One hundred years of Milanković cycles

To the Editor — This year marks one hundred years since the publication of the book that outlined one of the most influential scientific theories in climate science: Milutin Milanković's *Mathematical Theory of Heat Phenomena Produced by Solar Radiation*[1] (Fig. 1). This work was the first complete mathematical explanation of how small changes in the rotation and paths of planets around the Sun influence the amount of solar radiation that planets receive, more simply referred to as insolation. In doing so, it provided the foundation for understanding Earth's climate history and the causes of its great ice ages[2]. Although to this day the theory continues to be applied throughout the climate sciences, the story of how it developed despite the hardships of war and imprisonment is not widely known. As scientists around the world cope with the array of challenges caused by the COVID-19 pandemic, Milanković's achievements remind us that great Earth science can sometimes arise in the face of adversity.

Milanković's personal memoirs[3] provide unique insights into the scientific and personal events surrounding the development of his theory. They describe his childhood in the Serbian enclave of Dalj in Austro-Hungary, his student days at the Vienna University of Technology where he also completed his doctorate, and his abandonment of a successful engineering career in Vienna for a professorship at the University of Belgrade. They also recount the turbulent times at the beginning of the twentieth century and their impact on his scientific progress.

Upon moving to Belgrade in 1909, Milanković sought a quiet research area that avoided the sorts of research questions that might lead to fierce competition between scientists. He found this at the intersection of applied mathematics, astronomy and climatology, where he resolved to bring a mathematical perspective to what had been a rather descriptive field of climate science. He began to grapple with a solution to the outstanding problem of explaining how changes in insolation occur and affect the global climate. However, only three years into his professorship he was drafted into the first Balkan War (1912–1913). Assigned, due to his profession, to foreign correspondence duty instead of being sent to the frontline, Milanković managed to publish some of his first works during this time[4,5].

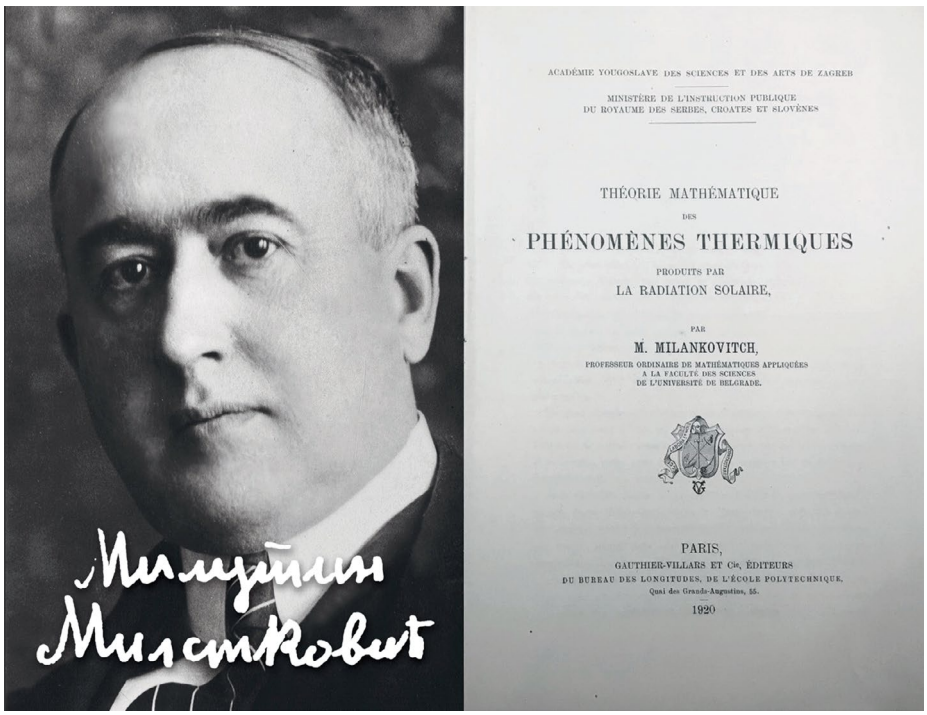

Fig. 1 | Milanković and his masterpiece. A photo of Milutin Milanković upon joining the Serbian Academy of Sciences in 1924 (left) and the front page of the *Theorie Mathematique des Phenomenes Thermiques Produits par la Radiation Solaire*, printed in Paris in 1920 (right). Credit: Image adapted with permission from Milutin Milanković Society Belgrade

Unfortunately, the end of the Balkan War in Serbia was only a temporary reprieve from conflict. Milanković was on the first leg of his honeymoon in his hometown in Austro-Hungary when World War I broke out. No longer an Austro-Hungarian citizen, he was subject to a new decree calling for the imprisonment of Serbian citizens. In the summer of 1914, he spent six weeks under house arrest, but was eventually imprisoned and later sent to a prisoner-of-war camp. His diary entry from his first night in prison reads "The guard received me very kindly, like a hotel receptionist receives an esteemed guest: 'I have,' he said, 'reserved for you a separate room.' […] I thanked him for his reception […] Sat on the bed, I looked around and started synchronizing with my new social position: that lonely room, away from the noise of people, felt made for scientific work […] In the suitcase I had my printed works and my notes on the cosmic problem, there was clean paper too and I started writing. It was far past midnight when I stopped. I looked around the room, wondering where I was. It felt like I was in a roadhouse on my trip through the Universe."[3]

At the prisoner-of-war camp in today's Austria, research was not possible and life became more difficult. The monotony and uncertainty, as well as the threat of disease, took its toll. Milanković's freedom was achieved thanks to the efforts of his wife, Kristina, who contacted many of his Austro-Hungarian friends and colleagues asking for help. Finally, the authorities were persuaded that Milanković was an esteemed scientist and he was released and allowed to live in Budapest under police surveillance.

Despite the adversity faced during his house arrest and imprisonment, Milanković continued to think about his scientific pursuits and, whenever possible, continued his calculations. Milanković's manuscript on a new mathematical theory of astronomical forcing[1] was finished in 1917, while he was still under police surveillance. Its printing was initially planned for 1918, but did not

come to fruition when the publisher ran out of paper due to the war. The manuscript was finally published in 1920.

After the end of World War I, Milanković was finally allowed to leave Budapest and returned to Belgrade with his wife and three-year-old son. In his typically dry way, he writes "After a comfortable 3-day cruise down the river Danube, I arrived to Belgrade on March 15th 1919, thus completing my exciting five-year wedding trip."[3]

While the idea of astronomical drivers of climate had been proposed before, Milanković's work was the first to explain how the full set of cyclic variations in Earth's orbit — eccentricity, obliquity and precession — caused distinct variations in incoming solar radiation at different latitudes and changed on multi-thousand-year timescales. By finding a general solution, which was also applicable to other planets, he laid the groundwork for understanding the pacing of cold and warm episodes in Earth's climate history.

To ensure that his scientific discoveries were available to future generations, he compiled his work on the astronomical forcing of climate into the famous *Canon of Insolation and the Ice-age Problem*[6]. During his lifetime, Milanković's theory of astronomical forcing gained substantial attention and support from scientists like Wladimir Köppen and Alfred Wegener, but lacked corroborating geological evidence. The long-awaited confirmation arrived with James Hays and collaborators[7] in 1976, who finally demonstrated that climate fingerprints in ocean sediment records contain the same temporal cycles as Milanković's theory predicted.

From a modern perspective, it may seem that the importance of Milanković's contribution lay solely in his mathematical achievements. But his memoirs and life also reveal a remarkable resilience in the course of developing one of the most beautiful theories in the Earth sciences. That Milanković persevered and prospered scientifically under such difficult circumstances should give hope and inspiration to scientists navigating the uncertain times that lie ahead. ❐

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