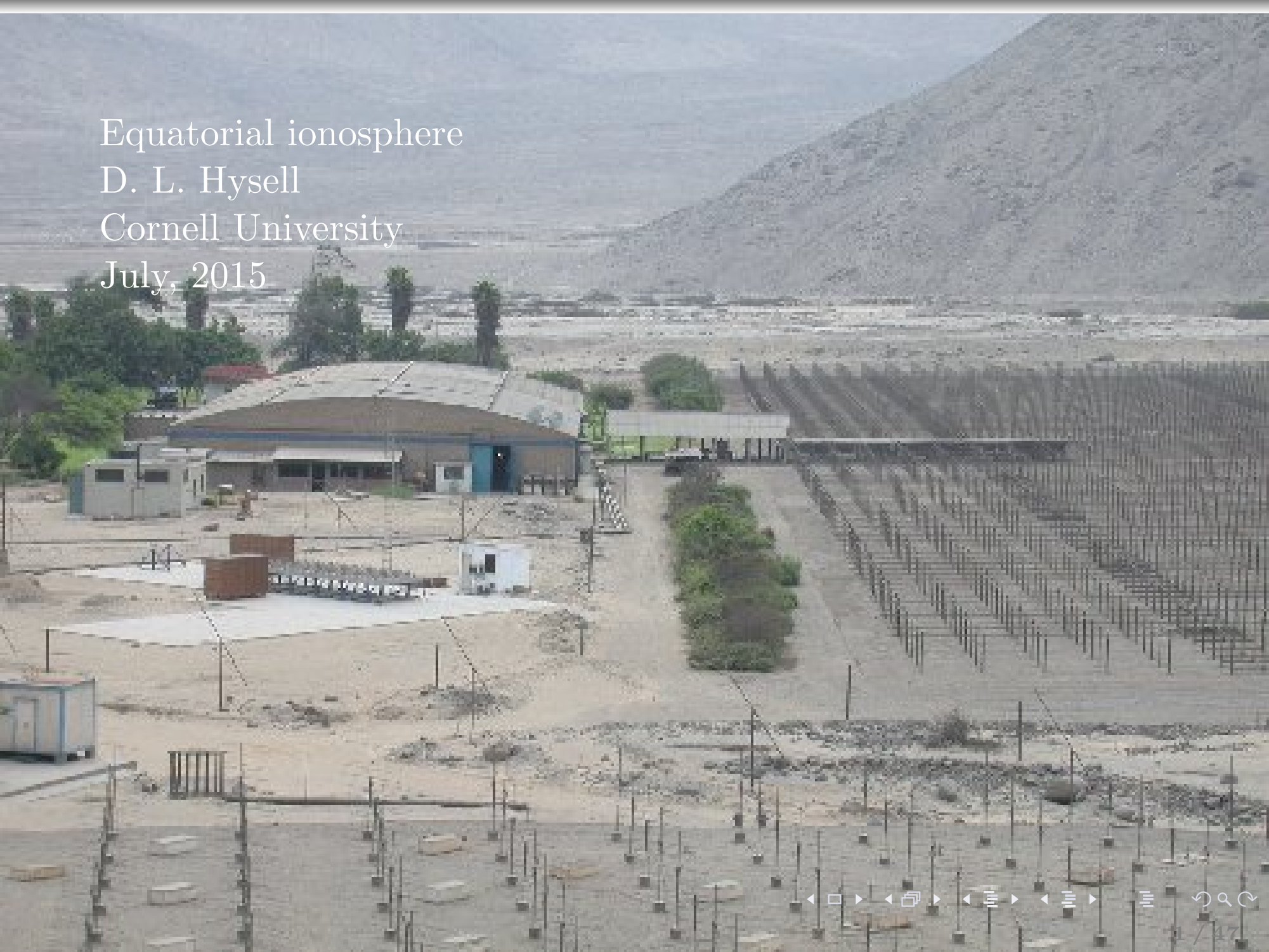
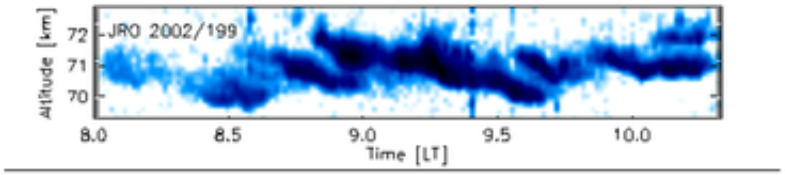
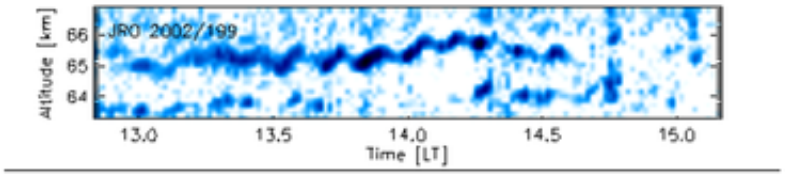


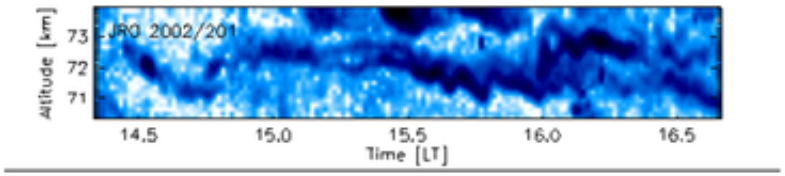
Equatorial ionosphere

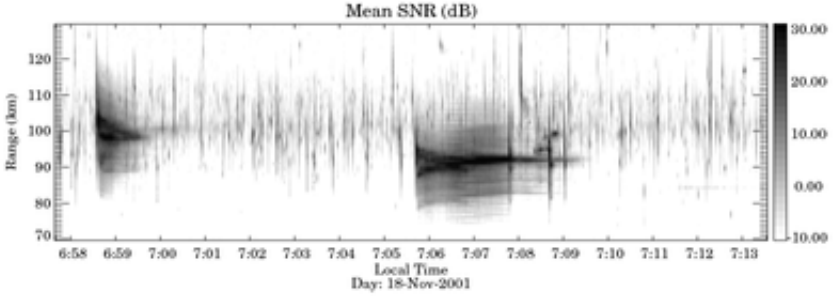
D. L. Hysell
Cornell University
July, 2015

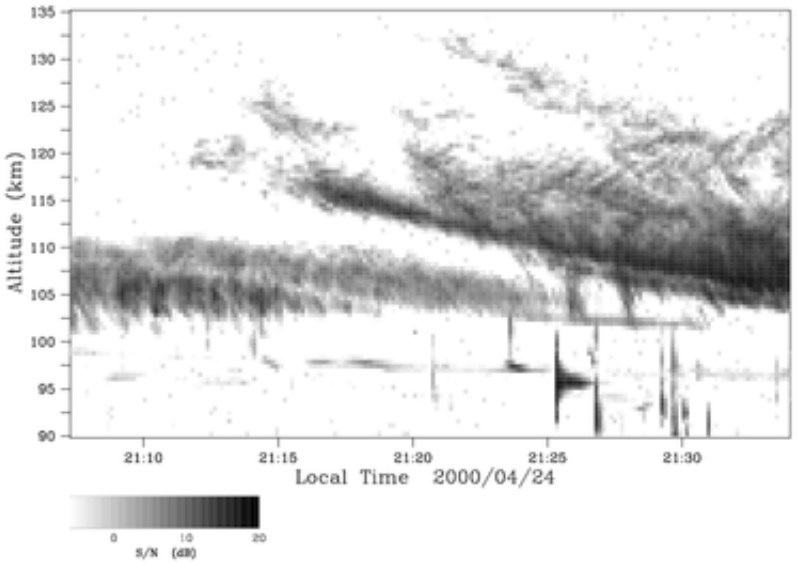
equatorial phenomena

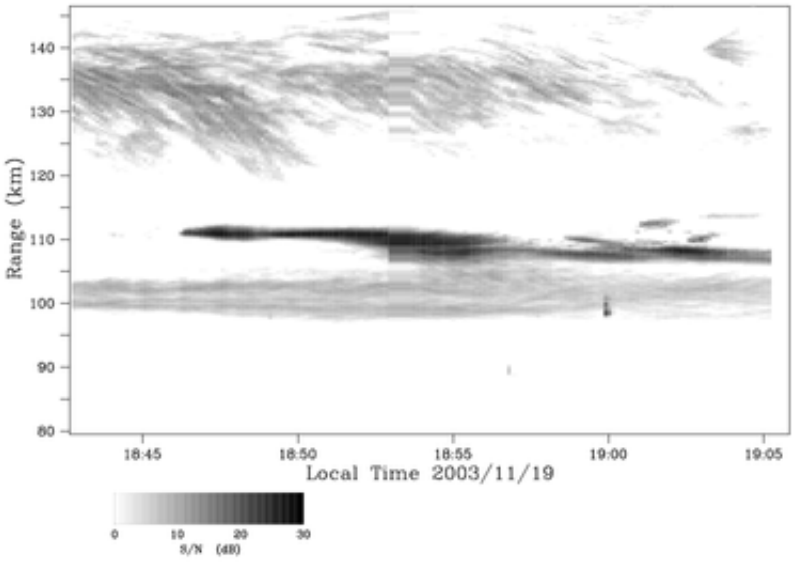






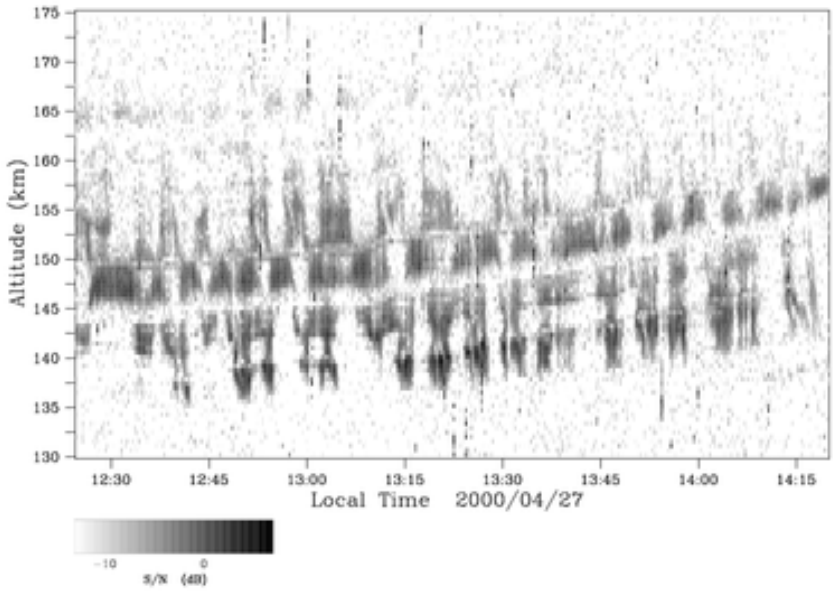


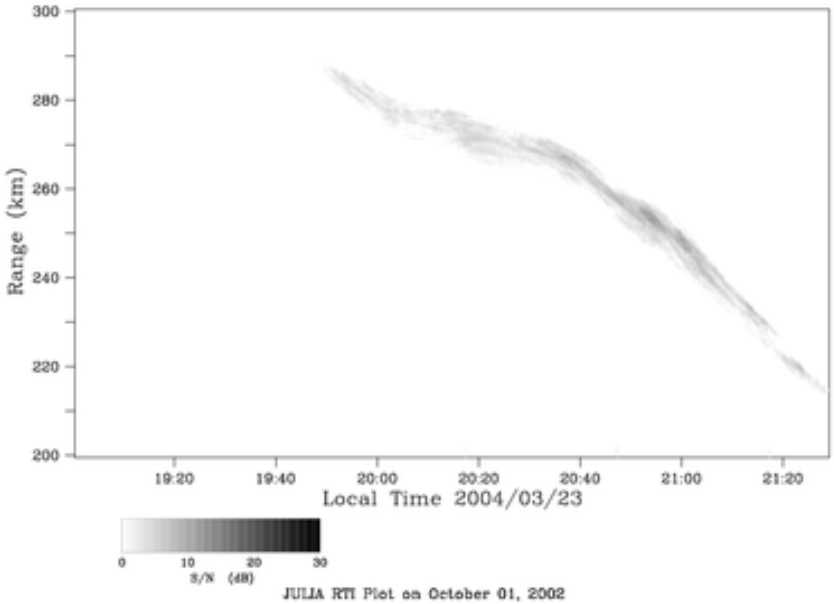


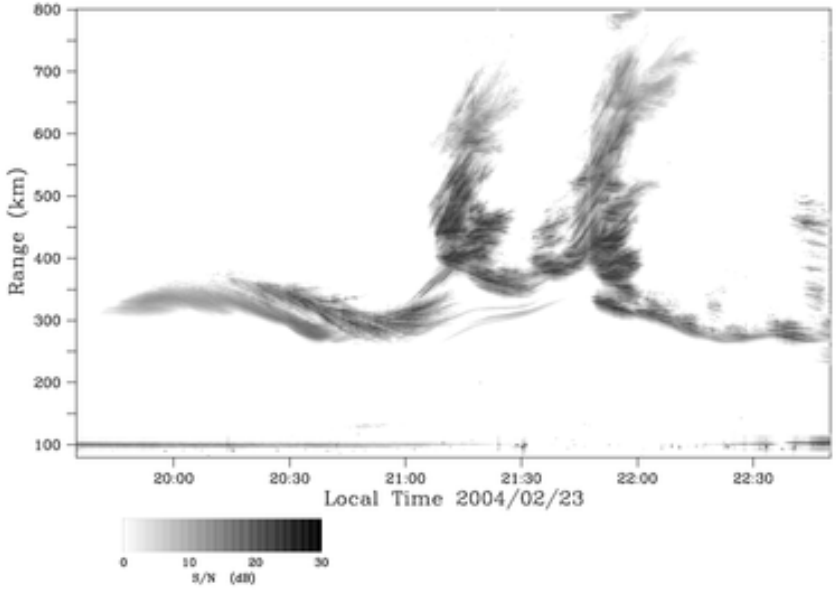


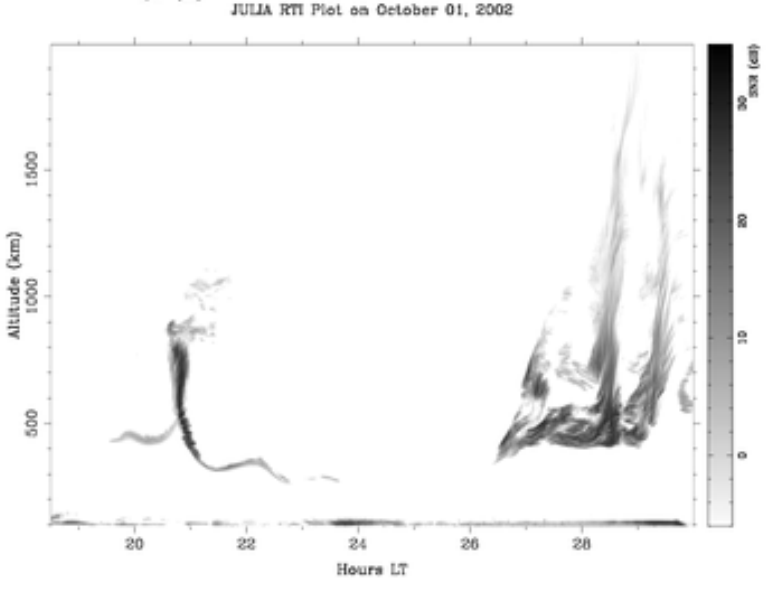
movie

more examples









outline

- survey of unique equatorial phenomena
- the geomagnetic field
- ionospheric structure
- plasma density, temperature, composition
- plasma drifts, dynamics; dynamo theory
- equatorial E region, electrojet
- neutral winds
- equatorial spread F

dipole magnetic field

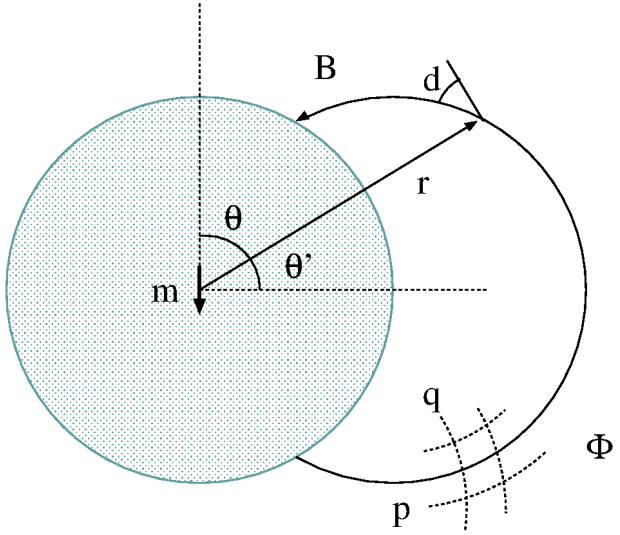
$$\phi_m = -\frac{\mathbf{m}\cdot\mathbf{r}}{r^3} = -\frac{\cos\theta}{r^2}$$

$$\mathbf{B} = -\nabla\phi_m = -\frac{2m\cos\theta}{r^3}\hat{r} - \frac{m\sin\theta}{r^3}\hat{\theta} = -\frac{3\hat{r}(\mathbf{m}\cdot\hat{r}) - \mathbf{m}}{r^3}$$

$$B = \frac{m}{r^3}\left(1+3\cos^2\theta\right)^{1/2}$$

$$\tan d = \frac{B_r}{B_\theta} = 2\tan\theta'$$

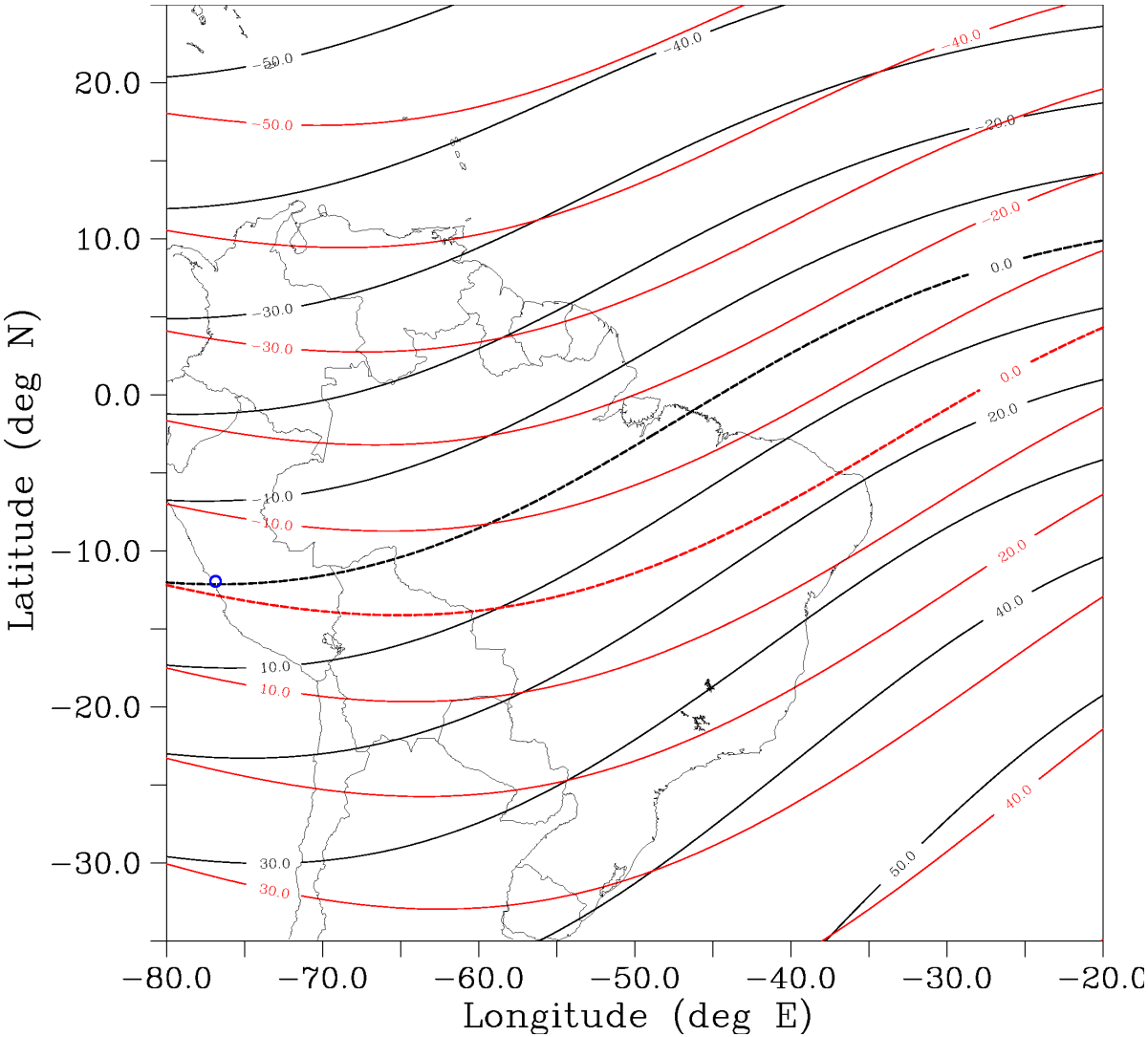
$$r = LR_e\sin^2\theta \quad (p = r/\sin^2\theta,\ q = \cos\theta/r^2, \Phi)$$



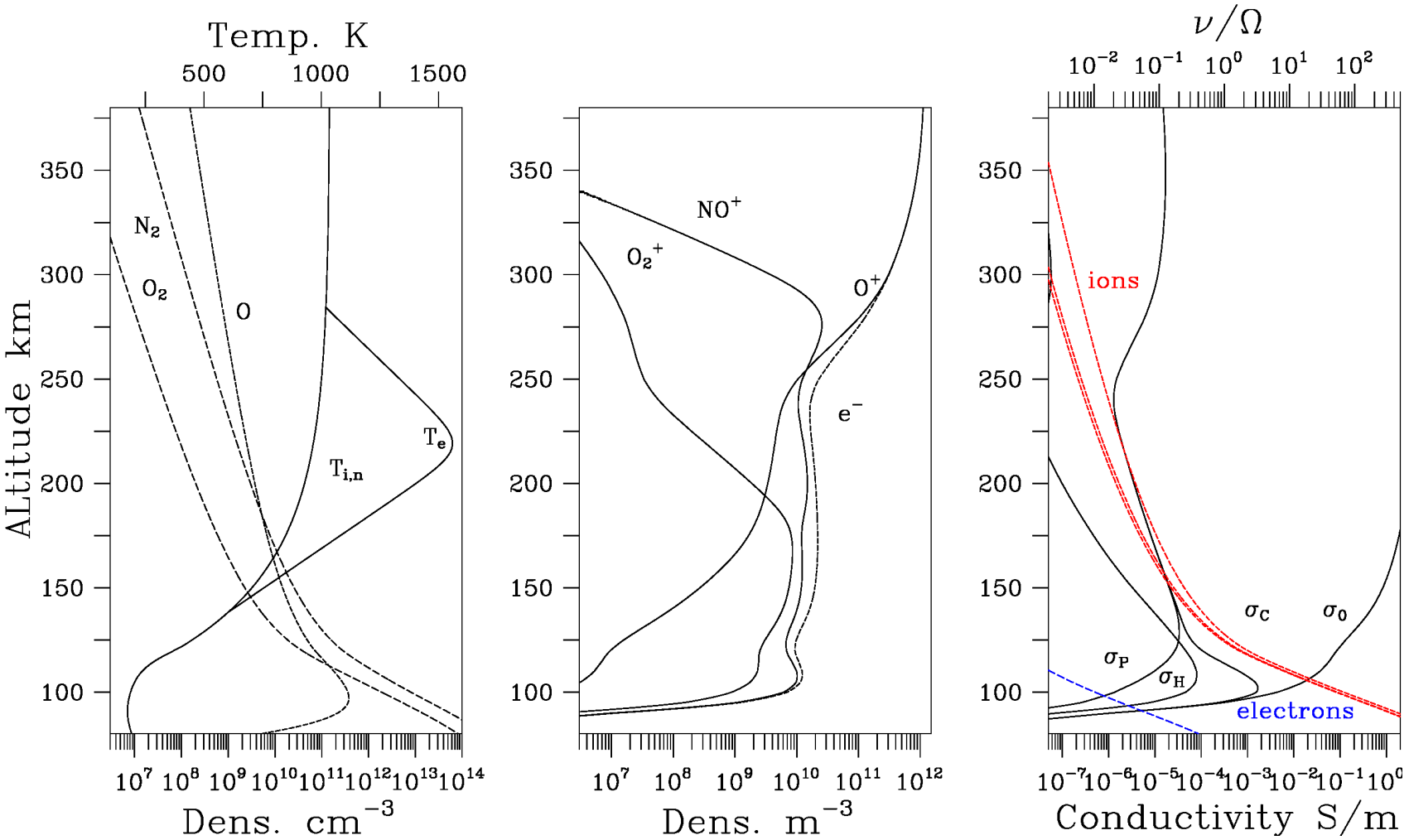
$$h_p = \sin^3\theta/\delta, h_q = r^3/\delta, h_\Phi = r\sin\theta$$

$$\delta = \sqrt{1+3\cos^2\theta}$$

non-dipole contribution



ionospheruc structure (model)



high altitude ISR

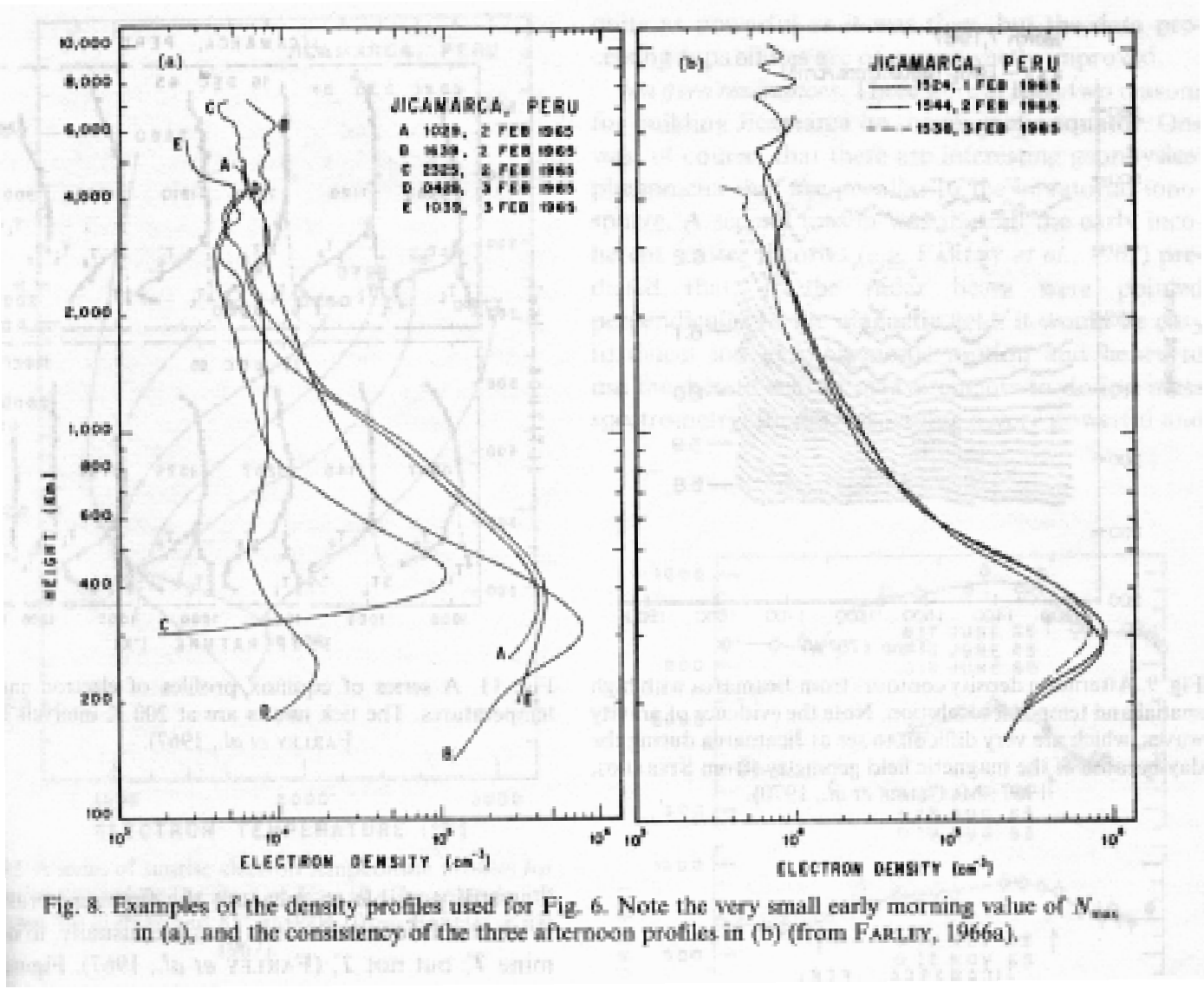
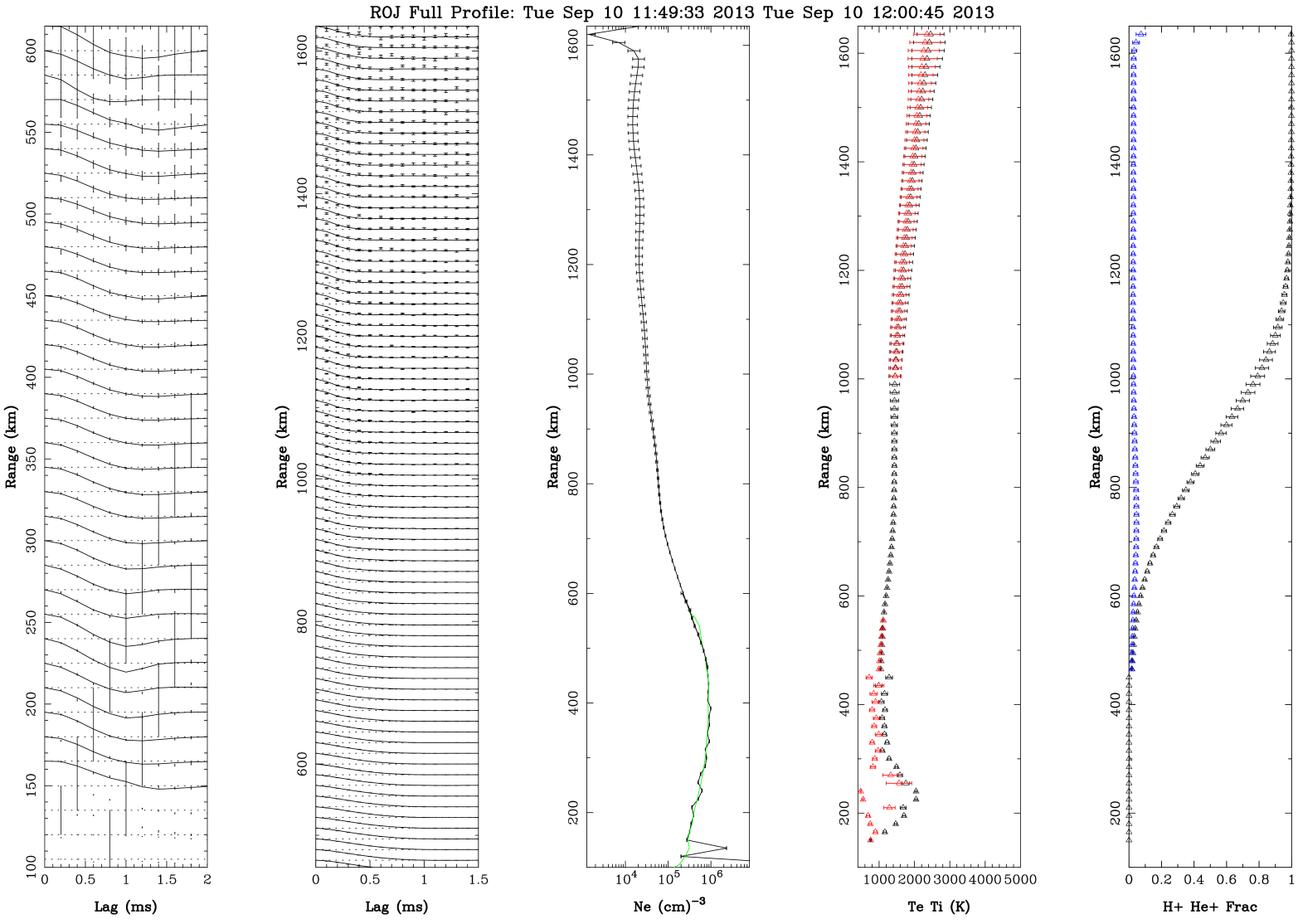


Fig. 8. Examples of the density profiles used for Fig. 6. Note the very small early morning value of N_{max} in (a), and the consistency of the three afternoon profiles in (b) (from FARLEY, 1966a).

After D. T. Farley, *J. Atmos. Sol. Terr. Phys.*, *53*, 665–675, 1991

profiles: 12 LT



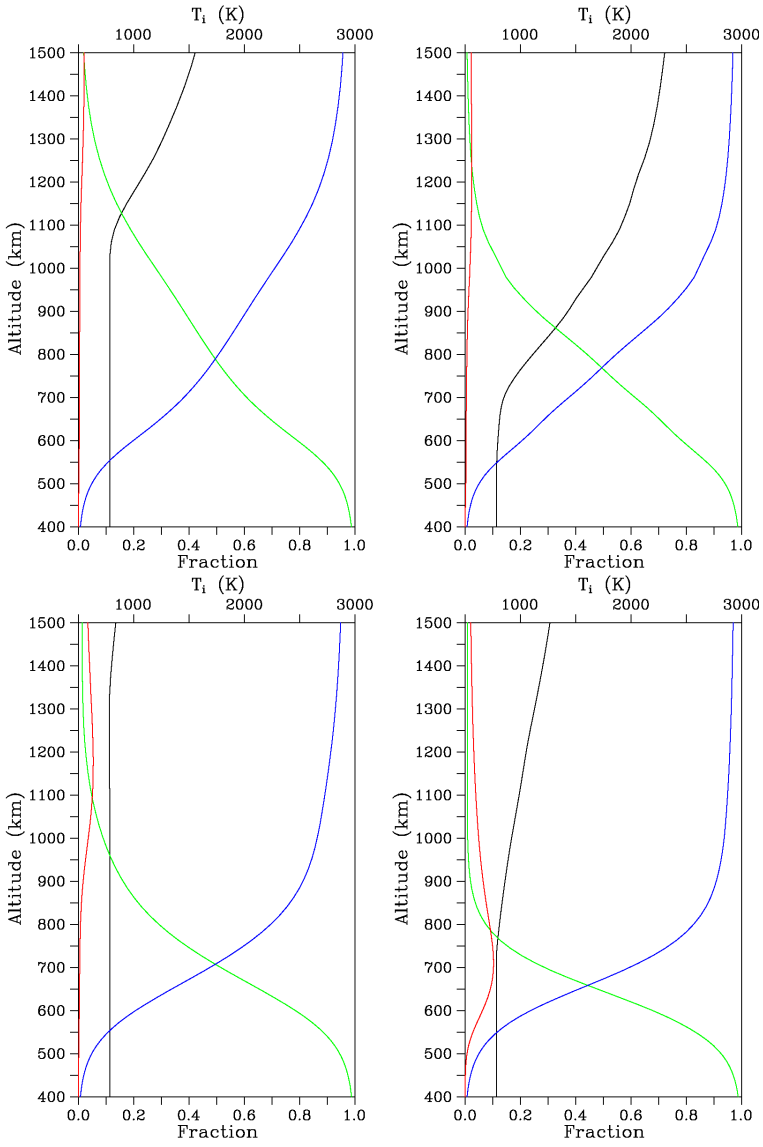
temperature and composition

- At low altitudes, composition controlled by local photochemistry, temperture controlled by local heating and cooling.
- At higher altitudes, material and heat transport (diffusion, thermal diffusion) become important. Heat budget in topside also affected by energetic electron transport.
- Main topside light-ion reactions are H^+– O^+ charge exchange for hydrogen ions and photoionization and charge exchange with molecular species for helium ions.

diffusive equilibrium (late afternoon)

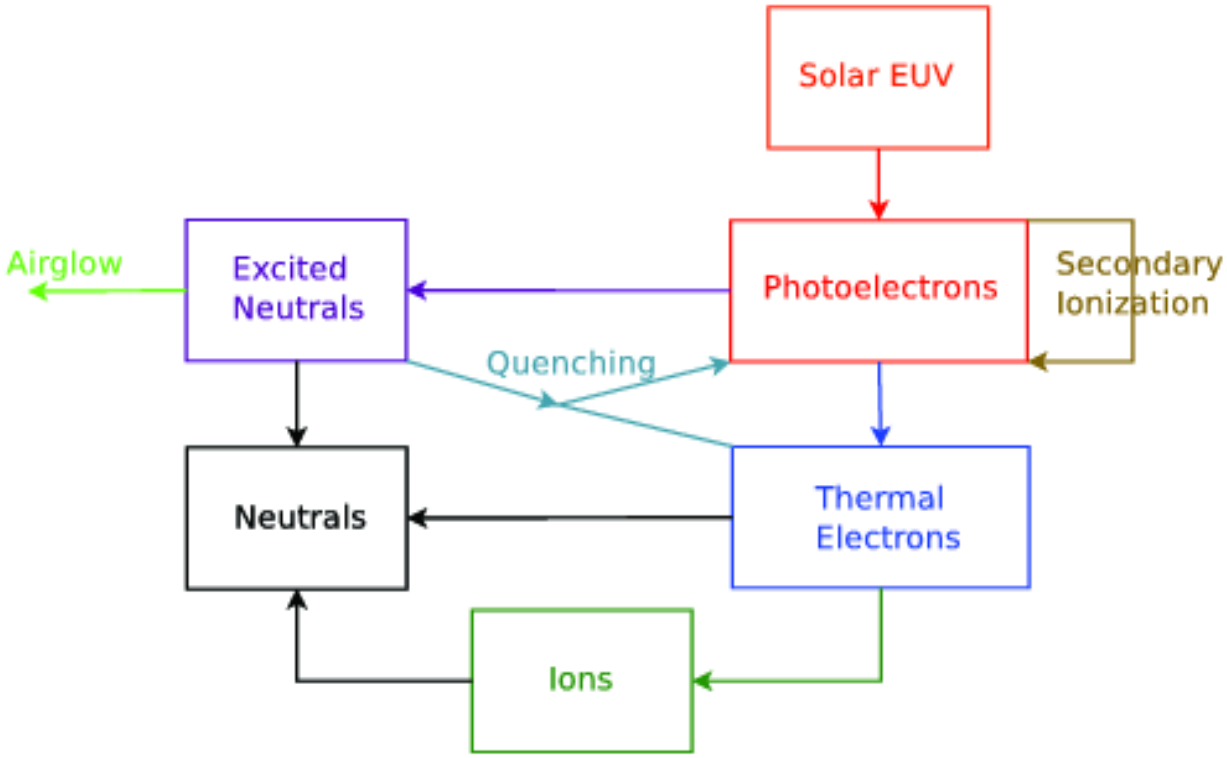
$$
\begin{aligned}
0 &= -K\nabla(n_j T)/n_j + eE - m_j g \\
0 &= -K\nabla(n_e T)/n_e - eE \\
n_e &= \sum_j n_j, \quad T_j = T_e = T
\end{aligned}
$$

$$
\begin{aligned}
\frac{n_j(z)}{n_e(z)} &= \frac{n_{\circ j} e^{-\int_\circ^z dz/H_j}}{\sum_i n_{\circ i} e^{-\int_\circ^z dz/H_i}} \\
H_j &\equiv \frac{KT(z)}{m_j g(z)}
\end{aligned}
$$



Equatorial ionosphere seldom in diffusive equilibrium!

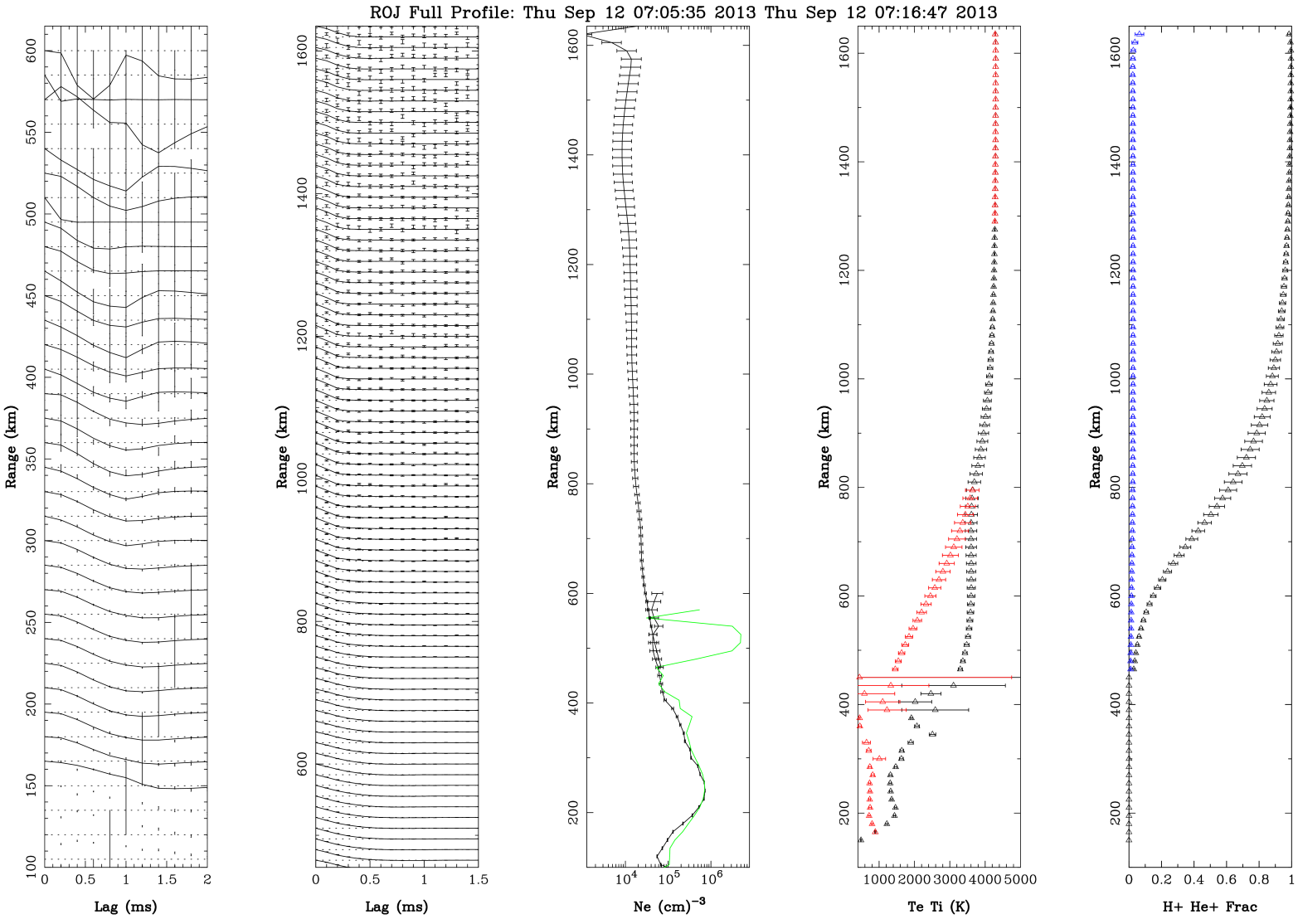
heat flow



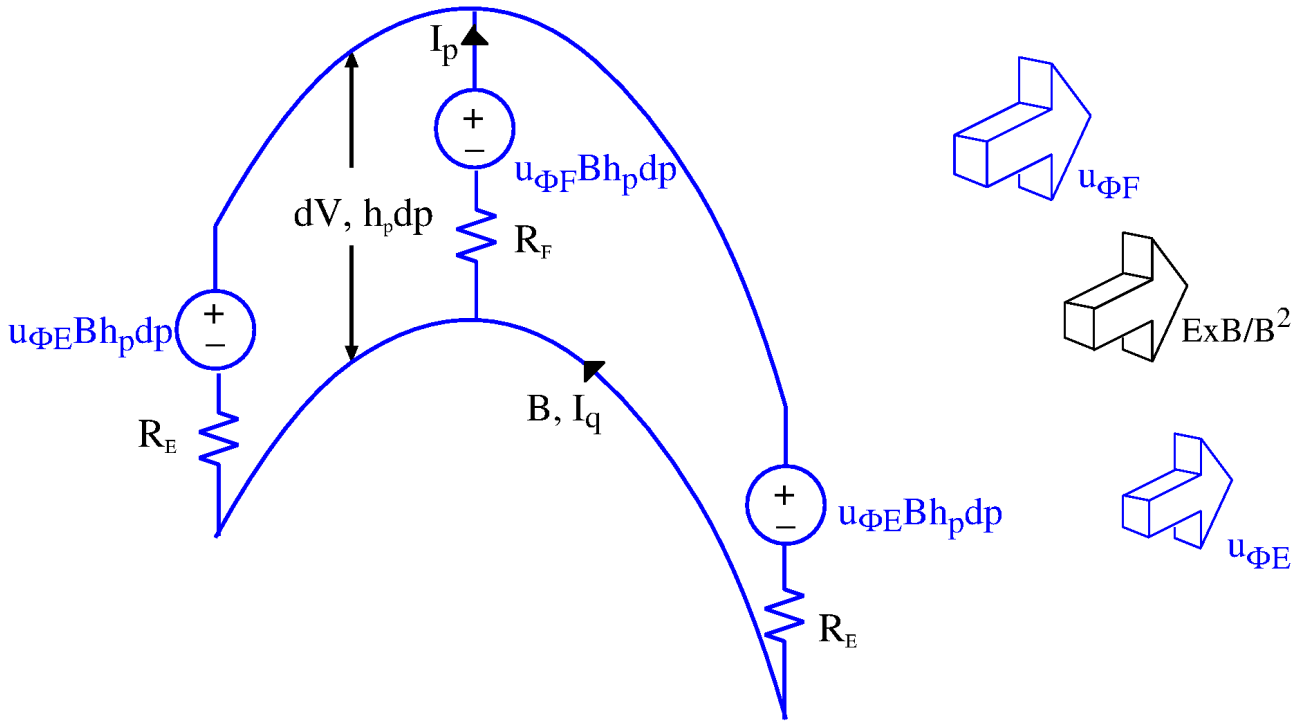
from Varney, Cornell Univ., 2012

Photoelectrons degraded by pitch-angle scattering, elastic, and inelastic collisions as they propagate along B, preserve the 1st adiabatic invariant, undergo trapping, and ultimately return to the thermal electron population.

profiles: 07 LT

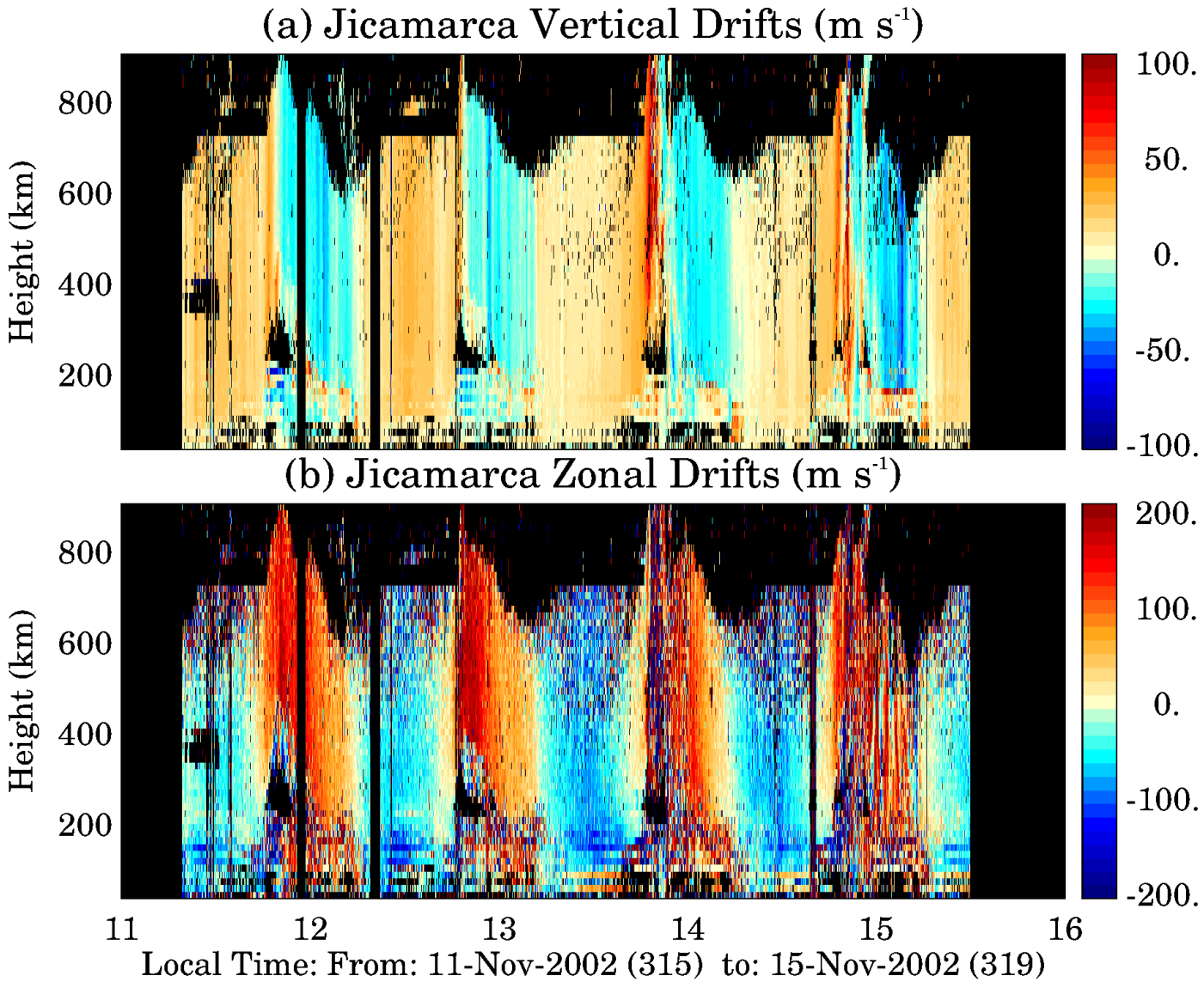


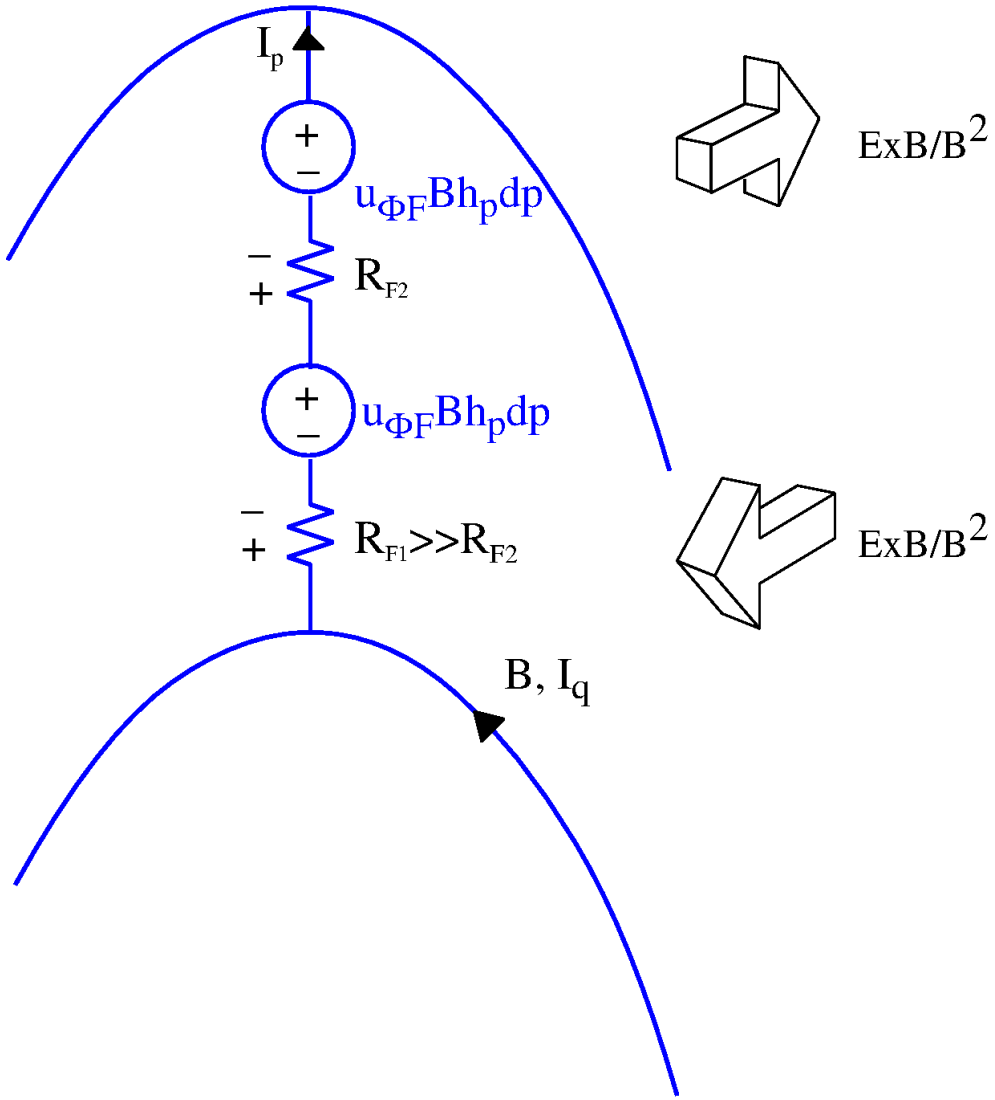
- quasineutrality ($\nabla \cdot \mathbf{J} = 0$) and Faraday's law for electrostatics together with high direct conductivity imply Kirchhoff's laws for circuits



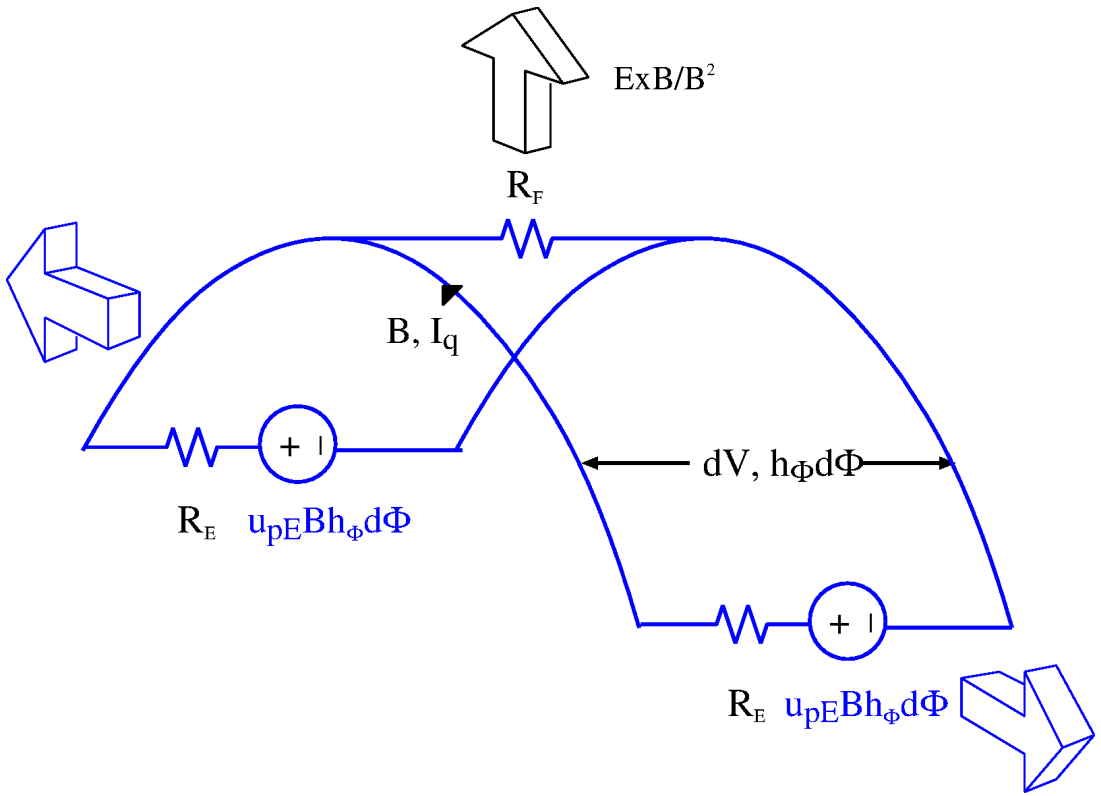
$$dV = \frac{u_{\Phi F} B h_p dp / R_F + u_{\Phi E} B h_p dp / R_E}{1/R_F + 1/R_E}$$

zonal drifts, super-rotation

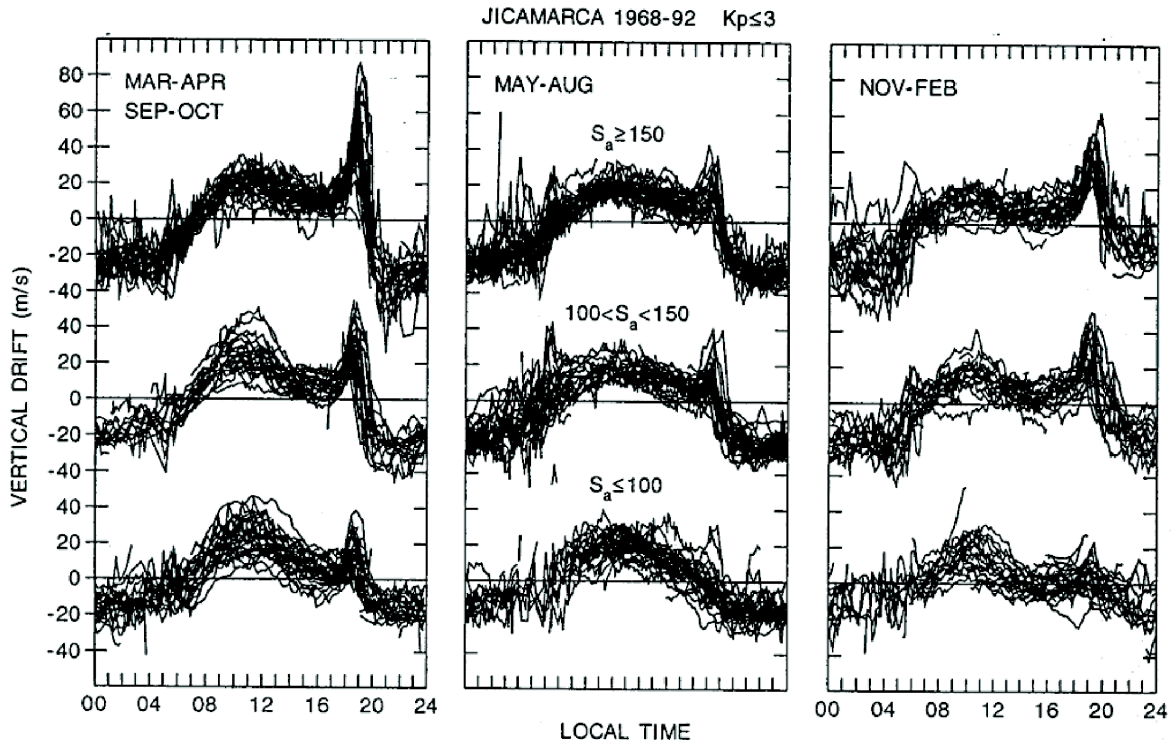



I_p
$u_{\Phi F}Bh_p dp$
R_{F2}
$u_{\Phi F}Bh_p dp$
$R_{F1}>>R_{F2}$
B, I_q
ExB/B^2
ExB/B^2

vertical drifts (daytime)

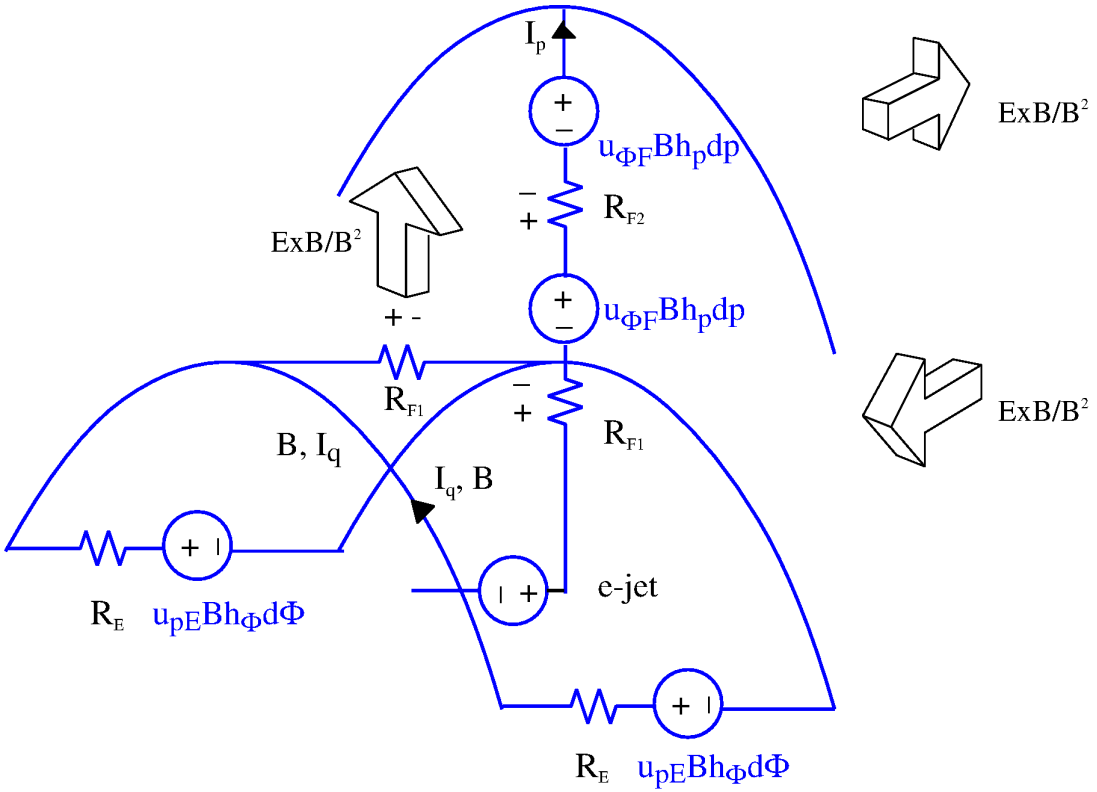


prereversal enhancement

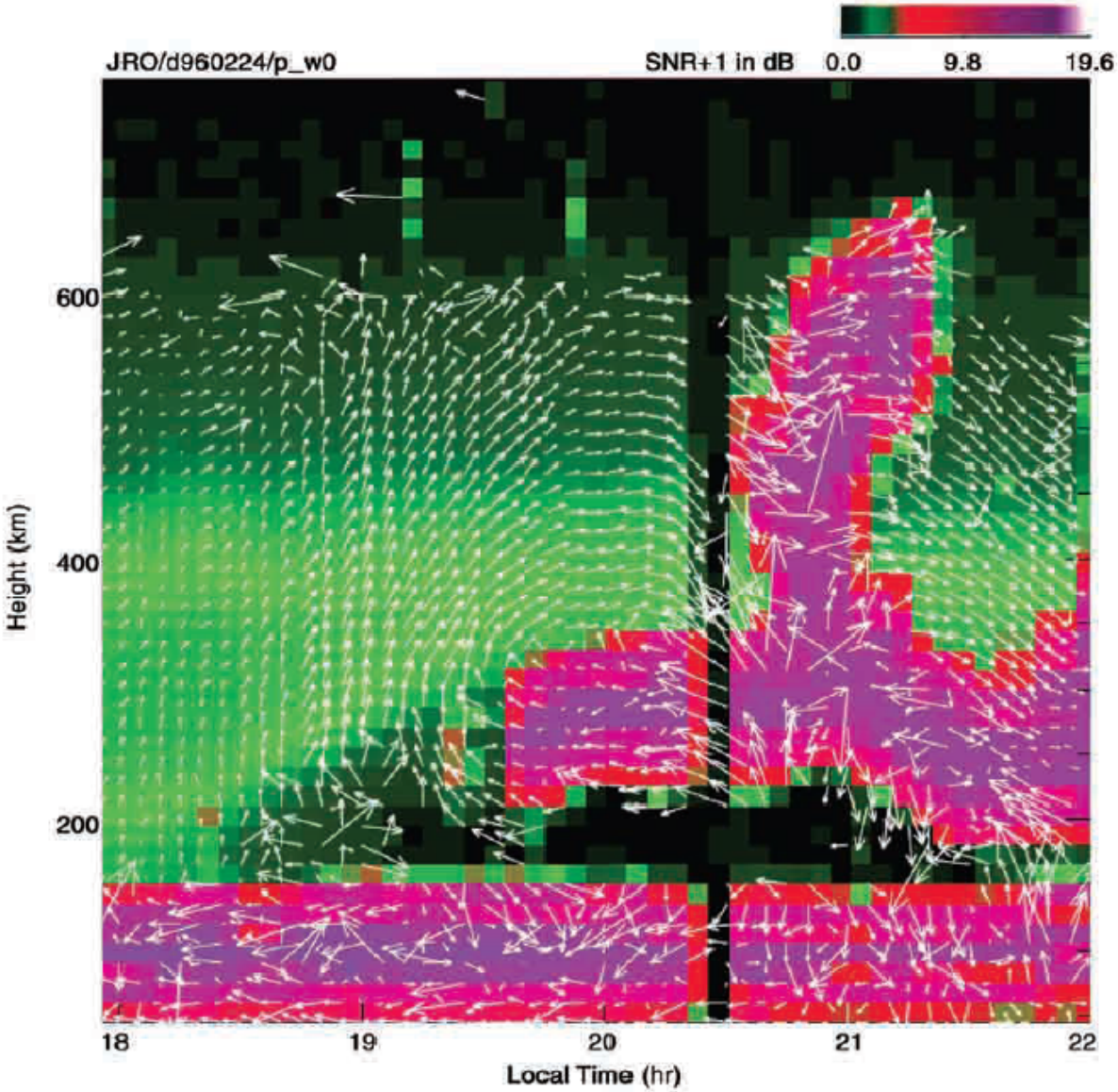


Scherliess and Fejer, *J. Geophys. Res.*, *104*, 682, 1999

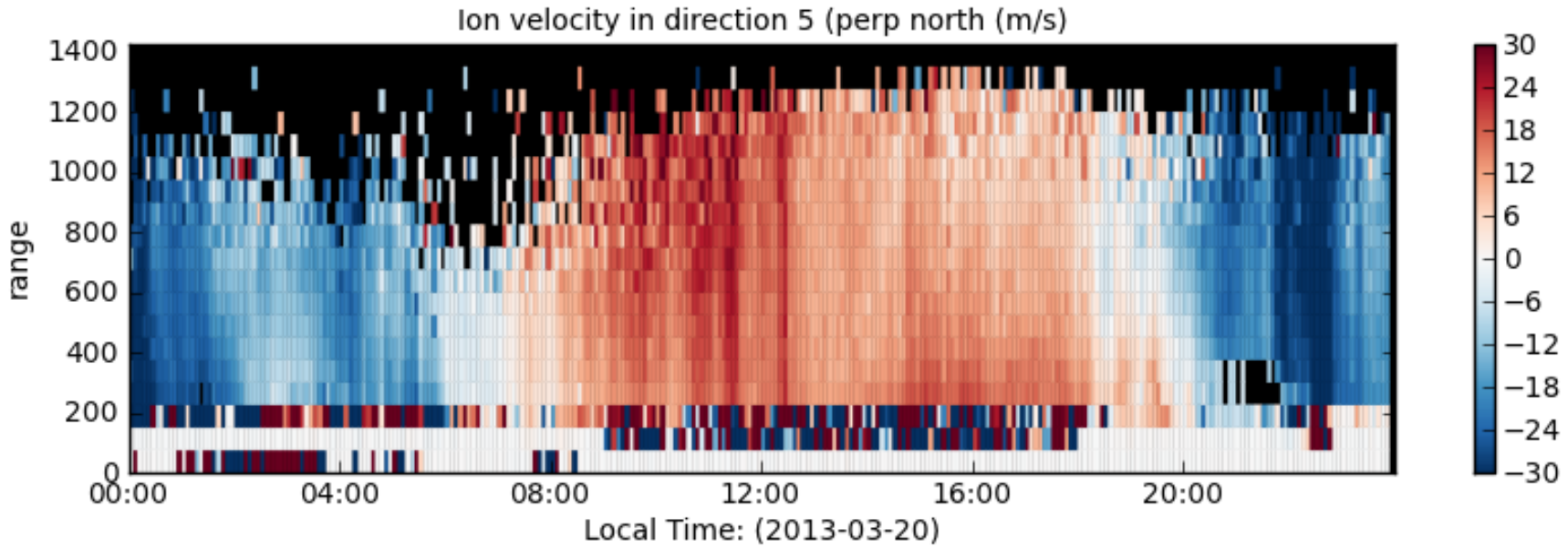
prereversal enhancement

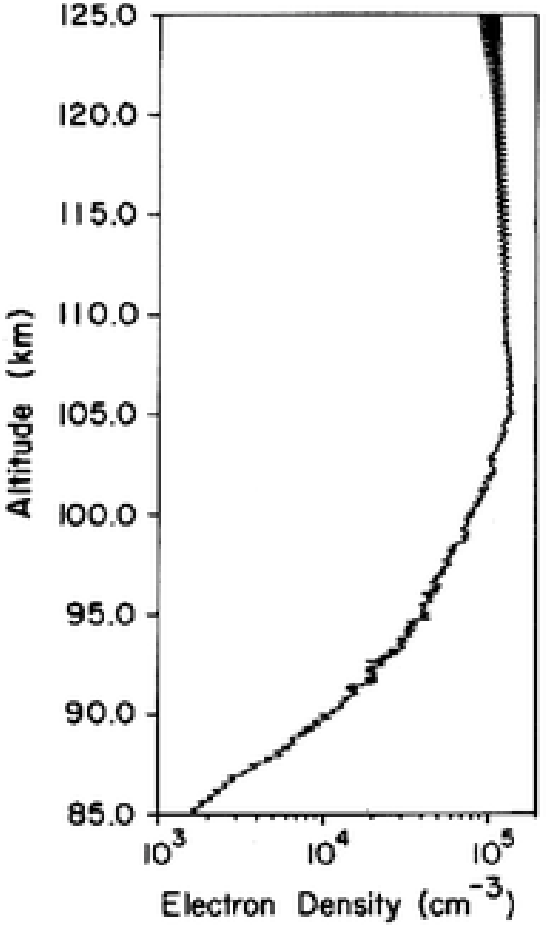


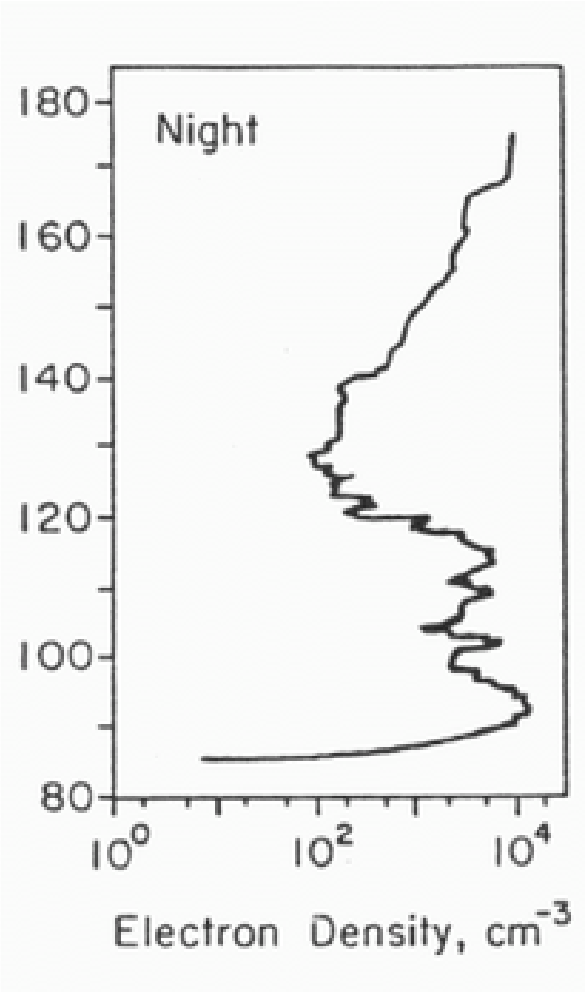
vorticity


JRO/d960224/p_w0
SNR+1 in dB
0.0
9.8
19.6
600
400
200
Height (km)
18
19
20
21
22
Local Time (hr)

topside drifts

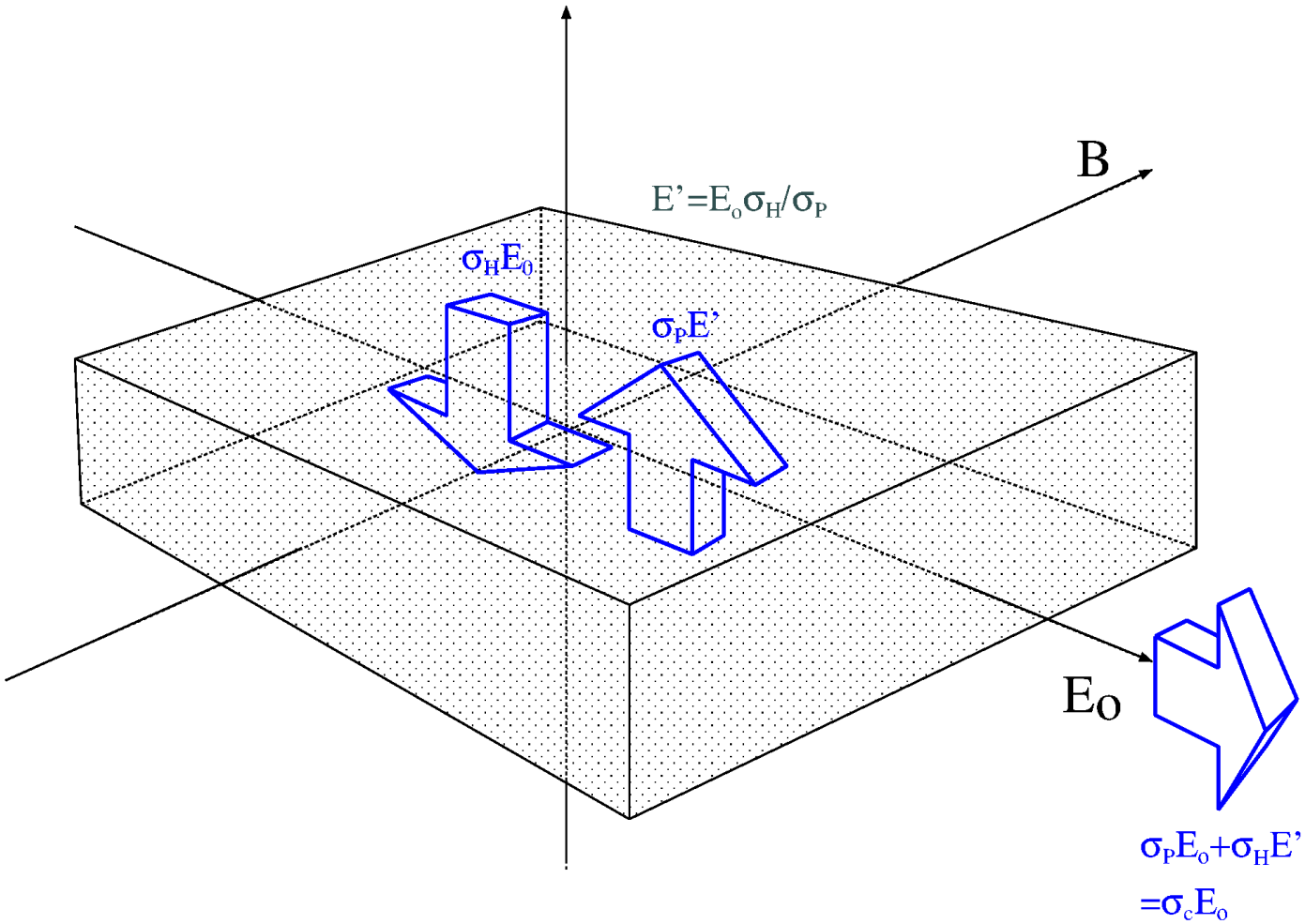




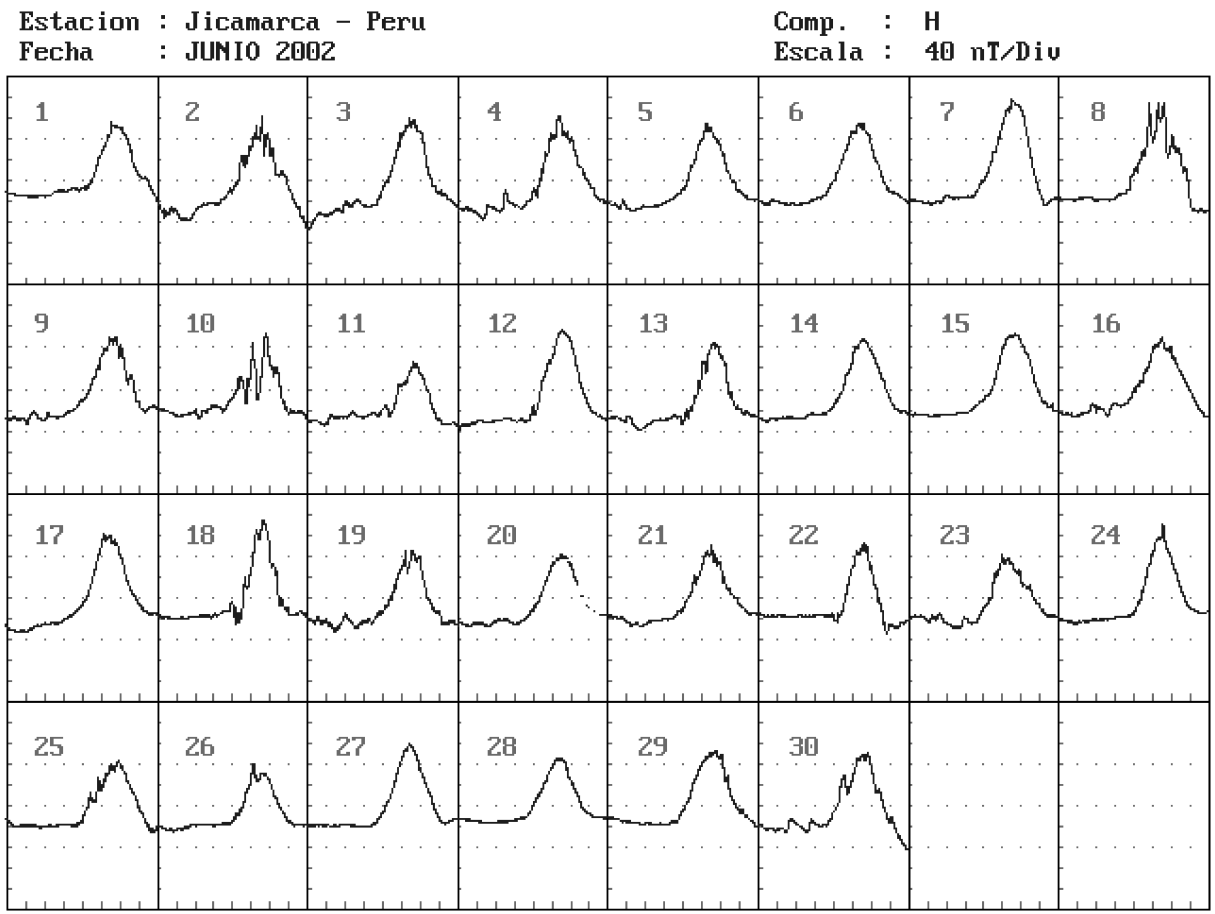


From Pfaff, *J. Atmos. Terr. Phys.*, *53*, 709, 1991 and Prakash et al., *Indian J. Radio Space Phys.*, *72*, 1, 1972.

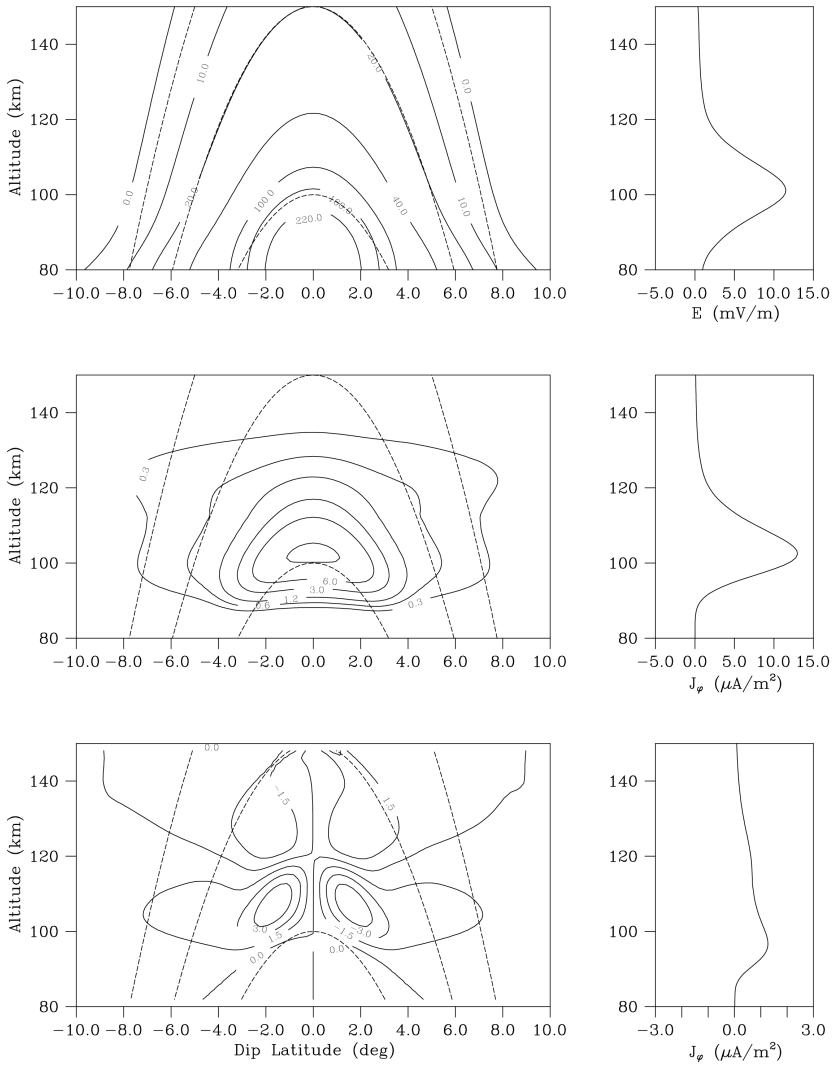
slab electrojet current model (daytime)

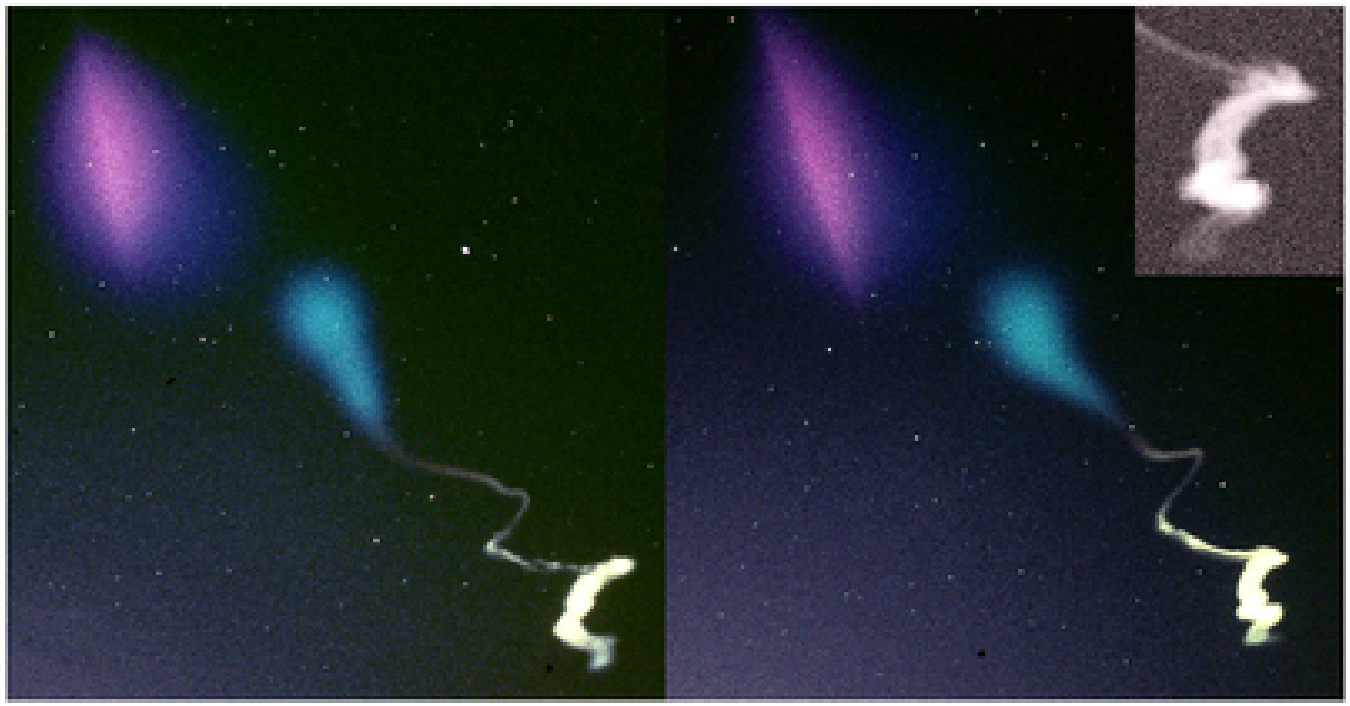


Jicamarca magnetometer



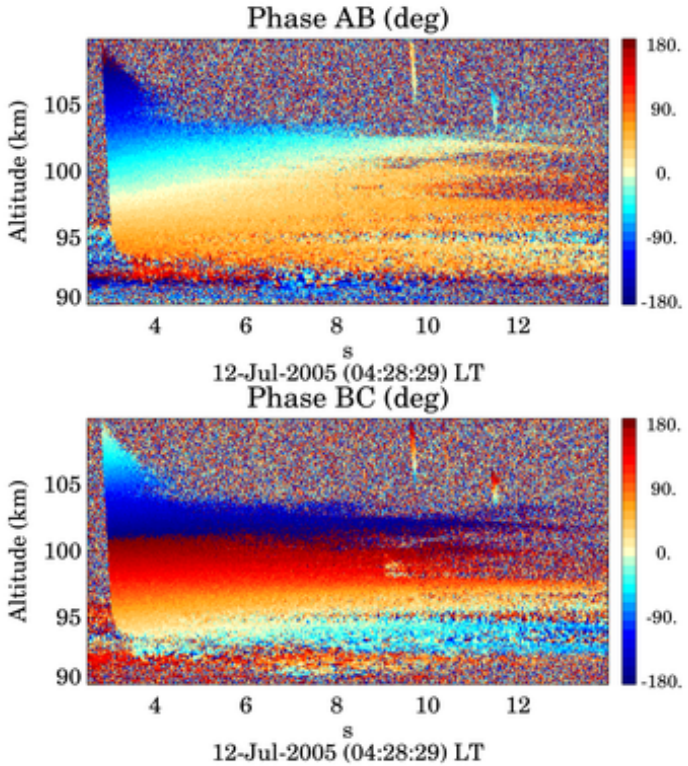
numerical model: $\nabla \cdot \mathbf{J} = 0$

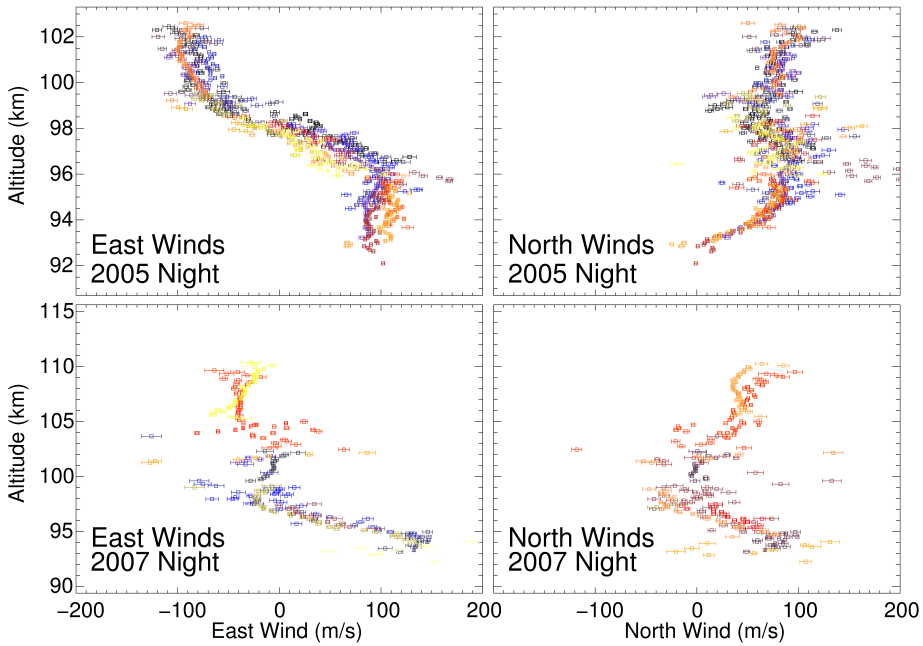




Larsen, M. F., *J. Geophys. Res.*, *107*, 10.1029/2001JA000218, 2002.

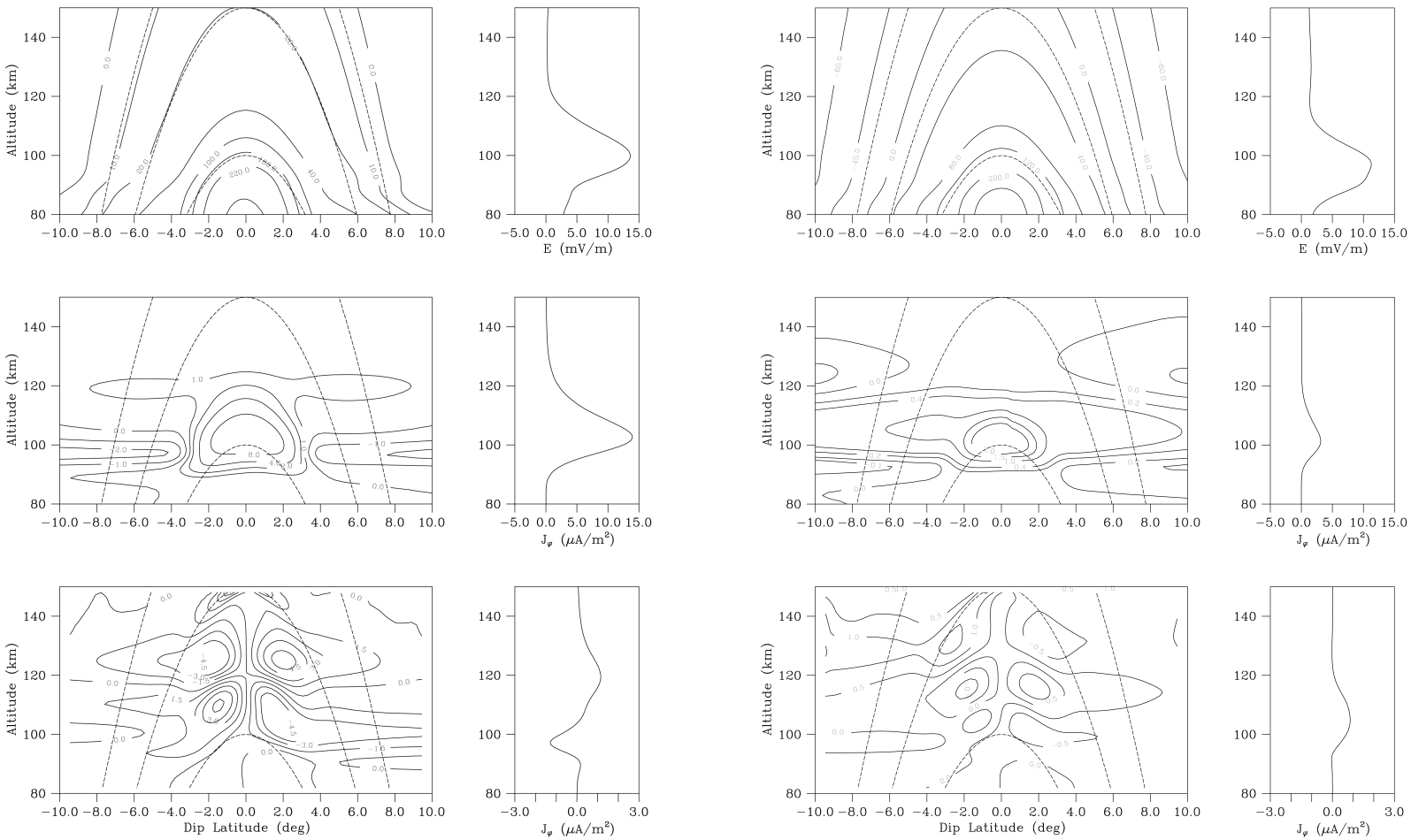
meteor trail winds



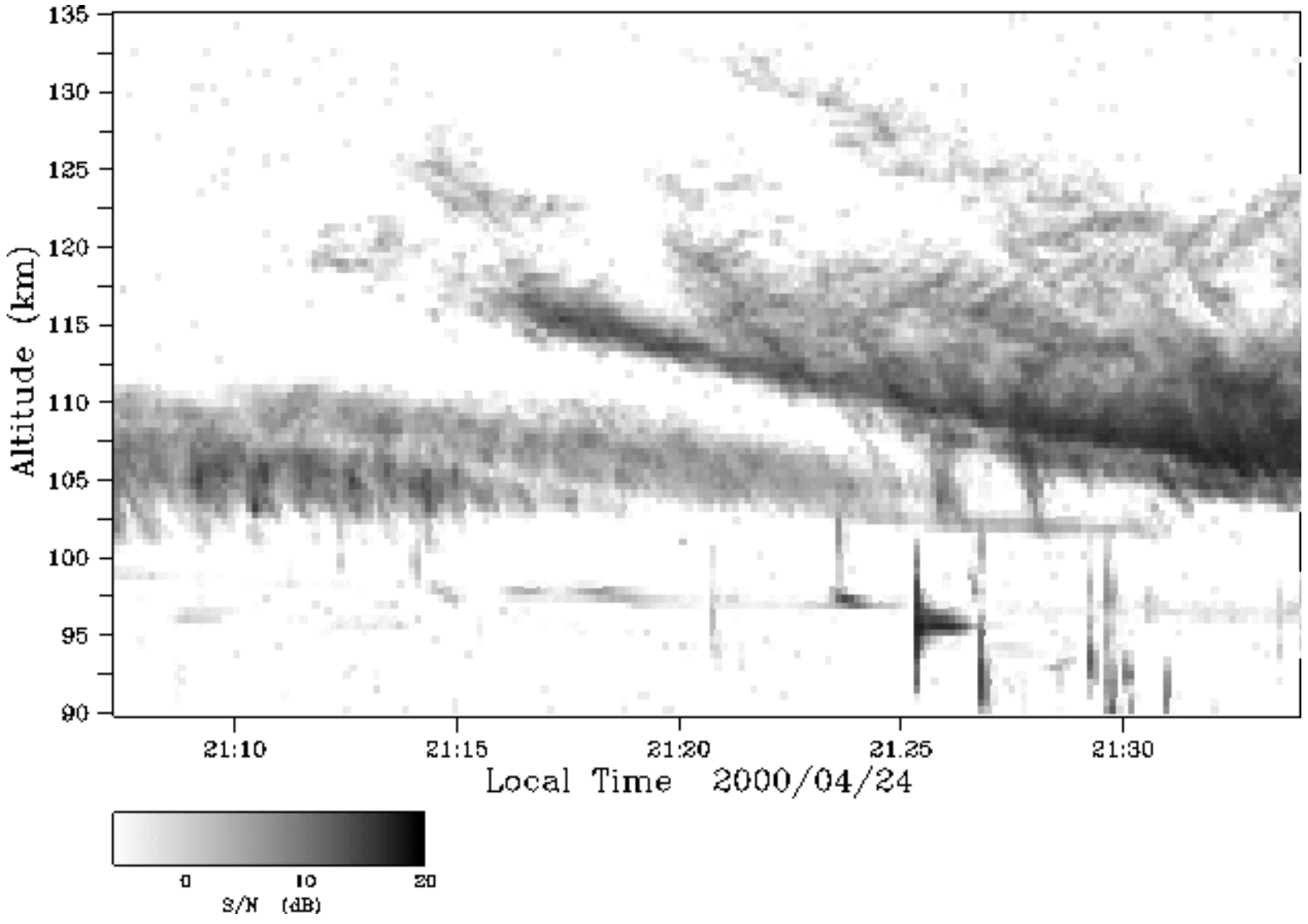


Oppenheim, M. M., et al., *Geophys. Res. Lett.*, *36*, L09817, 2009

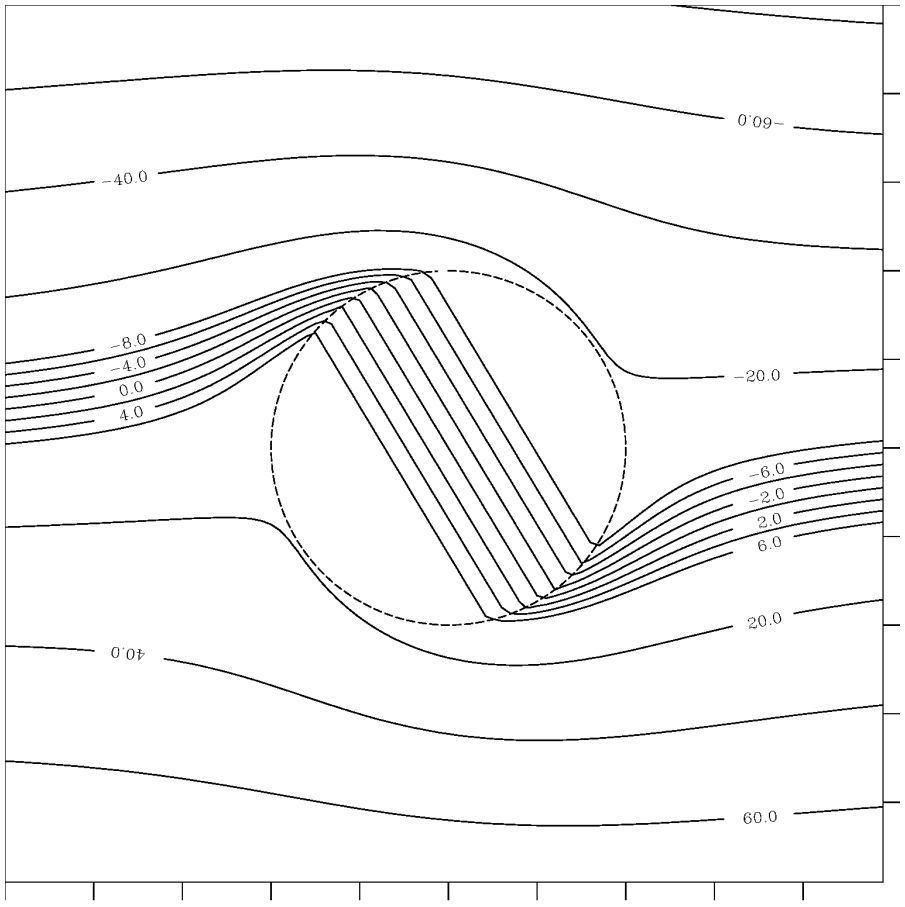
with TIME-GCM winds (noon, twilight)



electrojet plasma waves

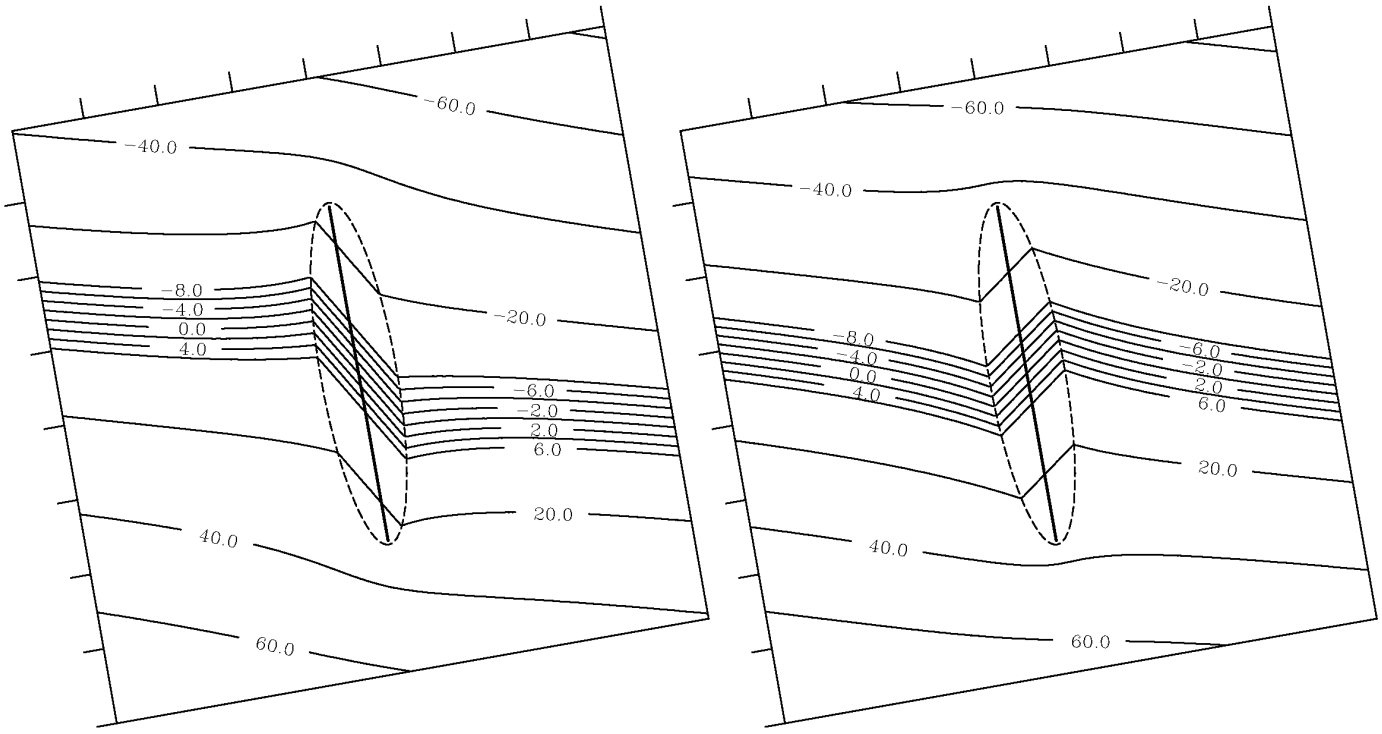


heuristic description of FBGD instability (daytime)



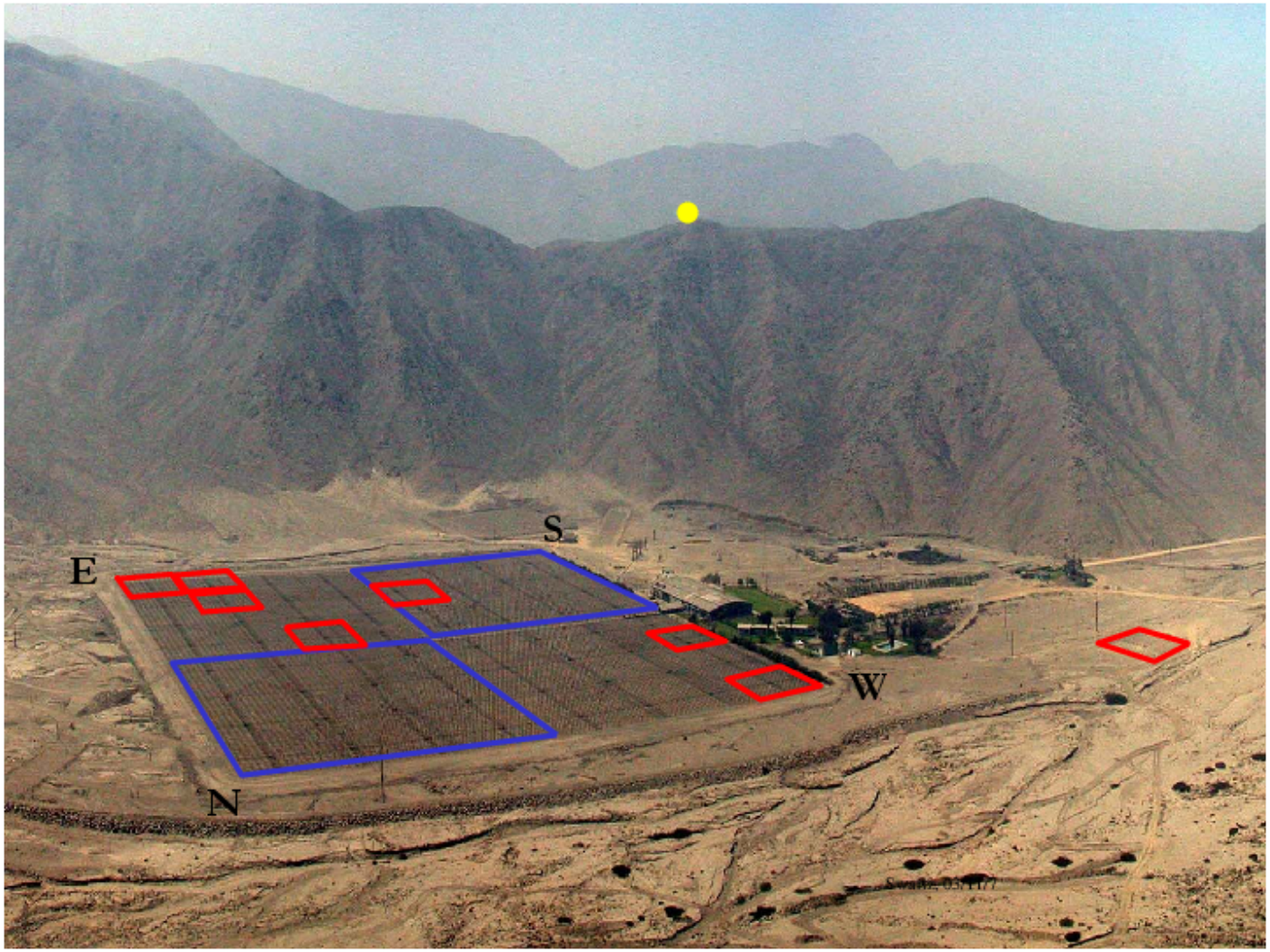
Solution of $\nabla \cdot \mathbf{J} = 0$ (equipotentials) for two-dimensional depletion interrupting electrojet current.

heuristic description of instability (daytime)



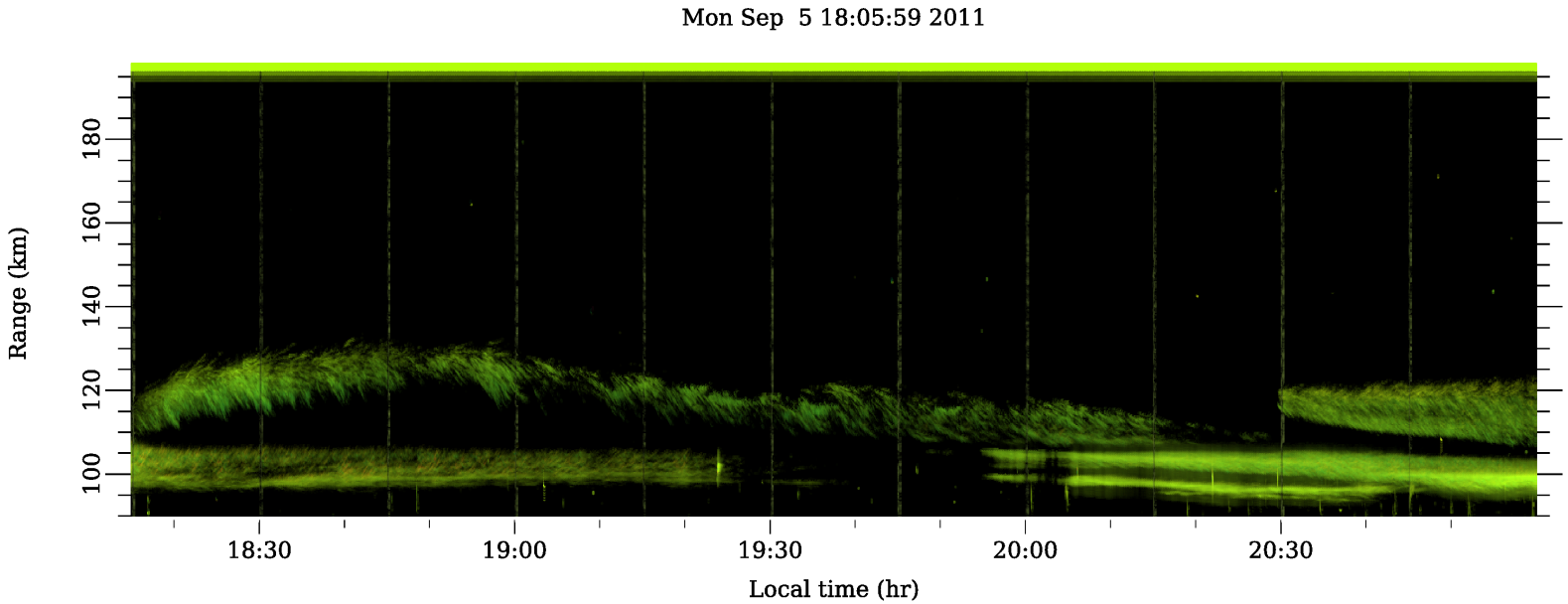
depletion — enhancement

radar imagery



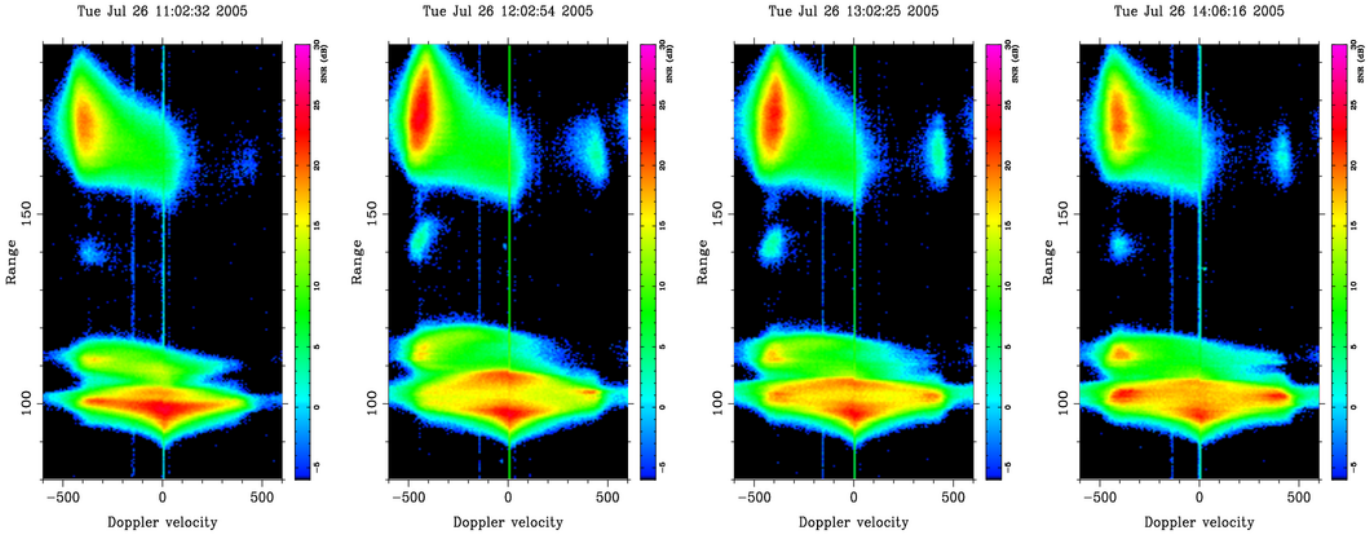
daytime nighttime

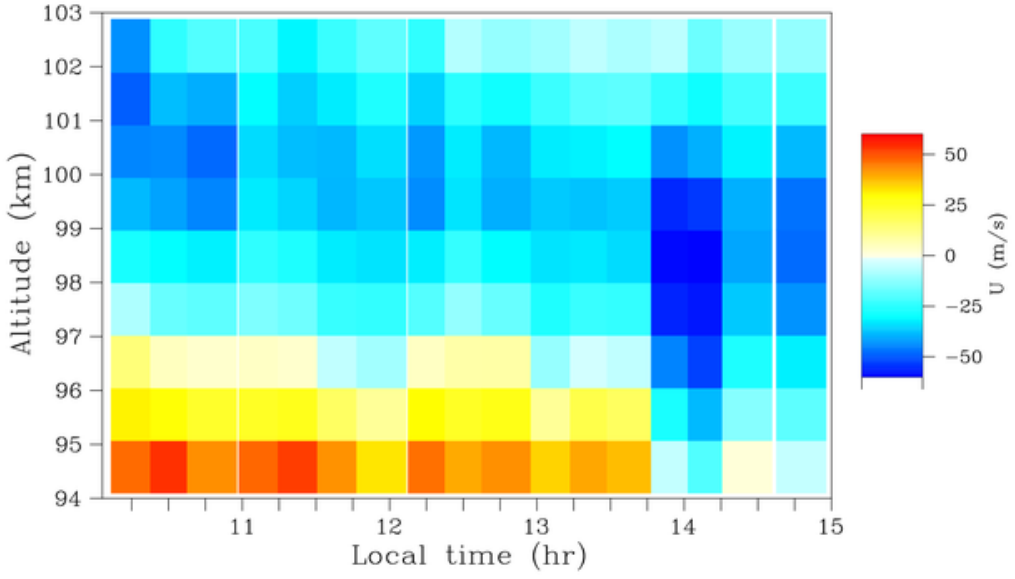
layered strata



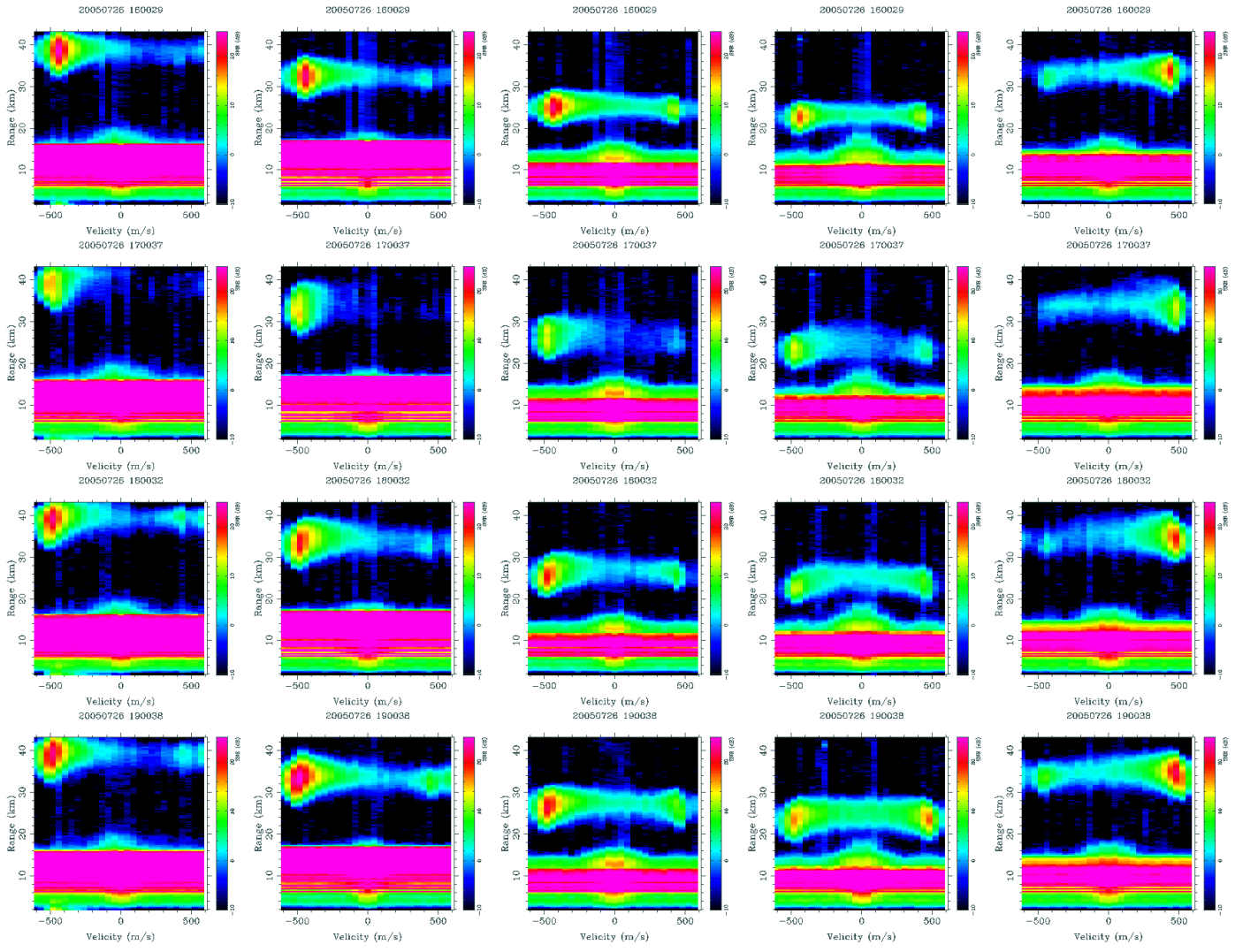
movie

oblique obs. with Yagi array

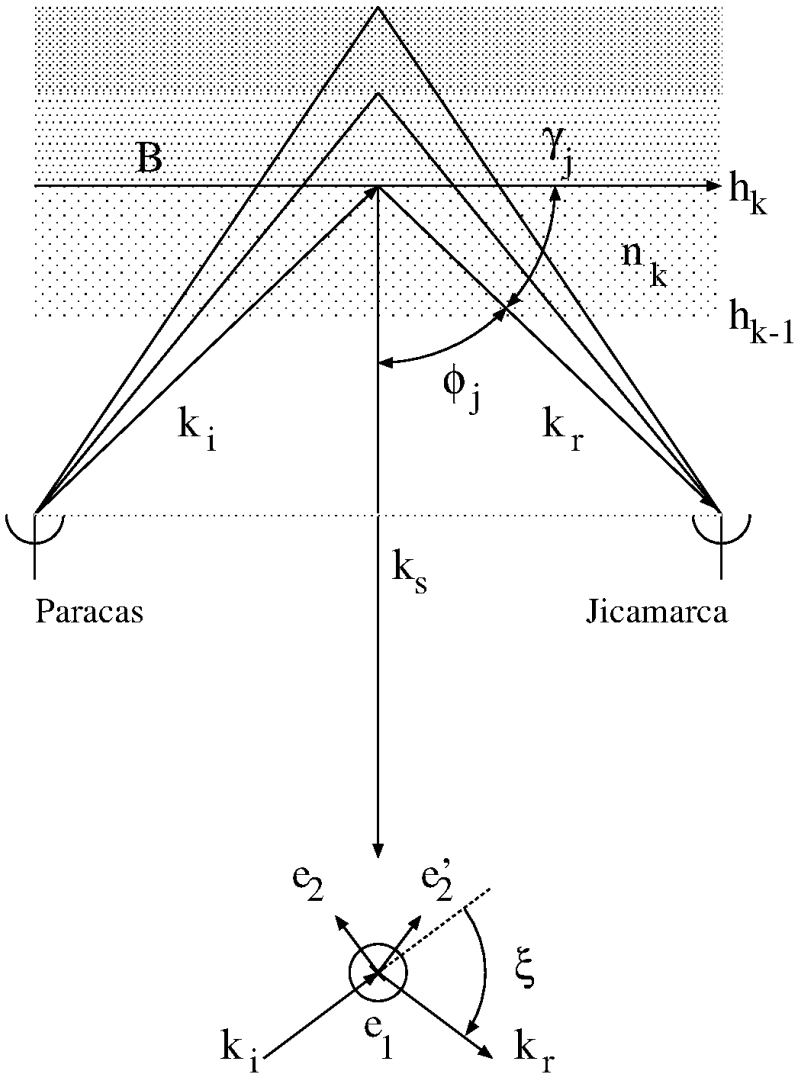




oblique obs. AMISR-7

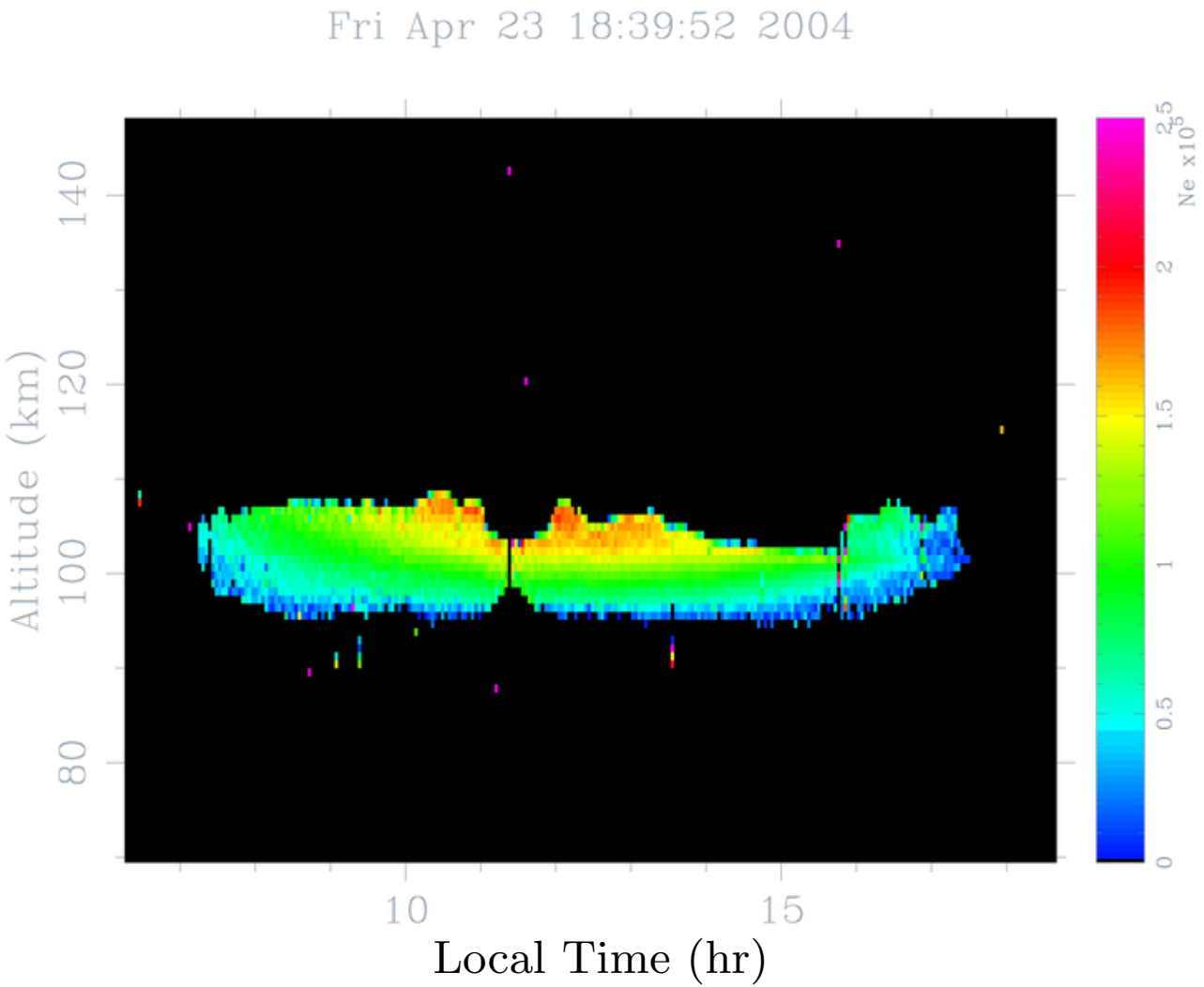


bistatic radar measurements

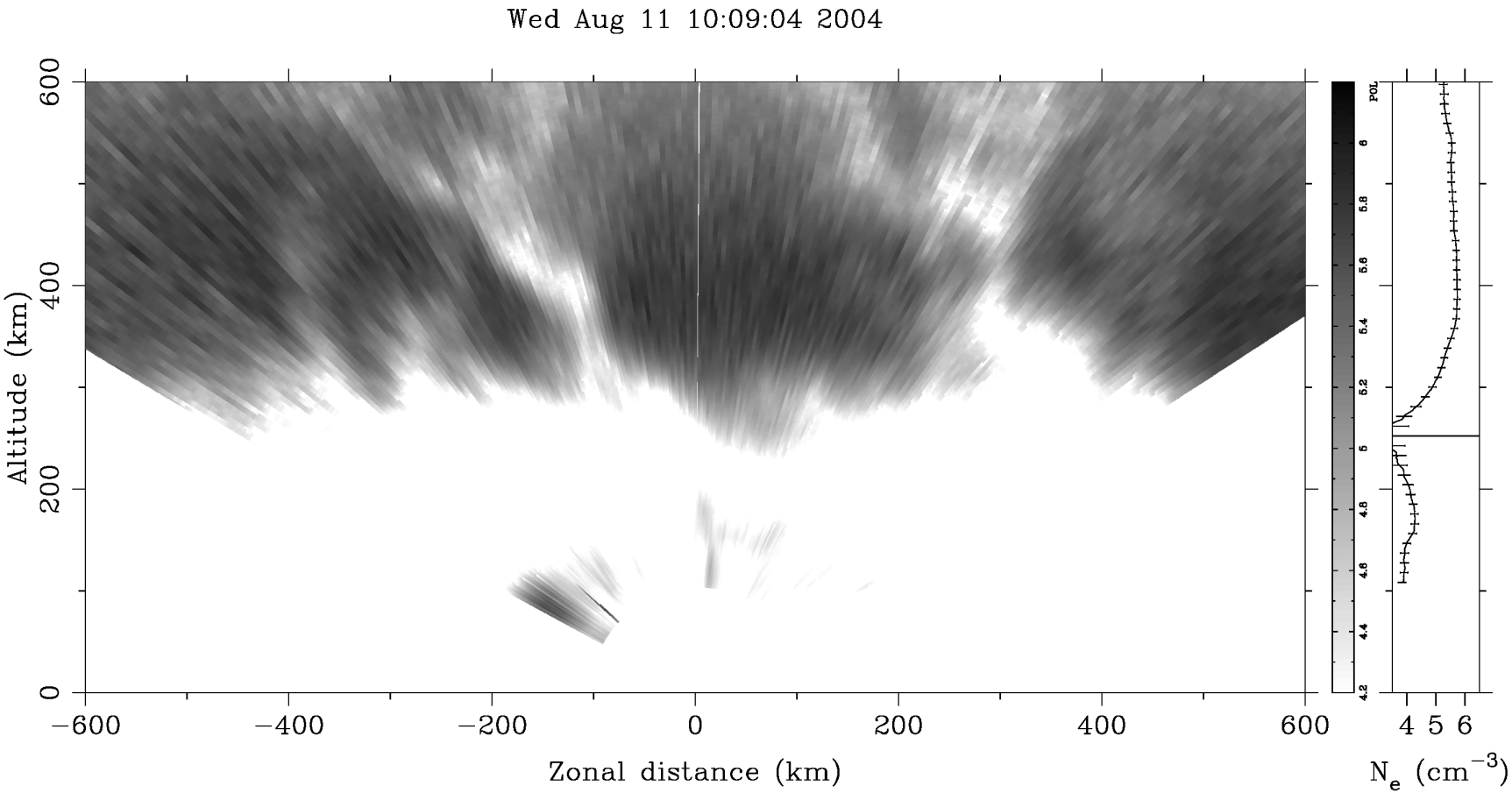


Paracas/ Jicamarca

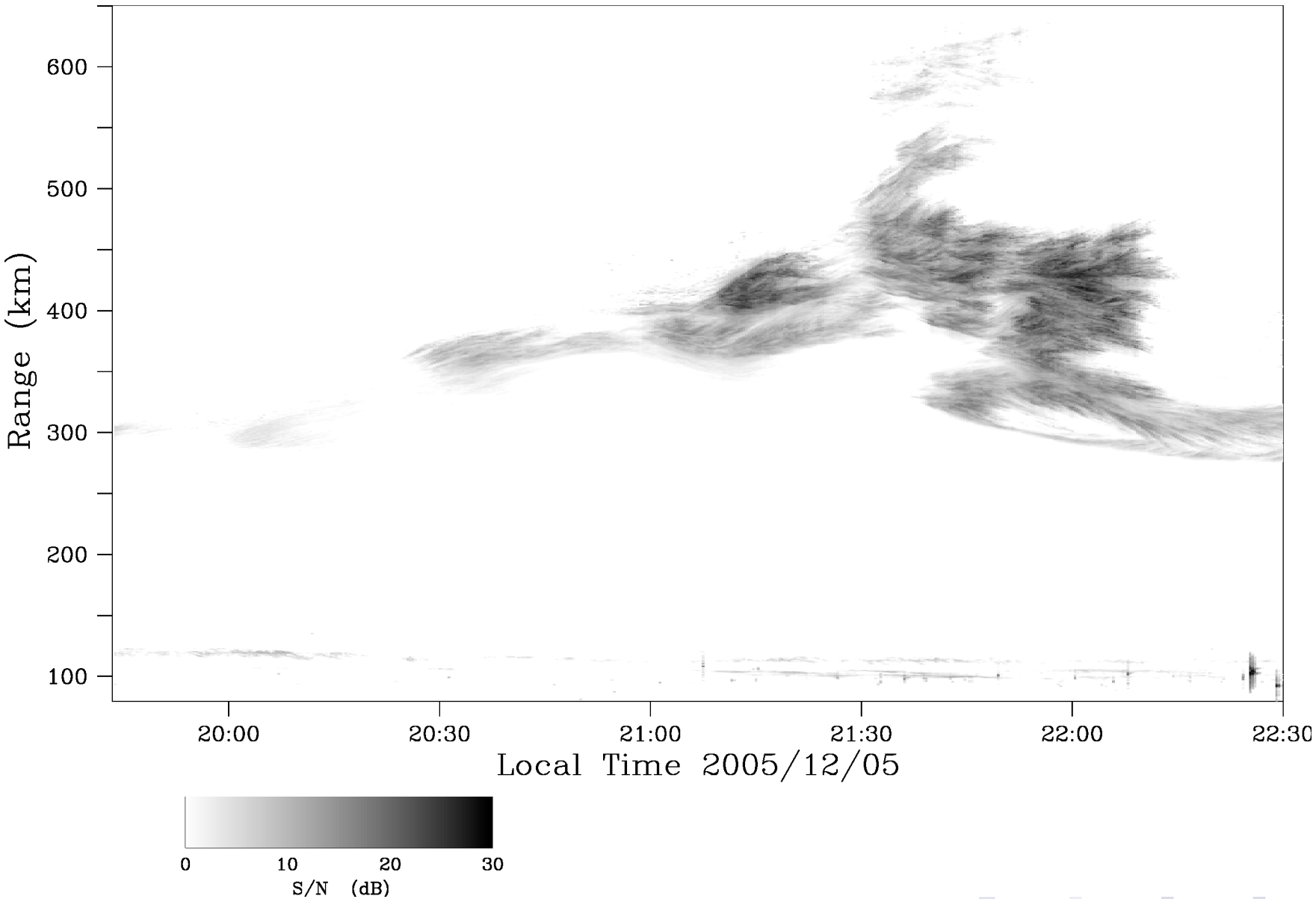
coherent scatter Faraday rotation



equatorial spread F

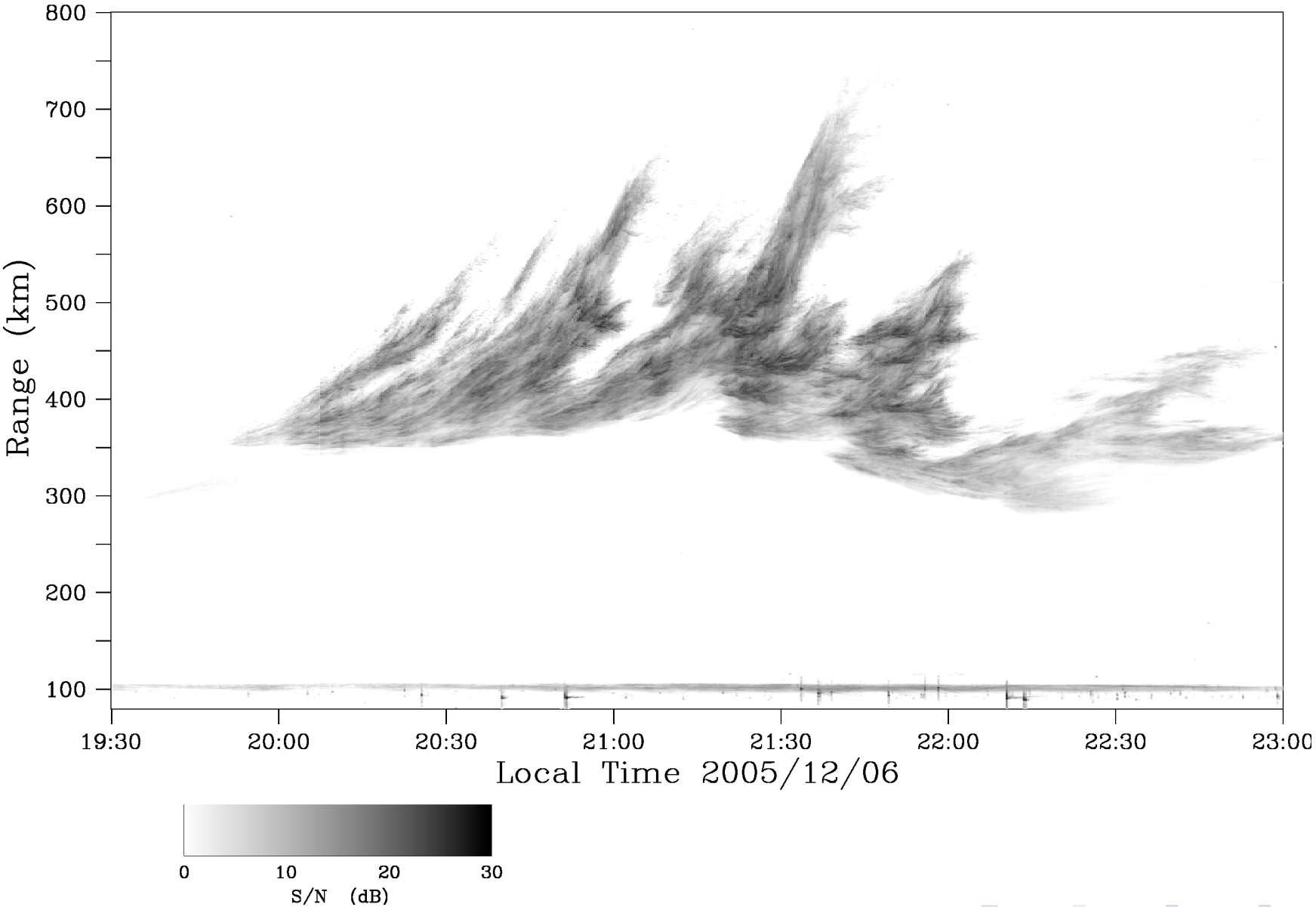


radar imagery



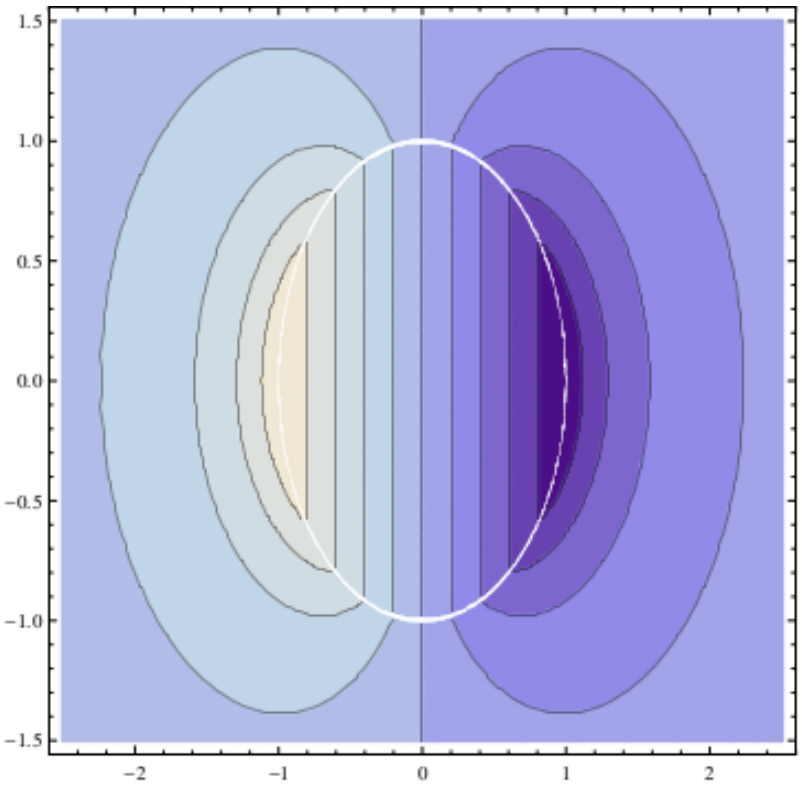
Dec 5

radar imagery

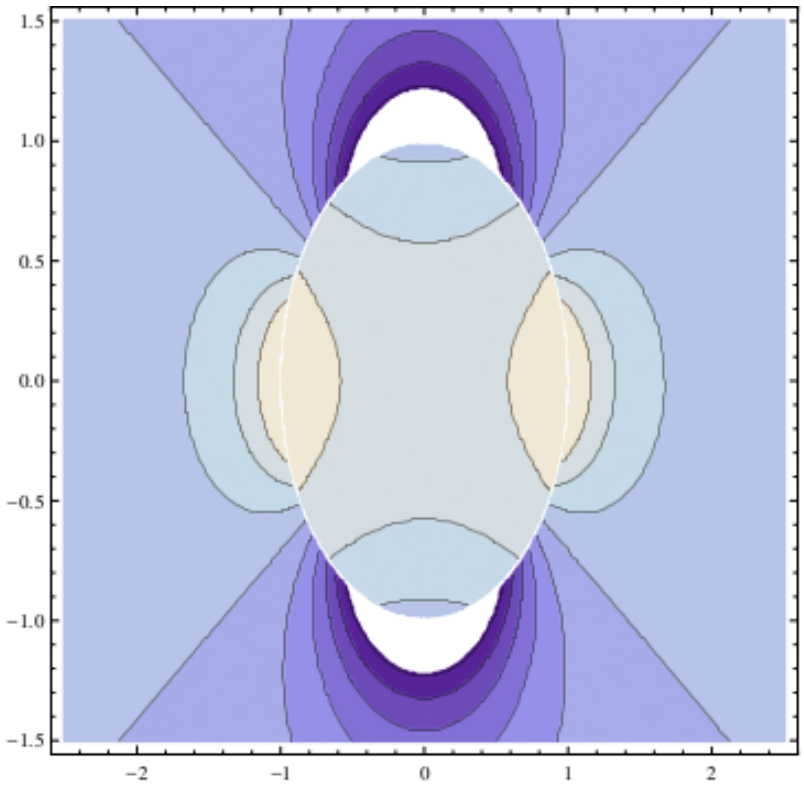


Dec 6 Dec 6 cont.

heuristic gRT theory: 3D warm plasmas; plan view



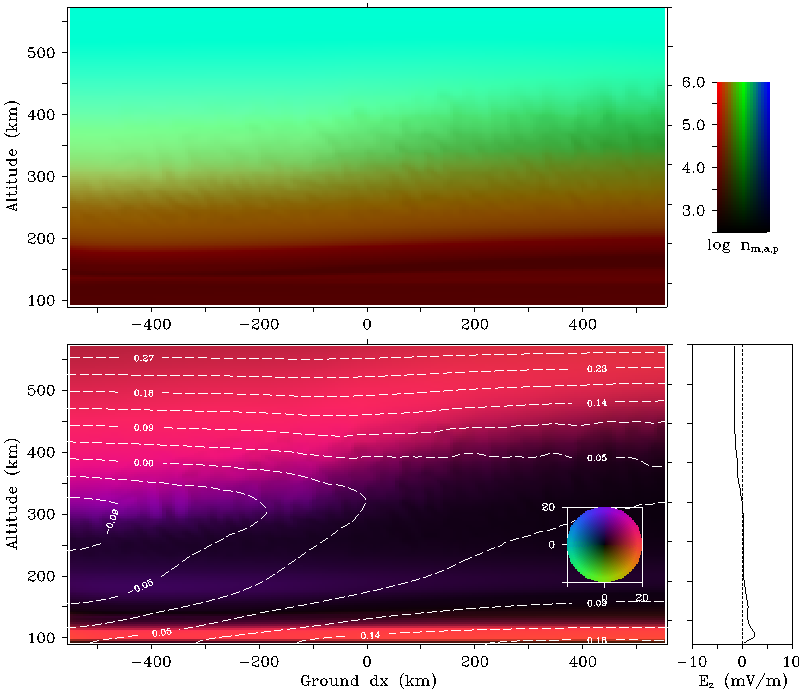
polarization



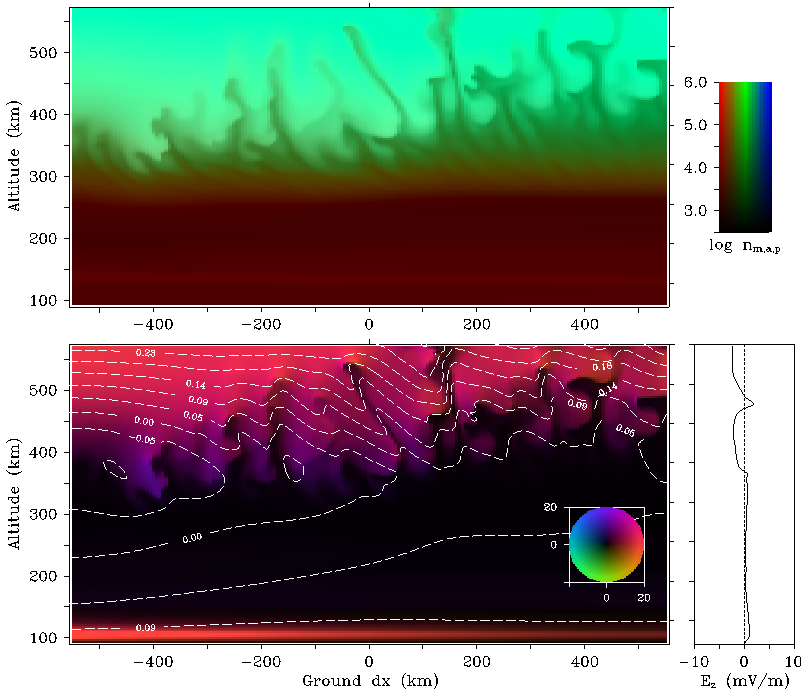
ambipolar diffusion

Drake, J. F., and J. D. Huba, *Phys. Rev. Lett.*, 58, 1987

3D numerical simulation (less diamagnetic current)

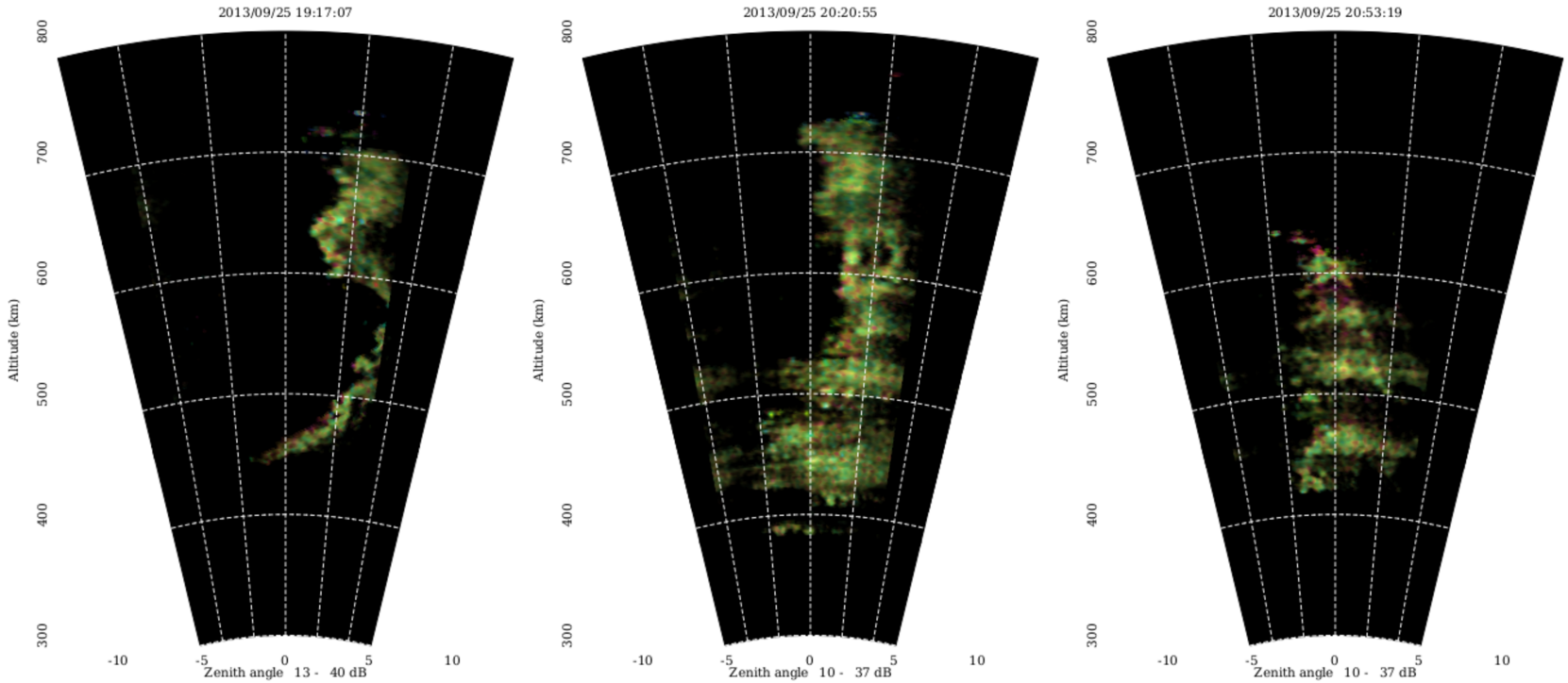


2345 UT + 25 min.

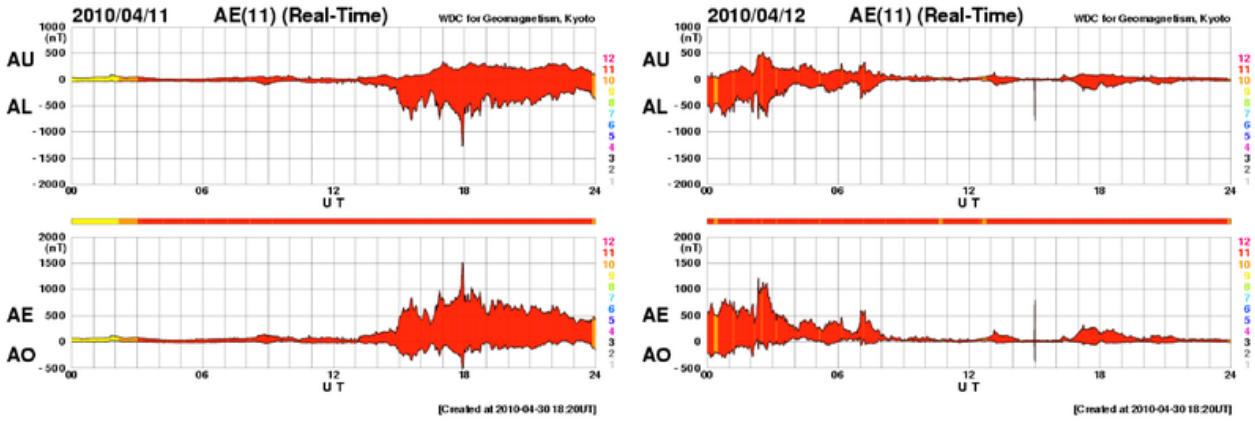


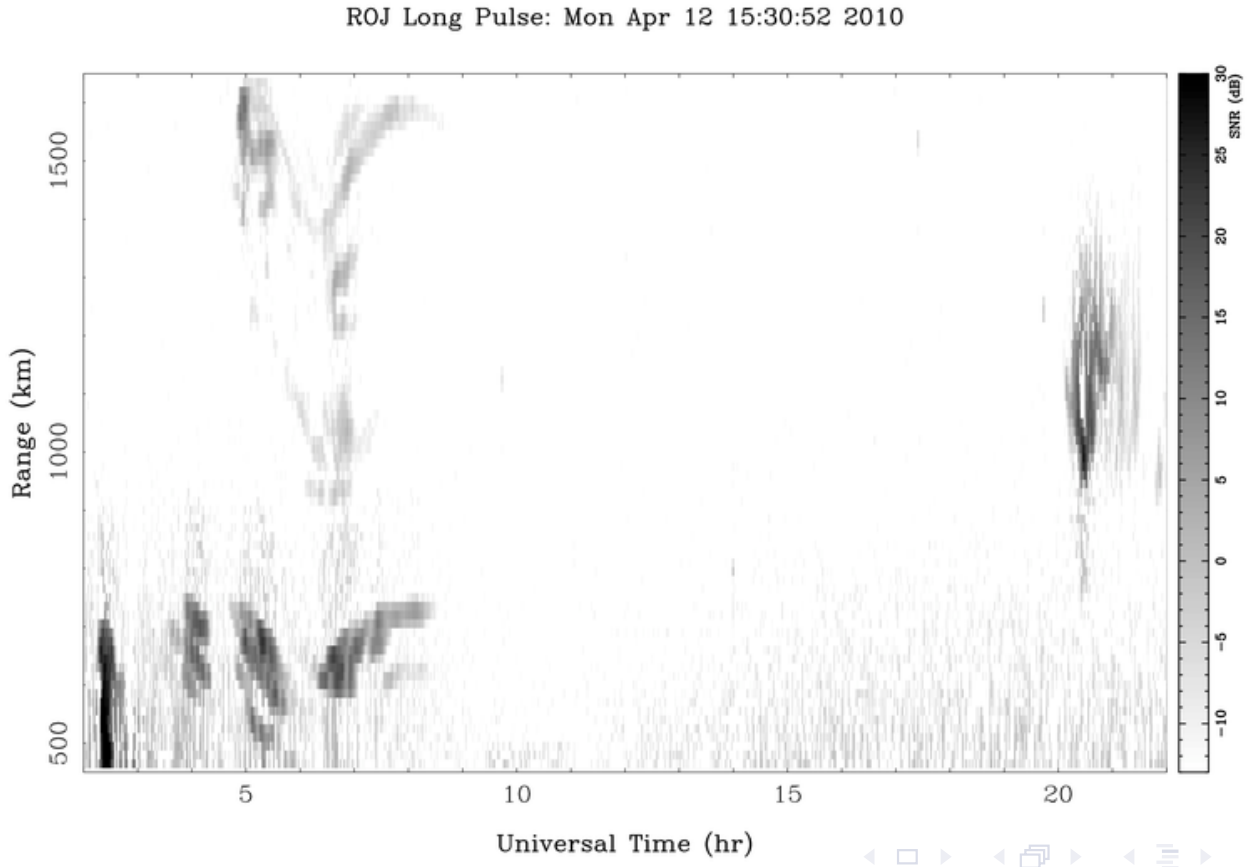
2345 UT + 75 min.

radar images – high activity



daytime spread F





unique behavior of equatorial ionosphere

- Topside composition not quite consistent with diffusive equilibrium.
- Heat flows from photoelectrons to thermal electrons to ions to neutrals. Energetic electron transport especially important around dawn.
- Dynamics arise from wind-driven ionospheric currents, inhomogeneous, anisotropic conductivity, and the requirement of quasineutrality. Interesting flow features accompany regions with steep conductivity gradients.
- Most obvious features are the evening vortex in the F region and the equatorial electrojet in the E region.
- Plasma instabilities arise when the flow around conductivity irregularities is such as to deepen the irregularities. The main instabilities are FBGD in the E region and ESF in the F region.

topics for study

	sunrise	daytime	twilight	nighttime	ISR	CSR
mesospheric echoes		✓				✓
meteor echoes	✓					✓
electrojet	✓	✓	✓	✓		✓
valley echoes			✓			✓
150-km echoes		✓				✓
spread F				✓		✓
Faraday rotation	✓	✓	✓	✓	✓	
temperature overshoot	✓				✓	
super rotation		✓		✓	✓	
evening vortex			✓		✓	
topside		✓			✓	