

# Permafrost carbon cycle

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The **Permafrost Carbon Cycle** is a sub-cycle of the larger global carbon cycle. Permafrost is defined as subsurface material that remains below 0° C (32° F) for at least two consecutive years. Because permafrost soils remain frozen for long periods of time, they store large amounts of carbon and other nutrients within their frozen framework during that time. Permafrost represents a large carbon reservoir that is seldom considered when determining global terrestrial carbon reservoirs. Recent and ongoing scientific research however, is changing this view.<sup>[1]</sup>

The permafrost carbon cycle (Arctic Carbon Cycle) deals with the transfer of carbon from permafrost soils to terrestrial vegetation and microbes, to the atmosphere, back to vegetation, and finally back to permafrost soils through burial and sedimentation due to cryogenic processes. Some of this carbon is transferred to the ocean and other portions of the globe through the global carbon cycle. The cycle includes the exchange of carbon dioxide and methane between terrestrial components and the atmosphere, as well as the transfer of carbon between land and water as methane, dissolved organic carbon, dissolved inorganic carbon, particulate inorganic carbon and particulate organic carbon.<sup>[2]</sup>

## Contents

- 1 Storage
  - 1.1 Processes
  - 1.2 Current estimates
- 2 Carbon release from permafrost
- 3 Environmental impacts
- 4 References
- 5 External links

## Storage

Soils, in general, are the largest reservoirs of carbon in terrestrial ecosystems. This is also true for soils in the Arctic that are underlain by permafrost. Determining carbon stocks in cryosols, that is, soils containing permafrost within two meters of the soil surface, was completed using the Northern and Mid Latitudes Soil Database.<sup>[3]</sup> Permafrost affected soils cover nearly 9% of the earth's land area, yet store between 25 and 50% of the soil organic carbon. These estimates show that permafrost soils are an important carbon pool.<sup>[4]</sup> These soils not only contain large amounts of carbon, but also sequester carbon through cryoturbation and cryogenic processes.<sup>[3][5]</sup>

## Processes

Carbon is not produced by permafrost. Organic carbon derived from terrestrial vegetation must be incorporated into the soil column and subsequently be incorporated into permafrost to be effectively stored. Because permafrost responds to climate changes slowly, carbon storage removes carbon from the atmosphere for long periods of time. Radiocarbon dating techniques reveal that carbon within permafrost is often thousands of years

old.<sup>[6][7]</sup> Carbon storage in permafrost is the result of two primary processes.

- The first process that captures carbon and stores it is syngenetic permafrost growth. This process is the result of a constant active layer thickness and energy exchange between permafrost, active layer, biosphere, and atmosphere, resulting in the vertical increase of the soil surface elevation. This aggradation of soil is the result of aeolian or fluvial sedimentation and/or peat formation. Peat accumulation rates are as high as 0.5mm/yr while sedimentation may cause a rise of 0.7mm/yr. Thick silt deposits resulting from abundant loess deposition during the last glacial maximum form thick carbon-rich soils known as yedoma.<sup>[8]</sup> As this process occurs, the organic and mineral soil that is deposited is incorporated into the permafrost as the permafrost surface rises.
- The second process responsible for storing carbon is cryoturbation, the mixing of soil due to freeze-thaw cycles. Cryoturbation moves carbon from the surface to depths within the soil profile. Frost heaving is the most common form of cryoturbation. Eventually, carbon that originates at the surface moves deep enough into the active layer to be incorporated into permafrost. When cryoturbation and the deposition of sediments act together, carbon storage rates increase.<sup>[8]</sup>

## Current estimates

The amount of carbon stored in permafrost soils is poorly understood. Current research activities seek to better understand the carbon content of soils throughout the soil column. Recent studies (2009) estimate that northern circumpolar permafrost soil carbon content equals approximately 1672 Pg.<sup>[5]</sup> (1 Pg = 1 Gt = 10<sup>15</sup>g) This estimation of the amount of carbon stored in permafrost soils is more than double the amount currently in the atmosphere.<sup>[1]</sup> This most recent assessment of carbon content in permafrost soils breaks the soil column into three horizons, 0–30 cm, 0–100 cm, and 1–300 cm. The uppermost horizon, 0–30 cm contains approximately 191 Pg of organic carbon. The 0–100 cm horizon contains an estimated 496 Pg of organic carbon, and the 0–300 cm horizon contains an estimated 1024 Pg of organic carbon. These estimates more than doubled the previously known carbon pools in permafrost soils.<sup>[3][4][5]</sup> Additional carbon stocks exist in yedoma (407 Pg), carbon rich loess deposits found throughout Siberia and isolated regions of North America, and deltaic deposits (241 Pg) throughout the Arctic. These deposits are generally deeper than the 3 m investigated in traditional studies.<sup>[5]</sup> Many concerns arise because of the large amount of carbon stored in permafrost soils. Until recently, the amount of carbon present in permafrost was not taken into account in climate models and global carbon budgets.<sup>[1][8]</sup> Thawing permafrost may release great quantities of old carbon stored in permafrost to the atmosphere.

## Carbon release from permafrost

Carbon stored within arctic soils and permafrost is susceptible to release due to several different mechanisms. Carbon that is stored in permafrost is released back into the atmosphere as either carbon dioxide (CO<sub>2</sub>) or methane (CH<sub>4</sub>). Aerobic respiration releases carbon dioxide, while anaerobic respiration releases methane.

- Microbial activity releases carbon through respiration. Increased microbial decomposition due to warming conditions is believed to be a major source of carbon to the atmosphere. The rate of microbial decomposition within organic soils, including thawed permafrost, depends on environmental controls. These controls include soil temperature, moisture availability, nutrient availability, and oxygen availability.<sup>[8]</sup>
- Methane clathrate, or hydrates, occur within and below permafrost soils. Because of the low permeability of permafrost soils, methane gas is unable to migrate vertically through the soil column. As

permafrost temperature increases, permeability also increases, allowing once trapped methane gas to move vertically and escape. Dissociation of gas hydrates is common along the Arctic coastline, yet estimates for dissociation of gas hydrates from terrestrial permafrost remains unclear.<sup>[2]</sup>

- Thermokarst/permafrost degradation as a result of climate change and increased mean annual air temperatures throughout the Arctic threatens to release large quantities of carbon back into the atmosphere. The spatial extent of permafrost decreases in warming climate, releasing large amounts of stored carbon.<sup>[1]</sup>
- As air and permafrost temperatures change, above ground vegetation also changes. Increasing temperatures facilitate the transfer of soil carbon to growing vegetation on the surface. This transfer removes carbon from the soil and relocates it to the terrestrial carbon pool where plants process, store, and respire it, moving it to the atmosphere.<sup>[9]</sup>
- Forest fires in the boreal forests and tundra fires alter the landscape and release large quantities of stored organic carbon into the atmosphere through combustion. As these fires burn, they remove organic matter from the surface. Removal of the protective organic mat that insulates the soil exposes the underlying soil and permafrost to increased solar radiation, which in turn increases the soil temperature, active layer thickness, and changes soil moisture. Changes in the soil moisture and saturation alter the ratio of oxic to anoxic decomposition within the soil.<sup>[10]</sup>
- Hydrologic processes remove and mobilize carbon, carrying it downstream. Mobilization occurs due to leaching, litter fall, and erosion. Mobilization is believed to be primarily due to increased primary production in the Arctic resulting in increased leaf litter entering streams and increasing the dissolved organic carbon content of the stream. Leaching of soil organic carbon from permafrost soils is also accelerated by warming climate and by erosion along river and stream banks freeing the carbon from the previously frozen soil.<sup>[6]</sup>

Carbon is continually cycling between soils, vegetation, and the atmosphere. Currently, carbon flux from permafrost soils is minimal, however studies suggest that future warming and permafrost degradation will increase the CO<sub>2</sub> flux from the soils. Thaw deepens the active layer, exposing old carbon that has been in storage for decades, to centuries, to millennia. The amount of carbon that will be released from warming conditions depends on depth of thaw, carbon content within the thawed soil, and physical changes to the environment.<sup>[7]</sup> The likelihood of the entire carbon pool mobilizing and entering the atmosphere is low despite the large volumes stored in the soil. Although temperatures are projected to rise, it does not imply complete loss of permafrost and mobilization of the entire carbon pool. Much of the ground underlain by permafrost will remain frozen even if warming temperatures increase the thaw depth or increase thermokarsting and permafrost degradation.<sup>[4]</sup>

## Environmental impacts

Warmer conditions are expected to cause spatial declines in permafrost extent and thickening of the active layer. This decline in the extent and volume of permafrost enables the mobilization of stored soil organic carbon to the biosphere and atmosphere as carbon dioxide and methane.<sup>[1]</sup> Additionally, these changes are believed to impact ecosystems and alter the vegetation that is present on the surface.<sup>[9]</sup> Increased carbon uptake by plants is expected to be relatively small when compared to the amount of carbon released by permafrost degradation. Tundra vegetation contains 0.4 kg of carbon per m<sup>2</sup> while a shift to boreal forests could increase the above ground carbon pool to 5 kg of carbon per m<sup>2</sup>. Tundra soil however, contains ten times that amount.<sup>[8]</sup>

Additionally, a sudden and steady release of carbon dioxide and methane from permafrost soils may lead to a positive feedback cycle where warming releases carbon dioxide into the atmosphere. This carbon dioxide, a

greenhouse gas, causes atmospheric concentrations to increase, causing subsequent warming.<sup>[5]</sup> This scenario is thought to be a potential runaway climate change scenario.

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## External links

- International Permafrost Association (<http://ipa.arcticportal.org/>)
- Center for Permafrost (<http://cenperm.ku.dk/>)
- Carbon in Arctic Reservoirs Vulnerability Experiment (<http://science.nasa.gov/missions/carve/>)

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