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Revolution and Insolation
How Milutin Milanković has assembled the puzzle of the climate?

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Milutin Milanković (1879 – 1958), professor of Applied Mathematics at Belgrade University, was a Serbian mathematician, famous for his revolution in the understanding of climate change dynamics. He set up climatology as an exact science, initiated numerical modeling of the climate and facilitated mathematical interpretation of long quasi-periodic climate changes, and created the basic organon for the understanding of the Earth's ice ages which is one of the main scientific challenges today. He demonstrated the interrelatedness of celestial mechanics and the Earth sciences, enabled consistent transition from celestial mechanics to the Earth sciences and transformation of descriptive sciences into exact ones. Considering seasonal and latitudinal distribution of the Earth's insolation, caused by changes in the Earth's orbital geometry, Milanković formulated the astronomical theory of climate as a generalized mathematical theory of insolation - the only theory of climate that can be verified mathematically and tested geologically.

MILUTIN MILANKOVIĆ (Milutin Milankovitch) was born in the in village of Dalj (28. May 1879), in the Slavonia region, part of Austria-Hungary, where his ancestors settled at the end of the seventeenth century after the great migration of Serbs from Kosovo and Metohija province escaping Turkish oppression Turkish occupation and Albanian terror. His family was wealthy, and through the centuries esteemed as philosophers, inventors, professors, lawyers, and civil servants. Milanković's father Milan was a merchant who died early, leaving behind a wife and six children, Milutin being the youngest of them. Tutored by his mother Jelisaveta and uncle Vasa Muačević, Milanković was thoroughly educated at home and at high school in Osek (now Osijek). His teacher of mathematics, Vladimir Varićak, later a member of the Yugoslav Academy of Sciences, noticed his exceptional abilities and versed him in mathematical sciences, remaining his lifelong friend and adviser.

Figure 1. Confirmation of enrollment of the Technical School in Vienna

In 1896, Milanković enrolled at the Technical School in Vienna, with a major in civil engineering. Eight years later he gained a PhD in technical sciences with a thesis titled *Theory of Pressure Curves*, published in 1907. In his successful career as a civil engineer he was particularly interested in the theory of reinforced concrete. His ability to solve civil engineering problems mathematically was evident in his early articles and in his four patents granted in Austria and Hungary.

Figure 2. Milanković's patent certificate No.25292 from year 1906.

1) Board for the Dynamic of the Climate System and the Work of Milutin Milanković, SASA, Knez Mihajlova 35, 11000 Belgrade, SERBIA

Moreover, he had one more ballistic patent granted by the Kingdom of Yugoslavia where he constructed a very efficient rocket projectile which unfortunately was not implemented in the Yugoslav army. The performance of this weapon was so advanced that its implementation probably would prevent efficient German air raids during the April war in 1941 in Yugoslavia. A very similar principle, almost the same, was used later in the Russian strategic nuclear missile Satan.[2]

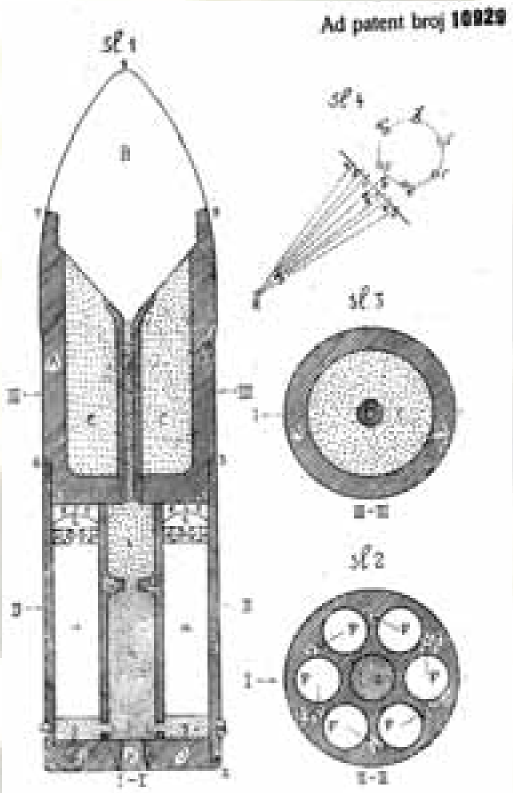

Figure 3. Patent cerificate No.10929 concerning Milanković's rocket projectile

Milanković never abandoned his engineer's profession: even as a renowned scientist he constructed buildings, railroads, airports, bridges, dams, and aqueducts all over central Europe. Between two world wars, in 1926, he was engaged in constructing and supervising twelve large hangars for the Kingdom of Yugoslavia Air Force, to be made of reinforced concrete. He worked as a civil engineer, part time, for the next ten years. In 1956 he outlined an ideal mathematical picture of an edifice of the maximal height which could be constructed on the Earth: a rotationally symmetrical building made of reinforced concrete 21.646 kilometers high, with a base diameter of 112.84 kilometers.[3]

In 1909, Milanković came to Belgrade University and became a citizen of the Kingdom of Serbia. He taught a course in Applied Mathematics, uncommon for European universities, which included three seemingly diverse subjects: rational mechanics, celestial mechanics, and theoretical physics. It was this approach which, in his opinion, helped him establish climatology as an integral, holistic science.

[2] Industrial Patent Office of the Kingdom of Yugoslavia. Patent grant no. 10929/1933.

[3] The more about his engineering's activities and overall work see: Aleksandar Petrović, *Cycles and Records – Opus Solis of Milutin Milanković*, Serbian Academy of Science and Arts, Belgrade 2009.

Figure 4. Milutin Milanković, 1922.

Milanković's work was interrupted constantly by turbulent historical events. He started working on the astronomical theory of climate in 1912 when his first paper was completed in the same moment when the First Balkan War broke out. In 1914, when World War I begun the Austro-Hungarian authorities arrested him while he was spending his honeymoon in Dalj. He was interned in Budapest, where he was allowed to work in the library of the Hungarian Academy of Sciences. In spite of all these and many forthcoming obstacles (Austrian plunder of Belgrade University during World War I, German demolition of the National Library at the beginning of April 1941, and of the library of the Mathematical Institute founded by him at the end of World War II, when he also was forced to leave his home for several months because of the severe Allies' - USA and UK bombings of Belgrade), he was constantly elaborating his theory for nearly four decades. He published about forty important papers until 1941, when he combined them in his masterwork *Canon of Insolation and the Ice-Age Problem* which was written in German and published in Belgrade by the Royal Serbian Academy of Science.[4] It was also released under dramatic circumstances, saved by a miracle from a Belgrade printing shop destroyed at the by Germans beginning of the Word War II.[5]

Figure 5. Milanković's masterpiece from 1941: Canon of Insolation of the Earth and its Application to the Problem of the Ice Ages

[4] Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem**',** **(***Canon of Insolation of the Earth and Its Application to the Problem of the Ice Ages***),** Koniglich serbichen Akademie, Belgrade, 1941

[5] When the German occupators demanded from the Belgrade University professors to sign an appeal to Serbian people requesting loyality to the occupational authorities and to show their support to the occupation of their country in that way, Milutin Milanković was one of the professors who refused to do it. Milanković, ona of the most famous and most quoted world scientists ever, thus showed his patriotism and anti-Fascism.

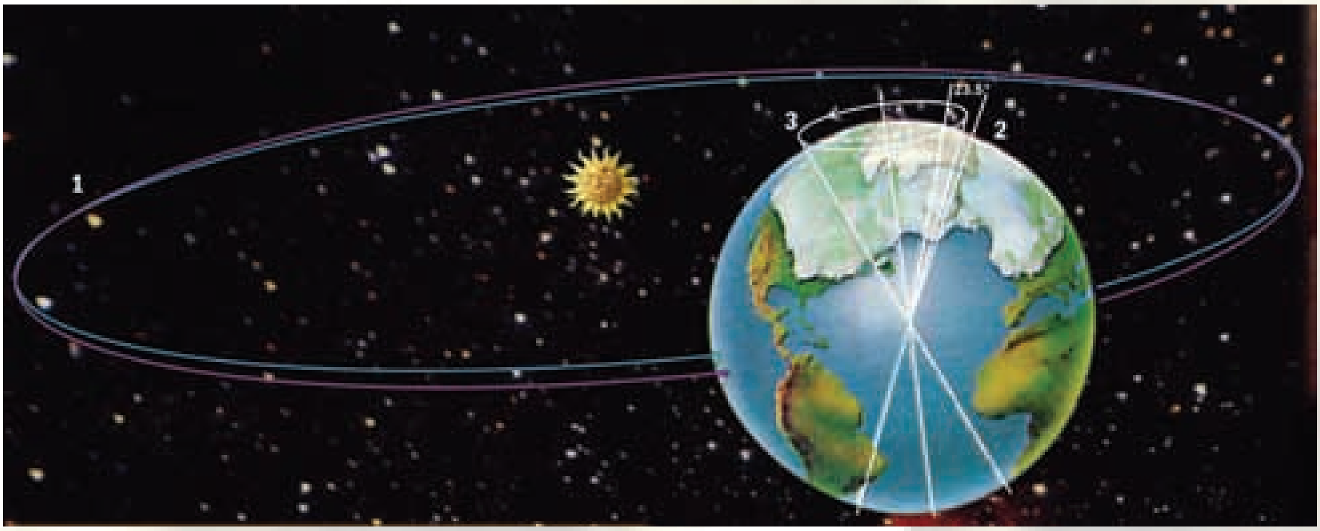

Figure 6. Three astonomical cycled that force climate change on the Earth
1) Changes in orbits eccentricity; 2) Changes in obliquity; 3) Precession of the equinoxes

The idea of climate changes emerged in the European scientific community almost two centuries ago when geology found evidence for the existence of the Ice Age. After that, it took a few decades for the Earth science to assure itself, by geological data, of the existence of several "ice ages" which froze vast areas of Eurasia and Northern America significantly lowering the level of the oceans and seas. As soon as the idea became plausible, earth scientists started making hypotheses to explain it. Many trials had been made: some almost immediately proved to be wrong, some were partially successful and lasted for some time, some were completely disputable, suitable neither to be proved, nor to be opposed. The most of these hypotheses were dealing with processes observed (or supposed to be possible) on the Earth: high content of volcanic dust in the atmosphere, perturbations of the Earth's magnetic field, fluctuations in the distribution of carbon dioxide between the atmosphere and the ocean, changes of the deep circulation of the oceans.

Parallely, there were also several attempts to explain the climate change by the influence of astronomical forces (the most comprehensive of them was the theory by James Croll in the 60-es of XIX century). But, due to many scientific, personal and social circumstances, none of them could prove to be accurate. Moreover, the imperfection of such theories was understood as inaptitude of any astronomical factor to be the cause of climatic change. Therefore the riddle of ice ages remained unsolved for another several decades.

Milanković directed his main efforts towards astronomical explanation of the origin of the Pleistocene ice ages. He calculated the impact of the Earth's secular orbital cycles (eccentricity, obliquity, precession) on Earth's insolation and consequent effect on the process of climate change. These perennial orbital variations that he took into consideration, along with their influence on planets' climates, today are called Milanković cycles. In his mentioned 1912 article "On the Mathematical Theory of Climate", and after that in six papers published until 1914, Milanković introduced, for the first time, advanced mathematics into climatology.[6]

[6] See: Aleksandar Petrovic, *Milutin Milankovic and the Mathematical Theory of Climate Change*, Serbian Society of History of Science, Belgrade 2002.

Milanković's position at the University, where he thought three usually diversed subjects, immersed him in a non-specialized, holistic culture of university education in Serbia at the beginning of 20th century and allowed him to work at the intersection of scientific fields. It provided him with a broad vision of an integrated cosmic science that could be applied to very specific problems in geophysics, climatology - including the problem of past ice ages, and the temperatures of other planets. University blueprint, "acquiring unity among the sciences," was in complete dissonance with the prevailing scientific specialization-driven culture of Europe of that time, but without that cultural peculiarity the problems he correctly solved would not even have been posed. Milanković himself was assured that the mystery of the ice ages had not been resolved yet because its solution was hidden somewhere in the interstices between many individual disciplines. He wrote in his memoirs:

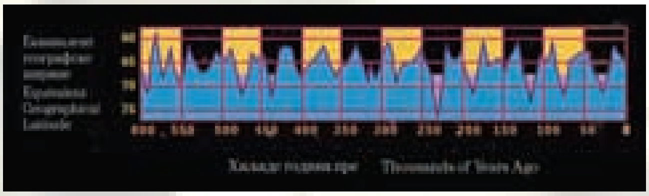

Figure 7. Curve of Insolation

"*The reason for that lays in the fact that one has, in order to get to the bottom of the problem, to solve a set of rather complicated component problems which really belong to different sciences that are sharply separated one from the other... Therefore, the question was not answered, and it was left amid a triangle between spherical astronomy, celestial mechanics and theoretical physics. The chair at Belgrade University offered to me included all the three sciences which were separated at other Universities. Therefore I was able to discern that cosmic problem, to see his importance and to start with its unraveling.*"[7]

This methodological approach, substantially different from other universities, forced him to set appropriate, firm ground for understanding the core of the climate problem.

[7] Milutin Milanković, *Mémoires, Expériences, Knowledges*, Agency for Textbooks, Belgrade 1997, pp.468.

"*That coincidence, which enabled me to adhere to the given problem, it was not pure accident although it looked like that. Exactly because I was involved in all the mentioned sciences, it was possible for me to smell out that problem and to estimate its importance.*"[8]

He was aware that divided scientific experience, separated astronomical and geological thinking, made the comprehension of the climate impossible. It was a blind way which ultimately should have been replaced by a new, open methodology - the triangle which couples sciences to frame Proteus like climate dynamics. He began the work on the problem of ever changing climate by dealing with previous theories, determining their lacks and faults. Milanković tried to continue the work of his predecessors, but in a basically different way: he was not searching for the causes of the Earth's ice ages, but trying to develop a general mathematical theory of climate applicable to all planets. His aim was an integral, mathematically accurate theory which connects thermal regimes of the planets to their movement around the Sun. He wrote: "...such a theory would enable us to go beyond the range of direct observations, not only in space, but also in time..."[9] It would allow reconstruction of the Earth's climate, its predictions as well, giving us in the same time the first reliable data about the climate conditions on other planets.

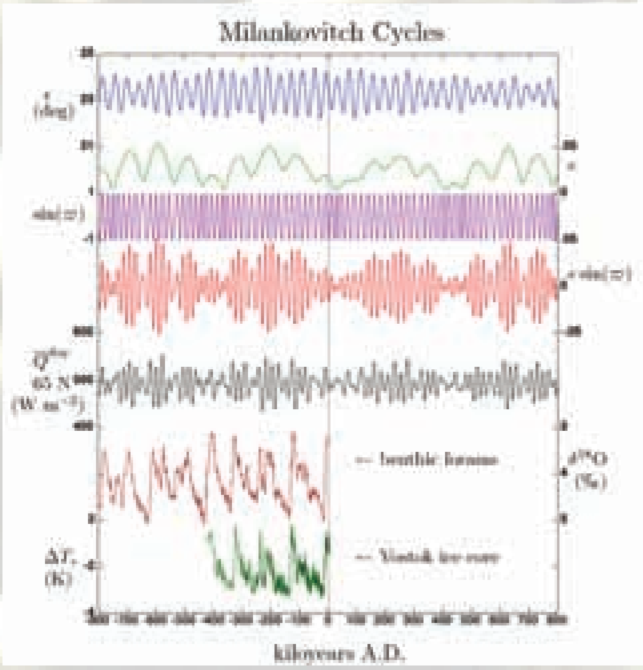

Figure 8. Milanković's cycles and their geological response

In the center of his theory Milanković put the Sun, the only source of heat and light in the Solar system. The planets orbit the Sun moving along slightly elongated paths that ever change due to the gravitational force (which depends on their masses and distances). Such changes in the geometry of an orbit lead to the changes in the insolation (**in**coming **sol**ar radi**ation**) - quantity of heat received by any spot at the surface of a planet. And, Milanković concluded, the overall sum of such changes must lead to the change of the thermal regime of the whole planet. So, he tried not only to prove his idea, but to calculate the exact value of the thermal change. Consequently, his theory has two parts, the astronomical and the physical one.

In the astronomical part of his work Milanković calculated the changes of the insolation of the uppermost layer of the Earth's atmosphere depending on the changes in the Earth's distance from the Sun (i.e. on the shape and magnitude of its orbit), and on the declination of Sun's rays relative to that surface unit (i.e. on orientation and inclination of rotation axis, and geographical latitude). In his investigation he incorporated three major astronomical periodicities:

1. Variation in eccentricity of the Earth's orbit, from an almost exact circle to a slightly elongated shape, with the periodicity of about 100.000 years, which influences seasonal differences: when the Earth is closest to the Sun, it receives more solar radiation. If that occurs during winter, winter is less severe. If a hemisphere has its summer while closest to the Sun, summers are relatively warm. In addition, a more eccentric orbit will change the length of seasons in each hemisphere by changing the length of time between the vernal and autumnal equinoxes.
2. Variation in obliquity, i.e., the tilt, of the Earth's axis away from the orbital plane, from 22.1° to 24.5°; periodicity 41,000 years. At higher tilts, the seasonality at high latitudes becomes more extreme; changes in tilt have little effect in the tropics, maximum effect at the poles. For 1° of obliquity increase, the total energy received by the summer hemisphere increases by -1%. Presently, the Earth's tilt is 23.5°.
3. Precession of the equinoxes, i.e. revolution of the Earth's axis, where one revolution is completed in about 23,000 and 19,000 years. It is a rather complex phenomenon, caused by two factors: a wobble of the Earth's axis, and a turning-around of the elliptical orbit of the Earth itself. It affects the direction of the Earth's axis, not its tilt. Because the direction of the wobble is opposite to the movement of the Earth around the Sun, thus, for example, 11,000 years from now, the North Pole of the Earth will not be pointing towards the North Star, but it will be pointing away by an angle of about 47°, close to the star Vega. The combined and complex wobbly motion of the Earth has the following result: the equinoxes do not keep occurring during the same day of the calendar, but slowly shift. As a result of this migration of equinoxes we have today relatively short, warm winters in the northern hemisphere and relatively long, cool summers; 11,000 years ago the opposite was true. This is the principal manifestation of the precession - the relative length of the seasons varies cyclically with time.

These three variations, superposed, constantly change the Earth's position relatively to the Sun, and, consequently, the insolation of any given spot on its surface.

In the second, physical part of the theory, Milanković had to make use of a number of physical laws in order to discover the relations between irradiation and temperature of the planets. He had to introduce various parameters for the determination of the atmosphere and the ground influences on the transformation of incoming radiation. Milanković here went deeply into the realm of meteorology and climatology, endowing them with a set of valuable and much needed new insights and parameters for a successful use of the mathematical apparatus. First, he did not take in consideration the currents caused by the unequal heating of the atmosphere and the oceans, so the climate he had

[8] Ibid, pp.817.
[9] Milutin Milanković, *Mémoires, Expériences, Knowledges*, Agency for Textbooks, Belgrade 1997, p. 466.

computed corresponded to the so-called solar climate**.** For an additional insight, he determined the mean annual solar temperatures of all of the latitudes 0° - 90°, their vertical structure at radiation equilibrium, and the influence of the mean content of water vapor upon it. Then, he mathematically described the exchange of heat in the ground, being aware that ground plays an important climatic role as a reservoir of incoming solar radiation, and determined the average annual heat balance of the atmosphere.

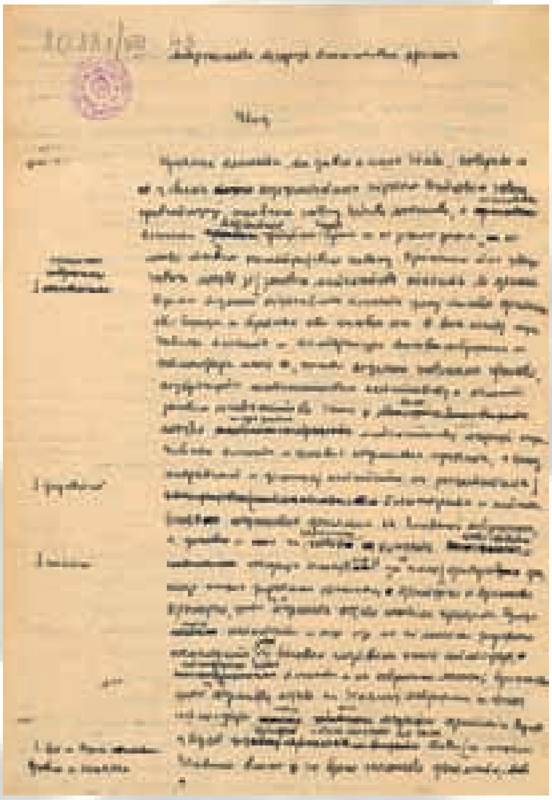

Figure 9. Milutin Milanković's Astronomic Theory on climate changes, manuscript of the first page of his work (This theory is written in Serbien Cyrillic)

The earth's envelope of water and air is a heat engine powered by sunlight heat arriving mainly at the equator and is carried by air and water towards both Polar Regions. Changes in the amount of heat received, and in a way it is redistributed, alter global climate and cause ice ages. Polar land masses are ideal for glaciation because they receive less direct sunlight than lower attitudes. Although land masses are more easily glaciated than ocean basins, sea water or large lakes are essential to glaciation since evaporated water provides the snowfall necessary for building ice sheets.

When these, the most important problems of the theory were solved, and a firm foundation for a further work built, Milanković published his *Mathematical Theory of Thermal Phenomena Produced by Solar Radiation* in 1920. It attracted the attention of climatologist Wladimir Köppen and his son-in-law, geophysicist Alfred Wegener. In 1922, they invited him to cooperate in their work *Climates of Geological Past.* His task was to find out, using his method, the secular changes in insolation during the past 650 millennia. Köppen suggested paying special attention to secular changes in summer insolation at latitudes around 60°N, being convinced that a reduction in summer insolation at these latitudes is needed for a southward movement of the ice boundary. Another key was the insight that the insolation at high latitudes in the northern hemisphere is prevalent because most of the land that can support expanded ice accumulation belongs to this hemisphere.

With these considerations in mind, and using his method, Milanković calculated the amplitudes of secular changes which had occurred in the summer insolation at the latitudes of 55°, 60° and 65° N during the last 650,000 years, transforming his numerical results into fictitious oscillations in latitudes in order to obtain a vivid graphical picture. The quantities of heat supplied to individual latitudes by radiation during the caloric half-years were presented in canonic units in *Canon's* Table XXV. This table, with 5,600 numbers, "mathematically represent[ed] the history of insolation for the past 600 millennia — a so called Canon of insolation"[10]. Accordingly "with this canon one could attempt to study the phenomenon of the Ice Ages"[11].

The table, transformed to a jagged line, later called 'Radiation Curve' or 'Curve of Insolation' was shown for the first time in Wegener – Köppen's book, published in 1924. One of the most important results of that publication was that Köppen in radiation diagrams recognized the evolution of then believed to have happened four glacial periods. After that, the radiation curves gained wide publicity and served as a starting point for other basic studies by climatologists and geologists. A few decades later it was realized that the four glacial periods (Günz, Miindel, Riss, Würm) proposed by German geographers Penck and Briickner, in fact did not exist; however, the relevance of Milanković's Curve of Insolation was verified when new evidences for the cyclicity of glaciations were obtained from the records left in deep-sea sediments (Hays, Imbrie, Shackelton, 1976).[12]

Figure 10. Milutin Milanković in his study 1949.

In his subsequent work Milanković extended his curve to cover the past million years, following this by a reexamination of the accuracy of ice-ages chronology by renewed computations of secular changes of astronomical elements, this time on the basis of more accurate determination of planets' masses. New calculations were not different very much from the previous ones. Subsequently he presented continuous radiation curves for the entire surface of the Earth and computed variations of insolation at eight northern and eight southern latitudes, for both the

[10] Milutin Milankovic, *Canon of Insolation of Earth and its Application to the Problem of Ice Age*, Agency for Textbooks, Belgrade 1997, p. 512. Translated into English by Israel Program for Scientific Translation under the auspices of US Department of Commerce and the National Science Foundation.

[11] Milutin Milanković, *Mémoires, Expériences, Knowledges*, Agency for Textbooks, Belgrade 1997, p. 543.

[12] Hays, James D., John Imbrie, and Nicolas J. Shackleton, *Variations in the Earth's Orbit: Pacemaker of the Ice Ages*, "Science" 194, 1976, стр. 1121–1132.

winter and summer half-years and for the top of the atmosphere as well. He showed that seasonal differences in insolation caused by the precessional cycle are prevalent at the lower latitudes then at the higher ones, where the influence of variations in axial obliquity is dominant. He also deduced that the altitude of the snow line was highly dependent (correlation factor of 0.996) on the radiant energy received during the caloric summer half-year. He made tables for easy determination of the displacement of snow line at individual latitudes caused by their changes in solar insolation. Going further, he calculated the changes of the polar ice caps, which reflect a considerable part of incoming heat into outer space. He established a mathematical relationship between enlarged ice caps of the Earth and their cooling action, and showed that such diminishing of insolation represents a secondary effect, but still sufficient (when added to secular changes of insolation) to cause the great glaciations of prehistoric times in their full extent.

Figure 10. Golden doktor diplom (17.12.1954)

The most important results of Milanković's thirty years research were summarized, completed, and presented to scientific public in his capital work *Canon of Insolation*. World War II events were not favorable for continual scientific work, but Milanković was not upset, because he considered his theory capable to live on its own. Indeed, the development of climatology confirmed persuasively that *Canon of Insolation* is not the most reliable approach to the climate change problem only, but it is the pivot point of revolutionary reversal of the old earth sciences' paradigm. Historically Milankovic's revolution was prepared by the first attack on the "normal" geological paradigm performed by the Swiss naturalist Louis Agassiz who delivered his famous *Neuchatel lecture* at a conference of the Swiss Society of Natural Sciences in 1837.[13] He pointed at «erratic boulders» of granite resting upon limestone of the Jura Mountains - huge stones which were detected at geologically not adequate sites. The phenomenon of "erratic boulders", huge stones transported by the glaciers, has quaked "stationary" geology because it was incapable to explain them in any reasonable way. Rejecting Agassiz explanations, geologists considered the idea of glaciers which transports stones "mechanically senseless". Alexander von Humboldt promptly advised Agassiz to leave this research and to return to his exploration of fossil fishes.[14]

The second massive attack on normal geological paradigm happened in 1912, the same year when Milanković started rehabilitation of the astronomical theory of climate change. A german scientist, Alfred Wegener, who got his PhD in astronomy, and performed his research in meteorology, questioned dominant geological beliefs, renouncing the ruling concept of sink bridges between continents, and arguing in favor of continent's shifting. Milanković was not trained as meteorologist, but he realized that "most of meteorology is nothing but a collection off innumerable empirical findings, mainly numerical data, with traces of physics used to explain some of them... Mathematics was even less applied, nothing more than elementary calculus... Advanced mathematics had no role in that science..."[15] He understood clearly that is not possible to solve the problem of climate change from the ground of specialized science. Leaned on the celestial mechanics, theoretical physics and spherical astronomy he established climatology as an exact science. He realized that the astronomical theory before him had fallen into disrepute not because of any intrinsic weakness, but because of insufficient knowledge of celestial mechanics, imperfect mathematical skill, and lack of reliable stratigraphic records.

Figure 11. Milutin Milanković: "Through Space and Centuries", 1943.

It was one among the most powerful and productive revolutions of Earth science at the beginning of the XX century. As it was said "the formulation and step-wise confirmation of the Milankovitch theory is one of the great scientific success stories the last century."[16] Owing to his theory it became evident that there has been multitude of ice the last ages during the Earth history. Particularly million years have been marked by many cycles of continental glaciation and melting. Changes in global temperature have caused massive glacial advances and retreats. That insight was confirmed definitively through the major paleoclimatological projects CLIMAP,

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[13] Luis Agassiz, *Études sur les glaciers*, Aux frais de l'auteur, Neuchâtel, 1840.

[14] Alexander von Humboldt, *Cosmos*, vol IV, Bohn 1852, pp. 459.

[15] Milutin Milanković, *Mémoires, Expériences, Knowledges*, Agency for Textbooks, Belgrade 1997, p. 457.

[16] Wolfgang Berger, Torsten Bickert, Eystein Jansen, Gerold Wefer, Memorie Yasuda, *The central mystery of the Quaternary Ice Age: a view from the South Pacific*, "Oceanus", Winter 1993

COHMAP and SPECMAP which mapped out the patterns of global climate change. They have demonstrated the central role of Milanković forcing, along with the response of the climate system, and made transparent that the climate system appears to act in response to insolation forcing in each Milanković cycle.

In the past several decades new cognitions launch a series of new questions which challenges Milanković's theory as well. There are geological evidences which raise questions and models which dispute it because of difficulties in reconciling theory with certain singular observations and the presence of non-orbital spectral peaks in the climate record. The detailed mechanism involved in the transformation of orbit parameter variations into climate variations are not yet known and nerther is consequently, the accurate determination of the response time between astronomical forcing and climate change.

Nevertheless, the Milanković's theory can be still tested and it is frequently confirmed by making a "simplest possible" assumption: that frequencies in the system input (orbital variations) appear linearly in the system output (climate variations). Many independent investigators appear to see clear evidence of such astronomical forcing, as well as evidence suggesting that climate system responds nonlinearly to all Milanković frequencies.

Figure 12. Reform Julian calendar, 1923.

Climatic shifts are seen in ocean floor sediments as changes in the kind of shells and minerals deposited. Since sediment accumulation is continuous and undisturbed in much of the deep sea, layered oceanic cores provide an unbroken record of climatic change. Analysis of cores from many areas can be combined on a map to show the geographical extent of these different ice ages climates. Oxygen isotopes ratios in the ice can be related to the atmospheric temperature at the time the snow crystallized and fell. We are now in a relatively warm period (interglacial follows one of several glacial periods). It is not certain when the present interglacial will end, but even minor climatic changes affect the world's population in major ways.

All existing uncertainties do not disregard validity of *Canon of Insolation* as a method on which the contemporary climatology is based. It is unavoidable that Milanković saved the almost discarded astronomical theory of climate and established a firm buckle, linking the exact sciences (celestial mechanics, spherical astronomy, mathematical physics) and descriptive sciences (geology, meteorology, geography, oceanology, glaciology). He set a reliable method for reconstruction and prediction of climate, which is basically still valid. "It remains, however, that the basic of all sciences involved in any theory of paleoclimates can be found in the Milanković's *Canon*. Critically read, it will remain for ever a milestone in climate science. It is owing to the careful work by Milanković that we may expect starting to understand how the Earth system is responding to the astronomical forcing and how it might behave in the future."[17]

Figure 13. Participants All-Ortohodox council of churcles in May 1923, in Constantinople (M.Milanković sitting right and)

Milutin Milanković has created the most accurate calendar so far its deviation from the solar year is only two second. Gregorian calendar has a deviation of 26 seconds while the deviation of Julian calendar is even 14 minutes and 14 seconds. The calendar ob the Serbian scientist has been made to overlap with the dates of Gregorian calendar untie 2800.

At the All-Orthodox Conference held in May 1923 in Constantinople (Istanbul), Milanković received an official letter of praise and gratitude for the reform of Julian calendar from the Synod of Orthodox Churches, signed by Ecumenical Patriarch Meletius IV.

Figure 14. Crater on the Moon named after Milutin Milanković

[17] Andre Berger, Fedor Mesinger, *Canon of Insolation*, "Bulletin of the American Meteorological Society" 81, 2000, p. 1615.

NASA lists the Serbian scientist Milutin Milanković among the most important scientists of all times who did research on the Earth. Two craters, on Mars and Moon, and a minor planet were named after him. Since 1993 a Milutin Milanković medal has been awarded by the European Geophysical Society (now EGU) for contributions in the area of climate.

Milanković died on 12 December 1958 in Belgrade. He wrote a lot about his life and work, especially in "Memories, reminiscences and knowledge". He was rightfully called "*a traveler through space and time*" and this will be his synonym for ever.

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REVOLUCIJA I OSUNČAVANJE
Kako je Milutin Milanković sklopio slagalicu klime?

Milutin Milanković (1879-1958), profesor primenjene matematike na Beogradskom univerzitetu je srpski matematičar poznat po svom revolucionarom razumevanju dinamike klimatskih promena. Uspostavio je klimatologiju kao egzaktnu nauku, začetnik je numeričkog modelovanja klime, omogućio je matematičku interpretaciju dugih kvazi-periodičnih klimatskih promena i tvorac je osnovnog *organona* za razumevanje nastanka ledenih doba, jednog od glavnih naučnih izazova danas. Pokazao je povezanost nebeske mehanike i nauka o Zemlji, omogućio je dosledno spajanje nebeske mehanike i nauka o Zemlji i preobrazio deskriptivne nauke u egzaktne. Razmatrajući sezonski i latitudinalni raspored osunčavanja Zemlje, koja zavisi od promena u orbitalnoj geometriji Zemlje, Milanković je formulisao astronomsku teoriju klime kao opštu matematičku teoriju osunčavanja, stvarajući tako jedinu teoriju klime koja se može matematički proveriti i geološkim potvrditi.

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РЕВОЛЮЦИЯ И ИНСОЛЯЦИОННОЕ ВЫВЕТРИВАНИЕ
Как Милутин Миланкович решил загадку климата?

Милутин Миланкович (1879-1958.), профессор прикладной математики на Университете в Белграде, был сербским математиком, известным по своему революционному пониманию динамики климатических изменений. Он установил климатологию как точную науку, является основоположником цифрового моделирования климата, он упростил математические интерпретирования долгих квазипериодичных климатических изменений и является создателем основного *орг̄анона* для понимания земной ледяной эпохи, сегодня являющейся одним из главных научных вызовов. Миланкович демонстрировал взаимную связь механики небесных тел и земных наук, обеспечил постоянный переход из механики небесных тел в земную науку и преобразование обширных-описательных наук в точные науки. Учитывая сезонное и латитудинальное распределение земного инсоляционного выветривания, которое является следствием изменений в орбитальной геометрии Земли, Миланкович сформулировал астрономическую теорию климата в качестве обобщённой математической теории инсоляционного выветривания - единственную теорию климата, которую возможно потвердить математическим способом и проверить геологическим путём.

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REVOLUTION ET INSOLATION
Comment Milutin Milanković a résolu l'énigme du climat ?

Milutin Milanković (1879-1958) professeur des mathématiques appliquées à l'Université de Belgrade, était mathématicien serbe connu par sa compréhension révolutionnaire des changements climatiques. Il a établi la climatologie comme science exacte ; il est initiateur de la modélisation numérique du climat ; il a aussi simplifié les interprétations mathématiques de longs quasi-périodiques changements climatiques et il est créateur de l'organon de base pour la compréhension de la période glaciale sur la Terre qui représente un de principaux défis scientifiques aujourd'hui. Il a démontré les rapports mutuels entre la mécanique des corps célestes et les sciences de la Terre. Il a permis la transition consistante de la mécanique des corps célestes en science de la Terre et la transformation des sciences descriptives en sciences exactes. Prenant en considération la distribution saisonnière et latitudinale de l'insolation de la Terre Milanković a formulé la théorie astronomique du climat comme la théorie généralisé mathématique de l'insolation – la seule théorie sur le climat pouvant ȩtre confirmée et testée par la méthode géologique.