British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

An automatic method for detection and classification of Ionospheric Alfvén Resonances using signal and image processing techniques

Ciarán D. Beggan[1] [ciar@bgs.ac.uk]
[1]British Geological Survey, West Mains Road, Edinburgh, United Kingdom

Induction coils permit us to measure the very rapid changes of the magnetic field. In June 2012, the British Geological Survey Geomagnetism team installed two high frequency (100 Hz) induction coil magnetometers at the Eskdalemuir Observatory (55.3° N, 3.2° W, L ≈ 3), in the Scottish Borders of the United Kingdom (Figure 1). The Eskdalemuir Observatory is one of the longest running geophysical sites in the UK (beginning operation in 1908) and is located in a rural valley with a quiet magnetic environment. The coils record magnetic field changes over an effective frequency range of about 0.1–40Hz, and encompass phenomena such as the Schumann resonances, magnetospheric pulsations and Ionospheric Alfvén Resonances (IAR).

In this poster we focus on the IAR, which are related to the vibration of magnetic field lines passing through the ionosphere, believed to be mainly excited by lower atmospheric electrical discharges. In order to quantify the daily, seasonal and annual changes of the SRS, we developed a new method to identify the fringes and to quantify their occurrence, frequency (*f*) and the change in frequency (Δf) over time. We present rhe method and results from 18 months of analysed data (Sep 2012 –Feb 2014).

Instrumentation

Figure 1: Induction coils at Eskdalemuir [55.3° N, 356.8° E] in the Scottish Borders, UK. Left image: Location of Eskdalemuir and the BGS Induction coils. Right image: The North-South coil (white tube, foreground) is located in a rural valley (background), protected from wind, rain and snow under a non-magnetic wooden cover (shown upright in midground). The signal is digitized close to the coil before being converted to a higher voltage at a breakout box and sent to a logging computer in a vault approximately 150m away.

The instrumentation consists of two induction coil magnetometers, N-S and E-W orientated (Figure 1), connected to a Guralp digitizer. The digitizer converts the output signal for wired transmission to a computer logger located in a nearby vault. The data from the induction coils are recorded at 100Hz by the onsite computer where they are collated into hourly files. The data are automatically collected once per hour and permanently stored on the BGS network. Daily processing produces a set of spectrograph images for display on the BGS Geomagnetism website (c.f. QR code)

Data Analysis

The IAR typically manifest as a series of spectral resonances structures (SRS) within the 1-6Hz frequency range, usually appearing a fine bands or fringes in spectrogram plots. The SRS tend to occur daily between 18.00–06.00UT at the Eskdalemuir site, disappearing during the daylight hours. They usually start as a single low frequency before bifurcating into 5–10 separate fringes, increasing in frequency until around midnight. The fringes also widen in frequency before fading around 06.00UT. Occasionally, the fringes decrease in frequency slightly around 03.00UT before fading. Figure 2 shows some example days with IAR. Data are plotted from midday to midday. The colour scale is in Log(pT^2). Time is in UT.

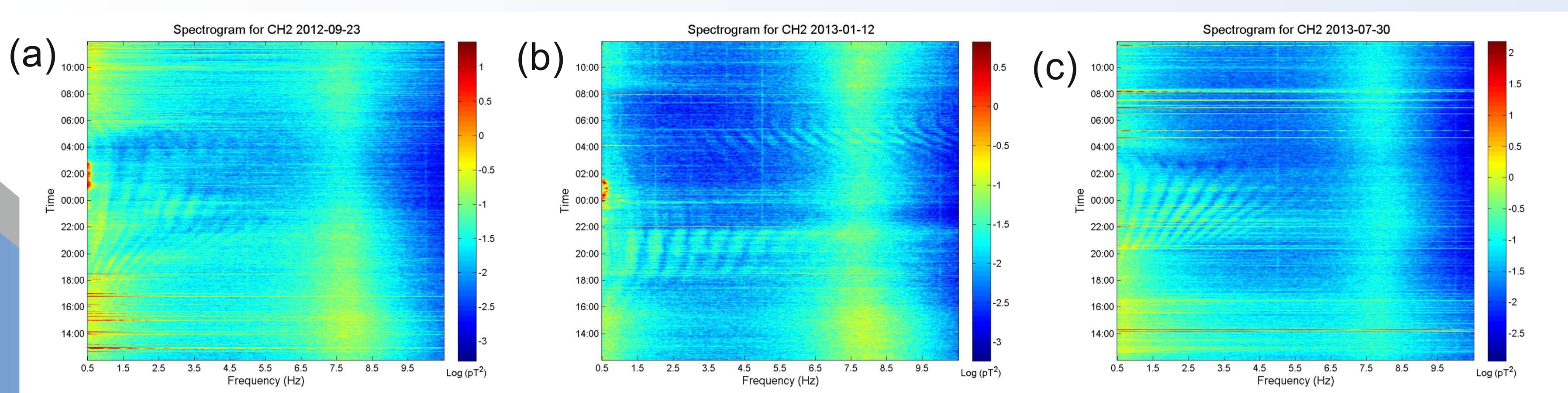


Figure 2: Example spectrograms with IAR from the East-West (Channel2) coil. Data have been Butterworth bandpass-filtered (0.5–10Hz). Scale is in Log (pT^2). Dates:(a) 23-Sep-2012, (b) 12-Jan-2013 and (c) 30-Jul-2013

Daily Spectrograms: http://www.geomag.bgs.ac.uk/research/inductioncoils.html
This Poster: http://nora.nerc.ac.uk/id/eprint/506963

Signal and Image Processing

The method is fully automatic once the various thresholds have been set from inspection. However, as in any system, there is a trade-off to be made between detection and sensitivity to noise. Figure 3 outlines the protocol and results for the 14-15th February 2014 (i.e. a 'good' day with low Kp and no local lightning activity or noise).

The processing method starts with detrending and filtering the raw digitiser data from 0.5-10 Hz using a Butterworth five pole filter in the time domain (a,b,c). A series of FFT are computed using the Welch method with 100 seconds of filtered data to producing 864 1-D spectra plots per day which produce a spectrogram (d). The individual spectra are scaled using the instrument response and digitizer calibration values. The smoothed non-stationary IAR peaks in each time slice are identified using the residuals from a best-fit sixth order spline fit to remove the background trend (e). A peak finding algorithm is used to identify the highest points in the detrended spectra (f). The positions of the peaks from each time-slice are then placed into a matrix which is treated as an image of 'spots' (g).

The next stage attempts to identify continuous IAR peaks by using image processing techniques. The 'spots' are eroded to remove spurious noise and then dilated to create connected lines (h). Lines that are shorter than a threshold value are also deemed to be noise and removed (i). Finally, in combination with the spectrogram image of that day, the maximum amplitude location of the IAR are identified. The peaks can now be mapped as (almost) continuous lines throughout the spectrogram (j).

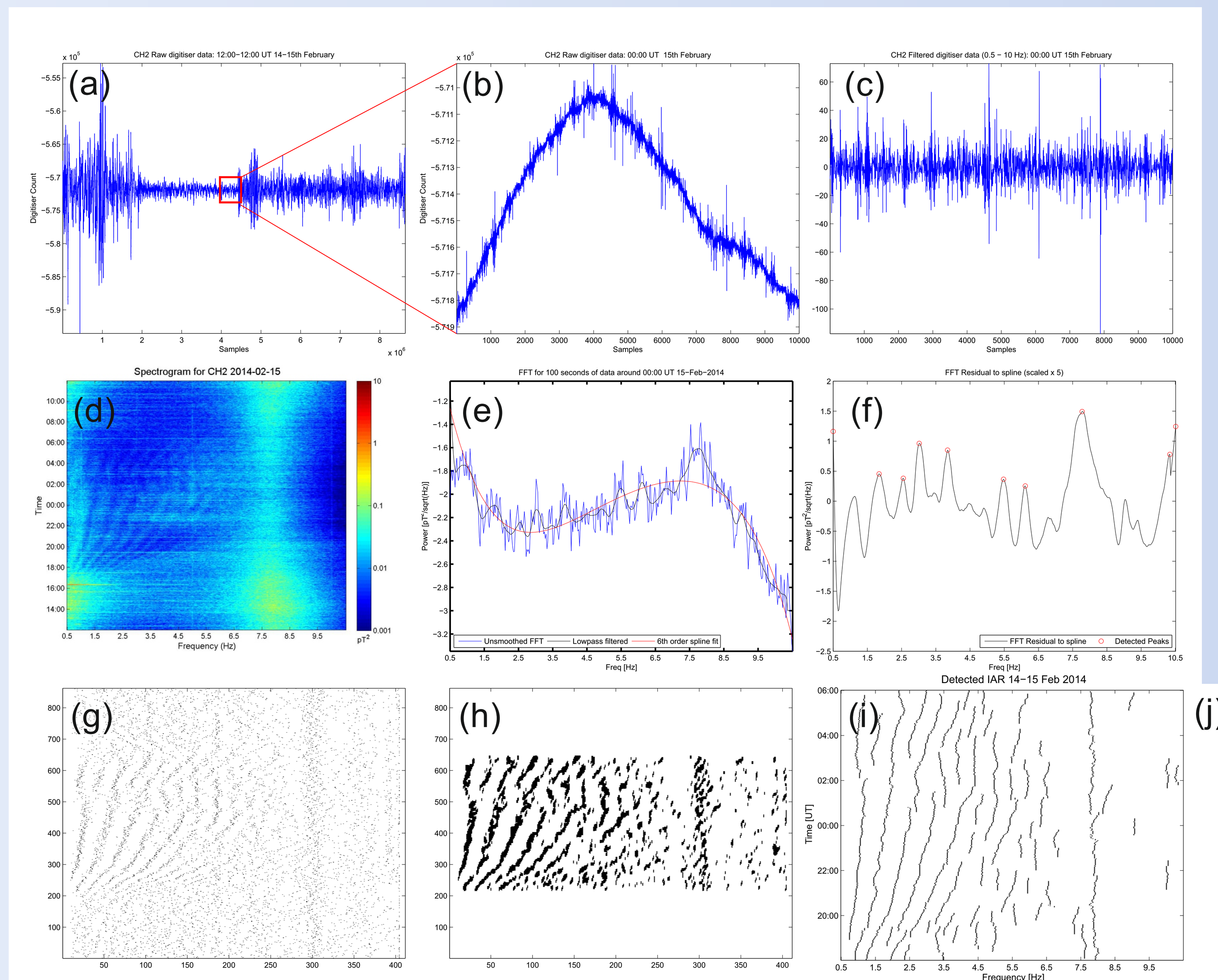
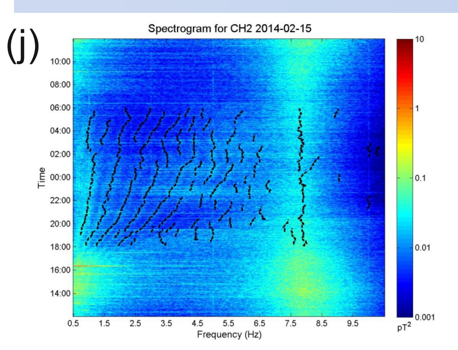


Figure 3: Protocol for identifying continuous IAR in induction coil data. See text for details. (a,b,c) Detrending and filtering of raw data. (*d*) Spectrogram. (*e,f*) Single FFT of 100 seconds of data, smoothed with back ground removed with main peaks identified (*g,h,i*) Image analysis used to identify continuous peaks. (*j*) IAR overlain on (d).

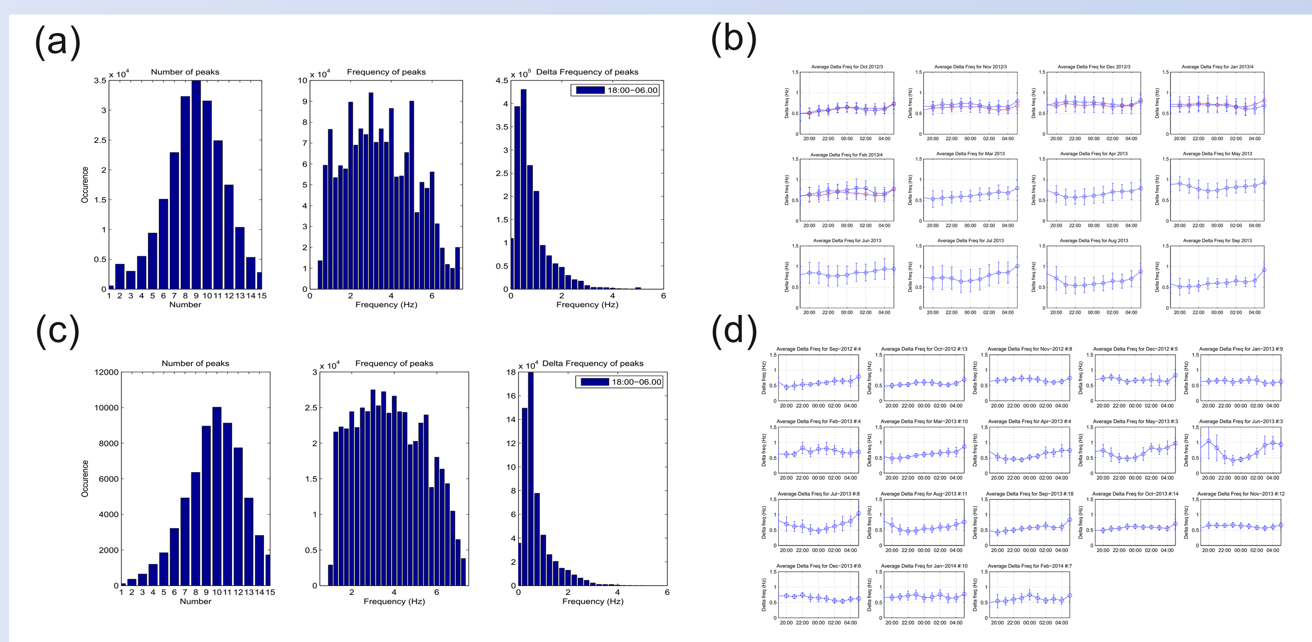


Results

We analyse 18 months of data (Sep2012 – Mar2014). Figure 4 shows the output from the automatic method for all days (a,b) and selected 'good' days (c,d) where IAR are clearly visible to the eye and the detected IAR are deemed accurate with little noise. There are three main parameters of IAR that are usually described in the literature on observations: occurrence rate, frequency peak (*f*) and the average frequency difference (Δf). The histograms (a,c) describe the distribution of number of peaks detected between 0.5 and 7.5 Hz, the frequency each peak occurs at and the average Δf (a diagnostic of the ionosphere). The time series plots show the average Δf in each hour of UT over a month. Error bars show the 1σ standard deviation.

The histograms show that 8-10 peaks seems to be average occurrence number with Δf = 0.25-0.75Hz. The Δf varies seasonally (b,d), reaching a maximum around solstice periods and a minimum around the northern hemisphere summer.

Figure 4:
Upper row: All data
Lower row: 'Good' days
(a,c) Histograms of the distribution of number of peaks detected between 0.5 and 7.5 Hz, the frequency each peak occurs at and the average Δf.
(b,d) The time series plots show the average Δf in each hour over a month.



References

[1] Odzimek, A., Kulak, A., Michalec, A. and J. Kubisz (2006), An automatic method to determine the frequency scale of the ionospheric Alfvén resonator using data from Hylaty station, Poland, *Annales Geophysicae,* **24,** 2151-2158
[2] Hayakawa, M., Molchanov, O.A., Yu. Schekotov, A. and Federov, E. (2004), Observation of ionospheric Alfvén resonance at a middle latitude station, *Advances in Polar and Upper Atmosphere Research*, **18**, 65-76
[3] Bösinger, T., Haldoupis, C., Belyaeev, P.P., Yakunin, M.N., Semenova, N.V., Demekhov, A.G. and V. Angelopoulos (2002), Spectral properties of the ionospheric Alfvén resonator observed at low-latitude station (L=1.3), *Journal of Geophysical Research*, **107 (A10)**, 1281, 1-9

Acknowledgements

I wish to thank the BGS Geomagnetism engineering team for installation and running of the coils and computer systems. This includes: Simon Flower, Ted Harris, Tony Swan and Tom Shanahan. I also acknowledge Kittiphon Boonma at the University of Edinburgh for helping in the early stages of this research.

EGU 2014 Meeting, Vienna, Austria
ST3.1: Open Session on the Ionosphere and Thermosphere
Monday 28th April: #12330