Understanding HamSCI-TAPR Magnetometer Measurements and Observations

Rachel (Umbel) Frissell[1], Nathaniel Frissell[1], Majid Mokhtari[1], Dave Witten[2], Hyomin Kim[3]

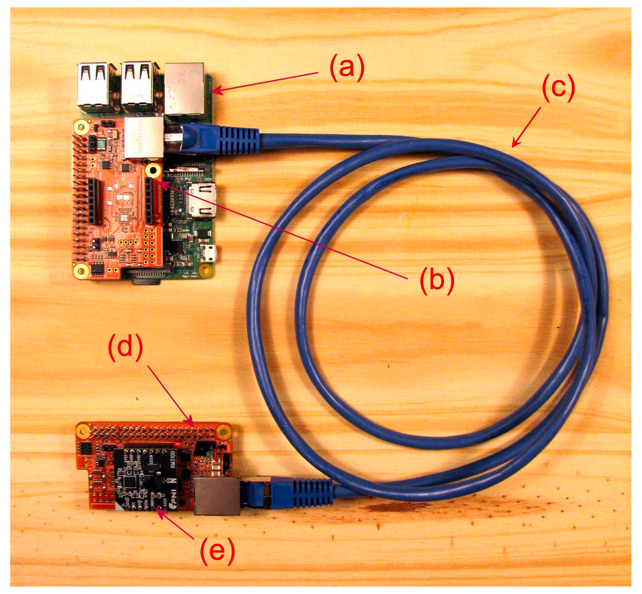
[1]University of Scranton [2]HamSCI Community, [3]New Jersey Institute of Technology

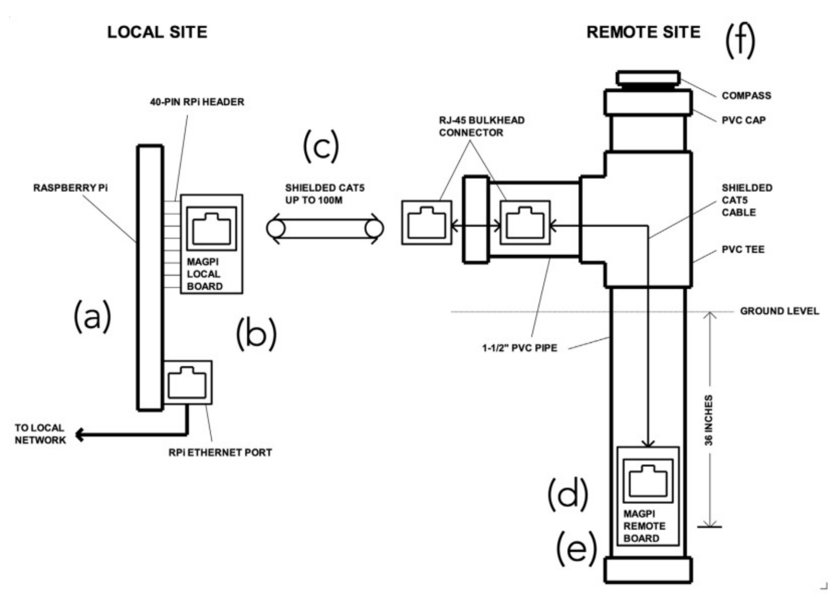
Abstract

Measurements and observations are important to any project. Understanding where the measurements came from and how they are collected is vital. In this presentation, we will aim to describe what a magnetometer is, how it works, and what information it can tell us about space weather/physics focus on what measurements and observations we can collect from the magnetometers– specifically HamSCI-TAPR magnetometers as various magnetometers will have different capabilities. Furthermore, we will outline an experimental procedure to help the user better understand the collected measurements and observations from the HamSCI-TAPR magnetometer. We will focus on some questions such as, what can HamSCI magnetometer measurements and observations tell us? How do we know good vs bad HamSCI-TAPR magnetometer data? Do we need to calibrate the measurements and observations of the HamSCI-TAPR magnetometer data? Why do we collect three components of the magnetic field yet primarily use only the horizontal component. How does the internal magnetic field of the Earth impact the magnetic field around the Earth? Where can we see and access the raw measurements and observations from the HamSCI-TAPR magnetometers? How are the measurements and observations displayed? By answering these questions and outlining the experiment(s), we hope to provide an education guide to help users better understand how the HamSCI-TAPR magnetometers record observations and measurements and what insight they can give us into better understanding various space weather/physics phenomena.

HamSCI Magnetometer – An Overview

The HamSCI magnetometer is part of the multi-instrument system used to make ground-based measurements of the space environment which is termed, 'Personal Space Weather Station.' The HamSCI magnetometer is unique as it employs a low-cost, commercial off-the-shelf, magneto-inductive sensor technology to record three-axis magnetic field variations with a field resolution of less than 3 nT at 1 Hz sample rate. Target specifications and performance level of the magnetometer are: a) time-varying field measurements in three axes; b) about 3 nT resolution at 1 Hz sample rate; c) about 50 to 100 miles spacing.

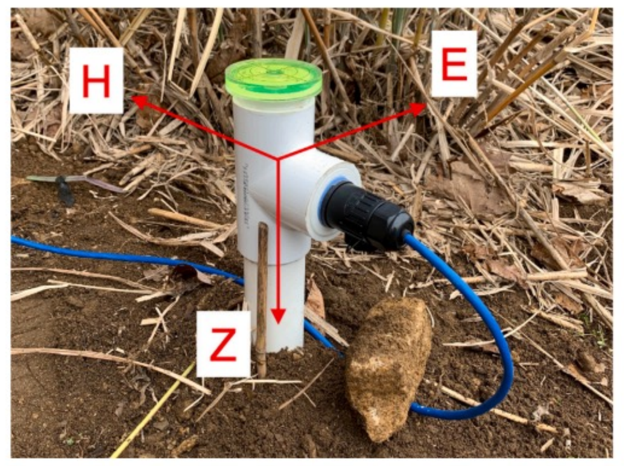




(Left) Photo of HamSCI-TAPR Ground Magnetometer Circuitry. (Right) Diagram of HamSCI-TAPR ground magnetometer in PVC pipe housing for remote board ground burial. Magnetometers are buried in the ground to provide temperature stability, which is critical to making accurate measurements. Labels parts are: (a) local computer (i.e. Raspberry Pi); (b) local magnetometer support board extender; (c) shielded CAT5 interconnecting cable; (d) remote magnetometer support board extender; (e) PNI RM3100 magnetic sensor; and (f) magnetic sensor burial parts kit. Figures from Kim et al. (2024), https://doi.org/10.1016/j.ohx.2024.e00580.

Location, Location, Location! How are these placed?

The magnetometer should be placed away from any electromagnetic interference sources which can affect reliable measurements and kept as constat a temperature as possible. As stated in Kim et. Al, the sensor should be oriented in compliance with the widely accepted geomagnetic coordinate system 'HEZ' in which, H points towards the local geomagnetic north in the horizontal place, Z points towards the center of the Earth, and E points geomagnetically East.



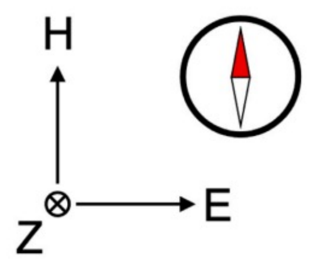
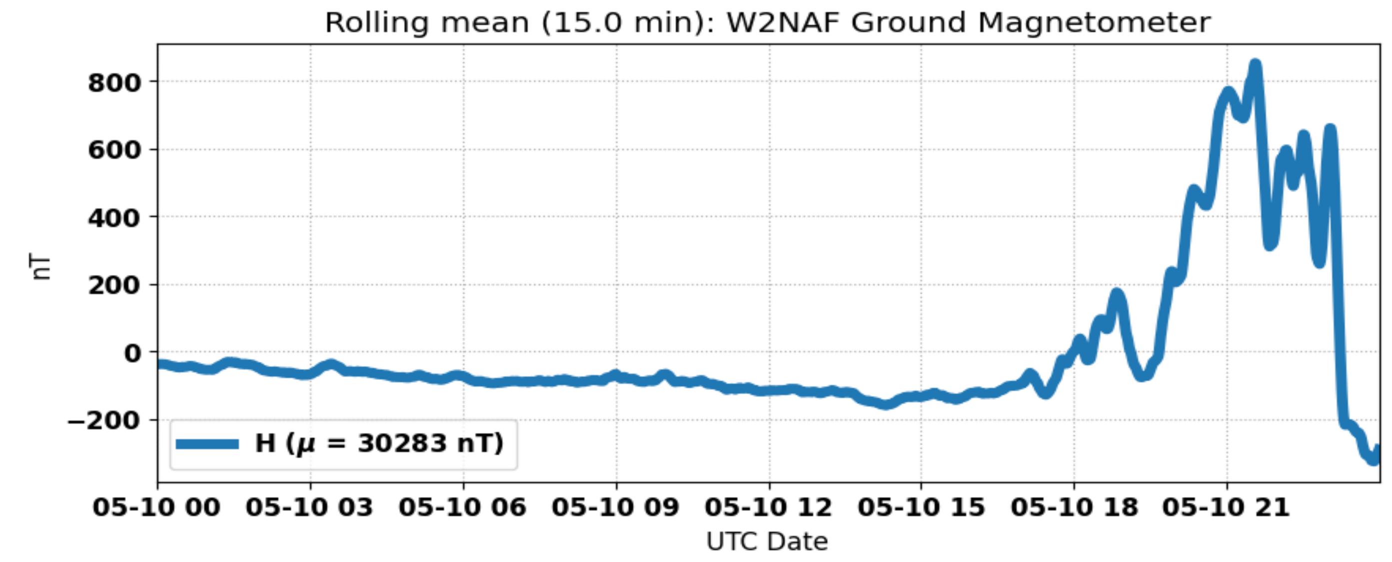


Photo of HamSCI-TAPR magnetometer PVC Pipe enclosure buried in ground with diagram of magnetic coordinate system. H points towards magnetic north, Z is vertically down, and E is orthogonal to H and Z according to the right-hand rule. Figure from Kim et al. (2024), https://doi.org/10.1016/j.ohx.2024.e00580.

A Learning Experiment: Python Edition

During the Gannon storm, May 10th, 2024, the HamSCI-TAPR magnetometer at W2NAF station recorded data. From this plot, can we replicate the findings in a lab? How much approximation do we need to employ? Is this a viable learning exercise?

As ground-based magnetometers are relatively cheap in terms of scientific instrumentation, we are proposing a learning experiment to probe how readily we can reproduce the results from May 10th. To start, we collected the magnetometer data and loaded it into python:



It is important to note, the background was subtracted from the raw data and a 15-minute rolling average was applied. Now, we are going to try to determine the current we would need to generate to reproduce this plot. Once that is determined, we will use a set of Helmholtz coils to produce a magnetic field and a signal generator for the current. Our hope is to produce a similar plot in the laboratory as to one that is seen here. A few challenges include the set-up is designed to be affordable to an undergraduate lab class.

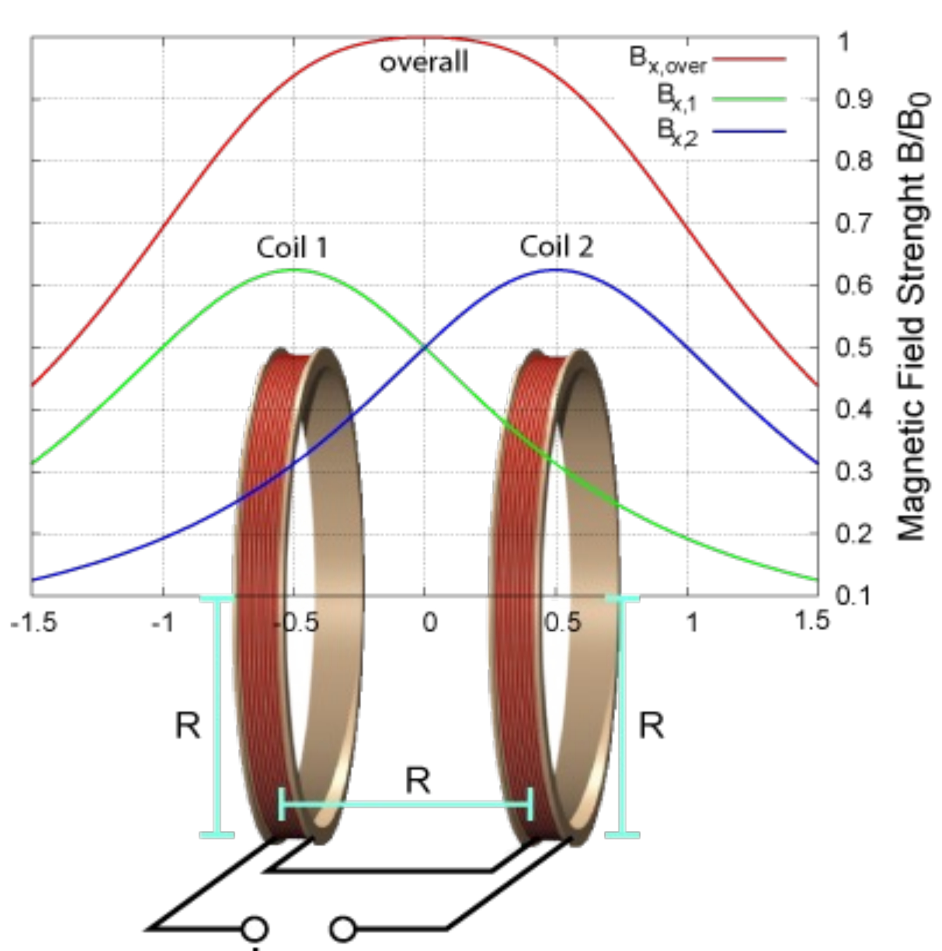
The magnetic field from a set of Helmholtz coils is as follows:

$$B = \frac{1}{2}\mu_0 N I R^2 * \left(\frac{1}{\left(\left(x-\frac{d}{2}\right)^2 + R^2\right)^{\frac{3}{2}}} + \frac{1}{\left(\left(x+\frac{d}{2}\right)^2 + R^2\right)^{\frac{3}{2}}} \right)$$

With the sensor at the center of the coils, the magnetic field simplifies to:

$$B = \mu_0 \frac{8\, I\, N}{\sqrt{125}\, R})$$

Below is a schematic of the magnetic field produced by two Helmholtz coils, from Electron Motion in Electric and Magnetic Field by Stefan Richtberg.

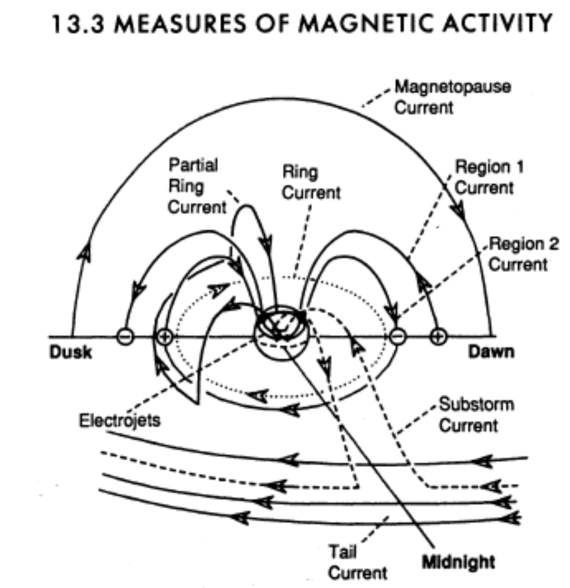


Stefan Richtberg, https://virtuelle-experimente.de, CC BY-NC-SA 3.0, Electron Motion in Electric and Magnetic Fields

Further Discussion –Ring Current

Ring current which may be defined as an electric current carried by charged particles trapped in a planet's magnetosphere is approximately four Earth Radi away as the E-region of the ionosphere is approximately 10 km away. From the previous discussion, is it possible to predict the magnetic field of each of these regions from a ground based instrument. Perhaps better stated, what approximations and considerations do we need to take into account to solve this simplified problem.

From Kivelson and Russell, we see the following schematic of various current systems linking the magnetospheric and ionospheric currents.



If we approximate the curvature of the ring current as a 'straight' line, we can simplify this problem into finding the magnetic field of the line charge from a distance, d away.

Reviewing magnetostatics from M. Sadiku, we can relate the magnetic flux density B, to the magnetic field intensity H by:

$$B = \mu H$$

where $H = \frac{I}{l}$ and $B = \frac{\Psi}{S}$

Furthermore, for a linear current, Biot-Savart law can be written as:

$$H = \int_L \frac{I\, d\mathbf{I}\ x\ \boldsymbol{a}_R}{4\, \pi\, R^2}$$

When the conductor is semi-infinite, we can simply the equation to:

$$H = \frac{I}{4\, \pi\, \rho} \boldsymbol{a}_\varphi$$

If we take rho as approximately the distance from the line charge of interest to our ground-based instrument, we can estimate the auroral electrojet by using a distance of 10,000 meters and we can estimate the ring current by using a distance of four earth radii. We now consider a few questions. What can we learn from this exercise, is this a reasonable approximation or not? Perhaps, even if it is a large approximation, it may serve a learning and discussion starting point to the interested observer.

References

Hyomin, Kim, David Witten, Julius Madey, Nathaniel Frissell, John Gibbons, William Engelke, Anderson Liddle, Nicholas Muscolino, Joseph Visone, Zhaoshu Cao, Citizen science: Development of a low-cost magnetometer system for a coordinated space weather monitoring, HardwareX, Volume 20, 2024, e00580, ISSN 2468-0672, https://doi.org/10.1016/j.ohx.2024.e00580

Richtberg, Stefan, https://virtuelle-experimente.de, CC BY-NC-SA 3.0, Electron Motion in Electric and Magnetic Fields

Kivelson, M. G. and C. T. Russell, "Introduction to Space Physics," Cambridge University Press, Cambridge, 1995.

Sadiku, M. "Elements of Electromagnetics," Oxford University Press, Incorporated, 2018.

rachel.frissell@scranton.edu