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Late Holocene glacial history of the Copper River Delta, coastal south-central Alaska, and controls on valley glacier fluctuations

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A R T I C L E I N F O

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A B S T R A C T

Fluctuations of four valley glaciers in coastal south-central Alaska are reconstructed for the past two millennia. Tree-ring crossdates on 216 glacially killed stumps and logs provide the primary age control, and are integrated with glacial stratigraphy, ages of living trees on extant landforms, and historic forefield photographs to constrain former ice margin positions. Sheridan Glacier shows four distinct phases of advance: in the 530s to *c*.640s in the First Millennium A.D., and the 1240s to 1280s, 1510s to 1700s, and *c*.1810s to 1860s during the Little Ice Age (LIA). The latter two LIA advances are also recorded on the forefields of nearby Scott, Sherman and Saddlebag glaciers. Comparison of the Sheridan record with other two-millennia long tree-ring constrained valley glacier histories from south-central Alaska and Switzerland shows the same four intervals of advance. These expansions were coeval with decreases in insolation, supporting solar irradiance as the primary pacemaker for centennial-scale fluctuations of mid-latitude valley glaciers prior to the 20th century. Volcanic aerosols, coupled atmospheric-oceanic systems, and local glacier-specific effects may be important to glacier fluctuations as supplemental forcing factors, for causing decadal-scale differences between regions, and as a climatic filter affecting the magnitude of advances.

1. Introduction

Valley glacier fluctuations are a key record for understanding the natural forcings and spatial expression of late Holocene climate change. Termini of valley glaciers respond within years to decades of a change in climate by advancing or retreating (Jóhannesson et al., 1989; Raper and Braithwaite, 2009), and leave characteristic sediments and landforms as records of past termini positions. Dates on trimlines and moraines reveal when termini reached and receded from maxima, while forefield organic materials interbedded with or incorporated into glacigenic sediments constrain intervals of ice minima and re-advance. When dated by tree-ring crossdates, these glacier forefield records have enabled termini fluctuations over the last one to two millennia to be reconstructed with very high spatial and temporal detail (e.g. Luckman, 1995; Holzhauser et al., 2005; Barclay et al., 2009a).

While valley glacier histories have been developed for many mountain areas of the world (Davis et al., 2009), there remains uncertainty as to what climatic forcings have been the dominant cause of termini fluctuations prior to the twentieth century. Some authors have emphasized solar irradiance as the primary driver (e.g. Denton and Karlén, 1973; Wiles et al., 2004; Hormes et al., 2006) while others have linked past glacier fluctuations to volcanic activity, changes in atmospheric–oceanic systems, and feedbacks such as sea ice formation (e.g. Porter, 1986; Denton and Broecker, 2008; Licciardi et al., 2009; Schaefer et al., 2009; Miller et al., 2012; Putnam et al., 2012; Lowell et al., 2013). Further interpretive complications arise from local factors such as glacier size, geometry, debris cover, and terminal environment (e.g. Pelto and Hedlund, 2001; Boyce et al., 2007; Kirkbride and Winkler, 2012), which can influence the specific response of ice margins to climatic forcing.

In this paper we use tree-ring crossdates to detail the late Holocene history of four valley glaciers that terminate on the Copper River Delta in coastal south-central Alaska. One of these records, that of Sheridan Glacier, spans almost 2000 years and is the most complete and best-constrained valley glacier history yet developed in Alaska. These data are then used to consider the relative roles of global to regional climate forcing factors and non-climatic local effects on valley glacier histories.

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1.1. Study area

The Copper River Delta is a low relief foreland situated between Prince William Sound and the mouth of the Copper River (Fig. 1). The four study glaciers (Table 1) all flow southwards from an area of Paleogene-age sedimentary and granitoid rocks (Winkler and Plafker, 1993) in the Chugach Mountains. Peaks around the névés of the four glaciers are generally around 1200 m and locally reach to 1909 m above sea level. Sheridan and Saddlebag glaciers both currently terminate in proglacial lakes that are dammed by late Holocene moraines and associated deposits, while Scott and Sherman glaciers are fronted by vigorous outwash river systems.

Climate on the Copper River Delta is maritime with mean monthly temperatures of −4.1 °C in January and 12.5 °C in July (1971–2000, NCDC normals) being recorded at the Cordova Airport (Fig. 1). Average annual precipitation is 2445 mm and is distributed throughout the year with a peak in September and October. Climax forests on outwash are usually dominated by Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), while mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) is generally more common on moraines, hillslopes and at higher elevations. Sitka alder (*Alnus crispa* (Ait.) Pursh ssp. *sinuata* (Reg.) Hult.) and black cottonwood (*Populus trichocarpa* Torr. & Gray) dominate early successional stages on recently disturbed or deglaciated ground (Boggs, 2000).

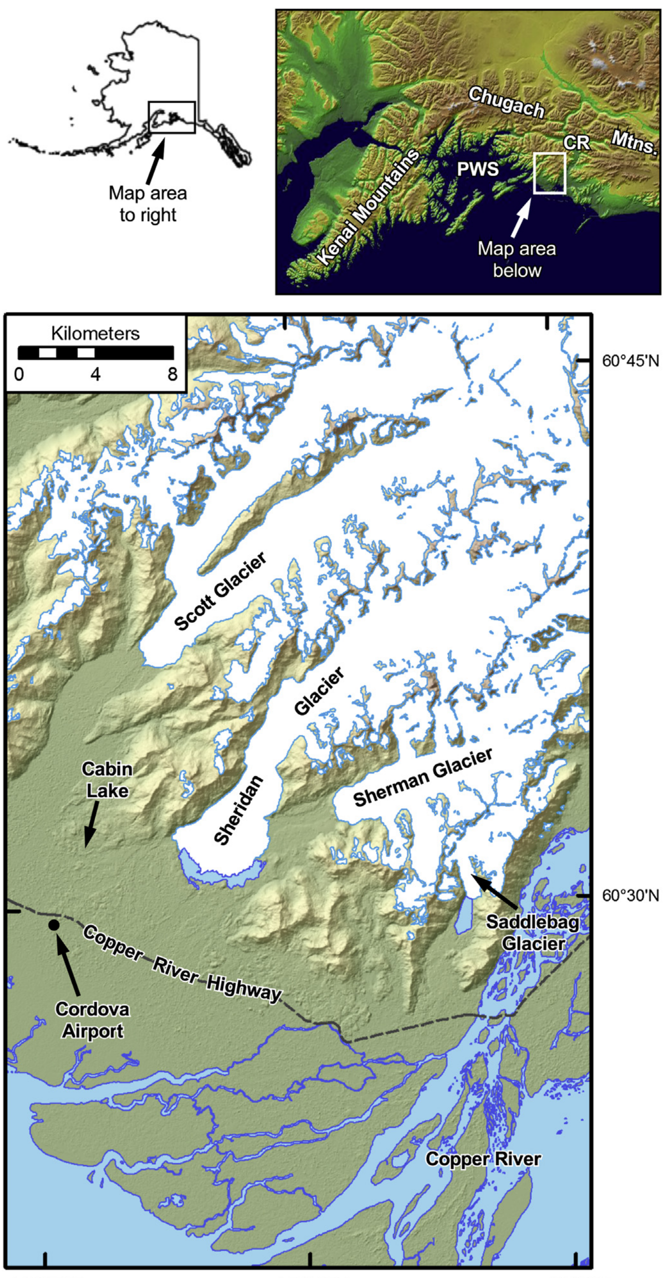

Fig. 1. Copper River Delta study area. PWS: Prince William Sound. CR: Copper River.

Table 1
Copper River Delta glacier characteristics.

Name	Length (km)	Terminus elevation (m)	Main flow direction
Scott	24	150	SW
Sheridan	24	50	SW–SSW
Sherman	13	120	WSW
Saddlebag	8	85	S

The Copper River Delta is located above the Aleutian megathrust and was co-seismically uplifted about two meters during the 1964 M9.2 earthquake (Plafker, 1969). Previous large earthquakes about 800 and 1500 years ago (Hutchinson and Crowell, 2007; Shennan et al., 2008) may have similarly uplifted the area, while drowned tree stumps at the seaward edge of the delta record gradual land surface subsidence during inter-seismic periods (Plafker, 1990). The glacier forefields of this study are high enough above sea level and sufficiently dominated by glacial processes so as to have minimal influences in the stratigraphic and landform record from vertical tectonic displacements. However, co-seismic landslides such as the 1964 large volume rock avalanche onto Sherman Glacier (Shreve, 1966) can potentially alter mass balance and thus affect glacier dynamics (Bull and Marangunic, 1968).

1.2. Previous studies

The study glaciers were first described and sketched from a distance by expeditions traveling along the Copper River Delta shoreline in 1884 (Abercrombie, 1900) and 1886 (Seton-Karr, 1887). Although the earliest glacier maps erroneously show Sheridan and Sherman as two tributaries feeding a single terminus (Brooks, 1908; Grant and Higgins, 1909), closer observations in 1910 (Tarr and Martin, 1914) established that these were two separate glaciers and this is reflected on maps thereafter (e.g. Chapin, 1913). Tarr and Martin (1914) also noted that both Sheridan and Saddlebag glaciers were thinning and beginning to retreat from recent maxima. At Sheridan Glacier this marginal retreat amounted to 335 m from a major moraine and forest trimline by 1925–26 (Lutz, 1930), and in 1931 Wentworth and Ray (1936) noted further retreat and thinning.

Lutz (1930) examined the reforestation process on recently deglaciated ground at Sheridan Glacier and found the pioneer species to be spruce, mountain hemlock, alder and cottonwood. Both tree ages on moraines and radiocarbon ages from glacially killed stumps and logs were used by Tuthill et al. (1968) to develop a late Holocene history of Sheridan and Sherman glaciers. Field (1975) used the observations of earlier workers together with aerial photographs to summarize retreat of all four of the study glaciers from the early to middle 20th century. We incorporate key results from these prior workers with our own data in our reconstructed histories of the forefields.

2. Methods

Fieldwork for this study was completed in the summers of 1993, 1999, and 2002. Living trees and recently logged stumps on