Climate Volatility and Human Adaptation in the Eastern Arctic

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

This thesis explores the relationship between climate volatility and human occupation in the Eastern Arctic, focusing on three key regions: Greenland, Ellesmere Island, and Baffin Island. Using paleoclimatic data from ice cores and sea surface temperature reconstructions, this study applies rolling standard deviations to measure climate volatility. These data are then overlaid with radiocarbon-dated archaeological sites to assess how fluctuations in climate influenced cultural transitions and subsistence strategies across different Arctic populations, including the Saqqaq, Dorset, and Thule cultures. The findings reveal that periods of heightened climate volatility often corresponded with significant shifts in settlement patterns and resource exploitation strategies. The Thule culture thrived during periods of relatively volatile conditions of the Little Ice Age, while the Dorset culture faced increasing challenges as climate conditions became more volatile, contributing to their decline. The earlier Pre-Dorset and Saqqaq cultures demonstrated remarkable resilience in the face of climatic fluctuations, suggesting a high degree of adaptability to environmental changes.

This research provides critical insights into how past Arctic populations responded to periods of environmental stress, highlighting the importance of flexibility, technological innovation, and resource diversification in their survival. By drawing on paleoclimatic data and archaeological evidence, this study contributes to broader anthropological discussions on human adaptation to climate change and offers valuable lessons for contemporary communities facing similar challenges in the modern Arctic.

Acknowledgements

I would like to express my deepest gratitude to Dr. Robert Park, my thesis supervisor, for his invaluable guidance, insight, and encouragement throughout the course of this research. His expertise in Arctic archaeology and unwavering support were instrumental in shaping this project, and I am deeply appreciative of the time and effort he dedicated to helping me navigate the complexities of this study.

I would also like to extend my thanks to the Canadian Archaeological Radiocarbon Database (CARD) for providing access to their extensive repository of radiocarbon data. The data made available through CARD was essential in facilitating the comparative analysis presented in this thesis.

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Introduction

Climate change and environmental instability have played pivotal roles in shaping human societies, particularly in extreme environments like the Arctic. The Arctic's dynamic climate has been a critical factor influencing human survival, adaptation, and migration over millennia (Friesen et al. 2020; Mudie et al. 2005, 114). As modern societies grapple with the escalating impacts of climate change, studying how past Arctic populations responded to volatile climatic conditions offers invaluable insights into resilience and adaptation strategies (Friesen et al. 2020).

This thesis examines the relationship between climate volatility and human occupation in the Eastern Arctic, specifically focusing on how fluctuations in climate correlated with cultural shifts in this region. Using a paleoclimatic reconstruction based on ice core data from the Agassiz ice cap on Ellesmere Island and the Renland ice cap in eastern Greenland, I analyze fluctuations in temperature to understand how climate volatility affected the settlement patterns of ancient Arctic cultures. Additionally, I incorporate sea surface temperature data from Disko Bay to replicate the broader sea surface temperature patterns in the Baffin Bay region, including the Kane Basin, a key area which is a consistent open-water polynya (although variable in extent) due to strong ocean currents, which are crucial to the marine ecosystem that many Arctic cultures relied upon.

For the purposes of this thesis, climate volatility measures fluctuations in temperature or sea surface temperatures (SSTs) over a defined temporal window, which in this study is a 100-year rolling period. Specifically, volatility is characterized by significant deviations from the mean temperature or SST, as measured by the rolling standard deviations calculated for each dataset. This method allows for the identification of periods during which the climate exhibited

higher variability, indicating potential instability in environmental conditions. Climate volatility in this context is distinct from gradual, long-term warming or cooling trends. For example, a period of sustained warming or cooling over several centuries may not necessarily be classified as volatile unless it also includes significant short-term fluctuations that exceed the established threshold for standard deviations. Thus, the threshold for defining a volatile period is based on standard deviation peaks that indicate heightened fluctuations, as opposed to more stable periods where deviations remain closer to the average. By adopting this approach, this study differentiates volatile periods—characterized by significant environmental unpredictability—from more stable, albeit changing, climatic conditions. These volatile periods are of particular interest due to their potential impact on resource availability and human settlement patterns in the Arctic.

For individuals living during times of heightened climate volatility, the effects would have been both immediate and profound. Imagine an Inuk hunter, living with his family—his parents, his wife, and his young children. His grandfather and father may have passed down crucial knowledge about the best places and times for seal hunting, such as a particular bay that traditionally provided ample seals every March. However, in a period of extreme climate volatility, this information could become unreliable. Sudden shifts in temperature might cause sea ice to form later or break up earlier than expected, rendering the usual hunting grounds inaccessible or unsafe. The hunter would find himself needing to adapt on the fly, potentially risking his safety by venturing onto thin ice or being forced to travel much farther to find stable hunting grounds. The environmental knowledge inherited from his ancestors—once a dependable guide—might no longer align with the new, unpredictable conditions, pushing him to develop new strategies or even relocate to ensure his family's survival. Such volatility could disrupt not

only hunting patterns but also the community's broader social and cultural structures, as people adjusted to the increasingly uncertain environment.

The study focuses on key cultural groups, including the Thule, Dorset, and Saqqaq populations, to assess how periods of climate volatility correlated with changes in human settlement, resource use, and site abandonment. The expanded geographical scope includes archaeological sites on eastern Baffin Island and eastern Ellesmere Island, where the same regional climatic forces likely shaped human activity. By using Eastern Arctic paleoclimatic data, I aim to shed light on how environmental variability affected these human populations across the broader region.

The primary objective of this thesis is to determine whether periods of heightened climate volatility can be shown to correlate with archaeologically identified human occupation and abandonment in the Eastern Arctic, particularly in relation to subsistence strategies and resilience mechanisms. By overlaying climate data with archaeological site occupation timelines, this research provides a clearer picture of how ancient societies adapted to environmental stress. Moreover, the findings have direct implications for Public Issues Anthropology, offering insights into how past responses to environmental change can inform current approaches to climate adaptation and management of cultural heritage in vulnerable Arctic regions.

Modern climate studies often associate global warming with increased climate volatility, highlighting the unpredictable nature of extreme weather events. While this study examines historical periods of climate volatility, it is important to note that volatility is not exclusively tied to warming trends. Historical data suggest that both warming and cooling phases can exhibit varying levels of volatility, influenced by complex interactions between atmospheric, oceanic, and cryospheric systems (Friesen et al. 2020; D'Andrea et al. 2011).

This research not only enhances our understanding of human-environment interactions in the past but also contributes to contemporary debates about climate change, human adaptability, and the protection of Arctic cultural resources. As archaeological sites in the Arctic face increasing risks from both environmental degradation and climate-driven changes, the need to understand past resilience strategies is more pressing than ever.

2. Literature Review/Background

2.1 Introduction to Paleoclimatology in the Eastern Arctic

Understanding the paleoclimatic history of the Eastern Arctic is crucial for interpreting the environmental conditions that shaped human occupation in this region. The Arctic's climate has undergone significant fluctuations throughout the Holocene, driven by changes in temperature, sea ice cover, and oceanic circulation patterns (Kim and Nam 2014; Mudie et al. 2005, 113; Opel et al. 2018). The use of paleoclimatic reconstructions from ice cores, sea surface temperatures, and other proxies has provided critical insights into the timing and nature of these fluctuations (Friesen et al. 2020, Mason et al. 2001).

Ice cores, particularly from the Agassiz ice cap on Ellesmere Island and the Renland ice cap in eastern Greenland, have been pivotal in reconstructing long-term temperature patterns (Vinther et al. 2009). These cores contain detailed records of past climate, including variations in δ18O isotopic concentrations, which serve as proxies for past temperature changes (Ramstein 2021; Vinther et al. 2009). Studies such as those by Vinther et al. (2009) have used these ice core records to reconstruct temperature deviations across the Holocene, allowing for the identification of periods of warming and cooling that may have impacted human populations in the region.

In addition to temperature reconstructions, sea surface temperature data from sediment cores collected in Disko Bay provides valuable information about past oceanic conditions in the Baffin Bay region (Ouellet-Bernier et al 2014; Ramstein 2021). The Baffin Bay and Kane Basin areas are known for their significant polynyas, areas of open water surrounded by sea ice that play a critical role in the marine ecosystem (Dyke and England 2003; Schledermann 1980). These polynyas are essential for sustaining marine life, which in turn supported the subsistence

economies of Arctic cultures, including the Dorset, Thule, and Saqqaq (Schledermann 1980). Sea surface temperature reconstructions allow researchers to track changes in ocean temperatures, which can provide clues about the availability of marine resources and the overall climatic stability of the region (Friesen et al. 2020; Ouellet-Bernier 2014; Ramstein 2021).

Recent palaeoclimatological studies have focused on understanding how marine and terrestrial climate systems interacted to generate alternating periods of relative stability and heightened variability (Friesen et al. 2020; Opel et al. 2018). These have largely concentrated on examining long-term climate trends, often identifying warmer or cooler phases and correlating these with human migration patterns or shifts in subsistence strategies. For instance, Friesen et al. (2020) discuss how Late Dorset migrations correlate with the generally warming temperatures of the Medieval Climate Anomaly (MCA), noting that these movements "coincide quite closely with the generally warming temperatures of the MCA at a hemispheric level" (p. 151). However, they caution that these studies are often "based mainly on interpretations of trends in reconstructed temperature," which may not capture short-term or annual variability crucial for understanding human responses to environmental instability (Friesen et al. 2020, 151).

While these studies provide valuable insights into the effects of broad climatic trends, they tend to overlook climate volatility—the short-term, unpredictable fluctuations that can disrupt established ecological patterns and human adaptive strategies. This study addresses this gap by focusing on volatility rather than just general warming or cooling phases, seeking to understand how periods of intense climate variability might have impacted Arctic populations differently than more gradual shifts. The integration of ice core data from Greenland and Ellesmere Island with sea surface temperature reconstructions from Disko Bay offers a comprehensive review of the climate in the Eastern Arctic, highlighting the broader climatic

forces that caused both long-term steady conditions and abrupt fluctuations, which in turn influenced human settlement and resource availability.

2.2 Human Occupation and Climate Interaction

The Arctic is home to a rich archaeological record, with human occupation dating back thousands of years, marked by cultures such as the Saqqaq, Dorset, Thule, and later, the Norse settlers in Greenland (Dugmore et al. 2012; McGhee 1969; Schledermann 1980). These cultures were deeply connected to their environment, with subsistence strategies and settlement patterns that were directly influenced by climatic conditions (Friesen 2010; McGhee 1969; Schledermann 1980). As a result, shifts in climate – whether gradual or abrupt – played a pivotal role in shaping the trajectory of human occupation in the Arctic (Dyke and England 2003; Friesen et al. 2020; McGhee 1969).

Previous studies of Arctic paleoclimatology have concentrated heavily on temperature trends, focusing on whether specific periods were warmer or cooler relative to modern standards. For example, Mudie et al. (2005) examined sea surface temperature variations, framing them as 2-4°C cooler or up to 6°C warmer compared to today. Similarly, D'Andrea et al. (2011) noted abrupt Holocene temperature changes in West Greenland, presenting these findings in terms of temperature deviations relative to current baselines. These studies reflect a common trend of using modern baselines to assess past climates, typically describing periods as warmer or colder compared to averages from the 20th century. While these approaches have provided valuable insights into broad temperature trends, they often overlook the finer-scale fluctuations within these periods.

In contrast, this thesis emphasizes climate volatility - a concept focused on the degree of fluctuation and instability within shorter time windows. Instead of merely assessing whether the climate was warmer or cooler overall, I examine how frequent and intense climate shifts were, using rolling standard deviations to measure variability. This focus on volatility allows for the identification of periods during which human populations in the Arctic may have faced greater environmental unpredictability, which could have affected resource availability and settlement patterns.

2.2.1. The Saqqaq/Pre-Dorset Cultures

The Saqqaq culture (c. 2500–800 BCE), closely related to Pre-Dorset cultures as a geographic variant, represents one of the earliest human groups to occupy Greenland, and their subsistence economy was largely dependent on marine and terrestrial resources (Milne and Park 2016; Gronnow 2016). Studies of the Saqqaq archaeological record, particularly at sites such as Qeqertasussuk, have revealed a close connection between the availability of marine resources and Saqqaq subsistence practices (Gronnow 2016). During periods of relative climate stability, the Saqqaq were able to exploit marine mammals, fish, and terrestrial animals, while periods of environmental instability may have challenged their ability to sustain their settlements (Gronnow 2016).

Evidence from Saqqaq sites suggests that climate fluctuations, particularly changes in sea ice extent and SSTs, would have directly impacted the availability of key resources (Gronnow 2016, 31). Research indicates that the Saqqaq population likely experienced pressures from environmental instability, leading to shifts in settlement patterns, which may have included population decline or migration during periods of heightened climate volatility (Gronnow 2016, 32). D'Andrea and colleagues (2011, 9767) noted that a combination of climatic and ecological

factors likely influenced the eventual abandonment of Saqqaq sites, particularly during colder periods when expanded sea ice hindered marine hunting activities.

2.2.2. The Dorset Culture

Following the Saqqaq, the Dorset culture (c. 500 BCE–1500 CE) flourished in the Arctic, occupying much of what is now the Eastern Arctic, including Baffin Island and Ellesmere Island (Park 1993). The Dorset were highly specialized in their use of sea ice for hunting marine mammals, and their adaptation to extreme Arctic conditions has been well-documented (Schledermann 1980; McGhee 2001). While some research, such as that by Milne et al. (2012), has suggested that the decline of the Dorset coincided with environmental changes, including shifts in sea ice extent and resource availability, there has been less focus on the specific role of climate volatility—the frequent and unpredictable fluctuations in climate—on Dorset adaptation and eventual decline.

This thesis builds on previous work by focusing specifically on how periods of heightened climate volatility, as defined by increased variability in temperature and sea ice conditions, may have created challenges for the Dorset. Rather than examining the overall warming or cooling trends, I explore how frequent shifts in climate created unstable conditions that disrupted traditional hunting strategies and settlement patterns. By applying a volatility framework, this study provides a more detailed understanding of the short-term climatic fluctuations that could have impacted Dorset resilience and adaptability.

The Dorset culture's reliance on sea ice made them particularly vulnerable to climate shifts, especially during periods of warming that reduced sea ice cover and limited access to marine resources. While researchers like Maxwell (1985) and McGhee (1996) have highlighted

the role of warming trends, such as those during the Medieval Warm Period, in contributing to the Dorset's decline, it is important to differentiate these sustained warming phases from periods of climate volatility. The concept of volatility, as used in this study, refers not just to warming or cooling but to the frequent and unpredictable fluctuations in climate that may have further stressed the Dorset's ability to adapt. Unlike a consistent warming trend, volatility implies greater instability, where rapid changes in sea ice cover or temperature could have created ongoing challenges for the Dorset's subsistence strategies and settlement patterns.

This distinction is critical to understanding how the Dorset, reliant on stable environmental conditions for marine hunting, may have struggled to adapt not only to long-term warming but also to the unpredictability brought by frequent climate fluctuations. During this period, the Thule culture, more technologically and socially adaptable, began to expand into regions previously occupied by the Dorset (McGhee 1996).

2.2.3. The Thule Culture

The Thule people (c. 1000 CE – 1600 CE) are often viewed as the direct ancestors of modern Inuit populations, and their ability to thrive in the Arctic is attributed to their adaptability and reliance on diverse subsistence strategies (Friesen 2010; Mason et al. 2001; McGhee 1969). The Thule were highly mobile, using advanced maritime technologies, such as umiaks and kayaks, to hunt bowhead whales, seals, and other marine species (Friesen 2010; Mason 2020). This allowed them to exploit resources across vast areas, from western Alaska to eastern Greenland.

The expansion of the Thule into Greenland and Baffin Island occurred during a period of relative climate stability, though they later experienced significant environmental changes during

the Little Ice Age (c. 1300–1850 CE) (Friesen et al. 2020; Fitzhugh 2004). While the Thule were highly adaptable, capable of adjusting their subsistence strategies to cope with colder temperatures and shifting resource availability, periods of heightened climate volatility may have presented unique challenges to their social structure. The unpredictable shifts in temperature and sea ice cover during these volatile periods could have disrupted established patterns of resource distribution and trade, leading to fragmentation or transformation within Thule communities (Friesen et al. 2020). These sudden climatic shifts likely required rapid adaptation, which may have forced changes in social organization as different groups reacted to the fluctuating environment.

2.2.4. Eastern Baffin Island and Ellesmere Island Archaeology

The archaeological record of eastern Baffin Island and eastern Ellesmere Island also reflects periods of occupation that were closely tied to climatic conditions. The Pre-Dorset groups, followed by the Dorset and Thule, left behind evidence of settlements that correspond with periods of relative climate stability (Friesen et al 2020; Schledermann 1980). Schledermann (1980) has highlighted the importance of marine resources, particularly during periods when polynyas provided consistent access to open water and marine life.

The climate-volatility hypothesis is further supported by evidence of temporary site abandonment during periods of rapid climatic shifts, suggesting that populations moved in response to environmental stress caused by these fluctuations (Friesen et al. 2020, 143; Dyke and Savelle 2009, 377; D'Andrea et al. 2011, 9697). While previous research has referred to these movements as a reaction to "climatic stress," this thesis specifically investigates climate volatility, which focuses on the unpredictability and intensity of climatic fluctuations over short periods. By integrating paleoclimatic data, such as ice cores and sea surface temperature

reconstructions, with archaeological timelines, this study provides a clearer understanding of how these populations adapted or relocated in the face of heightened environmental instability (Dugmore et al. 2007; Mason et al. 2001).

2.3. Methodological Approaches to Analyzing Climate Volatility

Defining climate volatility is crucial for understanding the environmental challenges faced by Arctic populations. In this study, climate volatility refers to the frequency and intensity of short-term fluctuations in temperature or sea surface temperatures over time, rather than long-term trends of warming or cooling. These fluctuations, which can occur within decades, represent periods of heightened climatic instability that may disrupt ecosystems and human activity.

Quantifying climate volatility is essential to grasp how these fluctuations impacted human settlement and survival (Friesen et al. 2020). To achieve this, paleoclimatic data, such as temperature reconstructions and sea surface temperatures, are analyzed using statistical methods designed to highlight periods of increased variability (Mudie et al. 2005; Vinther et al. 2009; D'Andrea et al. 2011; Friesen et al. 2020). One widely used approach is the calculation of standard deviations, which identifies periods of heightened climatic instability by measuring how much climate metrics deviate from their mean values over a set temporal window (Dansgaard et al. 1993; Dugmore et al. 2012).

2.3.1. Rolling Standard Deviations and Climate Volatility

The rolling standard deviation is a statistical tool that quantifies how much data points deviate from the mean over a specific time period—in this case, temperature and sea surface temperature fluctuations over 100-year intervals. By applying this method to long-term

paleoclimatic datasets, it becomes possible to detect periods of climate volatility—defined here as times when the climate exhibited greater and more frequent short-term fluctuations than the background level of variability. These periods are marked by heightened environmental instability compared to other times of relative stability, during which climatic conditions were more predictable and less erratic.

In the context of Arctic paleoclimatology, Vinther et al. (2009) and D'Andrea et al. (2011) applied similar statistical approaches to ice core data to reconstruct Holocene temperature variations. Their analyses identified distinct periods of increased temperature variability, characterized by frequent and intense climate fluctuations. It is important to note that major climatic events like the Medieval Warm Period and the Little Ice Age, while significant in terms of long-term warming or cooling, do not inherently represent periods of volatility unless accompanied by heightened variability within shorter time frames. Volatile periods are specifically defined by increased unpredictability, rather than simply being warm or cold phases, and such fluctuations could have had profound impacts on Arctic ecosystems and the human populations that depended on them.

2.3.2 Applying Rolling Standard Deviations to Ice Core and Sea Surface Temperature Data

In this study, rolling standard deviations are applied to temperature deviation data from the Agassiz ice cap on Ellesmere Island and the Renland ice cap in eastern Greenland. These ice cores provide detailed records of past temperatures, with δ18O isotope values serving as reliable proxies for temperature changes over time (Vinther et al. 2009). By calculating the rolling standard deviations for these ice core records, it is possible to identify periods when the Arctic climate was particularly volatile - characterized by increased frequency and intensity of short-

term fluctuations in temperature, rather than gradual or rapid shifts between warm and cold conditions.

In addition to ice core data, sea surface temperature data from Disko Bay is subjected to similar analysis (Ouellet-Bernier et al. 2014). Disko Bay, and by extension the Baffin Bay region and Kane Basin, is characterized by the presence of polynyas – areas of open water surrounded by sea ice that remain unfrozen throughout the year (Schledermann 1980). These polynyas are crucial for sustaining marine ecosystems, and any significant fluctuations in sea surface temperatures can have cascading effects on marine life, which Arctic cultures relied on for subsistence (Dyke and England 2003). By applying rolling standard deviations to sea surface temperature data, this research identifies periods of marine volatility, which likely influenced human subsistence patterns and settlement decisions (Friesen et al. 2020).

2.3.3. Limitations and Considerations

While rolling standard deviations provide a valuable measure of climate volatility, it is important to recognize the limitations of this method. Volatility detected in temperature reconstructions may not capture all the environmental variables influencing human behaviour, such as sea ice extent, snow accumulation, or extreme weather events. Furthermore, the spatial resolution of the ice core and sea surface temperature data may not always align perfectly with specific archaeological sites, particularly in regions like eastern Baffin Island and eastern Ellesmere Island.

Despite these limitations, the rolling standard deviation approach offers a robust framework for analyzing climate instability and its potential impacts on human populations. By examining both temperature and sea surface temperature volatility, this study aims to provide a

comprehensive understanding of how environmental fluctuations shaped the development and survival of Arctic cultures.

3. Methods

This study employs a multi-disciplinary approach to examine the relationship between climate volatility and human occupation in the Eastern Arctic, focusing on the integration of paleoclimatic data and archaeological evidence. The methodological framework is designed to quantify periods of environmental instability and correlate these with changes in settlement patterns among key Arctic cultures, including the Saqqaq, Dorset, and Thule populations.

3.1. Study Area

The study area covers the Eastern Arctic, particularly western Greenland, eastern Baffin Island, and eastern Ellesmere Island. This region is key to understanding past Arctic human occupation due to its long history of habitation by cultures such as the Saqqaq, Dorset, and Thule. The focus on these areas also aligns with the availability of high-quality paleoclimatic data and archaeological evidence. The main focus for Greenland is the immediate area surrounding Disko Bay, particularly the Saqqaq era site known as Qeqertasussuk (chosen for its well-dated archaeological site with multiple occupation horizons) (Gronnow 2016). The archaeological focus on Ellesmere Island is the Knud Peninsula bordering the Kane Basin as numerous communal dwelling sites from both Dorset and Thule areas were found there (CARD). Finally, the focus for Baffin Island is the immediate area surrounding Cumberland Sound as it offers numerous dwelling sites across different time periods and is directly opposite Disko Bay via Baffin Bay (CARD).

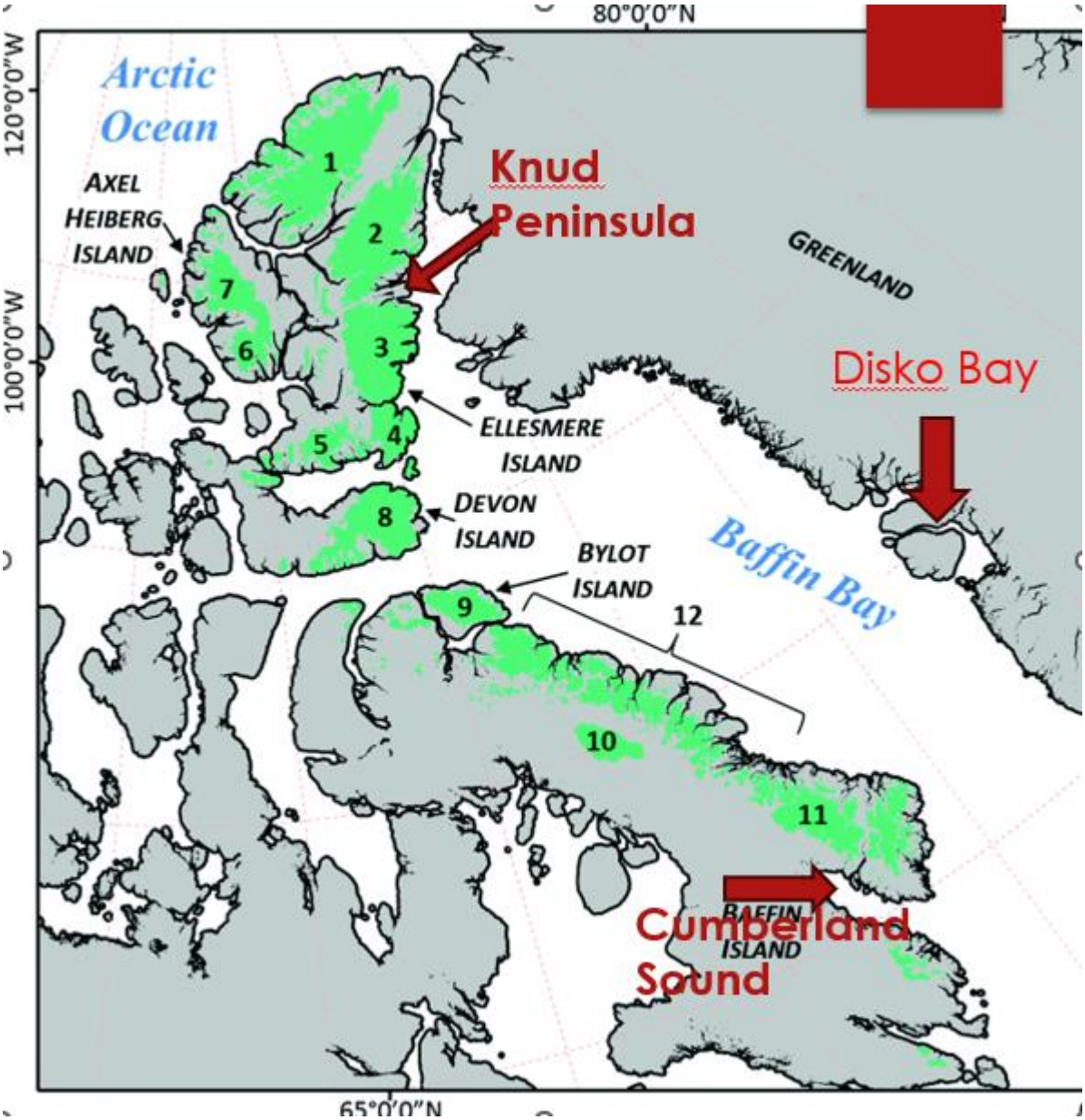


Figure 3.1. Map of the Eastern Arctic with the three study areas highlighted.

The ice core data comes from two major sources: the Agassiz ice cap in the Canadian High Arctic and the Renland ice cap in eastern Greenland, both of which provide high-resolution temperature reconstructions (Vinther et al. 2009; NOAA). Disko Bay, located off the west coast of Greenland, provides critical sea surface temperature data, representing marine conditions in Baffin Bay and the Kane Basin (Ouellet-Bernier et al. 2014; NOAA). These datasets are essential

for understanding both terrestrial and marine climatic conditions, as fluctuations in temperature and sea surface temperatures would have directly influenced the availability of resources. For example, marine resources such as seals and fish may have been affected by changes in sea ice density and distribution, altering their accessibility to Arctic populations. Similarly, shifts in seasonal timing of ice formation and breakup could have impacted hunting strategies, while fluctuations in terrestrial conditions may have influenced the availability of vegetation and land-based prey. These environmental factors collectively shaped the sustainability of human settlements in the region (Ramstein 2021; Friesen et al. 2020).

3.2. Data Sources

The paleoclimatic data used in this study include both temperature and sea surface temperature reconstructions. These datasets serve as proxies for environmental conditions over time and are key to quantifying climate volatility in the Eastern Arctic.

- Temperature Data (Ice Cores): This study uses temperature reconstructions based on four ice cores from the Agassiz ice cap (located in the Canadian High Arctic) and one ice core from the Renland ice cap (located in eastern Greenland). These ice cores are synchronized to the Greenland Ice Core Chronology 2005 (GICC05), which is based on annual layer counts from the DYE-3, GRIP, and NGRIP ice cores. Synchronization between the cores was achieved by matching volcanic reference horizons seen in electrical conductivity measurements (ECM), with the Agassiz cores matched to the NGRIP ECM signal and the Renland core matched to the GRIP ECM signal (Vinther et al. 2009).

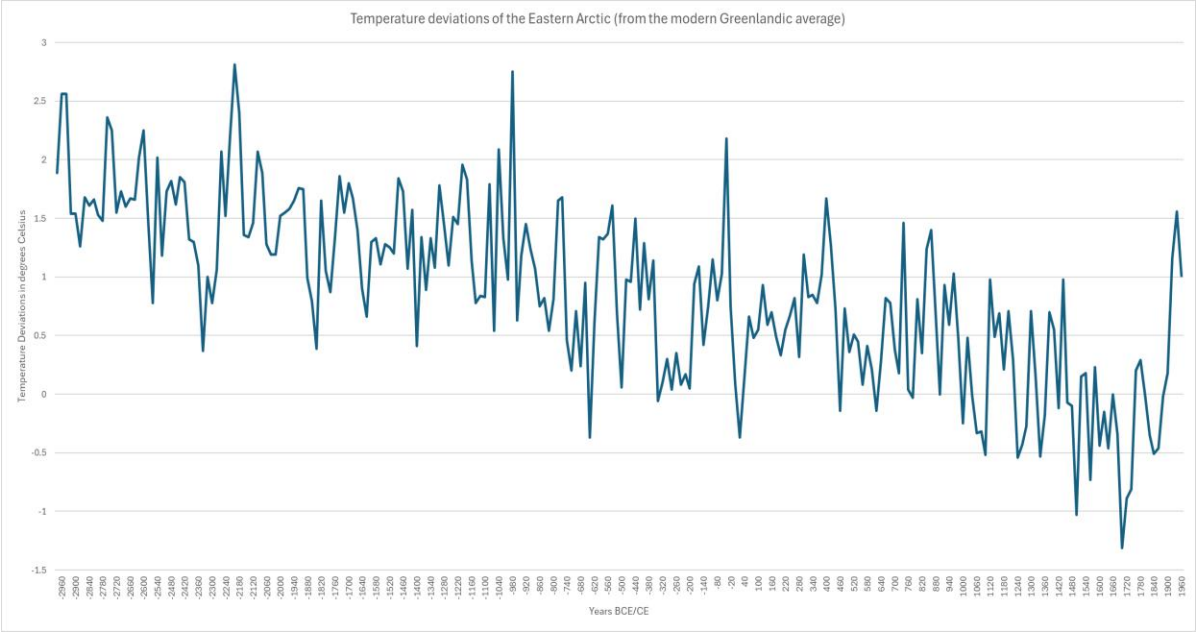


Fig.3.2.1. Temperature deviations from modern Greenlandic average gathered from Agassiz-Renland ice cores. (Vinther et al. 2009, NOAA)

The temperature deviations in the ice cores are based on δ18O isotope concentrations, which serve as a proxy for past temperature fluctuations (Ramstein 2021). The reconstructed temperatures are presented as deviations from modern averages, calibrated to borehole temperature records from Camp Century, NGRIP, GRIP, and DYE-3. This data is critical for understanding terrestrial climate conditions in the Eastern Arctic. (Vinther et al. 2009; Ramstein 2021).

- Sea Surface Temperature Data: The sea surface temperature data are derived from micropaleontological analyses of a sediment core raised in Disko Bay, Greenland (Ouellet-Bernier et al. 2014). The modern analogue technique (MAT), applied to dinocyst assemblages in the core, provides reconstructions of sea surface conditions in the Baffin Bay region (Ouellet-Bernier et al. 2014; Ramstein 2021). These reconstructions reflect postglacial conditions and offer insights into marine temperature fluctuations during key

periods, such as the Medieval Warm Period and the Little Ice Age (Ouellet-Bernier et al. 2014).

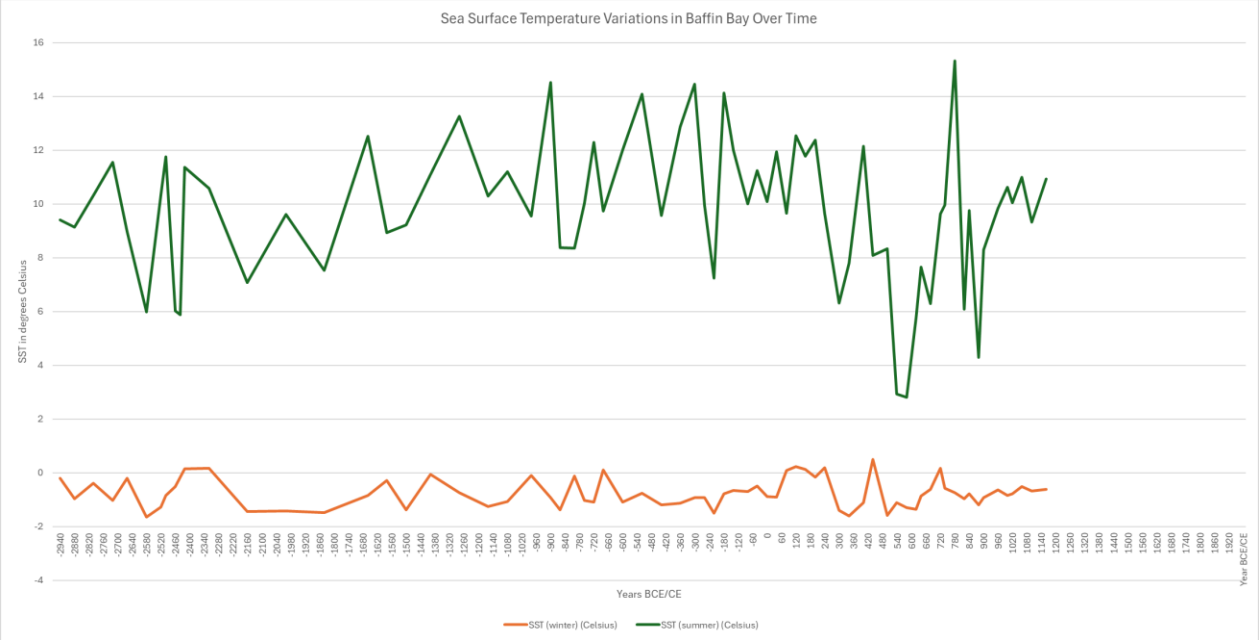


Fig. 3.2.2. Sea surface temperature variations in Baffin Bay over time, gathered from sediment core data from Disko Bay. (Ouellet-Bernier et al. 2014, NOAA)

The sea surface temperature data represent broader conditions in Baffin Bay, a critical marine ecosystem influenced by the presence of polynyas, which provide year-round open water surrounded by sea ice (Schledermann 1980). This region is integral to the survival of Arctic populations, as polynyas support the marine species that were crucial to subsistence (Dyke and England 2003).

3.3. **Quantifying Climate Volatility**

To measure climate volatility, this study combines rolling standard deviations from both temperature and sea surface temperature data into a single, normalized volatility metric. Each dataset—temperature deviations from ice cores and sea surface temperature data from Disko

Bay—was normalized by recalculating each rolling standard deviation as a percentage of its highest recorded amplitude. This approach ensures that no single dataset over-influences the combined measure, allowing for a balanced assessment of climate volatility across different environmental factors.

Rolling standard deviations were calculated using a 100-year rolling window for both temperature deviations and sea surface temperatures. This method captures fluctuations over a moving 100-year period, providing a dynamic and comprehensive measure of climate volatility over time. By combining the normalized rolling standard deviations, this approach highlights periods when climate variability was especially pronounced, marking times of potential environmental stress for Arctic populations.

To enhance interpretability, this combined volatility metric was overlaid with designated zones representing high and low volatility thresholds. Periods of high volatility, indicated by the shaded red area, mark times when Arctic populations would likely have faced significant environmental instability, with frequent and unpredictable fluctuations in climate. Conversely, periods of low volatility, represented by the shaded blue area, reflect more stable environmental conditions, allowing for greater predictability in seasonal cycles and resource availability. These thresholds were established by calculating rolling standard deviations and defining high-volatility periods as those exceeding the 50^{th} percentile of normalized variability, while low-volatility periods fell below the 25^{th} percentile. Thie method ensures that the thresholds reflect statistically significant deviations from baseline variability. The study seeks to identify patterns of correlation between these thresholds and archaeological timelines. These high and low volatility zones help contextualize the environmental pressures Arctic communities may have faced over time, particularly regarding their subsistence and settlement strategies.

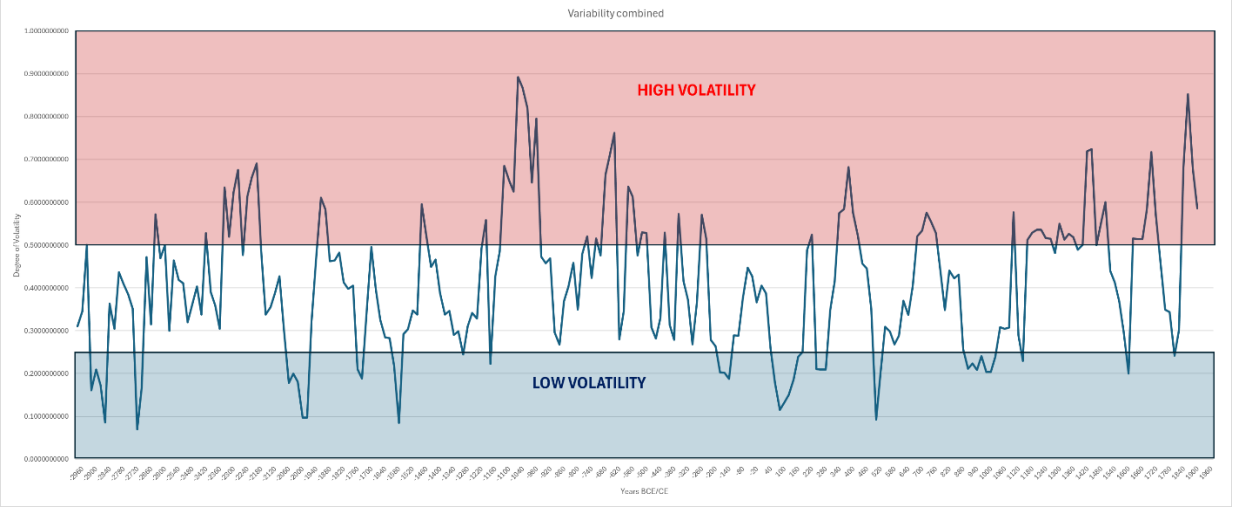


Figure 3.3.1. Combined Climate Volatility Metric for the Eastern Arctic (3000 BCE – 1960 CE). This figure illustrates the normalized volatility metric created by combining the rolling standard deviations of temperature deviations from Greenland ice cores and sea surface temperatures from Disko Bay. Each dataset was normalized to its highest recorded amplitude before combining, ensuring a balanced representation of climate variability across different environmental factors. The shaded areas indicate designated zones of volatility: the red zone represents periods of high volatility, marked by significant environmental instability, while the blue zone represents periods of low volatility, suggesting greater climate stability. The middle zone, which falls between these thresholds, indicates moderate or "typical" volatility. This zone reflects periods of dynamic but less extreme variability compared to the high and low thresholds, suggesting a balance between environmental predictability and instability. Peaks in the volatility metric within the high volatility zone indicate times when unpredictable shifts in climate may have disrupted traditional resource-gathering activities, whereas periods in the low volatility zone suggest a more stable environment conducive to established subsistence practices. This metric highlights the dynamic nature of Arctic climate variability over the past 5,000 years and its potential impacts on human settlement patterns and resource availability.

3.4. **Archaeological Data**

Archaeological data in this study include radiocarbon-dated occupation periods for key Arctic cultures, including the Saqqaq, Dorset, and Thule. These data were gathered from the Canadian Archaeological Radiocarbon Database (CARD) which offers an extensive database of sites along with their respective calibrated radiocarbon dates. Sites were chosen based on their geographic proximity to Baffin Bay and the amount of radiocarbon samples available to date. The radiocarbon dates were calibrated and converted into conventional BCE/CE year-dates aligning with the paleoclimatic data. Major archaeological sites included in this study are:

- Greenland: The multi-horizon site of Qeqertasussuk, which provides a detailed record of occupation across two millennia, perfect for analyzing a static locations usage during periods of volatility/stability (Gronnow 2006).
- Ellesmere Island: Sites clustered around the Knud Peninsula on eastern Ellesmere. This peninsula offers an abundance of archaeological sites (such as remnants of a communal hearth (referred to as “longhouse” in source) and clustered homes) (CARD).
- Eastern Baffin Island: Sites with occupations associated with the Dorset and Thule cultures located in the vicinity of Cumberland Sound, an inlet connected to Davis Strait. Sites such as Qiqitalakjuak, Niutang, and Amaroktalik offer previously published radiocarbon dates for dwellings along with hunted animal remains at this site, indicating adaptive strategies and use of these areas for hunting/settlement. (CARD).

These radiocarbon dates provide temporal markers for periods of human occupation, allowing the study to compare these periods with the rolling standard deviations of climate data.

The overlay of archaeological data on the climate volatility graph offers a visual representation of potential correlations between climate instability and human occupation or abandonment.

3.5. Data Integration and Analysis

The final step in the analysis involved integrating the paleoclimatic and archaeological data. This integration was accomplished by overlaying the radiocarbon-dated occupation periods for key archaeological sites onto the combined climate volatility graph, which displays the normalized rolling standard deviations of temperature and sea surface temperatures over time. This approach allows for a unified view of climate volatility across terrestrial and marine environments, highlighting periods when Arctic populations may have faced significant environmental stress.

The combined climate volatility graphs were created in Excel by plotting the normalized rolling standard deviations for temperature and sea surface temperatures against a BCE/CE timeline. To facilitate interpretation, high and low volatility zones were shaded to represent periods of increased environmental instability (high volatility) and stability (low volatility). The occupation periods for each culture (e.g., Saqqaq, Dorset, Thule, and Norse) were then overlaid on these volatility zones, aligning archaeological timelines with the climate data.

The temporal resolution of the datasets used in this study varies significantly, requiring careful consideration during data integration. Ice core and sea surface temperature data provide high-resolution records, often on an annual or decadal scale, allowing for detailed reconstructions of climatic fluctuations. In contrast, radiocarbon dates for archaeological sites typically represent broader temporal ranges due to calibration uncertainties and the marine reservoir effect, often spanning several decades or more. To address these differences,

archaeological data were placed on the graphs encompassing the entirety of their calibrated dates, ensuring that the periods of occupation were fully included, while also likely including periods immediately before and after the actual occupations themselves, which are impossible to pinpoint with absolute certainty.

Rather than a regional approach, this analysis focuses on each cultural occupation period in turn, enabling a detailed examination of how specific Arctic cultures responded to periods of high and low climate volatility. This method provides a nuanced view of the relationship between environmental conditions and cultural adaptation strategies. The integrated graphs, with volatility zones and occupation periods highlighted, serve as central evidence for this study, visually indicating whether periods of climate volatility correlated with shifts in human occupation, subsistence strategies, or settlement patterns. The results of this integrated analysis will be explored in detail in the next section (Results).

4. Results

4.1. Saqqaq/Pre-Dorset

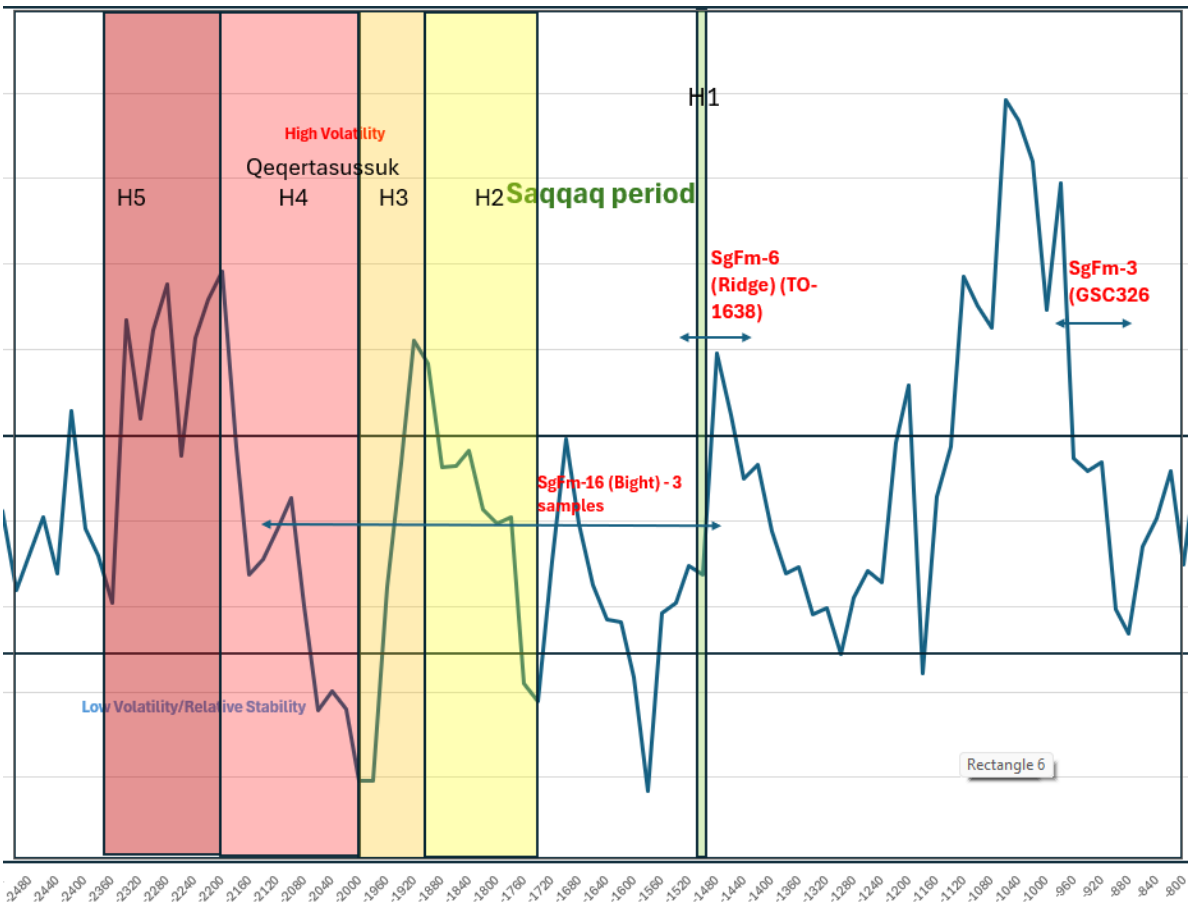


Fig. 4.1. Saqqaq cultural occupation period. Radiocarbon dates overlaid onto climate volatility graph for period. Shaded bands represent specific horizons of Qeqertasussuk. Horizontal lines represent calibrated radiocarbon dates of Pre-Dorset archaeological sites on Knud Peninsula, Ellesmere Island. Volatility is highly variable with periods of high, moderate and low volatility throughout Saqqaq occupation.

The Saqqaq culture represents one of the earliest significant human occupations in Greenland, with substantial evidence of settlement in Disko Bay, particularly at the well-documented site of Qeqertasussuk (Gronnow 2016). Qeqertasussuk provides a detailed record of

Saqqaq adaptation to the climate, as shown by five distinct occupational horizons (H1 to H5), each reflecting different environmental conditions as indicated by the combined climate volatility metric (Gronnow 2016). The integration of archaeological data with climate volatility measurements reveals patterns suggesting that Saqqaq settlement and subsistence strategies were directly influenced by environmental stability and instability.

Horizon 5 (H5), the earliest occupational phase at Qeqertasussuk, coincides with a period of high climate volatility, with temperature standard deviations fluctuating between 0.45 and 0.7. The limited number of artifacts and the absence of substantial structural features in H5 suggest that the Saqqaq faced challenges in establishing a lasting presence at the site during this period of environmental instability. The high volatility likely created unreliable resource availability, as fluctuations in temperature and sea ice conditions would have disrupted marine hunting and fishing activities essential to Saqqaq subsistence. Consequently, this horizon may represent an exploratory phase or intermittent occupation, as the Saqqaq tested the viability of settling on this isolated island (Gronnow 2016).

In contrast, Horizon 4 (H4) shows evidence of more stable climatic conditions. Volatility starts at a relatively high level but decreases significantly throughout this horizon, aligning with the first substantial evidence of intensive Saqqaq occupation. Archaeological findings from H4 include the remains of dwellings, stone-built fireplaces, and an abundance of Saqqaq artifacts, indicating a shift toward more permanent occupation and complex settlement patterns (Gronnow 2016). The reduction in climate volatility during this horizon may have created a predictable environment conducive to the Saqqaq's reliance on marine resources, enabling the establishment of semi-permanent structures and supporting a more sustained and organized use of the island. The apparent return to Qeqertasussuk after the challenging conditions of H5 may suggest either a

cultural transition within the Saqqaq population, where improved strategies or technology allowed for better resource exploitation, or the arrival of a different group with distinctive adaptive approaches. This shift highlights the dynamic interplay between environmental conditions and human decision-making in the region.

Horizon 3 (H3) at Qeqertasussuk represents a period of moderate to high volatility, with conditions becoming increasingly unstable toward the end of the horizon. The temperature volatility metric starts at a low of 0.09 and rises to 0.6 by the horizon's end, indicating a shift toward a more unpredictable climate. Despite this increase in variability, the archaeological evidence from H3 suggests that the Saqqaq maintained a strong and sustained presence at the site, potentially reflecting their capacity to adapt to moderately volatile conditions. Excavations have revealed a continued abundance of artifacts, suggesting that the Saqqaq had established well-adapted subsistence strategies that allowed them to endure these fluctuations, at least initially, by adjusting their hunting and gathering strategies to seasonal resource changes. (Gronnow 2016). However, the increased volatility toward the end of H3 may have started to strain these adaptive strategies, as the Saqqaq likely faced growing challenges in maintaining rsourcce availability and stability. While moderate volatility appears manageable, the progressive shift to higher instability reinforces the broader idea that heightened volatility, when prolonged, can ultimately destabilize human settlement systems and subsistence practices.

Horizon 2 (H2) aligns with a period of reduced climate volatility, with standard deviations in temperature stabilizing between 0.2 and 0.55. This relative stability corresponds with what appears to be one of the most sustained and intensive phases of occupation at Qeqertasussuk. Archaeological evidence from H2 includes numerous artifacts, well-preserved dwelling structures, and other signs of prolonged habitation, suggesting that the Saqqaq

experienced a phase of stability that supported more predictable resource availability (Gronnow 2016). While reduced climate volatility and its influence on settlement stability are indeed characteristic of Arctic cultures, the evidence from H2 provides a particularly detailed case study of how such stability facilitated the Saqqaq's reliance on marine and terrestrial resources, enabling the establishment of a semi-permanent settlement. The alignment of reduced climate volatility with more permanent settlement features reinforces the broader pattern observed across Arctic populations but also highlights the specific ways in which the Saqqaq adapted to localized conditions.. This phase may have encouraged not only stability in occupation but also cultural growth and complexity, as indicated by the diversity and abundance of material culture found in H2.

In Horizon 1 (H1), the final phase of Saqqaq occupation at Qeqertasussuk, we see evidence of a more moderate yet increasing volatility in climate following a period of abandonment. Stratigraphic records and artifact distributions suggest that H1 is temporally distinct from the other horizons, indicating a gap in occupation. This horizon is marked by sporadic artifacts scattered across the layer, reflecting a less intensive use of the site, possibly for seasonal hunting rather than continuous habitation (Gronnow 2016). The moderate volatility during H1, paired with increasing instability, suggests that environmental conditions may have remained somewhat unpredictable, preventing the re-establishment of a long-term settlement. Instead, the Saqqaq likely used Qeqertasussuk opportunistically, capitalizing on seasonal resource peaks rather than attempting to maintain a permanent presence (Gronnow 2016). During the ~250-year gap between H1 and H2, it is possible that Saqqaq groups relocated to areas with more stable environmental conditions or greater resource reliability. Sites further inland or along other parts of Greenland's west coast, where marine and terrestrial resources might have been

less affected by climate instability, could have served as temporary refuges. Alternatively, the Saqqaq may have adopted a more nomadic lifestyle, dispersing across a broader territory to exploit resources opportunistically, reflecting a regional response to fluctuating conditions.

Additional insights into early Arctic sites during the same period are provided by Pre-Dorset sites on the Knud Peninsula. SgFm-16 (Bight), for instance, produced diagnostic artifacts closely related to the Saqqaq complex in Greenland, suggesting cultural connections between these groups (Schledermann 1990; CARD). This site, characterized by medium volatility, offers a maximum age limit through a driftwood sample, indicating it was occupied during a time of moderate environmental instability (Schledermann 1990; CARD). The SgFm-6 (Ridge) site also yielded a large number of artifacts characteristic of the late Pre-Dorset period, situated in a period of high climate volatility (Schledermann 1990; CARD). The presence of a dwelling feature, despite the challenging conditions, implies that Pre-Dorset populations, like the Saqqaq, had adapted to some degree of environmental unpredictability, though perhaps with less permanence than later Saqqaq occupations (CARD).

The SgFm-3 (Longhouse) site further illustrates the relationship between climate and settlement strategies. This site, featuring communal cooking features and large dwelling structures, contains an "Early Dorset Ridge" component dated by a charred bone sample (Schledermann 1990; CARD). The bone sample’s unusual carbon ratio, likely indicating sea mammals, suggests a mixed subsistence strategy tailored to the moderate volatility of the time (Schledermann 1990). Together, these Knud Peninsula sites reflect how Pre-Dorset populations navigated fluctuating climates, building upon the foundation of adaptation that Saqqaq communities had established.

Across these horizons, Qeqertasussuk offers a unique perspective on the relationship between climate volatility and the Saqqaq settlement. The archaeological evidence suggests that periods of reduced volatility—such as those in H2 and parts of H4—correlate with more intensive and complex site use, whereas high-volatility phases, particularly H5, appear to constrain the development of stable occupation structures. This pattern aligns with data from Knud Peninsula sites, where moderate volatility allowed for occupation and resource use but did not foster the same level of permanence and complexity observed at Qeqertasussuk during periods of low volatility. Together, these findings highlight the Saqqaq's reliance on stable environmental conditions for sustained settlement, providing insight into how early Arctic populations adapted to the dynamic and often challenging climate of the region.

4.2. Dorset Period

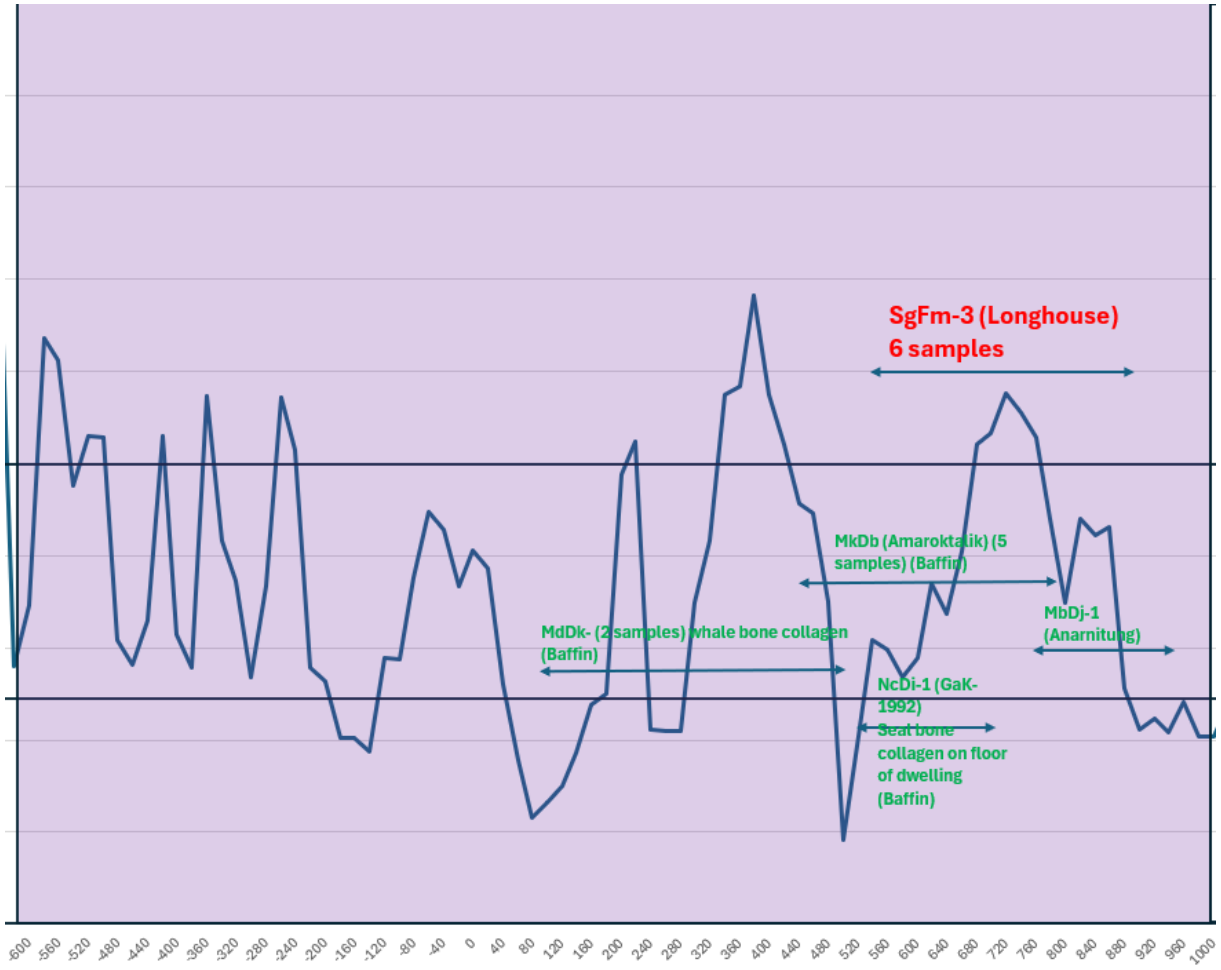


Figure 4.2. Radiocarbon Dates of Dorset period sites overlaid onto climate volatility chart. Horizontal lines represent calibrated radiocarbon dates of archaeological sites/artifacts. Green represents Cumberland Sound sites, red represents Knud Peninsula site. Overall a period of moderate volatility.

The Dorset culture represents a critical period of adaptation and innovation in the Arctic, where communities developed strategies to cope with shifting environmental conditions. The climate volatility chart for the Dorset period (Figure 4.2) overlays archaeological occupation data from sites in Cumberland Sound and the Knud Peninsula, highlighting how periods of high,

medium, and low climate volatility may have influenced settlement and subsistence practices. This period includes sites such as MdDk-1 and MkDb-1 in Cumberland Sound, as well as SgFm-3 (Longhouse) on the Knud Peninsula.

MdDk-1 (Cumberland Sound) consists of two whale bone collagen samples, providing insight into marine subsistence practices during a period of medium climate volatility, where standard deviations range between 0.25 and 0.5 (CARD). The choice of whale bone collagen for dating suggests a focus on large marine mammals, indicating that the Dorset people likely adapted their hunting strategies to an environment where ice conditions and marine mammal availability were somewhat unpredictable. While the Dorset may not have had precise predictive capabilities regarding resource availability, this archaeological evidence indicates that they employed flexible strategies, such as diversifying prey and adjusting hunting locations seasonally, to cope with environmental variability. This period also overlaps with a notably volatile period around the year 400, perhaps representing an increased reliance on larger marine mammals rather than ice-edge hunting due to an unpredictable sea ice-edge, as these animals provided a more substantial caloric yield relative to effort.

MkDb-1 (Amaroktalik), another site in Cumberland Sound, provides more nuanced data through five dates obtained from different pretreatment methods and combustion stages on a whale vertebra (CARD). Located 10 meters above sea level within beach boulders on a terrace, this site's placement may reflect a strategic adaptation to multiple environmental and subsistence factors. While the elevated location might not entirely shield occupants from harsh climatic conditions, it could provide certain advantages, such as reducing vulnerability to coastal flooding, ensuring proximity to open water during seasonal hunting, and providing a vantage point to monitor ie and animal movements. (CARD). The medium volatility period captured in

MkDb-1 implies that while the Dorset faced some degree of environmental instability, they managed to sustain a presence in areas where marine resources were accessible. This site's multiple dates reflect an attempt to accurately assess the occupation period, suggesting an emphasis on resource predictability amid moderate environmental fluctuations.

NcDi-1 (GaK-1992) provides valuable context with seal bone collagen found on the floor of a dwelling, indicating a focus on marine hunting within a habitation context (CARD). As the volatility data suggests a rise from low to moderate fluctuations, it is likely that this period enabled more predictable access to seals, which were essential for subsistence and a mainstay of the Dorset culture. The presence of seal bones within a dwelling reflects the integration of marine resources directly into domestic spaces, highlighting how Dorset communities organized their living environments around available food sources. The moderate volatility seen during this period aligns with a stable subsistence pattern that the Dorset could maintain over time, leveraging consistent yet adaptable practices to manage resource fluctuations.

MbDj-1 (Anarnitung), also located in Cumberland Sound, represents a large settlement with 15 Thule winter houses, although the site is mostly destroyed today (CARD). The dating of this site involved complex considerations due to marine reservoir effects on sea mammal bones. By applying stylistic comparisons and adjusting for isotopic fractionation, researchers have deduced an approximate occupation timeframe (Schledermann 1990; CARD). The moderate to high volatility reflected during the period aligns with a likely fluctuating marine environment, where periods of resource scarcity and abundance alternated, challenging Dorset residents to adapt to shifting conditions. Anarnitung's Thule winter houses indicate a later occupation phase that built on Dorset-era adaptations but would have required continued adjustments in subsistence practices to cope with increasing volatility (Schledermann 1990; CARD).

SgFm-3 (Longhouse) on the Knud Peninsula exemplifies the communal nature of Dorset living arrangements, with joined cooking features that extend 30-40 meters, located near extensive dwellings (Bowman et al. 1990; Schledermann 1990; CARD). The site's complex organization reflects a communal adaptation to environmental challenges, but this aggregation may also have been driven by social factors, such as the need for cooperative hunting or cultural practices that emphasized communal living. While it may seem counterintuitive in a subsistence context for groups to aggregate during periods of anything other than low volatility, such gatherings might have provided collective resilience against resource uncertainty. Communal structures could have facilitated resource pooling, risk-sharing, and knowledge exchange, mitigating the impacts of moderate volatility on individual households.

Radiocarbon dates from charred willow wood and specific charred bones provide insight into the Dorset's use of both local and imported materials, reflecting trade or resource acquisition strategies across a volatile landscape (Bowman et al. 1990; Schledermann 1990; CARD). The "Early Dorset Ridge" component, dated by charred bone, further emphasizes the community's adaptive strategies. The unusual isotopic ratios in these charred bones are significant because they suggest dietary inputs that deviate from typical local resource consumption. This anomaly may indicate reliance on marine mammals from different ecological zones, shifts in prey selection, or even trade networks that supplemented local diets during periods of resource stress (CARD). This medium volatility context likely allowed the Dorset to maintain communal structures and resource-sharing practices, enabling them to endure periods of moderate instability without abandoning the site.

The combined evidence from these Dorset sites suggests that communities were able to hunt and sustain themselves in a moderately volatile environment by diversifying their

subsistence practices and establishing communal strategies to manage resource uncertainty. While not as stable as the Saqqaq period's lower-volatility phases, the Dorset were able to persist through these fluctuations, as shown by their focus on marine resources and communal living arrangements. This adaptability, however, faced limits, as evidenced by the eventual shift to Thule culture. Whether this shift represents a cultural transition within existing populations or a replacement by migrating Thule groups remains a topic of ongoing debate. The introduction of new technological and subsistence strategies by the Thule, such as advanced maritime technologies and expanded hunting practices, suggests a significant transformation in how Arctic populations navigated increasingly volatile conditions.

4.3. Thule Period

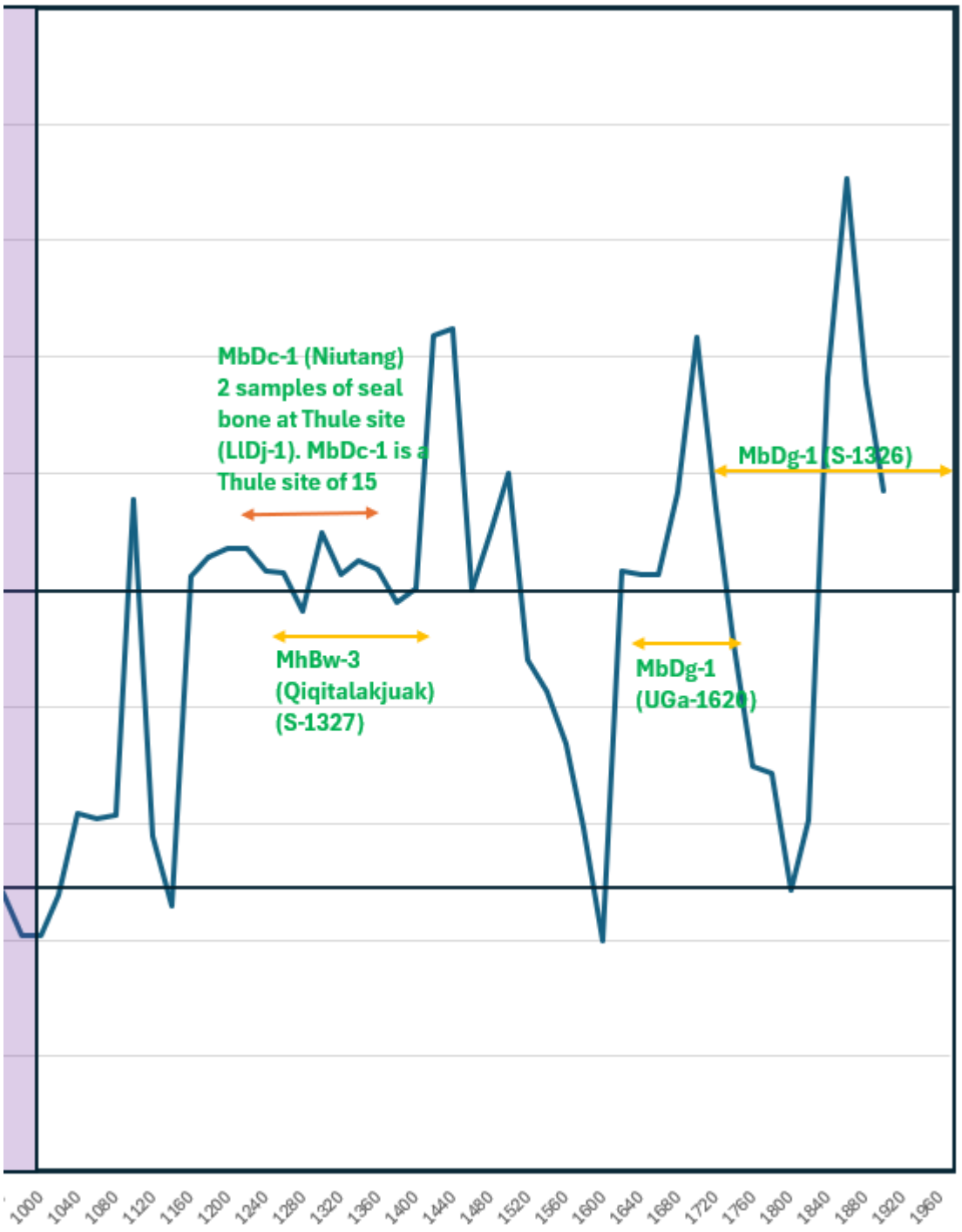


Fig. 4.3 Thule archaeological site occupation dates overlaid onto climate volatility chart.

Horizontal lines represent calibrated radiocarbon dates of Thule period sites.

The Thule culture, known for its adaptability and sophisticated marine subsistence strategies, occupied the Arctic during a period of marked climate volatility (Friesen et al. 2020). This high volatility presented both opportunities and challenges, as fluctuations in sea surface temperatures and terrestrial climate conditions impacted the availability and reliability of marine and terrestrial resources. The Thule's occupation of sites such as MbDg-1 (Cumberland Sound), MhBw-3 (Qiqitalakjuak, Baffin Island), and MbDc-1 (Niutang) reveals how they navigated and responded to these unpredictable conditions.

MbDg-1 (Cumberland Sound) is an important Thule site containing nine winter houses. Notably, the construction at MbDg-1 lacks some of the architectural features typical of Thule winter houses in the eastern Canadian Arctic, such as boulder and slab rock construction for floors, doorways, or platforms (Schledermann 1976). The presence of whale bone fragments and other artifacts suggests that this site was used by Thule occupants, though there is also evidence of historic reoccupation through the presence of European artifacts (Schledermann 1976). Given the site's lack of characteristic Thule architecture, it is possible that the structures at MbDg-1 represent qarmat dwellings, a semi-subterranean house form commonly used in the historic period (Schledermann 1976; CARD0. The high volatility throughout this period, as seen in the climate data, likely forced adaptations in building practices, subsistence, and mobility. The use of flexible, temporary structures may have been a response to fluctuating resource availability, allowing the Thule to remain mobile and adapt quickly to changing environmental conditions (Schledermann 1976; CARD).

At MhBw-3 (Qiqitalakjuak) on Baffin Island, the Thule established a winter settlement comprising four Thule winter houses (CARD). This site, situated in a highly volatile climate period, reflects the Thule's ability to occupy multiple sites with seasonal or temporary structures,

thus maintaining flexibility in the face of environmental instability (Schledermann 1990). The consistent presence of these winter houses during periods of high climate volatility suggests that the Thule employed a dispersed settlement strategy, occupying different sites across Baffin Island and Cumberland Sound to exploit various seasonal resources (Schledermann 1990). This adaptive strategy may have been critical in ensuring food security and resource stability, particularly when marine hunting was affected by unpredictable sea ice formation and melting cycles (Friesen et al. 2020). The occupation of MhBw-3 during periods of extreme volatility illustrates the Thule's resilience and capacity to manage resource risk by diversifying settlement locations.

MbDc-1 (Niutang), another significant Thule site in Cumberland Sound, is notable for its extensive archaeological features, including 16 house ruins, tent rings, qarmat structures, caches, and a large burial ground (CARD; Schledermann 1975). Unfortunately, much of this site has been damaged over time, limiting our understanding of its full cultural significance (Schgledermann 1975). However, the presence of various dwelling types suggests a complex settlement pattern adapted to high climate volatility. The qarmat structures and caches point to a semi-permanent or seasonally flexible settlement approach, likely aimed at storing resources for periods when marine hunting was less predictable (Schledermann 1975). The burial ground, a rare feature among Thule sites, may indicate a prolonged or culturally significant occupation phase at Niutang, despite the challenges posed by the volatile environment (Schledermann 1975). This combination of flexibility in housing, storage facilities, and burial grounds reflects an intricate response to environmental uncertainty, emphasizing the Thule's strategic adaptation to high volatility conditions.

Throughout this period of high climate volatility, the Thule managed to maintain a strong presence across Cumberland Sound and Baffin Island, demonstrating their exceptional resilience. The frequent establishment of winter houses, qarmat structures, and resource caches underscores their reliance on a highly adaptive strategy suited to unpredictable resource availability. By diversifying their settlement patterns and modifying architectural practices, the Thule exhibited a remarkable capacity to thrive in even the most volatile climatic conditions. This adaptability highlights the Thule's profound understanding of their environment, as well as their innovative approach to survival in the fluctuating Arctic climate.

5. Discussion

Climate volatility in the Arctic had a profound impact on the daily lives of its inhabitants, as evidenced by the archaeological and paleoclimatic data analyzed in this study. Current discussions on climate change often emphasize the role of global warming in driving increased volatility, characterized by more frequent and sever weather events (IPCC 2022). While contemporary climate change mechanisms, such as amplified Arctic warming and disrupted jet stream patterns, can exacerbate volatility, historical records show that heightened variability is not restricted to warmer periods. For example, periods like the Little Ice Age were marked by notable climatic instability despite overall cooling trends (Friesen et al. 2020; D'Andrea et al. 2011). This historical perspective underscores that volatility is a function of complex climatic interactions rather than a direct outcome of warming or cooling trends alone. By contextualizing modern volatility within this broader framework, the findings of this study demonstrate that environmental unpredictability has been a recurring feature across both warming and cooling phases. Periods of high climate volatility, marked by sharp fluctuations in temperature and sea ice extent, would have presented significant challenges to Arctic populations who relied heavily on stable environmental conditions for their subsistence practices. According to Park's work on human adaptations to frozen coastal environments, Arctic inhabitants developed an array of strategies to cope with their dynamic surroundings, from flexible settlement patterns to diversified hunting and gathering methods (Park 2010). These adaptations were essential for survival, as the extreme variability in climate conditions would have frequently disrupted traditional resource cycles.

During periods of heightened climate volatility, such as those recorded during specific occupational horizons at Qeqertasussuk, the Saqqaq and later Thule populations would have

encountered considerable uncertainty in their access to vital resources. Hunting and fishing, which were central to their daily lives, would have been directly impacted by changes in sea ice and seasonal weather patterns. As sea ice conditions became less predictable, access to marine mammals, which were essential for food, clothing, and tool-making, would have been compromised. Park underscores the importance of these resources to coastal Inuit populations, highlighting how shifts in sea ice could limit hunting opportunities and, in turn, stress the community's food supply (Park 2012). To adapt, inhabitants may have altered their hunting strategies, migrating to different areas in pursuit of more reliable hunting grounds, or timing their activities to coincide with brief windows of environmental stability.

Resource availability also influenced settlement patterns, with communities likely adopting a more mobile lifestyle during volatile periods to follow seasonal resources. This flexibility is echoed in Park's observations on the adaptations of Inuit communities, who skillfully navigated the frozen coastal environment by moving between sites as resource patterns shifted (Park 2012). For instance, at sites such as SgFm-3 on the Knud Peninsula, evidence suggests that dwellings were often temporary or seasonal, reflecting a need for adaptability in response to climatic stress. Communities would have constructed these dwellings with ease of dismantling and reassembly in mind, allowing them to relocate when necessary, a strategy that minimized the risks associated with staying in one place too long under unpredictable conditions.

In addition to physical adaptations, social structures would have played a crucial role in helping communities withstand environmental pressures. High volatility likely intensified the importance of social networks and cooperative resource sharing, as families and neighboring groups pooled their resources to buffer against scarcity. Park's research on Inuit adaptation highlights how social cooperation was integral to survival in the Arctic, with groups working

together to maximize resource use and sustain collective well-being during difficult periods (Park 2010; Park 2012). This cooperative approach would have been especially important in the face of sudden climate shifts that made traditional knowledge less reliable. Knowledge of seasonal cycles and migration routes, typically passed down through generations, may have required frequent updating, with community leaders and elders adapting cultural practices to align with changing conditions.

Periods of reduced climate volatility, in contrast, would have allowed communities to establish more permanent settlements and engage in regular, predictable resource extraction activities. Evidence from the more stable Horizon 4 at Qeqertasussuk suggests that the Saqqaq could afford to build more substantial dwellings and accumulate resources over time when climate conditions were consistent. These stable periods would have allowed for the transmission of knowledge without constant recalibration, as resource patterns were more predictable and communities could rely on established practices. Park's work emphasizes that in the absence of environmental volatility, Arctic cultures could focus on cultural development and refinement of subsistence practices, passing down reliable methods for hunting, fishing, and resource management without the frequent need to adapt (Park 2010; Park 2012)

However, even during stable times, Arctic populations had to remain vigilant and responsive to potential climatic changes, as their environment could shift quickly. The resilience of these communities is reflected in their capacity to balance periods of relative stability with readiness for abrupt shifts in climate. The fluctuating conditions of the Little Ice Age, for instance, may have led to increased volatility after a period of stability, posing new challenges that demanded both physical adaptability and social ingenuity (Friesen et al. 2020). By fostering a culture of resilience and maintaining flexible practices, Arctic populations were able to navigate an

environment characterized by constant, and sometimes extreme, change (Friesen et al. 2020; Park 2010).

6. Conclusion

This thesis has demonstrated how climate volatility differed somewhat between the periods of the Saqqaq, Dorset, and Thule cultures in the Eastern Arctic, with each group developing unique strategies to navigate the challenges posed by an unpredictable environment. By using rolling standard deviations to quantify climate volatility, this study captured significant climatic fluctuations and offered insights into how these shifts influenced cultural responses, from subsistence practices to settlement organization. The findings highlight that while high volatility posed severe challenges, these Arctic cultures demonstrated remarkable resilience, employing flexible strategies that allowed them to adapt to and, at times, thrive under dynamic conditions.

Importantly, the strongest correlations observed in this study occur within individual cultures, where the Saqqaq, Dorset, and Thule each responded to climate volatility with distinct technological and behavioural adaptations. These intra-cultural patterns reveal how each group leveraged specific strategies – such as the Saqqaq's reliance on predictable marine resources, the Dorset's communal organization and diversification of prey, and the Thule's technological innovations in maritime hunting – to navigate environmental challenges. These correlations underscore that while the overarching narrative highlights the pressures of climate volatility across Arctic prehistory, the nuanced responses of each culture reflect localized adaptations that were uniquely shaped by their environmental and social contexts.

However, this study also faced limitations that suggest avenues for further research. The original scope of this thesis was intended to encompass the broader North American Arctic, but this goal was constrained by limited access to paleoclimatic data. The volatile climate of today, underscored by events such as Hurricane Helene, directly impacted this research; the storm's destruction in North Carolina restricted access to NOAA's data resources, underscoring how

today's exceptional climate instability can even influence the study of past climate volatility. This unexpected limitation forced a narrower geographic focus on Greenland and Cumberland Sound. While this focus provided valuable insights, the incorporation of additional paleoclimatic proxies and archaeological sites across the broader North American Arctic would allow for a more comprehensive understanding of how climate volatility impacted human adaptation on a regional scale.

Expanding the range of paleoclimatic proxies, such as ice core isotopic analyses, sediment core studies, and additional sea surface temperature records, could reveal a more nuanced view of past climate conditions and their variability. By correlating these detailed climate records with a wider range of archaeological sites and cultural phases, future research could identify more precise patterns of human adaptation, migration, and settlement in response to environmental stresses. Such research could also benefit from incorporating more diverse proxies, including biological indicators like pollen and diatom records, which would provide further context on ecological changes and resource availability.

This study's findings carry significant implications for Public Issues Anthropology, as they reflect the ways in which current climate volatility affects not only contemporary communities but also the study of past human experiences. The impacts of modern climate instability on this research illustrate a pressing reality: as we face unprecedented volatility, both human societies and the study of climate volatility itself are at the mercy of these changing conditions. The experiences of the Saqqaq, Dorset, and Thule cultures offer valuable lessons on resilience, cooperation, and adaptability, underscoring the need for flexible and sustainable responses to climate challenges both past and present.

In conclusion, this thesis provides an important perspective on the dynamic relationship between Arctic communities and their environment, while also underscoring the broader implications of our present-day climate crisis. Although limited in scope, these findings contribute to the growing field of climate anthropology, offering a foundation for future research that could further illuminate the interplay between climate volatility and human resilience.

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Appendix

This dataset provides paleoclimatic data for Eastern Arctic regions, including temperature deviations from modern averages and sea surface temperature records. The data covers periods extending back over 10,000 years BP, offering insights into the variability of climate over time. The measurements are expressed in terms of depth, age (in years BP), and temperature deviations, providing a basis for understanding climate volatility and its potential impact on human occupation patterns in the Arctic.

Sea Surface Temperature Data: (Ouellet-Bernier 2014) (NOAA) This is sea surface temperature data, gathered from NOAA's paleoclimatological database. By using the modern analogue method of analysing dinocysts from sediment cores from the seafloor of Disko Bay, Greenland, accurate recordings of sea surface temperatures can be reconstructed.

Depth (m)	Age (BP)	Temperature (°C)	Temperature-1 (°C)
0.03	803	-0.61	10.93
0.09	859	-0.67	9.32
0.13	896	-0.51	10.99
0.17	933	-0.78	10.04
0.20	961	-0.85	10.62
0.25	1007	-0.63	9.83
0.30	1054	-0.92	8.29
0.33	1078	-1.19	4.30
0.37	1112	-0.77	9.76
0.40	1137	-0.97	6.09
0.45	1178	-0.74	15.33
0.49	1212	-0.58	9.96
0.52	1237	0.16	9.63
0.57	1278	-0.62	6.29
0.61	1312	-0.87	7.66
0.65	1345	-1.35	5.76
0.69	1378	-1.29	2.80
0.73	1420	-1.11	2.94
0.77	1469	-1.58	8.34
0.81	1518	0.49	8.08
0.85	1567	-1.10	12.15
0.89	1616	-1.60	7.79
0.93	1665	-1.39	6.32
0.97	1714	0.19	9.64
1.01	1762	-0.16	12.37

Depth (m)	Age (BP)	Temperature (°C)	Temperature-1 (°C)
1.05	1803	0.12	11.77
1.09	1844	0.24	12.54
1.13	1885	0.09	9.66
1.17	1926	-0.91	11.94
1.21	1967	-0.88	10.09
1.25	2009	-0.48	11.23
1.29	2050	-0.69	10.01
1.34	2101	-0.65	12.01
1.37	2132	-0.78	14.12
1.41	2173	-1.49	7.23
1.45	2214	-0.92	9.94
1.49	2251	-0.92	14.46
1.53	2326	-1.12	12.86
1.57	2401	-1.19	9.57
1.61	2477	-0.76	14.08
1.65	2552	-1.09	12.01
1.69	2631	0.11	9.74
1.73	2676	-1.09	12.28
1.77	2721	-1.02	10.02
1.81	2766	-0.12	8.35
1.85	2811	-1.38	8.37
1.89	2856	-0.92	14.51
1.93	2944	-0.10	9.54
1.97	3046	-1.06	11.20
2.00	3122	-1.25	10.30
2.05	3250	-0.74	13.26
2.09	3352	-0.05	11.09
2.13	3456	-1.38	9.21
2.17	3539	-0.29	8.93
2.21	3622	-0.83	12.52
2.25	3809	-1.48	7.53
2.29	3967	-1.41	9.62
2.33	4125	-1.43	7.07
2.37	4283	0.16	10.58
2.41	4389	0.14	11.37
2.45	4407	-0.17	5.88
2.49	4425	-1.46	5.88

Depth (m)	Age (BP)	Temperature (°C)	Temperature-1 (°C)
2.53	4444	-0.51	6.02
2.57	4462	-0.85	11.76
2.61	4480	-1.28	10.34
2.65	4546	-1.65	5.99
2.69	4618	-0.21	8.98
2.73	4690	-1.03	11.55
2.77	4763	-0.38	10.32
2.81	4835	-0.97	9.14
2.85	4907	-0.20	9.40
2.89	4980	-1.04	11.57
2.93	5052	-0.09	9.68
2.97	5122	-0.91	10.21

Temperature Deviation Data: (Vinther et al. 2009)(NOAA): This is the temperature deviation data gathered from the Renland-Agassiz ice cores (NOAA) and calibrated with the Greenland Ice Sheet Project. By examining oxygen isotopes of successive layers of the ice cores, accurate reconstructions of air temperature can be performed. Years are in BP2K (years before 2000 CE), and temp_20yr represents in degrees Celsius how much in that 20 year period from the next entry temperature deviated from the modern Greenlandic norm.

age_calBP2k	temp_20yr
40	-1
60	1.56
80	1.16
100	0.18
120	-0.02
140	-0.46
160	-0.51
180	-0.35
200	-0.01
220	0.29
240	0.20
260	-0.81
280	-0.89

300	-1.31
320	-0.34
340	0.00
360	-0.46
380	-0.15
400	-0.44
420	0.23
440	-0.73
460	0.18
480	0.15
500	-1.03
520	-0.10
540	-0.07
560	0.98
580	-0.12
600	0.55
620	0.70
640	-0.18
660	-0.53
680	0.15
700	0.71
720	-0.27
740	-0.43
760	-0.54
780	0.29
800	0.71
820	0.21
840	0.69
860	0.49
880	0.98

900	-0.52
920	-0.32
940	-0.33
960	-0.01
980	0.48
1000	-0.25
1020	0.47
1040	1.03
1060	0.59
1080	0.93
1100	0.00
1120	0.66
1140	1.40
1160	1.24
1180	0.35
1200	0.81
1220	-0.03
1240	0.04
1260	1.46
1280	0.18
1300	0.38
1320	0.78
1340	0.82
1360	0.29
1380	-0.14
1400	0.21
1420	0.41
1440	0.08
1460	0.45
1480	0.51

1500	0.36
1520	0.73
1540	-0.14
1560	0.72
1580	1.27
1600	1.67
1620	1.02
1640	0.78
1660	0.85
1680	0.83
1700	1.19
1720	0.32
1740	0.82
1760	0.67
1780	0.55
1800	0.33
1820	0.49
1840	0.70
1860	0.59
1880	0.93
1900	0.55
1920	0.48
1940	0.66
1960	0.14
1980	-0.37
2000	0.09
2020	0.75
2040	2.18
2060	1.03
2080	0.80

2100	1.15
2120	0.74
2140	0.42
2160	1.09
2180	0.94
2200	0.05
2220	0.17
2240	0.08
2260	0.35
2280	0.04
2300	0.30
2320	0.10
2340	-0.06
2360	1.14
2380	0.81
2400	1.29
2420	0.72
2440	1.50
2460	0.96
2480	0.98
2500	0.06
2520	0.69
2540	1.61
2560	1.37
2580	1.32
2600	1.34
2620	0.61
2640	-0.37
2660	0.95
2680	0.24

2700	0.71
2720	0.20
2740	0.46
2760	1.68
2780	1.65
2800	0.81
2820	0.54
2840	0.82
2860	0.75
2880	1.07
2900	1.24
2920	1.45
2940	1.18
2960	0.63
2980	2.75
3000	0.98
3020	1.33
3040	2.09
3060	0.54
3080	1.79
3100	0.83
3120	0.84
3140	0.78
3160	1.14
3180	1.83
3200	1.96
3220	1.45
3240	1.51
3260	1.10
3280	1.45

3300	1.78
3320	1.08
3340	1.33
3360	0.89
3380	1.34
3400	0.41
3420	1.57
3440	1.07
3460	1.73
3480	1.84
3500	1.20
3520	1.25
3540	1.28
3560	1.11
3580	1.33
3600	1.30
3620	0.66
3640	0.90
3660	1.40
3680	1.67
3700	1.80
3720	1.55
3740	1.86
3760	1.34
3780	0.87
3800	1.05
3820	1.65
3840	0.39
3860	0.79
3880	0.99

3900	1.75
3920	1.76
3940	1.65
3960	1.58
3980	1.55
4000	1.52
4020	1.19
4040	1.19
4060	1.28
4080	1.89
4100	2.07
4120	1.46
4140	1.34
4160	1.36
4180	2.40
4200	2.81
4220	2.20
4240	1.52
4260	2.07
4280	1.06
4300	0.78
4320	1.00
4340	0.37
4360	1.10
4380	1.30
4400	1.32
4420	1.81
4440	1.85
4460	1.62
4480	1.82

4500	1.73
4520	1.18
4540	2.02
4560	0.78
4580	1.48
4600	2.25
4620	2.02
4640	1.66
4660	1.67
4680	1.60
4700	1.73
4720	1.55
4740	2.25
4760	2.36
4780	1.48
4800	1.53
4820	1.66
4840	1.61
4860	1.68
4880	1.26
4900	1.54
4920	1.54
4940	2.56
4960	2.56
4980	1.89
5000	2.72