

TOWARDS A PHYSICAL INTERPRETATION OF THE END OF THE HOLOCENE MOIST PERIOD IN THE NEAR EAST

With 1 figure

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Zusammenfassung: Zur physikalischen Deutung des Endes der holozänen Feuchtperiode im Nahen Osten

Die offenbar gleichzeitige Aufgabe von Arad und anderen Siedlungen um 4600 v.h. wirft die Frage nach einer möglicherweise klimatischen Ursache – etwa ein drastischer, kurzfristiger Rückgang der Niederschläge – als auslösendes Moment auf. Die Änderung des Jahresgangs der extraterrestrischen Einstrahlung (infolge der Präzession des Perihels) verläuft viel zu langsam. Auch die entsprechende Verschiebung der großen Klimazonen zwischen etwa 5500 und 3500 v.h. liefert keine befriedigende Lösung für ein abruptes, regionales Ereignis. Vergleichende Untersuchungen des Klima-Ablaufs, besonders der detailreichen Gletscherschwankungen in den Alpen und der Geschichte des Toten Meeres, führen zu einer (scheinbaren) Diskrepanz. Tatsächlich treten im letzten Jahrtausend alpine Gletschervorstöße (Kaltphasen) überwiegend gleichzeitig auf mit Tiefständen des Toten Meeres, und umgekehrt. Das braucht nicht nur auf einem (kaum beobachteten) gegenläufigen Verhalten von Sommer- und Winterregen zu beruhen. Untersuchungen über den Zusammenhang zwischen Anomalien der Winterregen in der Süd-Türkei und der großräumigen Höhendruckverteilung erlauben eine sinnvolle Interpretation dieser (zunächst überraschenden) Gleichzeitigkeit.

Palaeoclimatology has reached, within the last 30 years, a much higher level than before: series of cores from the ocean bottom, from large ice-sheets, from bogs and fossil lakes, advanced statistical evaluation of microfossils and pollen have gradually revealed a rather consistent picture of the complex evolution of climate since the peak of the last glaciation, about 18 ka (ka = 1000 years) ago. It is now certain, that – after a long period of ice growth due to the strong evaporation from relatively warm oceans – this peak and the first 4–5 ka after were characterized by a wide-spread aridity which caused e. g. a remarkable shrinkage of tropical rain-forests. This contributed also to the retreat of undernourished ice-sheets and mountain glaciers.

The end of this period, around about 13 ka BP, was distinguished by a rather rapid transition into a warmer phase (in Central Europe the Bölling-Alleröd Interstadial) which led to a rapid expansion of tropical rain-forests, indicating (together with a wealth of other evidence) a simultaneous increase of

water vapour and carbon dioxide spreading from the oceans (SHACKLETON 1977 and many other authors).

The occurrence of an extended moist period, lasting from before 12 ka until 5 ka in the whole arid belt of the Old World and extending from Rajasthan to the African west coast, has now been generally recognized. Convincing evidence had been found by excavations and borings in all parts of this belt, dated by radio-carbon methods – the available evidence soon precluded most uncertainties. Even most of the groundwater now exploited at many places has been formed during this moist period or long before. After many speculations the use of simplified climate models has given a convincing rational interpretation of this moist period. It was based on the long-period variations of the earth's orbit as described by MILANKOVITCH (since 1920) and A. BERGER (see his review paper 1988). Apart from small variations of the obliquity (i. e. the angle between the earth's rotation axis and its orbital plane), the decisive parameter is the precession of the perihelion (the shortest distance between sun and earth along its elliptical path). While the actual seasonal position of the perihelion (January 4) favors insolation of the southern hemisphere during the austral summer, the northern hemisphere receives, at the upper boundary of the atmosphere, during its summer solstice about 7% less solar energy.

11 ka ago the situation was reversed: the northern hemisphere obtained during its summer about 7% more than now. This was essentially effective at the continents, while the northern oceans, with their high seasonal storage capacity, were little affected since they received less radiation during winter. It can easily be understood that the seasonal contrast between continents and oceans had been substantially larger than nowadays, and that the monsoonal circulation had been distinctly intensified. Using models of increasing complexity, KUTZBACH and his collaborators could outline a convincing quantitative model, which proved to be coherent with the geological evidence found at a multitude of fossil and still existing lakes in the whole belt (KUTZBACH a. STREET-PERROTT 1985).

In comparison, the situation for the Americas is slightly different – here the moist period ended

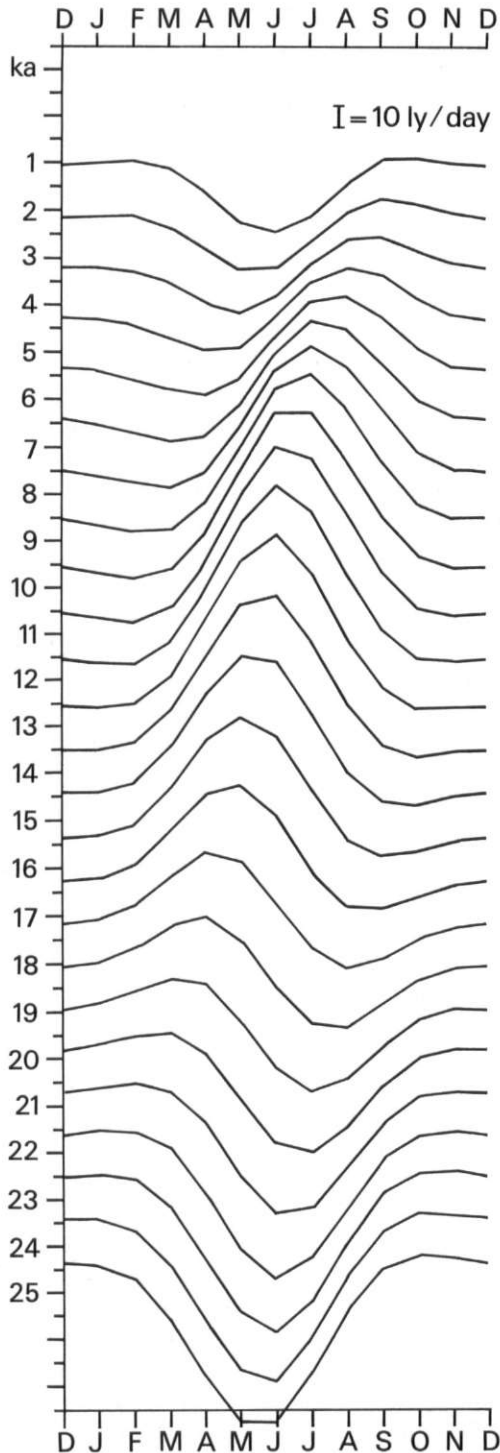


Fig. 1: Annual variation of extraterrestrial radiation at lat. 60°N for each millennium of the last 25 ka
Source: BERGER 1988

Jahresgang der extraterrestrischen Sonneneinstrahlung in 60°N für jedes Jahrtausend ab 25 ka vh.

already about 9 ka, due to different boundary conditions. Here attention shall only be concentrated to the final phase of this evolution: its transition to a quasi-stable climate as dominating the last four millennia. The term "quasi-stable" is used only with hesitation: at least along the margins of the large climatic belts, smaller but still efficient climate changes happened at time-scales of a few centuries or below.

It was the merit of A. BERGER to evaluate the seasonal variations of extraterrestrial solar radiation in a form which could immediately be used in climate models. Here we use his computations of the month-to-month deviations from a reference value separately for each millennium. Fig. 1 gives a small fraction of his diagrams, valid for Lat. 60°N and the last 25 ka. Inspection of the time variations of the insolation for summer (June–August) indicates a most rapid decrease around 6–4 ka BP. This drop was anti-parallel to the most rapid increase around 15–13 ka, initiating the onset of the Bölling warm phase. This astronomical event set the general pace of the transition. At 6000 BP, the orbitally modulated anomaly of the seasonal radiation maximum was delayed to July, and migrated, between 5000 and 4000 BP, to August/September, while the minimum anomaly was displaced to April. These modulations indicate a relative delay of the seasonal march of radiation, together with an effective reduction of its June maximum. At about 4500 BP, this reduction reached 16 Watt/m² or nearly 5% of its (extraterrestrial) value at 11000 BP. Due to the heat storage capacity of the oceans and the high albedo of continental iceshields, the large-scale response of the climatic system to orbitally induced variations usually is delayed by about 3 millennia (BERGER 1988). How could such a slow transition – causing a maximal change of extraterrestrial summer radiation of 0.4 Watt/m² (or about 0.1%) per century – lead to a climatic event felt by the living people (probably) in the life-time of human beings and to such nearly simultaneous changes of socio-cultural patterns as described from Ancient Arad (AMIRAN 1991)?

To solve this enigma we should first look to the contemporaneous climatic changes in other latitudes, e. g. in tropical Africa, in the Arctic, in the Alps, in the USSR, as well as to the Sahara. In the latter the evidence of the end of the moist period (mostly after 5500 BP) is not very well defined – regional differences in this vast area and inaccuracies of the chronology may have contributed to this uncertainty.

In the Tropics (especially Africa in Lat. 9–27°N) the relative number of full lakes decreased, around 4500 BP, from 95% to 35% – here disregarding

minor variations of the water budget and of the chronology (KUTZBACH a. STREET-PERROTT 1985). Model studies (with the NCAR community model) demonstrated between 6000 and 3000 BP, using Milankovitch forcing, a strong decrease of the difference P-E (precipitation-evaporation) from its maximum to a value not significantly deviating from actual values. The peak of the Holocene warming was reached in the Arctic not before about 3800 BP; it ended with a hitherto unexplained cooling which led, in North America, to a cooling of several degrees C and a "Neoglacial", i. e. a readvance of glaciers. Evidence found in the Soviet Union apparently did not coincide with that found in Canada and Alaska. In Siberia, the end of the warmest period (i. e. the transition between Atlanticum and Subboreal I) with an early cooling and an expansion of tundra was dated 4600 BP (KHOTINSKY in VELICHKO 1984). BORZENKOVA a. ZUBAKOV noted warm phases ("thermomers") around 4700 and 4100 BP. In the Canadian Arctic NICHOLS found evidence for the climatic optimum during 6000-5000 BP and - after a limited cooling - a recovery of this warm period (about 3° warmer than now) about 4500 BP (estimated). Simultaneously, evidence exists for the beginning of a partially ice-free Arctic Ocean, with abundant driftwood reaching northern Greenland from Siberia. In Europe, the evolution was more gradual: after the disappearance of the Fennoscandian Ice Sheet (about 8 ka BP) a warm period (Atlanticum) began, favoured by the still existing core of the Laurentide Ice at Labrador/Baffinland, which led to prevailing southwesterlies over Europe and warm air advection.

However, detailed studies in the Alps (GAMPER a. SUTER 1982) and Scandinavia revealed the occurrence of several limited advances and regression of glaciers, apparently all within the limits of the last fluctuation between 1850 (advance) and 1980 (retreat). Such glacier advances, indicating cold intervals lasting 1-3 centuries, happened e. g. around 5200, 4600 BP (Piura-Rotmoos I, II in the Alps), 3300 (Löbben) and 2600 BP (Göschenen I).

Cold phases with advancing glaciers in the Alps are usually considered as correlated with cold upper troughs causing strong rainfall in the western and central Mediterranean. However, this is not valid for the eastern part of the Mediterranean. Recent data revealed a lack of correlations between the Jerusalem rainfall and long records from Malta, Algeria and Gibraltar. These data of interannual fluctuations cannot be extended much beyond about 1850. The excellent Dead Sea record (KLEIN 1986, cf. also KLEIN a. FLOHN 1987) allows a comparison with the proxy

data from the Alps (PFISTER 1984) since 1525 and - to some extent - from western Europe back to the beginning of our millennium (ALEXANDRE 1987, PFISTER 1985). This indicates that most high stands of the Dead Sea coincide with a recession of Alpine glaciers, which generally is related to warm summers with few invasions of polar air masses. Vice-versa the marked period of cold summers in the Alps 1342-1347 (PFISTER 1985) coincided with an unusual deep level in the Dead Sea. Indeed, anomalies of summer weather in Central Europe should have small impact on the winter rains of the eastern Mediterranean. Minima of the Dead Sea level, as indicators for insufficient regional winter rains, occurred around 1650, 1700, 1760, 1820 - this lasting with minor fluctuations until 1880. Of the maxima of the Dead Sea level, only the peak around 1570-80 coincided with a period of marked glacier advances in the Alps. The marked long high stand of the Dead Sea between 1180 and 1320 was synchronous (ALEXANDRE 1987) with a winter climate "moyennement froid", but with a glacier recession in the Alps.

Any conclusion from the teleconnections must take into account several sources of error (chronological uncertainties, local or regional variations). Nevertheless, we note, around the critical date of 4600 BP, the rather abrupt termination of the moist Holocene period in the subtropics together with a marked warming in several regions of the Arctic, especially in the Canadian part. The end of the moist Holocene period in northern Africa should have been accompanied by the end of the occasional rainfall during the summer half-year, reaching the Negev from the south. These large-scale events may have contributed to a rearrangement of the quasi-stationary anomalies in the mid-latitudes, here with a century-long cold trough in the west-central Mediterranean and a transition from a moderately humid phase into an extended period of increased aridity. This rearrangement is apparently related to the beginning of the warmest period of the Holocene, noted in the Arctic as well as in the Alps - the first probably leading to the Holocene minimum of the temperature gradient (Equator-Pole) and thus to the lowest intensity of the atmospheric circulation.

On a monthly time-scale, investigations on synoptic climatology can give a firm basis on such teleconnections which remain, before the time of reliable instrumental observations, at least partly ambiguous and inconclusive. Most conclusive - much more than surface pressure - is a comparison of mid-tropospheric flow patterns (e. g. at the 500 hPa level, equivalent to an altitude of 5-6 km) in months

with very high and those with very low area-averaged rainfall. Such a study is available for the Mediterranean coasts of Turkey (ERDOGMUS 1982) – here the rainfall conditions could deviate, in some secondary points, from those of the northern Negev. In this thesis the author selects 15 (14) months with particularly high (179% of normal) and low (37%) precipitation during the rainy season November–March. Then the average anomaly pattern of the 500 hPa geopotential is given for the two opposite groups. Simultaneously the frequency of negative or positive anomalies have also been mapped, indicating only minor differences from the average anomaly pattern. Strong rainfall is correlated with a marked (cold) trough centered at Long. 20–25°E, reaching southward to Lat. 35°N at least. For strong Negev rainfall, this upper trough should extend farther south, to Lat. 25°N, and its axis should be situated near Long. 30°E. Very low rainfall occurs, when a (warm) anticyclonic ridge occupies the same longitudes (20–30°E), often as an extension of a larger anticyclone spreading diagonally from Spain to the Baltic.

In the first case, the Alps are placed on the anticyclonic rear of the trough, extending over western and central Europe – this indicates the meteorological cause of the coincidence of most Dead Sea maxima with recession phases at the Alps. The second case is not so convincing – typical cases with strong precipitation, especially of snowfall during summer above 2000 m altitude, occur in cases where the trough axis is situated near Long. 5–10°E. During the cool season, this situation may lead – with a very broad trough – to a sequence of cyclones travelling eastward all along the Mediterranean, it may also be well correlated with an anticyclonic ridge in its eastern part and dry conditions over Israel together with southern Turkey. Most probably, these (partly bimodal) meteorological conditions provide the key for our understanding of the climatic teleconnections between the Alps and the Negev. We may conclude that the occurrence of a marked cold period in the Alps, with advancing glaciers, may well coincide with a rather abrupt transition from moderately humid conditions to a severe and wide-spread aridity in the Near East, which excluded rain-fed subsistence agriculture and forced emigration.

One of the most interesting issues of climatic fluctuations is the question of their time-scale. Recently, DANSGAARD et al. (1989) have presented convincing evidence that the transition between Younger Dryas cold period and Preboreal did not take, in southern Greenland, more time than 50 resp. 20 years, based

on annual layering of the ice-core. Many examples have been discussed in BERGER a. LABEYRIE (1985), together with recently observed regional discontinuities (FLOHN 1986) occurring at a time-scale near one year.

The mere facts of abandonment of apparently flourishing settlements without signs of war or epidemics suggest the possibility of abrupt events. Up to now no clear sign of an abrupt termination of the Holocene moist period has been found – which, however, does not exclude such a case. The immediate trigger could have been a total or nearly total absence of rainfall for several years – a case for which no evidence nor counterevidence exists. One could imagine a rapid drop of ocean temperature in the easternmost extension of the Mediterranean, such as a sudden disappearance of a rather shallow layer of freshened water (above a “halocline”) caused, during the moist Holocene, by the much intensified floods of the Nile river (ROSSIGNOL-STRICK et al. 1982). This could be coupled with a marked decrease of sea surface temperatures and thus a stabilization of the marine boundary layer also during the winter rainy season.

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