Contemporary global warming *versus* climate change in the Holocene

Leszek Marks[1]

A b s t r a c t. Cyclical climate change is characteristic of the Holocene, with successive warmings and coolings. A solar forcing mechanism has steered Holocene climate change, expressed by 9 cooling phases known as Bond events. There is reliable geological evidence that the temperatures of most warming phases in the Holocene were globally higher or similar to that of the current warming period, Arctic sea ice was less extensive and most mountain glaciers in the northern hemisphere either disappeared or were smaller. During the African Humid Period in the Early and Middle Holocene, much stronger summer monsoons made the Sahara green with growth of savanna vegetation, huge lakes and extensive peat bogs. The modern warming is part of a climatic cycle with a progressive warming after the Little Ice Age, the last cold episode of which occurred at the beginning of the 19th century. Successive climate projections of the Intergovernmental Panel on Climate Change are based on the assumption that the modern temperature rise is steered exclusively by the increasing content of human-induced CO_2 in the atmosphere. If compared with the observational data, these projected temperatures have been highly overestimated.

Keywords: *palaeoclimate, solar activity, Holocene Thermal Maximum, African Humid Period, Medieval Warming Period, Little Ice Age*

Modern global warming is expressed by rising air temperature on the Earth since the termination of the Little Ice Age (LIA), that is, during the last 200 years. A cyclic behaviour of various climate parameters has modified the warming rate and the rise of temperature was frequently interrupted by stability phases or coolings. In turn, these have stimulated changes in other climate parameters as well as modified natural processes and the human economy.

Both in scientific and public circulation, the idea of global anthropogenic warming predominates. It has been primarily postulated by the Intergovernmental Panel on Climate Change (IPCC), founded in 1988 by the World Meteorological Organization and the United Nations Environment Programme to assess the risk of human influence on climate change. According to IPCC, the phenomenon of the modern warming has been caused by the increasing content of CO_2 in the atmosphere due to the burning of fossil fuels. This is believed to force sea level rise, glacier melting, ocean acidification, more frequent and more intensive extreme weather phenomena (hurricanes, floods and draughts) and massive extinction of many species of flora and fauna. Such approach makes IPCC predict catastrophic climate change, based on climate models supplied with data of meteorological measurements collected in climate databases of the National Oceanic and Atmospheric Administration – National Climatic Data Center (NOAA NCDC), Hadley Centre Climatic Research Unit of the University of East Anglia in Norwich (HadCRUT) and National Aenorautics and Space Administration – Goddard Institute for Space Studies in New York (NASA GISS).

The climate models have not been verified by their application to reconstructions of past climate changes and this makes the IPCC-presented climate change forecasts unbelievable. The curve of reconstructed temperature in the last millennium of the northern hemisphere, prepared by Mann *et al.* (1998) and reproduced by IPCC (2001), obtained the nickname 'the hockey stick' after its shape. This temperature curve was heavily criticized both for major deficiencies in its palaeoclimatic proxies and statistical methods used to construct it (McIntyre, McKitrick, 2003, 2005; Soon, Baliunas, 2003; Montford, 2010; McShane, Wyner, 2011). Despite its unreliability, the 'hockey stick' was included in the last report of IPCC (2021), and it is also frequently and thoughtlessly reproduced to this day by climate alarmists and media.

This paper presents the current state of knowledge of the climate change in the Holocene. The geological record of the climate change in this epoch has been verified by the results of archaeological, historical and meteorological investigations (Marks, 2016). Determination of the steering forces of modern warming is among the current scientific priorities in the world and, therefore, geological input is an important contribution to the discussion about human impact on the climate.

RECORDS OF THE HOLOCENE CLIMATE CHANGE

The accuracy of reconstruction of climate change depends on the resolution of primary data and is incomparably smaller if based on the geological rather than on the instrumental meteorological record. In case of the geological data, the resolution depends on factors such as the sedimentation rate of deposits that supply information on climate in the past. The sedimentation rate can be roughly estimated at ~3 cm/1000 yrs in deep-sea sediments, and 30–50 cm/1000 yrs at the continental slope. In lake sediments the sedimentation rate is ~40 cm/1000 yrs whereas buildup of ice on the Antarctic Ice Sheet equals ~4 m/1000 yrs and on the Greenland Ice Sheet it is ~25 m/1000 yrs. The geological records enable reconstruction of some climate parameters only, including mean annual and seasonal air temperature, mean annual precipitation, composition of the atmosphere and selected elements of atmospheric and oceanic circulation.

[1] Polish Geological Institute – National Research Institute, Rakowiecka 4, 00-975, Warsaw, Poland; e-mail: lmar@pgi.gov.pl; ORCID ID: 0000-0002-4507-1828

Reconstructions of the mean temperature at the Earth's surface are generally based on a few hundred low-precision uncalibrated proxy thermometers that provide a reading once a decade to once a century or two at best. Additionally, the occurrence of extreme climate events can be established, but their geological record can be generally similar to that of standard climate phenomena that last for a much longer time.

The current interglacial of the Holocene started 11.7 ka cal BP (Walker *et al.*, 2018), with progressively increasing human impact on the Earth's environment, especially strong during the past decades (Gibbard *et al.*, 2021). Geological examination of past climate changes is crucial to distinguish the natural and the human-induced factors of the current climate change. The most important climate-steering factor is solar radiation, subjected to cyclical changes caused by the Sun's activity that supplies with over 99% of the energy that is responsible for the climate of the Earth. Geological reconstructions show that rises and falls in the temperature on the Earth are dependent on the sunspot cycles (Table 1; Easterbrook, 2011; Usoskin *et al.*, 2016; Usoskin, 2023), and these in turn respond to the varying magnetic activity of the Sun.

Parallel to a record of solar activity, 1000-year temperature cycles have been traced back through the Holocene, based on proxy measurements in borehole cores of deep-sea sediments from the North Atlantic and compared to the GRIP and GISP2 time scales of the Greenland ice cores (Bond *et al.*, 1997). Nine cold Bond Events were distinguished based on ice-rafted debris (IRD) in the North Atlantic sediments, reflecting substantial coolings and changes in ocean surface circulation, indicated also by changing faunal assemblages. They have also been detected in terrestrial deposits in many regions of the world (Vahrenholt, Lüning, 2014). Temperature minima of these Bond Events (numbered from 8 to 0) occurred at about 11.1, 10.3, 9.4, 8.2, 5.9, 4.2, 2.8, 1.4 and 0.4 ka BP (Fig. 1). They were found coincident with episodes of low solar activity that corresponded to the combined Eddy's and Hallstatt's solar cycles (Table 1).

Table 1. Cycles of the Sun activity reflected by the number of spots on its surface (after Vahrenholt, Lüning, 2014)

Names of sunspot cycles	Mean duration (years)	Time interval (years)
Schwabe	11	9–14
Hale	22	18–26
Gleissberg	87	60–20
Suess/de Vries	210	180–220
Eddy	1000	900–1100
Hallstatt	2300	2200–2400

The natural input of solar energy is transformed by different external and internal factors to modulate climate on the Earth. Latitudinal insolation in the Holocene depended on the Earth's orbital parameters (Milankovič cycles). In comparison with the present values, summer temperatures in the northern hemisphere were higher in the Early and Middle Holocene (Beer, Van Geel, 2008; Beer, Wanner, 2012). Winter temperatures in the southern hemisphere were higher in the Middle Holocene, followed by higher temperatures in the northern hemisphere in the Late Holocene. In the coming 3 ka, lower temperatures are expected everywhere, except for the intertropical zone where higher winter temperatures are expected (Marks, 2016).

A stabilizing effect on the Earth's climate in the Holocene was the generally stable setting of oceans and continents, sea currents and large glacial bodies. Global thermohaline circulation, with weakening and strengthening episodes, is among the main driving forces, responsible for heat transfer inthe oceans (cf. Labeyrie *et al.*, 1987; Broecker, Denton, 1989). The Atlantic Meridional Overturning Circulation is an important component of the global thermohaline circulation, with successive weakening and strengthening episodes in the Holocene, interlinked in the Pleistocene with glaciation phases of the northern continents and changes in the main oceanic currents (McManus *et al.*, 2004). Change in global temperatures, primarily connected with variations in solar activity, influenced the atmospheric circulation patterns. Among them, the North Atlantic Oscillation showed significant interdecadal variability that steered the climate, especially during winters in the North Atlantic region, the Arctic and the subtropical Atlantic Ocean (Hurrell *et al.*, 2003).

The natural rhythm of climate change during the Holocene was disturbed by large volcanic eruptions. Emission of

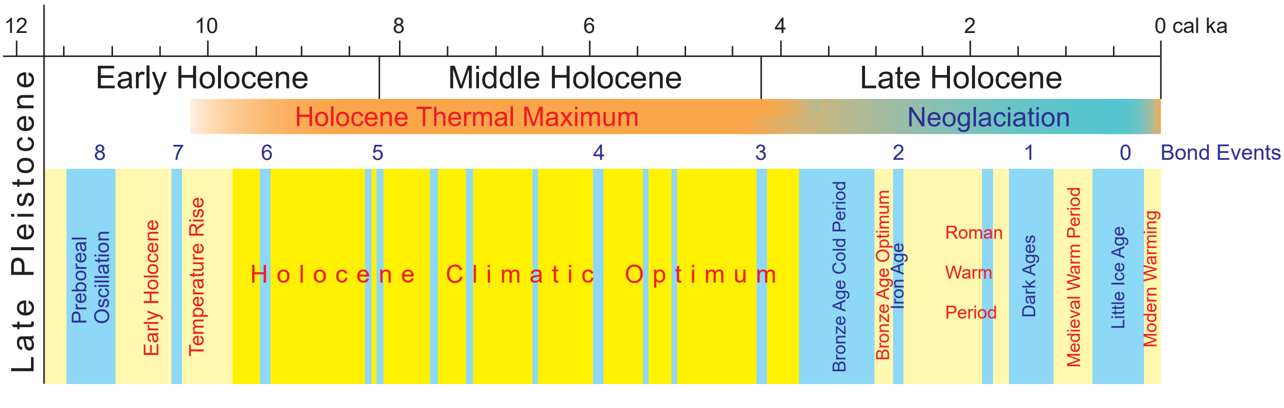

Fig. 1. Climate change in the Holocene, adapted from Palacios *et al.* (2024a) and modified: warm periods are in yellow and less warm in pale yellow, and cold in blue; Bond Events are after Bond *et al.* (1997, 2001) and geochronology after Walker *et al.* (2019)

dust into the atmosphere was responsible for a couple of cold events during the Holocene (Shindell *et al*., 2003). Such eruptions can be detected by concentrations of SO_2 in polar ice core records (Zielinski *et al*., 1994; Castellano *et al*., 2004). The extent of the vegetation cover had an important, but very complex, effect on the climate (Foley *et al*., 2003), because the evaporative cooling by a forest mitigated warmings and limited dust mobilisation (Bonan, 2008). The atmospheric CO_2 concentration decreased in the Early Holocene and started to increase since 7 ka, being independent of temperature variations (Palacios *et al*., 2024a). Ocean-atmosphere interchange was the main source of CO_2 until the recent decades when the anthropogenic emission of CO_2 became significant (Brovkin *et al*., 2019).

REGIONAL CLIMATE CHANGE IN THE HOLOCENE

There were regional differences, expressed not only by time-transgressive maxima and minima but also by opposite trends in temperature (Beer, Van Geel, 2008; Beer, Van Wanner, 2012). The Holocene Thermal Maximum (HTM) is a period that extended from 9800–5700 BP and is well-documented in the geological literature. The temperature varied considerably in the Holocene, but its maximum values were reached in many areas, though not at the same time. Geological data indicate that the HTM in central Europe occurred in the Middle Holocene (Fig. 1) and was expressed by a warm and stable climate, with mean annual air temperature 1.0–3.5°C higher than the modern one (Renssen *et al*., 2012; Kaufman *et al*., 2020). Based on pollen and chironomid data from mid- and high-latitudes, the warmest climate occurred at 7–5 ka cal BP, when summer temperatures could be as much as 3–4°C higher than in the LIA (Płóciennik *et al*., 2011; Renssen *et al*., 2012; Luoto *et al*., 2019; Kotrys *et al*., 2020). Such temperatures could be over 3 times higher than those presented by Kaufman *et al.* (2020) and IPCC (2021), and so there is no confidence that temperatures in the modern warming are higher than in the Middle Holocene (Vinós, 2022).

Arctic

At the beginning of the Holocene the Greenland Ice Sheet was larger than at present, while the other northern ice sheets (Laurentide, Scandinavian and Icelandic) were still extensive. The temperature of surface sea water in the North Atlantic was 1–5°C and on Spitsbergen 2°C higher than in modern times (Mangerud, Svendsen, 2018). In southern Spitsbergen, the strait along the present Hornsund Fiord was ice-free at least from 10.9 to 3.9 ka cal BP (Osika *et al*., 2022). Then, the strait was closed but it became open again in the Medieval Warm Period (MWP; 1.3–0.7 ka cal BP) when the Hornsund glaciers receded. Subsequent glacier advances led to the strait's closure in the LIA.

Studies of driftwood on the northeastern beach of Greenland and other islands in the Canadian Arctic proved (Dyke, Savelle, 2000; Funder *et al*., 2011) that there were several periods in the Holocene when there was no sea ice nearshore, in turn making stranding of driftwood of spruce from Canada or larch from Siberia possible. Reconstruction of surface currents in the Holocene shows the travel routes of driftwood in the Arctic Ocean, indicating a limited pack ice in different sectors in summer, especially at 6–5, 4.5–2.5, 2.0–1.8, 1.0–0.7 and since 0.2 ka cal BP. This coincides with the melting phases noted in the Greenland Ice Sheet cores (Westhoff *et al*., 2022).

Glacier advances

Glaciers advanced several times in the Holocene, namely at: 10.0–8.8 ka (in many areas, but in the southern hemisphere they were more extensive than during the LIA), ~8.2 ka, 7.3–5.9 ka (2–3 advances), 5.1–4.2 ka (1–2 advances), 4.2–1.9 ka (1–2 advances, in the southern hemisphere they were more extensive than during the LIA), 1.9–0.9 ka (1–3 advances, locally glaciers were more extensive than during the LIA), 0.9–0.1 ka (LIA, in Europe and North America maximal extents in the Holocene), 1950–2000 (different areas). Due to higher temperatures, glaciers completely or mostly disappeared before 6 ka in many regions of the northern hemisphere (Palacios *et al*., 2024a), e.g. in Scandinavia (Nesje, Kvamme, 1991). A period of successive glacier rebuilding and advances in the world since ~5 ka BP was named the Neoglaciation (Denton, Porter, 1970).

Asian and African monsoons

Changes of summer insolation in the northern hemisphere steered the monsoon intensity in Asia and Africa, and this was reflected by a shift of the Intertropical Convergence Zone at higher and lower latitudes (Wen *et al*., 2022; Palacios *et al*., 2024a). The intensity of the Asian monsoon increased progressively until it reached its northernmost extent at 9.6–5.5 ka. This stabilized the climate in Asia during the Middle Holocene, though it was interrupted by short and sharp episodes of decreased monsoon intensity connected with the Bond Events 9.4 and 8.2 ka (Wang *et al*., 2005). A weakening trend of the monsoon has begun since 5.5 ka, with sharp decreases during the 4.2 and 2.8 ka Bond Events (Fleitmann *et al*., 2003) when many lakes in India and China disappeared (Goldsmith *et al*., 2022). The monsoon became stronger after 1.4 ka, reflecting temperature strengthening during the MWP, then it weakened during the LIA and became stronger again in the modern warm period (Gupta *et al*., 2003).

The West African Monsoon strengthened at the beginning of the Holocene, reaching in summer the latitude 32°N (Fig. 2) and this favoured the formation of huge lakes and extensive peat bogs in the area of Sahara, accompanied by a drainage network (Renssen *et al*., 2006; Chandan, Peltier, 2020; Menviel *et al*., 2021). The African Humid Period lasted for most of the Middle Holocene, but the progressing decrease of insolation from 5 ka (De Menocal, 2015) made the Intertropical Convergence Zone migrate southwards and caused desertification of the Sahara, reflected by a loss of vegetation cover and increased dust content in the atmosphere (Renssen *et al*., 2006; Burrough, Thomas, 2013; Menviel *et al*., 2021).

Climate change after the Holocene Thermal Maximum

The temperature deduced from the oxygen isotope curve in the Greenland ice core GISP2 shows that several warmings occurred after the Holocene Thermal Maximum (Fig. 1; Drake, 2012). These were periods during which great progress in the development of human societies occurred: Late Bronze Age, Roman Warm Period and the MWP.

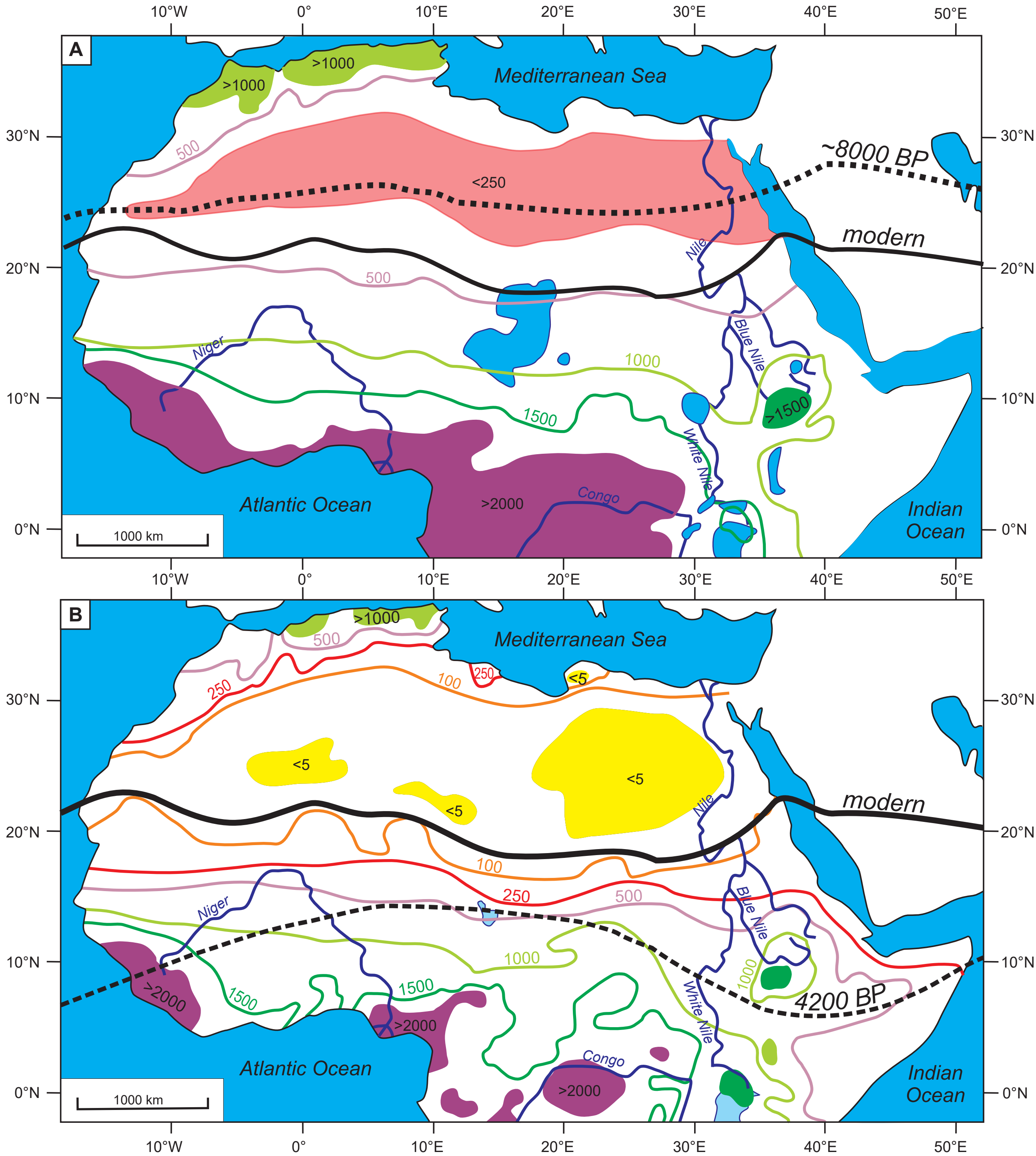

Fig. 2. North African precipitation (isohyets): **A** – the African Humid Period, **B** – the present day; black lines indicate location of the Intertropical Convergence Zone in the northern hemisphere summer at ~8 and 4.2 ka BP, and modern (after Welc, Marks, 2014; Palacios *et al*., 2024a, modified)

The separating cold Bond Events, named the Iron Age and Dark Ages Cold Periods respectively, were expressed by economic, intellectual and cultural decline. The temperature history since 900 CE was based firstly on the estimated climate history of central England (Lamb, 1977; IPCC, 1990). This showed a distinct warming of ~1.3°C when compared with the LIA (Moberg *et al*., 2005; D'Arrigo *et al*., 2006; Mann *et al*., 2009). This warming was a result of natural processes, because human activity could not have had any significant effect on temperature changes before 1900 CE. The Roman Warm Period (250 BC–450 CE), the MWP (950–1250 CE) and the Modern Warming Period reflect 1000-cycles with high solar radiation (Table 1; Vahrenholt, Lüning, 2014).

DISCUSSION

The claim of the IPPC (2021) that '…*the latest decade was warmer than any multi-century period after the Last Interglacial, around 125,000 years ago*' ignores all the knowledge about reconstructed temperatures in the Holocene, based on multi-proxy palaeoclimatic data.

Despite the extensive northern ice sheets, the increased summer insolation in the northern hemisphere caused a warming trend from the beginning of the Holocene and lasting until the Middle Holocene (Palacios *et al.*, 2024a). This warming trend was reversed from 6–5 ka onwards, due to decreased summer insolation in the northern hemisphere. Such general warming or cooling trends in the Holocene were interrupted by short periods with opposite and abrupt temperature changes (Fig. 1).

The African Humid Period is directly related to orbital precession patterns, being when the Earth was closest to the Sun (i.e. at perihelion) during summer in the northern hemisphere (Shanahan *et al.*, 2015; Menviel *et al.*, 2021; Palacios *et al.*, 2024a). The maximum summer insolation in this hemisphere reinforced the West African Monsoon to its maximum providing high humidity in the Sahara, accompanied by an intensified Asian summer monsoon and complemented by moisture coming from the Atlantic (Goldsmith *et al.*, 2022). This warmed the Mediterranean, high evaporation of which brought winter rains in northern Sahara (Cheddadi *et al.*, 2021), making farming in Egypt possible already at the beginning of the Middle Holocene (Welc *et al.*, 2023).

A solar forcing mechanism as a steering force for the Holocene climate change, expressed by the Bond Events (Bond *et al.*, 1997, 2001), has been completely neglected by the IPCC (2001; Scafetta, Vahrenholt, 2023). Finally, Mann *et al.* (2009) admitted that the MWP existed but to diminish its significance considered it as the Medieval Climatic Anomaly, declared its local peculiarity limited to the North Atlantic region, just as he considered the LIA to be only a European phenomenon. There are now dozens of scientific publications that show the pattern of the 1,000-year climate cycles in the Holocene, occurring on all continents. The MWP and the LIA occurred not only in Europe (Palacios *et al.*, 2024b) and North America but also in Tibet, Mongolia, Yakutia, Australia, Oman, Chile and many other regions (D'Arrigo *et al.*, 2006; Bird *et al.*, 2011; Vinós, 2022). These warm and cold periods are the effect of the global atmospheric reorganization induced by changing solar activity, especially strongly expressed in the North Atlantic atmosphere-oceanic system that is a hotspot for planetary climate variability, both during glacial and interglacial periods (Vinós, 2022).

The modern warming represents a part of the cyclical climate change after the LIA, the last cold episode of which occurred at the beginning of the 19th century. The LIA with low temperatures is named the pre-industrial period by the advocates of global anthropogenic warming and such an approach helps them to promote the idea that an increased human emission of CO_2 (especially in the 20th century) is the only reason for rising temperatures on Earth. They do not bother with the evidence that the mutual time relations of global temperature and contents of CO_2 in the atmosphere in 1980–2019 indicate a leading role of temperature, a rise of which was followed in that time by a 6-month delay in the rise of CO_2 (Humlum *et al.*, 2012; Koutsoyiannis, Kundzewicz, 2020).

The official curve of the global mean annual temperature anomalies based on regular measurements (https://data.giss.nasa.gov/gistemp/graphs_v4/) overlaps slightly with the temperature projections in reports of the IPCC (1990, 1995, 2001, 2007, 2014, 2021). These IPCC projections were created by climate models, based on the assumption that the modern temperature rise is steered exclusively by the increasing content of human-induced CO_2 in the atmosphere while the role of water vapour as the main greenhouse gas is neglected (cf. Hołyst, 2020). Such an approach makes the IPCC-projected temperature highly overestimated if compared with the observational data (Fig. 3). Despite the lockdowns during the Covid-19 pandemic in 2020–2021, connected with large cutbacks in transport, travel, industrial production and energy generation, no reduction in atmospheric CO_2 was noted. This fact suggests that the proposed reductions in global energy use would be most probably highly ineffective in limiting the level of atmospheric CO_2.

CONCLUSIONS

The Holocene climate change was characterized by cyclical warmings (such as: Holocene Thermal Maximum, Late Bronze Age, Roman Warm Period, MWP) and coolings (Bond Events: including Iron Age Cold Period, Dark Ages Cold Period and LIA). The IPCC claims that current warming is unprecedented in the last 2000 or even the last 125,000 years; this statement is very unconvincing and it is not supported by the geological data. There is good evidence that both in the last 2000 years as well during the Holocene Thermal

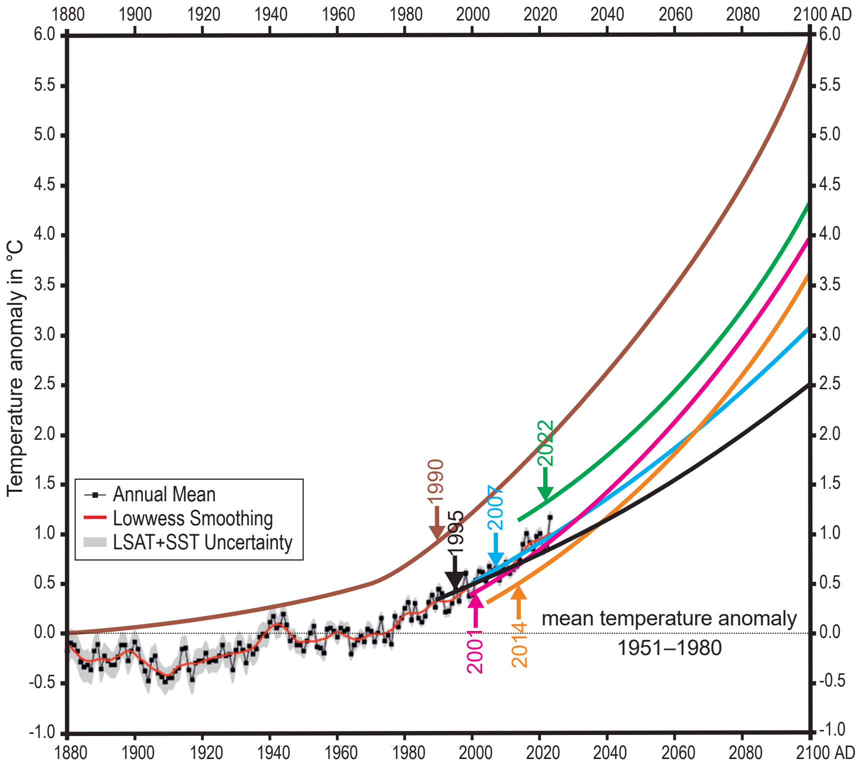

Fig. 3. Global estimates of mean annual temperature anomalies (1880–2023), based on land and ocean data (https://data.giss.nasa.gov/gistemp/graphs_v4/) and temperature projections to AD 2100 in the successive IPCC reports (1990, 1995, 2001, 2007, 2014, 2021)

Maximum, temperatures were higher or broadly similar to the ones in the current warming period, the Arctic sea ice was less extensive and most mountain glaciers (especially in the northern hemisphere) either disappeared or were smaller. Much stronger summer monsoons in the Early and Middle Holocene made the Sahara green with savanna vegetation, huge lakes and extensive peat bogs. The terms '*the Holocene Thermal Maximum*' and '*the Holocene Climatic Optimum*' are avoided by the IPCC (2021), and its popularized statements making the current warming look '*unprecedented'* and therefore *'unique*' are false and flatten the climate history (cf. Marcott *et al.*, 2013).

The climate is a product of complicated interdependence of many factors that have not been yet sufficiently recognized qualitatively and quantitatively. It is a great scientific challenge that requires an extensive interdisciplinary research. There is a crucial need to make climate science less political and climate policy more scientific.

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