Early to Mid-Holocene Glacier Fluctuations in Glacier Bay, Alaska

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Abstract. The history of glacial activity in Glacier Bay during the Holocene is not well known. Radiocarbon dating of trees overridden by glacial advance, coupled to sedimentological and geomorphological evidence, provide rates and positions of ice margins over the last 9,000 radiocarbon (C14) years before present (BP). Major periods of ice advance were initiated in both the East and West Arms prior to 9,000 C14 years BP and continued through at least 6,800 C14 years BP. This advance apparently reached as far south as Geikie Inlet, but whether it extended beyond this point is not yet known. Ice receded to the upper reaches of both Arms prior to a second advance that began at about 5,000 C14 yrs BP. Glaciers appear to have continued to expand to Francis Island without interruption through 4,000 C14 yrs BP. Our data suggest that two and possibly three advances of ice, each separated by a recession of unknown extent, took place after ~3,200 C14 years BP, culminating in the Little Ice Age advance. Glacial expansion is commonly thought to occur during a period of colder climate; however, our data suggest that ice growth during the Early Holocene (9,000 years BP) continued after climatic changes of the Holocene thermal maximum had begun. Current investigations are evaluating signals in the tree-ring record for possible causes including external forcing such as El Nino, Pacific Decadal Oscillation and Arctic Oscillation.

Introduction

As part of our on-going, long-term analyses of the physical systems in Glacier Bay, we have been studying various lines of evidence for the activity of glaciers and the climate during the Holocene period that began about 13,500 years ago. Previous work in the Glacier Bay region has suggested that glacial activity was asynchronous in the East and West Arms; recently gathered climate data (see Finnegan and others, this volume) suggest that prevailing storm tracks and orographic effects of the Fairweather Range produce precipitation gradients that may in part explain such differences. Our sampling and analysis of interstadial wood suggest that these apparent differences in glacial activity between the East and West Arms of Glacier Bay can be more precisely delineated. Because there is a considerable amount of interstadial wood, continued sampling may allow us to produce an unprecedented tree-ring chronology and paleoclimatic record for the Holocene period of southeast Alaska.

In this paper, we present preliminary results of our study of glacial activity during the early to mid-Holocene. Our data suggest that ice advanced twice across much of Glacier Bay during this period, with significant recession to the heads of inlets between each advance, and further that glaciers in the West and East Arms did so asynchronously. In addition, the earliest recorded ice advance apparently took place when temperature globally was the warmest in the Holocene (e.g. Kaufmann, and others, 2004). Our on-going studies of the tree rings from stumps overridden during the advances will help us understand the regional climate during this time.

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Methods

We used standard geological methods to develop the glacial history. These methods included defining the glacial stratigraphy by sedimentological analysis of deposits (e.g. Benn and Evans, 1998), and by dating wood, peat, and soil horizons in these deposits using radiocarbon methods (e.g. Bowman, 1990). We also sought to locate as many *in situ* tree stumps overridden by advancing glacier ice as possible. Precise radiocarbon dating using the Accelerator Mass Spectrometry (AMS) technique (e.g. Gove, 1999) on these stumps provides a location and time for which we can be sure ice was present. Each stump, log, and geologic section is located using GPS, and these locations subsequently were entered into a database from which we created a GIS coverage. By locating the *in situ* stumps and logs on a base map, the distribution of dates reveals the timing of ice advance through the East and West Arms into the lower bay. Reconstructing the history of glacial advance and retreat is a complex process, given the dimensions of Glacier Bay, sparse distribution of glacial deposits, multiple ice sources, and remote locations that we must access on foot.

Although approximately 200 stumps and logs have been radiocarbon-dated (fig. 1), including stratigraphic sections in Reid, McBride, Upper Muir, Wachusett, and Tidal inlets, the history of ice advance and recession reported in this summary remains preliminary.

Results

Two periods of ice advance, separated by an extensive recession of the glaciers between each, are evident. Our data suggest that ice was advancing into the uppermost reaches of Tarr Inlet, near the present terminus of Grand Pacific Glacier, by about 8,800 C14 yrs BP (fig. 2). It was similarly advancing into the upper reaches of Muir Inlet near the Muir Glacier

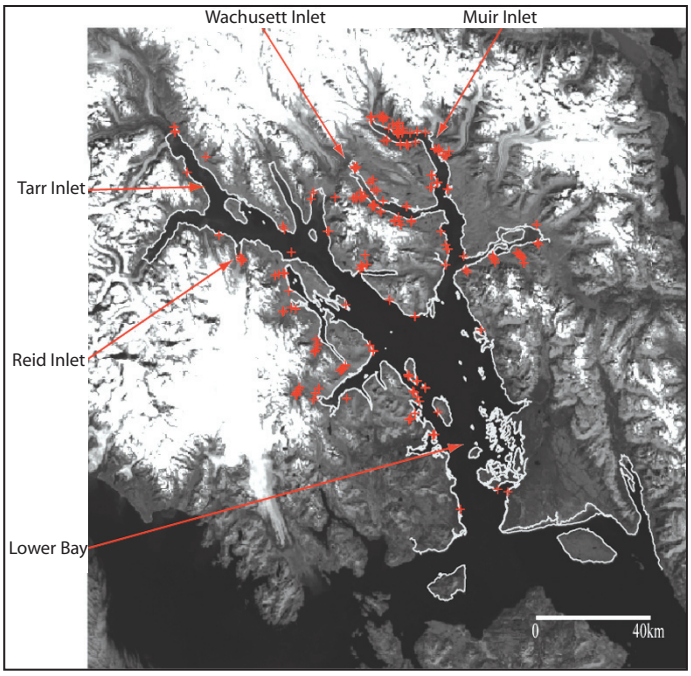

Figure 1. Landsat ETM + image of Glacier Bay National Park and Preserve with locations (crosses) of overridden tree stumps and logs.

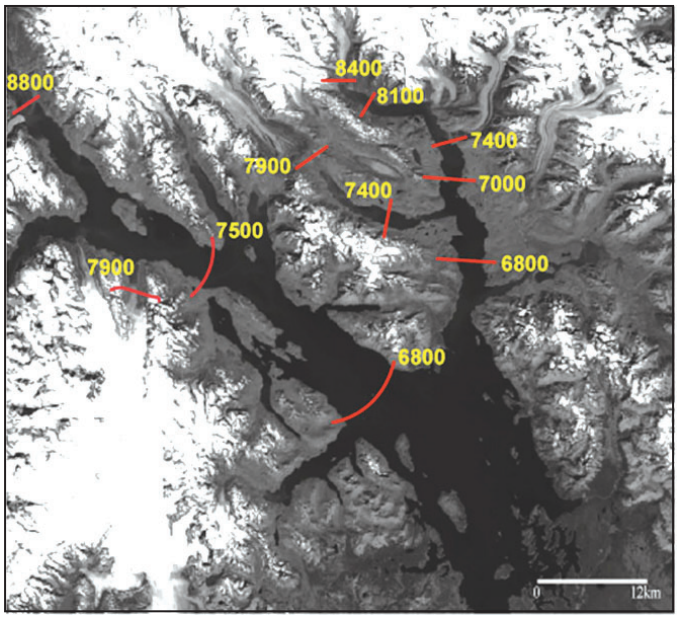

Figure 2. Positions of ice margins in the East and West Arms of Glacier Bay during the period of approximately 9,000 C14 yrs BP to 6,800 C14 yrs BP.

terminus, but slightly later at about 8,400 C14 yrs BP. This advance apparently lasted until approximately 6,800 C14 yrs BP, terminating in the lower reaches of Muir Inlet near the mouth of Adams Inlet and in the lower bay near the mouth of Geikie Inlet. Our preliminary data suggest that the glaciers of the East and West Arms did not coalesce to form a single lobe. But our data in the area of Sebree Island southward to Beartrack Cove are extremely sparse and further study is required to determine if this is an accurate assessment.

Calculations using the centerline of each fjord as a measure of distance indicate that ice advanced at rates ranging from ~20 to 49 m/yr, averaging nearly 32 m/yr through Tarr Inlet to the mouth of Geikie Inlet. In Muir and Wachusett Inlets, the rates ranged from ~10 to 64 m/yr, but with about the same average rate over the course of the advance to near Adams Inlet. The range in rates is preliminary as we have limited sites along each fjord to base this calculation.

A period of ice recession appears to have begun some time after 6,800 C14 years BP, with the subsequent interstadial period lasting until about 5,000 C14 yrs BP. Overridden trees at the head of Reid Inlet indicate a second ice advance began there about 4,900 C14 yrs BP, one that appears to have lasted until at least 4,000 C14 yrs BP, with ice terminating its advance near Francis Island (fig. 3). There are also multiple stumps just beyond the 4,100 to 4,000 year old ice margin position that occur on the north end of Willoughby Island; these date from the period ~3,400 to 3,200 yrs BP, suggesting that the same ice mass may have been responsible for their deaths. To date however, we have no compelling evidence to indicate that these are two unique ice marginal positions, or they represent the same event.

In addition, we currently lack evidence of a similar age advance in the East Arm. Overridden stumps and associated glacial deposits have been dated from about 3,000 C14 yrs BP and younger, but glacial deposits and associated trees from the period between 6,800 and 3,400 yrs BP have not been located. Our preliminary conclusion is that the ice masses behaved

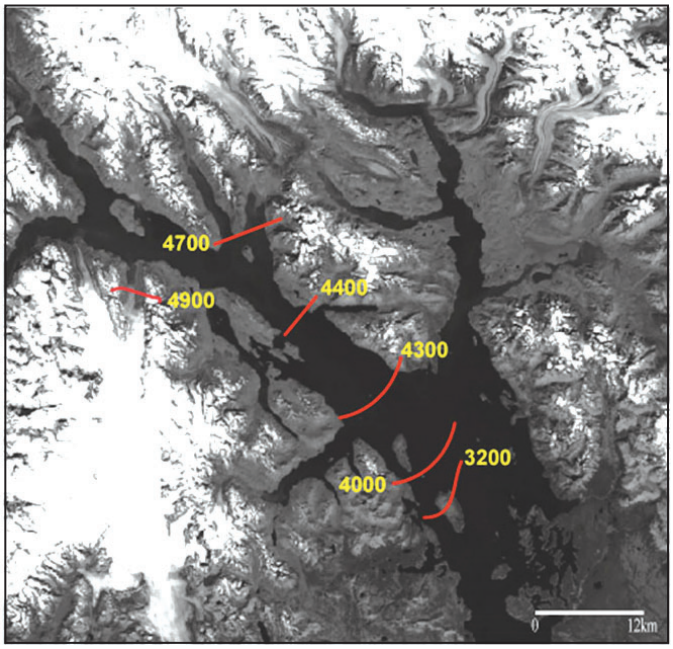

Figure 3. Positions of ice margins in the West Arm of Glacier Bay during the period of approximately 5,000 C14 yrs BP to 4,000 C14 yrs BP; the margin at 3,200 C14 yrs BP is speculative.

differently in the two arms; until additional studies are completed, we remain unsure as to whether glacial deposits and trees from this time have been lost during subsequent ice advances, or we have simply not yet found them.

Rates of ice margin advance from Reid Inlet to the southern tip of Francis Island apparently were much higher than those of the previous glaciation and ranged from ~47 to 72 m/yr. We have no explanation of why rates were higher and we continue to work on this question by seeking additional deposits and dates from trees between Reid Inlet and Drake Island.

Discussion and Conclusions

Our preliminary findings indicate that Glacier Bay was glaciated twice during the early to mid-Holocene period. The first advance was underway by 8,800 C14 yrs BP, lasting until about 6,800 C14 yrs BP. This advance took place in both the East and West Arms, but the two glaciers apparently did not coalesce in the upper part of the lower bay. A subsequent advance in the West Arm was underway about 4,900 C14 yrs BP, reaching Francis Island about 4,100 yrs BP. We have not found compelling evidence of a comparable advance in the East Arm. Both the West and East Arms bear evidence of ice advance ca. 3,000 yrs BP, but we lack sufficient data to constrain this event further at this time.

The length of time between termination of the 9,000 yr advance and initiation of the 5,000 yr advance was 1,200 years or less. We do not yet know how rapid the recession was post-6,800 yrs BP, but it was long enough to develop a mature forest.

It is interesting to note that the oldest dates for the earliest ice advance occur at the present margins of the active glaciers at the heads of each fiord. Whether we have now reached the furthest point of retreat of ice during the Holocene is not known, but it could be that with further thinning and recession of ice, additional evidence will be uncovered and extend the distance of ice recession further.

As our research continues, we will evaluate the paleoclimate of the Holocene by studying tree-ring records from the overridden stumps. Globally, the early Holocene has been characterized as the warmest of the last 12,000 years and yet our data indicate a sustained ice advance took place in Glacier Bay during that time. The tree-ring record may provide data on past temperatures and precipitation in the Park (e.g. Fritts, 2001) that will help us understand why glaciation occurred. Ultimately, this record of climate will be useful in calibrating climate models for predicting future changes in regional and global climate.

Management Implications

The record of glaciations during the Holocene is essential to understanding how the landscape of Glacier Bay developed, and when and where humans may have inhabited or used the resources of the park region. It is also important to note that a paleoclimatic record of the last 10,000 years may be present in the overridden forests. This record will be necessary for calibrating predictive models of future changes in global and regional climate, and to forecast their potential effects on the park. Data from tree-ring and other types of records are lacking in this climatically sensitive region of the North Pacific, and the record preserved in the ancient forests of Glacier Bay is the longest and most extensive in this region. However, it is critical to realize that once overridden stumps, logs, and glacial deposits are exposed by erosion or uplift of shore zones, they become subject to rapid degradation within a few years or less. It is thus crucial that locating and sampling of these rare, ancient forest remnants continue before they are gone and the record is forever lost.

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