[https://doi.org/10.69646/bbbs2402]
[Plenary Lecture]

Milutin Milanković and climate changes - Ice ages secret

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Abstract: The astronomical factors that lead to the periodical formation of the Ice Age and the work of Milutin Milanković on the solution of the secret of their creation were discussed and analyzed.

Keywords: Ice ages, Milutin Milanković, History of science

Introduction

The cause of ice ages, a periodic massive cooling in Europe, when, in the greatest cold periods, in many places on the old continent it was like today in Antarctica, was a great scientific puzzle at the beginning of the twentieth century. As early as 1837, German botanist Karl Friedrich Schimper (1803-1867) introduced the term "Ice Age" and assumed that during the Earth's history there were periods of cold climate with formation of glaciers.

Many theories attempting to solve the puzzle of ice ages have been formulated, some of which could not be proven and some were contested by new evidence. Danish-Norwegian geologist Jens Esmark (1763-1839), perhaps the first in 1824, searched in the astronomy the causes of the ice ages, assuming

that on their appearance influence the changes in the Earth's path around the Sun. However, mathematician Joseph Alfons Ademar (1797-1862) published the first true astronomical theory in his book "The Sea Revolution" in 1842, where he denoted the changes of the Earth's path around the Sun as the main cause of ice ages.

Among other pioneers who sought extraterrestrial causes of ice ages, particularly is important Scottish scientist James Croll (1821-1890) who emphasized in a series of works that the periods of glaciation are due to the combination of three astronomical causes, that is, because of the change in the inclination of the Earth's axis, precession and changes in the eccentricity of the Earth's orbit around the Sun. He had only available calculations of Earth orbit changes and the precession in the last 100 000 years, performed by Le Verrier (Urbain Jean Joseph Le Verrier, 1811-1877) and insufficiently accurate data on changes in the inclination of the Earth's axis, so that his considerations indicated that the astronomical causes of the Ice Age had occurred 240,000 years ago and ended before about 80 000 years. This was in contradiction with the data obtained by geologists, showing that the ice age ended about 10,000 years ago. This was the situation with Ice Ages puzzle at the beginning of the twentieth century, when Milutin Milanković started to work on the solution of this problem. The aim of this article is to present its work on it and his solution.

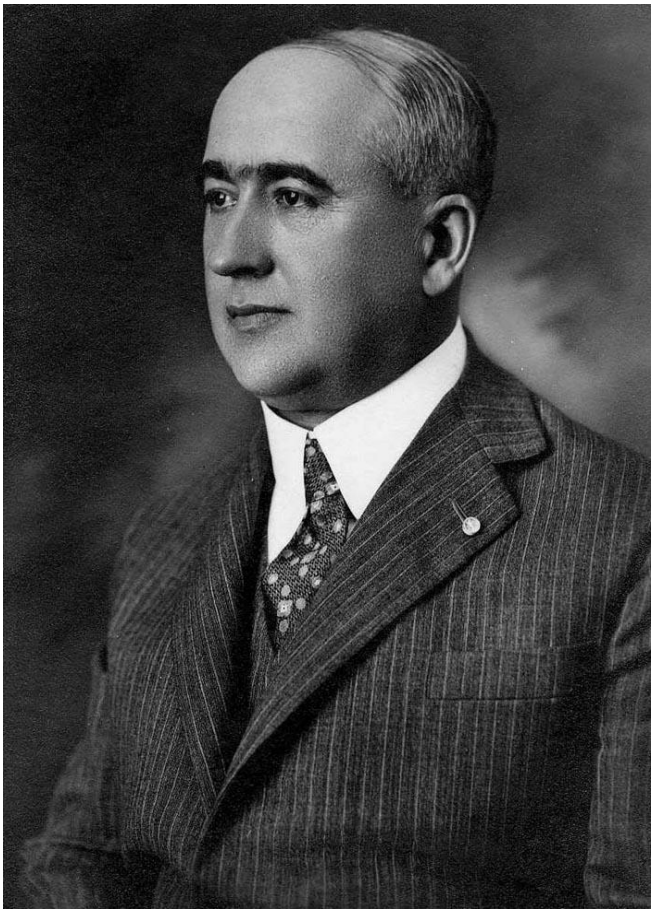

Figure 1. Milutin Milanković (Source: http://arhiva.unilib.rs/unilib/o_nama/izlozbe/milankovic_virtuelna/images/portret01.jpg)

The secret of Ice Ages

Upon his arrival in Belgrade in 1909, Milutin Milanković, begins to work on the investigation of astronomical causes influencing on the formation of an ice age. Unlike Croll, who could only use Le Verrier's calculations of the eccentricity of the Earth's orbit around the Sun and the precession during the last hundred thousand years, now were available Ludwig Pilgrim's

calculations about change not only of eccentricity and precession, but also of the inclination of the Earth's axis for the last one million years.

Let's consider more in detail the significance of these three astronomical causes of climate change on Earth.

a) The change of the inclination of the Earth's axis between 22,1 and 24,5° with a period of 41,000 years, which leads to changes of the conditions of insulation at a selected point on the surface of our planet.

To understand why this change is meaningful, imagine what would happen if there were no such inclination. Then throughout the year, at every point on Earth, there would always be the same seasons. In the north there would be eternal winter which would lead to the spread of the ice cover and its penetration to the south. In Europe, a constant Ice Age would dominate. Such an extreme situation should only show how much are important for the climate changes even less than the change of 2.4 degrees.

(b) The precession (which has several causes), due to which the spring or gamma point (the point in the sky in which the Sun appears at the beginning of the spring) moves along the apparent annual path of the Sun, with a period whose average value in the last 600,000 years, considered by Milanković (when all the causes are taken into account), is 22,000 years, which affects the duration of the seasons.

On its way around the Sun, the Earth behaves like a top spinning slowly, and its axis describes the surface of a cone. This phenomenon is called precession. It is also influenced by the Moon that causes additional "staggering" of our planet called nutation. How can this affect the amount of heat that comes from the Sun?

If someone asks when our planet is closest to the Sun, how many would answer it is in winter, around January the 3rd?

But because of this, it moves faster around the Sun than when it's furthest from our star (around 4 July), so that in Europe the coldest season lasts for seven days and fourteen hours less than the hottest. But due to the precession, it will change and the time will come when it will take longer. Namely, the warmer part of the year in Europe is the time when the Sun apparently moves from spring to autumn equinox. The spring point moves along the apparent path of the Sun, while, in reality, this point moves on the elliptical path of the Earth. If the spring begins when the Earth is closest or farthest from the Sun, the warmer and cooler half of the year have the same length. If it is the closest to the Sun in the middle of winter or summer, the difference in the warmer and cooler half of the year is greatest.

(b) The change of the eccentricity of the Earth's path around the Sun with a period of 100,000 years, results in a change of the distance from the Sun, which has an influence on the duration of the seasons.

French astronomer, Urbain Jean Joseph Le Verrier, who became famous for discovering the planet Neptune, showed that the Earth's path cyclically becomes more circular and more elliptical, with eccentricity changing from one to six percent, which also affects the duration of the seasons.

Although the changes due to each of these causes are small, when all three act together, their influence becomes significant.

The problem that should solve Milanković was how to observe the effect of these influences, or what to measure. While Ademar and Croll considered that cold winters should be considered, he accepted the advice of Wladimir Peter Köppen (1846-1940) that cold summers are much more important for the formation of ice ages, as proposed by Joseph John Murphy 1869. Namely, in Siberia, where winter temperature goes up to -50^{o}C and in the summer up to +30^{o}C there are no glaciers, since high

summer temperatures cause snow melting. And a large part of Greenland, where winter temperature is about -10ºC and in the summer +8ºC, is under the snow and ice. In addition, Milanković noted that for the spread of glaciers to the south are particularly important weather conditions at great latitudes, in areas where, if there is a cooling down, ice from the north first starts to spread. Therefore, Milanković calculates how, during the last 600,000 years, changes the geographical width of the point that receives from the Sun as much heat as it receives a point at 65° latitude today, or to which today's latitude, corresponds the insulation at 65° at a time of the past. Note that this is practically rounded the latitude of the polar circle (about 66,562º), passing through the southern part of Greenland, Iceland, Lapland in Scandinavia, the north of Siberia, Alaska and north of the Canada.

Milanković obtained his famous curve of insulation which minima coincide with four assumed Ice Ages during the last 600,000 years (Günz, Mindel, Riss and Würm).

Milanković had his solution of Ice Ages secret dispersed in 28 articles and he realised the need to present it to the scientific community as a unique publication. Because of this he wrote in German his most important work, *Canon of Earth insulation and its influence on the problem of Ice Ages*, were he gave te complete solution of this puzzle.

Milutin Milankovć is the most significant Serbian astronomer. As a difference from Nikola Tesla and Mihajlo Pupin, which their discoveries made abroad, Milanković became world famous working in Belgrade.

In honor of his achievements, on XIV Congress of International Astronomical Union (IAU) in Brighton, a crater on the invisible side of the Moon (with coordinates +170º +77º) obtained his name. On XV Congress of IAU in Sidney, his name obtained a crater on Mars (with coordinates +147º, +55º), and in 1982, the minor planet 1936 GA, discovered in 1936 by Milorad

Protić and Pero Djurković, obtained the name 1605 Milankovć. This minor planet is on average distance from the Earth of around 450 millions kilometers, while the closest distance is 270 millions kilometers. Its diameter is 32.5 km and the period of its revolution around the Sun is 5.2 years.

Milanković was three times elected for the vice president of the Serbian Academy of Sciences and Arts and was a member of JAZU (Zagreb) and of Academy of natural sciences "Leopoldina" from Hale. European Geophysical Union has from 1993 as an award medal "Milutin Milanković" and NASA put his name in a list of fifteen most important scientists for Geoscience of all times.