bogs are generally found.

Each square meter of a peat bog contains anywhere from a few to many hundreds of kilograms of undecomposed organic matter, for a total of 200 billion to 450 billion metric tons of carbon sequestered in peat bogs worldwide. This figure is equivalent to up to 65 years’ worth of the world’s current carbon emissions from fossil-fuel burning.

<http://news.harvard.edu/gazette/story/2008/11/global-warming-predicted-to-hasten-carbon-release-from-peat-bogs/>

#### Peatlands are a major storage of carbon in the world. They account for 550 Gt carbon worldwide.

Peat fires, such as those take place in Southeast Asia every year and also in Russia, release huge amounts of CO<sub>2</sub> as well. Altogether global CO<sub>2</sub> emissions amount to at least 2,000 million tonnes annually, equivalent to 5% of the global fossil fuel emissions.

<http://www.wetlands.org/Whatarewetlands/Peatlands/Carbonemissionsfrompeatlands/tabid/2738/Default.aspx>

Drainage of peat soils results in carbon dioxide (CO<sub>2</sub>) and nitrous oxide (N<sub>2</sub>O) emissions of globally 2-3 Gt CO<sub>2</sub>-eq per year (Joosten & Couwenberg 2009)

[http://www.wetlands.org/Portals/0/publications/Report/web\\_Methane\\_emissions\\_from\\_peat\\_soils.pdf](http://www.wetlands.org/Portals/0/publications/Report/web_Methane_emissions_from_peat_soils.pdf)

Peatlands are also expected to be impacted by global climate change. Peat is made up of dead organic material, and so is very rich in carbon. It consists of 90% water and 10% plant matter, and is mostly found at the high latitudes of the northern hemisphere, both at the surface and below. Some of this peat is found underneath the permafrost layer, which means the carbon it harbors could be in jeopardy should the permafrost melt. In a study of the world's peatlands, [one recent study](#) found that if the globe warms 1°C over the next few decades, this could lead to a release of 38-100 million tons of carbon per year from peat alone.

[https://www.wunderground.com/resources/climate/melting\\_permafrost.asp](https://www.wunderground.com/resources/climate/melting_permafrost.asp)

## E. Reservoirs

Methane emissions from reservoirs contribute about .7GTC of CO2 equivalent per year, resulting in about 30 GTC through 2060 and 60 GTC through 2100.

<http://www.climatecentral.org/news/greenhouse-gases-reservoirs-fuel-climate-change-20745>

" Globally, reservoirs are responsible for about 1.3 percent of the world's man-made greenhouse gas emissions each year"