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

M. L. Parkinson and others?

Department of Physics, La Trobe University, Melbourne, Victoria 3086, Australia.
SuperDARN Backscatter Parameters

Small-scale convection vorticies (~10s km)

\[ J_{\text{up}} \quad E \quad E \quad X \quad J_{\text{dn}} \]
Definition of the Height-Integrated Pedersen Conductivity, $\Sigma_p$

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
$\nu_{in} =$ ion neutral collision frequency
$\Omega_i =$ 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:

$$\Sigma_p = \int_h^\infty \sigma_p dh$$

It is enhanced by direct solar illumination, particle precipitation, and plasma transport.
Electrodynamic Consequences of Enhanced $\Sigma_p$

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

$$\nabla \cdot J = 0$$

Some familiar ideas and outrageous generalisations:

[1] Field-perpendicular electric fields $E_\perp$ are suppressed in regions of enhanced $\Sigma_p$ (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 $\Sigma_p$ (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 SuperDARN Doppler spectral widths also suppressed in regions of enhanced $\Sigma_p$???
Suppression of Electric Fields and Irregularities in Regions of Enhanced $\Sigma_p$

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

<table>
<thead>
<tr>
<th>Magnetic Latitude</th>
<th>Applied V, E</th>
<th>Current $J_p$</th>
<th>Back E</th>
<th>Resultant E</th>
</tr>
</thead>
<tbody>
<tr>
<td>High $n_e\Sigma_p$</td>
<td>- - - - + + + + - - - - + + + +</td>
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<tr>
<td>Low $n_e\Sigma_p$</td>
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<tr>
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</tbody>
</table>

$J_{\parallel}$ Up

$J_{\parallel}$ Dn

Magnetic Longitude
Suppression of Electric Fields and Irregularities in Regions of Enhanced $\Sigma_p$

The $B$-perpendicular current sheets are closed by $B$-parallel current sheets.
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.
Mechanisms Enhancing SuperDARN Doppler Spectral Widths

SuperDARN Doppler spectral widths are a measure of the lifetime 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).


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 SuperDARN spectral widths is controlled by the multiplicative effect of the electric field fluctuation drivers and suppressors. Here we emphasise the role of $\Sigma_p$ as a suppressor (though it may also regulate the driver):

Electric Field Fluctuation Drivers $\times$ Electric Field Fluctuation Suppressors, $\Sigma_p$

Thus, changes in SuperDARN 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 $\Sigma_p$ 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


Suppression of small-scale ionospheric electric fields where $\Sigma_p$ 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


Electric field fluctuations in the Pc 1 (and greater) frequency range and SuperDARN Doppler spectral widths were suppressed in regions of more energetic ion precipitation, and presumably larger $\Sigma_p$.

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.

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

Threshold: 150 m s\(^{-1}\)

Threshold: 50 m s\(^{-1}\)
Spectral Width Boundary (SWB) vs. MLAT and Time

(a)

TIGER Full Scans, 1 April 2000

(b)
(a) Macquarie Island fluxgate magnetometer

(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\(^{-1}\)
Spatial and temporal variability in SuperDARN 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, $\Sigma_p$.

The spectral width boundary (SWB) is often a better proxy for the poleward edge of height-integrated Pedersen conductivity enhanced by hot particle-integrated 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 $\Sigma_p$.

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.