Dayside Ionospheric Response to X-Class Solar Flare Events Observed with Reverse Beacon Network High Frequency Communication Links

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Introduction

- A solar flare is an event in which high levels of UV and X-ray radiation are emanated by the sun and whose dominant effect on Earth's ionosphere is an increase in photoionization, primarily in the D-layer, which extends from 50-80 km in altitude (Poole, 1999)
- The ionosphere's D-layer is largely responsible for absorption of High Frequency (HF) radio waves (Larson, 2010), which range between 3 MHz and 30 MHz, so as ionization is increased during flare events communication can be diminished or lost completely in what is called a Shortwave Fadeout (Milsom et. al., 1994)
- Fadeout can occur in minutes and recovery afterwards lasts on the order of hours, which is why understanding these flare effects is of critical importance

Research Questions:

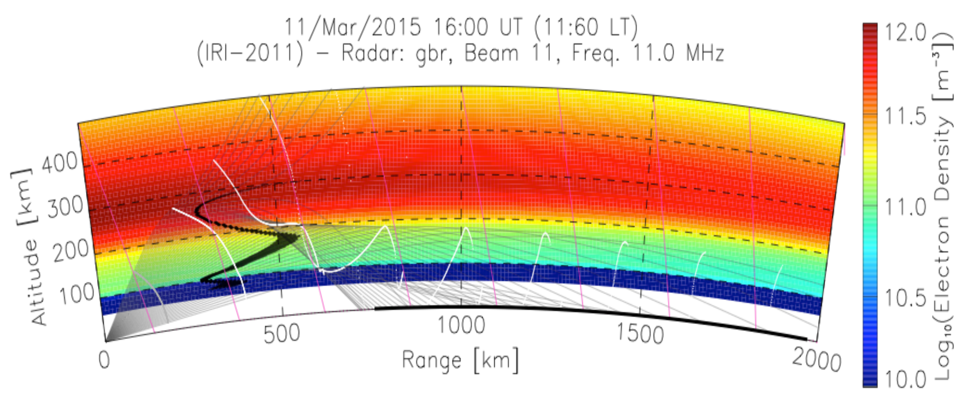
1. **What is the spatial extent of the solar flare impact on the ionosphere?**
2. **What is the temporal response of the ionosphere and HF communications to the solar flare impact?**
3. **How does HF communication link quality respond to the solar flare as a function of frequency?**

Instrumentation/Method

- **The Super Dual Auroral Radar Network (SuperDARN), a network of HF radars that measure ionosphere velocity using Doppler shift (Frissell et. al., 2014), was used to provide data during flare events**
- **SuperDARN detects a ground scatter band that results from waves reflecting off of the ionosphere and ground, and this band is degraded during flare events.**
- **To see the spatial distribution of flare effects, four radars were used that were located across North America (see Figure 2)**
- **The Reverse Beacon Network (RBN) was utilized to measure HF communication**
- **The RBN is an array of passive receivers that record radio communication links of amateur (ham) operators (Frissell et. al., 2014)**
- **Ham radio is restricted to frequency bands within HF radio, so 5 frequencies being 3.5 MHz, 7 MHz, 14 MHz, 21 MHz, and 28 MHz were chosen to be studied**
- **X-ray flux data within the 0.05-0.4 nm and 0.1-0.8 nm ranges was used from GOES Satellite 15, a geostationary weather satellite**

Figure 1

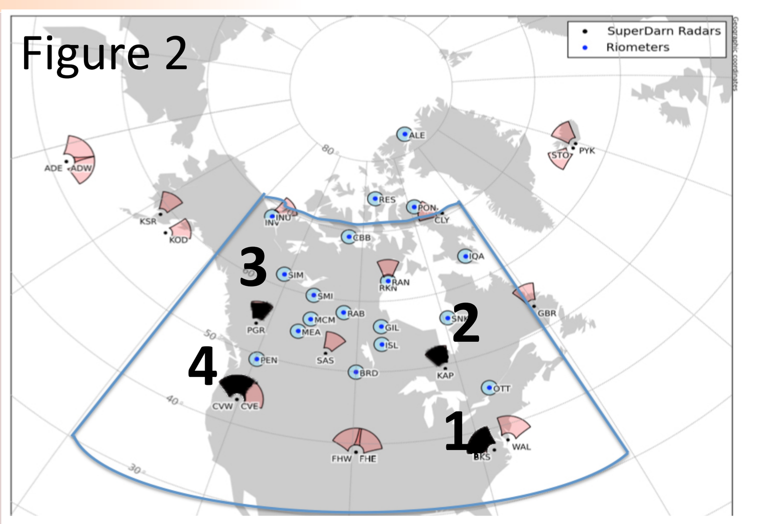
The right figure shows radio propagation paths for March 11th, 2015.



- **To measure ionospheric absorption during flare events, riometers operated by the Canadian Space Weather Forecast Centre were used**
- **Riometers measure VHF radio noise, typically ~30 MHz, from extraterrestrial sources through the ionosphere**
- **In the presence of solar flares radio noise drops due to increased absorption from photoionization, and thus the absorption is found by comparing the flare effects to expected quiet time values of radio noise**

- **Since amateur radio is a global communication system, constraints of RBN spot locations had to be made**
- **The latitude of the transmission or reception of a spot was limited to between 30° N and 80° N**
- **Similarly, the longitude was restricted to between 60° W and 130° W (See Figure 2)**

Figure 2



Isolated area for RBN spots, with SuperDARN sites in black

Case Studies

- The March 11th, 2015 event (left column below) was classified as a X2.2 flare, whereas the October 25th, 2014 event (right column below) was an X1.0 flare, meaning it was less than half the intensity of the March event
- Note that the rise and fall in X-ray flux on March 11th was more rapid than on October 25th (see Figure 3)

Figure 3

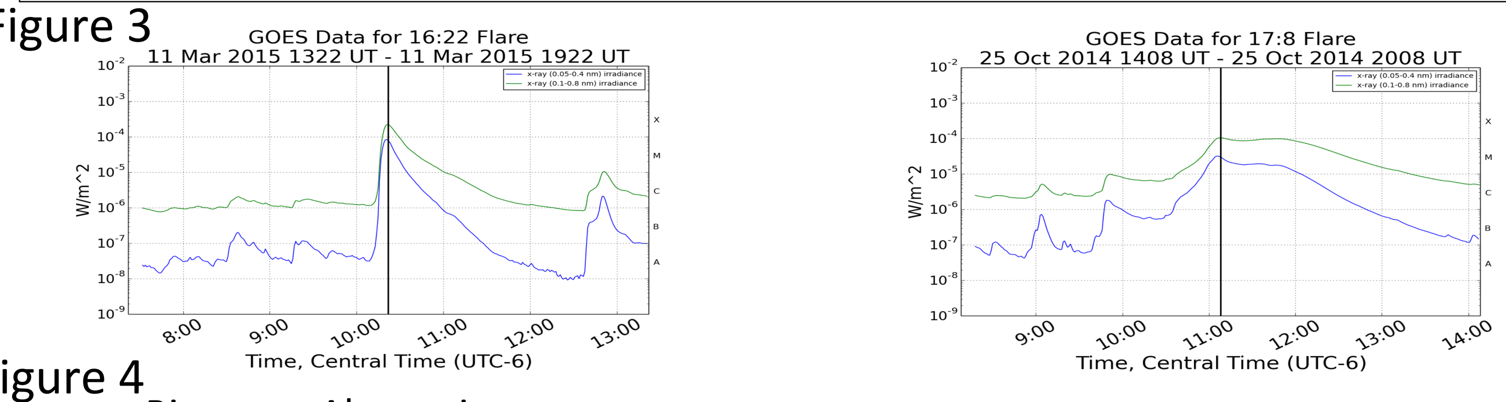


Figure 4

Riometer Absorption

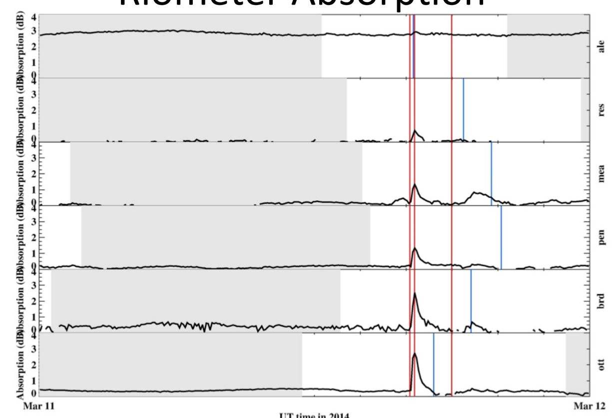


Figure three shows the GOES X-ray data for three hours before and after each event, with the flare time marked with a black line. Figure 4 is the riometer data for the day of March 11th, where the riometers are arranged from top to bottom in decreasing latitude locations.

Figure 5

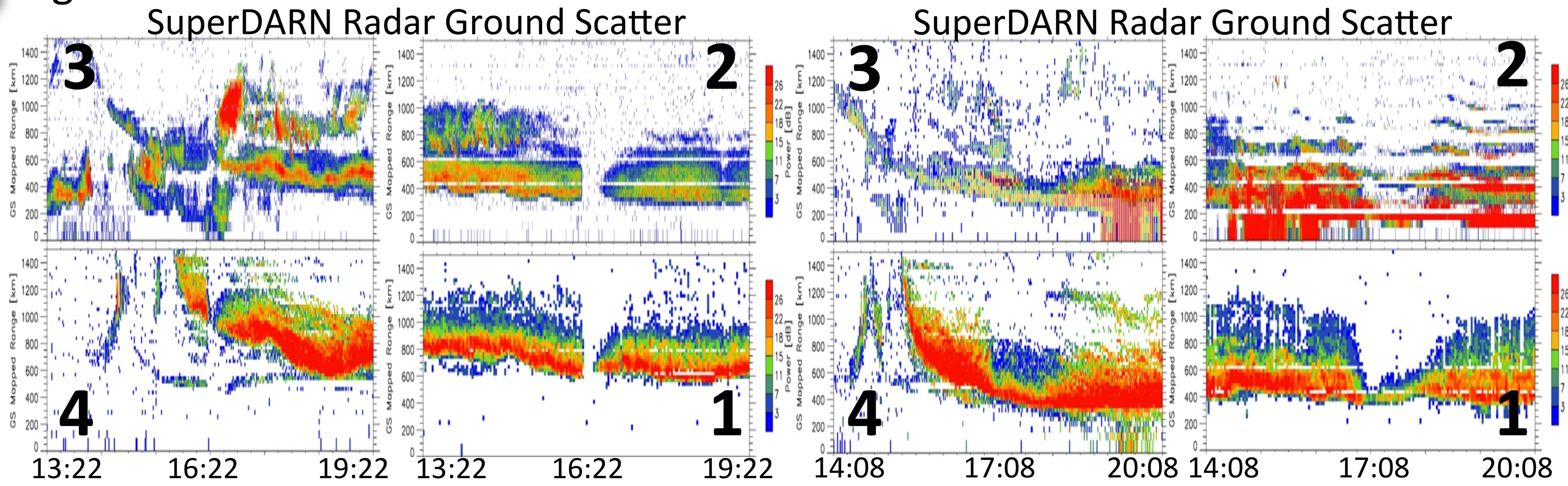


Figure 5 (above) shows the radar 3 hours before and after each flare, with radars numbers labeled as in figure 2. Note the complete fadeout for March 11th but not for October 25th. Figure 6 (below) shows the global RBN links before (left plots) and after (right plots) each event. The drop in spots is apparent on the dayside, seen as the white area.

Figure 6

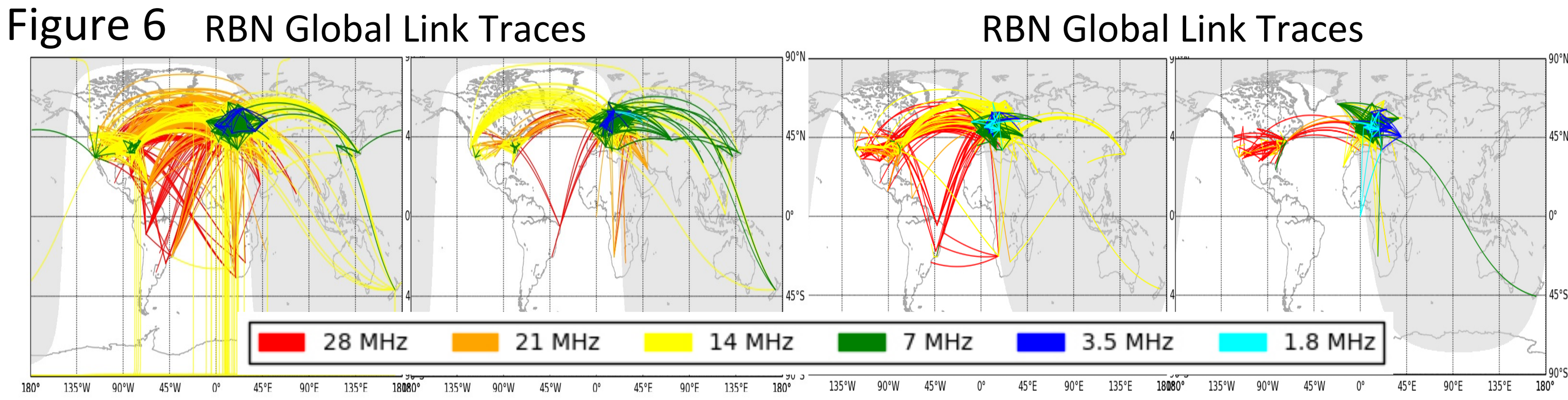


Figure 7

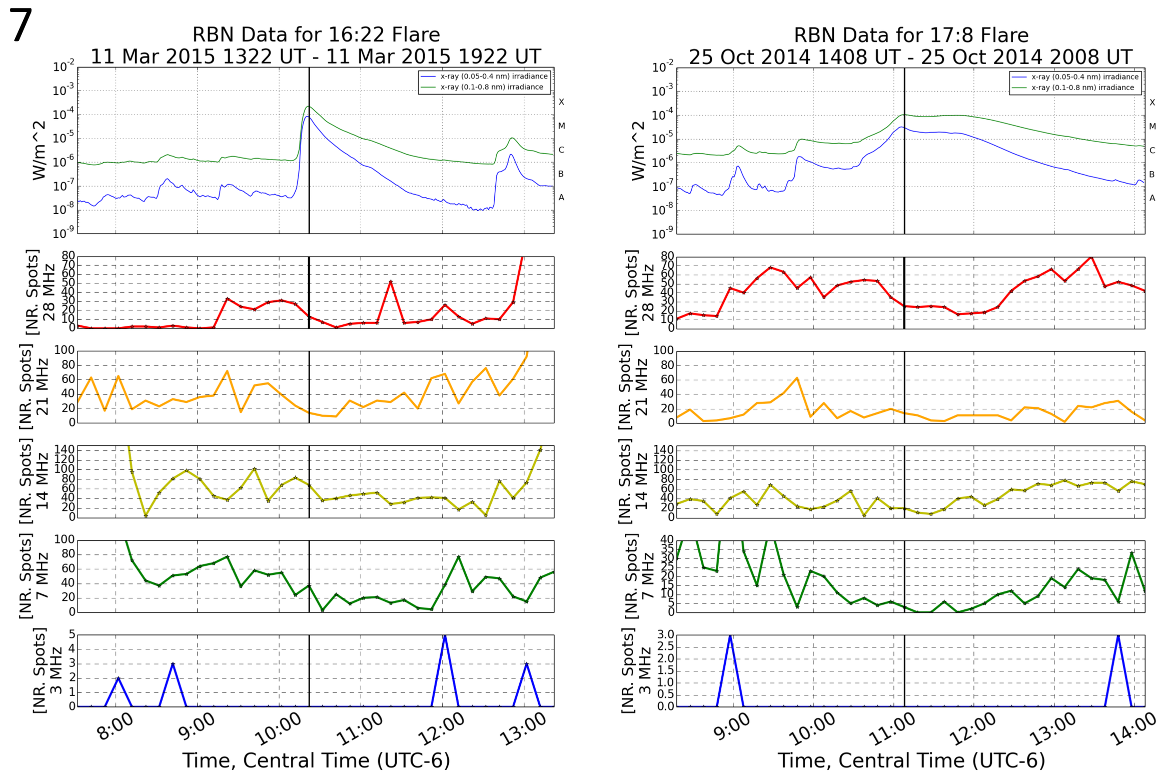


Figure 7 shows the number of spots for each frequency three hours prior to and following each event, with the flare time marked with a black line.

RBN Superposed Epoch Analysis

Figure 8

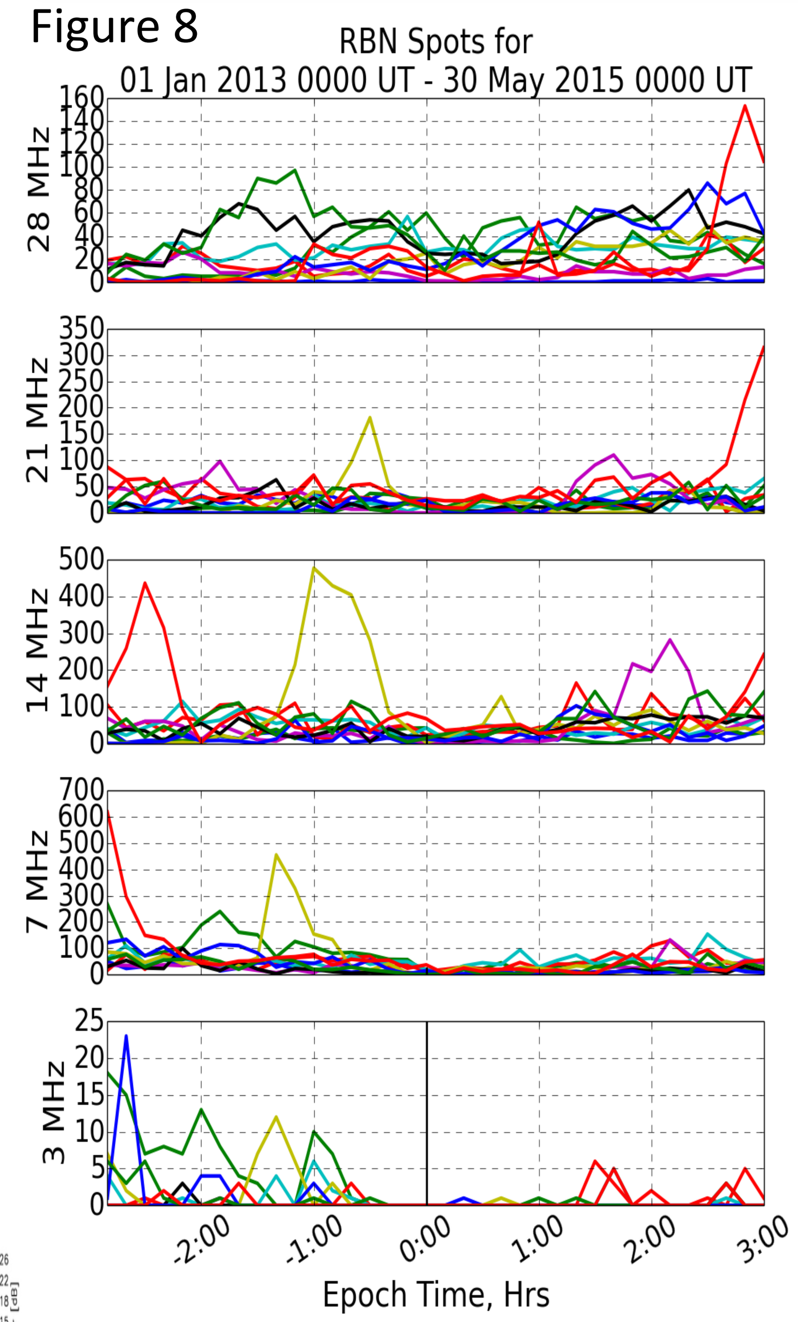
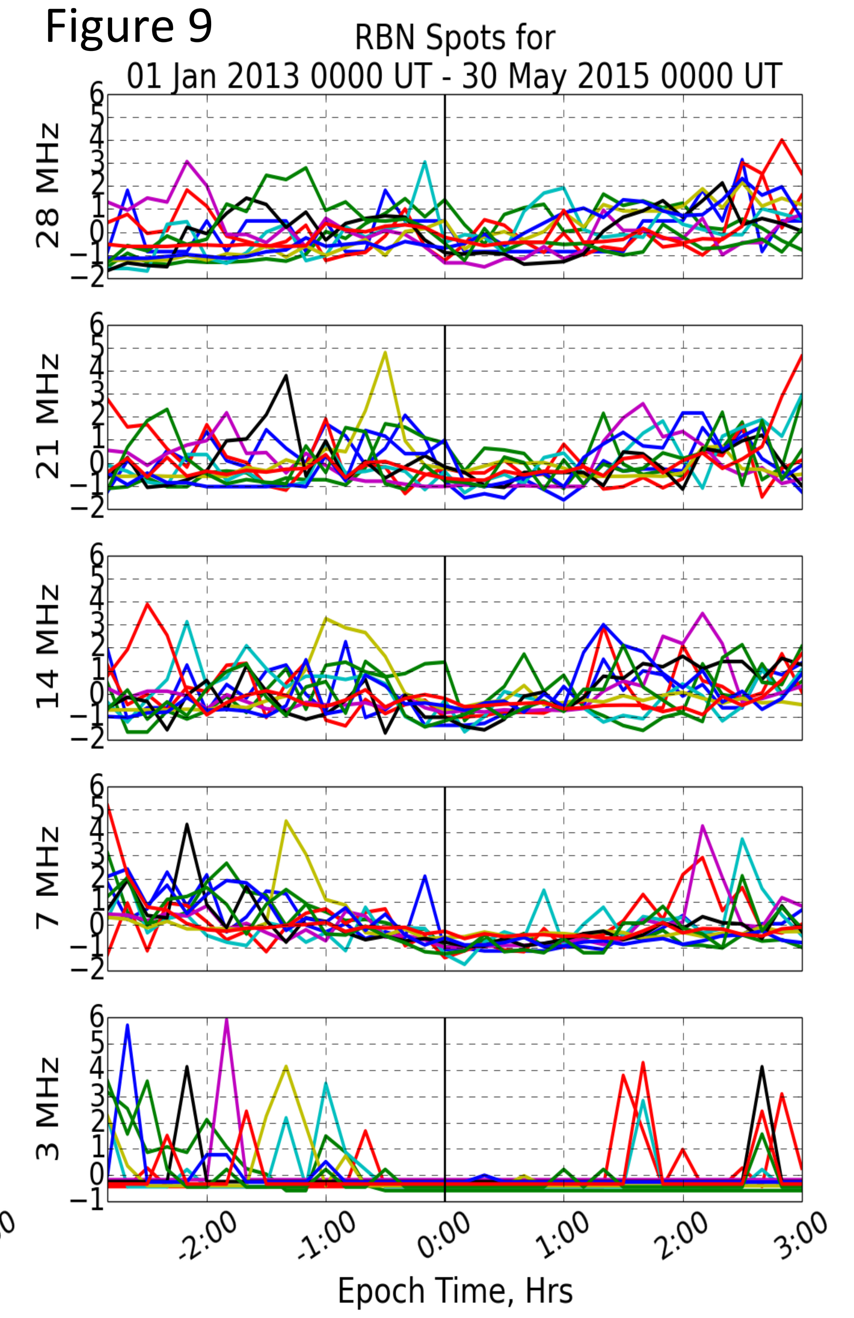


Figure 9



- A Superposed Epoch analysis was performed on dayside flares from 2013 to the present (see Figure 8 above)
- Due to the daily fluctuations in ham operator numbers, the data was scaled to better visualize the trends (Figure 9) by the formula:

$$NewVals = \frac{OldVals - mean(OldVals)}{std(OldVals)}$$

- Here the radio fadeout is seen across all frequencies, with lower bands having prolonged degradation

Conclusions

1. Results from SuperDARN and RBN data show that solar flares impact HF radio over the entire dayside
2. Communication loss is related to flare intensity and distribution
   1. Higher intensity flare events can cause complete Shortwave fadeout, whereas weaker flares may inhibit radio propagation partially
   2. The rate of communication loss is proportional to the increase in X-ray intensity
   3. The period of recovery is influenced by both the intensity of the flare and the rate at which X-ray flux declines after peak
3. There is a relationship between frequency degradation during flares
   1. Lower frequencies experience fadeout prior to flare peak, with recovery being longer
   2. The degree of loss if more severe as frequency decrease
4. Further research should focus on quantifying the relationship between flare characteristics and fadeout

References and Acknowledgments

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