An examination of HF radar observations during a super geomagnetic storm

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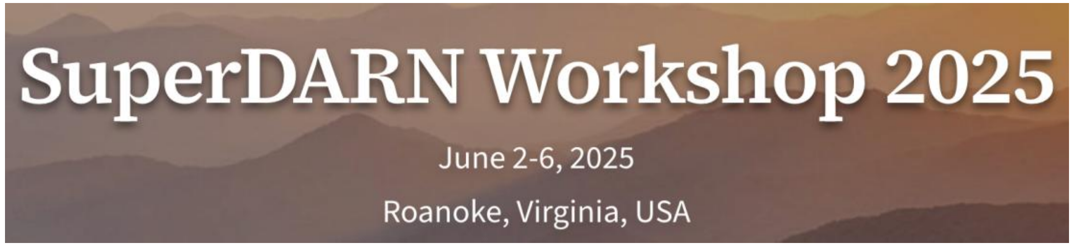
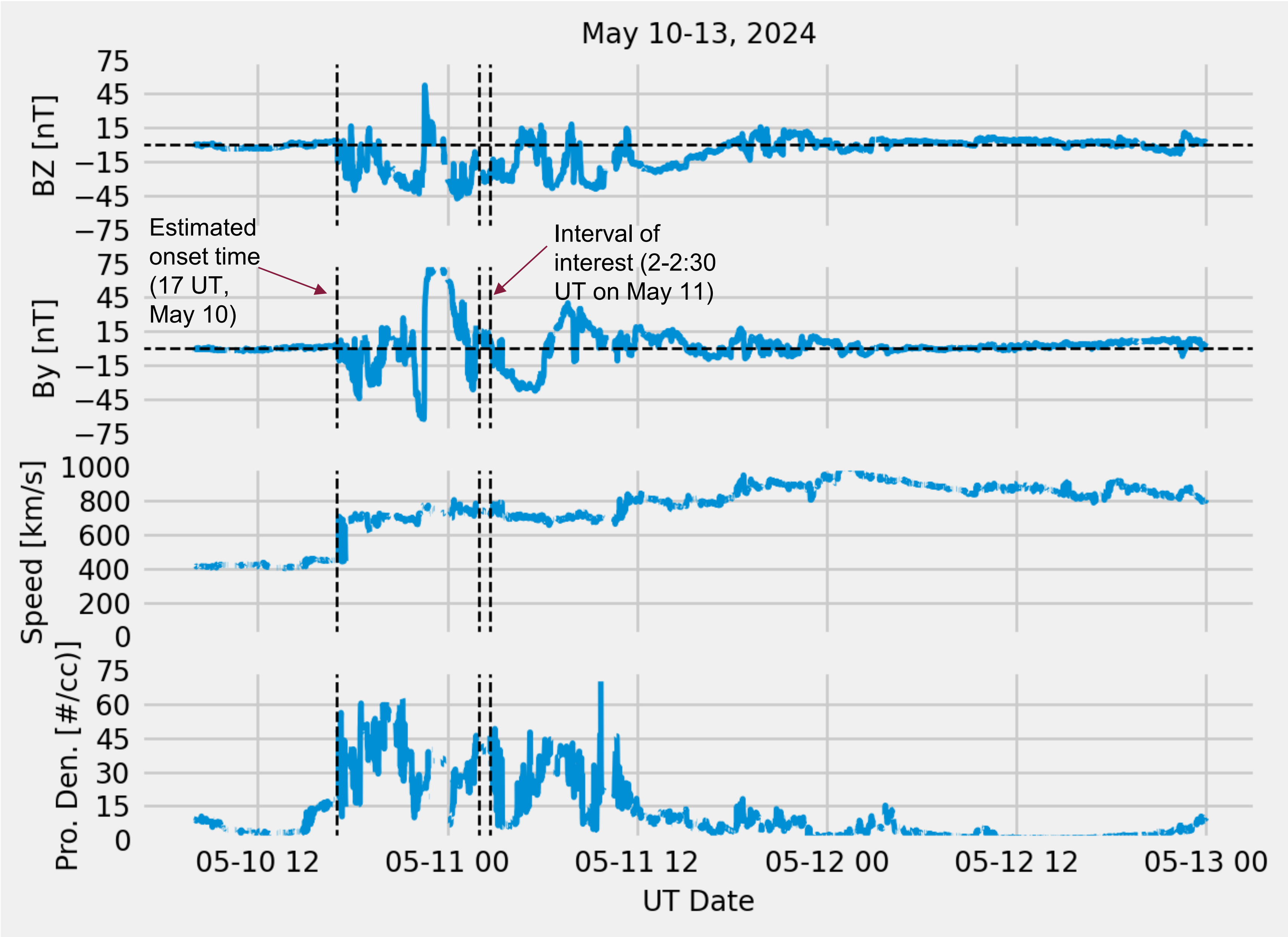


IMF and Solar Wind

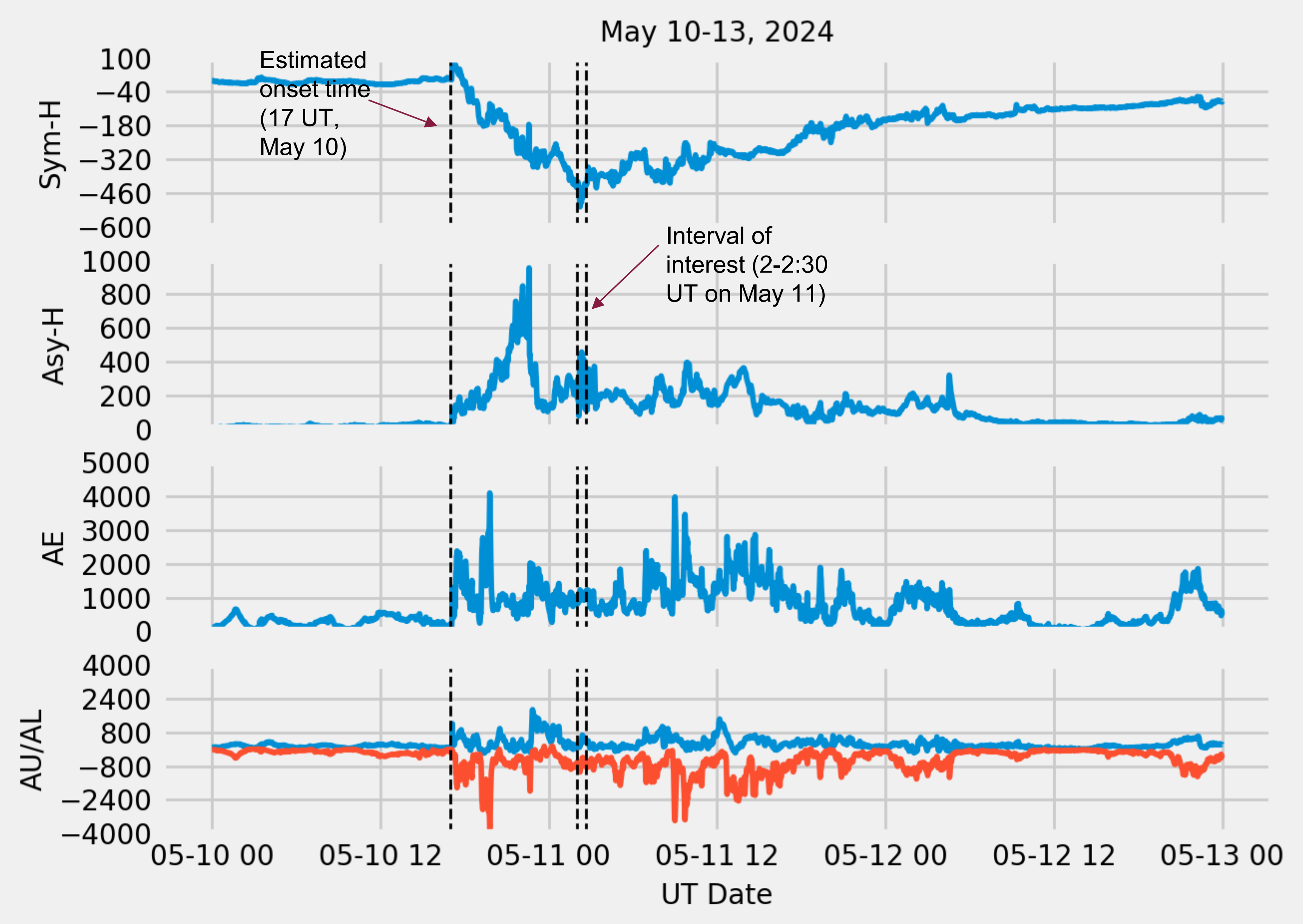
3 days of IMF and Solar wind data from May 10 to May 13, 2024.

The initial phase of the storm started ~17 UT on May 10, when IMF magnitude and SW velocity both increased sharply.



Geomagnetic Activity

SSC feature was observed at ~17 UT reaching 80 nT magnitude and was followed by a main phase that lasted ~9 hours until a minimum in SymH near -500 nT was reached at 02:00 UT on May 11.

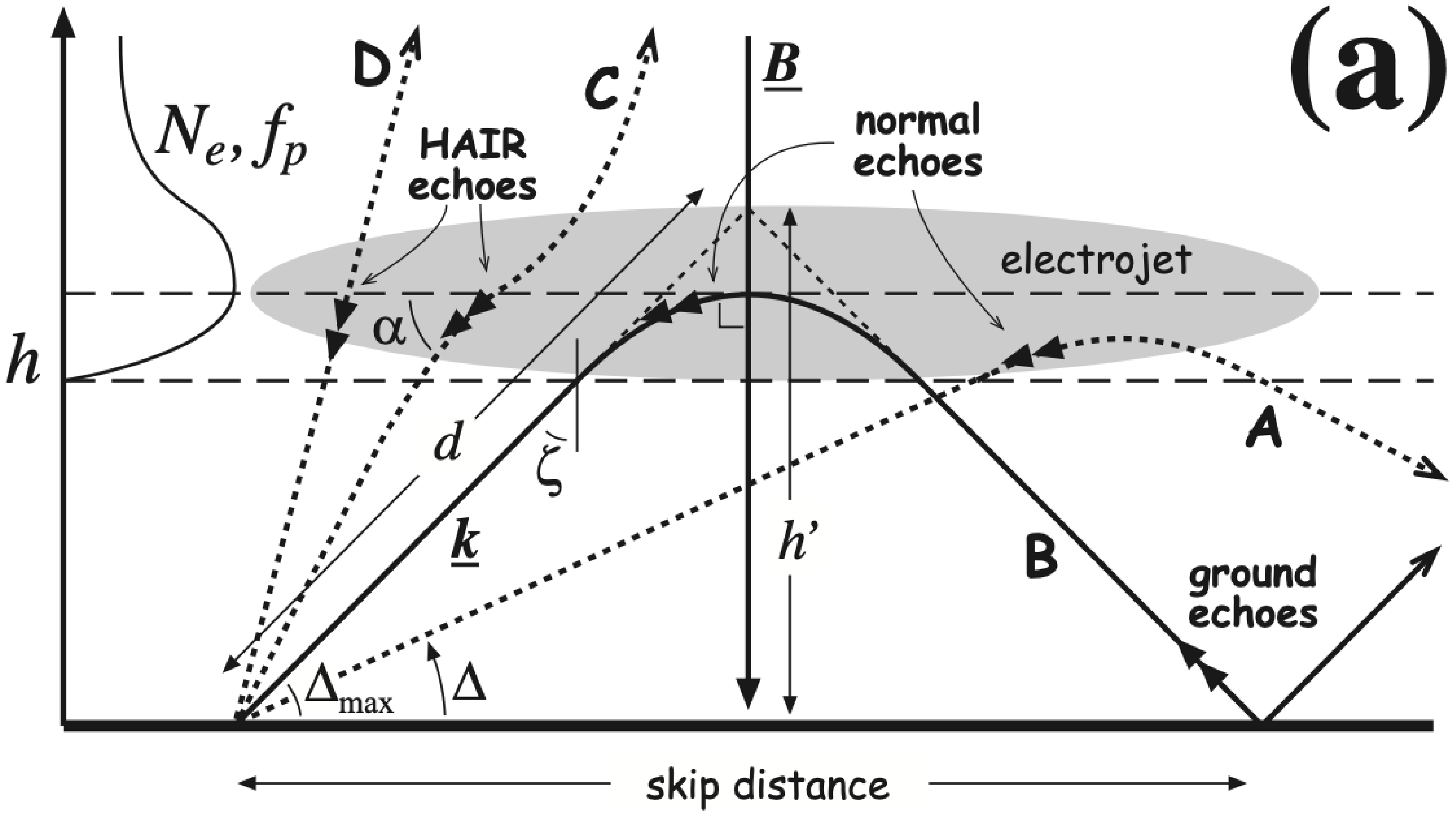


Disturbed Time SuperDARN Backscatter

- E-region echoes typically originate in the auroral electrojets – a region full of irregularities.

- Previous studies such as *Milan et al., [2004]; Ponomarenko et al., [2016]; St.-Maurice et al., [2019]* presented observations of large aspect angle backscatter in SuperDARN.

- *Foster et al., [1988]* and *Rietveld et al., [1991]* discussed the possibility of high aspect angle backscatter during red aurora.



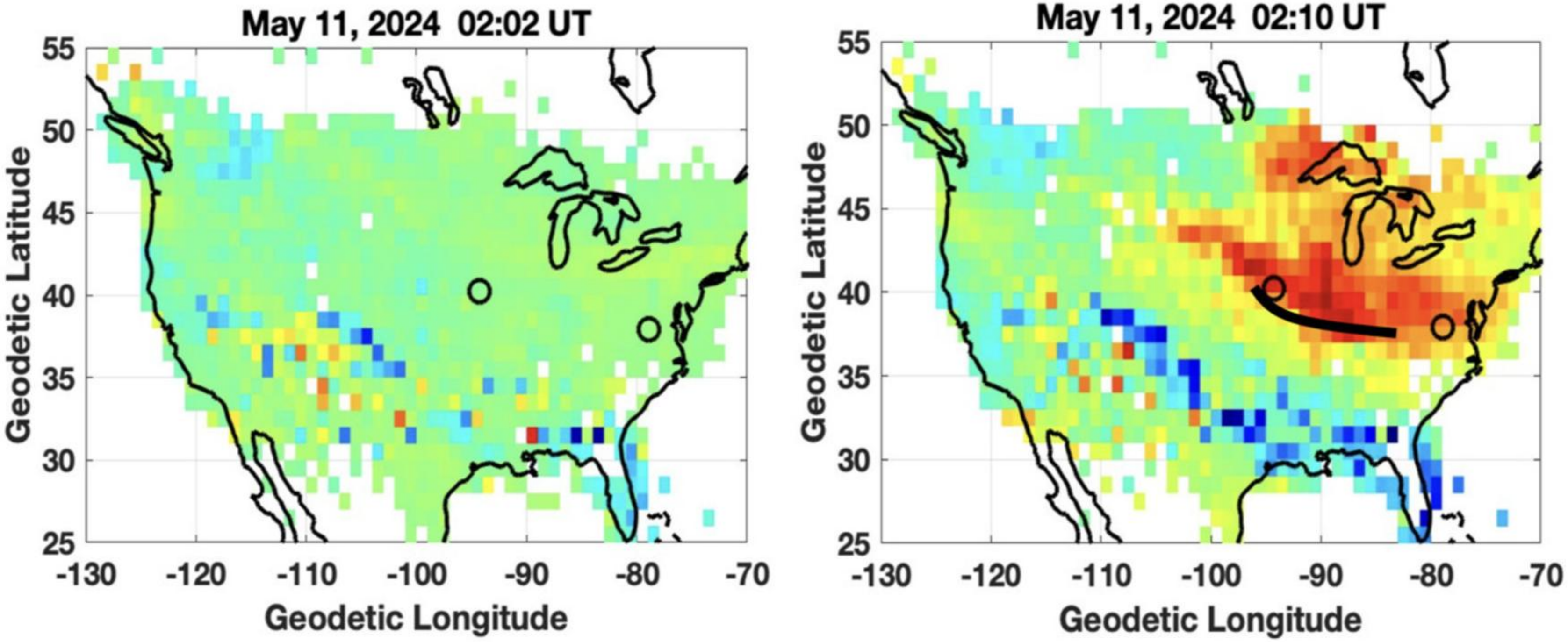
Milan et al., [2004]

SuperDARN response to the extreme aurora

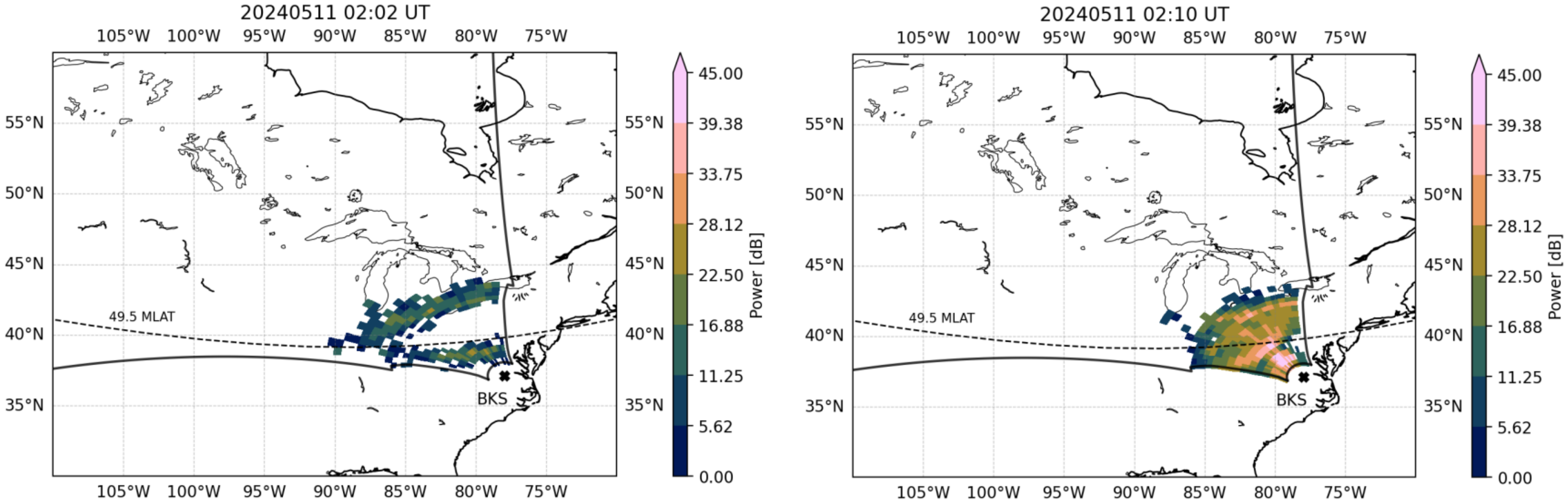
The intense soft electron precipitation event reported by *Foster et al., [2024]* was in the field-of-view of the BKS radar.

The observations before the onset of red aurora at 2:02 UT were typical of nightside observations with E-region ionospheric backscatter.

By 2:10 UT, with the arrival of the precipitation, intense ionospheric backscatter blanketed the entire near-range region.



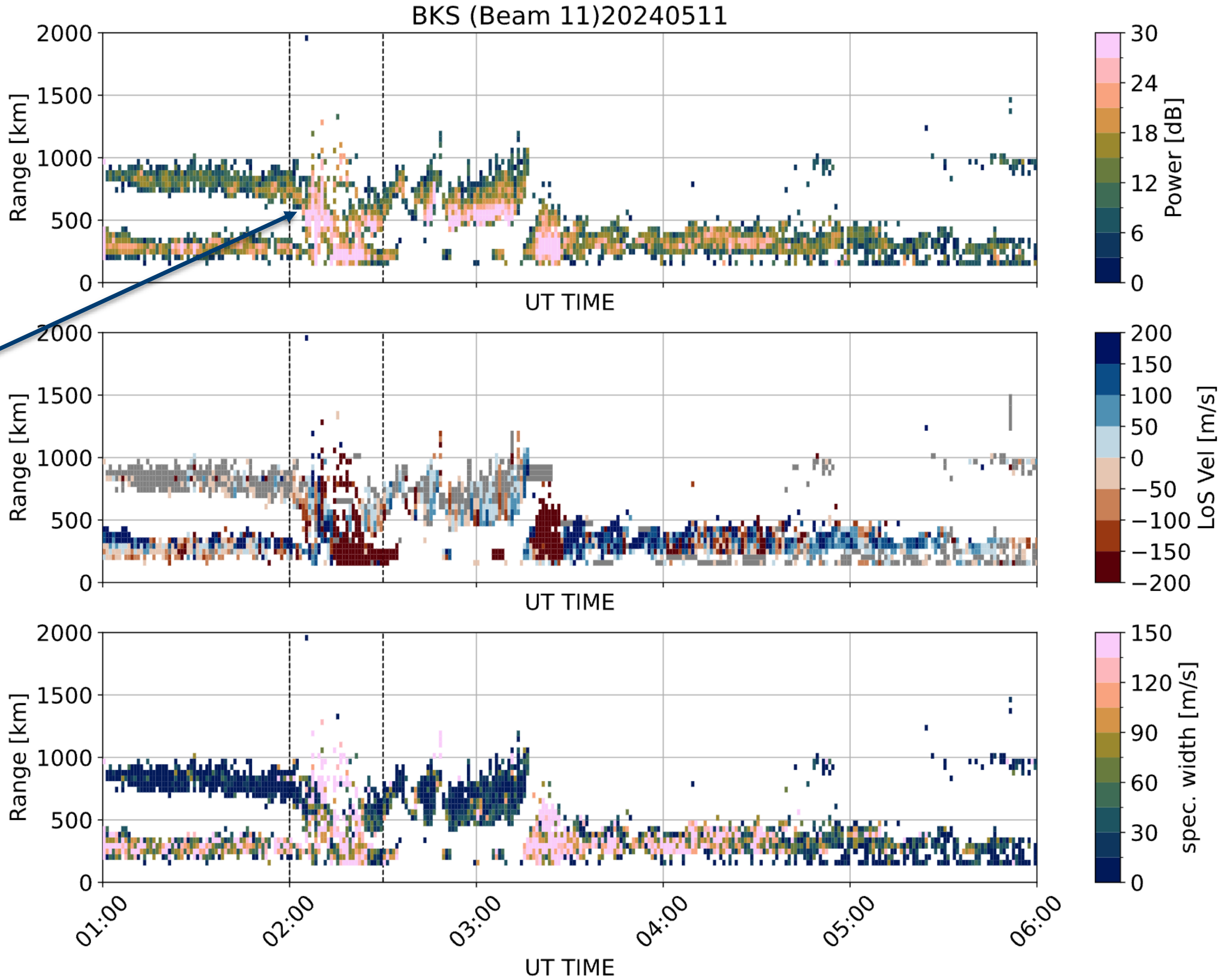
Foster et al., [2024]



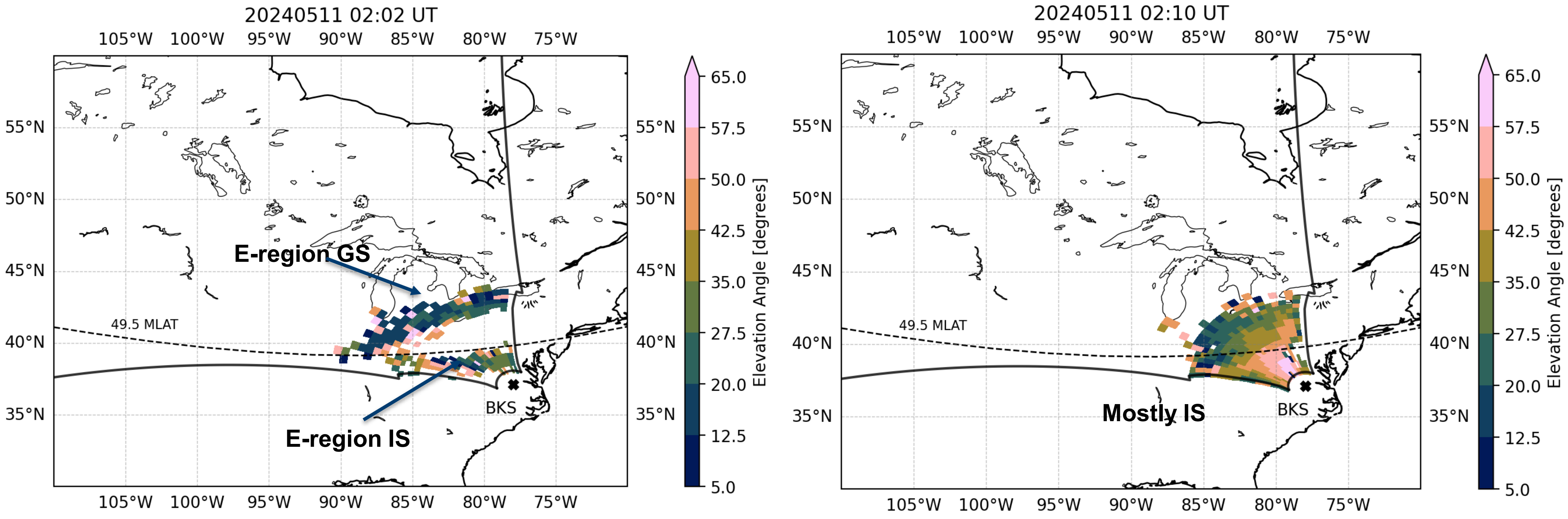
Change in BKS backscatter pattern

Ionospheric and ground scatter were observed between 1 and 2 UT.

Ground scatter was replaced by strong ionospheric scatter at closer ranges by 2:10 UT.



Elevation and Virtual height characteristics of the backscatter



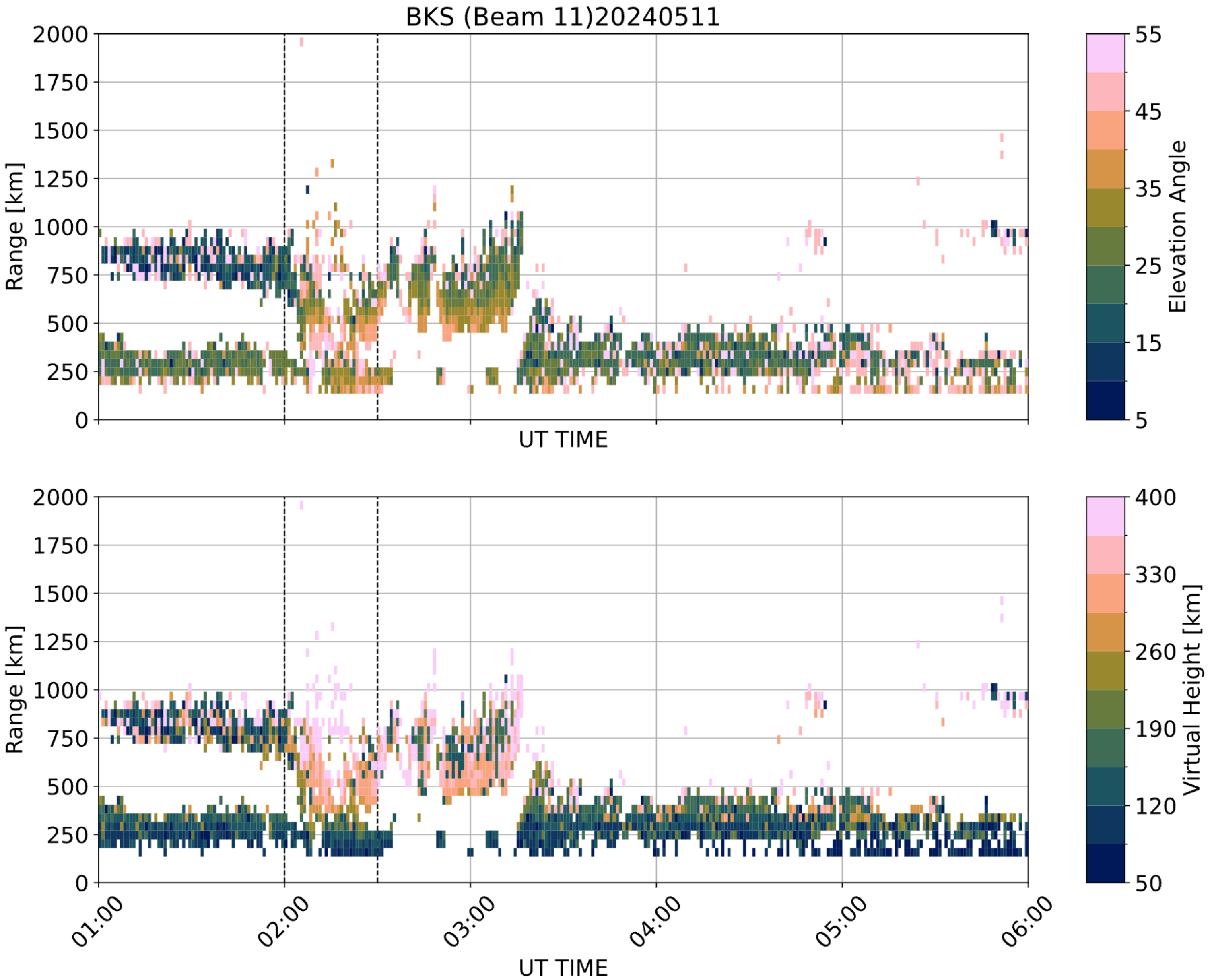
Backscatter from a broad range of elevation angles (20°-55°) than normal, including very high one's (≥ 50°), is observed during the interval. There is an overall trend for elevation angle to drop with range. The high elevation angle backscatter corresponds to unusually high virtual heights (>250-300 km) at near ranges.

Elevation and Virtual height characteristics of the backscatter

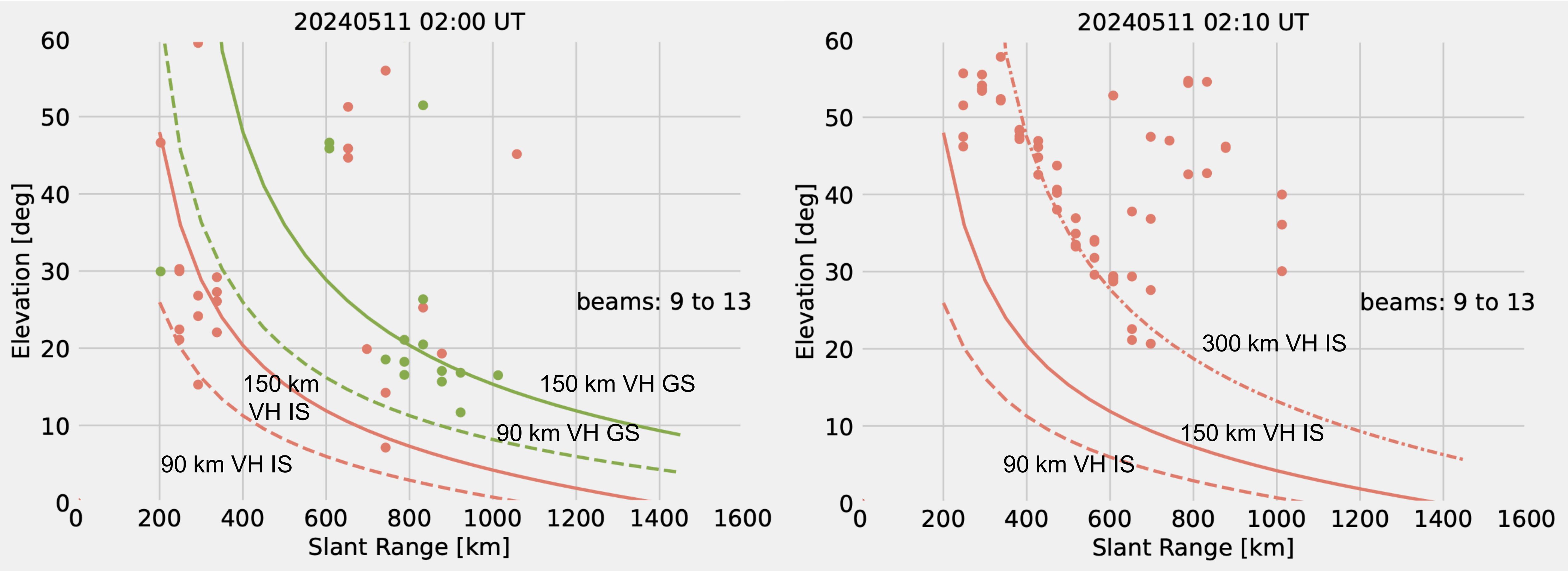
A new population of backscatter with very high elevation angles reaching 55^{o} is observed during the interval after 2 UT.

The corresponding virtual height of the echoes reaches 300-350 km.

High elevation/virtual height ionospheric backscatter is unusual at these ranges.



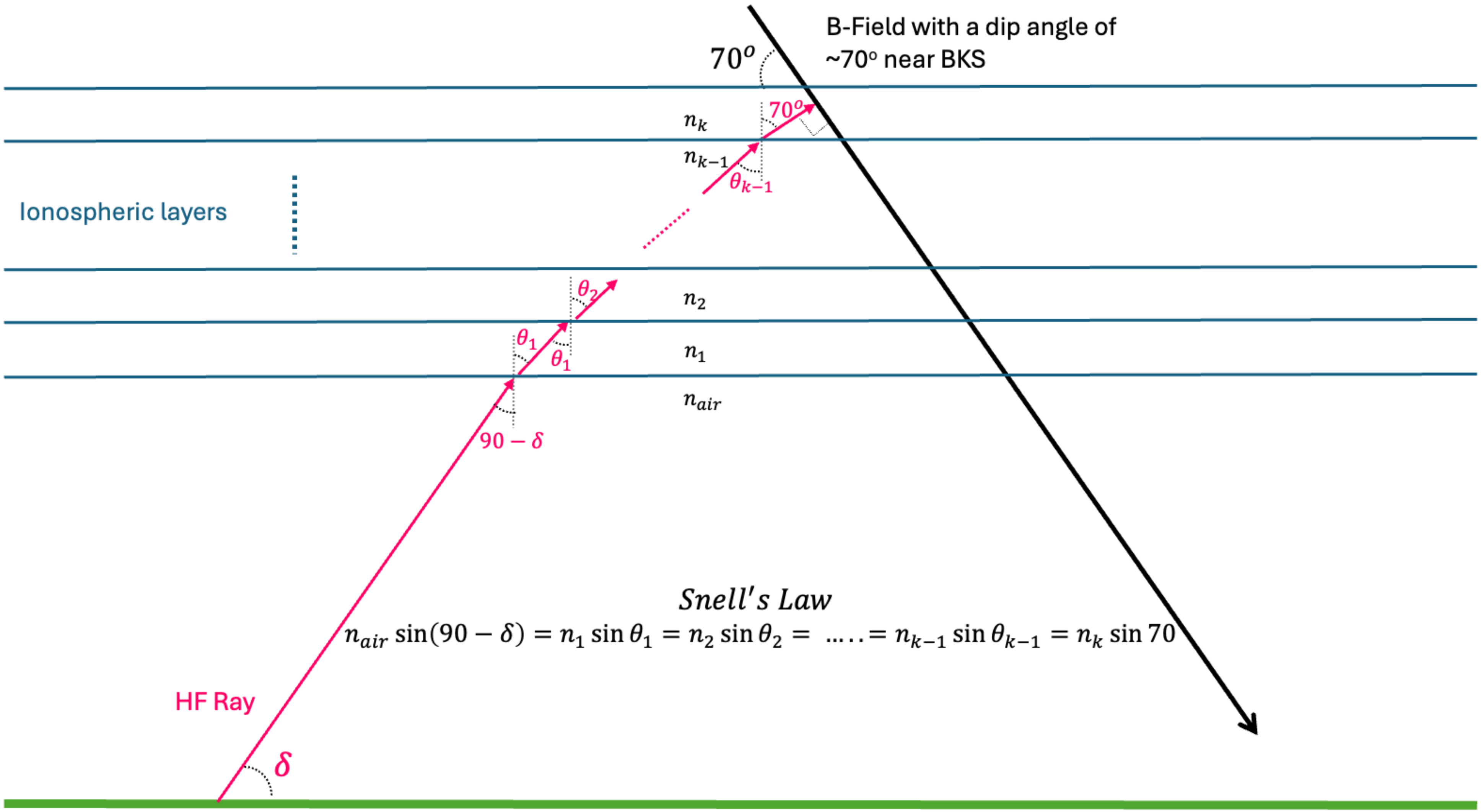
Elevation and Virtual height characteristics of the backscatter



Prior to the event, both IS and GS are observed between 90 and 150 km virtual heights predominantly.

During the precipitation event, IS is observed at 300 km virtual height predominantly.

Estimating Ne in the scattering volume



$$n_{air} cos\delta = n_k \sin 70\,;\, n_{air}=1$$

$$n_k = \sqrt{1 - \frac{81 N_e^K}{f^2}}\;;f = 10\,MHz$$

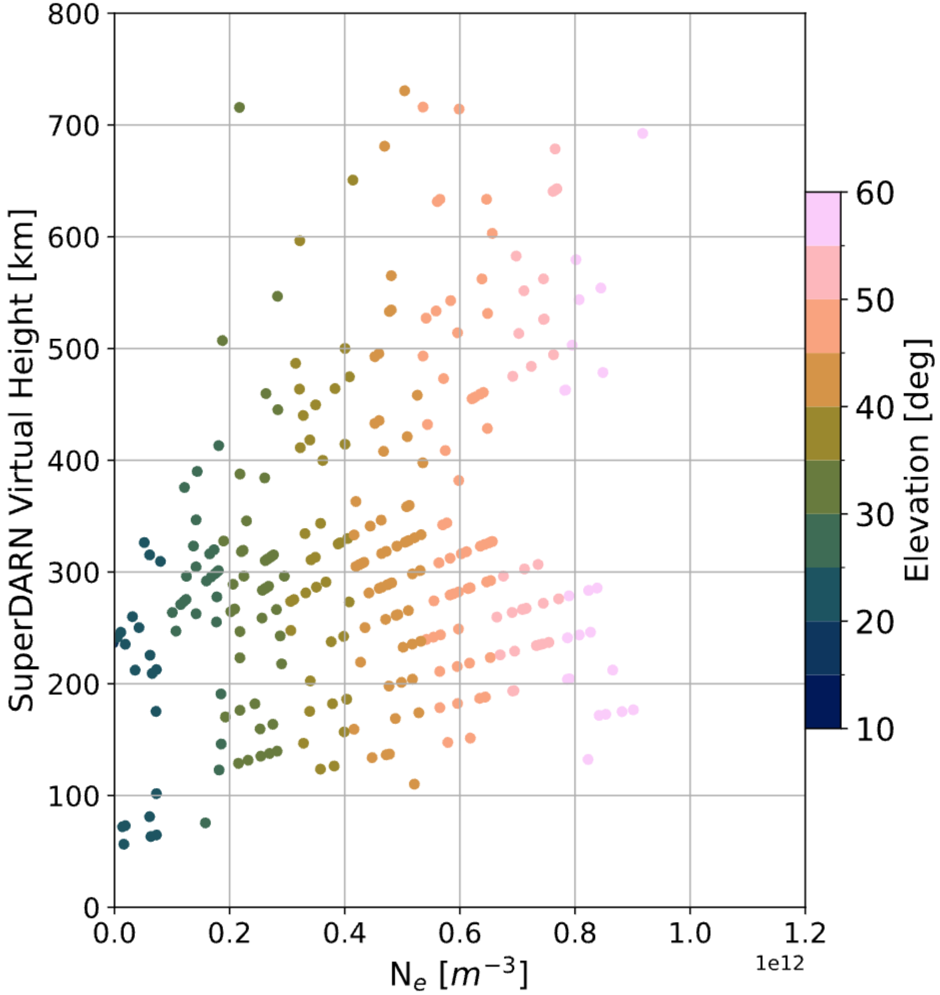
$$N_e^K = \left(\frac{1 - 1.132cos^2\delta}{81}\right) x\; 1e14\; m^{-3}$$

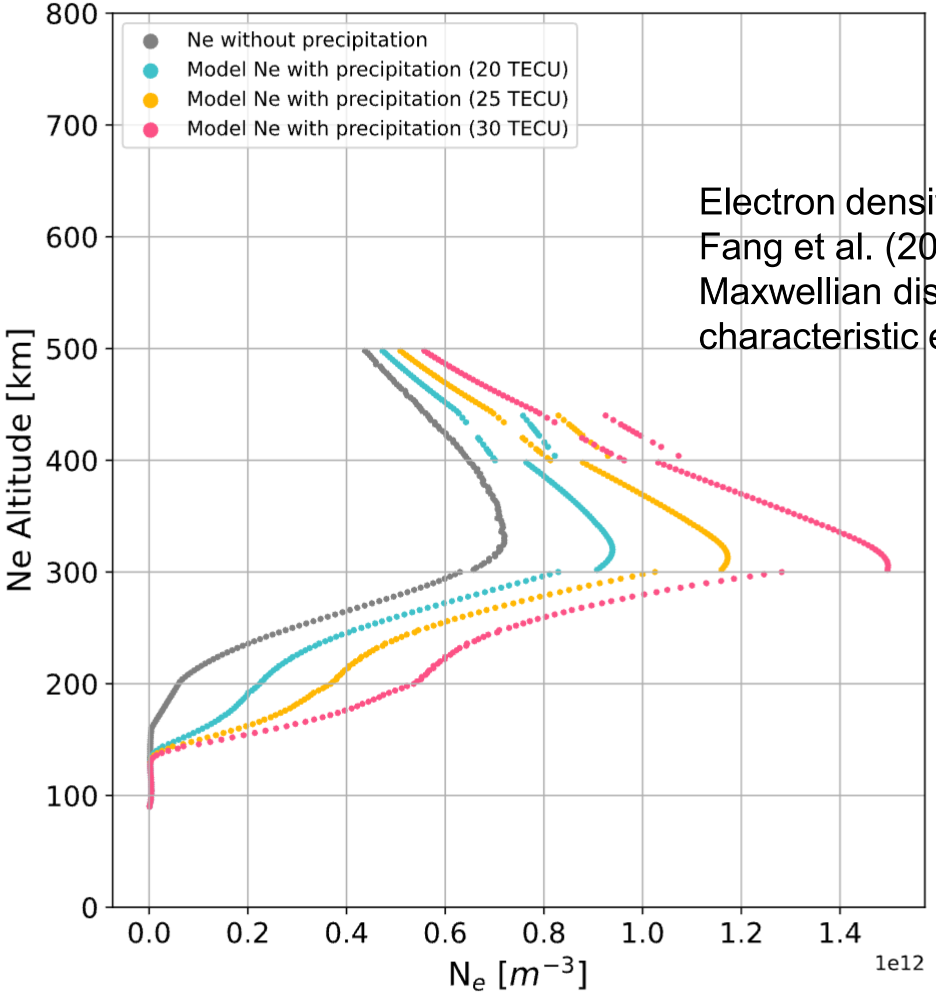
$$H_{Virtual}^K = R_s sin\delta$$

This is a simplified version of the *Greenwald et al., [2016]* approach.

Using Snell's Law, we can estimate the electron density of the layer (here kth layer) where the ray turns perpendicular to the B-field. The virtual height of the kth layer can be estimated from slant range and elevation angle.

Ne variability in the scattering volume

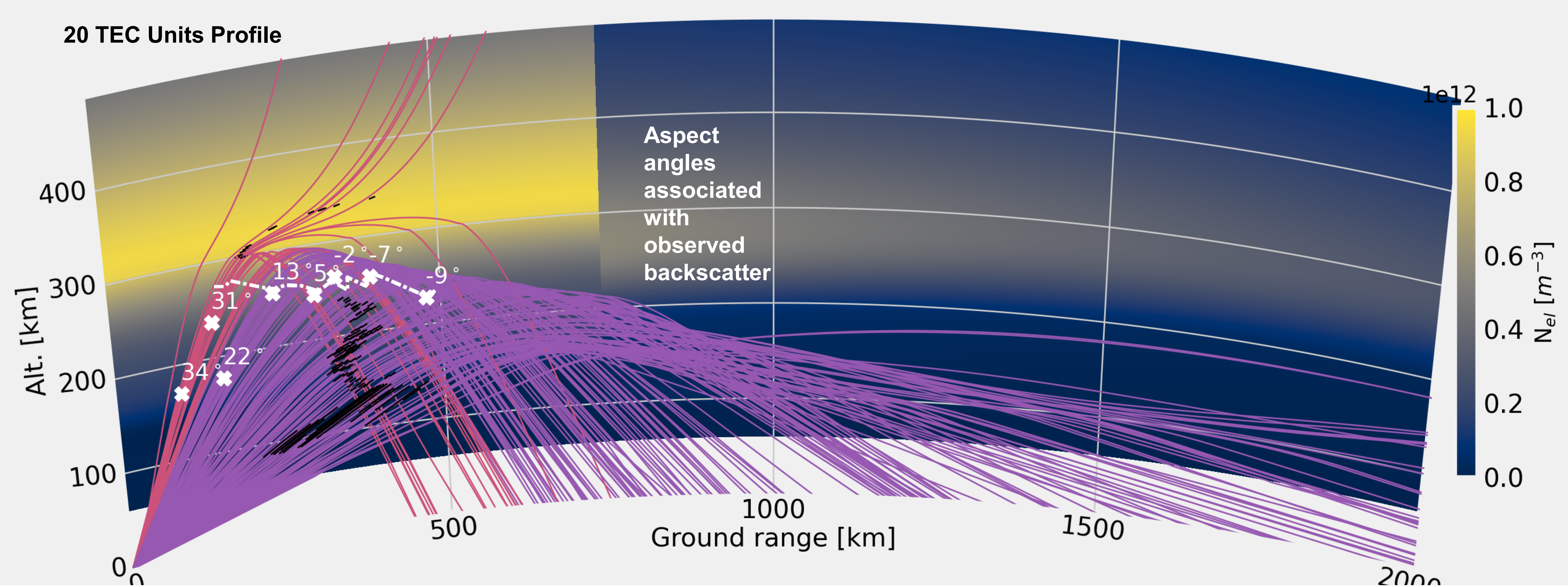




Electron density profiles using the Fang et al. (2010) model and a Maxwellian distribution, for a 200 eV characteristic energy.

Since the backscatter is observed over a broad range of elevation angles, the electron densities also cover a broad range over a small virtual height region.

Ray-tracing through the *Fang et al., [2010]* profiles



Ray-tracing through the *Fang et al., [2010]* profile suggests that the backscatter likely is originating between 250 and 300 km altitude, and also suggests that the denser ionosphere can produce ground backscatter.

Conclusions

- Extremely intense and brief low-energy precipitation associated with a substorm break up was observed during the May 11, 2024 super storm over the eastern half of the United States.
- This intense precipitation event was located in the field-of-view of the BKS SuperDARN radar, which observed strong ionospheric backscatter in the near-to-middle ranges collocated with the precipitation. This backscatter spanned a broad range of elevation angles, including unusually high ones.
- Elevation and virtual height characteristics suggest that the backscatter is observed at much higher altitudes than typically expected at these close ranges.
- One possibility is that strong soft electron precipitation and red aurora can generate small-scale irregularities that are not necessarily field-aligned which can produce intense radar backscatter.

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Supplementary material about calibrating the interferometer

Figure-s1: BKS interferometer – "tuned" tdiff

- Slant Range vs Elevation angle plot for May - Nov 2024. Default "tdiff" of 332 ns is used here.
- Ionospheric scatter corresponds to nighttime freq (11-12 MHz), and ground scatter to daytime frequencies (14-15 MHz).

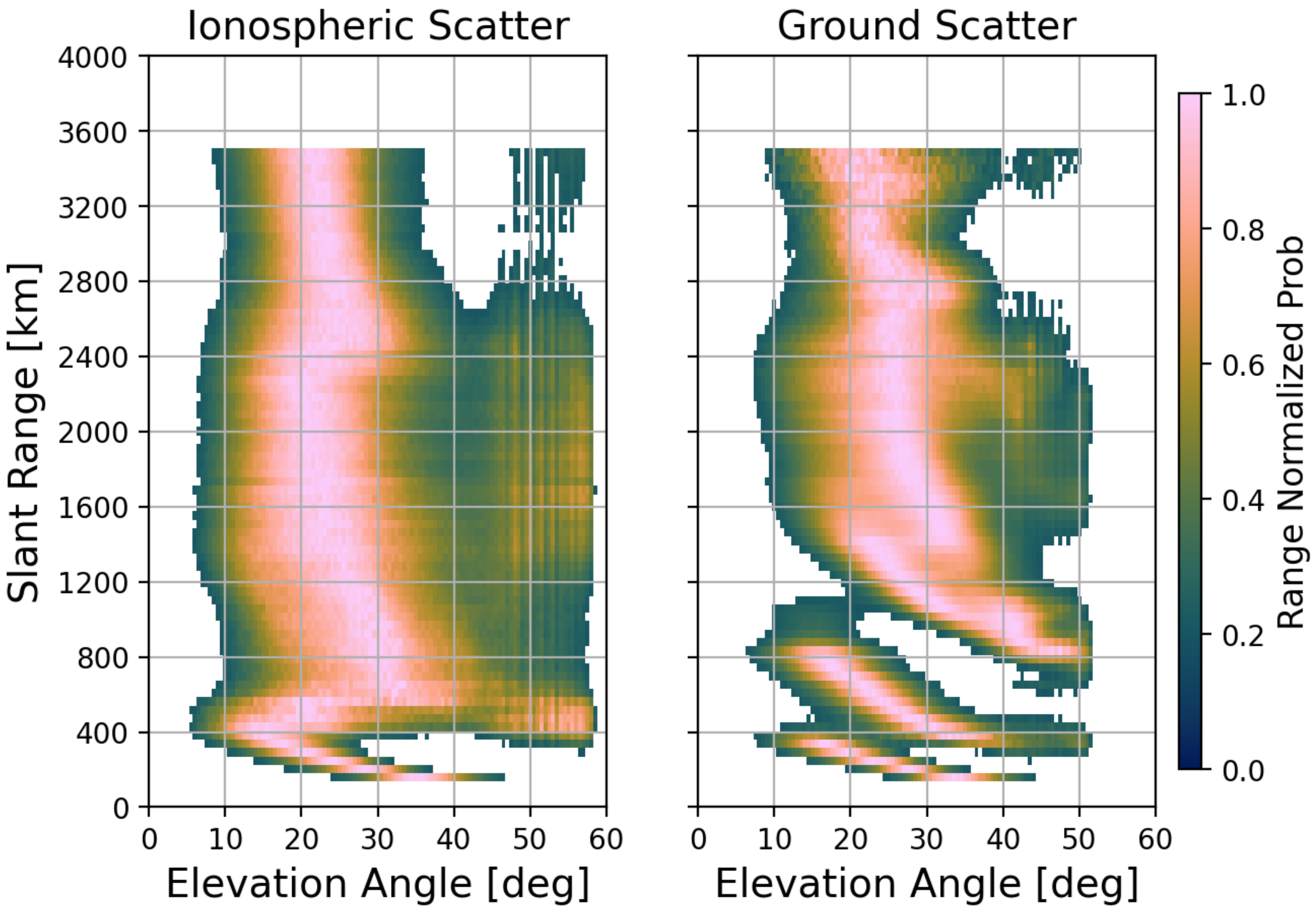
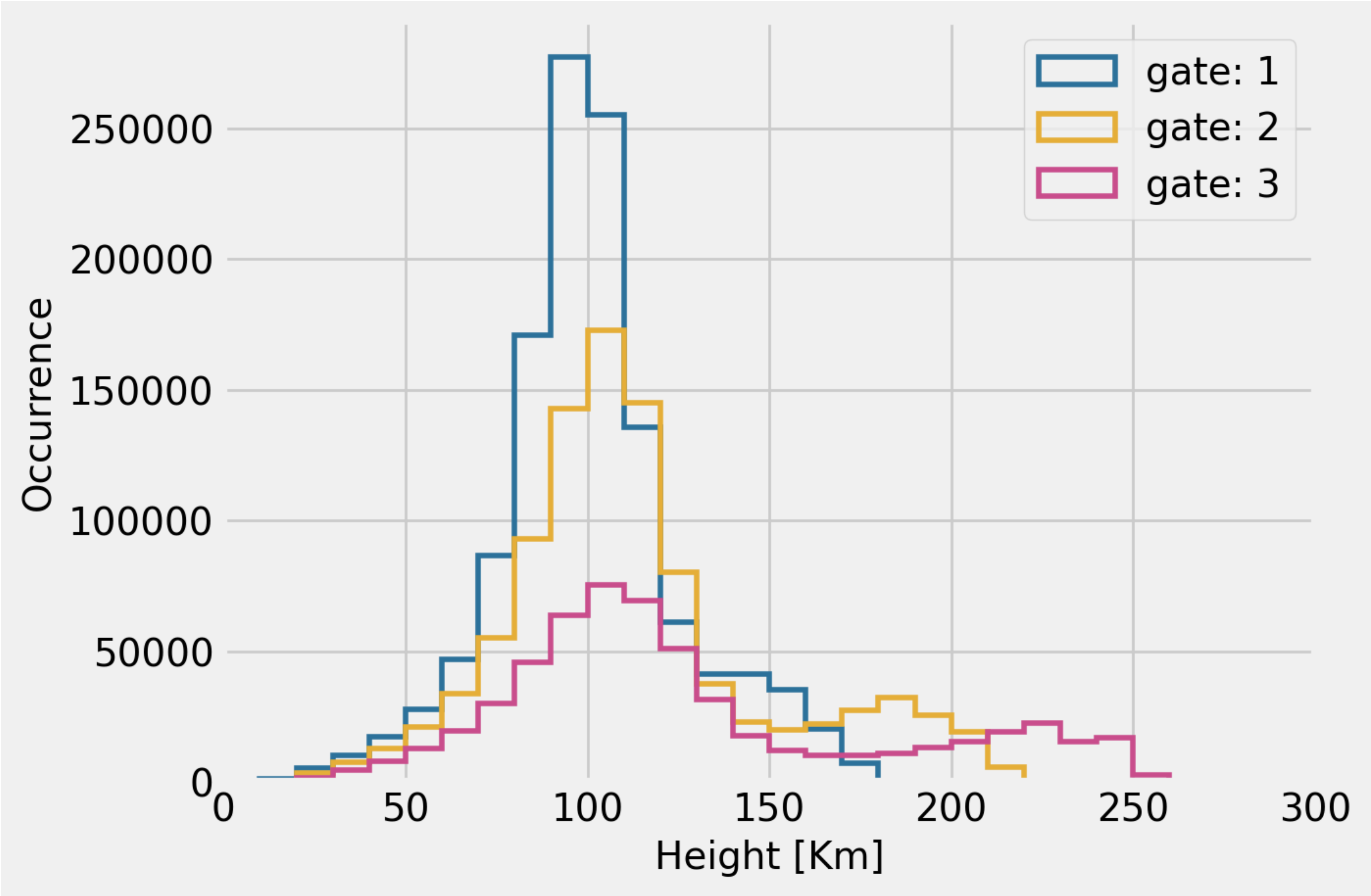


Figure-s2: Tuning using meteor echoes and/or VHM!



EXTRA