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AN OVERVIEW OF SOLAR ACTIVITY AND CLIMATIC CHANGES

UNA VISIÓN DE LA ACTIVIDAD SOLAR Y EL CAMBIO CLIMÁTICO

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Climatic changes are not an exclusively terrestrial phenomenon. Evidences of changes exist in climatic patterns in other planets of the Solar System. The complexity of global climate changes on Earth requires a multidisciplinary approach due to different factors and concomitant contributing phenomenology. In particular, purely astronomical phenomena have had an incidence in the variability of the Earth climate and weather. This paper resumes some of the evidences that point toward a relationship between solar activity and climatic changes occurred on our planet.

Los cambios climáticos no son un proceso exclusivamente terrestre, pues existen evidencias de grandes cambios en los patrones climáticos en otros planetas del Sistema Solar. Por su complejidad, requieren de un estudio multidisciplinario debido a los diferentes factores y fenomenologías concomitantes que contribuyen a su desarrollo. En particular, fenómenos puramente astronómicos han tenido y tienen una incidencia en la variabilidad del clima en la Tierra. En este artículo, se revisan algunas de las evidencias que apuntan hacia una relación de la actividad solar con grandes cambios climáticos ocurridos en nuestro planeta.

Keywords. Climate dynamics global change, 92.70.Gt, solar activity, 96.60.Q-, solar irradiance, 96.60.Ub, sunspots, 96.60.qd, cosmic rays, 96.50.S-

INTRODUCTION

The climate changes on Earth are at present one of the most controversial debates including not only scientists but also politicians. Many scientists believe that the observed warming is more likely attributable to natural causes than to human activities and some of them are talking about future global cooling. Others conclude that the real cause, human or natural, is up to now unknown.

Global climatic changes are not an exclusively terrestrial phenomenon. Evidence of changes exists in climatic patterns in other planets of the Solar System such Venus and Mars [1-3]. In particular, the controversial possible link between the variability exhibited in many ways in the solar activity and the variability of the Earth climate has been studied for many decades.

In 1801 one of the most prominent astronomers, Sir William Herschel, was interested on the fluctuation of the price of wheat in England and if it was somehow related with the appearance of sunspots. Comparing the archived data of prices as a proxy for climate with sunspots number recorded in previous times, Herschel noticed that the price of wheat was higher when there were fewer sunspots. This result supported the Herschel's idea that when the Sun was highly spotted, it may lead us to expect mild season and, on the contrary, few spots should point to a severe season. He published a paper in which he pointed out: "The influence of this eminent body [referring the Sun] on the globe we inhabit, is so great, and so widely diffused, that it becomes almost a duty for us to study the operations which are carried on upon the solar surface" [4].

The earliest studies in this matter are from the beginning of the 20th century and were focused on the possible relationship between the variation of the so called "solar constant" and the sunspot number with some meteorological parameters such as atmospheric absorption of water vapor [5], Earth's surface temperature [6], precipitation [7,8], atmospheric pressure [8], etc.

This paper summarizes the lecture 'Solar Activity and Climate Change' given at the IX Congress of the Cuban Society of Physics. Some evidences that point towards a relationship of the solar activity with the climatic changes occurring on Earth are given.

SUNSPOTS AND SOLAR CYCLES

Solar activity is a complex phenomenon related with the outflow of strong magnetic field through the photosphere and can be divided into different scenarios (such as sunspots, X-ray bright points, plagues, etc.) and transient events (such as coronal mass ejections, Hα flares, radio bursts, etc.). The sunspots are the most significative indicator of the solar activity and they are recorded since 1610. It is well-known that the appearance of sunspots follows a cycle of eleven years in average. The Wolf number is one of the most used indexes to count the number, not only of individual spots but also of groups of them, reflecting well the state of the solar activity.

There are evidences of prolonged periods of rather low temperature on Earth in ancient time. The best known is called Little Ice Age. It was a prolonged period in which the mean Earth temperature was substantially low, even if not a real ice age. There is no consensus in order to fix the start and the end of the Little Ice Age; generally its start is fixed after year 1550 and prolonged more than one century. The period was characterized by severe winters in Europe and North America, increased little glaciations in widely spread regions, uncommon frozen rivers and lakes, and permanent snow on some mountains at levels where it is unusual.

On the contrary, a prolonged anomalous warm period known as Medieval Warm Period (or Medieval Climatic Optimum) occurred between years 950 and 1250. This warmer period is evidenced by radiocarbon data records and some historical endeavor as the Vikings icefree sea trips to Greenland and North America.

These prolonged periods with anomalous temperature coincide temporally with longlasting intervals when the solar activity was atypical. This was pointed out first by J. E. Eddy [9], who claimed the temporal coincidence between Maunder Minimum, an exceptional period lasting nearly 100 years (from 1645 –or probably before– to 1725) when the presence of sunspots was very scarce, and the interval of colder weather on Earth (Little Ice Age). On the other hand, the Medieval Warm Period was temporarily coincident with a long period when the solar activity was notably high as is evidenced by minimal ^{10}Be and ^{14}C content in trees. The anticorrelation be-tween concentration of ^{10}Be and ^{14}C isotopes and solar activity is known (i.e. [10]). There are also other periods with notably low solar activity concomitant with abnormally low temperature on Earth.

Solar total irradiance was at first believed as an important factor influencing some weather anomalies and it seems to correlate well with some meteorological parameters. The solar total irradiance was assumed as constant with calculated value of 1376 Wm^{-2}. However the 'solar constant' is not really a constant. Two of the earliest papers reporting this value are [5, 11]. Satellite meas-ures confirm the variation of about 0.1 % centered on the assumed 'constant' value. However its variation of approximately 0.1 % seems very small to provoke significant changes in climate [12, 13]. So, in which way solar cycles can be suggested as proxy of the solar influence on Earth's climate? The lengths of solar cycles are not rigorously lasting 11 years. There are shorter cycles (for example the cycle No. 8 was lasting 9.6 years) and longer cycles (for example the cycle No. 13 had duration 12.1 years). The relation between the length of the solar cycles and the global Earth's temperature variation was found (figure 1), suggesting that the length of solar cycles is in some way related to its effect on global climate changes although no physical mechanism had been proposed [14, 15]. Notice in figure 1 the significant decay of the tem-perature with minimum in the 70's in spite of the con-tinuous increase of the CO_2 emission. The temperature anomaly seems to follow the solar cycle length and not the continuous increase of CO_2.

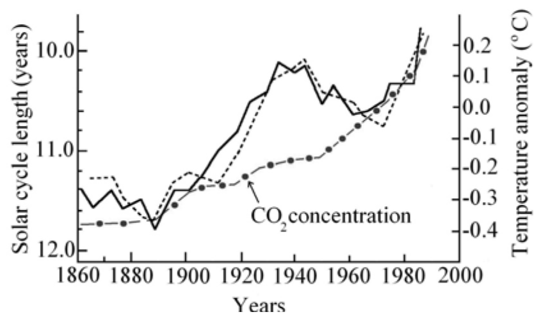

Figure 1. Solar cycle length (solid line) and Northern hemi-sphere temperature anomalies (dashed line) as function of time (years). The cycle length is plotted at its central time. CO_2 con-centration in the atmosphere (dotted line) is pointed by the ar-row. Figure adapted from Friis-Christensen and Lassen [14].

On the other hand, it is known that the shortest solar cycles correspond to periods of high solar activity and the longest cycles to weaker activity. In this sense, an inverse correlation between the length of cycles and the changes in brightness in solar-type stars was found [16].

COSMIC RAYS

Cosmic rays are energetic particles (mainly atomic nuclei) mostly of extra-galactic origin (such as rotating neutron stars and supernovae, which are not so rare in the Universe). Most of the cosmic rays are protons and generally their energy is 10^3 MeV or more per nucleon, while their velocities approach the speed of light. Cosmic rays were discovered thanks to the ionization they produce in Earth's atmosphere. This ionization strongly increases with height.

Cosmic rays should show a constant intensity level at the Earth as they are continuously and isotropically impacting the solar system. Nevertheless before cosmic rays reach Earth, they must penetrate the heliosphere (the region in the interplanetary space conformed and dominated by the outflow of solar plasma). The helio-sphere is produced by the solar wind (mainly protons and electrons) that are continuously escaping, almost radially, from the Sun in all directions and extends far beyond the Pluto's orbit. The heliosphere magnetic structure varies on average time scale of 11-years and follows the changes and the evolution of the magnetic field configuration of the solar active regions.

It is well known from [17, 18] that the intensity of cosmic rays in the Earth's atmosphere level exhibits a variation with 11-year periodicity (on average) that is anticorrelated with the solar activity. The solar wind modulates the flux of cosmic rays reaching the heliosphere. The strong magnetic field acts as diffusive barriers to the cosmic rays. Figure 2 displays the anticorrelation between the count rate of cosmic ray during years 1700 - 1900 [19] and the corresponding solar activity (here represented by the Wolf number).

The first suggestion of a physical connection between solar activity, cosmic rays and Earth's climate was sug-gested by E. P. Ney [20] who pointed out that if climate is sensitive to the amount of tropospheric ionization, it would also be sensitive to solar activity since the solar wind modulates the cosmic ray flux, and with it the amount of tropospheric ionization.

In [21] a strong correlation between the variation of 3-4 % of the global cloud cover and cosmic ray flux is presented. That is, an inverse correlation with solar activity. Other papers on this subject indicate strong correlation too [22-24]. Figure 3 plots the variation of low-altitude cloud cover and the variation of cosmic ray flux (both in %).

The possible cosmic ray influence on the atmosphere dynamics seems to involve changes in the stratospheric ionization by cosmic rays affecting the microphysical processes such as nucleation and growth of the cloud particles and hence the cloud formation [25].

OTHER SOLAR FACTORS

Solar activity due to ultraviolet emission and to particles generated in major solar events influences on the ozone concentration. Ultraviolet emission follows the 11-years solar cycle variation. Enhanced ultraviolet radiation reaching Earth's stratosphere diminishes the ozone con-centration through the reaction $h\nu + O_3 \rightarrow O_2 + O$.

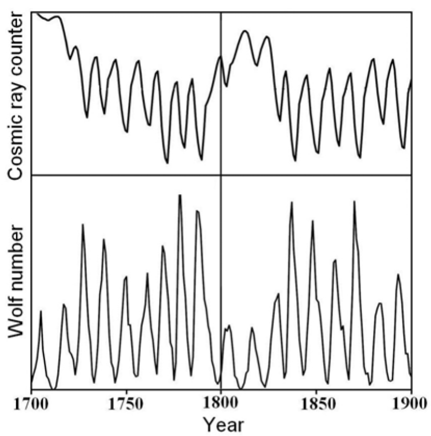

Figure 2. In the upper panel the reconstructed count rate of cosmic rays in years 1700 - 1900 [19] is given. In the lower panel the Wolf number for the same period is reported.

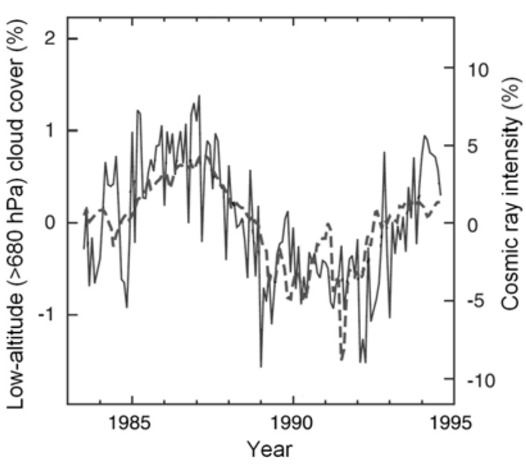

Figure 3. Monthly variation of low-altitude (> 680 hPa) cloud cover (solid line) and cosmic rays (dashed line) neutron counts (> 12.91 GeV). Figure reconstructed after Marsh and Svensmark [23].

is also influenced by significant fluxes of solar energetic protons (with energies up to 10 MeV) released in large solar events, through the production of both HO_x (H, OH, HO_2) and NO_y (N, NO, NO_2, NO_3) constituents via $HO_x + O_3$ and $NO_y + O_3$ (see [26] for a detailed review). First evidences that ozone in the mesosphere could be depleted as consequence of large solar events were observed after the occurrence of the large solar burst in November 2, 1969 [27]. After one of the largest solar bursts event occurred during July 14-16, 2000 (referred in the literature as Bastille Day Flare) a shortterm (~one day) middle mesospheric ozone decreased of over 70% and a longer-term (several days) upper stratospheric ozone depletion of up to 9% [28] followed. Therefore during major solar flares events the ozone shield is reduced.

FUTURE

The sunspot minimum between cycles 23 and 24 has been significantly long (the longest since the beginning of the space era) being one of the most remarkable minima in the last hundred years. The majority of the models for solar cycles predict low activity for the current cycle (24) [29-31]. In [30] current cycle 24 with intensity 23 % lower than previous cycle 23 is predicted. Further more, cycle 25 should be 5 % lower than cycle 24.

Regarding this, plotting the magnetic field strength of sunspots during years 1998 - 2005 (covering practically the entire previous cycle 23 with maximum in 2001) a decrease in the observed magnetic field strength was found with approximate rate of 50 G per year [32]. Therefore these authors concluded that, if this tendency continues, it would produce important changes for the next few solar cycles lowering the solar activity considerably: the number of the sunspots in the current cycle would be drastically reduced, and virtually no sunspots should be visible on disk during cycle 25.

Figure 4 shows the calculated magnetic field distribution function for sunspot umbral magnetic field in the last cycle 23 and the computed values for the current and the next cycle using the observed decrease rate of the magnetic field strength [33]. The magnetic field probability distribution function diminishes dramatically for the next cycle. This also suggests that the cycle 25 should be practically sunspot free.

As consequence of that and taking into consideration a) the above suggested correlation between the variation of the cloud cover and cosmic ray flux, and b) the mentioned correlation between the solar cycle lengths and solar activity, some scientists assert that not a global warming but a possible global cooling would be expected after year 2020 due to the predicted substantially low solar activity.

In this way, figure 5 shows a comparison between the solar cycles 3, 4, 5, 6 and 7 and the cycles 22, 23 and the current 24. The cycles 5, 6 and 7 were notably poor in sunspots (period named Dalton Minimum). During this epoch prolonged periods of anomalously low tempera-tures occurred. An example of this is the so called 'Year without a summer' in 1816 in which severe cold summer caused the average global temperature decrease by about 0.4-0.7° C. Superimposed to these cycles are plotted the solar cycles 22, 23 and the current cycle 24. Notice the resemblance between cycles 3 and 22 and between cycles 4 and 23. As mentioned, the models predict for the current cycle 24 low activity and consequently should be comparable with cycle 5. According to [33] the cycle 25 could be comparable with the cycle 6 or even lower.

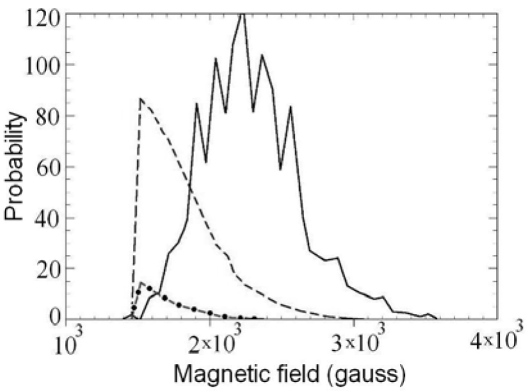

Figure 4. Calculated magnetic field probability distribution function for sunspot umbral magnetic field in the last cycle (23) and computed values for the current and the next cycle 25 using the observed decrease rate of the magnetic field strength. Solid line for cycle 23, dashed line for current cycle and dotted line for next cycle 25. Figure reconstructed after [33].

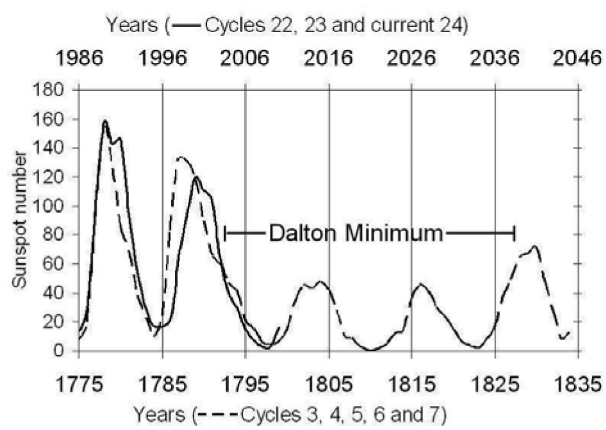

Figure 5. Solar cycles 3, 4, 5, 6 and 7 in dashed line (referred to lower x-axis). Cycles 22, 23 and current 24 in solid line (referred to upper x-axis). Period of Dalton Minimum of sunspots is indicated.

CONCLUSIONS

Paraphrasing the well-known Beatles' song, we all live in a yellow star: strictly speaking the solar activity extends beyond Pluto's orbit, so the Earth is inside it. Solar magnetic field lines expand outward reaching Earth and solar radiative and corpuscular emission continuously impacts our planet. This emission can be highly variable over large, medium and short time-scale.

Is the Sun activity capable of influencing the Earth's weather and climate? If yes, in which way? The literature on this subject covers a period of more than 100 years. Nevertheless until very recently, studies on Sun-weather/climate possible relationships had not been taken with sufficient attention by many scientists. There is an important amount of evidences pointing to the solar activity as influencing the Earth's weather/climate directly or indirectly. More specific, the average state of the heliosphere seems to determine in some way the Earth's global climate. In this respect, the scientific community should take that in consideration. It is necessary to make a right balance between both anthropogenic and solar factors impacting the Earth's global climate changes.

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