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ABRUPT CHANGES AND THE ASTRONOMICAL THEORY OF CLIMATE?

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Abstract. The past 3.2 Myr have seen drastic climate changes with the development, waxing and waning of huge continental ice sheets over the Northern Hemisphere. These striking phenomena have been observed in various records from ice cores, as well as marine and terrestrial sediments. These proxy records showed periodicities associated with the three orbital parameters that affect our planet's insolation, namely eccentricity, obliquity and precession. Until recently, these periodicities were considered as the canonical ones for the Quaternary Period and beyond. However, the improvement of the time resolution of available records has allowed one to describe climate changes occurring abruptly and with periodicities that are not related to those of the orbital parameters. In this paper, we show that, in fact, these abrupt climate changes may still be related, albeit indirectly, to the astronomical theory of climate.

Key words: Abrupt climate changes, Astronomical theory, Ice sheets, Dansgaard-Oeschger events, Bond cycles

1. MOTIVATION AND FINDINGS

Abrupt climate changes constitute a new field of research, which addresses fluctuations that occur in a relatively short time interval of some tens of years, up to a hundred. Such characteristic times do not correspond to the tens or hundreds of thousands of years that the astronomical theory of climate deals with. This theory involves parameters that are external to the climate system, whose variations are reliably known, and whose periodicities are nearly constant during a large part of Earth history [1-6]

2. QUATERNARY VARIABILITY

Abrupt changes conversely rely on fast responses to internal factors, which varied considerably during the past 2.6 Myr, and yielded more apparently irregular fluctuations. In this presentation, we recount the main climate variations determined from U1308 North Atlantic marine record, which yields a detailed calving history of the Northern Hemisphere ice sheets over the past 3.2 Myr [7]. The magnitude and periodicity of the ice rafted debris (detritic material transported by icebergs – IRD [8]) events observed in U1308 allow determining the timing of the occurrence of these particular abrupt climate changes, with the larger ones being named Heinrich events (HE) [9,10]).

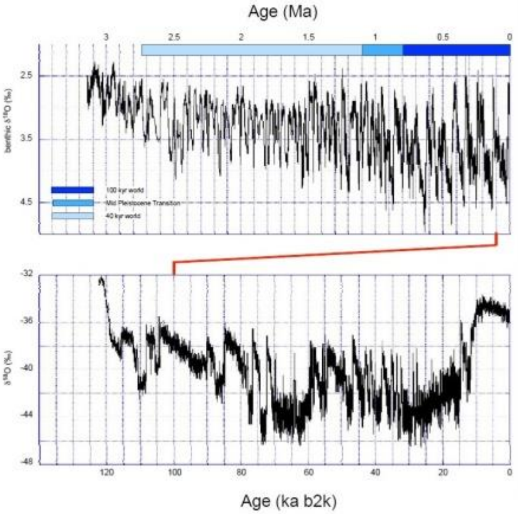

Figure 1: *Proxy records of the last 3.2 Myr and 122 kyr of Earth history. Top: 3.2 Myr record Earth history from benthic δ^{18}O of the U1308 marine core* [7] *with indication of the 40 kyr, 100 kyr and Mid-Pleistocene transition intervals, and Bottom: 122 kyr b2k record of the δ^{18}O of the NGRIP ice core* [11]. *b2k: before A.D. 2000.*

The North Atlantic core U1308 is representative of the main climate variations occurring during the past 3.2 Myr. The variation in the benthic δ^{18}O of this marine record in Fig. 2 clearly shows an orbitally driven pacing with a 40-kyr periodicity in the early-to-mid record, while the last 0.65 Myr show a new pacing of about 100 kyr. The IRD record, expressed by the δ^{18}O of bulk carbonate, indicates several key changes. At 2.75 Myr b2k, the first occurrence of IRD is recorded in the North Atlantic. This corresponds to the evidence of coastal glaciers and little ice sheets in the Northern Hemisphere, mainly over Greenland and Fennoscandia, which could have calved into the ocean under appropriate environmental conditions. At 1.5 Myr b2k and onward, the delivery of icebergs to the North Atlantic increases and becomes persistent during the glacial intervals.

It is after this key date of 1.5 Myr b2k that the pacing of the major climate changes evolved from the 40-kyr cycle world to the 100-kyr cycle world, during the so-called Mid-Pleistocene Transition [12], between 1.2 Myr b2k and 0.8 Myr b2k. At 0.9 Myr b2k, the global ice volume increase is mostly concentrated in the Northern Hemisphere, with the Laurentide and the British Isles– Fennoscandian ice sheets expanding southward, inland and out over the continental shelves. The same date of 1.5 Myr corresponds also to the first major expansion of the Alpine ice cap [13,14]. At 0.65 Myr the first HEs appear, which correspond to massive iceberg discharges into the Labrador Sea, mainly originating from the Laurentide ice sheet but with the Euroasian ice sheets also contributing [15].

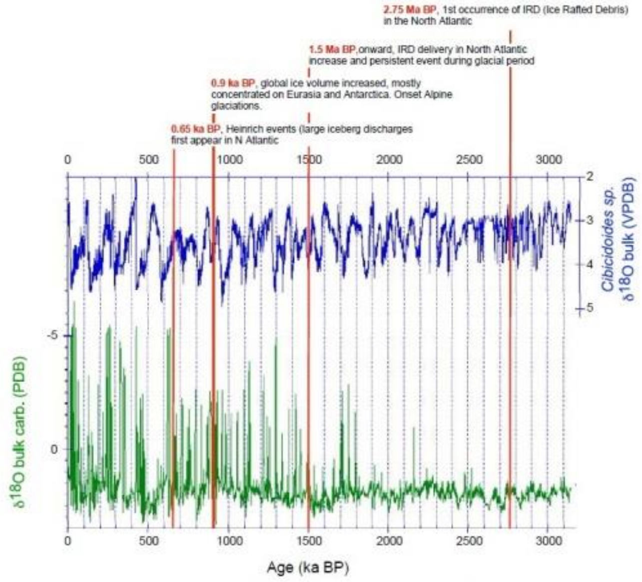

Figure 2: *Variations of benthic (Cibicidoides sp.) $\delta^{18}O$ and of the bulk carbonates $\delta^{18}O$ (from* [7]*). Red vertical bars represent the five thresholds described by* [7] *and also determined by the recurrence analy-sis of these data* [16].

3. THE LAST 130,000 YEAR VARIABILITY

While representative of the main climate variations occurring during the past 3.2 Myr, the δ^{18}O signal in the U1308 record of Fig. 2 only displays the classical periodicities contained in the orbital parameters. Numerous Greenland ice cores, however, have shown that other periodicities were present during the Quaternary, at least during the most recent climate cycle of the last 130,000 years [11,17,20,]. The δ^{18}O record of these ice cores also shows the occurrence of abrupt climate changes (Fig. 3) that correspond to intense warmings over the Greenland ice sheet by an average of 10-12°C [21] in about 50 years [22,23].

These intense warmings have been named Dansgaard-Oeschger (DO) events, and they correspond to warmer conditions in Europe — as indicated by pollen counts [24] and by loesspaleosols [23], and to North Atlantic Sea surface warming [10,25]. These so-called interstadial warmings lasted several hundred years [23] before the climate returned to glacial conditions, called stadials, in two main steps. The stadials were characterized by cold sea surface water in the North Atlantic [10,26], steppe-like, subtropical vegetation [27,28]and loess deposition in Europe [29,31].

Twenty-six of these stadial–interstadial cycles, also called DO cycles, have been identified [19]and they support an interpretation of these changes as resulting from internal, Earth-bound processes, as opposed to being the response to an external forcing. Moreover, the length of the interstadials appears to be related to the mean global sea level variation [32].

The long interstadials that occurred between 120 kyr and 80 kyr and between 59 kyr and 40 kyr are associated with the highest sea levels: –15 m to –45 m and –50 m to –75 m, respectively. Conversely, interstadials after 80 kyr and after 40 kyr are associated with lower sea level values, with the lowest ones, down to –125 m, having occurred during the Last Glacial Maximum (Fig. 3).

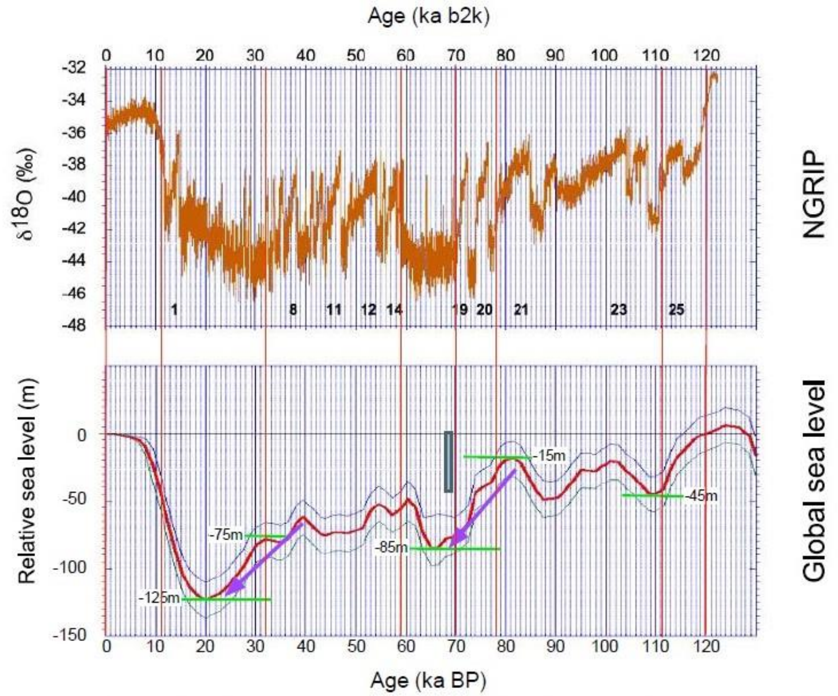

Figure 3: *The last glacial cycle in NGRIP and in sea level. Top, NGRIP* $\delta^{18}O$ *variations over the last 122 kyr b2k* [11], *indicating several canonical Dansgaard-Oeschger events with the number assigned to them in* [19], *Bottom, variation of the sea level over the last 122 kyr BP, as reconstructed from benthic* $\delta^{18}O$ *foraminifera in* [32]*: the bold red line gives the global mean sea level (m) below present sea level, and the light blue lines are the corresponding minima and maxima. Horizontal green bars indicate several key values of sea level. Modified from* [16].

Such a link between the interstadial length and sea level is expected from a simple Binge- Purge mechanism [33] with largest ice sheets expected to be easier to destabilize. Accordingly, the interval embedding the shortest DO cycles corresponds to the maximum extension of the Laurentide and Eurasian ice sheets. As DO cycles have been found also in the previous glacials down to 800 kyr [34], one can assume this pattern of climate variability has been occurring since 0.9 Myr BP, when the global ice volume increased, as indicated previously (Fig. 2).

The Greenland δ^{18}O variability has been described fairly consistently using several Northern Hemisphere records [23, 26, 35,37]**.** Its comparison with the Southern Hemisphere via synchronization of the records using the CH_4 signal, a global proxy, shows an anti-phasing between the two hemispheres, with a gradual cooling in the South roughly when the North was experiencing its abrupt warmings [38,39]. A simple model has been proposed in [36] to reconstruct this "polar seesaw" in the climate variability of the two hemispheres, as represented by the δ^{18}O records of NGRIP and the West Antarctic Ice Sheet (WAIS) Divide, respectively, over the last 60 kyr. This simple model relies on interactions between ice shelves, sea ice, the atmospheric temperature over Greenland and the North Atlantic Overturning Circulation to reproduce successfully the millennial-scale variability observed in the two hemispheres, without having to invoke the classical summer insolation curve at 65°N. [3].

4. THE BOND CYCLES

One can combine the observations of abrupt warmings — namely the DO events discussed in the previous section — with the marine IRD events, including the Heinrich events. Doing so allows one to propose a fairly simple mechanism that would generate the observed abrupt climate changes of the last 0.9 Myr.

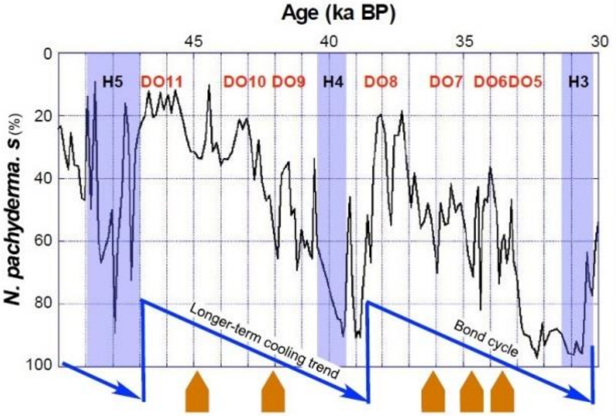

Figure 4: *Amended Bond cycle mechanism. Variations in the percentage of Neoglobo - quadrina pachyderma (s.), a species indicative of cold surface water, that illustrate two Bond cycles; from DSDP 609*[10]. *These variations are showing a series of Dansgaard - Oeschger cycles composed of an abrupt warming (DO) and followed by a return to glacial conditions represented by "stadials". Every Bond Cycle corresponds to a long term cooling trend starting by a strong warming and ending with a stadial embedding a massive iceberg discharge into the North Atlantic (Heinrich event – H, with the assigned number by* [10]*). IRD events observed by* [37] *in contemporaneous marine records and embedded in stadials are indicated by triangles. Modified from* [16].

This mechanism relies on amended Bond cycles [15], which group DO events and the associated stadials into a trend of increasing cooling intensity [37,40,41], with IRD events embedded into every stadial, the latest being an HE [16]; see Fig. 4. These Bond cycles may have occurred during the last 0.9 Myr, when Northern Hemisphere ice sheets reached their maximum extent and volume (Fig. 2), thus becoming a major player in the climate dynamics of the Late Pleistocene.

As we saw in the previous section, DO cycles and their polar seesaw can be explained entirely by intrinsic climate variability, without any external forcing [36]. The amended Bond cycle mechanism of [15], while purely descriptive, also relies essentially on processes intrinsic to the Earth system, and it does not specifically appeal to external forcing, orbital or otherwise.

To the extent that the waxing and waning of Northern Hemisphere ice sheets during Quaternary glaciation cycles is orbitally paced, it appears, though, that the abrupt climate changes observed during the Mid- and Late Pleistocene are also linked to the astronomical theory of climate, albeit rather indirectly.

5. CONCLUDING REMARKS

- Dynamical interactions between the ocean, the cryosphere with its continental ice sheets and sea ice cover, the vegetation and the atmosphere are at play in generating the millennial-scale variability that leads to abrupt climate changes. The specific triggering processes of these interactions, though, are still under discussion.

- Present investigations point to internal mechanisms being responsible for these millennialscale events, such as periodic calving of ice sheets and intrinsic oscillations of the ice sheet– ocean–atmosphere system; see[45,42].

- Moreover, the millennial scale variability is observed from the very beginning of the last glacial cycle, and during previous glacial cycles, at least for the last 800 kyr – 900 kyr, when considering the first occurrence of Heinrich events.

- Still, we have seen that orbital forcing, as postulated by Milankovitch [1-4], sets the stage for these internal processes and modulates their period and amplitude.

Orbital-scale and millennial variabilities appear to interact during the Quaternary with millennial variability generally increasing in intensity as ice sheets grew larger in size. Thus, abrupt climate changes are definitively related, albeit indirectly, to the astronomical theory of climate.

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References

[1.] Milankovic, M.: 1920, Théorie mathématique des Phénomènes thermiques produits par la radiation solaire, Académie Yougoslave des Sciences et des Arts de Zagreb (Ed.), Paris: Gauthier Villars.

[2.] Milankovic, M.: 1941, Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem, Belgrad:e Royal Serbian Sciences. (English translation Beograd 1998).

[3.] Berger, A. L.: 1977, Support for astronomical theory of climatic change, Quat. Res., 269, 44–45.

[4.] Berger, A. L.: 1978, Long-term variations of caloric insolation resulting from the Earth’s orbital elements., Nature, 9, 139–167.

[5.] Varadi, F., Runnegar, B., Ghil, M.: 2003, Successive refinements in long-term integrations of planetary orbits, Astrophys.. J., 592, 620–630 (2003).

[6.] Hoffman, P. F., Abbot, D. S., Ashkenazy, Y., Benn, D. I., Brocks, J. J., Cohen, P. A., Cox, G. M.,Creveling, J. R., Donnadieu, Y., Erwin, D. H., Fairchild, I. J., Ferreira, D., Goodman, J. C., Halverson,G. P., Jansen, M. F., Le Hir, G., Love, G. D., Macdonald, F. A., Maloof, A. C., Partin, C. A., Ramstein, G., Rose, B. E. J., Rose, C. V., Sadler, P. M., Tziperman, E., Voigt, A., Warren, S. G.: 2017, Snowball Earth climate dynamics and Cryogenian geology-geobiology, Sci. Adv., 3, e1600983.

[7.] Hodell, D. A. Channell, J. E. T.: 2016, Mode transitions in Northern Hemisphere glaciation: coevolution of millennial and orbital variability in Quaternary climate, Clim. Past, 12, 1805–1828.

[8.] Ruddiman, W. F.: 1977, Late Quaternary deposition of ice) rafted sand in subpolar North-Atlantic (Lat 40-degrees to 65-degrees-N), Geol. Soc. Am. Bull., 88, 1813–1827.

[9.] Broecker, W., Bond, G., Klas, M., Clark, E., McManus, J.: 1992, Origin of the northern Atlantic's Heinrich events. Clim. Dyn., **6**, 265–273

[10.] Bond, G., Heinrich, H., Broecker, W., Labeyrie, L., McManus, J., Andrews, J., Huon, S., Jantschik, R., Clasen, S., Simet, C., Tedesco, K., Klas, M., Bonani, G., Ivy, S.: 1992, Evidence for massive discharges of icebergs into the North Atlantic Ocean during the last glacial period, Nature, 360, 245– 249.

[11.] Rasmussen, S. O., Bigler, M., Blockley, S. P., Blunier, T., Buchardt, S. L., Clausen, H. B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S. J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W. Z., Lowe, J. J., Pedro, J. B., Popp, T., Seierstad, I. K., Steffensen, J. P., Svensson, A. M., Vallelonga, P., Vinther, B. M., Walker, M. J. C., Wheatley, J. J., Winstrup, M.: 2à14, A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy, Quat. Sci. Rev., 106, 14–28.

[12.] Clark, P. U., Archer, D., Pollard, D., Blum, J. D., Rial, J. A., Brovkin, V., Mix, A. C., Pisias, N. G., Roy, M.: 2006, The middle Pleistocene transition: characteristics, mechanisms, and implications for long-term changes in atmospheric pCO_2, Quat. Sci. Rev., 25, 3150–3184.

[13.] Muttoni, G., Carcano, C., Garzanti, E., Ghielmi, M., Piccin, A., Pini, R., Rogledi, S., Sciunnach, D.: 2003, Onset of major Pleistocene glaciations in the Alps, Geology, 31, 989–992.

[14.] Knudsen, M. F., Norgaard, J., Grischott, R., Kober, F., Egholm, D. L., Hansen, T. M., Jansen, J. D.: 2020, New cosmogenic nuclide burial-dating model indicates onset of major glaciations in the Alps during Middle Pleistocene Transition, Earth Planet. Sci. Lett., 549, 116491.

[15.] Broecker, W. S.: 1994, Massive iceberg discharges as triggers for global climate change. Nature, 372, 421–424

[16.] Rousseau, D.-D., Bagniewski, W., Ghil, M., 2021, Are abrupt climate changes related to the

[17.] Dansgaard, W., Johnsen, S. J., Moller, J., Langway, C. C.: 1969, One thousand centuries of climatic record from Camp Century on the Greenland ice sheet. Science, 166, 377–381

[18.] Johnsen, S. J., Dansgaard, W., Clausen, H. B., Langway, C. C.: 1972, Oxygen isotope profiles through the Antartic and Greenland ice sheets. Nature, 235, 429–434.

[19.] Dansgaard, W., Johnsen, S. J., Clausen, H. B., Dahi-Jensen, D., Gundestrup, N. S., Hammer, C. U., Hvidberg, C. S., Steffensen, J. P., Sveinbjöprnsdottir, A. E., Jouzel, J., Bond, G.: 1993, Evidence for general instability of past climate from a 250-kyr ice-core record. Nature, 364, 218-220

[20.] Johnsen, S. J., Dahl-Jensen, D., Gundestrup, N., Steffensen, J. P., Clausen, H. B., Miller, H., Masson-Delmotte, V., Sveinbjörnsdottir, A. E., White, J.: 2001, Oxygen isotope and palaeotemperature records from six Greenland ice-core stations: Camp Century, Dye-3, GRIP, GISP2, Renland and NorthGRIP, J. Quat. Sci., 16, 299–307.

[21.] Kindler, P., Guillevic, M., Baumgartner, M., Schwander, J., Landais, A., Leuenberger, M.: 2014, Temperature reconstruction from 10 to 120 kyr b2k from the NGRIP ice core, Clim. Past, 10, 887–902.

[22.] Wolff, E. W., Chappellaz, J., Blunier, T., Rasmussen, S. O., Svensson, A.: 2010, Millennial-scalevariability during the last glacial: The ice core record, Quat. Sci. Rev., 29, 2828–2838.

[23.] Rousseau, D.-D., Boers, N., Sima, A., Svensson, A., Bigler, M., Lagroix, F., Taylor, S., Antoine, P.: 2017, (MIS3 & 2) millennial oscillations in Greenland dust and Eurasian aeolian records - A paleosol perspective, Quat. Sci. Rev., 169, 99–113.

[24.] Fletcher, W. J., Goni, M. F. S., Allen, J. R. M., Cheddadi, R., Combourieu-Nebout, N., Huntley, B., Lawson, I., Londeix, L., Magri, D., Margari, V., Mueller, U. C., Naughton, F., Novenko, E., Roucoux, K., and Tzedakis, P. C.: 2010, Millennial-scale variability during the last glacial in vegetation records from Europe, Quat. Sci. Rev., 29, 2839–2864.

[25.] Henry, L. G., McManus, J. F., Curry, W. B., Roberts, N. L., Piotrowski, A. M., Keigwin, L. D.: 2016, North Atlantic ocean circulation and abrupt climate change during the last glaciation, Science, 353, 470–474.

[26.] Bond, G., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J., Bonani, G.: 1993, Correlations between climate records from North Atlantic sediments and Greenland ice., Nature, 365,143–147.

[27.] Sanchez-Goni, M. F., Turon, J. L., Eynaud, F., Gendreau, S.: 2000, European climatic response to millennial-scale changes in the atmosphere-ocean system during the last glacial period, Quat. Res., 54, 394–403.

[28.] Sanchez-Goni, M. F., Cacho, I., Turon, J. L., Guiot, J., Sierro, F. J., Peypouquet, J. P., Grimalt, J. O., Shackleton, N. J.: 2002, Synchroneity between marine and terrestrial responses to millennial scale climatic variability during the last glacial period in the Mediterranean region, Clim. Dyn., 19, 95–105.

[29.] Rousseau, D.-D., Antoine, P., Hatté, C., Lang, A., Zöller, L., Fontugne, M., Ben Othman, D., Luck, J. M., Moine, O., Labonne, M., Bentaleb, I., Jolly, D.: 2002, Abrupt millennial climatic changes from Nussloch (Germany) Upper Weichselian eolian records during the Last Glaciation, Quat. Sci. Rev., 21, 1577–1582.

[30.] Rousseau, D.-D., Svensson, A., Bigler, M., Sima, A., Steffensen, J. P., Boers, N.: 2017, Eurasian contribution to the last glacial dust cycle: how are loess sequences built? Clim. Past, 13, 1181-1197.

[31.] Rousseau, D.-D., Antoine, P., Sun, Y.: 2021, How dusty was the last glacial maximum over Europe? Quat. Sci. Rev., 254, 6775–6775.

[32.] Waelbroeck, C., Labeyrie, L., Michel, E., Duplessy, J. C., McManus, J. F., Lambeck, K., Balbon, E., Labracherie, M.: 2002, Sea-level and deep water temperatures changes derived from benthic foraminifera isotopic records, Quat. Sci. Rev., 21, 295–305.

[33.] MacAyeal, D. R.: 1993, Binge/Purge oscillations of the Laurentide ice-sheet as a cause of the North-Atlantics Heinrich events, Paleoceanography, 8, 775–784.

[34.] Barker, S., Knorr, G., Edwards, R. L., Parrenin, F., Putnam, A. E., Skinner, L. C., Wolff, E.Ziegler, M.: 2011, 800,000 Years of Abrupt Climate Variability, Science, 334, 347–351.

[35.] Wang, Y. J., Cheng, H., Edwards, R.L., An, Z.S., Wu, J.Y., Shen, C.C., Dorale, J.A.: 2001, A high-resolution absolute-dated Late Pleistocene monsoon record from Hulu Cave, China, Science. 294, 2345–2348 (2001).

[36.] Rahmstorf, S.: 2002, Ocean circulation and climate during the past 120,000 years, Nature. 419, 207–214.

[37.] Clark, P. U., Hostetler, S. W., Pisias, N. G., Schmittner, A., Meissner, K. J.: 2007, Mechanisms foran ~7-kyr climate and sea-level oscillation during marine isotope stage 3. in Ocean circulation: Mechanism and Impacts-Past and Future changes of Meridional Overturning, Eds. A. Schmittner, Chiang, J. C. H., and S. R. Hemming, AGU Monograph 173, 209-246.

[38.] Blunier, T., Brook, E. J.: 2001, Timing of millennial-scale climate change in Antarctica and Greenland during the last glacial period, Science, 291, 109–112.

[39.] Buizert, C., Adrian, B., Ahn, J., Albert, M., Alley, R. B., Baggenstos, D., Bauska, T. K., Bay, R. C., Bencivengo, B. B., Bentley, C. R., Brook, E. J., Chellman, N. J., Clow, G. D., Cole-Dai, J., Conway, H., Cravens, E., Cuffey, K. M., Dunbar, N. W., Edwards, J. S., Fegyveresi, J. M., Ferris, D. G., Fitzpatrick, J. J., Fudge, T. J., Gibson, C. J., Gkinis, V., Goetz, J. J., Gregory, S., Hargreaves, G. M., Iverson, N., Johnson, J. A., Jones, T. R., Kalk, M. L., Kippenhan, M. J., Koffman, B. G., Kreutz, K., Kuhl, T.W., Lebar, D. A., Lee, J. E., Marcott, S. A., Markle, B. R., Maselli, O. J., McConnell, J. R.,McGwire, K. C., Mitchell, L. E., Mortensen, N. B., Neff, P. D., Nishiizumi, K., Nunn, R. M., Orsi, A.

J., Pasteris, D. R., Pedro, J. B., Pettit, E. C., Price, P. B., Priscu, J. C., Rhodes, R. H., Rosen, J. L., Schauer, A. J., Schoenemann, S. W., Sendelbach, P. J., Severinghaus, J. P., Shturmakov, A. J., Sigl, M., Slawny, K. R., Souney, J. M., Sowers, T. A., Spencer, M. K., Steig, E. J., Taylor, K. C., Twickler, M. S., Vaughn, B. H., Voigt, D. E., Waddington, E. D., Welten, K. C., Wendricks, A. W., White, J. W. C., Winstrup, M., Wong, G. J., Woodruff, T. E., Wais Divide Project Members: 2015, Precise interpolar phasing of abrupt climate change during the last ice age, Nature, 520, 661-665.

[40.] Alley, R. B.: 1998, Palaeoclimatology - Icing the north Atlantic, Nature, 392, 336-337.

[41.] Alley, R. B., Clark, P. U., Keigwin, L. D., Webb, R. S.: 1999, Making sense of millenial-scale climate change. in Mechanisms of global climate change at millenial time scales", Eds. P. U. Clark, R. Webb, et L. D. Keigwin, Geophysical Monograph. AGU, 385–394.

[42.] Ghil, M., Childress, S.: 1987, Topics in Geophysical Fluid Dynamics: Atmospheric Dynamics, Dynamo Theory and Climate Dynamics, Springer-Verlag, New-York.

[43.] Ghil, M., 1994, Cryothermodynamics: The chaotic dynamics of paleoclimate, Phys. D, 77, 130– 159.

[44.] Ghil, M., Lucarini, V., 2020: The physics of climate variability and climate change, Rev. Mod. Phys., 92, 035002.

[45.] Ghil, M.: 2021, Orbital insolation variations, intrinsic climate variability, and Quaternary glaciations. In: Milutin Milanković: The Past 100 Years, and the Future, Proceedings of the Workshop Honoring the Milutin Milanković Jubilee, Eds. Z. Stevanović, M. Dinić, Milutin Milanković Association, Belgrade (in press).