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WPŁYW CZŁOWIEKA NA HOLOCEŃSKIE OPTIMUM KLIMATYCZNE
HUMAN IMPACT ON THE HOLOCENE CLIMATIC OPTIMUM

Introducion

If anthropogenic climate warming in the 21st century could be excluded, the warmest period of the Holocene occurred from 11,000 to 5,000 years ago. It is called the Holocene Climatic Optimum (HCO). This name was given not because it was the warmest time of the current interglacial (initially temperatures were lower than today although they were rising fast), but because at that time deserts in the Northern Hemisphere were much smaller. During the HCO not only the Sahara and Arabian Peninsula were mostly steppe or savanna, but also deserts in Central Asia, the Middle East, Iran, India and in Inner Mongolia were mostly covered with vegetation (deMenocal et al. 2000; Parker et al. 2004; Jiang et al. 2006; Djamali et al. 2010; Spengler, Willcox 2013). Approximately 15 million km² of current deserts were covered with vegetation. This corresponds to 3% of the Earth's surface, but since these areas are relatively close to the equator, they constitute about 5% of the Earth's projected area.

If we assume that covering these deserts with vegetation decreased their albedo from 0.4 to 0.2 (by 0.2), it decreased the albedo of the entire planet by 1%. Probably during HCO albedo was not 0.3, as it is today (Goode et al. 2001), but 0.29. This caused an increase in temperature of the planet by about 1°C and a shift of climate zones toward the poles (e.g., replacing some tundra by taiga), which further reduced albedo and warmed the climate in a positive feedback mechanism.

The most spectacular manifestation of the Holocene Climatic Optimum was the African Humid Period (AHP) and the Green Sahara Phenomenon. Throughout the Pleistocene an obvious prerequisite for the onset and persistence of the Green Sahara has been an increase in rainfall. The main source of rain for North Africa is the African Monsoon (AM) blowing in summer from the Gulf of Guinea through the Sahel towards the central and western Sahara. But this is not the only source of water. In the Horn of Africa and

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the eastern part of the Sahara, some moisture comes from the Indian Ocean, delivered in summer by the boreal East African Monsoon (bEAM). Additionally, in spring and autumn, abundant rainfall transported from the Indian Ocean is provided by the Walker circulation to the regions closest to the equator. By the end of spring, rainfall carried by the Walker circulation shifts north, until it eventually becomes bEAM in summer. Some rain that falls in spring near the equator (mainly in the Congo River basin) becomes the source of so-called secondary condensation rainfall in the eastern Sahel and the Abyssinian Plateau in summer. Secondary condensation rainfall can be easily traced because it is enriched in Deuterium, a heavy hydrogen isotope (Costa et al. 2014). In turn, the northernmost part of the Sahara and the African coast of the Mediterranean Sea receive rainfall mainly in winter. These rains are brought by the Middle-Latitudes Westerlies (MLW) from the Atlantic in November through February (Fig. 1).

The source of moisture carried to equatorial Africa from the Indian Ocean may also be the cyclically occurring Indian Ocean Dipole (IOD). It was first described less than 30 years ago (Webster et al. 1999; Abram et al. 2007; 2020). The IOD is an anomalous upwelling in the eastern equatorial Indian Ocean, which causes cooling and drought in western Indonesia and heavier precipitation in equatorial eastern Africa. Today, it typically ac-

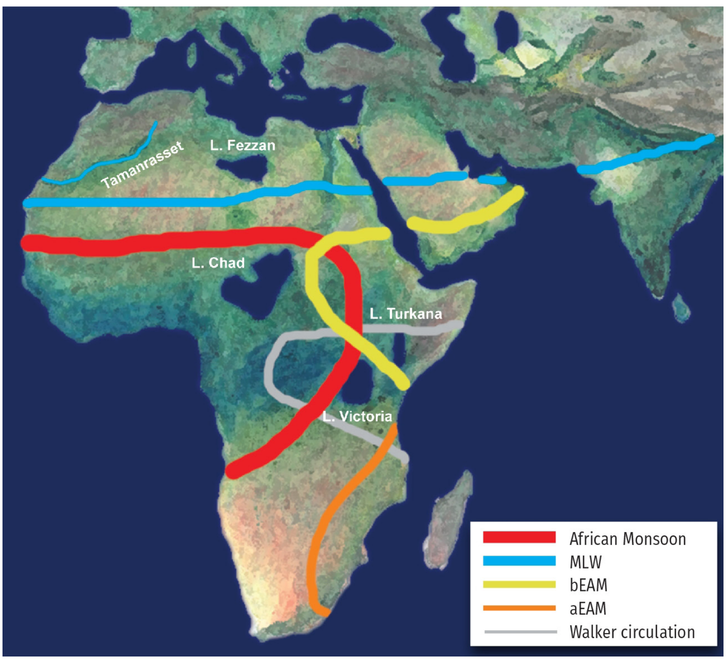

Fig. 1. The African Humid Period (Green Sahara phenomenon) and the course of monsoons about 8300 years ago (Schefuß et al. 2005).

companies the strong El-Niño phase of ENSO, but occasionally it is also associated with exceptionally strong Indian Summer Monsoon (ISM).

The IOD was more common during the HCO than it is today, despite the ENSO phenomenon being very rare at that time. Therefore, it is speculated that during the HCO, the IOD was occurring together with stronger ISM (Abram et al. 2007), as it sometimes happens today. However, as we know that winds driving the ISM were relatively weak before 8.2 ky ago, another explanation of more common IOD can be proposed: stronger Walker circulation could have caused an anomalous Ekman pumping in the western Indian Ocean and, in parallel, a stronger Ekman upwelling in the eastern Indian Ocean, which was responsible for development of the IOD.

Climate model simulations dedicated to the AHP have been primarily focused on determining what conditions had to be met for the Green Sahara Phenomenon to persist. These are not necessarily the same conditions that had to be fulfilled for the AHP to begin or finish because at least a slightly stronger stimulus is needed to disrupt the system's equilibrium than to maintain that equilibrium. Therefore, the search for the causes of AHP should focus on finding sources of disturbances in the equilibrium state. Especially because the onset and termination of the HCO occurred abruptly.

It is commonly accepted that the most important factor responsible for the emergence and persistence of the AHP is high insolation of the Northern Hemisphere. Insolation depends on so-called orbital factors. In the past, high insolation was the only source of higher temperatures in the Northern Hemisphere. However, this may not be the case in the future, as anthropogenic climate warming is increasingly affecting land and air temperature, and even sea surface temperature (Gleckler et al. 2016; Durack et al. 2018).

Insolation of the Northern Hemisphere depends on the so-called Milankovitch cycles, which consist of three orbital factors: the tilt of the Earth's axis to the plane of its orbit, changes in the eccentricity of this orbit, and the so-called precession of the Earth's rotational axis (it means that the North Pole does not always point towards the North Star, as the axis of the Earth traces a circular path in a cycle lasting 26,000 years). In addition to the Milankovitch cycles, the so-called precession of equinoxes is very important for the insolation of the Northern Hemisphere. This means that the perihelion (the closest distance to the Sun) of Earth's elliptical orbit currently falls on January 3rd (which is why the Southern Hemisphere receives nearly 7% more solar radiation than the Northern Hemisphere), while around 10,000 years ago it fell in the middle of summer in the Northern Hemisphere.

Other orbital factors have negligible significance. To the contrary, a very important factor influencing the strength and range of summer monsoons is vegetation, as it changes surface albedo and increases air humidity over the Sahara. The greener the Sahara, the lower the albedo, the more solar energy is absorbed by the Earth's surface, the more the surface warms, which warms and expands the air in the lower layers of the atmosphere, making the buoyancy forces lifting this air stronger (due to greater evaporation and transpiration this air is also more humid), which on one hand increases the chance of cloud formation, and on the other hand weakens the descending winds in the Hadley cell, which are responsible for evaporating clouds and cause high temperature of the Sahara surface. In short: the denser the vegetation cover in the tropics (e.g., in the Sahara), the greater the probability of cloudiness and rain. This is an example of positive feedback (the effect amplifies the cause).

Computer simulations conducted using various software, assuming changing orbital conditions and vegetation cover (Braconnot et al. 2012; Rachmayani et al. 2015), have never provided a satisfactory explanation of why the AHP occurred, why it lasted several thousand years, and why it ended so abruptly. All simulations lacked about 20-50% of rainfall for the AHP to occur. Also, recent investigations (Bian et al. 2024) showed only a small shift of Intertropical Convergence Zone (ITCZ) north, by about 1° (111 km). Therefore, in recent years, there has been an explosion of research for other factors that might have influenced the occurrence or termination of the AHP. However, most of the newly analyzed factors should be considered rather effects than causes of the climatic changes. For example, studies on the amount of dust in the air over the Sahara (Pausata et al. 2016), the influence of lakes and swamps (Krinner et al. 2012), or the impact of climate cooling at high latitudes in the Northern Hemisphere, which was accompanied by a northward shift and a change in the intensity of the periodically occurring summer jet streams (African Easterly and Tropical Easterly Jet Streams) were performed (Collins et al. 2017).

The reason why increased dust in the air over the Sahara could be both a cause and an effect of the Sahara's transformation into a desert does not require further explanation. Also cooling in high latitudes could be a consequence of the Sahara's desertification, because desertification increased its albedo, resulting in cooling of the entire planet. In addition to searching for further factors increasing rainfall in the Sahara, correlations between known factors should also be closely examined. Particularly since many of these correlations are positive or negative feedbacks.

Objectives and methods

This article aims to search for factors and feedbacks responsible for the development of the Holocene Climatic Optimum and Green Sahara phenomenon.

It seems that the impact of increased humidity in Asia and greater water transport from the Indian Ocean has been underestimated in the hitherto simulations. In 2019, I proposed a hypothesis that a condition for the occurrence of the AHP and the Green Sahara Phenomenon during the HCO was an increased humidity in Asia, especially Central Asia and the Middle East, as it caused glaciers in the mountains surrounding Tibet from the west (the Himalayas, Hindukush, Pamir, and Kunlun Mountains) to expand, which resulted in changing the strength and direction of summer monsoons. This hypothesis is based on data from the literature.

Results

Greater humidity in Central Asia weakened the Siberian High and the Indian Winter Monsoon (IWM) (Lehmkuhl, Haselein 2000). According to these authors, during the Holocene Climatic Optimum, the Earth's greater axial tilt, higher ocean temperatures, and a larger temperature gradient between the oceans and land caused stronger westerly low-pressure eddies (MLW) in winter, which were a source of moisture for middle latitudes of Eurasia, including the Middle East. The weaker Siberian High allowed MLWs to reach farther east, making the center of Asia even wetter. The wetter core of Asia further weakened the Siberian High. The relationship between winter MLWs and the weaker Siberian High is positive feedback.

A weaker IWM also ensured greater rainfall and weaker dust storms in the Arabian Peninsula and in the Horn of Africa. Furthermore, the weakening of the IWM increased Sea Surface Temperature (SST) in the western part of the Indian Ocean at the end of winter, thereby enlarging the Indian Ocean Warm Pool (IOWP) for the summer monsoons: Indian Summer Monsoon (ISM) and boreal East African Monsoon (bEAM).

This hypothesis is based on data from the literature that indicate that during the HCO glaciers in the mountains surrounding Tibet from the west began to expand during the deglaciation and reached their maximum extent in the early Holocene, during the Greenlandian stage (Zheng et al. 1990; Li, Shi 1992; Owen et al. 2008; Seong et al. 2009). A high-pressure air cell developing over these glaciers weakened winds driving the ISM and shifted them away from Tibet, thereby driving these winds to the west – towards Pakistan and the Middle East. Since the presence of glaciers in mountains surrounding Tibet depends definitely on snowfall not rainfall (i.e., mainly on winter precipitation), the condition for the enlargement of these glaciers is a greater amount of moisture carried in winter by the MLW, not in summer by the ISM (Bookhagen, Burbank 2010).

MLW blow between the polar circles and the tropics and transport moisture from west to east in the form of large, cyclonic vortices. In the Northern Hemisphere, the initial source of this moisture is the warm sea current of the North Atlantic: The Gulf Stream.

Carried by the MLW, water is being transported in a leapfrog manner, rather than as a continuous flow: the cyclone carries it thousands of kilometres to the east, where it falls as rain or snow, then evaporates to be transported further east by another cyclone. Most snow that falls in the Himalayas comes from water that has evaporated in the Middle East. Some winter snowfall in the Himalayas also derives from moisture evaporating from the Indus and Ganges plains, brought there in summer by the ISM.

To explain how larger glaciers in the mountains around Tibet could have contributed to the creation of the Green Sahara, I developed the concept of the ISM-bEAM oscillation. It is known that the ISM and bEAM originate from the same Indian Ocean Warm Pool (IOWP). The ISM-bEAM oscillation means that a weakening of the wind driving the ISM causes a larger portion of the IOWP to remain for bEAM and vice versa. If it coincided with the Green Sahara (lower albedo of the Sahara), which facilitated convection of the warmed air, a low-pressure cell developing above north Africa in summer could grow bigger. Subsequently, this cell propelled stronger winds driving the bEAM.

The hypothesis that a wetter Central Asia and the Middle East contributed to the occurrence of the AHP by increasing glaciers in mountains surrounding Tibet, which led to weakening of winds driving the ISM and increased water transport to the Sahara from the Indian Ocean is attractive, because it helps to answer several questions.

1. First: it may explain why the AHP began even before the Holocene and why its onset was so rapid, as well as why the development of the AHP slowed down during the Younger Dryas and started declining during the 8.2 ky event, when MLW were much weaker. We know that these glaciers were expanding during the deglaciation and reached their maximum extent in the first stage of the Holocene (Richards et al. 2000, Finkel et al. 2003), when the climate was the warmest and the most humid. If the presence of a high-pressure cell over these glaciers increased the precipitation carried to Africa from the Indian Ocean by the Walker circulation and bEAM (due to the ISM-bEAM oscillation), it would explain why the AHP could have begun even before the onset of the Holocene, before the summer monsoons fully developed.
2. Second: this hypothesis may explain why about 7,500 years ago, the amount of water in the Nile decreased sharply, causing the Nile's floods to become less devastating. Calming of the Nile's floods allowed people to reoccupy the valley of this river. The reason could have been the 8.2 ky event, which lasted 600 years, when weakening the Gulf Stream reduced precipitation carried by the MLW. This resulted in gradual shrinking of glaciers in the Himalayas. The 8.2 ky event resembled the Younger Dryas. It was probably, similarly as the Younger Dryas, caused by the outflow of cold, fresh water from proglacial lakes into the Atlantic. This caused the northern

Atlantic to freeze and stopped the Gulf Stream, which reduced the amount of water provided by the MLW to Eurasia.

The reduction of glaciers in the mountains surrounding Tibet and the decrease of the high-pressure cell also strengthened winds driving the ISM. The finding that rainfall in the Western Ghats was relatively low during the Greenlandian stage of the Holocene, while about 8.2 thousand years ago it became the highest in the entire Holocene (Staubwasser et al. 2003) supports this hypothesis.

3. Third: this hypothesis may explain why during the HCO, the ENSO phenomenon (El Niño Southern Oscillation) was uncommon. During the HCO the water transport from the Indian Ocean by Walker circulation to the Nile and Congo River basins was so potent that perhaps for most of the year it exceeded 50,000 m^3/s. This estimation is based on the amount of water discharged by these rivers during the HCO (Yletyinen 2009). This transport must have been balanced by increased water transport from the Pacific Ocean to the Indian Ocean. This was happening, same as today, mainly through the Indonesian straits, but was larger. Therefore during the HCO the water level in the western Pacific was probably less likely to pile up and the El Niño phenomenon was less likely to develop. The lower sea surface temperature (SST) in the northern Pacific and higher SST in the northern Atlantic during the HCO than today support this hypothesis (Kim et al. 2004).
4. Fourth: if this hypothesis is correct, it explains not only the relatively rapid onset of the AHP but especially its abrupt termination surmounted by the turbulent 4.2 ky event. I described this in more detail in a separate article (Szczęsny 2019) and in a book (Szczęsny 2024). Here, I will only briefly present their content.

   Results of research from the cave in the Pamir Mountains showed that a prolonged drought lasting from 4,700 to 3,900 years ago was interrupted by a short episode of increased rainfall around 4,200 years ago (Wolff et al. 2017).

   The prolonged drought in the Pamir cave likely reflects the progressive reduction of glaciers there. This might be a consequence of a gradual decrease in precipitation delivered by the MLW, caused by gradually lowered groundwater levels and desertification in the Middle East. They could have been caused by demographic explosion powered by popularization of agriculture and animal husbandry, which is called the Neolithic Revolution. The negative consequence of the Neolithic was predatory land management by farmers and herders in the Middle East and the Sahara, which accelerated desertification.

   Desiccation of the Sahara could have been accelerated directly by farmers and herders living there, but also indirectly by farmers and herders living in the Middle East,

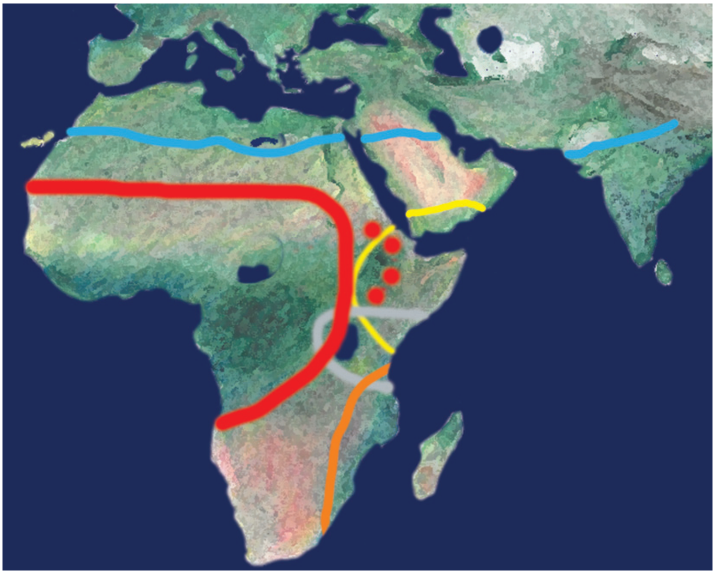

Fig. 2. Monsoons in Africa 4.9 ky BP (deMenocal et al. 2000; Costa et al. 2014).

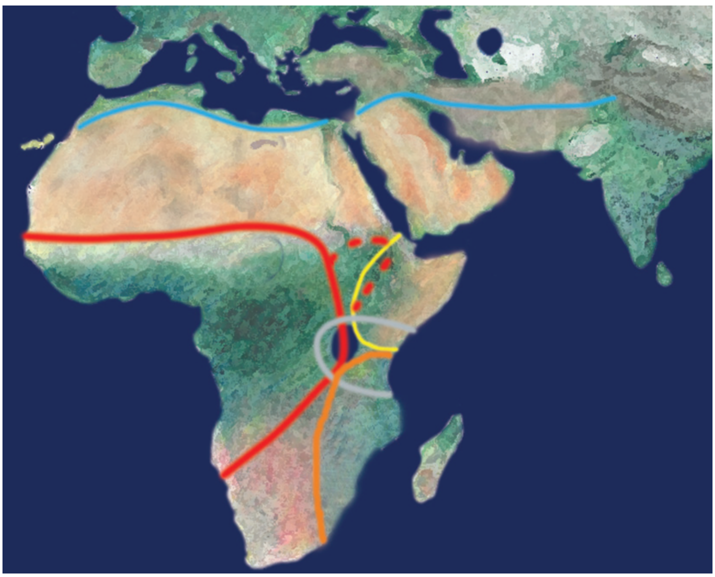

Fig. 3. Monsoons in Africa since 4.2 ky ago until present (Kuper 2006).

because their activity lowered the groundwater level and decreased the amount of moisture carried by the MLW towards Tibet, which caused shrinking of glaciers in mountains surrounding Tibet. This process enhanced the winds driving the ISM and left less moisture for the bEAM in the mechanism of ISM-bEAM oscillation (Fig. 2, Fig. 3). Enhancing winds propelling the ISM did not necessarily cause greater rainfall carried by this monsoon, because concomitantly the Sea Surface Temperature (SST) of the western Indian Ocean decreased, due to strengthening Siberian High. A stronger Siberian High is evidenced by a prolonged decrease in air temperature from about 4,000 to 2,600 years ago in Altai mountains (Aizen et al. 2016).

. Fifth: it provides a hypothesis on the possible origin of the 4.2 ky event – the drought and cooling that lasted almost 200 years and resulted in the termination of most Neolithic civilizations. Until now no widely accepted explanation of the origin of the 4.2 ky event is known, which is why I proposed my own hypothesis.

The sudden increase in rainfall in the Pamir around 4,200 years ago is surprising. It was not a result of increased rainfall in the Middle East, as there was an extreme drought there at that time. It must have resulted from excessive evaporation west of the Pamir. I hypothesized that catastrophically high evaporation of water in the Middle East was caused by the Gutian invasion. Deliberate arson of fields and steppe, practiced during several decades of that war, could have caused a rapid desertification (Figs. 4, 5, 6). If this hypothesis were confirmed, the 4.2 ky event could be called the greatest climate catastrophe caused by humans so far.

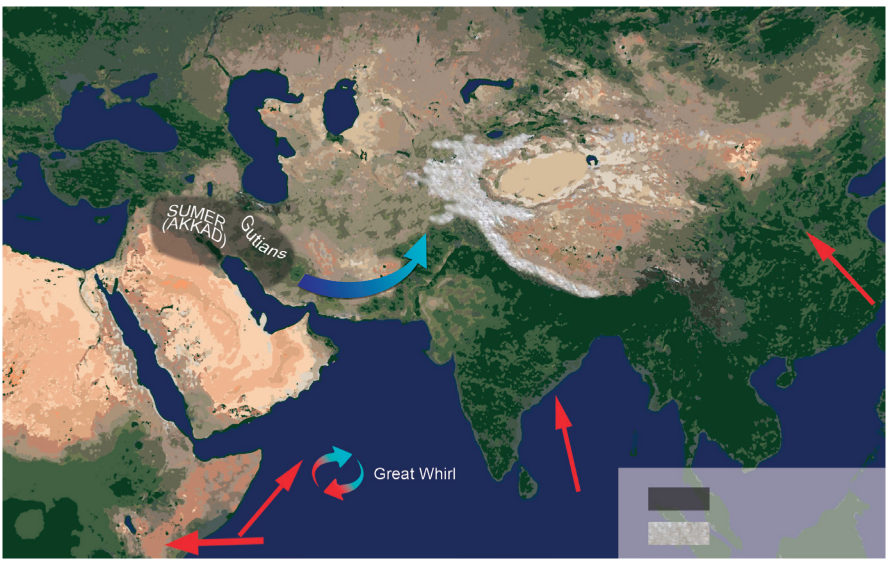

Fig. 4. The origin of the 4.2 ky event. Multidecadal war and wildfires in the Middle East caused a multidecadal snow cover in mountains around western part of Tibet. Curved arrow shows the direction of transport of moisture by MLW. Straight arrows show the strength and prevalent direction of monsoon-driving winds.

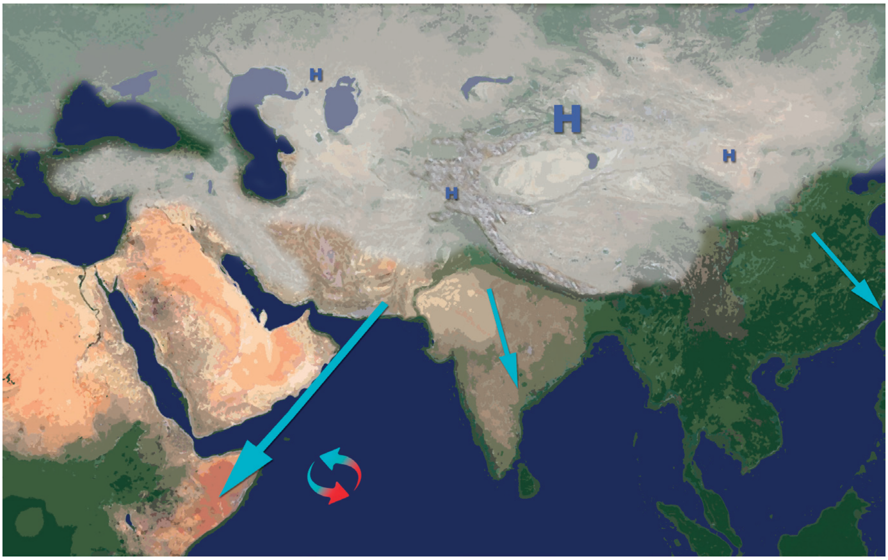

Fig. 5. The 4.2 ky event during winter. An extremely strong Indian Winter Monsoon caused cold and dry conditions in the Horn of Africa, as well as drought in Deccan Peninsula. It also reversed the Great Whirl east off the coast of Somalia. Straight arrows show the strength and prevalent direction of monsoon-driving winds. H – high pressure area.

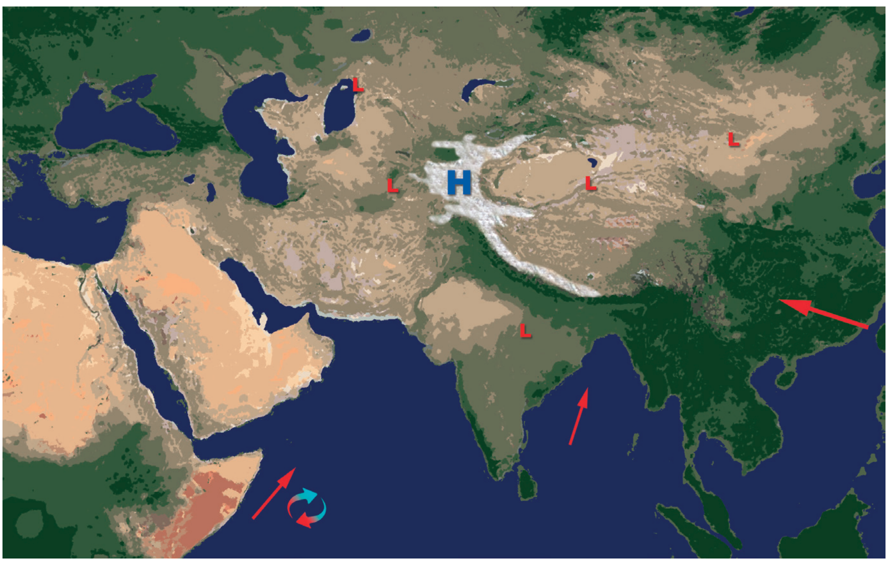

Fig. 6 The 4.2 ky event during summer. Note weaker low air pressure area which causes weaker winds propelling Indian Summer Monsoon. Straight arrows show the strength and prevalent direction of monsoon-driving winds. L – low pressure area.

Pamir mountains are located beyond the reach of the ISM, which is why they receive all their precipitation from the MLW, most of it in winter. These winds, in the form of cyclones, transport the moisture from the Middle East to Pamir. Because 4,200 years ago there was an extreme drought in the Middle East, the only explanation for the sudden increase in rainfall in Pamir 4,200 years ago was an excessive evaporation of water in the Middle East.

Numerous Sumerian and Acadian records from that time, immortalized by scribes on clay tablets, depict the horror of the Gutian conquest — initially it was an invasion of the Iranian Plateau and Elam, and subsequently of the Acadian Empire (Mesopotamia). These "lamentations" do not contain description of battles. They describe only destruction, wildfires, rivers' drying out, etc., as if during that war no battles were fought. It can be hypothesized that the Gutians, who were using horses domesticated by Indo-Europeans, were probably Indo-Europeans themselves. Their method of waging wars was probably surprise attack and scorched-earth tactics. By burning fields and steppe, they destroyed and conquered countries east of Mesopotamia and, for 34 years, they even occupied the fertile plains.

Conclusions

The hypothesis that the source of the missing moisture for the Sahara during the AHP was water evaporating from the Indian Ocean, despite being simple and coherent, has a fundamental flaw—it is based on sparse evidence. To verify this hypothesis, it would be necessary to obtain similar data on Holocene precipitation from other caves in Pamir or Tian Shan mountains, where the ISM does not reach.

There is also deficiency of data regarding precipitation in the Aral Sea basin, that is, in the Amu Darya and Syr Darya river basins during the HCO. To confirm increased precipitation during the HCO delivered by the MLW, it would be necessary to demonstrate increased runoff of the Amu Darya and Syr Darya during that time. To achieve this, studies of fossil plant pollen from the Aral Sea basin and creating with their use temperature and humidity indices, similar to those performed for the Altai Mountains (Blyakharchuk et al. 2007; Zhang, Feng 2018), would probably be the most valuable in deducing this precipitation.

Also, marine sediment cores from the seabed off the western coast of India would facilitate a precise timing of onset and termination of precipitation in Western Ghats (western coast of India). Data from sediment cores from the seabed off the coast of Somalia would provide information about the temperature of the western Indian Ocean.

This temperature drops with the strengthening of winds propelling summer monsoons but also with the strengthening of the Siberian High. Correlating data about rainfall in western India with water temperature off the coast of Somalia would allow us to draw conclusions about the strength of the Siberian High and IWM.

To determine the temporal correlations between the size of glaciers in the Himalayas and the humidity of the Middle East, more lacustrine data from the bottom of dried-up lakes that existed in the Iranian Plateau several thousand years ago and data regarding glacial moraines in the Himalayas, as well as the composition of stalactites and stalagmites in the caves around Tibet are needed.

We know that the development of the AHP slowed down during the Younger Dryas and that AHP's decline was triggered by the 8.2 ky event. Both of these periods of climate cooling began abruptly, with a sudden weakening of the Gulf Stream, probably caused by the outflow of fresh water from proglacial lakes to the Atlantic. More precise radiocarbon dating of the Green Sahara period would allow determining whether the decrease in precipitation occurred simultaneously with the onset of the Younger Dryas and the 8.2 ky event, or with some delay. If the decrease in precipitation happened with a delay, it would support the hypothesis that the cause of the reduced precipitation in the Sahara was the shrinkage of glaciers in the mountains surrounding Tibet, as it takes more time to melt glaciers than to weaken the Gulf Stream when northern Atlantic becomes suddenly frozen.

A preferable method of verification of aforementioned hypotheses would be applying computerized programs designed for simulation of climate change. Ideally, several laboratories should conduct these simulations independently, using different software.

Verifying this hypothesis would not only resolve whether humans caused the climate catastrophe 4,200 years ago. The 4.2 ky event, like all climate catastrophes experienced by humanity so far, was characterized by cooling and drying, not by warming. Verification of this hypothesis would help to answer the question of whether we can harness climate warming and use the feedback mechanisms governing the climate to increase precipitation delivered to the Middle East and Central Asia by the MLW. The knowledge obtained from these analyses could help restore glaciers in the Himalayas despite the current climate warming. We know that over the last 100,000 years, these glaciers expanded most rapidly and became the largest during the first, wettest stage of the Holocene (the Greenlandian stage), when the temperature on Earth rose to values similar to those at the beginning of the current century.

From there, it is a straight way to apply this knowledge in actions aimed at increasing precipitation transported by the MLW in winter. Larger precipitation in the Middle East and Central Asia would recreate conditions similar to the HCO, namely to green the majority of the Northern Hemisphere's deserts. This could be achieved, for example, by weakening the Siberian High by restoration of the Aral Sea, which dried up in the 20th century due to human activity. Restoration of the Aral Sea would probably cost less than today's global one-year spending on renewable energy technologies. It would weaken the Siberian High and increase winter precipitation in middle latitudes in Eurasia.

The proposal to restore the Aral Sea to weaken the Siberian High deserves consideration, especially since during the last decades of the 20th century a gradual weakening of the Siberian High (Panagiotopoulos et al. 2005), followed by its recovery during the first decades of the 21th century (Jeong et al. 2011) was observed. The gradual weakening of the Siberian High at the end of the 20th century can be explained by climate warming, which, among other effects, reduced the extent and duration of snow cover (decreased albedo). The rapid recovery of the Siberian High at the beginning of the 21st century is unfortunately bad news, as it is a symptom of a drop in groundwater level (desertification) in the interior of Asia. This corresponds with other observations, such as the decline in water outflow from Lake Baikal (i.e., a decrease in precipitation in this lake's tributaries) (Sorokovikova et al. 2019) observed in the 21st century and a growing gradient between winter and summer temperatures in Central Asia (Jiang et al. 2017). Both of these phenomena indicate a drop in groundwater levels in vast areas of Asia, which causes a decrease in the heat capacity of this continent (water has a high heat capacity) and leads to greater temperature differences between summer and winter, i.e., to a stronger Siberian High.

The proposal to restore the Aral Sea to weaken the Siberian High and increase the amount of water transported to the Middle East and Central Asia is currently a fiction. Nevertheless, the threat posed by climate warming encourages us to consider every, even the most fantastic actions. Provided they are safe and economically justified. The cheapest and safest way to reduce CO_2 levels in the atmosphere is to use photosynthesizing organisms to absorb CO_2 and transform it into the canopies, trunks and roots of plants, humus of more fertile soils, food for humans and animals, and biofuels. As for plants, it is enough to provide them with water and sunlight, to make them grow and multiply. Especially, because growing concentration of carbon dioxide in the atmosphere increases the intensity of photosynthesis.

Though we have raised the temperature on our planet, we have become increasingly aware of the mechanisms that govern its climate. It is possible that the warming our planet's climate that humanity has unwittingly caused will help to achieve a new climatic optimum.

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Streszczenie

W artykule przedstawiono poglądy na temat przyczyn występowania okresów wilgotnych w czasie plejstoceńskich interglacjałów, ze szczególnym uwzględnieniem obecnego interglacjału, holocenu. Panuje konsensus, że czynniki orbitalne, odpowiedzialne za większe nasłonecznienie półkuli północnej, wzmacniane przez gęstszą szatę roślinną, czyli niższe albedo powierzchni ziemi, są najważniejszym warunkiem wystąpienia zjawiska zielonej Sahary. Jednak we wszystkich symulacjach komputerowych brakuje około 20-50% opadów deszczu, aby to zjawisko mogło wystąpić. Autor wysuwa hipotezę, że warunkiem wystąpienia zielonej Sahary jest uruchomienie dodatnich sprzężeń zwrotnych, w których wzrost wilgotności centrum Azji powoduje osłabienie Wyżu Syberyjskiego, a to z kolei przyczynia się do zwiększenia zimowych opadów niesionych przez zachodnie wiatry średnich szerokości geograficznych (MLW). Wiatry te przynoszą zimą opady śniegu w góry otaczające od zachodu Tybet, co powoduje zwiększenie lodowców w tych górach. Latem nad tymi lodowcami tworzy się komórka powietrza o wysokim ciśnieniu, która osłabia wiatry napędzające indyjski monsun letni (ISM). Autor wprowadza pojęcie oscylacji ISM-bEAM, które oznacza, że osłabienie ISM nasila bEAM i *vice versa*. Z tego powodu większe lodowce w górach wokół Tybetu mogą powodować, że zwiększa się ilość opadów niesionych do Afryki od wschodu, znad Oceanu Indyjskiego. Dodanie tych opadów do opadów niesionych z południa przez monsun afrykański (AM) oraz od zachodu niesionych przez MLW może dostarczać wystarczającej ilości deszczu, aby zjawisko zielonej Sahary mogło wystąpić.

Autor wysuwa hipotezę, że rozpowszechnienie rolnictwa i hodowli zwierząt w neolicie było odpowiedzialne za spadek wód gruntowych na Bliskim Wschodzie, co spowodowało zmniejszenie lodowców wokół Tybetu i przyspieszyło przemianę Sahary w pustynię. Autor przedstawia, jakie

badania należy wykonać, żeby potwierdzić lub odrzucić jego hipotezy.
Autor proponuje, jak można by odtworzyć Optimum Klimatyczne Holocenu i zazielenić większość pustyń półkuli północnej, gdyby jego hipotezy okazały się prawdziwe.

Słowa kluczowe: optimum klimatyczne holocenu, afrykański okres wilgotny, zjawisko zielonej Sahary, globalne ocieplenie, zmiany klimatu, wysychanie Jeziora Aralskiego, odtworzenie Jeziora Aralskiego.

A b s t r a c t

The article presents views on the causes of humid periods during Pleistocene interglacials, with particular emphasis on the current interglacial, the Holocene. There is a consensus that orbital factors, responsible for greater insolation in the Northern Hemisphere, amplified by denser vegetation, i.e., lower albedo of the earth's surface, are the most important condition for the existence of the Green Sahara phenomenon. However, in all computer simulations, about 20-50% of rainfall is missing for this phenomenon to occur. The author puts forward a hypothesis that the condition for the development and occurrence of the Green Sahara is the activation of positive feedbacks, in which the increase in humidity in the center of Asia causes a weakening of the Siberian High, which in turn causes an increase in winter precipitation carried by Middle Latitude Westerlies (MLW). These winds bring snowfall in winter to the mountains surrounding Tibet from the west, which causes the glaciers in these mountains to grow. In summer, a high-pressure air cell is formed over these glaciers, which weakens the winds driving the Indian Summer Monsoon (ISM). The author introduces the concept of ISM-bEAM oscillation, which means that a weakening of the ISM causes a strengthening of the bEAM and vice versa. Because of this oscillation, larger glaciers in the mountains around Tibet may be responsible for stronger precipitation in north-eastern Africa, carried from the Indian Ocean. Adding this precipitation to the precipitation brought from the south by the African Monsoon (AM) and from the west by the MLW, may provide enough rain for the Green Sahara phenomenon to occur.
The author hypothesizes that the spread of agriculture and animal husbandry in the Neolithic was responsible for the drop in groundwater level in the Middle East, which caused the glaciers around Tibet to shrink, accelerating the transformation of the Sahara into a desert. The author presents what research needs to be done to confirm or reject his hypotheses.
The author proposes how the Holocene Climatic Optimum could be recreated and most of the deserts of the Northern Hemisphere greened if his hypotheses were confirmed.

Keywords: Holocene Climatic Optimum, African Humid Period, Green Sahara phenomenon, global warming, climate change, Aral Sea drying, Aral Sea restoration.