

## What quantity of CO2 emission-equivalents can be expected from natural feedbacks this century?

Bruce Parker (bruceparker@alum.mit.edu)

October 14, 2024

### Likely GHG emissions from natural sources

A view of recent web pages, journal articles, and news articles indicates that the emission-equivalents from natural resources could be significantly higher than the IPCC models expected (see Table 1 and Appendix A), which could result in a much smaller (or even negative) carbon budget. Because of the possible implications of these estimates, it would be very helpful to have “experts”:

- Review the feedbacks listed in the table for “completeness” (any left out? Any that should not be included? Any double-counted?)
- Update the values with the likely CO2e through 2100 (GTCO2e) included by the climate models for the various temperature increase targets in 2100.

	Feedback	Likely CO2e through 2100 (GTCO2e)	CO2e Through 2100 Included in Climate Models For Various Temperature Increase Targets in 2100 (GTCO2e)			
			1.5	2.0	2.5	3.0
A	Permafrost (CO2 and CH4)	200	225			
B	Subsea Permafrost (CH4)	150	0			
C	Amazon Rainforest Dieback (CO2)	100	0			
D	Arctic sea ice (Albedo)	320	150			
E	Northern hemisphere snow cover extent (Albedo)	200	95			
F	Peatlands (CH4)	100	61			
G	Wildfires (CO2)	200	73			
H	Surface Waters and Waste (CH4)	150				
I	Soils (extra due to higher temperatures) (CO2)	200				
J	Oceanic changes that reduce CO2 uptake (CO2)	???				
K	Antarctic sea ice (Albedo)	???				
L	Land use changes (CO2)	???				
M	Other forest dieback (CO2)	???				
N	Insect outbreaks (CO2)	???				
O	Desertification (CO2)	???				
P	Deforestation (Albedo)	???				
Q	Deforestation (CO2 and CH4)	???				
R	Other natural feedbacks (CO2 and CH4)	???				
	<b>Sub Total For CO2 and CH4</b>	<b>1100</b>	<b>337</b>			
	<b>Total</b>	<b>1650</b>	<b>582</b>			

Table 1. Likely CO2e through 2100 (GTCO2e) For Various Temperature Increases in 2100

## Appendix A – Emissions from Feedbacks

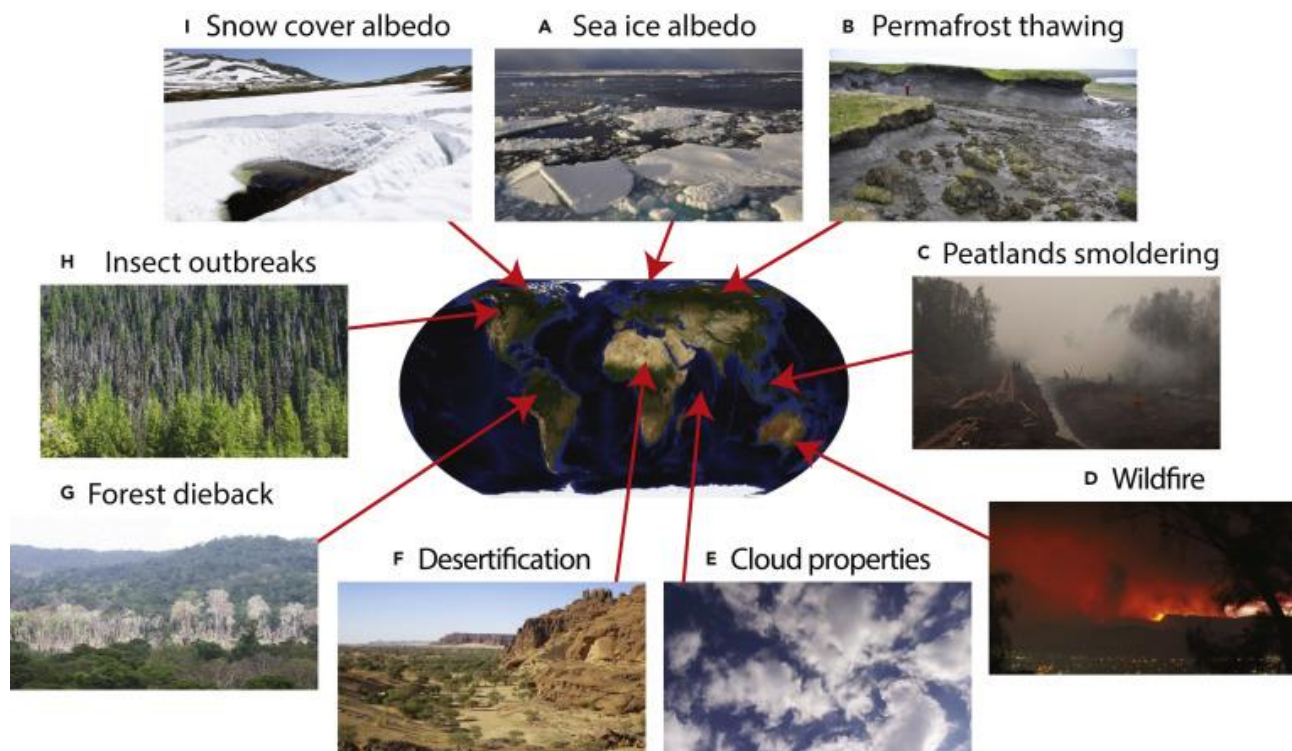
Note: ChatGPT was used to both provide background information and emission estimates for some of the feedbacks. It was assumed that an “expert” would replace these estimates with more appropriate values.

### Background – Feedback Loops and Tipping Points

#### Many risky feedback loops amplify the need for climate action

Many feedback loops significantly increase warming due to greenhouse gas emissions. However, not all of these feedbacks are fully accounted for in climate models. Thus, associated mitigation pathways could fail to sufficiently limit temperatures. A targeted expansion of research and an accelerated reduction of emissions are needed to minimize risks.

As we increasingly understand climate change as a series of disasters in the short term and a major threat in the longer term, many governmental jurisdictions and world scientists have declared a climate emergency.<sup>1</sup> In addition, nearly all countries have signed on to the Paris Accord, which calls for limiting warming to 2°C, and ideally 1.5°C. One of the main factors making climate change especially dangerous is the risk of amplifying climatic feedback loops. An amplifying, or positive, feedback on global warming is a process whereby an initial change that causes warming brings about another change that results in even more warming (Figure 1). Thus, it amplifies the effects of climate forcings—outside influences on the climate system such as changes in greenhouse gas concentrations. In part because of positive climate feedbacks, a very rapid drawdown in emissions will be required to limit future warming.



[https://www.cell.com/one-earth/fulltext/S2590-3322\(23\)00004-0](https://www.cell.com/one-earth/fulltext/S2590-3322(23)00004-0)

Airborne Fraction	Starting PPM		Since the airborne fraction is apt to rise this century, a good “planning” number for the expected emissions from natural feedbacks appears to be about 225 GTCO <sub>2</sub> per degree C of temperature increase (or 136 GTCO <sub>2</sub> /0.1 W/m <sup>-2</sup> )
	420	450	
45	230	246	
50	207	222	
	CO <sub>2</sub> Emissions for 0.166 W/m <sup>-2</sup>		

**The tipping points of climate change — and where we stand** Johan Rockström TED Video Aug 2024

<https://www.stockholmresilience.org/research/research-videos/2024-08-19-the-tipping-points-of-climate-change---and-where-we-stand.html>

**Arctic Sea Ice minimum 2024. Three degrees Celsius warming now baked in!**

[Just Have a Think](#)

Sep 15, 2024

Arctic Sea ice reaches its minimum extent each year around the middle of September. This year is one of the lowest in recorded history. Ocean temperatures have been so 'off the charts' in 2023 and 2024 that scientists fear those waters have reached their capacity to mop up after us humans and are now starting to release that energy. On our current trajectory, by 2100, our planet will reach a temperature not seen for 3 MILLION years!. So...what's the plan???

[https://www.youtube.com/watch?v=tO\\_ZHg5OCAg](https://www.youtube.com/watch?v=tO_ZHg5OCAg)

**4 hottest days ever observed raise fears of a planet nearing 'tipping points'**

Some of the major points:

\*\*\*\*\*

By the end of the week — which saw the four hottest days ever observed by scientists — dozens had been killed in the raging floodwaters and massive mudslides triggered by Typhoon Gaemi. Half of Jasper was reduced to ash.

These extraordinary global temperatures marked the culmination of an unprecedented global hot streak that has stunned even researchers who spent their whole careers studying climate change.

Since last July, Earth’s average temperature has consistently exceeded 1.5 degrees Celsius (2.7 degrees Fahrenheit) above preindustrial levels — a short-term breach of a threshold that scientists say cannot be crossed if the world hopes to avoid the worst consequences of planetary warming.

This “taste” of a 1.5 degree world showed how the natural systems that humans depend on could buckle amid soaring temperatures, said Johan Rockström, director of the Potsdam Institute for Climate Impact Research in Germany. Forests showed less ability to pull carbon out of the atmosphere. Sea ice around Antarctica dwindled to near record lows. Coral bleaching became so extreme scientists had to change their scale for measuring it.

Even as scientists forecast an end to the current record-breaking stretch, they warn it may prove difficult for parts of the planet to recover from the heat of the past year.

“The extreme events that we are now experiencing are indications of the weakening resilience of these systems,” Rockström said. “We cannot risk pushing this any further.”

What the world is seeing now, Rockström said, is a “worrying sign of potentially approaching tipping points.”

Robert Rohde, chief scientist for the climate data nonprofit Berkeley Earth, called these extreme events “suggestive” of what will happen to the planet if global temperatures consistently exceed 1.5 degrees Celsius of warming — something that researchers project will occur in the early 2030s.

Studies indicate that crossing that threshold could trigger irreversible changes in major Earth systems: the collapse of the Greenland ice sheet, complete loss of tropical coral reefs, abrupt thawing of some permafrost.

<https://www.washingtonpost.com/climate-environment/2024/07/27/hottest-days-ever-recorded-climate-change/>

[How 16 Tipping Points Could Push Our Entire Planet Into Crisis | World Economic Forum \(weforum.org\)](#)

**How 16 Tipping Points Could Push Our Entire Planet Into Crisis**

Posted January 24, 2023

In a presentation at Davos 2023, Professor Johan Rockström, Director of the Potsdam Institute for Climate Impact Research, talks about the 16 tipping points, the large biophysical systems that we have scientific evidence that regulates the state of the entire climate system on Earth.

Nine of these 16 tipping points are showing signs of instability; push them too far, and they will shift over from supporting humanity to starting to undermining humanity. Four of these are showing scientific evidence of now being at risk already at 1.5°C. We're approaching this point very rapidly. Two of them, the Greenland ice sheet and the West Antarctic ice sheet together, represent 10 meters of sea level rise.

Watch the full video to learn more about what Professor Johan Rockström shared about the tipping points in this session during the World Economic Forum's Annual Meeting 2023.

---

### **Tipping Elements - big risks in the Earth System**

Climate tipping elements are critical, large-scale components of the Earth system, which are characterized by a threshold behaviour. These systems appear to remain stable with increasing global temperature, but starting at a particular global temperature threshold, very small additional disturbances can 'tip' them into a qualitatively new state. If you imagine a pencil being slowly pushed further over a table edge. At first nothing happens; then it falls.

<https://www.pik-potsdam.de/en/output/infodesk/tipping-elements>

---

### **Risk of passing multiple climate tipping points escalates above 1.5°C global warming**

09/09/2022 - Multiple climate tipping points could be triggered if global temperature rises beyond 1.5°C above pre-industrial levels, according to a major new analysis published in the journal Science. Even at current levels of global heating the world is already at risk of passing five dangerous climate tipping points, and risks increase with each tenth of a degree of further warming. An international research team synthesised evidence for tipping points, their temperature thresholds, timescales, and impacts from a comprehensive review of over 200 papers published since 2008, when climate tipping points were first rigorously defined.

<https://www.pik-potsdam.de/en/news/latest-news/risk-of-passing-multiple-climate-tipping-points-escalates-above-1-5degc-global-warming>

A1	<b>Permafrost Emissions</b>			
	Today, at about 1.2°C, we are already committed to losing about 25% of surface permafrost, which would result in about 250 GtCO <sub>2</sub> .			
	Scenario	Temperature peak	Cumulative Gt CO <sub>2</sub> -eq (including CO <sub>2</sub> and CH <sub>4</sub> ) by 2100	Impacts
	Low emissions	1.6- 1.8°C...and declining Peak reached between 2060-2080	150-200	Once permafrost thaw is initiated, including by extreme summer heat events, the resulting emissions continue for centuries. As a result, permafrost emissions will continue even if temperatures slowly decline. Future generations will need to deploy and continue CO <sub>2</sub> removal strategies equal to these long-term emissions until they cease, simply to hold temperatures steady.
	Optimistic fulfillment of all current pledges	1.9°C Peak reached between 2120-40	220-300	These emissions will continue for one-two centuries after peak temperature is reached. Future generations will need to deploy and continue carbon dioxide removal strategies equal to these long-term emissions until they cease, simply to hold temperatures steady. Permafrost soils will disappear in extensive regions above the Arctic Circle, as well as below, and nearly all existing infrastructure built on permafrost soils will require replacement.
	Current implemented NDCs	3.1°C Peak reached between 2150-70	350-400	These emissions will continue for one-two centuries after peak temperature is reached. Future generations will need to deploy and continue carbon dioxide removal strategies equal to these long-term emissions until they cease well past 2300, simply to hold temperatures steady. Over 70% of original pre-industrial surface permafrost globally will have disappeared by the time of this peak. Extensive erosion, due to permafrost thaw, sea ice-free conditions and more violent storms will require extensive replacement of coastal and riverside Arctic infrastructure, especially in Russia and Canada.
Current emissions growth	4-5°C ...and rising Peak reached well after 2200	400-500+	These emissions will continue for one-two centuries after peak temperature is reached. Future generations will need to deploy and continue carbon dioxide removal strategies equal to these long-term emissions until they cease well past 2400, simply to hold temperatures steady. Surface permafrost soils will largely disappear globally. Infrastructure damage, especially in Siberia and Alaska, will be extreme. Emissions from permafrost thaw are essentially permanent on human timescales, because the long-term drawdown of carbon to re-build new permafrost	

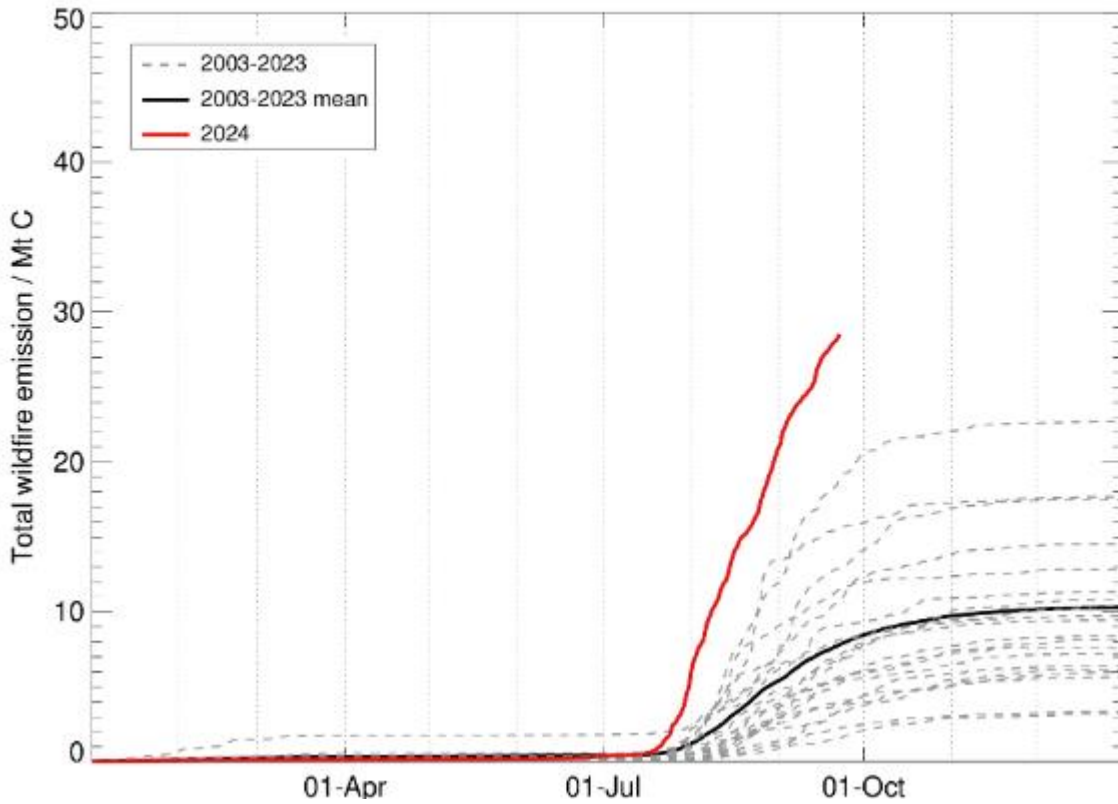
				soils takes thousands of years.
	<a href="https://unfccc.int/sites/default/files/resource/Permafrost%20v3.pdf">https://unfccc.int/sites/default/files/resource/Permafrost%20v3.pdf</a>			
A2	<p><b>Permafrost</b> How much carbon is contained in the surface permafrost</p> <p>ChatGPT said:</p> <p>The carbon stored in surface permafrost is substantial and represents a significant potential source of greenhouse gases if it thaws. Estimates suggest that permafrost, primarily in the Arctic and subarctic regions, contains around <b>1,500 billion tons (1,500 gigatons, or Gt)</b> of carbon. This carbon is trapped in the form of organic matter that has been frozen for thousands of years.</p> <p>Here is a more detailed breakdown:</p> <ol style="list-style-type: none"> <li>1. <b>Surface Permafrost:</b> The top few meters of permafrost (about 0-3 meters deep) hold a significant portion of this carbon. Estimates indicate that the top 3 meters of permafrost contain roughly <b>800-1,000 Gt of carbon</b>.</li> <li>2. <b>Deeper Permafrost:</b> Carbon is also stored at greater depths, up to tens of meters below the surface. Deeper permafrost layers contain additional carbon, bringing the total estimate for all permafrost carbon to around 1,500 Gt.</li> </ol> <p>For comparison, the amount of carbon currently in the atmosphere is around <b>880 Gt</b> (as of 2024). This means that if even a small fraction of the carbon stored in permafrost were to be released as CO<sub>2</sub> or methane (a potent greenhouse gas), it could significantly amplify global warming.</p> <p>The potential release of this permafrost carbon is a major concern for climate scientists, as thawing permafrost due to global warming could create a feedback loop, further accelerating climate change.</p>			
A3	<p><b>Expected Permafrost Emissions for 1.5°</b></p> <p>Climate feedback factor = 0.1 W/m-1 per degree C (=0.0870 + 0.013) =130 GTCO<sub>2</sub>e  <a href="https://doi.org/10.1017/9781009157896.007">https://doi.org/10.1017/9781009157896.007</a></p>			
B1	<p><b>Subsea Permafrost Emissions</b> Some permafrost is actually located beneath the coastal waters of the Arctic Ocean, on lands flooded at the end of the last Ice Age when sea levels rose. Its current and future contribution to carbon emissions remains uncertain, but could be significant. Recent estimates range from an additional 150–250 Gt CO<sub>2</sub> equivalent by 2100, especially with additional Arctic Ocean warming.  <a href="https://unfccc.int/sites/default/files/resource/Permafrost%20v3.pdf">https://unfccc.int/sites/default/files/resource/Permafrost%20v3.pdf</a></p>			
B2	<p><b>Methane Emissions From Seabed to Atmosphere in Polar Oceans Revealed by Direct Methane Flux Measurements</b> 26 July 2024</p> <p>Coastal regions of the Arctic Ocean and Southern Ocean are found to be sources of atmospheric methane</p> <p>The ocean releases elevated quantities of methane where seabed methane seeps have been observed in both the Arctic and Southern Oceans</p> <p>This study suggests a possible rise in methane release from oceanic areas with seabed seeps over last decades compared with a prior study</p> <p>As climate change drives increasing water temperatures, there is a potential for increased methane release from the seabed into the atmosphere, therefore on-going observations of methane release from polar oceans are necessary.</p>			

	<a href="https://doi.org/10.1029/2023JD040632">https://doi.org/10.1029/2023JD040632</a>
C1	<p><b>Amazon</b></p> <p>The Yale School of Forestry and Environmental Studies determined that all tropical forests combined contain about 25 percent of the world’s carbon, with the Amazon basin storing up to 140 billion tons (127 billion metric tons).</p> <p><a href="https://www.rainforesttrust.org/our-impact/rainforest-news/climate-change-series-part-1-rainforests-absorb-store-large-quantities-of-carbon-dioxide">https://www.rainforesttrust.org/our-impact/rainforest-news/climate-change-series-part-1-rainforests-absorb-store-large-quantities-of-carbon-dioxide</a></p>
C2	<p><b>‘Unprecedented’ stress in up to half of the Amazon may lead to tipping point by 2050 February 2024</b></p> <p>The Amazon rainforest is facing significant stress due to climate change, deforestation, and extreme weather events, potentially pushing it towards a tipping point where large areas could transition into a dry, savannah-like ecosystem by 2050. Researchers indicate that up to half of the Amazon might be exposed to compounding stressors, such as reduced rainfall and increased dry season length. If this tipping point is crossed, the shift could result in the collapse of the rainforest ecosystem and its replacement with a savannah-like environment</p> <p><a href="https://www.carbonbrief.org/unprecedented-stress-in-up-to-half-of-the-amazon-may-lead-to-tipping-point-by-2050/">https://www.carbonbrief.org/unprecedented-stress-in-up-to-half-of-the-amazon-may-lead-to-tipping-point-by-2050/</a></p> <p>A reasonable estimate of the contribution from Amazon deforestation in 2100 might be 100 GTCO2.</p>

C3

South America sees historic emissions during 2024 wildfire season September 2024

### Cumulative Total Wildfire Carbon Emissions (CAM5 GFASv1.2) Amazonas



<https://atmosphere.copernicus.eu/south-america-sees-historic-emissions-during-2024-wildfire-season>

D1

#### Arctic sea ice

Arctic sea ice plays a crucial role in regulating global climate by reflecting sunlight due to its high albedo, helping to keep the planet cooler. However, global warming has led to a significant decline in Arctic sea ice extent. As the ice melts, darker ocean water is exposed, which absorbs more solar radiation, leading to further warming in a process known as the ice-albedo feedback loop

(<https://e360.yale.edu/features/as-arctic-ocean-ice-disappears-global-climate-impacts-intensify-wadhams>)

D2

#### Arctic Sea Ice

- The findings, published in the journal [Nature Reviews Earth & Environment](#), suggest the first ice-free day in the Arctic could occur more than 10 years earlier than previous projections.
- The authors said consistently ice-free Septembers could be expected by 2035 to 2067. The exact year within that period is dependent on how quickly the world reduces the amount of fossil fuels burned.
- By the end of the century, there is potential for ice-free conditions between May and January under a high-emission scenario, and August to October under a low-emission scenario.

D3

#### Arctic Ice Cover, Ice Thickness and Tipping Points

Published: 19 January 2012

If the Arctic were ice-free for one month a year plus associated ice-extent decreases in other months then, without taking cloud changes into account, the global impact would be about 0.2°C of warming. If there were



	<p>no ice at all during the months of sunlight, the impact would close to 0.5°C of global warming.  <a href="https://link.springer.com/article/10.1007/s13280-011-0222-9">https://link.springer.com/article/10.1007/s13280-011-0222-9</a>  0.2°C of warming is equivalent to about 300 GTCO<sub>2</sub> (GTCO<sub>2</sub> budget for 1.5°C - &gt; GTCO<sub>2</sub> budget for 1.7°C))  RF from four weeks ice-free = 2/5 RF of totally ice-free = 0.28 (=0.71*2/5)</p>
D4	<p><b>Arctic sea ice and snow cover albedo variability and trends during the last three decades</b> June 2021</p> <p>Averaged over the globe, the annual mean radiative forcing at TOA associated with this total albedo decrease can be estimated as <math>0.37 \pm 0.13</math> W/m<sup>2</sup>, that is equivalent to 44% of the warming effect of anthropogenic CO<sub>2</sub> emissions during the same period (1982–2015) with separate contributions of 17% and 27% for snow cover and sea ice respectively. The same authors also estimated the amount of solar energy that would be added in the worst-case scenario of a complete disappearance of Arctic sea ice throughout the sunlit period of the year, obtaining a global radiative heating of 0.71 W/m<sup>2</sup> relative to the 1979 baseline state that is closely equivalent to the effect of one trillion tons of CO<sub>2</sub> emissions. However, these impressive estimates did not take into account the additional effect of snowline retreat on land, although this had already been well assessed.</p> <p><a href="https://www.sciencedirect.com/science/article/pii/S1873965220301390">https://www.sciencedirect.com/science/article/pii/S1873965220301390</a></p> <p>Since “consistently ice-free Septembers could be expected by 2035 to 2067” (see above) and “a complete disappearance of Arctic sea ice throughout the sunlit period of the year, obtaining a global radiative heating of 0.71 W/m<sup>2</sup> relative to the 1979 baseline state that is closely equivalent to the effect of one trillion tons of CO<sub>2</sub> emissions”, a reasonable estimate of the “CO<sub>2</sub>e equivalent” contribution from reduced Arctic sea ice in 2100 might be 300 GTCO<sub>2</sub>.</p>
D5	<p><b>Radiative Heating of an Ice-Free Arctic Ocean</b> June 2019</p> <p>Here we use satellite observations to estimate the amount of solar energy that would be added in the worst-case scenario of a complete disappearance of Arctic sea ice throughout the sunlit part of the year. Assuming constant cloudiness, we calculate a global radiative heating of 0.71 W/m<sup>2</sup> relative to the 1979 baseline state. This is equivalent to the effect of one trillion tons of CO<sub>2</sub> emissions. These results suggest that the additional heating due to complete Arctic sea ice loss would hasten global warming by an estimated 25 years.</p> <p><a href="https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL082914">https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL082914</a></p>
D6	<p><b>Arctic Sea Ice Chat GPT</b></p> <p>The IPCC climate models, as presented in the 2021 report Climate Change 2021: The Physical Science Basis, project that the Arctic could become ice-free in summer by the middle of the 21st century under various emissions scenarios. Specifically:</p> <p>High-emission scenario (SSP5-8.5): This pathway suggests that an ice-free Arctic is almost certain by 2050. Under this scenario, the Arctic could experience ice-free summers as early as the 2030s. If greenhouse gas emissions continue unabated, sea ice loss will accelerate, with ice-free conditions occurring nearly every summer.</p> <p>Intermediate scenarios (SSP2-4.5): Even with moderate reductions in emissions, the Arctic is still likely to experience ice-free summers by the second half of the century, potentially between 2050 and 2080.</p> <p>Low-emission scenario (SSP1-2.6): In this case, significant reductions in emissions slow the pace of ice loss, and the Arctic may retain some summer ice throughout the century. However, ice-free events remain possible later in the century.</p>

	<p>These projections are based on CMIP6 models, which simulate various possible future outcomes based on different levels of greenhouse gas concentrations. The loss of Arctic sea ice has significant global consequences, including enhanced Arctic warming (the albedo effect), disruptions to weather patterns, and feedback loops that further accelerate climate change</p>
D7	<p><b>Earth's Sea Ice Radiative Effect From 1980 to 2023</b> 17 July 2024</p> <p>Disappearing sea ice is therefore amplifying climate change by causing Earth to absorb roughly an additional 0.3 W m<sup>-2</sup> of solar power for each degree Celsius of global warming, a feedback that is stronger than that simulated by most climate models.</p> <p>The Arctic sea ice radiative effect has weakened at 0.04–0.05 W m<sup>-2</sup>decade<sup>-1</sup>, or by about 24%, since 1980</p> <p>The planetary cooling effect of global sea ice was about 0.25 W m<sup>-2</sup> (14%) weaker during 2016–2023 than during 1980–1988</p> <p>We estimate that the global sea ice albedo feedback was 0.24–0.38 W m<sup>-2</sup> K<sup>-1</sup> during 1980–2023.</p> <p><a href="https://doi.org/10.1029/2024GL109608">https://doi.org/10.1029/2024GL109608</a></p>
D8	<p><b>Mitigation implications of an ice-free summer in the Arctic Ocean</b></p> <p><a href="https://www.researchgate.net/publication/312514943_Mitigation_implications_of_an_ice-free_summer_in_the_Arctic_Ocean">https://www.researchgate.net/publication/312514943_Mitigation_implications_of_an_ice-free_summer_in_the_Arctic_Ocean</a></p>
D9	<p><b>Observationally-constrained projections of an ice-free Arctic even under a low emission scenario</b> June 2023</p> <p>The sixth assessment report of the IPCC assessed that the Arctic is projected to be on average practically ice-free in September near mid-century under intermediate and high greenhouse gas emissions scenarios, though not under low emissions scenarios, based on simulations from the latest generation Coupled Model Intercomparison Project Phase 6 (CMIP6) models. Here we show, using an attribution analysis approach, that a dominant influence of greenhouse gas increases on Arctic sea ice area is detectable in three observational datasets in all months of the year, but is on average underestimated by CMIP6 models. By scaling models' sea ice response to greenhouse gases to best match the observed trend in an approach validated in an imperfect model test, we project an ice-free Arctic in September under all scenarios considered. These results emphasize the profound impacts of greenhouse gas emissions on the Arctic, and demonstrate the importance of planning for and adapting to a seasonally ice-free Arctic in the near future.</p> <p><a href="https://www.nature.com/articles/s41467-023-38511-8">https://www.nature.com/articles/s41467-023-38511-8</a></p>
DA	<p><b>Google:</b></p> <p>The Arctic is projected to experience a continued decline in sea ice over the 21st century, with some climate models suggesting it could be essentially ice-free as early as 2030. Here are some projections for the decline of Arctic sea ice:</p> <p>Before 2050</p> <p>The Arctic Ocean is projected to become ice-free in September for the first time before 2050, regardless of emission scenarios.</p>

2081–2100

The Arctic Ocean is likely to become practically ice-free in September averaged over 2081–2100 under certain scenarios.

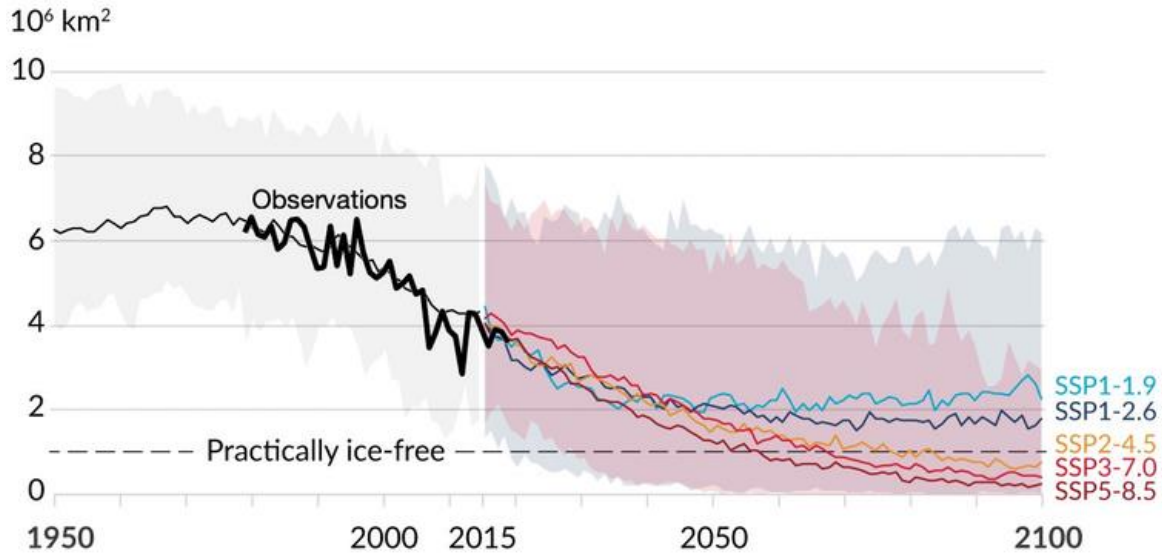
2100

Arctic sea ice is likely to melt away completely in September by the year 2100, even under a low-emission scenario.

Polar Science Center » Projections of an Ice-Diminished ...

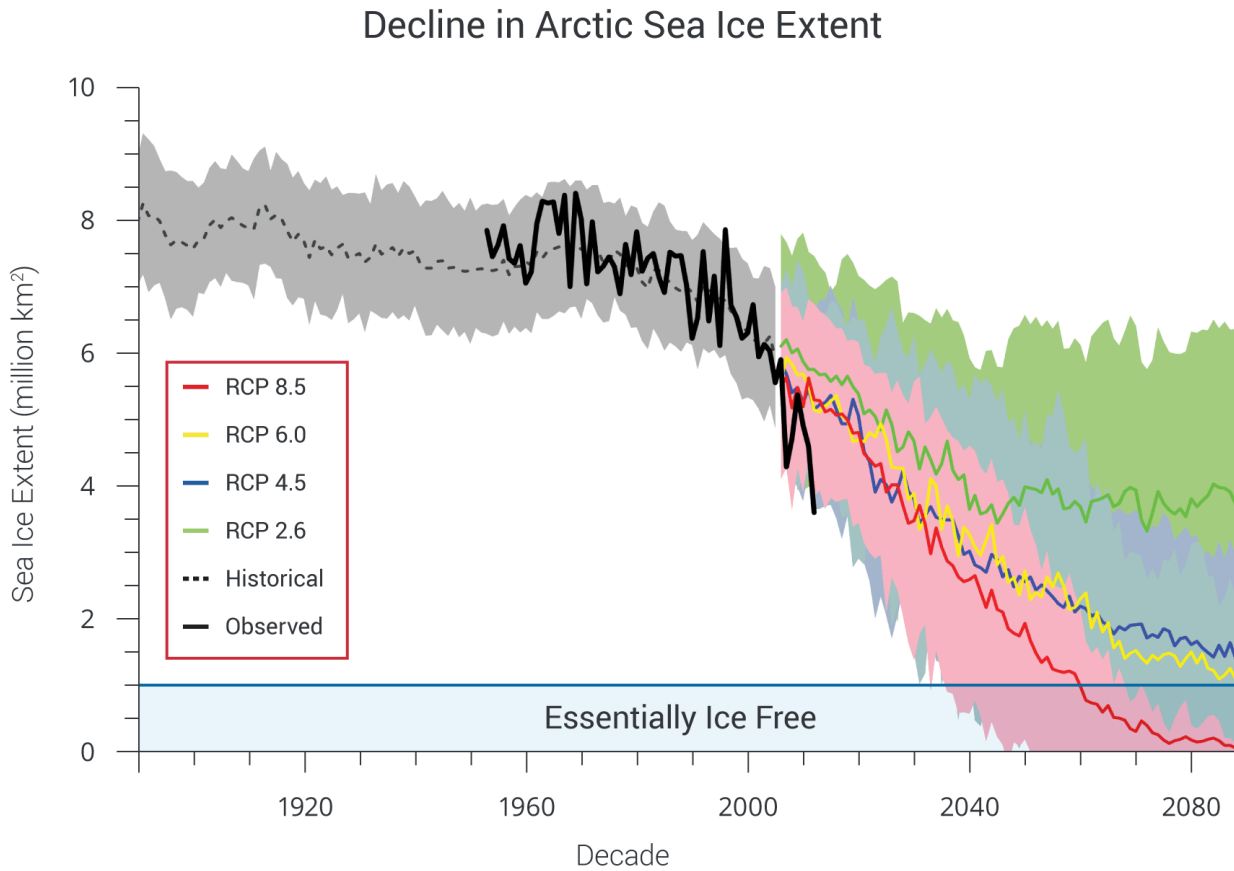
The Arctic has been warming at a rate not seen in at least 4,000 years. The melt season has lengthened by five days per decade since 1979, and the autumn freeze-up has been delayed

DB **Arctic sea ice hits its minimum extent for the year – 2 NASA scientists explain what’s driving the overall decline** 23 September 2021



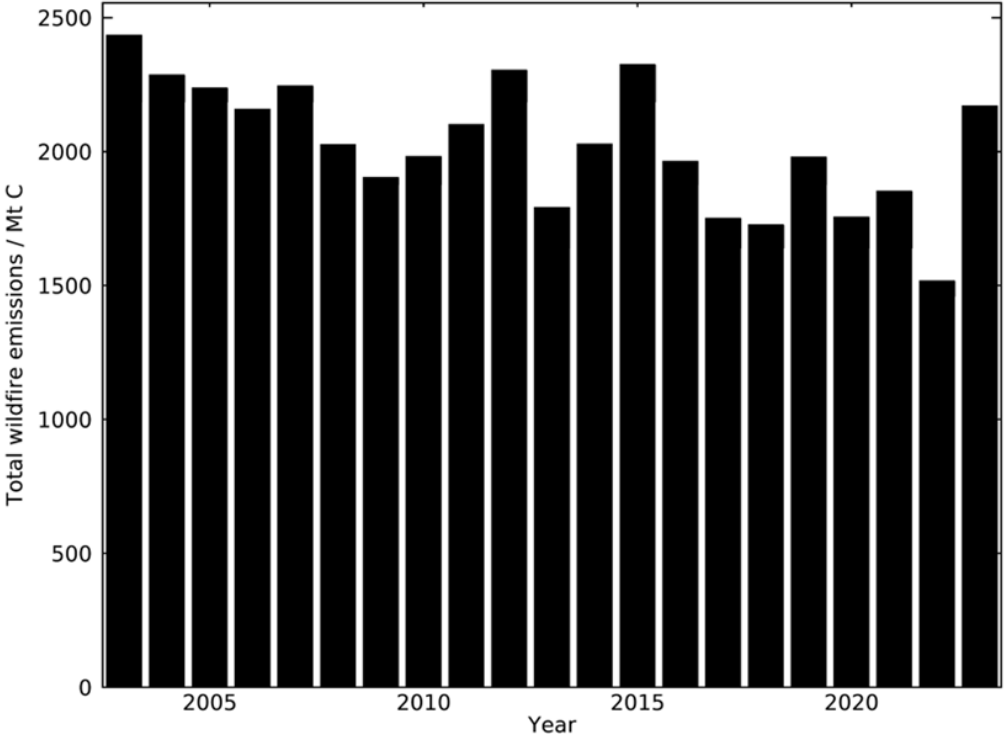

<https://www.preventionweb.net/news/arctic-sea-ice-hits-its-minimum-extent-year-2-nasa-scientists-explain-whats-driving-overall>

DC **Melting Ice**



<https://nca2014.globalchange.gov/report/our-changing-climate/melting-ice>

DC	<p><b>Calculations</b></p> <p>2024 ice cover extent = 4.5 km<sup>2</sup> (<a href="https://nsidc.org/sea-ice-today/sea-ice-tools/charctic-interactive-sea-ice-graph">https://nsidc.org/sea-ice-today/sea-ice-tools/charctic-interactive-sea-ice-graph</a>) = .11 W/m<sup>2</sup></p> <p>SSP1-2.6 1.5 Km<sup>2</sup> ice cover extent in 2100 = 0.23 W/m<sup>2</sup> for an increase of 0.12 W/m<sup>2</sup> (or 150 GTCO<sub>2</sub>e)</p> <p>Consistently ice-free Septembers could be expected by 2035 to 2067 (D2 above) so likely 6 weeks ice-free in 2100 = 0.35 W/m<sup>2</sup> for an increase after 2024 of 0.24 W/m<sup>2</sup> (or 320 GTCO<sub>2</sub>e)</p> <p>See <a href="https://ccdatacenter.org/documents/FeedbackFromArcticSeaIceMelt.xlsx">https://ccdatacenter.org/documents/FeedbackFromArcticSeaIceMelt.xlsx</a> worksheet SeaIceExtent for tables which can be used to determine the expected GTCO<sub>2</sub>e from RR (W/m<sup>2</sup>)</p> <p>See <a href="https://ccdatacenter.org/documents/ProjectingTheDeclineOfArcticSeaIce.pdf">https://ccdatacenter.org/documents/ProjectingTheDeclineOfArcticSeaIce.pdf</a> for a description of the model use to estimate RF from sea ice extent</p>
E	<p><b>Northern hemisphere snow cover extent</b></p> <p>Since the “separate contributions of 17% and 27% for snow cover and sea ice respectively”, (see above), a reasonable estimate of the “CO<sub>2</sub>e equivalent” contribution from reduced Northern hemisphere snow cover extent might be 95 GTCO<sub>2</sub>e (=150*17/27) for a 1.5°C scenario with 200 GTCO<sub>2</sub>e expected (=320*17/27)</p>
F	<p><b>Emissions from Peatlands</b></p> <p>(Analysis from ChatGPT)</p> <p>Peatlands are significant carbon stores, containing more carbon than all other vegetation types combined. When they are damaged, they release a substantial amount of greenhouse gases. Currently, emissions from degraded peatlands are estimated at 1.9 gigatonnes of CO<sub>2</sub> equivalent annually, making up nearly 5% of global anthropogenic greenhouse gas emissions. For example, in 2015, fires in Indonesian peatlands released nearly 16 million tonnes of CO<sub>2</sub> daily, surpassing the emissions of the entire U.S. economy at that time( <a href="https://www.iucn.org/resources/issues-brief/peatlands-and-climate-change">https://www.iucn.org/resources/issues-brief/peatlands-and-climate-change</a> )</p> <p>The degradation of peatlands primarily occurs due to activities like drainage, agricultural conversion, burning, and mining for fuel. Restoration efforts are crucial, as peatlands in their natural state can sequester 0.37 gigatonnes of CO<sub>2</sub> annually. Protecting and restoring peatlands is vital in mitigating climate change and achieving a zero-carbon society.</p> <p>Several projections suggest that if current trends continue, the cumulative emissions from peatlands could be substantial. For instance, if large-scale degradation of peatlands is not mitigated, emissions could contribute significantly to global carbon levels, with some estimates projecting up to 200 gigatonnes of CO<sub>2</sub> emissions by 2100 from peatlands alone. This figure would depend on factors such as land-use policies, conservation efforts, and the extent of peatland restoration.</p> <p><i>Note: A reasonable estimate of the “CO<sub>2</sub>e equivalent” contribution from peatlands in 2100 might be 100 GTCO<sub>2</sub>.</i></p>
F2	<p><b>Expected Wetlands Emissions for 1.5°</b></p> <p>Climate feedback factor = 0.3 W/m<sup>2</sup> per degree C =40 GTCO<sub>2</sub>e  <a href="https://doi.org/10.1017/9781009157896.007">https://doi.org/10.1017/9781009157896.007</a></p>

G1	<p><b>Wildfires</b></p> <p>By 2100, global wildfire occurrences are expected to increase significantly due to climate change. According to projections, the number of extreme wildfires could rise by up to 50%, even with efforts to reduce greenhouse gas emissions. This increase will impact areas not typically prone to wildfires, including the Arctic, central Europe, and parts of tropical forests like the southern Amazon. Wildfires will likely contribute to the release of large amounts of carbon dioxide into the atmosphere, further exacerbating global warming and creating a feedback loop that increases the risk of future fires (<a href="https://www.metoffice.gov.uk/about-us/news-and-media/media-centre/weather-and-climate-news/2022/up-to-50-increase-in-wildfires-by-2100">https://www.metoffice.gov.uk/about-us/news-and-media/media-centre/weather-and-climate-news/2022/up-to-50-increase-in-wildfires-by-2100</a>)</p>																																								
G2	<p><b>Wildfires</b></p> <p>Current global greenhouse gas emissions from wildfires are estimated to add around 5 to 8 billion tonnes of CO<sub>2</sub> annually. This accounts for a significant portion of the overall global CO<sub>2</sub> emissions, which total about 37 billion tonnes from fossil fuels and cement each year. The amount of emissions from wildfires can vary depending on the vegetation type and the area burned. However, some emissions from wildfires can be offset by the regrowth of vegetation in subsequent years, unlike emissions from fossil fuels (<a href="https://ourworldindata.org/wildfires">https://ourworldindata.org/wildfires</a> )</p>																																								
G3	<p><b>2023: A year of intense global wildfire activity</b></p> <p>According to CAMS estimates, global wildfires generated approximately 2,170 megatonnes of carbon emissions in 2023, of which the Canadian wildfires accounted for 22%</p> <p style="text-align: center;"><b>CAMS GFASv1.2 Annual Global Total Wildfire Carbon Emissions</b></p>  <table border="1" data-bbox="292 1008 1291 1743"> <caption>CAMS GFASv1.2 Annual Global Total Wildfire Carbon Emissions (Estimated values)</caption> <thead> <tr> <th>Year</th> <th>Total wildfire emissions / Mt C</th> </tr> </thead> <tbody> <tr><td>2005</td><td>2450</td></tr> <tr><td>2006</td><td>2300</td></tr> <tr><td>2007</td><td>2250</td></tr> <tr><td>2008</td><td>2150</td></tr> <tr><td>2009</td><td>2250</td></tr> <tr><td>2010</td><td>2050</td></tr> <tr><td>2011</td><td>1950</td></tr> <tr><td>2012</td><td>2000</td></tr> <tr><td>2013</td><td>2100</td></tr> <tr><td>2014</td><td>1800</td></tr> <tr><td>2015</td><td>2050</td></tr> <tr><td>2016</td><td>1950</td></tr> <tr><td>2017</td><td>1750</td></tr> <tr><td>2018</td><td>1750</td></tr> <tr><td>2019</td><td>1950</td></tr> <tr><td>2020</td><td>1750</td></tr> <tr><td>2021</td><td>1850</td></tr> <tr><td>2022</td><td>1550</td></tr> <tr><td>2023</td><td>2170</td></tr> </tbody> </table> <p style="text-align: center;">  </p> <p><a href="https://atmosphere.copernicus.eu/2023-year-intense-global-wildfire-activity">https://atmosphere.copernicus.eu/2023-year-intense-global-wildfire-activity</a></p>	Year	Total wildfire emissions / Mt C	2005	2450	2006	2300	2007	2250	2008	2150	2009	2250	2010	2050	2011	1950	2012	2000	2013	2100	2014	1800	2015	2050	2016	1950	2017	1750	2018	1750	2019	1950	2020	1750	2021	1850	2022	1550	2023	2170
Year	Total wildfire emissions / Mt C																																								
2005	2450																																								
2006	2300																																								
2007	2250																																								
2008	2150																																								
2009	2250																																								
2010	2050																																								
2011	1950																																								
2012	2000																																								
2013	2100																																								
2014	1800																																								
2015	2050																																								
2016	1950																																								
2017	1750																																								
2018	1750																																								
2019	1950																																								
2020	1750																																								
2021	1850																																								
2022	1550																																								
2023	2170																																								

G4	<p>If wildfires emit about 2.5 GTCO<sub>2</sub> per year through 2100 the total emissions would be almost 200 GTCO<sub>2</sub></p> <p><b>Fire weakens land carbon sinks before 1.5 °C</b> 03 October 2024</p> <p>We find that the global warming level at which fire began to impact global carbon storage significantly was 1.07 °C (0.8–1.34 °C) above pre-industrial levels and conclude that fire is already playing a major role in decreasing the effectiveness of land carbon sinks. We estimate that considering fire reduces the remaining carbon budget by 25 Gt CO<sub>2</sub> (~5%) for limiting temperature rise to 1.5 °C and 64 GtCO<sub>2</sub> (~5%) for 2.0 °C compared to previous estimates. Whereas limiting warming to 1.5 °C is still essential for avoiding the worst impacts of climate change, in many cases, we are already reaching the point of significant change in ecosystems rich in carbon and biodiversity..</p> <p><a href="https://www.nature.com/articles/s41561-024-01554-7">https://www.nature.com/articles/s41561-024-01554-7</a>  <i>How does about 2.5 GTCO<sub>2</sub> per year reconcile with 25 Gt CO<sub>2</sub> (~5%) for limiting temperature rise to 1.5 °C?</i></p>
G5	<p><b>Expected Fire Emissions for 1.5°</b></p> <p>Climate feedback factor = 0.036 W/m<sup>-1</sup> per degree C =47 GTCO<sub>2</sub>e  <a href="https://doi.org/10.1017/9781009157896.007">https://doi.org/10.1017/9781009157896.007</a></p>
H1	<p><b>Surface waters</b></p> <p>Surface waters emit greenhouse gases (GHGs) through a number of processes, including:</p> <ul style="list-style-type: none"> <li>• Coastal ecosystems The degradation of coastal ecosystems releases 0.15–1.02 billion tons of carbon dioxide (CO<sub>2</sub>) into the atmosphere annually. This is equivalent to 3–19% of the emissions from deforestation globally.</li> <li>• Reservoirs When reservoirs are created for hydropower, they release carbon that was previously stored in the river system. This happens when organic matter decomposes and releases CO<sub>2</sub> and methane. Reservoirs with poor water quality from algal blooms emit higher rates of methane.</li> <li>• Sewage Sewage discharged into rivers contains nutrients that promote the growth of algae and microorganisms. These organisms release CO<sub>2</sub> when they respire, but they also produce more CO<sub>2</sub> and methane when there is no oxygen.</li> <li>• Urban rivers Polluted urban rivers emit elevated levels of greenhouse gases.</li> </ul>
H2	<p><b>Reservoirs</b></p> <p>Current greenhouse gas emissions from reservoirs are higher than previously estimated, with global reservoirs producing around 1.07 gigatons of CO<sub>2</sub>-equivalent gases annually. This figure, which accounts for methane (CH<sub>4</sub>), CO<sub>2</sub>, and other gases, represents about 29% higher emissions per area than earlier studies suggested. Methane degassing—where methane passes through dams and bubbles up downstream—contributes significantly to this increase. (<a href="https://news.agu.org/press-release/greenhouse-gas-emissions-from-reservoirs-higher-than-previously-expected/">https://news.agu.org/press-release/greenhouse-gas-emissions-from-reservoirs-higher-than-previously-expected/</a> )</p>
H3	<p><b>Wastewater treatment</b></p> <p>On a global scale, wastewater treatment is estimated to contribute around 2% to the total anthropogenic GHG emissions [2,15]. It is estimated that between 2005 and 2030, annual non-CO<sub>2</sub> GHG emissions from wastewater treatment processes could range from 0.56 to 0.71 Gt of CO<sub>2</sub>-eq per year  (<a href="https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10716752/#:~:text=On%20a%20global%20scale%2C%20wastewater,eq%20per%20year%20%5B16%5D.">https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10716752/#:~:text=On%20a%20global%20scale%2C%20wastewater,eq%20per%20year%20%5B16%5D.</a> )</p>

H4	<p><b>Surface waters</b>          If surface waters emit about 2 GTCO<sub>2</sub> per year through 2100 the total emissions would be almost 150 GTCO<sub>2</sub></p>
I	<p><b>Soils</b>          (Chat GPT)</p> <p>Rising temperatures significantly influence emissions from soils, primarily through enhanced microbial activity and changes in soil processes. Here's a breakdown of how temperature affects soil emissions:</p> <p>Carbon Dioxide (CO<sub>2</sub>)</p> <p>Temperature Impact: For every 1°C increase in temperature, soil respiration can increase by approximately 10-20%. This is due to increased microbial activity and accelerated decomposition of organic matter.</p> <p>Current Estimates: While exact figures vary, rising temperatures are contributing to an estimated increase of several gigatons of CO<sub>2</sub> annually from soils, with total emissions currently estimated at 60-80 gigatons of CO<sub>2</sub> per year.</p> <p>If, due to temperature increases, soils emit about 2 GTCO<sub>2</sub> per year through 2100 the total emissions would be 150 GTCO<sub>2</sub></p>



J1	<p><b>Ocean iron cycle feedbacks decouple atmospheric CO<sub>2</sub> from meridional overturning circulation changes</b> 08 July 2024</p> <p>The ocean's Meridional Overturning Circulation (MOC) brings carbon- and nutrient-rich deep waters to the surface around Antarctica. Limited by light and dissolved iron, photosynthetic microbes incompletely consume these nutrients, the extent of which governs the escape of inorganic carbon into the atmosphere. Changes in MOC upwelling may have regulated Southern Ocean outgassing, resulting in glacial-interglacial atmospheric CO<sub>2</sub> oscillations. However, numerical models that explore this positive relationship do not typically include a feedback between biological activity and abundance of organic chelating ligands that control dissolved iron availability. Here, I show that incorporating a dynamic ligand parameterization inverts the modelled MOC-atmospheric CO<sub>2</sub> relationship: reduced MOC nutrient upwelling decreases biological activity, resulting in scant ligand production, enhanced iron limitation, incomplete nutrient usage, and ocean carbon outgassing, and vice versa. This first-order response suggests iron cycle feedbacks may be a critical driver of the ocean's response to climate changes, independent of external iron supply.</p> <p><a href="https://www.nature.com/articles/s41467-024-49274-1">https://www.nature.com/articles/s41467-024-49274-1</a></p> <p>Review of article  <b>Study: Weaker ocean circulation could enhance CO<sub>2</sub> buildup in the atmosphere</b>  New findings challenge current thinking on the ocean's role in storing carbon.  As the ocean gets weaker, it could release more carbon from the deep ocean into the atmosphere — rather than less, as some have predicted.  <a href="https://news.mit.edu/2024/study-weaker-ocean-circulation-could-enhance-co2-buildup-atmosphere-0708">https://news.mit.edu/2024/study-weaker-ocean-circulation-could-enhance-co2-buildup-atmosphere-0708</a></p>
J2	<p><b>Ocean stratification and CO<sub>2</sub> uptake</b> ChatGPT</p> <p>Ocean stratification plays a significant role in the uptake and storage of carbon dioxide (CO<sub>2</sub>) by the oceans, affecting the global carbon cycle and climate system. Here's a breakdown of the interaction between ocean stratification and CO<sub>2</sub> uptake:</p> <p><b>1. What is Ocean Stratification?</b></p> <p>Ocean stratification refers to the layering of water masses with different densities. This stratification is typically caused by variations in temperature (thermal stratification) and salinity (haline stratification). Warmer, lighter water tends to sit on top of colder, denser water, and differences in salinity can create similar effects. Stratification is most pronounced in tropical and subtropical regions, where surface waters are significantly warmer than deeper waters.</p> <p><b>2. How Stratification Affects CO<sub>2</sub> Uptake:</b></p> <p>The ocean acts as a major sink for atmospheric CO<sub>2</sub>, absorbing about 25-30% of the CO<sub>2</sub> emitted by human activities. The ability of the ocean to absorb CO<sub>2</sub> is largely influenced by physical processes such as mixing and the movement of water between the surface and deep layers.</p> <ul style="list-style-type: none"> <li>• <b>Reduced Vertical Mixing:</b> Stratified oceans experience reduced vertical mixing between surface waters (where CO<sub>2</sub> is absorbed) and deeper waters (where it is stored). Without mixing, CO<sub>2</sub> remains in the surface layer, limiting how much more CO<sub>2</sub> can be absorbed from the atmosphere. In normal conditions, mixing allows surface CO<sub>2</sub> to be transported to the deep ocean, where it can be stored for centuries or longer.</li> </ul>

- **Impact on the Biological Pump:** The biological pump is another key mechanism through which the ocean sequesters CO<sub>2</sub>. Phytoplankton in the surface layer absorb CO<sub>2</sub> during photosynthesis, and when they die, their organic matter sinks to deeper waters, sequestering carbon. Stratification reduces nutrient upwelling from deeper waters, which limits phytoplankton growth and weakens this biological pump.
- **Thermal Stratification and Solubility:** As surface waters warm, their capacity to hold CO<sub>2</sub> decreases because warmer water holds less dissolved gas than colder water (a process known as the solubility pump). Therefore, stronger thermal stratification due to global warming reduces the ocean's ability to absorb and store atmospheric CO<sub>2</sub>.

### 3. Feedback Effects:

Stratification has the potential to create feedback loops that exacerbate global warming:

- **Warming leads to more stratification:** As the planet warms, ocean surface waters warm more than deep waters, intensifying stratification. This reduces mixing, weakens the ocean's ability to uptake CO<sub>2</sub>, and allows more CO<sub>2</sub> to accumulate in the atmosphere, further amplifying global warming.
- **Decreased Ocean Buffering Capacity:** With weakened vertical mixing and reduced CO<sub>2</sub> uptake, the ocean's role as a buffer against climate change diminishes. This can lead to faster increases in atmospheric CO<sub>2</sub> levels, accelerating global warming.

### 4. Regional Variability:

Ocean stratification and its effects on CO<sub>2</sub> uptake vary significantly across different regions:

- **Tropics and Subtropics:** These regions are more strongly stratified due to higher surface temperatures, making them less effective at sequestering CO<sub>2</sub>.
- **Polar Regions:** In contrast, polar regions have weaker stratification, allowing for better mixing between surface and deep waters. However, rapid warming in the Arctic and Antarctic is beginning to affect stratification in these regions as well.

### 5. Future Outlook:

As climate change progresses, models predict that increased ocean stratification will further reduce the ocean's capacity to absorb CO<sub>2</sub>. This would place more pressure on other carbon sinks (such as forests) and make it even more crucial to reduce CO<sub>2</sub> emissions. Additionally, geoengineering solutions aimed at enhancing ocean CO<sub>2</sub> uptake (like ocean alkalinity enhancement or artificial upwelling) may be needed to counteract these changes, but their effectiveness depends on regional stratification patterns.

### Conclusion:

Ocean stratification significantly influences the ocean's ability to absorb and store CO<sub>2</sub>. As stratification intensifies due to global warming, the ocean's role as a carbon sink may diminish, potentially accelerating climate change. Understanding the interactions between stratification, CO<sub>2</sub> uptake, and other ocean processes is crucial for predicting future climate dynamics and developing effective mitigation strategies.

K	<p><b>Africa switches from carbon sink to carbon source 14 June 2024</b></p> <p>The continent now emits more greenhouse gases than it absorbs, and contributes 40% of global emissions from agriculture.</p> <p>It has taken less than 10 years for Africa to transition from being a net carbon sink to a net carbon source. The continent now emits more greenhouse gases than it absorbs.</p> <p>Looking at data between 2010 and 2019, researchers from the Futures Ecosystems for Africa programme, based at the University of the Witwatersrand, South Africa, looked at major potential carbon sources, such as agriculture and fossil fuel emissions. From Africa, the rise in emissions can be mainly contributed to fossil fuel burning and land transformation processes.</p> <p>Natural sources such as wildfires, and termites whose methane emissions have increased in line with climate and land use changes.</p> <p>“Africa still hovers around 4% of global fossil fuel emissions, but emits nearly 40% of the global emissions from land use, and is now, for the first time, contributing 3-5% of the growing amount of greenhouse gasses (GHG) in the atmosphere,” says Sally Archibald, the programme principal investigator.</p> <p><a href="https://www.nature.com/articles/d44148-024-00187-7">https://www.nature.com/articles/d44148-024-00187-7</a></p>
---	--