Sudden Frequency Deviations with Magnetic Effects Observed at Anchorage, Alaska

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Introduction: I previously reported an observation for 1 June 2024 of sudden frequency deviations (SFD) and radio blackout at 15 and 20 MHz (figure 1) {Reeve24}. These were produced by an X1.0 x-ray flare. An X1.2 x-ray flare 43 days later on 14 July produced SFDs at the same frequencies but no radio blackout (figure 2); the D-Region Absorption Prediction (D-RAP) plot shows the absorption too far west to affect the radio circuits (figure 3). The 14 July flare also produced geomagnetic effects described later. An M7.3 x-ray flare another 20 days later on 3 August produced strong SFDs (figure 4) and relatively minor radio blackout effects (figure 5). The principles of sudden frequency deviations may be found in {Reeve15}.

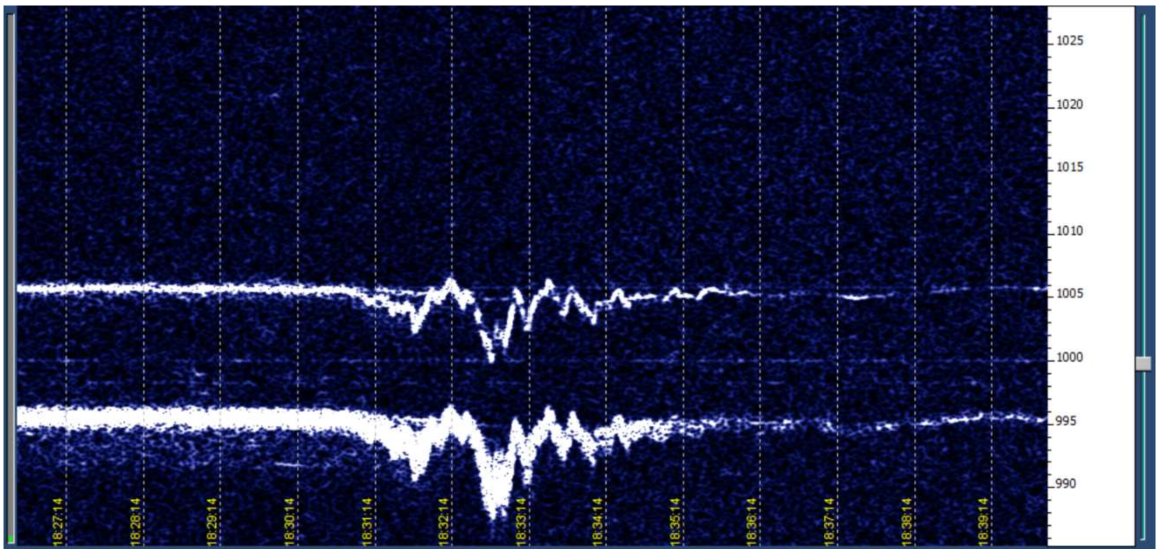

Figure 1 ~ Narrowband waterfall spectra from 1827 to 1840 UTC on 1 June observed at Anchorage, Alaska. The SFD starts at 1831 at both frequencies with a maximum peak-to-peak deviation of approximately 9 Hz at 15 MHz and 5 Hz at 20 MHz. The fainter traces following the SFDs indicate the onset of the radio blackout and reduced received signal levels. See text for a description of Argo plot features.

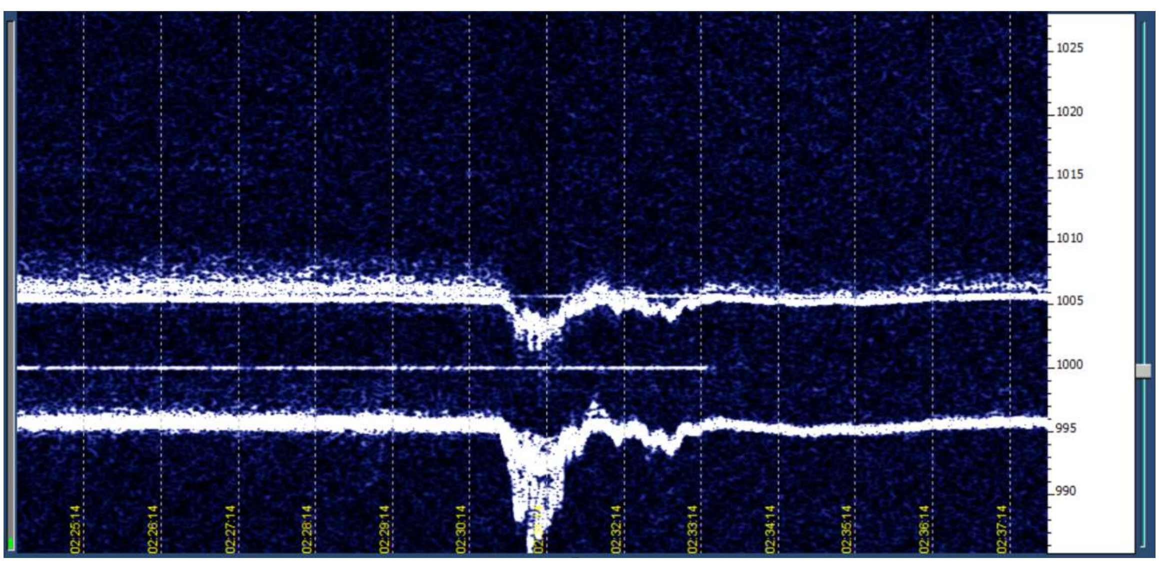

Figure 2 ~ Narrowband waterfall spectra from 0224 to 0238 UTC on 14 July observed at Anchorage, Alaska. The SFD starts just before 0231 at both frequencies with a maximum peak-to-peak deviation of at least 12 Hz at 15 MHz (lower trace) and 4 Hz at 20 MHz (upper trace). The thin trace at 1000 Hz is spurious but curiously ends at the time the SFDs end.

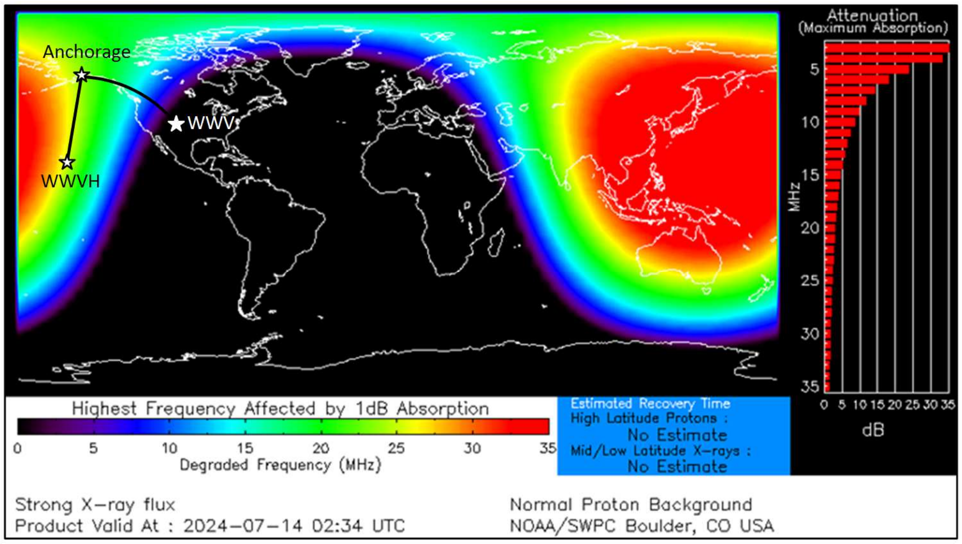

Figure 3 ~ Annotated D-RAP image for 0234 on 14 July shows that 20-26 MHz (green-yellow) are the highest frequencies to experience 1 dB absorption on southerly and westerly propagation paths to Anchorage at upper-left in southwestern Alaska from the WWVH in Hawaii and WWV in Colorado, respectively. Both path lengths are roughly 4000 km. Generally, lower frequencies experience more absorption (see histogram at right) but, in this case, absorption loss at 15 and 20 MHz was not apparent in the waterfall spectra shown above. Underlying image source: https://www.swpc.noaa.gov/products/d-region-absorption-predictions-d-rap

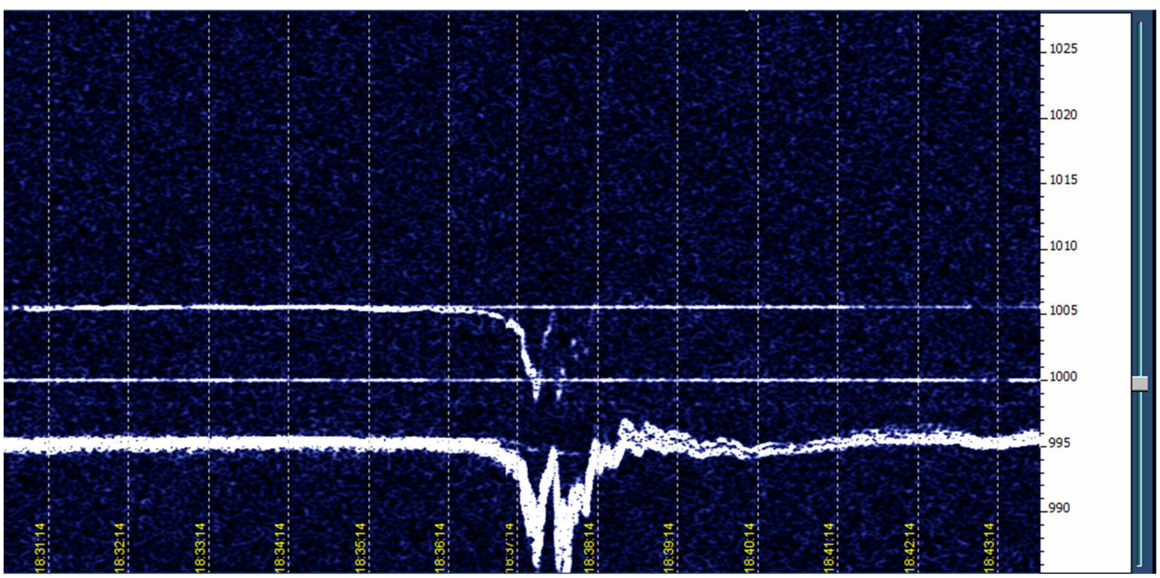

Figure 4 ~ Narrowband waterfall spectra from 1831 to 1844 UTC on 3 August observed at Anchorage, Alaska. The SFD starts at 1837 at both frequencies with a maximum peak-to-peak deviation of at least 12 Hz at 15 MHz (lower trace) and 6 Hz at 20 MHz (upper trace). The 20 MHz trace is relatively weak and appears to be an overlay of two signals but, since only WWV operates at 20 MHz, the straight thin trace probably is spurious. The thin trace at 1000 Hz is spurious. The double-peak may be caused by rapid expansion or contraction of the enhanced electron density slab or heating effects produced by the solar flare radiation. Real-time Argo plots are posted at: https://reeve.com/Meteor/Meteor_simple.html .

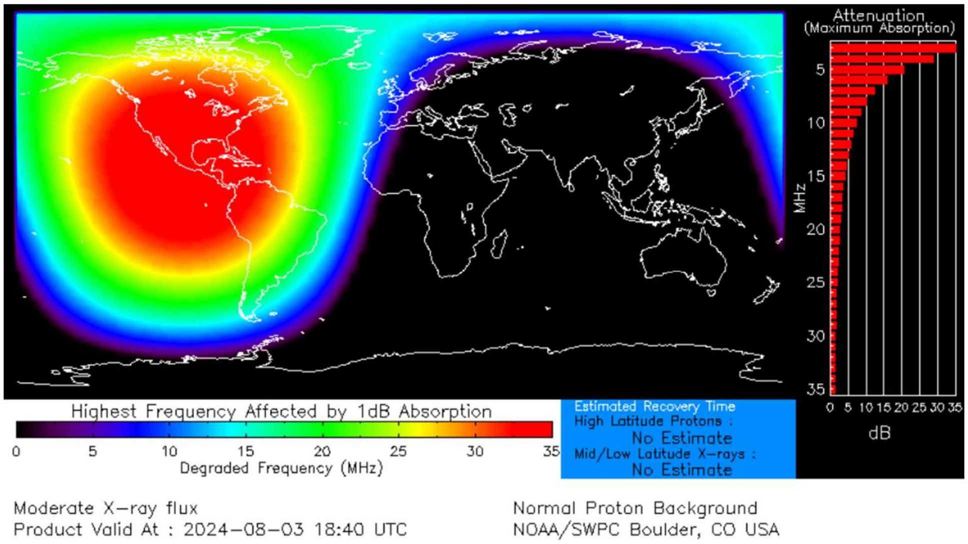

Figure 5 ~ D-RAP image for 1840 on 3 August shows 1 dB absorption at relatively high frequencies (26-35 MHz) with modest absorption at 15 and 20 MHz on the two radio paths to Anchorage. Image source: https://www.swpc.noaa.gov/products/d-region-absorption-predictions-d-rap

Geomagnetic effects: The 14 July flare produced a Solar Flare Effect (SFE), or Magnetic Crochet (so called because of its hook shape), that was detected by the Anchorage and HAARP SAM-III magnetometers (figure 6). No SFE was detected for the 3 August event.

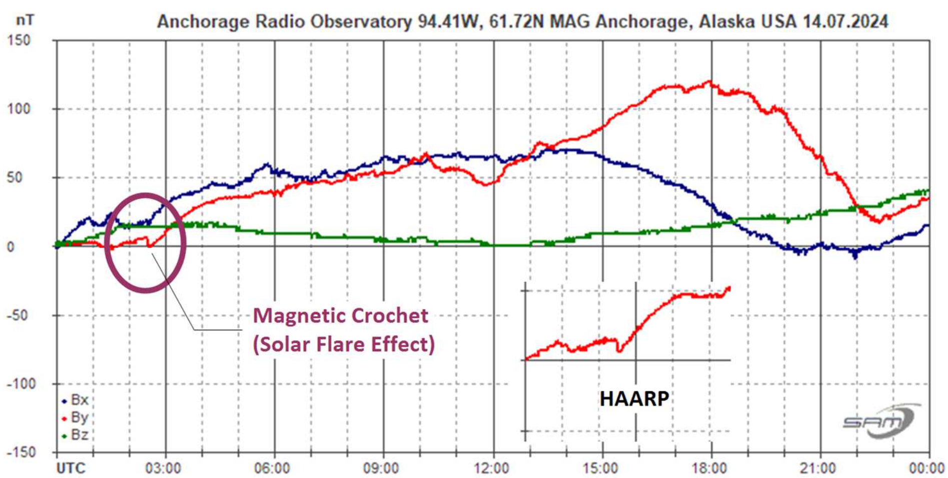

Figure 6 ~ Anchorage magnetogram for 14 July shows a Magnetic Crochet (circled). The effect, about 5 nT seen at 0230, is obvious only in the Y-component (east-west, red trace) of the local geomagnetic field. The local solar time was 4:30 pm. Inset shows the Y-component at the same scale observed by the SAM-III magnetometer at HAARP about 290 km east-northeast of Anchorage.

SFEs are very rare and are produced when a strong solar flare peaks very quickly. The rapid increase in x-ray radiation increases the electron density and conductivity in the ionosphere's D- and E-regions, quickly enabling higher current flow at those altitudes. The current produces a magnetic field that enhances or reduces Earth's ambient magnetic field at ground level depending on the magnetometer location with respect to the current. As the flare subsides, the ionosphere, electric currents and magnetic field return to their preflare conditions. Here, the rapid change in the external magnetic field momentarily opposed the local ambient field, reducing its east-west component by about 5 nT. For reference, the east-west component of the ambient field on 14 July at Anchorage was 3836 nT and 3932 nT at HAARP (values based on the *International Geomagnetic Reference Field, IGRF*, see {NOAA}).

SFEs are most often detected by magnetometers close to the sub-solar point, which is the point on Earth where the Sun is overhead and its radiation penetrating to the ionosphere is the strongest; however, in this case, the Sun was around 30° elevation and 4.4 hours west of Anchorage and 4.7 hours west of HAARP. The time offset is also seen in the first D-RAP image above (the Sun is at the center of the red area over the western Pacific).

<u>Instrumentation</u>: Icom R-8600 Communications Receivers were used at Anchorage Radio Observatory (figure 7). The receivers were connected through a receiver multicoupler to a rotatable KMA-1832 log periodic dipole array pointed south. The receivers were tuned nominally 1 kHz above the carrier frequency and set to the Lower Sideband (LSB) mode. This configuration demodulates as a nominal 1 kHz tone when the carrier is received. The demodulated audio outputs were connected to the PC soundcard Line In jack through a 6-port analog audio mixer.

The narrowband horizontal waterfall plots were produced by Argo software (see previous images). In the Argo plots, time is indicated left-to-right with 1 minute tick-marks (dotted vertical yellow lines). The frequencies of the demodulated carriers are indicated on the right vertical scale from 985 to 1030 Hz. The lower trace at 995 Hz corresponds to a 15 MHz carrier frequency (WWV and WWVH), and the trace at 1005 Hz near the middle of the frequency scale corresponds to a 20 MHz carrier frequency (WWV). Not seen in the plots is a trace at 1015 Hz corresponding to a 25 MHz transmitter (WWV), which was not being received at the time of the SFDs.

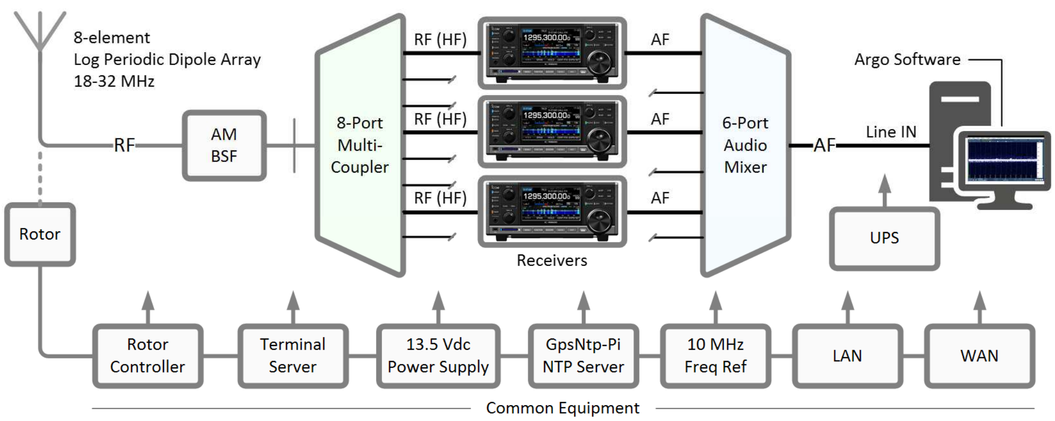

Figure 7 ~ Partial radio system block diagram. Only receivers, antenna and common equipment used in the present observations are shown here; additional receivers and antennas are equipped and assigned to projects as needed. The R8600 receivers are individually tuned to the desired carrier frequencies and offsets and the antenna is rotated south except when needed for other purposes. The horizontally polarized antenna has 8 elements and a design frequency range of 18 – 32 MHz but it is used over a much wider frequency range. A GNSS disciplined oscillator provides a 10 MHz reference frequency to the receivers, and a GNSS disciplined Network Time Protocol (NTP) server ensures accurate real-time clock and timestamps in the PC that runs the Argo software and other PCs on the LAN.

Geomagnetic observations were obtained from the SAM-III magnetometer at Anchorage Radio Observatory (figure 8). The SAM-III magnetometer at HAARP near Gakona provided confirmation of the SFE reported above. At Anchorage, the magnetometer sensors are remotely located approximately 30 m from the controller and 15 m from the LPDA antenna tower. To reduce temperature effects the sensors are buried 1 m below the ground surface in an area shaded by foliage. The three magnetic field sensors are configured in the *geocentric coordinate system* with the X-component sensor oriented +north, Y-component +east and Z-component vertical

+down. The magnetometer has been in-service since 2009. Real-time magnetograms for Anchorage are posted at: https://reeve.com/SAM/SAM_simple.html .

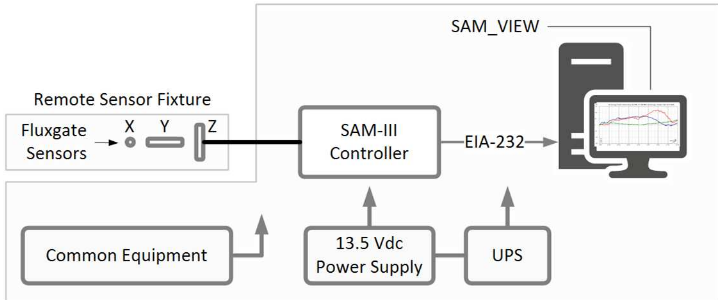

Figure 8 ~ SAM-III magnetometer block diagram. The magnetometer is configured to sample the three magnetic field components at 0.1 Hz rate. It displays the components in variometer mode but it also records absolute magnetic flux density measurements. The SAM-III uses some of the same common equipment as the radio equipment shown above (for example, NTP time server, LAN and WAN), but the controller is in a different physical location and the SAM_VIEW software runs on a different PC.

References:

{NOAA} Magnetic Field Calculators, Magnetic Field Estimated Values: https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#igrfwmm

{Reeve15} Reeve, W., Sudden Frequency Deviations Caused by Solar Flares, Part I ~ Concepts: https://reeve.com/Documents/Articles%20Papers/Propagation%20Anomalies/Reeve_SuddenFreqDevConcepts_P1.pdf

{Reeve24} Reeve, W., Sudden Frequency Deviations and Radio Blackout Observed at Anchorage, Alaska: https://reeve.com/Documents/Articles%20Papers/Observations/Reeve_SFD_01Jun2024.pdf