

기후 분과 [P-012]

Impact of Soil Moisture to Carbon Cycle Changes in Permafrost Regions in CESM2

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Permafrost regions store over 1,500 Gt of carbon, nearly double the amount present in the atmosphere. Like a 'sleeping giant,' permafrost will thaw as global warming continues, increasing soil moisture. In most global climate systems, changes in soil moisture can alter the carbon uptake capacity of that climate system over the long term. However, further research is needed on how increased soil moisture in permafrost regions will change the carbon uptake capacity of these regions, which represent a very large carbon pool. Carbon uptake capacity can be simply calculated as the difference between carbon uptake through plant photosynthesis and carbon release through microbial respiration. Here, increased soil moisture can aid plant growth, thereby increasing carbon uptake, but it can also enhance microbial metabolic activity, leading to increased carbon emissions. Therefore, by investigating whether soil moisture, which contributes in both directions, ultimately increases or decreases carbon uptake capacity, we can quantify the impact of soil moisture on carbon emissions from permafrost regions. This study investigates carbon emissions driven by soil moisture using multiple regression analysis. It aims to demonstrate the potential existence of a 'Moisture-amplified Permafrost Carbon Feedback' mechanism, where warming causes permafrost regions to thaw, increasing soil moisture, from a long-term climate perspective.

To achieve this, data from an experiment conducted at the IRCC (Irreversible Climate Change Research Center) was utilized. This experiment followed an SSP5-8.5-like scenario, where CO₂ emissions increased, then decreased at the same rate, before maintaining zero emissions. By employing this experiment, we can observe not only the effects of warming but also the influence of soil moisture during permafrost recovery periods following mitigation. In this study, multiple regression analysis was conducted alongside key variables affecting carbon emissions, such as temperature and precipitation, to isolate the effect of soil moisture on carbon emissions.

The analysis revealed that as warming persists and permafrost thaws, soil moisture increases. At this point, soil moisture leads to a reduction in carbon uptake capacity, resulting in carbon emissions instead. Carbon emissions driven by soil moisture contributed more strongly than any other variable during the warming period. This indicates that soil moisture significantly amplified carbon emissions from permafrost.

Furthermore, soil moisture can delay permafrost re-freezing during net-zero periods through mechanisms involving increased thermal capacity. This can sustain carbon emissions from permafrost, meaning soil moisture can indirectly continue to cause carbon emissions, even if not through a direct effect.

This study highlights the potential for soil moisture changes under future climate scenarios to amplify carbon loss from permafrost ecosystems. Furthermore, climate models still exhibit significant uncertainty in simulating soil moisture. Therefore, this research suggests that improvements in soil moisture modeling could enhance predictions of how permafrost carbon emissions will change in the future.

Keywords: Permafrost, Soil Moisture, Carbon Cycle, Permafrost Carbon Feedback