Sample of HF Radio Reflections from Aurora Observed at Anchorage, Alaska USA

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At almost exactly 0600 UTC on 20 February 2021 (9:00 pm local on 19 February), I noticed a bright wavering trace in the Argo plot running on one of my observatory PCs (figure 1). The associated receiver is tuned to 15 000 995 Hz LSB and the demodulated carrier is indicated at 995 Hz on the Argo plot. The trace had not been there for at least 15 min before. Coincidentally, I had my SAM-III magnetogram webpage displayed on the same PC, and it simultaneously showed a very rapid increase in the magnetic induction of all magnetic field components (figure 2).

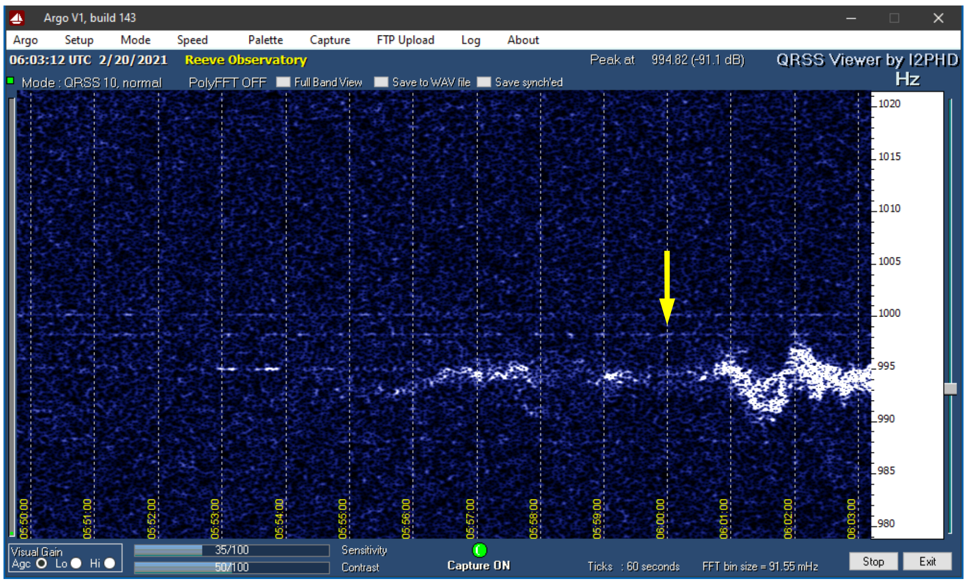


Figure 1 ~ 12-min Argo horizontal waterfall record from 20 February 2021 starting at 0538 and ending at 0603 UTC. The demodulated frequency is shown on the right vertical scale and time-stamps are shown along the bottom in yellow. In this case, the 15 MHz carrier is demodulated to 995 Hz. The yellow arrow marks the nominal start of the aurora reflections at 0600. The traces of aurora reflections exhibit a thick structure and rapid frequency shifts. The trace during *normal* propagation is thin and straight.

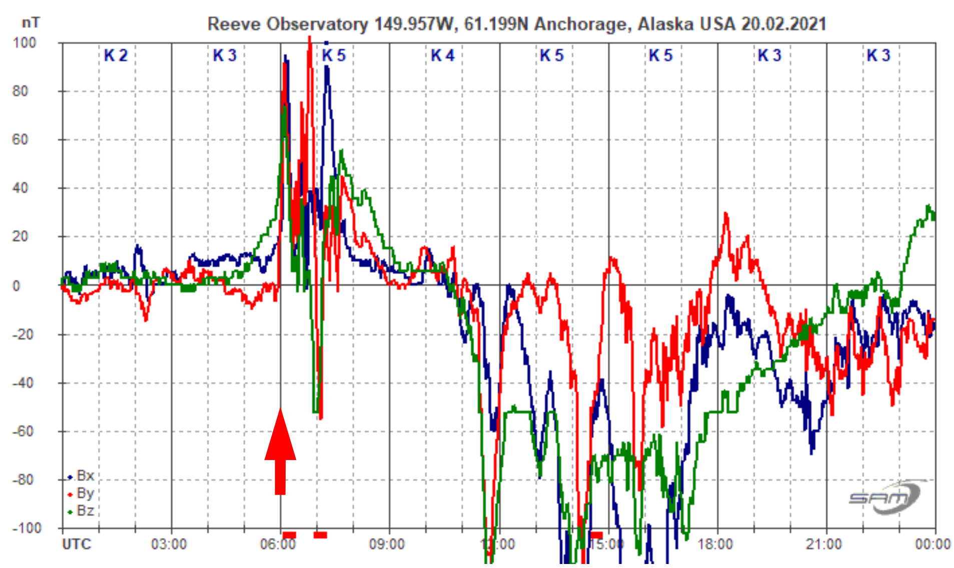


Figure 2 ~ 24-h SAM-III magnetogram for 20 February 2021. The vertical axis has been scaled to match the values for the time period 0600 to 0800; later activity is off-scale. Note the near-step-change in the red trace (By) at 0600 marked by the red arrow. Also, note that Earth's magnetic field almost returned to pre-storm levels by 0900, but then experienced a bay (decrease) lasting the rest of the day.

It is well-known that rapid field changes measured by ground magnetometers indicate the high-probability of aurora, which, in turn, indicates the possibility of radio reflections from the aurora (see sidebar at end). I have seen simultaneous magnetic activity and HF radio reflections in my SAM-III and Argo data many times but never before watched them in real-time. I usually see aurora radio reflections in data that are produced near local solar midnight (around 1000 UTC ±3 h), but the event described here occurred a little earlier. The event was not unique. The next night (21 February) the magnetic field By component rapidly increased at 0830 to K5 K-index resulting in 15 MHz enhancements and rapid frequency shifts similar to the night before. These events involved either the time-frequency station WWV or WWVH; however, because the propagation path between WWVH and Anchorage is oriented north-south, it is believed that WWVH is the one being reflected by the aurora (aurora reflections are most often received along north-south paths).

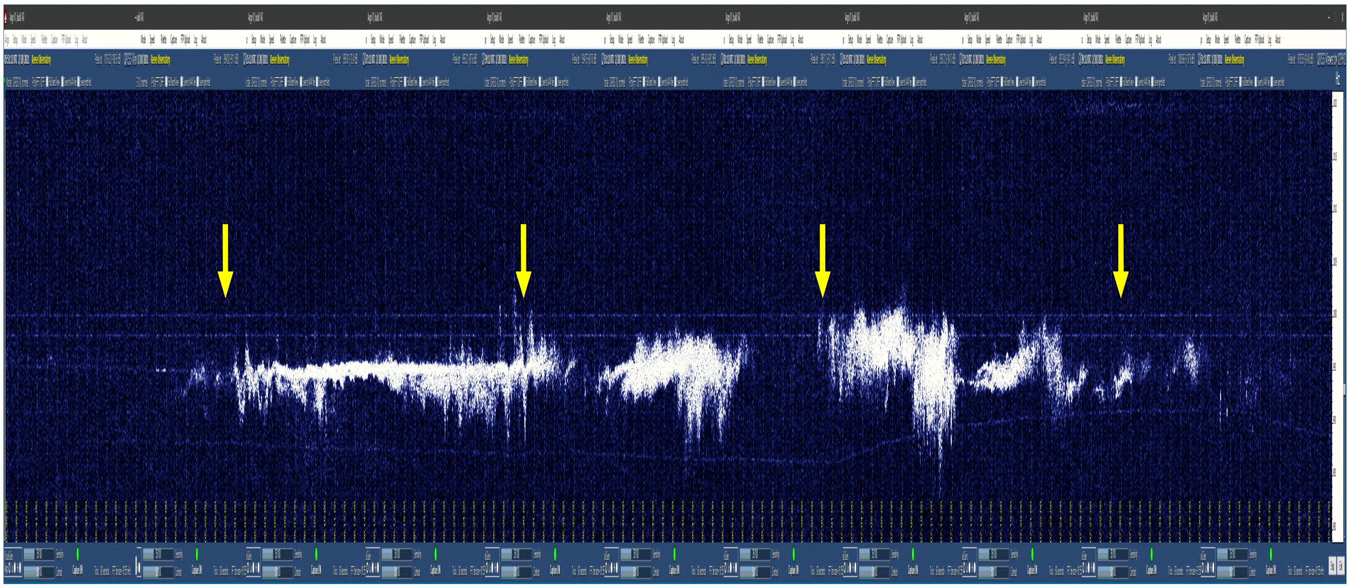


Figure 3 ~ Eleven Argo images spliced together for the time span 0538 to 0751 to cover the 2-h event. The spliced images have been stretched vertically to better show the Doppler frequency shifts of –11 to +7 Hz. Yellow arrows are time markers for (left-to-right) 0600, 0630, 0700 and 0730 UTC.

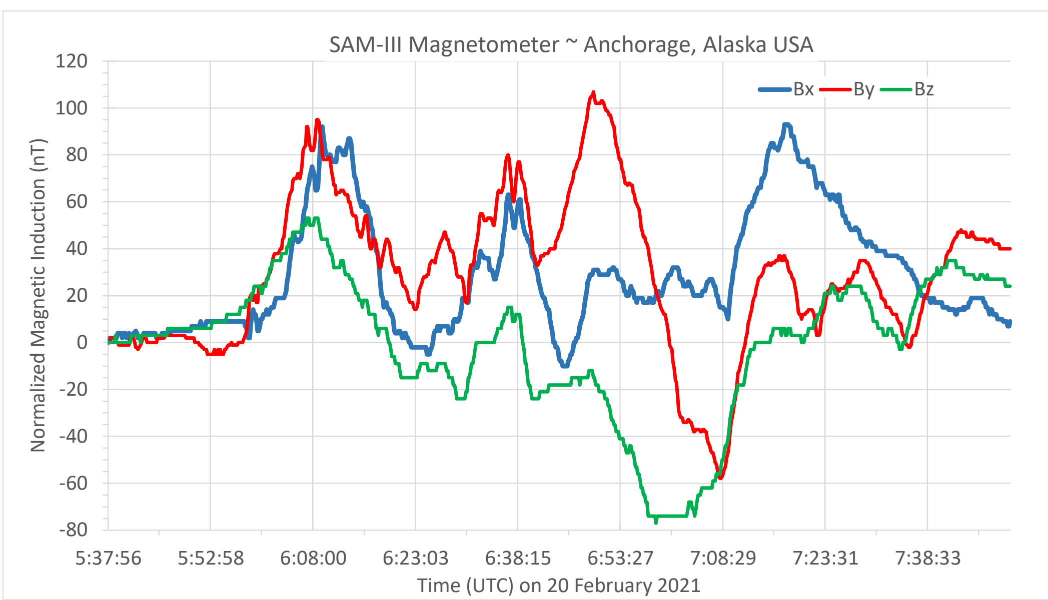
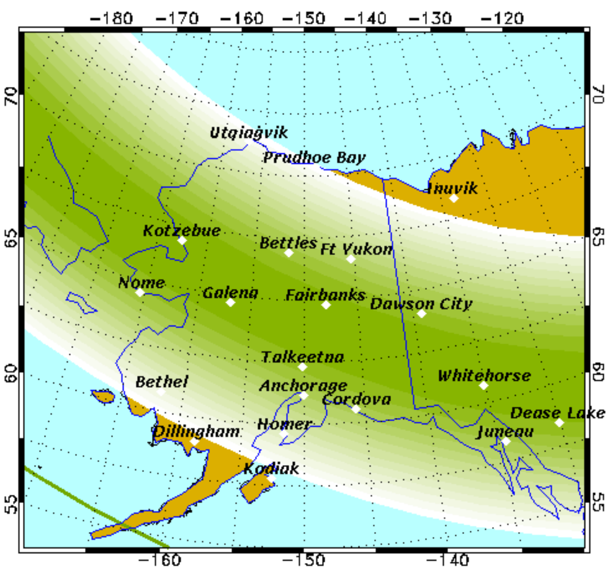


Figure 4 ~ Normalized magnetic data Bx, By and Bz from the Anchorage SAM-III magnetometer covering the same time period as the spliced Argo images shown in the previous figure. The perturbations shown here were followed by a K-index = K5 for the 3-h synoptic period 0600 to 0900 UTC.

This aurora reflection and magnetic event on 20 February lasted about 2 h. Each Argo horizontal waterfall image is 12 min long, so to show the entire event, I spliced 11 images staring at 0538 and ending 0751 UTC (figure 3). A characteristic of aurora radio reflections is their wild frequency changes from Doppler shifts caused by rapid changes in the electron cloud columns associated with the aurora – these changes could be in electron density or drift movement, or both. The frequency shifts are clearly evident in the spliced images but the Doppler frequency range of –11 to +7 Hz is low compared to many reflection events I have observed.

The SAM-III magnetic data is replotted for the 2-h period (figure 4). The data have been normalized to the value of each component at the beginning of the period so that only the positive and negative deflections through the period are shown. Aurora forecasts for 20 February showed the likely outcome of the geomagnetic activity (figure 5), but I could not verify them because aurora was not visible at my observatory due to light pollution.



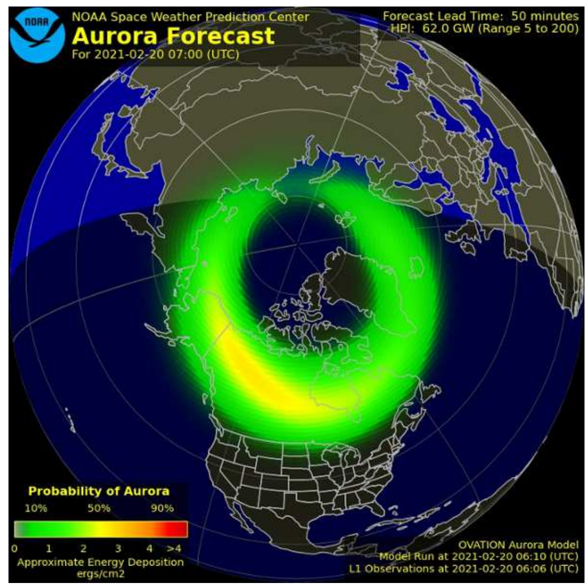


Figure 5 ~ Left: Aurora forecast for 20 February 2021 showing the maximum expansion of the auroral oval above Alaska. Anchorage normally is on the southern edge of the auroral oval but, as can be seen in this prediction, it is well embedded. Image source: University of Alaska Geophysical Institute {UAF-G}. Right: Northern hemisphere aurora forecast for 0600 UTC 20 February based on the OVATION Aurora Model shows similar predictions. Image source: Space Weather Prediction Center {SWPC}.

According to Space Weather Prediction Center (SWPC), Earth's magnetic field was under the influence of a coronal hole high-speed stream (CHHSS) during the period in question. Along with a solar wind velocity increase to 605 km s^{-1}, the Bz vector component of the interplanetary magnetic field (IMF) pointed southward several times to as much as –11 nT. A southward Bz can cause magnetic disturbances through magnetic reconnection with Earth's magnetosphere. (Note: The Bz component of the IMF is defined differently than the Bz component of Earth's magnetic field, see {Reeve15}). As seen in the 24-h SAM-III magnetogram above, magnetic storm conditions (K-index = K5) reappeared at 1100 and lasted until about 1800; however, these did not produce aurora radio reflections on 15, 20 or 25 MHz at Anchorage.

The WWV and WWVH transmitters are about 4000 km from Anchorage (figure 6) and involve multi-hop propagation. The reflections were observed with an Icom R-8600 general coverage receiver. The receiver AGC was turned off, and the receiver was connected to a rotatable 8-element log periodic dipole array through a multicoupler. Another R-8600 was monitoring WWV at 25 MHz but there were no reflections at that frequency. A block diagram shows the general configuration (figure 7). The Argo software is setup for QRSS10 mode with a waterfall length of 720 s (12 min). Argo is adjusted to show a frequency span from 980 to 1020 Hz, which encompasses the receiver settings mentioned above.

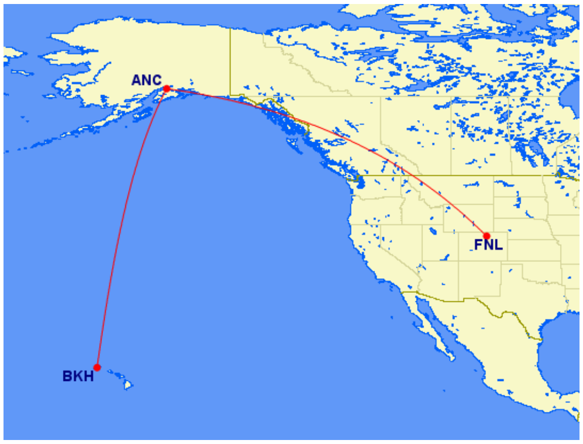


Figure 6 ~ Great circle paths shown in red between WWV near Fort Collins, Colorado (FNL) and Anchorage (ANC) and between WWVH near Kekaha on Kauai, Hawaii (BKH) and Anchorage. The WWVH path is 4414 km and almost entirely over water and encounters different propagation conditions than the WWV path, which is 3801 km and entirely over land. The paths are long enough to require multi-hop propagation. Anchorage is at the southern edge of the auroral oval, which introduces additional complicating factors in propagation toward Anchorage. It is believed that the aurora reflections involve WWVH because of its near-north-south alignment with Anchorage. Image from {GCMap}.

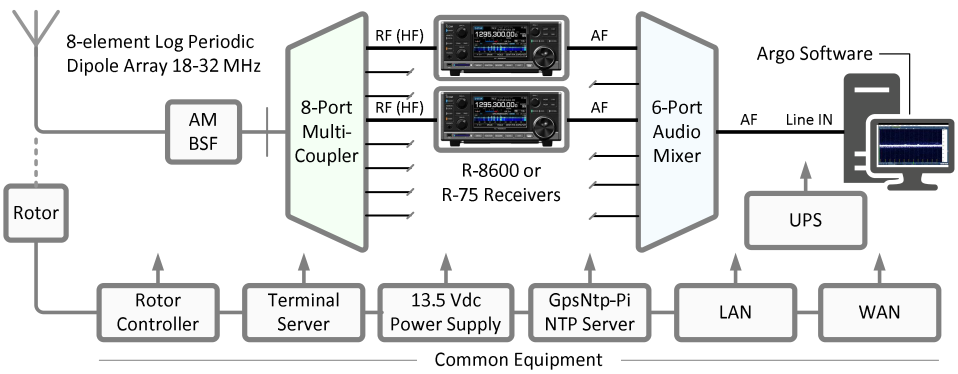


Figure 7 ~ Receiver and antenna system block diagram. PC timing is controlled by two GPS receiver-based network time servers. Common equipment includes infrastructure shared with other observatory equipment. The antenna usually was rotated to point at WWV on a true azimuth of 107°. Image ©2020 W. Reeve

Radio Aurora: Radio reflections from aurora involve solar wind coupling to the magnetosphere during magnetic reconnection (southward Bz in the IMF). The reconnection energizes magnetospheric electrons in the magnetotail. which move back toward Earth where they precipitate into the upper atmosphere along magnetic field lines marked by the *auroral oval*. The electrons collide with atomic and molecular gases in the atmosphere and increase the ionization and electron density, particularly at altitudes of around 100 km (ionosphere E-region). Some of the energy is converted to light and seen as sheets, rays and waves of visible aurora. Since the free electrons follow the magnetic field lines, they form tilted columns of relatively high-density clouds that are able to reflect radio waves. These reflected waves are received when the transmitter, reflective columns and receiver lie in a plane such that the incident and reflection angle are about the same. Rapid fading (also called *flutter* or *sputter*) is a characteristic of radio aurora due to changes in the electron density or drift or movement of the columnar field-aligned electron clouds.

Weblinks and references:

{GCMap} http://www.gcmap.com/mapui?P=FNL-anc-bkh
{Reeve15} http://www.reeve.com/Documents/SAM/GeomagnetismTutorial.pdf
{SWPC} https://www.swpc.noaa.gov/communities/space-weather-enthusiasts
{UAF-GI} https://www.gi.alaska.edu/monitors/aurora-forecast