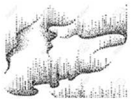
Radio Propagation Effects of a Severe Geomagnetic Disturbance

Whitham D. Reeve



Earth's magnetic field became severely disturbed on 1 December 2023 after the arrival of multiple coronal mass ejections (CME) that departed the Sun on 27 and 28 November. The collision of the first CME with Earth's magnetosphere produced a sudden impulse that was recorded by the Anchorage SAM-III magnetometer (figure 1). Another CME arrived about 90 minutes later. It had no obvious immediate effect on the geomagnetosphere but a disturbance was obvious a few hours later. These events involved not only disturbances to the geomagnetic field but also to Earth's ionosphere and HF radio propagation, which are discussed below.

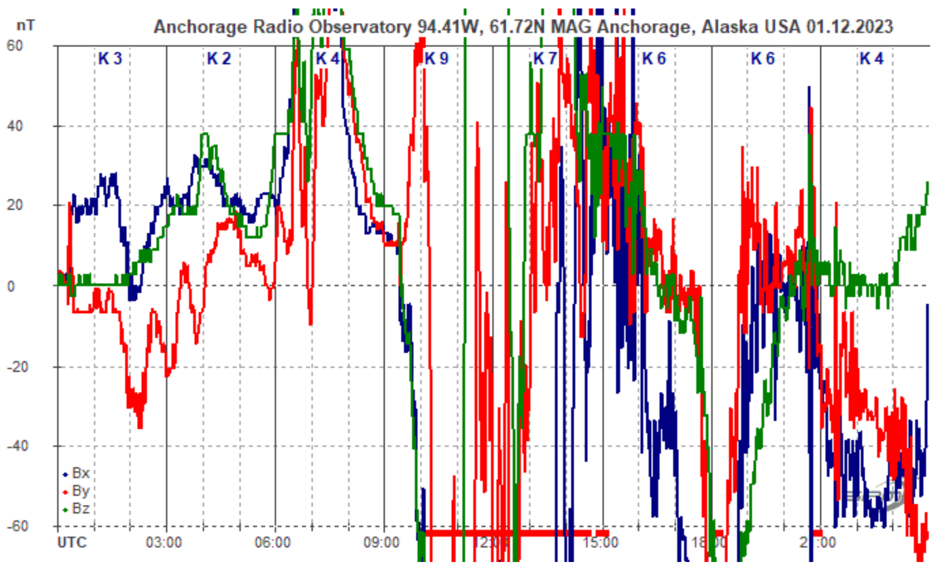


Figure 1 ~ Magnetogram (exaggerated vertical scale) at Anchorage, Alaska showing the sudden impulse at 0020 UTC on 1 December 2023; it is seen as a spike of 21 nT in By (red trace, east-west component) and rapid increase in Bx (blue trace, north-south component); Bz (green trace, vertical component) is unchanged until later. Earth's magnetic field did not become significantly disturbed until about 0600 when there was a rapid increase in all three magnetic components. This was followed 3 hours later by another much stronger increase in the By component and decrease in the Bx and Bz components. The vertical scale is exaggerated to show the deflection caused by the sudden impulse and this makes the traces of the later disturbances go off-scale.

The radio propagation effects were manifested in the HF radio band as sudden frequency deviations (figure 2) at the time of the sudden impulse and aurora radio reflections (figure 3) considerably later. Sudden frequency deviations (SFD) are caused by rapid electron density changes in the ionosphere, usually by the radiation from a solar flare; however, in this case, the ionosphere likely was compressed, heated and moved by the CME impact, which resulted in a rapid change in the wave number along the radio path. SFDs are discussed in detail in {Reeve15a} and {Reeve15b}. Auroral radio reflections are caused by increased electron density in the ionosphere's E-region due to increased precipitation and collisions of energetic solar wind particles that enter the magnetosphere and collide with the atmosphere. Aurora radio reflections are discussed in detail in {Reeve22}.

The instrumentation used for these observations was a SAM-III 3-axis magnetometer and three Icom R8600 Communications Receivers. The SAM-III uses its own software, SAM_VIEW, to collect and display data from each of three fluxgate sensors setup in the geographic coordinate system. The receivers are connected to a log periodic dipole array about 14 m above ground level. The demodulated audio output from each receiver is connected to a PC soundcard through an analog audio mixer. The receivers are setup to receive the WWV-WWVH time-frequency signals at 15, 20 and 25 MHz. The receivers are tuned with a nominal offset of 1 kHz above the carrier frequencies. With the receivers set to lower sideband (LSB) mode, the demodulated audio output is a nominal 1 kHz tone (each receiver uses a slightly different offset for identification). Argo software processes and displays narrowband waterfall spectra showing the demodulated signals from each receiver.

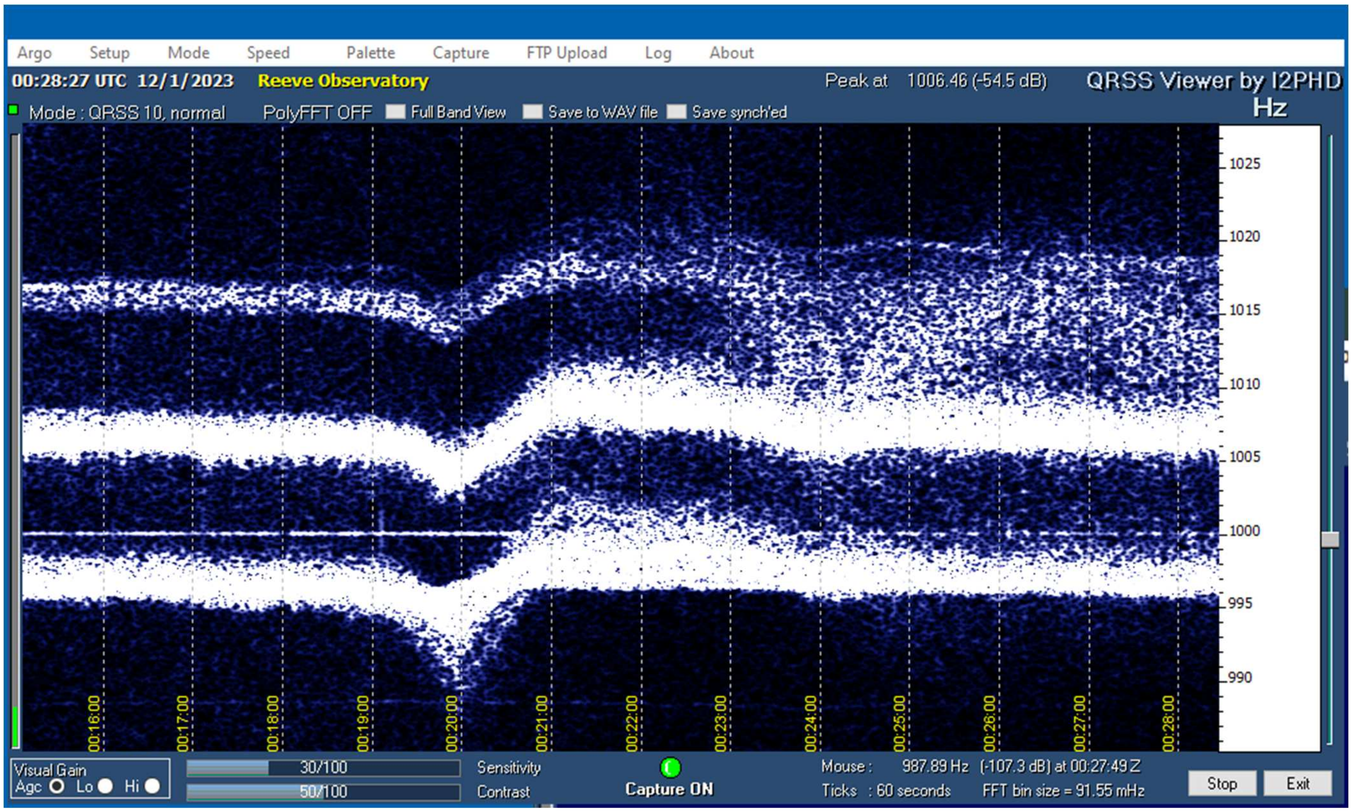


Figure 2 ~ Argo horizontal waterfall plot for 0015 to 0028 UTC on 1 December showing sudden frequency deviations of about 5 Hz at the time of CME impact with Earth's magnetosphere – the peak deviation was at 0020. The traces for three carrier frequencies are shown: Lower trace, either WWV or WWVH on 15 MHz; Middle trace, WWV on 20 MHz; Upper trace, WWV on 25 MHz. The diffuse nature of the traces is due to the rapid constructive and destructive combining of signals from multiple reflective propagation paths. The faint straight horizontal trace at 1000 Hz is a spurious signal.

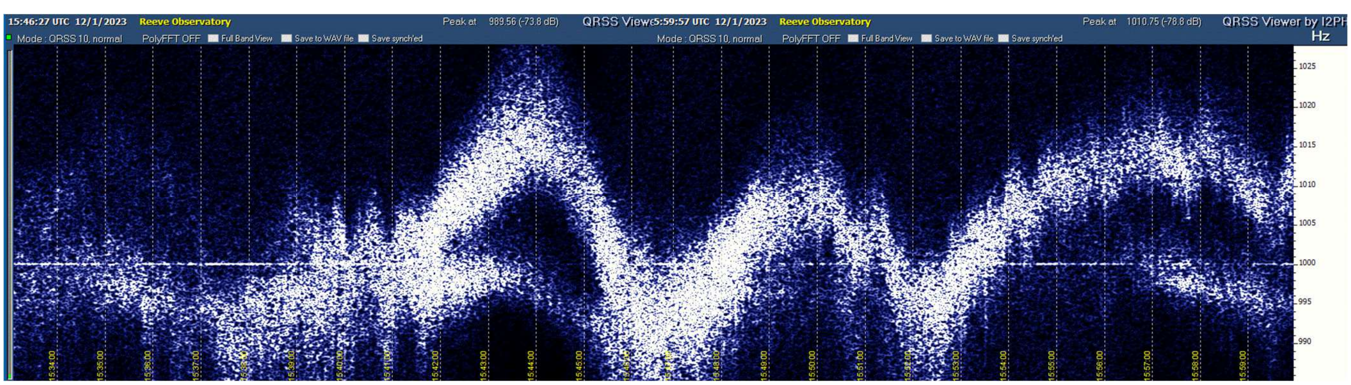


Figure 3 ~ Argo plot for 1534 to 1559 UTC, approximately 15 hours after the sudden frequency deviations above and several hours after the geomagnetic storm was well underway. The plot is two 12-minute Argo images that have been spliced together. The frequency scale on the right is 985 to 1028 Hz. The diffuse traces are the demodulated 15 MHz carrier, probably WWVH, after being reflected by aurora to the antenna and receiver system at Anchorage. Doppler frequency shifts caused by the rapidly moving electron clouds associated with the aurora led to the 25-30 Hz peak-peak quasi-cyclic frequency drift with an approximate period of 6 minutes. The faint straight horizontal trace at 1000 Hz is a spurious signal.

{Reeve15a} Reeve, W., Part I ~ Sudden Frequency Deviations Caused by Solar Flares, Concepts, 2015, download: https://reeve.com/Documents/Articles%20Papers/Propagation%20Anomalies/Reeve_SuddenFreqDevConcepts_P1.pdf

{Reeve15b} Reeve, W., Part II ~ Sudden Frequency Deviations Caused by Solar Flares, Instrumentation and Observations, 2015, download: https://reeve.com/Documents/Articles%20Papers/Propagation%20Anomalies/Reeve_SuddenFreqDevMeas_P2.pdf

{Reeve22} HF Aurora Reflections Observed at Anchorage, Alaska USA, 2022, download: https://reeve.com/Documents/Articles%20Papers/Reeve_AuroraRadioObsrv.pdf