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MILUTIN MILANKOVIĆ AND ASSOCIATES IN THE CREATION OF THE "*KANON*"

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Abstract. Milutin Milanković took a different approach to climatology, when compared to other meteorologists of his time, and can be considered a key figure in laying down the foundations of modern climatology, where celestial mechanics was the foundation upon which Milanković based his theory of climate change.

Under the guidance of Vojislav Mišković, director of the Astronomical Observatory, mathematicians Stanimir Fempl and Dragoslav Mitrinović performed the lengthy and very comprehensive calculations. At the University of Belgrade in 1932 their scientific endeavor was completed. This work involved a multidisciplinary approach. Mathematician Mihailo Petrović Alas published a paper about this important project.

The problem of the shape of the Earth and the position of the Earth's poles was addressed by Milanković in 1932 and 1933, prompted by earlier suggestions of Alfred Wegener (1880–1930). Milutin Milanković published papers on the subject of *Mathematical Climatology* in significant scientific publications, such as the *Handbook of Climatology* and Gutenberg's *Handbook of Geophysics*. However, his works were not easily accessible to the interested scientists because few of the libraries had all the volumes of these Handbooks and other journals. The idea of creating his *Kanon* was presented at a meeting of the Academy of Natural Sciences in Belgrade in 1938. Mathematician Tatomir Andjelić did a tremendous amount of work during the preparation of Milanković's *Kanon. Kanon* was published in 1941 in Belgrade.

After World War II, under the heading *Open Problems*, Milanković presented 26 topics related to his work for further investigation to members of the Mathematical Institute, the Astronomical Institute, as well as graduate and doctoral students. Among them are several topics that are related to his *Kanon.*

1. INTRODUCTION

Milutin Milanković (1879–1958) opted for a different approach to climatology than meteorologists at the time. Therefore, it can be considered that he participated in laying the foundations of modern climatology. Celestial mechanics was the basis upon which he founded the theory of climate change (Milanković 1952).

A great deal of work regarding the scientific research of Milutin Milanković has been done at the Astronomical Observatory in Belgrade. Based on the work of the French astronomer Le Verrier (1811–1877), the calculations of secular changes in the astronomical elements of the Earth's trajectory were revised, taking into account the mass of each of the planets known until 1928.

2. ASSOCIATES IN THE CREATION OF THE "KANON"

Under the guidance of Vojislav Mišković (1892–1976), director of the Astronomical Observatory, mathematicians Stanimir Fempl (1903–1985), then an assistant, and Dragoslav Mitrinović (1908–1995), then a student, performed the lengthy and very comprehensive calculations using mechanical calculators (Janc et al. 2019) (Fig. 1). Their scientific endeavor was completed. It consisted of forming

Figure 1: The astronomer's desk at the Museum Collection located at the Meteorological Observatory. It features the Original Odhner Gothenburg, one of the desktop computing machines that was used to perform Milanković's calculations. (Foto: N. Janc, 1987.).

an approximate picture of the insolation of the Earth's surface, as well as the relationship that exists between the insolation and the temperature of both the Earth's surface and the atmosphere. The work involved mathematicians and astronomers who taught mathematical physics, celestial mechanics and astronomy.

Mathematician Mihailo Petrović Alas (1868–1943) published a paper *Occasion of a Recent Application of Astronomy to Climatology* (1932) on this important multidisciplinary project. He said:

"This year, a new scientific endeavor was completed at the University of Belgrade this year, with the cooperation of mathematicians and astronomers who teach mathematical physics, celestial mechanics and astronomy at the University's Faculty of Natural Sciences. The endeavor consisted in forming an approximate picture of the course of the insolation of the Earth's surface, as well as the relationship between the Sun's surface and the temperature of the Earth's surface on one side and the atmosphere on the other.

No matter how difficult this task may have been, having consisted in re-doing the work all over again, because the corrections made on the masses of the planets originated from their last calculations, and then recalculating values of secular inequalities for the elements of motion of the planet (which included 600,000 years before 1800), Mr. Milanković took it without hesitation. Assisted by Mr. V. V. Mišković, Director of the Astronomical Observatory of the University of Belgrade, who took over all astronomical calculations, could successfully complete this work on testing his new theory of climate change on Earth." (Petrović 1932).

Dragoslav Mitrinović, professor of mathematics at the Department of Electrical Engineering in Belgrade, wrote in his memories:

"For the purpose of scientific research, Professor M. Milanković undertook at the Astronomical Observatory in Belgrade, during 1928 and 1929, the tedious work of recomputing the secular changes of the astronomical elements of the Earth's trajectory, based on Le Verrier's work, and taking into account the values of the masses of planets known by 1928. The work was organized like this. Stanimir Fempl, then a university teaching assistant, and I, then a student, independently of one another, had to perform the proposed calculations." (Mitrinović 1968).

In his work *Milanković's Contribution to the Astronomical Theory of Ice Ages* (1979), Stanimir Fempl, professor of mathematics at the Faculty of Civil Engineering in Belgrade, writes that Milanković initially used Stockwell's results, but later used results of Mišković. "He (Mišković) used LeVerrier's calculations as more reliable, but he made corrections according to new knowledge about planetary masses. He did that with the cooperation of his assistants, Dragoslav Mitrinović and Stanimir Fempl. The calculations lasted for almost three years. Mišković also determined the degree of accuracy with which the calculations were performed" (Fempl 1979).

In 1930, Mišković initiated and edited the *Yearbook*, which, from the following year, was renamed the *Yearbook of Our Sky*. The same year the second edition of the *Annuaire de l'Observatoire astronomique de l'Université de Belgrade* was published. On this occasion, Milanković sent his congratulations to Mišković in a letter dated November 24, 1930. Milanković also wrote that he realized that some of the tables could be further elaborated, e.g., Table 5 *Length of day and night in the polar zones*. (*Lange Tage und Nächte der Polarzonen*) (Janc et al. 2018). He asked Mišković to prepare some more tables for him, which he marked on a separate piece of paper; unfortunately, that paper was not preserved (Janc et al. 2018). He needed the tables by the second half of December 1930 for his paper *The Earth Rotation* that he was preparing for the *Handbook of Geophysics* (Janc et al. 2018).

The problem of the shape of the Earth and the position of the Earth's poles began to be addressed by Milanković in 1932 and 1933, following the earlier suggestions of Alfred Wegener (Andjelić 1979). Milutin Milanković has published papers on the subject of *Mathematical Climatology* in significant scientific publications, among which are the *Handbook of Climatology* and the Gutenberg's *Handbook of Geophysics*. However, as he noted, his works were hardly accessible to interested readers because few of the libraries had all the volumes of these *Handbooks* and other relevant journals (Milanković 1952). So, he decided to publish all his papers on the paleoclimatic problem in a separate book (Milanković 1952). This is how the idea of creating the *Kanon* was born. The idea and content of the book were presented on March 27, 1938 at a meeting of the Academy of Natural Sciences in Belgrade, when a decision was made to publish it as an edition of the Serbian Royal Academy, in German, so that it would be accessible also to foreign scientists (Milanković 1952).

Tatomir Andjelić (1903–1993) was a professor of theoretical mechanics at Faculty of Science in Belgrade and academician of SANU. In the period 1928–1945 he worked as a high school professor of mathematics and at the same time he was a teaching assistant in rational mechanics at the University of Belgrade. He performed a lot of work in checking formulas, numerical tables, languages, etc. in *Kanon* (Trifunović 2007).

The *Borba* newspaper published on March 15, 1958 an article entitled *Palms and Bananas in Belgrade*, which claims that "In the next 100,000 years we will not reach the Ice Age – according to the mathematician Fempl" and quoted him as saying: "The results I have received are not only very interesting, but are encouraging as well. It turned out that in the future, in forty thousand years, the amount of heat emitted by the sun would constantly increase in our northern hemisphere. In the southern hemisphere, in the temperate zone, where New Zealand is located, the picture will be quite different. Very high minimums will appear, ten thousand and twenty thousand years from now."

3. PROBLEMS TO BE WORKED ON

Milutin Milanković left room for future associates on *Kanon*. Under the title *Problems to be worked on*, he presented 26 topics that could be addressed by members of the Mathematical Institute, the Astronomical Institute, as well as by graduate students and doctoral students (Trifunović 1979). Given that Milanković mentions the Mathematical Institute, the list of topics must have emerged after the year 1946 (Trifunović 1979). Some of the topics:

For the Mathematical Institute

A model of secular insolation on Earth

For the Astronomical Institute

A new study of secular perturbations for the past and the future

A new determination of the aberration constant using extragalactic objects

For graduate students

Insolation of the Earth's tropical zone, the caloric equator

Exactly calculating the secular course of insolation of the Earth over the past 50,000 years and as many future years

Insolation curve based on the theory from Chapter XVIII of the *Kanon*

For Ph.D. candidates

The exact calculation of the coefficient *m*

Calculation of the annual insolation of the parallels $\omega = \omega(t)$; see "Theorie mathématique." From here, heat parameters are calculated… from the equation $\omega(t\square) = \omega(t\square + T/2)$.

The theory of meteors passing through the Earth's atmosphere

Calculation of the coefficients b_0, $b\square$, $b\square$, $b\square$ of Table VI ("Kanon", p. 312) using the method reported on p. 313–315 of "Kanon."

Study of atmospheric circulation, computational and by a model. To start with steady state. Mean annual temperatures (or insolation) on the parallels

Investigate separately the effect of changes in the inclination of the ecliptic on the insolation of the Earth with the assumption of a circular path, and then separately the influence of the change of eccentricity. That would be a quite simple derivation for geologists.

The problem of rolling snowballs

The problem of two bodies, §5 "Foundations of Celestial Mechanics" if M and therefore μ are considered to be variable (linear)

The list indicates that Milanković himself saw the need for certain topics in the *Kanon* to be processed in a modern way, given the new scientific data and numerical methods using modern computers (Trifunović, 1979).

4. CONCLUSION

The *Kanon* of Milutin Milanković was of crucial importance for understanding climate change and its causes. Under the leadership of Milanković, a multidisciplinary team was engaged in the realization of his idea and research, as

described by Mihailo Petrović Alas (1932). People from several disciplines were involved in various phases, both in terms of professional education and academic title, from students to PhD scientists and academics.

This paper precisely emphasizes this aspect of cooperation, which, as Trifunović (2007) writes, was the first case of teamwork in Serbian science, which helped to complete the exceptional work of Milutin Milanković.

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