The Impact on Climate Change Due to the Effect of Global Electromagnetic Waves of Solar Flare and Coronal Mass Ejections (CMEs) Phenomena

1,2N Mohamad Ansor, 1,2Z S Hamidi, 1,3N N M Shariff

1Institute of Science, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
2Faculty of Science, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
3 Academy of Contemporary Islamic Studies, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

Email address: nurain_ansor@yahoo.com

Abstract. Climate change has a close relation with the variability of the Sun’s energy radiated, which is associated with solar activity and this issue has been the top debate topic among climate scientists in finding out the main source of the changing in Earth’s climate. Previous studies were discussing on human activities and formation of $^{14}$C and $^{10}$Be isotopes which are likely contributing to the temperature increment of Earth’s surface. However, the pattern of climate on this planet is always depending on the condition of its main source of energy; the Sun. In this paper, we briefly review the impact of production of $^{14}$C and $^{10}$Be isotopes to Earth’s temperature. We also discussed in this article on how the variability of solar activity contributes to climate change. The main method in carrying out this study is by solar observation. We present the summary of several sets of significant solar events in 2017 and its relationship with Earth’s temperature. It is believed that Earth’s climate is likely to be affected by the variability of solar activity, in the sense that solar minimum in 2017 causes it to be the second highest annual temperature with 0.89°C warmer than normal temperature.

1. Introduction
Climate change basically refers to the concentration of carbon dioxide produced in Earth’s atmosphere. This phenomenon has been happening for the last 600,000 years and scientists believed that solar activity, which we are focusing on in this paper are solar flares and Coronal Mass Ejections have a crucial role in changing this climate. Solar flares and Coronal Mass Ejections (CMEs) emit radiation, which covers across the electromagnetic (EM) waves spectrum from radio waves up to gamma rays. High energy flares can disrupt our power grids, communications, Global Positioning System (GPS) signal and cover the Earth’s upper atmosphere with hazardous radiation [1]. Meanwhile, CME can trigger geomagnetic storm when it interrupts the Earth’s magnetic field. If worse, this storm can cause blackout in electrical power and damage the communications satellite [2]. Starting in 1860 until 1990, the global mean annual surface temperature increased by 0.55°C [3]. Hypothesis has been made on the warmer temperature that is caused by ongoing release of carbon dioxide gas from the industries. However, analysis of climate records propose that the cause of the warming is more than the influence of increasing carbon dioxide gases as the records expose outstanding inter-annual and inter-decadal variability [4]. Variability of solar activity modifies the
climate in so many ways. Solar activity can be minimized or maximum depends on the number of sunspots present on Sun’s surface. The long-term significant event in climate study is the Maunder Minimum (1645-1715) which is happened to coincide with the Little Ice Age, where our Earth was somehow cooler than present [5]. A study conducted by [6] has successfully shown the relation between the number of sunspots observed during the Maunder Minimum and Earth’s climate during the period. Maunder Minimum is described by its minimum sunspots observed by astronomers. As [7] discovered in their research, the Sun during Maunder Minimum was 0.25% less bright than it was during previous solar minimum in 1985-1986. It is estimated that the solar irradiance during the period is 0.24%, lesser from present that should contribute to decreasing global temperature by 0.2°C [6].

Global climate changes through total radiation which varies with solar activity, specifically in the ultraviolet (UV) range. At the first place, scientists assumed that the Total Solar Irradiance (TSI) was constant and unvarying when satellites have yet to be established in the space. Starting in 1978, when satellites have been launched, TSI could be measured by direct measurement by the satellites [8]. Later, [9] come up with their combined record to prove that TSI is not constant and is varied ~0.1% from minimum to maximum of solar cycle. A strong solar flare does not raise the TSI more than a hundredth percent, however they temporarily amplify the solar output at UV, radio and X-ray wavelengths [8].

2. Production of cosmogenic isotopes $^{14}$C and $^{10}$Be at Earth’s atmosphere

The formation of these isotopes are the consequences of cosmic rays of both galactic and solar origin and are formed in the upper atmosphere. They are produced from the change in cosmic ray flux fluctuations that intrude the Earth in which the fluctuations are caused by solar wind [10]. Solar wind includes the ejection of particles from the Sun through the interplanetary medium and can strongly influence the Earth’s magnetic field. The production of $^{14}$C is low as the Earth is shielded from cosmic rays due to prolonged solar magnetic field during high solar activity. Hence, low solar activity leads to more cosmic rays penetrate through Earth’s atmosphere and producing more $^{14}$C. Sudden increase in $^{14}$C concentration indicates a change towards colder or wetter climate, which shows that solar does play a role in climate change [10]. Therefore, data of $^{14}$C concentration can be a good measure for solar output [11].

However, records of $^{10}$Be are also taken into account as changes in $^{14}$C concentration is too weak to prove this assumption. The production of $^{10}$Be is the consequence of nuclear reactions induced by cosmic rays and happens in two lowest layers of the Earth’s atmosphere which are stratosphere and upper troposphere. Moreover, [12] found out that $^{14}$C and $^{10}$Be are alongside each other from 8000 to 5000 BP. This shows the variations of $^{10}$Be is also a good indicator in relating changing solar activity and cosmic ray intensity. A data record of $^{10}$Be concentration and $\delta^{18}$O which was produced by [9] shows strong fluctuations between $^{10}$Be concentration data of 40,000-11,000 years ago and $\delta^{18}$O record of the same ice core in which they are parallel to each other. This implies warm phases give low values of $^{10}$Be concentration and peaks in $^{10}$Be concentration happen during cold phases. Moreover, the difference in $^{10}$Be is believed to indicate changes in snow accumulation rate [13].

3. Solar Observation

In this study, we observed and analyzed several selected solar events based on class of solar flares that were occurred recently in 2017. Since 2017 was at solar minimum which implies solar activity was at inactive phase, we will correlate this event to the temperature changes in 2017. During solar minimum, smaller number of sunspots present on Sun’s surface. A sunspot is known as a coldest region on the Sun’s surface with a temperature of approximately 4000K and is appearing as black due to other surrounding of Sun’s surface has a temperature of about 6000K. Data for solar cycle progression with their respective sunspot number can be referred to Figure 1 which includes solar cycle 23 and 24. Every data is taken from [14] and is updated every month and later they are compiled and arranged by [15].
Focusing on 2017, sunspot number decreases which complies the condition of solar minimum with average sunspot number of 19 [14]. Decrease in sunspot number gives low chance information of many solar flares. However, there are still strong solar events recorded throughout the year, in which the strongest flare is X9.3. We summarized the top 10 strongest flares in Chart 1 with respective to their region, sunspot number and Kp-index adapted from [14]. Based on the chart, region 2673 has been the most active region throughout the year as it has always produced most of the strongest flares because it is a complex region with $\beta-\gamma-\delta$ classification. The highest flare was recorded on 6\textsuperscript{th} September with X9.3 magnitude.

![Chart 1. Summary of 10 selected solar events as in 2017](image1)

We are concerned on global annual mean surface air temperature based on land and ocean data and also annual mean temperature change for the hemisphere. Generally, 2017 has been the second hottest year on record since 1880 [16][17]. Figure 2 displays the global mean temperature based on land and ocean data adapted from NASA GISS. As shown in the figure, the second highest annual temperature...
is marked at 2017 to 0.89°C warmer than normal temperature, while 2016 holds the highest annual mean temperature by 0.99°C hotter.

Meanwhile, data of annual mean temperature change in North and South hemispheres also prove that 2017 is the second hottest year this Earth has been. It can be referred in Figure 3 which shows hemispheric temperature change since 1880. For the North Hemisphere, 2017 and 2015 have slightly the same annual mean temperature as they differ by only 0.01°C, in which the temperature anomaly of 2017 is 1.11°C and 2015 is 1.12°C. However, for South Hemisphere, 2017 still ranks the second highest temperature with 0.68°C warmer.

**Figure 2.** Global mean temperature based on land and ocean data since 1880 [16]

**Figure 3.** Hemisphere temperature change since 1880 [16]

4. **Correlation between solar activity and Earth’s temperature**
   In order to relate the variations of solar activity to Earth’s temperature, we apply the equation for the luminosity of the Sun which is given as
where, $r$ is radius of Sun, $\sigma$ is Stefan-Boltzmann constant and $T$ is temperature of Sun.

From the equation, Sun’s luminosity is directly proportional to Sun’s temperature, which means high temperature produces high energy radiated by the Sun. The Earth’s climate is strongly depending on solar radiation that is provided by the Sun. Some of solar radiation is absorbed by the Earth and some of it will be reflected back to space mostly by clouds and atmospheric particles to balance Earth’s energy and temperature. The amount of solar radiation absorbed and reflected determine the rising or declining in Earth’s climate. Generally, Earth’s system absorbs 71% of total incoming solar radiation and 29% is reflected back. When atoms and molecules absorb energy, the matter become excited and moves quickly and randomly and leads to increase in the matter’s temperature. If more energy is absorbed, more particles increase in temperature and eventually Earth’s atmosphere and surface start to warm up. The origin of this result goes back to Sun’s temperature, where, the hotter the Sun is, more solar energy is produced leads to high incoming energy absorbed by Earth. Meanwhile, the temperature of the Sun is based on the presence of sunspots; less sunspot number, more hotter the Sun will be.

5. Conclusion

Overall, this article reviews some evidences from previous studies and we present solar activity data throughout 2017 during solar minimum to prove the possibility of solar radiation emitted by solar flares and coronal mass ejections in changing Earth’s climate pattern. By gathering the data records, we believe climate change is contributed by the variability of solar activity, in which, solar minimum results in high solar radiation produced and received by the Earth. Hence, less amount of energy absorbed results in low of the Earth’s temperature.

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6. References

[1] Ramli, N., Hamidi, Z. S., Abidin, Z. Z., & Shahar, S. N. (2015). The Relation between Solar Radio Burst Types II, III and IV due to Solar Activities. International Conference on Space Source and Communication 2015, 123-127
[2] Shariff, N. N., Hamidi, Z. S., & Zainol, N. H. (2017). Analysis of slow partial halo CME events with velocity of 100-200 km/s: An observation through CALLISTO system. International Conference on Industrial Engineering, Management Science and Application 2017
[3] Parker, D. E., Jones, P. D., Folland, C. K., & Bevan, A. (1994). Interdecadal changes of surface temperature since the late nineteenth century. J Geophys Res 99 (D7), 14373-14399.
[4] Hady, A. A. (2013). Deep solar minimum and global climate changes. Journal of Advance Research 4, 209-214.
[5] Eddy, J. A. (1976). The Maunder Minimum. Science, 192, 1189-1202.
[6] Guinan, E. F., &Ribas, I. (2002). Our changing Sun: The role of solar nuclear evolution and magnetic activity on Earth's atmosphere and climate. ASP Conference Series 269, 85-104.
[7] Lean, J., Skumanich, A., & White, O. (1992). Estimating the Sun's radiative output during the Maunder Minimum. Geophysical Research Letters 19, 1591-1594.
[8] Tsiropoula, G. (2003). Signatures of solar activity variability in meteorological parameters. Journal of Atmospheric and Solar-Terrestrial Physics Vol. 65, 469-482.

[9] Frohlich, C., & Lean, J. (1998). Total solar irradiance variations. In: Deubner, F.L. (Ed), Proceedings of the IAU Symposium Vol. 185. Kluwer Academic Publisher, Dordrecht, 89-102.

[10] van Geel, B., Raspopov, O., Renssen, H., Plicht, V. D., Johannes, D. V., & Meijer, H. (1999). The Role of Solar Forcing Upon Climate Change. Quaternary Science Reviews, 331-338.

[11] Bard, E., Raisbeck, G. M., Yiou, F., & Jouzel, J. (1997). Solar Modulation of Cosmogenic Nuclide Production over The Last Million; Comparison between C-14 and Be-10 records. Earth and Planetary Science Letters 150, 453-462.

[12] Finkel, R. C., & Nishiizumi, K. (1997). Beryllium 10 concentrations in the Greenland Ice Sheet Project 2 ice core from 3-40ka. Journal of Geophysical Research 102, C12, 26699-26706.

[13] Yiou, F., Raisbeck, G. M., Baumgartner, S., Beer, J., Hammer, C., Johnsen, S., . . . Yiou, P. (1996). Beryllium 10 in the Greenland Ice Core Project ice core at Summit, Greenland. Journal of Geophysical Research, 102(C12), 26783-26794.

[14] SpaceWeatherLive. (2017). Retrieved from SpaceWeatherLive web site: https://www.spaceweatherlive.com/

[15] Space Weather Prediction Center National Oceanic and Atmospheric Administration. (2017). Retrieved from National Oceanic and Atmospheric Administration web site: https://www.swpc.noaa.gov/

[16] National Aeronautics and Space Administration Goddard Institute of Space Studies. (2018). Retrieved from National Aeronautics and Space Administration web site: https://data.giss.nasa.gov/gistemp

[17] National Aeronautics and Space Administration. (2017). Retrieved from National Aeronautics and Space Administration web site: https://www.nasa.gov/