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Geophysical signals in the 3-50 Hz ELF band

Ciarán Beggan[1] (ciar@bgs.ac.uk)
[1]British Geological Survey, Edinburgh, UK;

Overview

The British Geological Survey have been operating two high-frequency induction coil magnetometers (100 Hz cadence) at their observatory in Eskdalemuir (Scottish Borders) [54.3°N; 3.2°W] since Jun 2012 [Fig. 1]. They have an approximate sensitivity of 0.07 pT at 0.1—50 Hz. The geophysical signals within the dataset encompass the **Schumann Resonances (SR**) generated by energy from equatorial lightning refracting in the Earth-ionosphere cavity [Ref. 1], the **Ionospheric Alfvén Resonances (IAR)** of the upper ionosphere cavity and magnetospheric pulsations (0.001-10 Hz) triggered by geomagnetic storms. We can also observe several subharmonics of the UK 50 Hz power grid. On occasion, local lightning strikes can also be observed directly in the data.

These signals range in amplitude from 0.5 pT for the IAR to 5 pT for the SR and over 250 pT for lightning strikes. In this poster, we give examples of spectrograms showing each type of geophysical signal and describe their occurrence statistics and typical amplitude ranges.

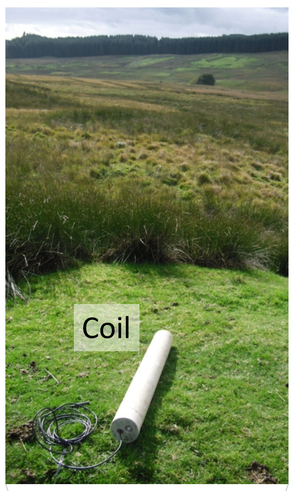

Figure 1: Induction coil (~1 m long) prior to installation at Eskdalemuir Geomagnetic Observatory (ESK) in the Scottish Borders.

1. Schumann Resonances and IAR

To create daily spectrograms, we divide the raw data into 100-second windows, bandpass between 3-40 Hz, compute 864 individual Welch periodograms, and take the logarithm for display purposes. Figure 2 (top) shows an example spectrogram for the period beginning at 12:00 UT on the 2nd December 2013. In the bottom panel we have selected three time periods and averaged over fifty minutes of data per periodogram to show the IAR and SR [c.f. Ref. 2].

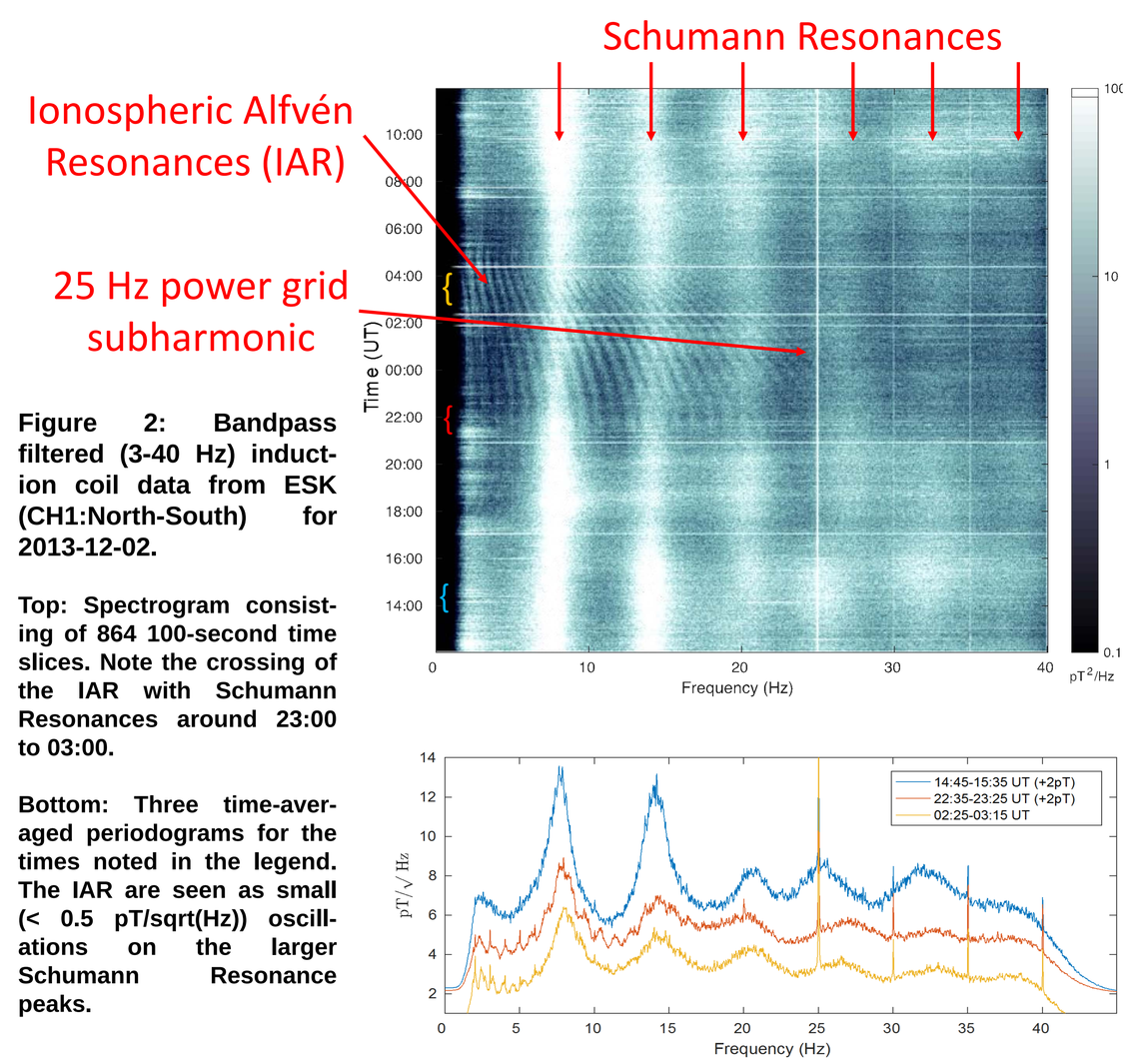

Figure 2: Bandpass filtered (3-40 Hz) induction coil data from ESK (CH1:North-South) for 2013-12-02.

Top: Spectrogram consisting of 864 100-second time slices. Note the crossing of the IAR with Schumann Resonances around 23:00 to 03:00.

Bottom: Three time-averaged periodograms for the times noted in the legend. The IAR are seen as small (< 0.5 pT/sqrt(Hz)) oscillations on the larger Schumann Resonance peaks.

2. Geomagnetic activity and seasonal occurrence

Using five years of observations, the occurrence of IAR, IAR interacting with SR, and pulsation events are correlated with Dst and Kp which are indicators of geomagnetic activity (Fig. 3, top and second rows). We also note the occurrence with calendar month and the occurrence as a percentage of the number of days per month (third and bottom panels).

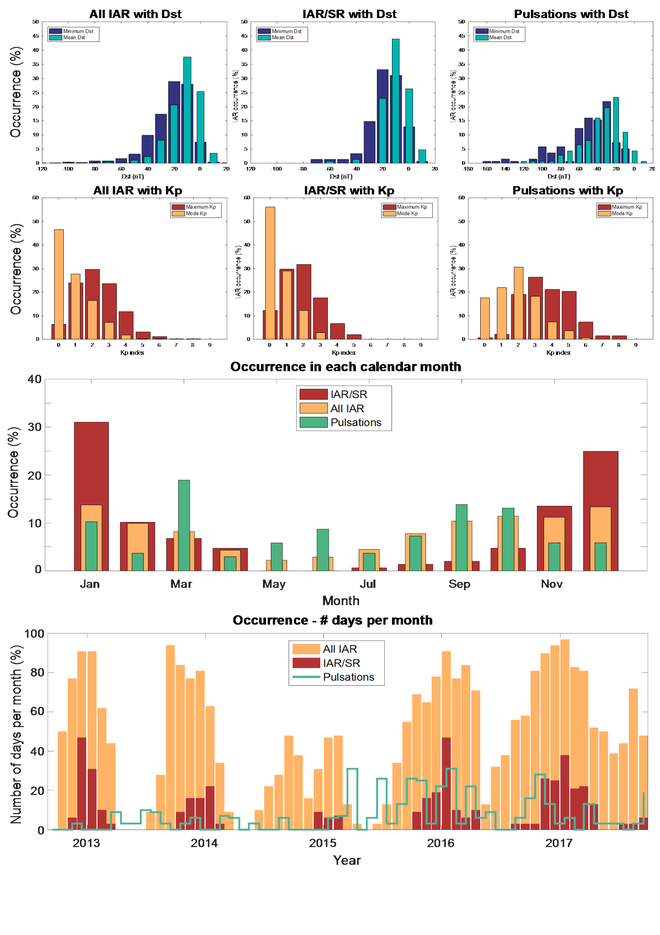

Figure 3: Occurrence statistics

Top row: Occurrence versus minimum recorded Dst and mean Dst values for each day where each phenomenon occurs. IAR and IAR interacting with SR occur in low to medium activity while pulsations occur across a wider range of Dst.

Second row: Occurrence versus maximum recorded Kp and most common (modal) Kp value for each day where each phenomenon occurs.

Third row: Percentage occurrence of each phenomenon per calendar month over five years of data. IAR occur in winter months generally. Pulsations peak around the equinoxes.

Bottom row: Percentage of days per month where each phenomenon was recorded for five years. As the solar cycle wanes from its peak in 2015 the occurrence of IAR has increased markedly.

3. Examples of global and local lightning activity

Figure 4 (top) shows examples of the lightning activity from the 'raw' data. Q-bursts are large lightning strikes somewhere on the globe which occur on average every two minutes. They are believed to be the source of gamma rays detected in space. Local lightning storms can produce strikes with magnetic fields of ~400 pT at Eskdalemuir Note that a 70 nT strike was reported from a storm in France in 2014 (Martin Fullerkrug, Univ. Bath, pers. comm.).

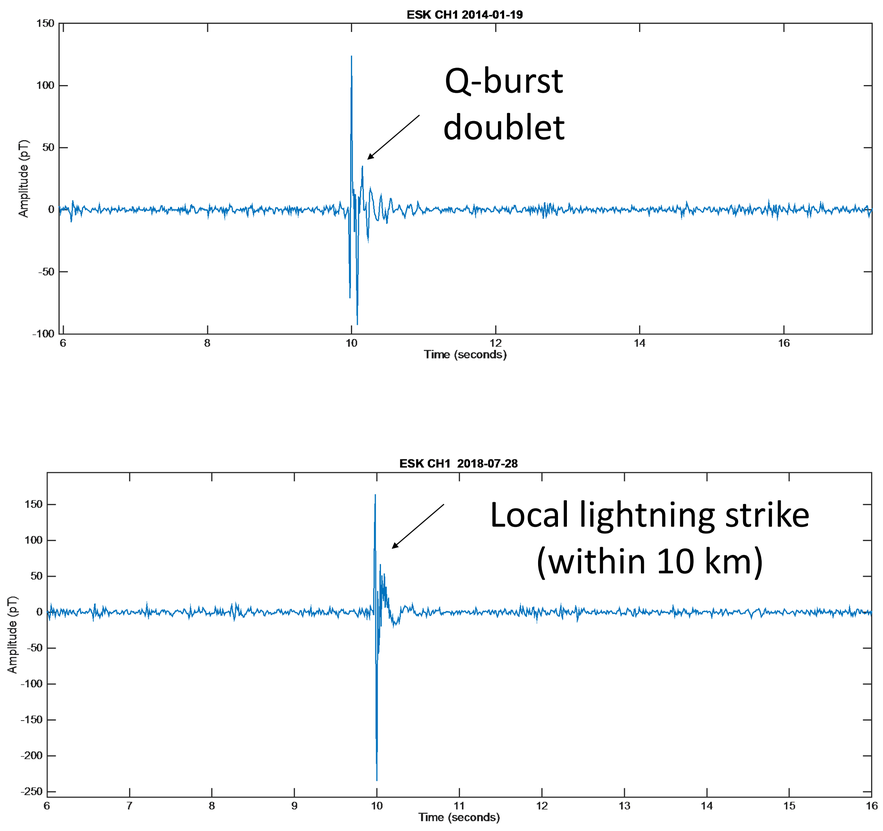

Figure 4: 'Raw' induction coil data band-passed from 3-40 Hz with an approximate counts per nT scaling of the digitiser values.

(Top): An example of a Q-burst from 19-Jan-2014 recorded in Channel 1 (North-South) with peak-to-peak value of ~225 pT. The doublet occurs from the EM radiation travelling around the Earth in two different directions.

(Bottom): Example of a thunderstorm passing over the induction coil on 28-Jul-2018. The largest magnetic field recorded is ~400 pT at 20:54:23 UT. The storm lasted around 3 hours.

Key points

- Schumann and Ionospheric Alfvén Resonances are readily detected in induction coil measurements
- The SR are continuous and have typical amplitudes of ~5 pT, occupying frequencies from 3-40 Hz
- The IAR appear at local night time under geomagnetically quiet conditions and have amplitudes of 0.5 pT
- Global lightning Q-bursts can be >200 pT and local lightning strikes even larger

[1] Nickolaenko, A.P. and M. Hayakawa (2002). *Resonances in the Earth-Ionosphere Cavity,* Volume 19 of Modern Approaches in Geophysics
[2] Beggan, C. D. & Musur, M. (2018). Observation of ionospheric Alfvén resonances at 1–30 Hz and their superposition with the Schumann resonances. Journal of Geophysical Research: Space Physics, 123. https://doi.org/10.1029/2018JA025264

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