An Analysis of the X1.59 Flare and Associated Events on 3rd July 2021

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Abstract. Solar flares are caused by a complex magnetic field on the surface of the Sun, which releases a large amount of radiation. We present an analysis of the X1.5 flare that occurred on 3rd July 2021 at 14:29 UT from the active region AR 2838. It was believed that some other events were related. Prior to satellite communication, the ionosphere was commonly used for radio communication. In case of enhanced excess photoionization due to solar activities, the D layer will not disappear after sunset. This includes the burst of the day, as well as the ionospheric response caused by the flare event. Although numerous studies have been conducted on the sun, its dynamic behavior has continued to draw the interest of astrophysicists to this area to this day.

1. Introduction
Solar flares are one of the major sun's activities described as a sudden, rapid giant explosion that occurs on the sun's photosphere. It included acceleration of erupted charged particles from the built-up magnetic energy to a very high energy of electromagnetic radiation[1]. During the solar maximum, the sun can produce many flares on the same day. Solar flares classify by A, B, C, M, or X on the peak flux in watt per meter square (Wm⁻²) along with the logarithmic scale 1-9. A-class is the weakest and X-class is the strongest flare class. As reported by [2], the biggest and strongest flares (X-class flare) can occur almost more than 10 times on average per year during the solar maximum phase. Severe radio blackout may happen when this strong flare directly occurs towards the Earth. The largest X-class flare was recorded on 4th November 2003 with a scale of X28 and this event was associated with a halo coronal mass ejections event with a speed exceed of 2657 kms⁻¹ and kinetic energy of 6 x 10³²erg [3]

An important method of detecting different types of solar bursts is the observation of radio region signals from ground-based stations, which are generally responsible for accelerating particles from the sun. Solar burst type III seems to be most dominant with a solar flare. Since it was first introduced by Wild in 1963, solar burst type III is said to be covered the frequency range from 500 Hz to 10 MHz [4, 5]. However, after decades of studies on solar burst characteristics, solar burst types III more commonly to be considered ranges between 10 kHz and 1 GHz. Originating from the interplanetary(IP) medium, there are three- sub-type of solar burst type III which are the one from energy system and small-scale energy (isolated type), the second type which occurs during the CME (complex type), and
Lastly the storms type of burst. Solar burst type III is a fast frequency drift burst and is often considered to be a pre-flare stage where an indication of electrons acceleration [6]. It can occur from one to three seconds for a single burst, one to five minutes for the group burst, and up to hours for the storm-like burst. Moreover, a high percentage of 60% type III burst was found to be time-synchronized with solar flares [7].

Until satellite communication became common, radio communication was commonly conducted in the ionosphere. It has three layers (D, E, and F), with D disappearing when the sun sets unless there is excessive photoionization from solar activities. As the signal bounces off the region, it travels to the other side of the Earth. Due to the region's ability to absorb and bend signals, it can cause a delay in the signal's transmission. Therefore, monitoring the ionosphere response to solar activities especially solar flares have been implemented to understand and expect the side effect to the communication system. There were a Doppler sounding system and Global Positioning System for the ionosphere monitoring, however sudden fade-out has happened due to abnormal condition within ionosphere region. Then, it said that by using the 24 satellites around Earth's atmosphere, GPS dual frequencies makes the best option in real-time monitoring system with higher precision, higher spatial, and temporal resolution data collected [8, 9].

From solar flare event, the intensity of narrow ribbon of current flowing eastward and electron density in the F-region increase and forming the excess ionization within E-layer and it causing the electron density of the ionosphere regions a significant increment and disrupt the signal transmitting [8, 10]. Signal strength will be reduced, and a poor signal will be received as the wave undergoes the absorption of wave signal or called attenuation. The changes in the region will tend to attenuate the wave signal and higher frequency will happen to attenuate more than the lower frequency [11]. One of the communications that using ionospheric wave propagation is high frequency (HF) radio; where has long coverage, high mobility, persistence, and low cost. This communication tends to be disrupted when there is a disturbance in the ionosphere layer [12]. In this study, we analyse the events that occur after the event of X1.59 flare on 3rd July 2021 includes the solar burst, coronal mass ejections, and ionosphere response.

2. Methods
All data for this study was obtained from the National Oceanic and Atmospheric Administration (NOAA) website, the NASA space weather monitor, and space weather live sites. Solar flare data is available on the NOAA websites with a location of the active region, classification of flares, etc. The magnetogram and the SDO/AIA Fe IX at 131Å band are used to observe the solar sunspot at 10 million Kelvin. As part of the Space Weather Monitor, D-region Absorption Prediction (D-Rap) provides archived data of SID events of HF signal analysis with flares. Space Weather Live is used to identify the Sun's conditions related to the ionospheric disturbance (solar wind speed, solar wind density, Kp index, etc.).

3. Result and discussion
The mechanism of solar flares is currently an area of research that got many astrophysicists’ attention these days. There are numerous of intense flare eruption occurred on 3rd July 2021. There were four active regions (AR) that appeared on the sun’s surface observed by HMI magnetogram (Figure 1) which were AR2835, AR2836, AR 2837, and AR2838. However, unlike the other AR, AR2838 which is located at the right top north hemisphere side (N24W88) found to be the only active region that erupting numerous flare events on this date with the six high-class flare events on Geostationary Operational Environment Satellite (GOES) scale. Three C-class flares, two M-class flares, and one X-class flare were among the six high-class flares. Our discussion focused on the analysis of the X-Class flare, which is said to be the first X-class flare in four years since September 2017. On the right side of figure 1, there is an image of the sun from the Atmospheric Imaging Assembly (AIA) onboard of Solar Dynamic Observatory (SDO) indicating the flare event in the corona.
As observed by GOES Xray Satellite, with a duration of 16 minutes, this X-class flare started at 14:18 UT with $4.81 \times 10^{-7} \text{ Wm}^{-2}$, rose to its peak at 14:29 UT with $1.59 \times 10^{-4} \text{ Wm}^{-2}$. Table 1 is the average value of the parameter of the sun's condition of the day.

| Solar wind | Sunspot Number | Radio Sun (10.7cm Flux) |
|------------|----------------|-------------------------|
| Speed 369.7 km/sec | Density 3.0 proton/cm$^3$ | 72 | 95 sfu |

Solar wind speed and density appear to be normal. The number of sunspots and the radio sun, however, are significant, increasing flare chances. On the same day, there was a coronal mass ejection event (Figure 2) that was observed on board STEREO as occurring at 105 degrees clockwise from the north and a maximum velocity of 500 km/s (Figure 2).

In Figure 3, an intermittent burst was detected from Bleien Observatory Switzerland (SWISS-BLEN7M) that can be accessed through eCALLISTO websites. The burst coincides with the flare near the peak time as it is observed with a wide range of radio frequencies from 470MHz to 750MHz. It has a string-like structure that indicates it as the fast drift burst (type III burst). The drift rate of this burst was calculated to be $-9.54 \text{ MHz/sec}$ which is a fast drift rate.
Figure 3. Solar burst type III on the peak time of X1.59 flare.

Figure 4. D-region Absorption Prediction (D-Rap) (credited to Space Weather monitor)

There was a shortwave blackout reported at the space weather observatory in Norway on this day. X-ray pulse of the flare believed has been briefly ionized the top part of Earth’s atmosphere and gives unusual signals below 30MHz propagations. As a surge of current flow that occurs while the event is in progress, this flare is said to be the one that causing magnetic crochet where the flares produced the radio burst, an ionospheric disturbance, a surge of current in the ground, and the deflection of the observatories’ local magnetic field (a rare event). The current flows from 60km to 100-600 km above the Earth’s surface due to the ionization and can alter the Earth’s polar magnetic field. D-Rap model detected a sudden ionospheric disturbance right after the peak time of the flare at 14:31 UT. The disturbance within the ionospheric region happens when the D-region ionization increases dramatically due to the solar flare event. When the Sun is directly overhead of one point, called a subsolar point, D-region ionization is at the highest state, and eventually the ionization and absorption
decrease and recovering as it distances away from it. However, the night side of the Earth is unaffected by this excess ionization. Figure 4 showing that by 1dB absorption, frequencies up to 35 MHz have degraded especially in the red-colored region. At the right side of the figure, there is an Attenuation bar graph that shows the maximum absorption ($A_{max}$) of frequencies that are attenuated. An example, for a 5MHz signal, the attenuated is high as 25dB. This degraded signal and attenuation event may notice by whom that depends on the high-frequency signal as they faced the unusual propagation signal.

4. Conclusion:
An X-class solar flare event has been observed to have produced a short-lived solar burst type III event. As a result, solar flares can disrupt radio signal transmission and have a significant impact on HF communication like the radio blackout in September 2017. Due to the strong x-ray flux during the solar flare event, high-frequency signals, like those used by aviation, are at risk of attenuation. Based on research done decades ago, solar activity will greatly affect the earth and its surroundings. Hence, it is important to continue studying our sun from time to time in order to understand its dynamic behavior.

References
[1] Heyvaerts J, Priest ER, Rust DM. An emerging flux model for the solar flare phenomenon. The Astrophysical Journal. 1977;216:123-37.
[2] Sharma A, More C. Effect of Solar X-ray Flares on VLF Radio Wave Signal Strength at 19.8 and 24 kHz Received at Khatav (India). Journal of Space Science & Technology. 2017;6(3).
[3] Ciavarella A, Raymond J. The current sheet associated with the 2003 November 4 coronal mass ejection: density, temperature, thickness, and line width. The Astrophysical Journal. 2008;686(2):1372.
[4] Wild JP, Smerd SF, Weiss AA. Solar Bursts. Annual Review of Astronomy and Astrophysics. 1963;1(1):291-366.
[5] Hamidi ZS, Shariff N. The Propagation of an Impulsive Coronal Mass Ejections (CMEs) due to the High Solar Flares and Moreton Waves. International Letters of Chemistry, Physics and Astronomy. 2014;33:118-26.
[6] Dulk GA. Type III solar radio bursts at long wavelengths. Geophysical monograph. 2000;119:291-336.
[7] Swarup G, Stone P, Maxwell A. The Association of Solar Radio Bursts with Flares and Prominences. The Astrophysical Journal. 1960;131:725.
[8] Liu JY. Ionospheric solar flare effects monitored by the ground-based GPS receivers: Theory and observation. Journal of Geophysical Research. 2004;109(A1).
[9] Zhang DH. Study of ionospheric response to the 4B flare on 28 October 2003 using International GPS Service network data. Journal of Geophysical Research. 2005;110(A3).
[10] Liu JY, Lin CH, Chen YI, Lin YC, Fang TW, Chen CH, et al. Solar flare signatures of the ionospheric GPS total electron content. Journal of Geophysical Research. 2006;111(A5).
[11] Hegde S, Bobra MG, Scherrer PH. Classifying Signatures of Sudden Ionospheric Disturbances. Research Notes of the AAS. 2018;2(3).
[12] Uryadov VP, Vybornov FI, Kolcheva AA, Vertogradov GG, Sklyarevsky MS, Egoshin IA, et al. Impact of heliogeophysical disturbances on ionospheric HF channels. Advances in Space Research. 2018;61(7):1837-49.

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