Supplement of Early-Holocene warming in Beringia and its mediation by sea-level and vegetation changes

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Supplementary Material

This supplement contains figures displaying 10-year long-term means or long-term mean differences (anomalies) from the various simulations. Each simulation is described by two pages of figures (A & B): Page A displays net radiation (Wm$^{-2}$), 2-m air temperature (°C), 500 mb heights (gpm) and winds (m s$^{-1}$), sea-level pressure (hPa) and surface winds (m s$^{-1}$), total cloud (fraction), precipitation rate (mm d$^{-1}$), and soil moisture (%). Page B displays surface energy-balance components including net shortwave radiation, net longwave radiation, net radiation, sensible heat flux, latent heat flux, and the heat flux into the substrate (or change in heat storage), all in Wm$^{-2}$, and 2-m air temperature (°C). (Net radiation and 2-m air temperature appear on both figures for convenience.) The sign convention for the energy-balance components is described below.

Figures:

1) Present-Day Simulation (with modern continental outlines)
2) Present-Day Simulation (with 11 ka continental outlines)
3) Present-Day Simulation (with modern continental outlines) minus Present-Day Simulation (with 11 ka continental outlines)
4) 11 ka Control Simulation
5) 11 ka Control Simulation minus Present-Day Simulation
6) 11 ka Control Simulation minus Present-Day Simulation (with 11 ka continental outlines)
7) 11 ka Sea-Level Simulation
8) 11 ka Sea-Level Simulation minus 11 ka Control Simulation
9) 11 ka Vegetation Simulation
10) 11 ka Vegetation Simulation minus 11 ka Control Simulation
11) 11 ka Lakes Simulation
12) 11 ka Lakes Simulation minus 11 ka Control Simulation
13) 11 ka All Simulation
14) 11 ka All Simulation minus 11 ka Control Simulation
15) 11 ka All Simulation minus Present-Day Simulation (with modern continental outlines)
16) 6 ka Simulation
17) 6 ka Simulation minus Present-Day Simulation (with modern continental outlines)
18) 6 ka Simulation minus 11 ka All Simulation
19)
Surface energy-balance components

The surface energy balance is given by

\[
\downarrow K - \uparrow K + \downarrow L - \uparrow L - Q_H - Q_E - Q_G = 0, \text{ or } Q_{net} = \downarrow K - \uparrow K + \downarrow L - \uparrow L, \text{ or } Q_{net} = Q_H + Q_E + Q_G, \text{ or } Q_{net} = Q_H + Q_E + \Delta Q_S
\]

where

\(\downarrow K\) = incoming shortwave radiation (all terms in Wm\(^{-2}\)),

\(\uparrow K\) = outgoing shortwave radiation,

\(Q_{net} = \downarrow K - \uparrow K\), net shortwave radiation, or \((1 - \alpha)\downarrow K\) where \(\alpha\) is the albedo of the surface,

\(\downarrow L\) = incoming longwave radiation,

\(\uparrow L\) = outgoing longwave radiation (~ \(T_{sfc}^4\) where \(T_{sfc}\) is the temperature of the surface),

\(Q_{net} = \downarrow L - \uparrow L\), or net longwave radiation,

\(Q_H\) = sensible heat flux,

\(Q_E\) = latent heat flux (~\(E\) or ~\(ET\), where \(E\) is evaporation and \(ET\) is evapotranspiration), and

\(Q_G = \Delta Q_S\), heat flux into or out of the substrate (land or water) or change in heat storage.
Sign conventions for and interpretation of surface energy-balance component

<table>
<thead>
<tr>
<th>Radiative components</th>
<th>Long-term mean</th>
<th>Long-term mean difference (anomalies)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net shortwave radiation, $K_{net}$</td>
<td>positive: toward surface (i.e., surface heating) negative: 0.0</td>
<td>positive: increased $K\downarrow$ or decreased albedo (e.g. sea-ice replaced by land) negative: decreased $K\downarrow$ or increased albedo (e.g. land replaced by sea-ice)</td>
</tr>
<tr>
<td>Net longwave radiation, $L_{net}$</td>
<td>positive: toward surface negative: from surface (i.e., surface cooling)</td>
<td>positive: increased $L\downarrow$ or decreased $L\uparrow$ negative: decreased $L\downarrow$ or increased $L\uparrow$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-radiative components</th>
<th>Long-term mean</th>
<th>Long-term mean difference (anomalies)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensible heat flux, $Q_H$</td>
<td>positive: heat flow from surface to atmosphere negative: heat flow from atmosphere to surface</td>
<td>positive: increased heating of atmosphere by surface or decreased heating of surface by atmosphere negative: decreased heating of atmosphere by surface or increased heating of surface by atmosphere</td>
</tr>
<tr>
<td>Latent heat flux, $Q_E$</td>
<td>positive: heat flow (via $E$ or $ET$) from surface to atmosphere negative: heat flow (via condensation) from atmosphere to surface</td>
<td>positive: increased $E$ or $ET$ (or decreased condensation) negative: decreased $E$ or $ET$ (or increased condensation)</td>
</tr>
<tr>
<td>Substrate heat flux, $Q_g = \Delta Q_S$</td>
<td>positive: heat flow from surface into substrate (land or water), i.e., into storage negative: heat flow from substrate to surface, i.e., from storage</td>
<td>positive: increased heat flow from surface to substrate (or increased flow into storage) negative: decreased heat flow from surface to substrate (or decreased flow into storage)</td>
</tr>
</tbody>
</table>
Present-Day Simulation (with 11 ka Continental Outlines) Long-Term Means

Net Radiation
2-m Air Temperature
500hPa Heights & Winds
Sea-Level Pressure & Winds
Total Cloud Fraction
Precipitation Rate
Soil Moisture

Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Suppl. Fig. 2A
Present-Day Simulation (with 11 ka Continental Outlines)

Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Suppl. Fig. 2B
Net Radiation

2-m Air Temperature

500hPa Heights & Winds

Sea-Level Pressure & Winds

Total Cloud Fraction

Precipitation Rate

Soil Moisture

Jan

Feb

Mar

Apr

May

Jun

Jul

Aug

Sep

Oct

Nov

Dec
Suppl. Fig. 4B

11 ka Control Simulation
Net Shortwave Radiation
Net Longwave Radiation
Net Radiation
Sensible Heat Flux
Latent Heat Flux
Substrate Heat Flux
2-m Air Temperature

Long-Term Means
Net Shortwave Radiation

Net Longwave Radiation

Net Radiation

Sensible Heat Flux

Latent Heat Flux

Substrate Heat Flux

2-m Air Temperature

Suppl. Fig. 7B
11 ka Lakes Simulation - 11 ka Control Simulation

Long-Term Mean Differences

Suppl. Fig. 12A
Net Radiation

2-m Air Temperature

500hPa Heights & Winds

Sea-Level Pressure & Winds

Total Cloud Fraction

Precipitation Rate

Soil Moisture

Jan

Feb

Mar

Apr

May

Jun

Jul

Aug

Sep

Oct

Nov

Dec

11 ka All Simulation - Present-Day Simulation

Long-Term Mean Differences

Suppl. Fig. 15A