SuperDARN observations of high-velocity E-region echoes from the eastward auroral electrojet

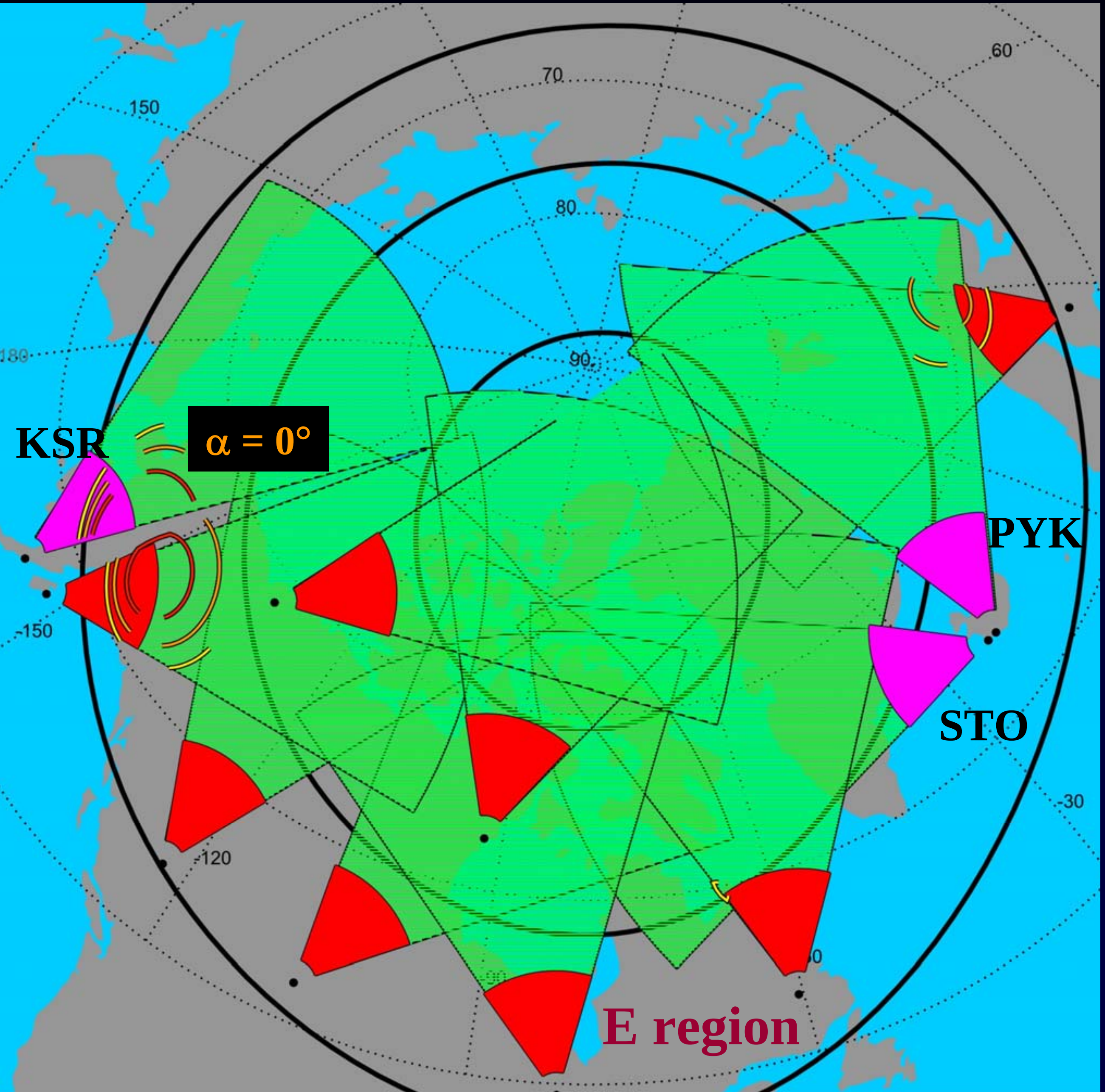
Roman A. Makarevich

Department of Physics, La Trobe University
Victoria, 3086, Australia

Abstract

A statistical analysis of short-range E-region echoes observed by the SuperDARN HF radars in the evening sector (16-22 MLT) over 3 years near the solar cycle peak is presented. Significant populations of the high-velocity (350-450 m/s) E-region echoes similar to the classical Type 1 echoes are observed by 4 zonally-looking SuperDARN radars at small magnetic L-shell angles. The spatial occurrence pattern of Type 1 echoes is investigated. It is shown that the latitudinal (slant range) extent of the region where Type 1 echoes occur increases as the L-shell angle decreases, which is interpreted as widening of the aspect angle instability cone with the flow angle decrease. The echoes with unusually high velocities (500-600 m/s) observed by the Syowa East HF radar are also investigated. These echoes are seen at all L-shell angles (15-75 deg) and their Doppler velocity increases with range and exhibits little variation with L-shell angle. There is strong evidence that these echoes are observed both inside and outside the modified two-stream instability cone and are likely to be secondary waves. The echoes occur at ranges 360-495 km when the strong low-velocity echoes (P > 30 dB, V < 200 m/s) are observed at ranges 225-360 km. The high-velocity auroral echoes appear to be similar to the vertically propagating Type 1 echoes from the equatorial electrojet and may be generated through the nonlinear three-wave interaction process.

Super Dual Auroral Radar Network



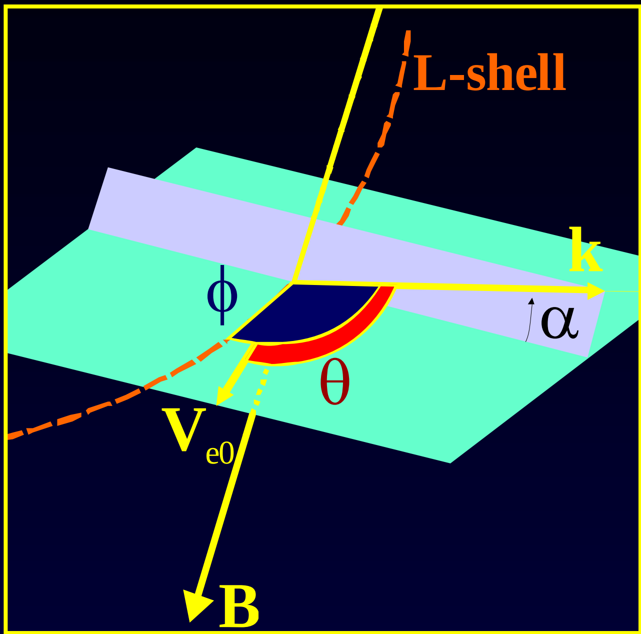
SuperDARN's aim is to monitor and study the global plasma convection.

At present the E-region echoes are assumed to be similar to the F-region echoes.

E-region echoes potentially constitute 13/70 ≅ 20% of all echoes.

These are most equatorial echoes detected in the regions critical to our understanding of sub-auroral and storm-time plasma dynamics.

E-region echoes



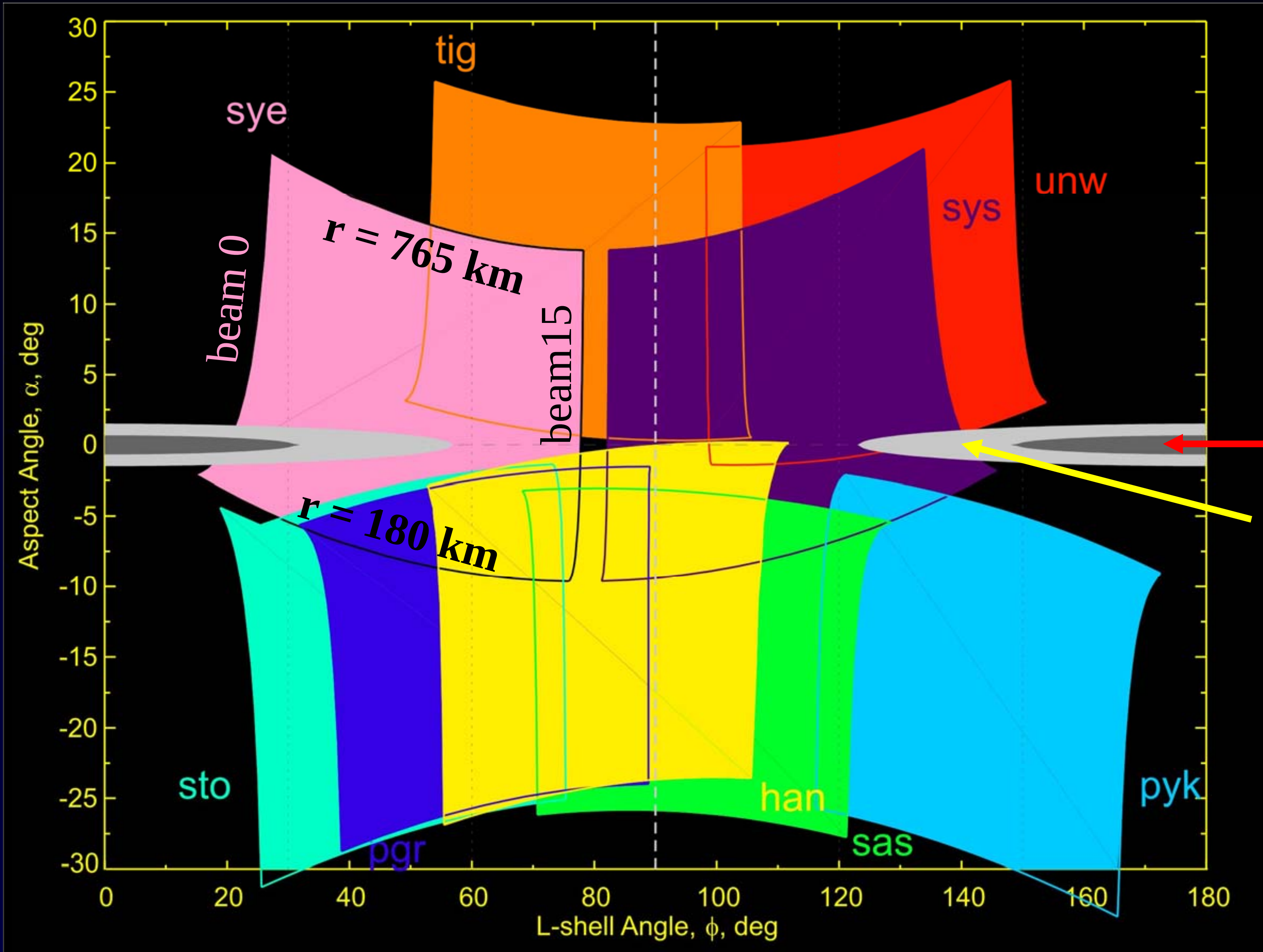
High-velocity E-region echoes near Cs = 400 m/s are believed to be generated by the modified two-stream instability (MTSI) inside the MTSI cone: at relatively small angles with respect to the plasma flow $\mathbf{V}_{e0}$ (flow angles $\theta < \sim 50°$) and at very small angles wrt to the magnetic field **B** (aspect angles $\alpha < 1°$).

Whether Doppler velocity of these echoes is Cs or some other model is not established.

Objectives

1. To determine which SuperDARN radars observe high-velocity echoes
2. To study their spatial occurrence patterns
3. To investigate echoes with particular high velocities ("super Cs")

SuperDARN Coverage in the E region



Radar should observe high-velocity echoes if its "α-ϕ footprint" overlaps with the MTSI cone

MTSI cone at 500 m/s

MTSI cone at 1000 m/s

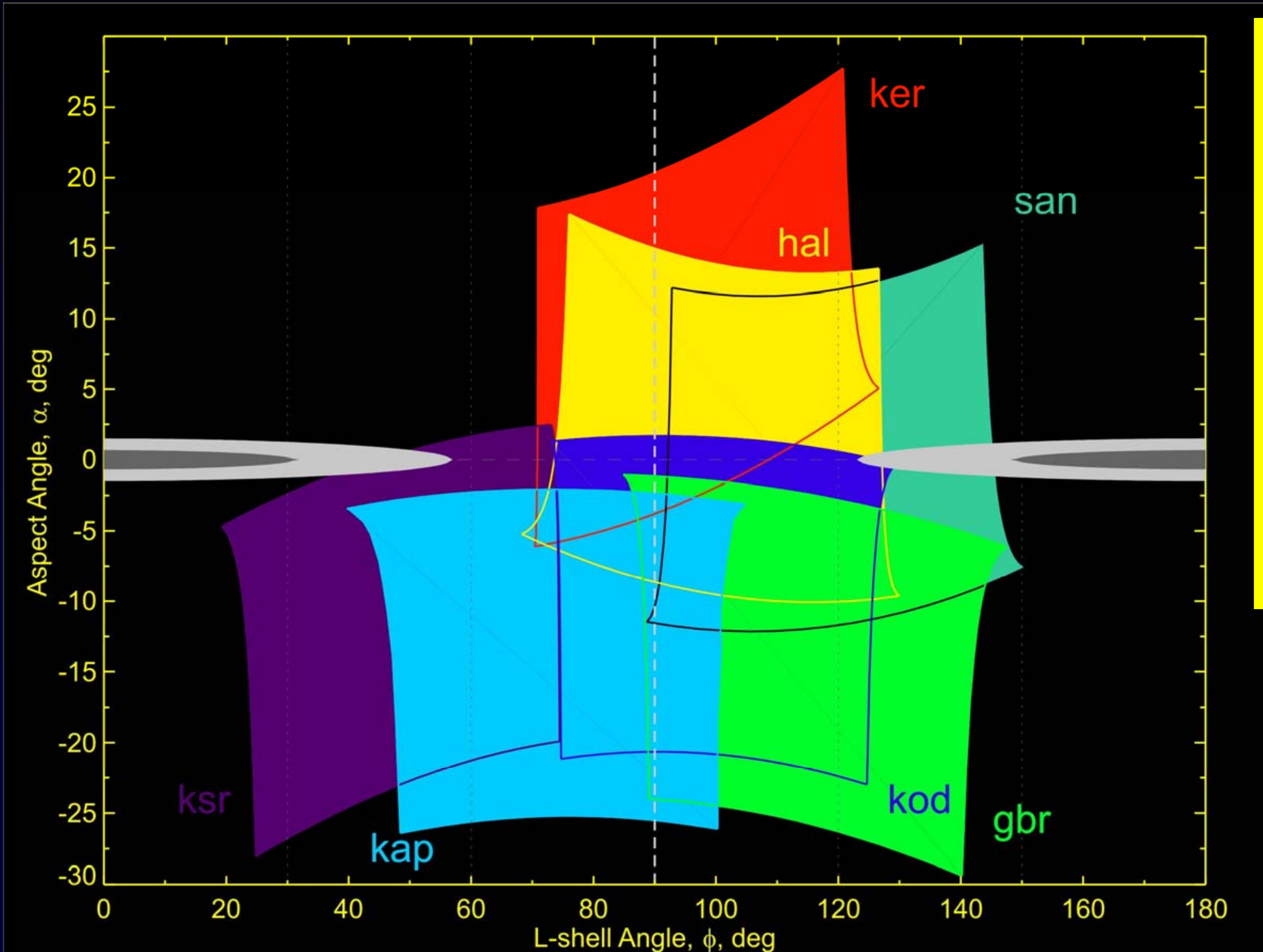
Prediction:

SYE has the best conditions

PYK, STO need some refraction (density)

SuperDARN coverage in the "α-ϕ space" was modeled using geometric aspect angles and L-shell angles

SuperDARN Coverage in the E region

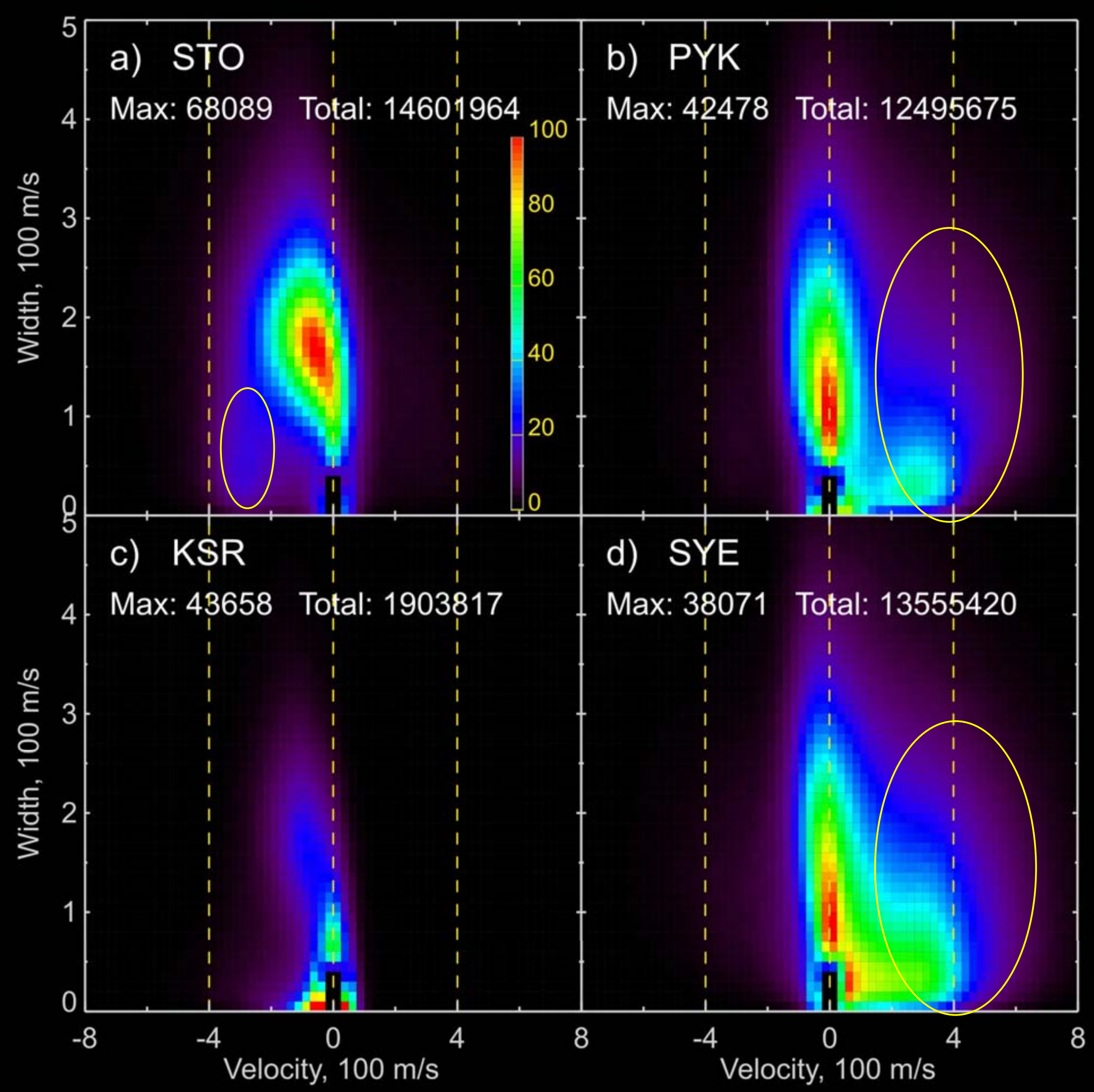


Prediction:

KSR require some refraction

SAN, SYS need strong convection GBR, KAP need enhanced density and convection

E-region Echo Populations: 2002-2004



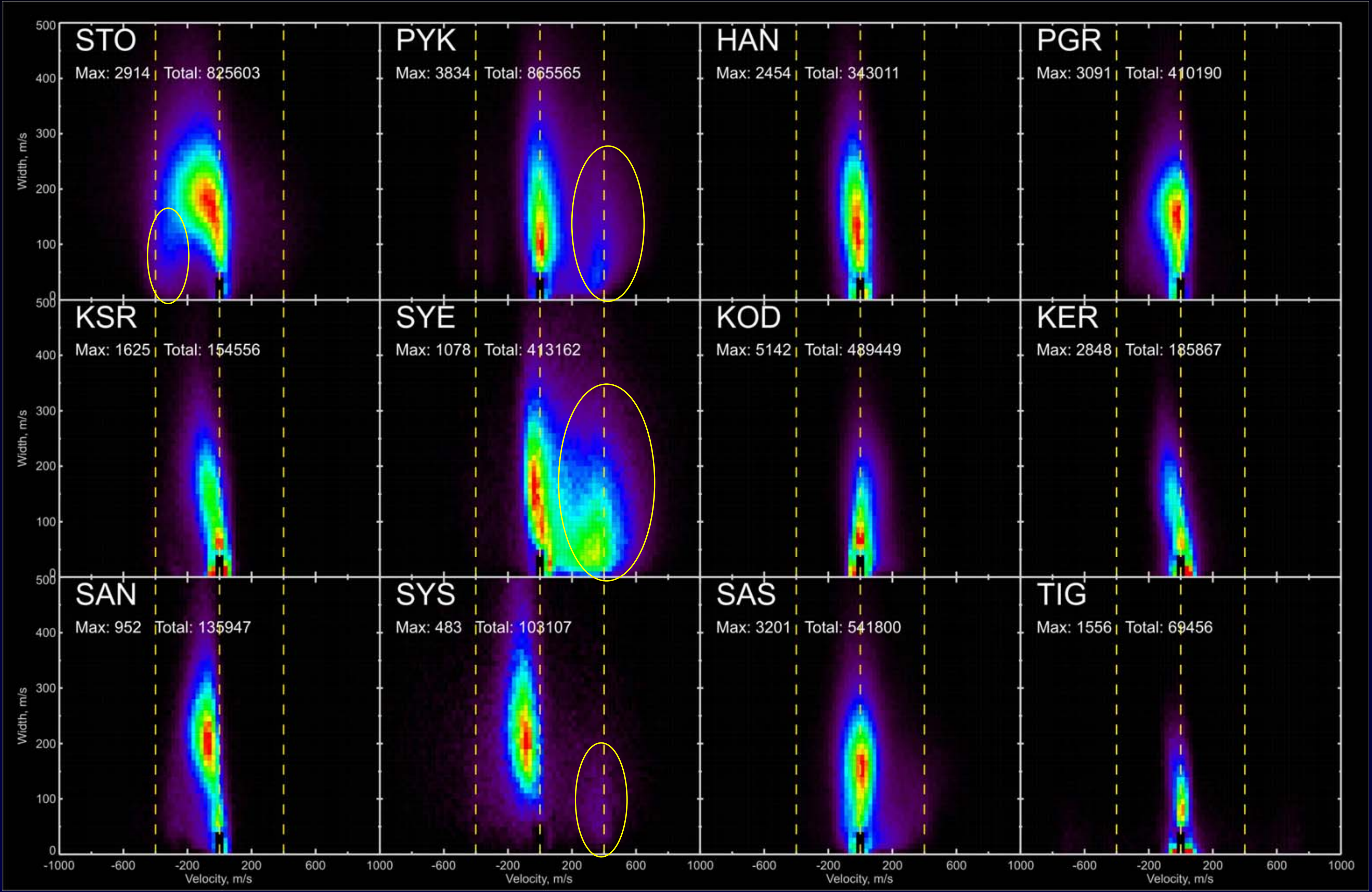
High-velocity echoes are observed by zonally looking radars on a statistical basis

SYE has the most prominent population

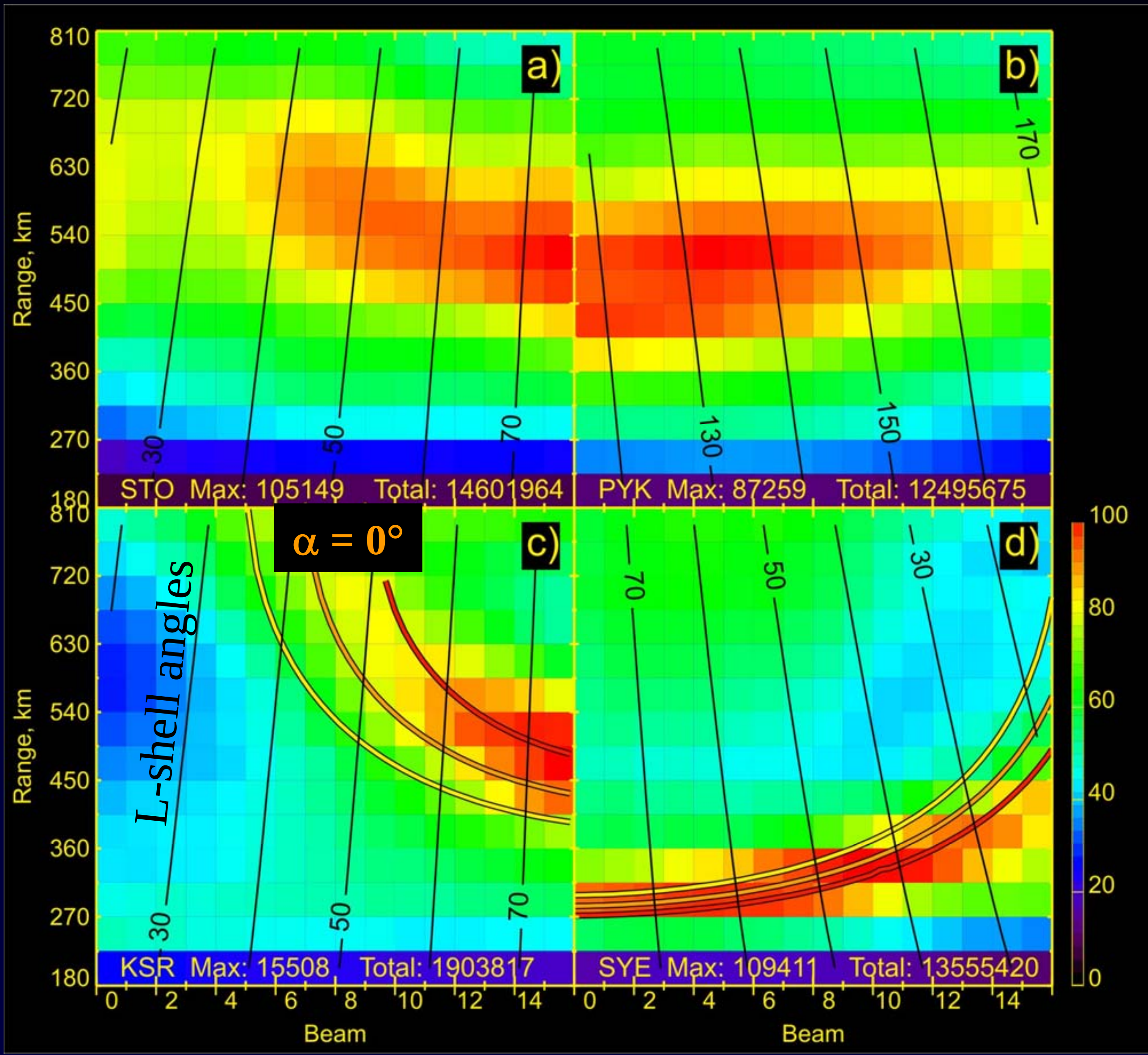
16-22 MLT

180 – 765 km

E-region Populations in Jan 2004



Occurrence Patterns: All Echoes

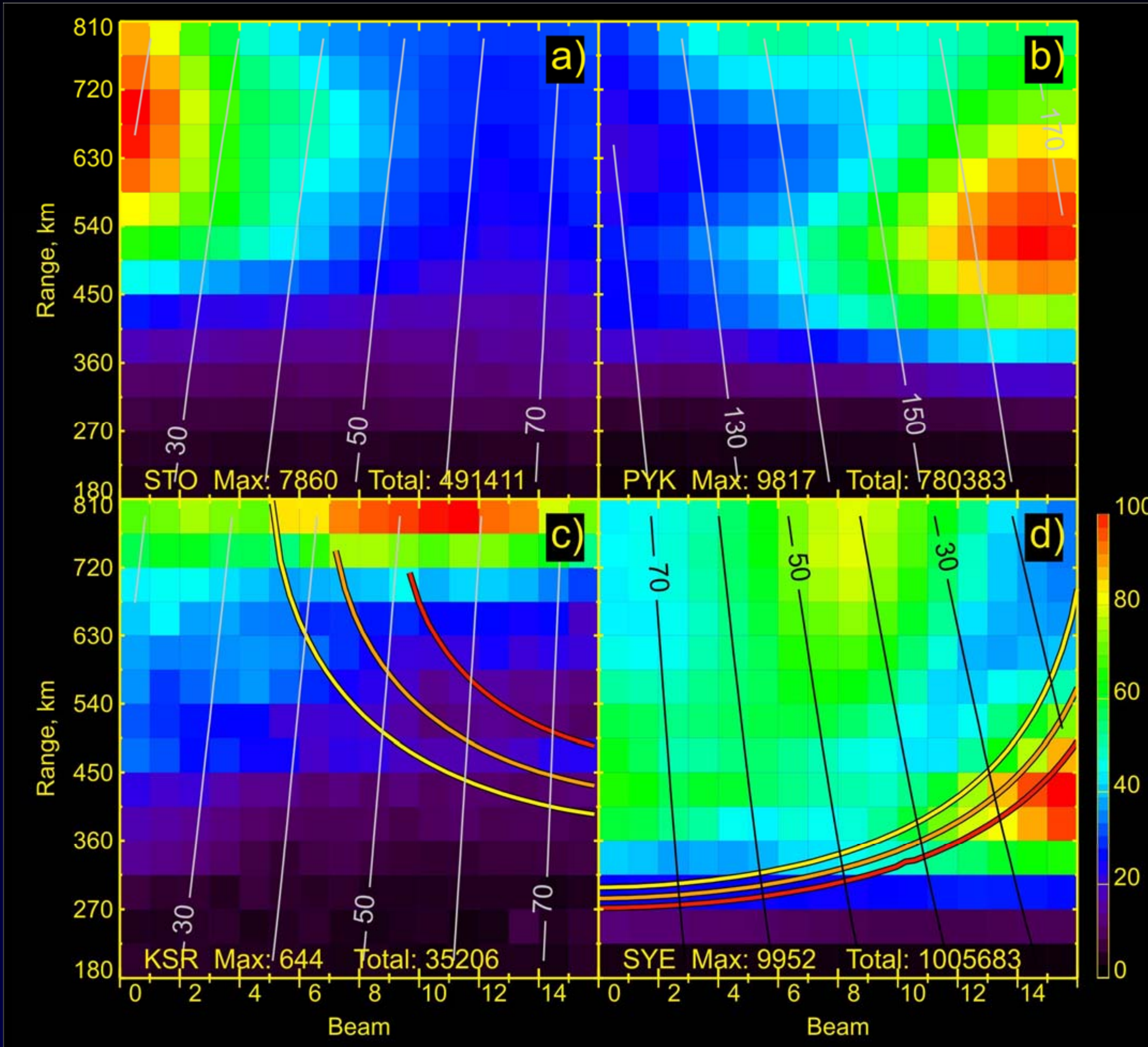


Echo distribution is approximately uniform across all beams

For KSR, SYE, the E-region band is roughly collocated with the lines of small geometric aspect angles

Short-range echoes: 2002-2004, 16-22 MLT

Occurrence Patterns: High-Velocity Echoes

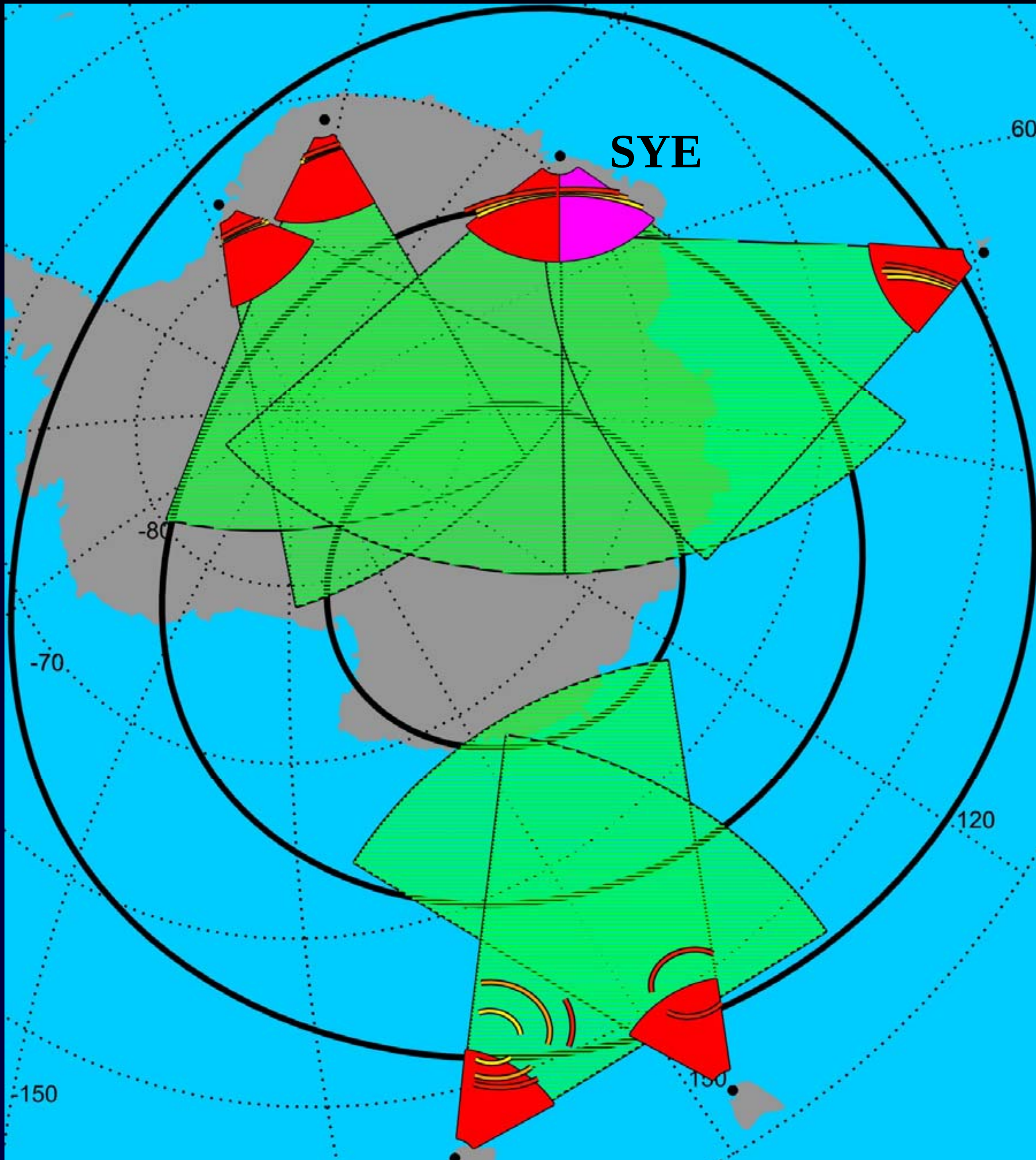


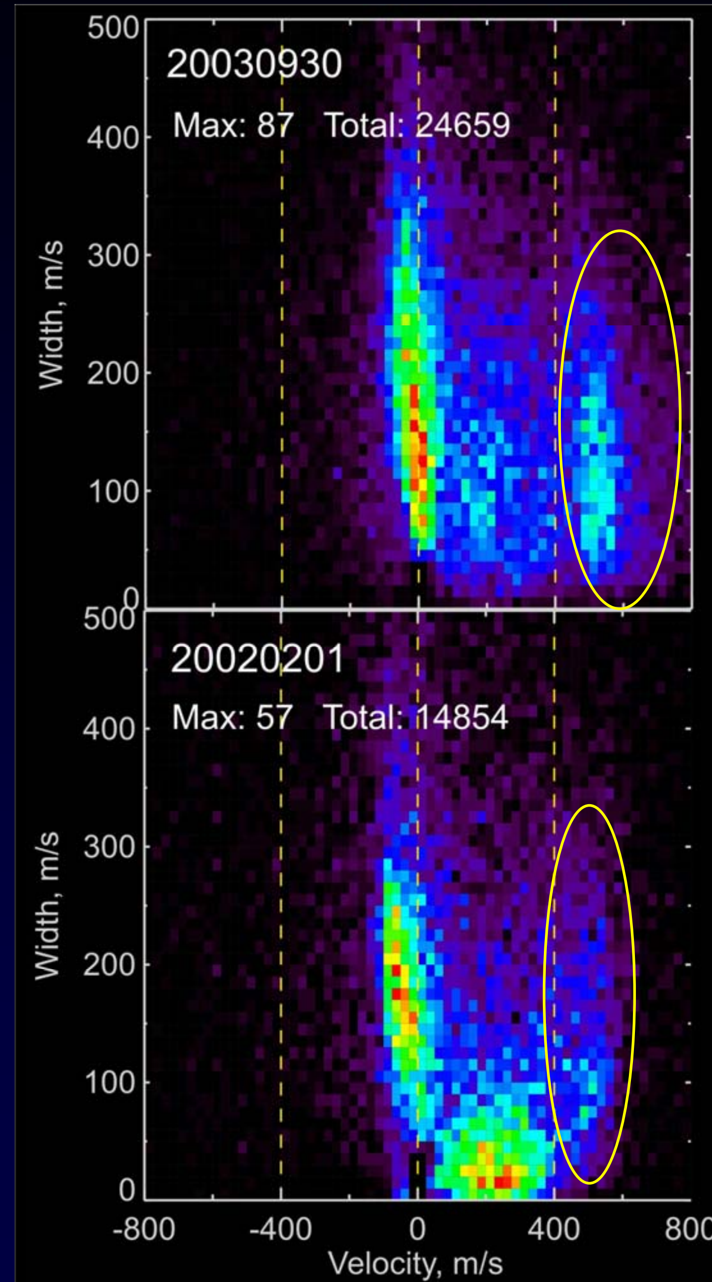
High-velocity echoes are observed mostly along the flow.

The latitudinal (slant range) extent of the region with HV echoes increases with L-shell angle decrease in agreement with the linear theory predictions (Slide 5).

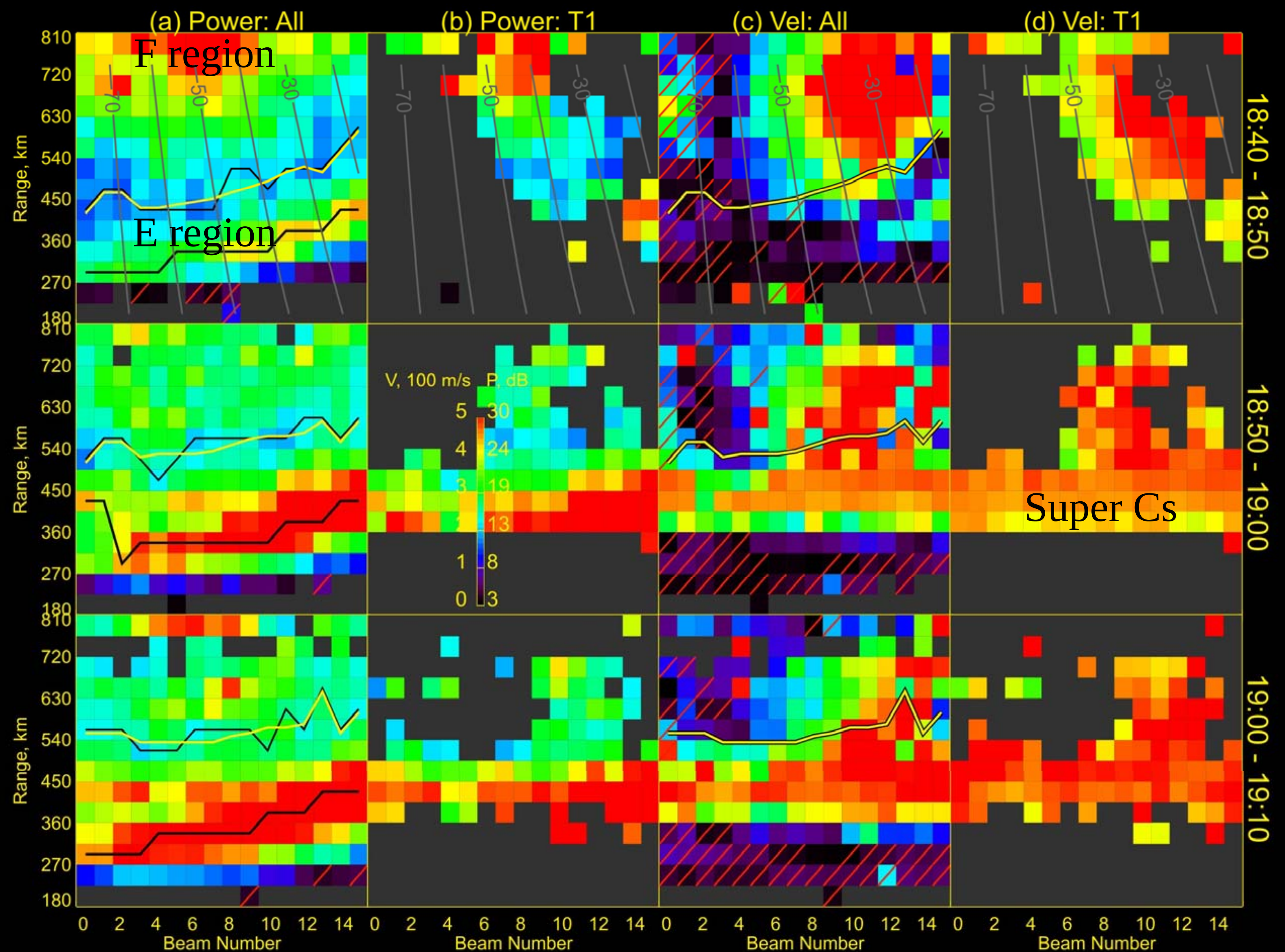
V = 350-450 m/s
W = 0-200 m/s

Syowa East Observations of Super Cs Echoes





Mean Power and Velocity



T1:
V = 500-700 m/s
W = 0-200 m/s

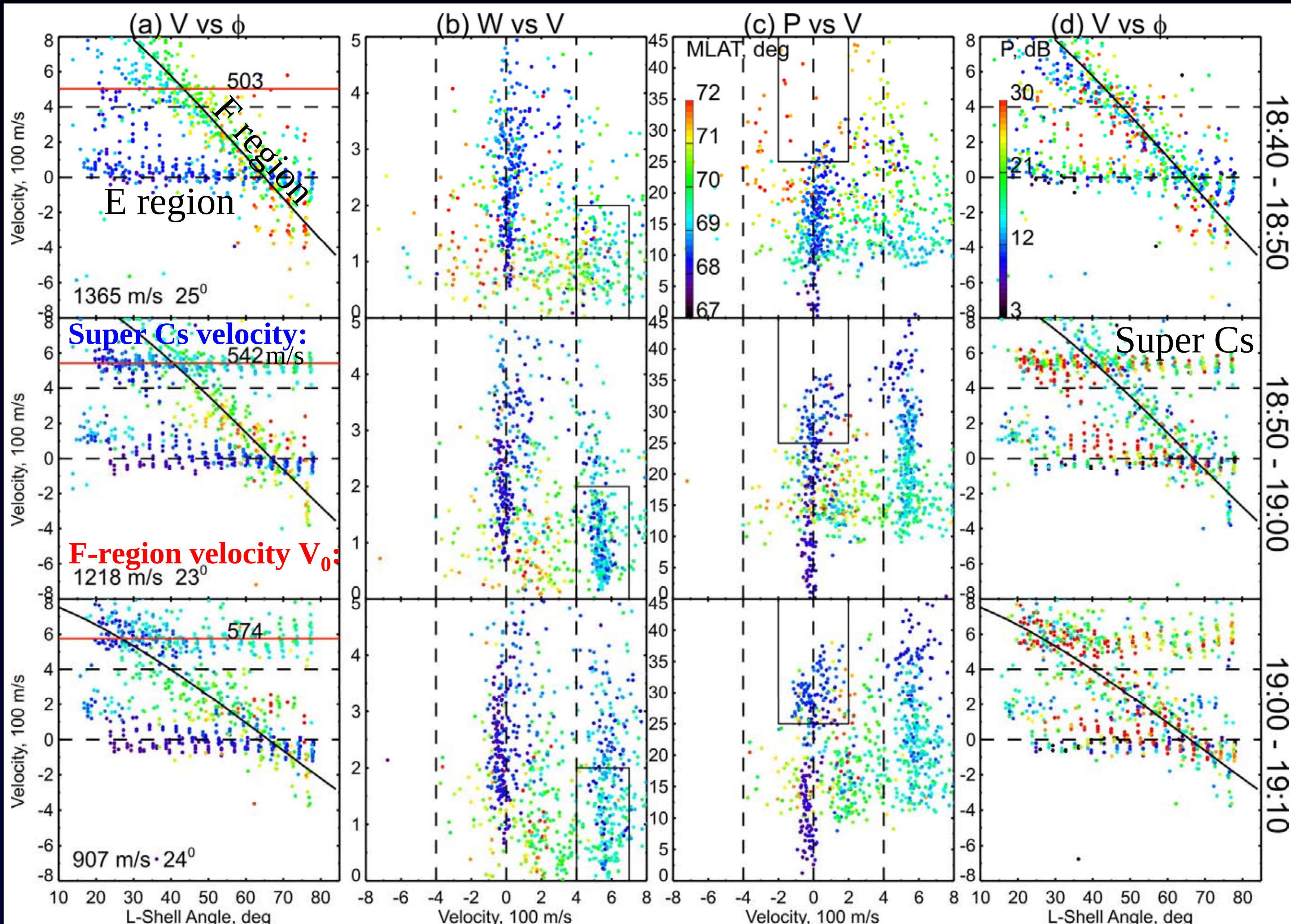
Super Cs (T1) echoes are observed:

at ranges 360-450 km

with velocities independent of beam direction and increasing with range

when high-power echoes are observed at ranges 225-305 km

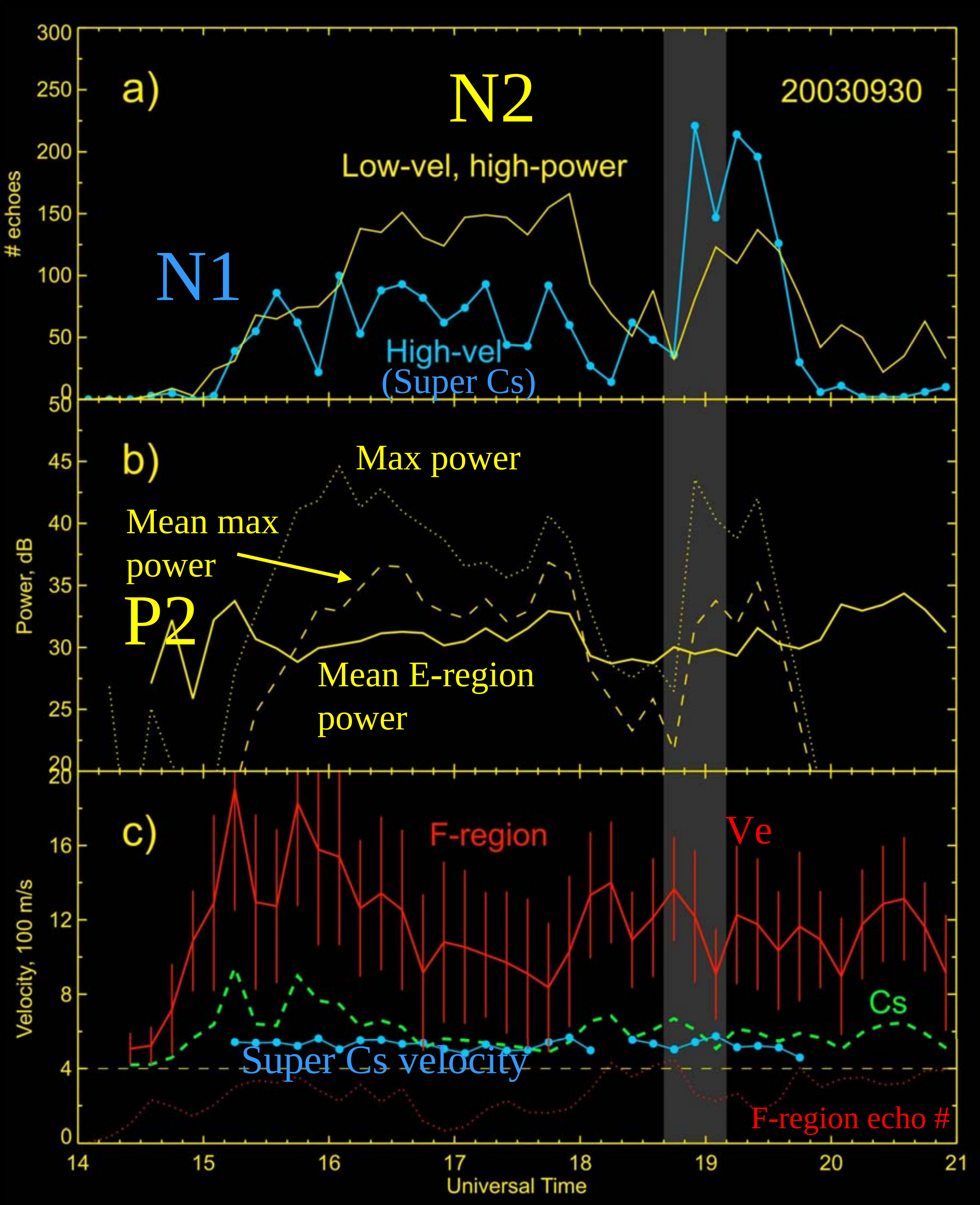
Scatter Plots



Super Cs velocity increases while the F-region plasma flow weakens

Super Cs echoes inside rectangle in (b) appear as high-power, low-velocity echoes appear inside rectangle in (c)

Time Variation



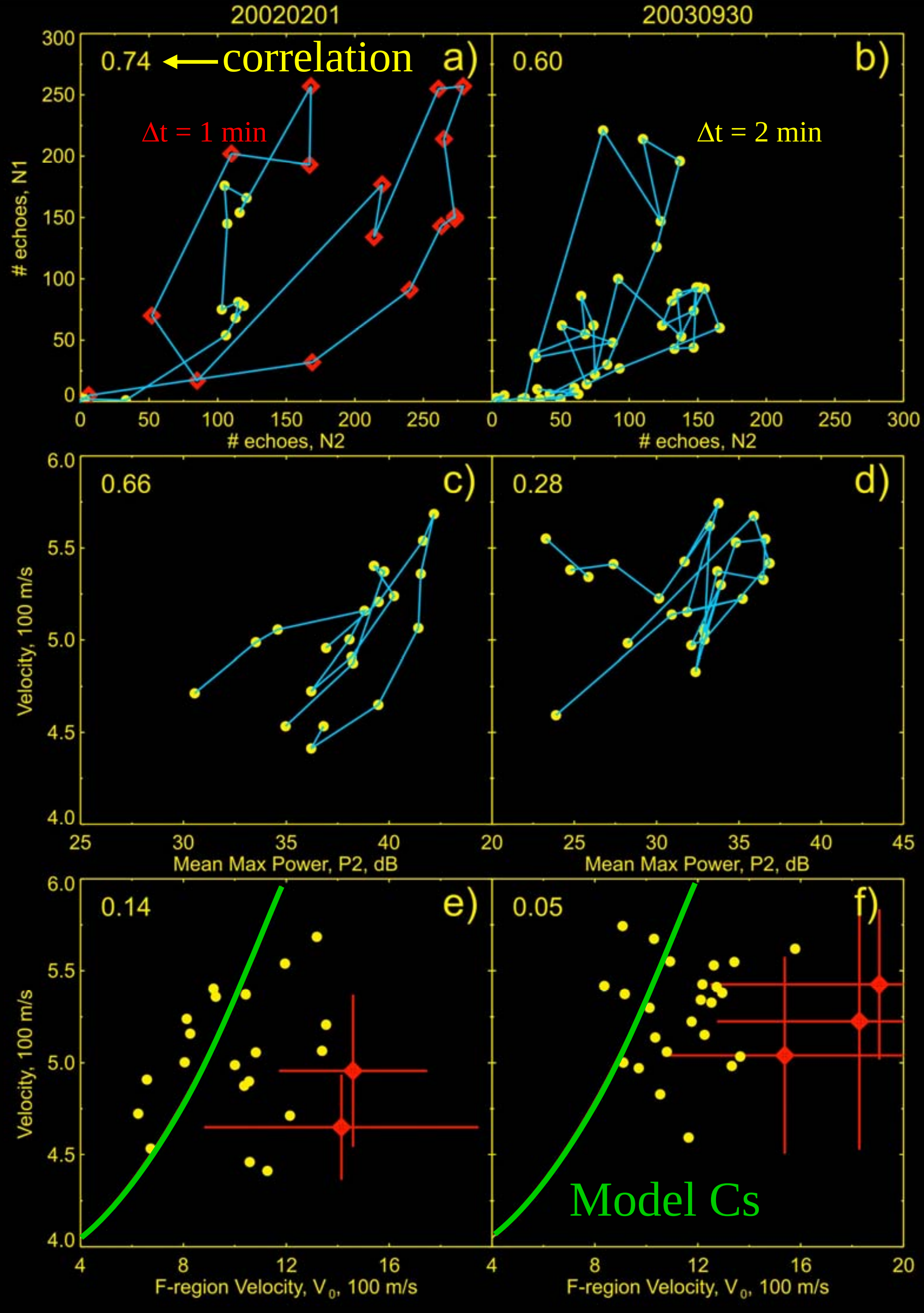
Number of high-velocity echoes N1 appears to correlate well with that of the low-velocity, high-power E-region echoes N2

It also correlates well with the maximum (along each beam) E-region power values averaged over all beams (mean max power or P2) and with the maximum power within the E-region band (max power)

Velocity of Super Cs echoes is close to model Cs values (determined from F-region plasma drift speed values V_0=Ve using the empirical formula below) except when Ve is large

$$C_S = 380 + 0.000155\,V_e^2$$

Scatter Plots



Correlation co-efficients between numbers of high-velocity echoes and low-velocity, high-power echoes are relatively high (0.74 and 0.60)

Correlation co-efficients between the velocity of high-velocity echoes and the mean max power of low-velocity, high-power echoes are lower (0.66 and 0.28) but most measurements adjacent in time (blue lines) show an increase

Correlation co-efficients between the velocity of high-velocity echoes and the model Cs velocity are negligible but measurements are consistent with the model Cs values within uncertainties (yellow dots) except for large F-region velocities (for which the model is not applicable anyway)

Summary and Conclusions

High-velocity E-region echoes near undisturbed Cs

- Observed by 4 zonally-looking SuperDARN HF radars at short ranges as significant statistical populations of echoes from the eastward electrojet.
- The electric field and aspect angle conditions strongly control their spatial occurrence in agreement with the modelling involving linear fluid theory of the Farley-Buneman instability.
- In particular, the latitudinal (slant range) extent of the occurrence region increases with the magnetic L-shell angle decrease, which is consistent with the aspect angle cone widening with the flow angle decrease as described by the FBI linear fluid theory.

The echoes with the Doppler velocities exceeding undisturbed Cs (“Super Cs echoes”)

1. Not present as a separate statistical population but rather occur on an event-by-event basis.
2. Observed in narrow bands at 360-450 km between the F-region and the low-velocity E-region echoes.
3. Their Doppler velocity is independent of the beam number (L-shell angle) and increases with range.
4. Associated with the strong low-velocity echoes.
5. Occur under the strong electric field conditions at all flow angles (including those outside the FBI flow angle cone).
6. Appear to be similar to the vertically propagating Type 1 echoes from the equatorial electrojet and may be generated through the nonlinear three-wave resonance interaction process.