Coincident multi-point observations of the E- and F-region decametre-scale plasma waves at high latitudes

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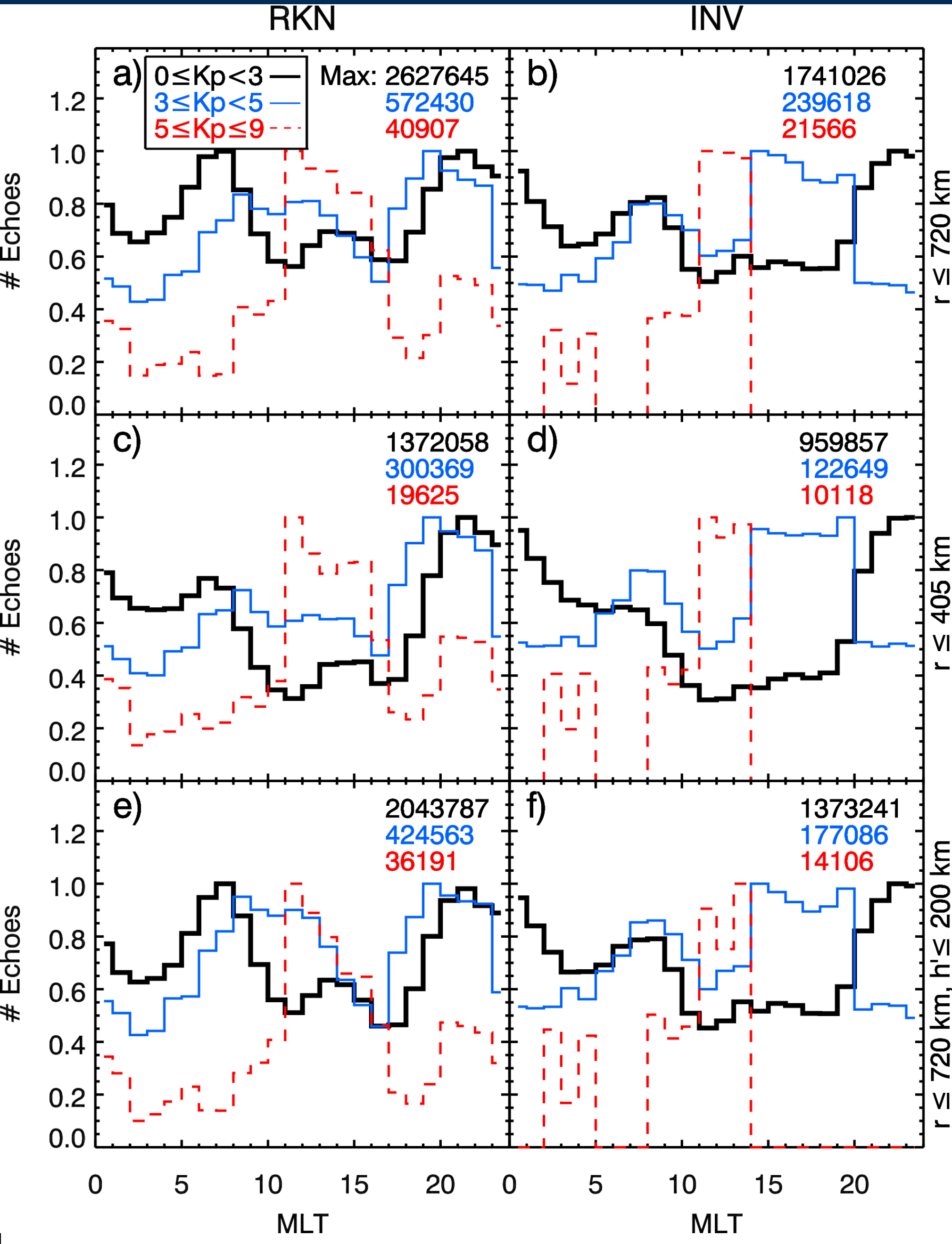
2011 SuperDARN Workshop May 30 - June 3, Dartmouth College Hanover, New Hampshire, USA

Abstract

Presented is a detailed analysis of the E-region backscatter observed by the PolarDARN component of the SuperDARN network. The statistical occurrence characteristics of the short-range echoes reveal significant differences from those of the auroral and sub-auroral SuperDARN radars. In particular, most backscatter is detected in the midnight sector in the closest range gates where the geometric aspect angles are quite large. One explanation offered is that layers of intense plasma density significantly refract the radar waves allowing the regular detection of plasma waves in the very short ranges. An analysis of the statistical echo types within the PolarDARN dataset showed similarities with the other SuperDARN radars, with the low-velocity echoes dominating both PolarDARN radar datasets. The high-velocity echoes were observed rather sporadically throughout the morning sector, during which the flow and aspect angles are expected to be small enough for routine backscatter to occur. The locations of the PolarDARN radars relative to the more-equatorward SuperDARN radars results in a new experimental setup that has coincident and simultaneous HF radar coverage of the E and F regions along connecting magnetic field lines. In this radar configuration, the SuperDARN plasma flow measurements are employed to investigate the E-region phase velocity dependence on the electric field strength and the flow angle at multiple locations. By employing elevation angle estimates, a marked decrease in the observed phase velocity with decreasing altitude is observed and is attributed to an increased number of collisions between the charged particles and the neutrals. It is also shown that the measured phase velocity normalised to the background plasma flow is smaller for higher electric fields, compared to that for smaller electric fields. This result is interpreted as being due to a change in the contribution of the convective effects on the plasma wave growth.

Diurnal variations



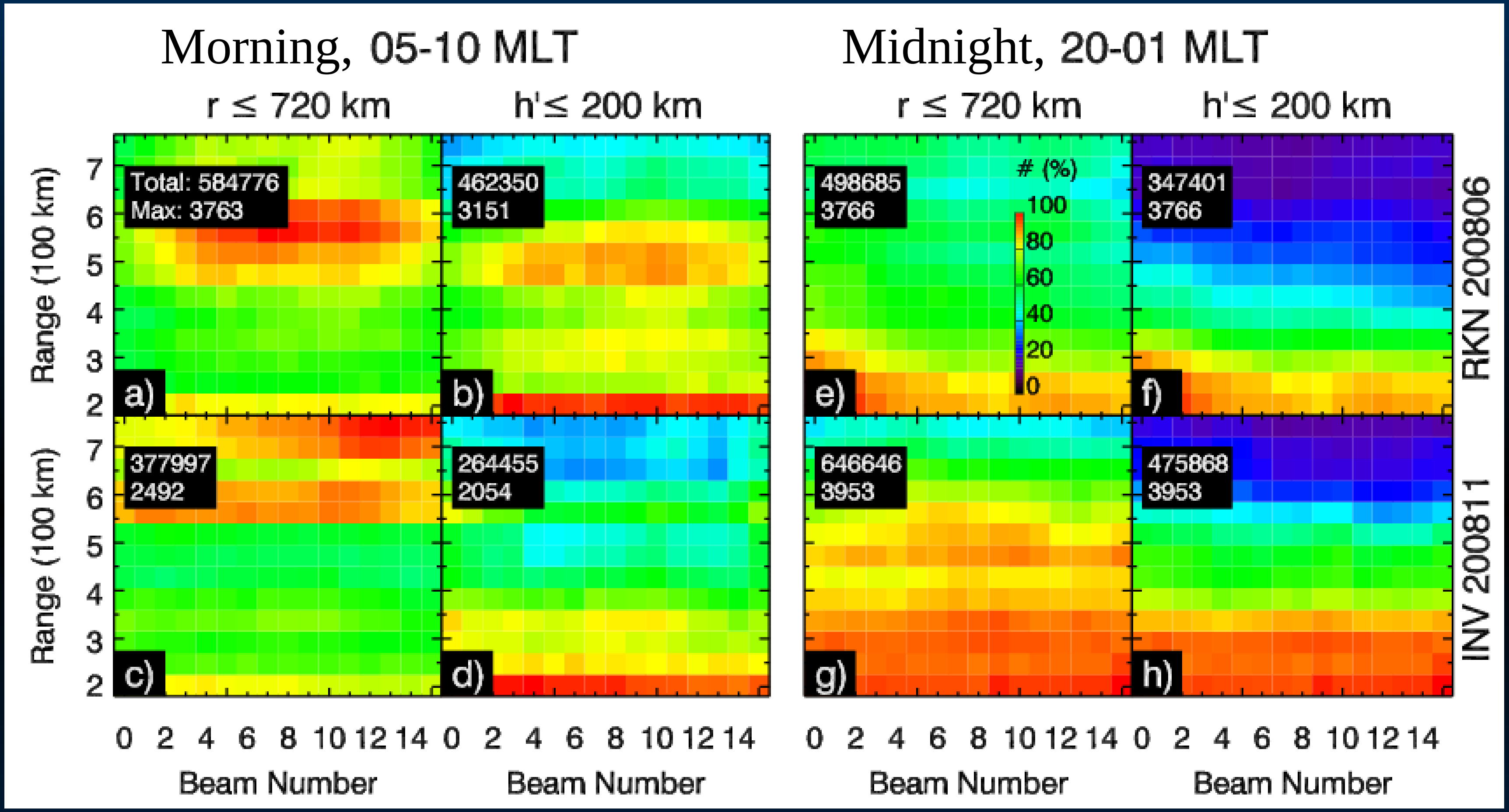
The Diurnal variations of echo occurrence are sorted according to Kp (specified in panel a) for three different F-region echo exclusion schemes; (1) r < 720 km, (2) r < 405 km and (3) r < 720 km and h' < 200 km.

There are three peaks in echo occurrence for low activity; morning, post-midday and pre-midnight.

Magnitude of morning peak significantly reduces when using the range cutoff at 405 km, implying that many far-range echoes are detected in the morning. However, when considering the virtual height exclusion the morning peak is almost unchanged.

Using the range cutoff of 405 km excludes many E-region echoes and therefore the additional criterion of virtual height is appropriate.

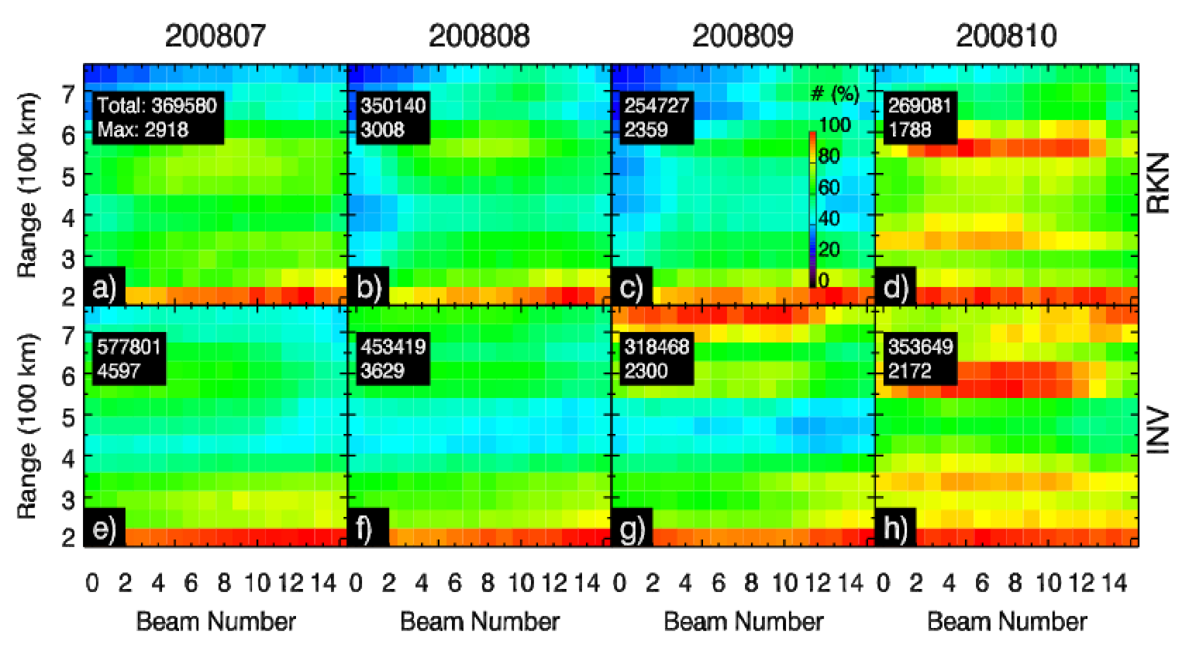
E- and F-region boundary determination



It is clear from the spatial echo occurrence patterns that in only considering the very-short ranges, a second E-region echo band in the morning sector at farther ranges is removed from the statistics.

In addition, it is noticeable that significant amounts of high altitude (i.e. F-region) echoes are removed by the virtual height exclusion (e.g. compare panels a and b or panels g and h).

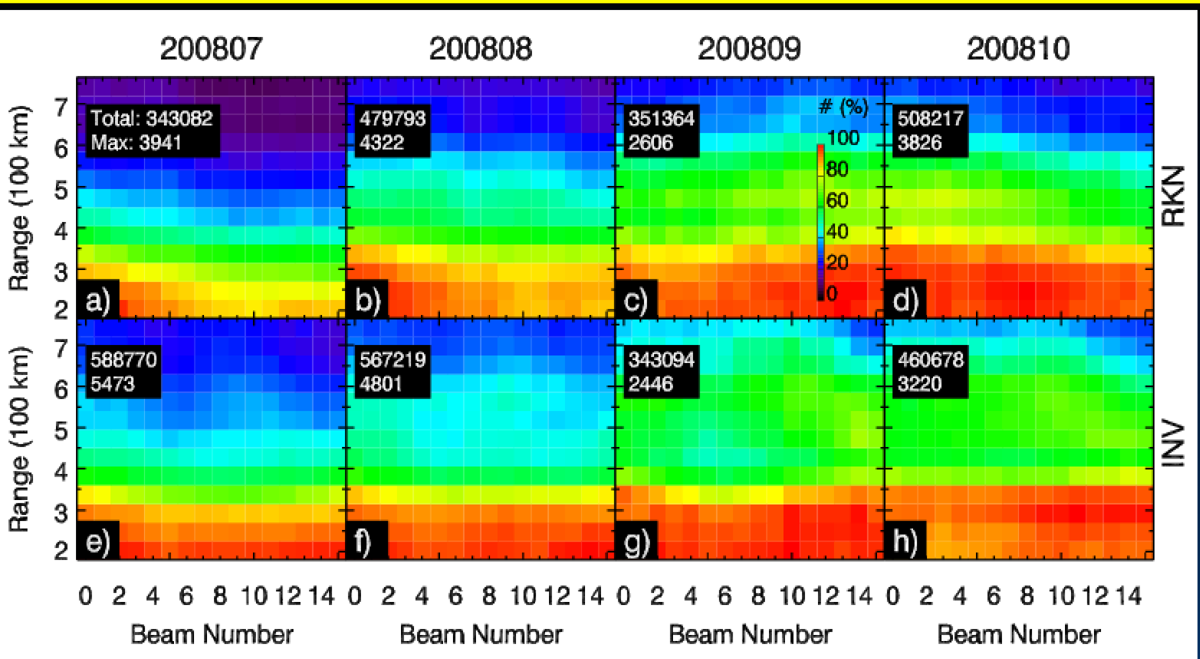
Spatial echo occurrence patterns



Morning sector:

Two E-region echo bands are present during each month considered; one at r ~ 540 km and another at r ~ 180 km.

Take note of the change in occurrence of the far-range band from month-to-month.



Midnight sector:

Only one echo band is observed in the midnight sector from ranges 180 – 450 km.

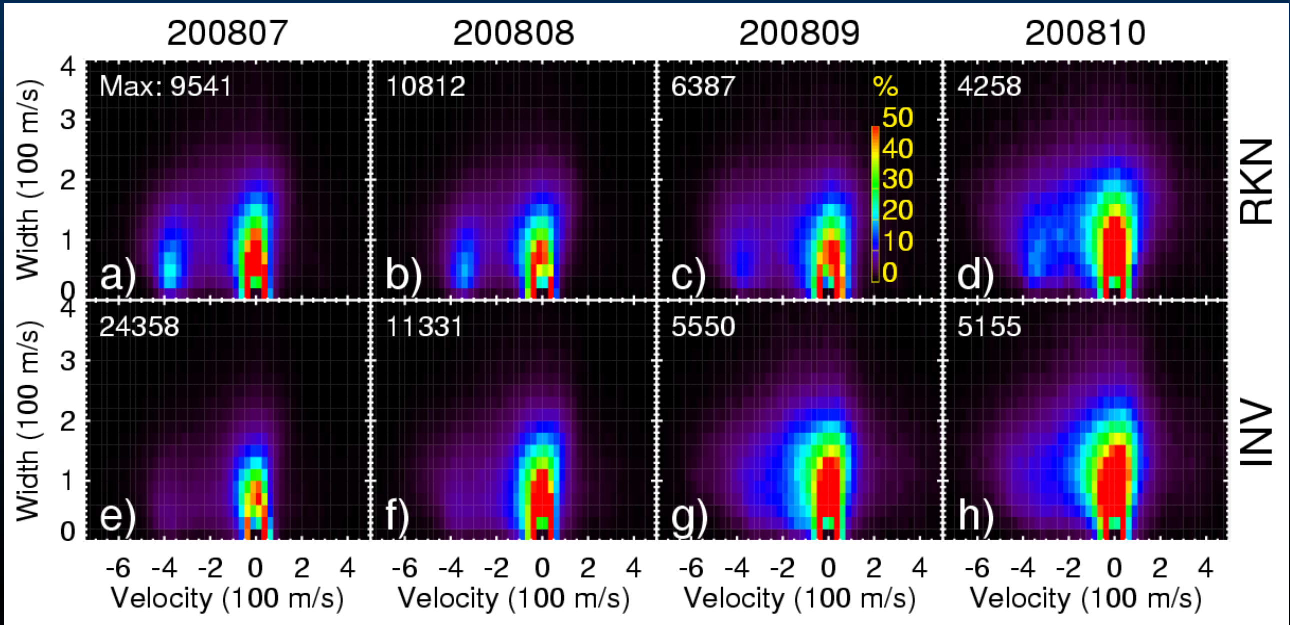
The upper boundary of the echo band increases in range as the month approaches winter for the northern hemisphere showing a seasonal trend.

Spectral parameter plots

Morning sector:

Two statistically significant E-region echo populations are observed in the morning sector; a low-velocity population at ~ 0 m/s and a high-velocity population at ~ -400 m/s.

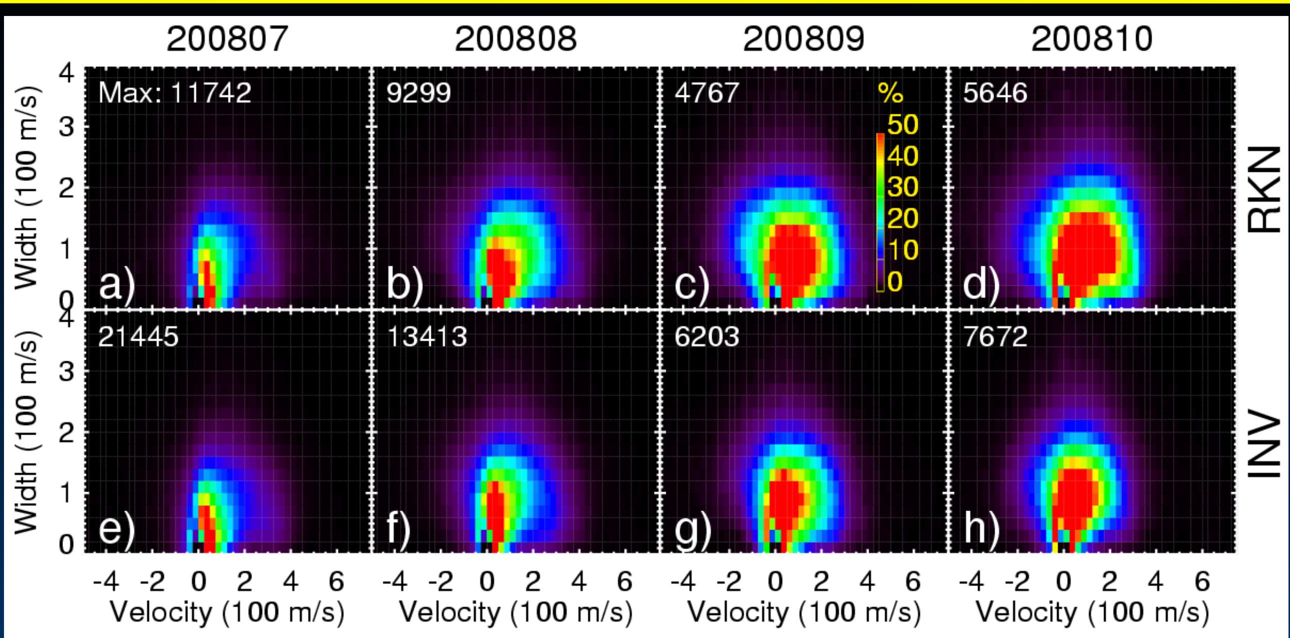
The change in occurrence of the high velocity population with the month is similar to that of the far-range echo band for both radar datasets.



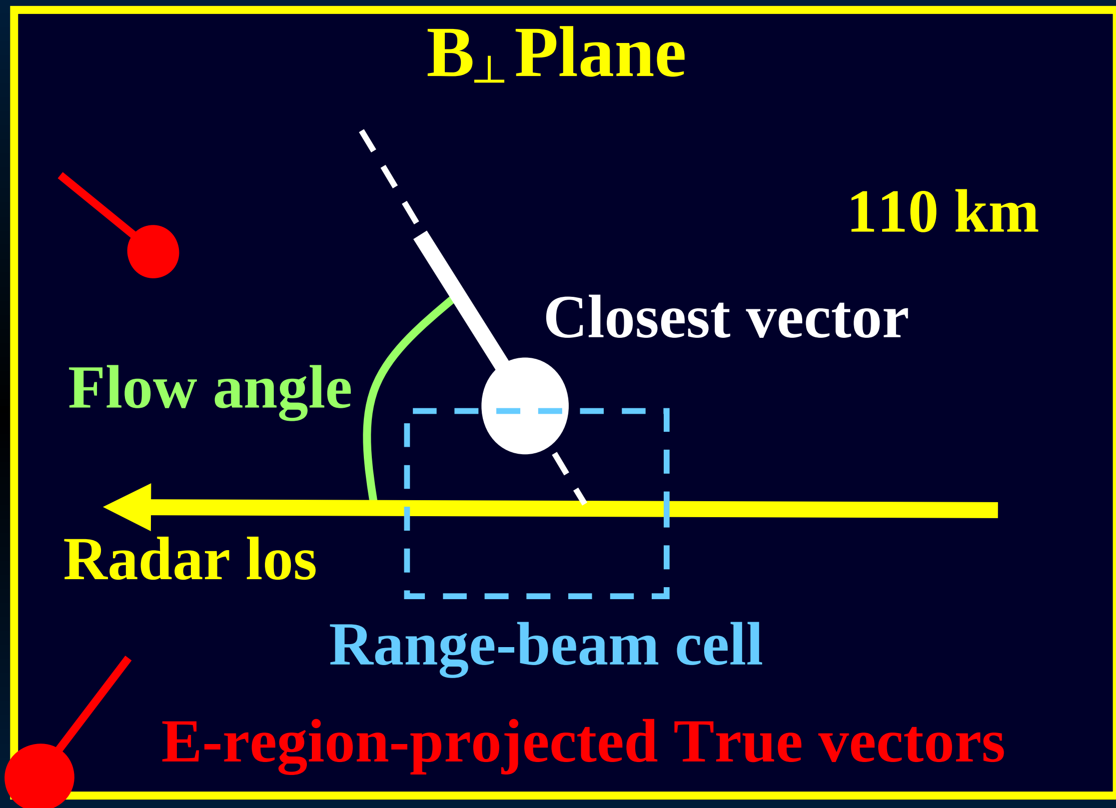
Midnight sector:

One very dominant population of echoes is observed by both radars in the midnight sector with phase velocities ~ 0 m/s.

From this, it is clear that the very-short range echoes observed by PolarDARN are mostly low-velocity echoes.



Flow angle definition using true vectors



- The true vectors were projected along the magnetic field lines to 110 km altitude

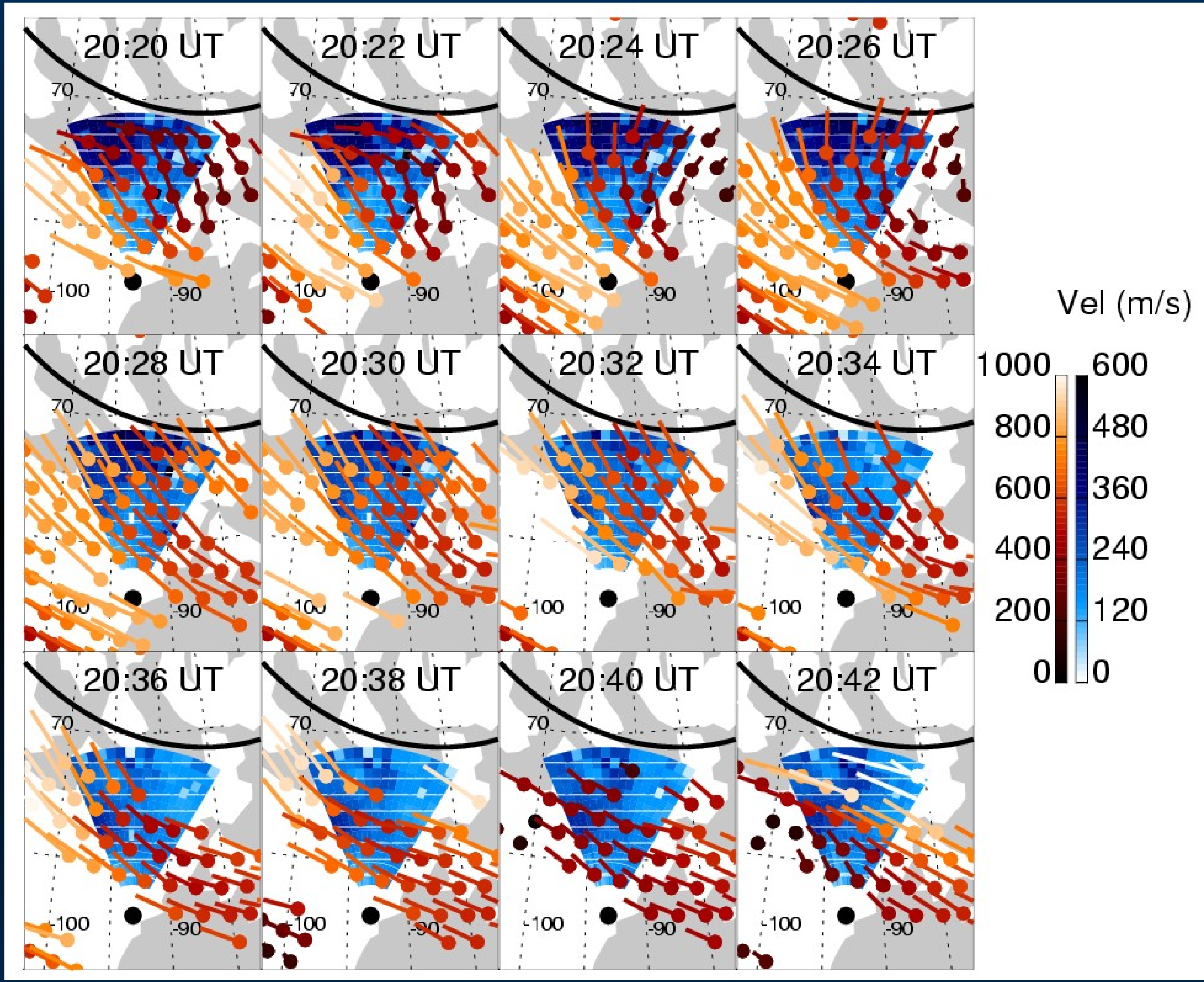
- The direction between the closest vector (distance < 100 km) and the radar l-o-s in each range-beam cell is taken as the flow angle

- The echo velocities are then normalised to the magnitude of the true vectors

Event studied: 6th Aug 2007

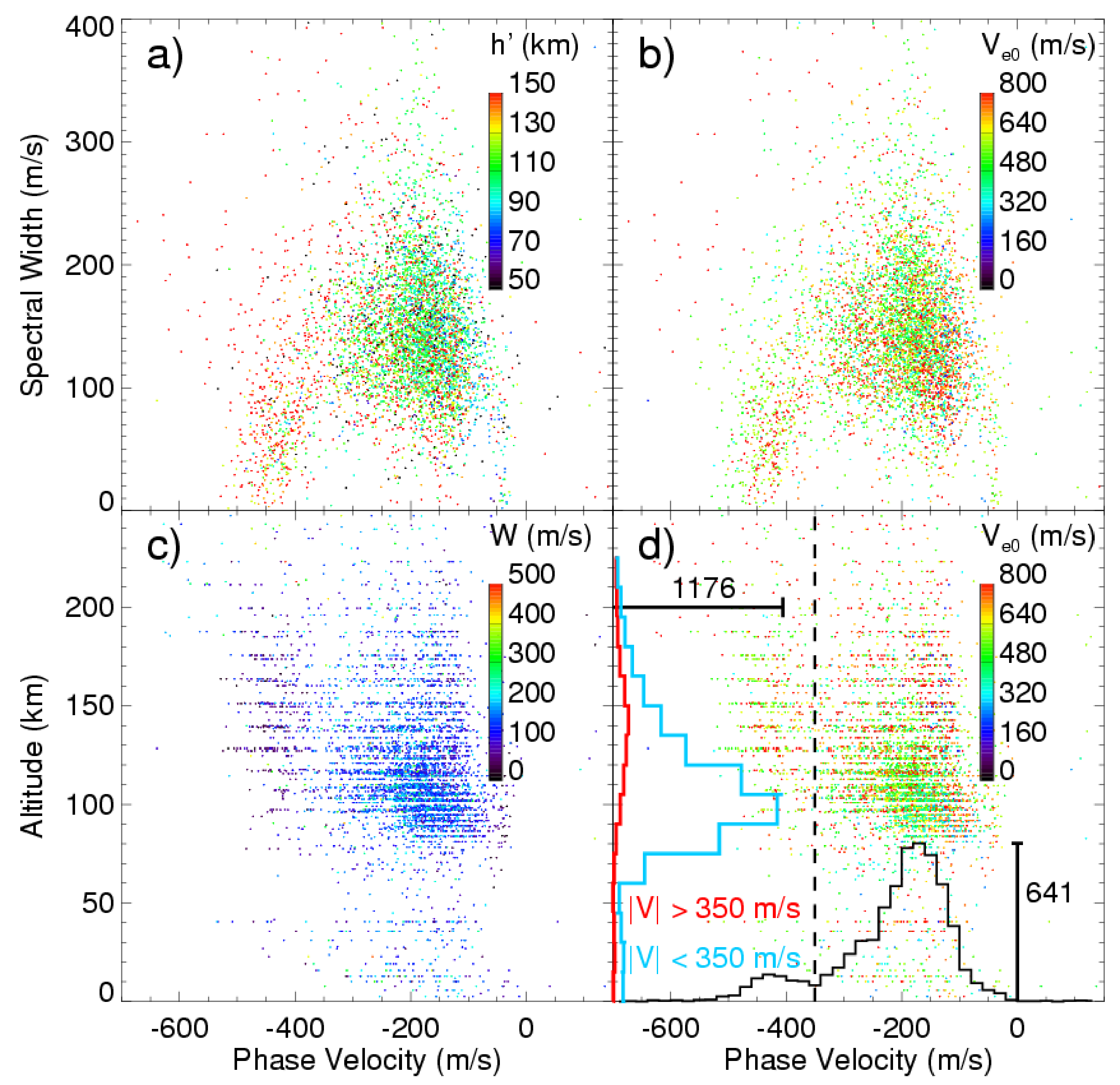
An abundance of overlapping SAS data during this interval lead to many plasma flow vectors being calculated for locations above the RKN short-range (i.e. E-region) field-of-view (FoV).

The non-uniformity of the plasma flow results in a much wider range of flow angles and flow magnitudes as compared to the standard L-shell angle technique used previously.



It is also worth noting that many high-velocity echoes were observed by RKN during this interval (dark blue cells).

Spectral parameters of 6th Aug 2007 event

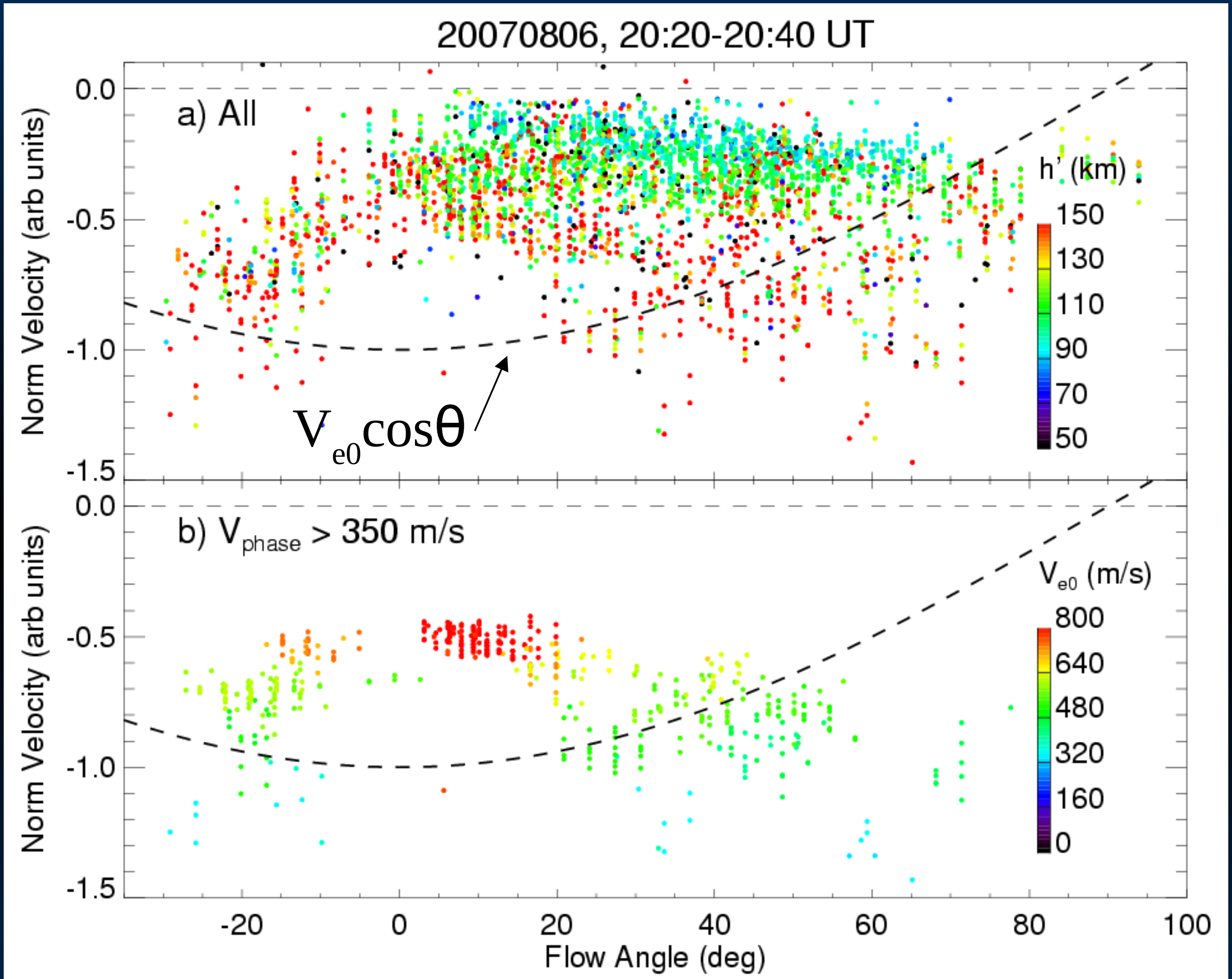


Two echo populations, which are representative of the statistical populations identified in the morning sector, were observed.

The high-velocity echoes are associated with higher altitudes than the low-velocity echoes, panels a and d.

The high-velocity echoes appear to be associated with both high and low plasma flow speeds, panel b (green and red points).

Normalised velocity vs flow angle



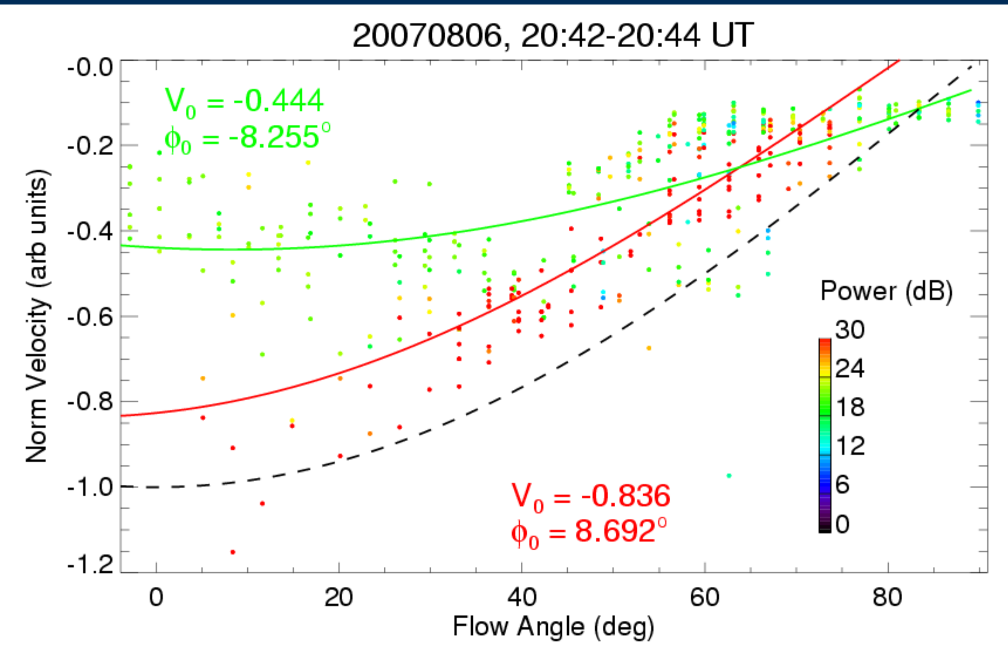
Many points have velocity magnitudes that are much less than the cosine of the plasma flow, dashed line.

A clear decrease in the magnitude of the normalised velocity with altitude is shown for flow angles 20°-60°, aqua to green points.

Also, high- and low-velocity populations are not clearly separated by flow angle dependence.

When only considering high-velocity echoes, panel b, it appears that those associated with larger flow speeds (and hence electric fields) are limited in their normalised velocity magnitude, whereas those associated with smaller flow speeds are not.

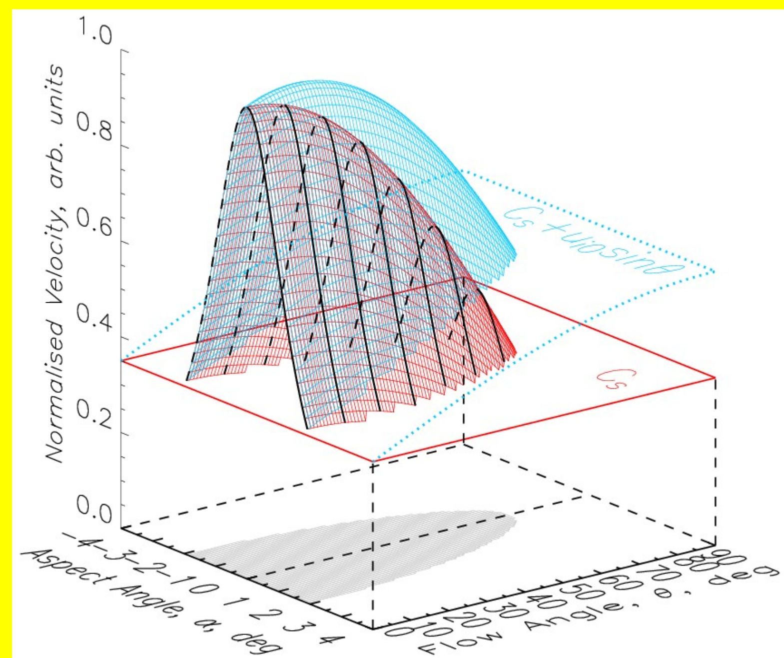
Aspect angle attenuation



The aspect angle attenuation of the phase velocity becomes clearer when the data from one scan is analysed and coloured in backscatter power.

As expected, the velocities of the high-power (25-35 dB) echoes are much less attenuated than those of the low-power (15-25 dB) echoes.

By using the predictions of the linear fluid theory, the aspect angles of 0.61° and 1.63° are determined for the high- and low-power echoes. From these, an aspect sensitivity can be estimated to be 9.8 dB/deg for the RKN observations, in line with previous observations.



Summary and Conclusions

The E-region echo occurrence patterns are very different for the PolarDARN radars as compared to that previously shown for the auroral SuperDARN radars

- 3 peaks in the diurnal variations, compared to 1-2 peaks observed by auroral radars previously
- both PolarDARN datasets were dominated by low-velocity echoes, with statistically significant quantities of high-velocity echoes observed in the morning sector
- spatial distributions of echoes revealed multiple E-region echo bands, near- and far-range
- majority of echoes were detected in midnight sector at locations of rather large aspect angles
- an explanation offered is that the echo occurrence levels are dramatically increased by intense ionisation layers that strongly refract the radar waves to orthogonality in the close range gates

By employing the SuperDARN plasma flow vectors on the same magnetic field lines as the PolarDARN E-region measurements,

- it was clearly demonstrated that the depression of the irregularity velocity below the plasma drift component becomes stronger with decreasing altitude
- an estimate for the aspect sensitivity of 9.8 dB/deg was determined for the RKN observations
- it was also found that the high-velocity echoes that were associated with larger electric fields exhibited velocities close to 0.5 times the background flow, whereas those associated with lower electric fields exhibited velocities closer to the cosine of the background plasma drift
- this is interpreted as being due to the transition of the plasma wave growth being dominated by convective processes for electric fields $< \sim 40$ mV/m to the convective processes becoming negligible for electric fields $> \sim 40$ mV/m