Determination of Heppner-Maynard boundary: ongoing problems and potential solutions

Pasha Ponomarenko

University of Saskatchewan, Saskatoon, Canada

Outline

- Background on SuperDARN HMB determination
  - Previous efforts on addressing issues with scatter-based HMB
- Mitigation of HF propagation effects using independent HMB determination
  - Kp/Sym-H based HMB
  - Comparative circulation map statistics
- Summary and remaining issues

Heppner-Maynard boundary

- Heppner-Maynard boundary (HMB) represents an equatorward boundary of the Dungey-cycle plasma circulation.
- It is a fixed-shape boundary derive based on satellite measurements of electric field.
- HMB size increases with increasing geomagnetic activity (Kp).

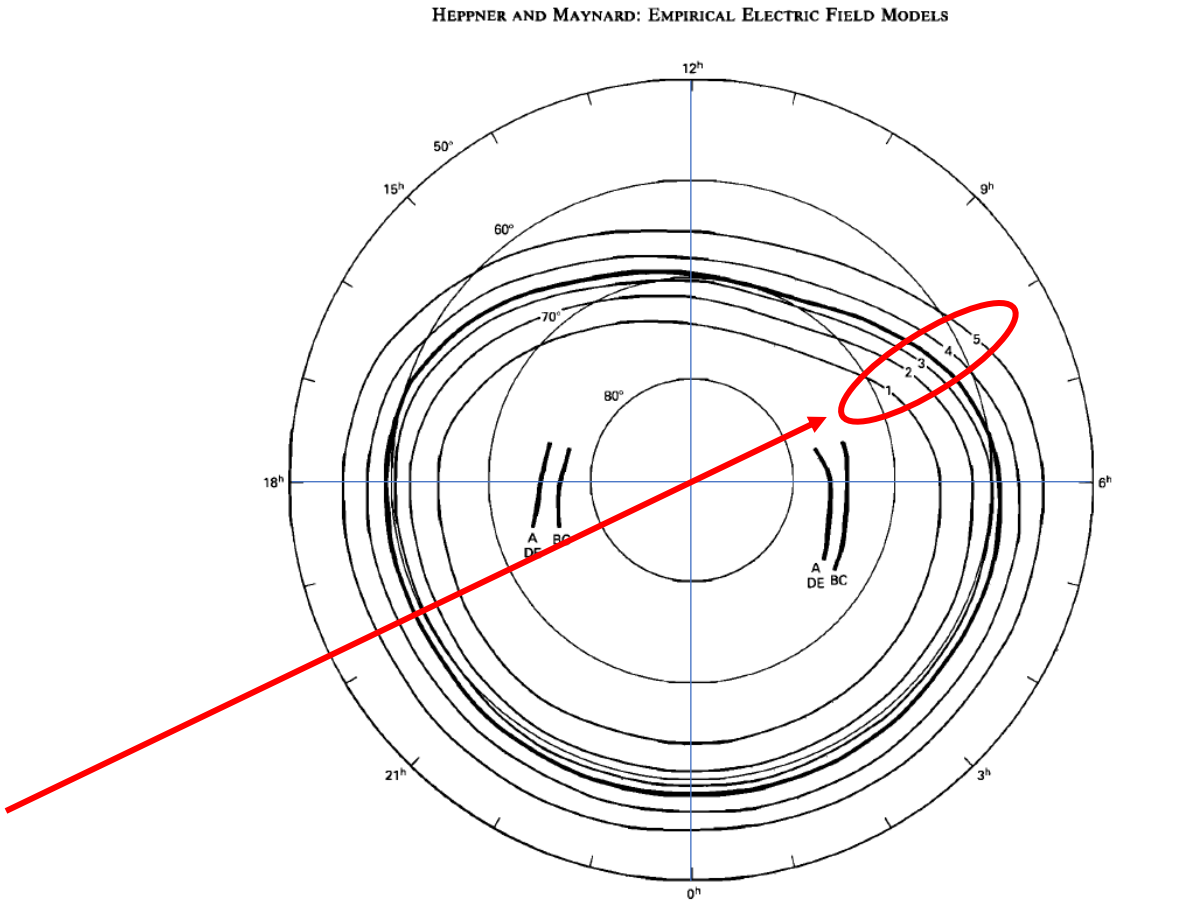


Fig. 10. Median locations of the low-latitude convection boundary for *Kp* values 1 through 5 and the 76-kV models. Average locations of the dawn-dusk polar cap boundary for signatures A, D, E, and H and signatures B, C, and G (all *Kp*'s, see text).

https://doi.org/10.1029/JA092iA05p04467

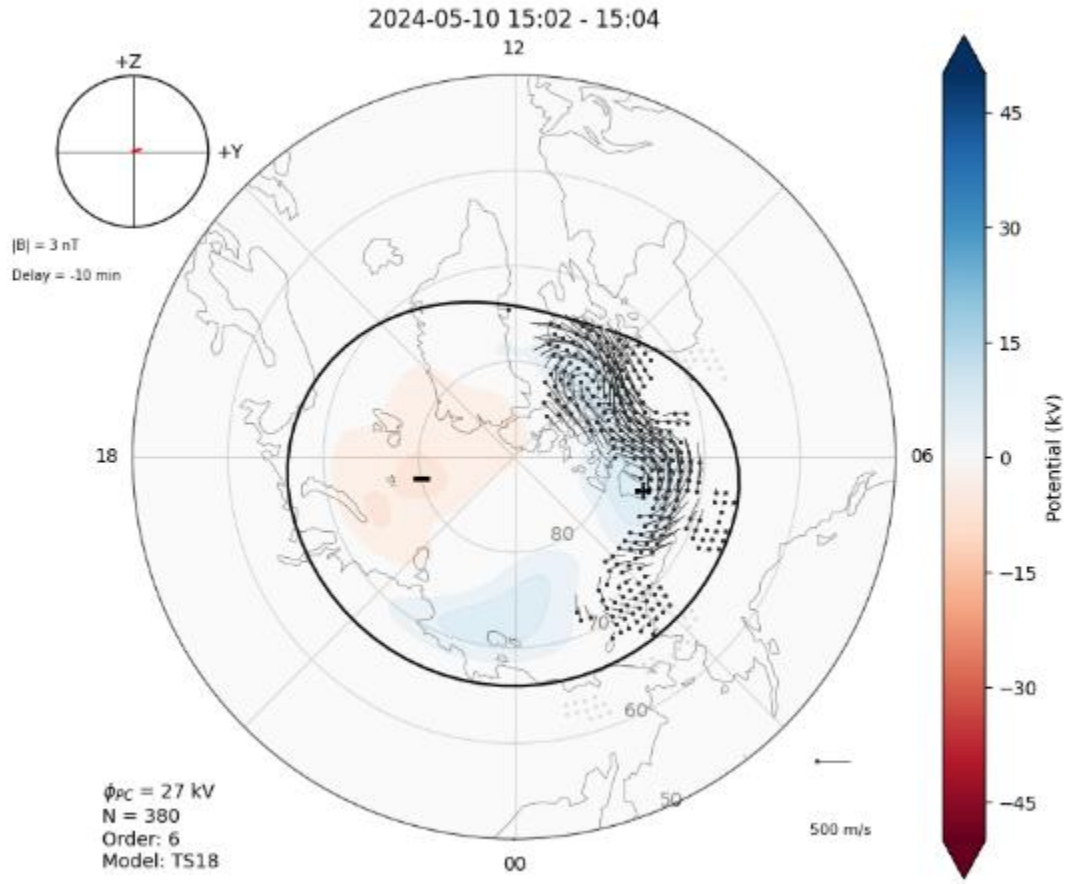
SuperDARN determination of HMB

- Scatter-based HMB:
  - lowest MLAT of sustained ionospheric scatter (≥ 3 grid cells) with the speed exceeding 100 m/s.

  https://doi.org/10.1029/2000JA000171
- Actual and potential issues
  - Propagation effects (limited coverage)

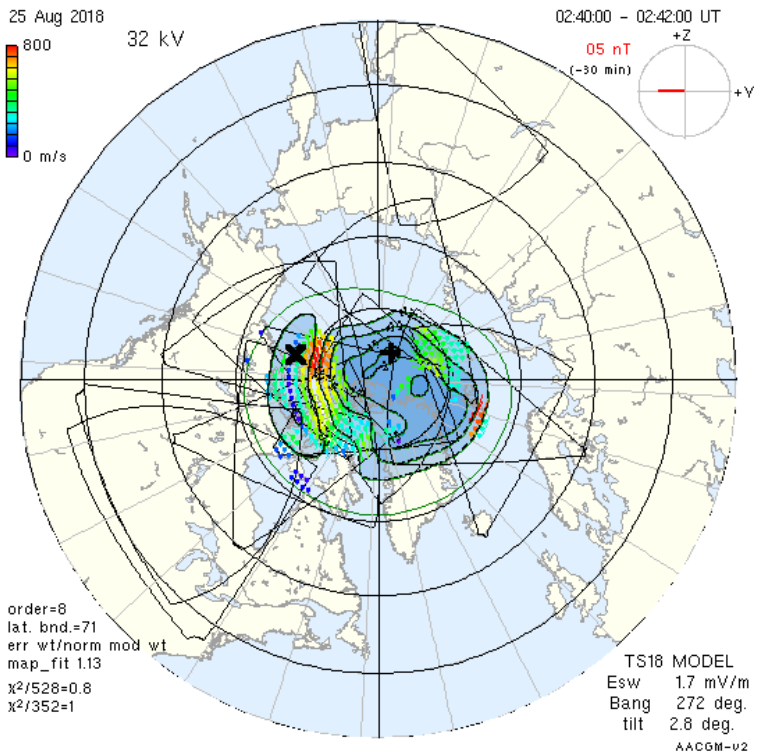
  https://doi.org/10.1029/2019JA027218

  https://doi.org/10.1029/2021JA029559;
  - Data quality (noise/interference);
  - Scatter type misidentification;
  - Accuracy of geolocation;
  - Velocity measurement errors etc.



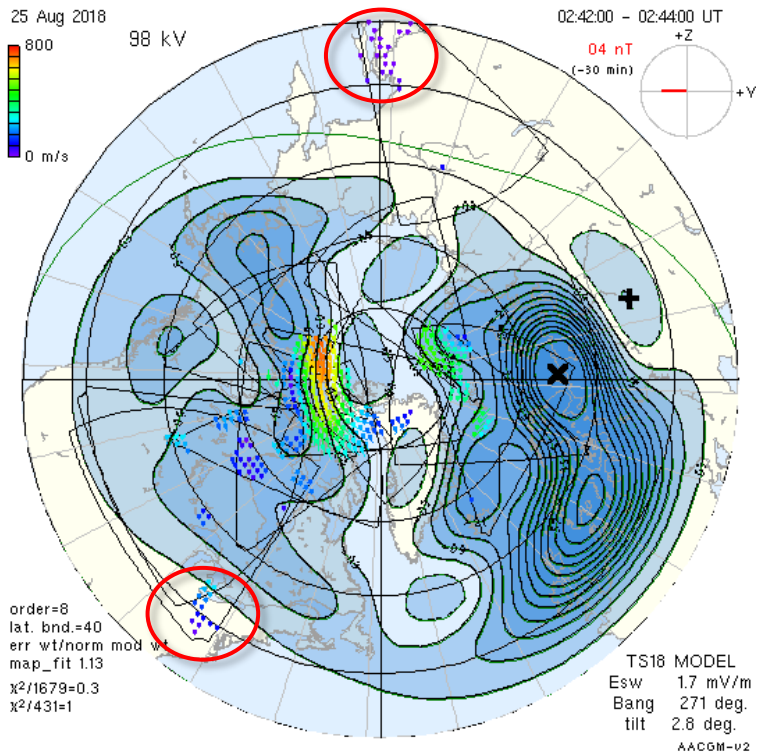
Previous problem: unphysically low HMB latitude

02:40-02:42UT



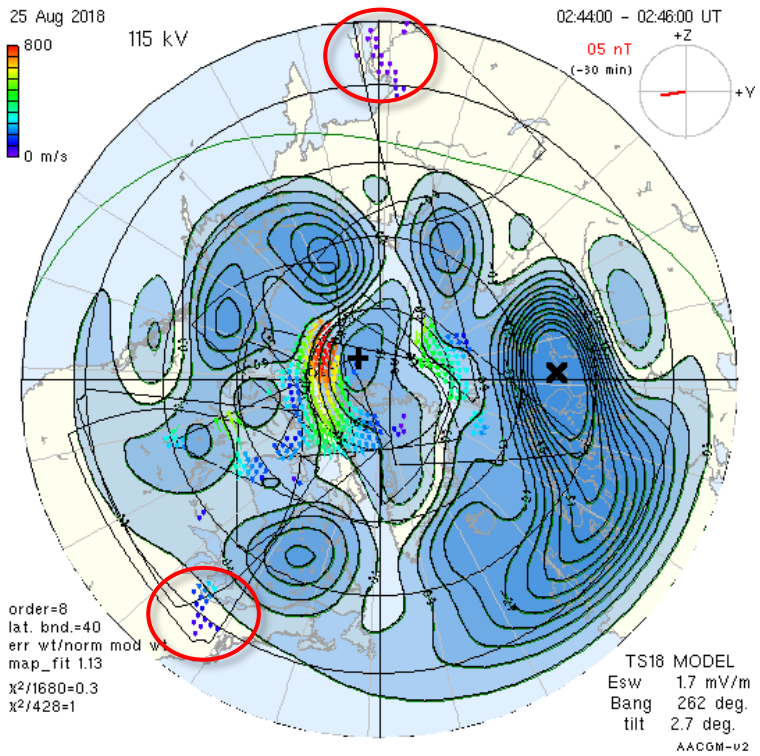
MLAT=71

02:42-02:44UT



MLAT=40

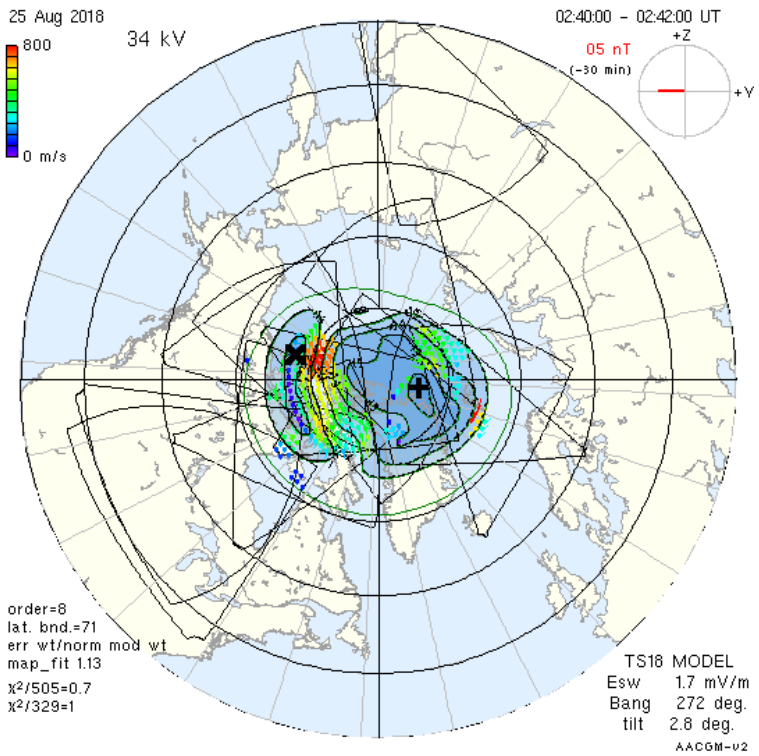
02:44-02:46UT



MLAT=40

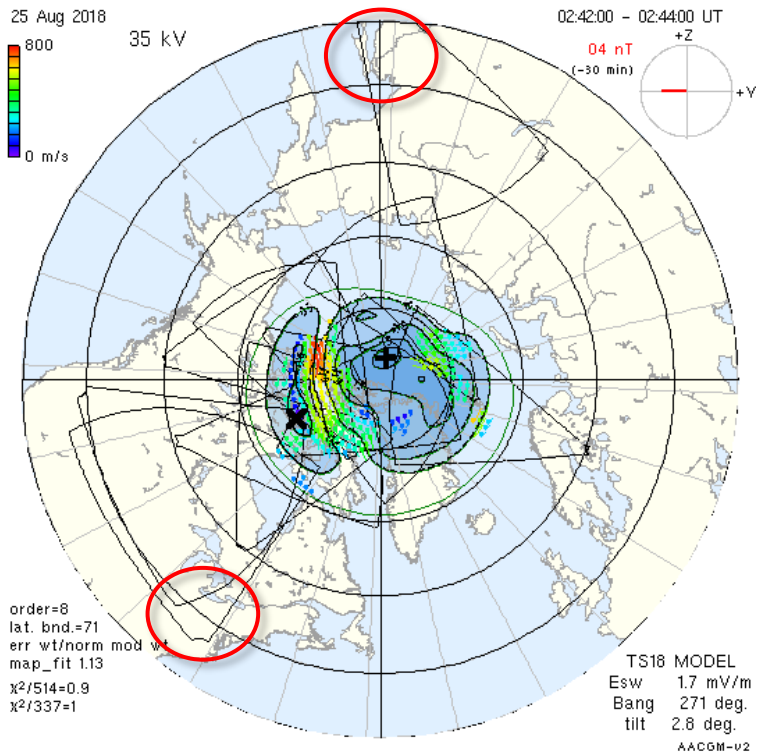
Previous work: Removing isolated data pixels

02:40-02:42UT



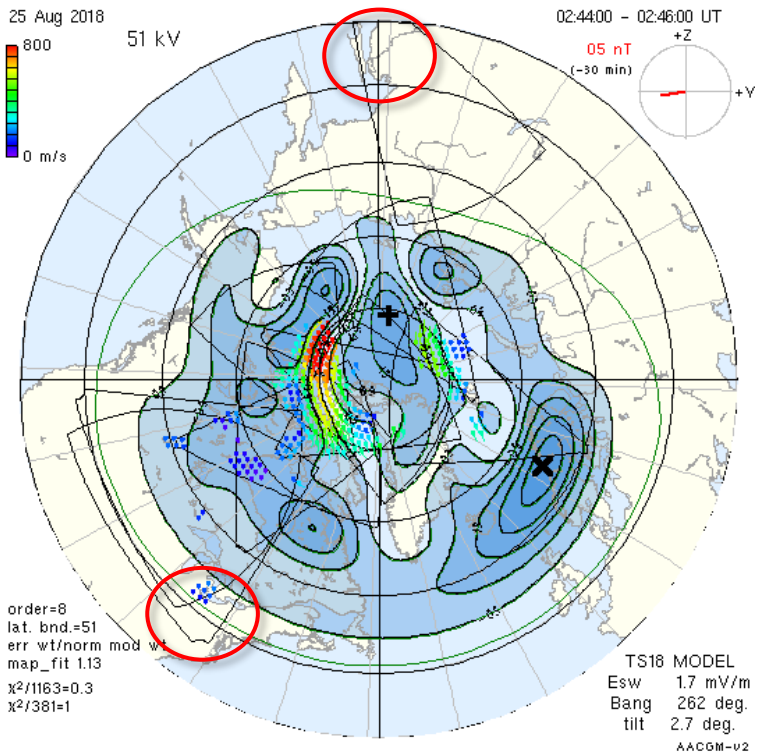
MLAT=71

02:42-02:44UT



MLAT=71

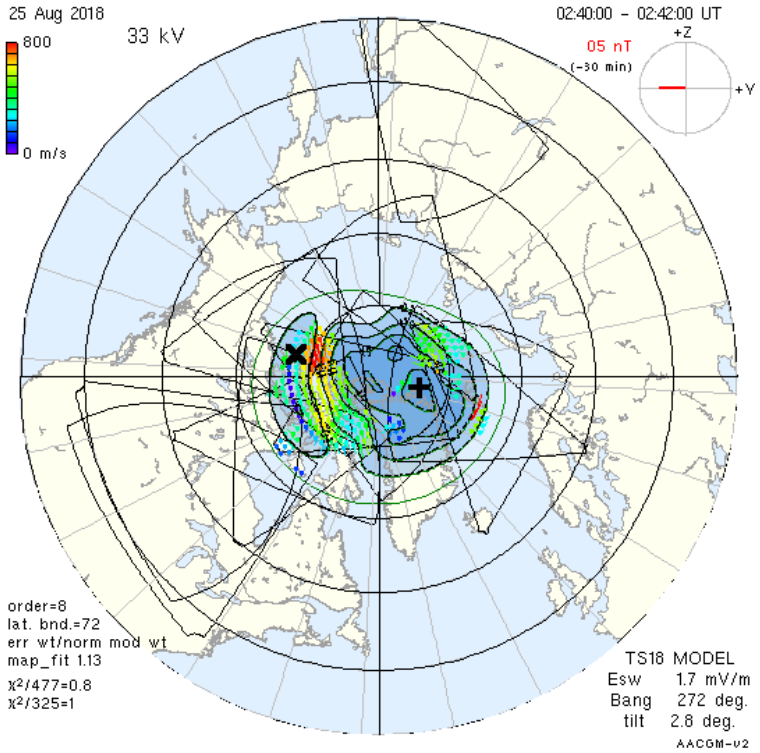
02:44-02:46UT



MLAT=51

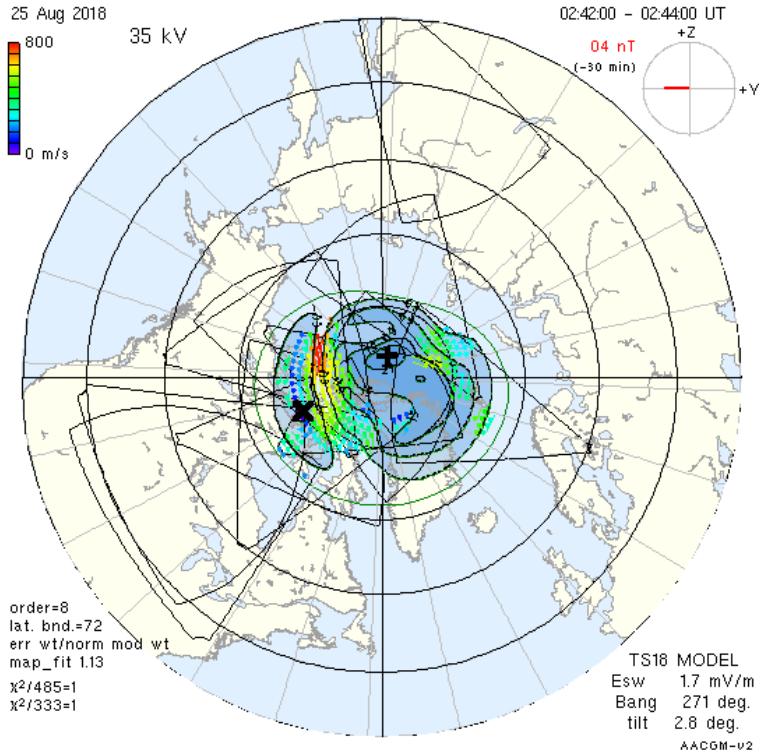
Previous work: Spectral width threshold >100 m/s for filtering out subauroral echoes

02:40-02:42UT



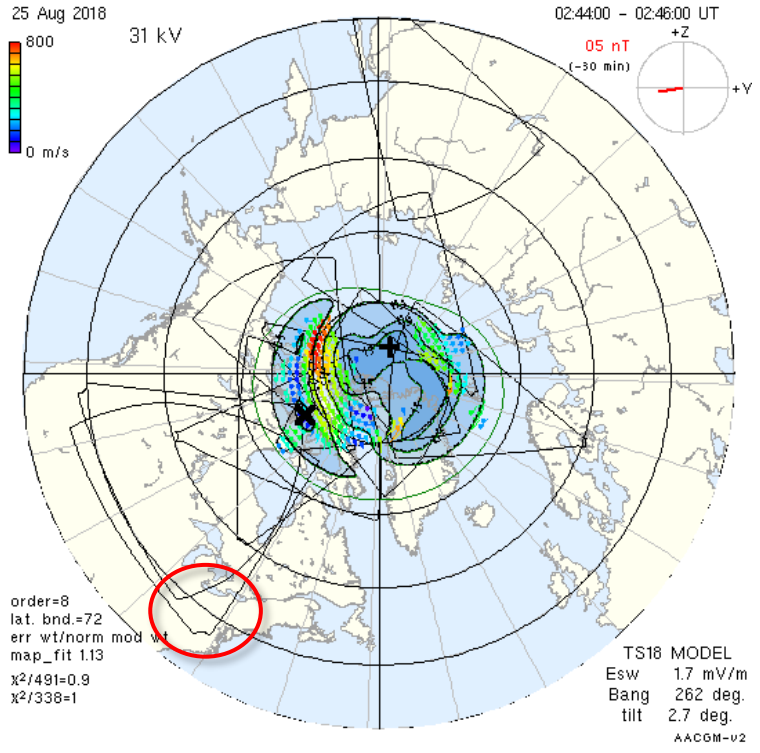
MLAT=72

02:42-02:44UT



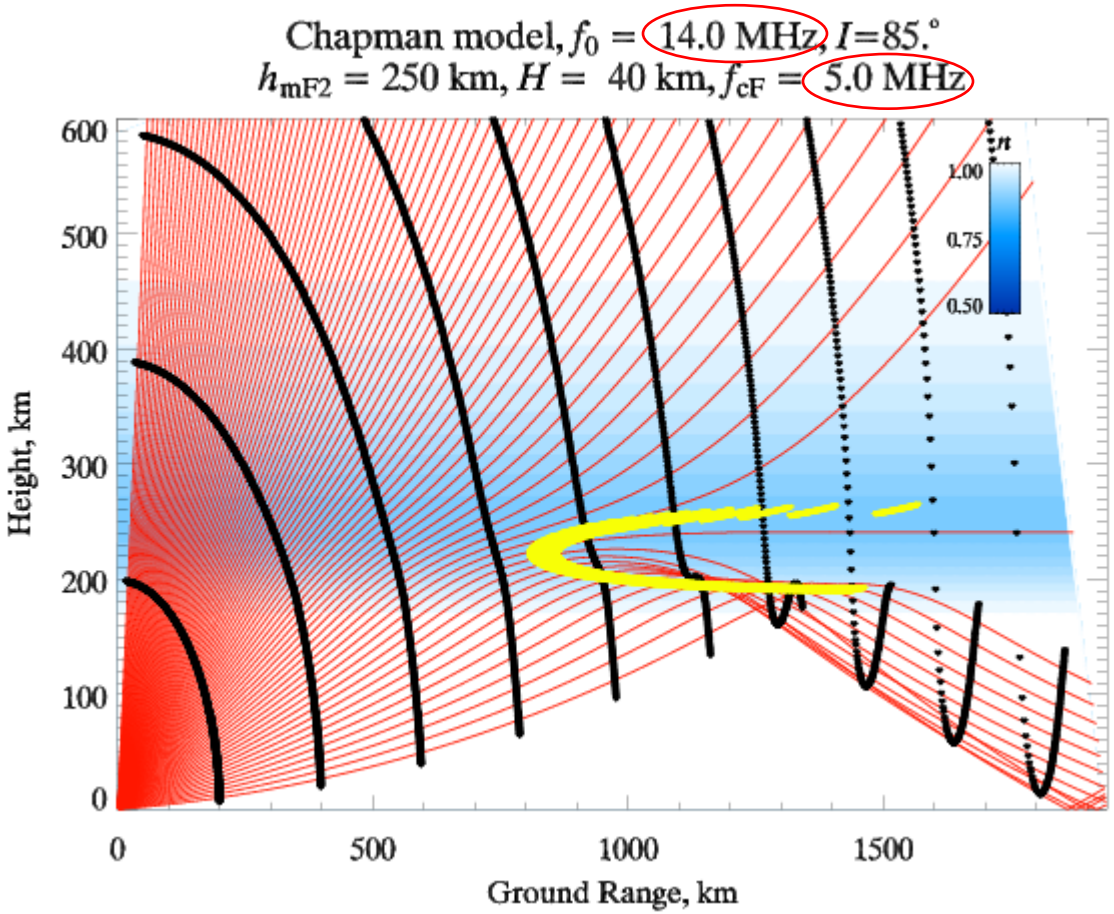
MLAT=72

02:44-02:46UT



MLAT=72

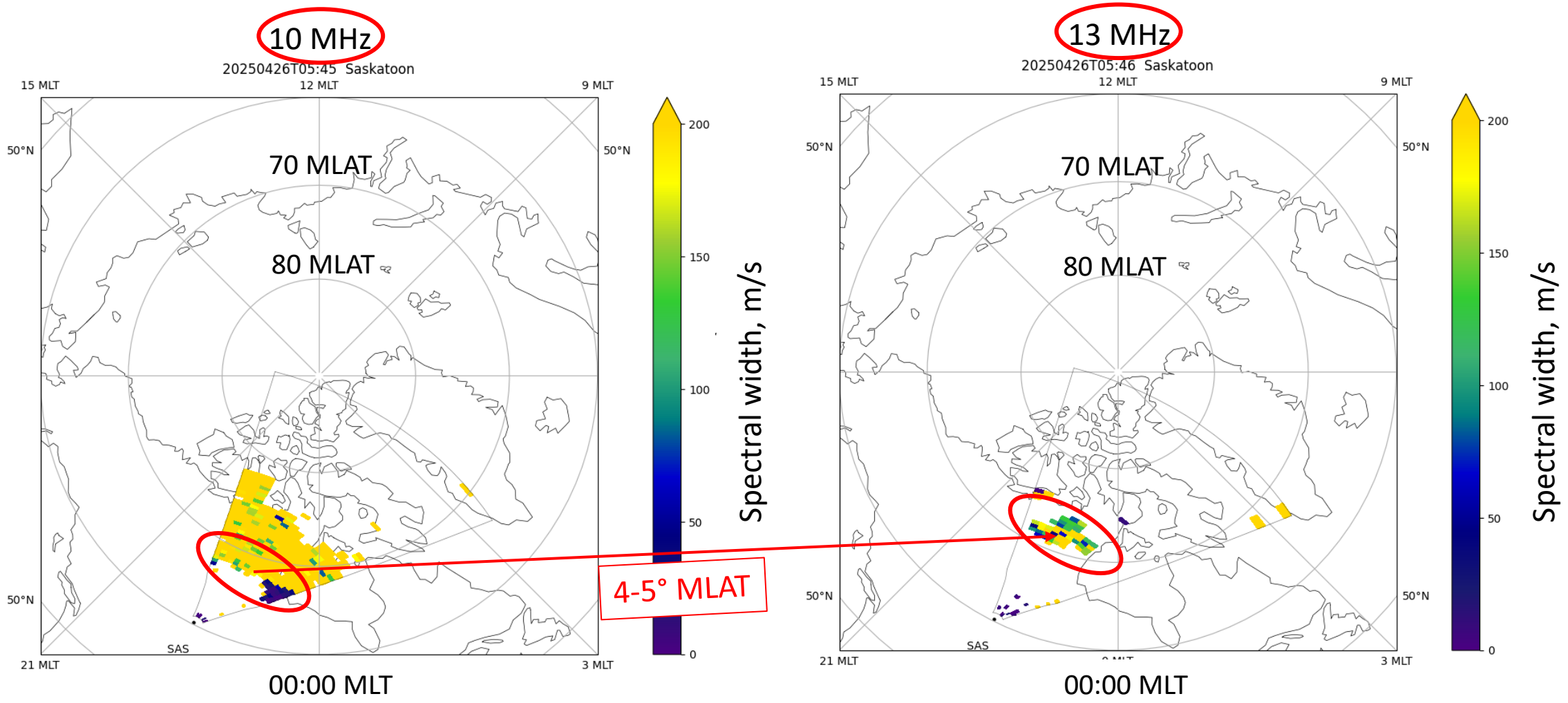
Remaining problem: poleward HMB offsets



With increasing radar frequency, the skip zone/scatter boundary moves away from the radar.

For the mostly poleward-looking SuperDARN radars this shifts HMB to artificially high latitudes (smaller "convection" pattern).

Frequency effect on scatter location: an example



Independent estimate of HMB location

- The original HM paper shows lower HMB MLAT for higher Kp values.
- A linear approximation seems to be good enough and provides the following dependence for 00 MLT boundary location:

$$MLAT = 66.125 - 2.125\,Kp$$

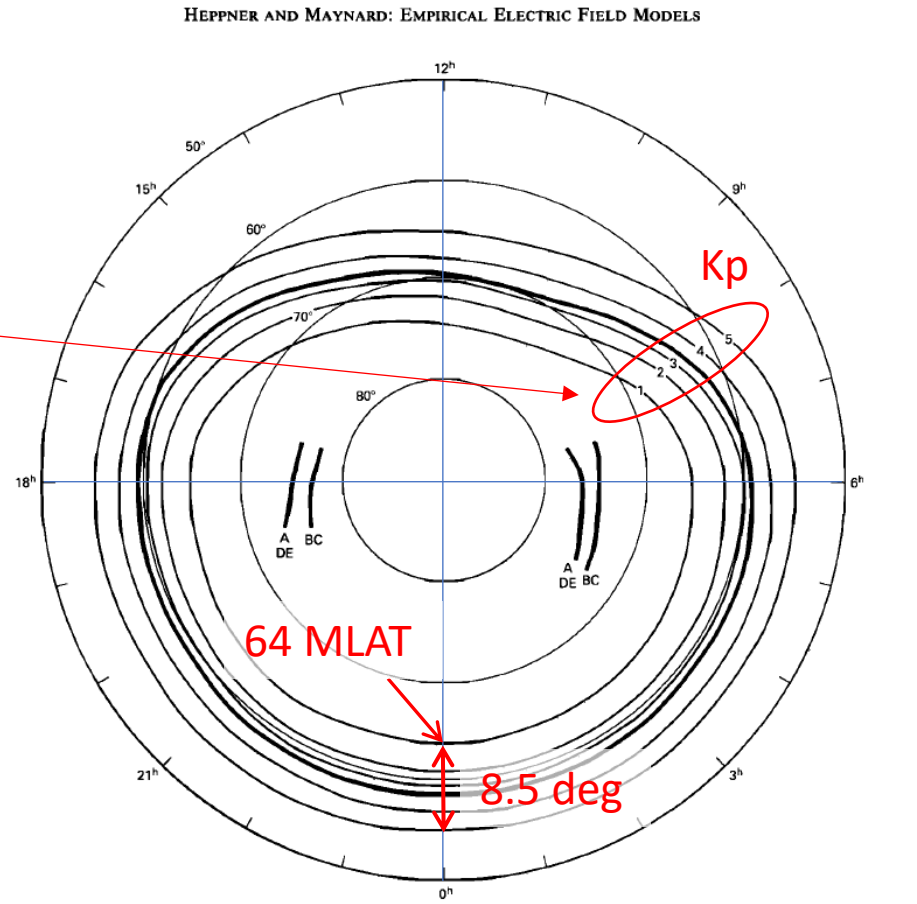
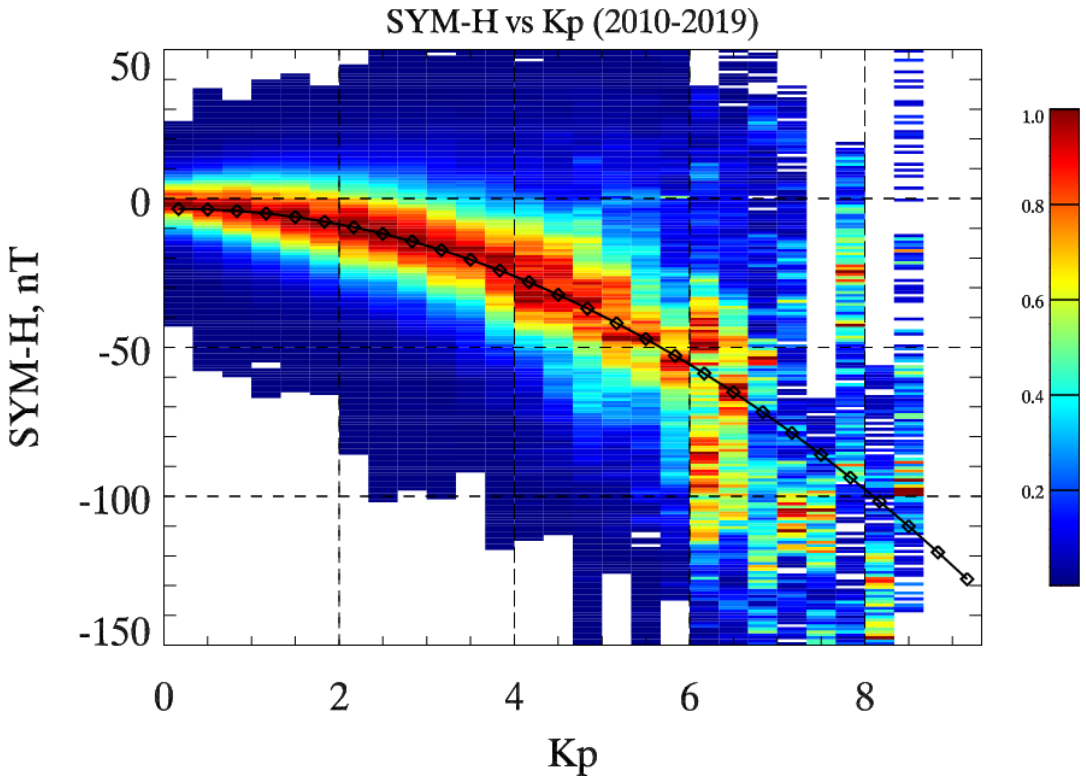


Fig. 10. Median locations of the low-latitude convection boundary for *Kp* values 1 through 5 and the 76-kV models. Average locations of the dawn-dusk polar cap boundary for signatures A, D, E, and H and signatures B, C, and G (all *Kp*'s, see text).

Fixing temporal resolution problem

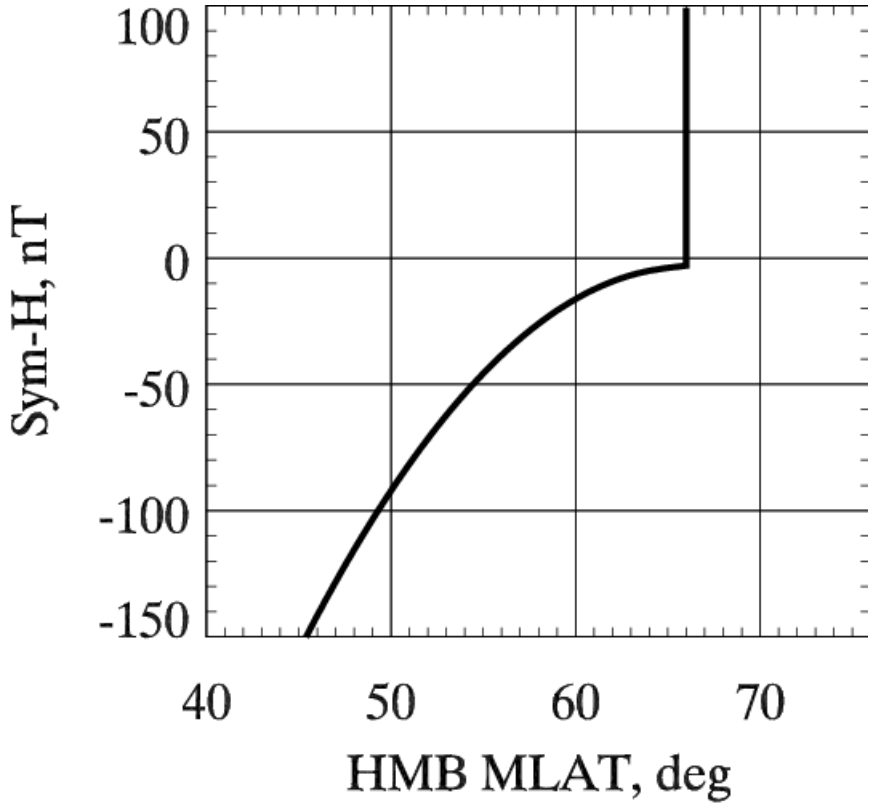
- However, Kp is a 3-hour index, and we need at least 1 minute sampling rate.
- What about Sym-H index? How is it related to Kp?
- Apparently, there is a nearly parabolic dependence

$$symH = -3.47 - 1.54\ Kp^2$$

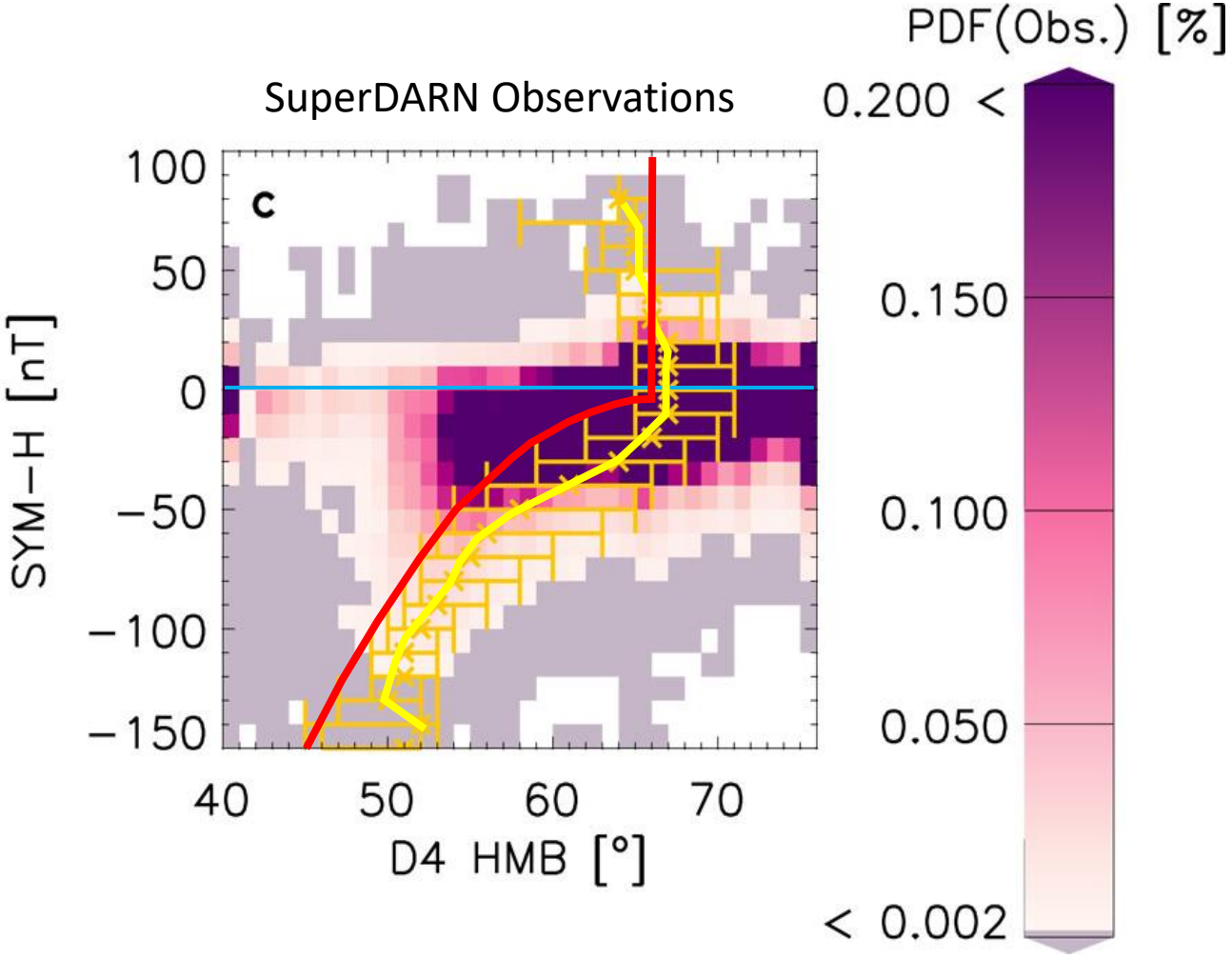


Parabolic dependence with saturation for Sym-H > 0

Empirical approximation



SuperDARN Observations



***Walach et al.*, https://doi.org/10.1029/2021JA029559**

Statistical data analysis details for 2024 (North)

FITACF data processing details:

version: FITACF2.5 & FITACF3.0;

***despecking applied**;*

no data from HKW/HOK due to cross-interference.

make_grid settings:

minimum spectral width: 100 m/s;

grid step: 2 min;

slant range: 800-2000 km (no 1.5-hop);

velocity max: 3000 m/s;

***velocity error: 100 m/s**;*

scatter type: ionospheric.

map_addhmb settings:

***minimum HMB latitude: 30 degrees**;*

***optional sym-H-based HMB**;*

minimum spectral width: 100 m/s.

map_addimf settings:

OMNI format IMF data;

time delay: 10 min.

map_addmodel settings:

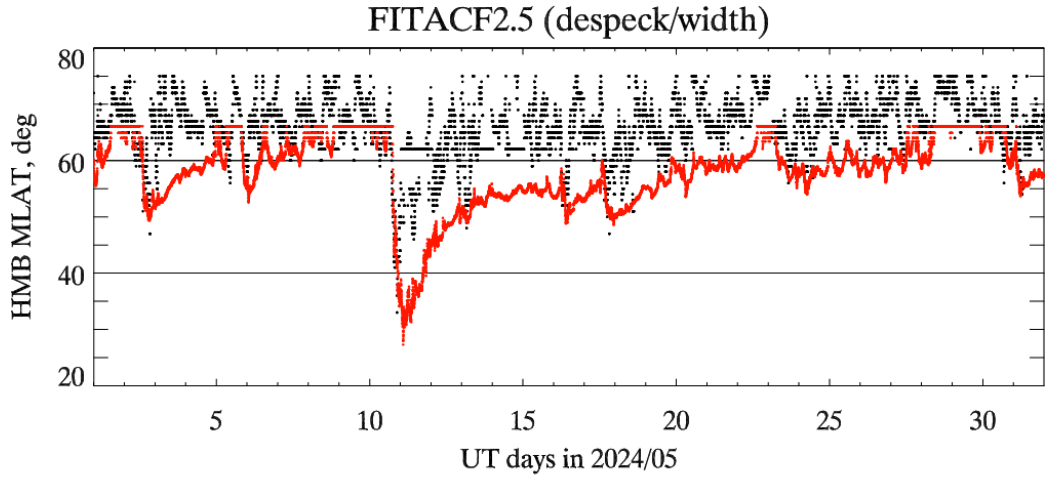
fitting order: 6;

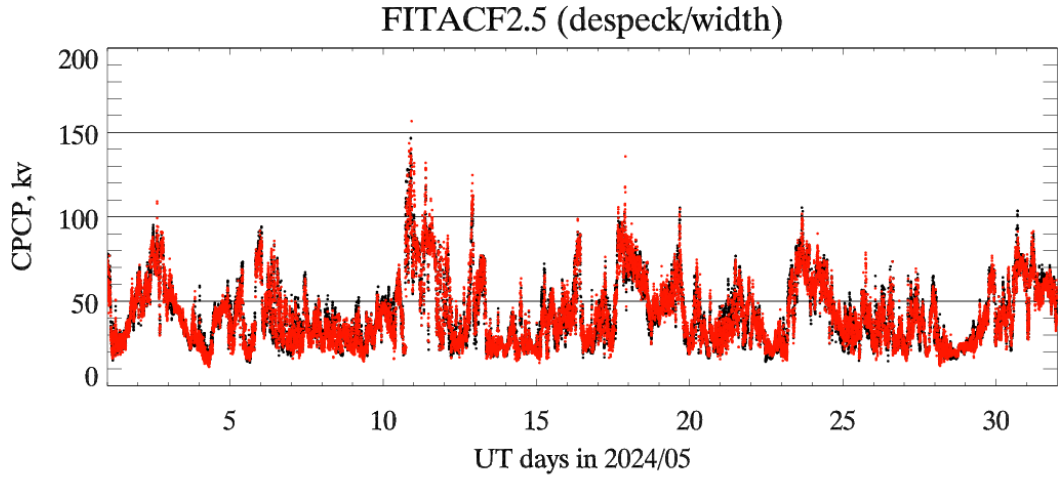
model doping level: low.

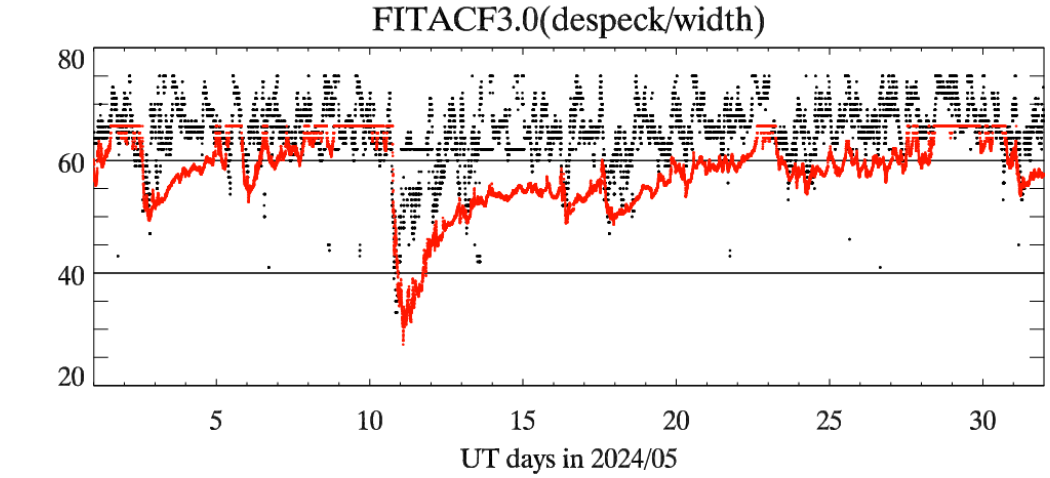
HMB location and CPCP for May 2024 superstorm

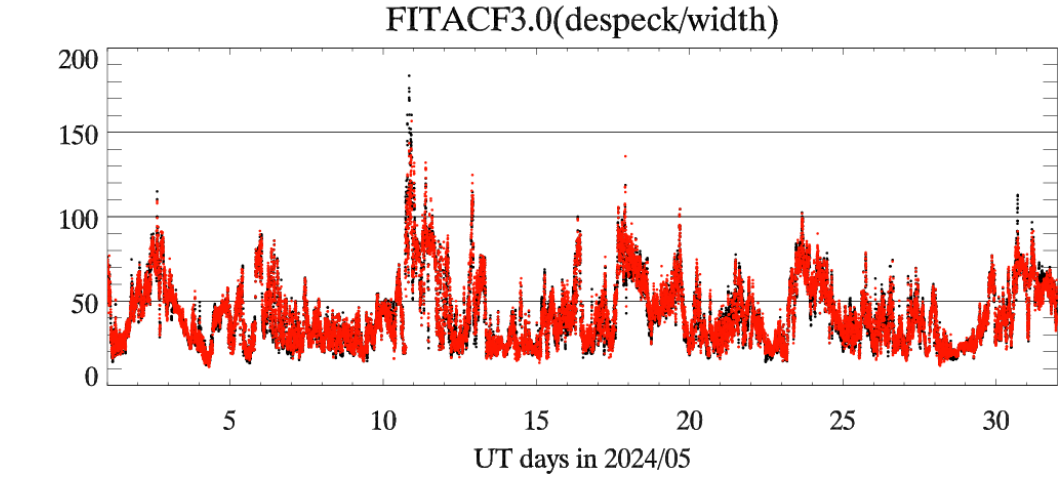
Black – conventional HMB

Red – FITACF3.0 with sym-H-based HMB





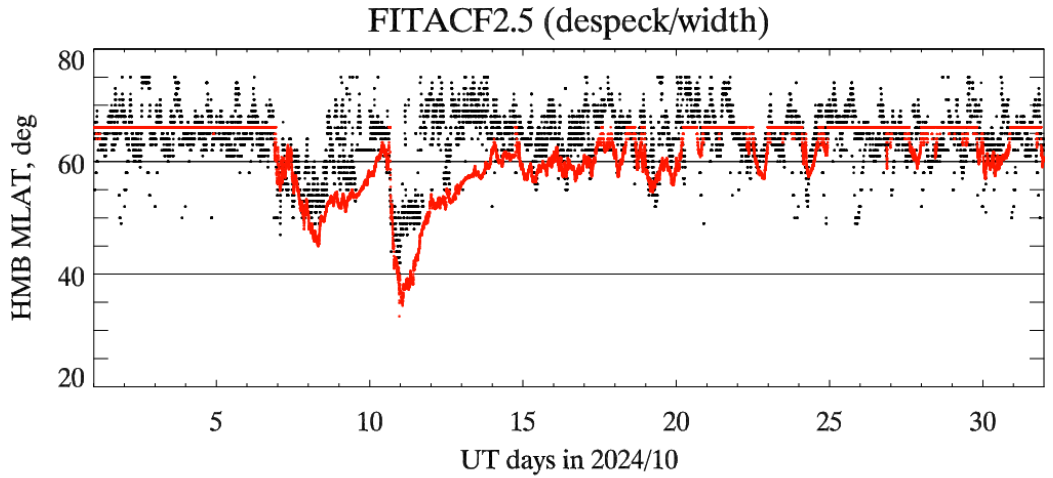


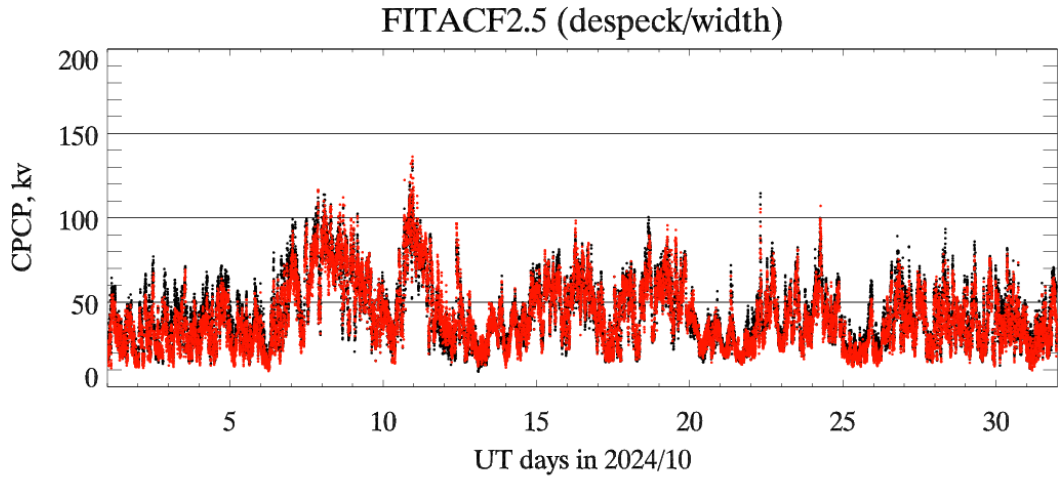


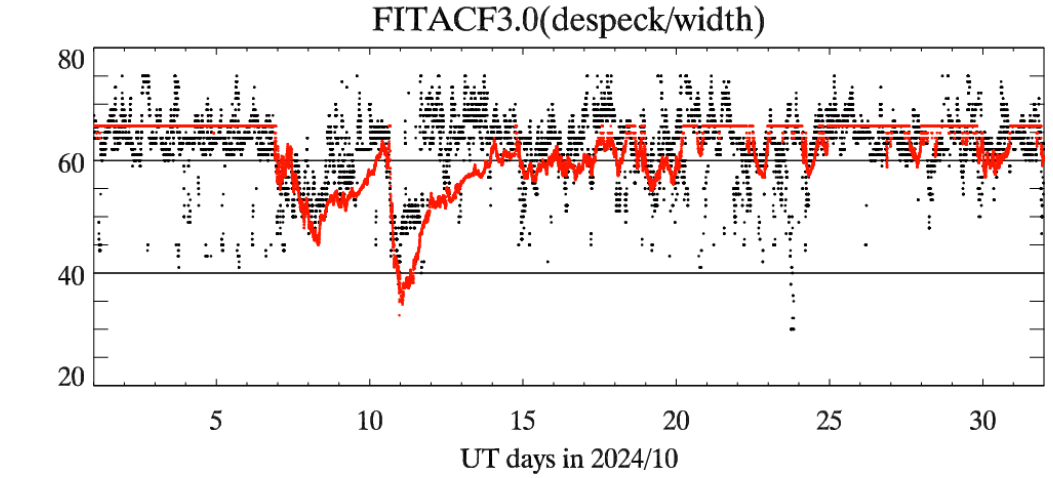
HMB location and CPCP for October 2024 storm

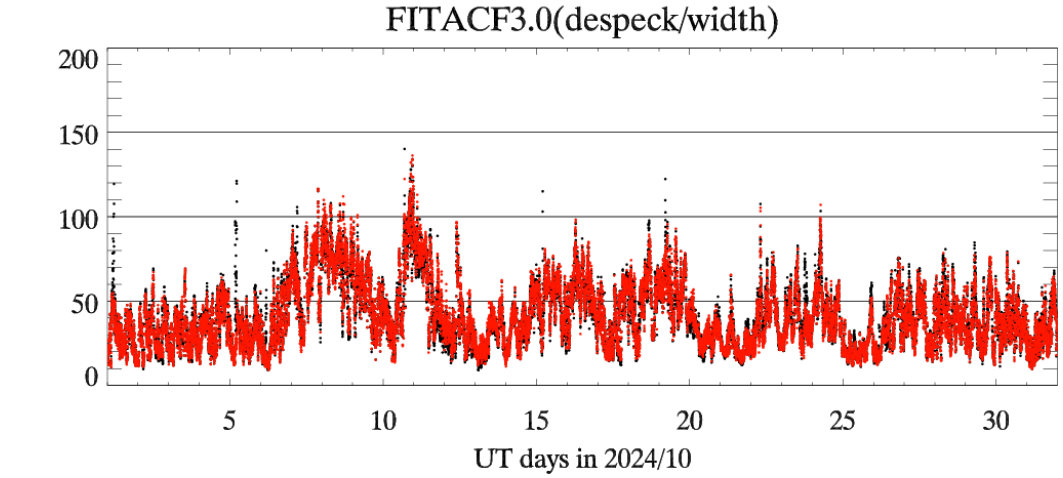
Black – conventional HMB

Red – FITACF3.0 with sym-H-based HMB

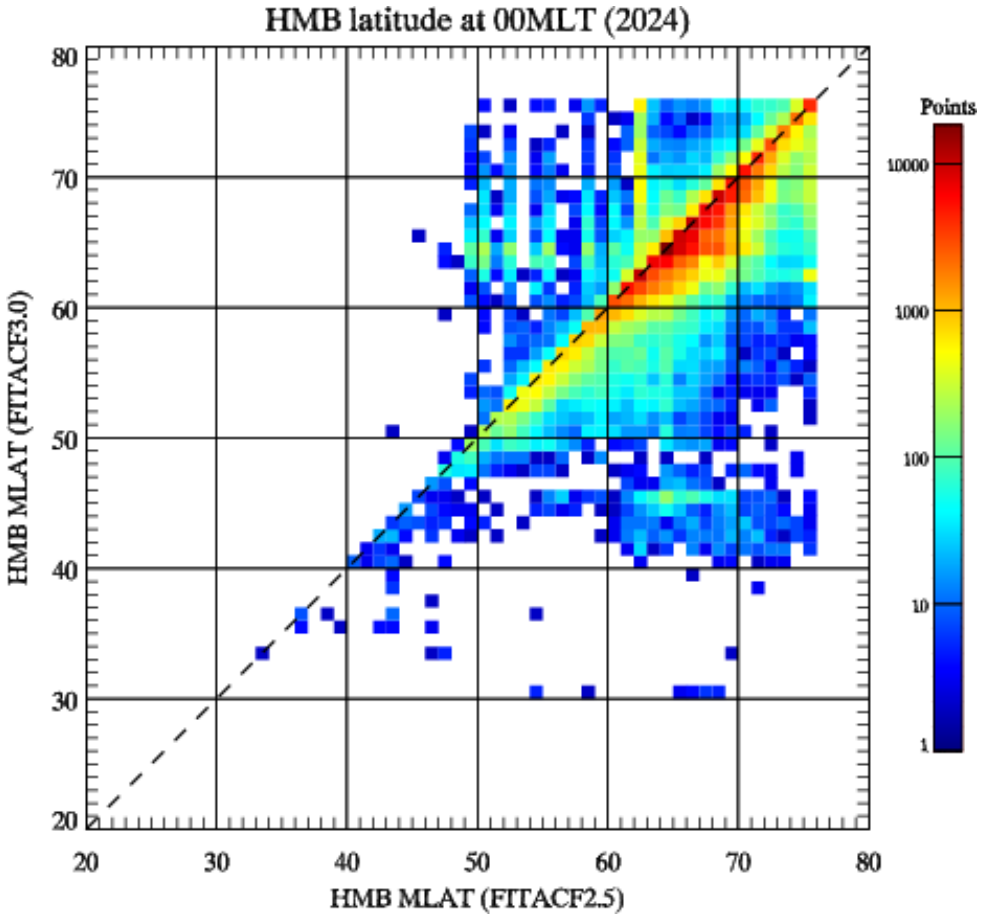


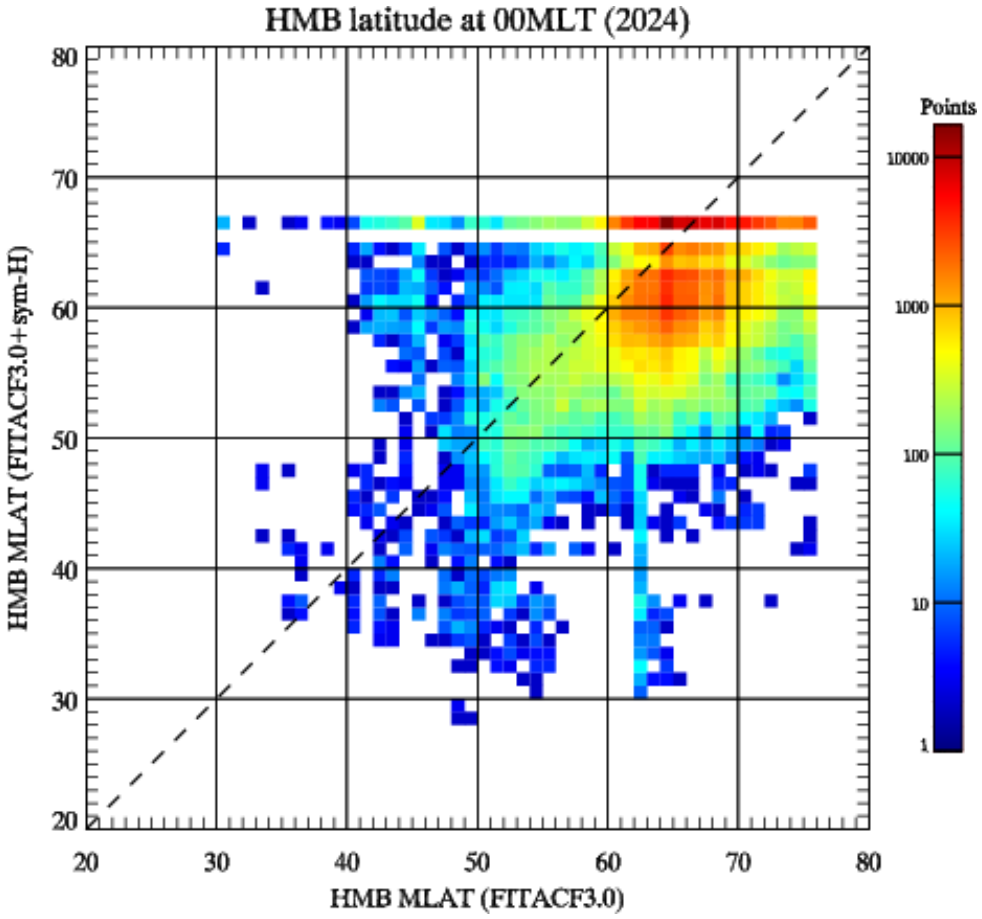




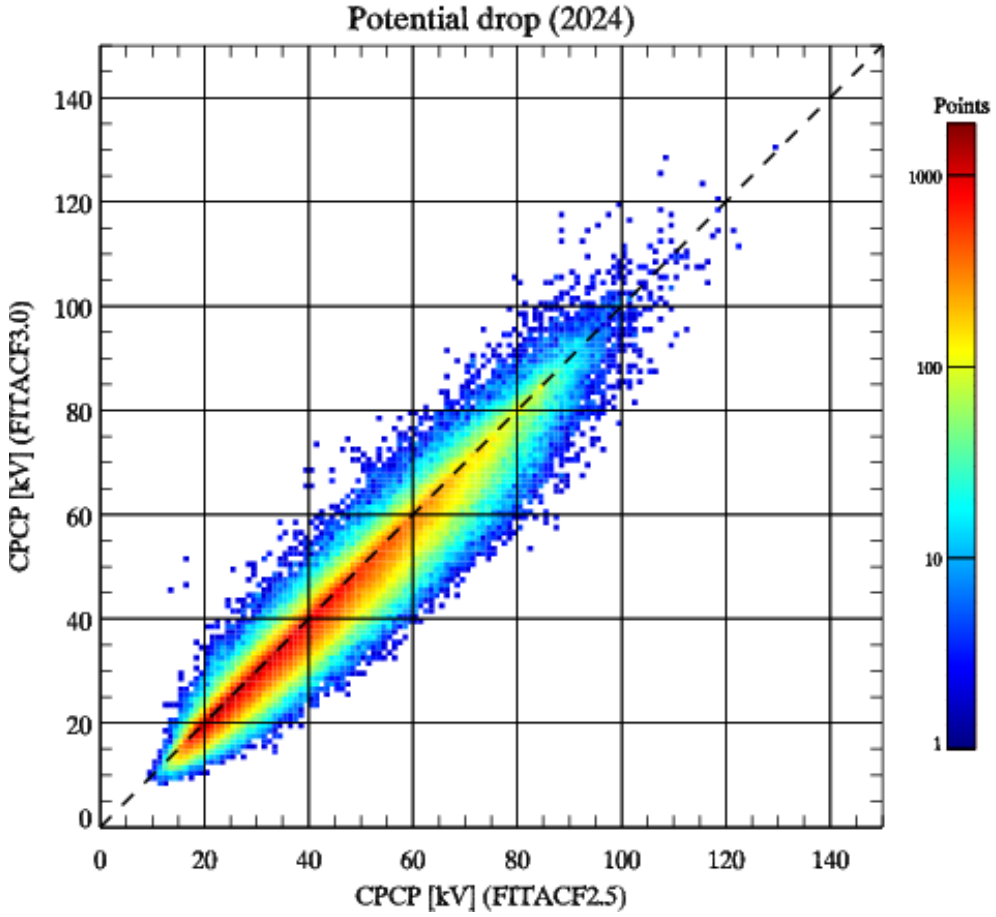


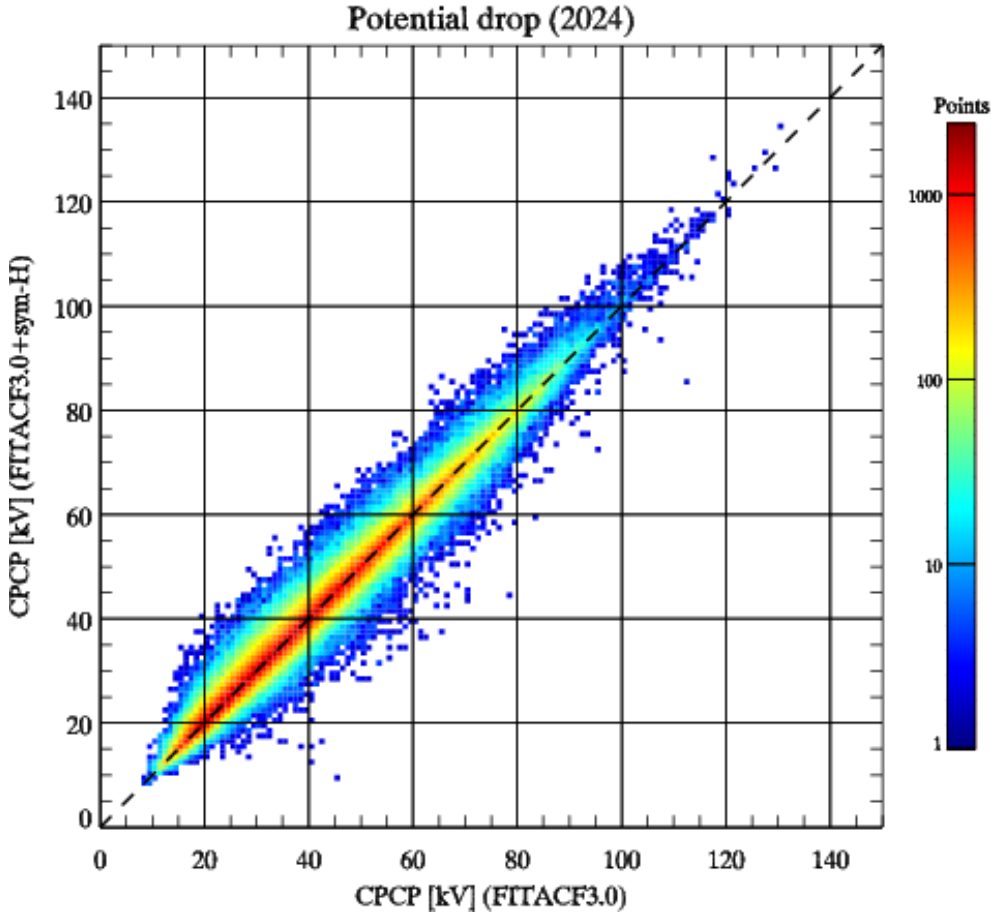
Annual LATMIN histograms





Cross-cap potential





Summary

- Application of despecking and a 100-m/s spectral width threshold at least partially mitigates the issue with the HMB being placed at an unphysically low MLAT. However, there is also an issue of placing it at too high latitudes due to the HF propagation effects. An independent estimate of the HMB location would be desirable to move away from the HF propagation and data analysis artifacts.
- Such an algorithm has been developed based on the empirical dependence of the HMB position on Kp. To provide the required temporal resolution, sym-H has been used as a Kp proxy based on a statistical relationship between the two indices obtained for 10 years of data.
- This approach shows a good agreement with the data-based HMB locations during periods with enhanced geomagnetic activity. It eliminates the necessity for the low-latitude limit for the HMB location (40 MLAT). The new approach is also instrumental in correcting the HF propagation effects leading to the unphysically high HMB latitudes.

Remaining issues

- What an actual HMB shape is:
  - How smooth it is.
  - If there are any SAPS.
- The CPCP value seems to be rather "robust" with respect to variations in the HMB location and to FITACF version (number of data points). Actually, it is more sensitive to the maximum spherical harmonic order and the IMF conditions.
- Wha is an actual contribution from observational data?
  - The same number of valid data cells covers different percentages of the "convection" area for different HMB locations. With higher activity levels, the relative contribution from the actual data decreases.
  - RST gives the total number of the grid cells with valid data at MLAT > 40 deg, which is not always the one used for fitting. When there is not enough data to define the HMB location, a "typical" value of 62 deg is used. In this case there are usually no actual data poleward of the HMB, so the maps are fully defined by the statistical model.

Number of vectors poleward of HMB and high-latitude circulation area covered by radar data