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THE CYCLES OF REVOLUTION: HOW WEGENER AND MILANKOVIĆ CHANGED THE EARTH SCIENCES

CIKLI REVOLUCIJE: KAKO STA WEGENER IN MILANKOVIĆ SPREMENILA VEDE O ZEMLJI

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Alfred Wegener at his first expedition to Greenland in 1906
(Source: Alfred-Wegener- Institut für Polar- und Meeresforschung,
http://www.awi.de/fileadmin/user_upload/ News/
Press_Releases/2005/4._Quarter/Wegener5_w.jpg).
Alfred Wegener na svoji prvi ekspediciji na Grenladnijo leta 1906
(vir: Inštitut Alfreda Wegenerja za preučevanje polarnih območij
in morij, http://www.awi.de/fileadmin/user_upload/News/
Press_Releases/2005/4._Quarter/Wegener5_w.jpg)

The cycles of revolution: how Wegener and Milanković changed the earth sciences

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ABSTRACT: The year 1912 is *annus mirabilis* for Earth sciences. In two crucial papers Alfred Wegener and Milutin Milanković independently set up revolutionary theories based on far-reaching visions of continental drift and climate orbital forcing. Their contributions simultaneously did for the Earth sciences what the theory of evolution did for biology and what the theory of relativity did for physics. They provided Earth sciences with a comprehensive perspective of Earth's dynamics in both astronomical and terrestrial terms, and revolutionized geology by abandoning the ideas of a climatologically self-sufficient Earth and unmovable continents – remnants of the old geocentric picture of the unmoving, centered Earth. In the secular sense they finally completed the heliocentric theory that was set up by Copernicus. This paper follows the strange synchronicity in their life and work cycles.

KEY WORDS: Alfred Wegener, Milutin Milanković, Vladimir Köppen, year 1912, astronomical theory of climate change, the origin of continents, heliocentric theory

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1 Introduction

One of the last major scientific revolutions occurred exactly one century ago in 1912, when two scientists, who did not know of each other at the time, changed the principle of Earth sciences. Paradoxically, the two scholars, Alfred Wegener (Figure 1) and Milutin Milanković (Milanković is the proper Serbian language orthography of his name. But more often used is Milankovich, Milankovitch or even Milankowitz) (Figure 2), were not even Earth scientists (Petrović and Marković 2010). Wegener was an astronomer and meteorologist interested in geophysics, while Milanković was a civil engineer interested in climatology.

2 Wegener's contribution

At the yearly gathering of the German Geological Association in Frankfurt on January 6, 1912, Alfred Wegener lectured on »The uprising of large features of the Earth's crust (continents and oceans) on a geophysical basis« (ger. *Die Heraushebung der Großformen der Erdrinde (Kontinente und Ozeane) auf geophysikalischer Grundlage*). Immediately afterward, he sent the lecture to the journal *Petermanns Geographische Mitteilungen*, which gave it a laconic name »The Origin of Continents« and published it in three parts (Wegener 1912). The lecture astonished all who were present, as it brought the reigning views on geology into question. Taken in continuity with the work of Louis Agassiz (1807–1873), it additionally strengthened the dynamic of the »erratic boulders« by bringing in the concept of »continental drift« and »wandering poles«.

Leaving the so far inviolable idea of sunken bridges between continents, Wegener postulates that a whole continent existed, Pangaea, which broke apart approximately 200 million years ago, its pieces eventually coming to their current positions. He noticed the congruence of South America and Africa's respective shapes – »*Doesn't the east coast of South America exactly fit the west coast of Africa, as if they were once one? That is the idea I wish to follow*,« he wrote to his future wife in 1910 (Wegener-Köppen 1955). In this way, he »*anticipated sea-floor spreading, the functional relationship between bathymetry and age or temperature below the sea floor, perhaps mantle convection, and some aspects of plate tectonics*« (Jacoby 1981). Sketching the similarities of geological structures, along with the climate of continents in the remote past, he cited numerous examples of identical fossils of animals that had lived on both continents hundreds of millions of years ago.

Apparently, it was all too dynamic for Earth science of that time, as from its static position it was suddenly thrust into a world that no longer seemed to have a terra firma. Wegener was perfectly aware that he had not only deeply disturbed the professional public, whose discomposure could not be quieted for a long time, but he also initiated a true revolution. »*If it was shown that harmony and reason came to the history of Earth, why would we hesitate to revert to old beliefs?*« (Wegener's letter to Köppen 1911) he writes to his father-in-law. When the book was translated into English in 1924, it brought up a wave of sharp criticism that kept it from being accepted until 1960. Although Wegener carefully collected geological evidence, American and British geologists standing on the barricades of the old paradigm laughed at him and his ideas. »Complete nonsense,« said the president of the American Geological Society, following his colleague's view that »*if we believe in this hypothesis, we must forget all that we have learned in the past 70 years and begin again«. British geologists were even more scathing, as they claimed that anyone who »values his reputation as a scientist of reason*« would not support the theory (Hughes 1994). At a meeting in New York in 1926, Wegener was received with heavy sarcasm. Critics called his theory »geopoetry«.

Albeit the utter incomprehension, Wegener's theses were the beginning of the *annus mirabilis* in which the new Earth science would be born.

3 Milanković's contribution

Only a few months later, Milutin Milanković published the paper »On the mathematical theory of climate« in the Serbian Royal Academy's journal *Glas* in which he looked at the then-current theories of astronomic influences that force the mechanism of thermal balance of the Earth, and prepared the mathematical methodology for a fundamentally different vision of climatic cycles (Milanković 1912). When Milanković initiated the study of astronomic theory of climate change, it was largely a forgotten relic in science. The leading scientific authorities found it interesting but useless because Ademar's, Croll's, and other similar lesser-known astronomic theories did not give satisfactory results in keeping with the in situ findings. Later, the consensus among geologists and climatologists led to opposition to Milanković's theory, the protagonist of which was Austrian geomorphologist Albrecht Penck, who was also a strong opponent of Wegener. After having attended a lecture given by Wegener to the Berlin Geographical Society on February 21st, 1921, Penck found that his hypothesis had »*something seductive*« but he remained firm that the shape of continents was the result of contraction and of vertical crustal movements. He was the unquestioned authority on paleoclimatology because, together with Eduard Brückner, he determined the phases of glaciation in the Alps (accepted in their time, later discarded).

Penck observed essential deficiencies in earlier astronomic theories of climate, not only pointing at their mistakes, but going a step further by rejecting the validity of such admissions in their entirety. He postulated that significant climatic deviation can occur due to periodic changes in Sun's thermal strength, and not because of the orbital dynamic of the Earth. He believed there were only four ice ages, and considered that climate change might be caused by variations of solar heat power, not by the orbital dynamics of the Earth.

Penck's beliefs brought him in the line with one of the most respected European climatologists, Julius von Hann, who was confused by the disaccord of the results of certain astronomic theories and as a consequence judged that they were useless in principle and that astronomic causes are not powerful enough to enforce a climatic change. It was not unknown to Milanković that »*all attempts to explain climatic change in this way were so unsuccessful that in 1908 the great Austrian climatologist von Hann discarded all of them, stating that from an astronomic standpoint one would infer the constancy of the Earth's climate before inferring its variability*« (Milanković 2009, 603).

Initially, Milanković, although not upset, strongly rejected Penck. »*Penck was an excellent observer, a pure empiric, but not a theorist. His world, limited to the Earth's surface, had only two dimensions. He couldn't peek deeply into the cosmos by his spiritual sight…*« He was equally decisive in rejecting Julius von Hann. »*Thus I replayed 'yes' to Julius Han's 'no', proving that the Earth climate changes, triggered by the astronomical*

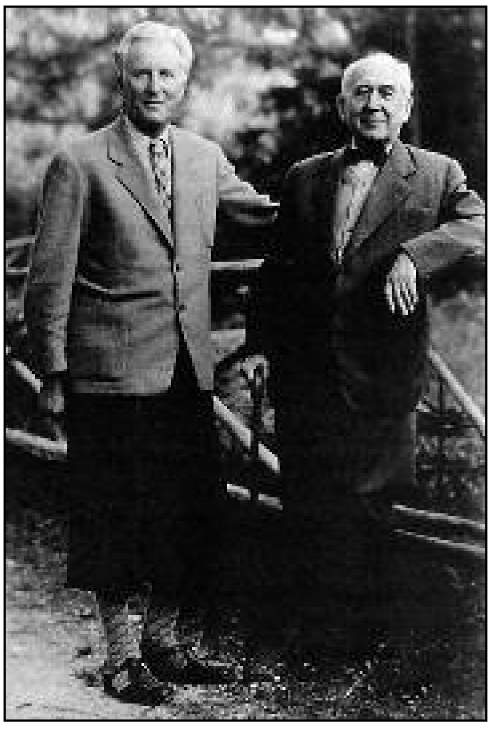


Figure 1: Milutin Milanković with his student from Slovenia Tedi Djivović (1952) (Archive of Serbian Academy of Sciences and Arts).

facts, are so strong that they had not passed away without any record. Hence in my first paper I showed how they could be subjected to calculations and by means of the Celestial Mechanics followed unto distant past.« (Milanković 2009, 693).

To make the matter even more difficult, meteorology being in the process of a strong development at that time did not consider it significant that the Sun be placed in the center of climatological questioning. Paraphrasing the belief of the particular science, Milanković says, »*Why take a route that goes through the faraway Sun in order to discover what happens on Earth, when on it, we have thousands of meteorological stations that inform us of all temperature occurrences in the layers of the Earth's atmosphere in which we live, accurately, more accurately than the most perfect theory can*« (Milanković 2009, 603).

As a consequence, Milanković, in the initial phases of his work, had the indifferent meteorology and climatology and almost the entire geology standing against him – the belief in the astronomic theory of climate seemed to vanish and the idea was practically forgotten. But he was both lucid and bold enough to estimate that astronomic theory had not fallen into crisis due to mistakes in principle, but rather that the fundamental reasons for its failure were in lack of cognition of celestial mechanics, the negligence of particular elements of the Earth's movement, and weak knowledge of mathematics. In order to save the idea that he found correct, next to the basic critics of existing work he made the next step, cosmically giant in its true sense: he thought of the astronomic theory of climate differently than all his predecessors. While they continued to solve the problem of ice ages, he turned to a great vision of modelling the climates of all planets in the solar system with a hard crust where the Earth was only a special case. On that route, he was the first to calculate climatic conditions on the Moon, Mars, Venus and Mercury. In the six works that followed till 1914, he transformed the understanding of climatic change – he brought higher mathematics into climatology, he framed it as an exact science and he commenced the numeric modelling of climate. In this way, he built a firm bridge to link the climatic change and celestial mechanics (Petrović 2009; 2011).

4 Current view

It is only when, from the interval of exactly one century, we look at Wegener's and Milanković's work and the synergy of their theories that we become aware of the depth of the revolution that they started. Their contributions simultaneously did for the Earth sciences what the theory of evolution did for biology and what Einstein's theory did for physics. They provided Earth sciences with a comprehensive perspective of Earth's revolution in both astronomical and terrestrial terms, and revolutionized them by abandoning the ideas of a climatologically self-sufficient Earth and unmovable continents – remnants of the old geocentric picture of an unmoving, centered Earth.

When Milanković's work appeared in the spring of 1912 (Milanković 1912), immediately following Wegener's in February of the same year, the world could no longer remain the same. The defense of the old paradigm was destined to failure, as the same thing had happened centuries earlier, when Copernicus' revolution destroyed 12 unmoving heavens and when the Earth was expelled from its center location to an unceasing orbit around the Sun. But the old geocentric paradigm of the unmovable *orbis* was not set down and abandoned in 1543 when Copernicus' *De revolutionibus orbis* was published – rather, it was discarded in 1912 when Milanković was about to find the mathematical proof of the heliocentric origin of the Earth's climate, and when Wegener originated his theory of continental drift. Now even the continents were beginning to move, and Milanković gave Wegener's new Earth a cosmic dimension, as he brought back and reinforced the Sun as the epicenter of Earth processes. This is the true reversal of Milanković's that markedly moved the Earth and its picture from the geocentric and steered it toward the heliocentric horizon, as his Canon of Insolation mathematically brought the Earth into canonical accord with the Sun.

In the face of the Earth sciences and their great advancement after 1912, there remains the task of understanding the far-reaching correlation between Wegener's and Milanković's theories. Additionally, one should notice the great similarity in their life paths which enabled the creation of their theories. Wegener and Milanković from the beginning appeared to move in synchronized cycles that intertwined from the beginning of their lives, not ceasing even after the scientists' deaths. Milanković was born the youngest of seven in 1879 in a small town, Dalj (today in eastern Croatia), on the shore of the Danube in the Austro-Hungarian Empire, while Wegener was born only a year later, in 1880, into a family of five children in Berlin, the metropolis of the German Empire. Both graduated at the top of their class; they enrolled in university in the same year – 1897 – and graduated the same year, in 1902. In 1904, they both received doctorates – Milanković in civil engineering, Wegener in astronomy. Their scientific careers were somehow opposite, but equally non-specific and non-conformist. Wegener studied astronomy, physics and meteorology at Friedrich Wilhelms University in Berlin, but abandoned his studies in favor of the Earth sciences. Milanković followed a more terrestrial discipline at the Technical University in Vienna, studying civil engineering, but he left in order to study the applied mathematics, astronomy, and climatology.

Their professional careers were launched in 1905. Wegener took up a post at the Royal Prussian Astronomical Observatory. He used kites and balloons to study the upper atmosphere. Milanković got a position of a civil engineer at Adolf Baron Pitel Betonbau corporation in Vienna. In only five years of employment as a civil engineer, he constructed over a hundred buildings, bridges, and dams all over Central Europe. In 1908, Wegener took a position at the University of Marburg. He lectured in meteorology and astronomy. Only one year later, in 1909, Milanković decided to leave his job as a successful civil engineer in Vienna in order to concentrate on celestial mechanics and climatology at the University of Belgrade where he taught the applied mathematics and gave lectures on three diverse subjects – theoretical physics, spherical astronomy and rational mechanics.

Starting his work on the climate change problem, Milanković was fully aware that »… *the question was not answered, and it was left amid a triangle between spherical astronomy, celestial mechanics and theoretical physics. The chair offered to me at Belgrade University included all the three sciences which were separated at other Universities. Therefore, I was able to discern that cosmic problem, to see its importance and to begin with its unraveling.*« (Milanković 2009, 480)

In 1912, when Wegener and Milanković published their respective milestone papers, both of them found themselves in personal and historical turmoil. Wegener, with his four man expedition to Greenland, escaped death only by a miracle while climbing a glacier that suddenly caved in. In the same year, Milanković joined the Serbian Army to fight successfully in the First Balkan Liberation War against Ottoman Empire. What a dangerous polar expedition was for Wegener, Milanković experienced in war. Subsequently, both scientists had their own private *annus mirabilis* in 1913: Milanković married Tinka Topuzović and Wegener married Elsa Köppen, the daughter of Vladimir Köppen.

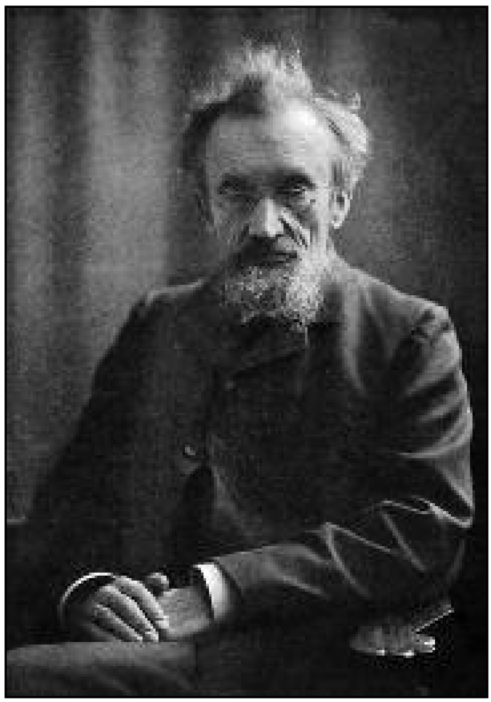


Figure 2: Wladimir Köppen (Archive of Serbian Academy of Sciences and Arts).

In contrast to the previous year, 1914 was *annus miserabilis*: Wegener joined the Austro-Hungarian army and served at the Eastern front. He was wounded twice. At the same time but on the opposite side, Milanković, a Serbian citizen, was arrested in Austria-Hungary while spending his honeymoon in Dalj, and he was imprisoned in the camp of Neszider. He kept a cool head in prison, saying that his »*small room, isolated from noise, seemed perfectly adequate for scientific work to me*« (Milanković 2009).

During the convalescent leave in 1915, Wegener set down a more in-depth version of The Origin of Continents (*Die Entstehung der Kontinente und Ozeane*), where he elaborated on his theory on the pan-continent (»*Urkontinent*«) in detail, giving it the Greek name *Pangaea* – All Earth, All Land. Similarly, Milanković finished his Theory of Thermal Phenomena Produced by Solar Radiation during his internment in Budapest in 1917 and published it after the war, in 1920. It was regarded as one of the most prominent scientific works written during the imprisonment of the author.

When Milanković received printed copies of his book from his Paris publisher, he sent one sample to Vladimir Köppen. Köppen was so impressed by Milanković's introduction of advanced mathematics into Earth sciences that he immediately wrote him a postcard, stating, »*I am impressed by the abundance of reason and clarity in your interpretation, and I am truly grateful for this precious gift. I am particularly interested in the calculation of secular thermal changes to which you came to a much different conclusion from Spitaler, as he did not take elliptical slope enough into consideration ...*« (Köppen's letter to Milanković 1921; Milanković 1997, 474).

Köppen quickly realized that he had found the most powerful ally ever in Milanković in his defense of Wegener's theory. For almost two decades, since the lecture before the German Geological Society, they had practically been at war with the geological academic community. Wegener was in an unenviable position; his theory was exposed to criticism and it seemed that, except for his father-in-law, Köppen, he had no other allies. Finding the destined support in Milanković, Köppen thought up an inventive step – together with Wegener he would engage in the writing of the work Climates of the Earth's Past. Then they were not alone against the world – Köppen's idea was that Milanković write the key chapter in their book. This is not so unusual in scientific practice, but this was a special case having to do with finding the Archimedean point that could move the world. Köppen therefore wrote to Milanković: »*I am, unfortunately, one weak mathematician, and I have a difficult time with patterns. But as geologists, in general, are even worse, and these are very important questions, I would ask for your friendly help, which you have already offered. Wegener and I would like it so much*«, concludes Köppen's letter, »*if you would give us one separate chapter about these things, which we would add without changes into our book*« (Köppen's letter to Milanković 1922; 1997, 478).

In early 1924, The Climates of the Geological Past (Ger. *Die Klimate der geologischen Vergangenheit unciihre Beziehung zur Entwickelungsgeschichte der Sonne*; Dubois) appeared as »*one of the founding texts of paleoclimatology providing crucial support to Milanković's theory on ice ages*« (Rubel and Kottek 2011). Köppen, Wegener and Milanković were finally together, the big picture was assembled – one portion was Earth sciences, the other was celestial mechanics, and no longer could merely rhetoric yet unconnected empirical arguments and manipulations attack. It was the first consequent, comprehensive view on Earth climate that was based on Wegener's theory on the continental drift. In one specific chapter, the scientific public could see the basic paleoclimatic instrument, Milanković's Curve of Insolation, which made mathematical reconstruction and prediction of climate dynamics possible. The Curve of Insolation, resulting from mathematical calculation instead of the empirical research with which it agreed, was the crowning achievement and evidence of accuracy of the new Earth science. Milanković's mathematical theory of climate change, from which the Curve originated, was a gift from heaven for his collaborators – the most persuasive proof of the new vision of the Earth sciences. Milanković was the key ally, his Curve of Insolation the exact confirmation of the thesis that Köppen and Wegener advocated, as Milanković's theory made the conversion from descriptive to exact Earth sciences possible.

Wegener planned to inform the scientific public of the new results and to reconcile them with the new view of the world. In September 1924 at the Innsbruck Congress of German Naturalists and Doctors he gave a lecture describing the just-published Climate's of the Earth's Past. Wegener already felt the ground firm beneath his feet, and his appearance gave no doubt to his theory. Introducing the book, he said: »*Leaving behind the old theories of the shriveling of the Earth, of the fall into the depths of what were once bridges that connected today's continents, and adopting facts showing the possibility of continental movement, it has becomes*

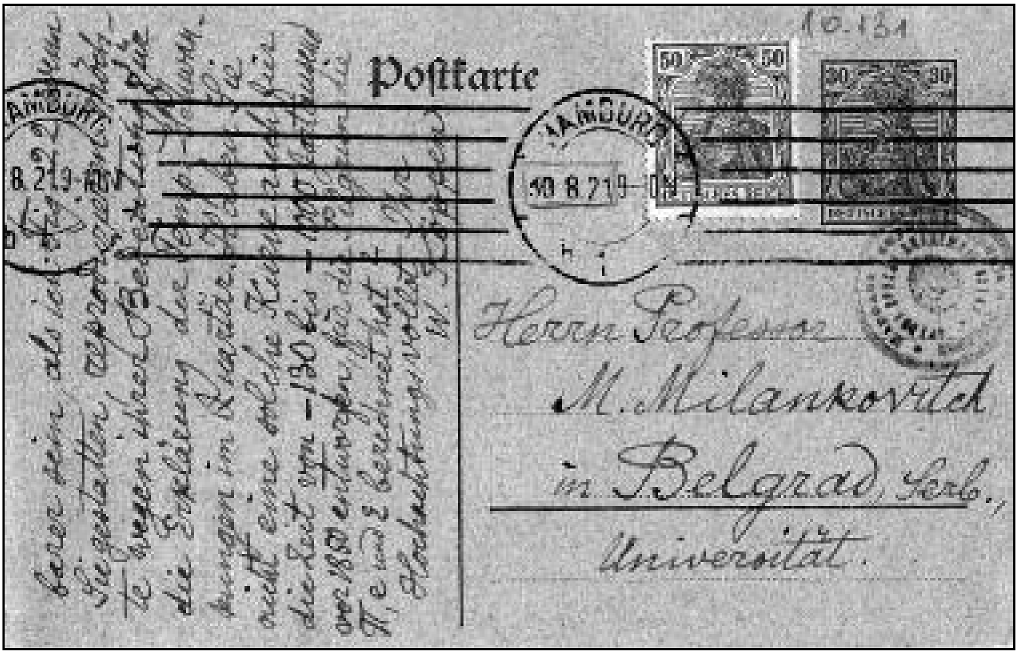


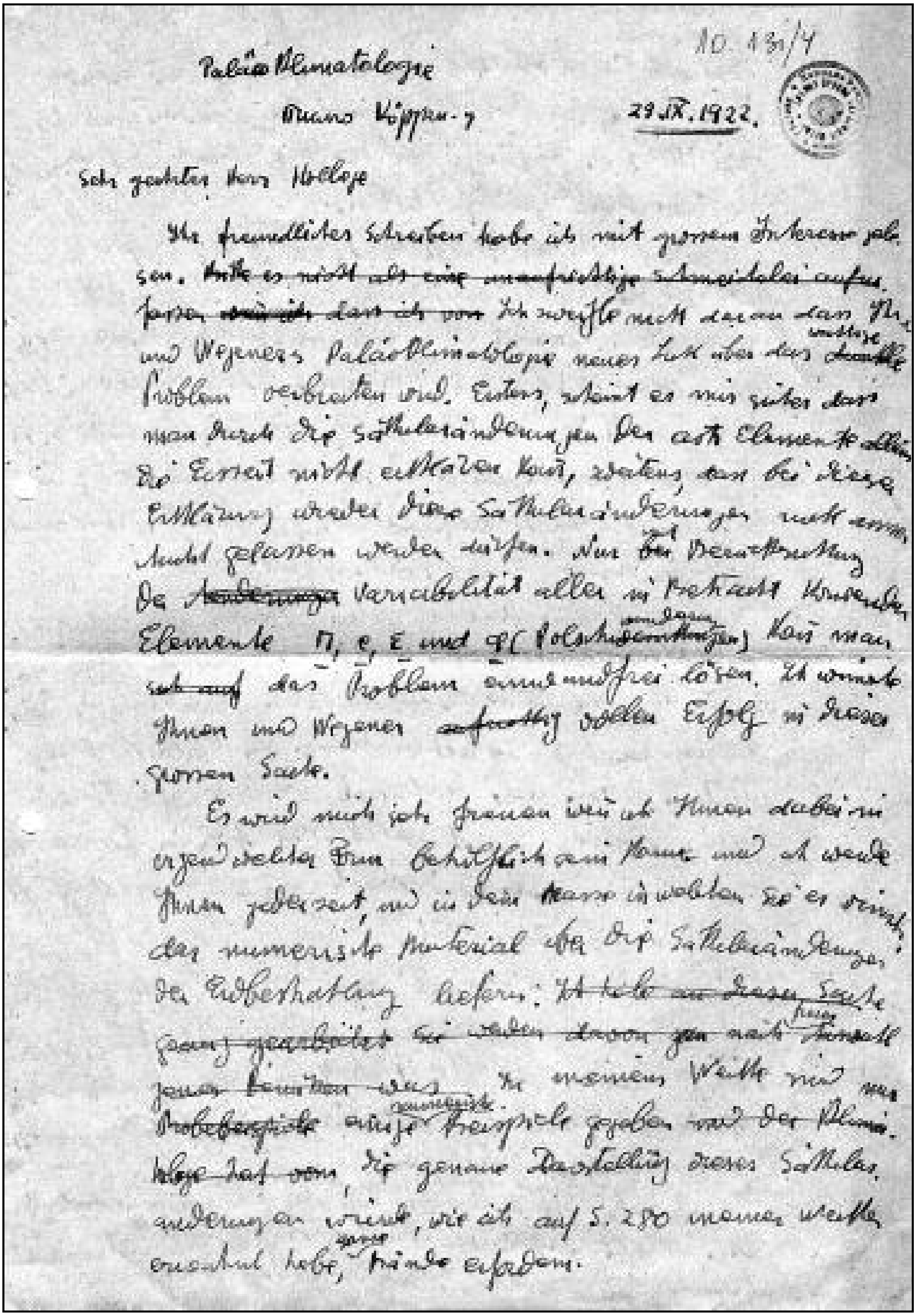
Figure 3. Postcard of Wladimir Köppen to Milanković (1921) (Archive of Serbian Academy of Sciences and Arts).

us to reconstruct, for every big segment of the geologic past, an internal position of the Earth's continents and with the position of its rotational pull on them …« (Milanković 2009, 603).

Then, he concluded triumphantly exposing Milanković's contribution: »*The most important thing is that, in this way, we have come to the absolute chronology of the entire Quaternary Period and achieved that which has, till now … been possible only for the last 10,000 years*« (Milanković 2009, 606).

Milanković noticed the victory even in Wegener's tone: »*In his lecture, Wegener spoke modestly and with reservation about his own theory of continental drift, but when he began to speak about my Curve … he raises his voice and speaks with élan*« (Milanković 2009, 606). Now, all three knew that they were victorious and their alliance was strong enough to result in the great scientific turnover that they were preparing. It was only left to discuss how to proceed.

In January of 1925, Milanković received a letter from Köppen stating that he, along with his son-in-law Wegener, expected him that summer at his house in Graz. That was the crucial time when they made the plan for future collaboration in creating the new science. From that collaboration and struggle against the old paradigm, the new Earth science was born. Milanković devoted the entire chapter of his memoirs to that unusual meeting. "‘*And before you,*’ Köppen told me, ‘*other scientists, Adhemar, Croll, Baal, Eckholm and Spitaler studied the astronomic reasons for climate change. But they did not come to acceptable results in their work. That is why our great, sadly already deceased climatologist von Hann, my dear friend, with whom I published our main meteorological journal, let go of them as useless. But you, not shrinking from his judgment, took that problem into your hands and solved it.*’ ‘*Forgive me,*’ I said, interrupting him, ‘*I didn't solve it, you did.*’ ‘*On the foundation of your calculations*!’ he replied … Wegener pondered, then said: ‘*As soon as I finish my report about the expedition to Greenland, I'll begin to prepare the fourth edition of my work on the creation of the continents and ocean …*‘ ‘*And I will,*’ I said, ‘*in the meantime, study all that the exact sciences said regarding the shape of the Earth and the possibility for the movement of poles of rotation … I will study all this, and then when we collaborate, maybe we can move the Earth's poles.*’ All three of us laughed and were happy as children preparing for some feat … At that, Wegener's little girl and Vasko (Milanković's son) ran in from the garden. »*We had great fun playing with balls, our children speaking to us, all flushed. Köppen laughed, looked at us two, and said, 'And we play beautifully with the ball of the Earth*« (Milanković 2009, 619).


Paläoklimatologie

Herrn Köppen

10. 131/4

29.IX.1922.

Sehr geehrter Herr Kollege

Ihr freundliches Schreiben habe ich mit großem Interesse gelesen. [illegible] Ich zweifle nicht daran dass Ihre und Wegeners Paläoklimatologie neues Licht über das wichtige Problem verbreiten wird. Erstens, scheint es mir sicher dass man durch die Säkularänderungen der acht Elemente allein die Eiszeit nicht erklären kann, zweitens dass bei dieser Erklärung weder diese Säkularänderungen nicht außer Acht gelassen werden dürfen. Nur bei Berücksichtigung der Variabilität aller in Betracht kommenden Elemente Π, e, ε und φ (Polschwankungen) kann man [illegible] das Problem einwandfrei lösen. Ich wünsche Ihnen und Wegener vollen Erfolg in dieser großen Sache.

Es wird mich sehr freuen wenn ich Ihnen dabei in irgendwelcher Form behilflich sein könnte und ich werde Ihnen jederzeit, und in dem Maße in welchem Sie es wünschen, das numerische Material über die Säkularänderungen der Erdbestrahlung liefern. [illegible] In meinem Werke [illegible] numerische Beispiele gegeben [illegible] die genaue Darstellung dieser Säkularänderungen wird, wie ich auf S. 280 meines Werkes erwähnt habe, ganz [illegible] erfordern.

Figure 4: Draft of Milanković's letter to Koppen (1922) (Archive of Serbian Academy of Sciences and Arts).

After this meeting, Köppen took his last big step – he got to work on the systematic development of the new Earth sciences. With the help of his co-editor, Rudolf Geiger, he launched his most ambitious project in 1927 – Handbook of Climatology (*Handbuch der Klimatologie*), which was never completed, but still ran to five volumes. Milanković was again the key contributor, and Köppen asked him to write the introductory chapter dealing with solar climate. Milanković titled it Mathematical Science of Climate and Astronomical Theory of the Variations of Climate (*Mathematische Klimalehre und astronomische Theorie der Klimaschwankungen*). By introducing the book with Milanković's writing, Köppen left nothing to chance. Judging by Milanković's memoirs, everybody was aware that they were not searching for a specific scientific result. They were looking for the new Earth sciences.

Milanković turned his back on the main stream of his work and rather focused on solving the questions of the movement of poles, which were not of the key importance to the astronomic theory of climate change. Wishing to further solidify the stance of Köppen and Wegener, he elaborated on a geophysical and mathematical model of a mechanism that could stand behind the movement of continents. After many years, Milanković set up his model, a type of continental forcing, which suggested something entirely understandable – that the Earth's core slides on a fluidal base. Albeit the idea was replaced with the theory of the plate tectonics, it was at that time a major step toward the understanding of the mechanism of continental shift, the wandering of poles, and above all, toward understanding that these processes could be described mathematically.

Neither Wegener nor Milanković saw acceptance of their theories during their lifetimes. But that stipulated that the cycles of correlation in their daily and scientific lives did not finish even after their deaths. It took half a century for Köppen's, Milanković's, and Wegener's theories to be confirmed by independent research and to be fully accepted. Rejection of Wegener's theory lasted until the 1960's, when exploration of the ocean bed confirmed it. Oceanic data convinced scientists that continents do indeed move. Wegener's theory of continental drift became the foundation for the present theory of plate tectonics. The same happened with Milanković. Only ten years later, in the 1970's, Milanković's astronomical theory of climate change was confirmed by the exploration of deep-sea sediment and records from various proxies all around the world. It became the canon of the present understanding of climate dynamics (Petrović 2004).

After that, it seems that the cycles continue to develop without end. The European Geosciences Union sponsors the Alfred Wegener Medal. The crater »Wegener« on the Moon and on Mars, as well as the asteroid 29227, are named after him. Craters on the Moon and Mars and the asteroid 193GA are named after Milanković. The European Geophysical Union (now European Geosciences Union) established Milanković's Medal to be awarded for crucial contributions to paleoclimatic research.

5 Conclusion

In one century the transition of Earth science which Köppen, Wegener and Milanković began was completed in the deepest scientific way. Milanković's and Wegener's theory is among the last heroic scientific attempts of the 20th century. Wegener stated that he had an »*obligation to be a hero*«. Milanković abandoned an extremely successful and profitable civil engineering career in Austria-Hungary to get a low-paying position as an associate professor at the University of Belgrade. But these romantic lives were full of revolutionary spirit, and therefore potentially dangerous for a pragmatically oriented science with little or no vision. This is why 1912 is the real *annus mirabilis* of the Earth sciences. It has the same significance for Earth science as 1905 has for physics. Cycles of Milanković's and Wegener's lives and their joint work left distinctive records in the history of the Earth sciences. The synergistic effort of both scientists changed the ruling paradigm, dethroned a geocentric and static causality and established a heliocentric and dynamic view over Earth history. Therefore, the study of Milanković and Wegener and of their *annus mirabilis* is necessary for the preservation of a true perspective of the development of the Earth sciences, and for the understanding of a decisive moment of its past as the basis for its future.

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Cikli revolucije: kako sta Wegener in Milanković spremenila vede o zemlji

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IZVLEČEK: Leto 1912 je bilo za vede o Zemlji pravi *annus mirabilis*, leto čudežev. Alfred Wegener in Milutin Milanković sta neodvisno drug od drugega napisala dva izredno pomembna članka, v katerih sta razvila revolucionarni teoriji, ki temeljita na oddaljeni viziji premikanja kontinentov in vpliva gibanja Zemlje, njene orbite in osi na stanje podnebja na Zemlji. Njuna prispevka sta za vede o Zemlji naredila to, kar je teorija evolucije naredila za biologijo, teorija relativnosti pa za fiziko. Oblikovala sta celovit pregled Zemljine dinamike tako z astronomskega kot zemeljskega vidika, v geologiji pa sta celo povzročila pravo revolucijo s tem, ko sta zavrgla ideji klimatološko samozadostne Zemlje in nepremičnih kontinentov – ostankov stare geocentrične predstave o negibni, centrirani Zemlji. V laičnem smislu sta končno dopolnila Kopernikovo heliocentrično teorijo. V tem članku je opisano zanimivo prepletanje njunega življenja in dela.

KLJUČNE BESEDE: Alfred Wegener, Milutin Milanković, Vladimir Köppen, leto 1912, astronomska teorija podnebnih sprememb, nastanek kontinentov, heliocentrična teorija

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Vsebina

1 Uvod

Ena od zadnjih velikih znanstvenih revolucij se je zgodila natanko pred stotimi leti, leta 1912, ko sta dva znanstvenika, ki drug za drugega sploh nista vedela, spremenila sam princip ved o Zemlji. Kar je še bolj presenetljivo, Alfred Wegener in Milutin Milanković (po srbskem pravopisu je pravilna oblika njegovega priimka Milanković, vendar se pogosteje uporablja Milankovich, Milankovitch ali celo Milankowitz) sploh nista bila geologa (Petrović in Marković 2010). Wegener je bil astronom in meteorolog, navdušen nad geofiziko, Milanković pa gradbeni inženir, ki se je ljubiteljsko ukvarjal s klimatologijo.

2 Wegenerjev prispevek

Na vsakoletnem srečanju nemškega geološkega združenja v Frankfurtu, ki je potekalo 6. januarja 1912, je imel Alfred Wegener predavanje z naslovom »Dvig večjih enot zemeljske skorje (kontinentov in oceanov) na geofizikalni podlagi« (nem. *Die Heraushebung der Großformen der Erdrinde (Kontinente und Ozeane) auf geophysikalischer Grundlage*). Takoj po srečanju je predavanje v obliki članka poslal tudi časopisu Petermanns Geographische Mitteilungen, kjer so ga kratko naslovili »Nastanek kontinentov« in objavili v treh delih (Wegener 1912). Predavanje je osupnilo vse prisotne, saj je pod vprašaj postavilo takratne prevladujoče poglede na geologijo. Wegener se je oprl na delo Louisa Agassiza (1807–1873), hkrati pa je še dodatno podkrepil dinamiko »eratskih balvanov«, ko je uvedel pojma »premikanje kontinentov« in »potovanje polov«.

Ovrgel je v tistih časih nedotakljivo idejo o izginulih mostovih med kontinenti in predpostavil, da je na začetku obstajal le en kontinent, Pangea, ki se je pred približno 200 milijoni let razdelil na več delov, ti pa so se nato počasi pomikali na zdajšnja mesta. Opazil je skladnost oblik Južne Amerike in Afrike: »*Ali ni tako, da se vzhodna obala Južne Amerike natanko prilega zahodni obali Afrike, kot da bi bili nekoč eno? To je ideja, ki bi jo rad natančneje raziskal,*« je zapisal v pismu bodoči ženi leta 1910 (Wegener-Köppen 1955). Na ta način je »predvidel širjenje oceanskega dna, funkcionalno razmerje med obliko morskega dna in starostjo ali temperaturo pod morskim dnom, morda konvekcijo zemeljskega plašča in nekatere vidike tektonike plošč« (Jacoby 1981). Poleg podnebja kontinentov v daljni preteklosti je opisal tudi podobnosti geoloških struktur in naštel številne primere povsem identičnih fosilov živali, ki so živele na obeh celinah pred več sto milijoni let.

Vse skupaj je bilo očitno preveč za takratno znanost o Zemlji, saj je bila iz svoje statične predstave potisnjena v svet, v katerem je nenadoma zmanjkalo »trdnih tal« pod nogami. Wegener se je dobro zavedal dejstva, da ni le globoko vznemiril strokovne javnosti, v kateri je še dolgo vrelo, temveč da je hkrati sprožil tudi pravo revolucijo. »*Zakaj ne bi zavrgli starih prepričanj, če je bilo dokazano, da sta v zgodovino Zemlje vstopila harmonija in razum?*« je pisal svojemu tastu (Wegenerjevo pismo Köppnu, 1911). Ko je bila knjiga leta 1924 prevedena v angleščino, je povzročila val ostrih kritik, zaradi katerih vse do leta 1960 ni doživela pravega sprejema. Čeprav je Wegener skrbno zbral geološke dokaze, so se ameriški in britanski geologi, ki so zagovarjali staro paradigmo, posmehovali tako njemu kot tudi njegovim idejam. »*Popoln nesmisel,*« je izjavil predsednik ameriškega geološkega združenja in soglašal z mnenjem svojega kolega, ki je rekel: »*Če verjamemo tej hipotezi, moramo pozabiti vse, kar smo se naučili v preteklih 70 letih, in začeti znova.*« Britanski geologi so bili še bolj neusmiljeni, saj so trdili, da nihče, ki »*ceni svoj ugled razumnega znanstvenika*«, ne bi podprl Wegenerjeve teorije (Hughes 1994). Na srečanju v New Yorku leta 1926 je bil Wegener sprejet z veliko posmehovanja. Kritiki so njegovo teorijo imenovali kar »geopoezija«.

Kljub temu obširnemu nerazumevanju so Wegenerjeve teze pomenile začetek leta čudežev, v katerem je bila rojena nova znanost o Zemlji.

3 Milankovićev prispevek

Le nekaj mesecev pozneje je Milutin Milanković v publikaciji Glas, ki jo je izdajala Srbska kraljeva akademija, objavil članek z naslovom »Prilog teoriji matematske klime« (K matematični teoriji podnebja), v katerem je povzel takrat aktualne teorije astronomskih vplivov, ki poganjajo mehanizem Zemljinega toplotnega ravnovesja, in zasnoval matematično metodologijo za povsem drugačen pogled na klimatske cikle (Milanković 1912). Ko je Milanković začel preučevati astronomsko teorijo podnebnih sprememb, je bila ta v stroki že povsem pozabljena. Vodilne znanstvene institucije so menile, da je teorija sicer zanimiva, a neuporabna, saj Ademarjeva, Crollova in druge podobne, manj znane astronomske teorije niso ponujale zadovoljivih rezultatov, ki bi jih potrjevale ugotovitve v naravi, na terenu. To enotno mnenje geologov in klimatologov je pozneje botrovalo tudi nasprotovanju Milankovićevi teoriji, pri čemer je bil najglasnejši avstrijski geomorfolog Albrecht Penck, ki je bil tudi velik Wegenerjev nasprotnik. Potem ko se je Penck 21. februarja 1921 udeležil Wegenerjevega predavanja berlinskemu geografskemu društvu, je zapisal, da je v njegovi hipotezi sicer »nekaj privlačnega«, a je kljub temu vztrajal pri stališču, da je oblika kontinentov posledica krčenja in vertikalnih premikov zemeljske skorje. V paleoklimatologiji je veljal za priznano avtoriteto, saj je skupaj z Eduardom Brücknerjem opredelil faze glaciacije v Alpah (takrat so bile sprejete, pozneje pa ovržene).

Penck je v zgodnejših astronomskih teorijah o podnebju opazil velike pomanjkljivosti, pri tem pa ni le izpostavil njihovih napak, temveč je naredil še korak dlje in v celoti zanikal veljavnost takšnih hipotez. Menil je, da so obstajale le štiri ledene dobe, in da se večja klimatska odstopanja pojavijo zaradi občasnih sprememb v toplotni moči sonca in ne zaradi Zemljine orbitalne dinamike.

Podobno je razmišljal tudi eden od najbolj spoštovanih evropskih klimatologov, Julius von Hann, ki je – zbegan zaradi nasprotujočih si rezultatov določenih astronomskih teorij – menil, da so te teorije v osnovi neuporabne in da astronomski pojavi niso dovolj močni, da bi spodbudili klimatske spremembe. Milanković se je zavedal, da »*so bili vsi poskusi tovrstne razlage klimatskih sprememb neuspešni in jih je zato veliki avstrijski klimatolog von Hann leta 1908 ovrgel s pojasnilom, da bi z astronomskega stališča prej sklepal na konstantnost kot pa na variabilnost zemeljskega podnebja*« (Milanković 2009, 603).

Vendar je Milanković, čeprav ni bil užaljen, najprej močno nasprotoval Pencku. »*Penck je odličen opazovalec, popoln empirik, ne pa teoretik. Njegov svet, omejen na površje Zemlje, ima le dve dimenziji. Ne zna se zazreti globlje v vesolje …*« Prav tako odločno je skritiziral tudi Juliusa von Hanna. »*Zato sem na von Hannov 'ne' odgovoril 'da' in dokazal, da so zemeljske klimatske spremembe, ki jih sprožijo astronomski pojavi, tako močne, da ne bi mogle miniti brez kakršnega koli dokaza o tem. Že v svojem prvem članku sem zapisal, kako jih je mogoče dokazati z izračuni in s pomočjo sledenja nebesni mehaniki v daljno preteklost.*« (Milanković 2009, 693).

Za dodatni zaplet je poskrbela še meteorologija, ki je takrat sicer zelo napredovala, vendar Sonca ni postavljala v središče klimatoloških razmišljanj. Milanković je parafraziral stališče meteorologije, ko je izjavil: »Zakaj bi šli po poti, ki pelje skozi oddaljeno Sonce, da bi ugotovili, kaj se dogaja na Zemlji, če pa imamo tu na tisoče meteoroloških postaj, ki nas obveščajo o vseh temperaturnih pojavih v plasteh Zemljine atmosfere, kjer živimo, in to natančno, natančneje od najpopolnejše teorije« (Milanković 2009, 603).

Tako je imel Milanković že na samem začetku svojega delovanja močne nasprotnike – brezbrižne meteorologe in klimatologe ter skoraj celotno geološko skupnost, in zdelo se je, da je ideja o astronomski teoriji podnebja praktično že povsem pozabljena, vendar je bil dovolj luciden in drzen za spoznanje, da astronomska teorija načeloma ni bila v nemilosti zaradi napak, temveč zaradi pomanjkljivega poznavanja nebesne mehanike, zanemarjanja določenih elementov premikanja Zemlje in šibkega matematičnega znanja. Ker je želel ohraniti idejo, ki je bila zanj pravilna, je poleg kritike obstoječega dela naredil še korak dalje, in ta korak je bil v svojem bistvu naravnost veličasten: o astronomski teoriji podnebja je razmišljal popolnoma drugače od svojih predhodnikov. Medtem ko so se drugi še naprej ukvarjali z reševanjem problema ledenih dob, se je on usmeril v obsežno vizijo modeliranja podnebij vseh planetov v sončnem sistemu s trdo skorjo, pri čemer je bila Zemlja le poseben primer. V tem smislu je bil prvi, ki je izračunal klimatske pogoje na Luni, Marsu, Veneri in Merkurju. V šestih delih, ki so si sledila po letu 1914, je povsem preoblikoval razumevanje podnebnih sprememb – v klimatologijo je vključil višjo matematiko, jo formuliral kot eksaktno znanost in se začel ukvarjati z numeričnim modeliranjem podnebja. Na ta način je tesno povezal podnebne spremembe in nebesno mehaniko (Petrović 2009; 2011).

Slika 1: Milutin Milanković s svojim študentom iz Slovenije, Tedijem Djivovićem (1952) (arhiv Srbske akademije znanosti in umetnosti).
Glej angleški del prispevka.

4 Sodobno stališče

Šele zdaj, po natanko stotih letih, se ob pregledu Wegenerjevega in Milankovićevega dela ter medsebojne usklajenosti njunih teorij začenjamo zavedati razsežnosti revolucije, ki sta jo sprožila. Njuna prispevka sta za vede o Zemlji naredila to, kar je teorija evolucije naredila za biologijo in Einsteinova teorija za fiziko. V geološkem smislu sta prispevala celovit pregled razvoja Zemlje tako z astronomskega kot zemeljskega vidika, povzročila pa sta celo pravo revolucijo, ker sta ovrgla ideji klimatološko samozadostne Zemlje in nepremičnih kontinentov – ostankov stare geocentrične predstave o negibni, centrirani Zemlji.

Ko se je spomladi leta 1912 (Milanković 1912), takoj po Wegenerjevi objavi februarja istega leta, pojavil še Milankovićev članek, svet enostavno ni mogel biti več tak kot prej. Zagovarjanje stare paradigme je bilo obsojeno na propad, tako kot stoletja pred tem, ko je Kopernikova revolucija izničila idejo o dvanajstih nepremičnih kroglah in je bila Zemlja s svojega središčnega položaja potisnjena v nenehno kroženje okoli Sonca. Pa vendar stara geocentrična ideja o nepremični orbiti ni bila ovržena že leta 1543, ko je bila objavljena Kopernikova knjiga »On the Revolutions of the Heavenly Spheres« (O kroženju nebesnih krogel), temveč šele leta 1912, ko je Milanković pridobil matematične dokaze o heliocentričnem izvoru podnebja na Zemlji in je Wegener predstavil svojo teorijo o premikanju kontinentov. Zdaj so se celo kontinenti začeli premikati, Milanković pa je Wegenerjevi novi Zemlji dodal še nebesno razsežnost s tem, ko je Sonce spet postavil v središče procesov na Zemlji. To je tisti pravi preobrat, ki ga je povzročil Milanković, ko je Zemljo in njeno podobo odločno premaknil iz geocentrizma v heliocentrizem, pri čemer je v svojem »načelu osončenja« Zemljo matematično postavil v korelacijo s Soncem.

Z vidika ved o Zemlji in njihovega velikega napredka po letu 1912 je daljnosežna korelacija med Wegenerjevo in Milankovićevo teorijo še vedno precej neraziskana. Poleg tega je treba omeniti tudi veliko podobnost njunih življenjskih poti, ki so jima omogočile, da sta lahko oblikovala svoji teoriji. Zdi se, da sta se že od samega začetka premikala v usklajenih ciklih, ki so se ves čas prepletali, to pa se je nadaljevalo tudi po njuni smrti. Milanković se je kot najmlajši od sedmih otrok rodil leta 1879 v majhnem mestecu Dalj ob Donavi (danes na Hrvaškem), Wegener pa leta 1880 v Berlinu, prestolnici takratnega Nemškega cesarstva. Bil je eden od petih otrok. Oba sta bila med najboljšimi študenti v svojem letniku in na univerzo sta se vpisala istega leta – 1897 – ter isto leto tudi diplomirala, leta 1902. Leta 1904 sta nato oba doktorirala – Milanković iz gradbeništva, Wegener pa iz astronomije. Njuni znanstveni karieri sta bili sicer precej različni, a enako neopredeljeni in nekonformistični. Wegener je študiral astronomijo, fiziko in meteorologijo na Univerzi Friedrich Wilhelms v Berlinu, vendar je študij pozneje opustil in se začel ukvarjati z vedami o Zemlji. Milankovića so zanimale bolj »zemeljske« vede in je na Tehnični univerzi na Dunaju študiral gradbeništvo, vendar je prav tako pustil ta študij in se usmeril v aplikativno matematiko, astronomijo in klimatologijo.

Oba sta se zaposlila leta 1905. Wegener je začel delati v Kraljevem pruskem astronomskem observatoriju. S pomočjo papirnatih zmajev in balonov je preučeval zgornjo atmosfero. Milanković se je zaposlil kot gradbeni inženir v podjetju Adolf Baron Pitel Betonbau na Dunaju. Že v prvih petih letih zaposlitve je zgradil več kot sto stavb, mostov in jezov po vsej srednji Evropi. Leta 1908 se je Wegener zaposlil na Univerzi v Marburgu. Predaval je meteorologijo in astronomijo. Leto pozneje, 1909, se je Milanković odločil, da bo zapustil delovno mesto uspešnega gradbenega inženirja na Dunaju in se raje posvetil nebesni mehaniki in klimatologiji na Univerzi v Beogradu. Tam je začel poučevati aplikativno matematiko in predaval tri različne predmete – teoretično fiziko, sferično astronomijo in racionalno mehaniko.

Ko se je lotil preučevanja problema podnebnih sprememb, se je Milanković dobro zavedal, da »… *to vprašanje še nima odgovora in da ostaja v nekakšnem trikotniku med sferično astronomijo, nebesno mehaniko in teoretično fiziko. Profesura, ki mi je bila ponujena na Univerzi v Beogradu, je vse tri vede združevala, medtem ko so jih na drugih univerzah ločevali. Tako sem lahko odkril ta veličastni problem, spoznal njegov pomen in ga začel preučevati.*« (Milanković 2009, 480)

Leta 1912, ko sta Wegener in Milanković objavila svoja prelomna članka, sta se hkrati oba znašla tudi v osebnem in zgodovinskem kaosu. Wegener, ki se je skupaj s tremi kolegi udeležil odprave na Grenlandijo, je le po čudežu preživel, ko so se mu med plezanjem po ledeniku nenadoma vdrla tla pod nogami, istega leta pa se je Milanković pridružil srbski vojski in se v prvi balkanski vojni uspešno boril proti otomanskemu cesarstvu. To, kako nevarna je bila polarna ekspedicija za Wegenerja, je Milanković izkusil v vojni. Na zasebnem področju je bilo leto čudežev za oba znanstvenika leto 1913: Milanković se je poročil s Tinko Topuzović, Wegener pa z Elso Köppen, hčerjo Vladimirja Köppna.

Slika 2: Vladimir Köppen (arhiv Srbske akademije znanosti in umetnosti).
Glej angleški del prispevka.

Potem pa je prišlo nesrečno leto 1914. Wegener se je pridružil avstroogrski vojski in služil na vzhodni fronti. Bil je dvakrat ranjen. Istočasno, a na nasprotni strani, so Milankovića med preživljanjem medenih tednov v Dalju kot srbskega državljana aretirali avstroogrski organi in ga poslali v taborišče Nezsider. V zaporu je ohranil mirno kri in celo zapisal, da je bila »majhna soba, odmaknjena od hrup, povsem dovolj za raziskovalno delo« (Milanković 2009).

Wegener je med okrevanjem leta 1915 zasnoval bolj poglobljeno različico Nastanka kontinentov (*Die Entstehung der Kontinente und Ozeane*), v kateri je natančneje razdelal svojo teorijo pankontinenta (»*Urkontinent*«) in ga poimenoval z grškim imenom *Pangea* – »vsa Zemlja«. Tudi Milanković je med internacijo v Budimpešti leta 1917 dokončal delo z naslovom Matematična teorija toplotnih pojavov, ki jih povzroči sevanje sonca (Theorie mathematique des phenomenes thermiques) ter ga objavil po vojni, leta 1920. To je bilo eno od najvidnejših znanstvenih del, napisanih med avtorjevim prestajanjem zaporne kazni.

Ko je Milanković od svojega pariškega izdajatelja prejel tiskane izvode svoje knjige, je enega poslal tudi Vladimirju Köppnu. Milankovićeva uporaba višje matematike v vedah o Zemlji je na Köppna naredila tak vtis, da mu je nemudoma pisal: »Navdušen sem nad smiselnostjo in jasnostjo vaše razlage in resnično sem hvaležen za to dragoceno darilo. Še zlasti me zanima izračun dolgotrajnih toplotnih sprememb, pri kateri ste prišli do precej drugačnega zaključka kot Spitaler, ki ni dovolj upošteval ekliptičnega naklona …« (Köppnovo pismo Milankoviću 1921; Milanković 1997).

Slika 3: Razglednica, ki jo je Vladimir Köppen poslal Milankoviću (1921) (arhiv Srbske akademije znanosti in umetnosti).
Glej angleški del prispevka.

Köppen je hitro spoznal, da je v Milankoviću našel najmočnejšega zaveznika pri svoji obrambi Wegenerjeve teorije. Wegener in Köppen sta bila skoraj dve desetletji, od predavanja nemškemu geološkemu združenju, na bojni nogi s celotno geološko skupnostjo. Wegener je bil v nezavidljivem položaju; njegova teorija je bila tarča samih kritik in videti je bilo, da z izjemo svojega tasta, Köppna, nima nobenega drugega zaveznika. Potem ko je našel podporo pri Milankoviću, se je Köppen iznajdljivo domislil, da bi skupaj z Wegenerjem sodeloval pri pisanju knjige Podnebja v geološki zgodovini (*Die Klimate der Geologischen Vorzeit*). Zdaj nista bila več sama proti vsemu svetu in Köppen je takoj predlagal, naj Milanković napiše osrednje poglavje v njuni knjigi. To v znanstveni praksi sicer ni tako neobičajno, vendar je bil omenjeni primer poseben, ker je bil povezan z iskanjem Arhimedove točke, ki bi lahko premaknila ves svet. Köppen je pisal Milankoviću: »*Na žalost sem slab matematik in imam težave z vzorci. Ker pa so geologi na splošno še slabši, to pa so zelo pomembna vprašanja, vas prosim za prijateljsko pomoč, ki ste jo že sami tako prijazno ponudili. Z Wegenerjem bi bila zelo vesela*«, zaključi Köppen v svojem pismu, »*če bi o teh zadevah napisali ločeno poglavje, ki bi ga midva nato neokrnjenega vključila v najino knjigo*« (Köppnovo pismo Milankoviću 1922; Milanković 1997, 478).

Knjiga Podnebja v geološki zgodovini (nem. *Die Klimate der geologischen Vergangenheit unciihre Beziehung zur Entwickelungsgeschichte der Sonne*) je bila objavljena leta 1924 kot »*eno od temeljnih besedil v paleoklimatologiji, ki hkrati predstavlja ključno podporo Milankovićevi teoriji o ledenih dobah*« (Rubel in Kottek 2011). Köppen, Wegener in Milanković so bili končno skupaj, velika slika je bila sestavljena – en del so predstavljale vede o Zemlji, drugega pa nebesna mehanika. Retorične, nepovezane in empirične manipulacije so končno izgubile vse argumente za napad. To je bil prvi resnično celovit pogled na zemeljsko podnebje, ki je temeljil na Wegenerjevi teoriji tektonike plošč. V enem od poglavij je bil znanstveni javnosti predstavljen osnovni paleoklimatski instrument, Milankovićeva krivulja osončenja, ki je omogočila matematično rekonstrukcijo in predvidevanje dinamike podnebnih sprememb. Krivulja osončenja, ki je izhajala iz matematičnega izračuna in ne iz empiričnih raziskav, s katerimi je sicer soglašala, je predstavljala vrhunec dolgoletnih prizadevanj in dokaz o pravilnosti novega pogleda na vede o Zemlji. Milankovićeva matematična teorija podnebnih sprememb, iz katere izhaja krivulja osončenja, je bila za njegove somišljenike poslana naravnost iz nebes – najprepričljivejši dokaz nove smeri na področju znanosti o Zemlji. Milanković je postal njihov glavni zaveznik, njegova krivulja osončenja pa natančna potrditev teze, ki sta jo zagovarjala Köppen in Wegener, saj je Milankovićeva teorija omogočila prehod iz opisnih v eksaktne znanosti o Zemlji.

Wegener je načrtoval, da bo znanstveni javnosti predstavil nove rezultate in jo soočil z novim pogledom na svet. Septembra 1924 je imel na kongresu nemških doktorjev in naravoslovcev v Innsbrucku predavanje o svoji pravkar objavljeni knjigi. Prav gotovo je tokrat lahko predaval z vso odločnostjo in že sam nastop je dal vedeti, da ne dvomi v svojo teorijo. Pri predstavitvi svoje knjige je dejal: »*Za seboj smo pustili zastarele teorije o krčenju Zemlje in padcu v globine, kjer so mostovi nekoč povezovali današnje kontinente, ter sprejeli dejstva, ki prikazujejo možnost premikanja celin, in zdaj je na nas, da za vsako pomembnejše obdobje geološke zgodovine rekonstruiramo notranji položaj kontinentov ter položaj rotacijske sile, ki jih je potiskala narazen …*« (Milanković 2009, 603).

Na koncu zmagoslavno razkrije Milankovićev prispevek: »Najpomembneje pa je to, da smo na ta način dobili vpogled v popolno kronologijo celotnega obdobja kvartarja in dosegli tisto, kar je bilo možno šele za zadnjih 10 000 letih« (Milanković 2009, 606).

Celo Milanković je opazil zmagoslavje v Wegenerjevem nastopu: »*Wegener je med predavanjem o svoji teoriji kontinentalnega premikanja govoril skromno in zadržano, ko pa je začel opisovati mojo idejo krivulje … je povzdignil glas in govoril s pravim zanosom*« (Milanković 2009, 606). Vsi trije so vedeli, da so zmagovalci in da je njihovo zavezništvo dovolj močno za veliki znanstveni preobrat, ki so ga pripravljali. Dogovoriti so se morali le še o tem, kako nadaljevati.

Januarja 1925 je Milanković prejel Köppnovo pismo, v katerem sta ga z Wegenerjem povabila, naj se jima poleti pridruži na njunem domu v Gradcu. To je bil tisti ključni trenutek, ko so izdelali načrt za nadaljnje sodelovanje pri oblikovanju novega pogleda na znanost. Iz te povezave in skupnega boja proti stari paradigmi je bila rojena povsem nova smer v znanosti o Zemlji. Milanković je v svojih spominih temu nenavadnemu srečanju posvetil celo poglavje. »*'Pred vami,' mi je dejal Köppen 'so že drugi znanstveniki, Adhemar, Croll, Baal, Eckholm in Spitaler, preučevali astronomske razloge za podnebne spremembe, vendar niso prišli do sprejemljivih rezultatov. Zato jih je naš veliki, a žal že preminuli klimatolog von Hann, moj dragi prijatelj, s katerim sva skupaj izdajala revijo s področja meteorologije, ovrgel kot neuporabne. Vi pa se niste ustrašili takšnega mnenja, problem ste vzeli v svoje roke in ga rešili.' 'Oprostite,'* sem ga prekinil, '*jaz ga nisem rešil, vi ste ga.' 'Na podlagi vaših izračunov,'* je odgovoril … Wegener se je zamislil, nato pa dejal: *'Takoj ko dokončam poročilo o odpravi na Grenlandijo, bom začel pripravljati četrto izdajo moje knjige o nastanku kontinentov in oceana …' 'Jaz pa bom medtem preučil vse, kar so eksaktne znanosti povedale o obliki Zemlje in potencialnem premikanju rotacijskih polov … vse to bom preštudiral in ko bomo spet sodelovali, morda lahko dejansko premaknemo zemeljske pole,'* sem dodal. Vsi trije smo se zasmejali, srečni kot otroci, ki se pripravljajo na zabavo … V tistem trenutku sta z vrta pritekla Wegenerjeva hčerka in Vasko (Milankovićev sin). *'Igrala sva se z žogo, zabavno je bilo', sta rekla otroka vsa zadihana. Köppen se je zasmejal, naju pogledal in pripomnil: 'Mi pa se medtem čudovito zabavamo z žogo, ki ji pravimo Zemlja.'*« (Milanković 2009, 619).

Slika 4: Osnutek Milankovićevega pisma Köppnu (1922) (arhiv Srbske akademije znanosti in umetnosti).
Glej angleški del prispevka.

Po tem srečanju je Köppen naredil še svoj zadnji veliki korak – sistematično se je začel ukvarjati z razvojem novih ved o Zemlji. S pomočjo sourednika, Rudolfa Geigerja, je leta 1927 začel pripravljati svoj najambicioznejši projekt – Priročnik o klimatologiji (*Handbuch der Klimatologie*), ki nikoli ni bil dokončan, vendar vseeno obsega kar pet zvezkov. Milanković je spet prispeval ključne podatke in Köppen ga je prosil, naj napiše spremno besedo na temo podnebnega stanja na Soncu. Milanković je svoj prispevek naslovil z »Matematična klimatologija in astronomska teorija podnebnih sprememb« (*Mathematische Klimalehre und astronomische Theorie der Klimaschwankungen*). S tem, ko je Milankovića uvrstil na začetek knjige, Köppen ni ničesar prepustil naključju. V Milankovićevih spominih je jasno opisano, kako so se vsi trije zavedali, da ne iščejo določenega znanstvenega rezultata, temveč želijo povsem spremeniti pogled na vede o Zemlji.

Milanković je takrat opustil glavno smer svojega dela in se osredotočil na vprašanja premikanja zemeljskih polov, ki niso bila ključnega pomena za astronomsko teorijo podnebnih sprememb. Ker je želel še dodatno podkrepiti Köppnovo in Wegenerjevo stališče, se je začel ukvarjati z geofizikalnim in matematičnim modelom mehanizma, ki bi lahko predstavljal osnovo za premikanje kontinentov. Po nekaj letih je Milanković uspel oblikovati svoj model kontinentalnih sil, ki je prikazoval nekaj povsem razumljivega – da se središče Zemlje premika na fluidni osnovi. Čeprav je to idejo pozneje izpodrinila teorija tektonike plošč, je v tistih časih pomenila velik napredek pri poznavanju mehanizma premikanja kontinentov in potovanja polov ter razumevanju, da je vse te procese mogoče matematično opisati.

Ne Wegener in ne Milanković v času svojega življenja nista doživela priznanja, vendar pa sta se njuni zasebni in strokovni poti še po smrti ves čas prepletali. Pol stoletja je trajalo, da je neodvisna znanost potrdila

Köppnove, Milankovićeve in Wegenerjeve teorije ter jih v celoti sprejela. Wegenerjeva teorija je veljala za nepravilno vse do 60-ih let prejšnjega stoletja, ko so raziskave morskega dna potrdile, da je imel prav. Podatki iz oceanov so končno prepričali znanstvenike, da se celine dejansko premikajo. Wegenerjeva teorija o premikanju kontinentov predstavlja temelj današnje teorije o tektoniki plošč. Enako se je zgodilo z Milankovićem. Le 10 let pozneje, v 1970-ih, so raziskave globokomorskih sedimentov in po vsem svetu zbrani podatki potrdili Milankovićevo astronomsko teorijo podnebnih sprememb, ki je postala prava »biblija« sodobnega razumevanja podnebnih aktivnosti (Petrović 2004).

Po tem se zdi, da se cikli še naprej razvijajo in ni videti konca. Evropsko geoznanstveno združenje (EGU) podeljuje medaljo Alfreda Wegenerja. Po njem so poimenovali tudi krater »Wegener« na Luni in na Marsu ter asteroid 29227. Kraterja na Luni in Marsu ter asteroid 193GA so poimenovani po Milankoviću. Evropsko geofizikalno združenje (zdaj Evropsko geoznanstveno združenje) podeljuje Milankovićevo medaljo za ključne prispevke k paleoklimatskim raziskavam.

5 Sklep

Veda o Zemlji je v zadnjem stoletju doživela radikalne spremembe, ki so jih sprožili Köppen, Wegener in Milanković. Milankovićeva in Wegenerjeva teorija je eden od zadnjih resnično junaških znanstvenih dosežkov v 20. stoletju. Wegener je izjavil, da ima »dolžnost biti heroj«. Milanković je celo pustil izredno uspešno in donosno kariero gradbenega inženirja, da se je zaposlil na slabo plačanem delovnem mestu izrednega profesorja na Univerzi v Beogradu. To je bilo romantično življenje, polno nekega revolucionarnega duha in zaradi tega potencialno nevarno za ozko usmerjeno znanost brez vsakršne vizije. Leto 1912 je bilo resnično pravo leto čudežev za vede o Zemlji. Za to področje je bilo enako pomembno kot je bilo leto 1905 za fiziko. Cikli Milankovićevega in Wegenerjevega življenja ter njunega skupnega dela so pustili pomemben pečat v zgodovini ved o Zemlji. Skupna prizadevanja obeh znanstvenikov so spremenila vladajočo paradigmo, vrgla s prestola geocentrično in statično kavzalnost ter vzpostavila heliocentričen in dinamičen pogled na zgodovino Zemlje. Zato so Milankovićeve in Wegenerjeve raziskave ter dosežki njunega leta čudežev nujni za ohranjanje prave perspektive razvoja znanosti o Zemlji in razumevanje odločilnega trenutka njihove preteklosti kot temelja za njihovo prihodnost.

6 Literatura

Glej angleški del prispevka.