HAARP Riometer Observations ~ 17 March 2025

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Introduction: The *Relative Ionospheric Opacity Meter*, or Riometer, is a very stable receiver and antenna system used to measure radio wave absorption in the D-region of the terrestrial ionosphere. The signal source for the Riometer is the Galactic synchrotron radiation that pervades the Milky Way Galaxy (figure 1). The Riometer frequency is set far above the ionosphere's E- and F-region critical frequencies so that any decrease in the received Galactic background radiation is attributed to D-region absorption. The measured absorption at the Riometer frequency may then be translated to other frequencies of interest using empirically derived formulas.

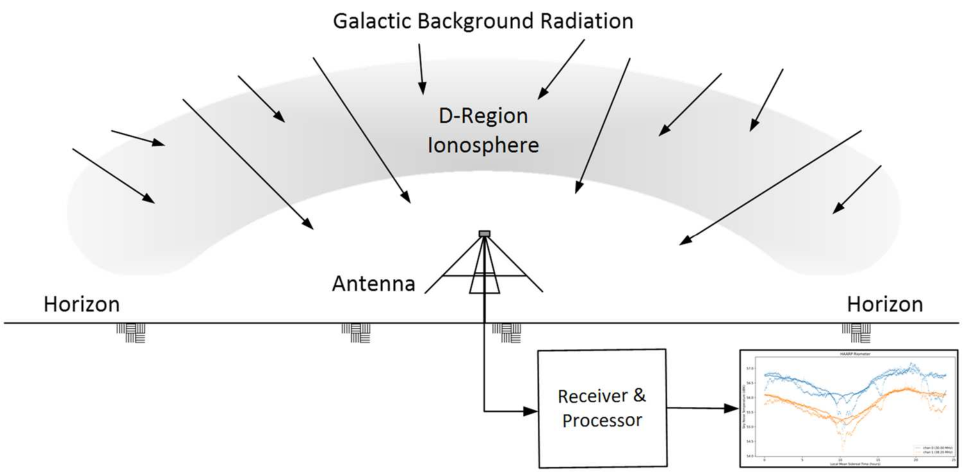

Figure 1 ~ The ever-present Galactic background radiation received on the ground follows a consistent pattern throughout each day when the ionosphere is quiet. When the ionosphere is disturbed, the absorption increases in the D-region and is seen as a reduction in the received power compared to a quiet day.

A new Riometer was commissioned at the HAARP facility in Alaska in January of 2025 and its data is the basis for this article. The new Riometer is one of several diagnostic instruments located near the *Ionospheric Research Instrument* (IRI) at the HAARP facility. It complements the existing ionosonde, which is a diagnostic instrument used to determine the critical frequencies for heating experiments in the ionosphere's E- and F-regions. However, D-region absorption often prevents the ionosonde from determining the upper region critical frequencies, so the Riometer is used to determine when those conditions occur and what changes to an experiment are necessary.

Absorption: D-region absorption has three primary causes, which depend somewhat on the latitude. At lower latitudes (< 60° magnetic) solar flare radiation can deeply penetrate Earth's atmosphere and reach the ionosphere's D-region, causing a sudden increase in electron density and the possibility of electron collisions with neutral atmospheric particles. The higher collision rate leads directly to a significant and rapid increase in the amount of absorption. Absorption from solar flares is a daytime phenomenon.

Absorption caused by solar flares at higher latitudes (≥ 60° magnetic) does occur but is less frequent than at lower latitudes because the flare radiation penetrates the atmosphere obliquely, losing its energy as it travels farther to the D-region. HAARP's magnetic latitude is 63° north and, depending on magnetic conditions, it sits near the southern edge or directly below the *Auroral Oval*. The Auroral Oval is the donut shaped region at high latitudes that marks the footprints of magnetic field lines where aurora and other electromagnetic phenomena are produced.

Absorption at higher latitudes is more commonly from two sources of *particle precipitation*. In general, precipitation patterns are controlled by Earth's magnetic field and the sources of the particles (figure 2). These phenomena can produce absorption during the day or night:

- *Solar Energetic Particles* (SEP). SEPs, mostly protons, are associated with particularly strong solar flares. The highly energetic protons, travelling at fractions of light speed, are able to enter the magnetosphere where they become trapped by Earth's densely packed magnetic field lines whose footprints map to Earth's polar cap. As the protons spiral down the magnetic field lines (precipitate), they collide with atmospheric molecules and atoms in the D-region, which increases the ionization. The electrons are excited by radio waves, in this case the sky noise, and have a higher probability of collisions and, thus, absorption. This phenomenon ordinarily occurs within roughly 20° latitude of the magnetic poles and so is called *Polar Cap Absorption* (PCA). However, during magnetically disturbed periods, the protons may precipitate into the Auroral Oval. PCA events are indicated on the D-Region Absorption Prediction (D-RAP) plots posted by NOAA at: https://www.swpc.noaa.gov/products/d-region-absorption-predictions-d-rap ;
- *Magnetic disturbance*. if the Interplanetary Magnetic Field (IMF), which is blown by the solar wind, has a southward component, it is able to merge with Earth's magnetic field and cause a magnetic disturbance. Energetic electrons in the solar wind, enhanced by a coronal hole high-speed stream (CHHSS) or coronal mass ejection (CME), are able to enter the magnetosphere where they are trapped by the terrestrial magnetic field lines marked by the Auroral Oval. A related source of energetic electrons is the magnetotail. The electrons are temporarily stored there, and the process of reconnection in the magnetotail, related to a previous merging event on the Sunward side, convects them toward Earth where they precipitate along the magnetic field lines marked by the Auroral Oval. The precipitating electrons collide with neutral atmospheric particles, increasing the ionization and the likelihood of further collisions and absorption. This cause of absorption is far more common at higher latitudes than any other.

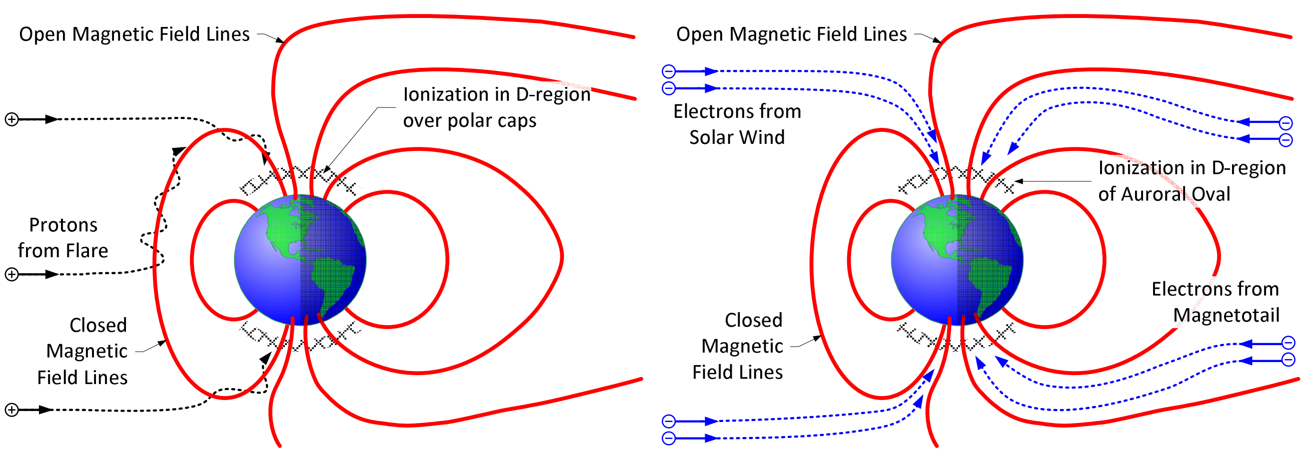

Figure 2 ~ Energetic particle precipitation. Left: Protons accelerated by a strong solar flare reach Earth in minutes to hours where they are trapped by closed magnetic field lines; Right: Energetic electrons from coronal hole high-speed streams or coronal mass ejections reach Earth days after leaving the Sun. They enter the magnetosphere along open magnetic field lines during a magnetic disturbance or are convected along field lines during reconnection in the magnetotail.

Events of 17 March: Even though there is a lower likelihood of solar flare effects on absorption at higher latitudes, two solar x-ray flares (table 1) occurred during the local morning and afternoon on 17 March, both of which led to absorption events in the D-region above the HAARP facility. Coincidentally, these events occurred only three days before the Spring (Vernal) Equinox when the Sun is directly above the equator.

Table 1 ~ Flares relevant to absorption events on 17 March. Times are UTC.

Type	**Begin**	**Max**	**End**	**Magnitude**	Data source: Space Weather Prediction
X-Ray	1545	1604	1614	C6.6	Center Events Report:
X-Ray	1925	1933	1940	M1.0	ftp://ftp.swpc.noaa.gov/pub/indices/events/

Particle precipitation related to a magnetic disturbance, specifically a magnetic bay (decrease in the local magnetic field flux density), caused absorption that preceded the solar flares. The absorption of Galactic background radiation caused by particle precipitation reached a maximum at about 1430 while the bay reached a minimum field intensity at about 1500.

The first flare peaked at 1604. The associated absorption was signified by a relatively sharp decrease similar to the preceding precipitation event. The second flare peaked at 1933 and caused a somewhat broad double-dip decrease in the received Galactic background radiation. Figure 3 shows the Riometer data from 17 March overlaid with the x-ray flux measured by the GOES spacecraft (https://www.swpc.noaa.gov/products/goes-x-ray-flux) and the local magnetic flux density measured by the HAARP SAM-III magnetometer (https://reeve.com/SAM/SAM-HAARP/SAM-HAARP_simple.html).

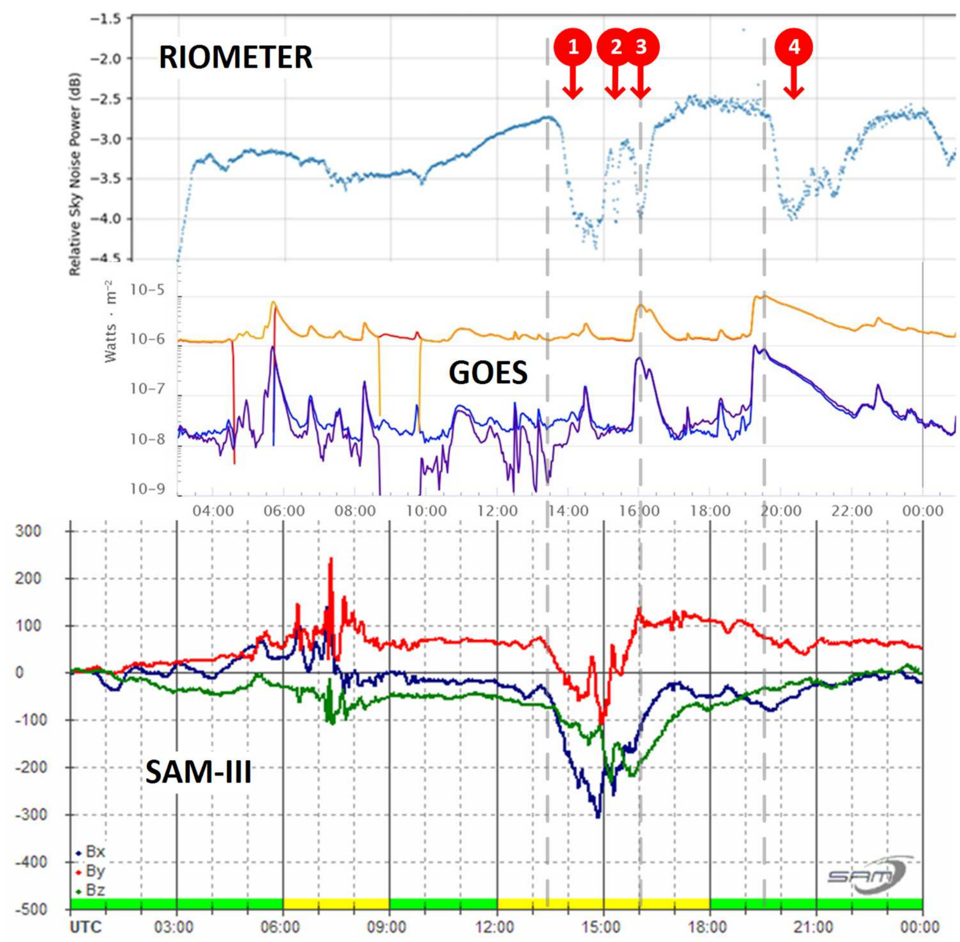

Figure 3 ~ Overlaid plots from 17 March with the same time scale. See text for explanations of each trace and time lines.

The upper (light-blue) trace is the HAARP Riometer 30.3 MHz receiver channel. The plot does not include a quiet day curve, which normally would be used to establish relative received power levels when no absorption is present. The trace shows the ratio of received sky noise to the Riometer's internal reference noise source in dB.

Directly below the Riometer trace are the x-ray flux plots from the two GOES spacecraft. Shown are the GOES short wavelength channel (0.5 to 4 Å, blue traces) and long wavelength channel (1 to 8 Å, orange traces). Below the GOES plots is the magnetogram from the local SAM-III magnetometer located about 2.3 km southeast of the Riometer. The three magnetic field components are: Bx (north-south, red trace); By (east-west, blue trace); Bz (vertical, green trace).

The gray vertical dashed lines mark the following UTC epochs:

- 1320: Beginning of magnetic bay that reached approximately –300 nT at 1500. The first significant absorption event ❶, dipping about 1.25 dB at 30.3 MHz and lasting 1.5 hours, started only a few minutes into the bay. It was followed at 1500 by a second absorption event ❷, a sharp 0.9 dB decrease lasting about 15 minutes. The second event appears to be related to magnetic fluctuations within the bay;
- 1604: Peak of C6.6 x-ray flare. The third absorption event ❸, about 1 dB at 1600, correlates well with this flare. Note that the flare flux required about 1 hour to decay to the background level while the received sky noise recovered much faster;
- 1933: Peak of M1.0 x-ray flare. The fourth absorption event ❹, almost 1.5 dB, correlates well with this flare and is much broader than the previous event. Also, unlike the previous event, the absorption recovered at about the same rate as the flare flux.

Instrumentation:

- Riometer with LWA Antenna, 2-channel, 30.3 MHz & 38.2 MHz, Keo Scientific, Calgary, Alberta, Canada
- SAM-III Magnetometer, 3-axis, Reeve Engineers, Anchorage, Alaska USA
- GOES (Geostationary Operational Environmental Satellite), NOAA, https://www.goes-r.gov/