MagArrow

UAS Deployable Magnetometer

User Guide

V. 1
Rev. D

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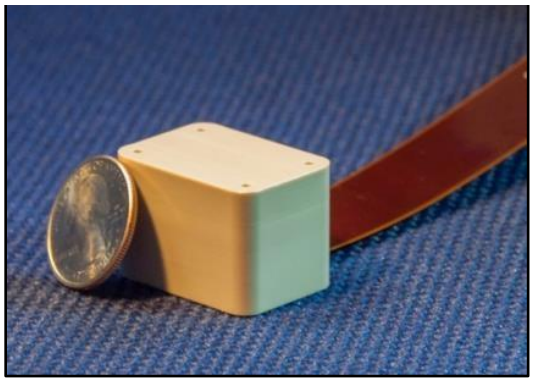
Contents

The MagArrow

The MagArrow is a laser-pumped, cesium vapor (Cs133 non-radioactive) total field scalar magnetometer. The MagArrow's light weight of 1 kg makes it ideal for use with unmanned aerial systems (UAS) that can support 2kg+ payloads. Within its aerodynamic carbon fiber housing, the MagArrow contains:

- MFAM miniature magnetometer
- GPS
- Wireless Connection Point
- SD Memory Card
- USB Drive
- Gyro, Compass, and Accelerometer
- Battery

The MFAM miniature magnetometer comprises two high-performance cesium sensors attached to one sensor driver module. The two sensors are used together in order to eliminate the dead zone and reduce heading error. Its small weight, low power, and 1000Hz sampling rate make the MFAM a revolutionary sensor in the geophysical market.



One MFAM Sensor

The pulse per second (PPS) signal from the GPS synchronizes the sampling rate to ensure 1000 samples are recorded per second. (See Appendix C for a detailed definition of PPS.) Data is downloaded via WiFi, so the 32 GB SD memory card never needs to be removed. The USB drive holds the latest MagArrow firmware and can be used for fast field upgrades. The MagArrow uses non-magnetic lithium polymer batteries for power, which the user must source locally.

During survey operations, the MagArrow gathers and stores the data in a binary format onto the SD card (*.magdata). This binary data can then be downloaded onto a PC, tablet, or cell phone via the system's on-board Wireless access point. Software is provided that converts the binary data into a CSV file for use in Surfer, Geosoft Oasis Montaj, Quinsy, and other magnetic data processing programs.

Unpacking the MagArrow

Your MagArrow is shipped in a rugged black case with safety latches that require you to first push the button on the latch before raising the latch and opening the lid. To close the latches, just push down on them.

To repack for transit, place the MagArrow upside down so it sits securely in the foam. Close all latches.

The case should also contain:

- AC Power Adapter
- Screwdriver & Drill Bit (JIS#1)
- USB Drive with User Manual and Survey Manager Software

Recommended Non-Magnetic Lithium Polymer Batteries

Please note that batteries have not shipped with your MagArrow. You must source the recommended batteries and battery charger locally. Note that your batteries must have the XT60 connector.

Geometrics recommends 1800 mAh lithium polymer batteries from Zippy or Turnigy and the 2200 mAh lithium polymer battery from Turnigy. The 2200mAh battery from Zippy is too wide and won't fit in the MagArrow's battery compartment. These batteries have been verified by Geometrics to be non-magnetic, and therefore, the best option for MagArrow surveys. They should be available from various online vendors including the Hobby King website:

https://hobbyking.com/en_us/zippy-flightmax-1800mah-3s1p-20c.html (Zippy Flightmax 3S1P 1800 mAH Lipo Pack)

https://hobbyking.com/en_us/turnigy-nano-tech-1800mah-3s-65-130c-lipo-pack.html (Turnigy nano-tech 1800mah 3S 65~130C Lipo Pack)

https://hobbyking.com/en_us/turnigy-nano-tech-2200mah-3s-45-90c-lipo-pack.html (Turnigy nano-tech 2200mah 3S 45~90C Lipo Pack)

http://electronicarc.com/catalogo/gens-ace-2200mah-111v-2550c-3s1p-lipo-battery-withb-xt60-con-p-2353.html (Gens Ace 2200mah 11.1V 25C 3S1P)

A single 1800 mAh battery will run the MagArrow for about 2 hours; the 2200 mAh, about 3 hours. It is recommended to have at least two spare batteries so that one may be charging while the other is in use.

We recommend this battery charger and discharger for use with the MagArrow:

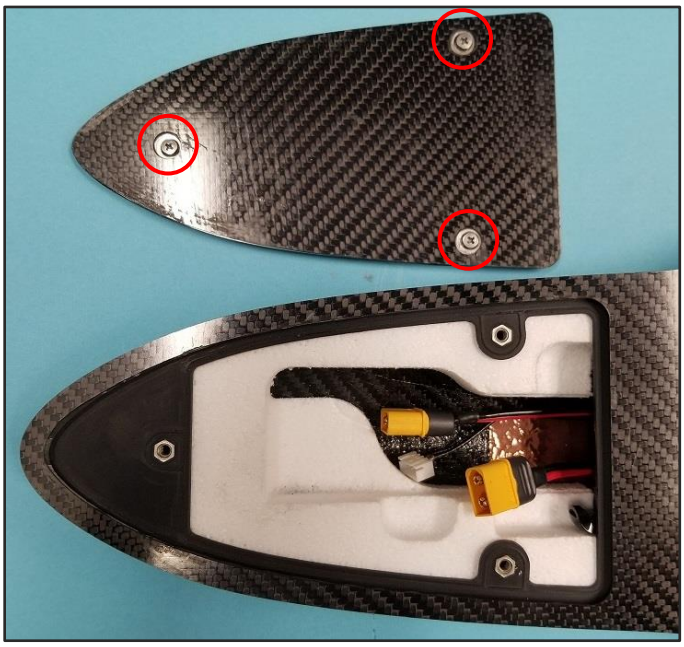
https://hobbyking.com/en_us/accuell-s60-ac-charger-us-plug.html

This is a balanced charger that charges one lithium battery pack at a time. Each of the three battery cells within the battery pack are charged independently. It has a discharge mode to automatically lower the battery charge state to 30%. **IMPORTANT: It is required by law to reduce the battery charge state of these lithium polymer batteries to 30% before shipment**.

Installing the Battery

On the bottom of the MagArrow, there is a door to the battery compartment where the batteries will be stored.

1. Remove the battery compartment cover with the provided JIS#1 screwdriver. It is very important to only use the provided JIS#1 screwdriver to tighten or loosen the battery door screws (see red). **Do not use a Phillips Screwdriver**.

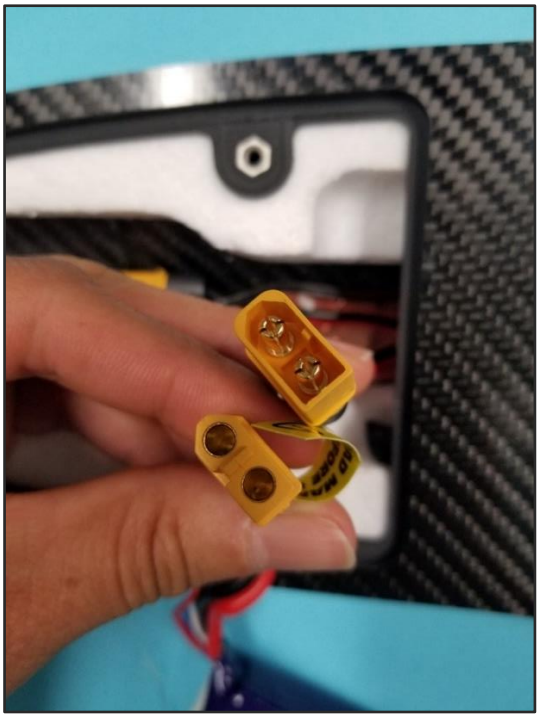


Battery Compartment Door Removed

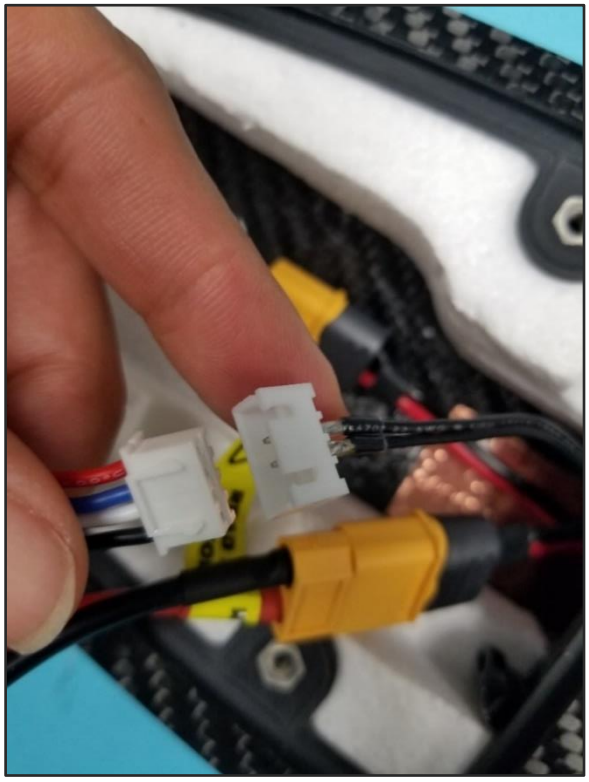
2. Proper battery placement inside the battery compartment is as shown in the figure above. The battery leads must be housed towards the pointed front of the MagArrow.

Proper Placement of Battery Pack

3. There are two yellow battery connectors and one white cell voltage monitoring connector within the battery compartment. Locate one of the yellow battery connectors and the white cell voltage monitoring connector. Plug the lithium battery connector (yellow) into the yellow connector. **Note: The second yellow connector is used when hot-swapping batteries. This will allow you to disconnect the discharged battery without losing power to the magnetometer.**



4. After making the power connection, plug the white connector into the white lithium battery connector. This connection is for monitoring the three internal cells of the batterie's voltage. Be careful not to connect them backwards.



5. Slide the battery into the compartment and carefully tuck the wires alongside the battery.

Hot Swapping the Battery

For quick battery changes, the new battery pack can be plugged into the second (unused) yellow battery connector before disconnecting the depleted battery. This method of swapping batteries does not require shutting the system down, which will save time. See the instructions below on how to hot swap the battery.

1. Loosen the screws on the battery cover with the screwdriver and remove the cover.

2. Grasp the sides of the battery at the cutouts provided, and then lift up as shown in the figure above.
3. Locate the spare yellow connector and plug in the new battery pack while the depleted battery is still connected.
4. Unplug the depleted battery pack from the yellow and white connectors.
5. Plug the white voltage monitoring connector to the connector on the new battery pack.
6. Put battery and connectors into the space provided.
7. Turn the system ON before replacing the battery compartment cover (see next section Powering On/Off).

*Note: The MagArrow is equipped with internal electronics so that the unit automatically draws power from whichever battery is more fully charged. **The MagArrow will automatically shut down when the battery voltage gets too low for proper operation, about ~30%.**

Powering On/Off

There is a black Power button located inside the battery compartment. The button has a smooth round top about 5mm in diameter and requires little force. It is used to Power On, Power Off, and Reset the system.

- **To Turn On** – With the battery compartment door off, fully press, and then release the black Power button. The LED lights on the underside of the system will immediately flash twice when the power button is pressed.
- **To Turn Off** – Press and hold the power button for 3 seconds. The LED lights will to flash rapidly for the 3 seconds before the system completely shuts down.
- Replace the battery compartment door. To prevent side stress, place the three screws in each of the three holes and tighten them just to the point of resistance. After the three screws are placed, do a second pass to torque them to a comfortable, secure tightness.

Resetting the System

It may be necessary, on occasion, to reset the MagArrow. For example, the system may require reset in the event of a glitch with the Web Browser. There are two options when this happens:

- Turn the system OFF and then back ON, or
- Reset the system – Press the Power button once

While the unit is operating, **a quick push of the Power button** signals to the processor used for logging and WiFi connectivity that the user wishes for it to restart **without disturbing the magnetometer operation**. The rapidly flashing LEDs indicate that the button press has been registered.

Powering On/Off reboots both the system software and the magnetometer physics package.

Resetting only reboots the system software, and therefore reduces the startup time significantly.

Try using the reset function first, and if that does not fix the error, then cycle the power.

LED Status

When the system is powered on, the two bright LEDs on the underside of the MagArrow will flash. The pattern of flashing will depend on the system status.

These LEDs visually provide some status information when the MagArrow is out of range for WiFi communication. If the wireless system does not start correctly, you won't be able to communicate with the system, and you should contact Geometrics for assistance.

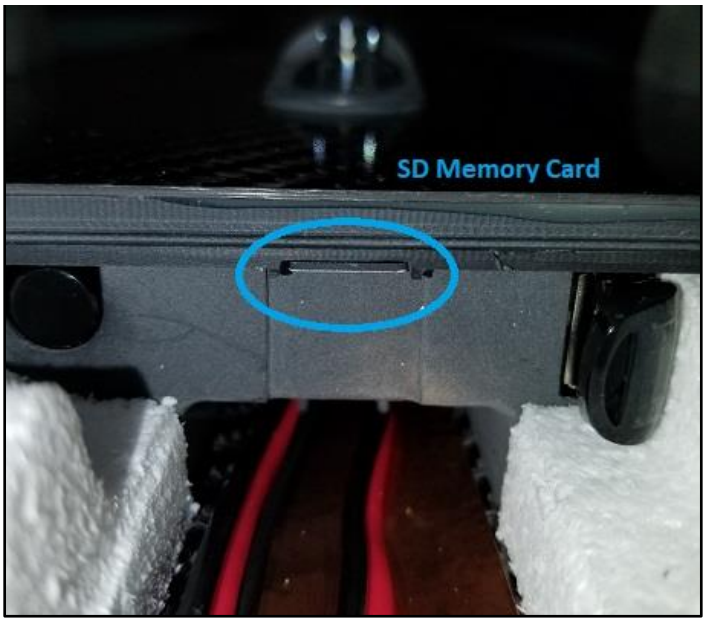
Table 1 - LED Patterns

LED Pattern	**Meaning**
Single Flash - 4 second pause	Starting Sequence - No WiFi Connection
Double Flash - 4 second pause	Connected to WiFi - GPS not Locked
Single Flash - 1 second pause	Standby - No WiFi Connection
Double Flash - 1 second pause	Connected to WiFi - GPS Locked
5 Flashes - 1 second pause	Needs User Attention. See Troubleshooting section
Rapid Flashing	Shutting Down

Note: The bottom of the MagArrow is dark and shaded, which allows the operator to see the LEDs from a considerable distance. At extreme distances, binoculars may help the observer.

There are two lights inside the battery compartment that can also be used for troubleshooting. Please see the Troubleshooting section below for more details.

SD Memory Card



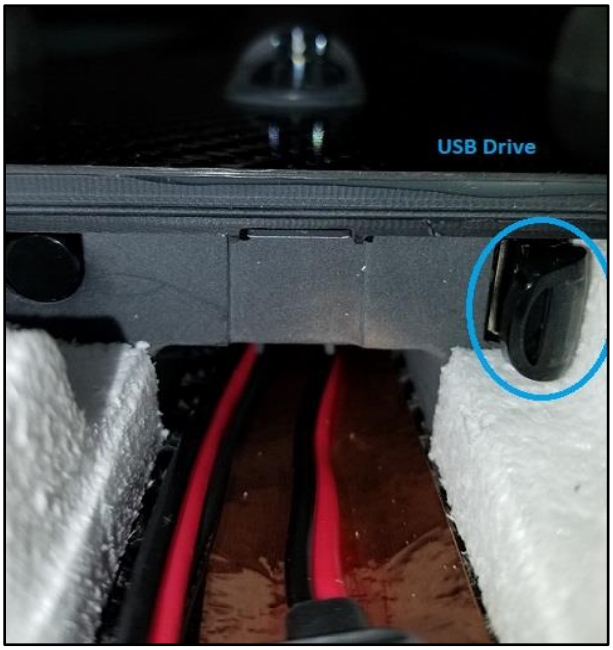
The MagArrow stores data on the 32 GB Micro SD memory card which is located inside the battery compartment and next to the power button. This SD card is U3 speed class.

In case of a WiFi failure, you may remove the SD card and read it using an SD card reader. However, under normal circumstances, the user should not need to remove the SD card. If removal is required, first power off the unit and remove the battery.

The SD card holder uses a spring latch, so to remove the card, first push the card inward and then release. The card should pop out. Use caution to ensure that the SD card is not lost when ejected.

To ensure the safety of your data, please practice proper media management.

USB Flash Drive



The MagArrow contains a USB Flash Drive inside the battery compartment. The primary purpose of this USB is to allow for upgrading the software quickly and easily. The USB drive contains a binary file with the most recent software. When the system turns on, this file is automatically read and loaded. For system upgrades, Geometrics will provide the most recent software binary file for upload onto the USB.

This USB Flash Drive has been verified to be non-magnetic. It is highly recommended that you do **NOT** install any other USB Drive into the MagArrow because many USB flash drives are magnetic. A flash drive that is magnetic would bring unwanted noise into the magnetic field measurements.

The USB drive should not be removed unless absolutely necessary. If the USB drive needs to be removed, first unplug and remove the battery, then remove the flash drive.

WiFi

Any device with a web browser and WiFi capability (smart phone, computer, tablet, etc.) can control the MagArrow, including logging starts and stops as well as data downloading. The WiFi firmware inside of the MagArrow stores data to the Micro SD card, controlled through a WiFi interface via any standard internet browser (such as Google Chrome or Firefox).

The FCC ID for the WiFi module built into the MagArrow system is: Z64-CC3100MODR1

If required, the Certification can be found here:
https://apps.fcc.gov/oetcf/tcb/reports/Tcb731GrantForm.cfm?mode=COPY&RequestTimeout=500&tcb_code=&application_id=05I87jydzWxU5bDoI51sfg%3D%3D&fcc_id=Z64-CC3100MODR1

GPS

The GPS inside the MagArrow has two functions. The first function is to provide the location at which measurements are made. The GPS will provide roughly 1.0 meter positional accuracy under good conditions. The second function utilizes the 1PPS to synchronize the sampling rate, ensuring that 1000 samples are recorded per second.

After turning the system on, it will take approximately 2-3 minutes to get a good satellite fix and for the PPS to begin synchronizing the measurement. The GPS requires signal from several satellites before it can generate the 1PPS pulse.

If you select **Start Logging** before there is a GPS fix, magnetic data will **NOT** be saved to file.

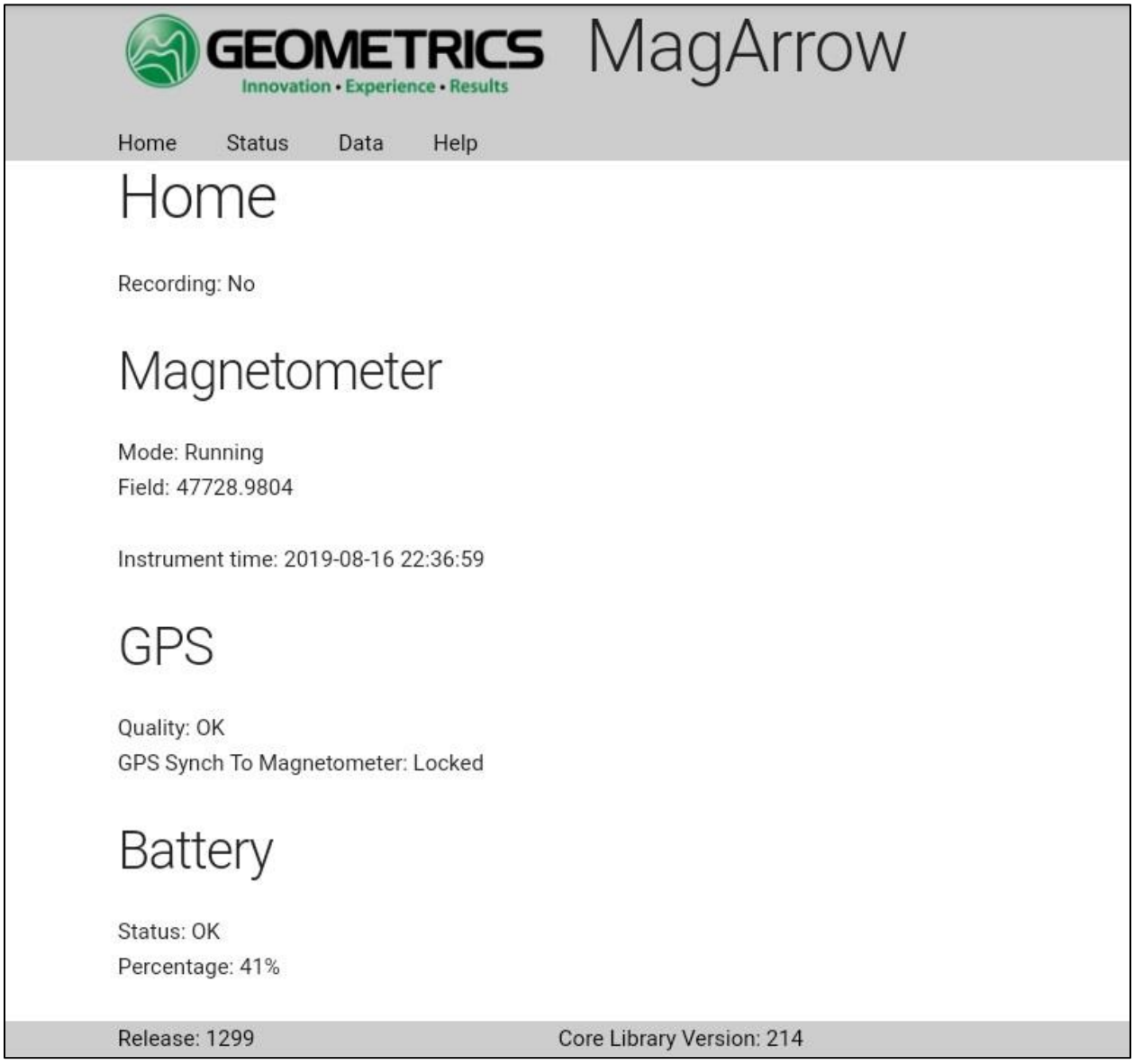
The GPS antenna is approximately 18.5 inches from the sensor.

Controlling the MagArrow via WiFi

The MagArrow creates a wireless access point with a unique name like "Blue Sky" or "Green Pond." This is an unsecured access point, which means it does not require a password to connect. To connect, go to the settings of your logging device, turn on WiFi, and connect to the MagArrow. It may take about 15 seconds for the tablet or other device to find the access point. Only one device can be connected to the MagArrow's wireless access point at a time. *When the device is successfully connected to the WiFi and GPS Sync is Locked, the LEDs will* ***flash twice followed by a 1 second pause.*** See LED Status section above for more information.

Open a browser on the logging device and type the following IP address into the web browser bar: **magarrow.net**. This will take you to the Home Page of the MagArrow's wireless control software. The sections below describe the features on each of the pages in the MagArrow web-based control program. In order, you will find the Home Page, Status Page, Data Page and Help.

Home Page



On the Home page, there is information about the status of the magnetometer, the GPS, and the battery. From top to bottom, here is what each item on the Home Page represents:

Recording: Yes/No - This indicates whether or not the system is currently saving data to the SD card.

Magnetometer

Mode: Running/Starting - This displays the current mode of the magnetometer.

> **Starting -** The magnetometer sensors are warming up. It is very likely that you will not see the Mode as Starting since it only takes one to two minutes for the sensors to warm up.
>
> **Running -** The sensors are currently running and operating normally.

Field: 47728.9804 - This is the magnetic field reading reported when the page was last refreshed. You may also see the term '**Invalid'.**

Press Home to refresh the page. The Field value should update, indicating that the system is recording changes in the magnetic field. If the field reading continues to say '**Invalid'**, it means that the magnetometer is near a very high magnetic field.

Instrument Time: 2019-08-16 22:36:59 - This shows UTC date and time from the GPS, respectively.

GPS

Quality: Unavailable; OK; Low Precision - This displays the current status of the GPS. This can either be OK, or Low Precision.

Unavailable - The GPS is not outputting position information**.**

OK - The Horizontal Dilution of Precision is less than 1.5. See Appendix C for more information about the Horizontal Dilution of Precision (HDOP).

Low Precision - The Horizontal Dilution of Precision is greater than 1.5.

GPS Synch to Magnetometer: Locked; Available/Not Locked; Not Found - This indicates that the PPS pulse is fixed and synchronizing the timing of the measurement.

Locked - The measurement timing is phase locked to the PPS.

Available/Not Locked - The GPS data is coming in, but the measurement is not phase locked to the PPS.

Not Found - There is no GPS fix. It is rare to see Not Locked and Not Found displayed here. If these are displayed, try moving to an area with open sky.

Battery

Status: OK; Low; Download Only; Critical - This shows the current status of the battery.

OK - The reported state of the battery when it has more than 30% charge remaining.

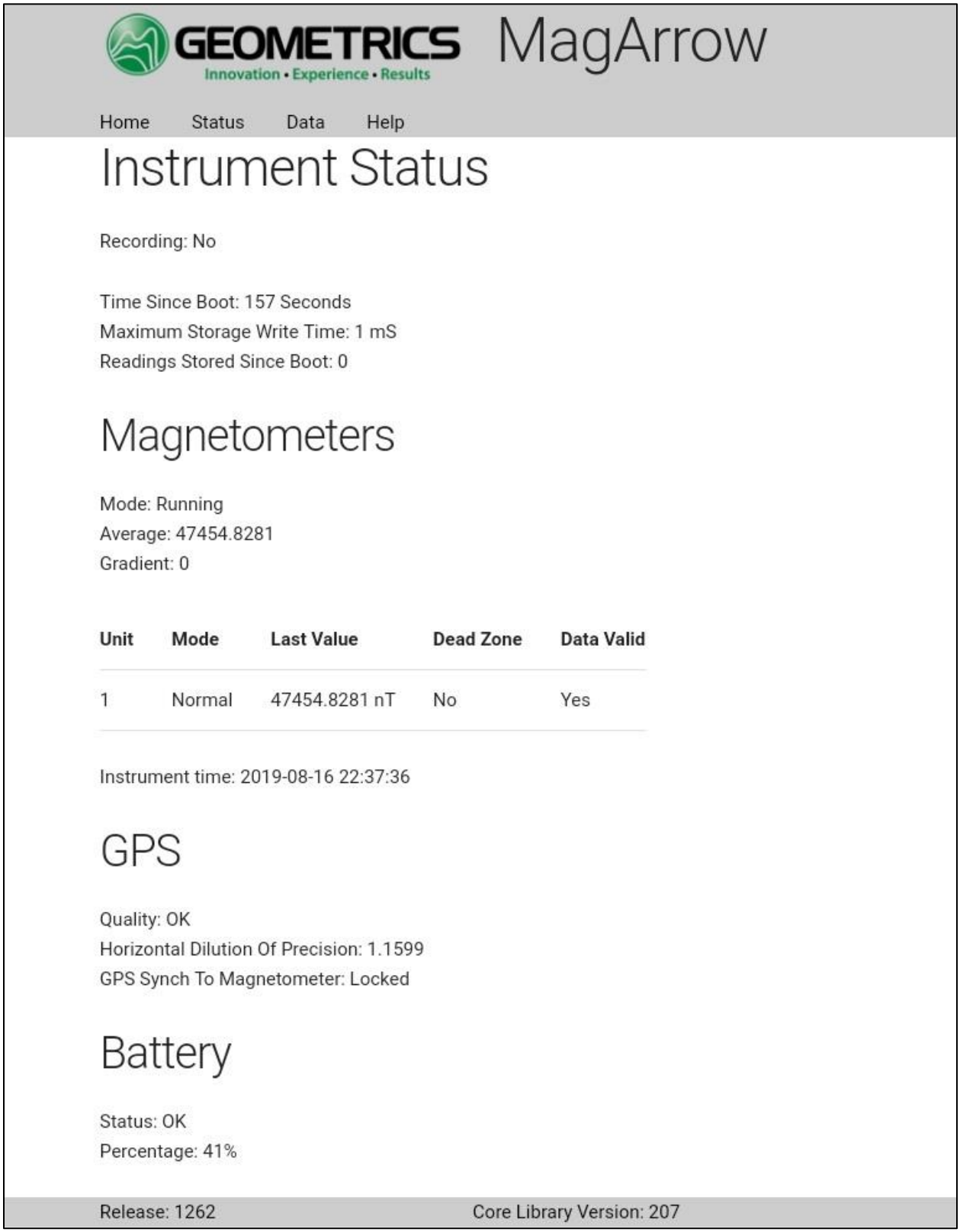
Low - The reported state when the battery has less than 30% charge remaining.

Download Only - The battery charge is too low to run the sensors, but still has enough charge to download data files. The WiFi will continue to function for a limited time in this condition. It is highly recommended to change the battery when the percentage drops to 30%. Hotswap.

Critical - The reported state when the system is near shut off. You are unlikely to see the critical state on the screen as the system may have already shut off. To prevent unexpected power loss, replace the depleted battery with one that is fully charged when the reported state is low. Hotswap.

Percentage - The approximate percentage of battery charge remaining.

Status Page


GEOMETRICS
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MagArrow
Home
Status
Data
Help
Instrument Status
Recording: No
Time Since Boot: 157 Seconds
Maximum Storage Write Time: 1 mS
Readings Stored Since Boot: 0
Magnetometers
Mode: Running
Average: 47454.8281
Gradient: 0
Unit
Mode
Last Value
Dead Zone
Data Valid
1
Normal
47454.8281 nT
No
Yes
Instrument time: 2019-08-16 22:37:36
GPS
Quality: OK
Horizontal Dilution Of Precision: 1.1599
GPS Synch To Magnetometer: Locked
Battery
Status: OK
Percentage: 41%
Release: 1262
Core Library Version: 207

Clicking Status on the top menu bar will bring you to the Status page. On this page, you will see similar information as on the Home page. Refresh the page by selecting Status. This will update the status information on the page.

Instrument Status

Recording: Yes/No - This indicates if the system is currently saving data to the SD card or not.

Time Since Boot: 157 Seconds - This conveys how long the system has been running, in seconds.

Maximum Storage Write Time: 1 mS - This shows the maximum time it takes to write information to storage.

> *This will have no practical use during survey operations and should only be used for troubleshooting or receiving support from Geometrics.*

Readings Stored Since Boot: 0 - This shows how many records have been stored since system boot.

Magnetometer

Instrument Mode: Running/Starting - This indicates that the magnetometer is currently running and operating normally.

> **Starting** - As it only takes one to two minutes for the sensors to warm up, it is unlikely that you will see this mode.
>
> **Running** - The sensors are currently running and operating normally.

Sensor Mode: Starting/Normal - This tells us the current mode/Status of each sensor.

> **Starting** - The sensor is warming up. As it only takes one to two minutes for the sensors to warm up, it is unlikely that you will see this mode.
>
> **Normal** - The sensors are currently running and operating normally.

Field: 47454.8281nT - This shows the last reading measured by the sensor when the browser was last updated. Clicking Status again will refresh the page and update this value.

Data Valid: Yes/No - This indicates whether the data being recorded is valid. **No** may be displayed here if the system is very close to a large magnetic gradient that is above the gradient tolerance.

Instrument Time: 2019-08-16 22:37:36 - This shows UTC date and time from the GPS.

GPS

Quality: Unavailable/OK/Low Precision - This displays the current status of the GPS.

> **Unavailable -** the GPS has not locked onto enough satellites.
>
> **OK** - the Horizontal Dilution of Precision is less than 1.5.

Low Precision - the Horizontal Dilution of Precision is greater than 1.5.

Horizontal Dilution of Precision: 1.6599 - HDOP is a term used in satellite navigation and geomatics engineering to specify the additional multiplicative effect of navigation satellite geometry on positional measurement precision. Please see Appendix C for additional information about GPS HDOP.

GPS Synch to Magnetometer: Locked/Not Locked/Not Found - This indicates that the PPS pulse is fixed and synchronizing the timing of the measurement. This ensures that exactly 1000 readings are recorded per second.

Locked - The measurement timing is phase locked to the PPS.

Not Locked - The GPS data is coming in, but the measurement is not phase locked to the PPS.

Not Found - There is no GPS fix. It is rare to see Not Locked and Not Found displayed here. If these are displayed, try moving to an area with open sky.

Battery

Status: OK - This shows the current status of the battery.

OK - The reported state when the battery has more than 30% charge remaining.

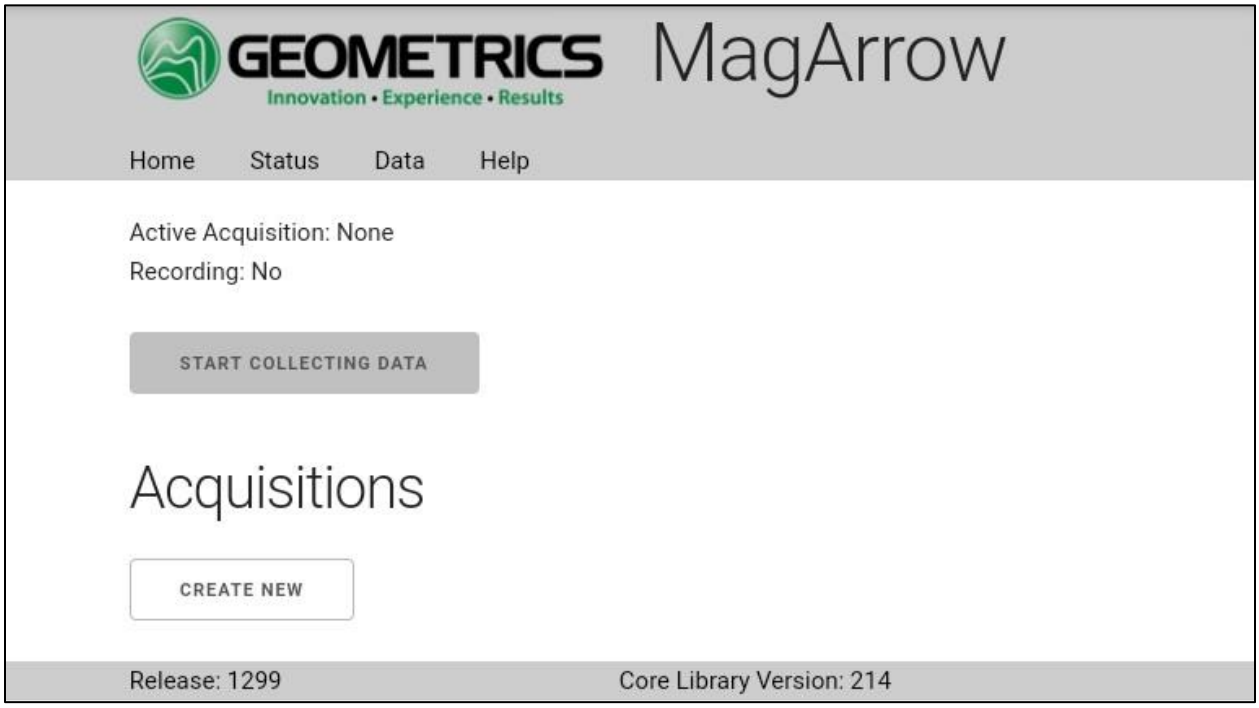
Low - The reported state when the battery has less than 30% charge remaining.

Download Only - The battery charge is too low to run the sensors, but still has enough charge to download data files. The WiFi will continue to function for a limited time in this condition. It is highly recommended to change the battery when the percentage drops to 30%.

Critical - The reported state when the system is near shut off. It is likely that Critical will never been seen on the screen as the system may have already shut off.

Percentage - The percentage of battery charge remaining.

Data Page



Clicking Data on the top menu bar will bring you to the Data page. This is the most interactive page, where you will create new surveys, control when data begins and stops recording, download data, and delete data.

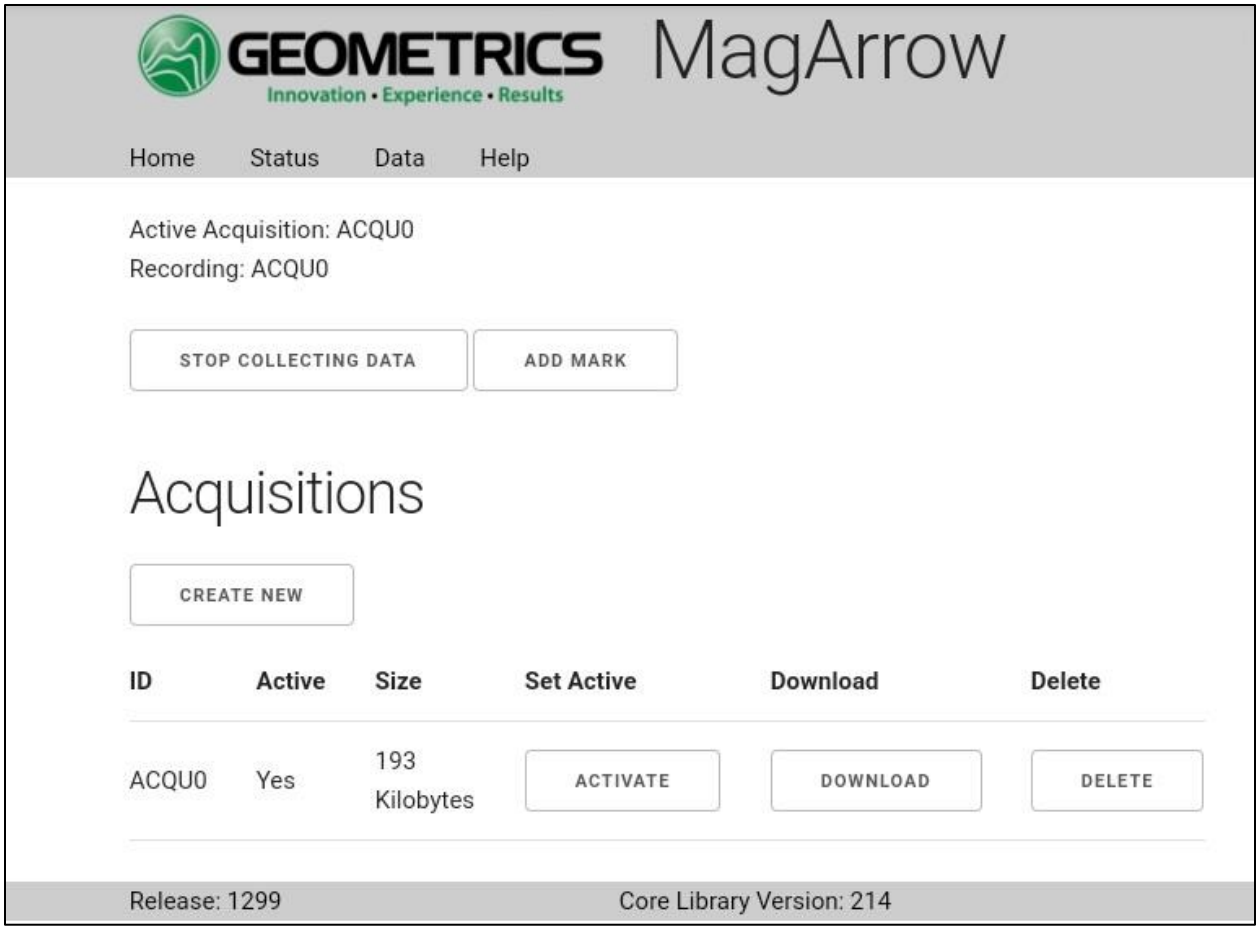
When you first get to the page, it may be fairly empty, and look similar to the screen capture above. This is because surveys have not been created yet.

To create a new survey, or Acquisition, click the **CREATE NEW** button. New acquisitions are numbered consecutively beginning with ACQU0, ACQU1, ACQU2, etc. You will see a chart activate with information about the newly created acquisition.

Active Acquisition: ACQU0 - The newly created acquisition automatically becomes the active acquisition.

Recording - Initially, this will say 'No', which means data is not being saved to storage. To begin recording and saving data for the active Acquisition, click **START COLLECTING DATA**.

It should now show the ID of the Active Acquisition next to **Recording**, as in the screen capture below.

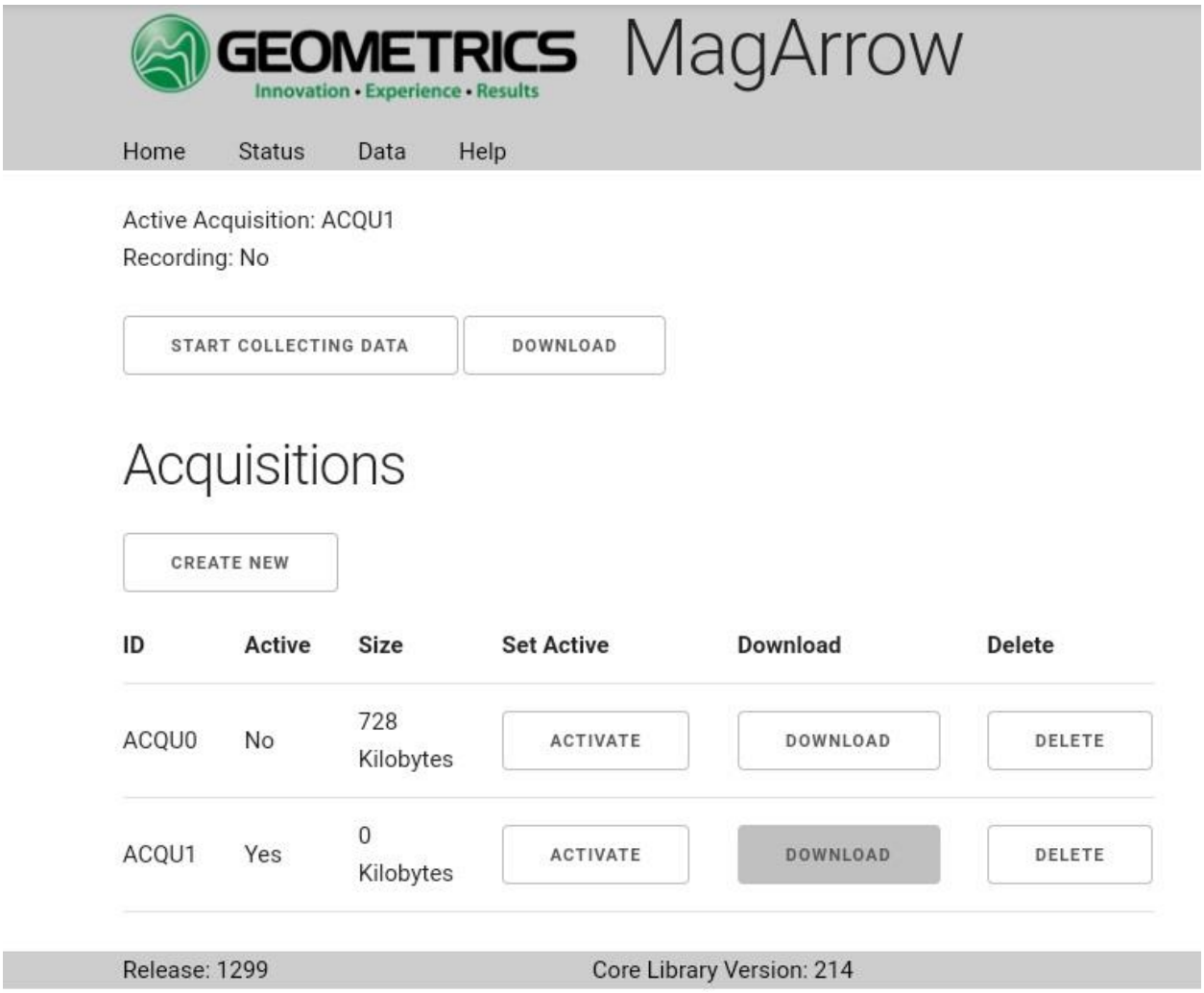


Click Data on the top menu bar on the page to refresh. This will update the **Size** of the acquisition file, indicating that data is being stored to that file.

You can set a mark in the dataset by selecting **ADD MARK**. A pop up will display beneath the search bar that will say "Mark placed in the data log successfully." This may be useful to mark obstructions, targets, or simple waypoints in the survey, making them easier to locate in the data during processing.

To stop recording data, click **STOP COLLECTING DATA**.

Select **CREATE NEW** beneath Acquisitions in order to create a new survey or acquisition. After a new survey is created, you'll notice it has been added to the list of acquisitions as in the screen capture below. The newly created survey will also become the Active Acquisition.



To download the data from the current Active Acquisition, either click the **DOWNLOAD** at the top of the page or the click the **DOWNLOAD** button within the list of Acquisitions. A small rectangular window will pop up at the bottom of the page that will show that the file (*.magdata) has been downloaded.

To delete an acquisition, click the **DELETE** button next to the acquisition you would like to delete.

To change the active acquisition, select **ACTIVATE** next to the acquisition you would like to be active.

Make sure to **STOP COLLECTING DATA** for the currently Active Acquisition before activating another survey.

Help Page

Clicking Help on the top menu bar will open a new tab in the web-browser. This tab contains quickly accessible online help instructions that are a condensed version of this User Manual for use in the field.

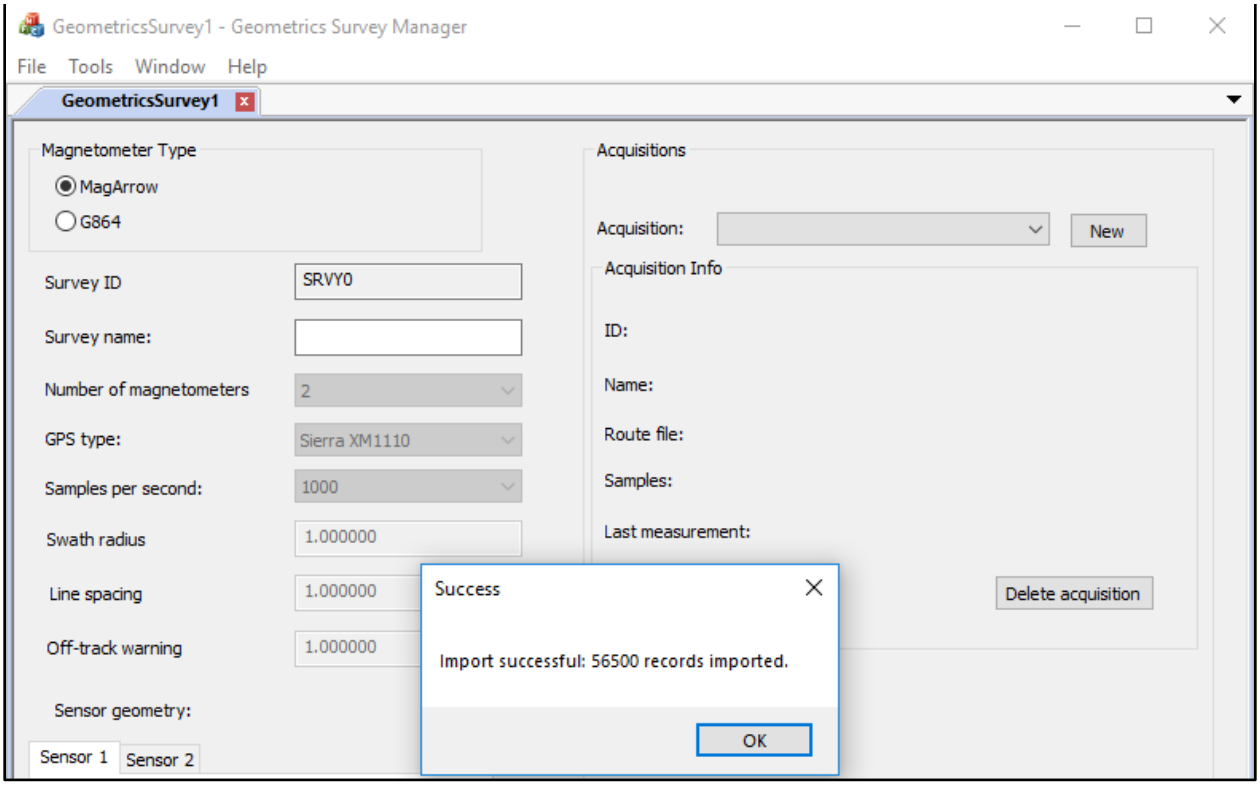
Survey Manager Software - Converting Data Files

The MagArrow's data output is a binary file in the form of ***.magdata**. This type of file is not readable by a text editor such as Notepad. To convert the binary file to a text file (***.csv**) use Survey Manager to import the binary file and export a CSV file. The Survey Manager program can be found on the Geometrics USB stick that shipped with the MagArrow. To download the software, run the application on your PC, and create a desktop shortcut.

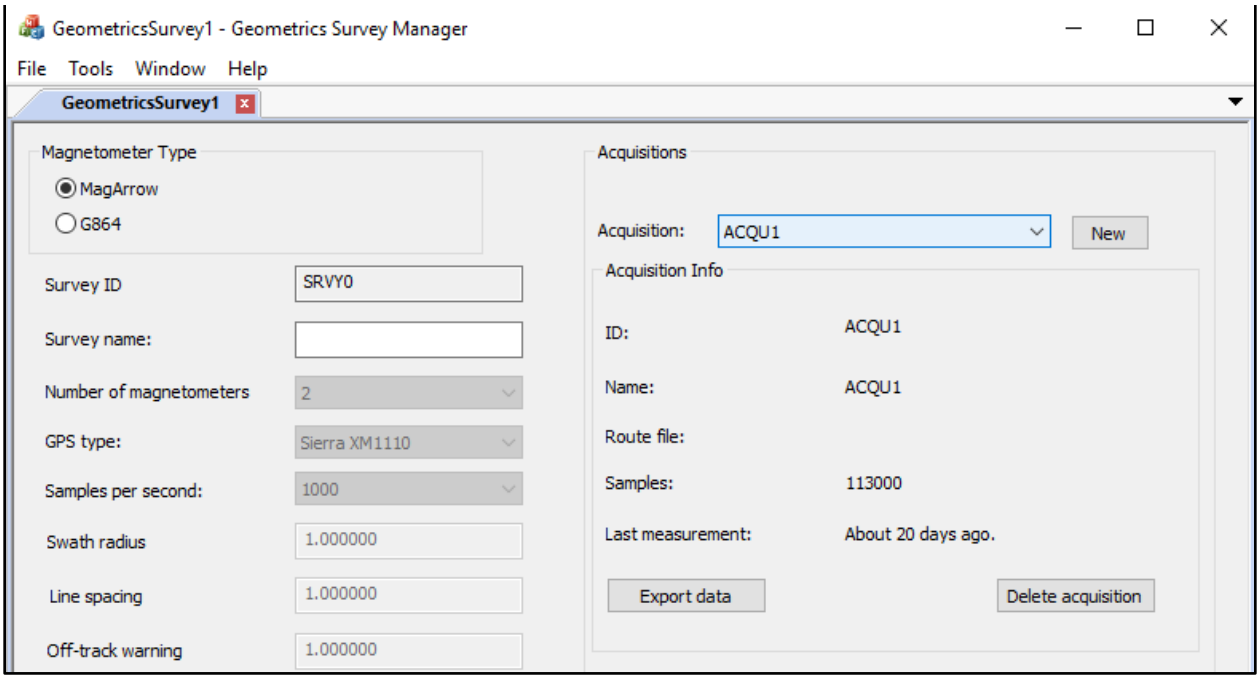
After you download Survey Manager onto your PC, open the program and select **MagArrow Supermag** from the list of Magnetometer Types. There is no need to fill in any of the blanks.

Select **File** from the top menu bar and select **Import Acquisition**. Go to the folder where you saved your downloaded *.magdata files. The files may be so large that you will want to import one at a time. You may select all of the files at once for import, but you will only be able to export one file at a time.

A window will pop up which says 'Import Successful' as shown in the screen capture below.



From here, on the right side of the window, under Acquisitions, click the down arrow and select the acquisition that was just imported, if you imported multiple. You will only be able to export one file at a time. To export select **Export data**.



You will be prompted to name and save the new CSV file. After saving, a pop up will appear stating that the Export has been completed. Click **OK**. You may now open and view your MagArrow data in a text editor program. Upon closing the Survey Manager program, it will ask if you would like to save the changes you've made. **Click 'Yes' if so.**

Data Format

Survey Manager outputs a file in ASCII format with comma separated values (***.csv**). The file will contain header information for each of the individual columns. In order from left to right, here is what each column represents:

Counter: A counter that increments by one for each new magnetometer reading. It serves to make data processing and troubleshooting easier. It does not necessarily start at 1 and stop at 1000 for each 1000 readings.

Date: The date the measurement was collected in UTC time.

Time: Recorded in UTC time, in HH:MM:SS.sss format, at which the measurement occurred. The readings with the fractional time "sss" of "000" are the ones that are aligned in time with the 1PPS pulse from the GPS.

Latitude: Degrees North or South as a decimal number, as recorded from the GPS.

Longitude: Degrees East or West as a decimal number, as recorded from the GPS.

Mag: The magnetic field reading in nanoTeslas (nT), as a decimal number.

MagValid: This indicates if the Mag reading is considered valid. It is a logical signal, with "1" meaning true.

**Below you will see a variety of values. These values are not always included in the data as a comma delimited value. This simply means that the value is not included with every magnetic field reading. This may occur because there are sensors inside the MagArrow sampling at different rates. For example, the GPS is sampling at 1Hz while the magnetometer is sampling at 1000Hz.*

Compass X: This is the strength of the magnetic field component at right angles to the mag arrow's body in nT. A positive value means that the earth's North Pole is to the right of the MagArrow in its normal flight orientation.

Compass Y: This is the strength of the magnetic field component in nT along the MagArrow's body. A positive value means that the earth's North Pole is behind the MagArrow in its normal flight orientation.

Compass Z: This is the strength of the magnetic field component along a line vertical with respect to the MagArrows flight orientation in nT. This number will be positive north of the equator.

Gyroscope X: This value indicates rotation around an axis running at right angles to the MagArrow's forward motion in normal orientation. A positive value indicates that the front of the MagArrow is moving upwards relative to its center of mass.

Gyroscope Y: This value indicates rotation around an axis running parallel to the MagArrow's forward motion in normal orientation. A positive value indicates that the right edge of the MagArrow is moving upwards relative to its center of mass.

Gyroscope Z: This value indicates rotation around a vertical axis with the MagArrow in its normal orientation. A positive value indicates that the front of the MagArrow is moving to the left relative to its center of mass.

AccelerometerX: This is the measured acceleration at right angles to flight path in the normal orientation of the MagArrow. The value will be near +1.0 when the right side of the MagArrow is pointed upwards.

AccelerometerY: This is the measured acceleration along the flight path in the normal orientation of the MagArrow. The value will be near +1.0 when the front of the MagArrow is pointed upwards.

AccelerometerZ: This is the measured vertical acceleration in G as a decimal number. When the MagArrow is in its normal flight orientation, this number will be near +1.0.

ImuTemperature: This is the temperature in decimal degrees C of the accelerometer.

Track: The true heading reported as an angle in decimal degrees (0 to 360).

LocationSource: A single letter to indicate the source of the location information.

I = Internally interpolated

G = GPS value

HDOP: The Horizontal Dilution of Precession as reported by the GPS module.

FixQuality: The satellite fix quality as reported by the GPS module.

SatellitesUsed: The number of satellites used, as reported by the GPS module.

Altitude: The altitude as reported by the GPS module.

HeightOverEllipsoid: The height over ellipsoid as reported by the GPS module. Height over ellipsoid, or elevation above ellipsoid, is the elevation above the earth as calculated using a mathematical model such as WGS84.

SpeedOverGround: The speed over the ground as reported by the GPS module.

MagneticVariation: This is the angle in decimal degrees between magnetic north and true north as reported by the GPS module.

VariationDirection: This the direction "East" or "West" associated with the Magnetic Variation value as reported by the GPS module.

ModeIndicator: This is the "Mode" value as reported by the GPS module.

GgaSentence: When included, this is a string enclosed in quotes containing the GGA sentence reported by the GPS module.

For example:

$GNGGA,231703.000,3724.014941,N,12153.347770,W,2,8,1.13,17.975,M,-25.501,M,,*40

For details on NMEA Sentences see http://aprs.gids.nl/nmea/

RmcSentence: When included, this is a string enclosed in quotes containing the RMC sentence reported by the GPS module.

For example:

$GNRMC,231703.000,A,3724.014941,N,12153.347770,W,0.26,112.72,211218,,,D*66

EventCode: When included, the EventCode covers any information that is doesn't fit in the previously described columns. This column contains a code indicating the nature of the event reported.

EventInfo: When included, this is an additional 32-bit data field that further describes the event.

EventDataLength: When included, this is the length in bytes of the following Event Data field for ease of data processing.

EventData: When included, this is the data associated with this event.

Tips on Running a MagArrow Survey

Here are some useful tips to get you started with planning and executing your MagArrow survey. Please note that individual survey requirements may vary.

Flight Planning and Preparation

A. Chose an appropriate Unmanned Aerial System (UAS). A suitable UAS is one that can lift over a 1.083kg payload and has a flight time, with this payload, of at least 30 minutes. A UAS with a payload capacity of 2.5kg or greater may be best.

B. Work with an experienced UAS pilot. Surveying with the MagArrow requires advanced UAS operating skills and familiarity with UAS, mission planning software, and flying with payloads.

C. Check FAA flight restrictions in the survey area. Make sure it is legal to fly. Make sure the appropriate licenses are obtained.

D. Test out various suspension systems. An ideal suspension system is one that reduces the swinging motion of the MagArrow. It is also important to suspend the MagArrow far enough beneath the UAS such that the electromagnetic field from the motors is not measured by the magnetometer. A good distance to start with is 3-4 meters from sensor to the UAS.

E. Get a good sense of the survey area. UAS carry magnetometer sensors at low altitudes, usually between 5 to 50m AGL (Above Ground Level). Note any terrain changes or obstacles in the area such as poles, fences, electrical cables, or trees. Damage to the MagArrow and/or the UAS system may occur without a careful field examination. We recommend a thorough LiDAR survey of the area prior to use of the MagArrow.

F. Plan the individual flights. A typical line spacing for a survey locating small ferrous objects, pipelines, abandoned wells, or other near surface targets is 10m. For near surface targets, the lower the sensor flies, the better the data and more defined the anomalies. Geologic mapping surveys can have much longer lines, wider line spacing, and can be flown at higher altitudes. Using a "rounded turn" at the end of the lines reduces the pendulum effect. This rounded turn should extend 50 meters beyond the limits of the survey area. Try and include a couple of tie lines orthogonal to the flight lines at 5 to 10 times the line spacing. A tie line is a survey line that connects a point to other surveyed lines and is used for leveling the data. The flight line data is leveled to the tie line data in post processing. In terms of data processing flow, tie line leveling is done after magnetic diurnal correction.

G. Upload the survey grid shape file to the UAS Mission control software. One example of mission control software is UgCs. The program should allow you to input survey routes, altitude, speed, set survey boundaries, customize turns, etc. A prior LiDAR survey here is key!

H. Charge batteries and make sure you have plenty spares. One 1900 mAh battery will last about 2 hours. The batteries charge quickly, in less than 30 minutes.

I. If using a base station for diurnal corrections, set it up away from everything, and at least 50m from roads, in a magnetically quiet area. For surveys over multiple days, it is best to place the base station in the same location for all days.

Flight Execution

A. Connect to MagArrow.net and check that the GPS is on and that GPS data is available. Only one device can be connected to the MagArrow's WiFi at one time.

B. Carry out the mission. Due to limitations with the UAS flight times, there may be several survey segments, which should not affect survey quality.

C. An ideal time to swap the batteries and download data from the MagArrow is while exchanging the UAS batteries. To avoid unexpected system shutdowns during flight, do not fly your MagArrow when it's battery percentage is under 30%. We suggest hot-swapping the batteries during the survey to avoid losing the GPS signal and having to warm up the sensors again.

D. Be careful during turns. The standard speed for magnetic surveys is between 5 and 10 m/s. If the UAS enters a U-turn at the end of a survey line at this speed, it will cause a pendulum motion of the magnetometer on a tow cable. To prevent this, add a overshoot segment to the mission control software parameters and reduce the flying speed to around 2 m/s for the overshoot segment.

E. Once the mission is complete, download the data. Only when the MagArrow is in WiFi range, can data be downloaded and status info updated. You can reset the system and the data will still be saved internally.

F. Convert the data into ASCII format using Survey Manager. Load data into Geosoft Oasis Montaj, Surfer, or another magnetic data processing program.

G. Compensation and/or noise reduction techniques can be used to minimize the magnetic effect of the UAS platform and its motion. Navigational and positional errors, radiated electromagnetic noise, and heading errors from the aircraft's induced and remnant magnetic fields are typically the major contributors of noise affecting the survey results.

Troubleshooting

Magnetometer

The magnetometer data reported as Invalid

1. The magnetometer may take 3-5 minutes to warm up.
2. If MagArrow is near a magnetic object move it away from the object.
3. Turn the MagArrow so that it points North.
4. If the MagArrow is near a large electric motor or other sources of large AC magnetic fields, move it away.

The magnetometer readings vary unreasonably

1. Ground yourself and all others before operation with the MagArrow (i.e. touch something metallic)
2. Have all the people nearby stop moving to see if one of them is very magnetic. Cellphones are extremely magnetic.
3. Try moving the magnetometer a short distance to see if the variation decreases.
4. If the MagArrow is resting on the ground, lift it approximately one meter off the ground.

WiFi

The WiFi access point is not found by the logging device

1. It may take about 15 seconds for the tablet or other device to find the WiFi access point. Only one device can be connected to the MagArrow's wireless access point at a time. Make sure no other devices are connected to the MagArrow's WiFi access point.

The WiFi connects but the web page is not found

1. Check that the SSID for the WiFi you are connected to matches the label on the MagArrow.

GPS

GPS Synch to Magnetometer indicates NOT FOUND or GPS status indicates Unavailable

1. Move the MagArrow to a location with a clear view of the sky.*
2. If there are nearby radio transmitters, move away from them.
3. Check that GPS satellite reception is normal on some other device such as a cell phone.

*The GPS satellite constellation comprises satellites in low earth orbit that provide the ranging signals and navigation data messages to the GPS receiver in the MagArrow. Users with a clear view of the sky will have a minimum of four GPS satellites in view. The satellites broadcast ranging signals and navigation data allowing the GPS receiver to measure their pseudoranges in order to estimate the MagArrow's position, in a passive, listen-only mode. A pseudorange is the pseudo distance between a satellite and a navigation satellite receiver.

The exact number of satellites operating at any particular time varies depending on the number of satellite outages and operational spares in orbit. The following link will obtain a simple text document maintained by the US Navy showing the status of the GPS satellites.
ftp://tycho.usno.navy.mil/pub/gps/gpstd.txt

LEDs

The large LEDs are flashing multiple times - 5 Rapid Flashes with a 1 second gap between them

Indicates that the system has a problem and needs user attention. These problems may include:

1. The battery has less than 30% of its charge remaining.

2. The SD card is not properly inserted.
3. The SD card is corrupted, has failed, or is slow. The maximum storage write time is slow (>1000ms.)
4. The SD card is full.
5. The magnetometer sensors are not producing good quality data or have failed.

Pressing the power button causes no LED flash

1. The most likely cause of this is a fully discharged battery.

Pressing the power button causes only a brief flash of the LEDs

1. Check that the cell voltage monitoring connector is correctly mated.
2. Replace the battery with one that is fully charged.

The large LEDs flash twice with a pause between pairs of flashes, but your device can't connect.

The two flashes indicate that the MagArrow is connected to some device.

1. Check the other phones and tablets to find the one it is connected to.
2. Disable that device's WiFi, either in the device's settings menu or by setting the device to "airplane mode".
3. Briefly press the power button on the MagArrow to restart the data logging and WiFi processor.
4. Try to connect.

System Boot Internal Light Indicators – There is one red and one green LED light inside the MagArrow's battery compartment. These two lights will flash in a specific sequence (described below) when the power button is pressed and the system is booting properly.

As soon as the power button is pressed, a red light, which sits between the Power Button and the USB, will be solid for about 3 seconds. Then a green light, located near the USB, will slowly flash and hold for about 1-2 seconds and then turn off. Then the red light will begin to flash at 10Hz (10 samples per second).

If the red light does not flash, but remains solid instead, the system did not boot correctly and the power should be cycled again. Cycle the power by pressing the power button once.

APPENDIX A: MagArrow Specifications

Operating Principle: Laser pumped cesium vapor (Cs133 non-radioactive) total field scalar magnetometer.

Operating Range: 20,000 to 100,000 nT.

Gradient Tolerance: 10,000nT/m.

Operating Zones: Configurable for operation anywhere in the world without dead zones.

Dead Zone: None.

Noise/Sensitivity: 0.005nT/sqrtHz $_{rms}$ typical.

Sample Rate: 1000 Hz. synchronized to GPS 1PPS

Bandwidth: 400Hz.

Heading Error: ± 5 nT over entire 360° equatorial and polar spins typical.

Output: WiFi data download over 2.4GHz WiFi access point.

GPS: Commercial grade with typical 1 m accuracy.

USB Port: Port for USB flash drive. Used for field upgrades.

Data Logger: Built in Data Logger.

Data Storage: 32 Gbyte Micro SD card, U3 speed class. Not field-accessible. Contact sales for higher capacities.

Data Download: over WiFi 2.4GHz using user-supplied browser-capable device. 10 minutes of data requires 1 minute to download.

IMU: Bosch BMI160 Accel/Gyro - 200 Hz sample rate.

Insentek Compass - 100 Hz Sample rate.

Total Weight: 1 kg without batteries. **Length:** 1 m.

Battery Recommendations: Non-magnetic 1800 mAh or 2200 mAh lithium polymer, 3cell 11.1v. Hot swappable.

Battery Connection: 2x XT60 connectors for 206 type batteries.

Power Consumption: Approximately 6 watts. With 12 volt power the current draw is about 420 milliamps (0.42 amps). On power up the inrush current is limited to 2 amps.

Operating Temperature: -10°C to +40°C (+14°F to +104°F).

Altitude: Up to 3,000 m (10,000 ft.). Typically limited by UAS maximum altitude. Can be flown at 5,000 m, however performance is not guaranteed at altitudes higher than 3,000 m.

Humidity: Non-condensing.

APPENDIX B: Firmware Updates

To update the MagArrow firmware, contact Geometrics. We will send you an email or a USD drive containing a zip file with the latest MagArrow firmware.

To perform the update, do the following:

1. Take the USB drive out of the MagArrow and plug in into a windows machine.
2. Unzip the file containing the firmware and run the installer.
3. Select the target directory as the USB drive.
4. Plug the USB drive back into the MagArrow and power it on.
5. Wait for the lights to start flashing. If they don't flash wait for 30 seconds and then reset the MagArrow.
6. If you opened the MagArrow website on any device previously, do a cache refresh (Generally Shift+F5 on Chrome) on each page of the website. Shift+Click on the browser refresh icon on desktop works too depending on your web browser.

APPENDIX C: Terminology Used with MFAM Based Magnetometers

Absolute:

An absolute magnetometer is one where the measured value is equal to the strength of the magnetic field and does not depend on other things such as time and temperature and orientation. The MFAM is an absolute magnetometer.

Cell:

The area within the sensor where the field measurement occurs. For the MFAM sensor, this area is a 5mm diameter volume at the center of the sensor assembly.

PPS:

A pulse per second (PPS or 1PPS) is an electrical signal that has a width of less than one second and a sharply rising or abruptly falling edge that accurately repeats once per second. PPS signals are output by radio beacons, frequency standards, other types of precision oscillators and some GPS receivers.

GPS HDOP, VDOP, PDOP:

Acronyms used when speaking of the loss of GPS position accuracy. Commonly, you will see the following acronyms used to describe the type of position accuracy in question.

- HDOP – horizontal dilution of precision
    - HDOP is a term used in satellite navigation and geomatics engineering to specify the additional multiplicative effect of navigation satellite geometry on positional measurement precision.
- VDOP – vertical dilution of precision
- PDOP – position (3D) dilution of precision
- TDOP – time dilution of precision
- GDOP – geometric dilution of precision

DOP Value	Rating	Description
<1	Ideal	This is the highest possible confidence level.
1-2	Excellent	At this confidence level, the position measurements are accurate enough to meet all but the most demanding applications.

2-5	Good	This represents a level that marks the minimum appropriate for making accurate surveys.
5-10	Moderate	The position measurements could be used for some cases, but the fix quality should be improved. A more open view of the sky is recommended.
10-20	Fair	This represents a low confidence level. Position measurements should be discarded or used only to indicate a very rough estimate of the current location.
>20	Poor	At this level, measurements are inaccurate by as much as 5 times the accuracy rating of the GPS.

Heading Error:

This is the error in measurement caused when the angle of the magnetic field passing through the optical package changes. There are several causes for this effect, the most obvious being magnetically dirty particles. Keeping the instrument clean helps to prevent heading error. However, some heading error is a natural result of the physics governing magnetometers.

Heater:

The small heater inside the sensor that heats the absorption cell, creating the atomic vapor necessary for taking measurements. This length of time is the primary reason for the warm-up time.

Optical Package:

Commonly referred to as the physics package. The optical package contains the contents of the sensor assembly, including the light source and laser diode.

Sensor Driver:

Commonly referred to as the "electronics", the sensor drive is all of the circuitry needed to convert the signal from the optical package to produce the output of digital field readings.

Warm Up Time:

After powering on, the time it takes for the sensor to reach optimal temperature, which allows the MFAM sensor to produce good quality field readings. The warm up time for the MFAM sensor is approximately 3 – 5 minutes after powering on.