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SEVENTEENTH CENTURY VOLCANIC-INDUCED COOLING SIGNALED BY TREE RING GROWTH, GULF OF ALASKA

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ABSTRACT

Oral histories from the Huna Tlingit of southeast Alaska chronicle an interval of extreme cold, when winter succeeded the previous winter without an intervening summer. At this time, the advance of the Sit'Tlein glacier forced the Huna Tlingit to emigrate from their homeland, in Glacier Bay, further southward. The timing of this protracted winter is uncertain. Recent work in Scotland links 17th-century volcanism to an extreme cooling event in the mid-to-high latitudes, and the coldest summers identified in multiple northwest European tree-ring series are 1698, 1699, and 1700. Seventeenth-century volcanism is likely the cause of the cold period documented along 55-60 N latitude in Europe. A similar marker has been identified, though not yet studied, in the North Pacific sector. We analyze tree ring data from Yellow Cedar (YC) and Mountain Hemlock (MH), two temperature sensitive tree species in Southeast Alaska, to provide insight into temperatures from 1550 to 1850 CE. We selected 13 total locations from the International Tree Ring Data Bank (ITRDB) with a combined sample size of approximately 300 trees during the 300-year window of interest. Trends in MH and YC ring thicknesses correlate strongly with the volcanic-induced cooling event previously documented in Scotland. Though 1698-99 is a strong candidate for the "winter following winter" documented in oral histories, it's possible that the longer period of cold we document in this study was responsible for the rapid advance of the Sit'Tlein glacier and the resulting migration of the Huna Tlingit people.

INTRODUCTION AND BACKGROUND

The focus of this study is to characterize a cooling event in the Gulf of Alaska during the late 1600s in a global context. This cooling event is well-established in other high-latitude regions, but it has only recently been identified in the Gulf of Alaska (GOA) based on summer temperature-sensitive tree ring chronologies, including Mountain Hemlock (Wiles et al., 2014). Several large volcanic eruptions (perhaps six) occurred throughout the 1600s, all of which were climatically effective; their release of gas and aerosols caused brief or even long-term climate changes (Briffa et. al., 1998). Briffa et al. (1998) used climate-proxy ice core data to date significant eruptions in the years 1601, 1641-43, 1659, 1675, 1695, and 1698/9. We focus on the 1690s eruptions, which fall within an interval of extreme cold documented in Scotland (D'Arrigo et. al., 2020).

D'Arrigo et al., (2020) attribute extreme cooling of Scotland and northwestern Europe during the late 1690s and early 1700s to volcanic-induced climate change. The coldest summers in multiple tree-ring series are 1698, 1699, and/or 1700, which correspond to the Seven Ill Years, a period of famine and economic hardship in Scotland (D'Arrigo et al., 2020). D'Arrigo et al., (2020) reconstructed Scottish mainland summer temperatures from 1200 to 2000 CE and demonstrated that the coldest decade during this period was the 1690s (Fig. 1). D'Arrigo et al. (2020) used historical datasets from the British Isles and northern Europe to corroborate Scottish data and established that the 1690s cooling was hemisphere-scale. D'Arrigo et al. (2020) suggest that the cause of

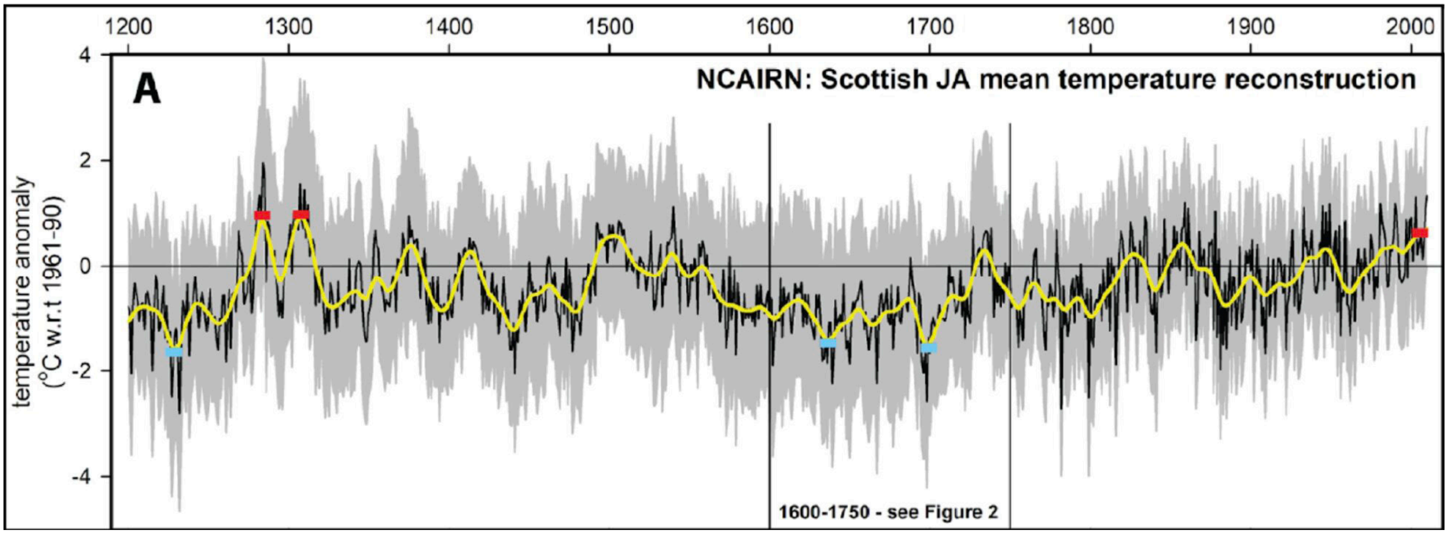

Figure 1. Scottish mainland summer (July-August) temperature reconstruction (D'Arrigo et al., 2020). The coldest decades, including the 1690s, are indicated by blue squares while the warmest are indicated by red squares. The yellow line represents a running average of the data.

this period of cold was a period of active volcanism in the seventeenth century.

The 1690s cold interval occurred during the Little Ice Age (LIA) (Crowley et al., 2008; Sun et al., 2022). Miller et al. (2012) postulate that cooling in the LIA was, in part, triggered by phases of frequent volcanism beginning around 1250 CE and intensifying around 1600 CE. The Maunder Minimum, a period of extremely low solar activity, also coincides with this period, amplifying cold temperature anomalies during the 1645-1715 interval (Bourgeois, 2015). The advance of glaciers in the Arctic and subarctic was a direct consequence of these feedback systems (Luckman, 2000). Lawson et al (unpublished) reconstructed the advance of the Tidewater (Sit' Tlein) glacier in southeast Alaska based on tree ring data. The rapid advance of the Sit' Tlein glacier coincides with the beginning of the eighteenth century, a result of the prevailing anomalously cold temperatures.

Leland et al. (2023) conducted a similar study in Alaska and established two climatically effective volcanic eruptions during the early 1800s that were responsible for another of the Little Ice Age's coldest intervals (Leland et al., 2023). A low-latitude, tropical eruption in 1809 triggered intense cooling in the Gulf of Alaska, identified through tree-ring proxy data (Leland et al., 2023). These studies along the Gulf of Alaska, based primarily on tree-ring-based temperature reconstructions, have demonstrated similar timing to cooling periods established at Scotland, also at high-latitude (e.g., Leland et al., 2023).

Lastly, oral histories from the Huna Tlingit of southeast Alaska chronicle an interval of extreme cold in their homeland, where winter abruptly succeeded the previous winter without an intervening summer (Hinkley et al., 2026). Huna Tlingit people "began to be in want of food," and shortly before or at this time, they were forced off their homeland in Glacier Bay due to the advancing Sit'Tlein glacier (Swanton, 1909). However, the precise timing of this protracted winter has only been speculated. The hunter-gatherer lifestyle of Alaska's coastal indigenous communities has long been threatened by climate change—particularly cooling periods that alter sea surface temperatures, disrupting both marine and terrestrial food sources (Crowell et al., 2023).

METHODS

We selected seven Yellow Cedar (YC) and six Mountain Hemlock (MH) locations for analysis from the International Tree Ring Data Bank (ITRDB; Fig. 2). We limited our analysis to data that included ring widths covering the entire interval of interest (1550 - 1850 CE) and at latitudes similar to northwestern Europe (between 55°N and 60°N). We focused on the interval from 1550 to 1850 CE for our analyses. Those not already standardized were first compiled in COFECHA (Holmes, 1983), a dendrochronology software program that crossdates tree-ring data serves as a quality control on tree-ring dating. The resulting COFECHA master chronologies retain their high frequency (year to year) variability and were used in subsequent analyses.

For each species, we combined ring width indices, by averaging the multiple ring-width series into one mean ring width index (RWI) for each year. With these data, we then smoothed chronologies for each species with a fifteen-year running average to eliminate small-scale variability. We correlated each chronology with mean summer (Jun-Aug) temperature data from Juneau, AK, in KNMI Climate Explorer (Trouet et al., 2013). Afterwards, we averaged the two species-specific chronologies to create a master temperature-sensitive chronology representative of the entire study area (Fig. 2). Finally, we applied 10-year running averages to each species-specific chronology to capture decadal variability.

RESULTS AND DISCUSSION

Tree ring data from the thirteen stands of temperature-sensitive tree species reveal similar ring width trends in response to shifting climate conditions through time (Fig. 3). Each species chronology shows similar fluctuations in ring width thicknesses during the period from 1550 to 1850 CE. Notable cold pulses are recorded by both species, including a pulse that occurs around the year 1700 CE (Fig. 3).

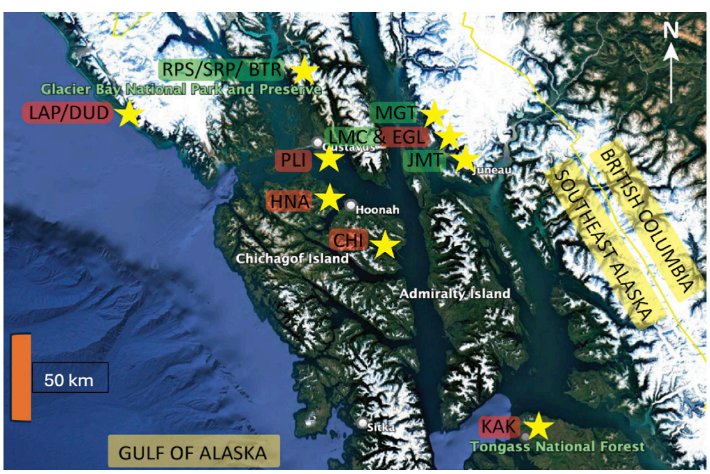

Figure 2. Locations of each tree ring chronology used for this study. Locations (yellow stars) are labeled with a three-letter abbreviation. Red shading represents Yellow Cedar stands, and green Mountain Hemlock sites. We obtained all data from the ITRDB.

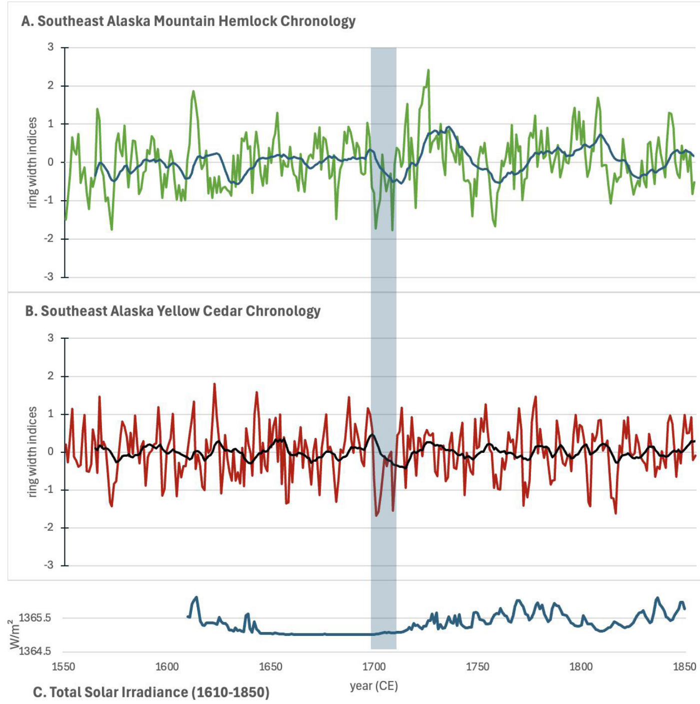

Figure 3. A. Averaged ring-width data from six Mountain Hemlock locations. Values above or below y=0 represent thicker or thinner than average ring widths, respectively. Blue line shows the 15-year rolling average of the data. B. Averaged ring-width data from seven Yellow Cedar locations. Values above or below y=0 represent thicker or thinner than average ring widths, respectively. Black line shows 15-year rolling average of the data. C. Reconstructed total solar irradiance reveals the presence of a Maunder Minimum from 1645-1715 (Lean et al., 1995) during the ongoing Little Ice Age. The period of intense cooling from 1695 to 1708 is shaded in blue.

The decadal moving averages reduce noise and small-scale variability, to each species-specific chronology (Fig. 4) and together the Mountain Hemlock (green line) and Yellow Cedar (red line) chronologies show consistency, especially relative to previously established regional and global (Fig. 1) cold pulses occurring around 1700 and 1810 CE. The ~1810 cooling is associated with a recently analyzed volcanic eruption and subsequent cooling (Leland et al., 2023). The ~1700 CE cooling event documented in the Gulf of Alaska correlates well with northwest European Summer Temperature reconstructions (Fig. 1) (D'Arrigo et al., 2020).

For the Mountain Hemlock species, the coldest year from 1550 to 1850 CE is 1706 (Table 1). For the Yellow Cedar species, the coldest year is 1698 (Table 1). The coldest decade for both species is 1697-1706. For the combined data, the coldest year in the Gulf of Alaska is 1698, and the coldest decade

Table 1. Ranked annual and decadal ring-width temperature proxy data.

	Mountain Hemlock		Yellow Cedar		Combined	
Rank	Annual	Decadal	Annual	Decadal	Annual	Decadal
1	1706	1697 - 1706	1698	1697 - 1706	1698	1697 - 1706
2	1572	1698 - 1707	1812	1698 - 1707	1706	1698 - 1707
3	1698	1696 - 1705	1699	1696 - 1705	1572	1696 - 1705
4	1755	1620 - 1629	1706	1696 - 1705	1699	1699 - 1708
5	1754	1618 - 1627	1572	1695 - 1704	1679	1695 - 1704
6	1550	1619 - 1628	1800	1624 - 1633	1571	1624 - 1633
7	1679	1695 - 1704	1768	1806 - 1815	1754	1751 - 1760
8	1571	1622 - 1631	1655	1567 - 1576	1768	1752 - 1761
9	1744	1751 - 1760	1571	1626 - 1635	1810	1567 - 1576
10	1699	1621 - 1630	1656	1752 - 1761	1755	1753 - 1762

Note: ranked from thinnest (low T) to thickest (high T) ring-widths.

is 1697-1706 (Table 1). The decadal rolling average on the combined data shows a pronounced period of prolonged cooling, from 1695 to 1708 (Fig. 4). Variability between the two species is sharply reduced during the 1690s cooling period, which correlates with the same period established in Northwestern Europe by D'Arrigo et al. (2020). In addition, an early 1800s cooling event displays a similar decrease in tree growth and corresponds well with the same cold period identified in the Gulf of Alaska by Leland et al. (2023).

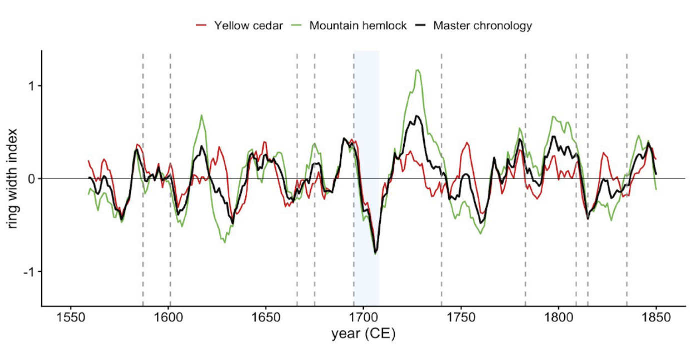

Figure 4. Decadal moving averages applied to Yellow Cedar (red line) and Mountain Hemlock (green line) species-specific chronologies. The black line represents the average of both species. A solid line at y = 0 represents the mean index. Vertical dashed lines represent climatically effective volcanic eruptions (Briffa et al., 1998). A period from 1695-1708 is shaded in pale blue, indicating the period of record cooling following the 1695 volcanic eruption with unknown origin, corresponding to table values (Table 1).

CONCLUSION

Yellow Cedar and Mountain Hemlock tree-ring-based summer temperature reconstructions in Southeast Alaska provide an improved understanding of volcanic activity's impact on regional temperature anomalies and climate extremes. The period of cold identified in Southeast Alaska during the 1690s and early 1700s reflects a similar duration and intensity to a previously identified event at similar latitudes in northwestern Europe. The consistency in data at both locations suggests that climatically effective eruptions in the late seventeenth century which prompted a period of intense cooling in the mid-to-high latitudes. The period of cold we document in this study had an impact on agriculture, socioeconomics, and human suffering, as recorded in the Seven Ill Years in Scotland. At the same time, unusual cold in Southeast Alaska may have forced human migration because of food insecurity and rapid glacial advance in Glacier Bay.

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