The Heinrich and Dansgaard–Oeschger Climatic Events During Marine Isotopic Stage 3

Jorge Rabassa and Juan Federico Ponce

Abstract The Marine Isotope Stage 3 (MIS 3) was an interstadial stage, a relatively warm climatic period which developed roughly between 60 and 50 and 30 cal. ka B.P. Several very cold periods, known as Heinrich (H) events, developed during MIS 3 as a result of partial collapse of the North American ice sheet margins, with formation of huge amounts of icebergs which, after melting in more temperate latitudes, would have inundated the North Atlantic Ocean with low salinity waters which would have impeded the penetration of the Gulf Stream into the North Atlantic Ocean. Several paleoclimatic moments with relatively warmer conditions, known as the Dansgaard–Oeschger (D-O) events, took place in-between the Heinrich (H) events, throughout MIS 3. These H and D-O cycles would have been very short in geological terms (perhaps even only around 1 kiloyears (kyr) each in some cases) and quite intense, with mean annual temperatures, for instance in the area of Beringia (the land bridge between Siberia and North America) ca. 5–8 °C higher than those active at the Last Glacial Maximum (LGM; ca. 24 cal. ka B.P.) and perhaps close to those occurring in past interglacial periods, respectively. Even though climate was warmer than during the LGM, total melting of the continental ice sheets did not take place; thus, global sea level was perhaps lower than today during the entire MIS 3. It was low enough to allow the persistence of Beringia, without any interruptions throughout the whole of MIS 3. The aim of this paper is to present basic paleoclimatic and paleogeographic information about MIS 3, which may be useful to understand the nature and evolution of the South American terrestrial and marine ecosystems later on during the LGM.

Keywords Late Quaternary paleoclimate · Marine Oxygen Isotope 3 · Dansgaard/Oeschger climatic events

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1 Introduction

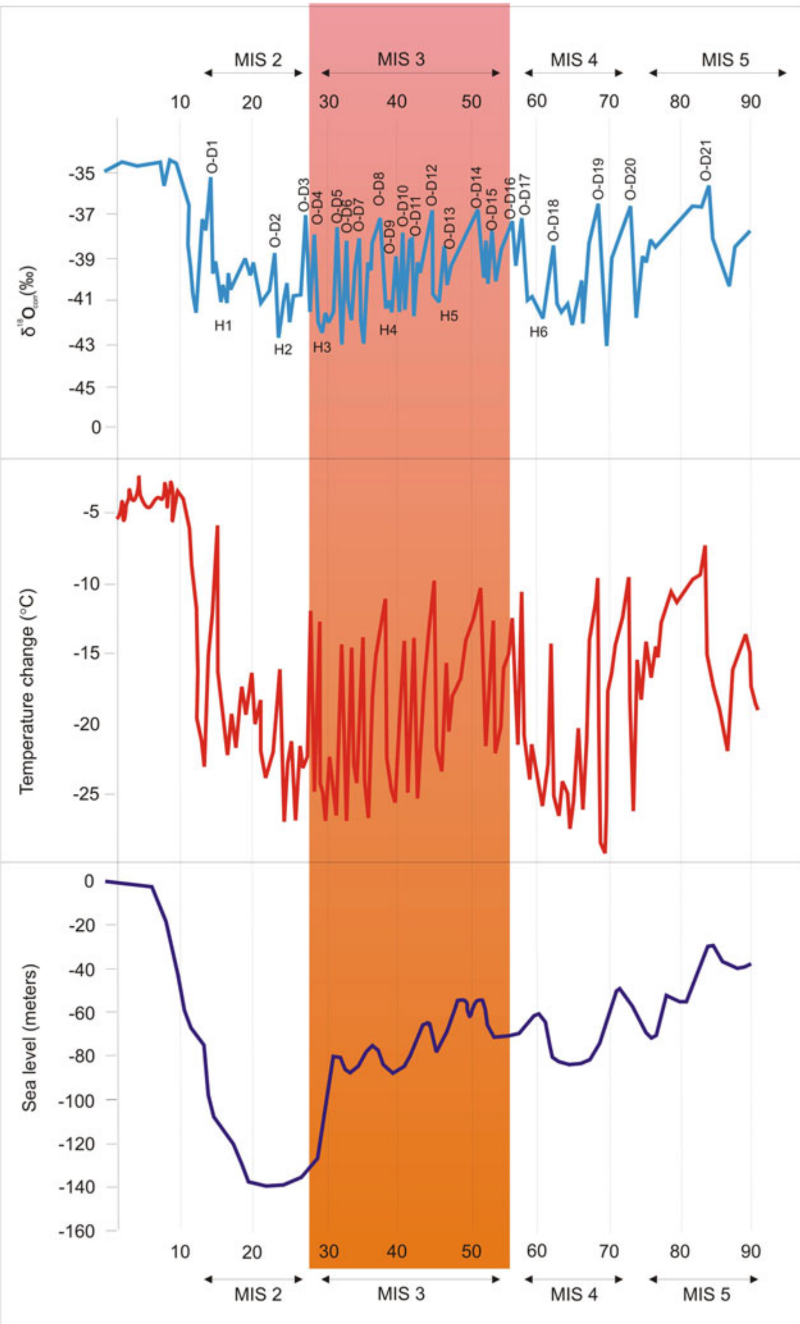
Middle and Late Pleistocene paleoclimates are characterized by climatic cycles that include glacial (colder) and interglacial (warmer) stages, with a total duration of ca. 100 kiloyears (kyr) each. The colder glacial periods, around 80–90 kyr duration, are longer than the interglacial ones, which are shorter and warmer, averaging 10–20 kyr. Glacial periods show significant paleoclimate variations, with colder events which are called "stadials" and warmer periods named as "interstadials." Full glacial conditions concerning both very low global temperatures and sea level stands are achieved only during stadials. Interstadials are characterized by warmer temperatures than those during the stadials, recession of the continental ice sheets (but not total vanishing), and rising sea levels to intermediate positions in between full glacial and interglacial times.

These cycles are very well exposed by the relative content of ^{18}O isotopes (∂^{18}O), or other proxy elements or substances contained in ice from polar ice cores, such as those in Greenland and Antarctica, as well as the variations of the same isotopes in foraminifera and/or ostracoda found in marine sedimentary cores [for explanation of the ∂^{18}O method, see Andrews (2000), and Wright (2000)]. In Fig. 1, the ∂^{18}O variations during the last glacial–interglacial cycle are depicted, starting with the final phases of the last interglacial. In this figure, isotope peaks pointing upwards correspond to warmer periods, whereas those pointing downwards are colder events.

The periods showing a specific trend of ∂^{18}O content are called "marine isotope stages" (MIS), and they correspond to moments with distinct global temperatures and climates. MIS 5 is the last full interglacial period and MIS 1 is the present interglacial. MIS 4 and 2 are colder, stadial events, the earlier corresponding to the process of building up of the continental ice sheets, and the latter representing the maximum of the Last Glaciation (LGM, ca. 24 cal. ka B.P.) and extending until the end of the Pleistocene (10 ^{14}C ka B.P.). MIS 3 corresponds to a long interstadial epoch which was much warmer than the following stadial period, that is, the LGM. MIS 3 lasted at least 25 kyr, perhaps even 30–35 kyr, between approximately 60–50 and 30 cal. ka B.P. The contents of this review paper are partly a summary of the corresponding sections in Rabassa and Ponce (2013).

2 The Climate of North America, Beringia, and the North Atlantic Ocean During MIS 3: The Heinrich and Dansgaard–Oeschger Events

During MIS 3, the North American and European ice caps receded from their outer positions achieved in MIS 4, and extensive portions of the landscape were abandoned by the ice; sea level stood between −55 and −90 m below present sea level (Figs. 3b, c; see Lambeck and Chappell 2001), only half to three quarters of the


MIS 2
MIS 3
MIS 4
MIS 5
10 20 30 40 50 60 70 80 90
δ18Ocorr(‰)
-35 -37 -39 -41 -43 -45 0
O-D1 O-D2 O-D3 O-D4 O-D5 O-D6 O-D7 O-D8 O-D9 O-D10 O-D11 O-D12 O-D13 O-D14 O-D15 O-D16 O-D17 O-D18 O-D19 O-D20 O-D21
H1 H2 H3 H4 H5 H6
Temperature change (°C)
-5 -10 -15 -20 -25
Sea level (meters)
0 -20 -40 -60 -80 -100 -120 -140 -160

◀ **Fig. 1** *upper* ∂^{18}O contents in Greenland for MIS 5 to MIS 2 following Uriarte Cantolla (2003); *middle* strong climatic variations in Greenland of up to 16 °C for MIS 5 to MIS 2 (in mean annual temperature; IPCC 2007), lower: global sea level curve, in meters, according to Lambeck and Chappell (2001). The *shaded area* corresponds approximately to the actual extent of MIS 3 (see Rabassa and Ponce 2013)

maximum sea level depression during MIS 2. As the ice was then receding in the Northern Hemisphere, the Gulf Current was able to penetrate to higher latitudes, bringing warmer and moister air to the North Atlantic Ocean, favoring the temporary restoration of milder climates and more temperate environments (Uriarte Cantolla 2003).

However, climate was neither stable nor homogeneous during MIS 3. Very strong, intense, and fast climatic changes took place during this period, indicated by significant ∂^{18}O variations. MIS 3 was a period of moderate insolation that is in sharp contrast with the insolation troughs of MIS 4 and MIS 2 (Andrews and Dyke 2007). Very cold periods named as Heinrich (H) events (named after the famous paleoclimatologist Hartmut Heinrich) alternated with much warmer and moister periods called as Dansgaard–Oeschger (D-O) events (named after the prestigious geochemists and glaciologists Willi Dansgaard, from Danemark, and Hans Oeschger, from Germany) (Heinrich 1988; Uriarte Cantolla 2003; Labeyrie et al. 2007).

During the Last Glaciation, there were at least six paleoclimatic episodes in which large amounts of glacial debris were ice-rafted and deposited at the bottom of the ocean in an area between 40° N and 55° N. The thickness of the resulting bottom sediments diminishes from west to east, and the dominant lithology types are those coming from North America and, particularly, the Hudson Bay (Heinrich 1988). Some of the icebergs reached up to 3000 km from their place of origin. The most appropriate explanatory theory is that the North American ice sheets outgrew their stable boundaries during certain moments of the Last Glaciation, reaching the outer edges of the continental shelves where they became unstable and collapsed, throwing huge amounts of icebergs into the North Atlantic Ocean. The high iceberg discharge would have interrupted the thermohaline circulation in the North Atlantic (Denton 2000). Other opinions suggest that the ice collapse was forced by subglacial melting due to ground heat trapped under the huge ice sheets (between 2 and 3 km thick), or even that the enormous pressure of the ice sheet during maximum expansion triggered local earthquakes (Uriarte Cantolla 2003).

The exceptional abundance of fresh water due to iceberg melting would have forced changes in the North Atlantic deep water production and limited the northernmost reach of the Gulf Stream, allowing the southward displacement of polar waters and subsequent temperature lowering (Bard et al. 2000). Once the iceberg discharge was completed, the size of the glaciers releasing along the North American coasts dramatically diminished, lowering also the supply of fresh water to the Northern Atlantic Ocean; thus, the Gulf Stream was reestablished. Therefore, a sharp increase in middle-to-high latitude temperatures took place, leading into a warm interstadial stage. These are known as the Dansgaard–Oeschger (D-O) events, in which mean annual temperature would have risen between 5 and 8 °C, perhaps during only a century or even less. Usually, D-O events are characterized by a rapid warming up to ca. 3–5 °C per century (Labeyrie et al. 2007). Moreover, during the D-O 19 event, around 70 ka ago, in MIS 4, the rise of temperature would have been up to 16 °C (Lang et al. 1999; Uriarte Cantolla 2003).

During these warmer events, a much larger evaporation rate and atmospheric moisture export from the Atlantic Ocean to the Pacific Ocean, across Middle America, would have taken place. These events would have forced an increase in the Atlantic Ocean salinity, and therefore a reinforcement of the thermohaline circulation and the Gulf Stream, which would have warmed the whole of the northern Atlantic Ocean, including Greenland (Peterson et al. 2000), heating very rapidly the atmosphere of the Northern Hemisphere, but without pushing a sudden rise in sea level because of their short duration. For instance, MIS 3 warm events in Greenland had rapid (even less than 1 kyr) changes of up to 15 °C between peaking H and D-O subsequent episodes (Fig. 1; see Labeyrie et al. 2007, for a detailed discussion). It is of high interest to note that there are clear paleoclimatic signals about the H and D-O events both in higher and lower latitudes, and in both the North Atlantic and North Pacific oceans at almost identical times (Labeyrie et al. 2007).

Sea-surface temperature (SST) during the D-O events was at least 4–6 °C higher than those of the LGM (ca. 24 cal. ka B.P.), suggesting that terrestrial temperatures were higher as well, indicating that mean annual temperature during these events was perhaps slightly colder than present conditions, but much warmer than full glacial conditions.

Six major Heinrich (H) events have been identified in MIS 2, MIS 3 and MIS 4, at approximately 17, 22, 29, 39, 45, and 61 cal. ka B.P., H1 being the younger episode and H6 the older one. H2 corresponds to the LGM. It has been suggested that the "Younger Dryas" cold event could be considered as the youngest Heinrich event, thus becoming a sort of H0. Likewise, at least 14 Dansgaard–Oeschger (D-O) events have been detected in the $\partial^{18}O$ curves, roughly at ca. 14, 23, 27, 29, 32, 33.5, 34, 38, 40, 41, 43, 45, 47, and 52 cal. ka B.P.; not all of them were of identical magnitude, but they were clearly warmer than the LGM in all cases (Table 1). As with Heinrich events, D-O 1 is the youngest event. The total length of each H or D-O events during MIS 3 is variable, but each whole cycle was probably around 1–2 kyr long in average. The longer and more intense are the D-O 8, 12 and 14 events, at ca. 38, 45 and 52 cal. ka B.P., respectively. However, violent secular transitions between events, of not more than 1–2 centuries long, have been quantified in the $\partial^{18}O$ curves. A detailed record of these variations during the last part of MIS 3, between 30 and 46 cal. ka B.P. is presented in Fig. 4. Particularly, Vidal et al. (1999) have found two very warm D-O events at ca. 43 and 33 cal. ka B.P., which would be triggered following H5 and H4 episodes, respectively. This figure illustrates the paleoclimatic and paleoenvironmental conditions both in Greenland and Antarctica, proving the global and possibly synchronous impact of these climatic changes. There are diverging opinions about such synchronicity (see, for instance, Blunier and Brook 2003; White and Steig 1998; Vidal et al. 1999; Rabassa 2008),

Table 1 List of Dansgaard–Oeschger events during MIS 3, with the relative position of sea level corresponding to each event. Chronology and sea level data from the literature cited in the text

Dansgaard-Oeschger (D-O) events	Age (cal. ka B.P.)	Sea level position (m below present sea level)
2	23.5	−140
3	27	−135
4	29	−128
5	31	−80
6	33.5	−87
7	34	−85
8	38	−78
9	40	−88
10	41	−85
11	43	−80
12	45	−65
13	47	−72
14	52	−55

but this is not a matter of discussion here. Isotopic data from caves in China as well as Greenland paleotemperatures for MIS 3 (Alley 2004) confirmed the regional impact of the MIS 3 climatic changes, both in temperature and precipitation, in such areas which are geographically related to northern North America. The region of Beringia, a huge land bridge that developed between Siberia and Alaska when sea level was lower than today, has been specially discussed because this area is highly relevant to the problem of the peopling of the Americas, perhaps as early as during MIS 3 (see Rabassa and Ponce 2013).

The palynological record for MIS 3 in NE Siberia shows that in the northern lowlands tundra predominated, under moderately warm environmental conditions (Lozhkin and Anderson 2007), probably together with isolated larch-birch tree communities. Based on pollen records, MIS 3 is represented in Siberia by the Karginski interstadial, which is separated into five environmental phases, as follows: ca. 50–45 ka B.P., warmer; ca. 45–43 ka B.P., cooler; ca. 43–33 ka B.P., maximum warmth, the so-called Malokhetski sub-horizon; ca. 33–30 ka B.P., cooler, the Konotzelski sub-horizon; and ca. 30–22 ka B.P., warmer, the Lipovskoy–Novoselovski sub-horizon (Lozhkin and Anderson 2007). Likewise, in northwestern North America, pollen records dating to MIS 3, between ca. 60 and 30 ka B.P., indicate widespread tundra across Alaska, perhaps with minor amounts of spruce in interior Alaska and Yukon (Bigelow 2007). In western Alaska, MIS 3 was characterized by grass, sedge, and *Artemisia*, with minor amounts of willow and birch. In the Yukon, spruce pollen frequencies of less than 20 % suggest the existence of scattered trees within widely extended birch/graminoid tundra (Bigelow 2007).

Similarly, paleoentomological studies in NW North America and NE Siberia have shown that climate was much milder during MIS 3 than during the LGM. Elias (2007) identified a "long MIS 3 interstadial complex in eastern Beringia," with warming intervals at 46.4, 36, and 33.6 ka B.P. The latter one is known from the Totaluk River beetle fauna, with an association indicating that the maximum temperature during this event was between 0.5 and 2.0 °C warmer than present. Other sites have indicated maximum temperatures only between 0.5 and 2.0 °C cooler than today. However, there are also faunas suggesting much cooler conditions, up to 7.0–8.0 °C cooler than present, proving the existence of dramatic temperature oscillations in this period. The identified beetle faunas are characterized by species which correspond to open-ground habitats, not necessarily occupied by trees. The open-ground or steppe tundra environments were maintained throughout MIS 3. Elias (2007) stated that, for this area, MIS 3 "oscillations coincide with climatic patterns inferred from oxygen isotope records in Greenland ice cores."

Elias and Brigham-Grette (2007) have identified substantial differences between western and eastern Beringia during MIS 3, dated between 48 and 28 ka B.P. In western Beringia, temperatures reached near present-day levels and the forest migrated northwards near its present position. Contrarily, in eastern Beringia there is little evidence of coniferous forest expansion during MIS 3. The Arctic regions reached temperatures perhaps up to 1.5 °C above present times at ca. 35 ka B.P., whereas in sub-arctic environments, temperature was ca. 2 °C below current conditions at the same time (Elias and Brigham-Grette 2007). In any case, the environmental conditions were not too different from those found today, and the region would have been fully accessible for humans during MIS 3.

Finally, the transition between MIS 3 to MIS 2 in eastern Beringia, from interstadial to full glacial conditions, has been dated in ca. 32–31 ka B.P.

Likewise, Sher and Kuzmina (2007) found, for the 35–40 ka B.P. period in northeastern Asia, beetle associations with a high percentage of arboreal, mostly shrub, pollen, in contrast to the completely grass-herb dominated spectra of the LGM. Though they acknowledged the possibility of radiocarbon dating problems, they identified xerophilic beetle species for the 48–34 ^{14}C ka B.P. period; then, an increase of Arctic species by 34 ^{14}C ka B.P., almost equating the LGM levels; and again xerophilic beetles with mesic tundra insects between 34 and 24 ^{14}C ka B.P. After this age, the beetle species indicated a gradual decrease in temperature towards the LGM. They also stated that the regional climate was much more continental during MIS 3 times than it is today, a condition which they assigned to a lower sea level (Table 1).

The vertebrate record of the Late Pleistocene in northern Asia shows evidence of faunas of a warm interval called the Briansk or Dunaevo interstadial, dated between 33 and 24 ka B.P., the last of a series of warm episodes along MIS 3 (Markova and Puzachenko 2007). The faunas characteristic of Beringia for this period are included in the Arctic sub-assemblage of the Mammoth I assemblage, with woolly mammoth, woolly rhinoceros, reindeer, Pleistocene bison, horse, rare saiga (an Asian antelope), arctic fox, cave hyena, cave bear, steppe pika (a small mammal of Asia and North America), arctic hare, several lemming species, and voles (small rodents from the northern hemisphere). No forest animals are found in this assemblage (Markova and Puzachenko 2007). The distribution and composition of this assemblage shows differences with present faunas, indicating a climate cooler than today; but this faunal association became later severely restricted in surficial terms during the LGM epoch. The abundance of large Pleistocene herbivores and cave carnivores during MIS 3 also depicts the large variations from today's faunas (Markova and Puzachenko 2007).

Relevant to the topics developed in the present paper, careful analysis of recently published glacial geological evidence in northern and northeastern Asia and northwestern North America is also pointing towards very warm conditions during MIS 3. Andrews and Dyke (2007) established that very soon after the MIS 4/MIS 3 transition rising insolation forced the retreat of the Laurentide Ice Sheet from the western Canadian lowlands, a condition that probably lasted for more than ca. 30–40 years, until the end of MIS 3, allowing the availability of the Yukon corridor for human displacements. Velichko et al. (2011) have identified a warm period during the Late Pleistocene in NE Europe which they named as the Middle Valdai. During this period, the ice had receded as far north as at least 68° N, with milder climates and temperate environments such as mixed forest of conifers and broad-leaved trees and southern taiga along the Arctic coasts around 38–40 ka B.P. They have called this period as a "mega-interstadial" or the "Leningrad or Bryansk mega-interval," with alternating warm and cool phases, rhythmic climate changes, and a main warm phase between 40 and 34 ka B.P., with environmental conditions quite close to that of Mulikino, the last interglacial or MIS 5e. They consider this period as "a short interglacial," extending over D-O 10 and 12 events, with a new warm pulse in the Dunaevo warming episode, dated at 31–25 ka B.P., the terminal phase of MIS 3.

Likewise, Vorren et al. (2011) have shown that the ice sheet of Northern Siberia was restricted only to the Kara Sea and Novaja Zemlya islands between 55 and 45 ka B.P., and that the Barents Sea was mostly ice free between 48 and 26 ka B.P. Moller et al. (2011) determined that there was no ice on the Taymir Peninsula and the Severnaya Zemlya island between 50 and 25 ka B.P. In NE Asia, sedimentology studies have shown that no major changes in the environment had occurred between 60 and 12 ka B.P., with a mosaic of arctic tundra and tundra-steppe communities dominating during the Karginsky interstadial (MIS 3) and the Sartan ice age (MIS 2) (Glushkova 2011). According to this author, climate was continental, with summer not colder than today but with colder winters. Glaciation was restricted to the mountain cirques during MIS 3, and much more reduced than during previous glaciations as well as in MIS 2. In contrast to the viewpoint of previous researchers, glaciers during the LGM were located then only in a few regions of the highest mountains. Therefore, it may be deduced that there were no physical restrictions to human displacement toward Beringia and Alaska during both cited isotope stages.

In the Verkhoyansk Mountains, an important orographic barrier across easternmost Siberia, the youngest proven glaciations dated back to ca. 50 ka B.P., and no LGM glaciations have been identified. East of this mountain range, restricted MIS 2 glaciation has been found, this being explained as a result of atmospheric paleocirculation and differential moisture availability (Stauch and Lehmkuhl 2011). It should then be noted that there were no ice barriers here for human displacement during MIS 3 and 2. It is also interesting to note that, similarly, there were no glaciers in the Central Alaska lowlands throughout the entire Late Pleistocene (Kaufman et al. 2011). Glaciation in the high mountains of easternmost Siberia was characterized by expansion of the glaciers between late MIS 5 and MIS 4, and significant retreat during MIS 3, with a short ice advance ca. 45–40 ka B.P. and a major readvance of the ice in MIS 2.

In northwestern North America, Clague and Ward (2011) presented a model of glaciation of British Columbia with glaciers limited to the summits and uppermost valleys for the 35–30 ka B.P. period, and full glacial conditions and closing of the Yukon corridor only ca. 25 ka B.P. A “non-glacial Olympia interval” is described for the 50–25 ka B.P. period, correlated with MIS 3. Thus, this information confirms that the Yukon corridor would have been available for humans entering from Beringia during a very long period before 25 ka B.P. In western Alberta, Jackson et al. (2011) have described nonglacial, fossil bearing sediments dated between 39 and 24 ka B.P., and correlated them to MIS 3, of clearly interglacial nature. In eastern Alberta, Barendregt (2011) mentioned “mid-Wisconsin interglacial sediments,” well dated between 65 and 23 ka B.P., also corresponding to MIS 3. Much farther south, the paleoclimate pattern is similar. Gillespie and Clark (2011) have identified very intense D-O events as far south as the Sierra Nevada of California, from D-O 8 (ca. 41–40 ka B.P.) to D-O 4 (31 ka B.P.), with intermediate warm episodes as D-O 7, 6 and 5, at ca. 36, 35 and 34 ka B.P., respectively.

The paleogeography of Beringia during MIS 3 has been analyzed and discussed by Rabassa and Ponce (2013). Sea level during the Late Pleistocene is one of the key questions concerning human population of the Americas, since the availability of a terrestrial path across Beringia allowed the eastwards displacement of Siberian humans into the new continent. The position of sea level during MIS 3 is crucial to understand that the Beringia land bridge was available for humans not only during the LGM but during many thousands of years before as well. The sea level curves by Lambeck and Chappell (2001) and Lambeck et al. (2002) are clearly indicating which would have been the position of the coastline during different times of MIS 3. Lambeck et al. (2002) estimated that, using data from Papua New Guinea and Australia, sea level was never below −50 m between 50 and 30 cal. ka B.P., thus fully supporting the paleogeographic reconstructions presented by Rabassa and Ponce (2013).

The last closure of the Bering Straits started at around 82 cal. ka B.P., when sea level lowered 45 m below its present position. The straits remained closed continuously until 11.5 cal. ka B.P. The figures presented here show that the closure period was perhaps as long as 70 kyr.

Fig. 2 Beringia, location map. See Rabassa and Ponce (2013)

During most of MIS 3 (between 55 and 30 cal. ka B.P.), sea level oscillated between a maximum elevation of −55 m (between 48,000 and 52,000 cal. year B.P., which would roughly correspond to the D-O 14 event) and a minimum stand at −90 m (at around 32,000 and 40,000 cal. year B.P., approximately, in coincidence with the H3 and H4 events).

During its lowermost position, an enormous plain connected both continents (Rabassa and Ponce 2013). Southwards, this plain would include the present Pribilof Islands and, towards the north, the present Wrangell Island (Fig. 2). Towards the NE, the plain would follow the northern coast of Alaska and parts of Canada, with a mean width of at least 80 km; it extended continuously until approximately longitude 128° W. Toward the NW, the plain formed a narrow wedge at the latitude of Wrangell Island (Fig. 2), to later on become in contact with another huge plain developed in northern Russia. This plain presented an enormous surface of approximately 1,200,000 km^2 between longitude W180° and W156°. It presented an extension as large as 1800 km in N–S direction at the longitude of the Bering Straits. Its relief was mostly flat, and the general slope was smaller than 0.2º, with a maximum local relief in the order of 60 m between its northern and southern extremes. According to the Lambeck and Chappell (2001) sea level curve, which

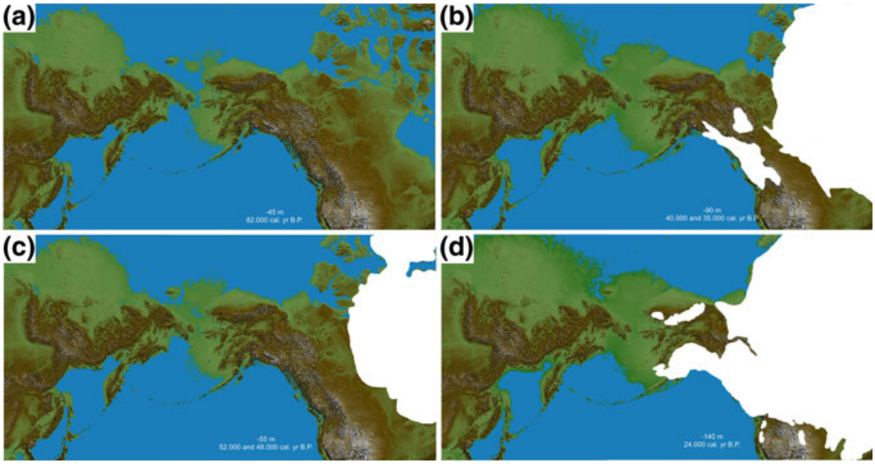


Fig. 3 **a**–**d** paleogeography of Beringia, with ancient positions of the coastline for lower sea levels during different moments of the Late Pleistocene (after Rabassa and Ponce 2013). Sea level information from Lambeck and Chappell (2001). *Whitish areas* correspond to the actual extent of the Laurentide and the Cordilleran ice sheets for the studied moments

relates sea level with ice volume on the continents, a sea level position at −90 m would be equivalent to the ice volume that existed around 13,000 cal. year B.P.

Dyke (2004) identified the existence of two main ice sheets in northern North America by 13 cal. ka B.P., the Cordilleran mountain ice sheet, developed on top of the Rocky Mountains and the Pacific Ranges, and the Laurentide Ice Sheet, of much larger size, extended over most of Canada and the whole of Greenland (Fig. 3b). This latter ice sheet had an approximate surface of 11 million km^2. In between them, there was an ice-free corridor which communicated Alaska with the rest of the continent (Fig. 3b). It had an approximate length of 1400 km in a NW–SE direction and a width which varied between 400 and 700 km (Fig. 3a). Immediately to the west of this corridor, another smaller ice sheet had developed over the Mackenzie Mountains. This situation would have represented the maximum ice extension during MIS 3, which would have been coincident with a sea level position of −90 m (Fig. 4).

The highest sea level position during MIS 3 was perhaps at −55 m. This condition took place in two periods, toward 52 and 48 ka B.P. and it is coincident with one of the warmest D-O oscillations (D-O event 14; Table 1) and with the smallest ice expansion during MIS 3. The geographical conditions of Beringia determined that the area lowlands were permanently devoid of ice during the Late Pleistocene; in spite of being cold enough, the land bridge was too dry to arid polar conditions to develop glaciers at low elevations (Elias and Brigham-Grette 2007). The absence of lowland glaciers allowed the availability of the land bridge for human displacement throughout MIS 3 and 2.

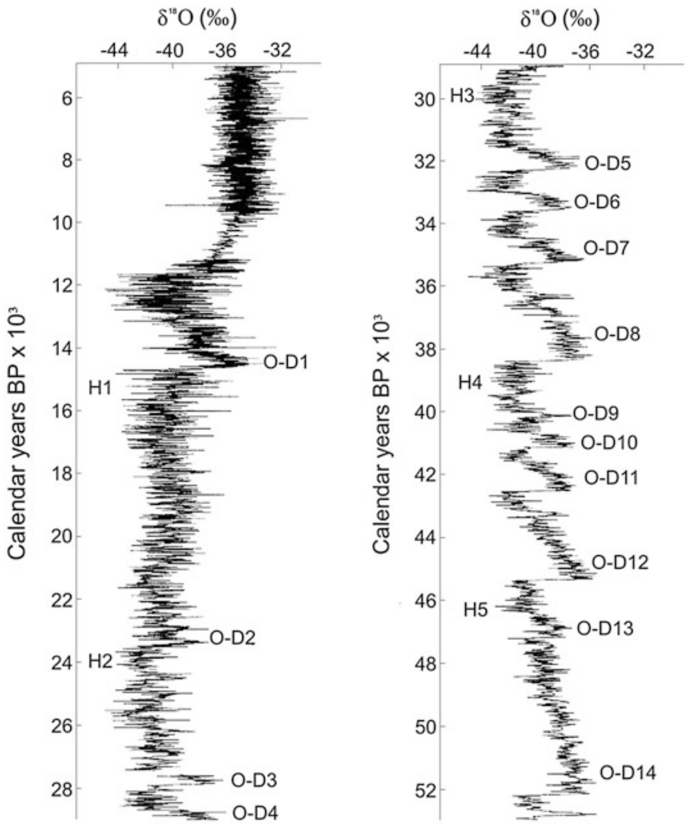


Fig. 4 Abrupt climatic oscillations during the last 90,000 years in GIPS II core from Greenland (after Denton 2000). *H1–H5* represents the cold Heinrich events. *O-D1–O-D14* corresponds to the Dansgaard–Oeschger warm events. See Rabassa and Ponce 2013

3 Final Remarks

Marine Isotope Stage 3 (MIS 3) was a period of very complex climatology, with previously unheard strong variability, with colder moments, named as Heinrich events, followed by warmer episodes, known as the Dansgaard/Oeschger events. Most authors agree that these paleoclimatic events are the result of higher discharge of icebergs and meltwater in the northern Atlantic Ocean, thus forcing a strong decrease in salinity, which would have impeded the penetration of the Gulf Stream into northern latitudes and therefore generating colder conditions. These are the Heinrich events. Later on, a gradual stabilization of the ocean/atmosphere system induced progressive entrance of the Gulf Stream, increasing the ocean temperature and, consequently, leading toward the Dansgaard/Oeschger events. These paleo-climatic changes were very fast and the duration of each event was quite short, between just a few centuries and a few millennia in each case. This highly complex paleoclimatology affected simultaneously the entire world, and their consequences are still very poorly known.

The period embraced by these changes is at the edge of the dating capability of the radiocarbon method, or even beyond it. This limitation has made very difficult to establish local and regional chronologies for this period, and a global record for these events is still uncertain. Future progress in dating techniques will certainly provide more reliable data, the impact of these paleoclimatic events will be better understood and their global correlation would be more accurate and meaningful.

Then and there, many paleoclimatic and paleobiogeographic circumstances will be properly interpreted and their influence upon MIS 2 and Holocene environments would be truthfully recognized.

Finally, the paleoclimatic history of Beringia during MIS 3 is particularly significant since it may have controlled the appropriate environmental conditions to allow the inbound displacement of the first waves of human peopling of the Americas, moving from Siberia to Alaska and northern Canada.

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