

21st century permafrost distribution under the scenario of RCP2.6 and RCP8.5 in Mongolia

Saruulzaya Adiya^{1*} and Enkhbat Erdenebat²

¹ Institute of Geography and Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia

² Research division of General circulation and Long-range prediction, Information and Research Institute of Meteorology, Hydrology and Environment, Ulaanbaatar, Mongolia

ARTICLE INFO: Received: 21 Jul, 2021; Accepted: 22 Dec, 2021

Abstract: Permafrost in Mongolia is at the southern edge of the Siberian permafrost, which is most vulnerable to climate change. In this study, we used ERA5-Land data to determine the distribution of permafrost in Mongolia, and used MIROC5 data for future projection of the soil temperature. The future change of soil temperature obtained during 2020–2100 under Representative Concentration Pathways (RCP) scenarios was RCP 2.6 and RCP 8.5 respectively. This is a first attempt to identify the distribution of permafrost using ERA5-Land data in Mongolia. We examined the projection of permafrost distribution using RCP 2.6 and RCP 8.5 scenarios in Mongolia. The rapid increase of near-surface temperature was obtained in RCP8.5 scenario during 2020-2100. Soil temperature also has a high increasing trend similar to the near-surface temperature in the RCP 8.5 scenario. Future projection suggests that permafrost will completely thaw in Mongolia when area-averaged soil temperature in Mongolia exceeds 1.8°C in comparison with the current climate.

Keywords: *permafrost; RCP2.6; RCP8.5; Mongolia;*

INTRODUCTION

In the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013), the global mean surface temperature combining land and ocean surface had changed by 0.85°C between 1880 and 2012 [1]. According to instrumental record, global mean temperatures in the 1980s, 1990s, and 2000s have been successively warmer than all previous decades [1]. Due to climate change, the frequency and intensity of extreme weather events have increased since the 1950s, particularly over Europe, North Asia, and Australia. In Mongolia, the target region in this

study, the annual mean surface air temperature has increased by 2.14°C during the period between 1940 and 2000.

Climate change projections, based on several global projection models, suggest that highest warming corresponds to the high-latitude regions, with some models predicting a 7–8°C warming over land in those regions by the end of the 21st century [1]. Thus, it is important to make a quantitative assessment for appropriate adaptation and mitigation strategies based on climate change projection.

*corresponding author: saruulzayaa@mas.ac.mn

<https://orcid.org/0000-0002-7969-3801>



The Author(s). 2021 Open access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

Although climate change is influencing a variety of sectors, permafrost might affect most due to the strong relationship between land and atmospheric interaction. Land degradation is affecting permafrost in various ways, one of which is that less thermal insulation from vegetation cover could induce a rapid thawing of the permafrost. Land degradation is accelerating due to overgrazing of livestock, poor land management lower precipitation, and increased temperature in Mongolia. As a product of a cold climate, permafrost is extremely sensitive to climate change. Permafrost, covering approximately 25% of the land area in the Northern Hemisphere, is defined as subsurface earth materials remaining below 0°C for two consecutive years [1, 2].

Permafrost controlled by air temperature in the thickness, presence, and geographic

extent reacts sensitively to changes in atmospheric temperature. Thawing permafrost and the resulting microbial decomposition of previously frozen organic carbon is one of the most significant potential feedbacks from terrestrial ecosystems to the atmosphere [3]. It is important to examine the potential rate of permafrost thawing with future projection, thus, a plan and action could be implemented in advance using the study results.

Permafrost in Mongolia is extremely vulnerable to an increasingly warmer climate [4], which consequently damages the livelihood of the local population and ecosystem within the region. In this study, we focused on evaluating the temporal and spatial change of permafrost in Mongolia using publically available future projection data for soil temperature.

MATERIALS AND METHODS

Data and Model

MIROC 5 (Model for Interdisciplinary Research on Climate version 5) is one of the best CMIP 5 GCMs simulating free atmosphere conditions. In this study, we used MIROC 5 [5] data for future projection of soil temperature. The future change of soil temperature obtained during 2020–2100 under Representative Concentration Pathways (RCP) scenarios RCP 2.6 and RCP 8.5. MIROC 5 has a resolution of 1.40625 degrees. MIROC 5 has a soil depth of 0.025, 0.15, 0.625, 1.5, 3, 9 meters, respectively.

ECMWF (European Centre for Medium-Range Weather Forecasts) reanalysis data for land component (ERA5 Land) was used to determine permafrost distribution in Mongolia [6]. ERA 5-Land has a spatial resolution of 0.1 degree and the duration of 1991-2020 is used. We report temperature projection data for a 10-

year average value between 2020 and 2100 and the historic period as a 30-year average value of years 1991–2020.

Permafrost is defined when the mean maximum temperature (1991-2020) from June to October is below 0.5°C. ERA 5-land data has four layers, 0-7 cm, 7-28 cm, 28-100 cm, and 100-289 cm respectively for soil temperature. ERA5-Land lacks deep soil temperature variation to identify permafrost. Gao et al., (2020) used ERA 5-Land to evaluate permafrost distribution in the northern hemisphere. Gao et al., (2020) concluded that ERA5-Land data has a cold bias in mid/low-latitude high-elevation areas, which suggests that ERA5-Land data is sufficient to identify the distribution of permafrost in the northern hemisphere [7].

RESULTS AND DISCUSSION

Future projection of near-surface temperature

Area averaged near-surface temperature in Mongolia is illustrated in Fig.1. RCP2.6 scenario has a minor increase in the temperature toward the end of the 21st century. RCP2.6 has a small variation of temperature during 2020-

2100 with a high uncertainty rate ($R^2=0.0115$). In contrast, the RCP8.5 scenario suggests a strong increase in the temperature with little uncertainty ($R^2=0.8$) in Mongolia.

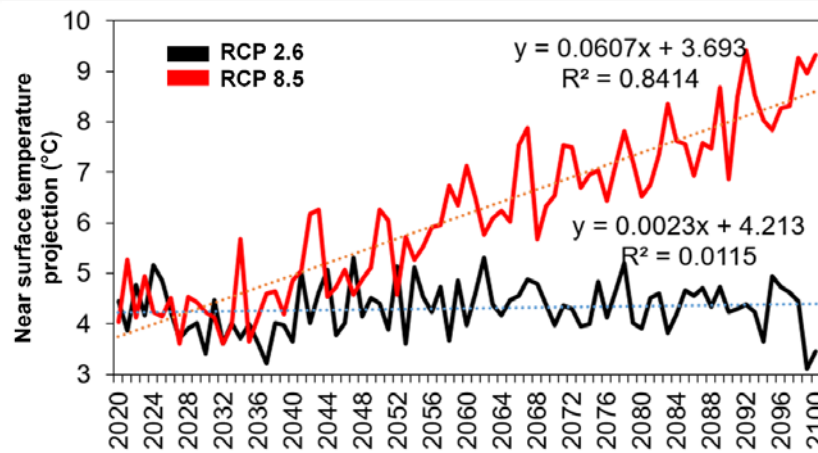


Figure 1. Near-surface temperature projection of RCP2.6 (black line) and RCP8.5 (red line) in Mongolia (42°N-52°N,90°E-120°E)

RCP projection of MIROC5 reveals that near-surface temperature in Mongolia has a similar increasing trend with global projection (Hartmann et al., 2013). Thus, it is necessary to evaluate the variability of permafrost in Mongolia under the condition of a warming climate.

Future projection of permafrost

ERA5-Land is examined to determine the horizontal distribution of permafrost in Mongolia using soil temperature data at a depth of 100-289 cm. 30-year mean maximum

temperature (1991-2020) is used for the analysis. Fig. 2 illustrates the horizontal distribution of permafrost area by ERA5-Land. Permafrost is dominantly distributed in Khangai and Khovsgol mountains and less distribution occurs in the Altai and Khentii mountain ranges. The coldest permafrosts correspond to Altai (-0.83), Khangai (-0.82°C), and Khovsgol (-0.66°C) mountain areas. Mild permafrosts are located in the Khentii (-0.34°C) mountains.

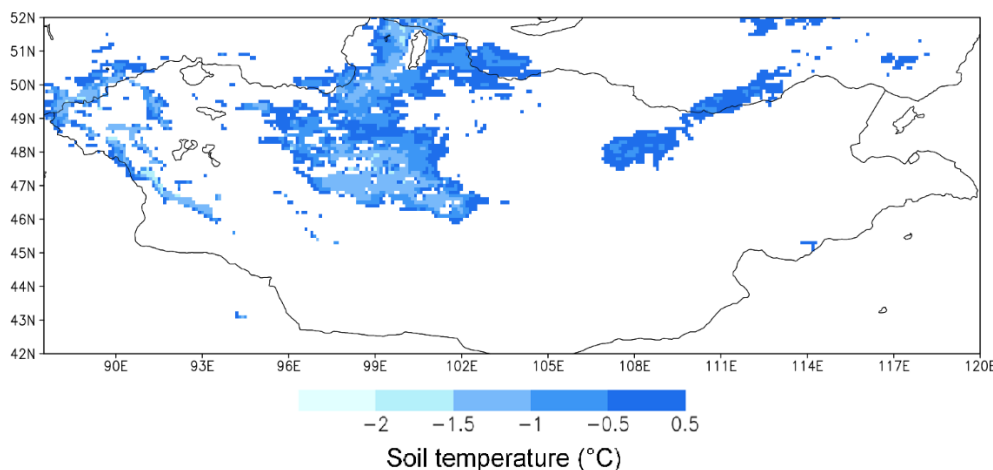


Figure 2. Permafrost distribution in Mongolia using ERA5-Land data

Future change of soil temperature at 3 m under RCP2.6 and RCP8.5 is illustrated in Fig. 3. Two scenarios show distinct differences for the soil temperature variation. RCP8.5 scenario suggests that at the end of the 21st century (2091-2100), area-averaged (90°E-

120°E,42°N-52°N) the soil temperature at 3 m could rise by 4.2°C in comparison with the current climate (2011-2020) in Mongolia. On the other hand, RCP2.6 suggests modest change (risen by 0.6°C) of climate in Mongolia for the same period.

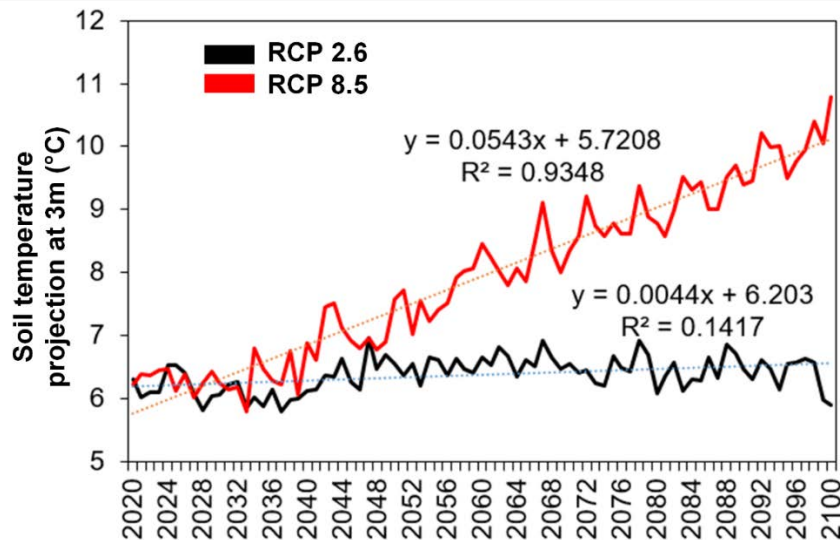


Figure 3. RCP2.6 (black line) and RCP8.5 (red line) projections for area-averaged (90°E-120°E, 42°N-52°N) soil temperature at 3m

Under the RCP2.6 scenario, soil temperature at 3 m has a modest change at the end of the 21st century (Fig. 3). Figure 4 illustrates the horizontal distribution of permafrost change under RCP2.6. The highest loss of permafrost could occur in the middle of the 21st century (Fig.4 c, d, and e). The most vulnerable permafrost is located in the Khentii mountain area, which could potentially disappear by the middle of the 21st century (Fig. 4e). At the end of the 21st century, permafrost distribution maintains the same level as the current climate condition.

Fig. 3 indicates a rapid increase in soil temperature towards the end of the 21st century

under the RCP8.5 scenario. This rapid increase closely corresponds to the horizontal distribution of e permafrost in Mongolia. Fig. 5 suggests that all the permafrost in Mongolia could disappear in the middle of the 21st century under the RCP8.5 scenario. The most vulnerable permafrost is located in Khentii Mountain (Fig. 2) that it may no longer exist in the early middle part of the century (Fig. 5c and d). According to the RCP8.5 scenario, permafrost will thaw completely when area-averaged (90°E-120°E, 42°N-52°N) soil temperature exceeds by 1.8°C in Mongolia.

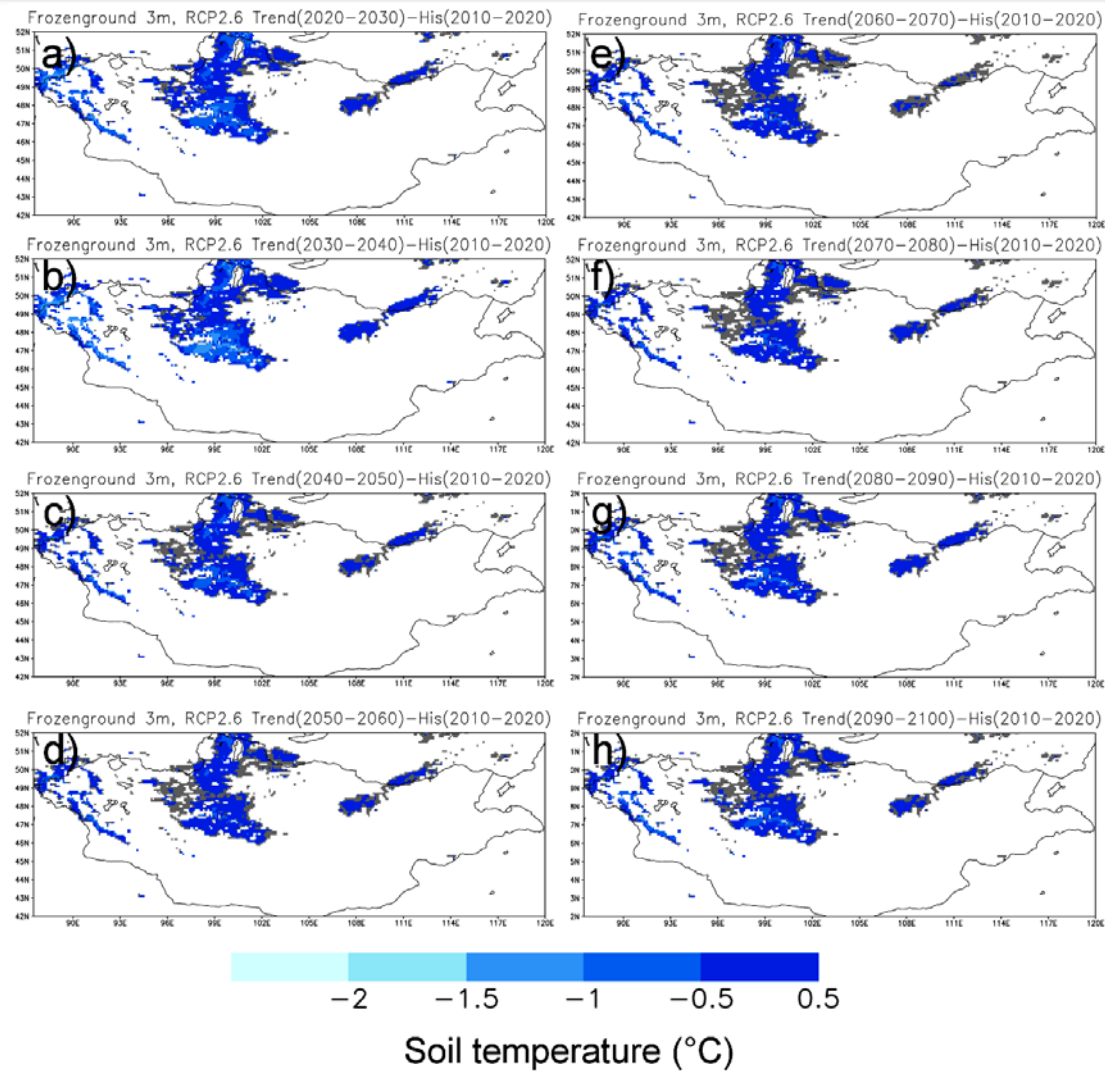


Figure 4. Permafrost change under RCP2.6 scenario in Mongolia. Gray color indicates the current distribution of permafrost; blue color - distribution of permafrost for the corresponding decades

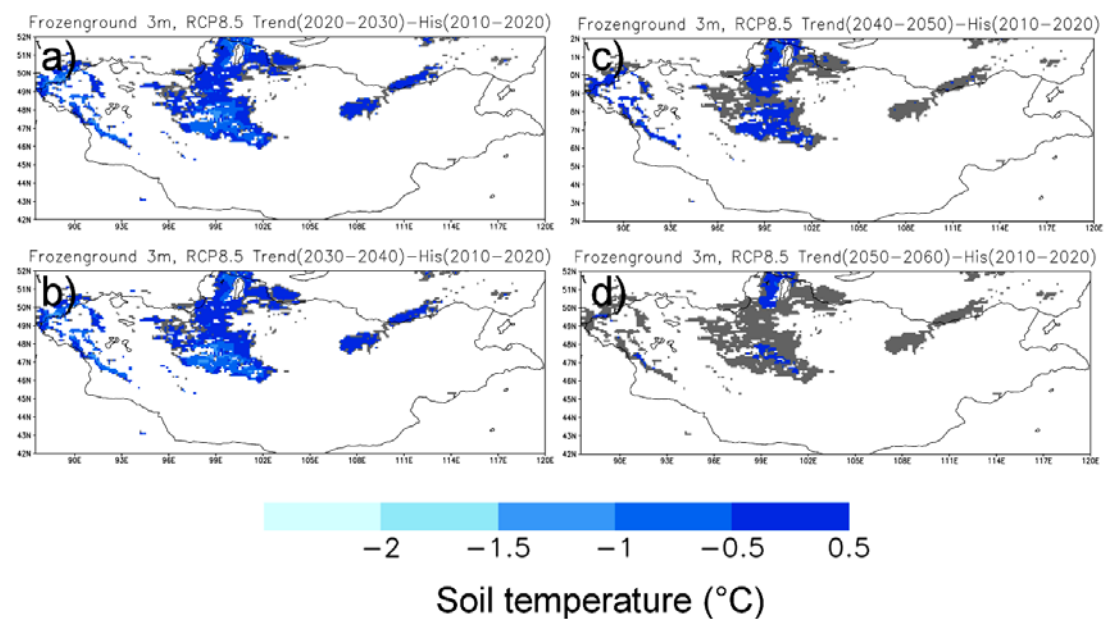


Figure 5. Same as Fig. 4 but for the RCP8.5 scenario

CONCLUSIONS

We carried out the study to identify permafrost distribution, using reanalysis data, and to evaluate the future change of permafrost distribution according to RCP2.6 and RCP8.5 scenarios in Mongolia. Using ERA5-Land data, we discovered that permafrost in the Khentii Mountains is the most vulnerable in Mongolia. Robust and widespread permafrost was identified in the Khangai and Khovsgol Mountains with soil temperature ranging from -0.6°C to -0.8°C . Future change of permafrost was evaluated with RCP2.6 and RCP8.5 scenarios. Under the RCP2.6 scenario, permafrost distribution will remain stable for the most part of the 21st century. Permafrost in Khentii Mountain will potentially melt under the modest scenario of RCP2.6 in the middle of the 21st century. The extreme case of RCP8.5 reveals the biggest impact on permafrost in Mongolia.

According to RCP8.5, permafrost will completely melt by the middle of the 21st century in Mongolia when soil temperature is expected to rise by 1.8°C in comparison with the current climate. This study suggests that 1.8°C of excessive soil temperature will result in complete thawing of permafrost with more carbon being released into the atmosphere. Thus, excessive carbon in the atmosphere will further enhance temperature increase via positive feedback between air temperature and permafrost.

Acknowledgements: This research work was carried out under “Responses of permafrost to climate change and their ecological impacts on the Mongolian Plateau” project. The project has been implemented by The Division of Permafrost Study, Institute of Geography and Geocology (IGG), Mongolian Academy of Sciences (MAS) which is funded by the Mongolian Foundation for Science and Technology.

REFERENCES

- Hartmann D. L. et al., 2013. Observations: Atmosphere and Surface. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- A. L. Washburn, Geocryology - A survey of Periglacial Processes and Environments, John and Wiley Sons Press, New York, 1979. p. 496.
- E. A. G. Schuur, J. Bockheim, J. Canadell, et al., Vulnerability of permafrost carbon to climate change: Implications for the global carbon cycle, *Bioscience* 58 (8) (2008), pp. 701–714.
- Saruulzaya, A. , Ishikawa, M. and Jambaljav, Y. (2016) Thermokarst Lake Changes in the Southern Fringe of Siberian Permafrost Region in Mongolia Using Corona, Landsat, and ALOS Satellite Imagery from 1962 to 2007. *Advances in Remote Sensing*, 5, pp. 215-231.
- Watanabe, M., Suzuki, T., O’ishi, R., Komuro, Y., Watanabe, S., Emori, S., Takemura, T., Chikira, M., Ogura, T., Sekiguchi, M. and Takata, K., 2010. Improved climate simulation by MIROC5: Mean states, variability, and climate sensitivity. *Journal of Climate*, 23(23), pp. 6312-6335.
- Muñoz Sabater, J., (2019): ERA5-Land hourly data from 1981 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). (<05Dec2020>), 10.24381/cds.e2161bac.
- Cao, B., Gruber, S., Zheng, D. and Li, X., 2020. The ERA5-Land soil temperature bias in permafrost regions. *The Cryosphere*, 14(8), pp. 2581-2595.