

2015 DOE Final UF Report: Effects of Warming the Deep Soil and Permafrost on Ecosystem Carbon Balance in Alaskan Tundra: A Coupled Measurement and Modeling Approach (Grant#DE-SC0006982)

The major research goal of this project was to understand and quantify the fate of carbon stored in permafrost ecosystems using a combination of field and laboratory experiments to measure isotope ratios and C fluxes in a tundra ecosystem exposed to experimental warming. Field measurements centered on the establishment of a two-factor experimental warming using a snow fence and open top chambers to increase winter and summer temperatures alone, and in combination, at a tundra field site at the Eight Mile Lake watershed near Healy, Alaska. The objective of this experimental warming was to significantly raise air and deep soil temperatures and increase the depth of thaw beyond that of previous warming experiments. Detecting the loss and fate of the old permafrost C pool remains a major challenge. Because soil C has been accumulating in these ecosystems over the past 10,000 years, there is a strong difference between the radiocarbon isotopic composition of C deep in the soil profile and permafrost compared to that near the soil surface. This large range of isotopic variability is unique to radiocarbon and provides a valuable and sensitive fingerprint for detecting the loss of old soil C as permafrost thaws.

As of this report, we have completed six years of the experimental warming manipulation. We are recording soil temperature differences as we expected in the plots where snow accumulated behind the snow fence. One key finding is that soil temperatures were 4-8 deg C warmer during the winter in the winter warming treatments. This temperature difference disappeared in the early spring when the snow pack was removed, but it resulted in a persistent difference in the depth of thaw throughout the growing season into late September, meaning that accumulated heat in the winter warming persisted for an entire season. This means that we were able to degrade surface permafrost without other experimental artifacts – the first experiment of this kind. Thaw depth in the soil warming treatment is >30% greater than control. The addition of summer warming via passive chambers warmed the air but did not alter the soil temperature regime or the thaw depth, much as we expected from previous passive warming experiments. Six years of warming has given us substantially better perspective of the changing dynamics over time in response to warming. Initially it appears that summer warming had the largest effect on carbon fluxes. Net ecosystem exchange (NEE) during the growing season was higher in the summer and annual warming as compared to the winter and control treatments, which did not differ. This increase in net uptake was a result of higher gross primary productivity (GPP) and higher ecosystem respiration (R_{eco}), with uptake stimulated more than loss in the summer warming treatment. Despite increases in thaw depth, the winter warming treatment did not have higher respiration than control; this may have been a result of the water table that kept the deep soil saturated late in the growing season when the thaw depths were at maximum. As warming progressed, the pattern differed: winter warming now had a big effect on GPP and R_{eco} along with the summer warming effect that was observed at the

outset of the experiment. Interestingly, the warming treatments all stimulated GPP more than R_{eco} such that the treatments stimulated the sink capacity of the ecosystem. This matched our prediction based on a natural permafrost thaw gradient where initially the warming effect on plants was greater than on soil processes such that increased losses were offset by uptake. Subsequent years followed this same pattern. Soil warming had a strong effect on plant uptake and this offset losses from the soil during the growing season. Furthermore, we made calculations to show that actual climate warming, which may be expected to continue during the fall season as well could contribute to ever larger releases than observed in the experiment itself where the fall period is not kept warmer until the accumulation of the snowpack can occur. Patterns of old carbon release matched our original hypothesis but also presented some surprises. Old carbon loss increased with warmer soils, but the control plots had the lowest radiocarbon respiration values, the metric of old carbon release. This was explained by increases in plant respiration in the warming treatments that introduced additional modern carbon into total ecosystem respiration. When the proportion of old carbon was factored along with total respiration losses, it was the warming treatments that lost the most old carbon even though it was partially obscured by new carbon inputs.

Finally, the period of time of this warming experiment has moved the tundra system beyond the initial perturbation caused by the manipulation. By the end of the project period, we now observe an unequivocal interaction between the soil and air warming treatment. In the first three years of the experiment, this interaction was not significant but has become so in subsequent years. The soil+air warmed treatment is stimulated compared to control, but the level of response is higher than air warming alone while lower than soil warming alone. This intriguing pattern is observed in carbon flux measurements, and also in measurements of plant biomass and soil nitrogen availability pointing towards a plant soil feedback effect that at the time of this report has not yet been explained. As key outcomes, this project has produced new papers published in the peer-reviewed literature, archived datasets that were used for model-data intercomparisons, trained graduate students and postdoctoral researchers, and has raised awareness about the vulnerability of permafrost carbon to a wider audience through various outreach efforts.