British Geological Survey

Merging magnetic field data from fluxgate and induction coil magnetometers to produce improved one-second values

Royal Astronomical Society

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Problem

DMI fluxgate magnetometer (FGE)
- ✓ Provides long-term stability at low frequencies.
- ✗ At high frequencies, instrument noise “masks” natural magnetic field signals.

Induction Coil magnetometer (IC)
- ✗ No long-term stability at low frequencies.
- ✓ Captures natural field signals at higher frequencies due to lower noise.

PROPOSED SOLUTION
Combining Fluxgate and Induction Coil Magnetometer Data

One minute mean values come from 1Hz FGE data. However, for space weather applications, 1 Hz FGE data are not good enough on their own to make 'true' one-second values.

We want to combine DMI FGE and IC systems to produce “better” *one-second* data.

RESULTS
Periodogram
Coherence Analysis

RESULTS
Spectrogram
CONCLUSION

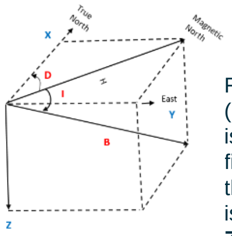

Fig 1A. [left] Magnetic field (**B**) as a vector quantity. **H** is the horizontal magnetic field in the X-Y plane. **D** is the magnetic declination. I is the magnetic inclination. **Z** is the vertical component of the magnetic field.

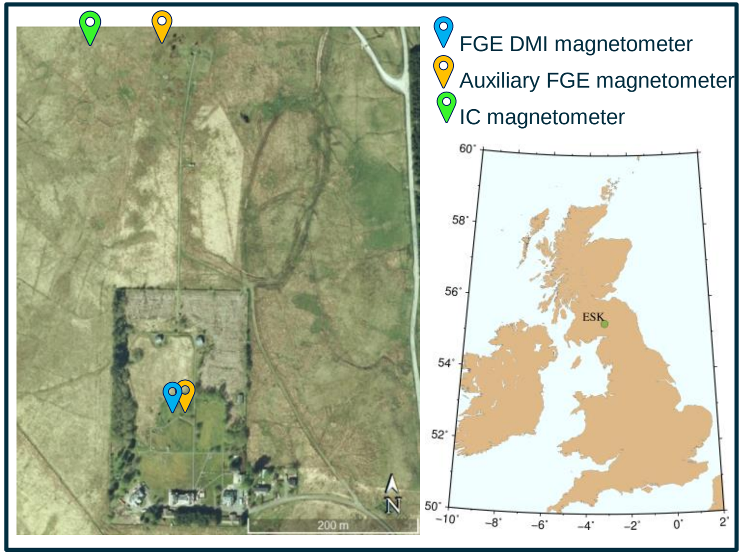

Fig 1B. [top] Eskdalemuir Geophysical Observatory (ESK) measures the Earth’s magnetic field 24 hours a day year round. Courtesy of Google Earth.

Fig 1C. [top] An induction coil magnetometer at ESK oriented in the X-Y direction.

Fig 1D. [below] close up of a DMI fluxgate magnetometer.

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CAN WE COMBINE FGE AND IC TO PRODUCE "BETTER" *ONE SECOND* DATA AT ESK?

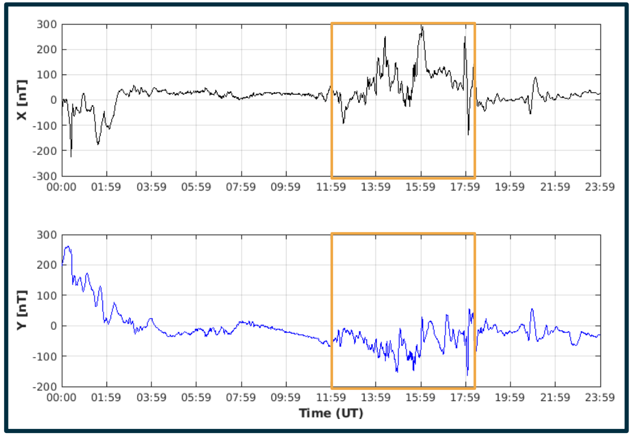

Fig 2A. [left] Magnetogram showing the X and Y component of the magnetic field at ESK for 08-Sep-2017 in one-minute resolution, time in UT. Unit is in nanotesla. Amber frames highlight periods of large natural field disturbances caused by a geomagnetic storm.

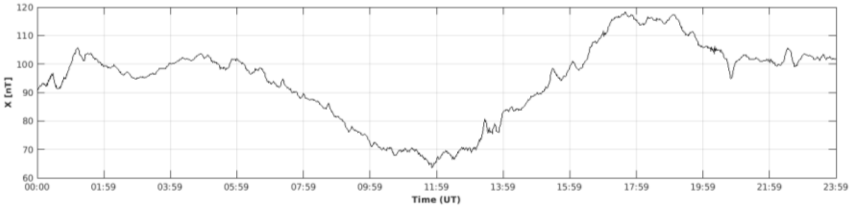

Fig 2B. Magnetogram showing the X component of the magnetic field at ESK for 05-Jun-2019, in one-minute resolution during a day of low geomagnetic activity.

Adapt technique developed by Brunke, *et al* (2017). They merged FGE and IC one-second data registered at similar latitude to ESK in their study.

scale factor noise-reduced value of $\boldsymbol{B_x}$

$$X_{FG}(t_i) = \int_{t_o}^{t_i} (\boldsymbol{C} \cdot U_{IC} + \boldsymbol{\Delta U})dt + \boldsymbol{B_x(t_0)}$$

constant offset

U_{IC}: induced voltage measured over Induction Coil (IC)

$X_{FG}(t_i)$: values recorded by the FGE at time t_i

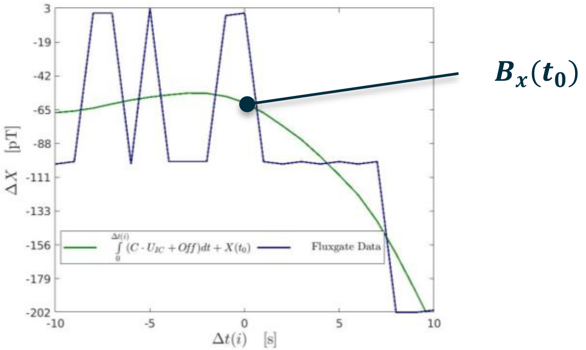

Fig 2C. Change in one-second FGE (blue curve) is fitted to one-second integrated IC (green curve) data co-aligned along the X-component at ESK and scaled to picotesla. Sample width is set to vary between -10s and 10s. Curves are fitted after adapting the three **parameters** in the equation [left]. $\boldsymbol{B_x(t_0)}$ is the merged value at time t= 0s; this is the desired, noise-reduced one-second value of $\boldsymbol{B_x}$.

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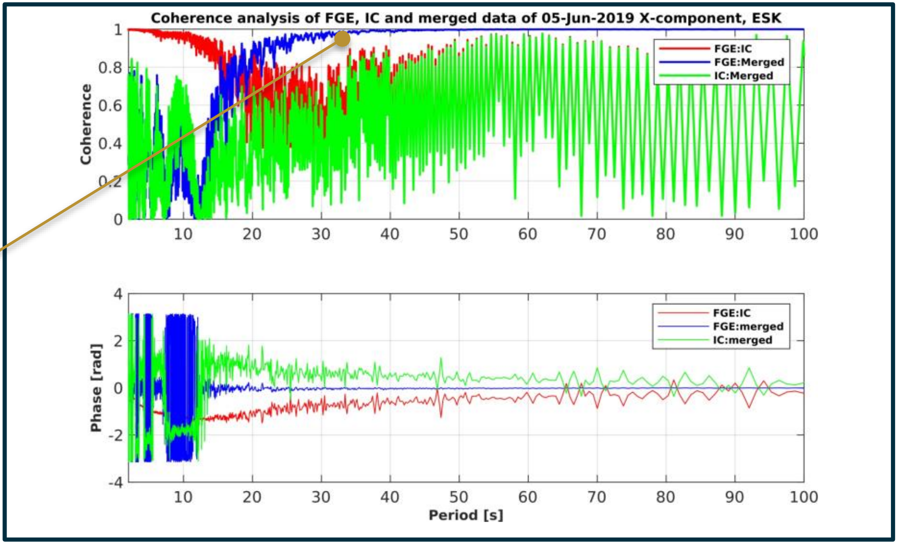
AFTER MERGING IC WITH FGE ONE-SECOND DATA

Fig 3A. [right] Coherence and phase difference between FGE, merged and IC data for 05-Jun-2019 for periods from 2 to 100s for the X-component. A value of 1 is perfect coherence. The coherence between merged data and FGE data matches well for low frequencies (larger periods).

Below 33s period, the IC and merged coherence shows a peak coherence value at 10s before dropping at periods below 10s.



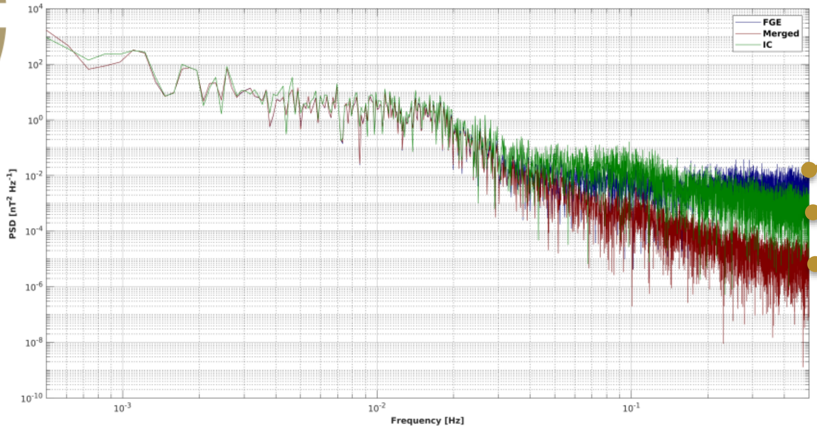


Fig 3B. [left] Periodogram showing power spectra of measured FGE (blue), merged data (green) and IC (red) for 05-Jun-2019.

FGE data reach constant noise level of 0.2 nT^2Hz^{-1} approaching 30 mHz

IC data reach a lower constant noise level at a higher frequency than FGE data

The merged data show the continuing decay for the natural field

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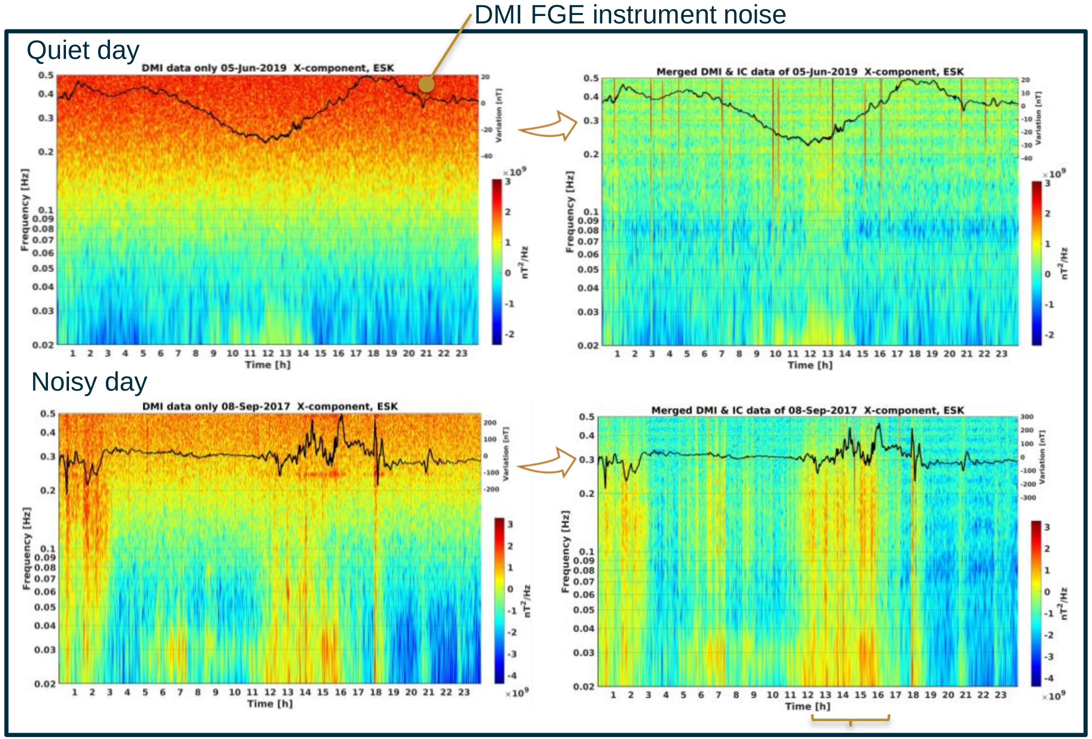
Fig 4A. Power spectra density (PSD) spectrograms are overlain with time-series of the natural field (black line). Left and right panels allow for direct comparison between PSD computed from FGE and from the merged one-second data in the X-component, for the same day, between 0.02 Hz to 0.5 Hz. Top panels show a before and after comparison of one-second data recorded on a day of low geomagnetic activity; bottom panels show data registered periods of major geomagnetic storm on 08-Sep-2017. In both dates, PSD generated from the merged data show less noise between 0.1 – 0.5 Hz.



Geomagnetic disturbance has more energy at high frequencies

CONCLUSION

One Hz data from two different, but complementary magnetometers at ESK are combined successfully. The induction coil has excellent high frequency sensitivity, but long-term drifts, while the FGE sensor has excellent long-term stability but high frequency noise issues.

The combined one-second data show strong improvement with lower noise at 2-10 seconds, while retaining excellent long-term stability.

REFERENCE

Brunke, H. P., Widmer-Schnidrig, R., and Korte, M. (2017). Merging Fluxgate and Induction Coil Data to produce low Noise geomagnetic Observatory Data meeting the INTERMAGNET Definitive One-second Data Standard, Geosci. Instrum. Method. Data Syst. Discuss., https://doi.org/10.5194/gi-6-1-2017

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