6

What Caused the Ice Ages?

Willy Woelfli[1] and Walter Baltensperger[2]
[1]*Institute for Particle Physics, ETHZ Hönggerberg, Zürich*
[2]*Centro Brasileiro de Pesquisas Físicas, Urca, Rio de Janeiro,*
[1]*Switzerland*
[2]*Brazil*

1. Introduction

In this didactic paper basic features of the Ice Ages will be illustrated using well known data. The empirical facts are confronted with two theories.

The usual attempt to explain the Ice Ages is based on two phenomena. First, the other planets of the solar system induce small and slow variations of Earth's orbit. They were introduced by Milankovich (Milankovitch, 1941). They lead to variations of the insolation on Earth. Secondly, various feedbacks in Earth's climate system are considered. An example of a positive feedback: cold brings snow, which reflects solar light efficiently, so that the temperature decreases. The question is, whether the feedbacks are large enough to produce the Ice Ages. The small quasi periodic changes of Earth's orbit follow directly from the laws of mechanics and gravity; they are not questioned. Milankovitch cycles in the climate should belong to any climate model. The problem is the size of the feedbacks, which at present produce our regular climate. This model of the Ice Ages, often simply called "the Milankovitch theory", is used by practically all members of the scientific community for the interpretation of the data.

The second theory, which has been developed by us, involves a very unusual astronomical action on Earth's climate system during the last 3 million years. The revealing observation is an asymmetry with respect to the present North Pole: when the glaciation was at its maximum, it reached the region of New York City, while East Siberia remained ice free. Evidently, the North Pole was in Greenland. Therefore, at the end of the Ice Ages it shifted geographically to its present position in the Arctic Sea. This involves a motion of the globe, not of the rotation axis. We claim that there are circumstances in which this is compatible with laws of nature and observations. A planetary object with a mass at least 1/10 of Earth's mass must pass very close to Earth. We shall call this planet "Z". The tidal forces induce a 1 per mil stretching deformation of Earth's globe. While this relaxes in a time of order one year the pole moves. Since Z has disappeared, it must have disintegrated and the fractions evaporated. By necessity, Z was hot, liquid and radiant. It moved in an extremely eccentric orbit. Its evaporation created a disk shaped cloud of ions around the Sun.

A disk shaped cloud has been postulated by R.A. Muller and G.J. MacDonald (Muller& MacDonald, 1995; 1997), since Earth's orbit would be in the cloud with a Milankovitch period of 100 000 years. This is the dominant climate cycle. During cold periods Earth's orbit was in the cloud. This is when fine grained inclusions were deposited into the ice. The cloud has its proper dynamics. It builds up to a density at which inelastic particle collisions induce its collapse. The resulting near-periodic time dependence resembles that of Dansgaard-Oeschger (Dansgaard, 1993) climate events. When the plane of Earth's orbit was outside the cloud, the Earth received additional scattered radiation. This occurred during the last interglacial, about 120 000 years ago, and again during most of the last 10 000 years. In this theory with a shift of the poles, the Ice Ages were a singular and now definitely finished period of Earth's history.

In short, this is the contents of this chapter. New is only the interpretation of "reverse Dansgaard–Oeschger events" in subsection 4.4.

At the present time, the study of the Ice Ages is a detective story. This chapter describes two possible culprits. One is the system itself, which produced the Ice Ages. Somewhat like the weather, which creates a storm on one day and sunshine on the next. The other possible culprit is an exceedingly rare external object: a hot planet. A good detective keeps more than one hypothesis in his mind.

2. Basic features of the Ice Ages

2.1 When did the Ice Ages begin?

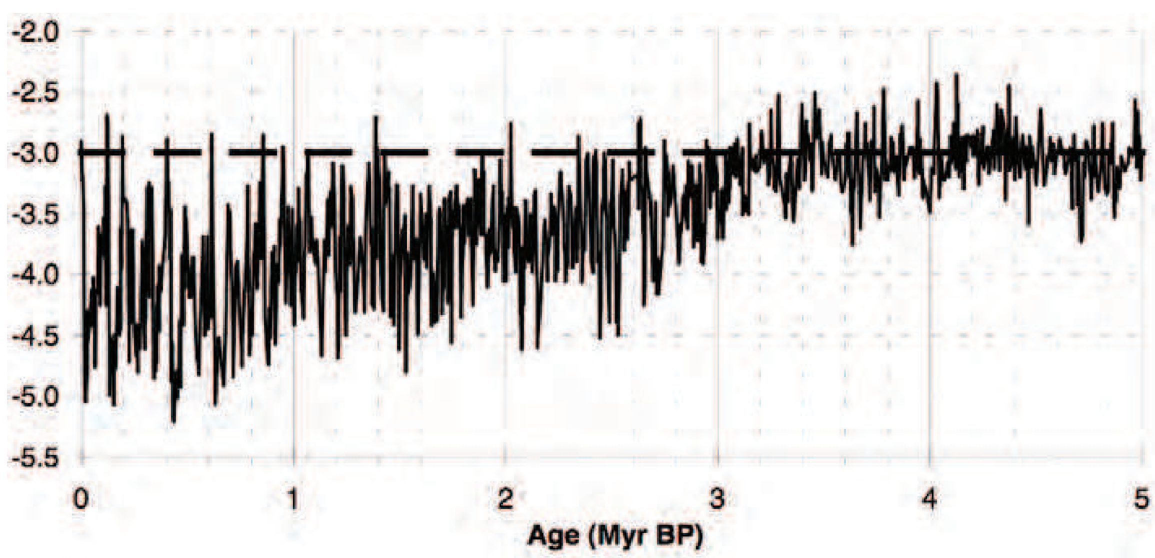


fig 1. Marine sediments contain information of the past. The ^{18}O to ^{16}O isotope ratio was measured on organic matter (Benthic foraminifera) as function of depth of the sediment. The diagram shows $\delta^{18}O$ for 5 million years. $\delta^{18}O$ is 1000 times the difference of the ^{18}O to ^{16}O ratio for the sample and a standard divided by the standard value. Lower $\delta^{18}O$ corresponds to colder climate. Measurements from the Atlantic Ocean east of Africa. (site 659: 18° 05′ N, 21° 02′ W). The horizontal dashed line corresponds to the present value. Data from (Clemens&Tiedemann, 1997).

We see in fig 1 that the Ice Ages began about 3.2 million years ago. Before that time the temperature was similar to that of our time. The mean temperature of the Ice Ages was low, but the temperature variations were large. In fig 1 with the scale of million years the end of the Ice Ages and the present situation are not visible.

2.2 When did the Ice Ages end

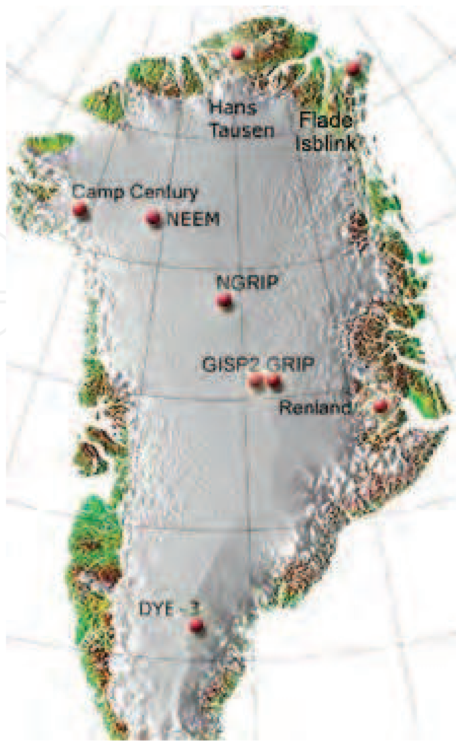


fig 2. Location of the GISP2 and NGRIP stations in central Greenland.

The ^{18}O to ^{16}O isotope ratio can also be measured as a function of depth in an ice core. Fig 2 shows the position of the GISP2 research station. Variations of the isotope ratio of Oxygen in Greenland arise from the following process. Water evaporates from tropical seas. On the way to arctic regions it rains. In the formation of ice particles or water droplets there is a slight preference for the heavier atom. This is actually a quantum effect, due to the fact that lighter atoms have a higher energy in a localized state. This selection is more effective at lower temperatures. Therefore, the lower the temperature between the tropical sea and the arctic position of GISP2, the more deficient in the heavier atom will the isotope ratio be. This indicates a temperature variation of the hemisphere. In fig 3 the red curve shows this as temperature at the site in Greenland for the last 20 000 years.

10 000 years ago the Ice Ages with its cold periods and violent climate changes stopped. This is the end of the geological period called Pleistocene and the beginning of the Holocene, which in its usual definition includes the present time. Most of the Holocene was warmer than at present. Its temperature variations of up to two degrees were much smaller than those of the Ice Ages. Still, they could be a respectable threat to civilization. The last 200 years were calm, so that man made changes (subsection 2.4) became a serious consideration.

2.3 Are we at present between two cold periods or did the Ice Ages end definitely?

This is the basic question of this paper. Are we in a warm peak like those of Fig 12 or in a period as before 3.2 Myr in fig 1 ?

The dominant theory assumes that the Ice Ages with all its variations were a product of the system. Small changes of Earth's orbit due to the other planets lead to small changes in solar

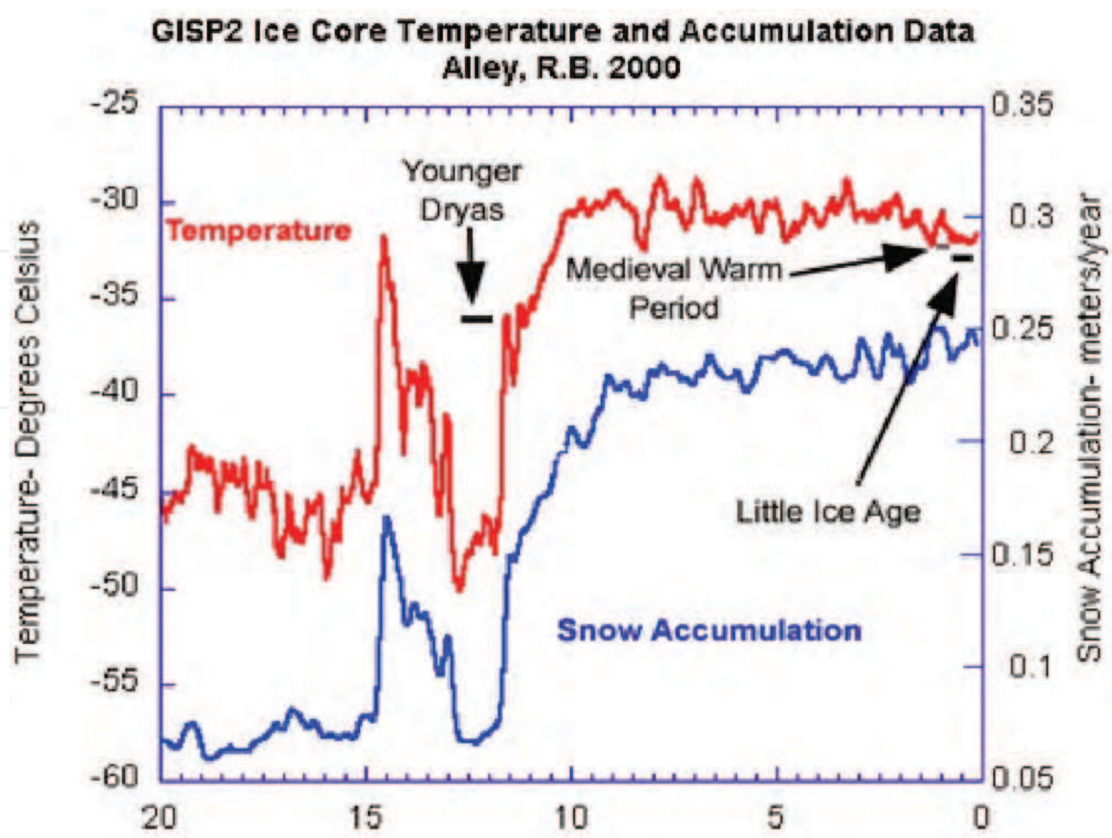


fig 3. Temperature at the site GISP2 in Greenland as inferred from the ^{18}O to ^{16}O ratio in an ice core for the last 20 kyr. Also shown (blue) is the yearly snow accumulation, which increases with temperature. Data from (Alley, 2000).

radiation on Earth, as first calculated by Milankovitch (Milankovitch, 1941). In many research projects Milankovitch cycles have been identified in the empirical data. This is common to all theories, since the variations of the solar radiation and some feedback undoubtedly exist. The distinction is quantitative: the main stream theory assumes the feedbacks to be sufficiently large to produce non linear effects and thereby the Ice Age mode of the climate system with cold periods and strong variations.

In the theory with a pole shift the Ice Ages were produced by an exceptional astronomic object, a hot evaporating planet Z, which no more exists. In this model the exceptional situation is gone and will not come back. This theory is actually not a wide open field, but a narrow window. It describes a barely possible sequence of events.

The mere fact that the Ice Ages had a beginning and apparently an end may favor the second theory, but it does not contradict the first. As an example, you may drive a car on a rainy day. The windscreen wiper works smoothly. Suddenly it starts jumping noisily over the window. The system went into a different mode. This may reverse after a while. In this case the noisy mode may start again. This simple mechanical system can work in two modes.

For much older geological times (about 600 to 750 million years ago) there are evidences for a "Snowball Earth" (Snowball, Bibl.). Then the continents were joined together. When the continent is one block, then it surrounds the rotation axis in the stable motion of the rotating globe. The causes of the "Snowball Earth" may be quite different from those of the Ice Ages.

2.4 How important are the man made climate changes?

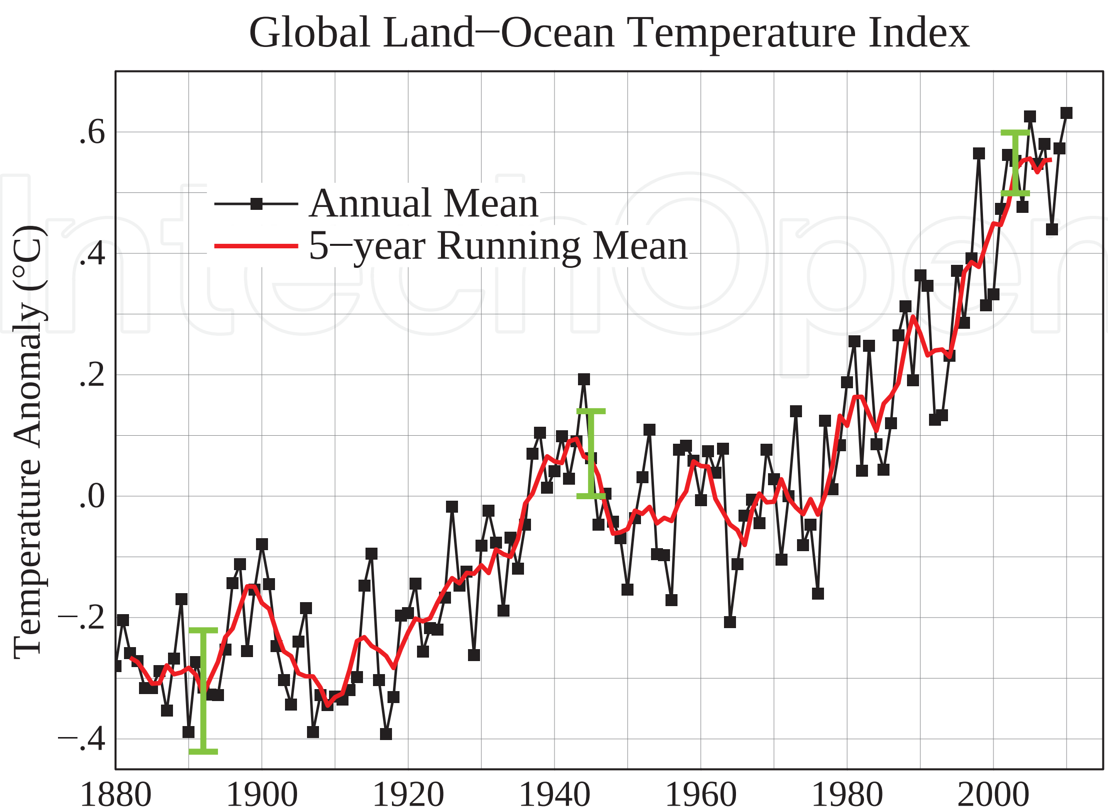


fig 4. Global averages of measured temperatures since 1880. Green intervals are estimated uncertainties. Figure from NASA.

Fig 4 shows instrumental mean global temperatures since 1880. The temperature increase of about 1 degree centigrade is most likely due to greenhouse gases, notably CO_2; it is human made. Since it modifies the environment to which plants, animals and ourselves are adjusted, we must consider it as bad. Fig 3 shows that the variations of the temperature of the last 10 000 years were larger, and in the Ice Ages they were so enormous that the mere survival of a species must have been an achievement.

The development of the human species in the last 2 to 3 million years was simultaneous with the Ice Ages; this is certainly not a mere coincidence. In the dramatic climate changes the innate reactions of the individuals may often have been inadequate. The large brain of the human species can carry a complex language. Thus humans dispose of a new type of information: orally transmitted experience. This was an advantage. It also created new problems: the language had to learned, so that the time of childhood was increased, the brain is energy consuming, and - last not least - there are two decision makers in one brain: the instinctive and the rational.

The climate changes of the Ice Ages inhibited organized civilizations; therefore we probably tend to underestimate the capabilities of the humans of those times. Even 8 000 years ago, when organized civilizations arouse, the climate showed considerable variations (Fig 3). The quiet period of the last 300 years may have helped the astounding development of our modern world.

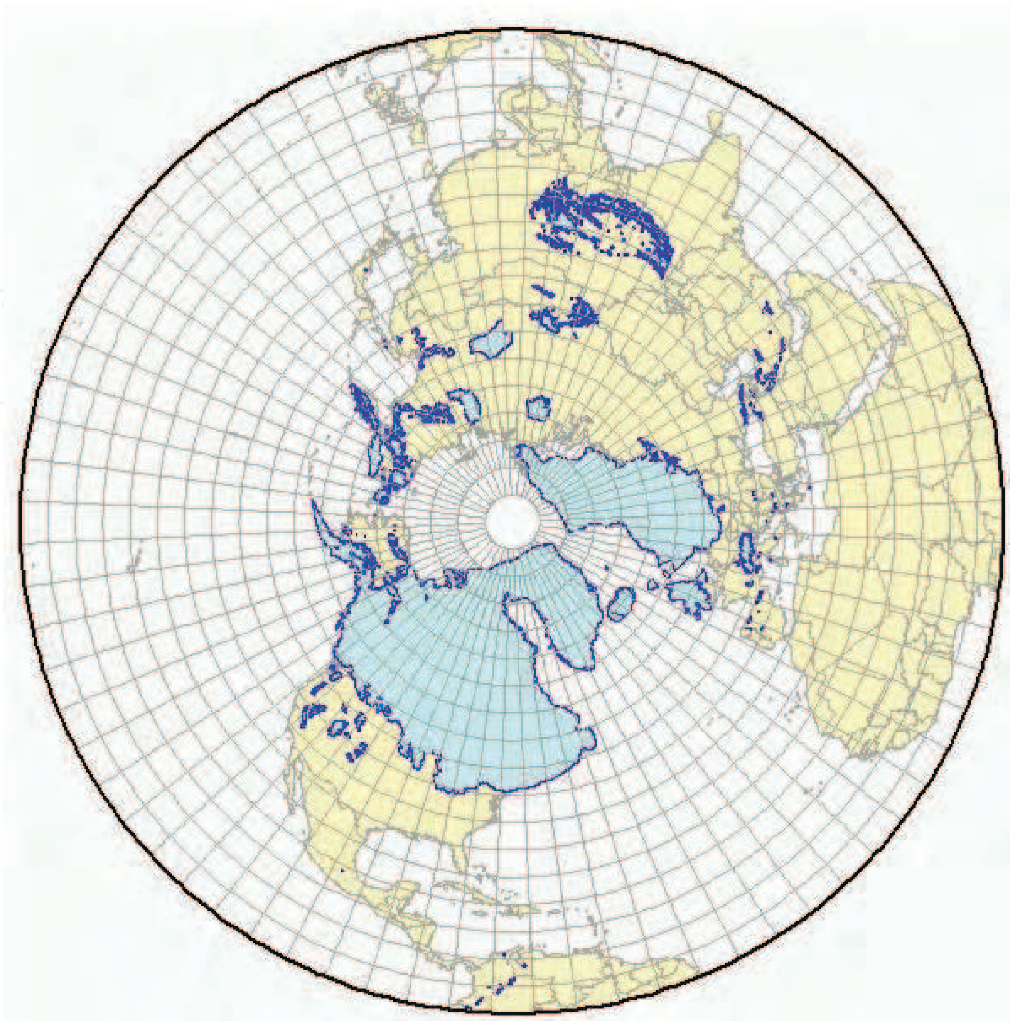


fig 5. The largest glaciation (about 20 000 years ago) was not symmetric with respect to the present position of the North Pole in the Arctic Sea. fig by J, Ehlers. Data from (Ehlers& Gibbard, 2004)

What value should we give to the measured mean temperature changes of fig 4? They are now larger than intrinsic fluctuations, which reversed the trend between 1940 and 1980. Clearly, we should avoid modifying the global climate, which is the basis of life of all plants and animals and ourselves. However, the answer depends on the theory of the Ice Ages. If the system itself produced the Ice Ages, then the most urgent questions are: Do we understand how the Ice Ages were switched on and off? Do the greenhouse gases increase or lower the chances that the system drops again into its Ice Age mode?

In the theory with a pole shift there is no danger of a new Ice Era, since astronomical observations show that the causes (a hot planet or its fractions and a disk shaped cloud of ions around the Sun) have disappeared. Therefore, the planetary system is now clean, and it is up to us that we do not perturb our climate. In this view, at least after the Little Ice Age, i.e. about 300 years ago, a new, clean period had started. In the Holocene, the warmer temperatures and their variations were produced by the cloud from the fractions of Z. At present this cloud does not exist any more. This geological period deserves to have a new name, such as the sometimes used ”Anthropocene”.

2.5 Why was the glaciation asymmetric with respect to the present position of the North Pole?

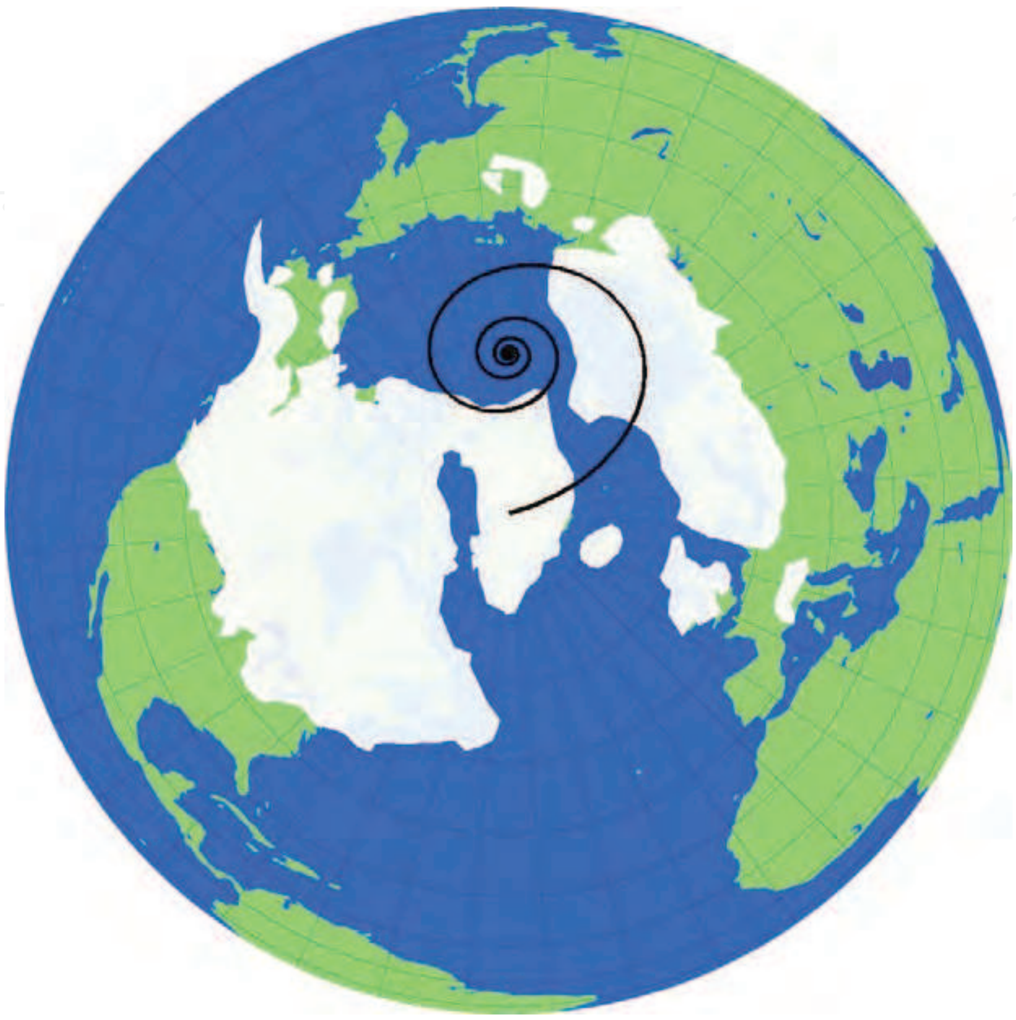


fig 6. Geographic shift of the North Pole: path from Greenland, the assumed center of the largest glaciation, to the present position in the Arctic Sea. One turn of the spiral takes about 400 days (Chandler period). fig from Woelfli et al. (2002)

The maximum ice distribution on land is clearly visible from erosion and moraines. It occurred about 20 000 years ago. The ice reached New York City, while East Siberia remained ice free. In fig 5 the center of the ice distribution is obviously not the present North Pole in the Arctic Sea. The glaciation suggests a position in Greenland, about 17° away from the present North Pole. The best suggested position depends on the influence attributed to the Atlantic Ocean.

Remains of mammoths have been found in East Siberia in regions with a high latitude, where at present these herbivores could not exist. In East Siberia herds of mammoths grazed within the arctic circle, even on islands in the Arctic Sea, which were connected with the mainland during the glacial periods. These facts were first reported in the Soviet literature and are confirmed by current investigations (Bocherens, 2003; Orlova et al., 2001; Schirrmeister et al., 2002). The data are complex, since the temperature varied between stadials and interstadials, but consistently this area was not ice covered. The yearly insolation decreases with increasing latitude. The present distribution of the flora on the globe suggests that in arctic regions the yearly insolation is insufficient for steppe plants.

While the North Pole changed from land to sea, the South Pole remained within the Antarctic continent. Correspondingly, the climate was less affected on the southern hemisphere.

These facts are explained by the shift of the poles, which is the basic assumption of the alternative theory.

The dominant theory discusses changes of the water currents in the oceans. In particular, during cold periods the Golf Stream is supposed to sink into the deep Atlantic and revert its direction before it reaches Northern Europe (fig 7). At present the importance of water streams as compared to air currents is questioned (Seager, 2006). The absence of glaciation in East Siberia is attributed to cold and dry air with the corresponding lack of snow (fig 3).

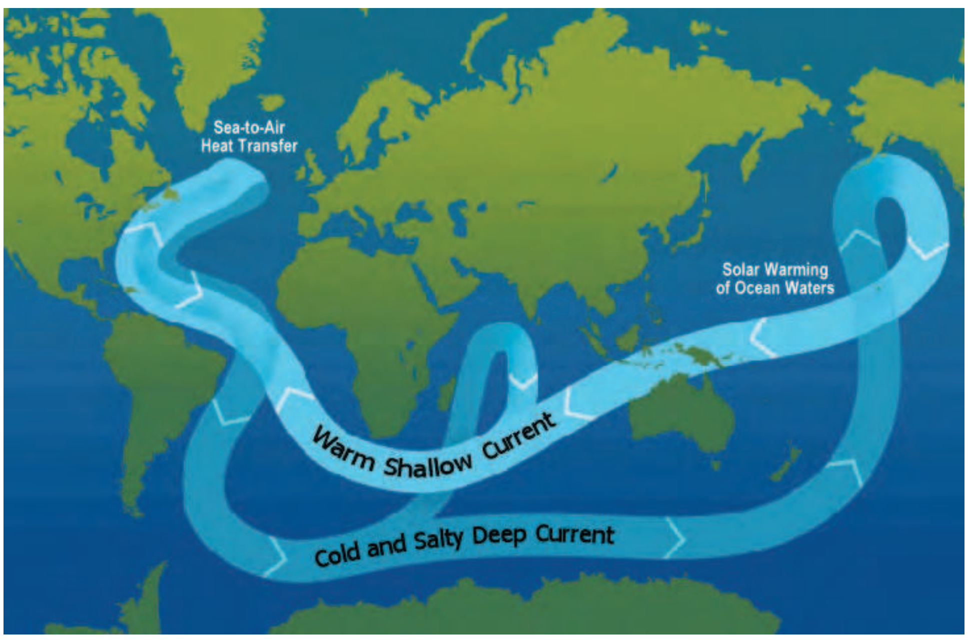


fig 7. Simplified picture of the ocean streams.

3. The rapid geographic shift of the poles

The observation that during the ice ages the North Pole was in Greenland was the motivation for postulating planet Z. At the the end of the Pleistocene the Earth turned relative to the fixed rotation axis. We claim, that a close passage of an object with about 1/10 the mass of the Earth could do the trick. Fig. 6 shows a calculated geographic path of the North Pole. One turn of the spiral takes about 400 days.

This event of the close passage of Z was complex. Z was scattered by a few degrees and, aided by the pressure of the hot interior, it decayed into several parts. The evaporation rate from the fractions is vastly increased, since their escape velocity is reduced. At present they do not exist any more. However, during their evaporation a dense disk shaped cloud around the Sun made an angle of a few degrees with Earth's orbit. Then most of the time the Earth was outside this cloud and received an increased amount of radiation due to scattered light from the cloud.

3.1 What is the physics of a rapid geographic pole shift?

This subsection is destined to those who want to know the mechanics that we used to describe the geographic motion of the pole. The inertial tensor of a rigid body with mass density $\rho(\vec{r})$ in a coordinate system fixed to this body and with the origin at the center of gravity is

$$I_{jk} = \int d^3r\, \rho(\vec{r})(r_j^2\delta_{jk} - r_j r_k) \tag{1}$$

The tensor I enters into the equation of motion for the rotation of the solid. This is the Euler equation, which determines the motion of the angular velocity vector $\vec{\omega}$ in coordinates fixed to the body:

$$\frac{dI\vec{\omega}}{dt} = [I\vec{\omega}, \vec{\omega}] \tag{2}$$

where the bracket signifies the vector product. The equation expresses the conservation of angular momentum in the moving coordinates.

We introduce a (dominant) relaxation time τ for global deformations. Let $I_0[\vec{\omega}]$ be the inertial tensor for the equilibrium shape of the globe with a rotation vector $\vec{\omega}$, i.e. for a globe with an increased radius at the corresponding equator. The inertial tensor $I(t)$ relaxes in direction to the one of the equilibrium shape $I_0[\omega(t)]$:

$$\frac{dI(t)}{dt} = -\frac{I(t) - I_0[\omega(t)]}{\tau} \tag{3}$$

The spiral of fig 6 is a numerical solution of the Euler and relaxation equations with τ =1 000 days. The Euler equation is valid for rigid solids only, but since $\vec{\omega}(t)$ varies much more rapidly than $I(t)$, it should hold approximately.

As initial condition, $I(0)$ was calculated for a globe with the increased radius at the equator and in addition a stretching deformation of one per mil in a direction 30° from the rotation axis. A real symmetric tensor can be represented by three axis. In the initial situation the longest axis of $I(0)$ makes an angle with the rotation axis. Then the rotation axis will precess around the main axis of I. This motion is similar, although much larger, than the observed "Chandler wobble". This is a minute geographic motion of the position of the rotation axis on the globe, in which the axis circles irregularly with a Chandler period of about 400 days. If the global deformation relaxes in a time, which is neither very short nor very long compared to this period, the geographic path of the rotation axis will be a spiral that ends at a different place than the starting point. This is the mechanics of a rapid geographic polar shift

3.2 Why was a polar shift considered impossible?

Already in the 19th century geologists wondered about the asymmetry of the glaciations as shown in fig 5. Then the possibility of a rapid geographic shift of the poles was studied by leading physicists including Lord Kelvin, J. C. Maxwell, G. Darwin and G.W. Schiaparelli. They concluded that a shift was impossible. A direct hit of an astronomic object of the required size would liberate an amount of energy incompatible with the continuation of life on Earth. A deformation of Earth, as we assume it, would relax too rapidly to allow the necessary shift. At that time, condensed matter was considered to be either solid or liquid, and in both cases the relaxation time would not be in the range of the Chandler period. Later, F. Klein and A. Sommerfeld (Klein & Sommerfeld,1910) in their compendium on the theory of the gyroscope remark, that there are also substances such as tar. The true relaxation of a deformed Earth to a new equilibrium shape is a complex phenomenon. We simply assume a relaxation time in the good range. Then the two formulas (2) and (3) indicate the essence of the phenomenon. That a rapid pole shift is possible has been pointed out by T. Gold (Gold,1955).

3.3 How could the Earth become stretched?

When a mass is not far from Earth, it accelerates the Earth as a whole, but the side near the mass more and the opposite side less. Thus the Earth is stretched by the tidal force. When the distance between Earth's center and the mass is large compared to the radii of these objects, the tidal force varies with the inverse third power of the distance. If the Moon were 10 times nearer, i.e. at 40 000 km, its tidal force would be 1 000 times larger. For the required pole shift this would not be sufficient. A 10 times bigger mass has to pass at half this distance to produce the 1 per mil stretching. When this happened, it produced a cataclysmic earthquake. Heavy animals could hardly survive.

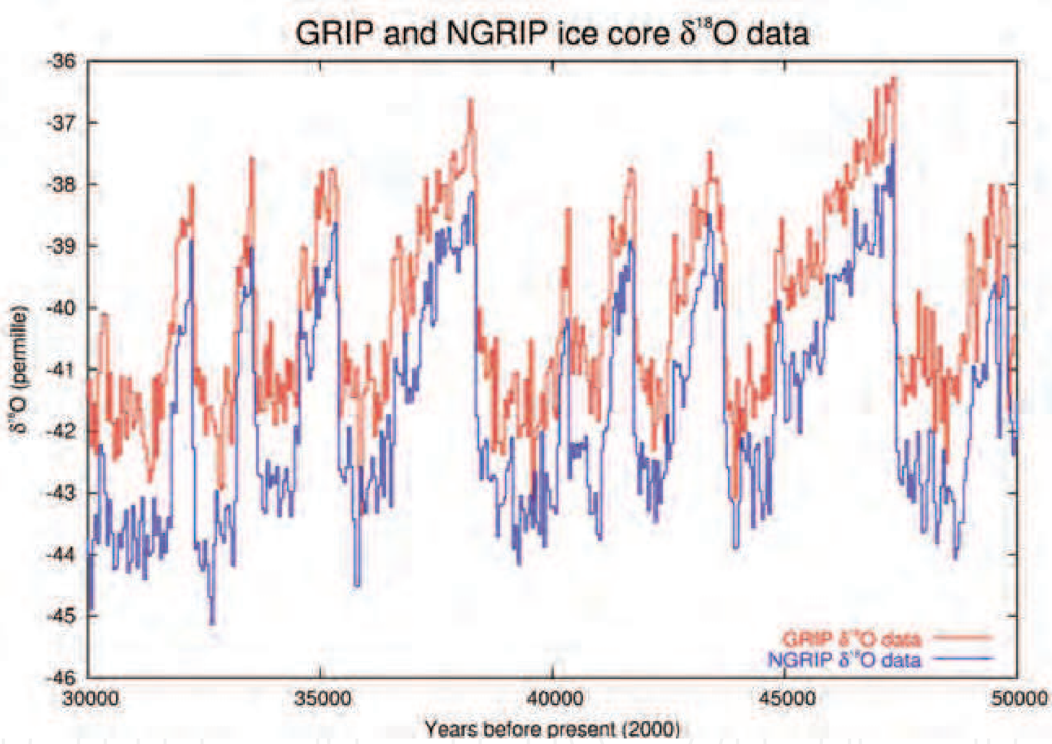


fig 8. Dansgaard-Oeschger Oxygen isotope variations in ice cores of two sites in Greenland

3.4 How could this passing mass disappear?

Earth created a tidal force on Z . Could this disintegrate this Mars sized object? In 1993 the comet Shoemaker-Levy 9 passed near Jupiter and broke into 21 fragments. This event was studied with a computer model by Erik Asphaug and Willy Benz (Asphaug & Benz,1996). Their fig 13 indicates that a Mars sized pile of stones (and therefore probably also a fluid sphere) passing near the Earth would not disintegrate into several fractions. However, if it were hot inside, the resulting pressure would tend to make it explode when deformed.

The evaporation from a planet is determined by gravity. The escape velocity of a fraction is smaller. This highly increases the evaporation rate. As the object loses mass, even molecules

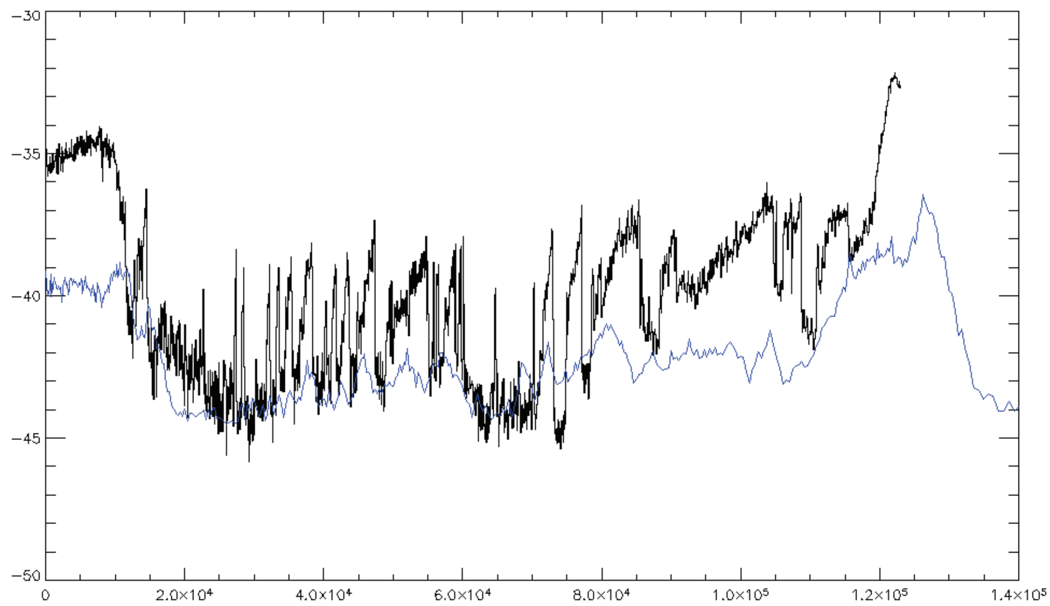


fig 9. Temperatures from Oxygen isotopes in Greenland (black) and Antartica (blue) between present and 140 000 years before present.

and clusters escape. Therefore, a fraction of a Mars sized object could evaporate within the 10 000 years of the Holocene.

The cloud produced by the evaporation of the fractions of Z will influence the climate on Earth during the Holocene. The close passage of Z near Earth scatters the fractions by a few degrees. In the case of the comet Shoemaker-Levy 9 the 21 fractions moved one behind the other practically on the same orbit. This indicates the possibility that during the Holocene the cloud continued to be disk shaped and furthermore that it made an angle with the plane of Earth's orbit.

3.5 How could this planet Z be hot?

Z must be hot, since otherwise it cannot disappear. Its orbit has to be extremely eccentric, so that it passes close to the Sun. Near the Sun it is heated inside by tidal work and outside by solar radiation. In our examples we often used an eccentricity $\epsilon = 0.973$. Then the ratio of the distance to the Sun at aphelion to that at parhelion becomes $(1+\epsilon)/(1-\epsilon) = 73$. During the Ice Ages Z was liquid and shining. It evaporated particles. Due to tidal work the parhelion distance slowly diminished. The cloud of evaporated particles became denser. Therefore, the characteristics of the Ice Age climate gradually increased. This effect is clearly visible in fig 1.

3.6 What were the chances of a close approach?

Since Z was in an extremely eccentric orbit, it passed radially through the sphere at the distance of Earth's orbit. This distance is the astronomic unit $A = 1.5 \cdot 10^8$ km. Let's suppose that the orbit of Z remained near the invariant plane, which is perpendicular to the angular momentum of the planetary system. Let's take near to mean within an angle of ± 1 degree. Then the crossings of Z at distance A are limited by a surface $S = 2\pi A \cdot 2(\pi/180)A$. For a near passage or hit the distance between the centers of Z and Earth have to come closer than $R = 20\,000$ km. The target surface is $T = \pi R^2$. Then $S/T = 4 \cdot 10^6$ is the typical number of

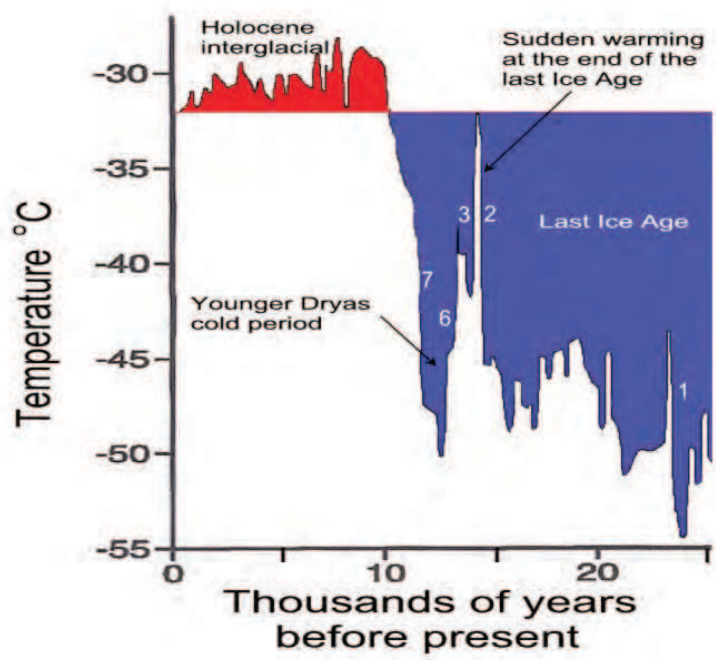


fig 10. The temperature change from Pleistocene to Holocene at GISP2. The change is representative for the northern hemisphere.

passages for one encounter. There is a lot of space in the planetary system! If the period of Z's orbit was of order 1 year, then it is expected to have spent of order 2 million years before the close encounter. This is the order of the time that the Ice Ages lasted.

An actual hit would occur at distances under $R/2$. Fortunately, a close passage between $R/2$ and R is 3 times more probable. Nevertheless, this shows that the scenario could not have happened several times while life on Earth developed. This hot planet must be something exceedingly rare and therefore unlikely to be observed.

The fact that Z is singular corresponds to a rare origin: perhaps a moon of Jupiter or even an object from interplanetary space (MOA & OGLE, 2011).

This theory with a pole shift is a narrow window. The necessary sequence of events is quite well defined. This is actually a strength of this model: if it fits the facts, then this is not adapted by hand. However, we must admit that our estimates were crude, mostly determining orders of magnitude. More detailed estimates should be made. If they differ from ours, they could close the window.

4. The disk shaped cloud around the Sun

4.1 How was this cloud created?

Z had sufficient mass to produce a 1 per mil stretching deformation on Earth during its close passage and it had to disintegrate into fractions in this event. Therefore it must have been hot inside. If its orbit was very eccentric, near the perihelion, say at about 4 million km from the Sun, it was heated inside by tidal work and on the illuminated surface by solar radiation. Evaporation was possible for particles which exceeded the escape velocity, which must have been about 5 km/s. As an example, for an ^{16}O atom the corresponding kinetic energy is 2.1

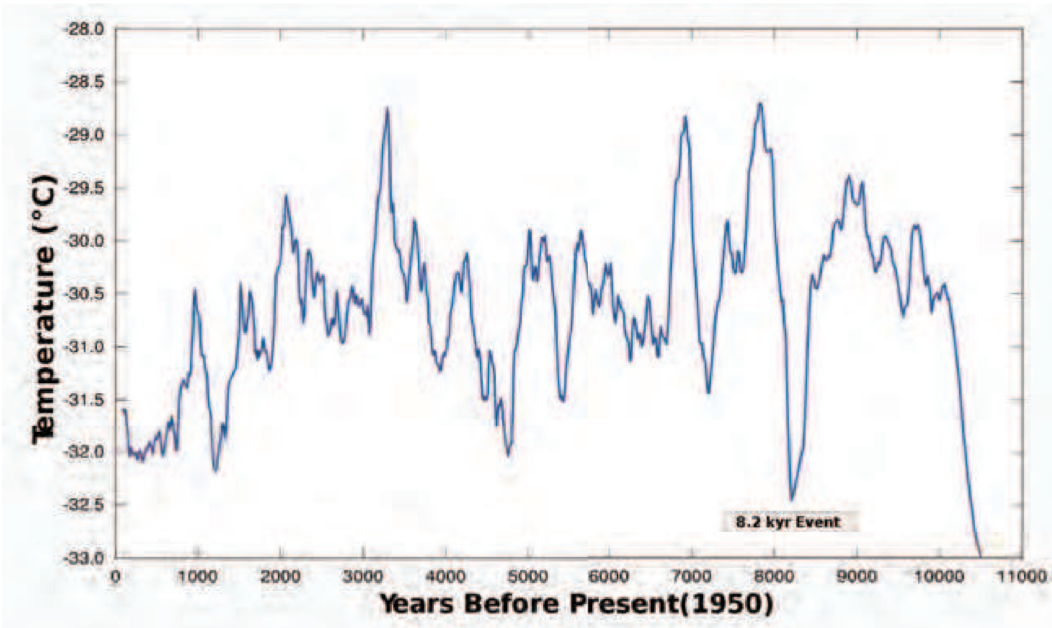


fig 11. Temperatures in the Holocene from isotope variations in ice at the Greenland station GISP2.

eV. Even for a temperature of $T = 1000^\circ$ this is 16 times larger than the mean thermal kinetic energy $\frac{3}{2}k_B T = 0.13$ eV. Evaporation against gravity favors light particles. The evaporated elements have a strong isotope effect.

The speed of Z is much higher than thermal velocities. The emitted particles start their journey practically with the velocity of Z. They are attracted to the Sun by gravity and repelled by the light pressure, which also decreases with the inverse square of the distance. Effectively, the particles suffer a reduced gravitational attraction. If light pressure on particles were a purely geometric question, the cross section of a spherical cluster would increase with the square of the diameter and the mass with the cube. Then for a density of 1000 kg/m^3, light pressure would dominate gravity, when the diameter of the sphere is less than $1.16 \cdot 10^{-6}$ m. At present in the solar system a weak dust cloud exists, which is visible in a dark night as Zodiacal light. This dust is due to asteroids, which disintegrate near the Sun.

The cloud produced by the evaporation from Z is quite different. Scattering of light from small objects is not a geometric problem. For atoms, ions or molecules quantum phenomena rule. If the particle has a dipole transition in the main solar spectrum, light pressure dominates. For that reason molecules and atoms (with the possible exception of Helium) cannot remain in an orbit around the Sun. Actually, molecules dissociate and atoms ionize. Then excitations by the solar radiation become quite rare. Some weak light scattering by the ions will persists from resonant scattering near the high end of the solar spectrum or from forbidden transitions.

4.2 How did the cloud disappear?

When Earth's orbit is in the cloud, it receives less solar radiation. A decrease of a few percent reduces the global temperature to the level of the cold periods.

The cloud is composed of ions in orbits, which are slightly different from that of Z due to thermal velocities and the interaction with solar light. The density of ions in the cloud

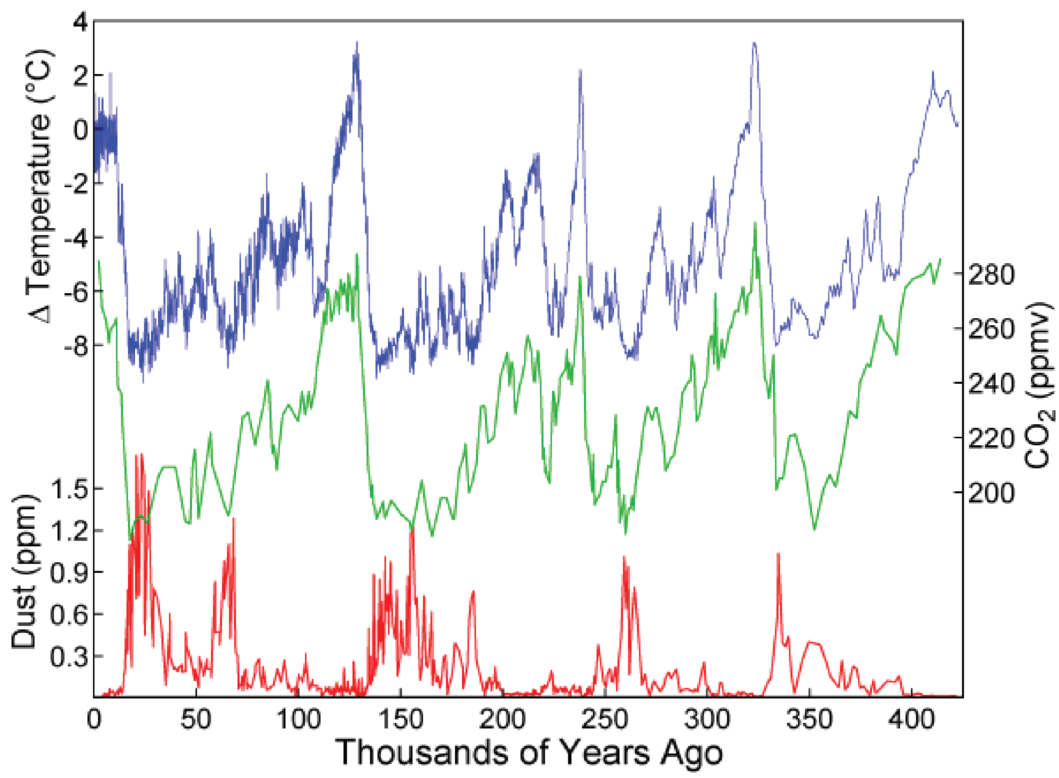


fig 12. Temperature Variations (blue), CO_2 (green) and Dust content (red) in an ice core from the Vostok station in Antarctica over the last 420 000 years. Data from (Petit et al.1999)

increases with each passage of Z near the Sun. Since the particles have planetary velocities, collisions between ions can be inelastic. They convert kinetic energy into light. The reduced orbits have a higher probability for further collisions. Light carries little momentum, so that these processes end in small orbits with the initial angular momentum (Woelfli& Baltensperger, 2007a). The Poynting-Robertson drag (Gustafson, 1994), a sort of friction with light, finally leads the particles into the Sun.

We frankly admit that this cloud of ions and electrons, this plasma, may have many properties unknown to us. Just imagine how a purely theoretical study of water vapor in Earth's atmosphere could miss the clouds and their amazing variety, which determine the weather. Possibly the plasma lowers the energy of electric fields diminishing the width of the cloud. Then this width could be smaller than what is expected from the initial thermal velocities of the particles. For us, the question whether electric discharges exist in the cloud, is open.

4.3 What caused the Dansgaard-Oeschger events?

Fig 8 shows isotope variations due to temperature changes of the northern hemisphere, which have first been described by Dansgaard and Oeschger (Dansgaard, 1993). The periods are too short to be connected with Milankovitch cycles of Earth's orbit. In the dominant model these variations are attributed to changes of water streams on the surface and depth of the oceans (fig 7).

We suggest that the gradual increase of the cloud's density followed by its collapse corresponds to the lowering of the global temperature followed by its rapid increase.

Fig 9 shows, that the Dansgaard-Oeschger temperature variations are much smaller in the Antarctic than in Greenland. This may be due to stronger feedbacks on the northern hemisphere.

4.4 Why was the Holocene mostly warmer than the present?

Various aspects of climate variability of the last 10 000 years, i.e. the Holocene, have been examined (Mayewski et al.,2004). Global temperature variations were found. Fig 11 shows data from the GISP 2 station: the temperature was mostly higher during the Holocene than at present. The main stream theory does not offer processes, that would explain the large temperature increases at the GISP2 station over the present temperature. The CO_2 content varied. However, the changes of CO_2 content followed the temperature variations and could not be the cause. Warmer oceans emitted CO_2 into the atmosphere and colder oceans absorbed it. The temperature varied too rapidly to be connected with Milankovitch changes of Earth's orbit.

In our model (Woelfli & Baltensperger,2007) a close approach of Z with Earth happened at the End of the Pleistocene. The hot planet disintegrated into several fractions, which evaporated during the Holocene. Therefore an intense disk shaped cloud existed around the Sun. Due to the scattering at the close encounter the plane of the orbits of the fractions probably made an angle of one or several degrees with the plane of Earth's orbit. Each year the Earth crossed this cloud twice, but most of the time it was outside and received scattered light. Since the outgoing radial component of the radiation flux is diminished inside the cloud, it must be larger outside. In addition the scattered light has tangential components. Therefore, outside the cloud there is additional radiation.

Thus the cloud cools the Earth in cold periods and it warms it in warm periods. In this last case, an increase in the clouds density increases the temperature gradually and the cloud's collapse diminishes it abruptly. Warm periods have reverse Dansgaard-Oeschger events with gradual warming and rapid cooling. In fig 11 this tendency is recognizable in contrast to the cold periods of fig 8 or fig 9.

4.5 Why was the last interglacial warmer than the present?

As seen in fig 12 the cold periods were separated by warm periods roughly with a 100 ka periodicity. The last interglacial began 127 kyr ago and lasted for about 9 000 years. It was warmer than the present time. Forests reached the North Cap, where now there is tundra. The sea level was 4 to 6 m higher. This indicates warmer oceans and less glaciation.

The cloud again offers an explanation. When the inclinations of Earth's orbit and of the cloud differed sufficiently so that the Earth was outside the cloud, then the Earth received solar light scattered by the cloud. Half a year one side of the Earth was illuminated and, after crossing the cloud, half a year the other side. Since the light comes from a planar cloud and Earth's obliquity to the orbit is only about 23°, this additional illumination changes essentially from one hemisphere to the other. When within the year this change happens depends on unknown details of the orbits. The additional illumination would be most effective, if each hemisphere received it during its winter.

What was the color of the scattered light ? This is not an easy question, since the particles in the cloud are ions without a dipole transition in the main solar spectrum. That may be an argument for the violet end of the solar spectrum. However, weak transitions of lower energy could also contribute.

4.6 Why were small grained inclusions in ice cores dense in cold periods?

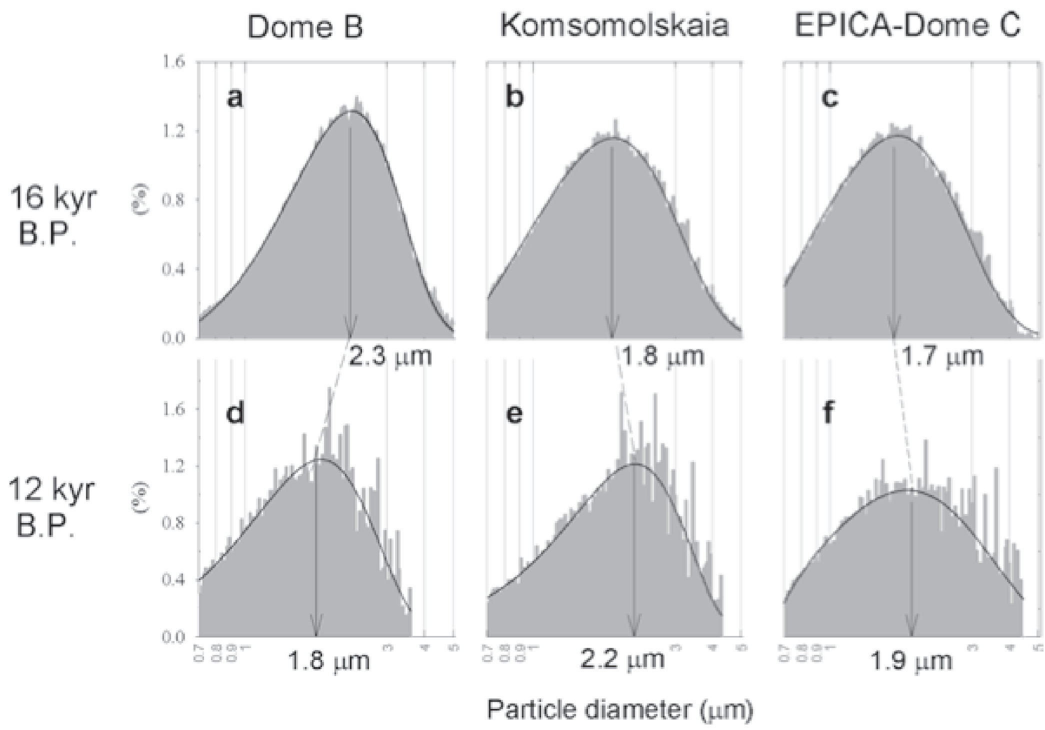


fig 13. Distribution of the small grained dust (radius $< 4\mu$m) from 3 Antarctic sites and two dates. Data from (Delmonte et al.2003).

The red curve of fig 12 represents the dust content in ice cores of the Vostok station in Antarctica. A comparison with the blue curve shows that the dust density is high during cold periods. Planet Z theory offers this interpretation: in cold periods Earth's orbit is in the cloud, so that particles enter into Earth's atmosphere, where they coagulate and are included in precipitation or sink to the ground.

The dust in the ice cores contains small (radius $< 4\mu$m) and large grains. The small grains have a bell shaped distribution as seen in fig 13. This regular distribution may result from a coagulation in the upper atmosphere (Baltensperger& Woelfli, 2009). In this case, the small grained dust would be extraterrestrial. The evaporation from Z would modify its isotope distributions. We suggest that this should be examined using the three stable isotopes of Mg. The absence of an isotope effect in Mg would be a severe difficulty for our theory. In order to determine the origin of the small grains the isotope distributions of Sr and Nd has been compared with that from samples from many regions of the globe (Delmonte et al., 2004b). An agreement was found between material from Antarctica and from Patagonia. In Table 1b of (Delmonte et al., 2004b) the samples of South America are dated; those of the Pampas have ages between 10 and 25 kyr. It was concluded that the small grains have been transported from Patagonia to Antactica (Delmonte et al., 2004b; Gaiero, 2007). However, it is also possible that the grains from the two regions have the same extraterrestrial origin.

Large dust particles in ice cores have more irregular size distributions. They have been examined carefully, since their mineralogical structure reveals their origin. The large grains from antarctic sites come from Patagonia, while those from Greenland originated in the Gobi desert (Biscaye et al., 1997). They must have been transported by storms.

5. The Milankovitch cycles

5.1 What are Milankovitch cycles?

The mass of the Sun is about 1000 times larger than the mass of all its planets. Therefore, the motion of a planet is an approximate two-body problem: planets move in Kepler orbits. Milankovitch considered the gravitational interactions between the planets and found that the parameters of the Kepler orbits suffered slow variations. Typically, the variations of an orbital parameter are dominated by one or a few frequencies. These are the Milankovitch cycles.

5.2 What produced the 100 000 year cycle of the Ice Ages?

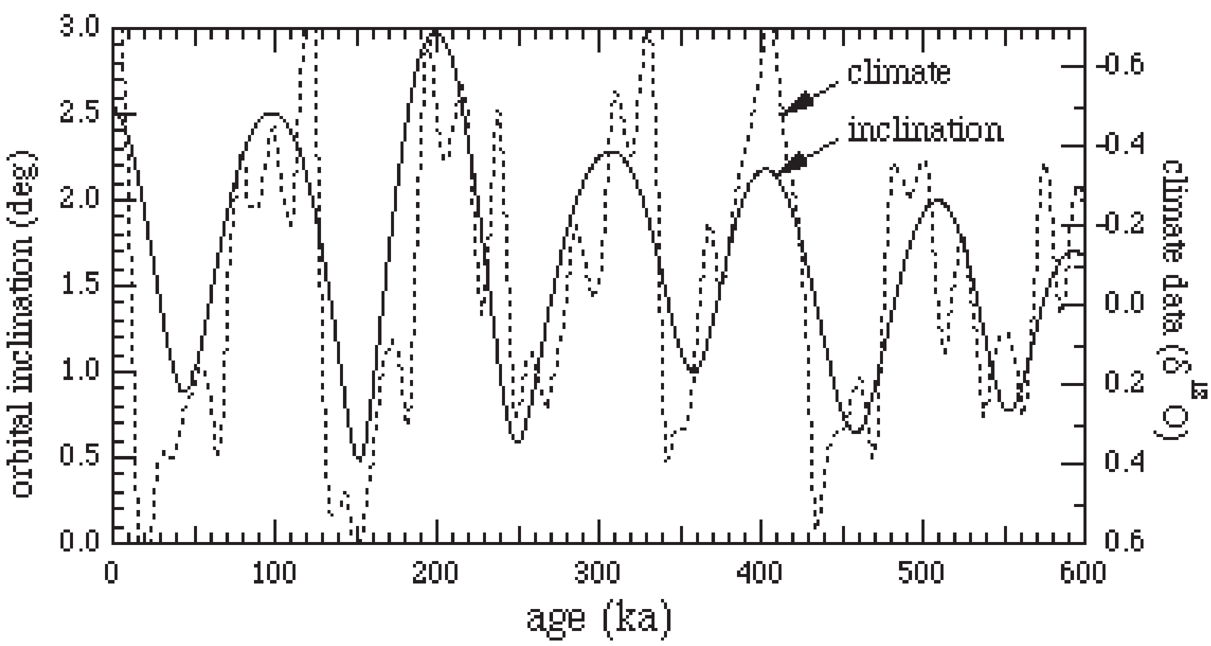


fig 14. The calculated inclination of Earth's orbit (full line) and the isotope variation $\delta^{18}O$ (dotted line) from (Imbrie et al., 1984) for 600 000 years. Figure from (Muller& MacDonald, 1995)

Figures 12, 14 and 15 show that 100 000 years is the strongest period of the Ice Ages. Earth's inclination, i.e. the angle between the plane of Earth's orbit and the invariant plane (perpendicular to the angular momentum vector of the planetary system) varies with this period. In view of this, R.A. Muller and G.J. MacDonald (Muller& MacDonald, 1995; 1997) postulated the existence of a disk shaped cloud around the Sun. Depending on the value of the inclination, the Earth would be inside the cloud and therefore in a cold period or outside in a warm period. In the planet Z theory, this cloud necessarily exists before the pole shift.

The dominant theory is based on the Milankovitch cycles. However, changes of the inclination are not relevant in this theory, since the Sun radiates with equal strength in all directions.

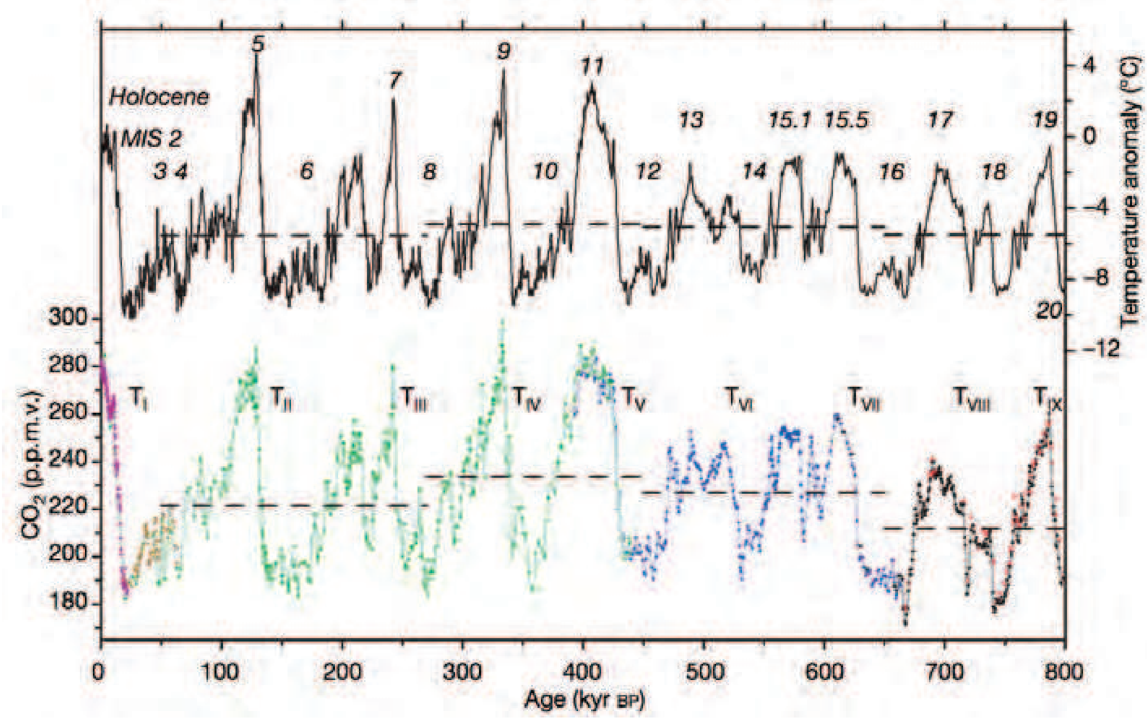


fig 15. Temperature anomaly with respect to the mean temperature of the last millennium (EPICA from antarctic Dome C) and CO_2 record from several research groups. A tendency of a sharp increase in temperature followed by a gradual decrease exists in the 100 kyr period. Figure from (Luethi & al., 2008)

Earth's orbital eccentricity has periods at 95 kyr, 105 kyr and 400 kyr. The problem is that with Earth's small eccentricity (< 0.05) the variations have little effect on the insulation. If one argues that strong feedbacks could amplify these effects, then it remains unclear, why the 400 ka period is not visible. Thus, the strongest period of the Ice Ages of the last million years remains unexplained in the dominant theory.

5.3 What determined the shape of the 100 kyr cycles?

fig 12 and 15 show that the 100 kyr cycles have a similar behavior as the Dansgaard-Oeschger events in fig 8: a rapid increase in temperature is followed by a gradual decrease. We do not know the origin of this. If in Dansgaard-Oeschger events the cloud builds up in a time of about 2 kyr and then collapses, this cannot be responsible for a 100 kyr buildup. There must be a climate relevant process on Earth or in the cloud or in their coupling, which requires 100 kyr for its formation. Does this shape simply indicate that creating ice in the cold takes more time than melting it?

5.4 Why could the 40 000 year cycle be dominant before 1 million years?

The 100 kyr cycle was only dominant in the last million years. Before that time a 40 kyr cycle appears. Since the Earth is essentially a sphere and its orbit nearly a circle, the total insulation on Earth is essentially constant. However, the axial tilt, the angle between Earth's axis and the perpendicular direction to the orbital plane, varies between 22.1° and 24.5° with a 41 kyr cycle. The larger this obliquity the more winter differs from summer on both hemispheres. Since the hemispheres differ from each other and feedbacks depend on the seasons, the obliquity affects

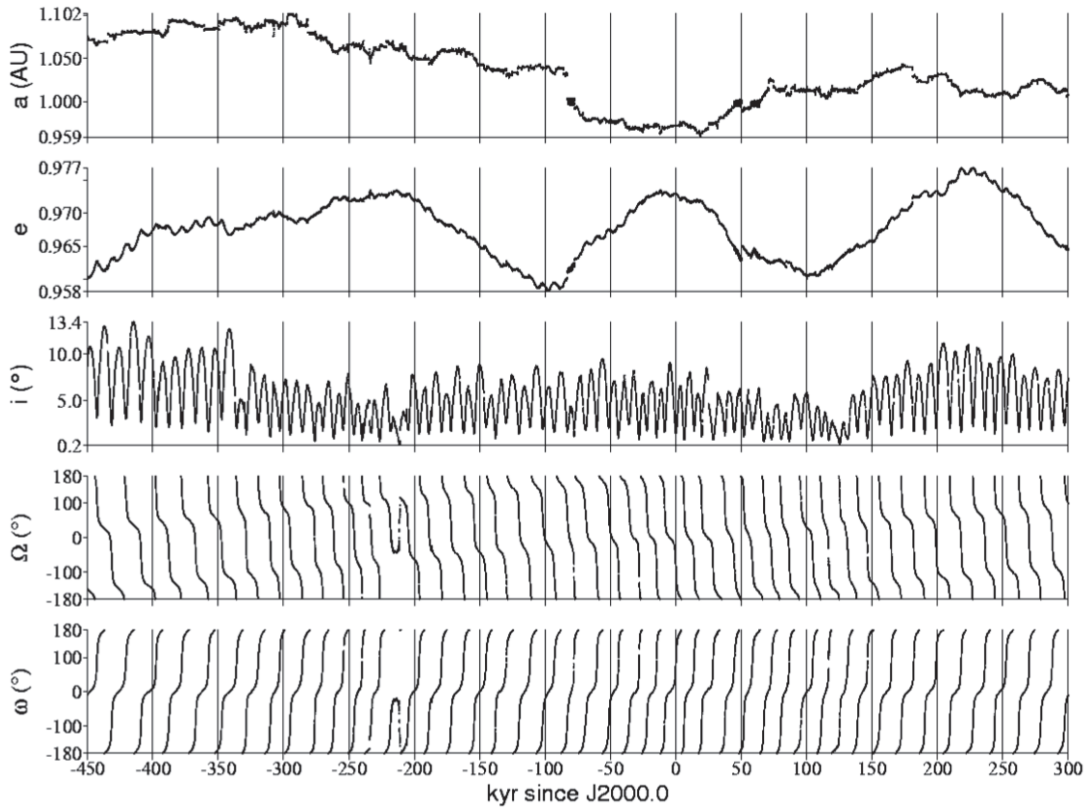


fig 16. Calculated Milankovitch variations of the orbital parameters of Z with assumed mass $0.11 M_E$. (a, semi-major axis; e, eccentricity; i, inclination; Ω, longitude of the perihelion; ω, argument of the perihelion) over 750 kyr. Note the short cycles of the inclination. Details of the calculation are found in section 2 of (Nufer et al., 1999).

the mean temperature. Evidently, an explanation of the 41° cycle involves detailed knowledge of the climate system.

The disk shaped cloud due to Z explains the 100 kyr climate cycle by the inclination cycle. However, in the theory with a pole shift we only know Earth's orbit after the cataclysmic encounter. Then Earth was scattered and this could change the angle of its motion by a sizable fraction of a degree. The fact, that the calculation backward in time is made with an invalid orbit may be a reason for a failure for large times. Furthermore, the existence of Z may have an unknown influence on Earth's orbit. In the theory with a pole shift long backward calculations are doubtful.

5.5 What about Milankovitch cycles of Z ?

For Z in an eccentric orbit a calculation of the Milankovitch variations is reported: fig 16 (Nufer et al., 1999). In this example, the inclination of Z shows variations of 10° with periods less than 10 kyr. Consequently, a single particle of the cloud emitted from this Z should have similar variations. However, in the interpretation of the 100 kyr climate cycle the cloud behaves like a disk in the invariant plane. For this to be true, the particles must be coupled somehow in this plasma of ions and electrons, so that their variations average out. At present this is an open problem.

In fig 11, occasionally, the temperature drops for times of the order of a few hundred years, notably at the 8.2 kyr Event. Then Earth entered the cloud in a motion too rapid for Earth's periods. In this case evidently the cloud continued to grow, since afterwards the temperature had gradually increased, as it should in a reverse Dansgaard–Oeschger event.

6. Does this paper lead to conclusions?

This depends on the reader, especially since two very different theories are confronted.

The dominant theory is based on the Milankovitch cycles. A wealth of research has shown that Milankovitch cycles appear in the climate data. The production of these data are one of the truly great scientific achievements of our time. In our view an influence of the Milankovitch cycles on climate is undisputed. The question is, whether the Ice Ages were produced by the Milankovitch variations and Earth's climate system alone. The dominant theory assumes that this is the case. It claims that feedbacks amplify small differences of the radiative input to the extend that the climate system can enter into a different mode.

The starting point of the alternative theory with a pole shift is the asymmetry of the glaciation with respect to the present position of the North Pole, as seen in fig 5. We claim that the geographic pole shift shown in fig 6 is both necessary and possible. It requires a hot planet, which produces a disc shaped cloud of ions around the Sun.

In a way the situation resembles that of a century ago, when the energies of electrons emitted by light from a metallic surface could not be explained by Maxwell's equations. These well proven equations continued to be valid, but something else had to be introduced: quantization. Quantum theory became a vast science with many applications. It was somewhat crazy at the beginning and continues to be so at present.

We claim that the Milankovitch cycles are valid, but a hot planet Z has to be introduced. Z was probably unique in the history of the Solar system, since it involved a danger of collision with Earth, which would have stopped the development of life. The requirements on Z are stringent. This theory is not a vast field, but a narrow possible window. Although the theory involves only known scientific concepts, the uniqueness of Z makes it look somewhat crazy.

If you accept Z, you understand

- the asymmetry of the glaciation (fig 5),
- the gradual lowering of the temperature and increase of the fluctuations during the Ice Ages (fig 1),
- the fact that the Ice Ages lasted for a time of order a few million years (fig 1),
- the rapid geographic shift of the poles, a cataclysmic event, which killed heavy animals (fig 6),
- the dominant 100 kyr cycle of the ice ages (fig 14),
- the high density of small grains in ice cores during cold periods (fig 12),
- the gradual decrease and rapid increase of the temperature of Dansgaard-Oeschger events (fig 9),
- the enhanced temperatures during the Holocene (figs 10 and 11) and the last interglacial (fig 12) as compared to the present,
- the reverse Dansgaard-Oeschger events (i.e. gradual increase and rapid decrease of the temperature) in the Holocene (fig 11),

This list contains basic properties. There are may special facts that become plausible: e.g. northern Amazon was a desert (Filho et al., 2002), because before the pole shift its latitude was that of the present Sahara, or Bolivia was humid (Baker, 2001), because it was at the equator, or lake Baikal was not frozen during the whole year in cold periods (Kashiwaya, 2001), since it was about 10° further south than at present.

So far the theory of the pole shift has only been sketched. Some of our estimates were just order of magnitude considerations. Further work would be highly valuable. Research on the Ice Ages is a detective story. A scientist should be able to keep more than one theory in his mind. Also, a hypothesis must be excluded by scientific arguments only.

The concept ”reverse Dansgaard-Oeschger event” visible in temperature variations of the Holoceen, fig 11, and its interpretation may be new. Otherwise, the aim of this chapter was didactic.

7. References

Alley R.B., (2000). The Younger Dryas cold interval as viewed from central Greenland. *Quaternary Science Reviews,* 19, 213–226.

Asphaug E. & Benz W. (1996). Size, density and structure of comet Shoemaker– Lewy-9 inferred from the physics of tidal breakup. *Icarus* 121, 225–248.

Baker A., Rigsby C.A., Seltzer G.O., Fritz Sh.C., Lowenstein T.K., Bacher N.P., Veliz C., (2001). Tropical climate changes at millennial and orbital time scales on the Bolivian Altiplano. *Nature* 409, 698–701.

Baltensperger W. & Woelfli W. (2009). Interpretation of the small grains in the inclusions of ice cores. URL: arxiv.org/abs/0909.5089

Biscaye P.E. et al. (1997). Asian provenance of glacial dust (stage 2) in the Greenland ice sheet project 2 ice core, Summit, Greenland. *Jour. Geophys. Res.* 102, 26 765–26 781.

Bocherens H. (2003). Isotopic biogeochemistry and the paleoecology of the mammoth steppe fauna. *Advances in Mammoth Research*, Deinsea 9, 57–76.

Clemens S.C. & Tiedemann R. (1997). Eccentricity forcing of Pliocene - Early Pleistocene climate revealed in marin oxygene-isotope record. *Nature* 385, 801–804.

Dansgaard W. et al. (1993). Evidence for general instability of past climate from a 250-kyr ice–core record. *Nature,* 364, 218–220.

Delmonte B. et al. (2004). Dust size evidence for opposite regional atmospheric circulation changes over east Antarctica during the last climatic transition. *Climate Dynamics* 23, 427–438.

Delmonte B. et al., (2004). Comparing the Epica and Vostok dust records during the last 220 000 years: stratigraphical correlation and provenance in glacial periods. *Earth Science Reviews* 6, 63–87.

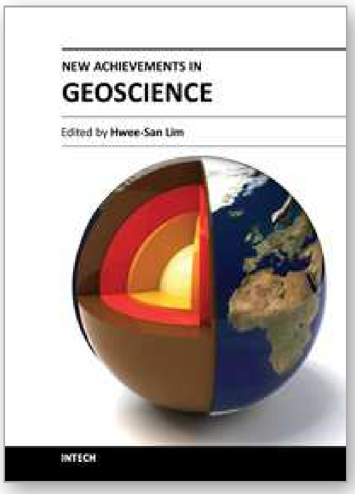
Ehlers J. & Gibbard P. (2004). Quaternary glaciations – Extent and Chronology. *Elsevier.*

Filho A. C., et al. (2002). Amazonian Paleodunes Provide Evidence for Drier Climate Phases during the Late Pleistocene-Holocene. *Quaternary Research* 58, 205–209. DOI: 10.1006/qres.2002.2345.

Gaiero Diego M., (2007). Dust provenance in Antarctic ice during glacial periods: From where in southern South America? *Geophysical Res. Lett.,* 34, L17707, doi:10.1029/2007GL030520.

Gold T. (1955). Instability of the Earth’s axis of rotation. *Nature* 175, 526–529.

Gustafson Bas, (1994). Physics of zodiacal dust. *Annual Rev. Earth and Planet. Science* 22, 552–554.
Imbrie J.J., (1984). *Milankovitch and Climate,* Part 1, (eds. A. L. Berger et al.), pp. 269–305.
Kashiwaya K, Ochiai S, Sakai H, Kawai T, (2001). Orbit-related long-term climate cycles revealed in a 12-Myr continental record from Lake Baikal. *Nature* 410, 71–74.
Klein F. & Sommerfeld A. (1910). Über die Theorie des Kreisels. *Teubner,* Leipzig.
Luethi D. et al. (2008). High–resolution carbon dioxide concentration record 650 000–800 000 years before present. *Nature* 453, 379–382.
Mayewski Paul A. et al. (2004). Holocene climate variability. *Quaternary Research* 62, 243-255.
Milankovitch M.M. (1941). Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitproblem. *Königliche Serbische Akademie,* Spez. Publikation 133, 1–633, Belgrad.
The Microlensing Observations in Astrophysics (MOA) Collaboration & The Optical Gravitational Lensing Experiment (OGLE) Collaboration, (2011). Unbound or distant planetary mass population detected by gravitational microlensing. *Nature* 473, 349–352.
Muller R.A. & MacDonald G.J. (1995). Glacial cycles and orbital inclination. *Nature* 377, 107–108.
Muller R.A. & MacDonald G.J. (1997). Glacial cycles and astronomical forcing. *Science* 277, 215–218.
Nufer R., Baltensperger W. & Woelfli W. (1999). Long term behaviour of a hypothetical planet in a highly eccentric orbit. URL http://xxx.lanl.gov/abs/astro-ph/9909464
Orlova L.A. et al. (2001). Chronology and environment of woolly mammoth (Mammuthus primigenius Blumenbach) extinction in northern Asia. *The World of Elephants,* International Congress, Rome, 718–721.
Petit J.R. et al. (1999). *Nature,* 399, 429–436.
Schirrmeister L. et al. (2002). Paleoenvironmental and paleoclimatic records from permafrost deposits in the Arctic region of Northern Siberia. *Quaternary International* 1998, 97–118.
Seager R. (2006). The Source of Europe's Mild Climate. *American Scientist* 94, 334–341.
Snowball bibliography, URL: www.snowballearth.org/bibliography.html
Tiedemann R., Sarntheim M. & Shackleton N.J. (1994). Astronomic time scale for the Pliocene Atlantic ^{18}O and dust flux records of Ocean Drilling site 659. *Paleoceanography* 9, 619–638.
Woelfli W.; Nufer R. & Baltensperger W. (2002). An additional planet as a model for the Pleistocene Ice Age. URL: arxiv.org/abs/physics/0204004
Woelfli W. & Baltensperger W. (2007a). Arctic East Siberia had a lower latitude in the Pleistocene. *Anais da Academia Brasileira de Ciências,* 79(2): 183–193.
Woelfli W. & Baltensperger W. (2007b). On the change of latitude of Arctic East Siberia at the end of the Pleistocene. URL: arxiv.org/abs/0704.2489



New Achievements in Geoscience
Edited by Dr. Hwee-San Lim

ISBN 978-953-51-0263-2
Hard cover, 212 pages
Publisher InTech
Published online 23, March, 2012
Published in print edition March, 2012