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THE CAUSE OF THE HOLOCENE CLIMATE CHANGE

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SUMMARY

The worldwide repeated changes of climate through the whole Quaternary era make it clear that the recent general weather conditions will not last forever, but will be substituted by a severe Glacial stage, similar to those recorded in the close geological past. It is highly important for humanity to know, at what time the climate deterioration is to be expected, which processes are ruling it and how to fight the incoming cooling trend.

The first results of a new method are described, based on the calculation of the main part of the past earth's heat budget. The heat reaction of the snowline is detected as being the principal key controlling the global climate change and as strongly amplifying any slight thermal impulse of interplanetary or terrestrial origin. The perturbations of the earth's orbital elements are found to be responsible for the general long-time climatic changes including the start and the end of the Holocene interglacial. The convincing proof for this statement lies in the isotope-dated geological evidence of the past 250,000 years. We are now able to date astronomically the various gross past climatic trends with a relatively high accuracy.

The short-range oscillations of climate observed during Holocene, may partly reflect the short-time movements of earth's rotational axis and/or the changes of the solar constant, both up to now very poorly investigated. Strong suspection, however, exists that the Little Ice Ages of the Late Holocene and the global warming which started at around A.D. 1890 are both the results of mans activity.

Further investigation in this branch is urgently needed, because the pronounced weather deterioration is expected to come in the close future.

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1. THE SEDIMENTARY CYCLE OF THE LOESS SERIES

When a comparative study of the numerous loess sections in the periglacial zone of Central Europe is made, mainly in the neighbourhood of Prague and Brno, Czechoslovakia, the surprisingly close correspondence of sedimentation sequences of clearly different ages is commonly observed. This observation has led to the definition of sedimentary cycles of first and second orders (K u k l a 1961), and a regional stratigraphical system, based on the cyclical division, is being used now in Czechoslovakia (K u k l a and L o ž e k 1961, K u k l a 1968, 1969). Figure 1 demonstrates the extent of the resemblance of the soils and sediment sequences of the last three first order "Glacial cycles". Each of them starts with a highly developed forest soil of the lessivé type, accompanied by rich molluscan faunas of mixed broadleaf forests pointing to highly maritime climates, warmer and wetter than that of the Holocene (L o ž e k 1964). Loess and the hillwash sediments intervene with the soil formation. Marks of gradually increasing continentality and temperature fall become more and more frequent in each one of the numerous subsequent oscillations, until at the end of the cycle the mightiest loess package is deposited enclosing arctic gley soils and assemblages of cold-resistant Columella malacofaunas. Two decalcified brown-earths provide the basis for the further subdivision of each "Glacial cycle" into three cycles of the secondary order, so-called "Stadial cycles".

According to the thicknesses of the corresponding soils and sediments in a similar morphological position, the timespan necessary for the completion of each Glacial cycle has been estimated to be roughly the same.

As for the youngest cycle, the available C^{14} dates demonstrate that it started much before 52,000 years B.P. and ended close to 10,500 years B.P. (K l í m a et al. 1962), thus showing its duration to be greater than 40 thousand years. Pedogenetical and paleontological evidence supported by analogy with Holocene suggests the contemporaneity of the basal brownearth of stadial cycle B2 and the basal parabrownearth of glacial cycle B with the high sea stands of 80,000 y.B.P. (Ouljian) and 120,000 y.B.P. (the Eem interglacial maximum), which have been dated by uranium-decay series in Northern Africa, in Bahamas and the Pacific. (S t e a r n s and T h u r b e r 1965, B a r n e s et al. 1956, B r o e c k e r and T h u r b e r, 1965). The youngest glacial cycle should have lasted approximately 115,000 years (i.e. the time-span between the Eemian optimum at 120,000 B.P. and the Holocene optimum, at roughly 5,000 B.P.).

In the Cervenú kopec loess deposit, where sediments of nine complete glacial cycles B to J rest one upon another in an uninterrupted telescopic superposition (K u k l a 1961a, K u k l a and L o ž e k 1961, K u k l a 1969), the last reversal of the geomagnetic field, marking the boundary of Brunhes and Matuyama paleomagnetic epochs, has been found inside cycle I, leaving seven complete glacial cycles as corresponding to the Brunhes Epoch (B u c h a et al. 1969). Because the Brunhes-Matuyama boundary by numerous K/Ar^{40} measurements in volcanics is fixed to lie between 700,000 and 1,000,000 years B.P. (D o u g a l l and C h a m a l a u n 1966, C o x, D o e l l and D a l r y m p l e 1965, and others), it is highly probable that each of the last seven glacial cycles has more or less the same duration of roughly 115,000 years. (Seven times 115,000 equals 805,000 years; together with the Holocene and the normally magnetized section of cycle I, the Brunhes/Matuyama boundary at Cervený kopec would be approximately 900,000 years old.)

Summarizing the available evidence, obtained in the continuous loess series in the periglacial zone of

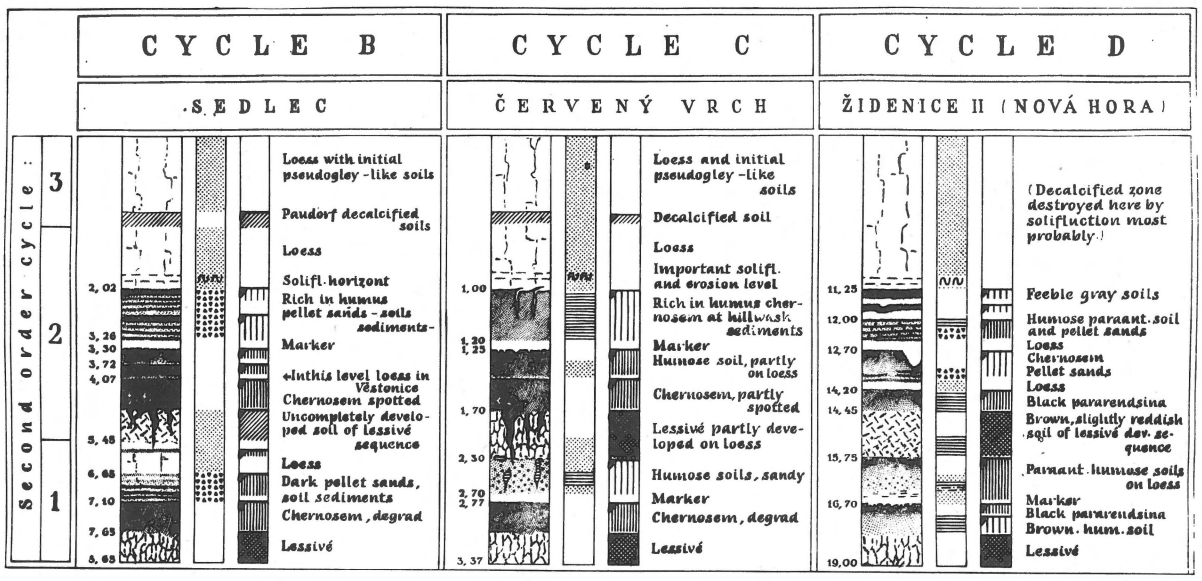


Fig. 1

Sedimentary cycles in the loesses of Central Europe.
Comparison of the observed sequences of three different glacial cycles, namely B, C, and D. To enable the comparison, the real thickness of the particular layers is not respected, but the absolute depth below surface is indicated by the figure given on the left side of each profile. Close repetition of sediments and soils of varied kind is striking. (After Kukla, 1961).

Central Europe, and covering the last 1 million years of the earth's history, the following facts seem to be most important for the understanding of the past climatic changes:

1. The climatic oscillations are as frequent in the oldest sediments studied as they were in the well-known past 30,000 years.

2. The change of climate was strictly periodical and the first order cycle covering one full glacial with one full interglacial seems to have been roughly of the same duration of 115,000 years through the whole period studied.

2. THE SEDIMENTARY CYCLE IN THE DEEP SEA SEDIMENTS

If the loess series in the periglacial zones provide the full record of climatic oscillations on the continents, the deep sea cores of Globigerina ooze are of the same significance in the seas. In fact, up to now, no other continuous stratigraphical system of the Quaternary has been discovered on earth, except the two mentioned above. The same principles as those observed in the loess sections should also hold for the deep sea sediments.

The evidence of climatic changes is obtained in the deep sea cores by three different methods, namely by measuring the O^{16}/O^{18} ratio in the calcareous skeletus of selected foraminiferal species (Emiliani 1955 etc.), by studying the changes in the relation of carbonate to other compounds in the ooze (Arrhenius 1952, Emiliani 1955, Olausson 1965 etc.), or by following the relative abundance of distinct foraminiferal species with known climatic requirements (Ericson et al. 1961). The results of the first two methods are in general agreement, showing both a relatively high number of oscillations in the sections, where the last method indicates presumably only few changes in temperature.

There is no absolute agreement as to the climatological significance of the O^{16}/O^{18} isotopic change, because this depends not only on temperature but also on the salinity of the sea water in the lifetime of the foraminifera. Whereas Emiliani and many others attribute the change to temperature variation only, considering the mixing of the oceans to be speedy and effective enough, does Olausson (1965) believe that after the rapid glacier melting the change of salinity of the surface waters alone produced all the observed isotopic changes. The compromise between the two opposite opinions is probably correct; anyhow the close connection of isotopic change with climatic oscillations remains valid in both explanations. The melting of glaciers must have been produced by global warming and vice versa, and the temperature rise must have influenced the sea surface temperature, too.

The recently published general sea-temperature curve of Emiliani (1968), obtained as the result of the investigation of numerous cores, clearly shows in its youngest part a repetition in two sections (stages 2-5 and stages 6 and 7). Each of them includes the same number of minor oscillations and shows the general gradual lowering of temperature from its start to its end. (Figure 2.) Their close resemblance to the loess sections in Central Europe is obvious. However, the time-scale of Emiliani is different from that resulting from the analysis of the loess section. Emiliani supposes that the sections of his stages 2 to 5 and 6 to 7 both covering the whole glacial-interglacial range, are not of the same length. Section 6 and 7 would have covered some 20,000 years less than section 2-5, and consequently, the glacial-interglacial cycle would have been regular only in temperature amplitude but not in time.

The time scale of Emiliani is based partly on C^{14}, partly on Th^{230}/Pa^{231} isotopic analyses (Rosholt et al. 1961). C^{14} dates reach back to about 30,000 years B.P. and are in good agreement with the dated evidence of climate changes over the continents. The Th^{230}/Pa^{231} analyses indicate a time-span back to about 170,000 years but they are completely in contradiction to the high stands as dated by the uranium-decay series (Kukla 1968). As Kukla (1969) demonstrates, the Th/Pa dates from the deep sea cores must have been influenced by a systematical error, probably due to the vertical migration of thorium. If they were correct, no compression of sediment with time could have occurred and, moreover, the past sedimentation rates must have been substantially higher than during the last 70,000 years, which is not possible. The time scales of Emiliani (1968) and Rosholt et al. (1961) for deep sea cores are systematically shortening towards the past, relative to the real time.

Summarizing the actual state of knowledge on deep sea cores the following observations are closely related to the global climate change mechanism:

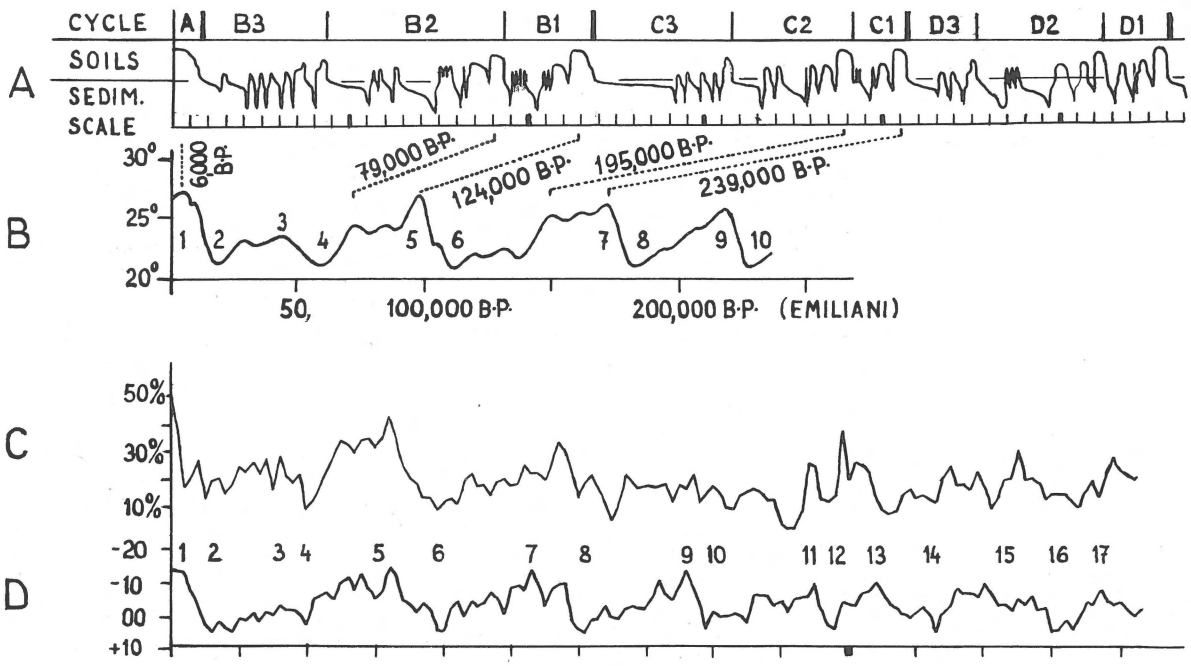


Fig. 2

The periodicity observed in the deep sea cores.
B: One of the latest interpretations of the O^{16}/O^{18} ratio measurements, carried out on the foraminifera extracted from deep-sea sediments. The generalized paleotemperature curve for surface waters of the Caribbean-equatorial Atlantic region, referred to an absolute time scale based in part on C^{14}, in part on Pa^{231}/Th^{230} measurements. (After Emiliani, 1968). The division of 2 to 5 seems to register the same number of minor temperature cycles as the following division 6 to 7. Tentative correlation with the loess-section curve (Kukla, 1968) is given. This curve shows the observed thickness in meters of sediments and soils from the best developed type localities in the Prague and Brno areas. (Curve A; "x" ordinate). The "y" ordinate represents the types of soils or sediments arranged in the order, in which they are supposed to succeed each other as the climate changes from cold (base), to warm (top). The highest stage of soil development is represented by lessivé or para-brown-earth, correlative with the peaks in sea surface temperatures and with the high sea stands. Absolute dating of soils, as indicated in the space between the curves A and B, is based on the past heat budget computations.
Curve C indicates the percentage of the fraction larger than 62 microns (mostly foraminifera) in deep sea core P 6304-9, with one of the most complete known records of young and middle Pleistocene climate change. Curve D gives the O^{16}/O^{18} ratio from the same core, in the pelagic foraminiferal species Globigerinoides saculifera (deviation in ‰ with respect to the Chicago standard PDB-1). In the upper ten meters of the core four sections can be clearly seen, each of them starting with generally low temperatures and ending with the highest recorded temperature levels (stages 5, 7, 9, 11). The thickness of sediment, corresponding to each particular section, is smaller when the section is older. Two explanations are possible: The older sections were shorter in time (Emiliani), or they correspond to a more or less equal time span, but underwent compactation (Kukla, 1969).

1. The oscillations in O^{16}/O^{18} ratio which reflect global temperature changes and/or changes in water volume bound to glaciers, are very frequent in both, the younger and the older parts of studied sections.

2. The range of the temperature changes remains almost constant.

3. At least two repeting glacial cycles with the same number of minor temperature oscillations are clearly registered, with temperature (and/or glaciers volume in reverse function) gradually decreasing towards the end of each cycle. Each cycle lasts longer than 50,000 years; the exact length is unknown, the available Pa/Th dates being incompatible with the U-decay data and thus not acceptable. The equal duration of about 115,000 years is highly-probable for the two cycles. This presumption is supported by a number of uranium-dated high sea stands from between 75-80 and 120,000 years B.P. and next between 190 and 230,000 years B.P., which must have been synchronous with the peaks in the sea surface temperatures (K u k l a 1968).

3. THE CYCLICAL PATTERN OF THE INSOLATION CHANGES

Milankovich (1920, 1941) continuing the previous work of others (Croll, Mishkovich, Spitaler, and others) calculated for the past 600,000 years the volumes of solar energy reaching the atmosphere over distinct latitudes, separately for the summer and winter seasons. His figures show a variation in time, which reflects the changes of three principal elements of the earth's orbit in respect to the sun. They are: eccentricity of the earth's orbit, the obliquity of the ecliptic, and the precession of the equinoxes. The variation of these elements is calculated using rules of celestial mechanics. However, it must be noted that the model as assumed by Milankovich is slightly simplified and does not recognize the varying weight distribution in the earth-moon rotational system. Thus the insolation change as given by Milankovich is likely to be correct only in smoothed general long-time amplitude but not in short time detail. Our figure 3 illustrates the principal elements involved in the Milankovich theory.

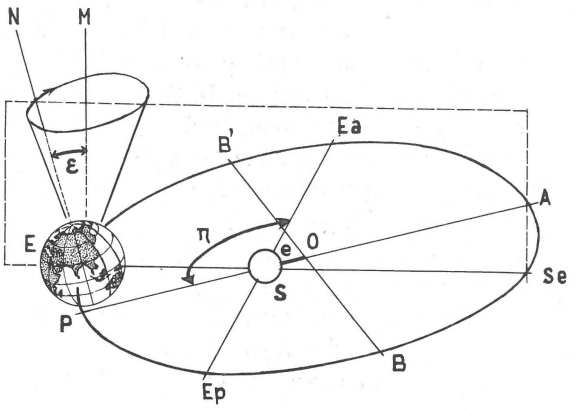


Fig. 3

Principal elements of the earth's orbit, influencing the varying distribution of incoming solar radiation in the past. The earth *(E)* describes around the sun *(S)* an elliptical orbit *P, B, A, B'*. *P* is the Perihelion, *A* is the Aphelion, *O* is the center of the ellipse. *P O A* is the major axis, B O B' is the minor axis of the ellipse. The *eccentricity (e)* is the ratio of *SO* to *OA;* it varies with time. In our figure the earth is exactly in the winter solstice, in the position when its rotational axis *SN* lies in the plane perpendicular to the plane of the earth's orbit (plane of the ecliptic), and cutting the sun. *SE* in the opposite position of the ecliptic is the summer solstice. Perpendicular to the line of the solstice through *S* in the plane of the ecliptic is the line of equinoxes *Ep, Ea*. Point *Ep* is the spring equinox, *Ea* autumnal. The angle *π (Ea S P)* is called the position or the longitude of the Perihelion.
Angle *E N M* indicates the inclination of the earth's axis to the plane of ecliptic, *E N* being perpendicular to the latter.
The earth's axis is continuously changing its orientation in space, so the angle or the so called *obliquity of the ecliptic* is the other variable in the sun-earth orbital system.
The shift of the earth's axis influences the position of the solstices and equinoxes, this phenomenon sometimes called the *precession of equinoxes,* is measured by the angle *π*; it represents the third variable in the sun-earth orbital system. (Partly after E.A. Bernard, 1967).

The insolation over the given latitude will be influenced by the secular variation of the distinct elements mentioned above in the following way:

1. The eccentricity of the earth's orbit, which varies in a complete cycle roughly every 92,000 years, produces the difference in the ratio between the heat obtained by the planet in summer and in winter time. The difference is greater with increasing eccentricity. The yearly total varies little.

2. The changing obliquity of the ecliptic, i.e. the changing angle of the earth's rotational axis to the plane of the ecliptic, completes its cycle in about 40,000 years. Due to this periodical movement the volume of energy transferred to the earth's lower latitudes changes, compared with the corresponding volumes in the higher latitudes. The yearly totals remain the same.

3. The precession of the equinoxes, caused principally by the gravitational attractions of the sun and the moon, completes its cycle irregularly in about 21,000-22,000 years and influences the length of the seasons and the distribution of the solar radiation obtained by the earth in the different seasons of the year. As a result of this movement, in a given hemisphere the earth gets sometimes more heat in winter and less in summer. The yearly total remains unchanged. Also the seasonal totals for both hemispheres, i.e., for example, the sum of the heat received in winter of the northern hemisphere and that obtained during the contemporary summer in the southern hemisphere, always remains the same. The resulting differences in the seasonal distribution of the obtained heat at any time are greater towards the poles and are practically of no significance in the equatorial belt. (Compare fig. 4).

4. Kukla (1968) pointed out that the time separating the minima of the so-called G1 and M1, equals that separating R1 and W1. He defined the so-called "normal cycle" in the seasonal insolation change, which is approximately 117,000 years long. Two normal cycles are always followed by "Long

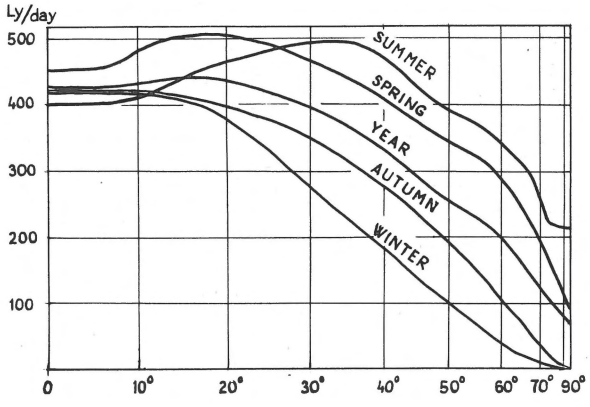


Fig. 4

Seasonal variation of effective incoming radiation in the northern hemisphere in the different seasons at distinct latitudes. *Su*-summer with June, July, August; *Sp*-spring with March, April and May; *Aut.*-autumn with September, October, November and the winter with December, January and February. (After H. Flohn, 1967).

cycle" of 125,000-126,000 years of duration, so that the period of all three cycles comes to its repetition in about 360,000 years (Fig. 5). The described periodicity is observable at least through the last 1 million of years covered by Milankovich's calculations. It is recognizable, too, in the younger part of the insolation curve by van Woerkom (1953), which is based upon slightly different presumptions on the sun-earth-moon system as used by Milankovich. The long periodicity described above is due to the interference of the earth's axis precession cycle with the eccentricity of the orbit cycle and is reflected in periods of extreme differences in seasonal insolation alternating with periods of much less expressed differences.

The important principle should always be borne in mind, when dealing with the mechanism of insolation change according to Milankovich: The yearly global totals of the solar energy reaching the upper part of the atmosphere remain practically constant, but its seasonal and latitudinal distribution varies.

Other extraterrestrial variables, which may have some relation to climate forming, are the changes in solar constant and in sunspot numbers.

Indirect measurements suggest that the solar constant may have varied in about 11 years in the order of 1% (Serkowski 1961). The variation followed the 11-years long sunspot cycle. It is possible that the solar constant may also vary over longer periods of time comparable to the duration of glacial/interglacial cycle, and that it may have lowered by about 10% during the past few millions of years, but there is not a single proof available for such a hypothesis (Mitchell 1965). Quite a number of authors tried to find an interrelationship between climatic trends and changing solar activity, as registered by sunspot numbers. A relatively reliable record of the sunspot numbers has existed since about 1750 and this has been extrapolated until 650 B.C. by Schove (1955), using auroral and other indirect historically recorded evidence. No change of solar constant was confirmed relative to the sunspot activity. The influence of the sunspots on the atmosphere's thermal transparency is highly probable. The 11-year cycle and the longer 80 to 90 year-cycle in sunspot numbers are evident. A 205 year-cycle and a longer cycle of about 400 years were suggested by Schove (1955) and Link, (1964), but no reliable evidence is available. When summarizing the facts related to the periodicities in the earth-sun orbital system the following points must be stressed:

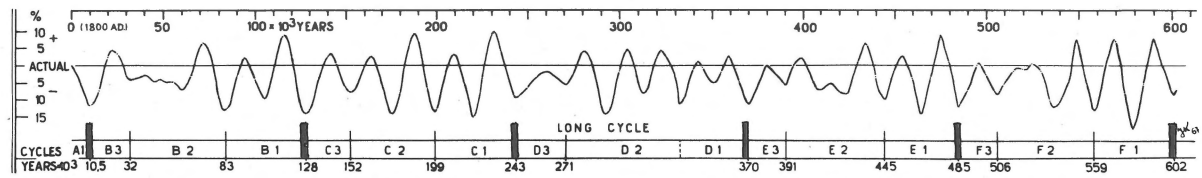


Fig. 5

General curve of winter half-year insolation for 55°N latitude based on Milankovichs' computations (1941), showing the presumed parallel with loess cycles.

The curve of the seasonal variation clearly demonstrates a period of roughly 117,000 years, starting with a high amplitude of the wave and ending with low amplitudes. Due to the interference of the more or less regular cycle of the obliquity of the ecliptic with the 40,000 years interval, each third period of seasonal insolation change is 10,000 years longer, lasting 125-127 millenia (Long Glacial Cycle). (After J. Kukla 1968).

1. The duration of the last generally cold spell of the Weichselian/Wisconsin glacial (from 22,000 till 10,000 B.P.) added to the generally warm Holocene, both well dated by C^{14} analyses, is equal to the length of the earth's axis precession cycle.

2. The 40,000 years difference between the U-dated high sea stands of Ouljian and Harounian closely resembles the duration of the cycles in the obliquity of the ecliptic. Periodicity of the same length is supposed to be registered in the carbonate frequency in the deep sea sediments (E m i l i a n i and G e i s s 1959).

3. The timespan corresponding to the full glacial/interglacial cycle, directly measured by U-decay series on the sea terraces (Eemian-Holstein) is 115,000 years. This figure is practically identical with the 117,000 years mean duration of the "normal glacial cycle", which controls the changing amplitude in the seasonal distribution of the solar incoming energy.

4. Strong climatic oscillations and fluctuations appeared in Main Wisconsin, Late Glacial and Holocene with much shorter periodicity than the one involved in the Croll-Milankovich mechanism.

4. THE EXISTING CHRONO-STRATIGRAPHICAL APPLICATIONS OF ASTRONOMICAL PERIODICITIES

Milankovich himself recognized that the climate response to the insolation change, if any, may be caused only by the different thermal reaction of continents and the seas, the continents being capable to bear glaciers, which for the sea is excluded. The northern hemisphere has about 50% of its surface in the middle latitudes covered by continents. while the southern hemisphere only 1%. Middle latitudes 40-60° are believed to be most sensitive to all kinds of impulses influencing glaciations. Therefore the curve of the summer insolation change over the 65°

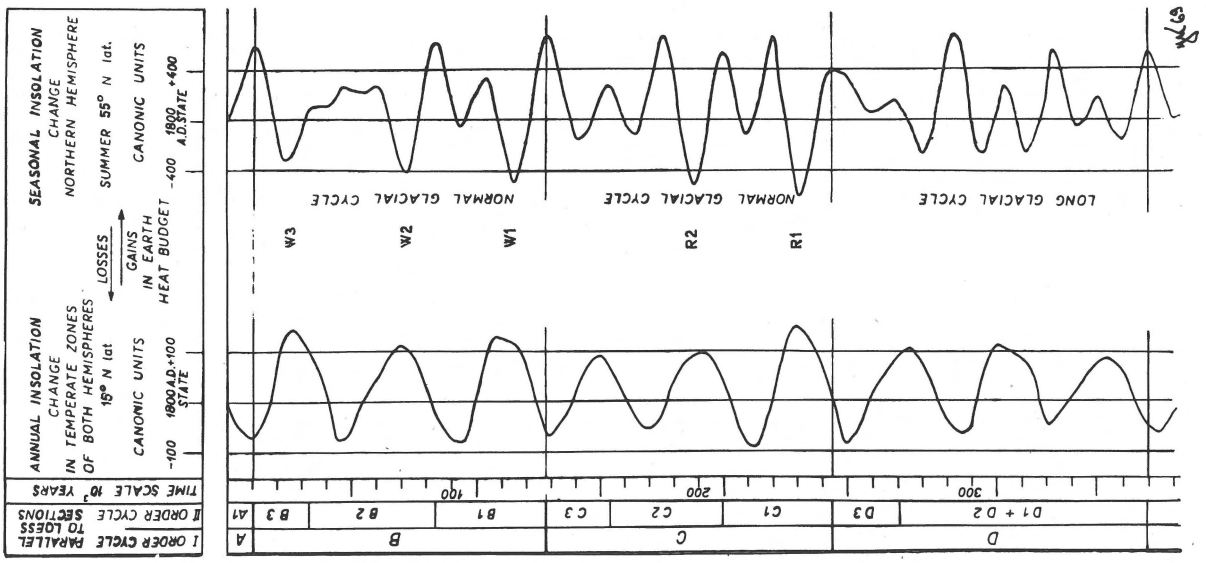


Fig. 6

Changes in insolation as calculated by Milankovich (1941), and compared with the cyclic division of loess sections.
The first curve indicates the deflections from the A.D. 1800 state in the yearly totals of insolation reaching the upper levels of atmosphere over the temperate latitudes of both hemispheres. The variation range is about 200 Canonic units or 2000 Ly/20,000 years, that means about *0.1 Ly/year.*
The losses are compensated by increased radiation at higher latitudes, but because of the highly reflecting snow, ice and cloud covers there, the compensation is never complete.
The second curve indicates the seasonal changes in insolation over the middle latitudes of the northern hemisphere in summer. The range is up to 1200 Can.Un./11,000 years, i.e. 1.1 Ly/year.
A very similar curve (corresponding to the 65°N) was the basis of numerous climatological applications of Milankovich's theory. The low summer insolation levels were erroneously supposed to iniciate the glaciations (compare R1, R2, W1, W2 and W3). However not the seasonal insolation change in summer but that in winter creates the so called heat reaction of the snow line (see text) and this in turn controls the global climate changes. (After J. Kukla, 1968a).

northern latitude has been constructed by Milankovich (in K ö p p e n-W e g e n e r 1924) and presented as directly responsible for the glaciations and deglaciations (compare Fig. 6!). The summer half year has been believed to be much more important than the winter (with opposite trends), because the incoming heat in summer is about 2 to 3 times higher than in winter and because the mountain glacier ablation has a direct response to the summer temperatures (see Fig. 4).

Soon after being published, the Milankovich curve was favoured greatly by Quaternary geologists, because it explained both: the periodical repetition of glaciations and a number of observed oscillations of lower rank, the principal features of the geological evidence almost everywhere. The insolation minima at 72,000 y.B.P. and 116,000 B.P. were considered correlative to the W1 and W2 cold stadials registered, as S o e r g e l (1937) believed, in the river terraces of Ulm and Unstruht. Similar deep minima of 188,000 B.P. and 232,000 B.P. were considered as corresponding to R2 and R1, respectively, and the still earlier minima of M2 and M1 and of G2 and G1 were distinguished.[2]) The time separating both minima in the corresponding twins of W, R, M, and G was 40 to 45,000 years, in clear relation to the effects of the obliquity of the ecliptic cycle.

Because the summer insolation trend is quite contradictory to the development of world climate in the Holocene and in the ultimate, relatively well-known section of the Pleistocene, the theory of the long retardation in the climate response to the insolation change has been developed (among many others W u n d t 1960, Z a u n e r 1959, F a i r b r i d g e 1961). But as B r o e c k e r (1965) remarked, no reasonable response time could explain the Main Würm cold trend, evidenced in deep sea cores as lasting from about 60,000 B.P. to 30,000 B.P. Another serious problem is connected with this theory: the insolation change is so small and slow that the autovariation processes, related to the evidenced quick oscillatory movements of continental ice sheets must very likely have compensated the solar radiation influence (Ö p i k 1953). B a c s á k (1955) developed the concept of four solar climatic types, caused by interference of the variables involved in the theory of Milankovich. His chronology is purely hypothetical and from about 20,000 years B.P. back to the past it is inconsistent with the geological evidence dated by isotopes. D o n n (1951) suggested the importance of the higher heat losses, caused by the higher reflection of atmosphere and the seas, when the radiation meets the earth under a low angle, which is the case in the polar regions. Of special importance in this context is the 41,000-year cycle, the periodicity of which is indicated by carbonate deposition cycles in many deep sea cores (E m i l i a n i and G e i s s 1959).

The strictly periodical change in the climate-indicating elements over the continents and in the oceans reveals without any doubt that the cause of glaciations and deglaciations is extraterrestrial. This is also the result of M i t c h e l l's (1965) review on the existing theories explaining the glaciations, including the air-sea-icecaps interaction processes, glaciers autovariation processes, volcanic ash explosions, carbon-dioxide content fluctuations in atmosphere, ozone amount variation in troposphere, ocean current changes, sunspot acitivity and the fluctuation in the earth's orbital elements as calculated by Croll and Milankovich. Mitchell concludes, that the Croll-Milankovich mechanism of varying insolation is, most likely, principally responsible for the gross climate changes, although the processes, by which the insolation should govern the climate, remain unclear. Some 25 years ago the chronology of the ice ages, based on Milankovich's astronomical calculations, was commonly accepted. Today, however, now that a number of isotope time measurements are available from the Pleistocene, only few authors believe that the calculated insolation change can be adequately used for dating.

Summarizing the present opinions on the effect of insolation change on the climate, the following points may be stressed:

1. The gross periodicity found in the perturbation mechanism of earth's orbital elements matches roughly in its duration the phase of the glacial-interglacial cycle, as fixed by the last isotope datings. Therefore the causal relationship between them seems to be highly probable.

2. The theories dealing with the mechanism through which the insolation should control the climate, remain, however, in the sphere of subjective poorly grounded hypotheses and in detail they are always in conflict with the dated geological evidence.

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[2]) The time scale is not exactly in B.P. because Milankovich reference point is A.D. 1800.)

The principal cause of the gross Quaternary climatic change remains unclear.

5. THE HOLOCENE CLIMATE CHANGE RECORD

The Holocene is the relatively best known period of the earth's history. Moreover, in its youngest phase we are able to observe the processes involved in the formation of the climate directly. A number of indicators, such as the historical records on agricultural taxes, irrigation water taxes, varve and tree-ring observation enable us to follow the available trends in world-wide meterology from the last one hundred years, or so, back to the past.

According to the available evidence the climate through the Holocene developed in the following way:

1. Between 11,000 B.P. and 10,000 B.P. the world-wide warming trend, registered by the Flandrian transgression, was globally speeded up, and the continental ice sheets of Eurasia and Northern America started their definite retreat from the middle latitudes. This event has been evidenced by the rapid and substantial change of the floral and faunal assemblages in the continents. Owing to the warming of the surface sea water, the foraminiferal species shifted their habitats some 800 kilometres to the north (Ericson-Wollin 1956, Ericson et al. 1961, Olausson 1961). The mean annual rate of mud-laden water influx to the ocean was about 5×10^{12} metric tons for the period of 10,800 to 9,000 B.P. the lithology of marine sediments commonly changed between 10,000 and 11,000 B.P. (Ericson et al. 1961, Fairbridge et al. 1965, Mörner 1969).

Most workers in Quaternary research take therefore the Holocene/Pleistocene boundary as to be correlated with the event described, which dates between 11 and 10 thousand years B.P. Because the year 10,500 B.P. is one of the peak years in the melting of the continental ice sheet (de Geer 1959), some authors propose this date as the arbitrary start of the Holocene.

2. The long general warming trend lasted till about 4,600 B.P. reaching about 6,000 B.P. the level regarded as the so-called post-glacial climatic optimum. The pollen diagrams from Scandinavia show the gradual replacement of grasses and shrubs of the tundra and steppes by the deciduous forests, which was completed at about 7,500 B.P. (lower boundary of pollen zone VI; Firbas 1949). The eustatic sea level and the continental evidence indicate short negative interruptions of the warming trend at about 8,000 B.P. (Bothnian), 7,600 and 6,800 B.P. Possible cooler oscillations may have occurred at 5,500 and 4,900 B.P. (Fairbridge 1967).

During this time the mean eustatic sea level in the Older Peron Submergence reached 3 meters above its present datum (Fairbridge 1961). The mean temperature in Sweden was determined as being 2.5°C above the present. The Nile was fed by heavy tropical rains, causing much higher floods than the present ones (Fairbridge 1963). Substantial organic productivity occurred in the Arctic ocean, which today is covered by pack ice, and therefore almost sterile.

3. Between approximately 4,600 and 4,000 B.P. cooling was registered in several parts of the world. The sea level should have dropped about 4 meters below the present mean (Bahama Emergence).

4. Between 4,000 and 3,450 B.P. milder conditions returned during the so-called Late Peron Submergence, but nowhere they reached the levels of climatic optimum. The younger Calais beds in Flanders were deposited at that time.

5. Between 3,450 and 2,700 B.P. the cold trend in two subsequent emergencies caused a drop of the sea level by about 4 meters, which was accompanied by the cool continental conditions of the so-called Late Subboreal phase in Scandinavian pollen sequences.

6. Between about 2,700 and 2,100 B.P. during the "Sub-atlantic" Phase or Greek Era, amelioration of the climate was recorded in Scandinavia and Europe, indicating warmer and more maritime climate than before.

7. Between 2,100 and 1,600 B.P., in the Roman Era, cooling is indicated by the worldwide Florida emergence, reaching a level of 2.5 meters below the present, by the evidence of extended glaciers in the Alps, and by a much wetter climate in North Africa and Central Asia, than the present one.

8. Between 1,600 and 750 B.P. (A.D. 350-1200) a general warm trend is registered, reaching its peak in the so-called "Little Climatic Optimum", with corresponding transgressions in the northern and southern hemisphere (Australia, New Zealand, Netherlands). The sea level was about 0.5 meter higher than nowadays, Central Europe was more maritime and

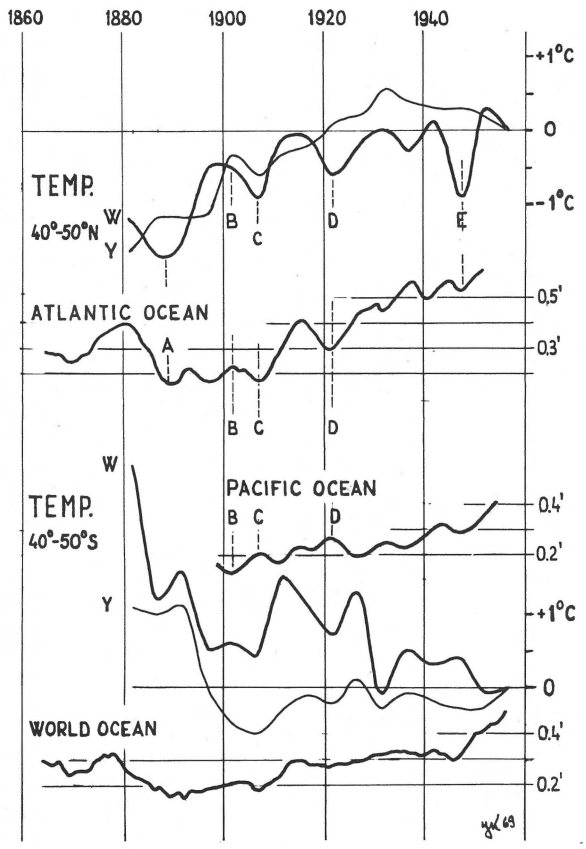


Fig. 7

Sea-level variations, the best indicator of global climate changes, compared with the mean temperatures over the middle latitudes of both hemispheres. The temperature scale is in 1°C the relative sea level variations are indicated in a 0,1 feet scale. The 5-years means of winter temperature over the latitudinal belt between 40-50°N (full line) are closely following the eustatic sea level movements of the Atlantic ocean (5-year means – most stations in the northern hemisphere). Compare points A, B, C, D, E for the coincidence of winter temperature (W) changes with the sea level change. The five year annual temperature means follow the sea level rise only generally.
The temperature trends over the southern hemisphere are in general but not in detail opposite to those of the northern hemisphere. The pacific ocean level shows partly movements opposite to that of the Atlantic, (positions B, C, D), the general rise is similar to that of the Atlantic Ocean. (Temperature change according to data of Willet H.C. (1950) and Mitchell M.J. Jr. (1961), the sea level movement after Fairbridge and Krebs (1962).

warm, Central Asia drier (Caspian Sea level dropped 0.5 m). Close to A.D. 1,000 the summer temperatures in Alaska were 2.5-3°C higher than today. Ellesmere Land in the Arctic was for the first time settled by Eskimos and Greenland by Vikings. The snow line in the Rocky Mountains was situated 300 meters higher than presently (F a i r b r i d g e 1967). The cool oscillation, lasting one century, is dated by the world-wide regressions between 1,250 - 1,150 B.P.

9. Between 750 B.P. and 60 B.P. (A.D. 1200-1890) the general cooling trend is evidenced everywhere. The progressive oscillatory drop of the world mean temperatures was accompanied by the fall of the mean sea level and by the rise of the Caspian Sea (less evaporation). Extremely cold winters were reported from Europe. A mild phase interrupted this trend between 400 and 500 B.P., when extensive coastal flooding was reported from Western Europe and a transgression occurred in New Zealand. The following period from 400 to 60 B.P. is often referred to as the "Little Ice Age", divided in 3 phases, according to S c h o v e (1961). Some North American glaciers reached their temporary maximum stands at about A.D. 1750, while the Caspian sea stood 2.5 m above its present level. The Sahara, the Nile Valley and the American Southwest suffered progressive desiccation during this period (F a i r b r i d g e 1967).

10. Since 70 B.P. (A.D. 1890, should be 1880 by others), a general warming takes place, with consequent sea-level rise of about 1 mm/year, decreasing continentality in Europe and with the rise of mean world temperatures, more especially of mean winter temperatures over the northern hemisphere (compare fig. 7). A cooling trend re-appeared from A.D. 1940.

An important methodological problem arisen when the climate changes are delt with indicated by palynological evidence. Only little agreement exists between the dated floral changes and their supposed relations to climatic trends (F r e n z e l 1967). Until 4,000-3,500 B.P. the Atlantic rich floral assemblages only show slight changes; afterwards a deterioration is recorded almost everywhere, including poorly inhabited countries, such as Northern America and Siberia. At that time in Europe, however, a large artificial deforestation took place; the evaluation of pollen-analytical evidence is therefore difficult and the results questionable. Our record of climate changes is based principally on the eustatic sea level movements, which may be only locally influenced by crustal subsidence, which, if not recognized, may lead to erroneous conclusions.

Thus, at the present state of knowledge, only the

following climate development would be generally acceptable as undoubtful: General warming, which was much faster at the beginning than later, led to a temperate period (Atlantic), lasting from about 6,000 B.P. to at least 5,000 B.P.; than slow cooling started and a general really significant deterioration of climate came during the first millenium B.C. and lasted until about A.D. 1900.

The later part of the Little Ice Age and the ultimate warming trend period are supported by a more or less world-wide network of meterological and oceanographical data. According to the record, from 1880 till 1940 the annual average temperature increased by about 0.6°C and winter temperatures over the northern hemisphere even more (M i t c h e l l 1967). Precipitation decreased in the tropics and along the continental coasts, atmospheric circulation has slightly weakened. The Spitzbergen region warmed up by more than 4°C, principally in winter and many Alpine and subarctic glaciers together with the arctic pack-ice area retreated since 1900 till 1940.

In the period from 1940 to 1960 the global trends of temperature, precipitation and atmospheric circulation show indications of reversal, thus for example NE Canada and NW Siberia cooled by about 2°C, principally in winter with the simultaneous enlargement of the Arctic peak-ice area.

Exceptions from the general trends existed in local areas. Thus from 1940 till 1960 the warming continued in the U.S.A., western Canada, eastern Europe and the Pacific coast of Asia. On the other hand, between 1900 and 1940 cooling tendencies existed in parts of Canada, southern Eurasia, and the continents of the southern hemisphere (information used from Mitchell 1967).

As for the eustatic sea level record, the trend is consistent with the general temperature means, except for the last 20 years, when the sea, according to F a i r b r i d g e and K r e b s (1962) has continued its rise. It has been suggested, however, that the rise after 1940 is valid for the eastern coast of the U.S.A. only, the rest of ocean showing definitely decreased rate of rise since about 1940. Figure 7, based on the data of W i l l e t t (1950), M i t c h e l l (1961), F a i r b r i d g e and K r e b s (1962) shows the changes in 5 year-means of temperature over the selected characteristic latitudes and the corresponding means in eustatic sea levels of the Atlantic and Pacific Oceans and the world mean sea level.

Dealing with the possible cause of the actually recorded climatic variations and fluctuations, the following remark of F a i r b r i d g e (1967) seems to us to be basically important: During the last 6000 years, no major changes occurred in the heights of mountains, the shape of oceans and the oceanic circulation, no important changes in planetary albedo caused by the varying ice sheets extent and no major changes in the volcanic acitivity took place to affect dust production or the CO_2 balance. Yet for the same 6000 years there is evidence that mountain glaciers have periodically grown and shrunk over many kilometers, systematic mean annual temperatures in many northern lands changed over a range of 5°C, some tropical regions became semiarid and returned to jungle. Fairbridge suggests that the role of time in

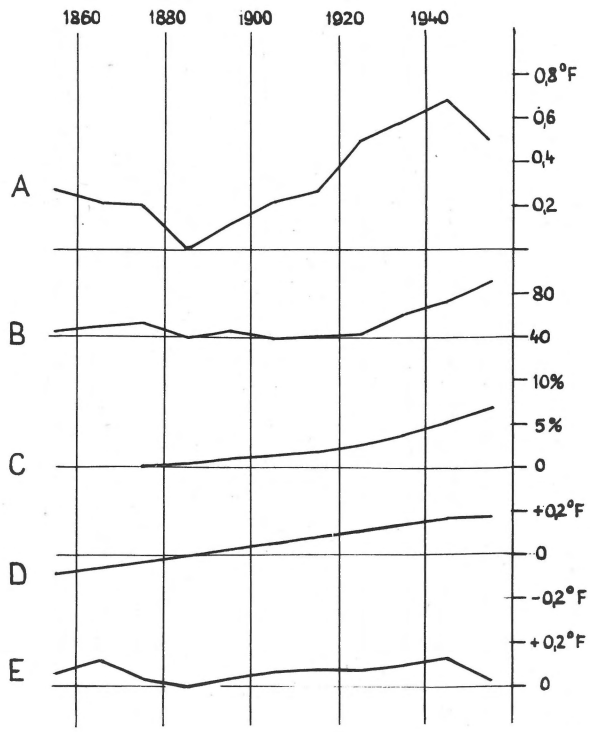


Fig. 8

The temperature rise from 1880 to 1940 (curve A), compared with sunspot activity (curve B), expressed in the Zurich numbers, with the increasing amount of carbon dioxide content (curve C), indicated in percent of deviation from 1870 level, with the influence of urban warming (curve D) and of volcanic activity (curve E), in degrees of Fahrenheit. The last curve is based on the presumption that frequent explosions of volcanic ash would increase the Earth's albedo and cool the globe. All curves are constructed using the decade means. (After J.M. Mitchell, Jr., 1967).

the cumulative buildup of climatic changes has been vastly subestimated by the past investigators, who confused mostly the gross effects of the great ice ages and the relatively small-scale effects of the historical climatic events.

Mitchell (1967) relates the observed mean world temperature trend with the number of sunspots, carbon-dioxide content in the atmosphere (mostly due to artificial fuel combustion), volcanic ash presence in the atmosphere and urban warming (see fig. 8), finding a general agreement with the last warming trend for all of them.

Summarizing the presented mostly direct meteorological and partly indirect historical evidence, we now stress the facts that we consider to be of primary importance for the climate change mechanism:

1. General long lasting recorded trends in temperature and sea level movements are globally consistent. On the contrary, short fluctuations are often contradictory for the southern and northern hemispheres. (Compare eustatic sea level change of the Atlantic Ocean and its prevailing part on the northern hemisphere, with that of the Pacific Ocean – mostly lying on the southern hemisphere.) The northern hemisphere trends seem to overwhelm the other half of the earth and to govern the global tendencies. (compare simultaneous sea level movements recorded in both hemispheres during the MIddle Ages, and the modern data measured, fig. 7.)

2. The mean winter temperature change in the middle latitudes of the northern hemisphere is highly consistent with the global climate trend. This relationship is probably maintained outside the range of the directly measured meteorological data, as is suggested by the medieval record of the extremely hard winters in Europe during the global cool phases. To a lesser extent the same seems to be true for the mean annual temperatures.

3. The ultimate global climate trend since 1850 seems to be consistent with the means of sunspot number changes. The observed relationship, however, cannot be used to explain the climatic oscillations in the Mid-Holocene and in Early Holocene, when according to indirect indications the sunspot number cycles have more or less maintained their recent amplitude.

4. Between A.D. 1880 and 1940 the general world-wide warming trend coincides with the carbon dioxide increase in the atmosphere, with urban warming and with the decrease of volcanic activity. None of these phenomenons, however, can logically explain the climate change before A.D. 1850 on a global scale.

5. Apparently only little change occurred in the extent of the highly reflecting ice sheets during the second half of the Holocene, but substantial changes were recorded in the mean snow line position and in the pack ice extents. Especially in winter the areas covered by both, must have varied greatly.

6. The climate oscillations and fluctuations during the Holocene are of such a short amplitude that they must be either incidental, or caused by other factors than those involved in the Croll-Milankovich hypothesis. The evidence is clearly contradictory with the theory of summer insolation change as governing the climate with thousands of years of retardation.

6. THE CONCEPT OF THE ENERGY BUDGET OF THE EARTH

The total energy used or converted in the Earth's atmosphere is, directly or indirectly, of solar origin. The incoming solar radiation meeting the top of the atmosphere is accepted to be 2.00 ± 0.04 gcal/cm^2/min (or expressed in another way, Ly/min). This value refers to the average radius of the earth's orbit and a plane perpendicular to the radiation. It varies only little with time, but strong variations are present in the ultraviolet end of the spectrum. The largest portion of the energy is provided in the visible and the near-infrared part of the spectrum, with a maximum close to 0.45 microns. The annual average of the incoming solar radiation received at the top of the atmosphere is 720 Ly/day.

Figure 9 from Mitchell (1965) shows the mean distribution of the incoming energy in the atmosphere and on the firm terrestrial surface. The diagram is based mostly on measurements and estimates valid for the northern hemisphere made by Budyko and Kondratiev (1964) and London (1957). The difference between the two hemispheres is negligible for the problem concerned. As may be seen in the sketch, not all the incoming solar energy reaches the earth's surface. Approximately 35% is reflected back into space, representing the so-called mean planetary albedo. Of this amount 24% are scattered back by clouds, 7% by air dust and haze and 4% by the surface of oceans and continents.

Out of the 65% of net obtained radiation about 47% is absorbed by the hydro- and lithosphere and the rest by the atmosphere, including clouds. The radiation obtained is returned into space by the long-wave re-radiation, thus balancing the budget.

The seasonal change in the mean heat budget of the northern hemisphere, as illustrated in the data of Budyko and Kondratiev (1964) is as follows:

Mean incoming solar radiation in:

	Winter (3 month)		Summer (3 month)		Year	
	Ly/min	%	Ly/min	%	Ly/min	%
Insolation at upper level of atmosphere	0,348	100	0,645	100	0,500	100
Absorption in the atmosphere, total	0,060	17	0,122	19	0,087	17,5
Absorption by hydrosphere and lithosphere	0,173	49,5	0,289	44,7	0,237	47,5
Reflection by clouds	0,078	22,4	0,162	25,1	0,121	24,2
Reflection by atmosphere excluding clouds	0,023	6,6	0,048	7,4	0,034	6,8
Reflection by the surface	0,015	4,3	0,024	3,7	0,021	4,2
Total reflection	0,116	33,3	0,234	36,2	0,176	35,2

As may be seen in the table, the heat losses caused by reflection are the only variables in the energy balance of the earth, considering that the long-wave heat re-radiation back to space works with relatively long delay. (The atmosphere in this sense is often compared to a thermal blanket.)

The reflection or albedo includes the part reflected by the atmosphere with clouds and that reflected by land and water surfaces.

The reflection power or albedo of the clouds is highly variable, due to their uneven thickness and transparency: According to diverse, mostly aircraft measurements (Averkijev 1951, Robinson 1958, Johnson 1954) typical values are:

	% reflection
Dense clouds (cumulus, stratocumulus)	55 – 80
Dense clouds (altostratus)	40 – 60
Thin clouds (cirrus)	35 – 40
Global mean for clouds	65

The relatively high albedo of the clouds, causing a deficit in the heat balance through the reflection of direct radiation back into space is to a high degree compensated by the other important characteristics: the isolating power of the clouds which substantially increases the so-called "greenhouse effect" of the atmosphere. The lesser amount of heat obtained in the daytime by the earth's surface under the cloudy sky will be largely counterbalanced by much lower losses of the accumulated heat during the night by long wave re-radiation.

According to diverse, mostly aircraft measurements (Averkijev 1951, Fritz 1948, Johnson 1954, Robinson 1958, Untersteiner 1967) the hydrosphere and lithosphere surfaces demonstrate the following characteristic albedo values:

	% reflection
Deep calm water (sea)	2 – 5
Water, rough surfaces	up to 50
Shallow water, such as bays, lakes, rivers	5 – 10
Dense forest	5 – 10
Dark soil surfaces, uncovered	5 – 15
Grass-covered surfaces, wet, green	10 – 15
Grass-covered surfaces, dry, yellow	15 – 25
Fields in summer, on the average	15 – 20
Sandy desert, light coloured rocks	30 – 35
Fresh snow, newly laid	75 – 85
Snow, moist, dirty, melting	40 – 60
Ice sheet, fresh surface, bare	about 60
Ice, melting, dirty	about 40
Pack ice, bare and puddles, in summer	about 50
Pack ice, snow covered, in winter	80 – 85

On the surface of the earth two different groups of albedo values may be distinguished: The first group includes snow, pack-ice and ice sheets in winter. Its corresponding albedo varies between 70 and 90%.

The second group includes the sea surfaces under normal conditions, lakes, rivers, vegetation-covered or bare soil, and sandy or rocky surfaces of the continents. Their albedo varies between 3 – 30%, with an average close to 10 or 20%.

7. THE HISTORICAL EARTH's ENERGY BALANCE CONCEPT

The direct relationship of the terrestrial heat budget to the global climate is beyond any doubt. The atmospheric circulation, controlling directly the momentaneous weather conditions in any given point of the earth, is kept going only by the obtained solar energy directly or indirectly transmitted. Therefore it may be attractive to compare changes in the terrestrial heat budget with the known trends in the

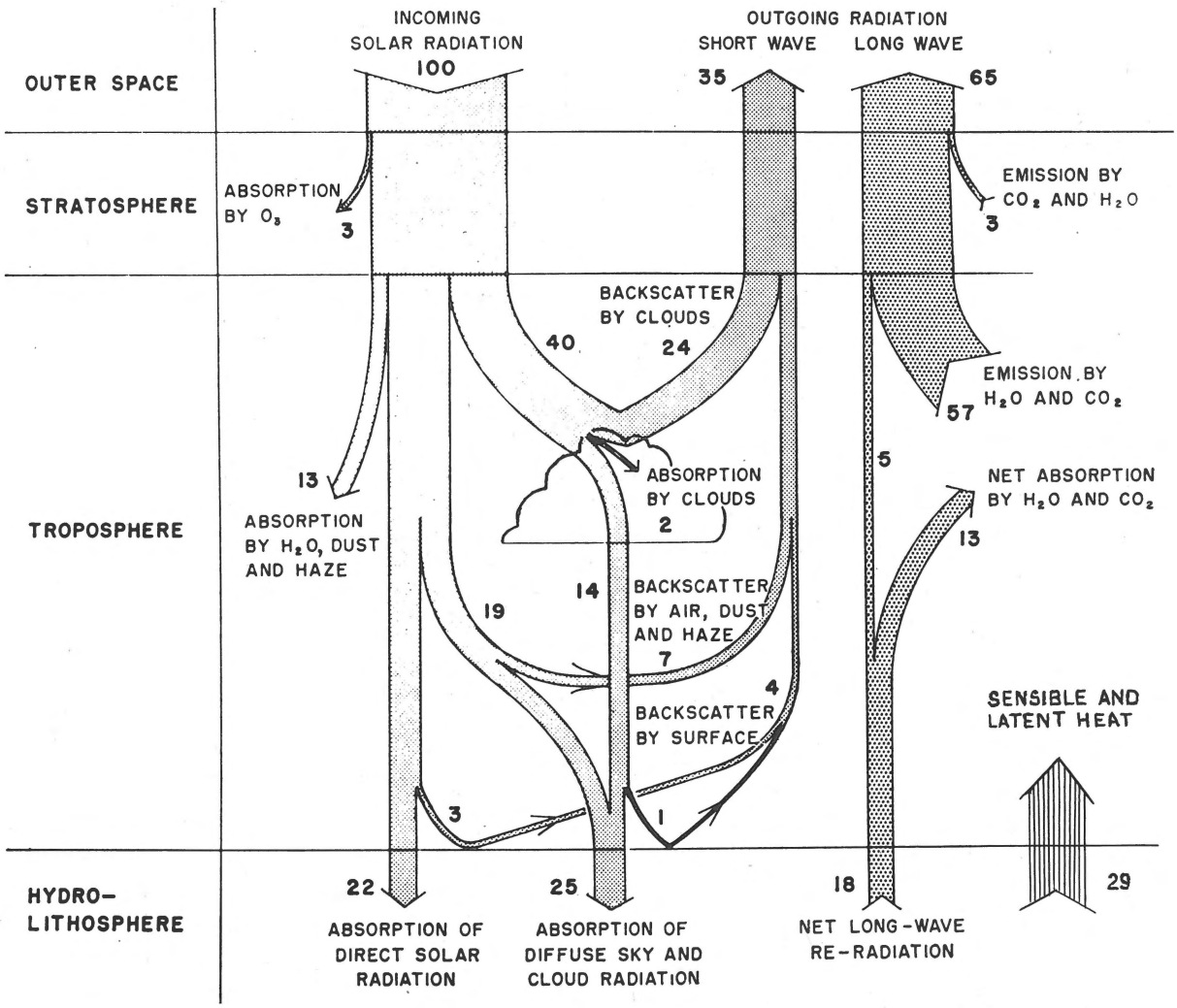


Fig. 9

Mean annual budget of the Earth, showing the distribution of incoming short-wave solar radiation and of long-wave terrestrial re-radiation. The units are in percentage of incoming radiation, reaching the top of the atmosphere. Based mostly on estimates of Budyko and Kondratiev, 1964, valid for the northern hemisphere. (After J.M. Mitchell Jr., 1965).

global climate development.

The task is much more difficult than it might seem. The global mapping of terrestrial albedo by satelites is available only for the last few years. The older ground records are incomplete especially over some parts of the oceans, and they do not reflect the variability in transparency of the cloud cover which controls the albedo. As for the last years, the following latitudinal distribution of cloudiness can be considered to be characteristic (based on data of C.E.P. Brooks 1951):

Cloud over latitudinal distribution (percentage):

	Northern Hemisphere Means									Southern Hemisphere Means									
	Latitude north of:									Latitude south of:									
Average of:	80°	70°	60°	50°	40°	30°	20°	10°	0°	0°	10°	20°	30°	40°	50°	60°	70°	80°	
Winter half-year	48	59	61	61	58	47	40	42	51	51	45	47	55	66	71	71	59	-	
Summer half-year	78	72	66	62	54	43	42	52	56	53	51	49	54	65	72	81	69	-	
Year total	63	66	63	62	56	45	41	47	53	52	48	48	54	66	72	76	64	-	

The following facts may be considered evident, logically explicable and generally valid:

1. There exists a clear zonal pattern in the latitudinal distribution of clouds.
2. The cloudiness in winter is generally lower than in summer, except for the middle latitudes between 30° and 50° of both hemispheres.
3. The minimum cloud cover in winter is reached between 10° and 30° on both hemispheres, and the maximum cover lies between 50° and 70°.
4. The summer minima lie between 10° and 40° of both hemispheres.
5. The gradient between the minimum and maximum monthly mean increases toward the poles, and is generally greater in the northern hemisphere.

Unluckily the older records of the cloudiness in global extense are deficient, short, and not very reliable. They do not cover a timespan long enough to allow the comparison with the climatic trends detected in the last hundred years. As for the earlier intervals, such as the Middle Holocene or Pleistocene, no reliable reconstruction of global clouds distribution can be made. Neither the marks of rain activity could be used as indirect indicators, because cloudiness and precipitation are not directly interrelated.

Therefore if we want to study the changes in the terrestrial heat budget of the past, we must exclude the clouds as a variable. The same is to be done with the reflection caused by the other compounds of the atmosphere, which in regional and time distribution is still more difficult to follow.

8. THE SIMPLIFIED MODEL OF THE EARTH, AS CONSIDERED IN THE PAST HEAT BUDGET RECONSTRUCTIONS

Let us assume that the atmosphere over the whole globe maintains its mean properties, including the distribution of clouds and that these conditions do not vary in time. Under these presumptions we may calculate approximately the heat volume absorbed directly by the earth's surface today, and, when using reliable reconstructions of past changes in vegetation cover and in ice and snow distribution, we may extrapolate our calculation back in time. Our model is generalised and rough and may therefore be used only for a rough basic analysis of the principles which

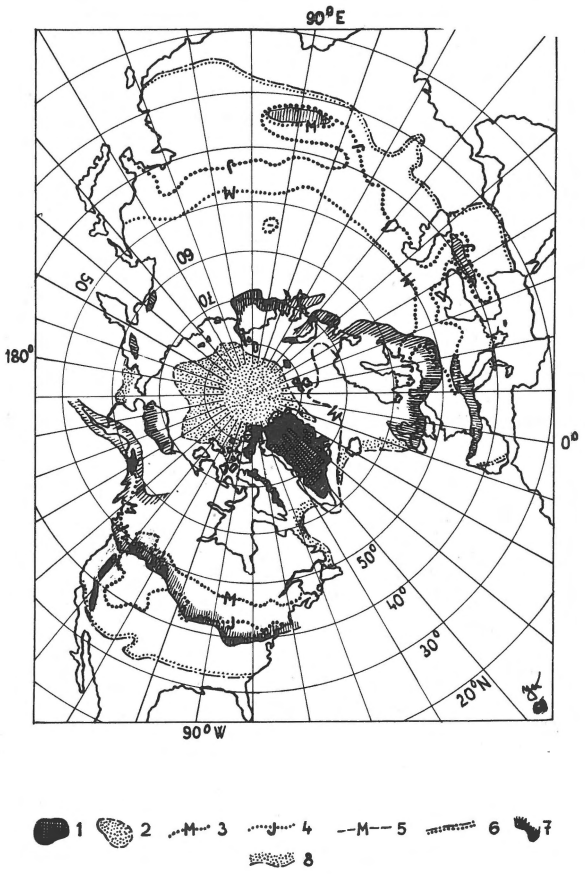


Fig. 10

Distribution of highly reflecting covers on the northern hemisphere at present and during the Pleniglacial.

1. recent extent of glaciers.
2. summer extent of the pack ice.
3. 50% probability line of snow covers on March 31, approximately representing the mean border of snow (thickness over 1 inch) in winter half-year in present conditions.
4. 50% probability line of one inch thick snow cover on January 31, present conditions.
5. Mean extent of pack-ice in April (respectively at the end of March) at present.
6. 50% probability line of the one inch thick snow cover on January 31, present time (southern maximum of recorded snowfall). This boundary also represents the approximate mean winter snow line in the Pleniglacial.
7. Maximum southern reach of continental ice sheets in the last Pleniglacial.
8. Postulated Pleniglacial mean winter-half-year border of the pack-ice in Arctic Ocean.

(constructed with the use of data from Dickson R.R. and Posey J. 1967, Ostenso N.A. 1966, Fr[illegible] 1967 [illegible]

The method to be used will be the following one (K u k l a 1968a):

1. The mean seasonal albedo will be found, separately for each latitudinal zone, for each hemisphere and for the two principal seasons of the year, taking into account the mean present conditions, that will be marked as B.
2. The corresponding values for multiples of the area, percentage of heat gain (100 – albedo) and insolation volume (according to M i l a n k o v i c h (1941) (table XXV) will be determined, added and then divided by the areal factor to obtain the mean value, valid for the corresponding hemisphere, or for the whole earth.
3. The same procedure will be repeated for selected past phases of the earth's history (Pleniglacial: E-conditions; Full interglacial: A-conditions).

The distribution of the oceans and continents and the areal factors used for distinct latitudinal zones are as follows (oceanic regions with seasonal pack ice cover are considered as belonging to the continents when marked with !):

Latitudinal zone:	Areal factor:	% of continents:
80–90°N	98	100 !
70–80 N	288	100 !
60–70 N	467	76
50–60 N	640	54
40–50 N	786	55
30–40 N	911	45
20–30 N	1007	not measured;
10–20 N	1074	no seasonal
0–10 N	1107	change in albedo
0–10 S	1107	„
10–20 S	1074	„
20–30 S	1007	„
30–40 S	911	10
40–50 S	786	3
50–60 S	640	0
60–70 S	467	0
70–80 S	288	100 !
80–90 S	98	100 !

The mean present conditions were assumed to be as follows (compare fig. 10):

1. The ice sheets and pack ice cover in summer the latitudinal zone 80-90°N and 70-90°S. This approximation differs from reality by about 5 degrees of latitude in the north, where the actual mean boundary lies close to 75°N. The northern reach of the 0.5 m thick ice-pack in September at 90°E is about 82°N, the southern extreme at 140°W is about 71°N in September; the Greenland ice sheet reaches to 61°N. In the Antarctic the pack-ice minimum extent in March varies from 67 to 71°S (after M a c k i n t o s h and H e r d m a n 1940) with the summer half-year mean boundary close to 66°S.

2. The pack ice limit in the winter half-year is close to 60°S and about 65-67°N (O s t e n s o 1967, S c h e l l 1967). In the calculated model the boundary has been assumed to lie at 70°N and 60°S.

3. The mean snow-line during the winter half-year in the Northern Hemisphere could be relatively exactly calculated from the snow-cover probability maps (D i c k s o n and P o s e y 1967). The mean line for continents is at 51°N and is roughly identical with the 50% probability line for 1 inch thick snow in March. The corresponding approximation in the model is: Snow all the winter north of 60°N, snow half of the winter north of 40°N. Because of their negligible extents, the winter snow covers over the southern hemisphere were not taken into consideration.

4. The mean albedo values have been assumed to be as follows:

a) Oceans and non-glaciated continents	20%
b) Ice sheets and pack ice in summer	60%
c) Snow-covered surface including ice sheets and pack-ice in winter	70%

5. In the first calculations (K u k l a 1968a) the influence of the dense forests reducing the mean winter albedo has not been taken into consideration. The coniferous trees, namely a few days after the last snowfall, shake off their snow cover and start to receive again a relatively high portion of incoming heat. The same to a lesser degree also occurs in the deciduous forests. Therefore in the newley revised calculations arbitrary ratios have been used to increase the obtained heat multiples in particular latitudinal zones. The factors are:

60° – 70°N	1.54
50° – 60°N	1.12
40° – 50°N	1.12

They vary according to the unequal proportions of forest belts in the particular latitude. No data, however, are available for the mean time of persistence of the snow cover on the tree branches; the ratio must be considered therefore as a mere estimate.

The volume of incoming radiation has been taken as one half of the quantity indicated by Milankovich (1941, table XXV) for his zero-check A.D. 1800. This is an approximation of 51% of radiation, either direct or indirect, that reaches the earth's surface as the global mean. No difference has been made between winter with higher values and summer with the lower ones. The computation was realized using the Canonic unit, which correspond approximately to 10 Ly (1 Ly = gcal/cm^2).

No correction was made for the angle under which the sunbeams reach the earth; for simplicity the angle of incidence has been considered to be close to the vertical.

The result for the year 1800 (Milankovich zero-check) is: northern hemisphere, partial heat gains:

Winter	.....	3780 Can units
Summer	.....	6140 „
Total	.....	9920 „

Southern hemisphere, partial heat gains:

Winter	.....	3790
Summer	.....	6230
Total	.....	10020

World:

Winter	.....	3785
Summer	.....	6180
Total	.....	9970

These figures are about 20% lower than one would obtain from the 720 Ly/day estimate of the extraterretrial incoming heat and 47.5% of superficially absorbed heat as the global means. The difference is mainly due to a high degree by the irrealistic supposition of equally distributed clouds. The dry belt of lower latitudes with relatively low mean albedo, gains in reality more heat than our simplified model indicates. For the purpose of our study, anyhow, this difference is of no importance.

The pleniglacial conditions were reconstructed for the last glacial stage, mostly using indirect evidence of vegetational cover, moraine stands and eustatic sea level evidence. This kind of indirect evidence, of course, is less reliable and the grade of approximation therefore higher. Generally it might be concluded that probably the mean winter extents of snow slightly overpassed their actual winter extreme stands.

The mean pleniglacial conditions have been assumed to be as follows (compare fig. 10):

1. The ice sheets and the perennial pack-ice extend on the average from 60°N to the north pole and from 60°S to the south pole. The limit for the northern hemisphere may seem to be too high when we think of the front moraines of Wisconsin glaciation situated between 40° – 50° in the U.S.A. and of the Weichselian moraines close to 50° in Europe. The mean figure, however, is highly influenced by northern Asia, which was ice free.

2. The pack-ice in the winter reached on the average probably to 60°N and 55°S.

3. The winter mean snow line has been assumed to lie between 30 and 40 degrees, close to the actual 0% probability boundary in January (which is at 33°N). The boundary for the snow cover persistent for the whole winter has therefore been drawn at up to 40°N, the boundary for half-winter snow-cover up at 30°N, and up to 30°S.

4. The same values of albedo have been taken into consideration as used for the recent model.

The coefficients for forest influence are as follows:

50 – 60°N	.....	1.15
40 – 50°N	.....	1.31
30 – 40°N	.....	1.10
30 – 40°S	.....	1.05
40 – 50°S	.....	1.005

The figure corresponding to 40 – 50°N, i.e. to the belt of steppes with dispersed cold resistant coniferous and deciduous forest patches is probably too high, but the coefficient for steppe surfaces in proportion to forests could not be safely estimated.

In the same way as in the Recent A.D. 1800 (B) model the corresponding partial heat balance by pleniglacial conditions has been calculated (E-model). For the sake of simplicity the enlargement of the continents was not taken into account. (the difference is about 5%).

9. THE HEAT BALANCE CHANGES IN THE PAST

Using Milankovich's (1941) data for the past distribution of insolation, the changes occurring in the heat balance of the Recent terrestrial model

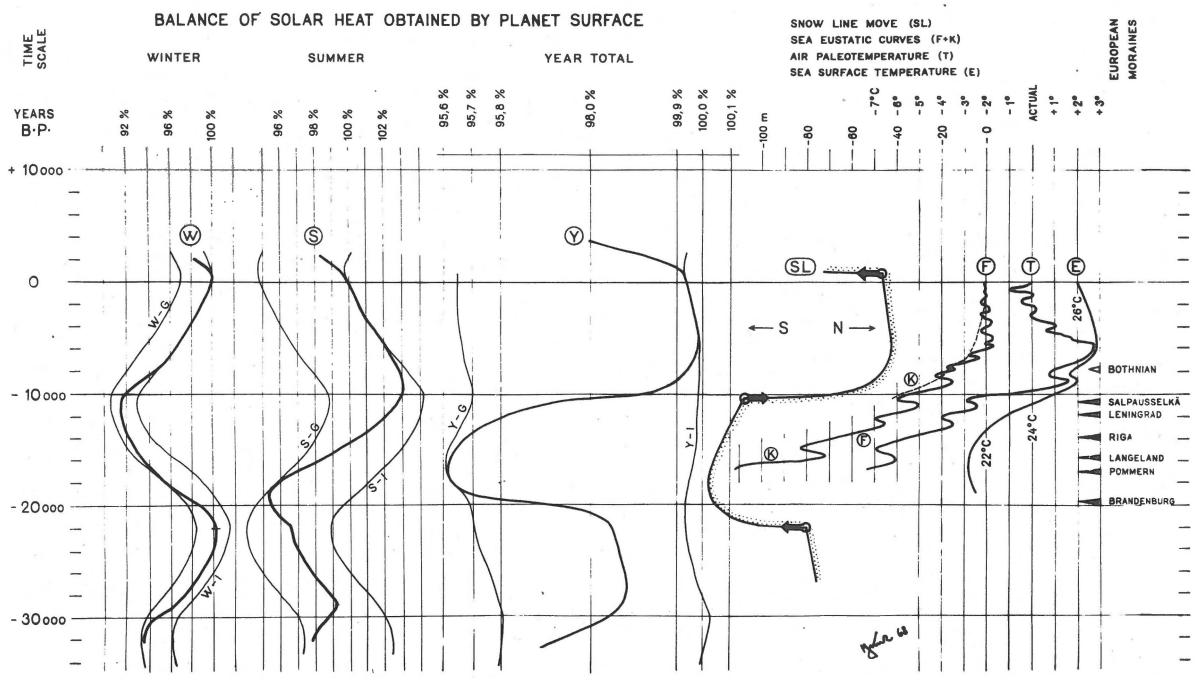


Fig. 11

Reconstructed partial heat balance of the northern hemisphere in the last 30,000 years, assuming invariable mean properties of the atmosphere including cloudiness, as observed at present. The heat obtained in winter half-year (W), summer half-year (S) and year total (Y) is indicated in percentage of the A.D. 1800 levels. Curves W-G, S-G and Y-G are computed considering pleniglacial extents of the highly reflecting covers to be constant (snow and pack-ice). Corresponding curves W-I, S-I and Y-I are computed considering constant present conditions.

On the right side the expected change of the geographical position of the mean snow line in winter (SL) from south (S) to North (N) is indicated.

The eustatic sea level rise according to Fairbridge (1965) is marked with *F*, that according to Kenney (1964) with *K*. The air temperature change as reconstructed from palynological data is shown as *T*., Emiliani's (1968) curve of the sea surface temperature for the Caribbean and equatorial Atlantic is marked as *E*.

have been followed 30,000 years back to the past (fig. 11, indexes I – interglacial). The same procedure has been applied to the pleniglacial model of the earth, assuming that the mean seasonal extents of ice and snow sheets would remain invariable for the whole time span assumed (indexes G – glacial). In K u k l a (1968) this calculation is made for both hemispheres till 140,000 B.P. Our figure 11, which completely suffices to demonstrate the principal rules of the process studied, corresponds to the northern hemisphere only.

The following conclusions are evident:

1. *If the mean yearly extents of ice and snow covers in the northern hemisphere were to remain constant and equivalent to the recent conditions (I-curves in fig. 11), then the difference in the partial heat budget caused by the earth's orbital elements perturbations, would amount for the last 30,000 years to 0.1% of the total volume.*
2. *When the pleniglacial conditions remain constant (G-curves in the fig. 11), then the difference would be 0.3%.*
3. *If, however, we take into account the real change from pleniglacial extents of ice and snow to their recent mean stands, then the pleniglacial heat budget is by 4.5% lower than the recent one (full curves in the fig. 11).*

From this it follows that:

A. *The difference in heat budget caused by variable extents of snow, pack-ice and glaciers is 15 times greater than the maximum differences caused by perturbation effects.*

B. If the insolation really influences the climate change, then this must be effected only through some mechanism that could move with the boundaries of the highly reflecting surfaces.

C. Retardation in the response of global climatic trends to insolation changes, assuming that these are in causative relation to the climate forming, is impossible.

10. THE SNOW LINE HEAT REACTION

The direct causative relation of the terrestrial heat budget to the climate, as explained above, is in modern meteorology beyond discussion. In our simplified earth's model with constant mean atmosphere, the principal variables are the areas of highly reflecting surfaces of ice, snow and pack-ice against the areas of seas and bare continents with low albedo.

The differences in the insolation at any time are principally seasonal. The seasonal gradient of the change is by far the only really substantial one.

Let us compare now the thermal reaction of the sea and land surface in the lower latitudes during the two seasons of the year. The surface albedo is more or less the same in winter as it is in summer, therefore the yearly total of the obtained heat will be almost constant. It doesn't matter whether more of the heat will be radiated in winter and less in summer or vice versa, if only the yearly total is constant.

For the ice sheet in the high latitudes the same consideration is roughly valid. There will be a slightly higher heat loss, if the volume of the winter radiation increases with respect to the summer one, because the albedo of the dirty and locally melting ice surface in summer is lower than in winter, but the principal relation remains the same.

Let us now consider a point on the continent in the middle latitudes. The surface in winter is covered by snow; in this circumstance 20% of the incoming energy will be absorbed and 80% lost through albedo. In summer the snow has melted. Than 80% of the incoming heat is absorbed and 20% lost by albedo (see fig. 12). Therefore if the heat volume transferred in winter tends to increase relative to that of summer, the losses due to albedo will be higher and the resulting heat balance will be lowered.

However, during the winter at any point of the snow boundary a specific phenomenon occurs, which may be called *the thermal (or heat) reaction of the snow line*. The boundaries of the snow-covered parts of the continents with the bare uncovered land are uninterruptedly shifted. They react sensitively to any change in the thermal income and in humidity. Figure 12 shows a theoretical example of such a boundary, where the thickness of the snow cover (left part of the diagram) is minimal and is kept in its constant position by the equilibrium thermal income T. If by only a slight increase in T by Δt the snow melts (the right part of the diagram 12), then the heat absorption by the uncovered surface will immediately increase 4 times.

In other words: The almost negligible increase in T by Δt results in the four-fold increase of the absorbed energy and in the corresponding reduction of the loss through albedo.

Even if the estimates used in our calculation may sometimes differ from reality, the rule will remain valid.

To illustrate the primary importance of the reaction to the climate forming, let us consider, for example a place, lying at 45°N latitude, in the period close after 10,000 B.P., viz. at the beginning of the Holocene. The model with the average constant conditions in atmosphere will be used in the same sense as before.

In the winter half year one half of the 6406 Can. units of M i l a n k o v i c h (1941) reached the surface of the particular place, which corresponds to the volume of:

(1)..... 32,000 Ly

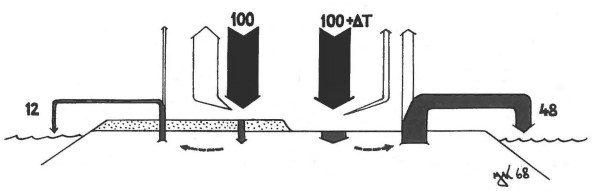


Fig. 12

The principle of the snow-line heat reaction. The snow covered area on the left reflects 80% and absorbs 20% of incoming radiation. 8% of re-radiated energy are lost to space and 12% distributed by the atmosphere and partly accumulated in the seas. After slight increase of incoming radiation by Δt, the snow melts and the bare surface absorbs 80% of which 48% are distributed by the atmosphere partly to the oceans. This situation is shown on the right side of the diagram.

According to Milankovich's table XXV this volume in the period between 10,000 B.P. and 5,000 B.P. increased yearly by:

(2) ..... 0.356 Ly/half-year

which is an equivalent of:

(2a) ..... 0.00195 Ly/day

This thermal gain is big enough to melt daily the snow cover (2 cm thickness, 0.25 g/cm^3 density, 0°C temperature and 79.2 gcal of specific heat) over the area of:

(3) ..... 5×10^{-5} cm^2

This area corresponds to one day action. In 183 days of the winter half-year the cleared surface will be 183 times greater, but its full thermal activity will last only half that time, i.e. 91 days.

If the surface had remained snow-covered, the absorbed heat would have amounted to 4800 cal/cm^2 (Ly). Without snow the surface would have retained 12,800 cal/cm^2, which is 8000 cal/cm^2 more. The total gain produced by a winter increase of 0.356 Ly/half-year, amounts therefore to:

(4) ..... $8000 \times 183 \times 5 \times 10^{-5}$ ..73 Ly/half-year

The net gain (4) is the 200 fold multiple of the original increase (2). Or in another way:

Yearly winter insolation increase
above the snow line of..... 0.01 ‰ per cm^2

increased the local
winter heat budget with ..... 7.60‰ per cm^2

The reaction described, however, is only the first phase of the specific process called the snow line thermal reaction. Its most important feature is the repercussion, creating an efficient avalanche effect.

When continuing the analyses of the chosen example, we may observe a net surplus of 73 Ly : 2 = 36 Ly disponible in the mid-winter above the snow-line area at the place studied. This energy is later re-radiated back into the atmosphere and space, but at least 10% is consumed in melting of snow in the neighbourhood of the snow line. The resulting 3.6 Ly gained in 1 cm^2 are sufficient to iniciate and complete the described thermal reaction over a 5 cm^2 of neighbouring area. *So the avalanche reaction starts and continues.*

Similar conditions as those observed at the snow line exist at the limits of the pack-ice.

The process opposite to the one described here occurs in the case of the heat loss caused by decreased radiation. In this case the newly fallen snow will not melt in the place where the temperature income would normally have sufficed to keep the balance.

The temperature surplus (or deficit) with respect to the former equilibrium state, may be, as explained above, of two different kinds:

1. The vertically transmitted direct or indirect heat, principally solar radiation.
2. The more or less horizontally distributed energy due to the action of the atmosphere (in this particular point we are abandoning the simplified model with inactive atmosphere).

It is quite evident that all kinds of temperature changes will influence the thermal balance at the snow line. However, only that sort of variation which will have the same trend for some longer time and at a global scale, will be able to "pull the trigger" of the avalanche snow line heat reaction. The interaction between the oceans and continents, working through the extensive sea-air interaction, will play a very important role, transporting the gains in energy to the main heat accumulators represented by the oceans. In the long run, this energy increase will be returned to the continents and speed the snow melting. A similar interaction exists between the glaciers on one side and the snow lines with pack-ice limits on the other side.

11. THE SENSITIVE ZONE

If the mean temperature supply to the snow-line area in winter time maintains its either increasing or decreasing trend for some time, the fast snow line heat reaction will start and in the self-accelerating process will shift the mean winter snow lines further to higher latitudes, and in the mountains to higher altitudes or vice versa.

Theoretically the snowline should be shifted either as far as the Pole or as the Equator. This, however, will never take place because of the heat retardation of the polar regions, because of the changing seasonal gradient of insolation towards lower latitudes (which becomes almost negligible around 15°N), because of

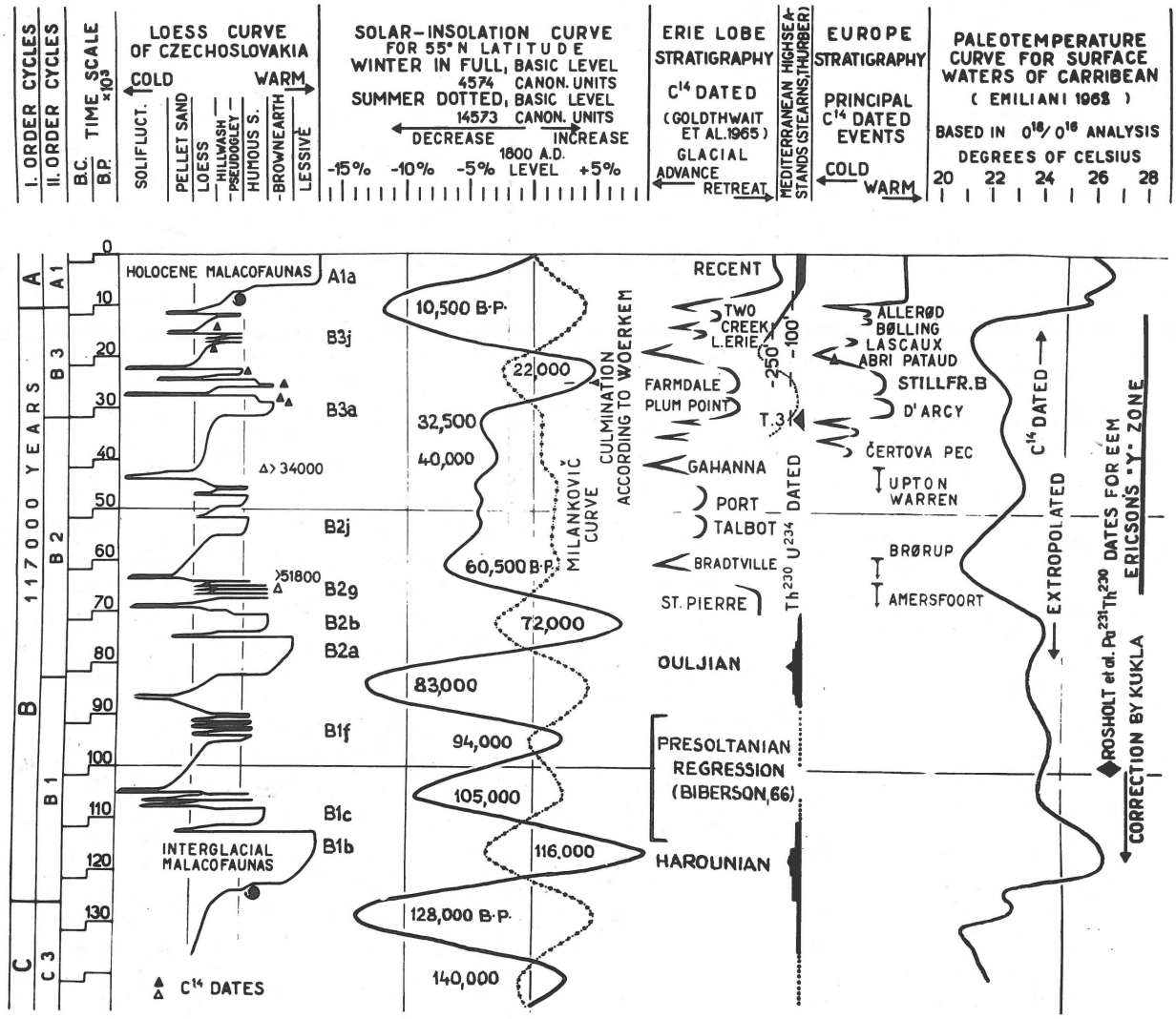


Fig. 13

Comparison of the seasonal insolation change with the geological evidence of climate changes in the past 140,000 years, dated by isotopes and with the Central European loess-curve. Indexes *Ala*, *B3j* and similar correspond to the most important soils as described in Czechoslovakia. Definite C14 dates are marked by solid triangles, others by an open triangle. Sources other than those mentioned above are Leroi-Gourhan (1965), Morrison and Frye (1965) and Movius (1960).

the stabilizing influence of the southern hemisphere in the heat budget of the northern hemisphere, (and especially in their lower latitudes), and for similar reasons.

The mean snow line in the Quaternary may probably have oscillated between 30°N (in the most severe glacials) and 60°N (in the full wet interglacials).

The area between these limits may be called the sensitive zone. It is this area of which the influence is crucial for the global climate forming mechanism.

12. THE BASIC PRINCIPLES OF CLIMATE FORMING

For our simplified model of the earth, as described above, the climatic change would be controlled by the following simple principles:

1. The change of the trend in seasonal distribution of

incoming solar energy is the impulse for the start of the rapid snow line heat reaction. If the winter insolation rate globally maintains an increasing or decreasing trend for some longer period, substantial changes will follow in the areal distribution of the highly reflective sheets of snow and of pack-ice. Winter in the northern hemisphere is the decisive season in this respect.

If, therefore, the winter insolation trend shows a decreasing tendency, snow sheets will extend and global cooling will follow.

If the winter insolation over the northern hemisphere were increasing, the snow sheet extention would be reduced and global warming would follow.

The snow-line shift would be fast at first, then slower, and would ultimately stop in the zone of thermal equilibrium established by the lateral heat flux.

2. *The shift of the mean snow line will be faster and more efficient, when the gradient of the seasonal change in thermal income will be higher and vice versa.*
3. *Any source of heat other than insolation, which could globally modify the thermal conditions above the winter snow lines and pack-ice boundaries will influence the development of world climate. (Solar constant changes, artificial heating and so on.)*
4. *Any large regional change in the extent of highly reflective winter surfaces will produce a world-wide climatic effect. For example, large-scale deforestations lead to the increase in winter albedo and to the lowering of the heat budget.*
5. *The change in the ratio between the continental area in the sensitive zone of the northern hemisphere and that of the sensitive zone of the southern hemisphere will be reflected in the amplitude of the climatic oscillations produced by the perturbation mechanism.*

   Today the ratio is over 50; a lower ratio would correspond to a more equal distribution of the continents over both hemispheres and therefore to smaller climatic effects produced by insolation change. Such was the situation in Tertiary time when the Central part of South America shifted closer to the south pole.
6. *The actual position of Antarctica around the south pole favours the glaciations, maintaining a lower level of the terrestrial heat budget. Thus the past change in its position must have influenced the climate. In the Tertiary Antarctica lay well off the pole.*
7. *The reaction of the snow line is faster and more efficient, when the winter insolation trend coincides with the trend of the heating of the equatorial belt. The latter varies according to the obliquity of the equinoxial cycle.*
8. *A new climatic trend starts with each change in the sense of the winter insolation shift. When governed by the earth's axis precession cycle of Milankovich, such a gross trend will last roughly 10-11 thousand years and will be composed of three principal phases:*

   Phase "a":
   The fast shift of the mean winter snow line from its present equilibrium stand to a new northern or southern balanced position. It is the phase of rapid cooling or warming with a duration of 2-4 thousand years.

   Phase "b":
   Stagnation or slow retreat of the mean snow line in the region of the new equilibrium stands. Opposite temperature change due to the starting influence of lateraly transported energy volumes controlled by summer insolation trends.

   Phase "c":
   The slow opposite move of the mean snow line towards the centre of the sensitive zone. Marked temperature trend opposite to the starting one, because of the dominant role of the increasing summer insolation in the global budget.

   These three phases, calculated on the basis of Milankovich's tables, may well be distinguished in fig. 11.

9. *Because of the principal role of winter insolation change for climate forming, the glacial-interglacial cycle of 117 millenia duration, recognized in the curves of seasonal insolation change, is with the highest probability the immediate cause of the glacial cycle observed in sedimentary records.*

13. THE POSSIBILITY OF COUNTERACTING OF THE ATMOSPHERE

The rules above listed may be valid under the condition that the long time changes in atmosphere do not counteract the primary effects of the snow line reaction. No phenomenon similar to the avalanche reaction of the snow cover is possible in atmosphere. The general tendency of atmosphere and cloudiness is self-regulation. Less clouds or less diffused water vapor permit more radiation to reach the ground, to increase the evaporation and so in turn to thicken the clouds and increase the water vapor content in the atmosphere. Thus the starting trend is stopped.

The rather regular distribution of clouds in both hemispheres and the deminished cloudiness in winter observed in both hemispheres are reliable indications that the atmosphere changes follow the same trends as the changes due to the interaction mechanism of the Earth's surface albedo-insolation. Eventual changes in the atmosphere affecting the climate, if any, are more likely to stay in phase with the ground processes than out of phase.

In any case, only a check against the isotope dated geological evidence can demonstrate whether the atmosphere counteracts the primary effects of the insolation-surface albedo of the heat budget system.

14. THE CHECK OF THE EVIDENCE OF GEOLOGICAL HISTORY

In fig. 11, the heat balance of the Northern Hemisphere, extended up to 30,000 years B.P., is compared with the available dated evidence of eustatic mean sea level, the air temperatures derived from palynological records, and with the O^{16}/O^{18} ratio in the sea water. The agreement is evident, at least for the record of gross climate changes.

In fig. 14 the data from the last 140,000 years of the Earth's history are compared with the winter insolation at 55°N. The coincidence of the cold Main Würm with the period of generally low winter insolation is striking. All three important dated high sea stands, namely Ouljian, Harounian and Flandrian are synchronous with the steep increase of the winter insolation over the northern hemisphere. The cold spell of stage 4 in deep see cores, dated around 60,000 or 65,000 years B.P. is consistent with the expressed rapid lowering of the winter insolation rate between 60,500 B.P. and 72,000 B.P.

The agreement of the principal isotope-dated events with the winter insolation trends persists within the entire scope of the C 14 method. Agreement clearly exists, too, between the high sea stands dated by the uranium-decay-series and the winter insolation trend for the period between 190,000 and 240,000 B.P. (as also shown in the loess section curve of K u k l a 1969).

In the following table the general climatic trends dated by the winter insolation change, are listed and arranged according to their expected intensity. For that purpose the interference with the obliquity of the equinoxes cycle has been taken into account, together with the gradient of the seasonal insolation change. The last three glacial cycles and the Holocene are included. The most intensive cold and warm trends with a rapid change of the seasonal insolation rates and in phase with the obliquity of the equinoxes cycle are marked with CCC (cold) or WWW (warm). Slowly changing trends or normal trends in seasonal change but out of phase with the obliquity cycle are denoted with C or W respectively. Intermediate tendencies are indicated with WW and CC. It must be stressed that the distinction is based on the intensity of the impulse only, the accumulative time effect not being taken into account.

The corresponding glacial cycles are roughly as follows:

A.P.	B.P.	
0.5 –	10.5	Holocene postglacial
–	72.0	Würm Main Glacial (Main glacial B)
–	128.0	Temperate period, interpreted as Eem interglacial or Interglacial III (Olausson), or as shorter Interglacial with stade and interstade (Biberson 1966)
–	187.5	Main glacial C (Kukla 1968, 1969)
–	242.5	Temperate period, Interglacial V of
–	282.0	Olausson Main glacial D (With high probability Saale resp. Riss)
–	370.0	Temperate period with intervening cold spells (with high probability including Holstein interglacial at some localities, e.g. Steinheim a/M).

The astronomically dated climatic trends after 380,000 B.P. (P. in this case equal to A.D. 1800; A.P. means after that year)

Time in 10^3 years B.P.	Thermal impulse	Parallel to the loess cycle in Europe	Other parallels: Continent	Sea
10.5A.P. – 0.5A.P.	CC	A1 Stadial	Holocene	Flandrian
0.5A.P. –10.5B.P.	WWW	A1 Interglacial	Holocene	high sea stand
–22.0	CCC	B3 Stade	Würm	Stage 2 (Emiliani)
–32.5	WW	B3 Interstade	Denekamp	
–40.0	C	B2 Stade		
–45.0	WW	B2 Interstade III	Hengelo	
–47.0	C	B2 Stade		
–60.5	W	B2 Interstade II	Port Talbot?	
–72.0	CCC	B2 Main stade		Stage 4 (Emiliani)
–83.0	WWW	B2 Interstade I	Soil B2a	Ouljian
–94.0	C	B1 Stade		
–105.0	W	B1 Interstade	Soil B1f	
–116.0	CC	B1 Stade		Presoltanian
–128.0	WWW	B1 Interglacial	Soil B1b	Harounian
–140.0	CCC	C3 Stade		
–152.0	WW	C3 Interstade		
–164.5	CC	C2 Stade		
–176.0	WW	C2 Interstade II		
–187.5	CCC	C2 Main stade		
–198.5	WWW	C2 Main interstade I	Soil C2a	High sea stands
–209.5	CC	C1 Stade		WW
–220.0	WW	C1 Interstade		
–232.5	CCC	C1 Stade		
–242.5	WWW	C1 Interglacial	Soil C1a	High sea stands
–260.0	CCC	C3 Stade		
–270.5	W	D3 Interstade		
–282.0	CC	D2 Stade		
–292.5	WWW	D2 Interstade III		
–304.0	CCC	D2 Stade		
–313.5	W	D2 Interstade II		
–323.5	CC	D2 Stade		
–333.0	WWW	D2 Interstade I	Soil D2a	
–342.0	CCC	D1 Stade		
–351.0	W	D1 Interstade		
–360.0	CC	D1 Stade		
–370.0	WWW	D1 Interglacial	Soil D1a	
–380.0	CCC	E3 Stade		

It should be mentioned that each of the stages listed in the table has a development of itself, which cannot be accurately dated in all its corresponding phases. The given date indicates the time when the particular temperature global trend started to be speeded up by the avalanche heat reaction of the snow line, not its absolute start.

Let us take the last two general climatic trends in the Earth's history as an example:

Climate development since 22,000 B.P.

Time (B.P.)	Phase	Trend	Snowline position
500A.P. – about 3,000	c	snow cooling	Northern equilibrium zone
about 3,000 – about 6,000	b	stabilized	Northern equilibrium zone
about 6,000 – 10,500	a	rapid warming	Rapid move towards N.
10,500 – about 16,000	c	slow warming	Southern equilibrium zone
about 16,000 – about 19,000	b	stabilized	Southern equilibrium zone
about 19,000 – 22,000	a	rapid cooling	Rapid move toward S.

Checking the result with the isotope dating, the following may be stated:

1. The dated evidence of general climatic trends in the last 25,000 years exactly fits the rules derived from the model of the earth with constant atmosphere.
2. Thus, the rules described above may be considered as controlling the complete earth's heat budget and through it the global climate.

15. THE CAUSE OF THE HOLOCENE CLIMATE DEVELOPMENT

At about 10,500 B.P. the winter insolation over the northern hemisphere started its general positive trend which still is continuing. (The event was not exactly synchronous over all latitudes.) However, long before that date, from about 16,000 B.P. the globe generally warmed up, maintaining however, cold winters with long lasting snow covers (compare fig. 11). Close to 10,500 B.P. the self-accelerating snow-line heat reaction started and quickly shifted the mean winter snow boundaries far to the north. This was the decisive cause of the deglaciation. The fastest increase of the heat budget since 16,000 B.P. resulted in the definite retreat of glaciers from the middle latitudes. Much milder winters and, much shorter duration of snow-covers, and the effect of the rapid snow-line retreat to the north caused the fastest change in vegetational cover recorded within the last 30,000 years.

After about 3 to 4 thousand years the climatic optimum was reached, thus ending the "a-phase" of the trend. The "b-phase" followed, more or less maintaining the situation stabilized (during the Atlantic period).

The general cooling, which started at about 4,600 B.P. and which probably is still in progress, is in good agreement with the slow decline in the world energy budget (compare with fig. 11), corresponding to the last "phase-c" of the Holocene general winter warming trend.

The natural end of the warming trend and thus the end of the Holocene interglacial and the Holocene high sea stand will become evident close to 500 A.P. respectively close to A.D. 2500, when, due to the precession cycle mechanism, the winter insolation above the northern hemisphere will start to decrease rapidly. The fast advance of the snow-line to the south will follow with the consequent substantial deficit in the heat budget.

It is quite possible that the turning point in the general curve of the winter insolation has already been passed by, but the noise of the short range

precession changes makes this fact very hard to be detected.

The latter was the principal reason of the general warming observed through the Holocene until now, and related to the Milankovich's perturbation mechanism.

Before we start to analyze the causes of the short range oscillations during the Holocene, let us first try to explain why the last interglacial optimum was much warmer and wetter, than the climatical optimum of the Holocene. The difference is so big, that some authors do not consider the Holocene to be the true interglacial. Some others (e.g. F a i r b r i d g e 1965) call the Holocene a dry interglacial, to indicate the principal difference from the much more humid and maritime Eemian.

The question remains whether natural causes were responsible for the difference, or whether the interference of Man did interrupt the natural trends before the full interglacial conditions could have been established. To find a reliable answer, the first halves of the two periods should be compared. Until about 5,000 B.P. the changes in vegetation cover caused by man were too restricted in extent, to have influenced the global trends. Consequently, the difference observed would be still more pronounced – the postglacial warming was slow when compared with that at the start of the Eemian (L o ž e k 1964 and others).

As explained above, the speed of the snow line heat reaction, which is the trigger of each deglaciation trend, highly depends on the yearly gradient in the energy surplus acting above the snow line.

From the past heat balance of the earth we have therefore computed the mean gradients of the winter half-year radiation increase and of the annual mean change of the absorbed energy, both valid for the northern hemisphere under the pleniglacial conditions E.

The results are:

Mean yearly gradient in the radiation absorbed by the surface of the northern hemisphere:

Time:	Between years B.P.:	Ly/winter half-year	Ly/year
Postglacial	10,000 – 5,000	+0.280	– 0.008
B interglacial (Eemian)	128,000 – 120,000	+0.400	– 0.035
C interglacial (Eem in some localities)	142,000 – 235,000	+0.370	– 0.005
D interglacial (Holstein in some localities)	370,000 – 365,000	+0.270	+ 0.009

Our comparison demonstrated that the postglacial radiation increase was about 30% lower than in the last interglacial. This fact may therefore adequately explain the observed difference. The Holocene increase rate was very similar to that of interglacial D (which on several localities corresponds to Holstein).

Both the Postglacial and the D-interglacial started the "long glacial cycle", with the characteristics in insolation change strongly different from the normal glacial cycle (such as, for instance cycle B, corresponding to Weichselian glaciation and Eemian). We may therefore predict in broad outline the future development of the Holocene by comparison with the record of the analogous cycle D.

After the warming, which lasted about 10 thousand years, the general cooling trend continued for some 9,000 years. In the European loess sections the corresponding layer is probably the humic chernosem, which marks the retreat of forests and the start of an increasing continentality. A similar trend is to be expected for about the next 10,000 years. Then two other warming periods might come, reestablishing the more or less maritime interglacial environments. (Future interstades A2 and A3.) The main glacial A, if man does not intervene, should start in about 80,000 years (for comparison see the chronology of the last three glacial cycles as given in table II).

The cause of the minor climatic oscillations that have occurred in the Late Glacial and in the Holocene, and which included short but very marked events of climate development opposite to the general trend cannot yet be explained. Some observations, however, may be stressed in this context:

1. The cooling and the increasing continentality globally observed from about A.D. 1200 is in phase with the large deforestation of Europe, with the consequent increase in mean winter albedo above the snow-covered fields and deforested land. A similar result must have had the large deforestation of the U.S.A. in the 18th and 19th centuries. A causal relationship cannot be excluded.

2. Some observations indicate that the mechanism mentioned above is not the only one involved. Some short-range periodicity reflected simultaneously in the mean winter temperatures and the ocean level changes of the northern hemisphere has been observed. For the last 50 years, the corresponding trends in the southern hemisphere were just in the opposite direction (fig. 7). This relationship seems to present a very strong argument in favour of the

controlling influence of the earth's axis precession on the world climate. It further demonstrates the primary role of the winter season in the general tendencies of global cooling or warming.

A number of shorter cycles may be due to the instability of the earth's axis. The 21,000-22,000 years precession cycle involved in the Milankovich's theory, and the short range periodicities, however, must govern the climatic change in the same way: functioning by means of the multiplying effect of the snow line heat reaction, which is able to amplify the slightest impulse to important effects of global extent.

3. Variations of the solar constant and the sunspot number periodicity, which evidently affect some organic life processes on our planet, may likewise bear some relations to the heat budget changes, but such relations up to now have not been elucidated.

The arrival of a natural cooling impulse is due very soon, so soon, that it represents an immanent threat to the future world economy. It will amount to about 0,2 Ly winter half-year in the mean of northern hemisphere (apparent value calculated on the basis of assumed constant E conditions). Impulses of about 0.3 Ly/winter half-year started the main glaciations. As in the highly urbanized areas of Europe and North America the actual artificial warming is postulated to proceed at analogous rate, the thermal balance of the snow lines may be maintained in these parts of the world.

However, in the sparcely populated areas of Asia, Canada and in the Central part of Northern America the negative snow-line heat reaction is threatening to become dangerous and to cause a rapid fall in the world mean temperatures.

The coming catastrophic climate deterioration is a fact which should be taken very seriously and some preventive measures should be planned.

First of all, systematic meteorological investigation are badly needed as a basis of any future defense programme.

Chemical research can assist, too. Some new fertilizers, for instance, cheap and applicable over the snow surface, with low freezing point in water solution or dark in colour, may solve the problem economically. It could melt the snow sooner in the spring, over the vast areas used for agriculture in the northern hemisphere.

The energy needed to compensate the negative of time; sudden and short-lasting heating of the Earth, such as for instance in nuclear war, thus cannot be recommended.

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