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Progress on Low-Cost Pulse-Counting Magnetometers for Geomagnetic Studies

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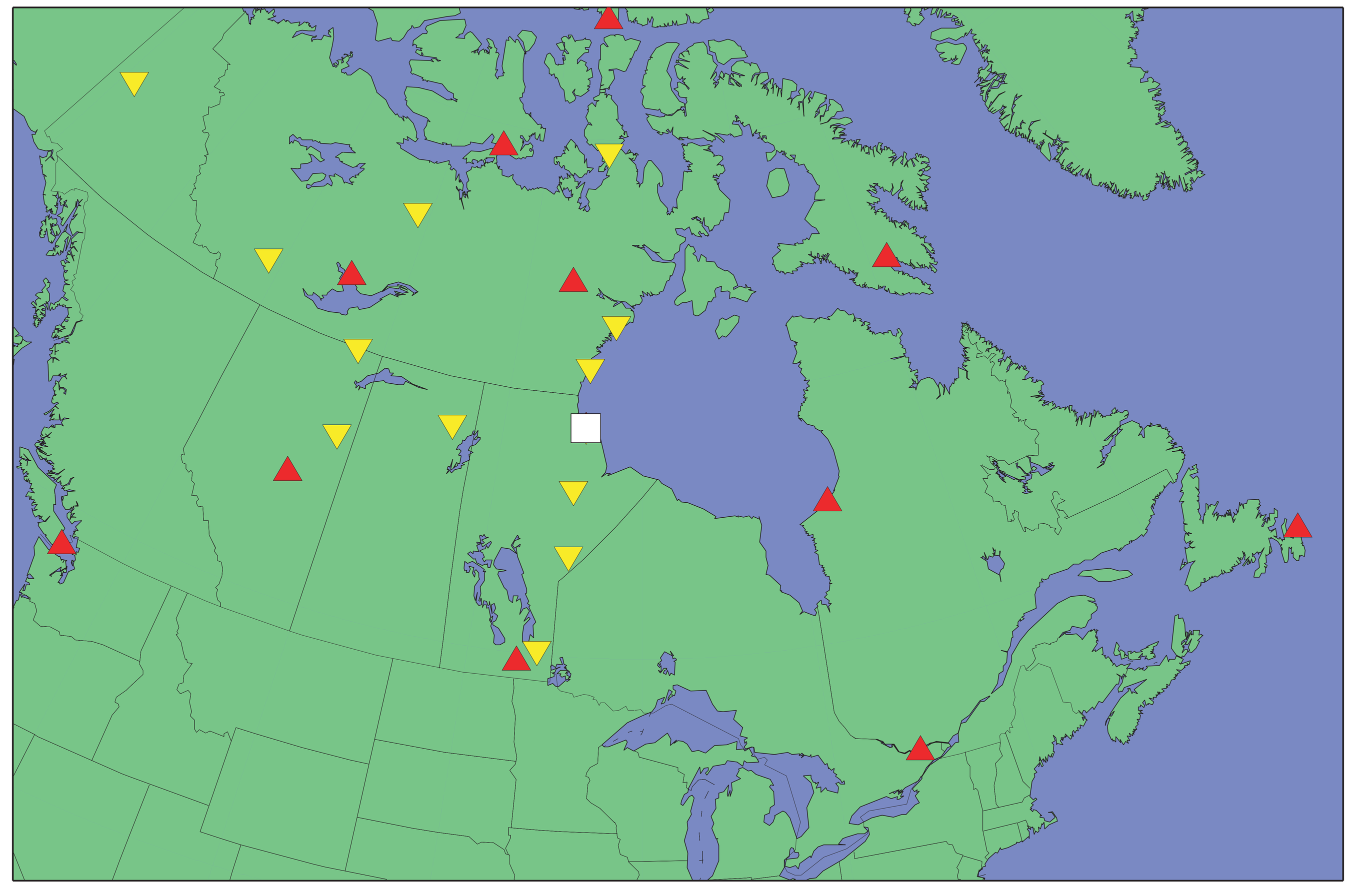
Abstract:
In keeping with the philosophy that "what the world needs now is a good $500 magnetometer", we have done further development and testing on what is now a relatively stable new design of triaxial magnetometer.
With one sensor per axis we routinely detect variations of less than 1 nT with one-second sampling.
Timing is derived from a GPS heartbeat pulse.
Experimentation showed that designs with two sensors per axis produced more problems than they solved.
Ground burial has been shown to be important due to the thermal sensitivity of the devices used.
In addition, accurate calibration requires measurement of small temperature changes.
A thermistor-based circuit which produces pulses whose frequency is related to temperature, but with a high frequency allowing accurate counting and thus detection of very small temperature changes, allows such calibration without any change in the basic design.
The design itself is based on PIC microcontrollers, now commonly used.
The viability of the intent to make a network of these inexpensive magnetometers in the Alberta (Canada) auroral zone has been demonstrated by a subauroral network of two-axis online (www.sam-europe.de) instruments run in Germany by amateurs.
It is suggested that the limiting factor in deployment of such low-cost magnetometers should be connectivity, which is improving rapidly. Thus high temporal and spatial resolution magnetic studies, particularly in the auroral zone, will be enabled by these instruments.

The Problem of Sparsity of Magnetometers

Ground magnetic fields arise from numerous sources. In order to determine the details of source regions and separate distant from proximal effects, close spacing of stations is needed in the auroral zone.

Magnetometers have been sparse up until now due to several factors, major among them being cost of instruments and lack of infrastructure in the auroral zone, including communications infrastructure.

Both of these factors are changing rapidly.



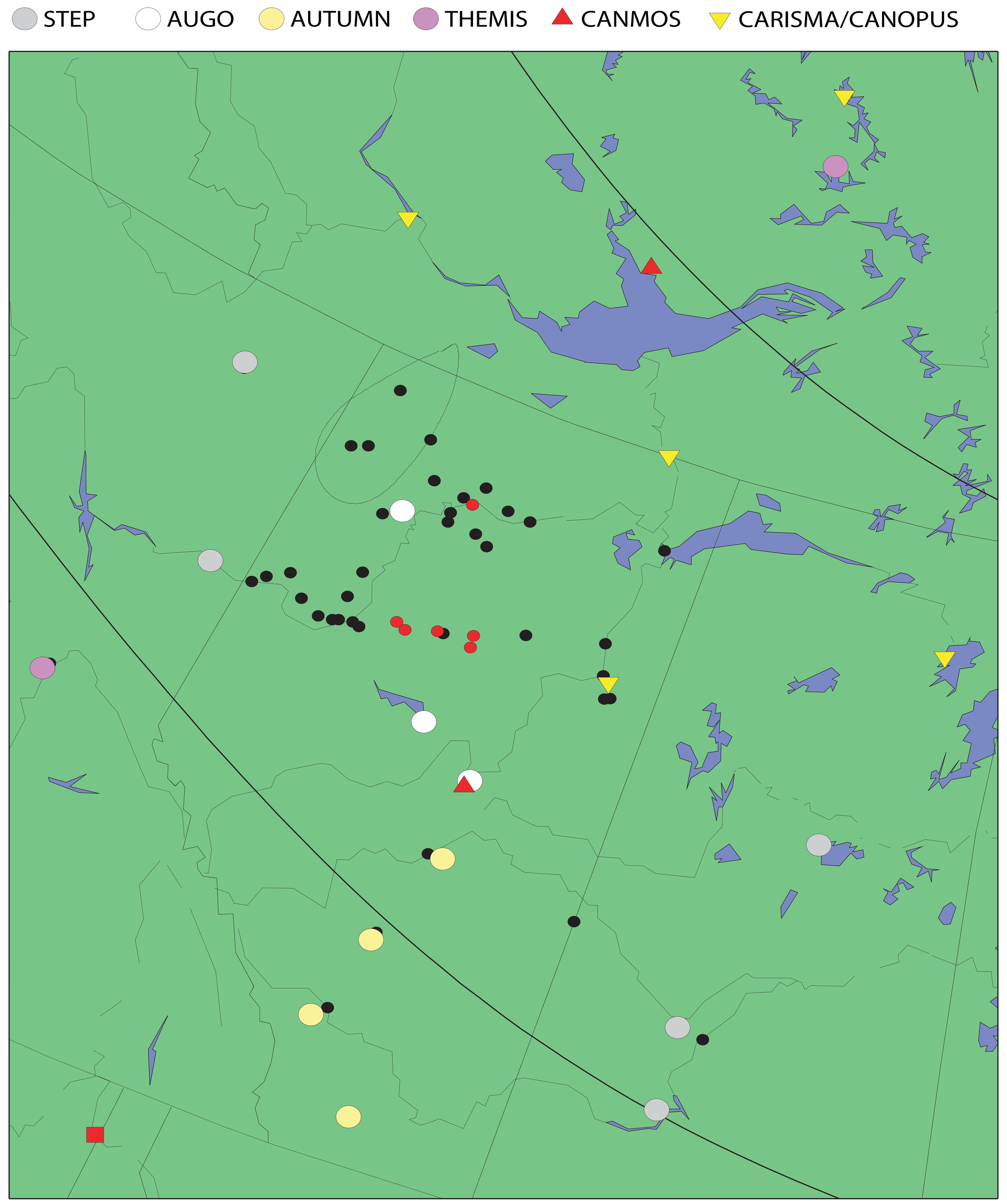
Canada's Government-Sponsored Magnetic Stations

Canada is a continental-scale country with 13 federal government (NRCan) observatories (red) and 13 CARISMA (formerly CANOPUS) observatories (yellow). There is overlap at Churchill (white square). Large regions of the country are not well covered by this set of observatories.

Optimal Auroral Zone Siting in Alberta

The province of Alberta in northwestern Canada is well situated with respect to the auroral zone. The map below shows the 60° and 70° geomagnetic field lines curving from upper left to lower right. Known operating magnetometers are shown. Within Alberta, locations between 56° and 60° geodetic that now have high speed Supernet internet service are shown as black dots and locations with Supernet at Northern Lakes College sites as red dots. The government-sponsored Supernet has made many auroral zone sites accessible for data transfer. Alberta also has the GOES-10 footpoint whose daily motion is shown by a thin oval line.

Magnetometers Operating Near Alberta



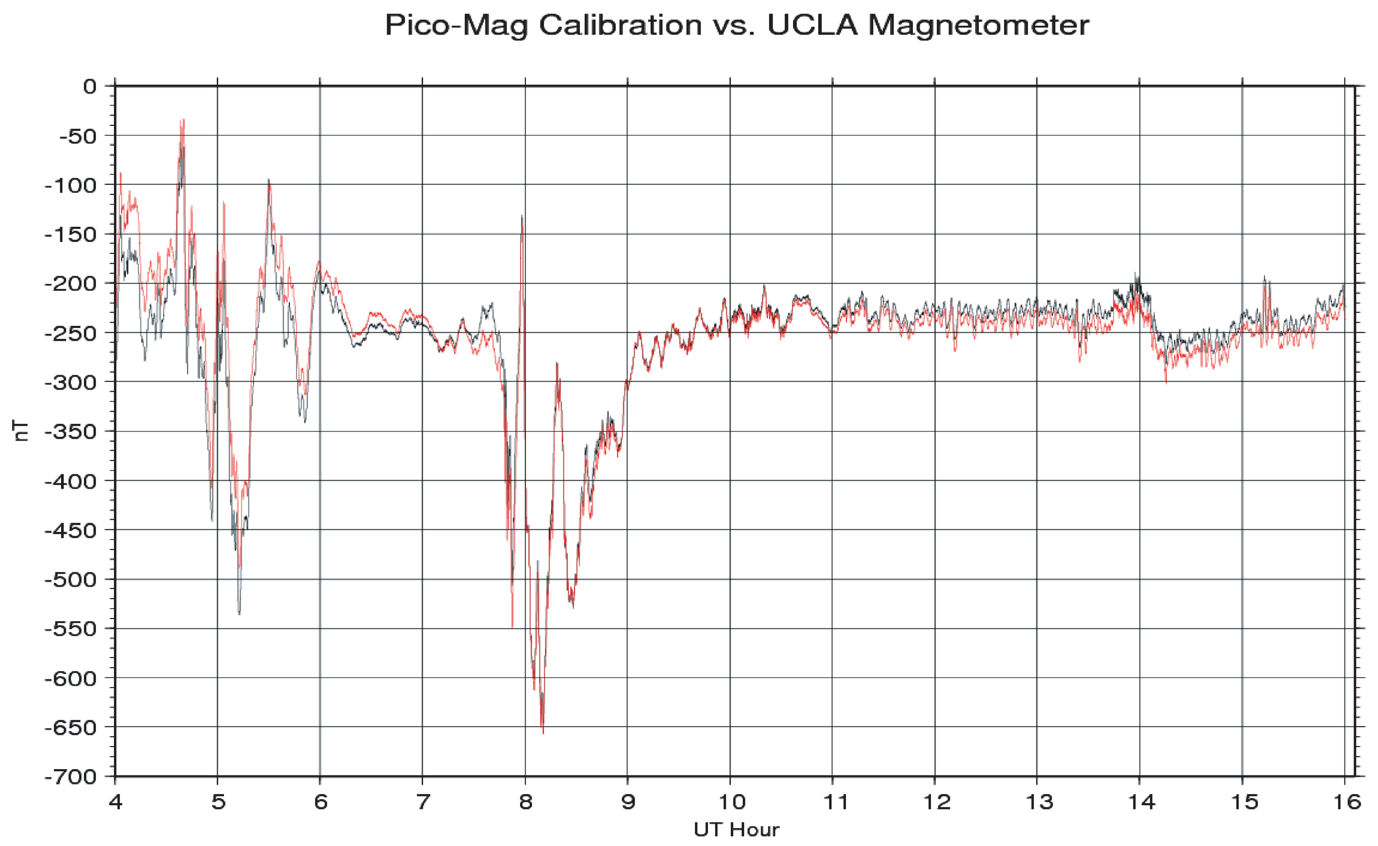
Pulse-Counting Magnetometers (PIComags)

The key technology for our inexpensive magnetometers is the Speake pulsed fluxgate head. The pulsed output is in the 10s of kHz and varies nonlinearly with the magnetic field parallel to the axis.

A pulse train is very easy to count with high precision using a microcontroller. We have found the PIC series from Microchip to be suitable as they are easy to program, have options for connection to a data logging PC, and have suitable counters.

There has been some parallel evolution since other groups have also made similar designs (see references).

It is of course essential that the inexpensive instrument give results of research caliber. The plot below shows a comparison between output from the Y axis of a triaxial PIComag (red) and that of the UCLA "small" magnetometer, both at Athabasca, on March 10, 2004. A temperature calibration based on measurements of the changing temperature in the observatory was performed.



Clearly, the PIComag is capable of resolution which for practical purposes is useful. In addition, it has GPS-based timing so that it can be used to study rapidly varying phenomena.

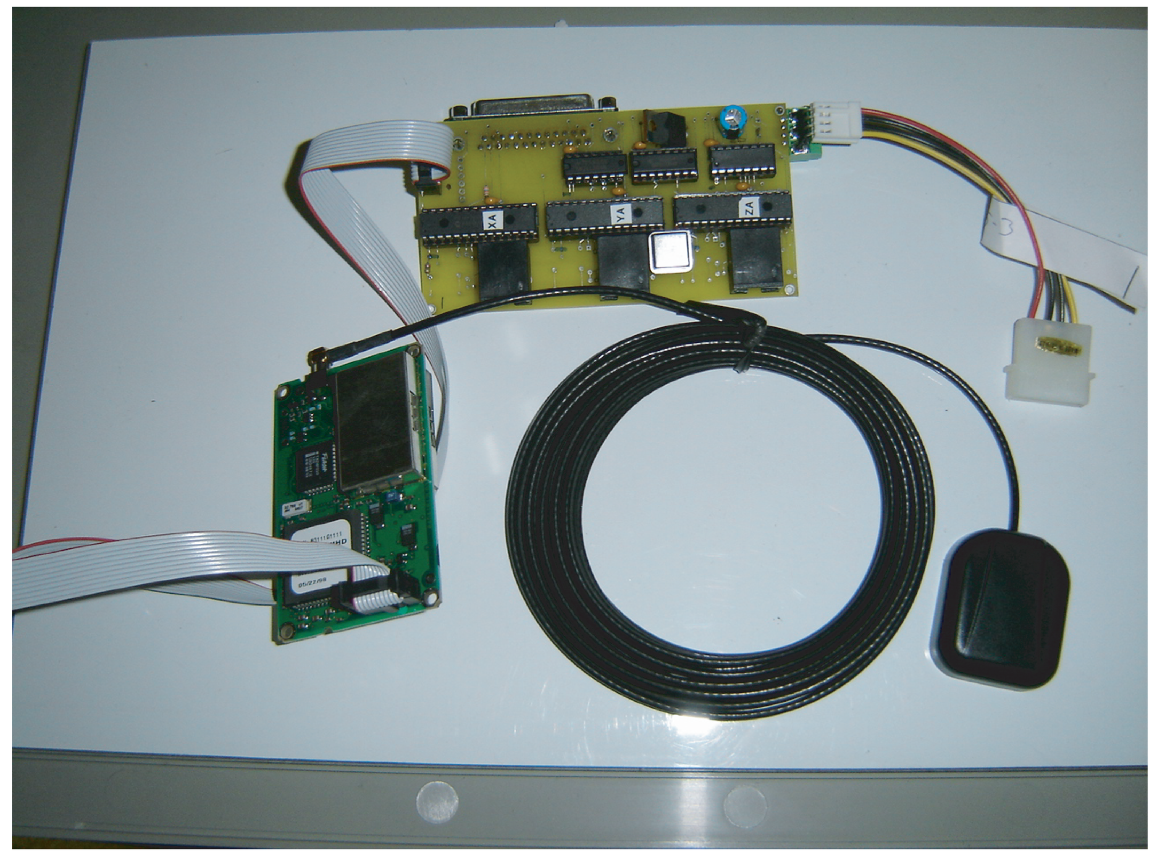
The limit of a PIComag with a simple counting circuit is slightly under 1 nT resolution, and it is optimally run at 1 Hz. These limits are not easily exceeded, but are suitable for many types of studies.

Technical Points

The Microchip PIC18F252 is an advanced 8-bit processor with 2 16-bit counters. We designed a board around it with the idea that opposed sensors would be used to increase resolution and reduce thermal effects. One PIC was thus needed per axis, for a total of three on the board. All get a heartbeat pulse from an Oncore GPS unit once per second, and an SPI read to a PC parallel port is done.

Our studies show that thermal calibration with good resolution is important. In addition, the two heads per axis can interact with each other and lock. We have developed a pulsed thermal sensor for very fine resolution and will use this and only three magnetic sensors.

Over our development and testing time, new PIC versions have come out. Premade development systems with these may be the way to go in future as one modern PIC can do more than the three PICs in our system.



Conclusions

We met our design goal of producing a research quality magnetometer at very low cost. A new and better PCB has been designed professionally. This or a design based on premade boards could allow many magnetometers to be deployed for reseach and education.

Acknowledgement

Rob Irwin of Northern Lakes College has been a key partner in AUGO array placements including a test PIComag. PIComag measurements and calibration were done by Ben Warrington, formerly of AUGO.
AUGO is the Athabasca University Geophysical Observatory.

References:

Simple Aurora Monitor pages: http://sam-europe.de/

Tekatch-Welch magnetometer: http://crocus.physics.mcmaster.ca/Magnetometer/TW/index.html

Microchip: http://www.microchip.com