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The Influence of Natural Cycles on Climate Change

Gordana Jovanovic
Faculty of Natural Sciences and Mathematics, University of Montenegro, Montenegro

Abstract: The influence of natural cycles on the climate of our planet was very successfully and in detail examined by Milutin Milankovitch. He described mathematically precisely how the movement of the Earth around the Sun over long periods of time is reflected in its climate at different latitudes. Modern researches show the existence of some other natural cycles — astronomical, related to the activity of the Sun and its cycles, and terrestrial, related to periodic processes on Earth such as El Niño and La Niña, which also affect the climate. This paper will discuss all these impacts as well as scientific predictions of the further course of climate change in this century.

Key words: climate change, cycles, Earth, Sun, solar activity

1. Introduction

Climate is the average state of weather elements in an area over a period of 30 years. The Sun is the source of energy for the Earth's climate system and each solar variation affects, in some way, the Earth climate system. Changes in the Earth's orbit and axial tilt are now recognized as key factors in the long term changes to Earth's climate that produce ice ages and warm periods [1-3]. Solar decadal variability, evidenced by sunspots, is also identified as a natural source of climate change. Earth's climate is influenced by its own internal variations like the El Niño and the La Niña events. El Niño and La Niña are the warm and cool phases of a recurring climate pattern across the tropical Pacific-the El Niño-Southern Oscillation, or ENSO [4-6]. Any assessment of climate variability and climate change depends crucially on the existence and accuracy of records of meteorological parameters. Ideally records would consists of long time series of measurements made by well-calibrated instruments located with high density across the globe. In practice, this ideal cannot be realized. It should be keep in mind that measurements with global coverage have only been made since the start of the satellite era in 1978 year. Instrumental records have been kept over the past few centuries at a few locations in Europe. For longer periods, and in remote regions, as with establishing a history of solar activity, climate records have to be reconstructed from indirect measures, or proxies [7]. These proxies provide information about weather conditions at a particular region through records of a physical, biological or chemical response to them. Records of temperature dating back hundreds of thousands of years have been derived from analysis of oxygen isotopes in ice cores obtained from Greenland and Antarctica. Evidence of very long term temperature variations can also be obtained from the width of tree rings or isotopic abundances in ocean sediments, corals or fossil pollen. A key concern of contemporary climate science is to attribute causes, including the contribution of solar variability, to the observed variations in temperature. A number of approaches have been used and in all cases great care needs to be taken to ascertain the statistical validity of the results in the context of natural variability in the temperature data.

Corresponding author: Gordana Jovanovic, Ph.D., Professor; research areas: waves and oscillations. E-mail: gordanaj@ucg.ac.me.

2. Millennial Timescales

Eighty-one years ago Milutin Milankovitch announced his capital research Canon of insolation [7]. In this research Milankovitch finds that the position of the Earth and the Sun is crucial for the Earth climate. These factors are astronomical and therefore they are not influenced by humans or their activity. The changes in these astronomical factors are long-term changes, so called secular changes. The degree to which the orbit differs from a circle is measured by its eccentricity — the smaller the value of the eccentricity the closer the orbit is to a circle. This eccentricity of the Earth's orbit around the Sun varies over time and has a maximum value of about 6% but is currently lower, at about 1.7%. This means that the Northern hemisphere receives about 7% less radiation in its summer, and 7% more in its winter, than the Southern in its equivalent seasons because the Earth is closer to the Sun in January than in July. The eccentricity varies with periods of around 100,000 and 413,000 years due to the gravitational influence of the Moon and other planets, primarily Jupiter and Saturn. The tilt (or obliquity) varies cyclically with a period of about 41,000 years, and the precession of the seasons varies with periods of up to about 26,000 years. These periodic changes are known as Milankovitch cycles, Fig. 1. The astronomical Milankovitch cycles lead to long-term changes in the average annual energy radiated by the Sun that is absorbed by the whole planet by different region of the Earth. It should have in mind that there are uneven distribution of land vs. the ocean in the Northern (about 39%) and Southern (about 19%) hemisphere. Therefore, solar radiation is unequally absorbed in these hemispheres [8]. For the Earth's climate more important is the Northern hemisphere absorption scenario because of the larger land surfaces which are more important in the Earth's energetic budget (the difference between absorbed and emitted solar radiation) than the ocean surfaces. Long-term changes in total solar irradiance (TSI), the spatially and spectrally integrated radiant energy from the Sun at a

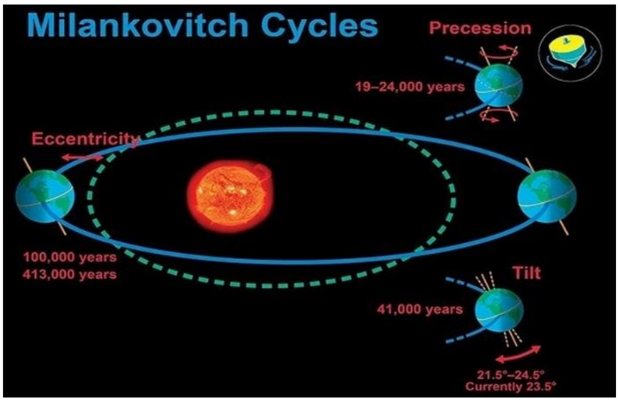

Fig. 1 Milankovitch cycles.

distance of one astronomical unit, cause changes in the temperature. This change further cause long-term subsequent secondary feedback influences and together they are enough to cause climate change in glacial/interglacial cycles. This was the Milankovitch's answer to the riddle of the ice age.

Solar variability on time scales of centuries to millennia can be reconstructed using cosmogenic radionuclides such as ^{10}Be and ^{14}C whose production rate in the atmosphere is modulated by solar activity [3]. Namely, galactic cosmic rays (GCR) intensity reflects solar activity because of modulation by solar magnetic fields carried away from the Sun by the solar wind. The larger the solar activity, the stronger the shielding, and the lower the cosmic ray intensity penetrating into the atmosphere. In the atmosphere cosmic rays interact with nitrogen and oxygen, producing cosmogenic radionuclides such as ^{10}Be and ^{14}C, so that measuring amounts of ^{10}Be and ^{14}C stored in terrestrial reservoirs provides a means to reconstruct the history of solar activity over millennia. These data are known as solar proxy. They can be stored in the ice cores and tree rings. The ^{14}C data are the means from tree cores in many parts of the world, but the ^{10}Be data are from two just ice cores, one from Antarctica and another from Greenland.

3. Centennial Timescales

On these timescales, long-term changes in the Earth's orbit may be disregarded. Quasi-bicentennial solar cycles are the primary cycles that govern variations in the 11-year subsidiary cycles in TSI and solar activity [8]. The length of the 11-year cycle depends on the phase of the quasi-bicentennial cycle and increases gradually from the growing phase to the maximum and descending phase of the quasi-bicentennial solar cycle. It is obvious that such relationship exists also for the 11-year cyclic variations in the TSI because the cyclic variations in solar activity and the TSI are interconnected and synchronized. Eleven-year cycles of solar activity developing in the descending phase of the quasi-bicentennial cycle have a duration of about P = 11.7±0.8 years, and they are ordinarily longer than in the cycle developing during the rising phase and maximum of the quasi-bicentennial cycle. These data can be explained by a decrease in the average duration of the last eight cycles of solar activity, from 15 to 22, which developed during the rising phase and maximum of the quasi-bicentennial cycle, down to P = 10.4 years, compared to the average duration of P = 10.9 years for the last 14 cycles of solar activity. This relationship allows us to predict not only the duration of the current 11-year cycle, but also the durations of the subsequent cycles 25 and 26, which will be formed during the descent of the current quasi-bicentennial cycle. The succeeding cycles 25, 26, and 27 in the phase of the decline of the quasi-bicentennial cycle are expected to begin in approximately 2020.7±0.6, 2032.2±1.2, and 2043.7±1.8, respectively. The inverse relationship between the length of 11-year solar cycles and their radiative forcing is attributed to the influence of the quasi-bicentennial solar cycle, which determines the total pattern of development of 11-year cycles. These facts prove once again that the 11-year cycles are genetically related to the quasi-bicentennial cycle, which determines the regular development of their duration and power as the filial 11-year cycles. In the growth phase of the quasi-bicentennial solar cycle, the Earth receives more solar energy than is emitted by radiation into space, and its average annual energy balance is positive (E > 0), and vice versa in the recession phase of the quasi-bicentennial cycle it is then negative (E < 0). As a result, the average annual energy balance of the Earth oscillates around the quasi-bicentennial equilibrium state.

Quasi-bicentennial variations in the TSI determine the mechanism of cyclic alternations in climate change and set the timescales for physical processes taking place in the Sun-Earth system. That is why the Earth's climate changes every 200±70 years.

Another interesting approach is done by Valentina Zharkova by introducing magnetic waves in defining solar activity [9-10]. This approach revealed a presence of grand solar cycles with duration of 350-400 years. She showed that these grand cycles are formed by the interferences of two magnetic waves with close but not equal frequencies produced at different depths of the solar interior. These grand cycles are always separated by grand solar minima of Maunder minimum type, which regularly occurred in the past forming well known Maunder, Wolf, Oort, Homeric and other grand minima. According to this study the contemporary grand solar minimum started in 2020 year and will last until 2053. During this minimum one would expect to see a reduction of the average terrestrial temperature by up to 1°C, especially during the periods of solar minima between the cycles 25-26 and 26-27, e.g., in the decade 2031-2043 year, Fig. 2. The reduction of a terrestrial temperature during the next 30 years can have important implications for different parts of the planet on vegetation, agriculture, precipitations in both Northern and Southern hemispheres. This global cooling during the upcoming grand solar minimum can offset for three decades any sign of global warming.

4. Decadal Timescales

The most famous features on the Sun at the decadal timescales are sunspots. Sunspots are dark features on the solar disk, Fig. 3. The number of sunspots has been carefully recorded and it is clear that the Sun is not the unchanging body traditionally assumed pre-Galileo. Fig. 4 shows the sunspot record revealing a cyclic behavior with sunspot number (SSN) growing and decaying on a timescale of 9-13 years. This has become known as the 11-year cycle, or simply the solar cycle. Electromagnetic radiation from the Sun varies within the 11-year solar cycle so that the Sun emits more radiation at sunspot maximum, i.e., when it is most covered with dark sunspots. In the background of this phenomena stands solar magnetic field, i.e., solar dynamo mechanism. Basically, the magnetic fields associated with the sunspots divert the convective upflow of energy so that the spots are dark, and although the greater portion of the blocked energy upflow is returned to the solar convection zone, some of it emerges in the areas surrounding the sunspots, leading to brightening there. Particularly interesting period of the solar activity was from 1645-1715 year, the Maunder Minimum, when the SSN declined to near zero. This period coincides with co called Little Ice Age in Europe and North America.

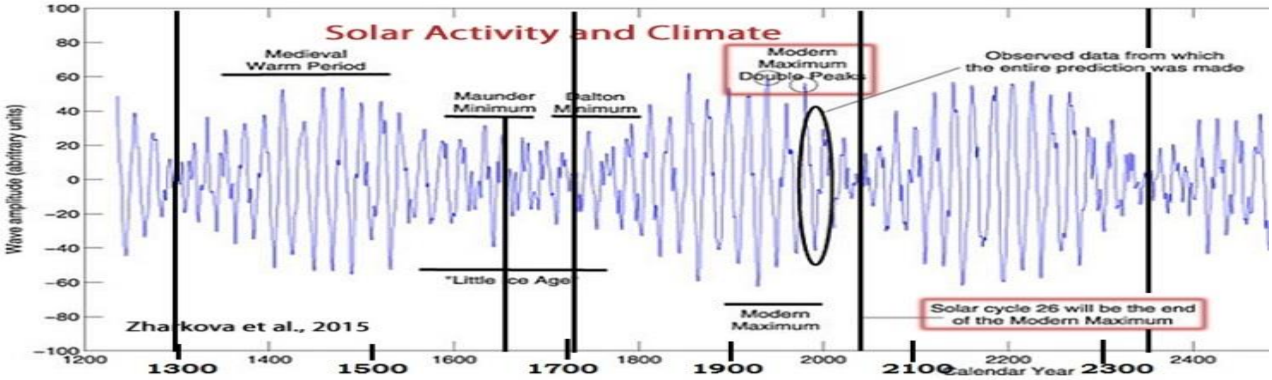

Fig. 2 Solar activity curve restored for 1200-3300 AD.

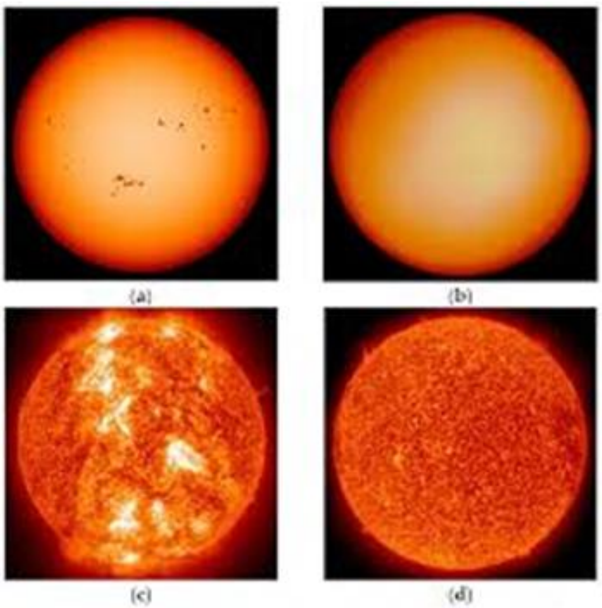

Fig. 3 Solar minimum and solar maximum activity with pronounced sunspots

The TSI varies with time having 0.1% variability over the course of the 11-year solar cycle. Larger percentage variations are seen in solar spectral range especially in ultraviolet (UV) emissions, which arise from the lower solar atmosphere (the chromosphere) and which influence the stratosphere in Earth's middle atmosphere between about 10 and 50 km. The UV part of the solar spectrum modulates ozone (O3) abundance, temperatures and winds in Earth's stratosphere [3]. Sufficiently long time series of observations of solar spectral irradiation (SSI) are not available. Therefore, numerical modeling is a useful approach to examine the influence of SSI on the Earth's climate [11]. The UV radiation-ozone-temperature path is an important mechanism of solar impact on climate although remains unclear to date. During the 11-year solar cycle UV intensity anomaly affects the O_3 concentration in stratosphere and its temperature too. UV radiation varies up to 6% over the solar cycle for the wavelength near 200 nm where oxygen dissociation and ozone production occur and up to 4% for the wavelength range 240-320 nm where absorption by stratospheric ozone is prevalent. This region of the atmosphere has the potential to affect the troposphere below it and hence the surface climate. Estimated stratospheric temperature changes associated with the 11-year solar cycle is about 2 K over the equatorial stratopause (~50 km) [3]. The direct effect of irradiance variations is amplified by an important feedback mechanism involving O_3 production. This is an additional source of heating. The origins of the observed lower stratospheric maximum and signal that penetrates deep into the troposphere at midlatitudes are less well understood and require transfer mechanism both-within the stratosphere and between the stratosphere and underlying troposphere. Ubiquitous gravito-acoustic waves can be a good candidate for these transfer mechanisms [12]. Changes in TSI can directly impact the surface while changes in UV directly impact the stratosphere. Therefore, stratosphere-troposphere coupling mechanism is necessary for these stratospheric changes to impact the surface temperatures. Much of the observational evidence for solar cycle influence appears to be regional rather than global mean values. This includes changes in the Hadley and Walker circulations which presents feedback mechanism that could increase solar input to some regions of the tropics and subtropics [13-14].

Since 1990, TSI has been gradually decreasing, Fig. 4. This decrease will be continued in cycle 25, which started in December 2019. According to Abdussamatov [15], since 1990 the Earth has radiated more energy back into the space than the solar energy it has absorbed. This could lead to the new ice age in the near future because the Earth will continue to have a negative average annual energy balance (E < 0) in cycles 25-28. This is known as a solar grand minimum. The maximum number of sunspots could reach 50±15 and 30±20 in cycles 25 and 26 respectively.

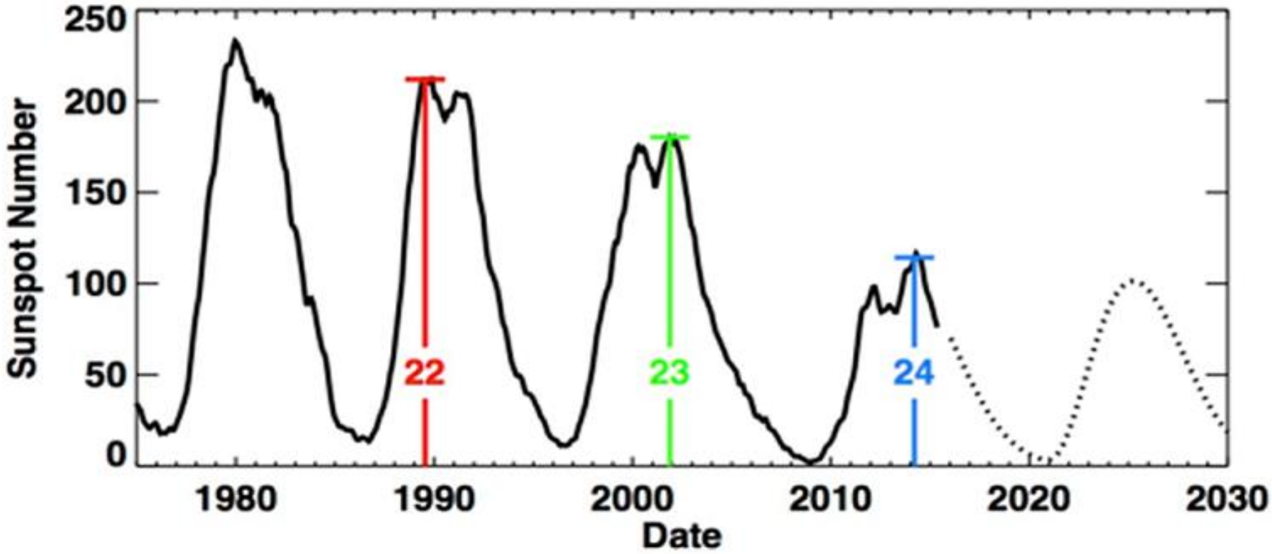

Fig. 4 Decaying solar cycles intensities since 1980 year.

4.1 El Ni Niño-Southern Oscillation

Some regions of the Earth exhibit quasi-oscillatory behavior in climate properties. These are Earth's natural patterns, each with identifiable characteristics which can be measured to give an indication of the strength of the pattern at any moment in time. One of them is El Niño-Southern Oscillation (ENSO) is primarily characterized by a periodic warming/cooling of the eastern tropical Pacific Ocean. This mode also incorporates an in-phase variation in the east-west gradient of surface air pressure over the western Pacific Ocean in the southern hemisphere tropics. ENSO is also associated with extreme weather (floods, droughts) over many other parts of the world. Its period varies between 3 and 7 years.

5. Conclusion

There is a need for a thorough understanding of how the Sun and other natural factors, such as the ENSO oscillation, affect the climate. This is important because it has long-term and short-term impacts and we need to know how they affect anthropogenic effects. Today, there is no consensus in the scientific community on the cause of climate change. There are opinions that human activities encourage climate change, but there are opposite approaches that natural factors primarily cause these changes. Future research should answer many open questions in this area. So, it is about interdisciplinary connection and cooperation of many scientists from different fields. Accurate theory of climate change mechanisms will provide a good basis for numerical models that would provide reliable predictions of climate change in the future.

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