Equatorial Aeronomy from a Radar Perspective

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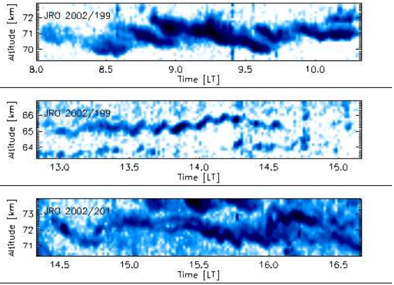
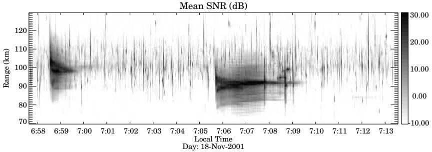
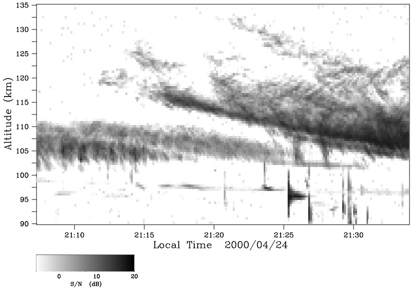
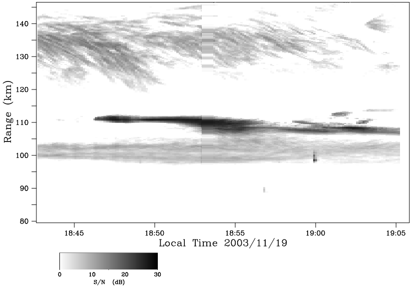
Jicamarca Radio Observatory

gallery i

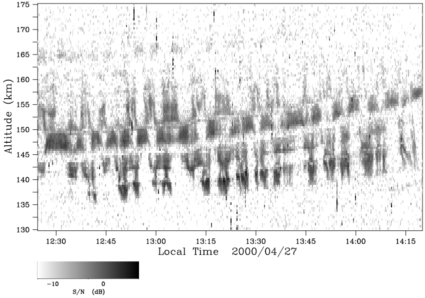

JRO 2002/199
Altitude [km]
72
71
70
8.0
8.5
9.0
9.5
10.0
Time [LT]
JRO 2002/199
Altitude [km]
66
65
64
13.0
13.5
14.0
14.5
15.0
Time [LT]
JRO 2002/201
Altitude [km]
73
72
71
14.5
15.0
15.5
16.0
16.5
Time [LT]

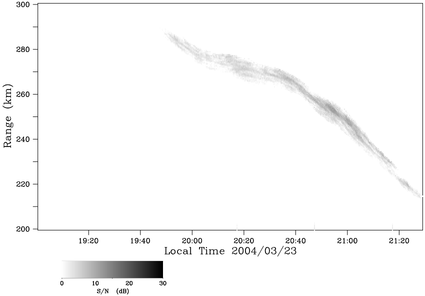

Mean SNR (dB)
Range (km)
120
110
100
90
80
70
6:58
6:59
7:00
7:01
7:02
7:03
7:04
7:05
7:06
7:07
7:08
7:09
7:10
7:11
7:12
7:13
Local Time
Day: 18-Nov-2001
30.00
20.00
10.00
0.00
-10.00

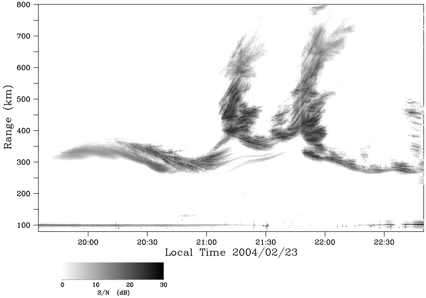

Altitude (km)
135
130
125
120
115
110
105
100
95
90
21:10
21:15
21:20
21:25
21:30
Local Time 2000/04/24
0
10
20
S/N (dB)

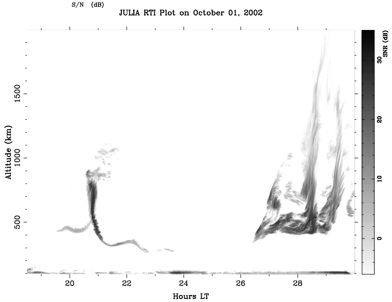

Range (km)
140
130
120
110
100
90
80
18:45
18:50
18:55
19:00
19:05
Local Time 2003/11/19
0
10
20
30
S/N (dB)

gallery ii


Altitude (km)
175
170
165
160
155
150
145
140
135
130
12:30
12:45
13:00
13:15
13:30
13:45
14:00
14:15
Local Time 2000/04/27
−10
0
S/N (dB)


Range (km)
300
280
260
240
220
200
19:20
19:40
20:00
20:20
20:40
21:00
21:20
Local Time 2004/03/23
0
10
20
30
S/N (dB)


Range (km)
800
700
600
500
400
300
200
100
20:00
20:30
21:00
21:30
22:00
22:30
Local Time 2004/02/23
0
10
20
30
S/N (dB)


JULIA RTI Plot on October 01, 2002
Altitude (km)
1500
1000
500
20
22
24
26
28
Hours LT
SNR (dB)
30
20
10
0

outline

- Survey of unique phenomena
- The geomagnetic field
- Ionospheric composition
- Thermal structure
- Conductivity
- Dielectric properties
- Electrodynamics
- Equatorial electrojet
- Equatorial ionospheric plasma instabilities

geomagnetic field (dipole part)

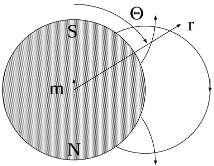
$$\phi_m = \frac{m\cos\theta}{r^2}$$

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

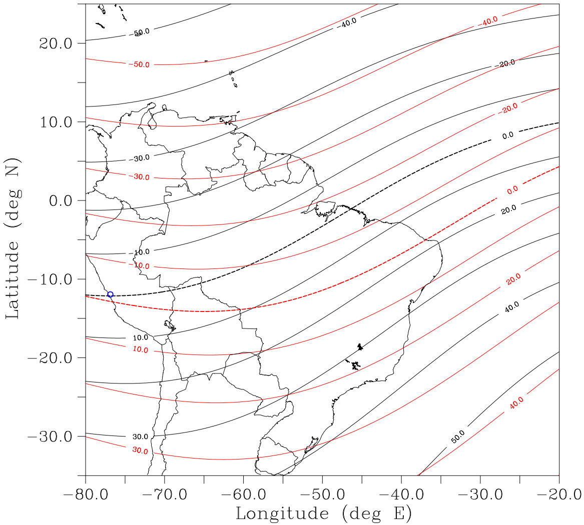
$$B = \frac{m}{r^3}\left(1 + 3\cos^2\theta\right)^{1/2}$$

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

$$r = LR_e\sin^2\theta$$



non-dipole field



ionospheric composition

$$\frac{\partial n}{\partial t} + \nabla \cdot (n\mathbf{v}) = q - L$$

$$q = I_\infty \eta \sigma n_n(h) e^{-\sigma \sec\chi n_n(h) H(h)} \quad \text{single wavelength, species}$$

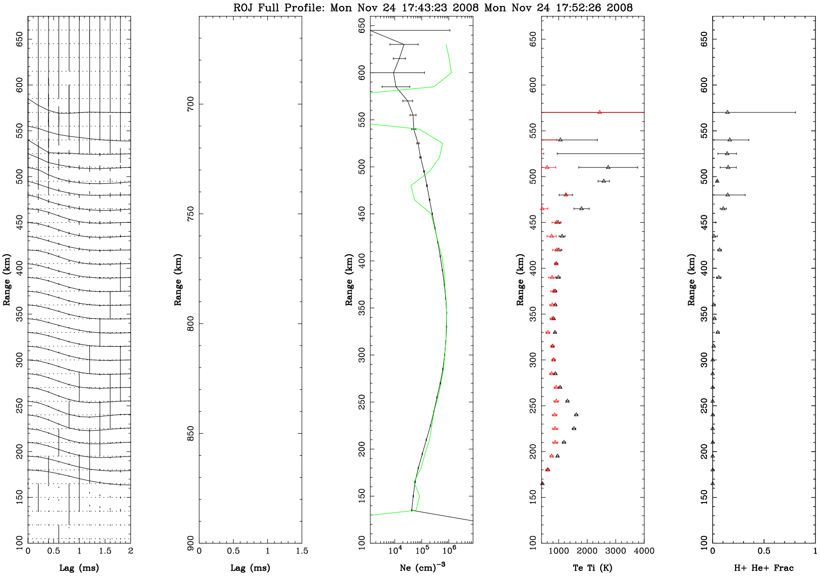
$$\frac{dn}{dt} = q - \alpha n_m n \quad \text{dissoc. recomb.}$$

$$\frac{dn_a}{dt} = q - \gamma N[m] n_a \quad \text{charge ex.}$$

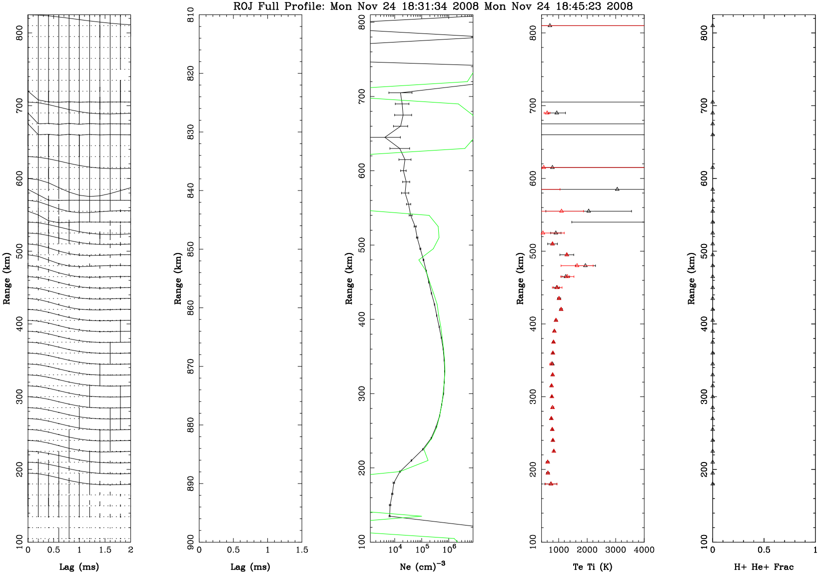
$$\frac{dn_m}{dt} = \underbrace{\gamma N[m]}_{\beta} n_a - \alpha n_m n$$

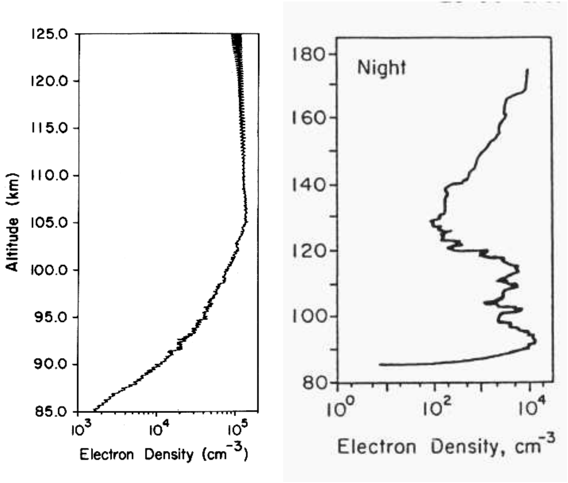
$$\frac{1}{q} = \frac{1}{\beta n} + \frac{1}{\alpha n^2}$$

F layer, 1752 LT



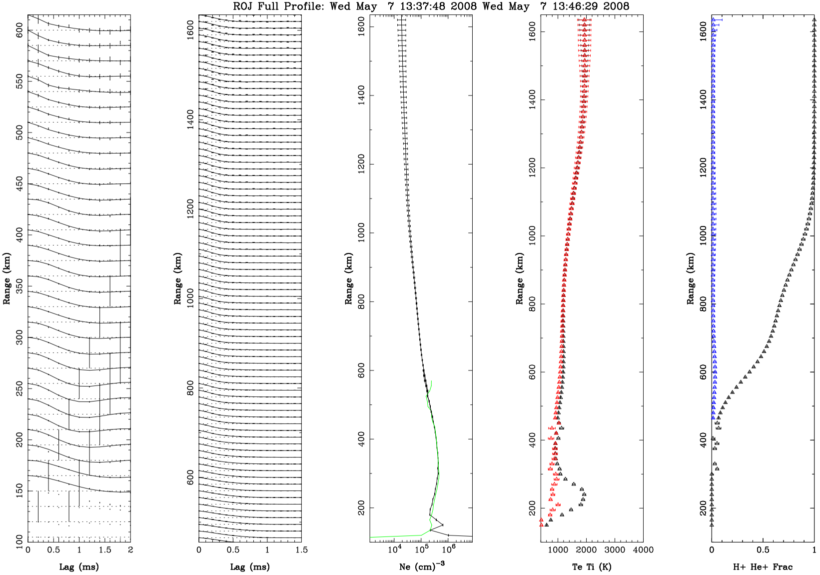
F layer, 1845 LT





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

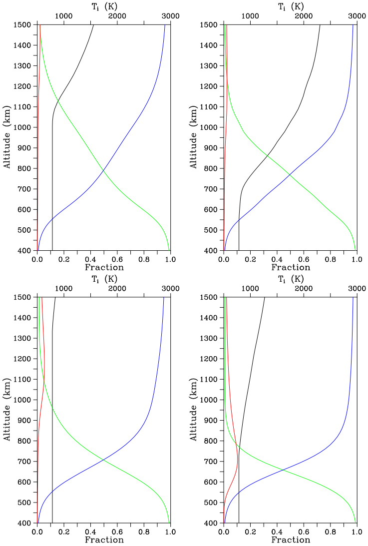
topside ionosphere



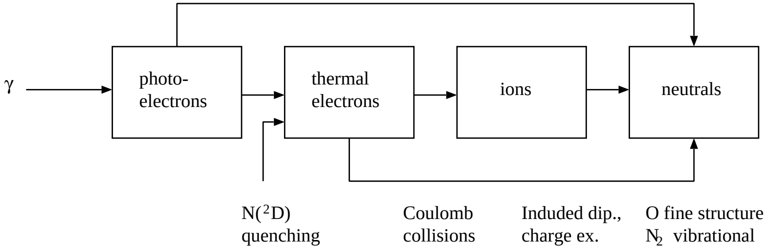
diffusive equilibrium

$$0 = -K\nabla(n_j T_j)/n_j + eE - m_j g$$
$$0 = -K\nabla(n_e T_e)/n_e - eE - m_e g$$
$$n_e = \sum_j n_j$$

$$\frac{n_j(z)}{n_e(z)} = \frac{n_{\circ j}(T_{\circ j}/T_j)e^{-\int_\circ^z dz/H_j}}{\sum_i n_{\circ i}(T_{\circ i}/T_i)e^{-\int_\circ^z dz/H_i}}$$
$$H_j \equiv \frac{KT_j(z)}{m_j g(z)}$$

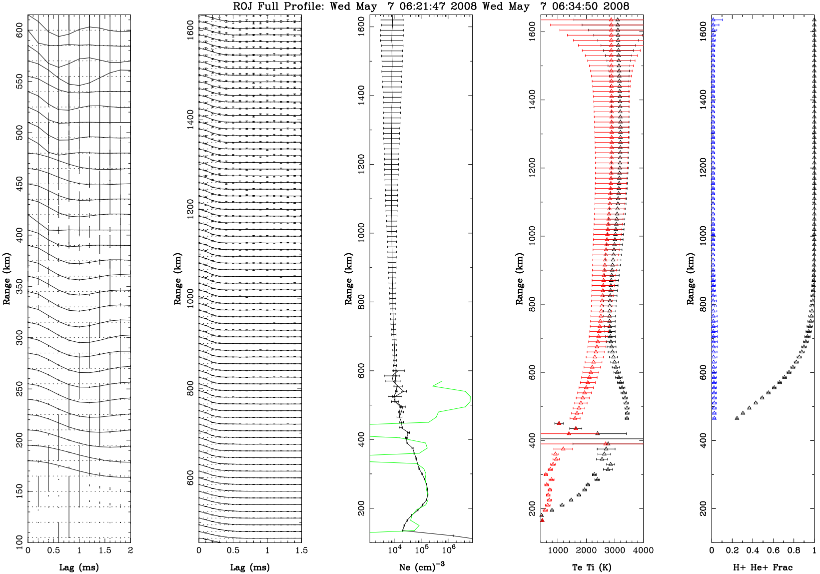


thermal structure

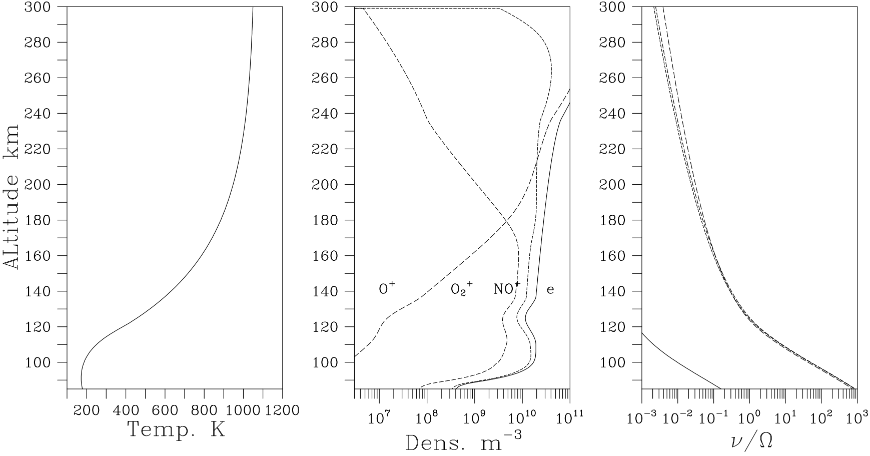


- Quasi equilibrium
- Local heating & cooling + photoelectron transport, conduction
- Rates are energy/velocity dependent
- Cooling via elastic and inelastic collisions
- Need to specify solar flux spectrum, absorbtion and ionization cross sections

topside ionosphere



temperature, composition, collisionality



plasma as conductor

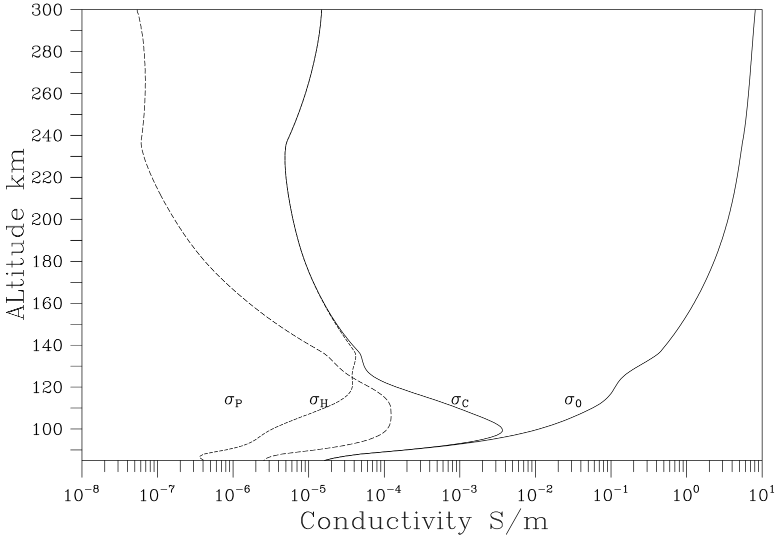
$$\mathbf{J} = \sigma_P (\mathbf{E}_\perp + \mathbf{u} \times \mathbf{B}) + \sigma_H \hat{b} \times \underbrace{(\mathbf{E}_\perp + \mathbf{u} \times \mathbf{B})}_{\mathbf{E}'_\perp} + \sigma_\circ \mathbf{E}_\parallel$$

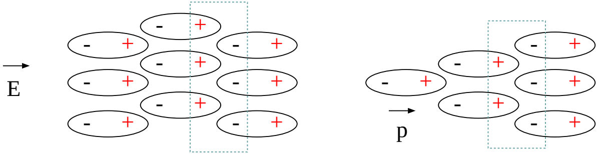
$$\sigma_P = e^2 \sum_j \frac{n_j \nu_j}{m_j(\nu_j^2 + \Omega_j^2)}$$

$$\sigma_H = e^2 \sum_j \frac{-n_j \Omega_j}{m_j(\nu_j^2 + \Omega_j^2)}$$

$$\sigma_\circ = e^2 \sum_j \frac{n_j}{m_j \nu_j}$$

profiles (twilight)

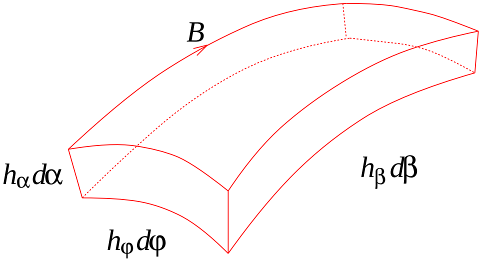




$$\begin{aligned}\epsilon_\circ \nabla \cdot \mathbf{E} &= -\nabla \cdot \mathbf{P} \quad = -\nabla \cdot (\epsilon_\circ \chi \mathbf{E}) \\ &= -\epsilon_\circ \nabla \ln(1+\chi) \cdot \mathbf{E}\end{aligned}$$

$$\nabla \cdot \mathbf{J} = \nabla \cdot \left(\sigma_P \mathbf{E}'_\perp + \sigma_\circ \mathbf{E}_\parallel + \sigma_H \hat{b} \times \mathbf{E}' \right) = 0 \longrightarrow$$

$$\begin{aligned}\tilde{\nabla} \cdot \mathbf{E}' &= -\nabla_\perp \ln\sigma_P \cdot \mathbf{E}'_\perp - \tilde{\nabla}_\parallel \ln\sigma_\circ \cdot \mathbf{E}_\parallel - \frac{\sigma_H}{\sigma_P} \mathbf{E}'_\perp \times \nabla_\perp \ln\sigma_H \cdot \hat{b} \\ \tilde{\nabla} &\equiv \nabla_\perp + \frac{\sigma_\circ}{\sigma_P} \nabla_\parallel \quad = \quad \nabla_\perp + \tilde{\nabla}_\parallel\end{aligned}$$

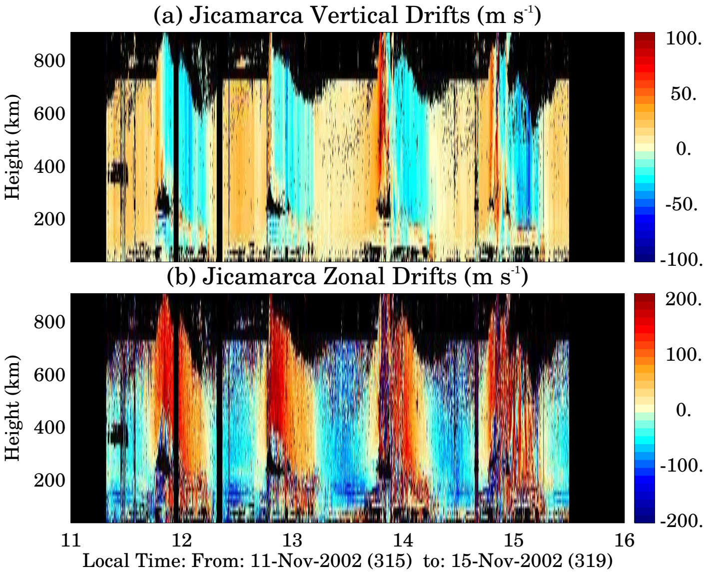


$$E_\alpha = \frac{E_\phi h_\phi \int \sigma_H h_\beta d\beta - \int (\sigma_P u_\phi + \sigma_H u_\alpha) B h_\phi h_\beta d\beta + dI/d\phi}{h_\alpha \int \sigma_P \frac{h_\phi h_\beta}{h_\alpha} d\beta}$$

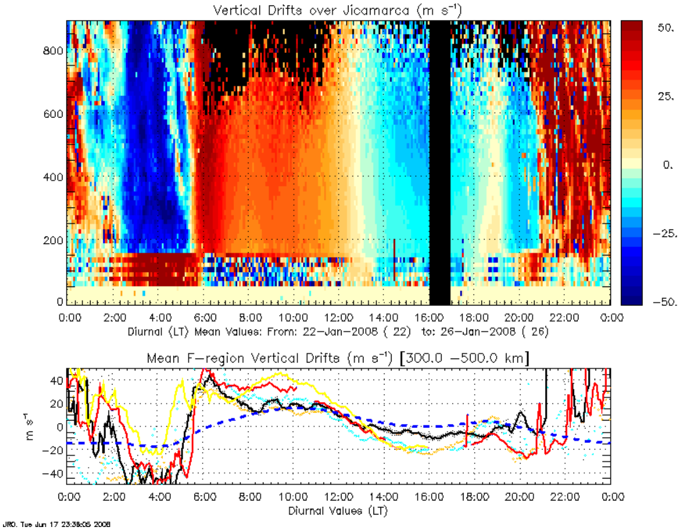
$$J_\phi = E_\phi \sigma_P + E_\alpha \sigma_H = E_\phi \sigma_c$$

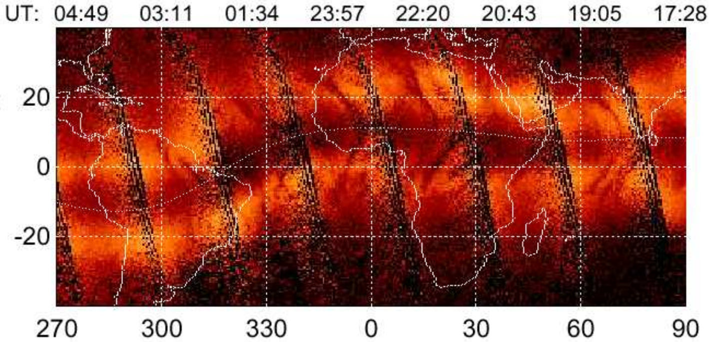
dynamical consequences

- Dawn-dusk electric field
- Super-rotation
- Prereversal enhancement
- Fountain effect, equatorial anomaly
- Stratospheric warming effects
- Bottomside shear, evening vortex
- Equatorial electrojet


(a) Jicamarca Vertical Drifts (m s^{-1})
Height (km)
800
600
400
200
100.
50.
0.
-50.
-100.
(b) Jicamarca Zonal Drifts (m s^{-1})
Height (km)
800
600
400
200
200.
100.
0.
-100.
-200.
11
12
13
14
15
16
Local Time: From: 11-Nov-2002 (315) to: 15-Nov-2002 (319)

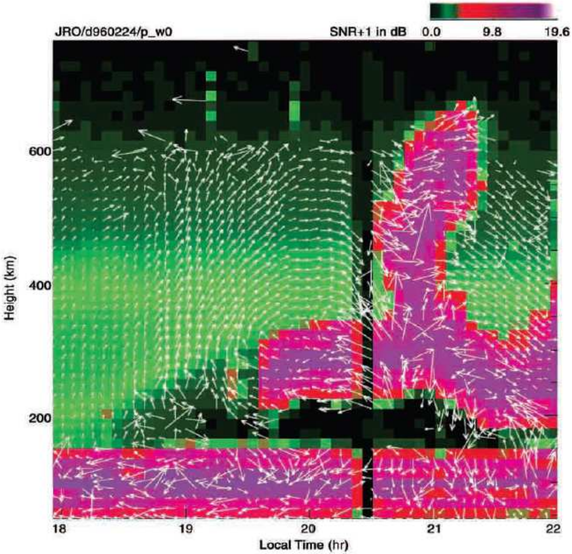
stratospheric warming



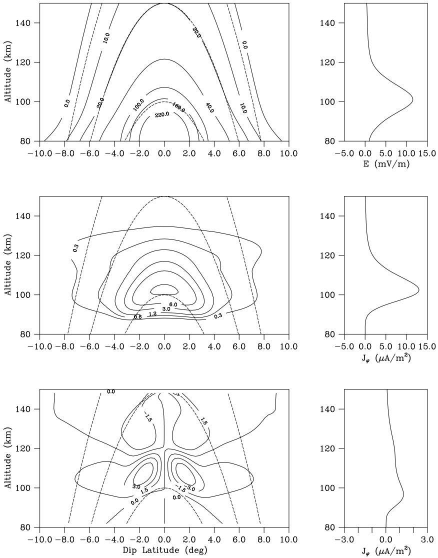


$$e + O^{+} \rightarrow O^{*} + 139\ \text{nm},\ I \propto n_e^2$$

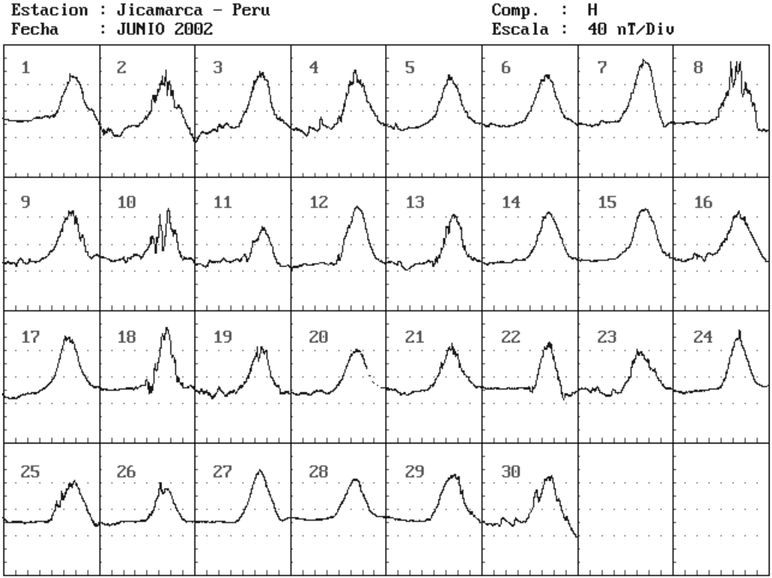
evening vortex

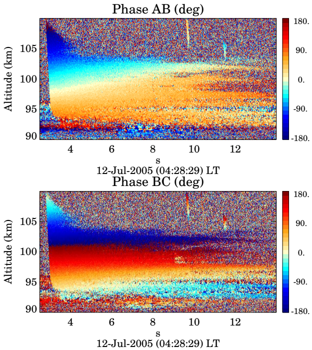


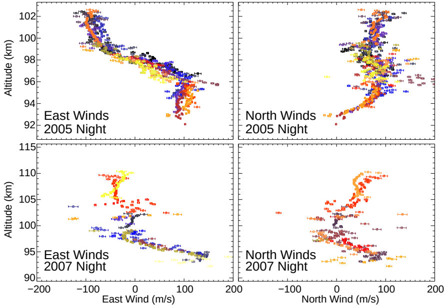
equatorial electrojet



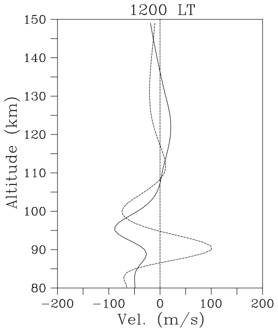
Jicamarca magnetometer



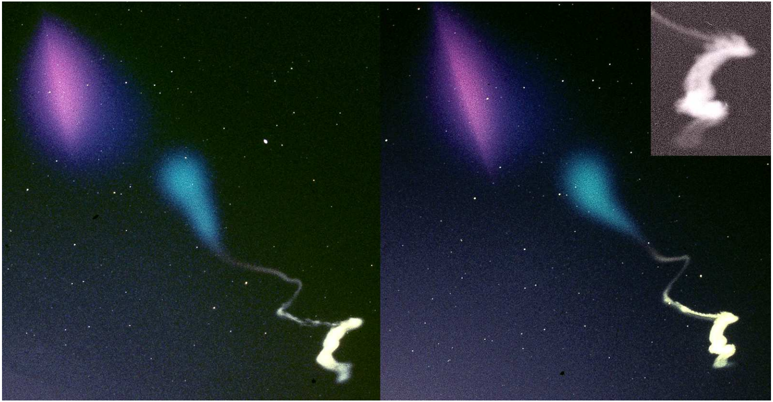

Phase AB (deg)
Altitude (km)
105
100
95
90
4
6
8
10
12
s
12-Jul-2005 (04:28:29) LT
180.
90.
0.
-90.
-180.
Phase BC (deg)
Altitude (km)
12-Jul-2005 (04:28:29) LT


Altitude (km)
East Winds
2005 Night
North Winds
2005 Night
East Winds
2007 Night
North Winds
2007 Night
−200
−100
0
100
200
East Wind (m/s)
North Wind (m/s)

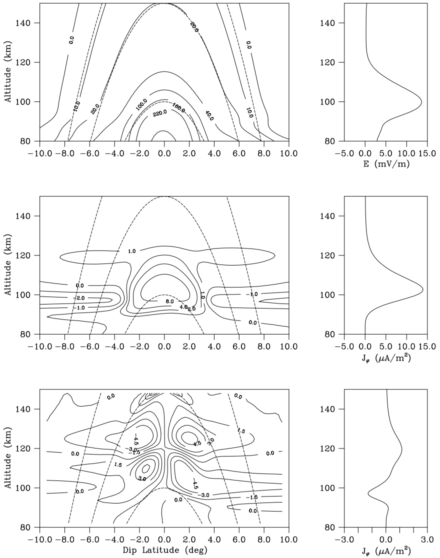
lower thermospheric winds



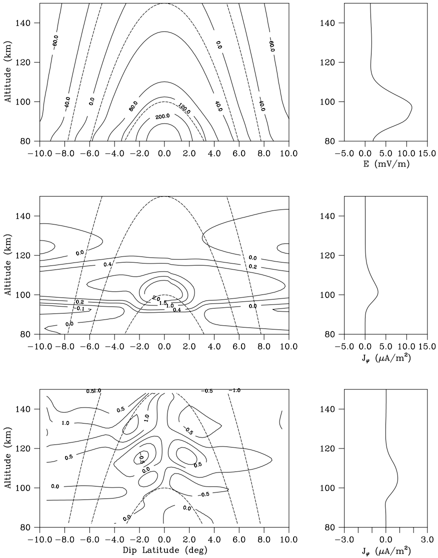
equatorial chemical releases



wind effects (noon)

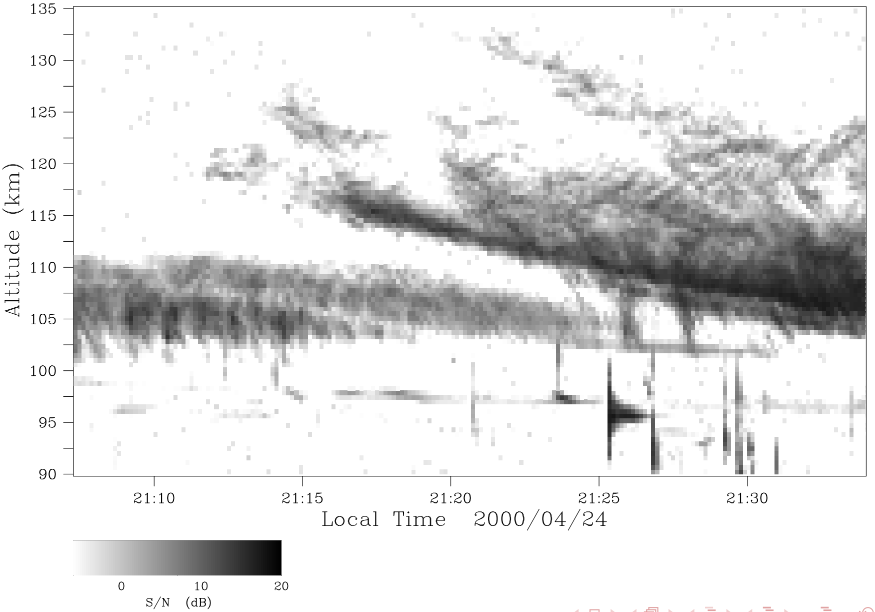


twilight

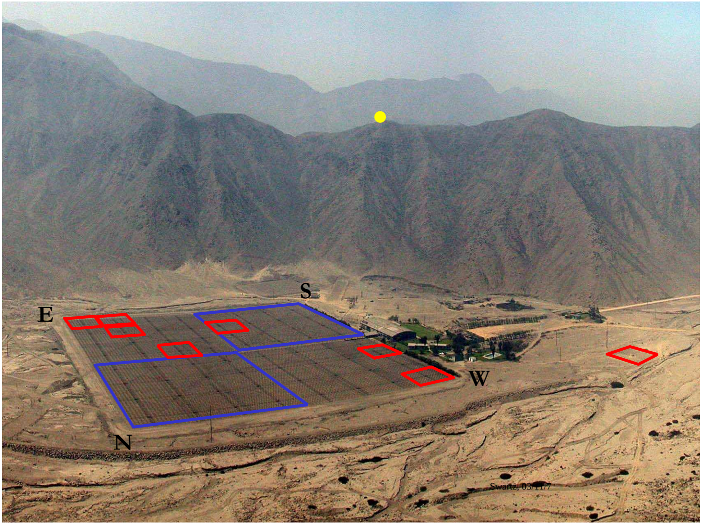


Altitude (km)
140
120
100
80
−10.0 −8.0 −6.0 −4.0 −2.0 0.0 2.0 4.0 6.0 8.0 10.0
−5.0 0.0 5.0 10.0 15.0
E (mV/m)
J_φ (μA/m^2)
−3.0 0.0 3.0
Dip Latitude (deg)

electrojet plasma waves

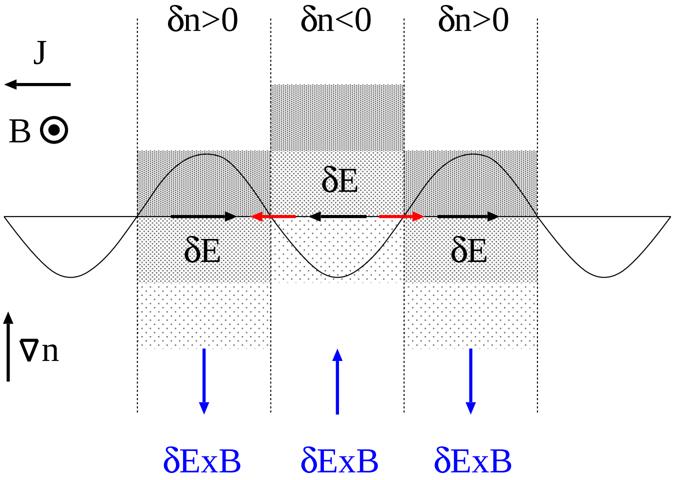


radar imagery



daytime nighttime

FBGD instability

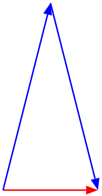


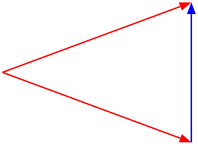
dispersion relation

$$\omega = \frac{\mathbf{k}\cdot(\mathbf{V}_{de}-\mathbf{V}_{di})}{(1+\psi)(1+k_\circ^2/k^2)} + \mathbf{k}\cdot\mathbf{V}_{di}$$

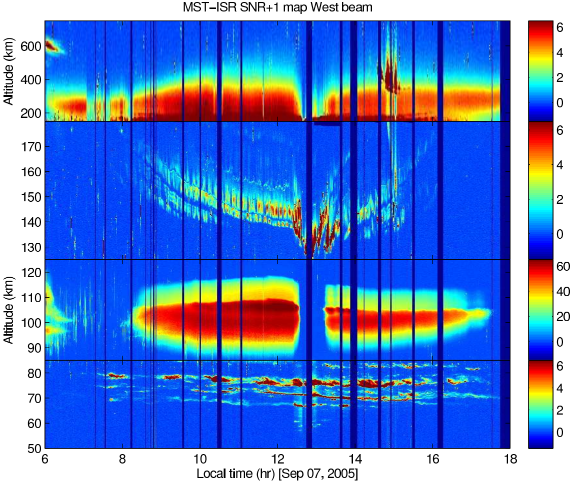
$$\gamma = \frac{\psi/\nu_i}{1+\psi}\left((\omega-\mathbf{k}\cdot\mathbf{V}_{di})^2 - k^2C_s^2\right) + \frac{k_\circ}{k}(\omega-\mathbf{k}\cdot\mathbf{V}_{di}) - 2\alpha n_\circ$$

$$\frac{k_\circ}{k} = \frac{1}{1+\psi}\frac{k_\perp}{k^2L}\frac{\nu_i}{\Omega_i}, \quad \psi \equiv \frac{\nu_e\nu_i}{\Omega_e\Omega_i}$$

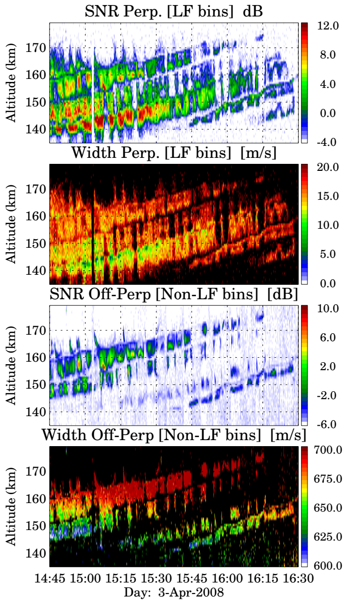




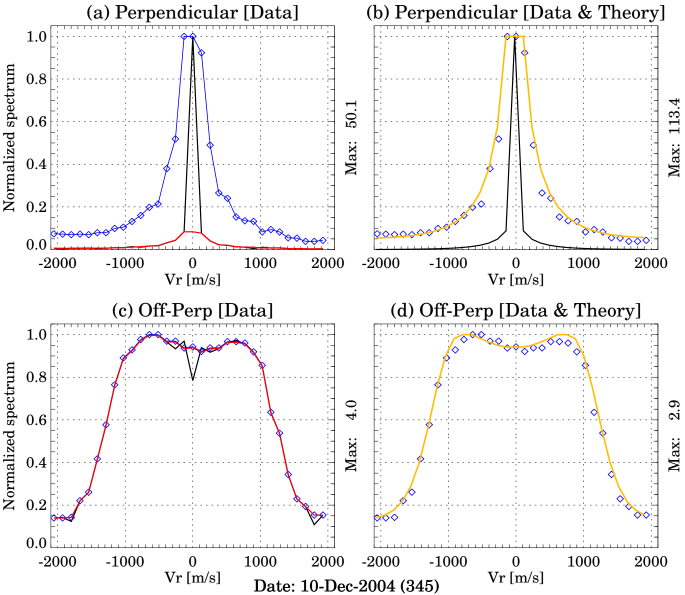
150 km echoes; solar flare



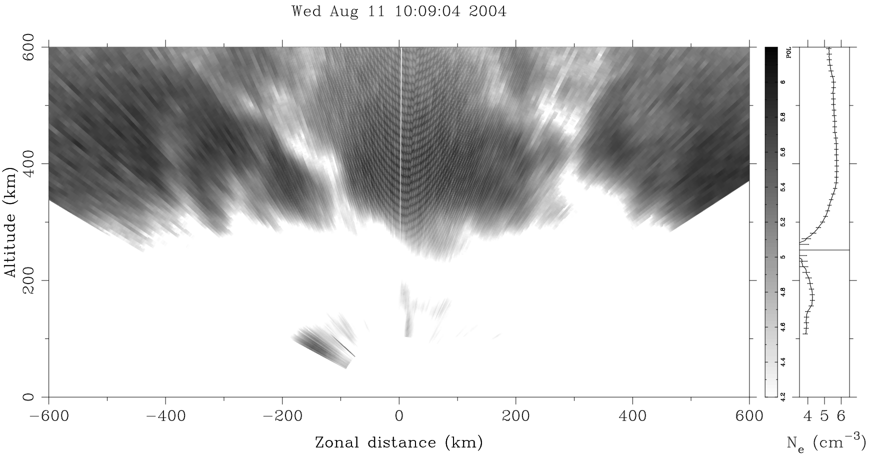
150 km echo spectra



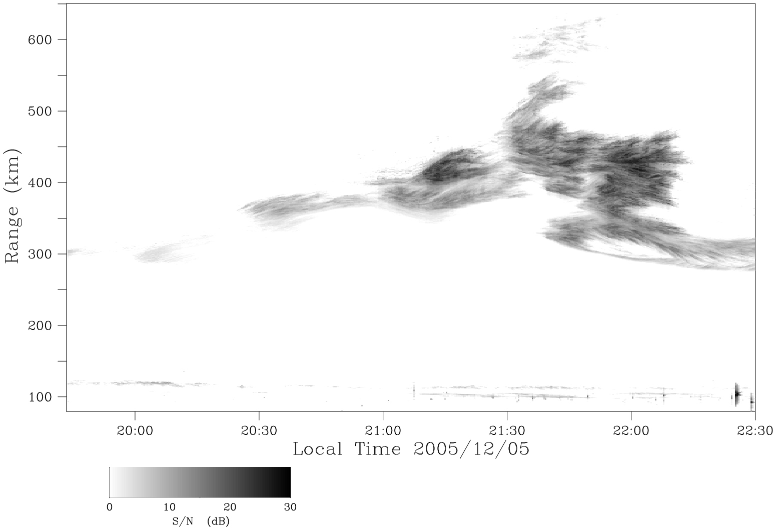
150 km echo/ISR spectra



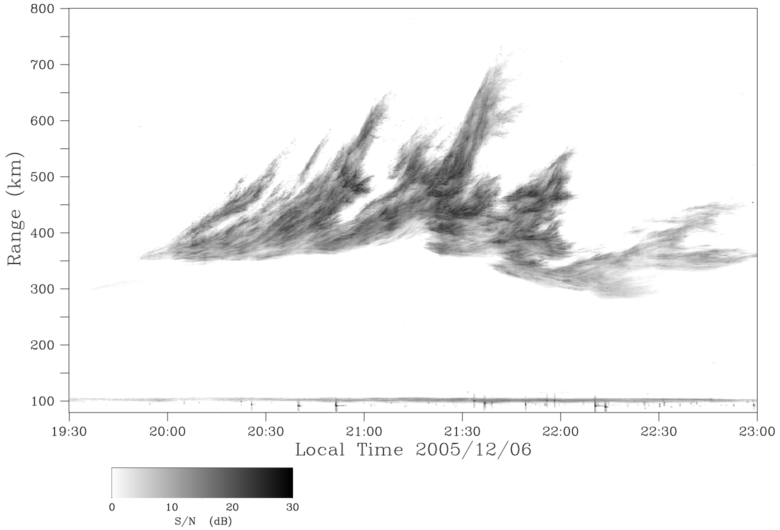
equatorial spread F



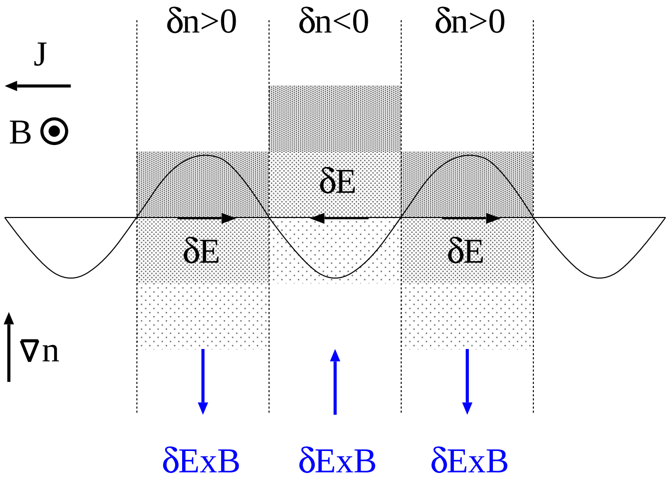
radar imagery



Dec 5



Dec 6 Dec 6 cont.


δn>0
δn<0
δn>0
J
B
δE
δE
δE
∇n
δExB
δExB
δExB

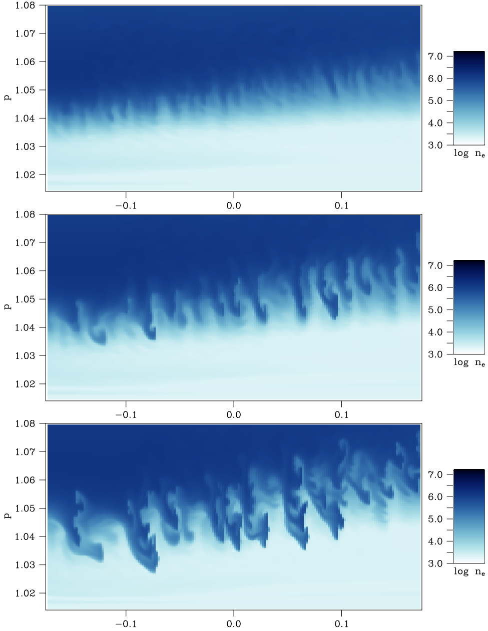
interchange instability

$$\gamma = \sqrt{\frac{\nu_{\rm in}^2}{4} + \frac{\nu_{\rm in}}{L}\frac{k_x^2}{k^2}\left(\frac{g}{\nu_{\rm in}} + \frac{E}{B} - u_z\right) R - \nu_{\rm in} k^2 D_a} - \frac{\nu_{\rm in}}{2}$$

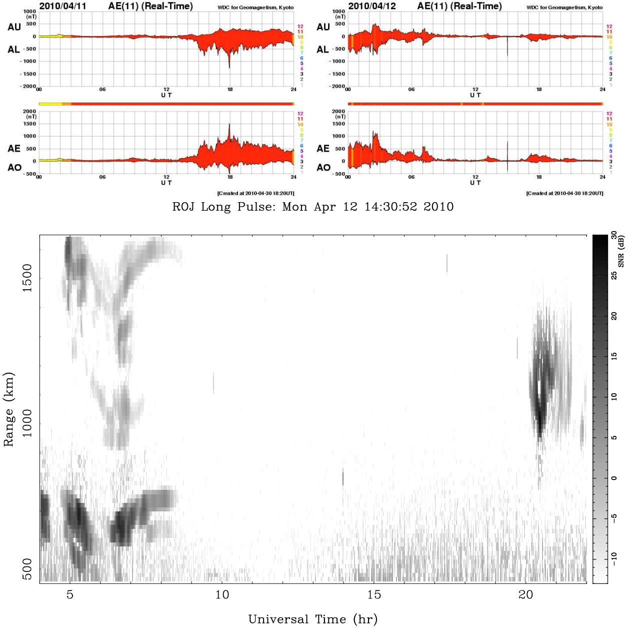
$$R \equiv \frac{\Sigma_F}{\Sigma_E + \Sigma_F}$$

- Finite L correction; fastest growing modes $\sim$ 1 km
- Shear flow, transient waves $\sim$ 30 km, steady-state $\sim$ 200 km
- Seeding (gravity waves)

numerical simulation



daytime spread F



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