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*Jain Atul[1]、Shu Shijie[1]、Barman Rahul[1]、El-Masri Bassil[1]
*Jain K Atul[1], Shijie Shu[1], Rahul Barman[1], Bassil El-Masri[1]

1.Department of Atmospheric Science, University of Illinois
1.Department of Atmospheric Science, University of Illinois

One of the major challenges in more detailed Earth system models (ESMs) is the treatment of the biophysical and biogeochemical processes and feedbacks and their impact on soil organic carbon (SOC), in the Northern high latitudes (NHL) permafrost region. . This is because a larger suite of active terrestrial processes coupled with scarcity of observational data introduce many challenges for modelling these processes. Nonetheless, several studies in the recent past have demonstrated improved permafrost modelling capabilities by incorporating soil/snow processes that critically influence the ground energetics in these environments, such as: deep soil layers and organic soils, and the effects of wind compaction and depth hoar formations, and structural properties of vegetation (phenology, assimilated vegetation C allocation to leaves, stems, and roots and root dynamics) However, no study has yet evaluated the combined effects of the improvements of these biogeophysical and biogeochemical processes for the entire NHL.

We use a land surface model, the Integrated Science Assessment Model (ISAM), to investigate the effects of feedbacks between the biogeochemical (C and N) and biogeophysical (water, and energy) processes on the model estimated soil organic carbon (SOC) for the NHL permafrost region. We not only focus on recent model improvements in the biogeophysical processes that are deemed important for the high latitude soils/snow and ppermafroest SOC; such as deep soil column, modulation of soil thermal and hydrological properties, wind compaction of snow, and depth hoar formation; but also biogeochemical processes that are important for soil biogeochemistry; such as dynamic phenology and root distribution, litter carbon decomposition rates and nitrogen amount remaining. We select multiple sites to evaluate the modeled processes. We then carried out several model simulations to study the effects of feedbacks between biogeochemical and biogeophysical processes on SOC in NHL.

After accounting for dynamic biogeochemical processes, ISAM is able to capture permafrost extend and and the carbon stored in NHLs, as well as the seasonal variability in leaf area index (LAI), and root distribution in the soil layers and the root response of soil water uptake and transpiration. The evaluation of the model results suggest that without accounting these processes, modelled growing season length (GSL) for NHL was almost two times higher as compared to measurements. To quantify the implication of these processes on the carbon and water fluxes, we compared the results of two different versions of ISAM, dynamic version which accounts for dynamic processes ($ISAM_{DYN}$) and static version which do not account for dynamic processes ($ISAM_{BC}$), with measurements from12 eddy covariance flux sites. The results show that $ISAM_{DYN}$, unlike $ISAM_{BC}$, is better able to capture the seasonal variability in GPP and energy fluxes. Our modelling analysis shows that by including the biophysical processes in addition to biogeochemical processes, the modelled NHL permafrost carbon increased by 30% from 328 to 447 GtC in the top one meter of soil which is in better agreement with observational estimates of 495 GtC (Northern Circumpolar Soil Carbon Database). Even though the inclusion of these processes generally reduced vegetation

productivity and litter production due to a decrease in soil temperature and liquid water content, increased soil carbon stocks highlight the dominance of soil water/temperature stress on decomposition processes. While continued improvements are required in the treatment of biogeochemistry, here we demonstrate the importance of soil/snow biogeophysical and biogeochemical processes in modelling permafrost carbon stocks, as important drivers of soil biogeochemical processes.

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