Siting of SAM-III Magnetometer Sensors ~ Case Study

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1. Introduction

The magnetic field measured by the SAM-III magnetometer sensors can be disturbed by natural events such as transients in the solar wind or by extraneous manmade magnetic fields or metallic objects in the vicinity. I am often asked how far the sensors need to be away from possible sources of manmade disturbances such as electric railroads, powerlines, driveways and roadways. To investigate manmade effects, I made simultaneous measurements in May 2016 of the three magnetic field components B_X, B_Y and B_Z (Geographic Coordinate System) at two sensor sites separated by about 45 m, one magnetically quiet and the other relatively noisy mostly due to vehicular traffic but also intentional changes in metallic objects near the sensors.

The distances involved and other details provided here give a first order indication of how vehicles, metal objects and temperature variations can affect sensor measurements. This information may help SAM-III users plan or modify their sensor installations. Users also may be interested in a paper that discusses SAM-III sensor burial depth to reduce or eliminate sensor output variations due to temperature changes; see {Burial}. Sensor installation itself is beyond the scope of this paper; that information can be found in the SAM-III Construction Manual; see section XVI of [SAM3]. For a geomagnetism tutorial, see {Geomag}.

2. Sensor locations for measurements

One set of three sensors is indoors and mounted in a laboratory test fixture (figure 2 and 3). This fixture may be moved around and the sensors are influenced by lab temperature variations and manmade magnetic disturbances from lab activity. The fixture was not moved during the measurements presented here. These sensors also are affected by magnetic variations due to vehicles moving in and out of the upper driveway about 15 m away and moving in and out of the upper garage about 5 m away. The lab test fixture is located about 2 m from its SAM-III controller and is used for live testing of SAM-III printed circuit boards.

The outdoor sensor fixture is permanently buried in soil about 1 m deep in a relatively magnetically quiet location surrounded by foliage. This fixture is about 12 m from its SAM-III controller, which is located in the lower garage/shop. The system has been in-place since 2010 and provides real-time online data here {SAMLive}.

Both fixtures are setup with respect to the Geographic Coordinate System (GCS, true north reference, see [SAM3]). Although the individual lab sensors are perpendicular to each other, they are not as accurately aligned in the GCS as the outdoor sensors. In both sensor setups, the sensor that measures the B_X component is oriented north-south, B_Y is oriented east-west and B_Z is oriented vertically. For reference, the magnetic field characteristics on 5 May 2016 at my site were {NGDC}:

- Geographic Latitude = 61.19928 °N : Longitude = 149.95652 °W
- Declination, D = 16.789° changing by –0.336 °/year
- Inclination, I = 74.192° changing by +0.006 °/year
- North component, X = 14 506.5 nT changing by +11.7 nT/year

- East component, Y = 4 376.7 nT changing by –89.4 nT/year
- Horizontal Intensity, H = 15 152.4 nT changing by –14.6 nT/year (vector sum of X and Y)
- Vertical component, Z = 53 518.7 nT changing by –32.1 nT/year
- Total Intensity, F = 55 622.3 nT changing by –34.9 nT/year (vector sum of X, Y and Z)

Figure 2 ~ Sensor fixtures. Left: Indoor lab sensor test fixture. The sensors are the small black objects spaced on the vertical wood stick, which is slightly < 1 m long. The X-axis sensor is located at the bottom, Y-axis is 300 mm above X, approximately in the middle, and Z-axis is 300 mm above Y at the top of the stick. The test fixture base is about 0.8 m above the lab baseboard heater and influenced by heat from it. Connections are made by clip-leads. Right: Outdoor sensor fixture posing on a sawhorse before burial in 2010. It was built using plastic DWV pipe and buried vertically so the middle sensor (the first perpendicular cylinder from the right) is about 1 m below the surface. The Z-axis is at the bottom (lower-right corner of the picture), X-axis above it (diagonally to the left in the picture) about 150 mm and Y-axis is closest to the surface and about 150 cm above X. The junction box for connecting the sensor cables is seen at the upper-left corner of the picture.

3. Measurements

Simultaneous magnetic measurements were made over several days by the two SAM-III systems described above. The comparative measurements are presented for each of three UTC days from 0000 to 2400: 3 May (figure 4), 4 May (figure 5) and 5 May (figure 6). The magnetogram images are annotated and keyed to the text immediately above. Note that for 4 and 5 May, the vertical scale on the magnetograms for the indoor sensors is twice the scale of the outdoor sensors. Additional comparative measurements are presented for each of four UTC days: 27 May (figure 7), 28 May (figure 8), 29 May 2016 (figure 9) and 30 May 2016 (figure 10), but these magnetograms are not annotated. This period covers a 3-day holiday (Memorial Day) with very little manmade activity.

Some differences in the measured ambient magnetic field components are expected because the two sensor fixtures have slightly different alignment with respect to the Geographic Coordinate System. Also, as seen in the previous section, the inclination at my site is 74°. Another name for inclination is *dip angle* and it is the angle of the magnetic field lines with respect to horizontal. A positive angle indicates the magnetic field lines are pointed downward. Generally, local magnetic field effects are observed in the B_Z component more so than the other axes, so the magnitude of effects at lower latitudes with smaller inclinations may be different.

Figure 3 ~ Plat showing SAM-III sensor locations and other details. The permanently buried outdoor sensor fixture is indicated by the red X at upper-right of the trapezoidal property. The temporary indoor fixture is indicated by the red X at lower-middle of the plat, inside the residence. Property lines are thick black lines, and roads and driveways are thick gray lines. For reference, the eastern property line is 78.2 m (256.7 ft). Katmai Circle, Sonstrom Drive and Kissee Court are not built for through traffic and serve only a few local residences.

The magnetic field sensors are temperature sensitive. A temperature data logger also was run in the lab during the 3 to 5 May period to allow comparison with the indoor sensors (figure 11). Although the logger resolution is only 0.1 °C, it still provides an adequate indication of the temperature variations in the lab. The indoor lab temperature varied from about +17 to +20 °C. For comparison, the outdoor ambient temperature varied from a low of +2 °C (night) to a high of +12 °C (day) during the same period, but the outdoor magnetic sensors are buried and thermally unaffected by daily temperature variations.

Date: 3 May 2016

1 Semi-permanent event, vehicle enters upper garage

2 Transient event, vehicle enters upper driveway and departs a couple minutes later

3 Semi-permanent event, vehicle leaves upper garage and returns several minutes later but parks in the upper driveway; over next 3 h, vehicle enters and leaves the upper driveway, and returns for the remainder of the day at 2000

4 Unknown vehicle traffic on upper driveway or possibly Katmai Circle

5 Unknown vehicle traffic on upper driveway or possibly Katmai Circle

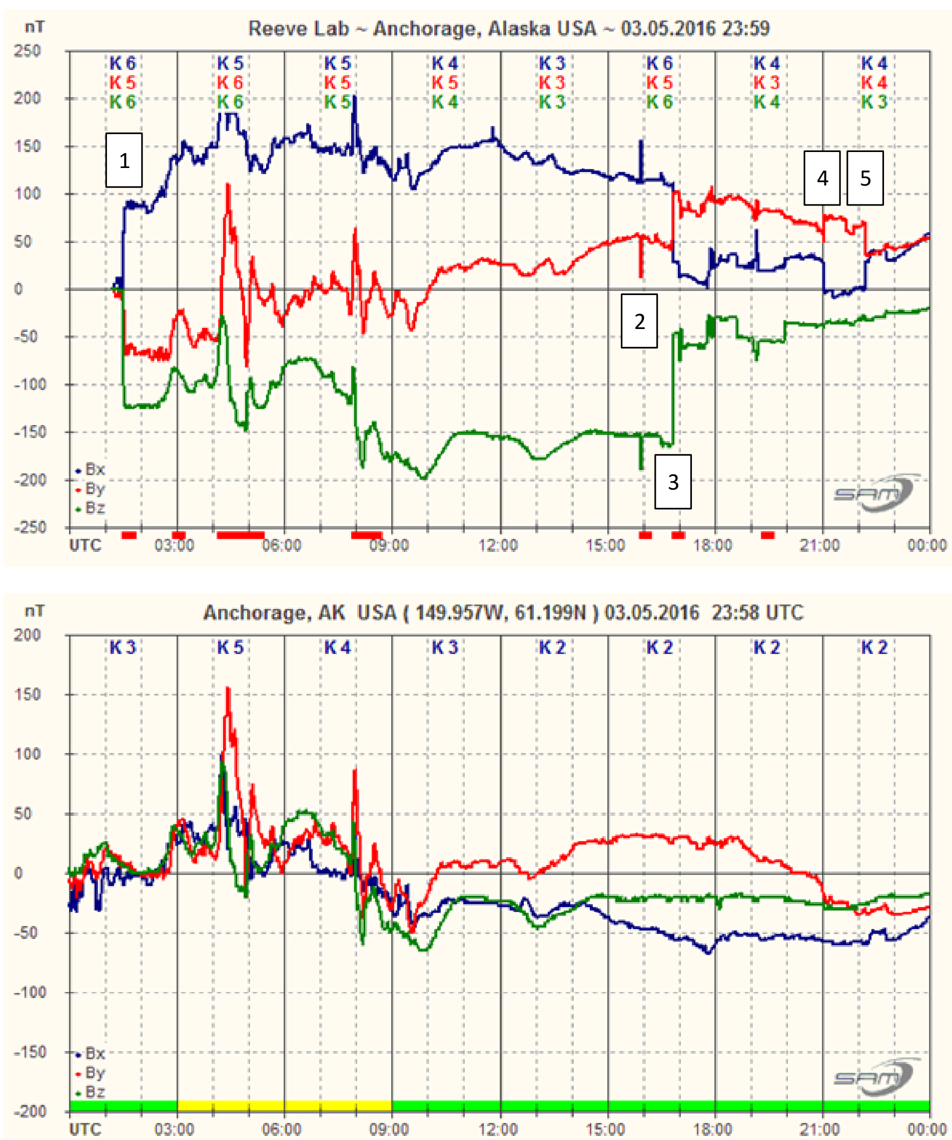


Figure 4 ~ 3 May 2016

Upper: Indoor measurements commenced at about 0115 and indicate natural magnetic activity comparable to the outdoor measurements shown below. Also shown here are rapid offsets at 0130 due to vehicle entering the upper garage and then leaving just before 1700. The spike just before 1600 is a vehicle entering the upper driveway for a couple minutes and then leaving. Temperature effects are masked by other effects.

Lower: Outdoor measurements show considerable natural magnetic activity through about 0930 but shows none of the transients seen in the indoor measurements above.

Date: 4 May 2016

1 Semi-permanent event, vehicle enters upper garage

2 Lab temperature variations throughout the night, sawtooth pattern on B_X. B_X is closest to lab heat source and B_Z is farthest

3 Transient event, vehicle enters upper driveway and departs after about 20 minutes

4 Semi-permanent event, vehicle leaves upper garage and then returns several minutes later to park in the upper driveway

5 Transient due to unknown vehicle traffic in upper driveway or Katmai Circle

6 Transient event due to unknown vehicle traffic in upper driveway or possibly Katmai Circle

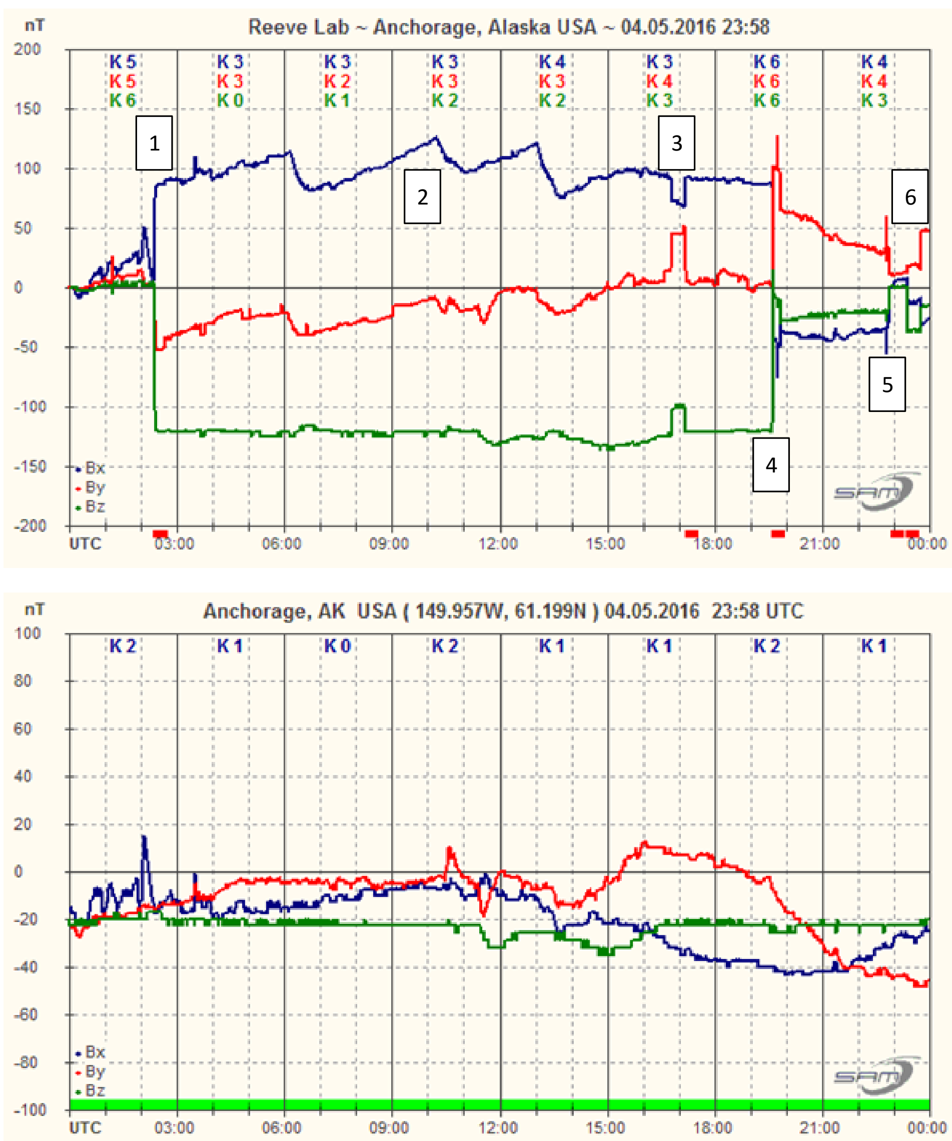


Figure 5 ~ 4 May 2016

Upper: Indoor measurements track the natural activity seen in the outdoor measurements below. Also seen are offsets due to the vehicle arriving at the upper garage at 0220 and departing at 1930. The sawtooth pattern in B_X (blue trace) between 0600 and 1500 is due to lab temperature changes of about ±1 °C. Note that vertical scale is twice the lower chart scale.

Lower: Outdoor measurements indicate a magnetically quiet day with only minor natural transients at 0200 and 1030.

Date: 5 May 2016

1 Vehicle enters upper driveway and leaves about 30 minutes later

2 Another vehicle enters upper driveway

3 Vehicle leaves upper driveway and another vehicle enters upper garage

4 Transient event, vehicle enters upper driveway and departs a couple minutes later

5 Vehicle leaves upper garage

6 Moved nearby lab equipment cart about 100 mm

7 8 Transient events due to vehicle traffic on upper driveway and possibly Katmai Circle

9 Vehicle returns and parks in upper driveway

10 Placed screwdriver about 0.5 m from sensor fixture for a few minutes and then moved away about 1 m

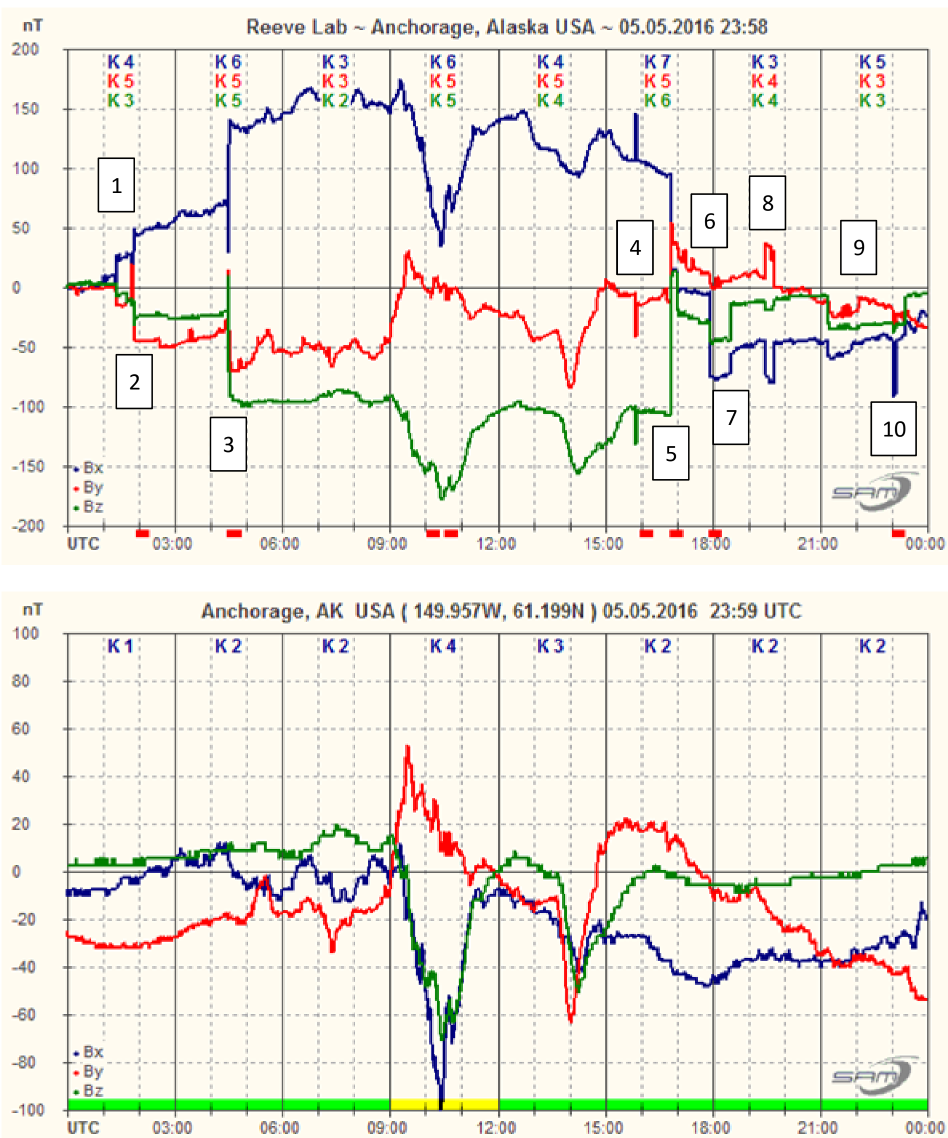
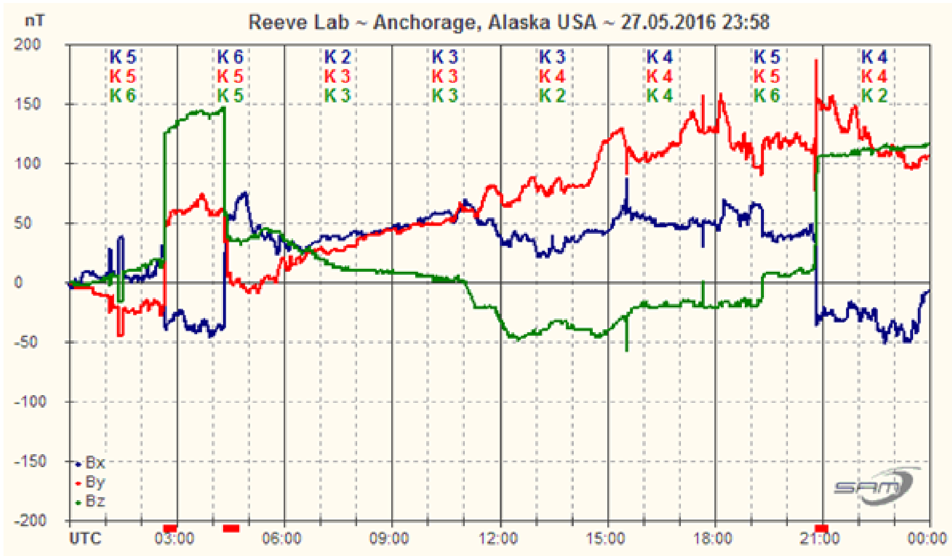


Figure 6 ~ 5 May 2016

Upper: Indoor measurements. At 1800 a lab equipment cart about 1 m from the indoor sensor fixture was moved about 100 mm. Note that vertical scale is twice the lower chart scale. Natural activity seen between 0900 and 1500 is comparable to outdoor measurements.

Lower: Outdoor measurements.

Date: 27 May 2016



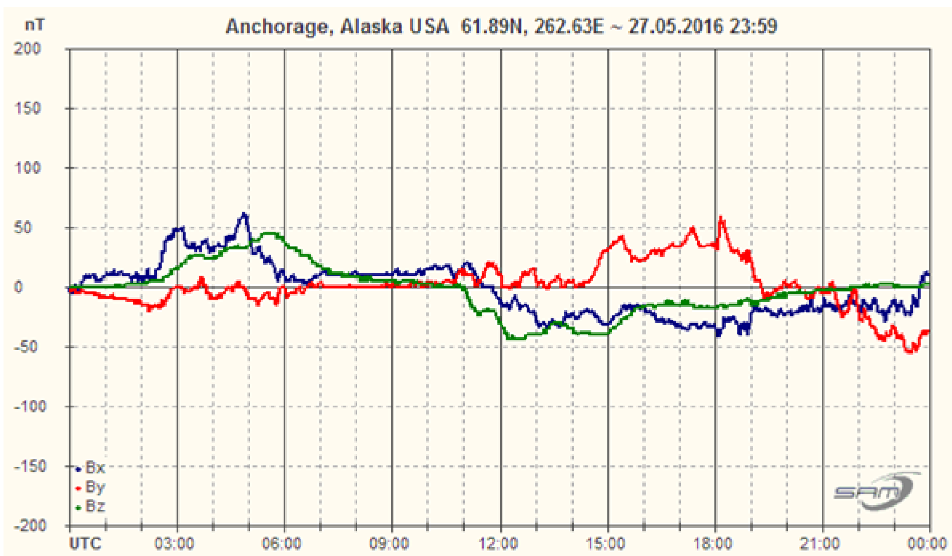
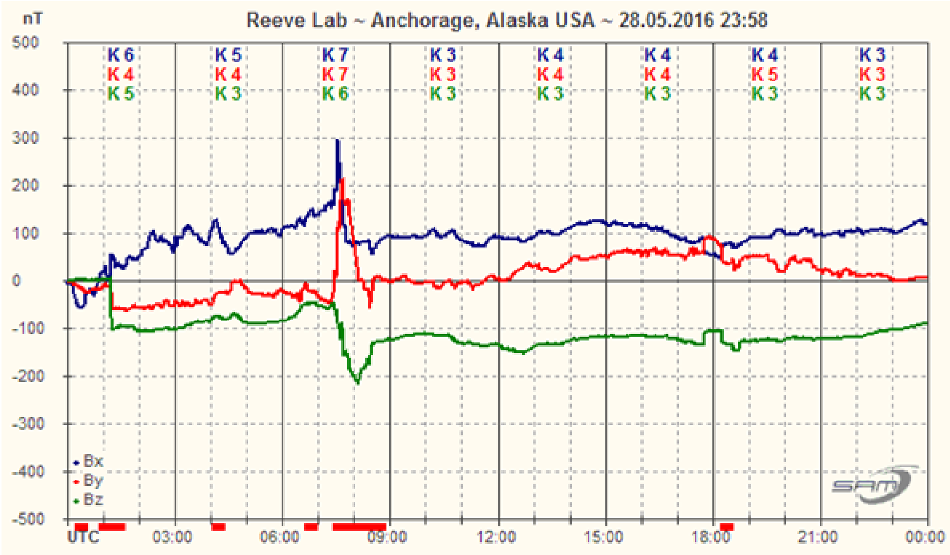


Figure 7 ~ 27 May 2016

Upper: Indoor measurements. Disturbances (offsets) due to vehicle entering and leaving garage are indicated at 0240, 0420 and 2050. Transients from vehicle traffic in driveway are indicated at 1530 and 1735.

Lower: Outdoor measurements showing a magnetically quiet day.

Date: 28 May 2016



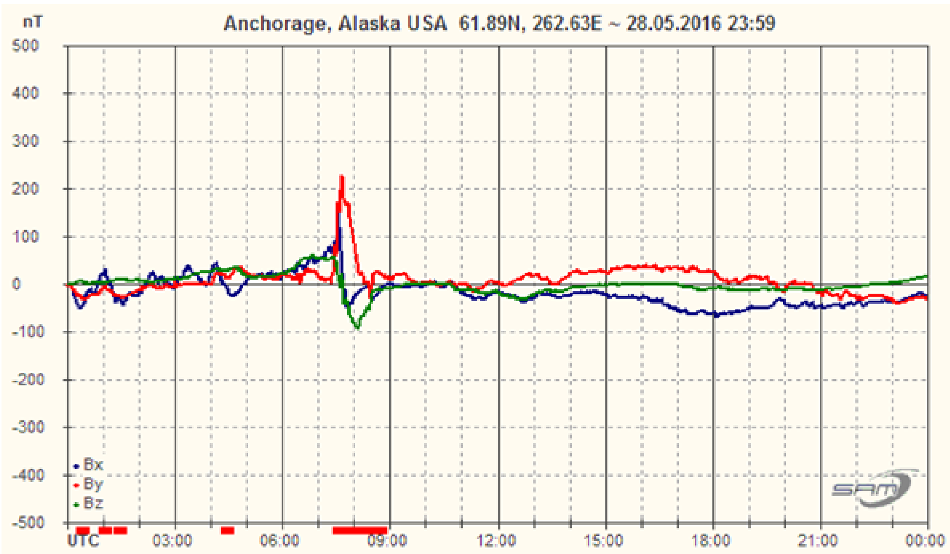
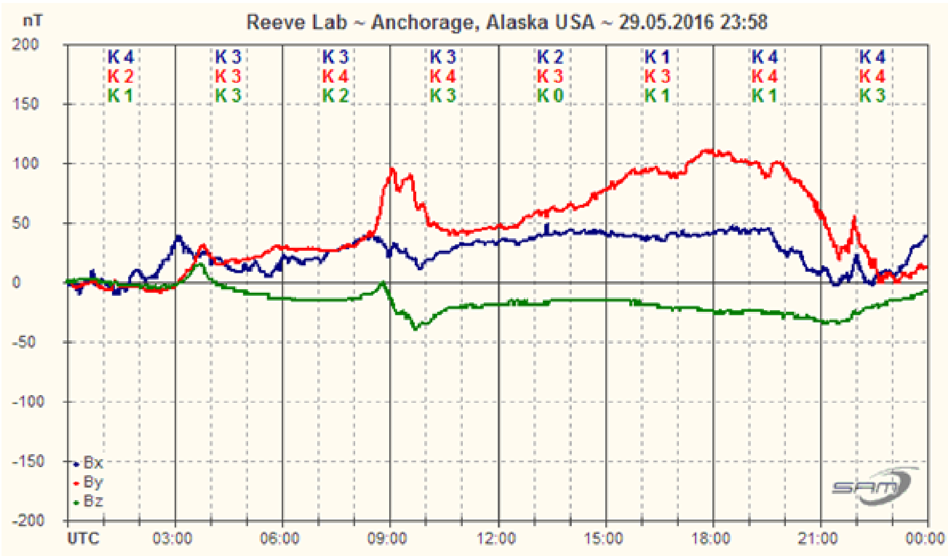


Figure 8 ~ 28 May 2016

Upper: Indoor measurements. Very little vehicular traffic is indicated on Saturday of this 3 day holiday weekend except at about 0110 and 1735/1820. Natural variations are comparable to outdoor measurements.

Lower: Outdoor measurements of a mostly magnetically quiet day with one transient starting about 0740.

Date: 29 May 2016



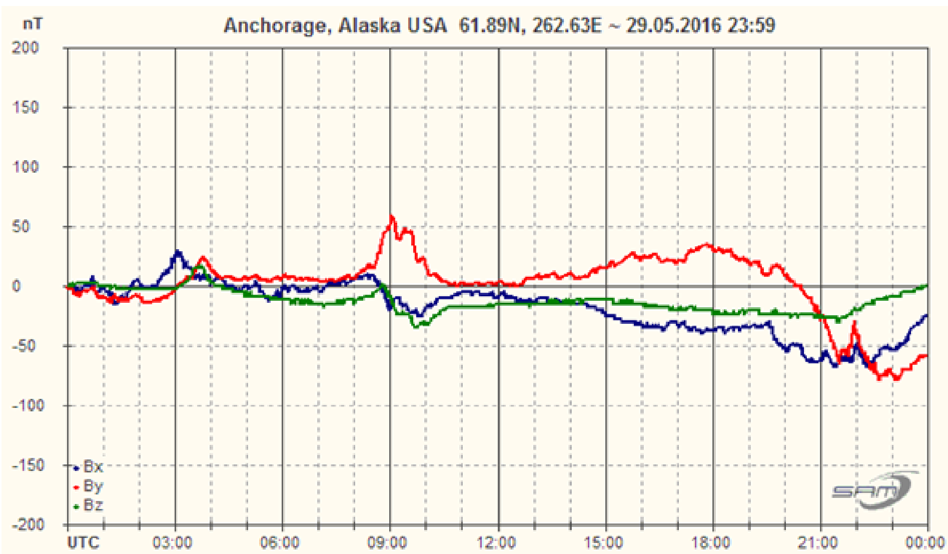
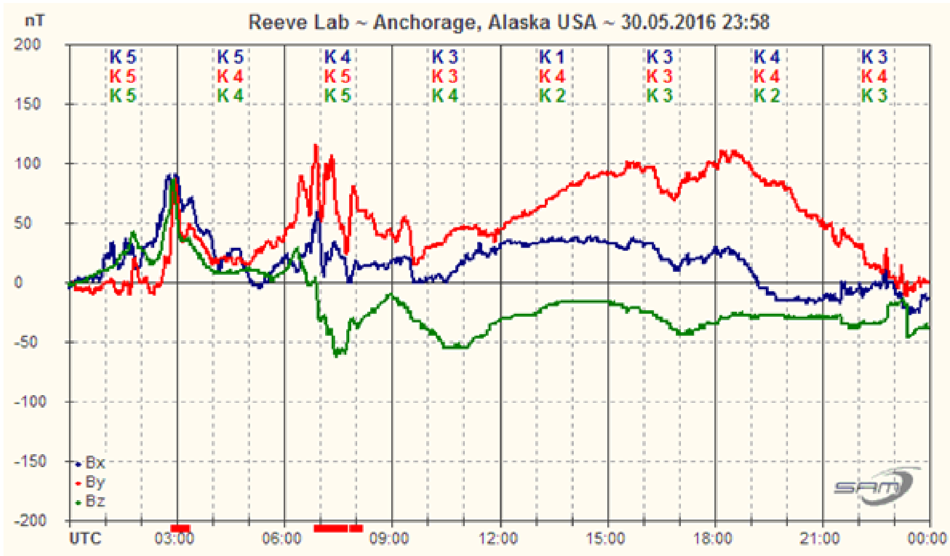


Figure 9 ~ 29 May 2016

Upper: Indoor measurements. Very little vehicular traffic is indicated on Sunday of this 3 day holiday weekend. Natural variations are comparable to outdoor measurements except for temperature drift.

Lower: Outdoor measurements show a magnetically quiet day.

Date: 30 May 2016



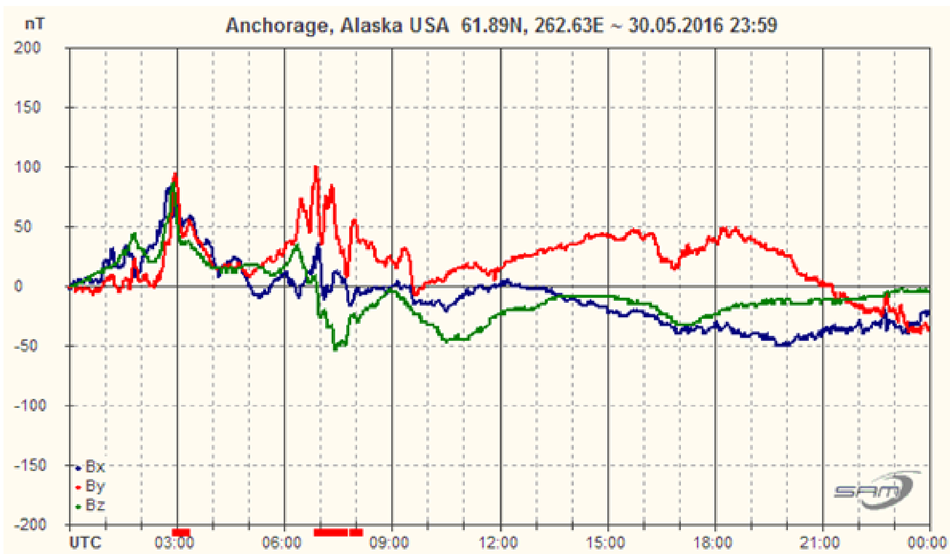


Figure 10 ~ 30 May 2016

Upper: Indoor measurements. Very little vehicular traffic is indicated on Monday of this 3 day holiday weekend. The geomagnetic field showed some unsettled and active behavior and is comparable to outdoor measurements except for temperature drift.

Lower: Outdoor measurements show the same natural activity as the indoor measurements.

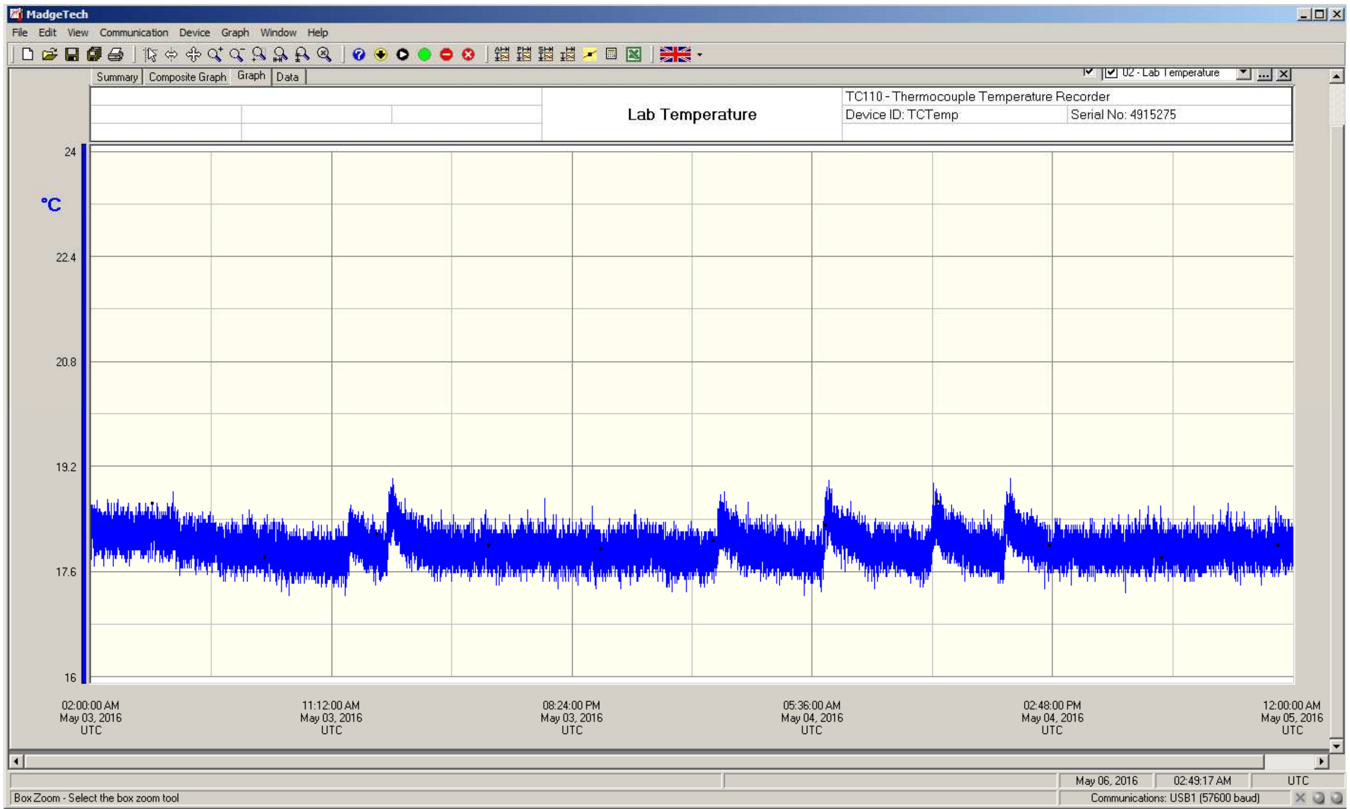


Figure 11 ~ Plot of lab free-air temperature during the study period 3 to 5 May. The temperature was measured with a thermocouple temperature recorder. Minimum and maximum temperatures were 17.24 and 19.80 °C. Average temperature was 17.98 °C with 0.229 °C standard deviation. The sawtooth pattern occurs as the lab is occasionally heated and then cooled over several hours.

4. Discussion

The previous section focused on magnetic variations measured by the indoor test fixture and compared them to the relatively quiet outdoor sensors. Most variations were caused by vehicular traffic on the upper driveway and garage, which are 15 and 5 m away, respectively, from the fixture. The driveway traffic caused readily identified variations, but some variations may have been caused by large roofing trucks on Katmai Circle about 25 m away from the indoor fixture. These trucks were going to and from a neighbor’s residence just east of my residence.

Magnetic disturbances caused by vehicles usually affected all three axes but not equally. The vertical z-axis (B_Z) often indicated higher deflections than the other two. This is typical of the z-axis – it usually is more sensitive to local magnetic variations than the other axes.

Examination of the magnetograms from the buried outdoor sensor fixture some tens of meters away shows no obvious effects from the upper driveway and garage traffic. However, the outdoor sensor fixture is about 20 m equidistance from two local residential access roads, Sonstrom Drive and Kissee Court. Magnetic disturbances to the outdoor sensors caused by traffic on these roadways are only occasionally detected during winter when road graders and dump trucks are clearing snow – these large metallic masses typically cause a small transient or spike. Also, this sensor fixture indicates a 30 nT offset when a neighbor’s landscapers park their flatbed truck with equipment trailer on the west side of Sonstrom Drive about 25 m east of the fixture location, but their regular pickup truck has no obvious affect. None of this type activity occurred during the study periods.

The lower driveway passes within 3 m of the outdoor sensors, and delivery trucks coming up the driveway usually cause a short transient. Interestingly, my own vehicle (about 1800 kg) is not indicated unless I stop adjacent to the sensor site (the sampling rate is 0.1 Hz so driving by the sensors would be detected in only one sample at the most). A lightly loaded, 10 m high single-phase overhead powerline oriented north-south passes about 14 m east of the buried sensors; its effects, if any, have never been noticed. Also, the outdoor sensors are within about 1 m of a galvanized steel chain-link fence along the east property line; this fence may distort the local magnetic field but the affects, if any, are not obvious.

It should be noted that even the slightest movement of a metallic object (such as a small screwdriver, belt buckle, keys) near the sensors will be indicated by a deflection on the magnetogram. Users often misinterpret these deflections as a problem with either the sensors or controller.

5. Conclusions

Based on subjective measurements discussed in this paper, a sensor fixture distance of 20 m from roadways and driveways may be enough to eliminate magnetogram variations caused by most passenger vehicle traffic. If the sensors are located closer, passing traffic generally is indicated by a transient, whereas vehicles parked nearby will cause a semi-permanent offset. Each site has its own magnetic characteristics so other considerations may be necessary. In particular, the soil conductivity, geomagnetic latitude, sensor configuration and nearby railways and powerlines may affect the clearance distances needed.

6. References

{Burial} Reeve, W., SAM-III Burial Depth of SAM-III Magnetometer Sensors, 2016, available here: http://www.reeve.com/Documents/SAM/Reeve_SAMSensorBurialDepth.pdf

{Geomag} Reeve, W., Geomagnetism Tutorial, 2011, available here: http://www.reeve.com/Documents/SAM/GeomagnetismTutorial.pdf

{NGDC} National Geographic Data Center Magnetic Field Calculator: http://www.ngdc.noaa.gov/geomag-web/?model=igrf#igrfwmm

[SAM3] SAM-III Simple Aurora Monitor, 3-Axis Geomagnetometer ~ Construction Manual, available here: http://www.reeve.com/Documents/SAM/SAM3ConstructionManual.pdf

{SAMLive} http://www.reeve.com/SAM/SAM_simple.html

Document information

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0.5 (Revised plat and added reference to landscapers, 11 Jul 2016)
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