Some Perspectives on the Late Quaternary Paleoclimate of Beringia

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Abstract: Analyses of the modern summer synoptic climatology of Beringia illustrate that the region cannot be treated as a homogeneous climatic unit as a result of different circulation controls that operate over the region. GCM (general circulation model) simulations and information from the modern synoptic climatology were used to infer the summer paleosynoptic climatology of the region since the last glacial maximum. Implications of surface climatic responses for the late Quaternary were compared with available proxy data, mostly from fossil pollen records. Results indicate that surface climatic responses differ spatially over Beringia, mostly as a result of variations in circulation controls such as the East Asian trough and Pacific subtropical high that are superimposed within external controls such as insolation and ice sheet size. Variations in these climatic controls offer important implications in assessing the vegetation histories of western Beringia versus eastern Beringia.

Introduction

Comparisons between GCM (general circulation model) simulations and proxy evidence of late Quaternary paleoclimates are at times complicated as a result of spatially heterogeneous climatic patterns suggested by the latter (*eg*, Mock and Bartlein 1995). Beringia, with its borders defined as from the Alaska/Canada border westward to the Indigirka River in Siberia (Figure 1), is a key region for studying late Quaternary paleoclimatic changes in the Arctic as a result of a growing body of modern and fossil records, particularly palynological ones (Bartlein *et al* 1991). Differences in the temporal and spatial variability of vegetation histories within Beringia may be explained by changes in atmospheric circulation controls, which create more heterogeneous surface climatic responses spatially as compared to larger-scale controls such as incoming insolation. This paper examines the summer synoptic climatology of Beringia since the last glacial maximum around 18,000 years ago (18 ka, radiocarbon years), using available GCM simulations as well as information from the modern synoptic climatology of the region. Proxy data, mostly from fossil pollen evidence, provided additional information on surface paleoclimatic responses.

Modern Summer Synoptic Climatology of Beringia

Composite difference maps of 500-mb heights, representing atmospheric circulation that causes abnormal temperature and precipitation anomalies at selected representative stations, were examined to determine the circulation controls that govern surface summer climate. In this paper,

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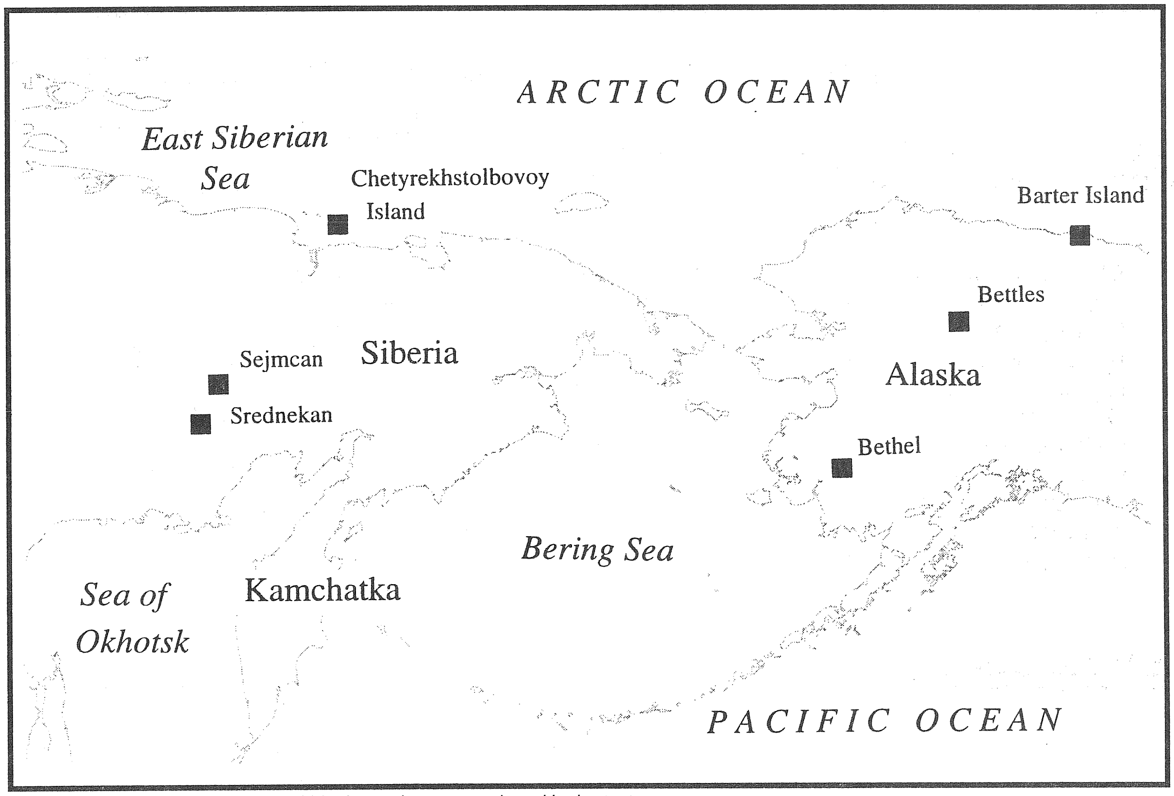

Figure 1. Beringia and locations within the region as mentioned in the text.

discussion is focused on sea-level composites for July temperature and 500-mb composites for July precipitation, as these height levels represent the clearest assessments of the synoptic climatology of the region. Circulation values for the months that have values greater than the 75th percentile were averaged. A similar procedure was conducted for months with values less than the 25th percentile, with the differences between the two extremes representing the composite differences (*eg,* Klein and Kline 1984). Negative anomalies on the maps represent increased cyclonic and counterclockwise flow around centers, and positive anomalies represent increased anticyclonic and clockwise flow around centers.

Sea-level composite difference maps of July temperature for selected sites in Beringia show some similarities and some differences (Figure 2). Positive anomalies located off the coast of Kamchatka are associated with increased southerly winds and warmer temperatures for western Beringia, as shown in the examples for Chetyrekhstolbovoy Island and Sejmcan. A reversal of anomaly signs suggests a weaker area of high pressure as compared to normal and, thus, increased frequency of northerly winds and colder temperatures for these locations. Although anomalies are generally weak over most of northern Asia, the negative and positive signs suggest that the pattern of ridges and troughs plays an important role in summer temperature variations as well, perhaps determining the mean position of the arctic front (Krebs and Barry 1970). Along the north coast of Alaska, as shown in the example for Barter Island, southerly flow around the Pacific subtropical high to the south plays a major role in governing temperature variations. However, the example for Bettles, Alaska, is typical for most sites south of the North Slope. Anomaly patterns suggest that a weakened Pacific subtropical high and a strengthened anticyclone over the Beaufort Sea enable increased easterly winds and thus warmer temperatures. A reversal of anomaly signs implies that increased westerly winds bring colder temperatures to the area.

The synoptic situations favoring precipitation differ from temperature by exhibiting more spatial variability in atmospheric circulation from site to site (Figure 3). First considering western Beringia, the 500-mb composite difference map for Chetyrekhstolbovoy Island July precipitation illustrates negative heights along northwestern Beringia that represent the East Asian trough, with positive anomalies adjacent and to the south representing northward shifts of the subtropical anticyclones. The East Asian trough is also clearly evident for Srednekan, but positive anomalies are mostly absent as a result of the trough being generally displaced farther southward due to the location of Srednekan. The trough enables

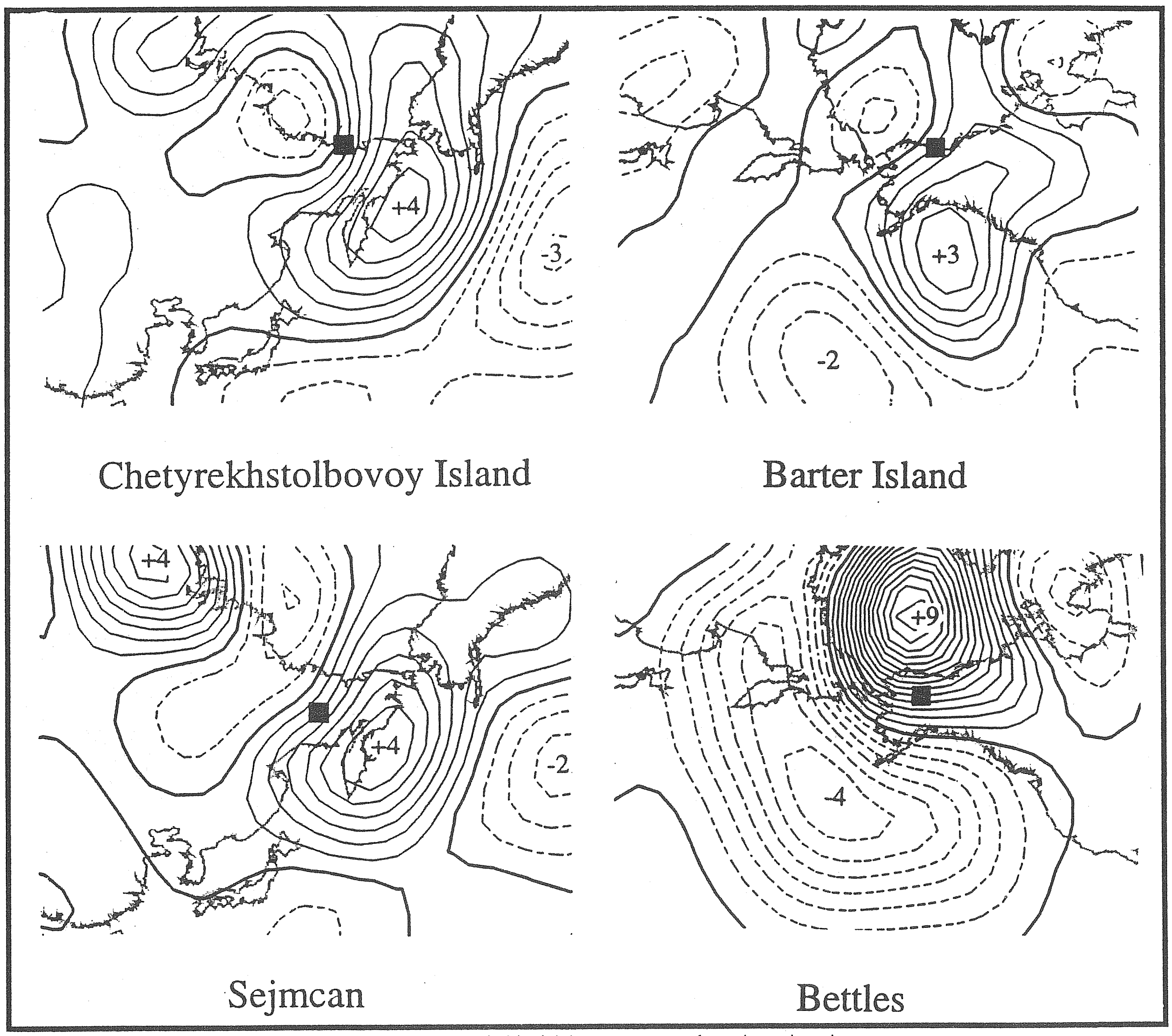

Figure 2. Sea-level pressure composite difference maps (mb) of July temperature for selected stations.

higher precipitation by allowing cyclogenesis to occur in the region, and perhaps also by retaining and steering storms coming from the west and southwest.

The 500-mb composite difference maps for Bettles and Bethel July precipitation both show that higher precipitation results from negative height anomalies centered to the north-northwest of their respective locations. This eastward extension of the East Asian summer trough allows storms from the East Siberian Sea to enter the region (Moritz 1979). However, the Bethel 500-mb composite map differs from that of Bettles by illustrating higher positive anomalies south of Alaska. These anomalies, representing a stronger and/or expanded Pacific subtropical high, combined with the zone of negative anomalies to the north, increases the frequency of westerly winds and storms into Bethel. Bettles, which is farther inland, is not affected as much by the subtropical high as a result of numerous mountain ranges impeding moisture coming directly from the Pacific. Therefore, negative anomalies over the Beaufort Sea are more important for enabling higher precipitation to occur at Bettles.

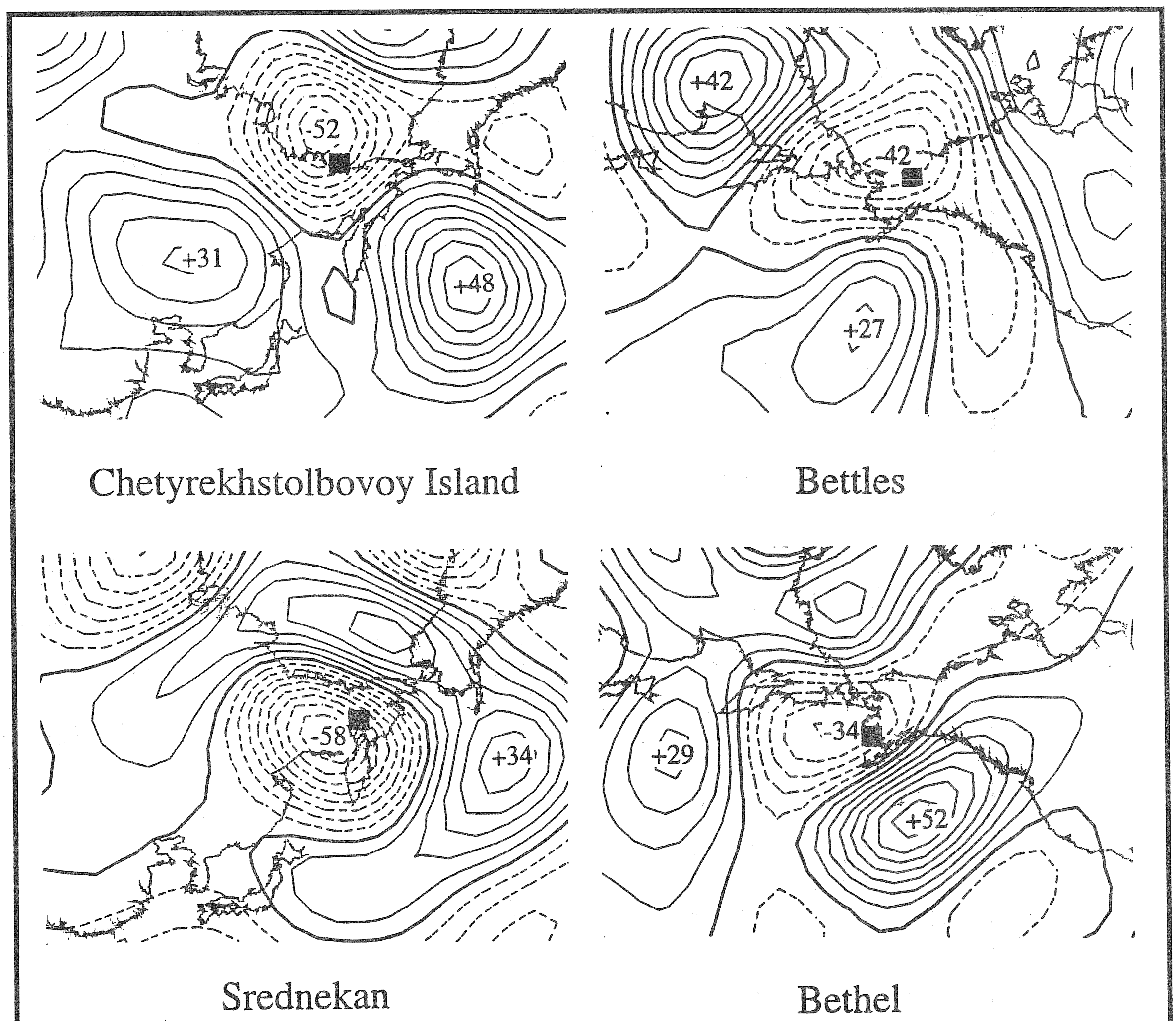

Figure 3. 500-mb composite difference maps (geopotential meters) of July precipitation for selected stations.

Summer Synoptic Climatology of Beringia Since the Last Glacial Maximum

General circulation models have some problems in simulating spatial patterns of temperature and precipitation, particularly the latter, at smaller spatial scales. These problems are the result of the models' limited grid-size resolution and portrayal of topographic features such as the Alaska and Brooks ranges, as well as the coastline of Beringia. However, GCMs have been proven to simulate large-scale synoptic patterns of paleoclimates fairly well for the mid-latitudes (COHMAP Members 1988). Therefore, this discussion focuses mostly on the synoptic patterns from the GCMs, since some uncertainty still remains in the simulations of surface climatic anomalies for Beringia, particularly for precipitation. The GCM simulations discussed come from both NCAR CCM 0 and NCAR CCM 1 (National Center for Atmospheric Research Community Climate Model), and simulations of both GCMs were conducted in roughly 3000-year intervals (COHMAP 1988; Kutzbach *et al* 1993; COHMAP Members, personal communication). Time periods are broadly summarized for discussion (Table 1) as the last glacial maximum (18-12 ka), the late glacial (12-9 ka), and the early-mid Holocene (9-5 ka).

GCM simulations for July atmospheric circulation around the last glacial maximum imply positive pressure anomalies over northern Siberia and negative pressure anomalies over much of the north Pacific Ocean. The positive anomalies suggest increased anticyclonic flow around western Beringia, which would create drier conditions relative to today (Table 1). The negative anomalies suggest a weaker Pacific subtropical high, thus preventing a strong, moist southwesterly flow over most of Alaska. Nearby ice sheets throughout Beringia would still, however, keep temperatures lower as compared to today. The weaker Pacific subtropical high during summer would also contribute to lower temperatures for Alaska. Overall, the paleoclimatic analyses suggest colder and drier summers, and these conditions correspond well with the implications of herb tundra that was prevalent over much of the region (Anderson and Brubaker 1994).

Model simulations from NCAR CCM 1 imply that negative pressure anomalies were predominant over most of Beringia during the late glacial. Synoptic interpretation, based on modern synoptic climatic reasoning, suggests that such widespread negative pressure anomalies would create widespread wetter and colder conditions than today. Such conditions during the late glacial, however, did not occur as suggested by fossil pollen and lake-level evidence — conversely most proxy data suggest the opposite (Anderson and Brubaker 1994; M. Edwards personal communication). Results from NCAR CCM 0 also show negative pressure anomalies prevalent over most of Beringia, but it also indicates anticyclonic flow over Alaska. The anticyclone over Alaska, would suggest stronger easterly flow, causing warmer and drier conditions compared to today.

These results are more consistent with the implications of a *Populus* woodland that indicate drier and warmer conditions (Anderson and Brubaker 1994). Thus perhaps the NCAR CCM 0 simulation better reflects the summer synoptic climatology during the late glacial. A stronger East Asian trough may have been prevalent during this time over western Beringia, but the subtropical high to the south may have also been stronger, so precipitation anomalies are inconclusive (Table 1). Temperatures throughout Beringia were generally warming from the full glacial due to the increased tilt of the earth's axis and timing of perihelion, but a stronger East Asian trough over western Beringia may have prevented summer temperatures from being above normal.

Both GCM simulations show a strengthening of the Pacific subtropical high during the early-mid Holocene, and the East Asian trough over western Beringia weakened to about as strong as today. These synoptic conditions suggest similar precipitation conditions in western Beringia as at present, perhaps consistent with vegetation reconstructions that indicate the establishment of the modern larch/pine forests by the early Holocene (Lozhkin *et al* 1993). A stronger Pacific subtropical high may cause increased summer precipitation for southern and central Alaska, and these conditions may have been more conducive for the spread and changes of spruce forests during this time. GCM simulations suggest positive temperature anomalies as a result of the orbital factors. The simulations also show that as the Holocene progressed, summer temperature and precipitation lowered toward values that are prevalent today.

Table 1
SUMMARY OF SUMMER SYNOPTIC CLIMATOLOGY OF WESTERN AND EASTERN BERINGIA AS ANALYZED FROM GCM SIMULATIONS AND MODERN SYNOPTIC CLIMATOLOGY

Climatic descriptions are relative to present-day conditions.

Period	Western Beringia	Eastern Beringia
Last Glacial Maximum (18-12 Ka)	Increased ridging; colder and drier.	Weaker subtropical high; colder and drier.
Late Glacial (12-9 Ka)	Gradual strengthening of subtropical high and East Asian trough, but location of the latter is uncertain; warming from full glacial and approximately equal precipitation compared to today.	Generally negative sea-level pressure anomalies, but an anticyclone over Alaska; warmer and drier.
Early to Mid-Holocene (9-6 Ka)	Conditions progress more toward present-day, but still stronger subtropical high; warmer.	Stronger Pacific subtropical high; warmer and wetter.

Conclusions

Modern synoptic climatic analyses show that the circulation controls that govern temperature and precipitation variations differ within the region — thus Beringia cannot be treated as a homogeneous unit climatically. Some climatic controls that affected paleoclimates in Beringia in the late Quaternary most likely differed as compared to those in the modern, but similarities in the circulation controls most likely also held true in the past and can provide an explanation of spatial heterogeneous paleoclimatic responses (Mock and Bartlein 1995). Analyses of the synoptic climatology of Beringia since the last glacial maximum suggest that changes in different circulation controls did occur, and these changes may help explain spatial variations in the vegetation histories of taxa, as the histories in western Beringia versus eastern Beringia are quite different. Some disagreements between GCM results, implications from paleoclimatic proxy data, and reasoning from modern synoptic climatology are still evident — this mostly deals with the problem of interpreting processes at different spatial scales. The continued refinement of GCMs, growing network of paleoclimatic proxy data, and the application of RCMs (regional climate models) will help resolve these problems.

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