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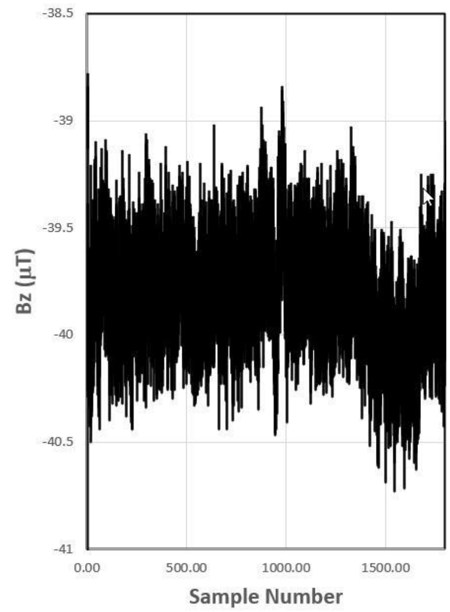
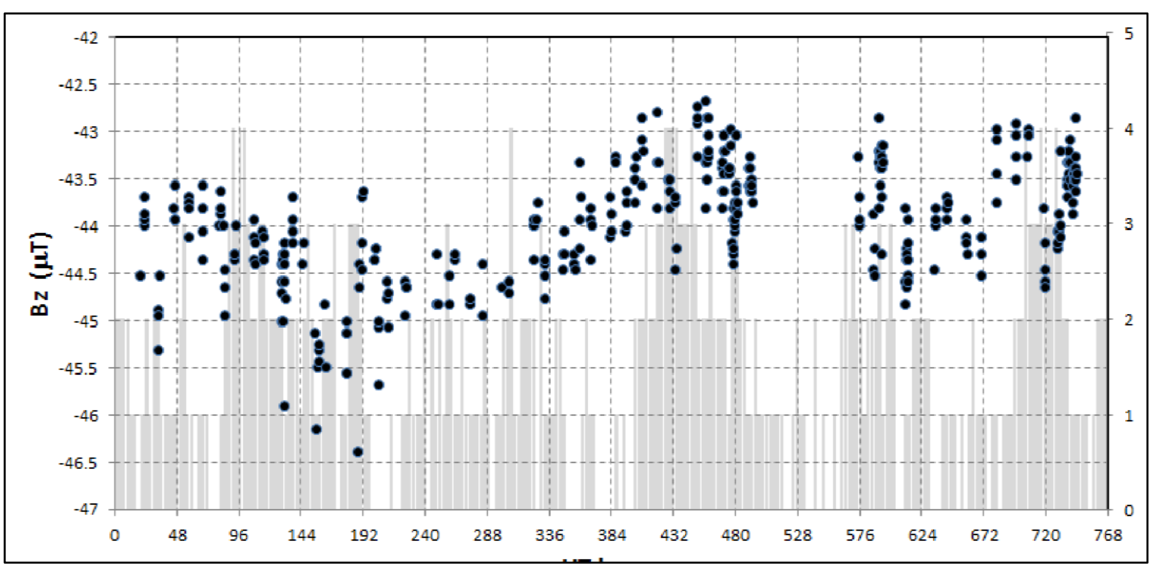


Smartphone Magnetometers for Space Weather Studies



Smartphone Magnetometers for Space Weather Studies

A NASA Educator's Guide

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Introduction

A magnetometer is a device that is used to detect and measure magnetic fields. It can be as simple as an ordinary compass that measures the local direction of the magnetic field polarity, or as sophisticated as the kinds of devices used by scientists which cost tens of thousands of dollars.

Magnetometers are important for studying space weather because some aspects of space weather involve sudden changes of Earth's magnetic field that occur during solar storms. These events can alter the strength of Earth's magnetic field at the ground by up to 5% and also cause changes in the orientation of Earth's magnetic field by several degrees.

This Guide shows how you can use your smartphone to detect geomagnetic storms. The first design senses the position of a suspended magnet as it responds to changes in Earth's field, while the second design is a direct measure of changes in Earth's magnetic field using many popular smartphone apps.

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Cover art: (Top left) Example of smartphone app display of magnetometer data. (Top right) Example of three hours of recording of Bz magnetic component showing noise. (Bottom) Example of geomagnetic storm events and measured data with a smartphone magnetometer. (Credit: The Author).

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Part I: Notes for Educators

NASA space missions often require measuring magnetism on the Sun, on Earth, and on other planets and bodies in our solar system. ***Heliophysics*** is the study of the Sun and its effects on the Earth and the solar system. Students will learn how Earth's magnetic field interacts with the solar wind and keeps the Earth safe and how studying magnetism can help scientists learn about the unique environment that the Sun creates in the solar system.

When your students use this guide, the following information will provide an educational context for its use. The project description includes information about the Next Generation Science Standards that apply and provides guiding questions and an assessment to help teachers gauge student performance in constructing the device, acquiring data, and interpreting the data.

1. Overview

Students will measure Earth's changing magnetic field during geomagnetic storms caused by increased solar activity. The Sun goes through an 11-year cycle with periods of increased numbers of sunspots that are related to the frequency of solar flares and other 'solar storms', which can affect Earth's magnetic field. Scientists refer to the effects of these solar storms as 'space weather.' The strongest storms occur during and just after a period in the Sun's cycle called Solar Maximum. Currently our sun is in its fourth year of sunspot cycle number 25 with a maximum predicted to occur sometime in 2024. Storms that are strong enough to be detected by smartphones only occur a few times each month during the time of peak solar activity. Be sure to check where the Sun is in its cycle before attempting this experiment with students. Use a service such as that provided by the NOAA Space Weather Prediction Center (https://swpc.noaa.gov) to see if a storm is occurring, or when the next one may arrive.

2. Objective

Students will be able to observe space weather phenomena that cause variation in Earth's magnetic field.

3. Explanation

Compared to professional magnetometers used at magnetic observatories, most of the simple designs such as soda bottle magnetometers and smartphone magnetometers are not sensitive enough to detect weak geomagnetic storms with Kp < 7, but they can be used to detect some of the stronger storms. The process requires careful analysis of the data. Severe storms with Kp>8 should be detectable in most locations across North America. These storm events, however, are rare and occur about once every few months during times when the Sun is active (called sunspot maximum). They are unpredictable, so you need to carefully monitor such space weather websites to see if a storm is likely in the next 24-48 hours.

4. Assessment

Use the answers to the questions during data analysis to determine if students can accurately collect and analyze data during a geomagnetic storm. These questions can include:

- What kinds of solar events can cause Earth's magnetic field to vary?
- Why are compass needles affected by solar storms?
- How does a magnetometer detect changes in Earth's magnetic field?
- What property of Earth's magnetic field is being measured by the magnetometer?
- What is the typical range of measurements that you detect during a strong storm?

5. Targeted NGSS Standards

Middle School

Appropriate for magnetometer designs involving simple magnets.

MS-PS2-3 Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

MS-PS2-5 Investigate and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

MS-PS2.B Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the charges, currents, or magnetic strengths involved and on the distances between the interacting objects.

High School

Appropriate for designs involving Hall sensors, photocells, smartphones, and Arduino.

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-PS3-5 Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

6. A Glossary of Terms

<u>Boom</u> – a mechanical device on a spacecraft that keeps certain sensitive instruments far from the spacecraft to reduce interference.

<u>Current</u> – a flow of charged particles such as electrons, measured in units called amperes

<u>Dynamo</u> – a device containing a rotating magnet that produces electrical currents

<u>Electromagnetic</u> – something that has both electrical and magnetic properties

<u>Field</u> – an influence, usually a force, that exists in the space surrounding an object

<u>Force</u> – an influence that causes nearby or distant objects to move, sometimes without physical contact

<u>Gauss</u> – a unit of measurement for magnetism in a system of units that also uses centimeters and grams

<u>Interstellar</u> – literally the space between stars, usually occupied by various thin gases and molecular clouds

<u>Magnetometer</u> – an instrument for measuring the intensity and direction of a magnetic field

<u>Polarity</u> – the direction of a force or current such as magnetism (North or South-type) or on a battery (positive or negative)

<u>Spacecraft</u> – a platform carried into space that contains a collection of instruments for examining distant objects and gathering data from environments in space

<u>Space weather</u> – a collection of phenomena that describe how Earth and the other planets respond to solar activity

<u>Sunspot</u> – a dark spot in the solar surface where very intense magnetic fields cause the gas to be cooler and emit less light, making a dark “spot” compared to the rest of the sun’s bright surface

Tesla – a unit of measurement for magnetism in a system that uses meters and kilograms; one Tesla equals 10,000 Gauss. As an example, the magnetic field at Earth's surface is about 50 microTeslas (0.00005 Tesla) or 0.5 Gauss in strength.

Vector – a quantity that is defined both by its amount and its direction. The motion of a body is defined by its velocity vector, which has an amount (called speed) and a direction (up, down, etc.).

Part II. The Smartphone Magnetometer

1. Background

You may not be aware of this, but in addition to cameras, smart devices have used magnetic sensors since the first smart device was commercialized in 2008. They are used to detect Earth's magnetic field so that the software can display information on the smart device screen as you move the smart device around. For example, when you use Google Maps to display your location, a tiny, shaded cone sweeps around your location on the display to show you the direction your phone is pointing. The software uses this information to tell you whether to travel north, south, east or west of your current location as you navigate. If you use star maps, the sensor tells the software in which direction the screen is pointing so it can show you what stars and constellations you should be seeing in that direction. App developers have also created numerous compass apps to make your phone work like an actual magnetic compass.

Figure 1. The Hall Effect produces voltage changes from applied magnetic fields but only along one direction.

The magnetic sensor, called a Hall Effect sensor, is only a few millimeters in size and has three components. Each of the sensors creates a voltage that can be measured by the smart device because the voltage is proportional to the applied magnetic field shown in Figure 1. By using three of these sensors, one along each of the three smart device Body

Axis (X, Y, Z), the magnetometer can measure the strength of an applied magnetic field in each of its three space components (Bx, By, Bz) defining the orientation of the magnetic field vector in space. The positive direction of the Z-axis is pointing away from the front of the smart device and is always perpendicular to the face of the device.

The X-axis is along the short length and increases to the right, and the Y-axis along the long length and increases upwards along the case.

Because Earth's magnetic field is fixed in space, smart devices can measure how the smart device is oriented in space on the surface of Earth. This is important in using real-time navigation maps, and keeping the display data in the right orientation to serve as a window as you move the phone around.

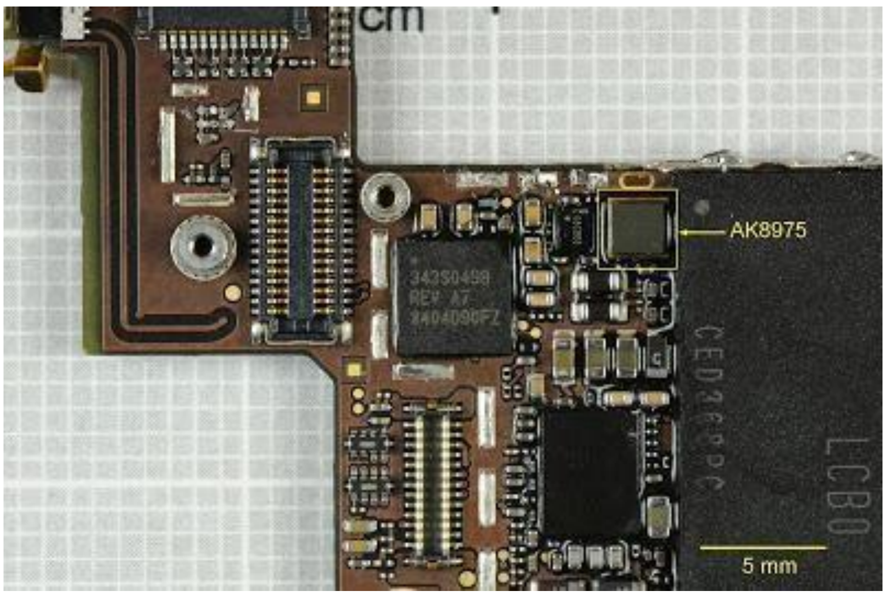

Figure 2. An example of the location of a Hall Effect magnetic sensor, AK8975, in a smart device. (Credit: BlueBugle.com)

2. A selection of apps for measuring magnetic fields

These apps are suitable for middle and high school students when data needs to be taken and saved for later analysis. They produce real-time moving graphs of the X, Y and Z components of the measured magnetic field and save the data into an exportable spreadsheet. These apps include *Teslameter 11th, Tesla Recorder*, and *Sensor Kinetics*, which are all available on both Android and iOS platforms. In this guide, we will use **Physics Toolbox**. This app displays graphical data from all the available smart device sensors. The magnetic field measurements can be displayed in real-time and stored in a .csv spreadsheet and exported via email to your laptop for future analysis.

Figure 3. Example of *Physics Toolbox* app magnetometer display.

Smart devices are complex electronic machines, and this has raised the question of whether strong magnetic fields can damage them. That is a more interesting and complicated question. Ever since the idea of magnetism came into the public consciousness in the 1800s, magnets and magnetic fields have been popular as examples of strong, invisible forces that can control, influence, or damage a variety of things from people to machinery. When television technology used cathode ray tubes to form pictures, people were often cautioned not to place toy magnets close to the screen. They did in fact cause the images to get distorted. Lasting damage could occur with parts of the ‘picture tube’ being magnetized causing permanent distortion. Technicians often brought a ‘degausser’ to their house calls to demagnetize the TV screen and return it to normal operation. So, people learned from this early TV technology that magnets could upset televisions, and this fear was also carried over to computer technology with the accidental erasure of data from old-style magnetic hard drives. Today, the advent of solid state rather than magnetic storage has rendered modern computers invulnerable to the kinds of magnets commonly found in a home or office. Smart devices, however, present a slightly different challenge.

Smart devices contain a variety of electrical components but also have sensors that present various degrees of vulnerability to external magnetic fields. The near-microscopic micro-electro-mechanical systems (MEMs) in these devices include accelerometers, microphones, gyroscopes, temperature and humidity sensors, light sensors, proximity and touch sensors, image sensors, magnetometers, barometric pressure sensors and fingerprint sensors. Although many of these are made from non-magnetic materials others such as the magnetometer, the accelerometer and gyroscope have metal components and contacts that could become magnetized. However, most of these components are based on gold which is non-magnetic, so the risk is very low for damage by an external magnet. The magnetometer, however, is expressly designed to detect and measure magnetic fields, so damage to this device is not out of the question. Because the magnetometer is involved in determining the orientation of the smart device and other functions, if it is compromised it can affect the smart device's performance.

This subject is the core of a lively discussion on the internet. The consensus is that typical household magnets (kitchen refrigerator magnets, small neodymium-alloy magnets, and so on) have insufficient strength to have an effect even in direct contact. Many smart device cases even use a thin neodymium magnet to keep the case closed. There are some suggestions that the presence of an extraordinarily strong magnetic field can cause the battery to work slightly harder to supply the right voltage and thus wear the battery out faster. Magnets can affect the internal magnetic sensors located inside the smart device and may even slightly magnetize some of the steel inside your phone. This magnetization could then interfere with the compass on your phone. Some GPS apps, such as *Google Maps*, rely on the compass to determine your location. Other apps, specifically game apps, also rely on compass readings.

If your compass becomes corrupt, these apps could become impossible to use. In Apple's Case Design Guidelines, they have included sections on Sensor Considerations and Magnetic Interference, including the line, "*Apple recommends avoiding the use of magnets and metal components in cases*." Therefore, manufacturers must ensure that the built-in magnetic compass cannot be affected by their cases. If you place a strong magnet next to the cell phone, the iron components inside the cell phone can be magnetized, which will make it difficult for the compass and other apps to work properly. *Google Maps* uses the compass to determine the direction of the phone, and many games use the compass to "calculate" the direction of the user. Magnetization of the optical image stabilization sensor system in iPhone rear-facing cameras has also been reported. Magnetic sensors determine the lens position so that the compensating motion can be set accurately. A strong magnetic field can interfere with these essential functions resulting in blurry images.

3. How strong is strong?

It is easy at this point to continue to support fears and even urban legends by simply offering a blanket statement like '*Do not place magnets close to your smart device to minimize any risks*' but that would be the wrong approach, and an un-scientific one, as well. Like solar photography, it is impossible to anticipate every situation in which smart devices and magnets can come into conjunction or the outcomes, but many of them will be harmless.

Our intentional use of the magnetometer, the highest-risk element for magnetic damage, to make intentional measurements of magnetic fields provides some guidance. A search through the many apps that are available for measuring magnetic fields, and especially the electronic magnetometer devices themselves, suggests that most apps and magnetometers have a range up to about 4,915 μT (0.005 Tesla), which is equivalent to 50 Gauss. When evaluated on an iPhone 6S running *Physics Toolbox*, if a toy bar magnet is placed closer than one inch from the magnetometer sensor, it will register 1,800 μT (0.0018 T or 18 Gauss) but the display will then stop updating values and 'hang up'.

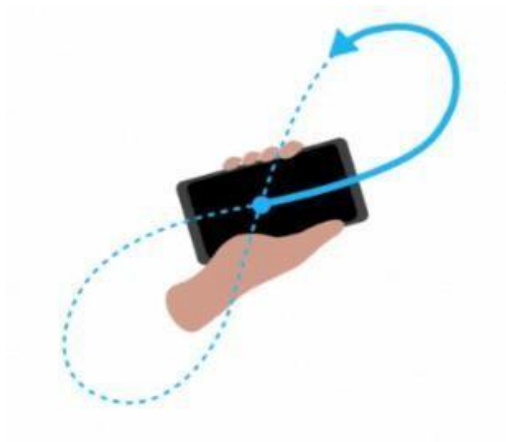

Figure 4. Calibration of smart device magnetometers using the 'figure 8' method.

When the display becomes unresponsive in this way, the app must be rebooted and the magnetometer re-calibrated. The same app on a Samsung Galaxy S8 reaches the limit of 4,915 μT and does not cause the *Physics Toolbox* app to crash. So, for the expected ranges of all the experiments in this Guide, the magnetic field exposure will be below the 18-gauss operating limits of both the magnetometer devices themselves and the apps operating on most platforms.

But just in case your app stops working due to a large magnetic field, you can recalibrate the magnetometer (see https://www.youtube.com/watch?v=zrEzMggOnFQ). With or without the magnetometer or compass display running, move your smart device in a figure eight motion in all 3D shown in Figure 4. This gives the magnetometer enough data to mathematically solve for the Earth's fixed magnetic field and the changing portion caused by your motion. The result will be normal magnetometer readings. To check, look at the X, Y, and Z values in your favorite app. They should not be larger than 70 μT for Earth's ordinary magnetic field. If the display seems stuck at values over 100 μT with no nearby magnets, repeat the figure eight motion and restart your app. Your compass bearings should also return to normal and show real-time changes as you rotate the smart device through the four cardinal directions.

Safety First: In general, when you are measuring the magnetic field of an unknown object, approach the object from a distance and discontinue measurements when the values exceed about 2000 μT.

Part III. A direct measure of Earth's magnetism using a smartphone.

1. Background

The simplest magnetometer designs are based on determining the position of a suspended magnet sensed by a reflected laser beam.

Devices that directly measure the geomagnetic field are the most elegant but also the most difficult to design and operate at the sensitivity levels needed for detecting slight, < 1 μT changes in the field caused by geomagnetic storm events. Hall effect sensors such as the ones in smartphones, are used to sense the orientation of the smartphone with respect to earth's magnetic field, which provides an external reference frame for VR and other gaming applications. Smartphone app developers use this feature to determine the orientation of the smartphone in space using the three axes of the geomagnetic field as a reference. In this design, we can also use a smartphone to directly measure the Bx, By and Bz values for the geomagnetic field and look for changes in them that coincide with strong geomagnetic storm events. In this design, we will continue to use the *Physics Toolbox* app because it allows recorded data to be exported for later analysis.

2. Procedure

Step 1) Place the smartphone on a tabletop or other surface that has been leveled.

3. Gathering Data

Step 2) Start the app and allow it to record data for 3-4 hours. Make sure the smartphone is fully charged.

4. Analyzing Data

Step 3) Export the data to MS Excel. Use the 'text to columns' function to expand the date with one value per column.

Step 4) Combine the X and Y values into a horizontal field value, $H = (X^2 + Y^2)^{1/2}$

Step 5) Plot the H and Z magnetic values on the same plot by highlighting the two columns and using the standard Excel plotting function. An example of the result should look like the graph in Figure 5, which displays data collected during calm and storm conditions.

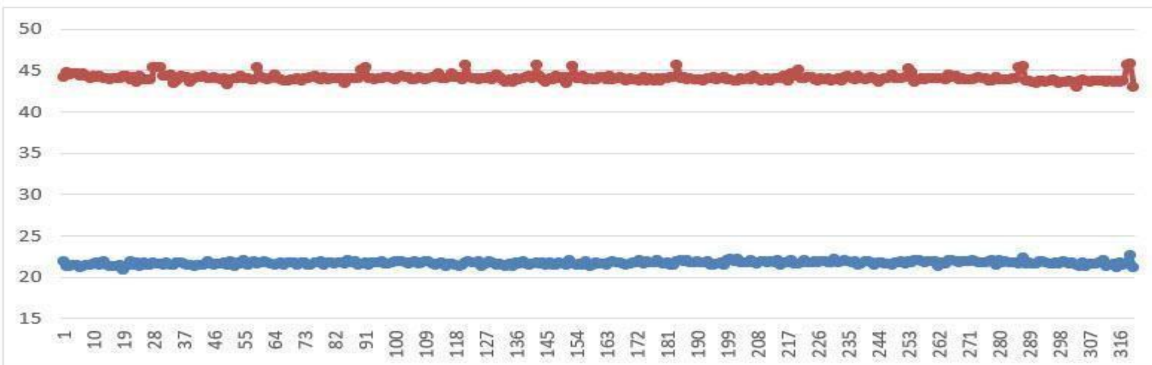

Figure 5. Example of a smartphone magnetometer plot.

The graph in Figure 5 displays H as the lower blue line and |Z| as the top red line. The vertical axis is the magnetic values in units of μT, and the horizontal axis is the sample number, with one sample made every second. The total duration was 316 seconds, or about 5 minutes. For longer measurements of several hours, you will notice many diverse kinds of artifacts. You are looking for smooth changes in the baseline values that appear and disappear over the course of several hours and have a maximum change of about one μT. Figure 6 shows what a severe Kp=9 geomagnetic storm such as the one in 2003 might look like with a smartphone magnetometer. The bottom trace in the figure is the normal magnetometer measurement noise in a smartphone. The middle trace is the actual data from the Fort Churchill magnetic observatory for the October 30, 2003, storm. The top trace is the predicted changes that would be measured by a smartphone magnetometer. The most severe (Kp=9) phase of the storm occurred between 6:00 and 8:00 UT with a change of -3.0 μT from the normal quiet state. This dip in the predicted smartphone data should be easily detected for a storm of this intensity.

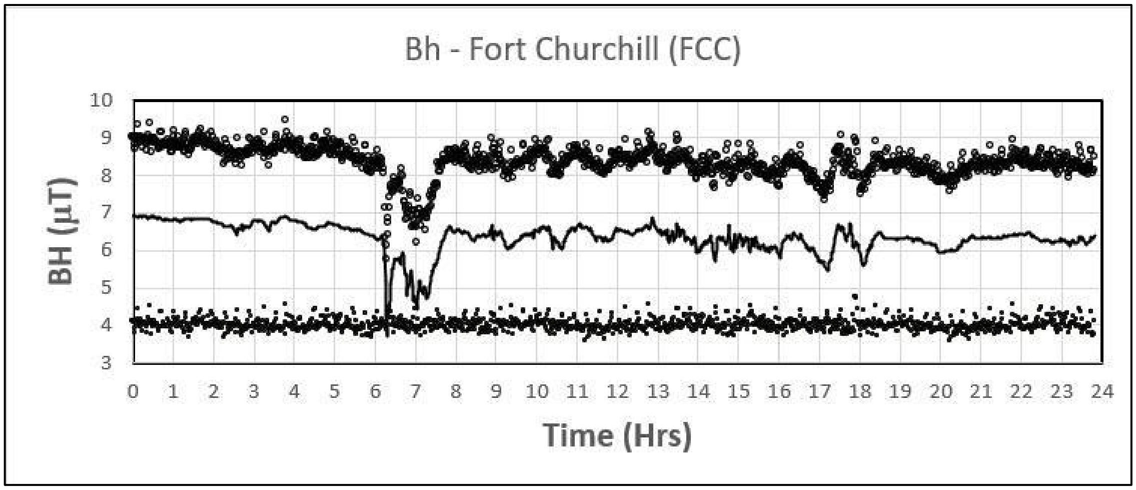

Figure 6. Predicted variation during a severe geomagnetic storm.

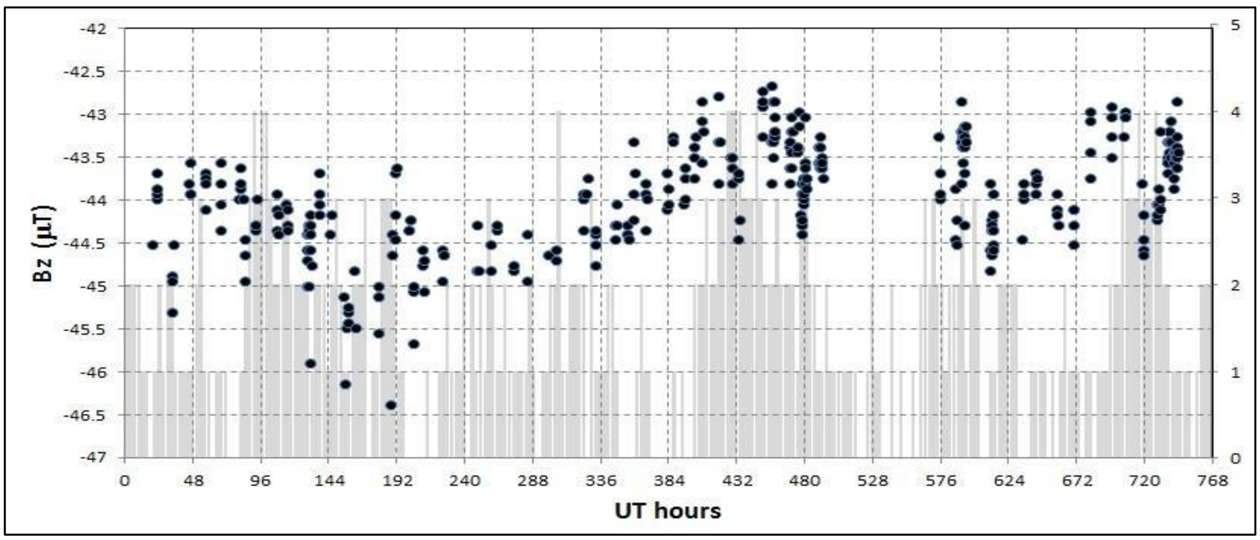

Figure 7. Example of a Kp = 4 magnetic storm (dots near UT=432h) detected on September 17, 2017, from Kensington, Maryland. The grey bars show the Kp index.

5. What to expect

Compared to professional magnetometers used at magnetic observatories, smartphones are not the ideal instruments to use to detect geomagnetic storms. But they can be used to detect some of the stronger storms at modest statistical confidence. The process requires careful analysis of the data recorded by smart devices. Generally, for severe storms with Kp>7, these events should be detectable in most locations across North America. These storm events, however, are exceedingly rare and occur about once every month during times when the Sun is active (called sunspot maximum). They are unpredictable, so you need to carefully monitor such space weather websites to see if a storm is likely in the next 24-48 hours.

Hall Effect sensors create a changing output voltage as the magnetic field that passes through them changes in strength. Various magneto-resistive materials are used to confine the response of each sensor to only one dimension of the applied field. An example of such a magnetometer sensor is the AK8963, 3-axis Electronic Compass IC (Asahi Kasei Microdevices, 2017), which is used in iPhone models 5, 5S, 6, 6Plus. This is a silicon monolithic Hall Effect sensor with a magnetic concentrator. The AK8963 chip's measurement range is from -4912 μT to +4912 μT (-49 Gauss to + 49 Gauss). The voltage generated is in analog form, so an on-chip analog-to-digital converter converts the output to either a 14-bit or a 16-bit data word.

Output data resolution is 0.15 μT/bit for the 16-bit model based on 1-bit for the sign of the number and 15-bits for the magnitude corresponding to 4912 μT. In continuous measurement mode, the magnetometer takes 8 samples per second for regular resolution and 100 samples/sec for high resolution measurements. The Samsung Galaxy S5 uses a Yamaha YAS532B 3-axis magnetometer (Yamaha, 2014) whose specifications indicate a 'sensitivity' of 0.15μT in the X-Y directions and 0.25 μT in the Z-direction, with maximum field strengths of 1200 μT. The sensitivity is like the iPhone AK8963 magnetometer chip, which was released on the iPhone 6S platform a month later.

Earth's magnetic field has a typical strength of approximately 50 μTesla (0.5 Gauss). Typical storm events shown in Table 4 can cause changes at a level of only a few μT according to the published high-latitude Kiruna Magnetic Observatory and the midlatitude Boulder Magnetic Observatory scales. It is apparent from the typical deviations from the baseline fields that environmental factors and instrumental effects need to be well-understood and controlled before attempting monitoring even for the most intense storm events. Clearly to detect significant magnetic storm events with Kp>5 we need to be able to reliably measure magnetic field changes of the order 0.2 to 1.5 μT with high statistical confidence. Given that the digitation noise for these platforms is of the order ±0.2 μT, it is likely that geomagnetic storm detection can be nominally achieved at the 3-sigma level for storms stronger than Kp = 7.

Table 4. Kp index compared to Kiruna and Boulder absolute magnetometry.

Kp index	Kiruna (μT)	Boulder (μT)	Condition
9	>1.5	>0.5	Extreme Storm – G5
8	0.99 to 1.5	0.33 to 0.5	Severe Storm – G4
7	0.6 to 0.99	0.2 to 0.33	Strong Storm – G3
6	0.36 to 0.6	0.12 to 0.2	Moderate Storm – G2
5	0.21 to 0.36	0.07 to 0.12	Minor Storm – G1
4	0.12 to 0.21	0.04 to 0.07	Active
3	0.06 to 0.12	0.02 to 0.04	Unsettled
2	0.03 to 0.06	0.01 to 0.02	Quiet

Kp index	Kiruna (μT)	Boulder (μT)	Condition
1	0.015 to 0.03	0.005 to 0.01	Quiet

To determine whether these simple smartphone magnetometers can in fact detect small storm-time field changes we need to establish the accuracy and linearity of the magnetometer output compared with those of magnetic observatories and other standard calibrators. This space weather application poses a considerable challenge to these simple magnetometers, which were only really designed to register, for example, compass directions to a precision of a few digitization bits accuracy (±3° in bearing corresponds to about ± 1 μT). Two different smartphone platforms were tested: Apple iPhone 6s (Released in September 2015) running iOS 9, and Samsung Galaxy Note 5 (Released in August 2015) running Android 7.0. The *Tesla Recorder* app was available for both platforms.

Optimally, one expects that as more samples are averaged, the deviations from the mean values will integrate down as $1/\sqrt{N}$ if the noise process is dominantly Gaussian in character. The presence of bimodal distributions in the x and y magnetic components Bx and By suggest that at least for these two sensors, the noise process is non-Gaussian. We can check this by constructing the noise spectrum for each data set by computing the standard deviation (sigma) of progressively larger set sizes and plotting the result on a sigma versus N plot. For Gaussian noise, the resulting sigma should follow a simple $1/\sqrt{N}$ law.

What was found was that both platforms and their magnetometer/ADC chip sets provide a distinctly non-Gaussian noise behavior in their output that declines to a plateau near 0.2 μT for N>40 samples. No further increase in the number of measurements will reduce the uncertainty in the derived mean value for Bx and By, however the Bz and |B| values show an expected decline following $1/\sqrt{N}$ for N<60 with a distinct flattening for N>60 that is especially pronounced for the Samsung platform. For both smartphones, we see the identical effect of the digitizer's ±1 Least Significant Bit (LSB) in setting the level of the white noise component that is reached after about 40-60 samples have been averaged, and no further averaging will further reduce this noise limit for smartphone and their differing magnetometer/ADC chip sets. This also suggests that no amount of combining magnetometer data from large numbers of observers will reduce this noise limit below about ±0.2 μT.

Based on these findings, the optimal data-taking strategy for smartphones involves placing them on a non-metallic table that has been leveled to better than a 1° tilt in each horizontal direction, ensuring that the Bz axis is exactly parallel to the standard geomagnetic Z-axis. There should be no metallic objects or electrical systems (motors, laptops, TVs) within two or three meters of the smartphone to minimize interference and improve magnetic shielding. The ambient temperature needs to be regulated for the duration of the entire storm observation period, which may last several months. Indoor locations are preferred because they tend to be regulated to be close to 68° F under most situations, and during most times of the year. At the start of the measurement session, the smartphone battery should be fully charged (100%). If battery charge falls below 20% while data-logging is taking place, it is acceptable to plug-in the charger while the app is running, but the resulting data from during the charging period **must be deleted** to eliminate the characteristic feature of this charging operation. Because the noise in the data is limited by the digitization of the ADC, data should not be averaged over more than 60 consecutive samples to reduce the noise. Typical noise levels that can be obtained under ideal conditions should be near ±0.2 μT.

6. Results for newer smartphone models.

Although older-model smartphones such as the iPhone 6 and the Galaxy 9s are still available, newer models such as the iPhones 12, 13 and 14 have now become available. A recent iPhone 13 (debut year 2021) was tested to determine whether the newer magnetometer chips have improved the sensitivity for detecting geomagnetic storms. The smartphone was placed on a tabletop and the *Physics Toolbox* 'Magnetometer' was run for about 30 minutes to record the local Bx, By and Bz. The geomagnetic field during this time was very calm at a value of Kp=1.0. At the measurement latitude of Maryland, the nearby magnetic observatory in Fredericksburg, VA (FRD)[1] recorded no disturbances greater than about ±1 nanoTesla (nT) as shown in Figure 8 between UT times of 9:00 and 9:30. Note that 1 nT = 0.001 μT. Even the largest deviation at the start of the trace was only ±5 nT. Figure 9, meanwhile, shows the corresponding iPhone 13-measured, Bz component.

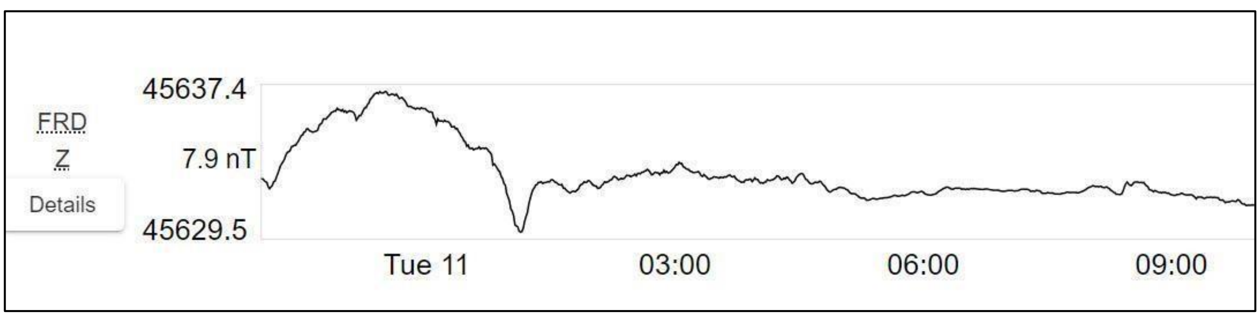

Figure 8. The Bz data from the Fredericksburg Magnetic Observatory.

[1] https://geomag.usgs.gov/plots/observatory?stations=FRD

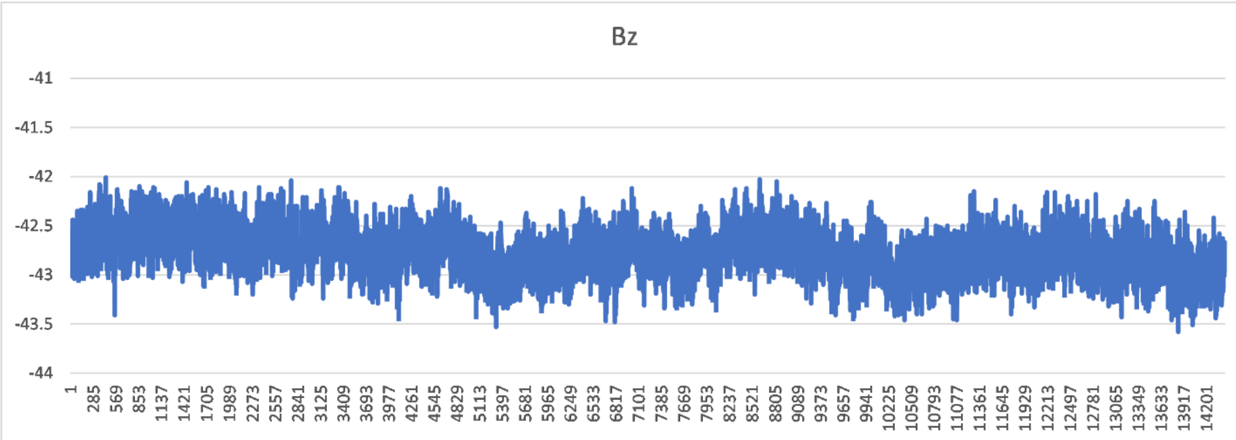

Figure 9. The Bz component of the local magnetic field as measured by an iPhone 13 Pro.

The value for Bz during this entire time represented by 14200 samples in Figure 9 was -42.77 ±0.22 μT. This means that, because 1000 nanoTeslas (nT) = 1 μT, the overall noise level is just ±220 nT. The first 2200 samples have fewer 'wiggles' and lead to Bz = -42.58 ±0.19 μT or a noise of ±190 nT. This is like the expected sensitivity of the A/D converter used in smartphones, which has a 1-LSB bit sensitivity of about 190 nT. In terms of the noise level, the new model evaluated is not even marginally better than the older models. However, the iPhone 13 does not have the odd baseline artifacts that the older iPhone 6s had, which is a considerable improvement. This will also make combining data from multiple sessions much easier and reliable for detecting weaker storm events.

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