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CLIMATE AND CAUSES OF ITS VARIABILITY

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The global warming has increased dramatically in the last 20 years. The IPCC report estimates that the 1990s were the warmest years since the beginning of instrumental records in 1861 and that 1998 may have been the warmest year on record. This increase in temperature over the last century is likely to have been the largest 100-year increase in the last 1000 years. Because of these dramatic climate changes of the last 100 years many scientists believe that human activities, such as burning fossil fuels, have contributed to global warming.

Two of the questions that now face scientists studying climate change are:

1. How has human activity influenced the climate?
2. How would the global climate change without human influence?

In order to answer the first question, scientists must answer the second question.

The total energy output of the sun is nearly constant. At the top of Earth’s atmosphere the total irradiance from the sun is about 1366 W/m². Imagine thirteen 100 Watt light bulbs shined all of their energy onto a square meter. During the course of an 11-year solar cycle, the average output of the sun changes by about 1-2 W/m² or about 0.1%. Thus, the solar constant varies between 1365 and 1367 W/m² and is therefore, not really a constant.

In other wavelengths such as the ultraviolet and extreme ultraviolet parts of the solar spectrum, the solar variability can be quite large. In the x-ray wavelengths, the sun can change brightness by a factor of 100 or even 1000 in just a few minutes but these wavelengths only affect the upper reaches of our atmosphere. Figure 2 shows a 5-year sequence of x-ray images of the sun from solar maximum to solar minimum. It is thought that the total solar output of the sun has changed by larger amounts over longer time scales. There is evidence that the total solar output may have been as low as 1360 W/m² during the 19th century and even lower than that during the 17th century. Thus over centennial time scales, the solar output may have changed by 0.5%.

The NOAA Space Environment Center (SEC) combines scientific research and an operational Space Weather Center to maintain a vigilant watch on solar activity. SEC’s primary mission is studying the affects of a variable sun on the upper atmosphere and the near-Earth space environment. Monitoring and understanding the solar effects on the middle and lower atmosphere is a new component of SEC’s mission. Present NOAA/SEC activities include monitoring the sun in x-ray and ultraviolet wavelengths as well as sunspots. NOAA recognizes the need for new efforts in this area and will include solar extreme ultraviolet measurements on the next generation of GOES spacecraft and total solar irradiance and solar spectral irradiance measurements as part of its upcoming NPOESS spacecraft mission [3].

The sun plays a role in our climate in direct and indirect ways. The sun changes in its activity on time scales that vary from 27 days to 11, 22, 80, 180 years and more. A more active sun is brighter due to the dominance of faculae over cooler sunspots with the result that the irradiance emitted by the sun and received by the earth is higher during active solar periods than during quiet solar periods. The amount of change of the solar irradiance based on satellite measurements since 1978 during the course of the 11 year cycle just 0.1% (Frohlich and Lean 1998) has caused many to conclude that the solar effect is negligible especially in recent years. Over the ultra long cycles (since the Maunder minimum), irradiance changes are estimated to be as high as 0.4% (Hoyt and Schatten (1993), Lean et al. (1995), Lean (2000), Lockwood and Stamper (1999) and Fligge and Solanki (2000)).

However this does not take into account the sun’s eruptional activity (flares, solar wind bursts from coronal mass ejections and solar wind bursts from coronal holes) which may have a much greater effect. This takes on more importance since Lockwood et al., (1999) showed how the total magnetic flux leaving the sun has increased by a factor of 2.3 since 1901. This eruptional activity may enhance warming through ultraviolet induced ozone chemical reactions in the high atmosphere or ionization in higher latitudes during solar induced geomagnetic storms. In addition, the work of Svensmark (1997), Bago and Butler (2000) Tinsley and Yu (2002) have documented the possible effects of the solar cycle on cosmic rays and through them the amount of low cloudiness. It may be that through these other indirect factors, solar variance is a much more important driver for climate change than currently assumed. Because, it is more easily measured and generally we find eruptional activity tracking well with the solar irradiance, we may utilize solar irradiance measurements as a surrogate or proxy for the total solar effect. Correlations with Total Solar Irradiance studies vary on the importance of direct solar irradiance especially in recent decades [1].

When Gleissberg (1958) first investigated solar cycle lengths, he found short cycles had high sunspot numbers and strong eruptive activity while long cycles were characterized by low maxima and fewer solar eruptions. This may explain why Friis-Christensen and Lassen (1991) found a correlation of solar cycle length with temperatures. With major geomagnetic storms, there is ionization warming in the polar auroral zone, an increase in solar wind with more general warming. Landscheidt (2003) showed a r^2 correlation of 0.92 between smoothed yearly global temperature anomalies and a smoothed geomagnetic index (aa index) with a tendency for temperatures to lag the solar by 4 to 8 years.

Ionization of the air occurs due to cosmic rays (CR), from the decay of trace radioactive isotopes, ionization by solar ultra violet light and electrical effects such as lightning. At cloud forming altitude (> 1000 m) over the land and at all altitudes over the sea CR are thought to dominate the production of ionization in the troposphere.

It was suggested long ago that CR could be connected with the weather and the climate and various mechanisms have been suggested.. Much publicity has been given to the observation that the reduction in the low cloud cover (LCC) observed during solar cycle 22 correlates well with the decrease in the cosmic ray (CR) rate as measured by neutron monitors. This led the groups to hypothesize that the reduction was caused by the influence of ionization from CRs on cloud cover. Furthermore, it has been suggested that this is a significant contributor to global warming. The basis of the suggestion is that the cosmic ray rate has been observed to decrease over the last century. This leads to less ionization in the atmosphere, reducing cloud cover according to the hypothesis, allowing more sunlight to warm the Earth. This suggestion has been questioned on the grounds of inconsistencies between different methods of measuring cloud cover and on the grounds of imperfect data analyses. Attempts have been made to look for local or regional correlations which find either nothing, the opposite correlation or some correlation. We discount these in order to investigate the hypothesis further and on a global scale. We further discount the likelihood that CR effects would change mainly the depth of the clouds, rather than the cloud cover. The suggestion was also questioned in a study of the long term CR rate where it was shown that this rate began to increase in 1985 yet global warming continued. Nevertheless, there may be some connection between clouds and ionization since it is well known that charged drops grow at smaller radii than uncharged drops, providing that the supersaturation is high enough [4].

A key aspect of the sun’s effect on climate is the indirect effect on the flux of Galactic Cosmic Rays (GCR) into the atmosphere. GCR is an ionizing radiation that supports low cloud formation. As the sun’s output increases the solar wind shields the atmosphere from GCR flux. Consequently the increased solar irradiance is accompanied by reduced low cloud cover, amplifying the climatic effect. Likewise when solar output declines, increased GCR flux enters the atmosphere, increasing low cloudiness and adding to the cooling effect associated with the diminished solar energy. The conjectured mechanism connecting GCR flux to cloud formation received experimental confirmation in the recent laboratory experiments of Svensmark (Proceedings of the Royal Society, Series A, October 2006), in which he demonstrated exactly how cosmic rays could make water droplet clouds.

Palle Bago and Butler showed in 2002 (Intl J Climat.) how the low clouds in all global regions changed with the 11 year cycle in inverse relation to the solar activity. Changes of 1 to 2% in low cloudiness could have a significant effect on temperatures through changes in albedo. K. Labitzke and H. van Loon have discovered a statistically significant connection between temperature-dependent 30-hP heights in the stratosphere and extreme in the 11-year sunspot cycle, which involves the troposphere and is strongest in special geographical regions. It is an indication of feed-back or resonance amplification that the temperature difference in the stratosphere between minimum and maximum of the 11-year cycle reaches 1.8° C and in the troposphere still 0.9° C. In the Subtropic troposphere this difference even amounts to 2° C. Northern and Southern Hemisphere show such sunspot related temperature patterns in a mirror-symmetric way. The geographic distribution of the temperature effect corroborates the hypothesis that a modulation of Hadley cell circulation is involved. Experiments with models have shown that winds in the lower stratosphere can have an impact on circulation in the troposphere. Strong temperature variations following the course of the 11-year sunspot cycle were not only observed in recent decades. According to M. Stuiver, P. M. Grootes, and T. F. Braziunas the GISP delta ^{18}O climate record shows a close correlation with the 11-year sunspot cycle for hundreds of years. This data point to a regional temperature variation of **2.6° C** following the sunspot rhythm [2].

A climatic effect caused by total irradiance variations becomes more effective when its impact lasts longer. The Milankovitch theory in its modern form shows that a change of **0.1%** effective during a very long interval can release a real ice-age . So it may be expected that the 90-year Gleissberg cycle of sunspot activity, which modulates the intensity of the 11-year cycle, possesses a considerable potential to accumulate an effective surplus of irradiance, or to induce a steadily decreasing level of radiant flux density, particularly since the Gleissberg cycle can reach a length of 120 years.

When satellite observations had established that the solar constant is variable, phenomenological regression models were developed which assess the variations in irradiance in past decades and centuries. The model developed by D. V. Hoyt and K. H. Schatten, shown in fig.1, is based on proxy data related to secular changes in the convective energy transport or the convective velocities in the sun. They include the solar cycle length, the equatorial solar rotation rate, and sunspot structure. This solar-irradiance model has only two parameters: the amplitude of variations of the 11-year cycle and the Gleissberg cycle. The thick curve in fig.1 shows the output of the model. The corresponding vertical axis on the left measures the irradiance in W/m^2. The dashed curve represents the smoothed annual mean Northern Hemisphere temperature variations (right scale) for 1700 – 1879 from B. S. Groveman and H. E. Landsberg, and for 1880 to the present from J. E. Hansen and S. Lebedeff. The two curves show a close correlation that point to a strong link between solar activity and climate.

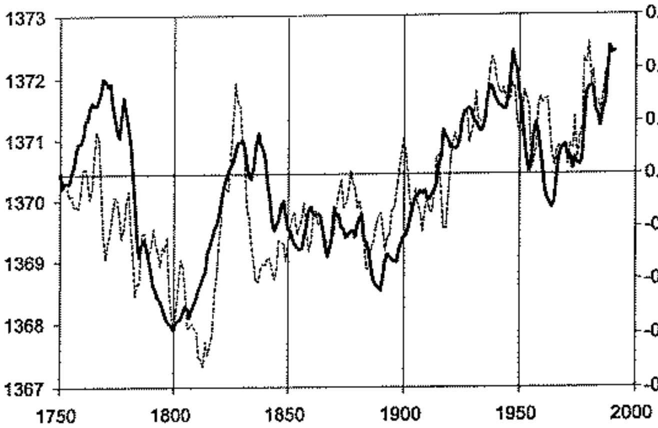

Fig.1.

Change in the ultraviolet radiation of the sun is much greater than in the range of visible radiation. The ultraviolet range of the spectrum lies between 100 Å and 3800 Å. Wavelengths below 1500 Å are called extreme ultraviolet (EUV). The variation in radiation between extrema of the 11-year sunspot cycle reaches 35% in the EUV- range, 20% at 1500 Å, and 7% around 2500 Å. At wavelengths above 2500 Å, the variation reaches still 2%. At the time of energetic solar eruptions, the UV-radiation increases by 16%. At a sunspot maximum the EUV-radiation raises the temperature in the Ionosphere by 300% in relation to the minimum. Yet most important is that the UV-radiation below 2900 Å is completely absorbed by ozone in the stratosphere. The resultant rise in temperature is augmented by positive feed-back, as the UV-radiation also generates new ozone. Satellite observations show that the ozone content grows by 2% from sunspot minimum to maximum. D. Rind and J. Overpeck are working on a model which explains how the rising temperature in the stratosphere influences the circulation in the troposphere. J. D. Haigh has already assessed this effect in quantitative terms and shows that temperature in the Subtropics and North Atlantic storm tracks are especially affected.

Variations in radiation are not the sun's only way to influence climate. Between energetic solar eruptions and galactic cosmic radiation modulated by the solar wind on the one hand and electric parameters of the atmosphere on the other, exist couplings, the strength of which varies by 10% in the course of days, years, and even decades . The most important change is to be found in the downward air-earth current density, which flows between the ionosphere and the surface. R. Markson and M. Muir have shown how this affects the thunderstorm activity, while B. A. Tinsley assumes that electrically induced changes in the microphysics of clouds (electrofreezing) enhance ice nucleation and formation of clouds. These approaches have the advantage to be independent of dynamic coupling between different layers of the atmosphere, since these variations affect the whole atmosphere

The most convincing argument yet, supporting a strong impact of the sun's activity on climate change, is a direct connection between cloud coverage and cosmic rays, discovered by H. Svensmark and E. Friis-Christensen in 1996. It is shown in fig.2.. Clouds have a hundred times stronger effect on weather and climate than carbon dioxide in the atmosphere. Even if the atmosphere's CO2 content doubled, its effect would be cancelled out if the cloud cover expanded by **1%**, as shown by H. E. Landsberg. Svensmark's and Friis-Christensen's result is therefore of great importance. The thin curve in fig.2 presents the monthly mean counting rates of neutrons measured by the ground-based monitor in Climax, Colorado (right scale). This is an indirect measure of the strength of galactic and solar cosmic rays. The thick curve plots the 12-month running average of the global cloud cover expressed as change in percent (left scale). It is based on homogeneous observations made by geostationary satellites over the oceans. The two curves show a close correlation. The correlation coefficient is r = 0.95.

Short-range variations in the intensity of cosmic rays, caused by energetic solar eruptions, have the same effect, though shorter. The plot shows that strong cosmic rays go along with a larger cloud cover, whereas weak cosmic rays shrink the cloud cover. The global cloud coverage diminished from its peak at the end of 1986 to its bottom in the middle of 1990 by more than **3%**. According to observations by V. Ramanathan, B. R. Barkstrom, and E. F. Harrison, clouds have a net cooling effect of **-17 W/m^2** . Svensmark and Friis-Christensen conclude from the diminution of this cooling effect between 1986 and 1990 that the solar irradiance has increased by about **1.5 W/m^2** within these three and a half years. A change of this order is quite remarkable, since the total radiative forcing by carbon dioxide accumulated since 1750 has been estimated by the IPCC not to go beyond 1.5 W/m^2 . This means that cosmic rays, strongly modulated by solar activity, achieve an effect within three and a half years for which the accumulation of carbon dioxide in the atmosphere needs centuries. This shows clearly to what extent the greenhouse effect has been overestimated in comparison with the solar contribution to climate change, which turns out to be the most important factor.

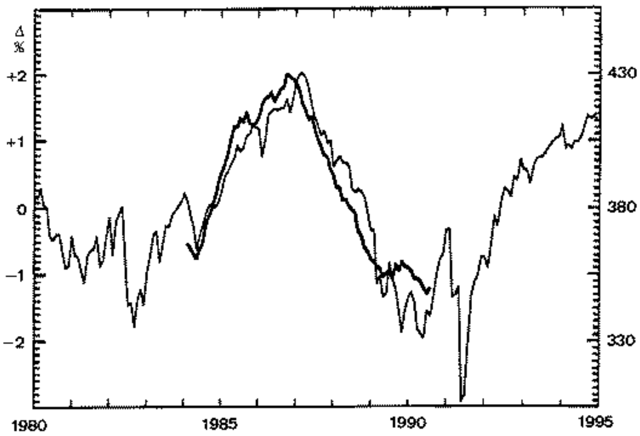

Fig.2.

There is also a physical explanation of the effect: the secondary ions produced by the cosmic rays serve as condensation nuclei with hygroscopic properties that enhance the formation of clouds. Meanwhile, H. Svensmark has extended his investigation that now covers the interval 1980 to 1996. As before, the correlation between cloud cover and cosmic rays is very close. Indirect measurements of the intensity of cosmic rays, which register myons instead of neutrons, go back to 1937. When H. Svensmark compared these data with global temperature in the Northern Hemisphere, he again found a strong correlation which indicates that the connection between cosmic rays, cloud cover, and global temperature is real.

The primary cause of the solar modulation of cosmic rays is not the level of sunspot activity, but the varying strength of the solar wind. This supersonic outflow of plasma originates in the very hot corona of the sun and carries ionized particles and magnetic field lines from the sun. While it is expanding towards the boundary of the solar system, cosmic ray particles interacting with it lose energy. When the solar wind blows heavily, cosmic rays are weak, and when the solar wind is in a lull, cosmic rays become strong. The highest velocities in the solar wind are caused by energetic solar eruptions and coronal holes. Strong eruptions (flares and eruptive prominences) avoid sunspot maxima and even occur close to sunspot minima. So sunspots are not a good indicator of solar wind strength. As cosmic rays, which have such a strong impact on cloud cover, are strongly modulated by eruptional features of the sun's activity, the solar contribution to climate change can no longer be considered negligible. This is all the more so as the already described changes in irradiance has an additional effect.

D. Rind and J. Overpeck have shown that at least half of the rise in temperature since the end of the Little Ice Age can be attributed to the parallel rise in the sun's irradiance. D. Hoyt and K. H. Schatten judge their elaborate results as follows: ***"From the record, we believe the sun plays a major role in natural secular climatic changes on time scales of decades to centuries.".*** E. S. Posmentier, W. H. Soon, and S. L. Baliunas **[88, 107]** eventually derive from a model based on the same solar factors as in the Hoyt-Schatten-model that **78% of the rise in temperature between 1885 and 1987 can be explained by the sun's varying irradiance.** An additional statistical experiment corroborates this result, though it omits the Svensmark effect and other solar-terrestrial relationships which are independent from irradiance. There is not much room left for the anthropogenic greenhouse effect. H. N. Priem aptly remarks:
"Recent studies show that solar variability rather than changing CO pressure is an important, probably the dominant climate forcing factor ... The current and anticipated fleet of spacecraft devoted to the study of solar and solar-terrestrial physics will therefore probably prove to have more bearing on the understanding and forecasting of climate change than the orchestrated assessments by politically motivated international panels biased towards global warming exclusively by the enhanced greenhouse effect."

Cycles of big fingers have a mean length of 35.8 years (178.8 years [big hand] / 5 = 35.76 years [big fingers]). They are closely connected with solar activity. They coincide with maxima and minima in the Gleissberg cycle and open up the possibility of predicting these crucial phases many years ahead. As will be shown below, they also define the length of the 22.1-year magnetic cycle of sunspot activity (Hale cycle). As far as climatic change is concerned, cycles of a length of 36 years are not new. Francis Bacon has already pointed to a cycle in the Netherlands with a length of 35 to 40 years with cool and wet phases followed by warm and dry periods. E. Brückner discovered this cycle again in 1887. He demonstrated that varied climatic phenomena in different regions of the world show synchronized phases in a cycle of 33 to 37 years. He had already surmised in those days a connection with the sun's activity. H. W. Clough followed this suggestion and found the Brückner cycle not only in 12 meteorological variables, but also in sunspots and especially in variations in the length of the 11-year sunspot cycle. D. V. Hoyt and K. H. Schatten think that the reality of the cycle is confirmed by Scandinavian tree ring data which show its rhythm over hundreds of years.

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კლიმატი და მისი ცვალებადობის გამომწვევი მიზეზები./მ.ტატიშვილი, ნ.ბოლაშვილი, ი.მკურნალიძე/ საქართველოს ტექნიკური უნივერსიტეტის ჰიდრომეტეოროლოგიის ინსტიტუტის შრომათა კრებული-2013.-ტ.119.-გვ.38-42-ქართ., რეზ. ქართ., ინგლ., რუს.

კლიმატის ცვლილების მიზეზებს იკვლევენ ორი მიმართულებით: ბუნებრივი და ანთროპოგენული. ორივე მიმართულებით მრავალი კვლევა ტარდება. ბევრი მეცნიერი-კლიმატოლოგი დარწმუნებულია, რომ ამჟამინდელი კლიმატის ცვლილება პირდაპირ დაკავშირებულია მზის აქტივობასთან, რომელიც განსაზღვრავს დედამიწაზე ტემპერატურას და ღრუბლიანობას. მზის აქტივობის ცვლილების დროითი მასშტაბი მოიცავს 27 დღიდან 11, 22, 80, 180 და მეტ წლებს. მას შემდეგ რაც თანამგზავრული დაკვირვებებით დადგინდა, რომ მზის მუდმივა ცვალებადია, შეიქმნა ფენომენოლოგიური რეგრესიული მოდელები მზის რადიაციის ცვლილების შეფასებისთვის გასულ ათწლეულებში და საუკუნეებში. მათი შედეგებიდან ცხადი ხდება, რომ მზის წვლილთან შედარებით სათბური გაზების როლი გადაფასებულია კლიმატის ცვლილებაში. ხოლო მრავალი მეცნიერის აზრით მზე შედის აქტივობის შემცირების ფაზაში რაც მომავალი 30წ განმავლობაში გამოიწვევს გლობალურ აცივებას.

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Climate change causes have been studied basically in two directions: natural and anthropogenic. Many studies have been devoted to both directions. A lot of scientist-climatologists believe that current climate change is directly connected with solar activity that determines temperature and cloud cover on the Earth. The sun changes in its activity on time scales that vary from 27 days to 11, 22, 80, 180 years and more. When satellite observations had established that the solar constant is variable, phenomenological regression models were developed which assess the variations in irradiance in past decades and centuries. The outputs show clearly that the greenhouse effect has been overestimated in comparison with the solar contribution to climate change. And according to enormous number of scientists the sun enters the phase of decreasing activity that would undoubtedly cause global cooling during future 30 years.

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КЛИМАТ И ПРИЧИНЫ ЕГО ИЗМЕНЧИВОСТИ/ М.Татишвили, Н.Болашвили, И.Мкурналидзе/ Сб. Трудов Института Гидрометеорологии Грузинского Технического Университета. -2013.-т.119.-с.38-42 -Груз., Рез. Груз., Анг., Рус.

Причины изменения климата были изучены в основном в двух направлениях: природные и антропогенные. Многие исследования были посвящены обоим направлениям.Многие ученые-климатологи считают, что нынешнее изменение климата напрямую связан с солнечной активностью, определяющей температуру и облачности на Земле. Солнце меняет свою деятельность на временных масштабах, которые варьируются от 27 дней до 11, 22, 80, 180 и более лет. Когда со спутниковых наблюдений было установлено, что солнечная постоянная переменная, феноменологическая регрессионные модели были разработаны, которые оценивают изменения радиации в последние десятилетия и века.Выводы ясно показывают, что парниковый эффект был завышен в сравнении с солнечным вкладом в изменение климата. И по мнению огромного числа ученых, солнце вступает в фазу снижения активности, что, несомненно, вызывает глобальное похолодание в течение будущих 30 лет.