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ALASKAN PEATLAND CARBON DYNAMICS DURING PAST WARM CLIMATE INTERVALS

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SUMMARY

Here we use the results from several projects on Alaskan peatlands to illustrate how peat carbon dynamics have responded to past warm climate intervals. Our thermokarst site in Arctic western Alaska shows rapid peat accumulation during the Bolling-Allerod warm period around 13,000 cal BP. During the Holocene thermal maximum around 10,000 cal BP, several sites in Alaska show about four-fold higher peat accumulation rates than the Holocene average; this rapid vertical growth is synchronous with rapid peatland formation and expansion on the landscape across Alaska. Two sites in the Susitna Basin show large magnitude increases in peat accumulation during the warm Medieval Climate Anomaly around 1000-500 cal BP. Furthermore, some peatlands in the Susitna Basin appear to have grown rapidly over the last several decades, likely in response to recent climate warming. Our evidence from Alaska indicates that peat accumulated rapidly during past warm climates, implying that warmth stimulates greater primary production than peat decomposition.

KEY WORDS: Holocene, Alaska, climate change, peatlands, carbon dynamics

INTRODUCTION

Northern circum-Arctic peatlands have accumulated a large belowground carbon pool since the last deglaciation, at about 500 GtC (Gorham, 1991; Yu et al., 2010). However, the fate of this large carbon pool under a warm climate in the future is still uncertain and debated. Here we present some preliminary results from our ongoing research over the last several years on peatland carbon dynamics in Alaska. We examined the responses of peatland carbon

accumulation to warm climate intervals since the last deglaciation using peat-core analysis from 7 peatland sites across Alaska. Our study sites span from boreal sites on the Kenai Peninsula and in the Susitna Basin in south-central Alaska (60-63°N) to arctic sites on the Seward Peninsula in western Alaska (about 65°N). We used this latitudinal gradient and different peatlands as a natural experiment to learn about the sensitivity of peatland carbon dynamics to climate change.

ALASKAN PEATLAND RECORDS: POSITIVE RESPONSE OF CARBON ACCUMULATION TO WARM CLIMATES?

Several warm climate periods since the ice retreat following the Last Glacial Maximum have been documented in high-latitude regions of the northern hemisphere. Abrupt Bolling warming was one of the major deglacial warming events, starting at 14,600 cal BP (Dansgaard et al., 1993). It was also a time of rapid sea level rise and other environmental changes. The Holocene thermal maximum (HTM) is the warmest climate interval during the pre-industrial Holocene, and its timing varies across different regions of the world (IPCC, 2007). In Alaska, the HTM occurred around 10,000 cal BP (Kaufman et al., 2004). During the last millennium, the Little Ice Age (LIA) at about 700-100 cal BP was a major cooling event, documented in many regions in the northern hemisphere (Mann et al., 2009), with strong evidence mostly from glacier dynamics (the largest Holocene glacier expansion) in Alaska (Barclay et al., 2009). A relative warm interval (Medieval Climate Anomaly; MCA) occurred at 1000-800 cal BP before the LIA. Also, there was a cold climate interval documented by glacier advance in Alaska around 1200 cal BP, called the First Millennium Advance (Barclay et al., 2009). These climate intervals documented by independent paleoclimate records in the literature were used to compare with our peat carbon accumulation records for understanding climate sensitivity of northern peatlands.

At our thermokarst site (Niukluk Lake peatland) on the Seward Peninsula in arctic western Alaska (Table 1), very rapid carbon accumulation in one core from a drained thermokarst lake basin (at ~70 $gC/m^2/yr$) occurred at 13,500-12,500 cal BP during the Bolling-Allerod warm period, compared to the average Holocene accumulation rate of ~20 $gC/m^2/yr$ at this site. The climate at the Bolling-Allerod time was likely more continental on the Seward Peninsula when the sea level was lower and the Bering Strait was mostly exposed. Thus, we hypothesize that the continental conditions under a general warm climate might have limited cooling effect of sea ice in the Bering Sea on terrestrial ecosystems. Well-preserved peat was also observed at that time at several other sites in Alaska, including Petersville peatland. Alternatively, the high accumulation rate was mostly related to local factors during the initial permafrost thaw, as high initial accumulation rates of Holocene-aged peats have been observed in drained lake basins on the northern Seward Peninsula (Jones et al., in review).

Table 1. Summary of peatland sites in Alaska and key evidence for their carbon dynamics response to past warm climates.

Site	Latitude	Longitude	Altitude (m asl)	Evidence	Reference
Kenai Gasfield	60.450	-151.250	17	Highest C accumulation rates at HTM; 4-fold higher than during the mid-Holocene	Yu et al., 2009; Jones and Yu, 2010
No Name Creek	60.633	-151.083	23	Highest C accumulation rates at HTM; about 4-fold higher than during the mid-Holocene	Yu et al., 2009; Jones and Yu, 2010
Petersville	62.417	-150.683	450	Unusually high C accumulation rates over the last 100 years, associated with major vegetation change	Loisel and Yu, in review
Herc	62.375	-151.081	250	Pronounced increase in peat C accumulation during the MCA at lowland site, but no change in C accumulation at moraine site	E. Klein, unpublished
M179	63.081	-149.527	460	Rapid peat C accumulation during the MCA; deposition hiatus at the LIA; and lower C accumulation rate at the FMA	Hunt, 2010
Yukon Delta	60.523	-161.093	28	Rapid C accumulation in recent decades or century, potentially in response to permafrost thaw	E. Klein, unpublished
Niukluk Lake	64.827	-163.454	16	Extremely rapid C accumulation during the late part of Bolling-Allerod warm period; long deposition hiatus during the Younger Dryas and the earliest Holocene	S. Hunt, unpublished

Notes: HTM = Holocene Thermal Maximum; FMA = First Millennium (Glacier) Advance; MCA = Medieval Climate Anomaly; LIA = Little Ice Age

Several sites on the Kenai Peninsula show peak carbon accumulation during the HTM around 10,000 cal BP, about four fold higher than the rest of the Holocene (Jones and Yu, 2010). A compilation of 33 sites from across northern peatlands shows a similar accumulation peak at about 10,000 cal BP (Yu et al., 2009), at the time of maximum summer insolation in the northern hemisphere, despite variable timings of the HTM. Also, the peak vertical peat accumulation corresponds with the maximum lateral peatland expansion in Alaska (Jones and Yu, 2010) and in northern peatlands as a whole (MacDonald et al., 2006). This suggests that vertical carbon accumulation and lateral expansion are related, possibly driven by similar, or even by the same ecosystem processes, which were enhanced by warmer summers and stronger seasonality in the early Holocene.

Carbon accumulation rates at M179 peatland, just south of the Alaska Range in the Susitna Basin, were >60 $gC/m^2/yr$ at 1000-450 cal BP during the warm MCA, much higher than the rates (<20 $gC/m^2/yr$) during the earlier FMA around 1200 cal BP and the LIA (deposition hiatus) (Hunt, 2010). At the Herc site, also in the Susitna Basin, a lowland peatland on an outwash channel shows a similar carbon accumulation pattern, with a peak during the MCA. However, a nearby peatland that is higher up on a moraine shows no obvious change in carbon accumulation rates over the last 1000 years, suggesting that peatland hydrology or hydrological sensitivity (as influenced by mineral substrate) is an important factor in affecting ecosystem processes and carbon accumulation.

Several cores from a peatland complex at Petersville in the Susitna Basin show extremely high carbon accumulation rates during the last 100 years. As recent peat has not experienced decomposition for a long time, we often see higher apparent carbon accumulation rates in young peat than in old peat. However, decomposition modeling analysis suggests that the recent accumulation is still high, even accounting for this ecosystem maturity effect (Loisel and Yu, in

review). Also, a major vegetation change from non-*Sphagnum* to *Sphagnum*-dominant peatlands occurred around the same time. A similar extremely high carbon accumulation in recent peat appears to occur at a thawed permafrost peatland site in the Yukon Delta in Southwest Alaska. The observed increase of carbon accumulation over the last century might have been in response to temperature and soil warming, especially in high-latitude regions. Furthermore, it appears that warming impacts on carbon accumulation are mediated through changes in vegetation and permafrost conditions.

CONCLUDING REMARKS

Our results from several peatland sites across Alaska show positive responses of peatland carbon accumulation to warm climates in the past. This suggests that high temperature stimulated more increase in plant productivity than peat decomposition. This implies that northern peatlands in sub-arctic and boreal regions may serve as a negative feedback to future climate warming, especially in regions that will not experience moisture deficits.

How these carbon-rich peatland ecosystems respond to future climate change is an important global change question. To further test the ideas that are generated from our studies in Alaska, we need to analyze peat accumulation from different types of peatlands (dry bogs vs. wet fens) in different regions (maritime vs. continental; peatlands at the center vs. margin of their distributions). Also, there is a need for data collection and modeling efforts to understand the relative roles of temperature and precipitation in controlling peat carbon accumulation at different time scales (from interannual to millennial) (Yu et al., 2011).

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