ALFRED-WEGENER-INSTITUT
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FACT SHEET

OUR CURRENT KNOWLEDGE OF

Permafrost

For decades, huge expanses of land at the higher latitudes which sit atop frozen soil – referred to as permafrost – have been thawing. When the subterranean organic matter, which accumulated over thousands of years in frozen soils, thaws and decomposes eventually, massive quantities of greenhouse gases can be released into the atmosphere, intensifying global warming. As such, the thawing of permafrost regions not only has local effects, but impacts the climate as a whole and people around the globe.

What is permafrost?

Researchers use the term permafrost, or permanently frozen ground, when the temperature of the ground remains under zero degrees Celsius for at least two consecutive years. The material can consist of rock, sediment or soil, and can contain varying quantities of ice. In some regions of the Arctic, the makeup is 70 per cent ice. Especially Northeast Siberia experienced extremely long and cold winters during the last ice ages, lasting from about 100,000 to 10,000 years ago. At the same time, the ground there was not protected by an ice sheet, and cold air deeply penetrated into the ground. As a result, the permafrost in this region reaches deep into the Earth – extending as far as 1.6 kilometres down. Most permafrost landscapes can be recognised by the typical patterning of their surface, for example polygons, formed by repeated deep freezing in winter. The very cold arctic winter temperatures cause the frozen soils to contract across the land surface, resulting in a regular pattern of cracks much like drying cracks. Subsequently, the centimetre-wide and metre-deep cracks are then filled with snow melt water during the spring thaw. Thanks to the soil's intense cold, the water then refreezes, creating vertical veins of ice that grow over decades to millennia into ice wedges.

A ten-metre high headwall made of ice and frozen sediments towers over the scientist. The wall is part of one of the largest thermoerosion features in the Arctic. (Photo: M. Fritz, Alfred-Wegener-Institut)

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What is the structure of permafrost soil?

Permafrost typically is overlain by an active layer, circa 15 - 100 centimetres of which thaw every summer. In this thin layer, the majority of biological and biochemical activity happens in arctic soils. Researchers regularly measure the temperatures of the active layer and the frozen layers beneath and track the boundary – the thaw depth – between them, saving their findings in the database of the Global Terrestrial Network for Permafrost (www.gtnp.org). While the thaw depth offers insights into short-term climate fluctuations, the temperatures of the permafrost's lower layers reflect longer-term climate changes, making it possible to gauge the effects of global warming on the polar and mountainous regions.

Where can permafrost be found?

Permafrost is much more common than generally assumed – and underlies roughly a quarter of the land area in the Northern Hemisphere. Though the majority is in the polar regions, it can also be found in high mountain ranges. As such, there is even alpine permafrost in Germany, namely on the Zugspitze. Depending on the areal extent, a distinction is made between continuous permafrost in colder regions, where at least 90 per cent of the land is underlain by permafrost; and discontinuous and sporadic permafrost in warmer regions, where the number lies between 10 and 90 per cent. There are also isolated "permafrost islands", which often exist underneath boreal peatlands.

How does permafrost thaw?

The thawing processes often are not linear. For example in Ny-Ålesund, where measurements of permafrost temperatures have been taken since 1998, AWI researchers have observed an intensive thawing process that has increased the active thaw layer by 50 centimetres. Farther down, however, the permafrost temperatures remain largely unchanged. In contrast, in the Lena Delta not only has the thaw layer moved deeper, the underlying permafrost is also rapidly warming – by more than 1.5 degrees Celsius since 2006 (recorded at a depth of ten metres).

On the plateau of Herschel Island AWI researchers investigate how quickly the permafrost is thawing, which nutrients the soils hold, and how the vegetation is changing in response to rising temperatures. (Photo: Alfred-Wegener-Institut/B. Radosavljevic)

What happens when permafrost thaws?

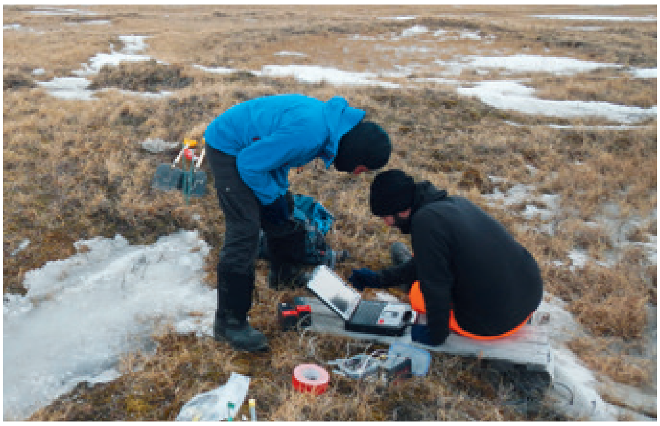
Just like a gigantic freezer, permafrost stores tremendous amounts of organic matter. Unlike in tropical or moderate climate zones, this organic material can't be broken down by microbes, since these bacteria only become active when the permafrost thaws. But if our climate continues to grow warmer, the door of that gigantic freezer is left open and the organic matter starts to decompose - carbon will be broken down and be released into the atmosphere as greenhouse gas, which will in turn accelerate the climate-warming process. The permafrost carbon feedback would affect the global climate system as a whole. Further, melting of ground ice present in permafrost can have drastic consequences for arctic landscapes and settled areas, because the land surface settles unevenly where ice turns to water and streets, railroad tracks, runways, buildings, and oil and gas pipelines become damaged.

Unfortunately, predicting the physical and biochemical development of permafrost is an extremely complex undertaking. Many surface characteristics change simultaneously, like snow cover and vegetation, which produces varied and often opposing effects. Further, human beings are increasingly interfering in landscape development. As such, predictions still involve a great deal of uncertainty. However, studies of past climate change such as during the period immediately after the last ice age when the Arctic warmed very rapidly have shown that permafrost was dramatically affected by warming, suggesting that permafrost may not be so permanent at last.

To what extent will thawing permafrost intensify climate change?

When permafrost thaws, bacteria and microorganisms will begin breaking down the plant and animal organic matter it contains. As a result, carbon dioxide or methane will be released, depending on how dry or wet the soil remains. Though methane only makes up two per cent of the greenhouse gases released, it's a highly potent gas; its global warming potential over a 100 year time frame is nearly 25 times higher than that of carbon dioxide. It was previously assumed that permafrost regions are carbon sinks. But there currently are only a few long-term measurement series that examine the carbon balance in permafrost regions year-round. One is from the AWI's Bayelva Permafrost Station near Ny-Ålesund (Svalbard); another is from Alaska. The readings in Alaska confirm that the area surveyed is a carbon sink. However, those from the Svalbard site show an annual carbon balance of about zero. In other words, here we see an equilibrium between the absorption of carbon by vegetation during the summer and the long "winter outgassing", during which microorganisms break down the carbon beneath the snow.

With the help of models, researchers now estimate that if global warming continues unabated, the greenhouse gas emissions from permafrost, disregarding all other sources, could produce an additional temperature increase of up to 0.29 degrees Celsius by the end of the century, and of up to 0.40 degrees by 2300.



AWI scientists investigate the permafrost in the Lena Delta. (Photo: Alfred-Wegener-Institut/T.Opel)

How much carbon is stored in the permafrost?

Experts estimate that the frozen ground contains somewhere between 1300 and 1600 billion tonnes of carbon. Our entire atmosphere, for comparison, currently contains about 800 billion tonnes of carbon. The permafrost carbon was produced by animal and vegetable matter that has been locked inside the Earth for thousands of years. Though the majority of the carbon can be found in the upper soil layers, there are also unknown quantities of carbon stored in the submarine permafrost – having first formed on land during the last ice age, this permafrost was covered by the rising seas when that age came to an end, and is now under the ocean floor.

How vulnerable is the permafrost?

Over the course of the last several decades, not just the atmosphere has grown warmer. In some areas the temperature of the upper permafrost layers has risen by roughly two degrees Celsius, as a result of which the border of the continuous permafrost has shifted farther north. In many parts of the world, the permafrost is thawing and decaying, a phenomenon documented by measurements from boreholes and other recordings in the GTN-P Database.

How long the permafrost will remain stable largely depends on the soil temperature. Additional factors include the surface energy balance, heat capacity and thermal conductivity, vegetation, snow cover and the presence of lakes and streams and/or groundwater in the immediate vicinity. Today Siberia is home to permafrost with the greatest extent, thickness and average coldness, with an annual mean temperature of about minus 10 degrees Celsius. The coldest spot, however, is located in northernmost Canada, with an annual mean temperature of minus 15 degrees Celsius. The permafrost on Spitsbergen is warm by comparison, with a mean temperature of minus two degrees Celsius. These temperatures are recorded at sufficient depth to be unaffected by seasonal variations.

Why are permafrost coasts increasingly crumbling?

Coastal erosion in the Arctic has intensified over the past several decades as a result of dwindling sea-ice cover on the Arctic Ocean during the summer, higher water temperatures and rising sea levels. When there is less sea ice, storms can produce larger waves that rapidly gnaw at the permafrost shores along the Arctic Ocean from June to October. On average the Arctic coastline recedes by circa half a metre per year, however, individual coasts that consist of ice-cemented permafrost sediments retreat with up to 25 metres per year. These rapid changes have major effects on ecosystems on or near the coast and their populaces, primarily through loss of land and the influx of sediment and nutrients in the water.

Erosion carries a buried glacier on Herschel Island to light. (Photo: Alfred-Wegener-Institut/B. Radosavljevic)

Will the tundra become greener if temperatures continue to rise?

If temperatures rise in the Arctic, it will stimulate plant growth and fixation of carbon in organic matter, initially counteracting the greenhouse gas emissions from the permafrost soils. However, in the long term and in the face of steadily rising temperatures, the emissions produced by microbial decomposition will surpass the plants ability to absorb carbon dioxide.

Is permafrost receding northwards?

The permafrost is rapidly receding, especially in the European part of the Russian Arctic. Between 1995 and 2005, the southern boundary of the regions with continuous permafrost, i.e. of those areas where at least 90 per cent of the landscape is underlain by permafrost, receded by up to 50 kilometres; in those with discontinuous permafrost, where the number lies between 10 and 90 per cent, the boundary receded by as much as 80 kilometres.

What are the current research needs?

- Understanding sudden thawing: At the regional level, permafrost can thaw extremely rapidly when it contains substantial amounts of ice that becomes subject to melting. As a result, the ground above starts to sink and water collects in the depressions, producing what are known as thermokarst lakes, under which the soil continues to thaw at an accelerated rate.

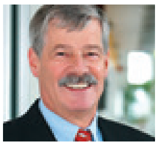
- Understanding changing landscapes: The type and amount of greenhouse gases the permafrost regions will release in the long term primarily depends on the characteristics of the ground. As such, whether these regions will become more wet (more methane) or dry (more carbon dioxide) due to global warming is a crucial question.

- Permafrost processes must be integrated into climate models in order to better grasp and predict future climate changes.

- Expanding the network of permafrost observatories: Researchers at the Alfred Wegener Institute are currently working to combine all current permafrost observatories into a single network, allowing data to more readily be compared.

- Intensifying remote monitoring of the permafrost regions in order to effectively increase the area covered. This can only be achieved with the help of satellites.

Contact the AWI experts



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