SOLAR MODULATION OF COSMIC RAYS AND ITS IMPORTANCE ON CLIMATE

Atanu Nag
Department of Physics, School of Sciences, IFTM University, Moradabad, Uttar Pradesh-244102, India
Email: tnnag79@gmail.com

Received on: August 31, 2022 | Accepted on: September 09, 2022

Abstract

The irradiance emitted by the sun when received by our earth is remarkably higher during the active solar periods than that during quiet sun. The charged cosmic ray nuclei, an outflow of material from the sun, have to overcome the magnetic field and is frozen in the ionized material expanding away from the sun. The galactic cosmic rays particles when modulated reveals first an anti-correlation of the neutron monitors data with the sun's sunspot numbers and it has about an 11 year cycle which is half of the magnetic cycle on the sun. Both positive and negative charged particles modulate following varying mechanisms in different solar polarities. In the paper, the outward and inward magnetic fields as well as the behavior of both positive and the negative solar polarities are being focussed. Terrestrial cosmic ray flux (CRF) modulated by the sun is an important solar influence which is being emphasized as one of the possible reasons affecting climate as it affects the electrical conductivity of the atmosphere following the mechanism of ion production. For variations in nucleation processes in clouds associated with the CRF there are demonstration of necessary amplification processes which is being considered at length. A rigorous study on the effects of the CRF on current density in addition to the associated microphysical responses extending to appropriate cloud models has been proposed as a further work pointing out that increased solar activity is a consequence of an increased dust. Finally, the variation of daily and monthly sunspot numbers for a period of two hundred years have been considered and then extending it, the sunspot number and open solar magnetic flux as well as the time lag as noted between cosmic ray and solar variability were being examined. From the analysis of the data the role of the sunspot number for global surface temperature is also examined.

Keywords: *Active solar periods, Cosmic ray nuclei, Magnetic field, Cosmic rays particles, Solar polarities, Cosmic ray flux, Sunspot number, Solar cycle*

1 Introduction

The sun is considered as the ultimate source of all energy on the Earth. The rays coming from the Sun heat the planet causing the churning motions of its atmosphere. The energy originating from the sun varies over an 11-year cycle [1-4]. However, this cycle changes the total amount of energy coming down to the Earth by 0.1 percent approximately. Though the sun's irradiance alters slowly with the solar cycles, the effects of increased activity of the sun including warming of the earth's atmosphere in low and mid latitudes by ozone reactions for the enhanced ultraviolet radiation, in higher latitudes due to geomagnetic activity and by increased solar radiative forcing owing to less clouds for cosmic reduction may largely magnify the overall solar effect on temperatures. As a matter of fact, the sun may influence the climatic condition on short and long time scales. The sun alters its activity on some of the time scales that change from 27 days to 11, 22, 80, 180 years and even more. An active sun is brighter owing to its dominance over the cooler sunspots. As a consequence the irradiance emitted by the sun and as received by our earth is greater during the active solar periods in comparison to that during quiet solar periods. It may be assumed that through a number of indirect factors, solar variance becomes an important driver for climate change than that of our present understanding. In general, it has been noted that eruptional activity tracking remarkably with the solar irradiance which can be used for solar irradiance measurements in order to gather further knowledge on the total solar effect.

2 Propagation of Cosmic rays in the Solar System

It is well known that the charged cosmic ray nuclei which are entering in the Solar system have to overcome the magnetic field which is carried by the solar wind, an outflow of material from the Sun. The structure of the magnetic field is complicated and is frozen in the ionized material which is expanding away from the Sun [5, 6]. It has been reported that in the vicinity of the Earth the solar wind velocity lies between 300 and 600 km/s with a mean kinetic energy of 500 MeV/particle. It has further been noted that the magnetic field strength is about 3×10^{-5} G and this is nearly 40 times lower in comparison to the kinetic energy of the solar wind particles [7].

The galactic cosmic rays particles when modulated in the solar system exhibits first as an anti-correlation of the neutron monitors data with the sun's sunspot numbers [8, 9]. The sunspot number finds the number of active regions on the Sun and it has about an 11 year cycle which is ½ of the magnetic cycle on the Sun. There is a noted 1 to 2 years delay after the changes of the sunspot number. Regions of outward polarity and inward polarity are found to be separated by the current sheet. The generation of the current sheet occurs by the combination of solar rotation and radial flow of the solar wind. In Figure 1 the outward and inward magnetic fields have shown in (a) and (b) respectively.

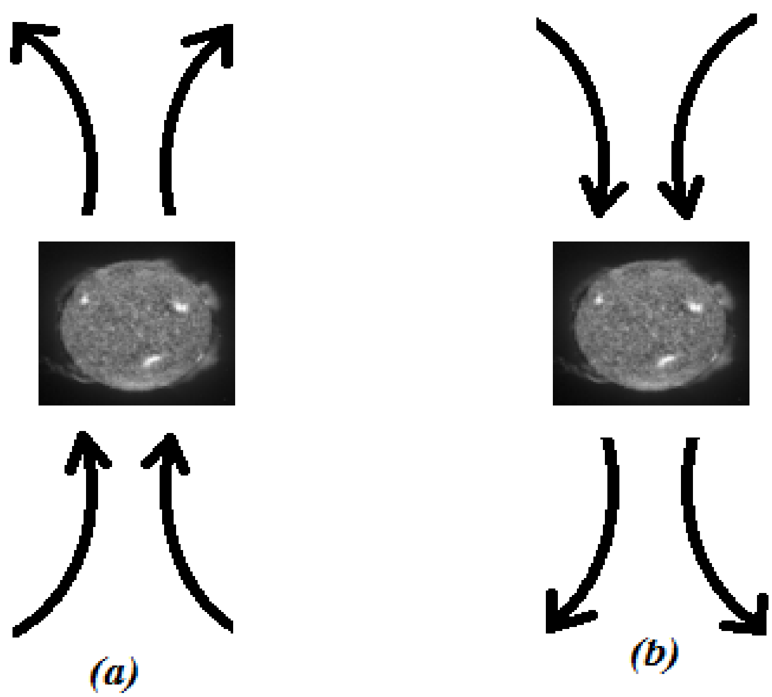

Figure 1 (a) Outward magnetic field, (b) Inward magnetic field

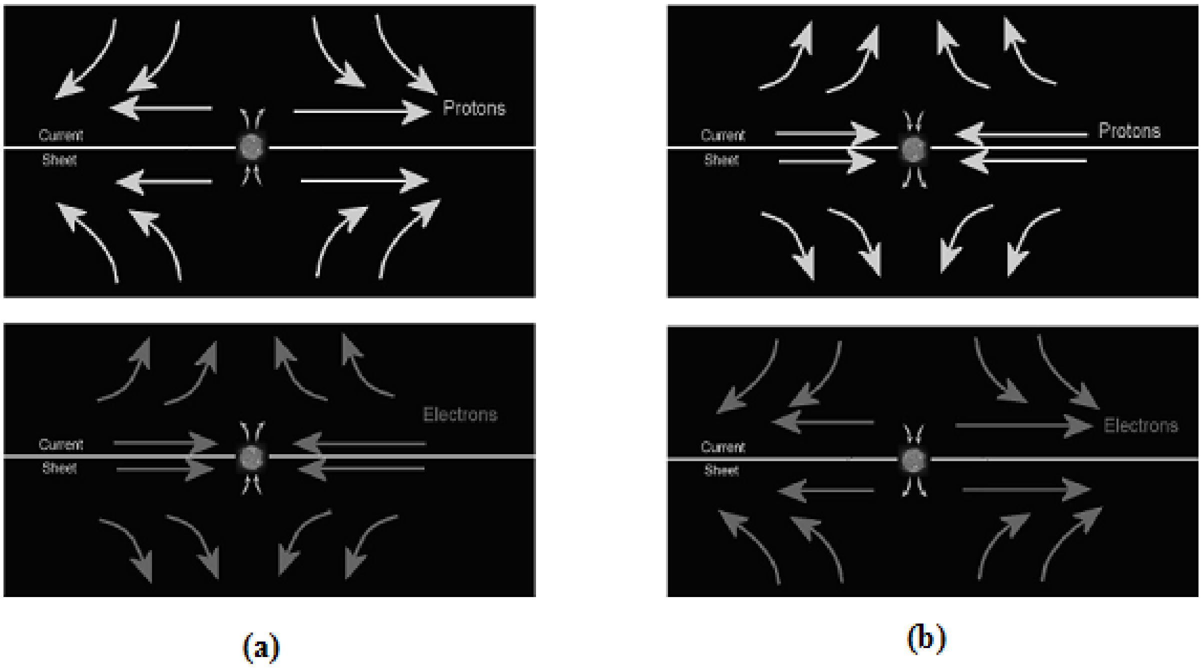

Figure 2 (a) Positive solar polarity (b) Negative solar polarity

A remarkable indication is there showing that both positive as well as negative charged particles modulate following different mechanisms and in various solar polarities. One very countable indication is about the different shape of the neutron monitors which is counted as a function of the solar polarity [6-9]. The direction of the sun's magnetic field in course of different solar polarities has some interesting features over the field. In general, cosmic ray particles gyrate around the magnetic field lines in the solar system. It has been observed that the efficient particle transport is perpendicular over the magnetic field lines. Electrons and antiprotons, the negatively charged particles, drift in the opposite way. Again if the solar polarity reverses the drift direction is also found to reverse. For all practical purposes, the motion is recognized as more complicated as the current sheet is not a plane. The behavior of the positive solar polarity and the negative solar polarity are illustrated in Figure 2 (a) and (b) respectively.

3 Terrestrial Cosmic Ray Fluxes Modulated by the Sun

It is an unsolved problem yet whether the variations in solar activity affect our Earth's atmosphere to a large extent or not. As the intensity of the solar radiation varies by a very small amount in course of a solar cycle, it is generally believed that the influence of the sun may not have major impact on the variations in Earth's climate [10]. It was proposed that terrestrial cosmic ray flux (CRF) modulated by the sun is an important solar influence which should be taken into account as one of the possible reasons affecting climate [11, 12]. This is considered a probable factor as it affects the electrical conductivity of the atmosphere following the mechanism of ion production. There is also a very good support because of the strong correlations noted between changes in carbon-14 and beryllium-10 accumulation rates with ice- rafted glacial debris. It was observed in the North Atlantic which in turn can contribute to the worldwide climate changes. It has also been supported from observational findings that the CRF modulated by sun, affects the atmospheric electricity to initiate a prolonged amplification mechanism to magnify the Sun's influence on the climate of the earth [13].

4 CRF impacts on cloud microphysical properties

The CRF variations, which may be either the drivers of climate change or may be treated as the merely proxies for irradiance variations, are being considered mainly. A process of amplification is essential to consider irrespective of whether the responsible input to the atmosphere is total solar irradiance, the ultraviolet irradiance or the CRF [14, 15]. For the first two processes no amplifying mechanism has yet been demonstrated properly but for variations in nucleation processes in clouds associated with the CRF there are good demonstration of necessary amplification processes. Dickinson interpreted ion-mediated nucleation of sulfate aerosols which affects the amount of high cloud cover [16]. A support for an alternative nucleation mechanism has been established further through few publications. Meteorological recognitions of temperature, pressure, dynamics as well as the cloud cover have been examined for the atmosphere which all have been identified to modulate the flow of the electric current density (*Jz*) in the downward direction at the time when analyzing the global electric circuit. It has been confirmed from different studies that the solar- modulated cosmic ray flux (CRF) is a very important modulator of *Jz*. The variations in rates of contact ice nucleation in addition to the concentrations of cloud condensation nuclei (CCN) and ice forming nuclei (IFN) affect the rates of precipitation [17]. Diurnal time scales for changes in Jz with meteorological responses clearly demonstrate considerable statistical significance. Similar processes affecting cloud coverage are also valid for the 11-year time scales. But it is important to note in this connection that depending on the cloud categories at varying altitudes and temperatures will exhibit a different response and for that reason a more complicated modeling is essential for the purpose of evaluating global mean effects.

5 Linkages for the Effect of Solar Activity

The scenarios for decreased solar activity is effective mainly at high latitudes as well as during the period of glacial periods as the IFN were available readily owing to the large dust load of the atmosphere during glacial times [18]. In fact, it is established that clays are very good IFN and constitute most of the nuclei in snow. This provides a circumstantial support for a Sun-weather relation as mainly mediated by the terrestrial CRF [19]. Thus suggests a rigorous study to examine the effects of the CRF on current density in addition to the associated microphysical responses extending to appropriate cloud models. Block diagram as shown in Figure 3 demonstrates how with the increased solar activity, various associated parameters like cosmic ray flux, air-earth current, contact nucleation and the precipitation are diminished, resulting finally an increased dust. In Figure 4, the variation of daily sunspot number by blue color and the monthly sunspot numbers by yellow color have been plotted for a period of 200 years from 1820 to 2020. On the other hand, in Figure 5 the sunspot number and open solar magnetic flux are plotted. In the same figure, it is also shown the time lag as noted between cosmic ray and solar variability.

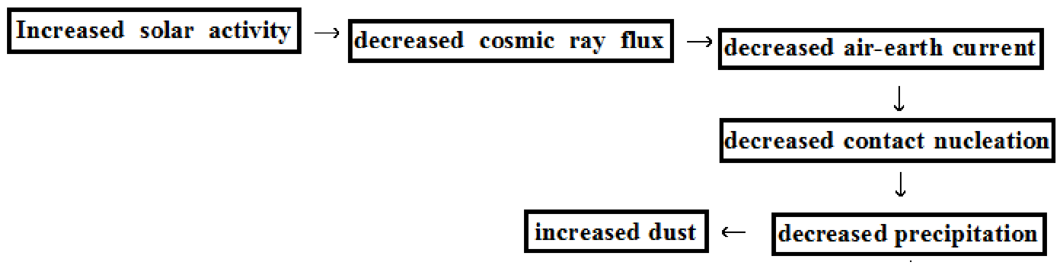

Figure 3 Increased solar activity as a consequence of an increased dust

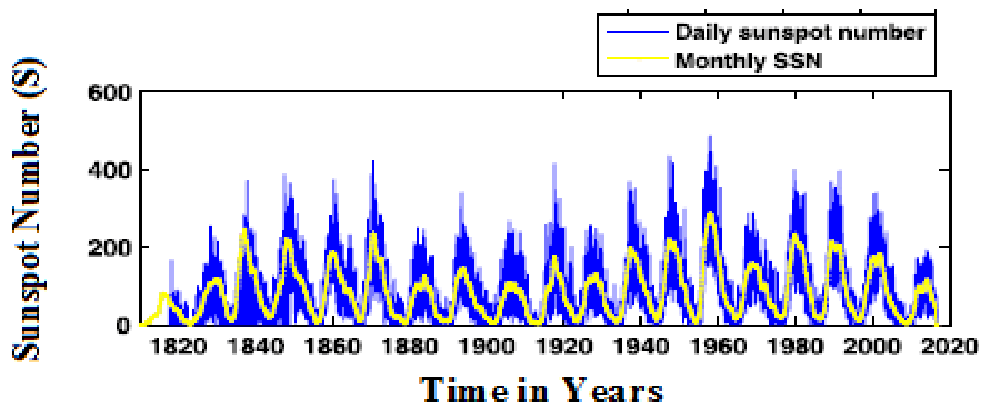

Figure 4 Variation of daily and monthly sunspot numbers for a period of two hundred years

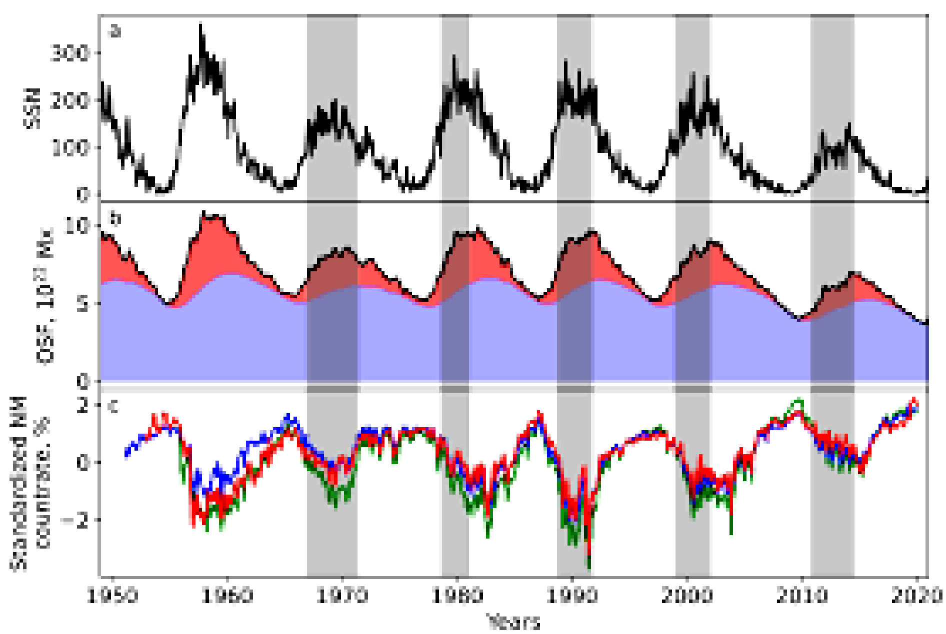

Figure 5 Sunspot number and open solar magnetic flux and also the time lag as noted between cosmic ray and solar variability (Courtesy: Springer Link)

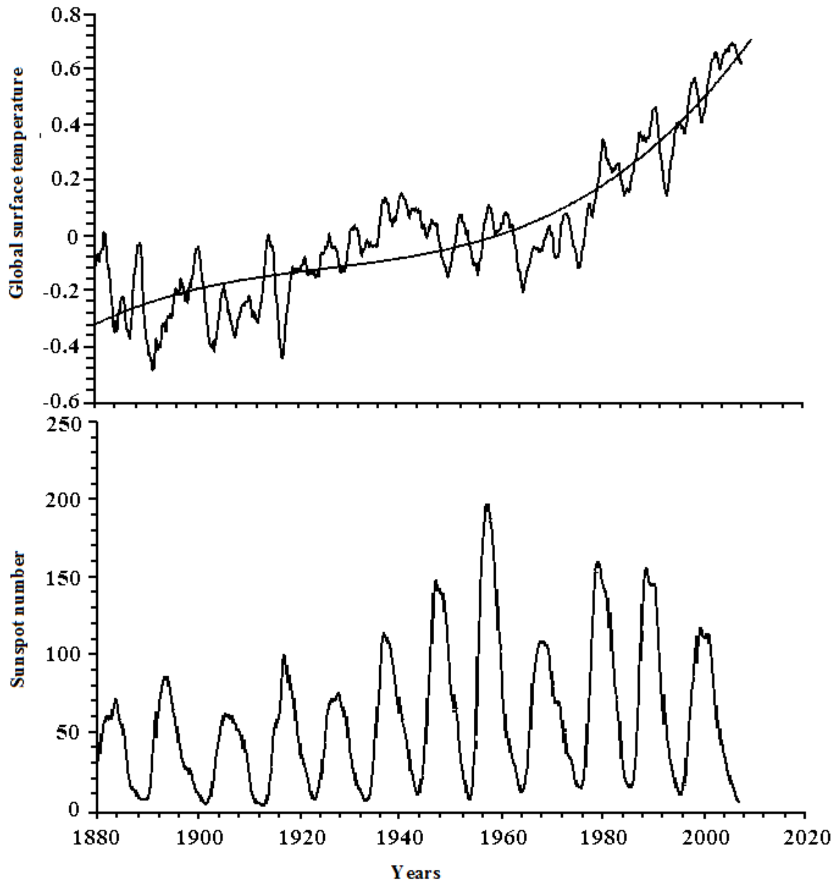

Figure 6 Global surface temperature and the sunspot number

6 Role of the Sunspot Number for Global Surface Temperature

Sun controls the weather and climate of any area significantly. Any variation in the energy as received from the Sun at the Earth's surface affect the climate. Under the condition of stable atmospheric conditions a balance is noted between the energy as received from the Sun as well as the energy radiated by the Earth into space in the form of long wave radiation associated with the mean temperature of the Earth over that area. A measurement of global surface temperature may be taken as a very crucial measure of climatic changes. A noticeable warming trend (~0.8 ± 0.18 ºC) in the global climate is found in the last 150 years in the global surface air temperature (Figure 6). A major part of this warming is assumed due to the increased greenhouse gases concentrations [19, 20]. But there appears to be some evidence that solar variability has also a fundamental role in global warming [3–9]. The well-known 11-year solar cycle and the corresponding variability that produces the electromagnetic atmosphere of Earth have given priority during the last decades [21].

7 Conclusions

It is well known that the sun’s irradiance or brightness varies slightly with the solar cycles. The indirect effects of increased activity of the sun including atmospheric warming in low and mid-latitudes because of ozone reactions owing to increased UV radiation and also by increased radiative forcing, in general, for fewer amounts of clouds mainly for cosmic ray reduction largely magnify the total solar effect on temperatures. Under the situation the sun has a vital role as the primary driver. It appears from the study that a very fundamental aspect of the sun's effect on climate is the indirect effect on the flux of Galactic Cosmic Rays (GCR) into the atmosphere. As the sun's output increases the solar wind, it shields the atmosphere from GCR flux. As a matter of fact, the increased solar irradiance is associated with the reduced low cloud cover causing an amplification of the climatic effect. Similarly when the solar output declines, an enhanced GCR flux penetrates into the atmosphere, resulting an increase of cloudiness and hence showing the cooling effect related to the reduced solar energy. The present analysis indicates that the total solar irradiance trend and the solar influence in the stratosphere may be the strong contributing factors to develop the mechanisms of tropospheric climate.

Acknowledgements

All the data sources used in the present study including the solar activity data are acknowledged.

References

1. Jørgensen, C.S., Karoff, C., Senthamizh Pavai, V. et al. *Sol Phys (2019) 294: 77*. Springer Netherlands, https://doi.org/10.1007/s11207-019-1465-z.
2. Potgeiter, M. (2013). "Solar Modulation of Cosmic Rays". *Living Reviews in Solar Physics*. 10 (1): 3. doi:10.12942/lrsp-2013-3.
3. Willson, Richard C. (2014). "ACRIM3 and the Total Solar Irradiance database". *Astrophysics and Space Science*. 352 (2): 341–352.
4. Usoskin, Ilya (2017). "A history of solar activity over millennia". *Living Reviews in Solar Physics*. 14 (1): 3 doi: 10.1007/s41116-017-0006-9.
5. "Detecting cosmic rays from a galaxy far, far away". *Science Daily*. 21 September 2017. Retrieved 26 December 2017.
6. "Cosmic Rays". Goddard Space Flight Center. *imagine.gsfc.nasa.gov*. Science Toolbox. National Aeronautics and Space Administration. Retrieved 23 March 2019.
7. Schirber, Michael (2014). "Synopsis: More dark matter hints from cosmic rays?". *Physical Review Letters*. 113 (12): 121102.
8. Benestad, Rasmus E. (9 March 2007). "'Cosmoclimatology' – tired old arguments in new clothes". Retrieved 13 November 2013.
9. *Lockwood, Mike (16 May 2012). "Solar Influence on Global and Regional Climates". Surveys in Geophysics. 33 (3–4): 503–534. doi:10.1007/s10712-012-9181-3.*
10. Christian, Eric. "Are cosmic rays electromagnetic radiation?". NASA. Archived from the original on 31 May 2000. Retrieved 11 December 2012.
11. Dembinski, H.; et al. (2018). "Data-driven model of the cosmic-ray flux and mass composition from 10 GeV to 10^11 GeV". *Proceedings of Science*. ICRC2017: 533. doi:10.22323/1.301.0533.
12. Lal, D.; Jull, A.J.T.; Pollard, D.; Vacher, L. (2005). "Evidence for large century time-scale changes in solar activity in the past 32 Kyr, based on in-situ cosmogenic ^{14}C in ice at Summit, Greenland". *Earth and Planetary Science Letters*. 234 (3–4): 335–349.
13. Ram, Michael,Brian A. Tinsley, The Terrestrial Cosmic Ray Flux: Its Importance for Climate, EOS, 2009, Volume90, Issue44, Pages 397-398.
14. Collins, W. D., and Coauthors, 2006: The formulation and atmospheric simulation of the Community Atmosphere Model version 3 (CAM3). *J. Climate*, 19, 2144–2161, doi:10.1175/JCLI3760.1.
15. Tao, W.-K., J. J. Shi, S. S. Chen, S. Lang, P.-L. Lin, S.-Y. Hong, C. Peters-Lidard, and A. Hou, 2011: The impact of microphysical schemes on hurricane intensity and track. *Asia-Pac. J. Atmos. Sci.*, 47, 1–16, doi:10.1007/s13143-011-1001-z.
16. Stephens, Graeme L. (2005-01-01). "Cloud Feedbacks in the Climate System: A Critical Review". *Journal of Climate*. 18 (2): 237–273.
17. R. Giles Harrison, Cloud Formation and the Possible Significance of Charge for Atmospheric Condensation and Ice Nuclei, 2000, Space Science Reviews 94(1):381-396, DOI: 10.1023/A: 1026708415235.

18. William J. R. Alexander, Linkages between solar activity and climatic responses, Energy & Environment, Vol. 16, No. 2 (2005), pp. 239-253
19. Eddy, J.A. 1981: Climate and the role of the Sun. *In* Rotberg and Rabb 1981, 145--67 (5).
20. Friis-Christensen, E. and K. Lassen 1991. Length of the solar cycle, an indication of solar activity closely associated with climate. *Science* 254, 698-700.
21. Dan Pangburn, Influence of sunspots on global mean surface temperature, Energy & Environment, Vol. 25, No. 8 (2014), pp. 1455-1471.