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Lika's Plitvice Lakes

National Park and UNESCO World Heritage Site

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CONTENTS

cover: Plitvice Lakes National Park in Croatia and not far from Otočac, Lika, and Karlovac. Since 1979, the park has been preserved as a UNESCO World Heritage Site. More on page 22.

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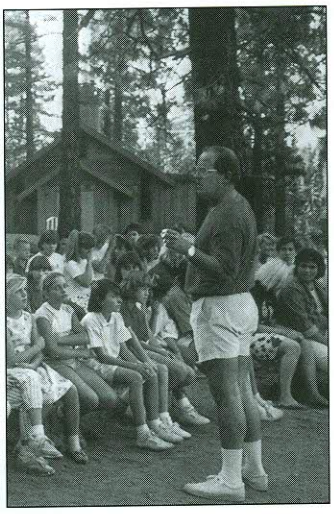
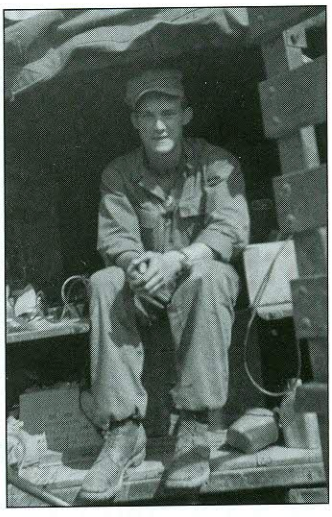
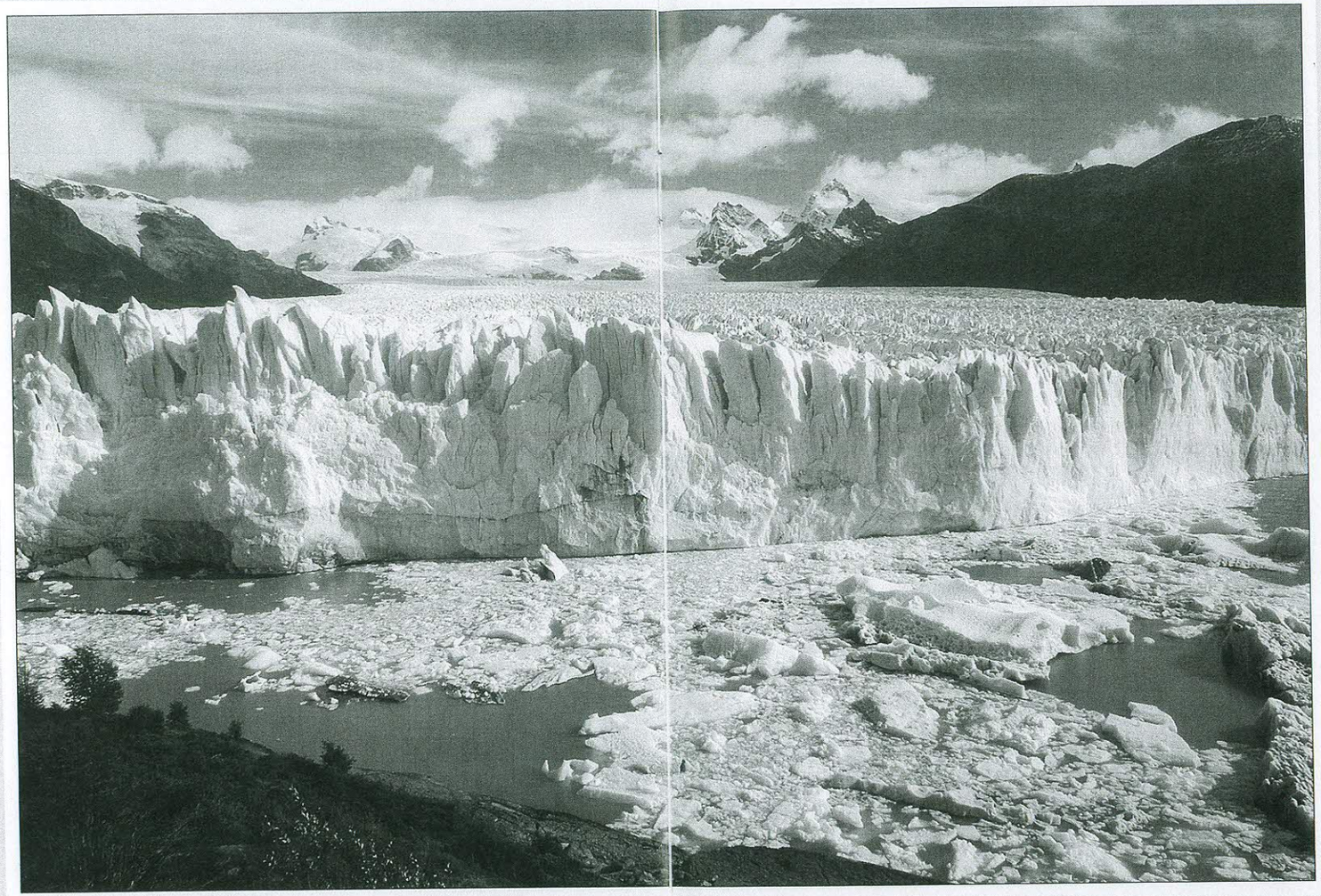


Paul Kral, director of the summer camp program, page 16.

Milutin Milankovitch and the theory of the Ice Ages , page 36.



Radioman Ted Erceg during the Korean War, page 42.



The waxing and waning of Ice Ages, forming glaciers like this one in Argentina, is explained by the Milankovitch Theory of Climate Changes, mathematically proven by the Serbian scientist in the 1920's.

A Passenger Through the Ice Ages

Milutin Milankovitch (1879-1958)

by Milos Rastovic

One of the most difficult riddles in the history of Earth Science is: what has caused the changes to the earth's climate since the Ice Ages? Milutin Milankovitch—a Serbian geophysicist, climatologist, astrophysicist, and mathematician—is best known in the history of science for postulating the most significant theory ever made for the cause of the Ice Ages. His theory relates long-term climate changes to the earth's orbital motion.

NASA, the United States' National Aeronautics and Space Administration, has ranked Milankovitch among the 15 best scientists in history, those who have shaped human civilization. Peter Huybers, a professor of Earth and Planetary Sciences at Harvard University, tested many hypotheses about changes in climate, and he confirmed the one proposed by Milankovitch.

The astronomical or orbital rotation theory, the Milankovitch Theory of Climate Changes, states that slow changes and variations in the earth's orbit throughout history coincide with the periods of deglaciations, the gradual melting away of glaciers, over the past million years. According to Huybers:

> These periods of deglaciation saw massive climate changes. We ought to understand what caused these massive changes in past climates if we are to predict long-term changes in future climates with any confidence. And at least now we know, with greater than 99 percent confidence, that interaction between obliquity [the changing angle] and precession [motion in the direction of the earth's axis of rotation] are among the factors that contribute to deglaciation.

Through experimentation, Huybers tested the connection between the earth's orbital cycles and deglaciations. He constructed glacial cycles and added similar distortions—such as noise and errors in timing—to geological data. He explained the results:

> At the same time we're seeing high obliquity, we also tend to get an alignment with precession whenever deglaciation occurs. When you get that alignment, the radiation that the Northern Hemisphere receives during summer increases by tens of watts per meter squared, and if large Northern ice sheets are present, they tend to disintegrate.
>
> These statistical findings agree exactly with what Milutin Milankovitch, a Serbian geophysicist, proposed in the first half of the 20th century. It could also be that orbital forcing causes a rise in atmospheric CO_2, and that it's the increased CO_2 that drives the loss of ice sheets.

Milankovitch's hypothesis concerning the causes of the Ice Ages is based upon claims made in the 19th century by French scientist Joseph Adhemar and Scottish scientist James Croll. Adhemar suggested that glaciation occurs when long winters coincide with the earth's aphelion, the farthest point in the earth's orbit around the sun. Croll, however, proposed that glaciation occurs whenever the earth's aphelion coincides with times during the winter when the intensity of insolation, or solar radiation, is weakest.

In the journal *Nature*, Huybers, with Maureen E. Raymo, a professor of Earth Sciences at Boston University, further described Milankovitch's suggestion about the influence of the earth's orbit on glaciation, or the times when the earth is covered by glaciers:

> "He [Milutin Milankovitch] argued that glaciation occurs when insolation [solar radiation] intensity is weak at high northern latitudes during summer. This happens when both Earth's spin axis is less tilted with respect to the orbital plane and aphelion [the farthest point from the sun] coincides with summer (not winter) in the Northern Hemisphere. According to Milankovi[t]c[h], when there is less insolation during the summer, snow and ice persist through the year, gradually accumulating into an ice sheet.

While Huybers was the first to test the connection between the earth's orbital cycles and deglaciations, Milutin Milankovitch was the first to launch and mathematically prove this hypothesis in the first half of the 20th century.

Milankovitch's theory claims that a dominant factor in Earth's orbital motion around the sun is cyclic variations and interaction between the earth and the sun. According to Milankovitch, there are three basic elements of these cyclic variations throughout history:

1. Earth's eccentricity (departure from circularity) in which the earth changes its circular orbit to the elliptic (a period of 105,000 years),
2. Obliquity—changes in the angle (axial tilt) with respect to the plane of the earth's orbit (a period of 41,000 years), and
3. Precession through time—changes in the direction of the earth's axis rotation (a period of 22,000 years).

Milankovitch posited that these three elements of cyclic variations have an effect on the earth's long-term climate changes, including the waxing and waning of the Ice Ages. Today, this theory of the three factors is known collectively as the Milankovitch Cycles.

Milankovitch was born on May 28, 1879, in the town of Dalj, Slavonia. At that time, Slavonia was part of the old Austro-Hungarian Empire, but it is now located in present-day Croatia.

According to his autobiography—*Recollection, Experiences and Vision*—his ancestors had lived in Dalj for two and a half centuries. The third generation of his family were intellectuals, including his grandfather, Todor, who finished law school.

Milutin Milankovitch's father, Milan, was a landlord, merchant, and local politician who died when Milutin was six years old. Milutin's mother, Jelisaveta, and his uncle, Vasa Maucevic, subsequently raised Jelisaveta's six children. Three of them died of tuberculosis in their youth.

Because of his own poor health, Milankovitch received his elementary education at home from private teachers, friends, and relatives. Included among them was his grandfather, Uros Milankovitch, a renowned philosopher.

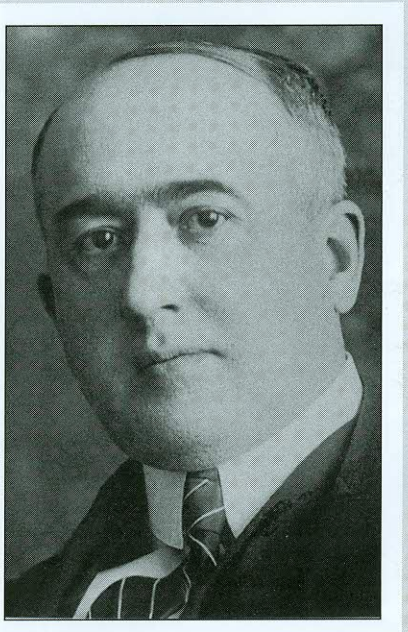
After attending high school in Osijek, Milankovitch studied civil engineering at the Vienna University of Technology. In 1904, he received a Ph.D. in technical science. While working as an engineer in Vienna, he registered six inventions and designed many bridges, aqueducts, and power plants in Austria-Hungary.

Despite a very successful career as an engineer, Milankovitch reached a turning point in his life in 1909 when he accepted an offer from Serbian scientists Jovan Cvijic, Mihailo Petrovic, and Bodgan Gavrilovic and became a professor of rational mechanics, celestial mechanics, and theoretical physics at the University of Belgrade. While he continued to design bridges and other structures in Serbia, he mostly focused his research on the long-standing puzzle of the Ice Ages, insolation, and the earth's temperature.

When World War I broke out five years later, in 1914, Milankovitch was in his native Dalj on his honeymoon with his wife Hristina Topuzovic, an opera singer. The Austro-Hungarian authorities arrested him because he was a Serbian citizen, and he was put in a prison camp in Nezider.

When Milankovitch's professor, Emanuel Czuber from the Vienna University of Technology, heard that his former student was in prison, he immediately intervened. As a result, Milankovitch was sent to Budapest where he spent a great deal of time in the library. After World War I (1914-1918), Milankovitch returned to Belgrade and continued as a professor at the University of Belgrade until his retirement in 1955.

In addition to his theory of climate change, he also made a major contribution to revising two of the most widely used calendars in the Western world—the Julian and the Gregorian. In 1923, at a congress of all of the Eastern Orthodox churches held in Constantinople, Milankovitch proposed a revision of the old Julian and Gregorian calendars.



Prof. Milutin Milankovitch (1879-1958). ***Serbian Academy of Sciences and Arts.***

According to Milankovitch, in the next 900 years, seven leap years should be removed from the Julian calendar. Instead of the 225 leap years, which were in the old Julian calendar, there should be only 218, because the Julian calendar loses one day every 128 years. He also found that the Gregorian calendar was not exact because it lost one day every 3,300 years.

For Milankovitch, leap years have to be divisible by four without a remainder. Secular years can be leaped if the number of their centuries is divided by ten with a remainder of two or six.

As a result, Milankovitch's year is 365.24222 days, which is very close to the tropical year (a complete cycle of seasons) of 365.24219 days. The difference between Milankovitch's findings and the tropical year is only two seconds per year: in the next 43,200 years, the difference will be only one day.

For this reason, Milankovitch's calendar is the most exact calendar in human history. Although the Eastern Orthodox churches accepted his calendar, it was never implemented.

Among the many books he had published, the *Canon of Insolation on the Earth and Its Application to the Problem of the Ice Ages* was the most important. In this book, he explained his crucial theory proposed in the 1920's, later known as the Milankovitch Theory, about the cause of climate change, the relationship between insolation and atmosphere, and the Ice Ages.

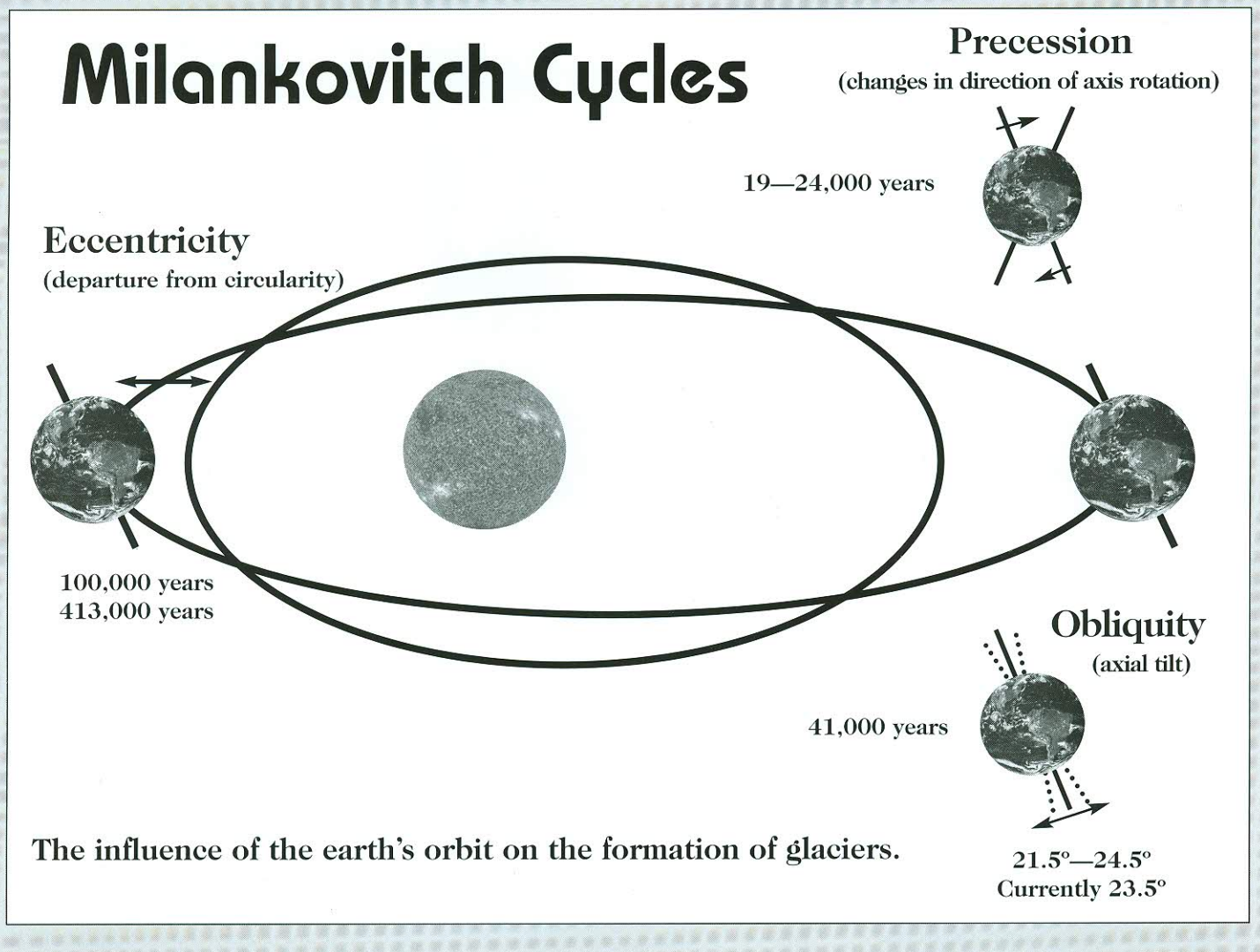
According to Milankovitch, the earth's orbit around the sun varies between circular and elliptical in a 105,000-year cycle. When the earth's orbit around the sun is more elliptical, there is a greater distance between the earth and the sun. Consequently, the earth when in perihelion, the closest point to the sun, is warmer than in aphelion, the farthest point from the sun.

He also found that a smaller angle of the earth's axis means less seasonal differences. By contrast, a greater angle of the earth's axis means a warmer summer and a cooler winter.

Unfortunately, the Milankovitch Theory was neglected for more than 50 years until J. D. Hays, John Imbrie, and N. J. Shackleton published a paper in 1976 in the journal *Science*. They found that the Milankovitch Theory corresponded to the periods of climate changes.

As a result, the National Research Council of the U.S. National Academy of Sciences confirmed the Milankovitch Theory in 1982: "...orbital variations remain the most thoroughly examined mechanism of climate change on time scales of tens of thousands of years and are by far the clearest case of a direct effect of changing insolation on the lower atmosphere of Earth."

By the beginning of World War II in 1941, Milankovitch was 63 years old. During the war, Milankovitch published another autobiography—*Recollection, Experiences and Vision*—and the popular science history books, *Through Space and Centuries* and *Through the Realm of*



The influence of the earth's orbit on the formation of glaciers.

Science. About his scientific work, Milankovitch said:

> In my scientific vocation, I have found a pleasant shelter by which I was protected from much turbulence that shook the world. Under that roof, I have prepared and equipped my scientific workshop, segregated from the wider world but in constant spiritual connection with famous scientists. I have created my scientific area, my indisputable spiritual property. In this workshop I have spent forty years, including short breaks, writing and publishing my papers.

After the war, Yugoslavia was under a Communist regime. While Milankovitch's only child, Vasko, emigrated to Australia, Milankovitch and his wife, Hristina, decided to stay in Yugoslavia.

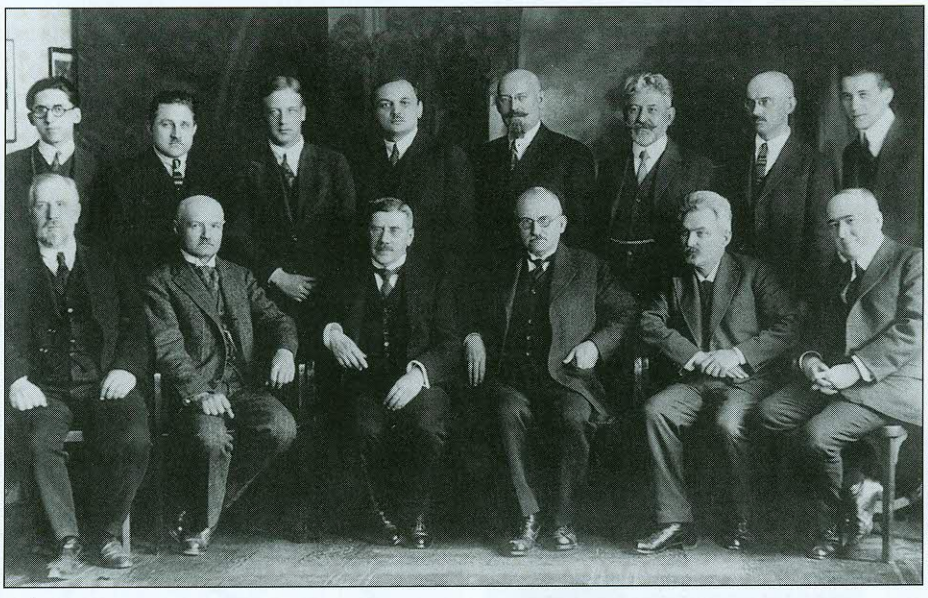
Milankovitch was a member of the Serbian Academy of Sciences and Arts, the Yugoslav Academy of Sciences and Arts, and the German Academy of Naturalists "Leopoldine" in Halle. In recognition of Milankovitch's contribution to science, the International Astronomical Union (IAU) named after Milankovitch a crater on the moon in 1970, a crater on Mars in 1973, and a main belt of asteroids, discovered in 1936 (1605 Milankovitch). Since 1993, the Milutin Milankovitch Medal has been awarded for contributions in the field of climate by the European Geophysical Society.

Milankovitch died on December 12, 1958, in Belgrade, and was buried in Dalj. Today, his house in Dalj is the Milutin Milankovitch Cultural and Scientific Center, which promotes the legacy of Milankovitch by organizing cultural and scientific events and by popularizing science.

Two international symposiums, one in 2004 and another in 2009, were organized under the patronage of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in honor of Milankovitch's scientific achievements. In 2012, because of Milankovitch's great contribution to science, the Serbian National Bank issued a bill with his image.

In 2012, Andre Berger of the *Universite de Catholique Louvian* in Belgium, Fedor Mesinger of the Serbian Academy of Sciences and Arts, and Djordje Sijacki of the University of Belgrade edited a volume entitled *Climate Change*, a compilation of the papers presented at the 2009 international symposium honoring Milutin Milankovitch. In it, they wrote the following dedication to Milankovitch's legacy:

> Thus, understanding paleoclimate, following in the footsteps of Milankovitch not only adds to our basic knowledge of the history of the world we live in, but it also adds to our abilities to anticipate future climate changes as the emission of greenhouse gasses by the increasing world population continues with little abatement in sight.



Dr. Milutin Milankovitch, seated on the far right, with his colleagues in the Department of Mathematics at the University of Belgrade. ***Courtesy of the Serbian Academy.***

Milankovitch's son, Vasko, wrote *The Memory of My Father* and, in it, described the character of his father in a very interesting way through a childhood memory:

Father was barely 5'7" tall and of fine frame. He had a prominent forehead and bushy brows over brown eyes which were always alert and quietly smiling...

He was not the bespectacled-professor-type of scientist as he enjoyed nature and loved all things aesthetically harmonious and maintained a constant interest in history, literature, painting, and sculpture....

His love for abstract pleasures did not preclude him from earthy enjoyment. He enjoyed a glass of fine wine with his meals and would later relax with a favorite cigar. He often shared a good joke, and not necessarily a clean one, either.

Mother was the master of our family. Father would call her the "Home Secretary" and always showed her great respect. He was the well-looked-after guest with no household duties.

He was popular with the ladies due to his excellent manners and because he was a good *raconteur*. His widely read book of popular astronomy, written in the form of letters to a lady friend, added to his popularity with women.

What those ladies never knew was that he really did not have a very high opinion of the fairer sex... He thought that they were less objective than men and had a more fragile nervous system. The real thread of larger problems would somehow escape them... in other words, he was a real male chauvinist!

I often recall an event of my youth ...Father and I were vacationing in Austria [where Vasko fractured his collar bone and was treated at the local hospital]. Later that afternoon and throughout dinner, Father was very absent-minded which was most unusual for him.

[Vasko was put to bed around 10:00, and Milutin left the door open in case Vasko needed him.] Instead of going to bed, he went to his desk, pulled some large sheets of paper from the centre drawer, lit the desk lamp, and sat down. "Something unusual must have happened," I thought. He never worked after dinner...

Father began writing fast, as I had never seen him before. The effect of my injection had worn off, and the splint was cutting painfully into my shoulders, and I could not sleep.

He got up, put his foot on the chair and his elbow on his knee, took his glasses off, and looked at me. He was not seeing me—he looked through me. He put the paper away, took out a new sheet, and started writing again.

The woolen strap was hurting me. I called out for him to lift me and put some cotton wool under the strap, but I could see that he did not hear me.

He kept on writing, and then he stopped and looked at the paper in front of him. He seemed to be revising all that he had written down, talking to himself... Then he stopped.

He then took out another sheet of paper and started writing again, but slowly this time. The tension on his face gradually dispersed, and his usual calm expression returned. Finally he slowed down and then stopped altogether.

He looked up and, recalling my presence, said, "Sorry, I forgot about you. Do you need anything?"

He lifted me into a comfortable position on the pillows, put pads of cotton wool behind the strap, and said, "I think I've got it."

"You got what?" I asked.

"The differential equation covering the movement of the poles. This equation has eluded me for quite some time. I am right now."

He patted me on my sound shoulder, went into his room, and a couple of minutes later, I could hear him gently snoring. ■

Special appreciation for information from NASA Earth Observatory; Peter Reuell's "Of Orbits and Ice Ages: Researcher Confirms That Axis Shifts Help to Propel Temperature Changes"; Maureen E. Raymo and Peter Huybers' "Unlocking the Mysteries of the Ice Ages"; Milutin Milankovic's Uspomene, Dozivljaji, Saznanje; *J. D. Hays, John Imbrie, and N. J. Shackleton's "Variations in the Earth's Orbit: Pacemaker of the Ice Ages"; National Research Council's* Solar Variability, Weather, and Climate*; The University Library "Svetozar Markovic," Belgrade:* Milutin Milankovi[t]c[h]: World Famous Scientist from Belgrade; *International Astronomic Union (IAU); European Geophysical Society: Awards & Medals—Milutin Milankovitch Medal; Andre Berger, Fedor Mesinger, and Djordje Sijacki's* Climate Change*; Vasko Milankovitch's* The Memory of My Father in *A. Berger, J. Imbrie, J. Hays, G. Kukla, and B. Saltzman's* Milankovitch and Climate: Understanding the Response to Astronomical Forcing.