The Importance of Ionospheric Pedersen Conductivity in the Control of SuperDARN Backscatter Power, LOS Doppler Velocity, and Spectral Width

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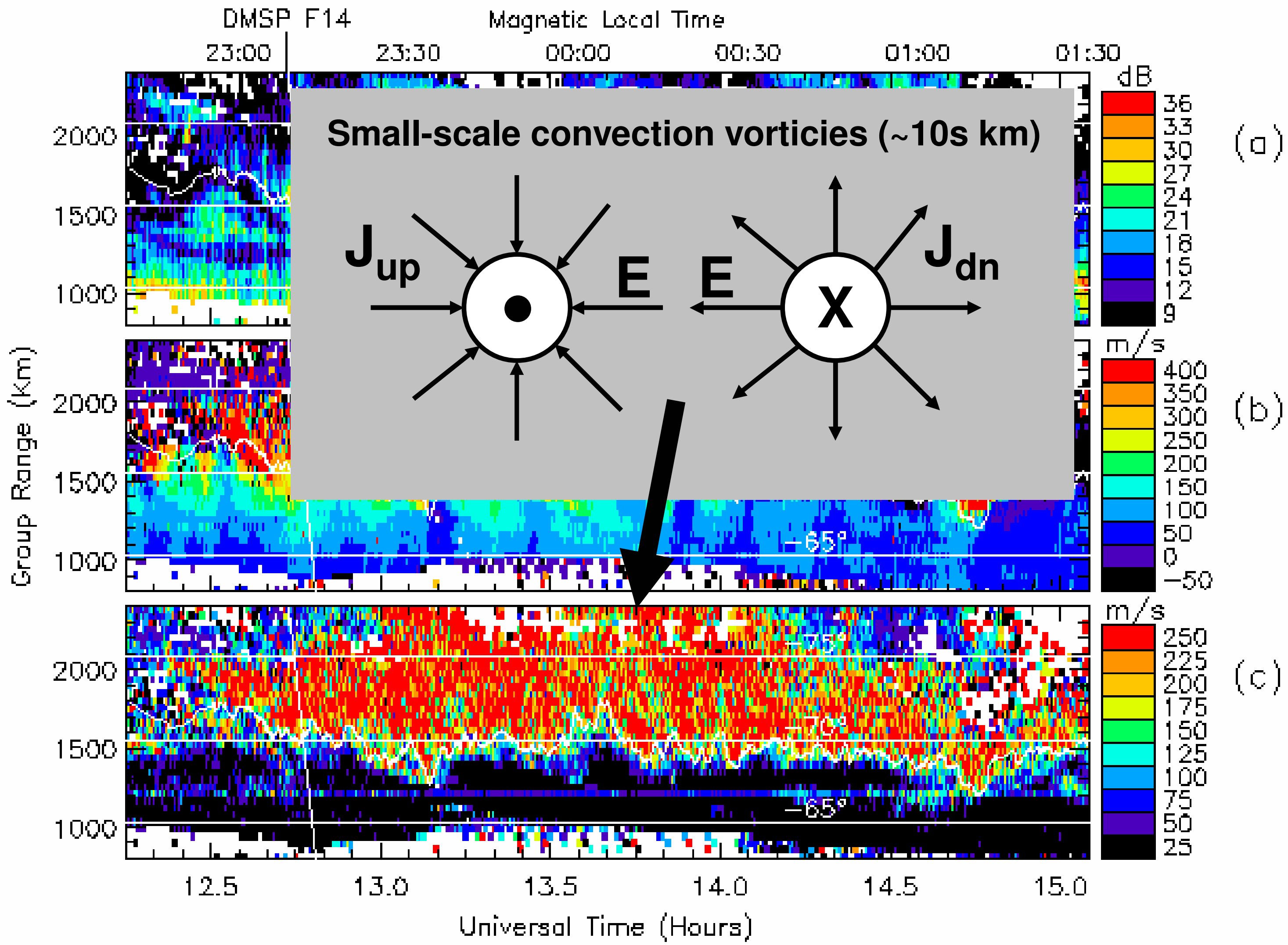
SuperDARN Backscatter Parameters



Definition of the Height-Integrated Pedersen Conductivity, Σ_p

Above 75 km the electron gas becomes collision-less, and the Pedersen conductivity is approximately:

$$\sigma_P \approx \frac{n_e e^2}{M_i \nu_{in}\left(1+\frac{\Omega_i^2}{\nu_{in}^2}\right)}$$

n_e = electron plasma density, M_i = ion mass

ν_{in} = ion neutral collision frequency

Ω_i = ion gyrofrequency

The Pedersen conductivity determines the field-perpendicular current density flowing in the direction of the field-perpendicular electric field. i.e., $J_\perp = \sigma_P E_\perp$

At high latitudes, the field-perpendicular direction is nearly horizontal.

The height-integrated Pedersen conductivity is: $\Sigma_P = \int_h \sigma_P dh$

It is enhanced by direct solar illumination, particle precipitation, and plasma transport.

Electrodynamic Consequences of Enhanced Σ_p

The ionosphere, magnetosphere, and thermosphere forms a coupled electrodynamic system which rapidly evolves until:

$$\nabla \bullet J = 0$$

Some familiar ideas and outrageous generalisations:

[1] Field-perpendicular electric fields $E_\perp$ are suppressed in regions of enhanced Σ_p (e.g. Milan et al, 1999; Parkinson et al, 2004). $E_\perp$ is strongest in the polar cap, weaker in the auroral oval, and weakest of all in the dayside mid-latitude ionosphere.

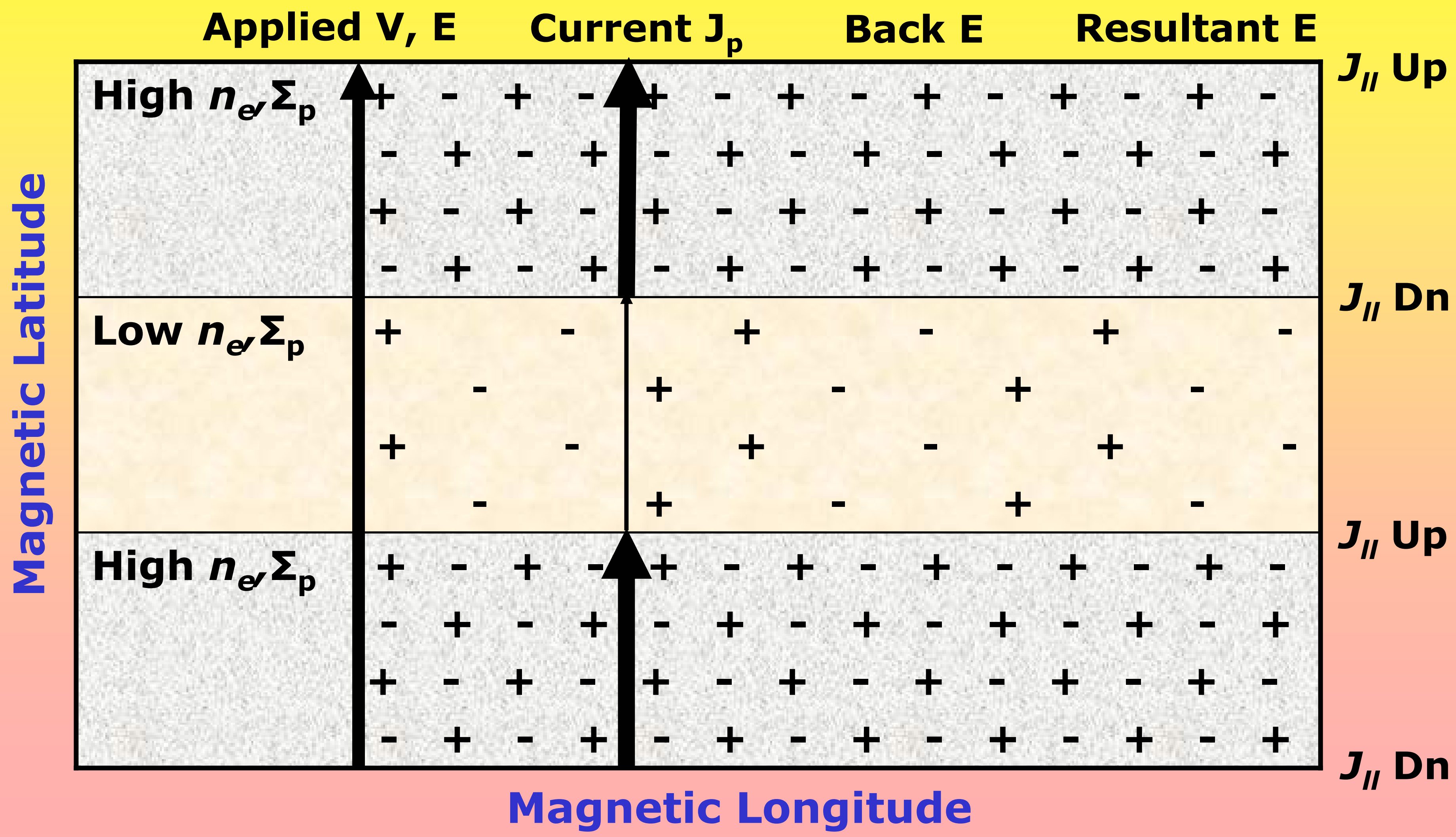
[2] Ionospheric irregularity production may be suppressed in regions of enhanced Σ_p (e.g. Milan et al, 1999). The growth rate of gradient drift waves is: $\gamma \propto (V-U)/L, \quad L = [(1/n_e)(dn_e/dx)]^{-1}$

The cross-field diffusion of ionospheric plasma is also enhanced (Vickrey and Kelley, 1982). Thus we expect weak irregularities.

[3] Are *Super*DARN Doppler spectral widths also suppressed in regions of enhanced Σ_p ???

Suppression of Electric Fields and Irregularities in Regions of Enhanced Σ_p

The *B*-perpendicular current sheets are closed by *B*-parallel current sheets



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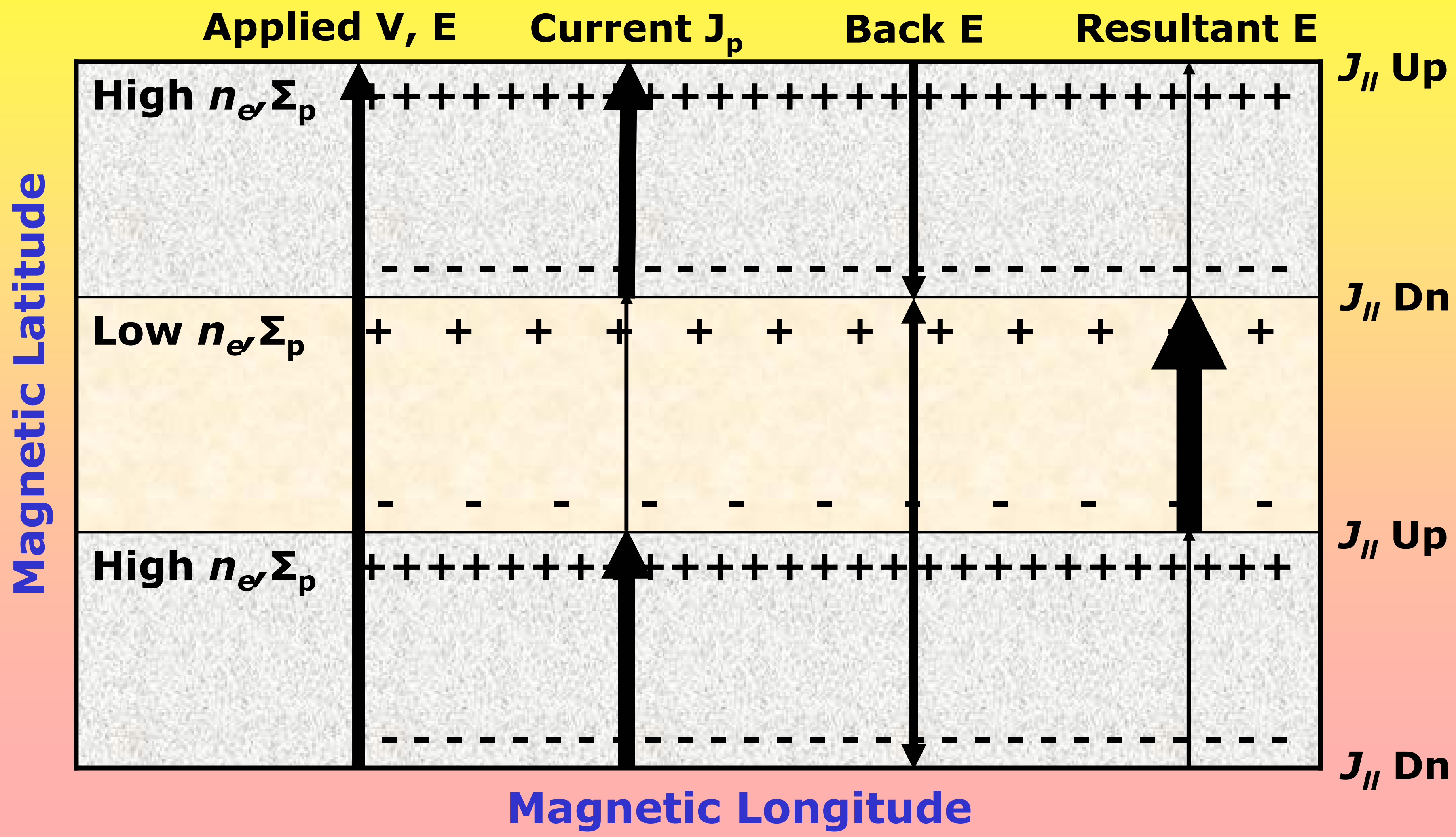


Basic Mechanics of the E×B Instability:

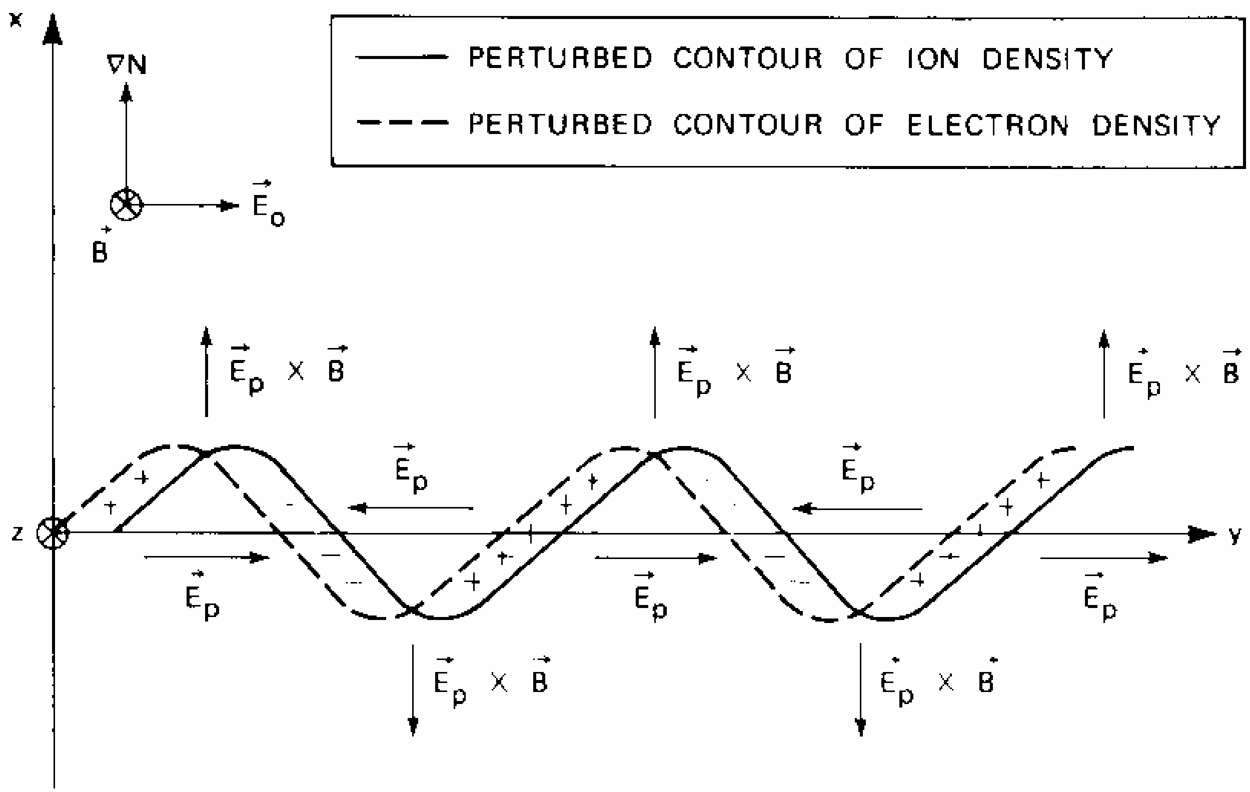


Fig. 21. Simplified schematic diagram showing the basic mechanics of the $\vec{E} \times \vec{B}$ instability. A Pedersen ion drift (to the right) leads to charge separation and the development of polarization electric fields, $\vec{E}_p$. The sense of $\vec{E}_p$ is to drive $\vec{E}_p \times \vec{B}$ motion that further enhances the original plasma perturbation.

Roland T. Tsunoda, "High-Latitude F Region Irregularities: A Review and Synthesis," Rev. Geophys., 26, 719-760, 1988

Mechanisms Enhancing SuperDARN Doppler Spectral Widths

***Super*DARN Doppler spectral widths are a measure of the life time of decametre-scale ionospheric irregularities and space and time variations in the line-of-sight Doppler velocity throughout the sampling volume and integration time. Complementary mechanisms have been proposed to explain the sometimes very large spectral widths (>500 m s^{-1}):**

[1] Non-uniform convection flows from small (~1 km) to large scales (~1000 km) (e.g. Parkinson et al, 1999; Andre et al, 2000).

[2] Electric field fluctuations due to ultra low frequency (ULF) wave activity in the Pc 1-2 frequency range (Andre et al, 1999, 2000).

[3] Radial electric fields emanating from fluctuating filamentary parallel currents (Huber and Sofko, 2000).

[4] Micro-scale plasma turbulence.

Understanding the causes of these drivers is an important topic in itself, but it is not the focus of this talk.

Doppler Spectral Width Hypothesis

The magnitude of *Super*DARN spectral widths is controlled by the multiplicative effect of the electric field fluctuation drivers and suppressors. Here we emphasise the role of Σ_p as a suppressor (though it may also regulate the driver):

Electric Field Fluctuation Drivers × **Electric Field Fluctuation Suppressors, Σ_p**

Thus, changes in *Super*DARN spectral widths will occur when and where there are changes in the behaviour of the drivers, suppressors, or both. For example, a spectral width boundary (SWB) will form at the equatorward edge of a high-latitude spectral width driver, which may also be closely aligned with the open-closed magnetic field line boundary (OCB). However, the SWB may often be a better proxy for the poleward edge of Σ_p enhanced by hot particle precipitation in the auroral zone. This boundary is sometimes aligned with the OCB anyway.

Suppression of Small-Scale (<100 km) Electric Field Fluctuations in the Auroral Zone

Weimer et al, "Auroral zone electric fields from DE 1 and DE 2 at magnetic conjunctions," JGR, vol. 90, pp. 7479-7494, 1985.

Suppression of small-scale ionospheric electric fields where Σ_p is enhanced is consistent with earlier theory (Lyons, 1980, 1981; Chiu et al, 1981).

Dynamics Explorer (DE)

DE 1 > 4500 km

DE 2 < 900 km

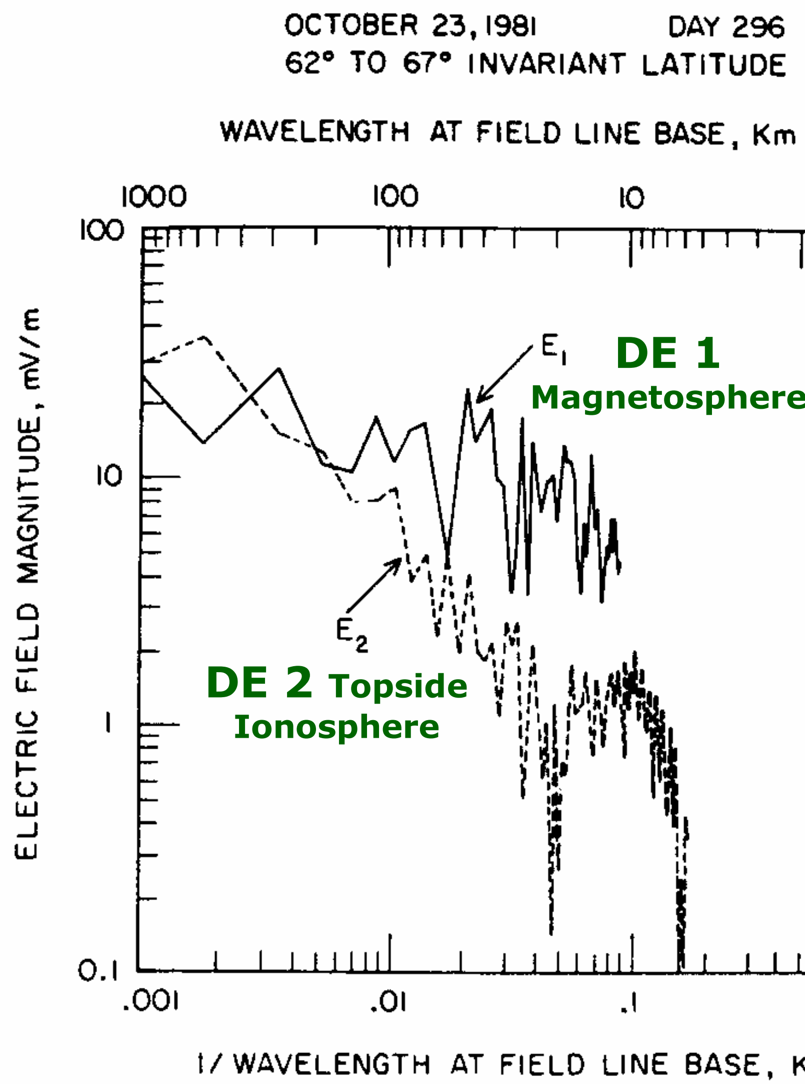


Fig. 4. Electric field spectrums from day 296 (October 23) of 1981. The spectrums are obtained from a Fourier transform of the electric field data between 62° and 67° invariant latitude. The solid line shows the spectrum of the electric field measured by DE 1. The solid line shows the spectrum of the electric field measured by DE 2. The ordinate values are obtained from the square root of the "spectral power density." The actual units are mV m^{-1} $km^{1/2}$.

Weimer et al, 1985

Suppression of Small-Scale (<100 km) Electric Field Fluctuations in the Auroral Zone

Dudeney et al, "The nightside ionospheric response to IMF B_y changes," JGR, vol. 25, pp. 2601-2604, 1998.

Electric field fluctuations in the Pc 1 (and greater) frequency range and *Super*DARN Doppler spectral widths were suppressed in regions of more energetic ion precipitation, and presumably larger Σ_p.

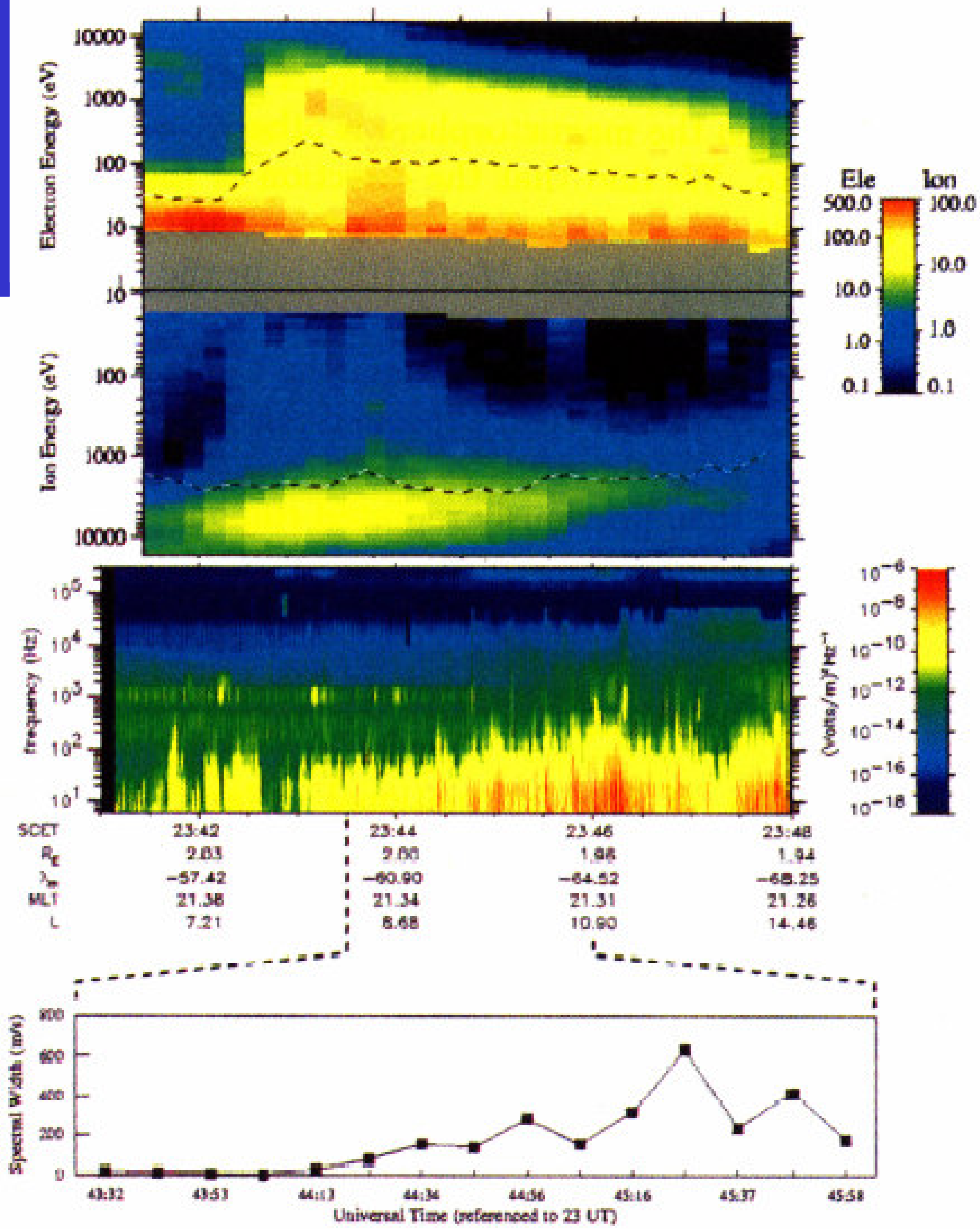
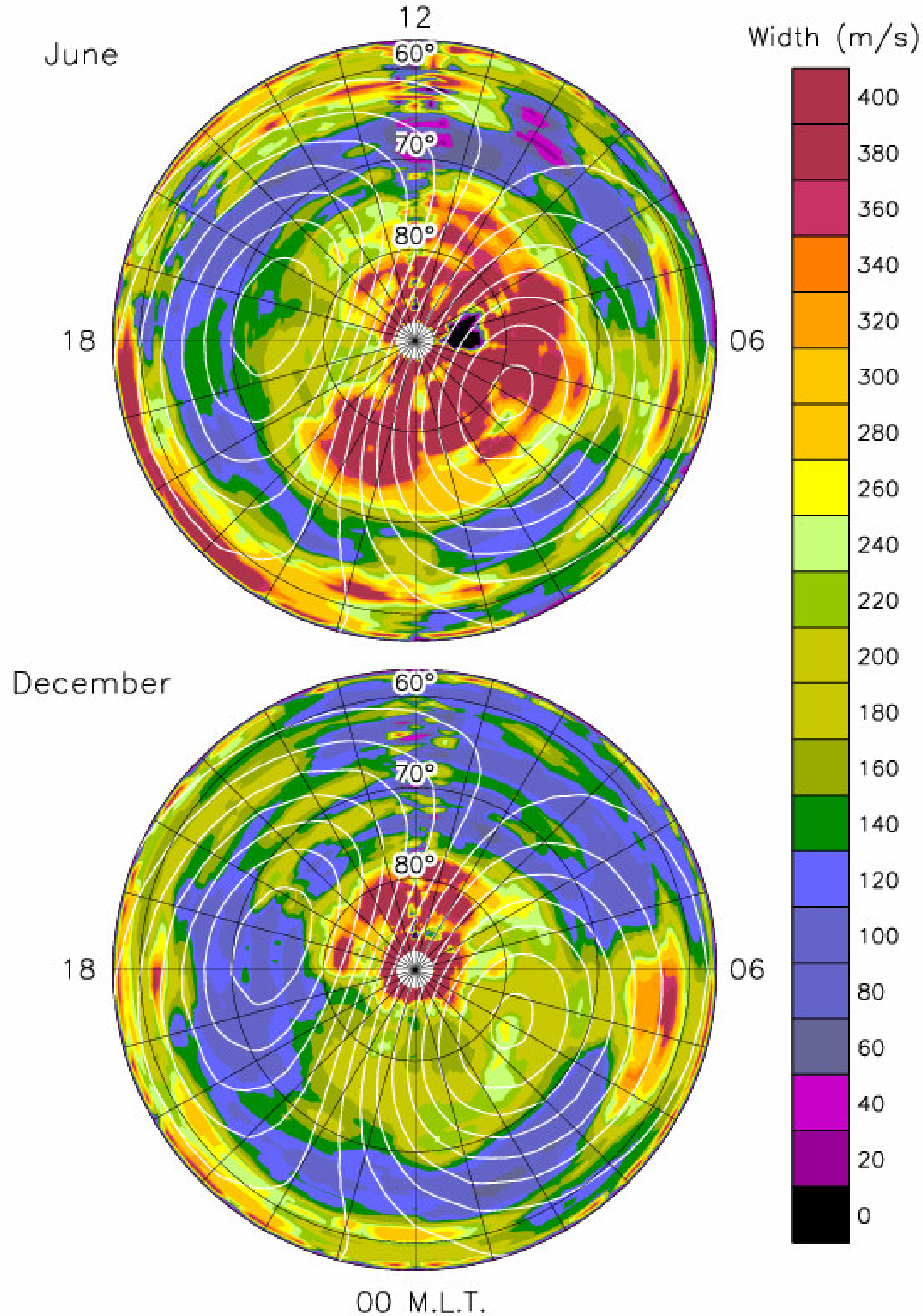


Figure 3. The top panels are the ion and electron spectrogram determined by the Hydra instrument on POLAR for the interval 2341–2348 UT. The third panel shows the corresponding electric wave data recorded by the PWI instrument on POLAR. The bottom panel gives the Halley HF radar line-of-sight velocity and the Doppler spectral width measurements at the ionospheric footprint of POLAR between 2343 and 2346 UT.

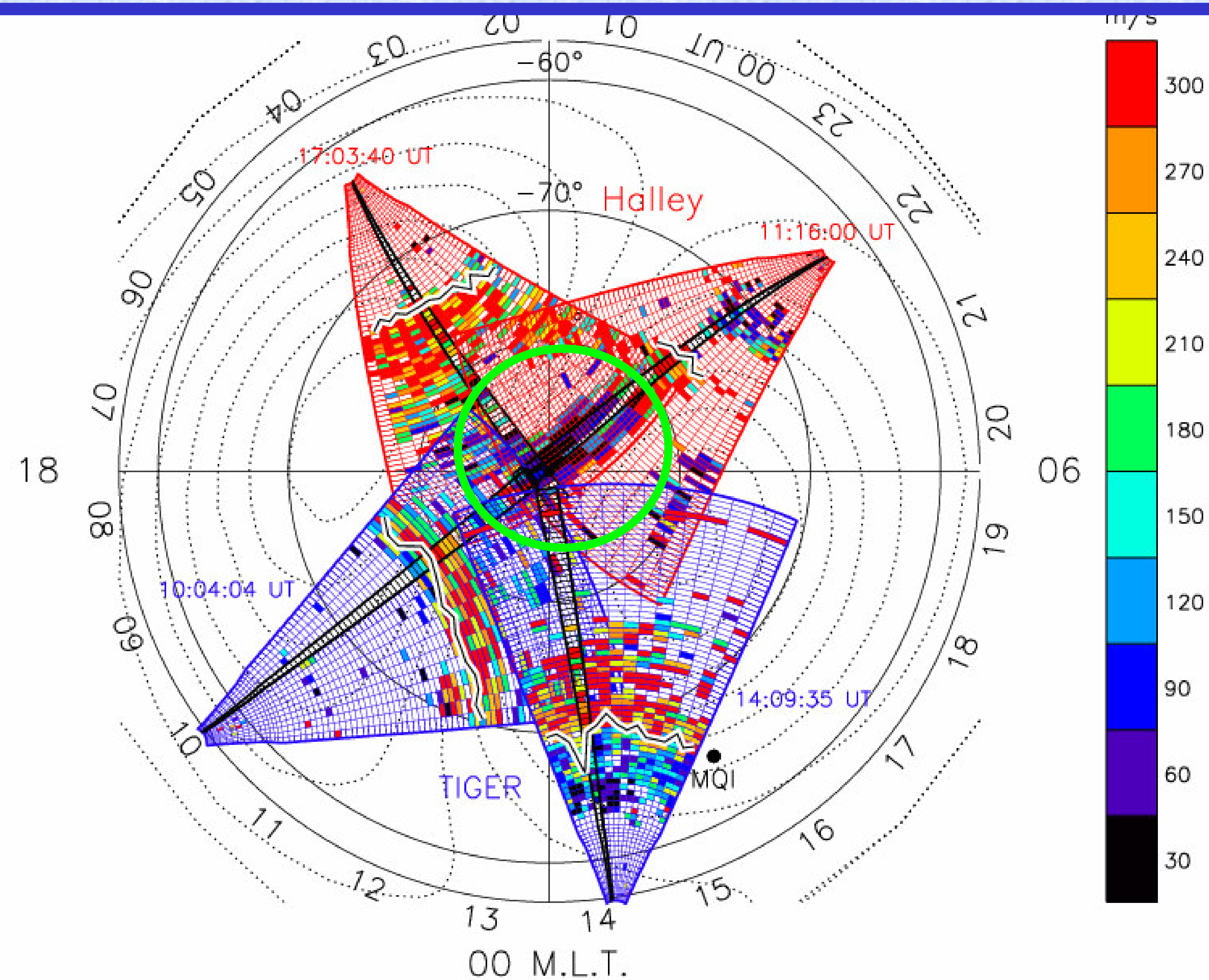
Suppression of TIGER Radar Spectral Widths by Insolation?

Parkinson et al, "On the occurrence and motion of decametre-scale irregularities in the sub-auroral, auroral, and polar cap ionosphere ," Ann. Geophysicae, vol. 21, pp. 1847-1868, 2003.

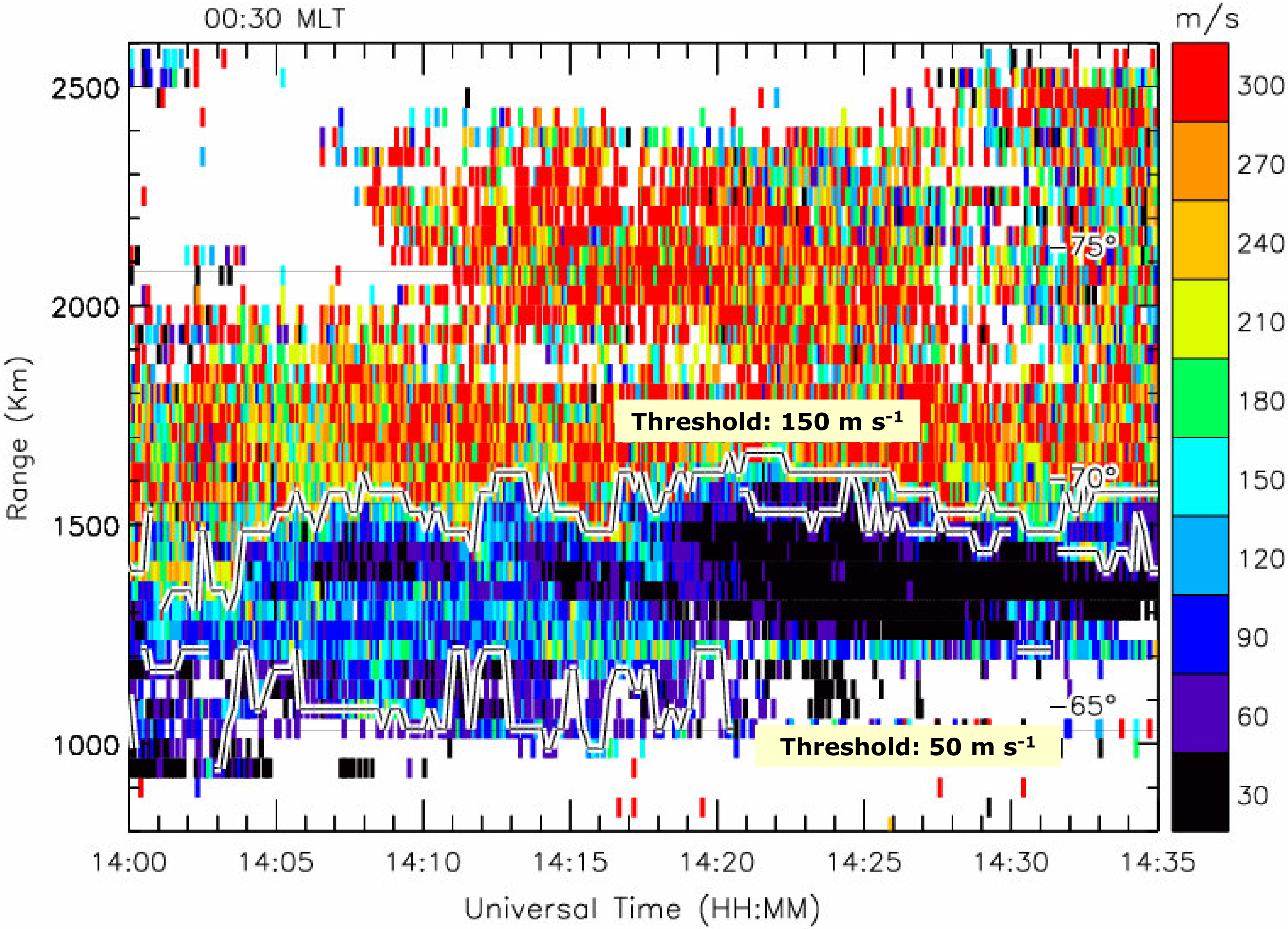
Regions with unusually large average spectral widths (>350 m s^{-1}) were suppressed during the austral summer solstice month, December 2000. They were confined to the noon-sector ionosphere poleward of −78°Λ, and the dawn sector near ~ −62°Λ.



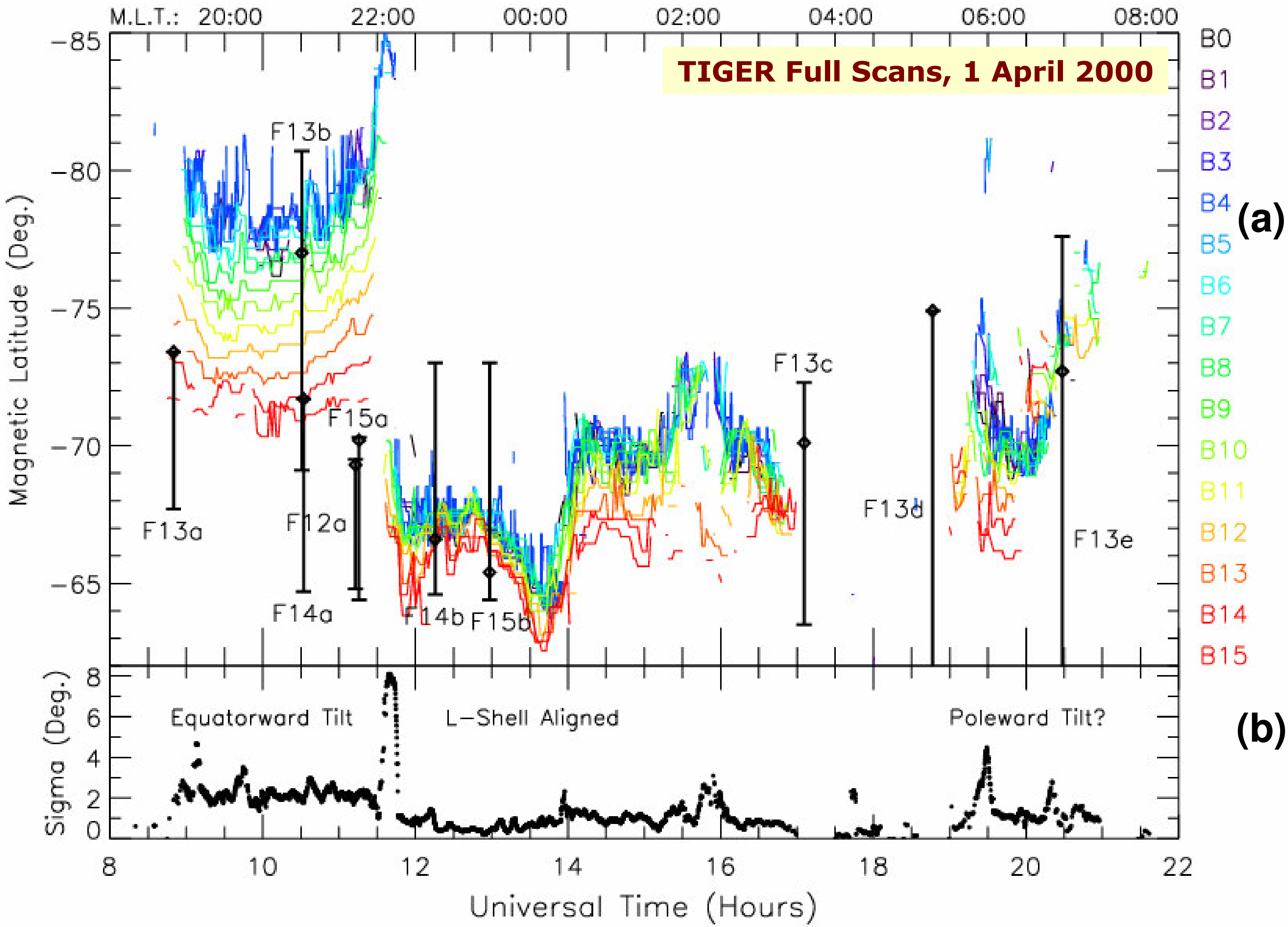
Multiple Spectral Width Distributions and Boundaries Consistent with Spatial and Temporal Variability in Drivers and Suppressors, Σ_p



Spectral Width vs. Group Range and Time, 1 April 2000



Spectral Width Boundary (SWB) vs. MLAT and Time



TIGER Spectral Width Boundary, 31 October 2000

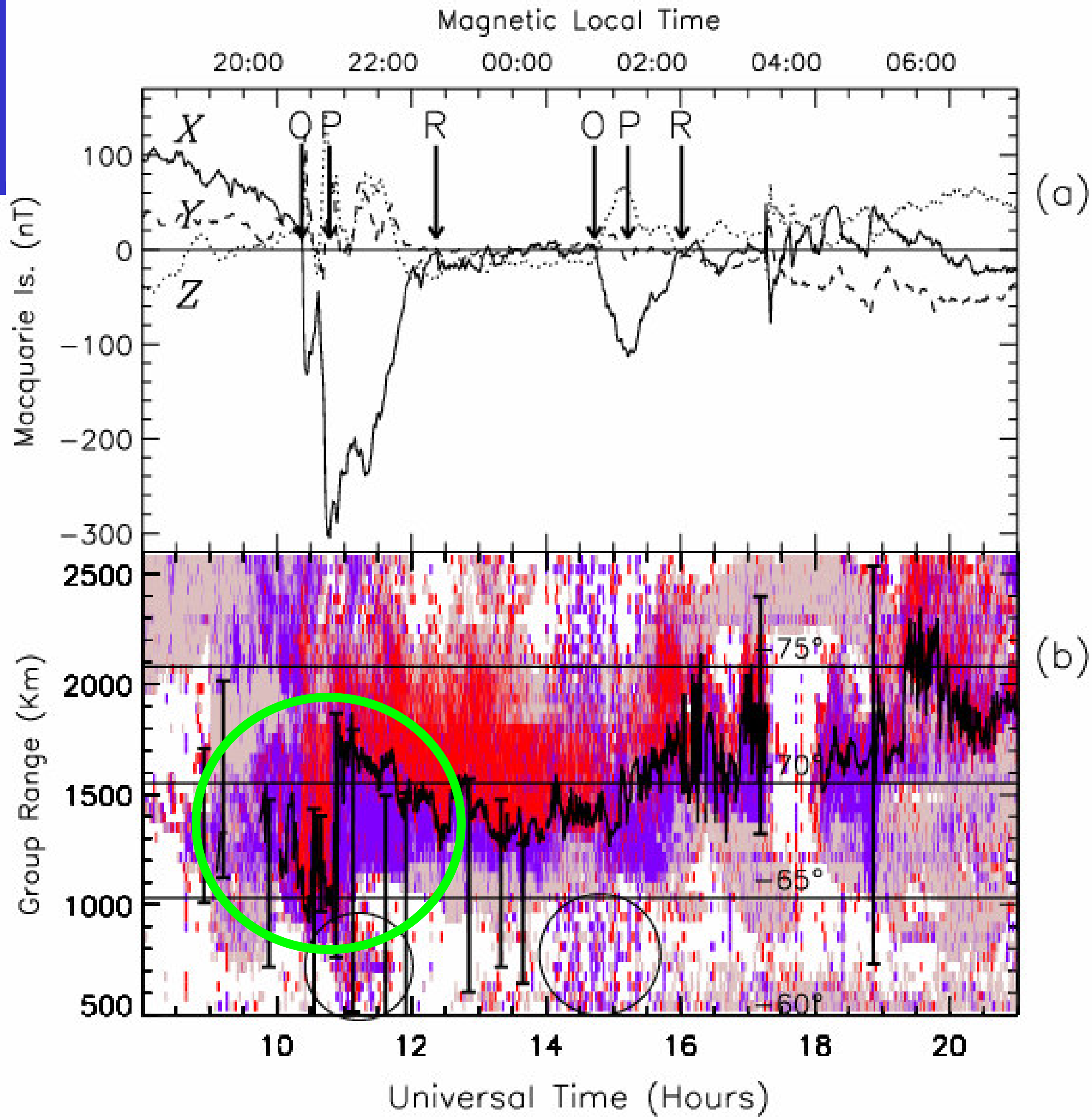
(a) Macquarie Island fluxgate magneto-meter

(b) Spectral widths vs. group range and time, beam 4

Ionospheric echoes, spectral width >200 m s^{-1}

Ionospheric echoes, Spectral width <200 m s^{-1}

Sea echoes, spectral width <30 m s^{-1}



Summary

- Spatial and temporal variability in *Super*DARN spectral widths is controlled by the multiplicative effect of changes in the magnetospheric driver(s) of electric field fluctuations with changes in the suppression of those fluctuations by the height-integrated Pedersen conductivity, Σ_p.
- The spectral width boundary (SWB) is often a better proxy for the poleward edge of height-integrated Pedersen conductivity enhanced by hot particle precipitation in the auroral zone. This proxy is often closely aligned with the open-closed magnetic field line boundary (OCB).
- There are multiple SWBs and multiple populations of spectral widths (in fact, an infinite number). These populations must arise because of spatial and temporal variations in the magnetospheric driver(s) and Σ_p.
- There are reproducible changes in the location of the nightside SWB organised according to substorm phase. The SWB usually expands equatorward during the growth phase, and then contracts suddenly during the recovery phase. The expansion is delayed after the expansion in the noon-sector ionosphere, and the contraction probably precedes the contraction in the noon-sector ionosphere.