Detection and Analysis of High-latitude Sporadic-E Layers using Incoherent Scatter Radar Observations

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1. Abstract

Sporadic-E (Es) layers are thin (1–5km) electron-density enhancements that form between 90 and 120 km altitude. Incoherent scatter radars (ISR) provide high-resolution, altitude-resolved measurements of the E-region. Since 2007, the Poker Flat ISR (65ºN, 147ºW) has operated in low-duty mode, producing a continuous dataset suitable for detecting Es events. Es layers are distinguishable from auroral precipitation by their narrow vertical extent and shorter temporal duration. We analyzed Es occurrences from 2007 to 2023, examining their seasonal, local time, and duration characteristics. We also studied a possible correlation between Es occurrence and Interplanetary Magnetic Field (IMF) B_yB_z orientation.

2. Motivation

- Es layers are well studied at low and mid-latitudes, but their occurrence at high latitudes remains less understood due to limited altitude-resolved observations.
- Es layers can disrupt radio and satellite signals by reflecting and scattering high-frequency waves, highlighting the need to understand their occurrence and improve predictability.

3. Science Questions

1. How does Sporadic E occurrence vary across seasons and local time at high latitudes?
2. Do seasonal and local time patterns of high-latitude Es resemble those at lower latitudes, suggesting shared formation mechanisms?
3. Does the IMF influence the formation of Es layers at high latitudes?

4. Methodology

PFISR Dataset (2007–2023) Alternating Code & Barker Code → **Generated daily electron density plots** → **Identification of the Sporadic E layer**

As shown in Figure 1 below, events were visually recognized by detecting sharp and sustained electron density enhancements. Through this method, 403 distinct events were successfully cataloged over the 17 years.

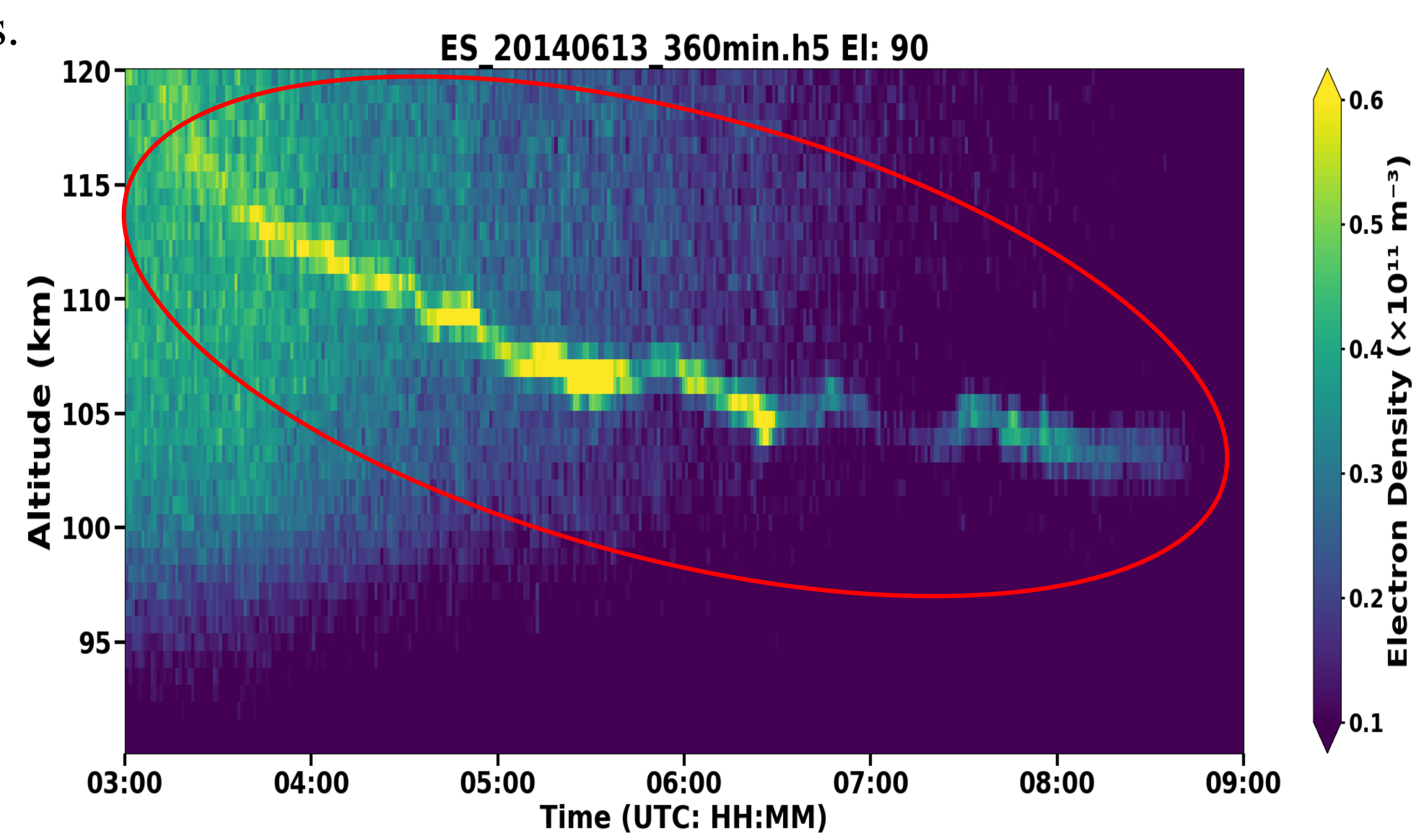

Figure 1: Electron density distribution between 90 km and 120 km on June 13, 2014. Red outline marks the location of an Es layer.

5. Results

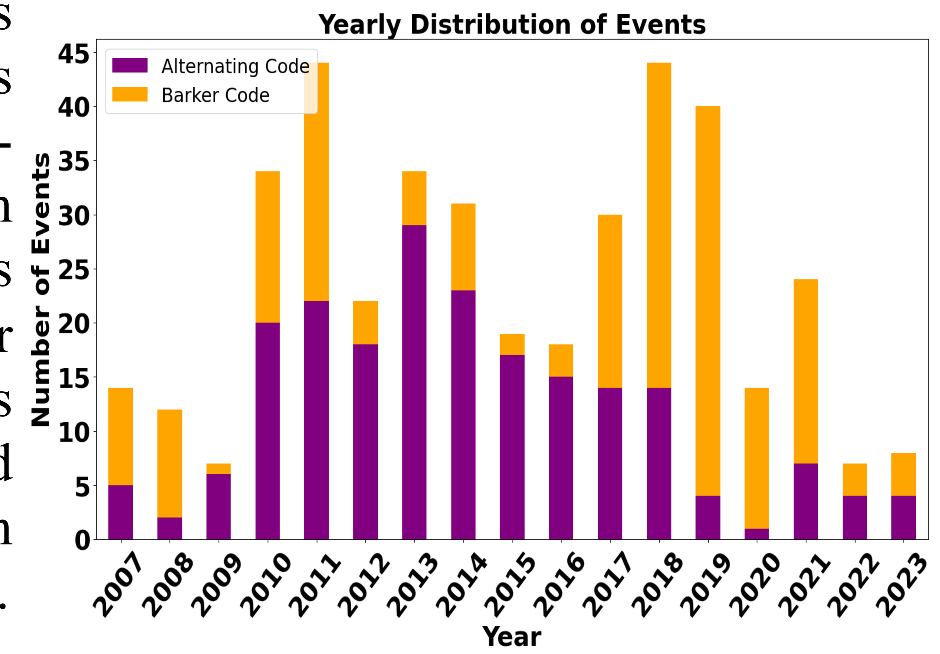

Figure 2: This figure shows **the number of detected events from 2007 to 2023**. **Event occurrence peaked during the periods 2010 –2014 and 2017–2019**, though the volume of available data varied across years. The plot also differentiates between the types of data collection codes used.

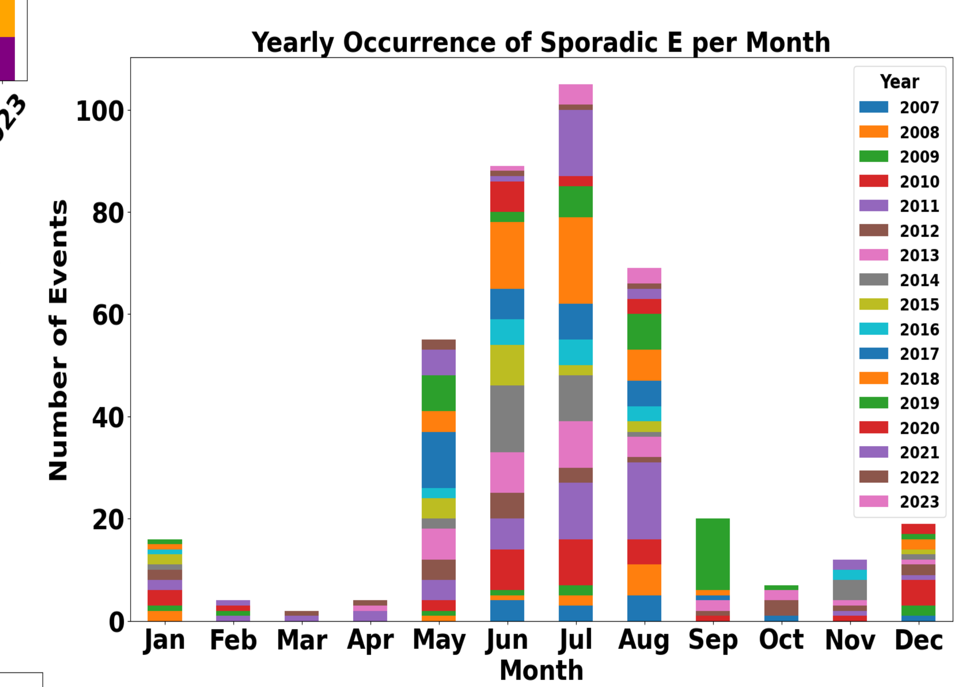

Figure 3: The figure shows **the number of events recorded each month throughout the study period**, with the **highest concentrations in summer and a smaller secondary peak in December and January.**

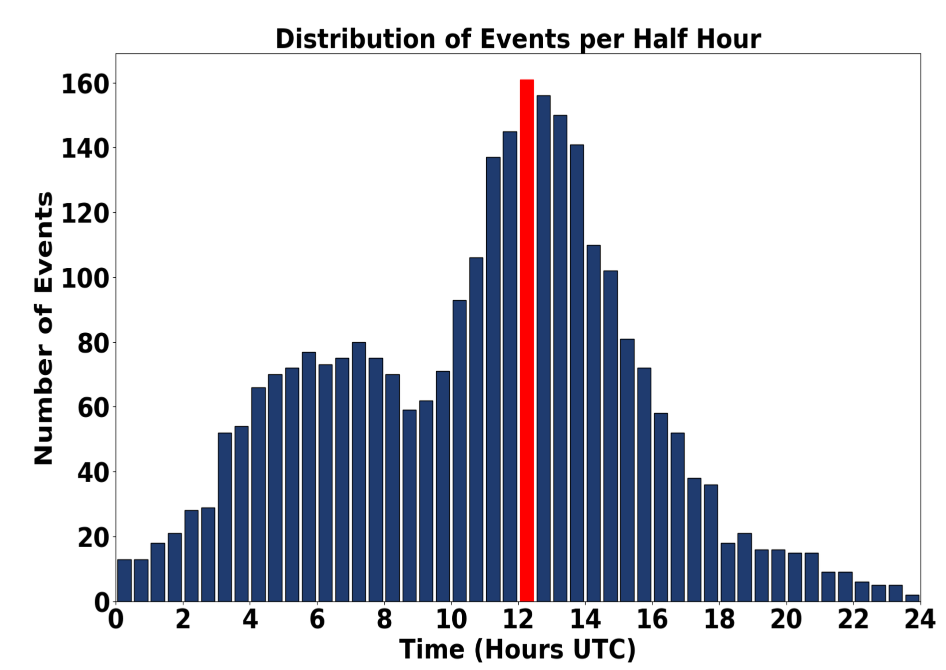

Figure 4: This figure displays **the frequency of events in 30-minute intervals throughout the day in UTC**. The distribution reveals a dominant pattern during nighttime hours, though seasonal effects may subtly affect the trend. **A prominent rise is observed near 12 UTC (corresponding to 3:00 am in LT, shaded in red), with a less pronounced increase around 6 UTC.**

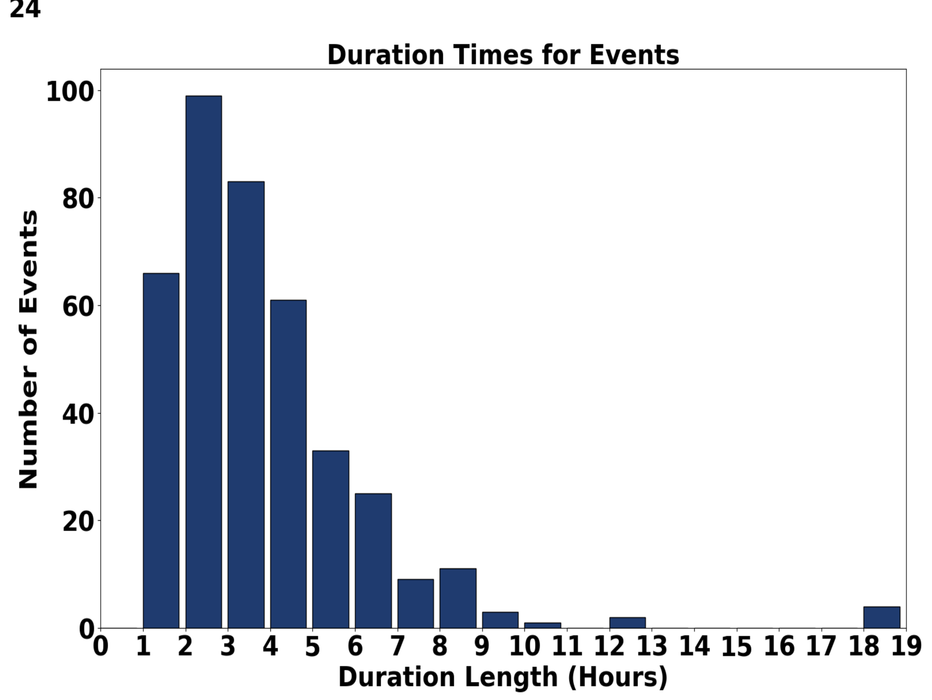

Figure 5: The figure shows **the distribution of events grouped by their duration in 30-minute intervals**. **Events lasting 2 to 3 hours were the most frequent, while those with longer durations appeared less often**. A few rare outliers were recorded with unusually long durations of 18–19 hours. These events significantly exceeded the typical duration range observed across the dataset.

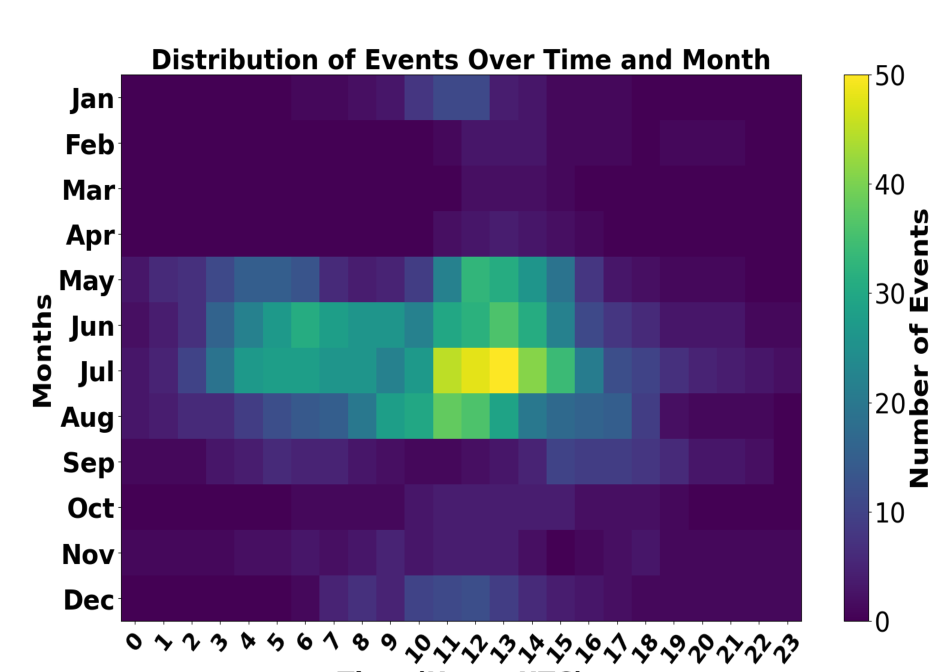

Figure 6: The plot illustrates **the distribution of events by time of day and month using data from 2007 to 2023**. **Most events occurred near magnetic midnight during the summer, with a smaller concentration around the same time in winter.** Overall, event frequency was higher during the early night compared to the early morning hours.

6. Es and IMF (Interplanetary Magnetic Field)

In this study, we investigated the relationship between high-latitude Es layer occurrence and the orientation of the interplanetary magnetic field (IMF), focusing on how variations in the By and Bz components may influence Es formation. We followed the approach of Voiculescu et al. (2006) using data from 2007 to 2023.

- Previous findings (Voiculescu et al., 2006)

  At Longyearbyen (75.2° N, polar cap boundary, 1999-2000):

  → Es favored during positive B_y and negative B_z

  At Thule (85.4° N, central polar cap, 1998-1999):

  → Es favored during positive B_y and positive B_z.

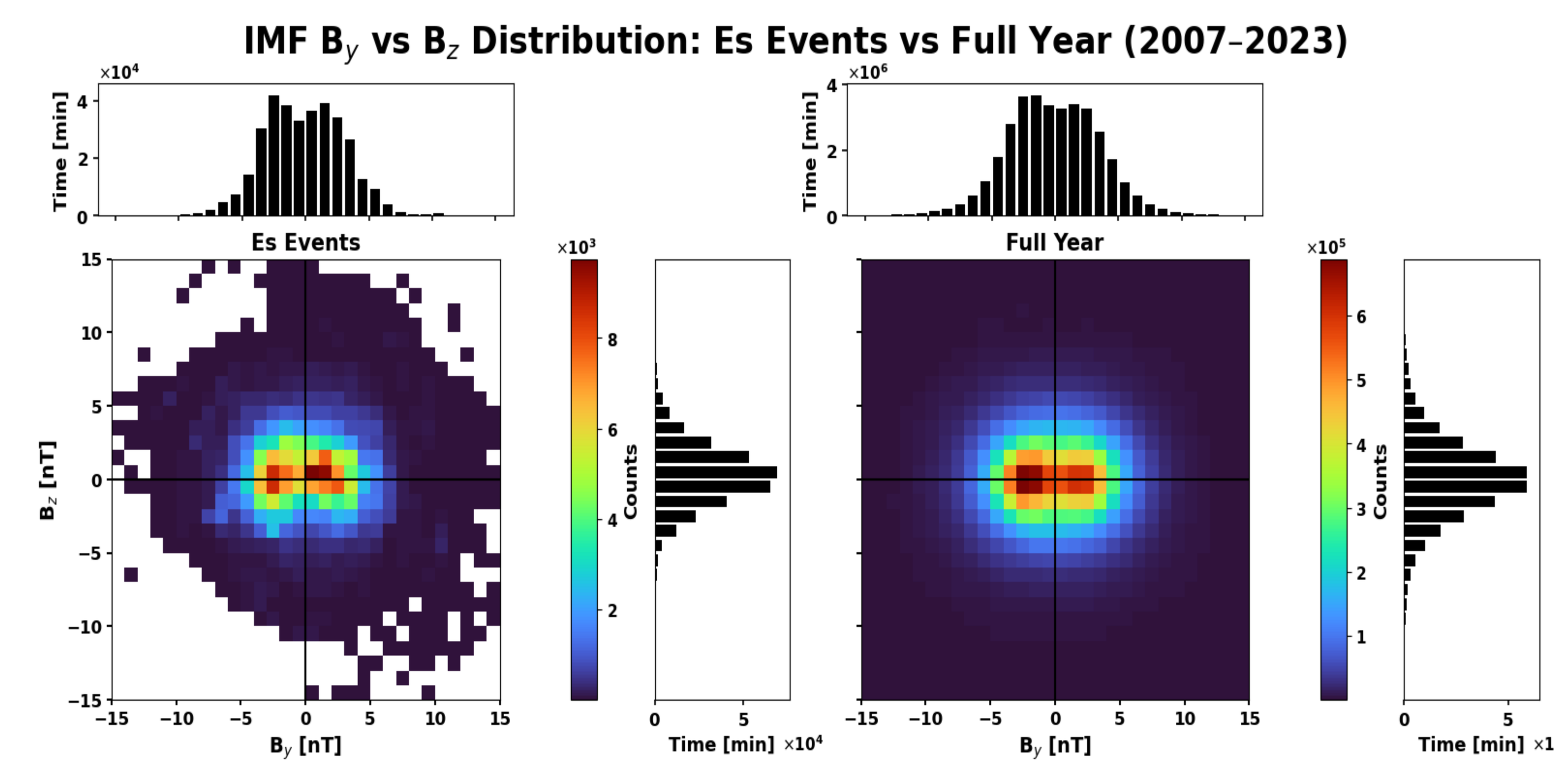

Figure 7: Joint distributions of IMF B_y and B_z during Es events (left) and full-year data (right) from 2007–2023. Marginal histograms and colorbars show duration and count intensity, revealing differences in IMF orientation. The pixel size in the B_yB_z plane is 1nT×1nT. In the color scale, white indicates zero value, and the colors from blue via yellow and green to red cover the range from small nonzero values to maximum.

- At Poker Flat (65° N, auroral zone, 2007-2023):

→ **No consistent preference for the IMF B_y and B_z quadrants.**

→ IMF and Es relationships may be latitude-dependent.

7. Conclusion

➢ **Es occurrence pattern**

High-latitude Sporadic-E layers show seasonal trends consistent with mid- and low-latitude studies, with the highest concentrations in summer and a smaller secondary peak during winter.

➢ **IMF influence**

The effect of IMF orientation on Es formation likely depends on factors such as geomagnetic latitude and background electric field configuration.

8. Future Work

We aim to investigate whether F-region plasma drifts, background electric fields, and solar cycle variability influence high-latitude Es formation.

9. References

1. Haldoupis, C. (2011). A Tutorial Review on Sporadic E Layers. In: Abdu, M., Pancheva, D. (eds) Aeronomy of the Earth's Atmosphere and Ionosphere.
2. Kirkwood, S., Nilsson, H. High-latitude Sporadic-E and other Thin Layers – the Role of Magnetospheric Electric Fields (2000).
3. Voiculescu, M., Aikio, A. T., Nygrén, T., and Ruohoniemi, J. M.: IMF effect on sporadic-E layers at two northern polar cap sites: Part I – Statistical study (2006).