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MILUTIN MILANKOVIĆ (1879 – 1958) ONE OF THE MOST SIGNIFICANT SCIENTISTS OF 20TH CENTURY

MILUTIN MILANKOVIĆ (1879. – 1958.) MEĐU NAJZNAČAJNIJIM ZNANSTVENICIMA XX. STOLJEĆA

SUMMARY

Milutin Milanković was born in 1879 in the village Dalj (near Osijek, Croatia). After finishing secondary school in Osijek he graduated construction sciences and obtained his doctoral degree in Vienna. Milanković gave three fundamental contributions to science: a) astronomical theories of climate change b) theory of the movement of Earth's poles and c) revised Julian calendar. His most significant publication is the book **'Canon** *of* **Insolation** *of* **Earth'** *(1941.)***.** *Milanković's theory of climate and the origin of glacial epochs (in science known as Milanković's cycles) were not verified until 1976 when empirical studies of deep-sea sediments proved the accuracy of his astronomic model and the precision of his mathematical calculations of the state of Earth's climate. From then on his work gained wide reputation in the scientific world and consequently his capital work 'Canon...' ranked among the most significant scientific works of the 20th century. In this scientific paper a short presentation is given on the life and work of Milanković; pointing out his significant publications, his cycles and sparse attention of the Croatian cultural circle to the work of this great scientist.*

Key words: *climate, cosmos climatology, Milutin Milanković, Milanković's cycles*

SAŽETAK

Akademik Milutin Milanković rođen je 1879. g. u Dalju (kraj Osijeka), osječki gimnazijalac, diplomirao građevinske znanosti i doktorira u Beču. Tri su važna Milan-kovićeva doprinosa znanosti: a) astronomska teorija klimatskih promjena, b) teorija kretanja Zemljinih polova i c) reforma julijanskog kalendara. Najznačajnija Milankovi-ćevo djelo je knjiga „Kanon osunčavanja Zemlje" (1941.). Milankovićeva teorija klime i nastanka ledenih doba (u znanosti poznata kao Milankovićevi ciklusi) dobila je potpunu znanstvenu verifikaciju tek 1976. g. kada su empirijska istraživanja dna oceana doka-zala ispravnost njegovog astronomskog modela i preciznost matematičkih izračuna stanja klime na Zemlji. Od tada Milankovićev rad dobiva veliki ugled u svjetskoj znanosti tako da se njegovo kapitalno djelo „Kanon..." svrstava u najznačajnija znan-stvena djela XX. st. Ovaj rad daje kratki prikaz života i rada Milutina Milankovića, prikazuje Milankovićeve cikluse te ukazuje na važnost vraćanja intelektualnog duga hrvatskog kulturnog kruga djelu ovog velikog znanstvenika .

Ključne riječi*: klima, kozmička klimatologija, Milutin Milanković, Milankovićevi ciklusi*

1. Excellent mathematician, civil engineer, astronomer and climatologist

Milutin Milanković was born (1879) in the village Dalj (near Osijek, Cro-atia). He received his elementary education at home from private teachers and completed grammar school in Osijek (1889-1896). He graduated in Construction Science in 1902 and received his PhD in Vienna (1904). After several ye-ars of using his knowledge as a planning engineer to design dams, bridges, viaducts, aqueducts and other structures in reinforced concrete (1905-1909) he mo-ved from Vienna to Belgrade where he was offered a place of an associate professor of applied mathe-matics - working in the domain of cosmos, physics, geophysics and celestial mechanics. Apart from that, he established the department for celestial mecha-nics. During this period he published his first scien-tific papers in the field of applied mathematics and celestial mechanics (1904-1911) and wrote about as-tronomical aspects of climate. [5] *Mathematical theory of climate* (1912), *Über ein Problem der Wärmeleitung und dessen Anwendung auf die Theorie des solaren Klimas* (1913) and *On the Issue of Astronomical Theory of Ice Ages* (1915). During World War I he was arrested but thanks to good social relationships was released and given the permission to spend his captivity in Budapest with all civil rights granted including the right to work. At the Hungarian Academy of Sciences he studied scientific literature on climatology. After the war, the Yugoslav Academy of Sciences and Arts - JAZU (today HAZU) published (1920) Milanković's book *Théorie Mathématique des Phénomenes thermiques produits the pair la radiatin solaire.* [17]

Between the Two World Wars Milanković achieved a good cooperation with the climatologist Wladimir Köppen (1846 – 1940) and geophysicist Alfred Wegener (1880 - 1930) and published several scientific papers and books in the field of cosmos climatology and the development of glacial epochs on Earth. His most significant publication of this time (1930) was *Mathematische Klima-lehre und Astronomische Theorie der Klimaschwankungen*.[18] At that time he became a regular member of the Serbian Academy of Sciences and Arts (SANU) and Germany's Academy of Natural Sciences in Halle. Moreover, he was an associate of JAZU and several other academies. On the eve of World War II (1941) he finished his book *Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem* [19]. This being his capital work includes results of earlier published 28 scientific papers together with new analyses. Milanković presented a comprehensive astronomic theory of climate of Earth (usable on other planets), explained the occurrence of glacial epochs and developed his theory of the movement of Earth's poles. After World War II he published several university textbooks and was appointed director of the Belgrade Observatory. He died in 1957 in Belgrade and was buried in Dalj. [14] [15]

Milanković gave three fundamental contributions to science: (a) astro-nomical theories of climate change, (b) theories of the movement of Earth's poles and (c) a revised Julian calendar. [9] [14] [25]

- Milanković's revised Julian calendar (1923) is astronomically the most precise calendar so far (corresponding to the date of the Gregorian calendar) which would have needed correction only after the year 28800; unfortunately this has not become a reality.

- Milanković is one of the founders of continental tectonic plates in geology. On Köppen's and Wegener's initiative he developed the secular motion of Earth's poles which proved that the position of continents in the geologic past was significantly different from current, that is,

that during time they had moved. Much later modern geophysical measurements confirmed this concept and exactness of his calculations.

- Working on the influence of astronomic factors on climate during the geo-logical history of Earth, Milanković used a precise method to explain the cold and warm periods as well as the development and withdrawal of glacial plates during 600,000 years before the year 1800. Using his own mathematical algorithm and previous research insight of the French mathematician Joseph Adhemar (1797–1862), Urbain Le Verie (1811–1877), the Scottish scientist James Croll (1821–1890) and the German mathematician Ludwig Pilgrim (1849-1927) – Milanković proved three astronomical factors of climate change in the geologic past. These are the three elements in self cycles: a) secular variations of the eccentricity of Earth's orbit, b) precession of Earth's axis of rotation, and c) variation of the obliquity of the rotation axis. He paid special attention to the insolation of area of 55^0, 60^0 and 65^0 North latitudes during summer periods – and discovered that it is the low insolation during summer that causes icy plates. Eventually Milanković's theories on climate were named Milanković's cycles. [14] In addition, he worked on scientific papers that dealt with the calculation of temperature of neighbouring planets (impressively correct calculations compared to the present ones which are acquired by the use of modern technology) [108]. Besides, Milanković is the founder of the cosmos climatology.

2. Milanković cycles

According to Milanković's theory of glacial epoch and interglacial peri-od on Earth, cyclic changes in Earth's movement around the Sun are caused by three variations: a) eccentricity of Earth's elliptical orbit, b) tilt of Earth's axes and c) precessions (rotation of the Earth's rotation axis).

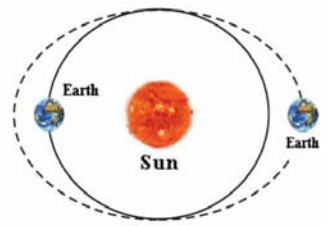
2.1. Eccentricity of orbits

Eccentricity of the elliptical form of Earth's path around the Sun is first of Milanković's three cycles. It deals with the constant fluctuation of the form of Earth's orbit - from 0 to 5 % elliptic; the orbital form of the ellipse varies from 0.005 to 0.06 in cycles of about 100,000 years (Fig 1)[109]. Such an elliptic of orbit determines how much Sun-rays insolate our planet; in the smaller elliptical orbit differences in the insolation during different periods of the year are not great while in the high ellipticity the differences between seasons are significant. The most remote node of Earth's movement around the Sun is called aphelion, and the nearest perihelion. When Earth is near perihelion winters are milder on the Northern Hemisphere, and when eccentricity is highest (the perihelion) then the seasonal difference of received heat is in a range between 20 to 30 % higher than on the aphelion. Current eccentricity of orbital ellipse is almost on the minimum of cycle (rates 0,017), and the seasonal difference of received heat amounts to about 7 %. [12]

[108] Unlike present astronomers and climatologists – which dispose of strong electronic com-puters and digital equipment (the drawing of graph …) – Milanković used only pencil, paper and the slide rule. Besides being a mathematical genius and great at observing problems, setting up of algorithms and formulas of calculations, Milanković demonstrated excellent dedication to his research work - for the processing of movements of astronomic elements of one planet around 80,000 computer actions were needed.

[109] Eccentricity of orbit discovered and first calculation of parameters presented (1609) Johannes Kepler; [21] the cycle is actually the average of about 95,000 and 123,000 years.

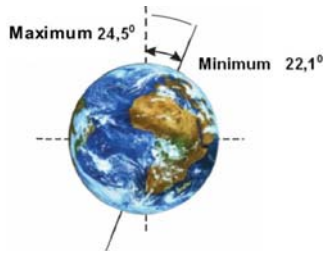
Figure 1. Eccentricity of Earth spheres around Sun



2.2. Change inclines Earth's axis

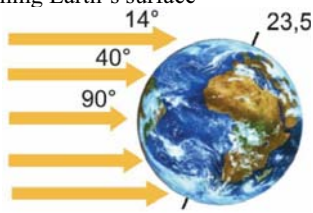
The Second cycle involves the change in the inclination of Earth's axis in relation to the plane of Earth's orbit around the Sun.[110] Oscillations in the tilt of Earth's axis are in a range of 22.1^0 to 24.5^0 (Fig. 2) and the cycle lasts 41,000 yrs. Today the inclination of Earth's axis is at level 23.5^0 but towards declining. Because of periodic variations of the inclination of Earth's axis the angle of sun-rays that reach Earth's surface changes (Fig. 3).

Figure 2. Change inclines Earth axes of rotation in relation to plane orbits



This has an effect on the characteristics of climate and seasons; when the tilt of Earth's axes is smaller insolation is more evenly distributed between winter and summer. A smaller tilt increases the difference in the radiation of equatorial zones and Polar Regions. When the tilt is bigger the difference in temperatures during seasons on higher geo-graphic latitudes is more significant, in other words, it has a small influence on the equator and a big one on the poles. [12] [14]

Figure 3. Angle of sun-rays reaching Earth's surface

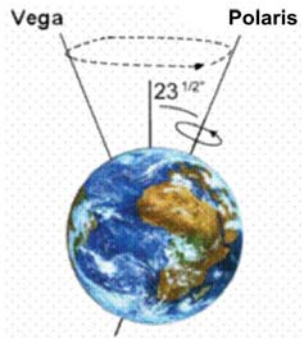


[110] The Chinese identified this manifestation about 1000 years BC. [21] They measured the difference between angle of Sun on horizon at noon during longest and shortest day of year.

Precession

Precession (revolution of Earth's rotational axis) is the result of spinning of Earth's rotational axes in a period of approximately 23,000 years. It affects the orientation of the axis but not her tilt (Fig 4). Throughout 12,000 years Earth's axis (imagined) is elongated in the direction of the Polaris which is already direc-ted towards the star Vega, in the constellation Lyre. As a consequence of these complex Earth's movements, days of equinoxes do not happen always on the same date (in the year), but (calendarically) move slowly.[111] How does the process of precession occur, in other words, what causes this pheno-menon? Earth does not have a form of a re-gular circle (it is flattened on the poles and the area of equator is a little bulged), and due to the axis being tilted in relation to ecliptic's plane and the plane of Moon's path, the Sun and the Moon unequally pull the part of the equatorial bulge towards them (in relation to the bulge on the other side). Because of that (virtually), Earth's axis does not stay motionless but moves on its own designing a circle on the celestial sphere. (Fig 4) [12] [14]

Figure 4. Revolution of Earth's rotational axes



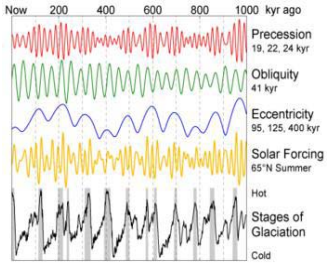
Nowadays Earth's axis on the Northern hemisphere - called Polaris (given the fact that is situated on the North Pole) - is oriented towards the star Alpha of the little Bear. In fact this axis passes the Polaris within a striking proximity (> 10). As the axis moves - in 12,000 years it will be aiming at the about 5° from the star Vega and will then become the Polaris.

2. 4. Simultaneous actions

The aforementioned three cycles affect the insolation on Earth simultaneously and are the primary cause of climate changes and responsible for the occurrence of glacial epochs. Calculating these parameters Milanković outlined seasonal modifications of variations for the three cycles covering a period of 600,000 years. The most important parameter of Milanković's theory is the amount of sun-rays that reach the ground in July on 65° north geographic latitude; because if the ground is not sufficiently warmed up in July the ice cover will spread and grow. If insolation is sufficient the ice cover will pull back. In this way, Milanković concluded that rather small orbital variations can cause significant fluc-tuations of the climate on our planet. Figure 5 illustrates simultaneous and integrated insolation on 65^0 north geographic latitude in a period of one million years. [12] [14]

[111] The first one to indicate this phenomenon was ancient Greek astronomer Hiparh - 130 years BC. [21]

Figure 5. Effect of Milanković's cycles on Earth's insolation



Source: [6]

3. Scientific verification of Milanković's climate theory

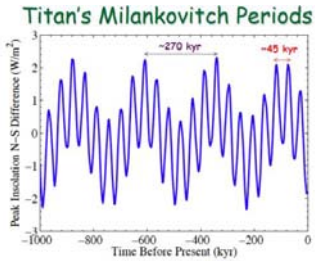
The scientific community needed many years before it accepted Milan-ković's theory on climate changes. It represented a turning point and exact evidence was required. At the beginning of 1970s one started with geologic research using deep sea probes into the seabed and with it support for the scientific verification of Milanković's theory. By the end of 1976 the journal *Science* [10] published results of a five-year probing of the seabed of ocean (project CLIMAP). Strata of sediments (up to 2,5 km depth) as a geological record of changes of the climate on Earth have proved the accuracy of Milanković's model and the precision of his mathematical calculations. What followed was a wide range of scientific meetings, scientific papers in journals and books which considered and confirmed Milanković's model of climate changes:

- In 1982 a symposium called *Milanković and Climate* was organized at the University of Colombia (New York, USA) including presentations and discussions by the 130 invited leading paleoclimatologists. During their presentations (90 scientific papers) one confirmed the existence of cycle insolation of Earth in periods of: 100,000, 41,000, 23,000 and 19,000 years (Milanković's cycles), and one larger cycle was identified from the year 413,000 [25]
- National Research Council of the U.S. National Academy of Sciences embraced (1982) Milanković's cycle model: '…orbital variations remain the most thoroughly examined mechanism of climatic change on time scales of tens of thousands of years and are by far the clearest case of a direct effect of changing insolation in the lower atmosphere of Earth.' [23]
- University Peruga (Italy) organized (1988) an international scientific conference *Ciklo-stratigraphy* during which new research methods were promoted. These involve Milanković's cycles of insolation and in rhythmic changes detect colder and warmer cycles of climate through which our planet has passed. [25]
- In 1992 in San Francisco (USA) an international symposium was dedicated to Milanković's theories under the name *Ten Years Later.* During the symposium results of a research report were analyzed as well as the effects of astronomic elements on Earth's climate. [10]
- In 1999 it was proven that versions of oxygen's isotope drafted in sediments at the bottom of the ocean really follow Milanković's prediction. [26]
- International Centre for Theoretical Physics (Trieste, Italy) organized the conference called *Milankovitch's Cycles over the Past 5 Million Years* (2007) during which results of a research on manifestations of global warming were analyzed and discussed
- Sponsored by UNESCO (on the occasion of 130-and the anniversary of Milanković's birth) in Belgrade a symposium was organized (2009) *Climate Change at the Eves of Second Decade of Century;*

Inferences from Paleoclimate and Regional Aspects on which in 50-tock the report world eminent researchers have presented latest recognition on actual climate changes and the global warming.

- Here one should add that Milanković cycles as a model influencing astronomic elements on the climate of planets is used in the cosmos research of planet of the Sun system. Fig. 6 shows the graph of Milanković's cycle for Saturn's moon Titan (from the Casini mission; 2004-2006). [24]

Figure 6. Milanković cycle of Titan insolation



Source: [24]

To conclude this shortened review of the verification of Milanković's cycles with quotations by eminent researchers: André Berger names Milanković '*the father of astronomic theory and climate modellings*' [24] Berger and Fedor Mecinger stress: "*Remain the fact that is a base every science is included into anybody climatic theory occurring in the Milanković's book."*(Canon) [2], groups of authors are led climatologist Laskerom remarks: '*Sons then, the under-standing of the climate response this orbital forcing has evolved, thigh all the necessary ingredients the for the insolation computations were present Milankovitch's work* '[16]

Finally, one needs to point out: Milanković's scientific papers according to the databases of the Science Citation Index have in the period 1945-2009 been quoted 1.066 times, [27] and in the last decade yearly number of quotation has increased. Towards the Google.scholar bases of quotations Milanković (to the middle of April 2012) appears in over 20.000 records. [7]

3.1. Praises and acknowledgments of world scientific publics

After scientific verifications of Milanković theory follows the signify-cant acknowledgment world scientific public honoring large scientist; [112]

- (1970) On the XIV Congress of International Astronomical Union in the Brighton one crater on the Moon (measures 34 kms; coordinates +170,+77) gets the name on Mi-lanković; [11]
- (1973) On the XV Congress of International Astronomical Union in the Sydney one crater on the Mars (has measured 118 kms; coordinates +147,+55) gets the name on Mi-lanković; [11]
- (1980) the Asteroid 1605 (marks 1936GA) which have discovered the Serbian astro-nomers Milorad Protić and Petar Ćurković has been called on Milanković name; [24]
- (1993) European Geophysical Society establishes the acknowledgment to the scien-tists for extraordinary research reports in the field long-term climate changes which has been called on Milanković; [4]

[112] In several scientific works and nonfictional articles stresses that the NASA has included Milanković among 5 (or 10) most significant scientists of 20th century in the area of sciences on the Earth. But on Web sites NASA have not been found the sheet with the rank of meritorious scientists; in fact it concerns to the web serial *On the Shoulders of Giants* - description of the most important reaching in the area of the astronomy. In this way NASA Earth Observatory in that serial has presented significant works of authors of the astronomy, among which is in three following text (2006) the model Milanković's cycles are presented.

- (2001) In the book *The Science* British Ph Ds Simon Singh and Susan Greenfield describes 250 scientist which has been formed our civilization – which has been in-cluded Milanković with their cycles of changes of climate; [27]
- (2004) American astrophysicist (and historian of science) John Gribin is in their book *Scientist: History of science is told through lives her largest of inventors* - on six pages writes on Milanković and his work of Earth climate; [8]
- (2009) UNESCO is this year would declare Milanković year; [14]
- (2010) The largest world Internet network Google has supplied on the 28, May (Milanković birthday) the main Web searcher page would dedicate Milanković. [7]

3.2. Milanković in the Croatian cultural circle

Although is born in Slavonia$_{(1)}$, although is the basically$_{(2)}$ and second-dary$_{(3)}$ education completely would realized in the Osijek, although has been the corresponding member of JAZU$_{(4)}$ (today HAZU), although the publisher his first scientific books have been the JAZU$_{(5)}$, although this book has been printed in the bishop's printing-office in the Zagreb$_{(6)}$ and although has been buried in the Slavonia$_{(7)}$ – Milanković is in the Croatian cultural circle every these years on margins of attention scientific, cultural and societal publics. That in the Croatia was able will have done counting the as activity in the return of the intellectual dept to scientist whose work counts in the top of scientific achievement of 20th century:

- (2002) International scientific conference *Serbs in the Eastern Croatia*, Osijek, 8.-9 June; on which are, among other, three reports (N. Pantić, M. Radovanac, S. Garonja-Radovanac) are dedicated to the Milanković work; SKD "Prosvjeta", Osijek; [1]
- (2002) the Appeal for the rebuilding of the Milanković birth house - which 9 June has signed participants of the sci. conference *Serbs in the Eastern Croatia* in the tour of devastated Milanković birth house in Dalj; [1]
- (2008) the Reprint of Milanković book *Astronomical theories of climate changes and her application in geophysics*; Prosvjeta', Zagreb. [21]
- (2008) International symposium *Creativity of Milutin Milanković*, Dalj, May 23-24; SANU, SKD Prosvjeta - Zagreb and Municipalities Erdut. [30]
- (2009) Rebuilding of Milanković birth house; are arranged museum and is placed Culturally-science center Milutin Milanković; Government of Republic Serbia, Mu-nicipality Erdut and Government of the Republic of Croatia. [15]
- (2009) Are founded CSC „Milutin Milanković" Dalj; Municipality Erdut. [15]
- (2009) Started Web sites about M. Milanković; CSC M. Milanković, Dalj [15]
- (2009) On the UNESKO symposium (Belgrade, 2009) fifth day has supplied this conferences in Dalj two lectures are kept (K. Pandžić and Z. Knežević) and debates presided over by climatologist André Berger; CSC M. Milanković. [15]
- (2010) Portal Essekeri (non-commercial project of company YPSILON Osijek - which from 2009 yr. announces the serial on important citizens of Osijek) has achieved the video and publish shorter story of Milanković life and his work realizing. [3]
- (2010) Academy regarding the marking 131 year of Milanković birth and three lectures (V. Paar, M. Ivanović, Z. Knežević); CSC M. Milanković, Dalj [15]
- (2010) On the building' wall of Department for physics of Universities J. J. Strossmayer student of Art Academies Igor Dešić has drawn (on the idea their friend, student of first-year physics Hrvoje Miloloža) graffit on „*Giants of the science*" on which is portraits five Croatian scientists: Ruđer of Bošković, Nikola Tesla, Milutin Milan-ković, Rudolf Štajner and Andrija Mohorovičić. [29]
- (2011) Conference *Milanković, calendar, time...*; six lectures (V. Paar, Z. Kne-žević, A. Petrović, R. Milošević, S. Marković, Đ. Đurić); CSC M. Milanković, Dalj. [15]

4. Conclusion

Milutin Milanković was born in Slavonia, a region in Eastern Croatia, was a grammar school pupil and member of JAZU (today HAZU) who despite life's hardships managed to achieve great things in scientific research. Milan-ković's contribution to science involves the field of astronomy and Earth science. He is the founder of the astronomical theory of climate and contributor of Canon of the Earth's Insolation, which characterizes the climates of all the planets of the Solar system through three cycles of Earth rotation and it's revolving around the Sun. His scientific papers on the calculation of tempe-rature of neighboring planets make him the founder of cosmos climatology. He is also coauthor of the theory of movement of tectonic plates and the moving of Earth poles. Milanković's theory on climate and the origin of glacial epochs on Earth received scientific verification following empirical studies of the seabed of oceans when accuracy of his astronomic model and precision of his mathematical calculations of climate states on Earth were proven. Astronomic factors that influence the climate of the planet are called Milanković's cycles and are used in cosmos research of the Sun system.

Milutin Milanković's scientific papers have gained worldwide repute-tion so that his work classifies among the most significant scientific contribu-tions of the 20th century - thanks to the international scientific and cultural public who with a series of events (giving names to objects in cosmos, naming of scientific prizes after Milanković, holding jubilee scientific conferences and other internationally renowned happenings) contributed to his being classified into the group of 250 greatest scientists in the world.

Eventhough some of his most important life situations as well as scientific events were related to Croatia, the then cultural circle did not pay enough attention to the work of this great scientist. One can conclude that the acknowledgement of intellectual debt owned to Milanković's work is modest and that this has mainly been left to the enthusiasm of a minority within the Serb community in Croatia and several European oriented individuals in Croatian science, culture and politics. Fifty years after Milanković's death his work is still in displeasure of a provincial spirit.

The overall reputation of the Republic of Croatia would gain more prominence and quality within the international scientific, cultural, political and economic circles, if in the same Croatian circles, and then in the general public, one would pay more attention to such individuals as was Milanković (one could use it as a historical brand). This is the specific lacmus of our openness and our criteria of values; i.e. to show the world how much we respect quality. Without these changes within our system of values there will not be much social nor economic development.-

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