EZIE-Mag: Empowering Students Nationwide in Space Science Exploration and Education

Jesper Gjerloev, Robin Barnes, Adebayo Eisape, Nelli Mosavi-Hoyer, Troy Cline, and Christine Kalapala, Peter Seelman, Harry Rathbun

Johns Hopkins University Applied Physics Laboratory

Abstract.
EZIE-Mag is a national STEM engagement program that is deploying 700 magnetometer kits free to schools across the United States. The EZIE-Mag is a comprehensive kit that provides science-quality measurements of earth's magnetic field at an ultra-low cost while being extremely easy to deploy and operate. The EZIE-Mag is part of the outreach component for the NASA Electrojet Zeeman Imaging Explorer (EZIE) mission and provides students the unprecedented opportunity to observe and collect meaningful scientific data. This will enable them to connect with scientists around the world, and create a memorable and meaningful experience. The target age group for this project is 8th grade and high school. The data collected by the students is complementary to the data made from the measurements of the flown component of the EZIE mission. EZIE-Mag will help students engage with the mission and develop skills, interest, and confidence by collecting data and working alongside EZIE scientists, thus allowing them to contribute as citizen scientists.

The data collected by students using the magnetometers will synergize with the comprehensive dataset gathered by the EZIE mission, thereby enriching the scientific understanding of space weather phenomena. The strategic focus on 8th-grade and high school students aligns with the overarching objective of nurturing a new generation of scientists and engineers. Through hands-on experience in collecting and working with data alongside EZIE scientists, students are positioned as citizen scientists, fostering the development of skills, interest, and confidence in the expansive field of space science. In summary, the EZIE-Mag initiative transcends its role as a mere data collection project; it emerges as a transformative STEM engagement program with the ability to empower students nationwide. By actively involving students in space science research, connecting them with the EZIE mission, and cultivating essential skills, EZIE-Mag contributes significantly to advancing both space science education and citizen science participation. The program's commitment to nationwide distribution and targeted outreach to underrepresented communities further underscores the project objective of fostering scientific interest in younger generations by making inclusion a cornerstone of the implementation.

1. Introduction.
Ground-based magnetometers have been the workhorse of the magnetosphere-ionosphere (M-I) community for decades and still are. The flow of energy between the magnetosphere and the ionosphere is primarily via electric current, electromagnetic waves, and the precipitation of charged particles along magnetic field lines. Figure 1 shows the location of the 584 scientific stations currently included in the SuperMAG collaboration. This plot includes all ground magnetometers that have been

operated for long periods of time for the purpose of monitoring M-I currents. The ground magnetometer dataset is unique as it provides nearly global, continuous, and decade-long monitoring, thereby allowing a wide range of studies to be conducted. Ionospheric currents have received considerable attention over many years of research since they are the dominant phenomenon at ionospheric altitudes compared to all other phenomena pertaining to magnetosphere-ionosphere coupling, involving many times more energy dissipation than particle precipitation (Foster et al, 1983; Lu et al., 1998). Thus, one of the major efforts in understanding the overall solar wind magnetosphere-ionosphere system is through studies of these parameters, especially at times of substorms and magnetic storms.

Figure 1, however, also illustrates the limitations of the magnetometer coverage. There are large regions with poor or no coverage and there is a very clear bias towards more western and more developed countries, as can be seen when comparing the coverage of Europe and Africa.

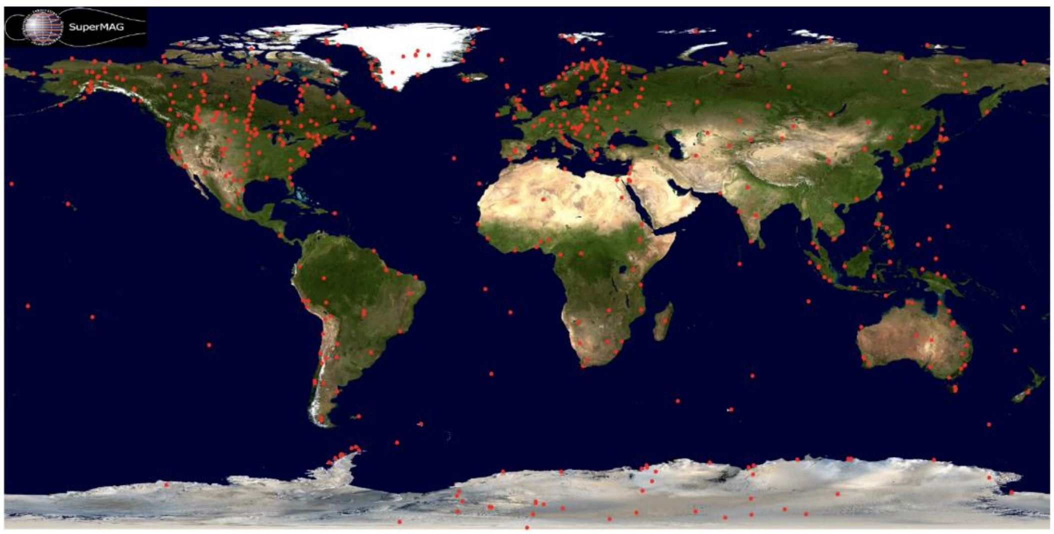

***Figure 1**. The ground-based magnetometer community provide a uniquely powerful dataset to study the electrical currents that flow in the near-Earth environment. EZIE-Mag allows students, citizen scientist, and developing countries to become an actively member this community.*

In this paper we argue that this shortcoming is largely due to the cost and complexity of operation. These factors exclude not only developing countries, but citizen scientists, schools, and other resource-constrained communities as well.

In this paper we argue that the EZIE-Mag magnetometer kit is one possible solution that allows everyone to produce science-quality measurements of the earth's magnetic field. It is made possible by the ultra-low cost, ease of use, and support provided by the EZIE-Mag team once the data have been obtained.

2. The EZIE-Mag Components

The EZIE-Mag project consists of 5 cornerstones. Each is briefly outlined below.

2.1 Hardware

The EZIE-Mag is a complete kit that includes a number of low-cost components:

Pi Zero WH	Raspberry Pi Zero single-board computer with Wi-Fi and PIO pin header
RM3100 Sensor	PNI RM3100 three-axis magnetometer sensor with I2C interface
GPS NEO-6M	GPS module with serial interface
MCP9808	High-accuracy I2C temperature sensor
GY-521 MPU-6050	Three-axis gyroscope and three-axis accelerometer
Perf Board	PCB prototyping perf board
DuPont Wires	DuPont jumper wires
PCB Header Pins	Breakaway PCB header pins
Case	Pelican weatherproof case
64-Gb Micro-SD Card	64-Gb high-endurance memory card
Power coord	30’ micro-USB cable

***Table 1**. All kit components are all COTS, high performance, and extremely low cost.*

The hardware solution is possible due to significant advances made by industry, specifically in the commercial sector. Commercial, off the shelf (COTS) solutions of science quality and extremely low cost enable implementation. The experience of the end user has been a driving design philosophy. The placements of the components are chosen so as to maximize ease of assembly, clarity of operation, and distance between the vector magnetometer sensor (VMS) and all other components. For example, there are LEDs mounted with the purpose of showing the operation of the individual components and for aesthetic appeal. The final layout is shown in Figure 2

2.2 Operating system

The operating system runs a full version of the Raspberry Pi OS, a Debian-based Linux Distribution. It is a custom software produced to interface with the hardware listed in Table 1. Some standard libraries are used for I2C bus communication to and from the sensors and UART communication with the GPS module. The EZIE-Mag runs its own Apache web server to provide the user with an intuitively laid-out dashboard. The user can either connect directly

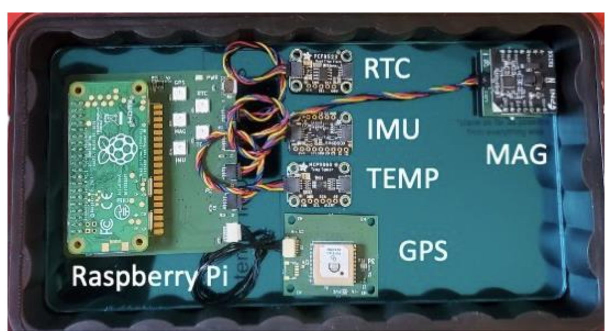

***Figure 2**. The component layout is a result of multiple iterations and is driven by efficiency, ease of assembly and clarity of operation.*

to the EZIE-Mag through its own built-in Wi-Fi Hotspot or configure it to connect to an existing network through the dashboard interface. The user-friendly interface (Figure 3) allows the user to view real-time data, download data, amongst a host of other features.

2.3 Post processing

The EZIE-Mag observations come with a few complications that needs to be addressed in the post-processing before any quantitative analysis and interpretation can be performed:

1) Uncontrolled deployment conditions,
2) Unknown reference frame (orientation of magnetometer axis),
3) Uncalibrated (sensor calibration parameters), and
4) Uncontrolled temperature.

The purpose of the post-processing package is to resolve these complications. As a background for understanding the processing, we encourage the reader to become familiar with the SuperMAG processing procedure (Gjerloev, 2012). There are, however, significant differences between the SuperMAG and EZIE-Mag projects. For example:

- EZIE-Mag requires a temperature calibration;
- EZIE-Mags does not assume that the Z-axis is vertical down.

The basic flow is shown in Fig 4 and the processing steps are explained briefly below.

Figure 3*.* *An intuitive interface allows the user to see real-time observations along with a long list of other controls using a smartphone, tablet, or computer.*

Step 1. The EZIE-Mag sampling rate is 40 Hz which is down-sampled to 1-Hz using a simple boxcar averaging. The data point is centered at 0.5 sec with a 1-sec cadence. Averaging is used since the raw data are discrete and as such the scaling of noise cannot be assumed to scale as $1/\sqrt{n}$ or in this case $1/\sqrt{40}$. This step is performed in real-time, and the 1-sec data is saved in hourly, daily, and weekly zip files for easy download.

Step 2. The VMS has significant temperature dependence. To allow for subsequent temperature calibration of the sensor data, the EZIE-Mag has a temperature sensor in addition to the temperature sensor onboard the VMS. The VMS temperature is used as the primary measurement. Calibration is performed as a multi-linear correlation analysis, where the component dependence is described as a multi-linear fit for magnetic field component *i*:

$$B_i = \beta_0 + \beta_1 T + \beta_2 \partial T/\partial t$$

where β_i are scalar constants, *T* is temperature and $\partial T/\partial t$ is the change in temperature as a function of time.

Step 3. The EZIE-Mag is deployed by the user with little, if any, alignment. The first part of the orientation problem is to align the magnetic field sensor z-axis with geographic down. This is done using the accelerometer sensor and assuming that the mounting in the box of these two different sensors does not violate this assumption. This is a single angle which is assumed constant in time and allows for derivation of B_z.

Step 4. Once the z-axis of the mag sensor is aligned with geographic down the two horizontal axes are aligned with local magnetic north B_N and, to complete the right-hand system, local magnetic east B_E. A complete explanation is provided in *Gjerloev* [2012].

Step 5. Rotate to geographic coordinates assuming that the local magnetic field system is as identified from the measurements. See *Gjerloev* [2012] for a complete explanation.

Step 6. The EZIE-Mag does not perform absolute field measurements, but it should be viewed as a so-called variometer—a magnetometer with the purpose of measuring variation in the field. With the measured field in a geographically referenced coordinate system, we simply determine the offset in each axis from an IGRF model and add the difference.

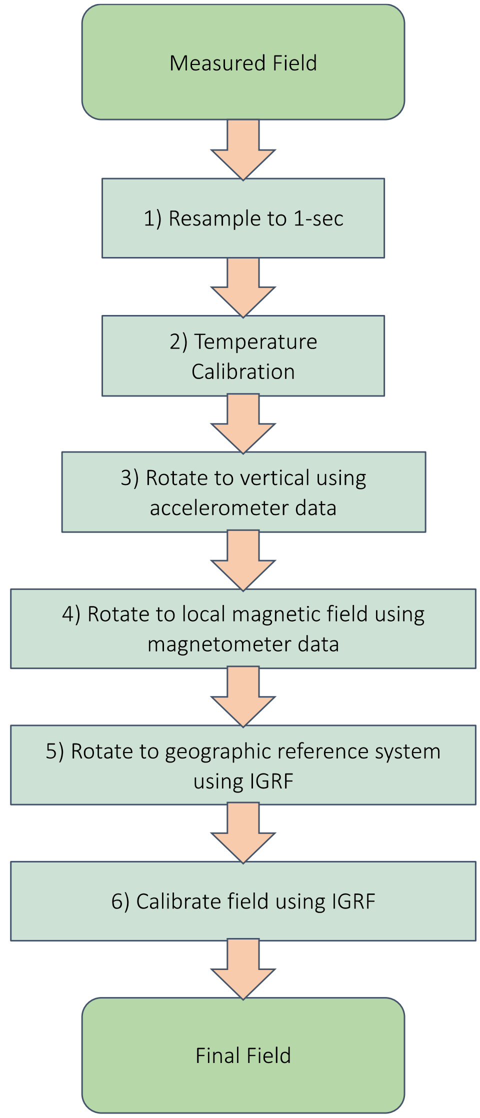

***Figure 4**. The basic processing flow is similar to the SuperMAG processing although steps 2 and 3 are needed for the EZIE-Mag.*

2.4 Website

The EZIE-Mag website is comprised of a series of shell scripts that process data as it is provided to the system. The scripts call a variety of utilities that create additional data products from the raw data and archive the locally. The website acts as the principal tool for working with EZIE-Mag data. Registered users can use the user interface to interactively generate web-based and publication-quality PDF plots. The interface is implemented using a combination of JavaScript, Common Gateway Interface (CGI) scripts, and Asynchronous JavaScript and XML (AJAX). As an additional and necessary benefit, the registration system incorporates a logging system that allows the usage statistics of individual users to be tracked, providing principal investigators with easy access to the feedback needed to justify future funding from their respective supporting agencies.

2.5 Outreach

The EZIE-Mag initiative transcends local boundaries, becoming a nationwide STEM engagement endeavor that aims to distribute 700 free magnetometers to schools across the United States, with a primary focus on underrepresented and indigenous communities. Tailored specifically for 8th-grade and high school students, this program seeks to deliver an immersive educational experience in the

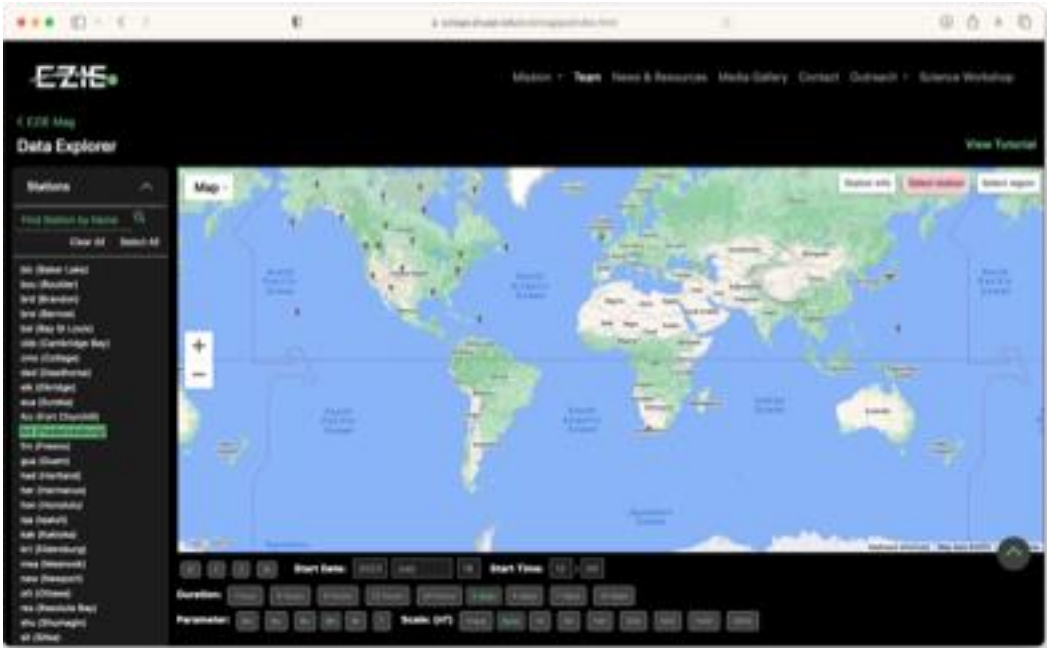

Figure 5. *The website is modelled after that of SuperMAG and provides a user-friendly interface to upload data and explore the complete dataset from around the world.*

field of space science. As an integral part of the broader EZIE Mission, this groundbreaking initiative signifies NASA's pioneering mission, allowing students unprecedented opportunities to actively observe, connect, collect, and analyze data. The program endeavors to create a memorable and meaningful experience for students by providing a unique avenue for their contribution to scientific research.

The data collected by the students will be complementary to data that the flown component of the EZIE mission will measure. EZIE-Mag will help students engage with the mission and develop skills, interest, and confidence by collecting data and working alongside the EZIE scientists, thus helping them become citizen scientists.

4. Summary and Conclusions

The EZIE-Mag is part of the outreach component for the NASA EZIE mission. It is an extremely ambitious project that is centered around the EZIE-Mag—a complete magnetometer kit that provides science-quality observations of the ground magnetic field. EZIE is the first mission that will allow students to observe the world, connect with the world, collect data, connect data, and create a memorable and meaningful experience. The program is a national STEM engagement program that is deploying 700 EZIE-Mag magnetometers for free to schools across the United States. The target age group for this project is 8th grade and high school. The data collected by the students are complementary to data that the measurement made by the actual EZIE mission. EZIE-Mag will help students engage with the mission and develop skills, interest, and confidence by collecting data and working alongside EZIE scientists, thus helping them become citizen scientists.

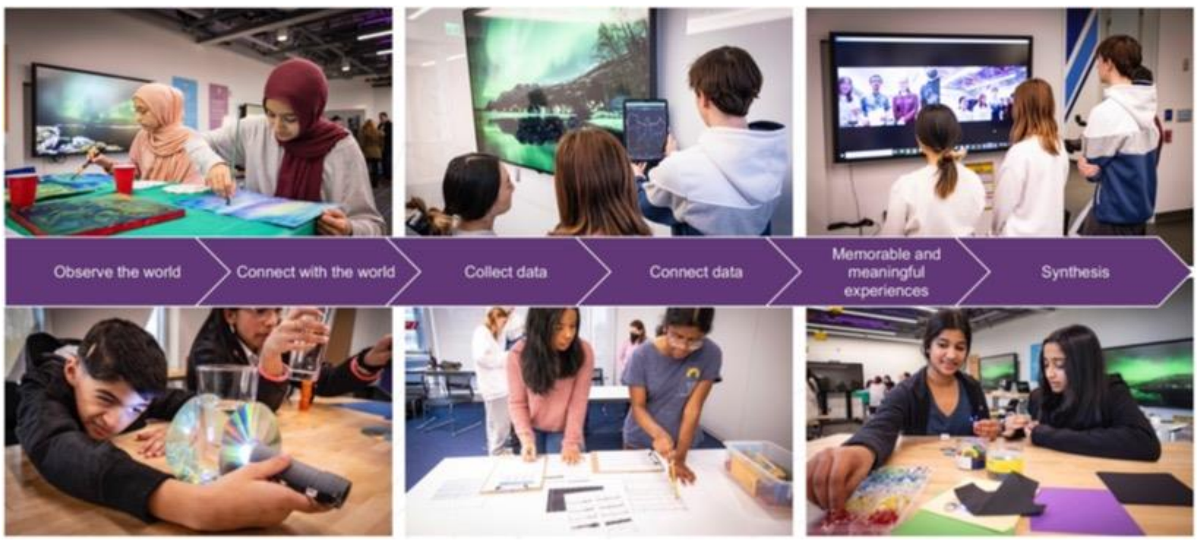

Figure 6. *The website is modelled after the SuperMAG website and provides a user-friendly interface to upload data and explore the full dataset from around the world.*