British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Observations of the interaction between Schumann and Ionospheric Alfvén Resonances

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Overview

Long-term measurements of the high-frequency magnetic field (0.1-100 Hz) have been made at Eskdalemuir (ESK) Observatory (55.3°N, -3.2°E; L = 3.5) in the UK since September 2012. We analyse five years of dynamic spectrograms to examine the occurrence and behaviour of the Schumann (SR) and Ionospheric Alfvén Resonances (IAR), as well as Pc1-type pulsations. The resonances, observed as diffuse bands, arise from reflections of energy both within the earth-ionosphere cavity and from the non-linear conductivity gradient of the ionosphere [Ref. 1].

Schumann Resonances occur continuously but we find that IAR are observed to arise at local night time in ~50% of days in the ESK data. Typically, IAR are found at frequencies of 1-8 Hz, but we find them extending out to 30 Hz and strongly interacting with the first three Schumann Resonances around 9% of the time. These interactions include constructive and destructive interference, non-linear frequency changes over the span of several hours and polarity enhancements. In addition, the magnitude of the IAR does not decline rapidly with frequency as often proposed. We find the IAR and interactions with SR are strongly controlled by season and geomagnetic activity. As current theoretical models do not account for many of these observations [e.g. Ref. 2], we suggest further work is needed to understand how and why they arise.

Key points

- Schumann and Ionospheric Alfvén Resonances are detected in induction coil measurements in the UK (0.1—100 Hz)
- IAR are observed ~50% of the days
- The two resonance types overlap in frequency domain, showing superposition in spectrograms, around 9% of the time
- The occurrence is strongly linked to season and geomagnetic activity
- Many 'unusual' days are observed in the dataset e.g. IAR > 25 Hz; IAR observed in summer time and co-occurrence with pulsations

1. IAR occurrence and interaction with SR

We analyzed 61 months of data from the start of September 2012 to the end of September 2017, generating 1765 complete spectrograms. To create daily spectrograms, we compute 864 individual periodograms and take the logarithm for display purposes. Figure 1 (left) shows an example spectrogram for the period beginning at 12:00 UT on the 2nd December 2013. The SR are the diffuse bands at 8, 14 and 21 Hz etc. The IAR are the thin fringes or bands visible from 18:00 to 06:00. A subharmonic of the power grid is visible at 25 Hz.

For each of these we visually inspected the image and noted occasions when IAR both (a) occurred and (b) showed obvious interference with SR. We also observed pulsations and sporadic man-made interference within the dataset. In general, IAR occur in approximately half of the days examined (900 days) with seasonal and inter-annual variation. IAR interacting with SR occur 148 times (9%) and pulsations are observed on 137 days.

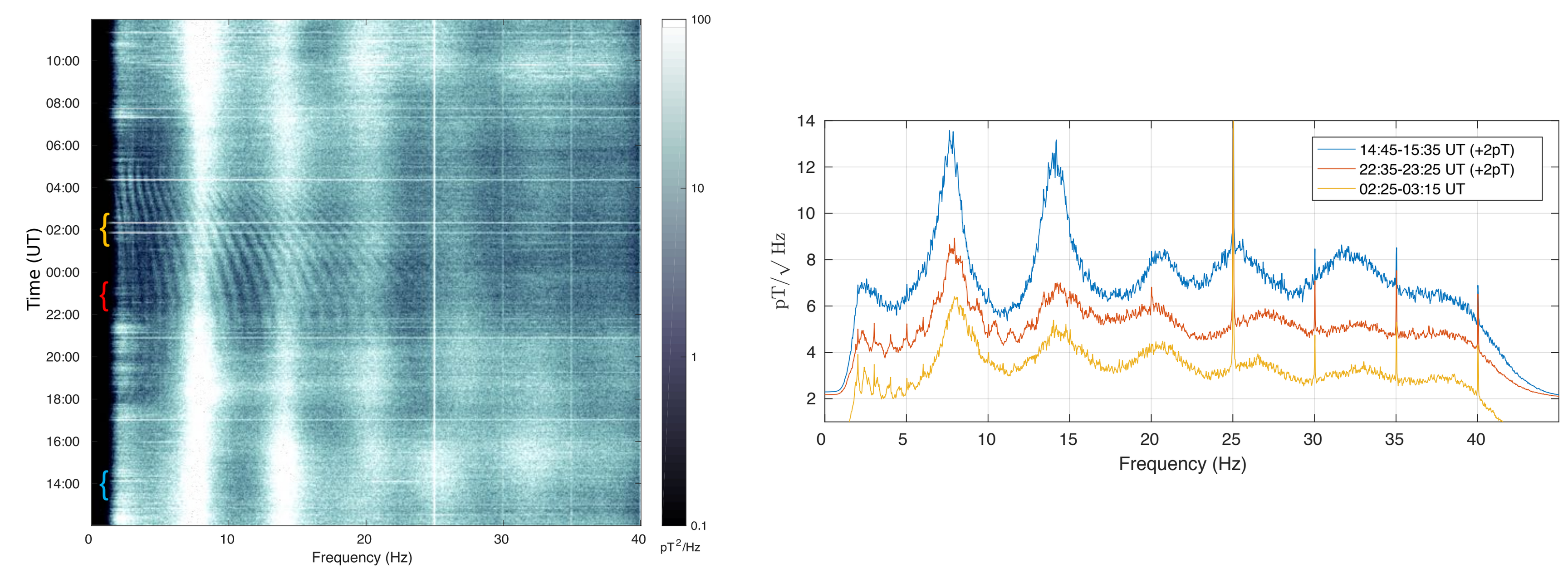

Figure 1: Bandpass filtered (3-40 Hz) induction coil data from Eskdalemuir (CH1:North-South) for 2013-12-02.
Left: Spectrogram consisting of 864 100-second time slices. Note the crossing of the IAR with Schumann Resonances around 23:00 to 03:00. The colour brackets indicate the data averaged to make the plot on the right.
Right: Three 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. Note the upper lines are offset by +2 pT/sqrt(Hz). The IAR appear to 'climb' over the SR.

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 (Figure 2, top and second row). We also note the occurrence with calendar month and the occurrence as a percentage of the number of days per month (third and bottom panel).

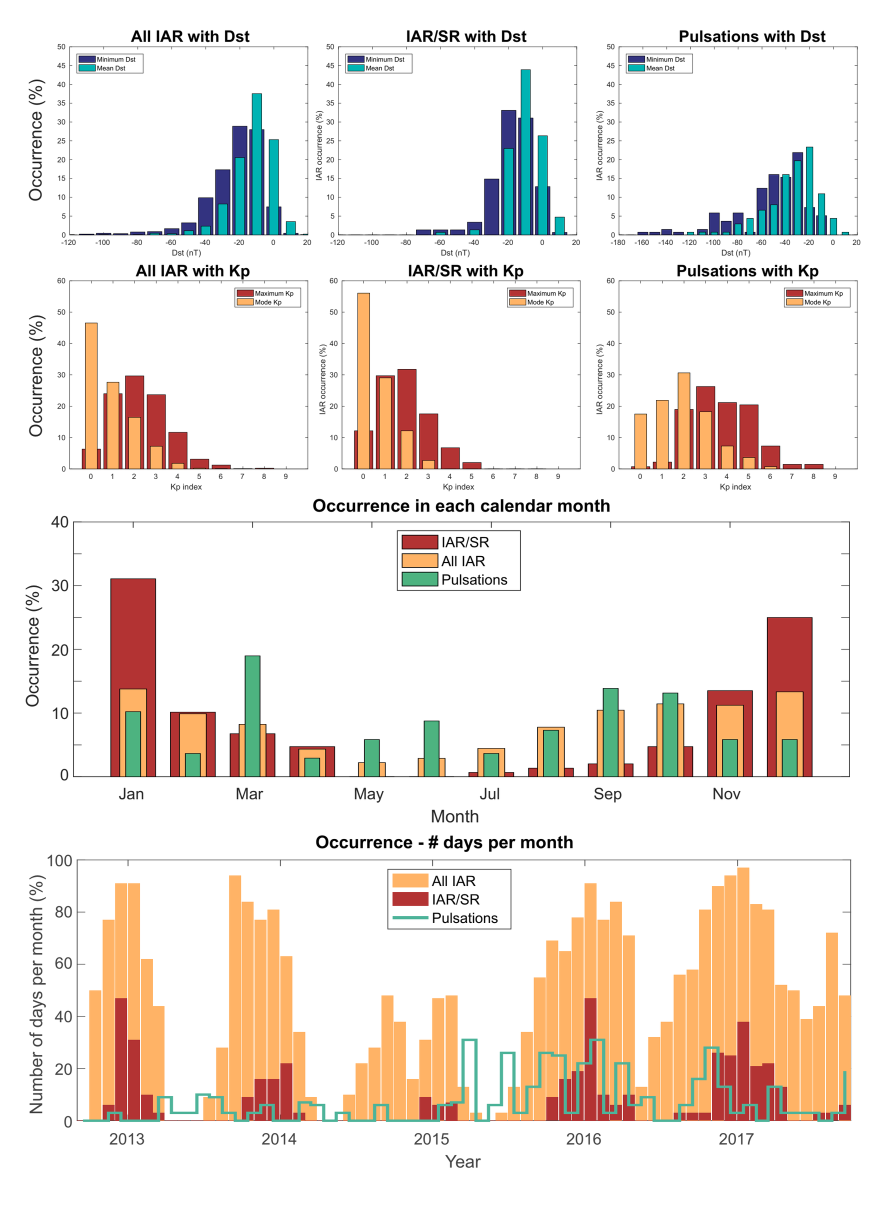

Figure 2: **Occurrence statistics**

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 the most unusual days

Figure 3 shows six examples of the most unusual days observed in the dataset. All days show IAR interacting with SR but we also observe deviations of the IAR away from their typical behaviour.

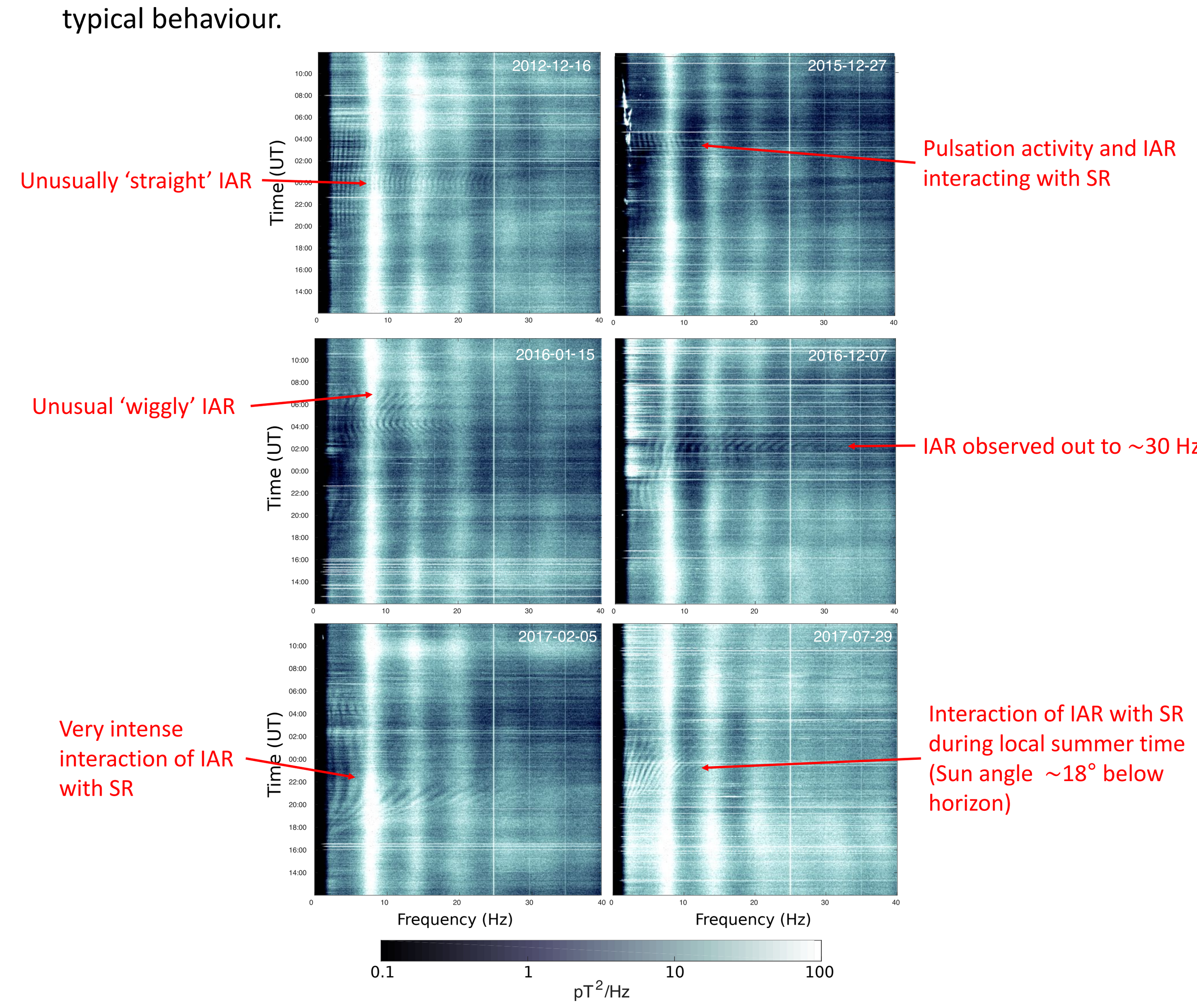

Figure 3: Six examples of days where IAR interact with the SR with unexplained behaviour, including IAR with unusual patterns of frequency variation, IAR at very high frequencies and IAR observed in summer time when the Sun angle is ~18° below the the horizon.

4. Key Questions

Observation	Explanation?
Extend from 1 Hz to 30 Hz	Not found in the literature
Strongly interact with the SR, including constructive/destructive interference with the first three resonances	Not found in the literature (though I. Mann has confirmed in CARISMA data, pers. comm. 2017)
Maintain a relatively constant magnitude across frequencies	Theoretical work suggests exponential decline with increasing frequency
Co-occur with pulsations	Not found in literature
Display unusual 'straightness' or 'wiggliness' that does not match independent measurements	Comparison made to f_0F_2 ionosonde data from UK. Found little correlation

⇒ These observations disagree with much of the theoretical modelling work and some of the previous IAR observations in the literature.

References
[1] Nickolaenko, A.P. and M. Hayakawa (2002). *Resonances in the Earth-Ionosphere Cavity,* Volume 19 of Modern Approaches in Geophysics
[2] Lysak, R. L. (1993), Generalized model of the ionospheric Alfven resonator, Geophysical Monograph Series, 80, 121--128.

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