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Animating the Temporal Progression of Cordilleran Deglaciation and Vegetation Succession in the Pacific Northwest during the late Quaternary Period

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HUXLEY COLLEGE OF THE ENVIRONMENT

The Cordilleran Ice Sheet

The topography of the Pacific Northwest, its fjords, inland waterways and islands, are a result of an extended period of glaciation and glacial retreat. This retreat influenced the physical features and the resulting succession of vegetation that led to the landscape we see today. Despite this importance of the Cordilleran ice sheet and the large volume of research on the topic, there lacks a good detailed animation of the movement of the entire ice sheet from the last glacial maximum to the present day. In this study, I used spatial data of the glacial extent at different periods of time during the Quaternary period to model and animate the movement of the Cordilleran ice sheet as it retreated from 18,000 BCE to 10,000 BCE. Fluctuations in the shape and size of the ice sheet are quantified and show how it lost and gained material over time. The visualization also revealed the sequential development of geologic events important to the region such as the opening of the Salish Sea to the Pacific Ocean. The resulting animation product can be used for educational and display purposes to illustrate the importance of the Cordilleran ice sheet on the development of the region's physical identity.

Of the two great ice sheets that covered North America during the Quaternary, the Cordilleran was the smaller of the two, and the Laurentide comprised much of the central and eastern parts of the continent, while the Cordilleran sat upon the lands of the northwest coast. The glacial periods of the Quaternary have been formative events for the entire region of the Pacific Northwest, responsible for the topography and inland waterways that influence the physical systems of the region's geology and ecology (Whitlock, 1992). Remnants of different glacial deposits in the form of moraine lines where glaciers would leave behind collected debris serve as one of the best indicators of periods of deglaciation as the Cordilleran ice sheet retreated from its southernmost extent in Washington up into British Columbia before eventually disappearing after 10,000 BCE (Booth et al., 2003). Based on moraine and radiocarbon information, the Cordilleran's southern extent was still growing approximately 18,750 years BCE when it crossed the national border, and reach edits southern limit in the Puget Lowlands at about 16,950 BCE (Porter et al., 1998). Following that it began to move northward in retreat, leaving behind a changing landscape.

Methods

The majority of my analysis was performed using the glacial data provided publically by J. Ehlers, P.L. Gibbard, and P.D. Hughes to complement their publication on worldwide quaternary glaciations (Ehlers et al., 2010). The information on periods of glacial extent went as far as 18,000 BCE. In order to create my visual representation, and gather unified areal statistics, I had to decide on a region of quadrangles to use for my analysis. Based on the image provided in the database as well as other visualizations of the extent of the Cordilleran (Booth et al., 2003). I selected a series of quadrangles with the goal to unify the different glacial covers into one coverage for the entire Cordilleran and parts of the western Laurentide. I used an iterator to export the input shapefiles into feature datasets within my geodatabase to maintain a level of organization based upon the combined quadrangles regions (Fig. 2)

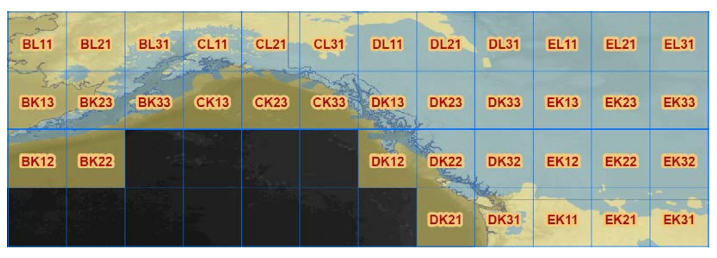
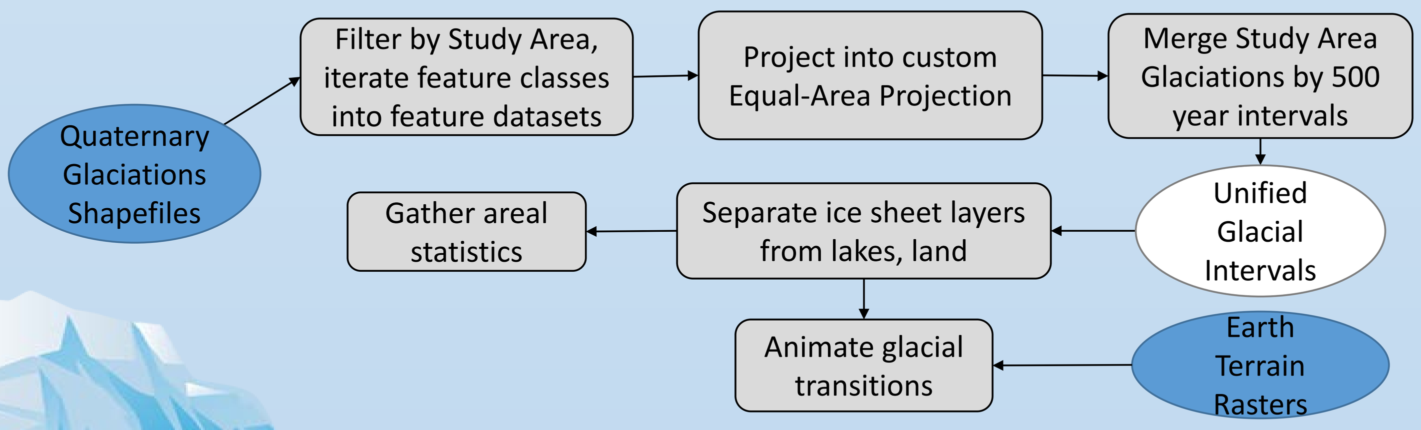


Figure 2: The Northwest American part of the reference map for the glaciation dataset. Each quadrangle is identified in yellow and possesses a coded set of two letters and two numbers. Shaded blue areas represents relative ice sheet extent

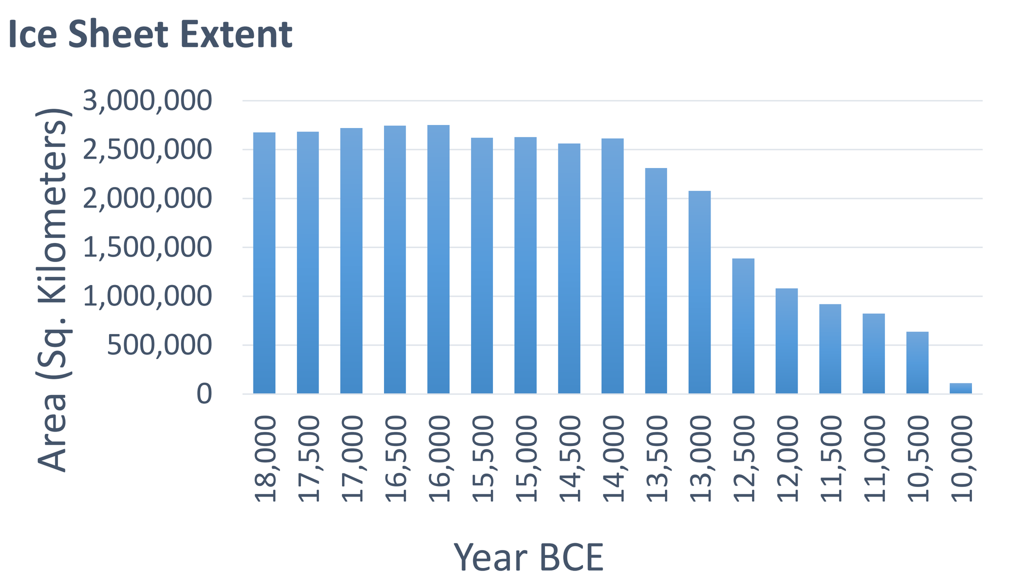
With these regions in place I designed a baseline model within ArcMap to project the quadrangles into a custom Contiguous Equidistant Conic projection and merge shapefiles for each lettered region from 18,000 BCE to 10,000 BCE for every 500 year increment. I then collected summary statistics to quantify my results.

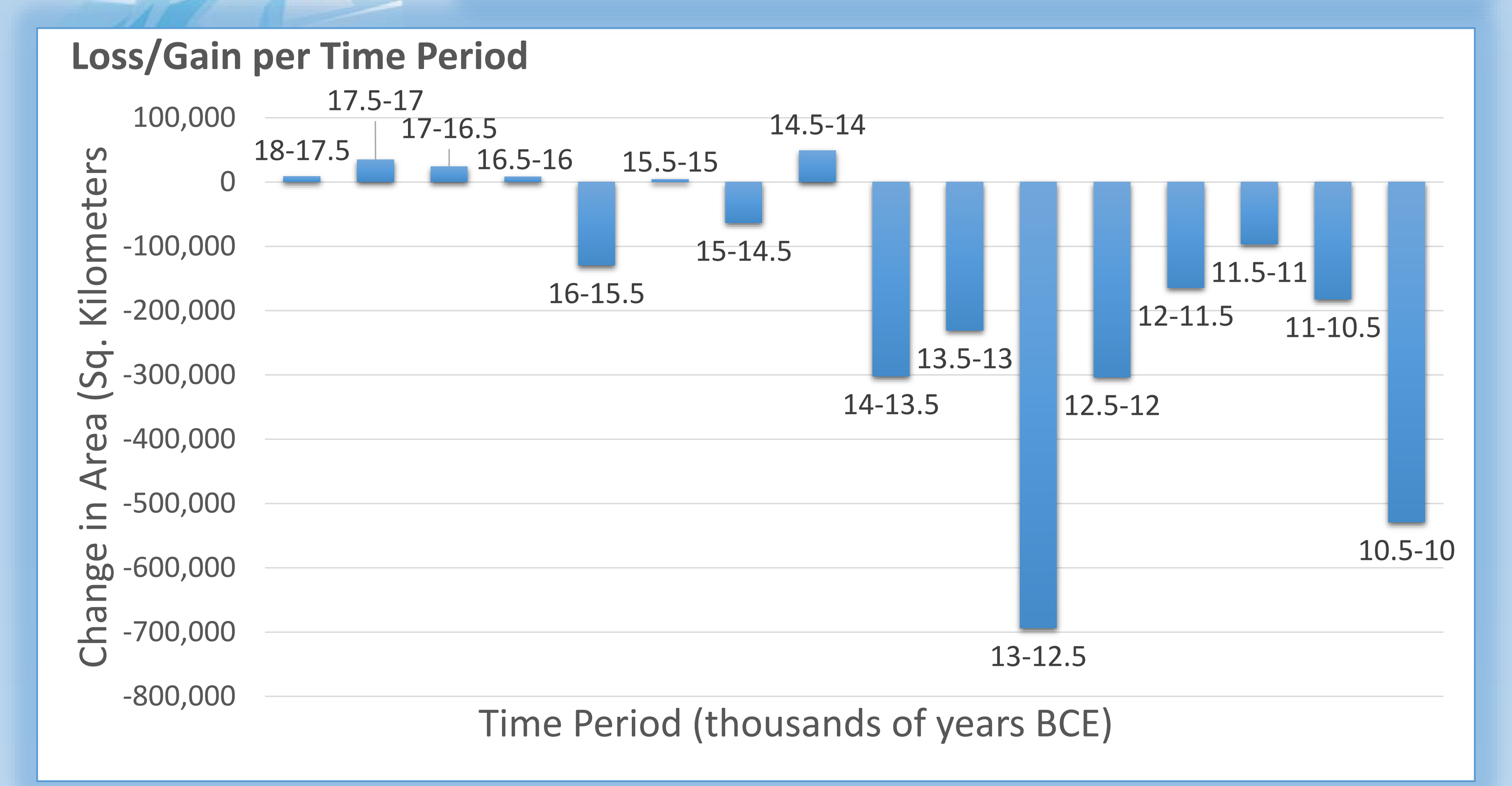


Results

The resulting areal statistics highlight a few important events in the deglaciation of the ice sheet. These can be seen in periods where the ice sheet undergoes dramatic reduction in size. Between 12,500 and 12,000 BCE the eastern edge of the Cordilleran had separated from the Laurentide, and a corridor of open land emerged between the two (Time Series A). The Puget Sound remained uncovered from 18,000 BCE to approximately 15,500 BCE, and remained covered from 15,500 BCE to 13,500 BCE. The greatest period of deglaciation occurred from 12,000 BCE to 11,500 BCE. The greatest extent of the ice was in 16,000 BCE. The least extent was 11,000 BCE as the Ice Sheet continued to disappear.

Time Period (Years BCE)	Ice Sheet Extent (sq. kilometers)
18,000	2,673,741
17,500	2,682,633
17,000	2,717,493
16,500	2,741,591
16,000	2,749,954
15,500	2,620,631
15,000	2,625,269
14,500	2,561,776
14,000	2,610,691
13,500	2,308,601
13,000	2,077,955
12,500	1,384,113
12,000	1,080,693
11,500	916,349
11,000	819,960
10,500	637,833
10,000	108,785





Sequential Progression of Cordilleran Retreat

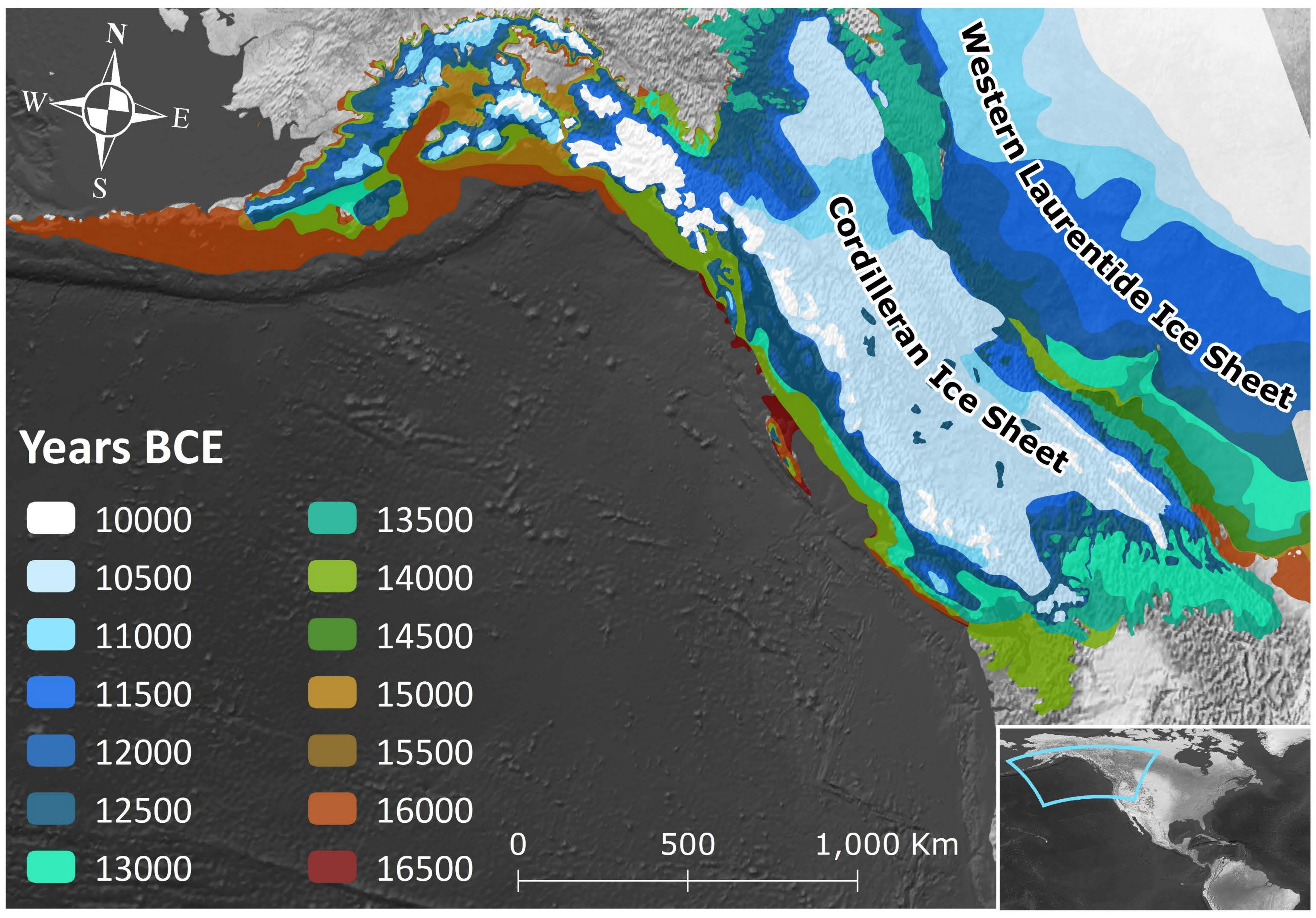
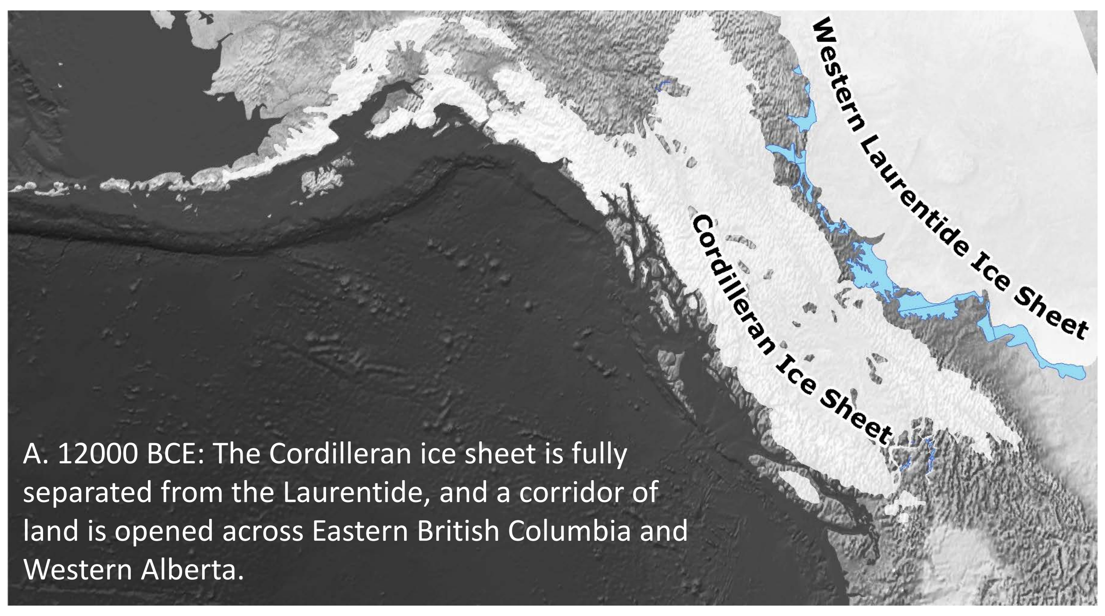


Figure 1: The Cordilleran and western Laurentide Ice sheets with extents symbolized by time interval. Visualization starts from 16500-16000, the period of greatest extent. Coordinate system is a custom Contiguous Equidistant Conic with a central meridian at West 130 degrees.

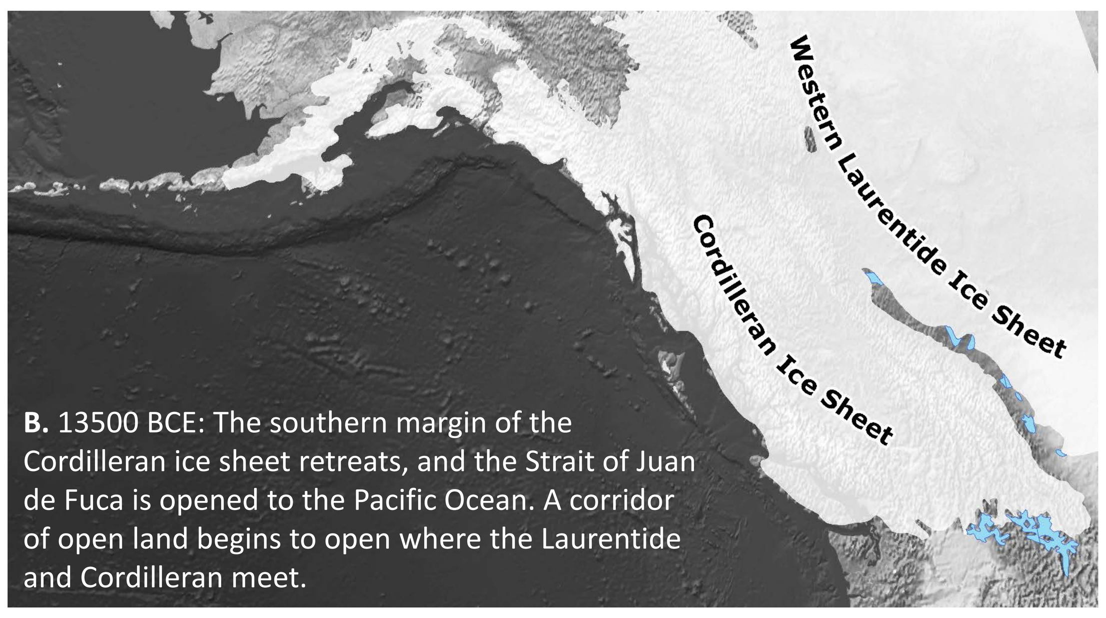
Conclusion

Collecting and putting together such a large database was a time consuming and difficult task, and I believe that public data on prehistoric climate or land cover should be more readily available. Additionally, since the glacial extents incorporate both the Laurentide and the Cordilleran the statistical analysis of the Cordilleran incorporated additional kilometers from portions of the Western Laurentide. The significance of my results however, help to show that what is commonly understood as the 'ice age' or last glacial maximum was not wholly stagnant. There were periods of change within its deglaciation phase where it grew, shrank and covered or uncovered different areas. These different rates of growth or decrease highlight important events in the region's history and may have proven important to the migration of marine and terrestrial life into the Pacific Northwest. The resulting animation and time series images illustrate the importance of the Cordilleran ice sheet on the development of the region's physical identity. Future analyses could expand the topic into vegetational succession, or more minute periods of glaciation that came in the following millennia.

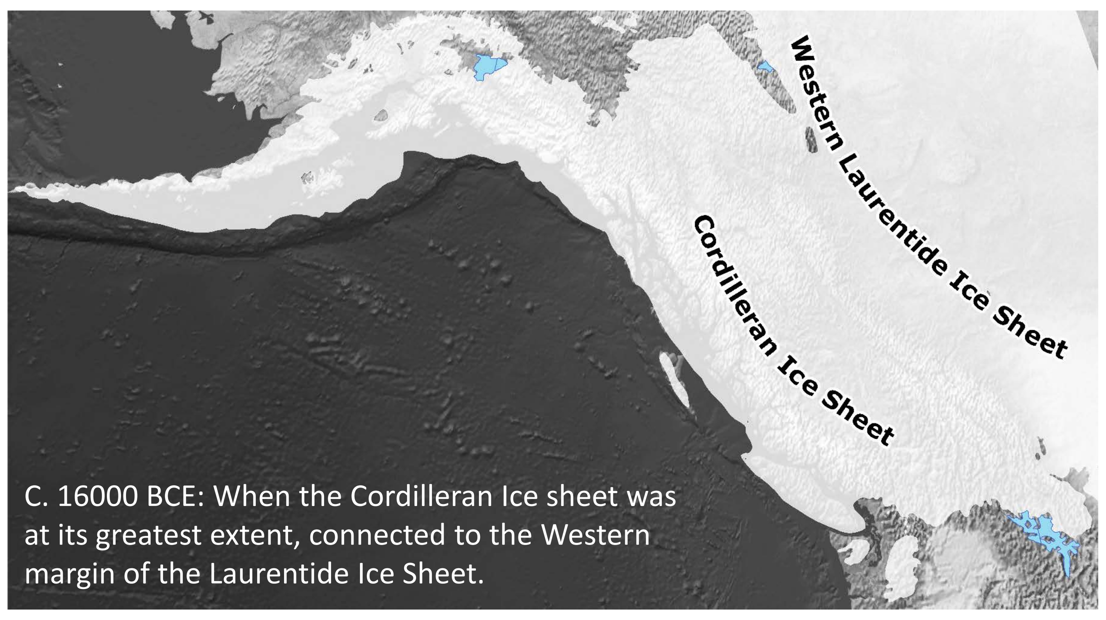
Time Series



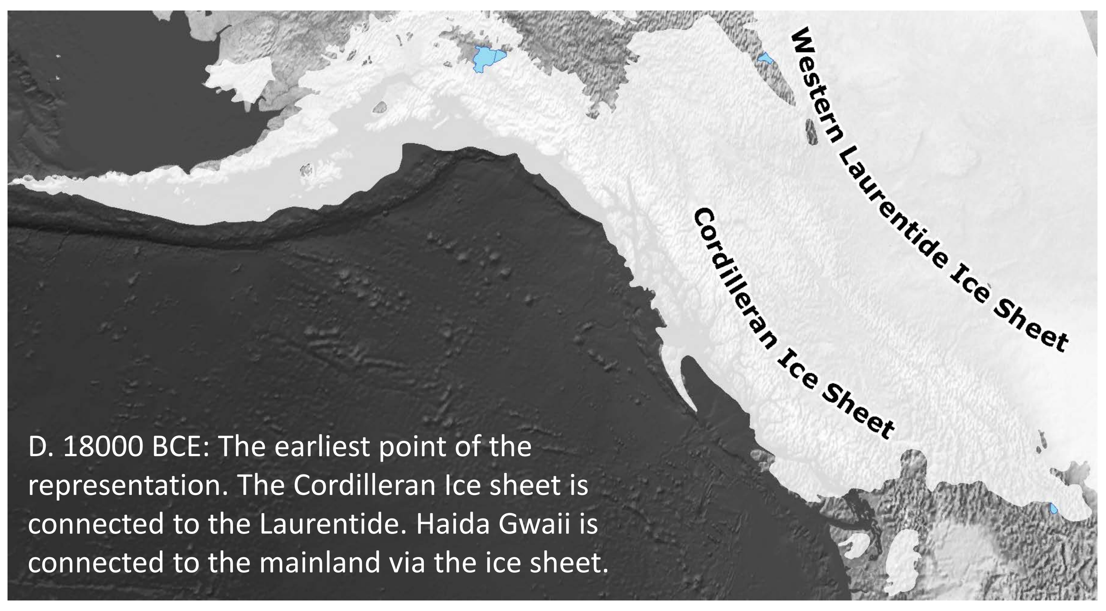
A. 12000 BCE: The Cordilleran ice sheet is fully separated from the Laurentide, and a corridor of land is opened across Eastern British Columbia and Western Alberta.



B. 13500 BCE: The southern margin of the Cordilleran ice sheet retreats, and the Strait of Juan de Fuca is opened to the Pacific Ocean. A corridor of open land begins to open where the Laurentide and Cordilleran meet.



C. 16000 BCE: When the Cordilleran Ice sheet was at its greatest extent, connected to the Western margin of the Laurentide Ice Sheet.



D. 18000 BCE: The earliest point of the representation. The Cordilleran Ice sheet is connected to the Laurentide. Haida Gwaii is connected to the mainland via the ice sheet.

Sources

Data

Ehlers, J., Gibbard, P. L., & Hughes, P. D. (2010). Quaternary Glaciations - Extent and Chronology. Retrieved April 11, 2017, from http://booksite.elsevier.com/9780444534477/index.php

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Literature

Booth, D. B., Troost, K. G., Clague, J. J., & Waitt, R. B. (2003). The Cordilleran Ice Sheet. *The Quaternary Period in the United States Developments in Quaternary Sciences,* 17-43. doi:10.1016/s1571-0866(03)01002-9 Glacial History of the Puget Sound. 2013. University of Washington.

Porter, S.C., Swanson, T.W., (1998). Radiocarbon Age Constraints on Rates of Advance and Retreat of the Puget Lobe of the Cordilleran Ice Sheet during the Last Glaciation. Quaternary Research, 50:3, 1998. doi: https://doi.org/10.1006/qres.1998.2004

Whitlock, C. (1992). Vegetational and Climatic History of the Pacific Northwest during the Last20,000 Years: Implications for Understanding Present-day Biodiversity. The NorthwestEnvironmental Journal, 8:5—28, 1992.

Images

Introduction Image: https://icedive.ca/w2/wp-content/uploads/2014/08/iceberg-detailed-sized-02.png

Ice Graphic: https://icedive.ca/w2/wp-content/uploads/2014/08/iceberg-detailed-sized-02.png