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CEDAR Prize Lecture

by David Hysell
Clemson University

A New Look at Low- and Mid-Latitude Ionospheric Irregularities

A new look at low– and mid–latitude ionospheric irregularities

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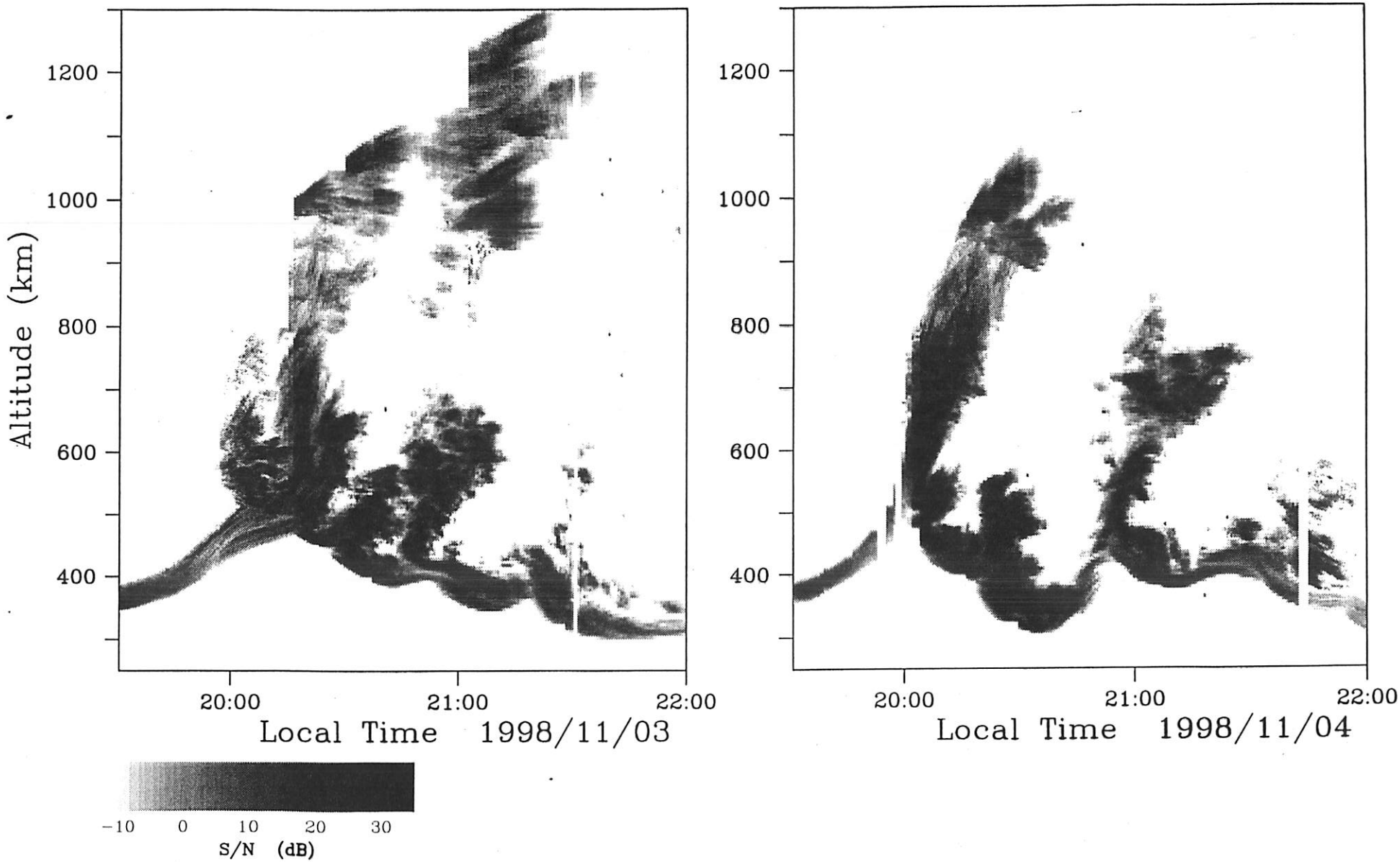
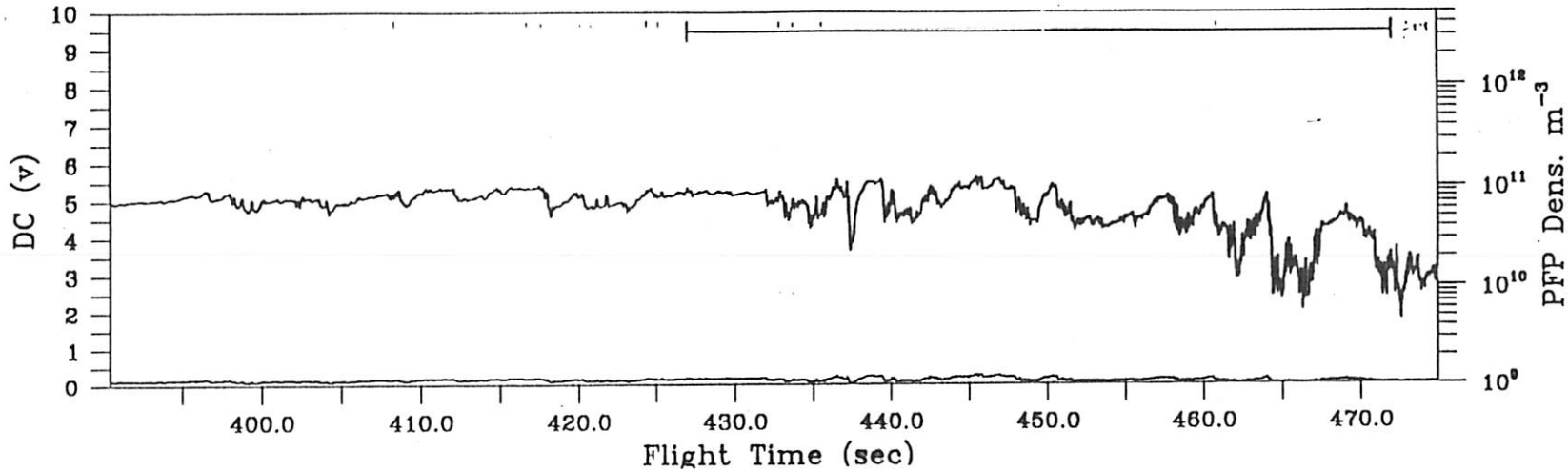
June 14, 1999

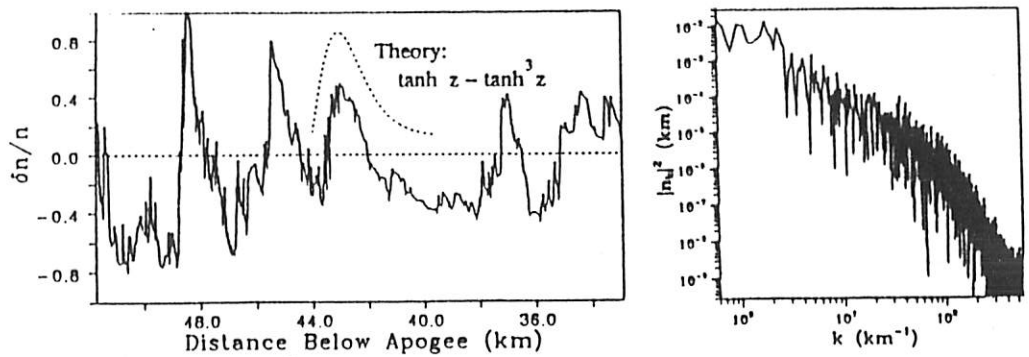
Joel Burcham
Rick McDaniel
Miguel Larsen
Bela Fejer
Ludger Scherliess
Mike Taylor
Ron Woodman

Topical outline

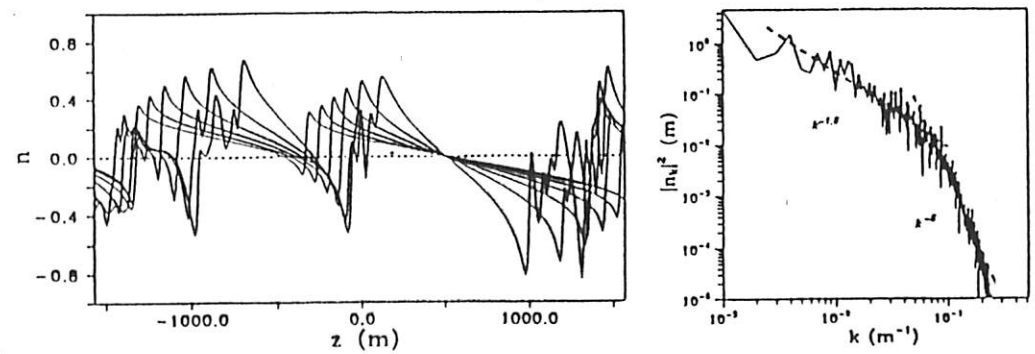
- *F* region irregularities at the dip equator
  - In–beam radar imaging at Jicamarca
- Equatorial electrojet irregularities
  - Long duration JULIA radar observations
- Midlatitude sporadic *E* layer echoes
  - HF radar at Clemson University


Altitude (km)
1200
1000
800
600
400
20:00
21:00
22:00
Local Time 1998/11/03
Local Time 1998/11/04
−10
0
10
20
30
S/N (dB)

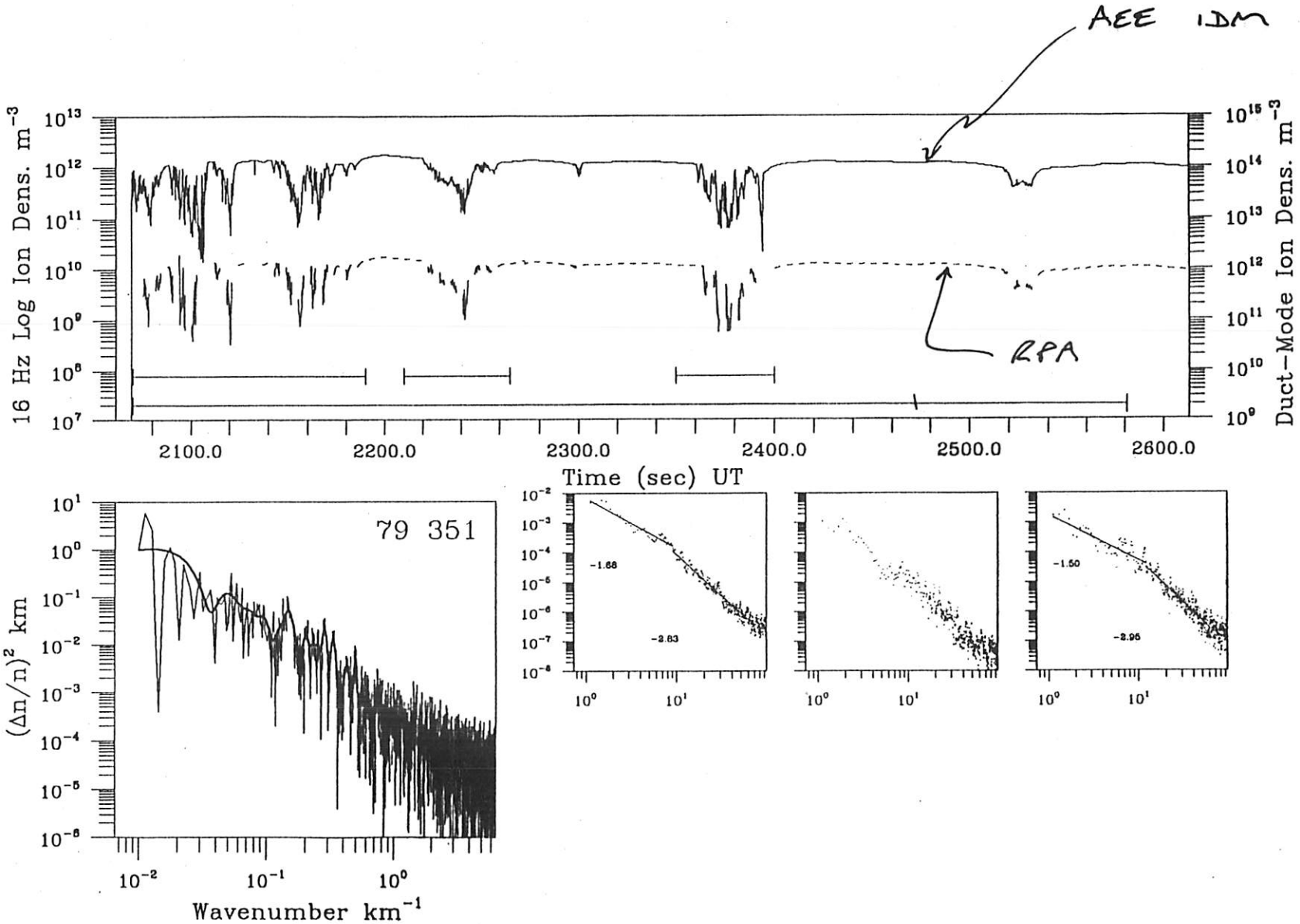


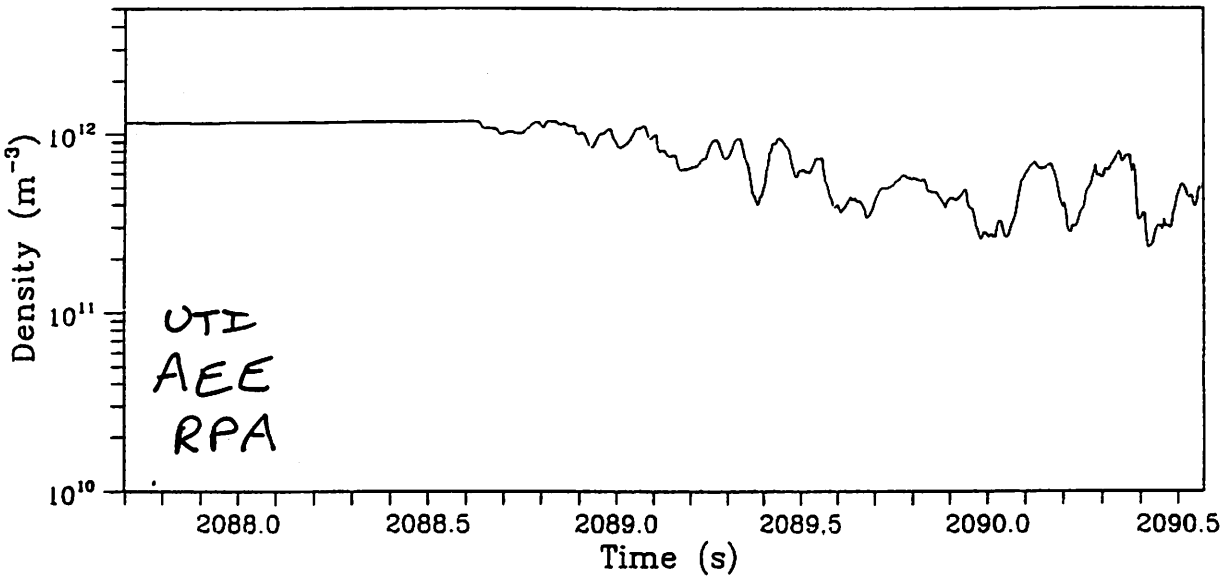


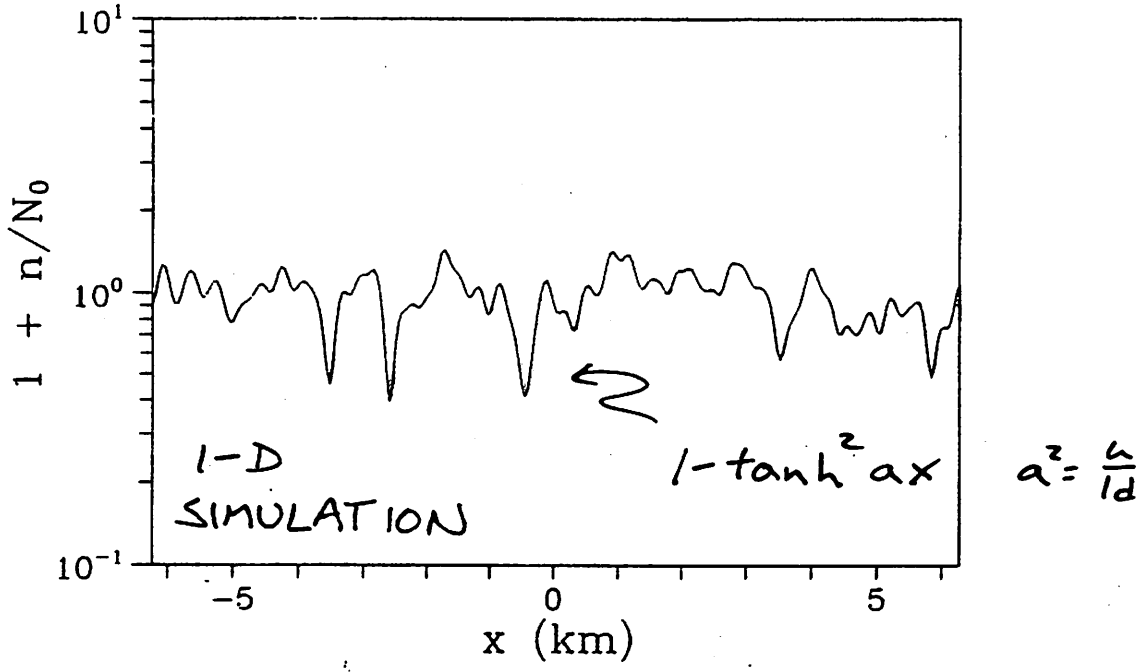
29.028
KWAJALEIN
PFAFF/KELLEY

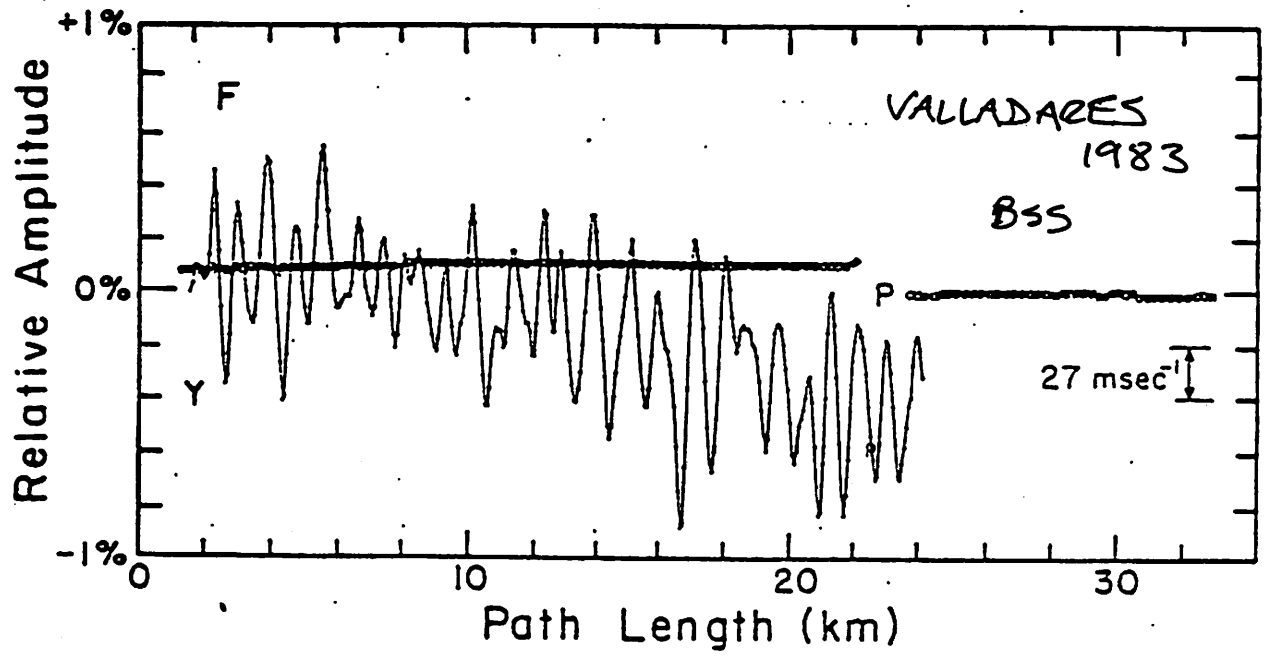


SIMULATION


AEE IDM
RPA
16 Hz Log Ion Dens. m^{-3}
Duct-Mode Ion Dens. m^{-3}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
2100.0
2200.0
2300.0
2400.0
2500.0
2600.0
Time (sec) UT
79 351
$(\Delta n/n)^2$ km
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-2}
10^{-1}
10^{0}
Wavenumber km^{-1}
-1.66
-2.83
-1.50
-2.95
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{0}
10^{1}


Density (m^{-3})
10^{12}
10^{11}
10^{10}
UTI
AEE
RPA
2088.0
2088.5
2089.0
2089.5
2090.0
2090.5
Time (s)


$1 + n/N_0$
10^1
10^0
10^{-1}
1-D
SIMULATION
$1-\tanh^2 ax$
$a^2 = \frac{\lambda}{l_d}$
−5
0
5
x (km)

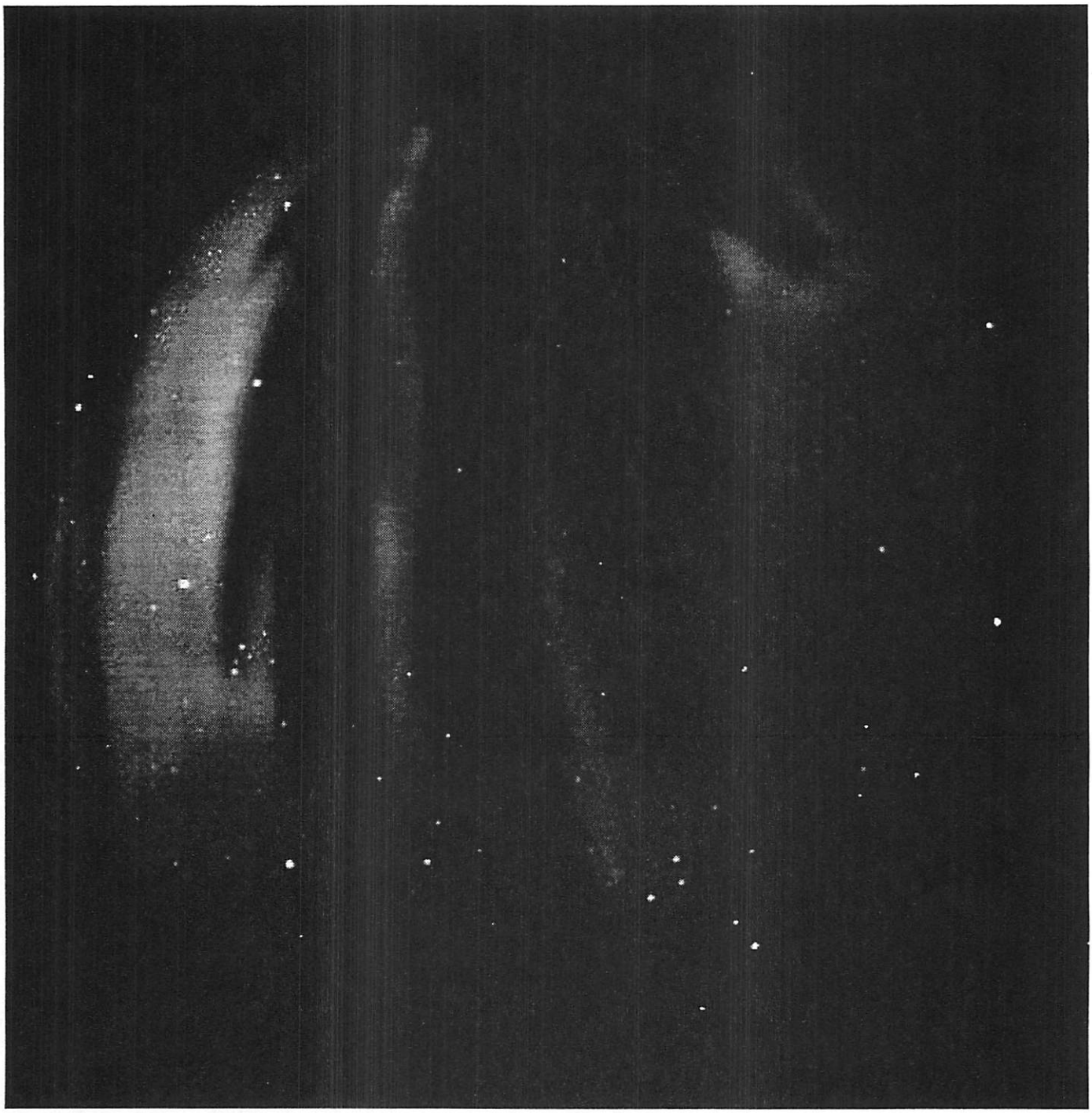

Relative Amplitude
+1%
0%
-1%
F
Y
P
VALLADARES
1983
B55
27 msec
0
10
20
30
Path Length (km)

MIKE TAYLOR

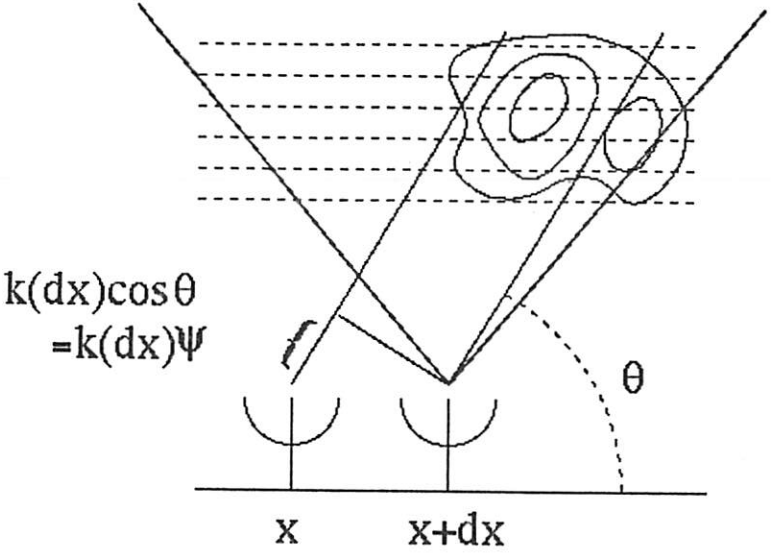
CACHOEIRA PAULISTA

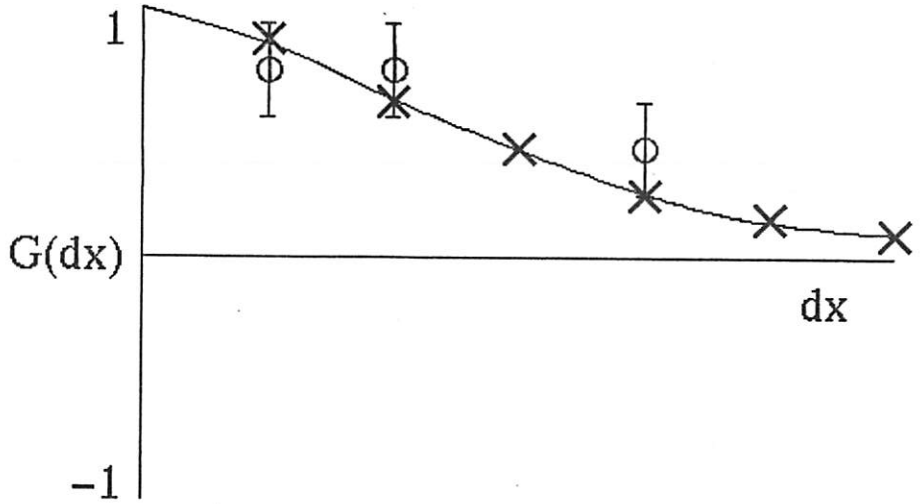
GSD 22.4S 45W

18/19 MAR 1:37 UT



In–Beam Radar Imaging



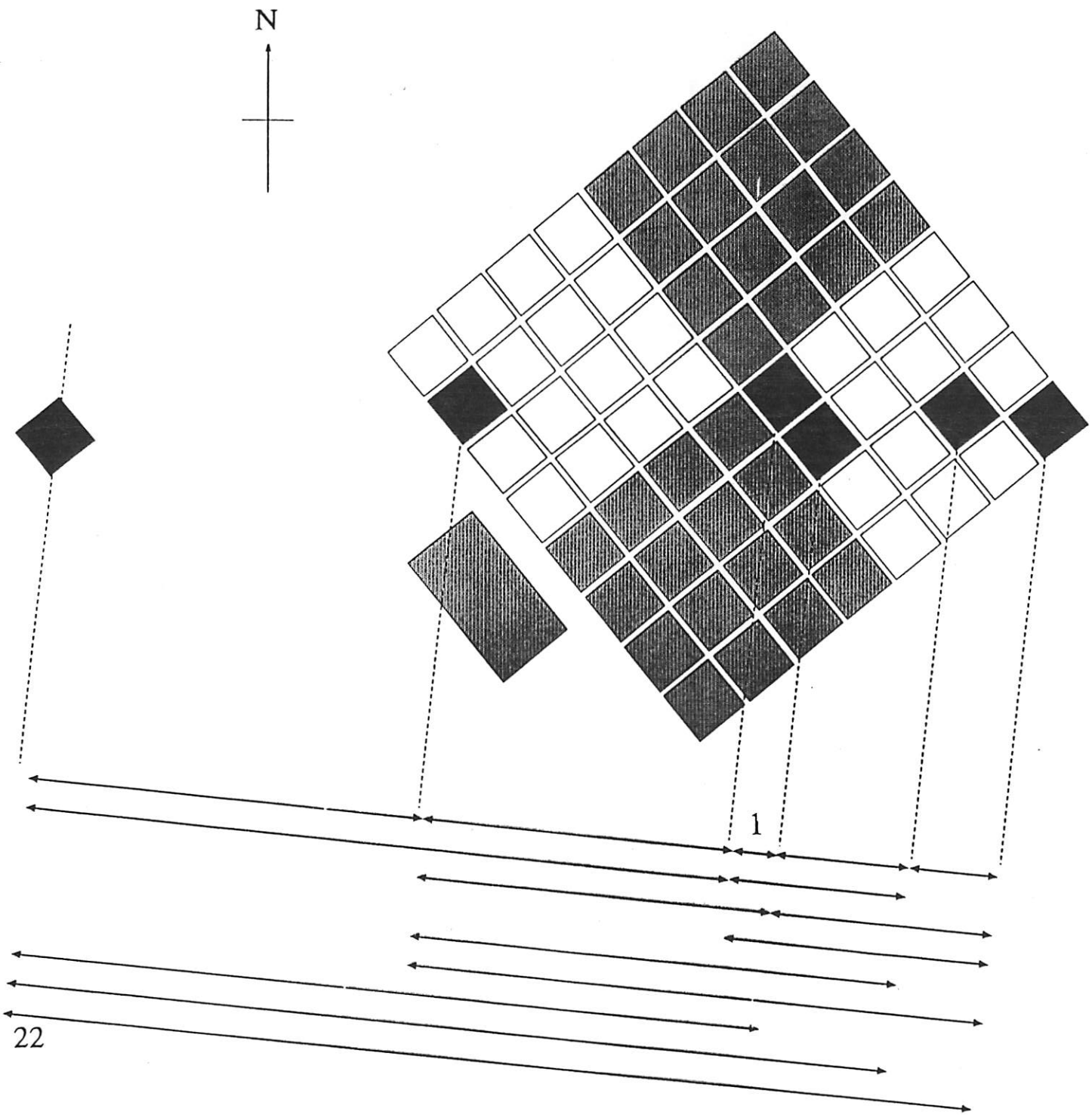


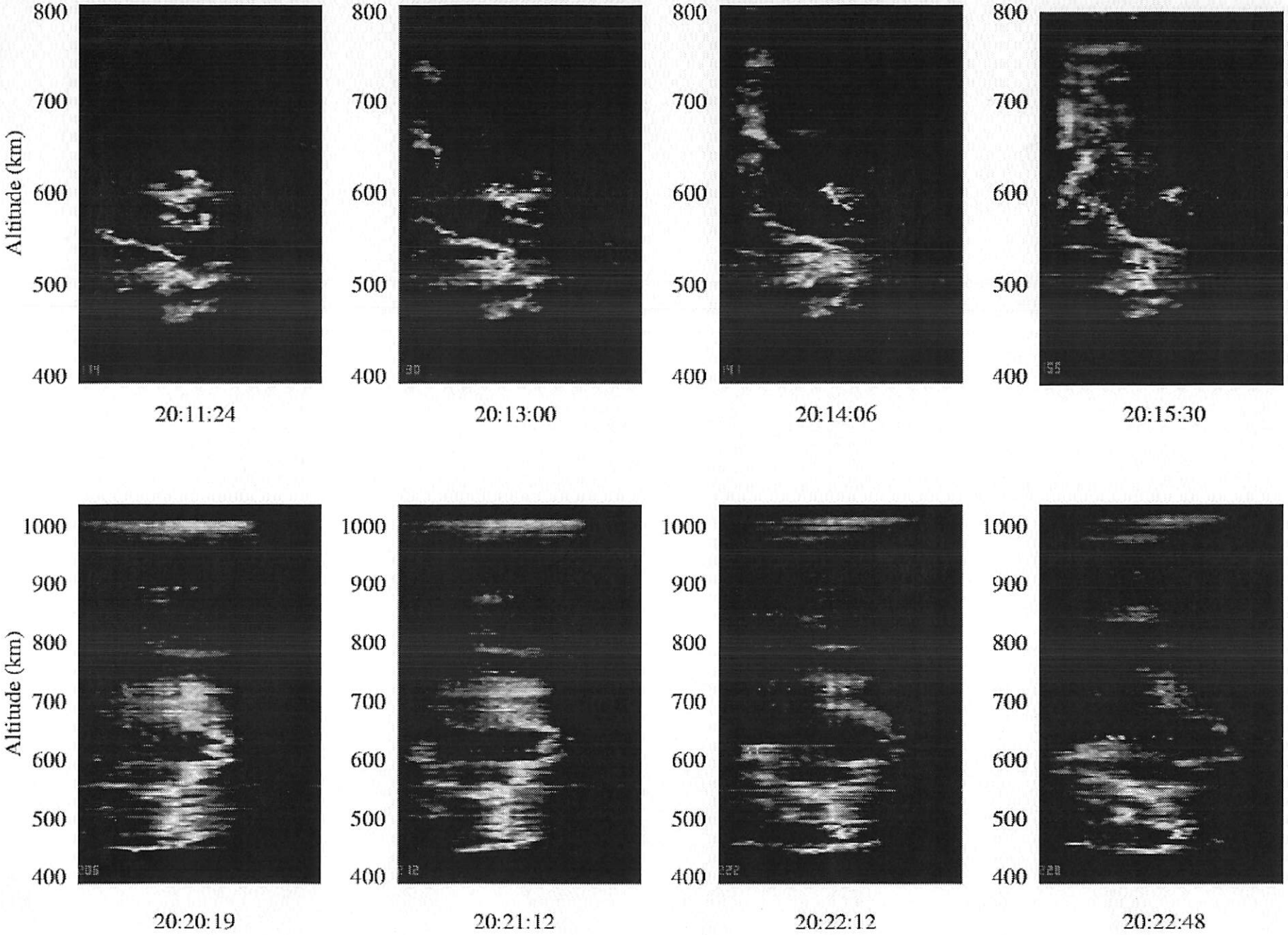
$$\underbrace{\langle g^*(x)g(x+dx)\rangle}_{G(dx)} = \int \frac{d\psi}{\sqrt{1-\psi^2}} e^{ik(dx)\psi} \underbrace{\langle |f(\psi)|^2 \rangle}_{F(\psi)}$$

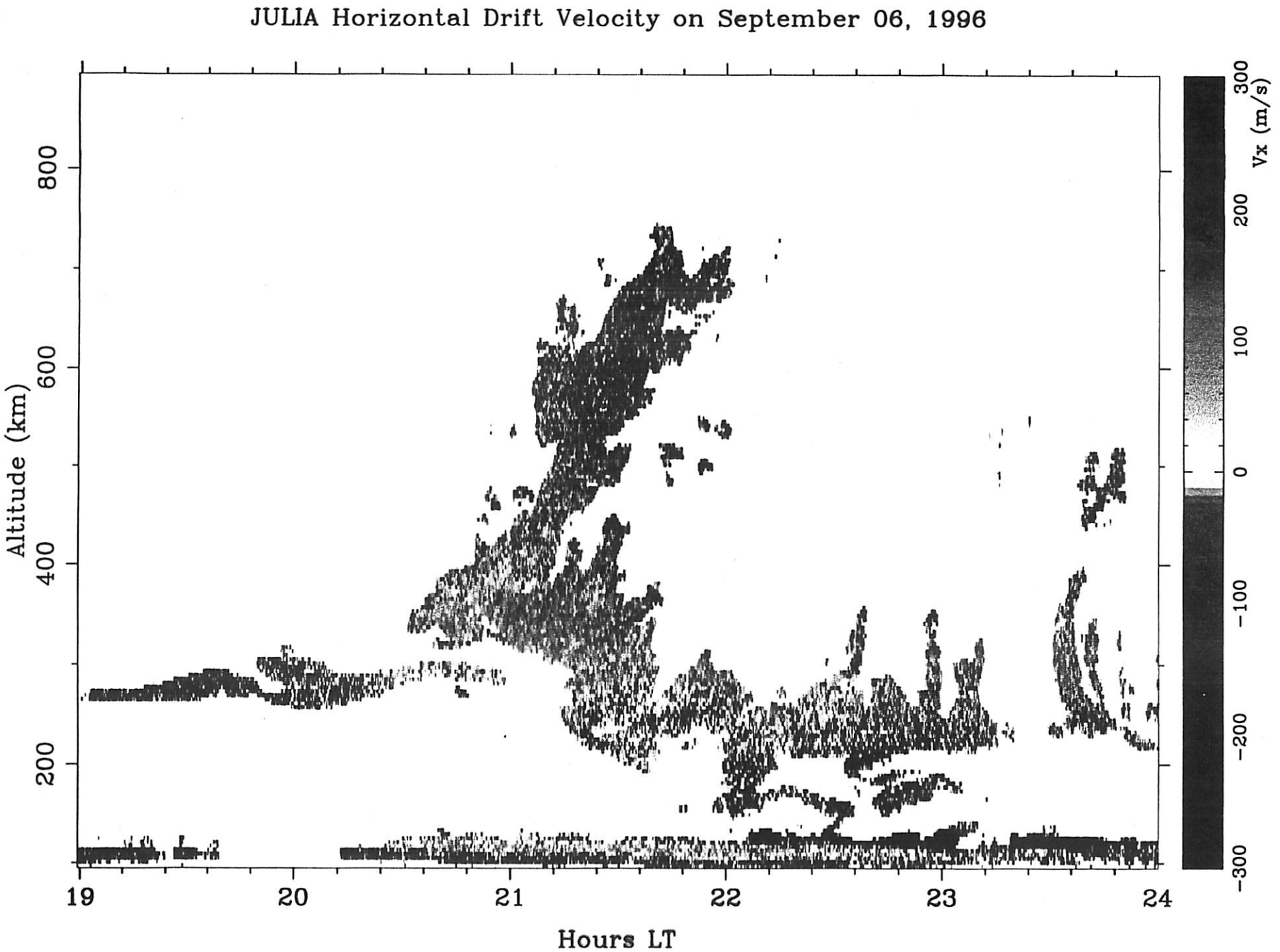
$$\text{Prob(conclusion} \mid \text{new data)} \propto \text{Prob(conclusion} \mid \text{old data)}$$

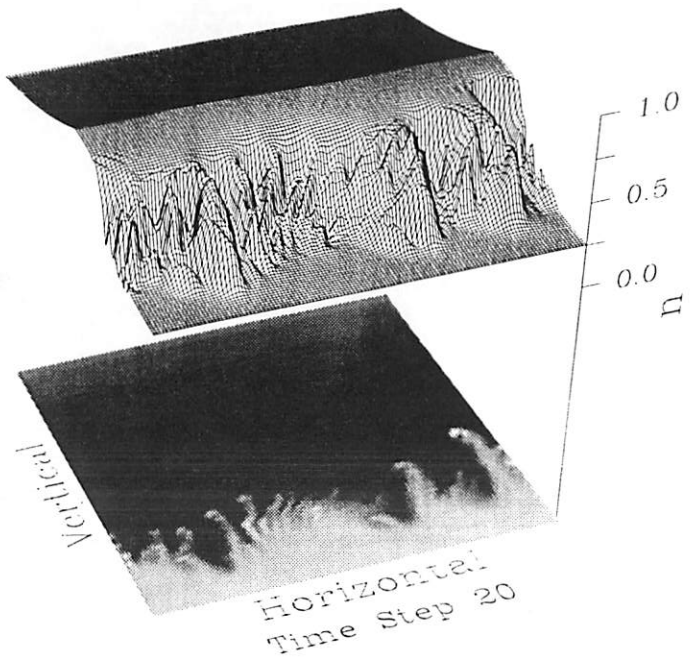
$$\times \text{ Prob(new data} \mid \text{conclusion)}$$

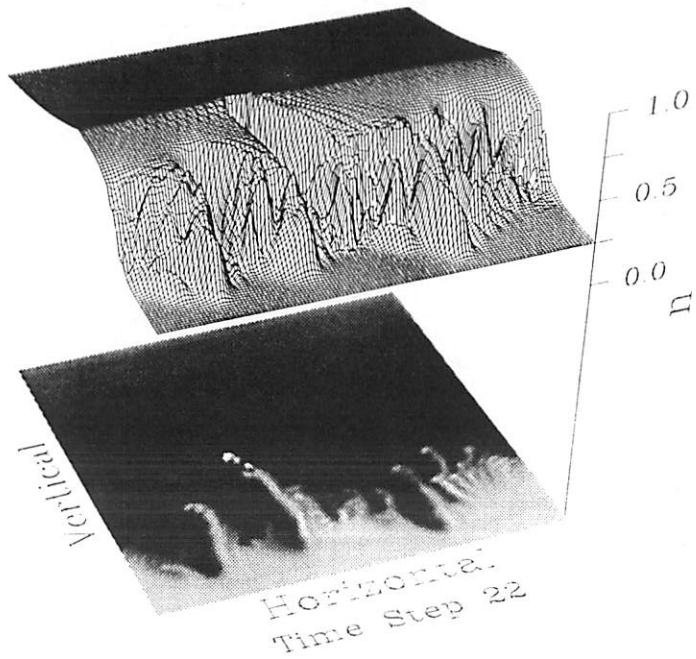
$$P(F) \propto -\int d\psi F(\psi) \ln F(\psi) \times \prod_j \exp\left(\frac{-(G_j - \hat{G}_j)^2}{2\sigma_j^2}\right)$$

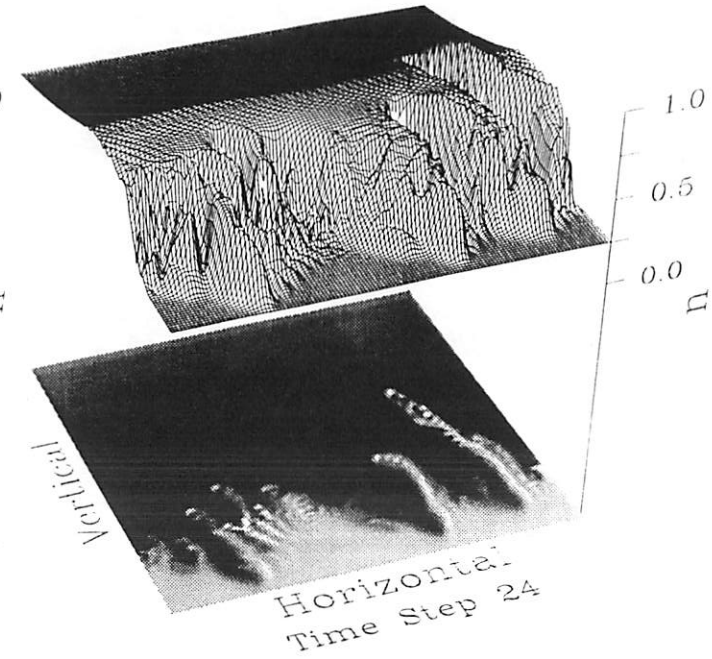

N
1
22


Altitude (km)
800
700
600
500
400
20:11:24
20:13:00
20:14:06
20:15:30
Altitude (km)
1000
900
800
700
600
500
400
20:20:19
20:21:12
20:22:12
20:22:48

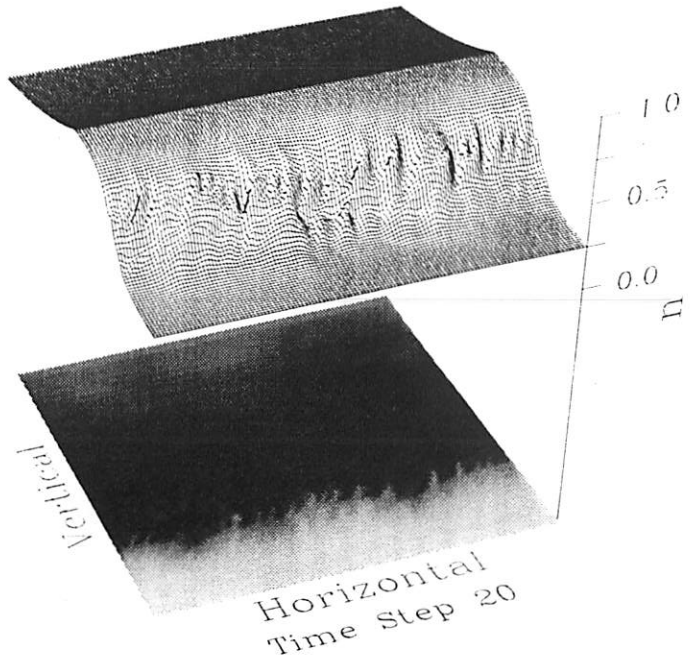

JULIA Horizontal Drift Velocity on September 06, 1996
Altitude (km)
800
600
400
200
19
20
21
22
23
24
Hours LT
Vx (m/s)
300
200
100
0
−100
−200
−300

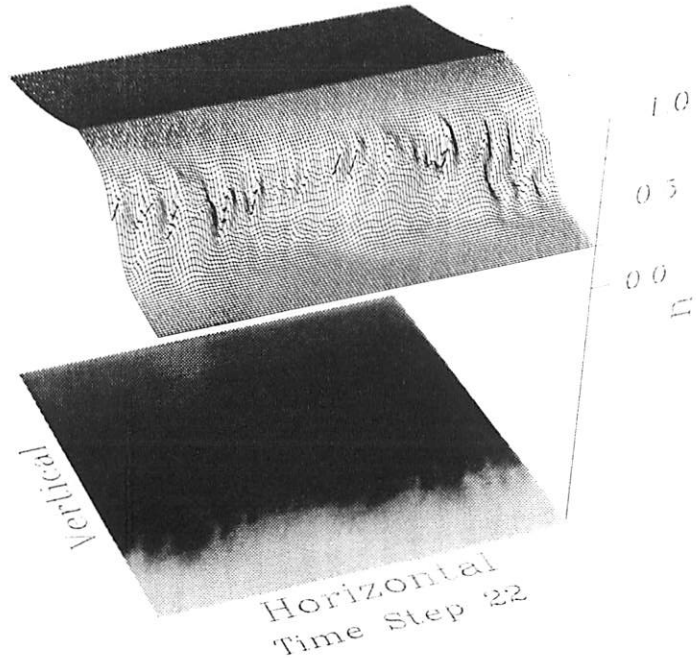


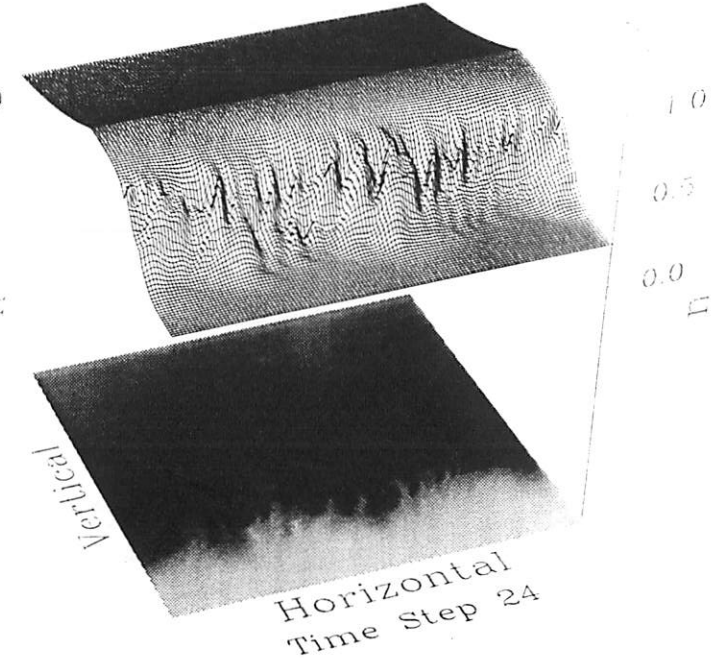




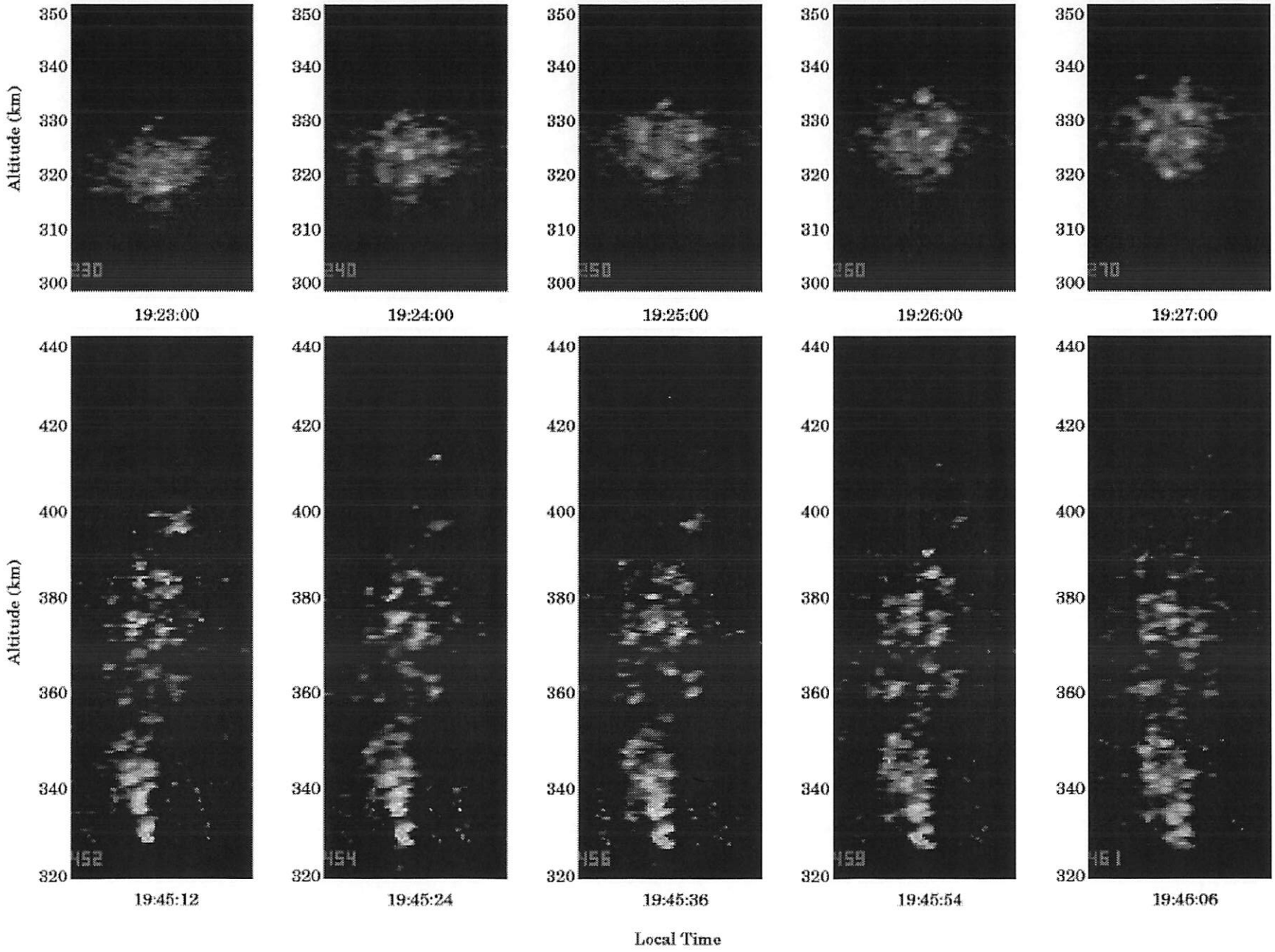
BOTTOMSIDE

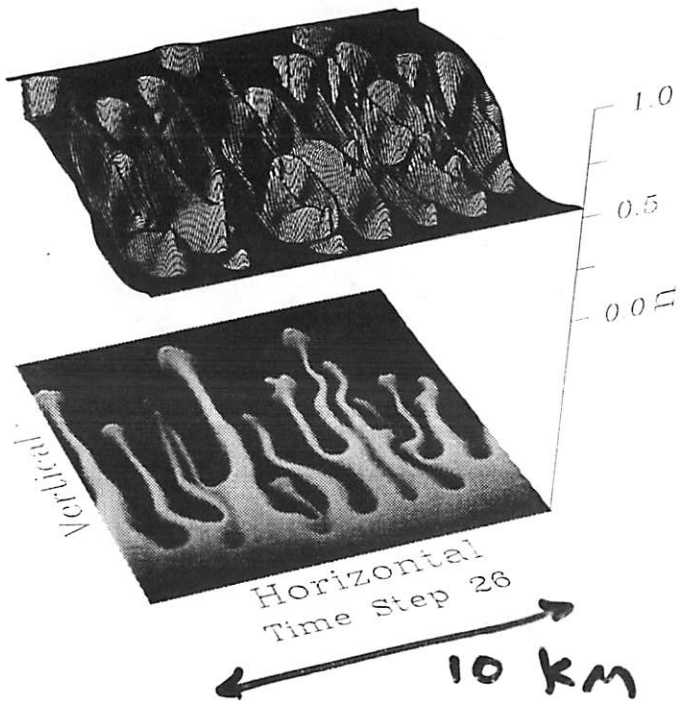


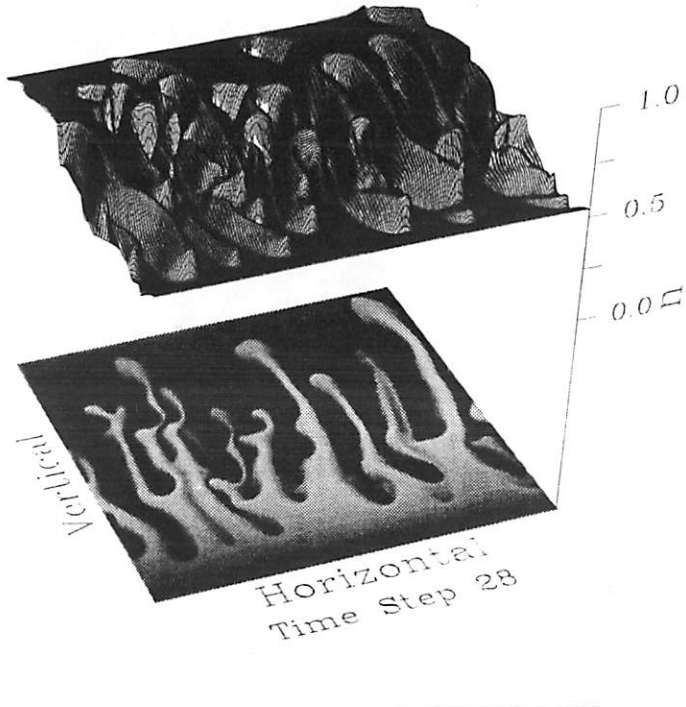


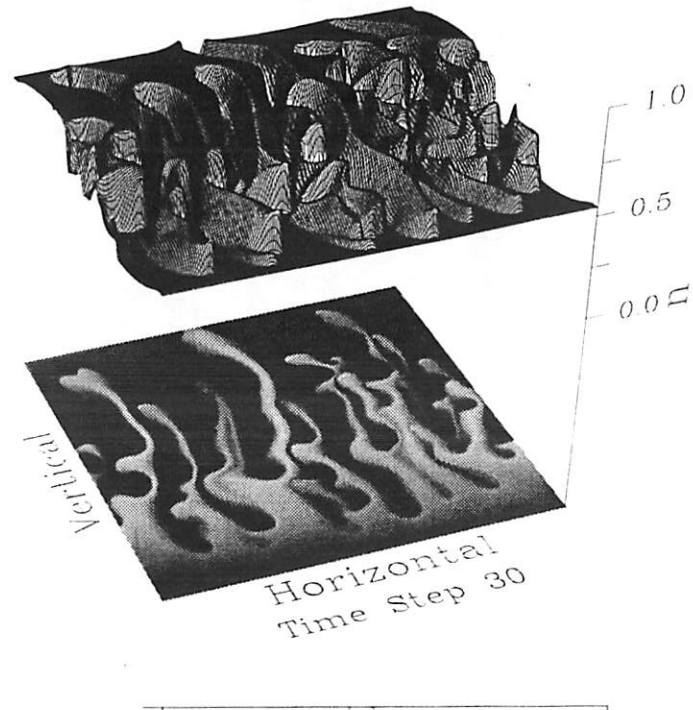


BOTTOM TYPE (AND BSS?)

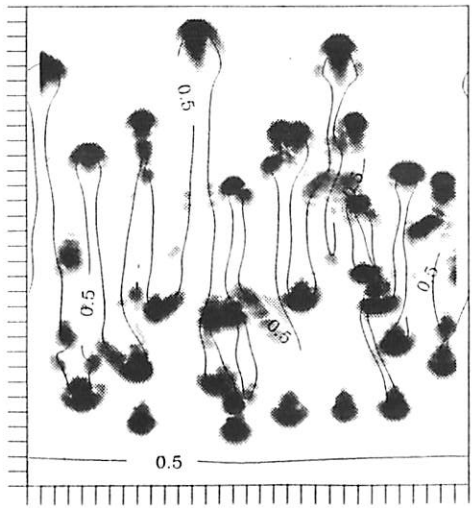

Altitude (km)
350
340
330
320
310
300
19:23:00
19:24:00
19:25:00
19:26:00
19:27:00
Altitude (km)
440
420
400
380
360
340
320
19:45:12
19:45:24
19:45:36
19:45:54
19:46:06
Local Time



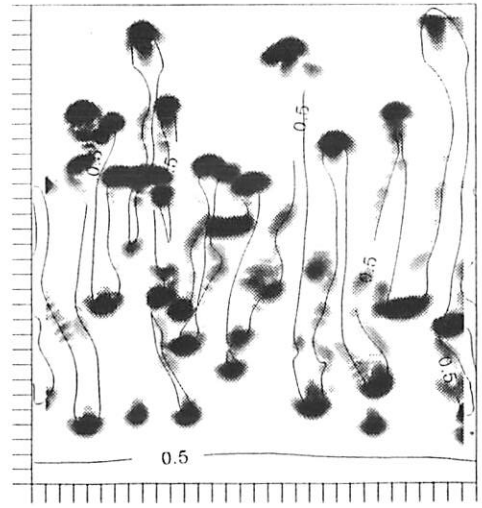




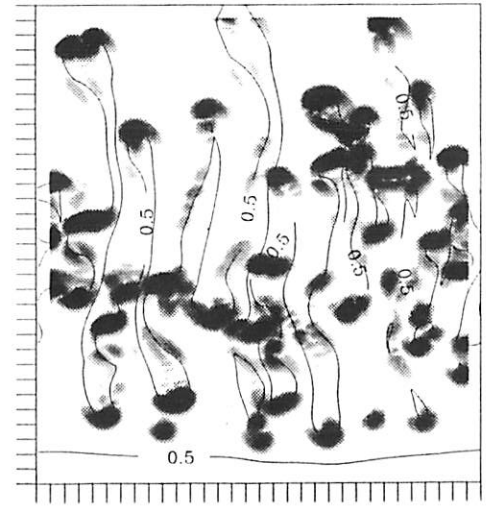
10 km



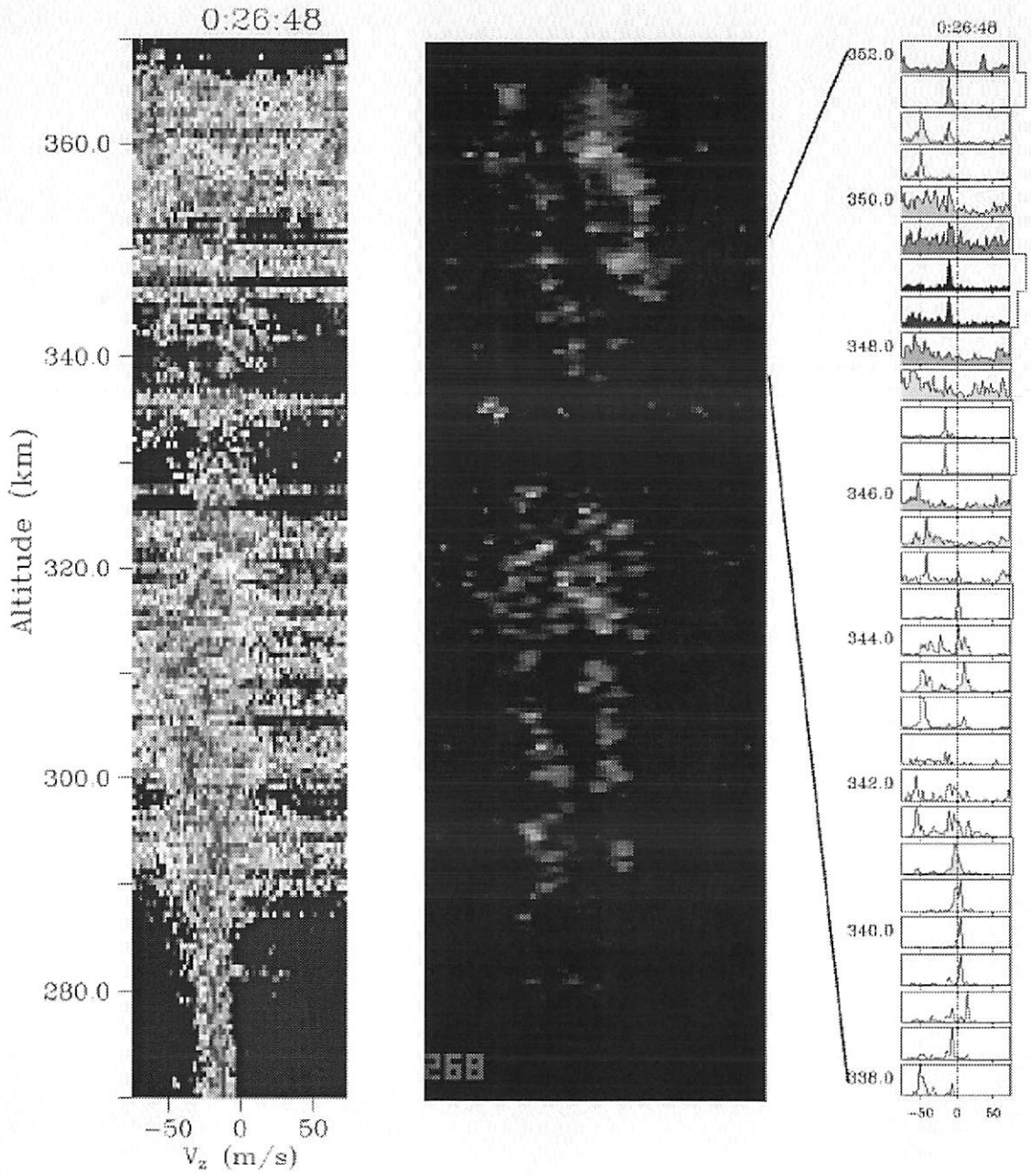
Timestep 26



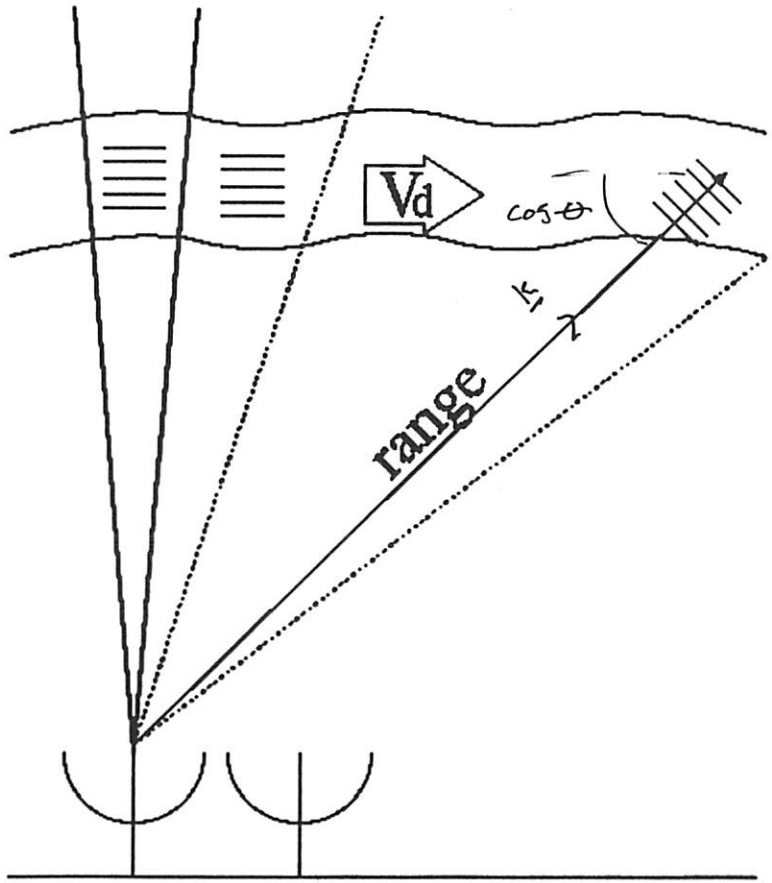
Timestep 28



Timestep 30


0:26:48
360.0
340.0
320.0
300.0
280.0
Altitude (km)
−50
0
50
V_z (m/s)
0:26:48
352.0
350.0
348.0
346.0
344.0
342.0
340.0
338.0
−50
0
50

Equatorial Electrojet



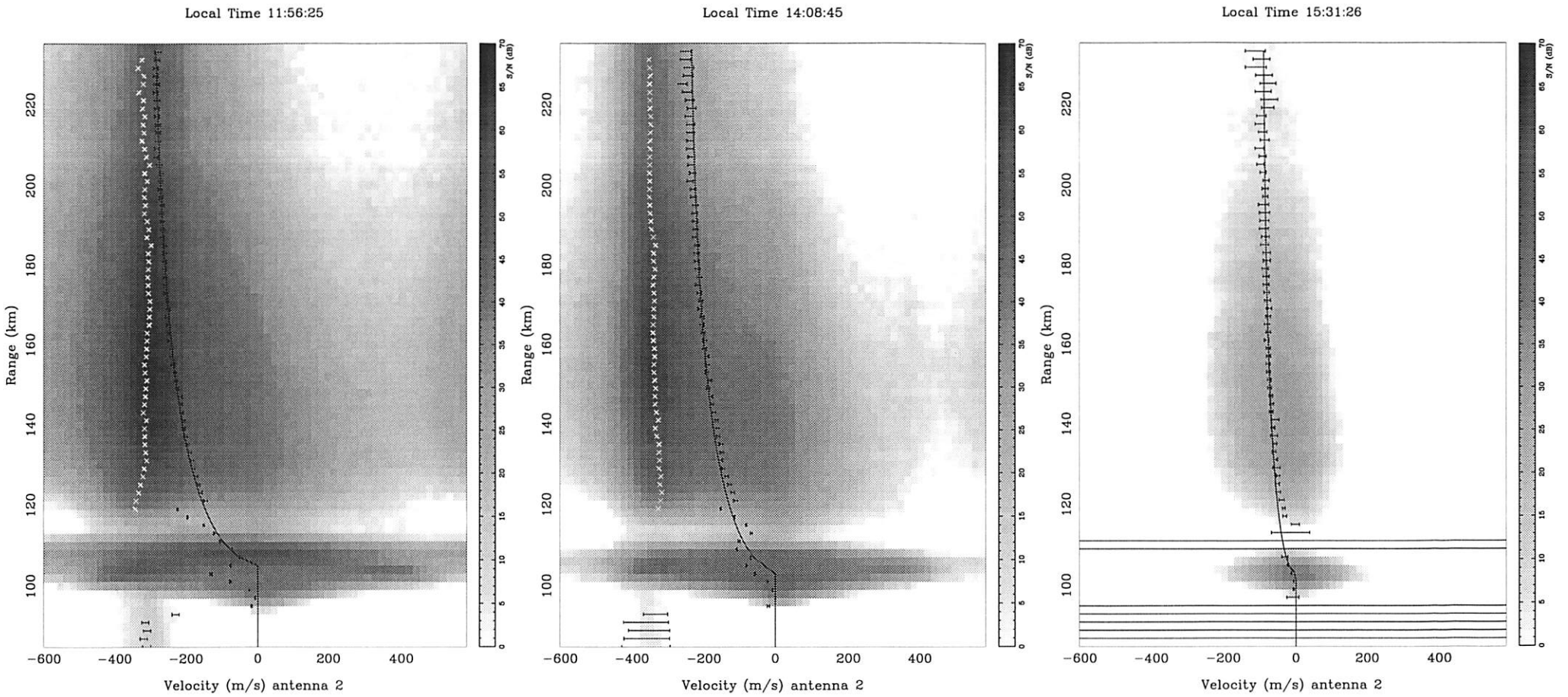
$$\omega_r(k) = \frac{\mathbf{k}\cdot(\mathbf{V}_n+\psi\mathbf{V}_i)}{1+\psi}\frac{1}{1+(k_o/k_x)^2}$$

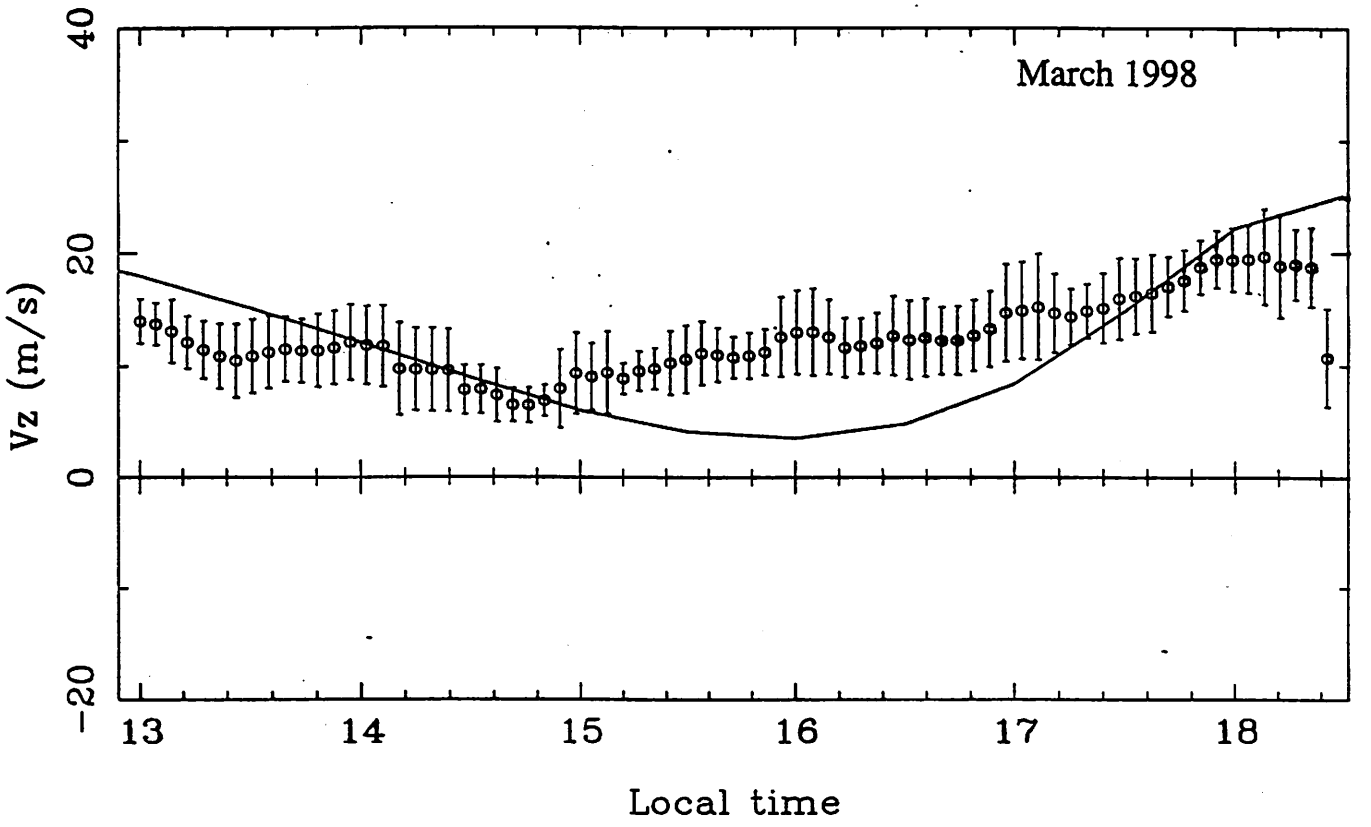
$$E_p(z) \approx E_o\frac{\sigma_H(z)}{\sigma_P(z)} - Bu$$

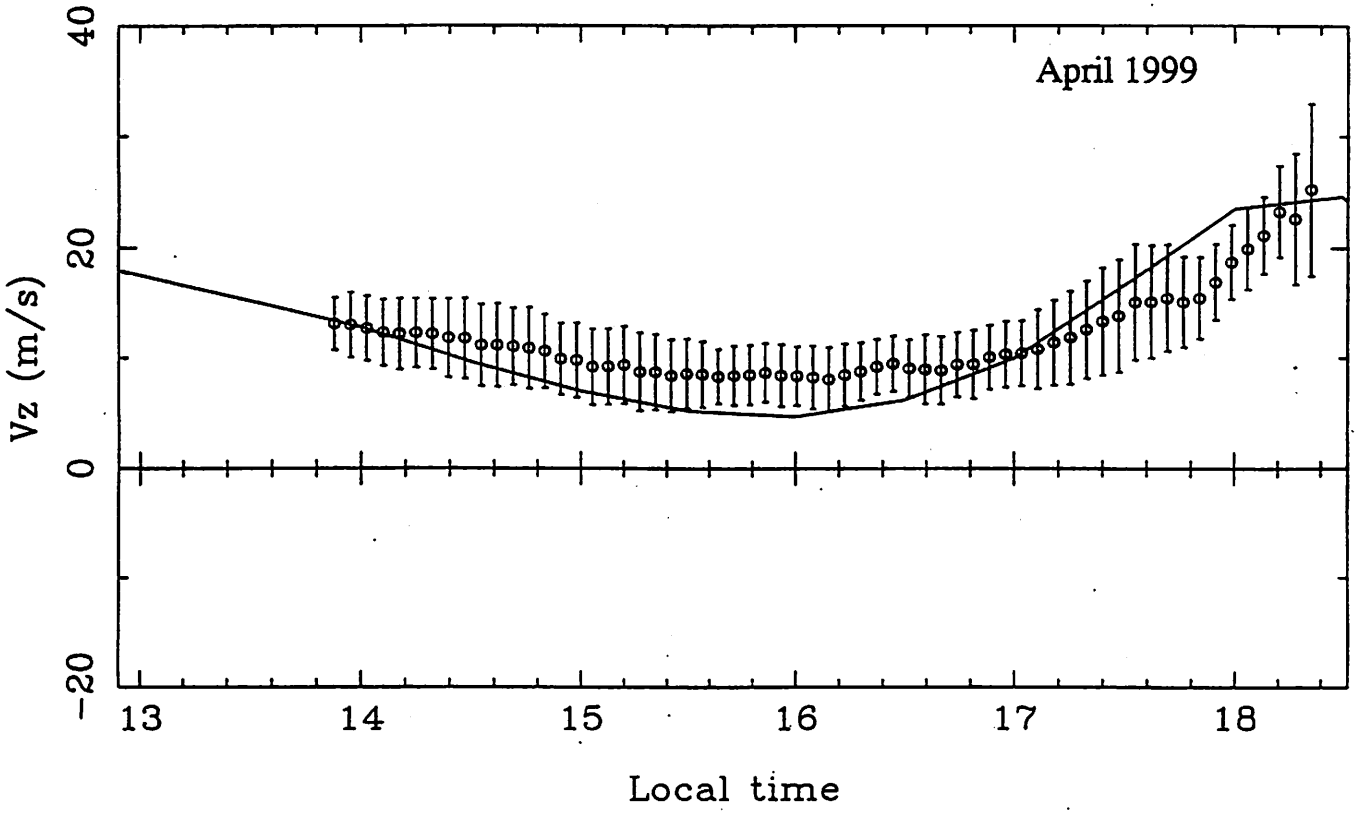
$$V(z) = \left[-\frac{E_o/B}{1+\psi}\left(\frac{\sigma_H(z)}{\sigma_P(z)} - \frac{\nu_n}{\Omega_n}\right)+u\right]\frac{1}{1+(k_o/k)^2}$$

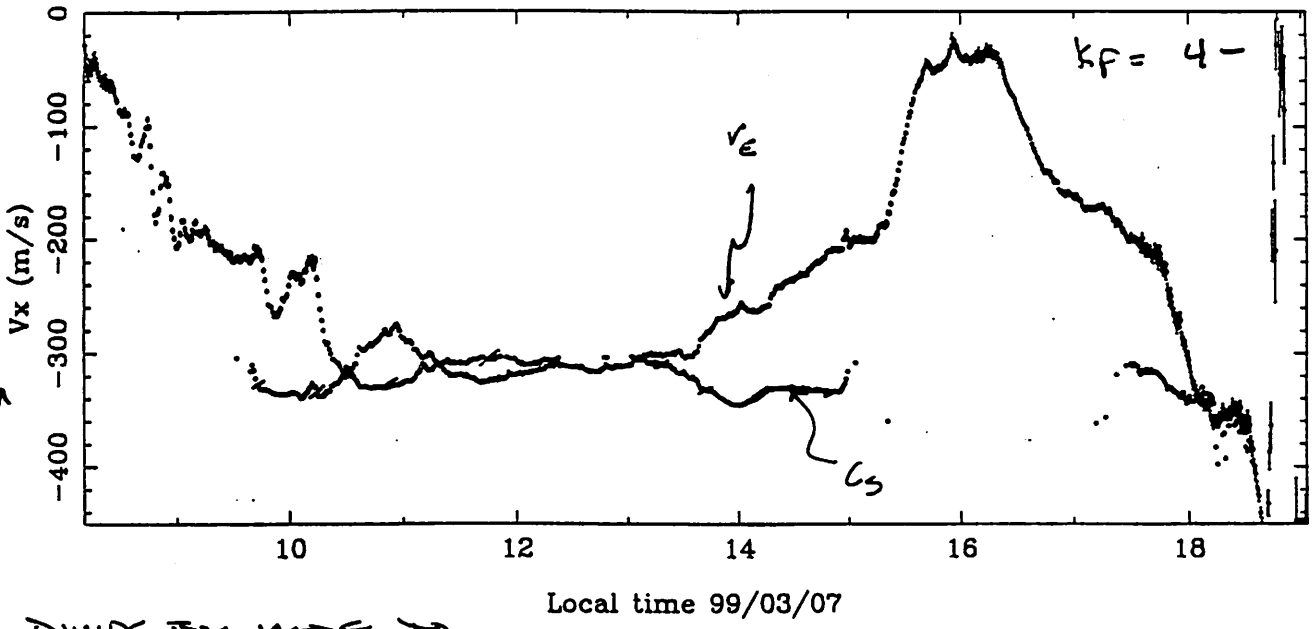
$$\sigma^*_{Pn} = \frac{1}{2}\frac{\psi}{\psi+1}\left(\frac{\Omega_n}{\nu_n}\right)^2\left(|\delta n/n|^2\right)\sigma_{Pn}$$

eg Fejer et al. '75, 84
Ronchi et al. '90

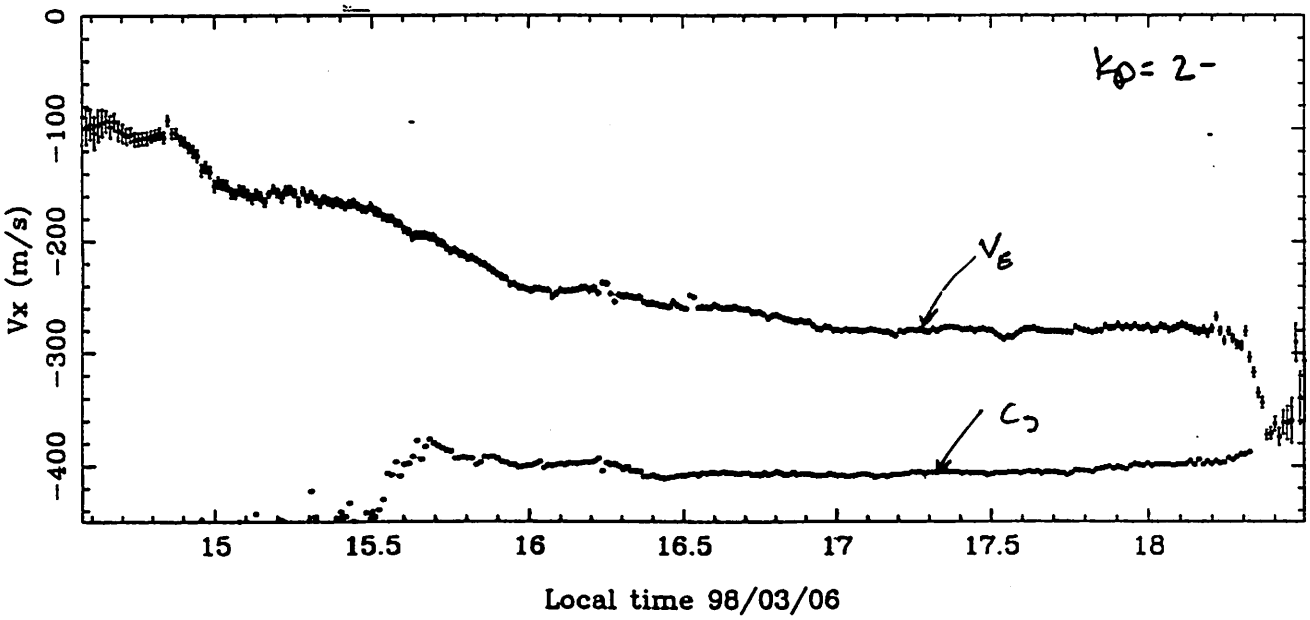

Local Time 11:56:25
Local Time 14:08:45
Local Time 15:31:26
Range (km)
Velocity (m/s) antenna 2
S/N (dB)
100
120
140
160
180
200
220
−600
−400
−200
0
200
400
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70

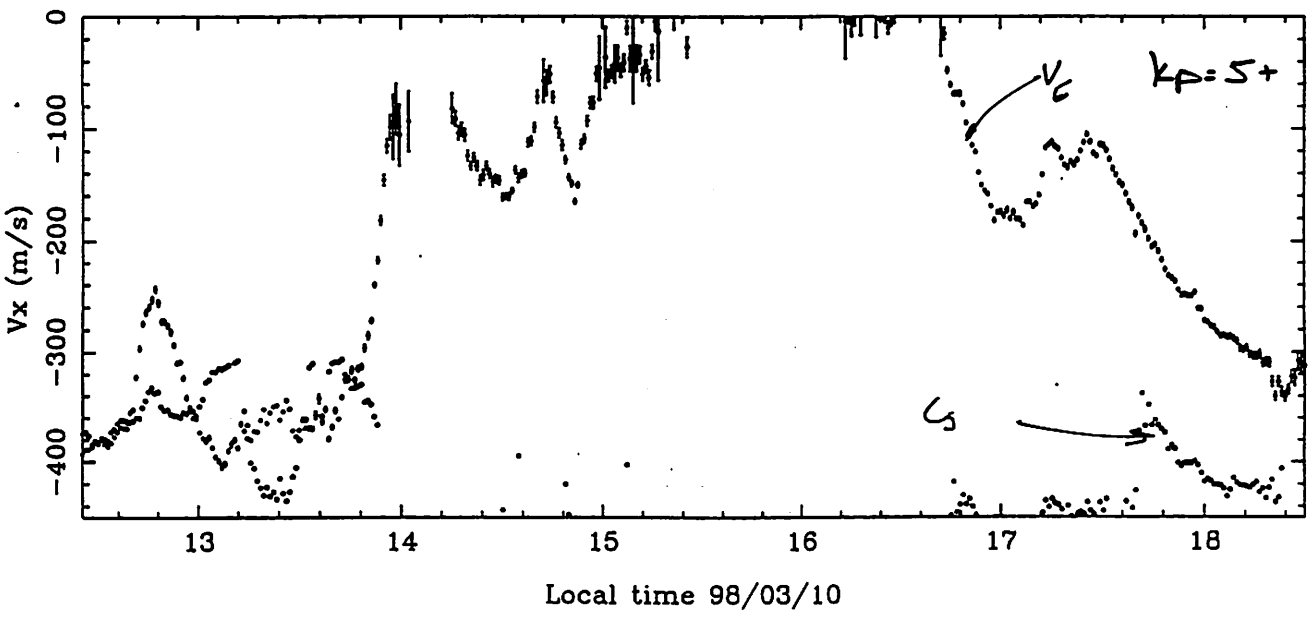

March 1998
Vz (m/s)
40
20
0
−20
13
14
15
16
17
18
Local time


April 1999
Vz (m/s)
40
20
0
−20
13
14
15
16
17
18
Local time

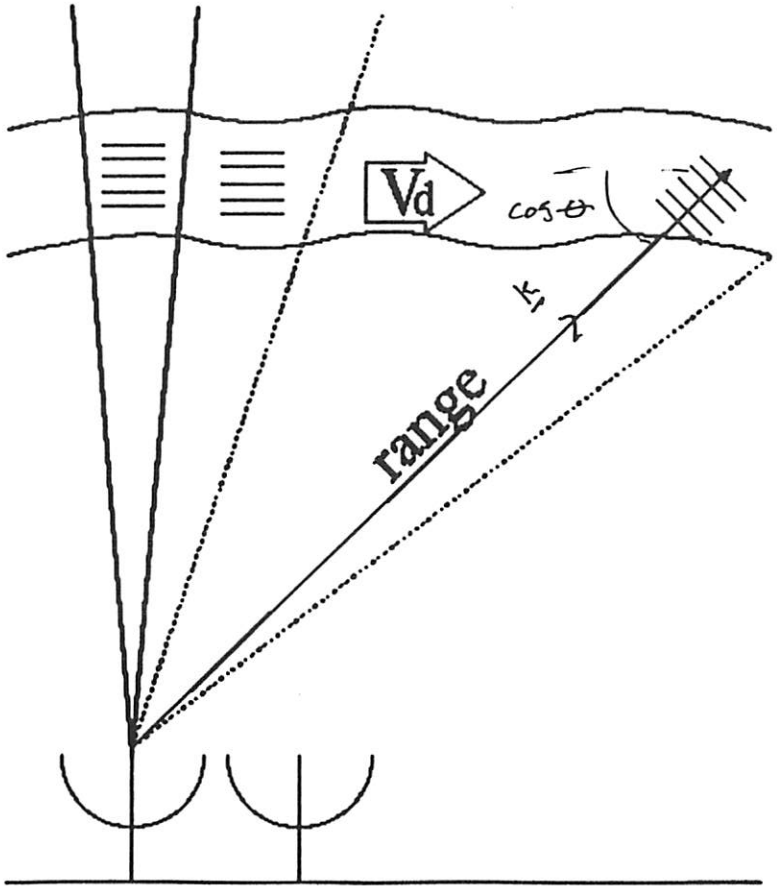


DIVIDE BY MODEL TO GET $E_0/15$ (~20)





Equatorial Electrojet



COS DEPENDENCE

$$\omega_r(k) = \frac{\mathbf{k}\cdot(\mathbf{V}_n+\psi\mathbf{V}_i)}{1+\psi}\frac{1}{1+(k_o/k_x)^2}$$

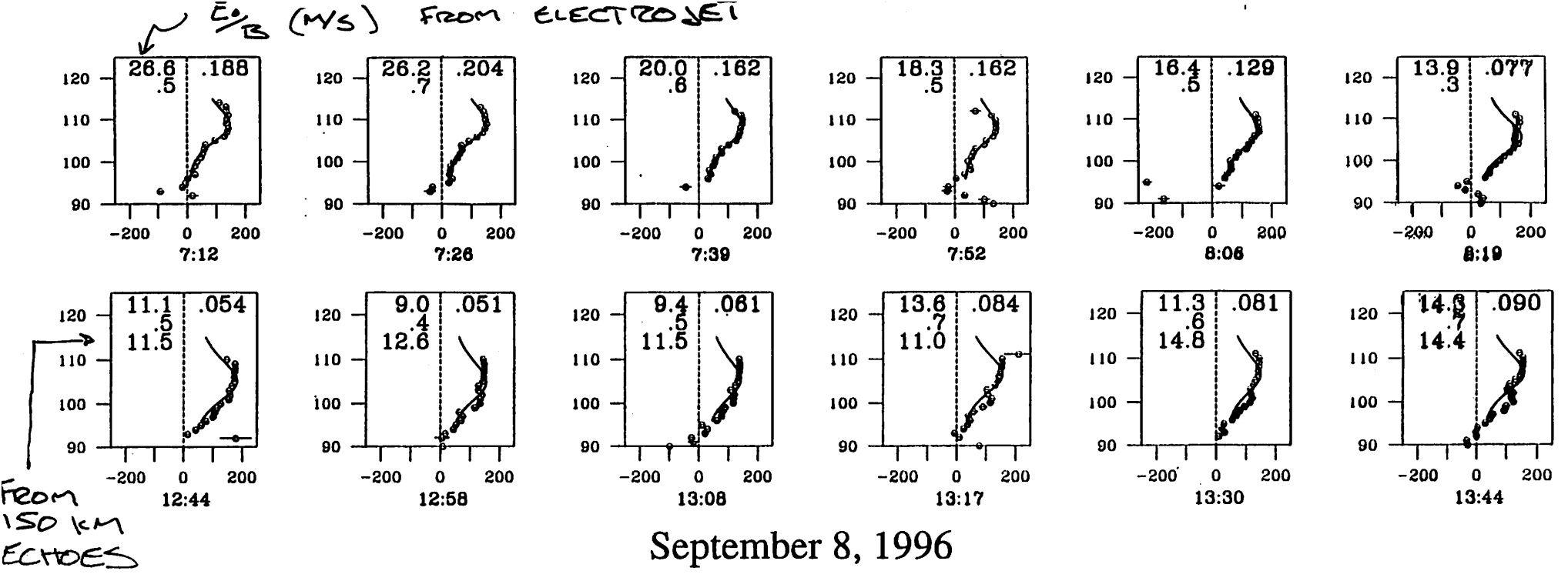
$$E_p(z) \approx E_o\frac{\sigma_H(z)}{\sigma_P(z)} - Bu$$

$$V(z) = \left[-\frac{E_o/B}{1+\psi}\left(\frac{\sigma_H(z)}{\sigma_P(z)} - \frac{\nu_n}{\Omega_n}\right) + u\right]\frac{1}{1+(k_o/k)^2}$$

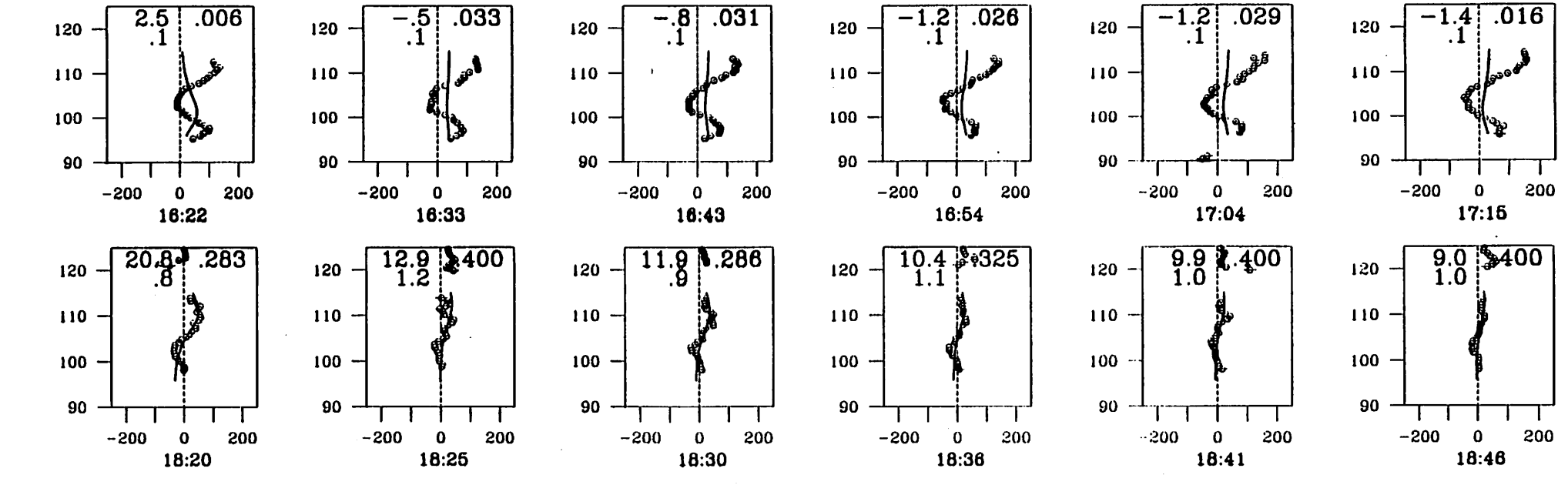
MODEL, WEIGHTED BY $S/N(z)$

$$\sigma^*_{Pn} = \frac{1}{2}\frac{\psi}{2\psi+1}\left(\frac{\Omega_n}{\nu_n}\right)^2\left(|\delta n/n|^2\right)\sigma_{Pn}$$

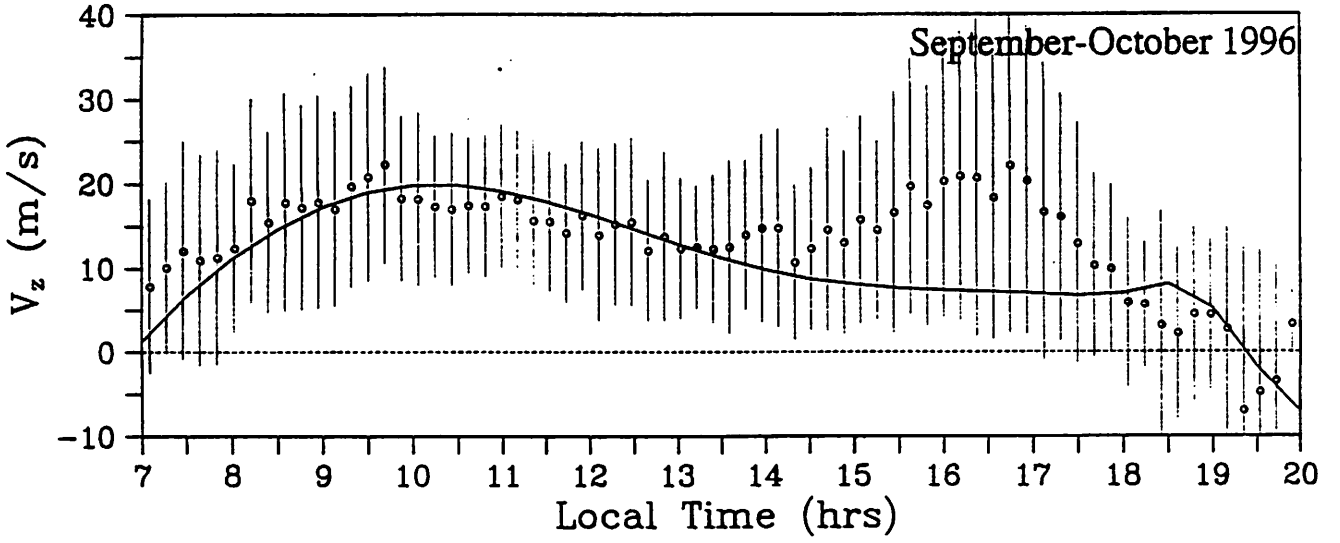
eg Fejer et al. '75, 84
Ronchi et al. '90

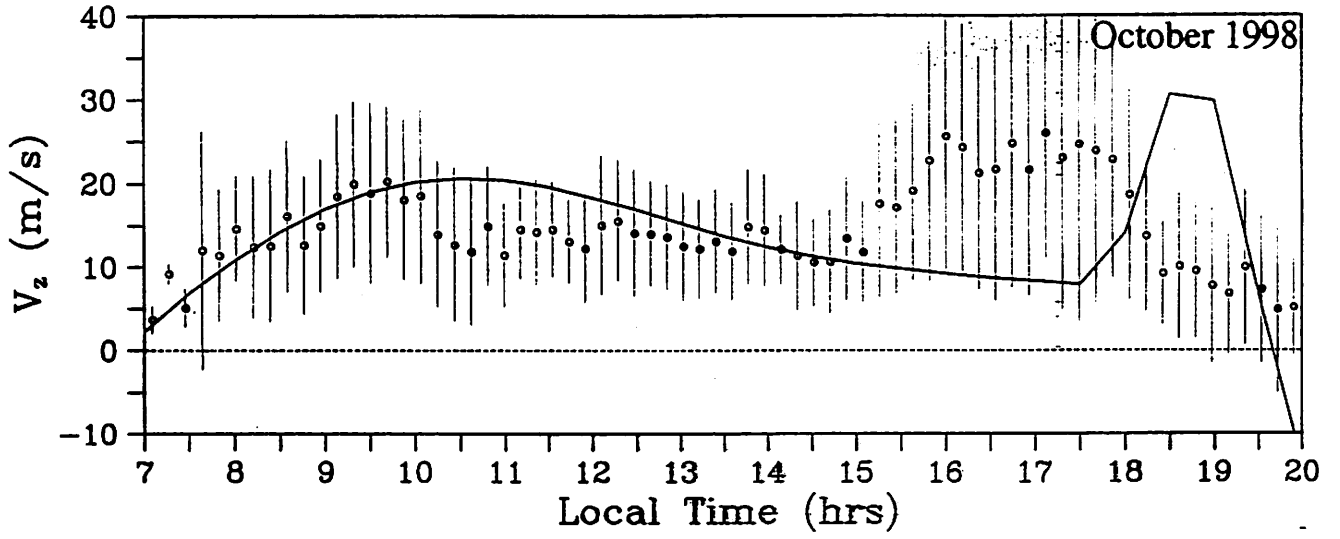


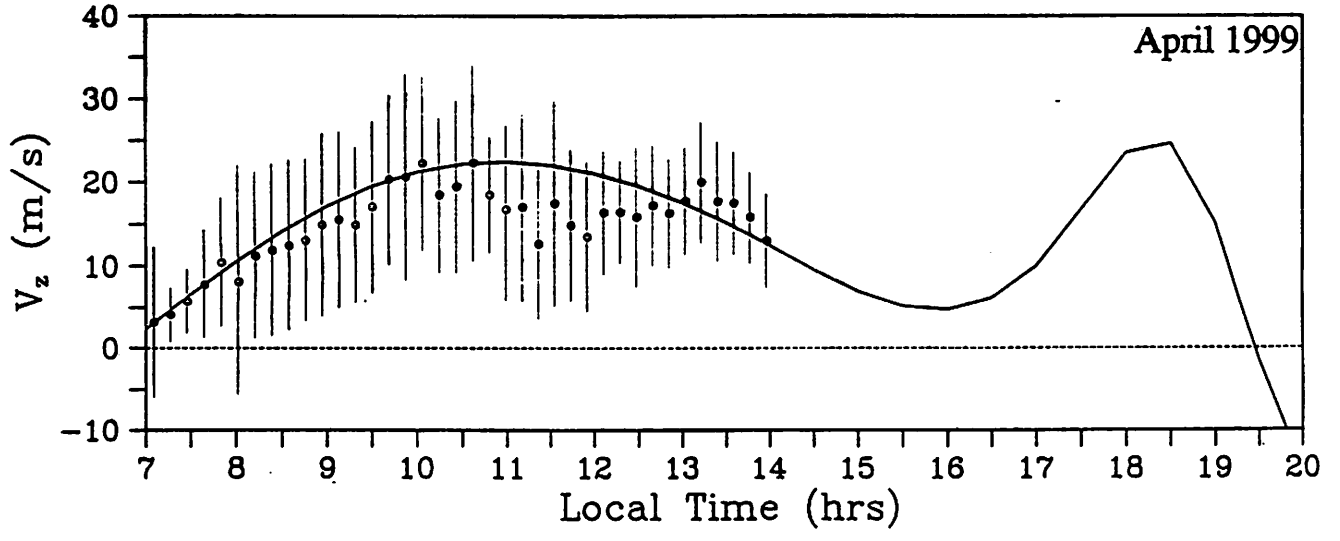
September 8, 1996

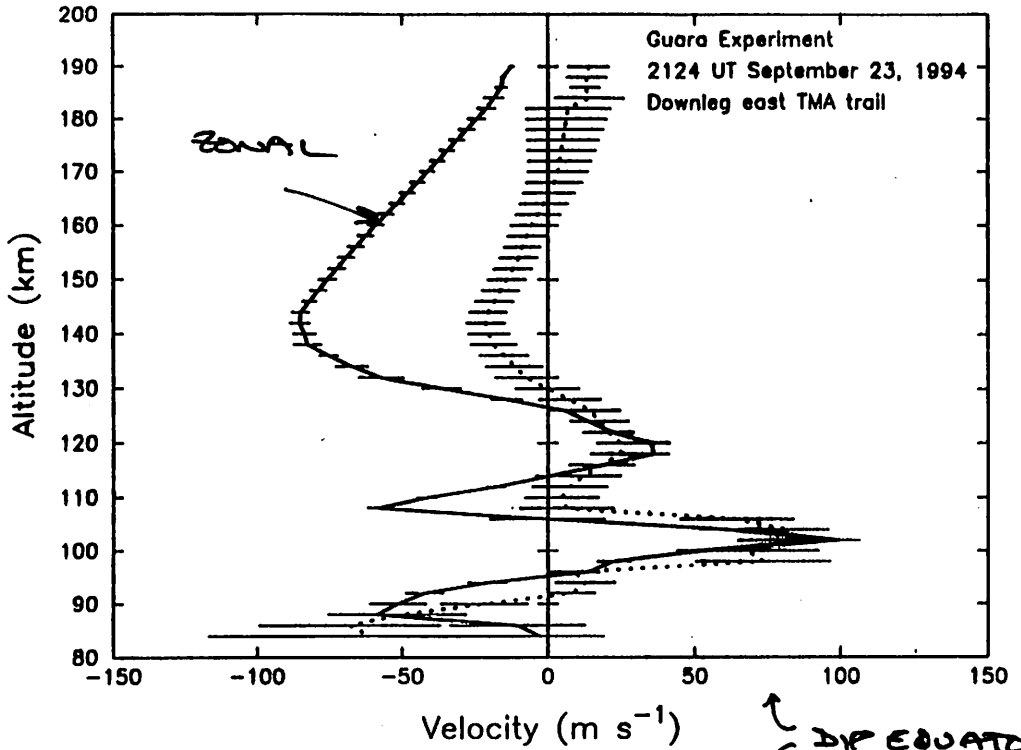


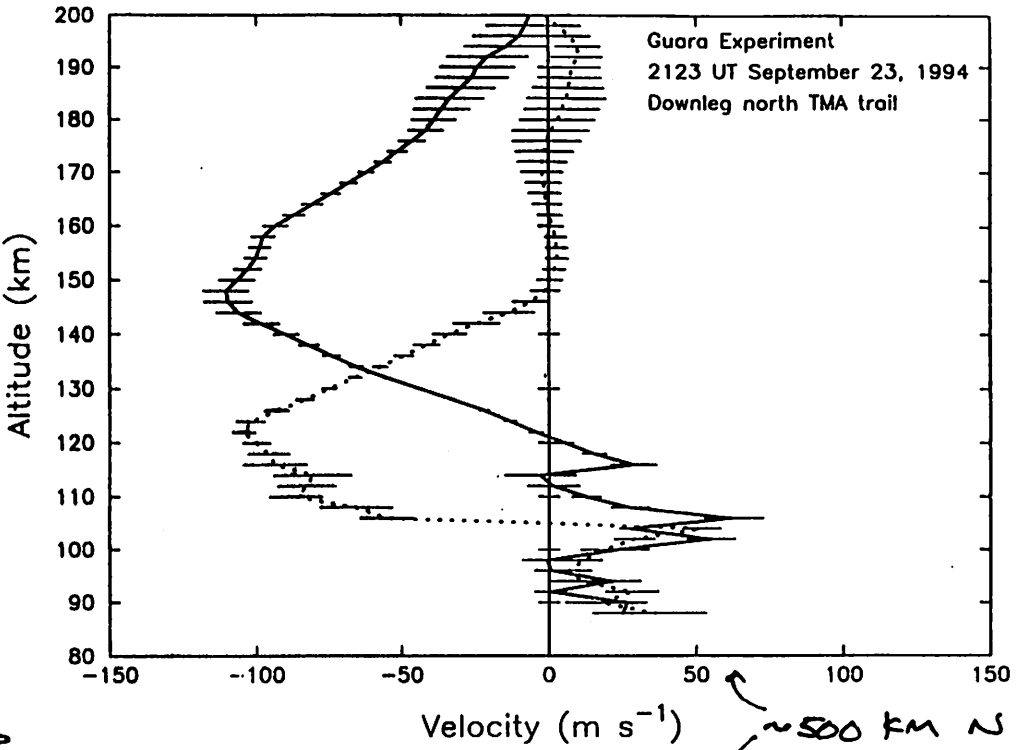
October 11, 1998


September-October 1996
V_z (m/s)
40
30
20
10
0
−10
7 8 9 10 11 12 13 14 15 16 17 18 19 20
Local Time (hrs)


October 1998
V_z (m/s)
40
30
20
10
0
−10
7 8 9 10 11 12 13 14 15 16 17 18 19 20
Local Time (hrs)

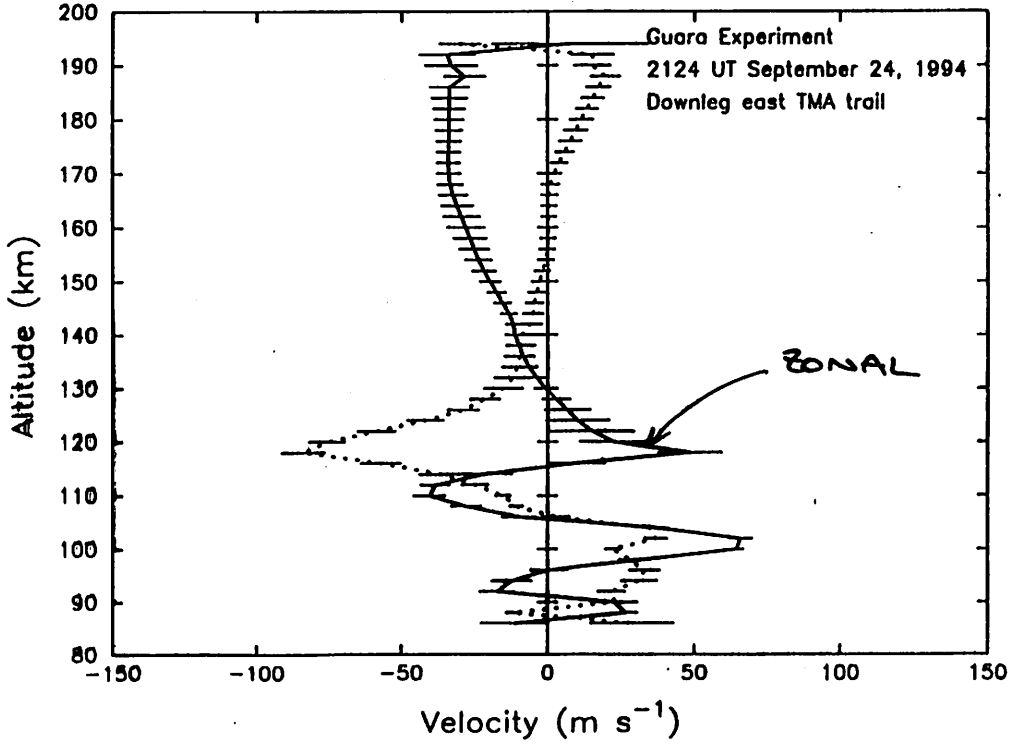

April 1999
V_z (m/s)
40
30
20
10
0
−10
7 8 9 10 11 12 13 14 15 16 17 18 19 20
Local Time (hrs)

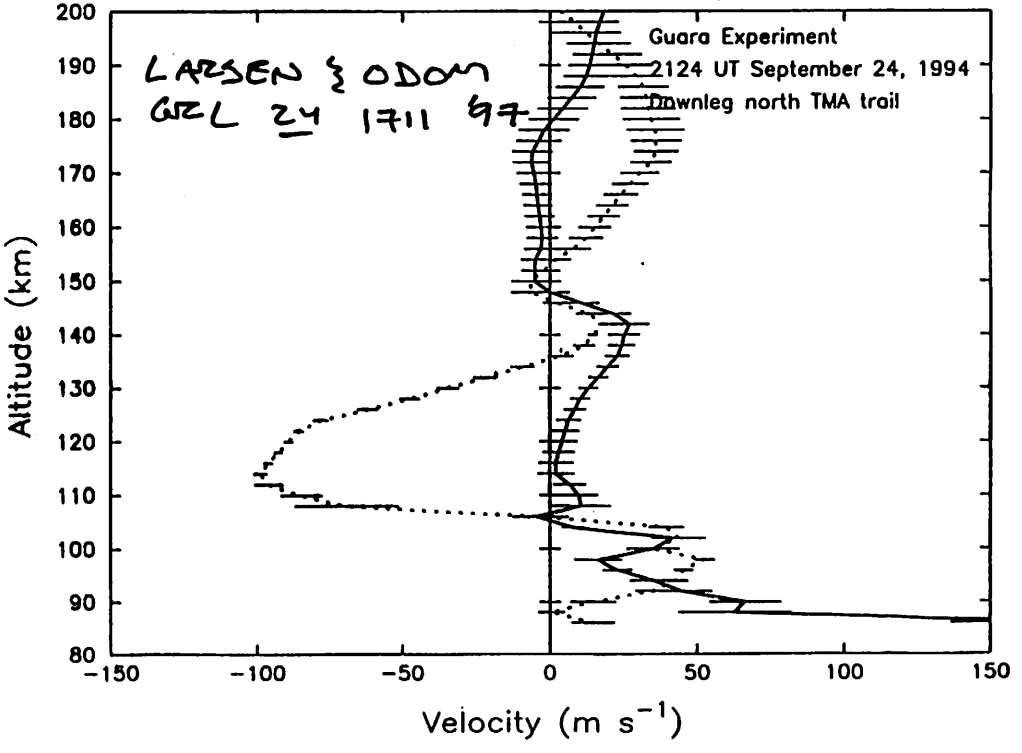


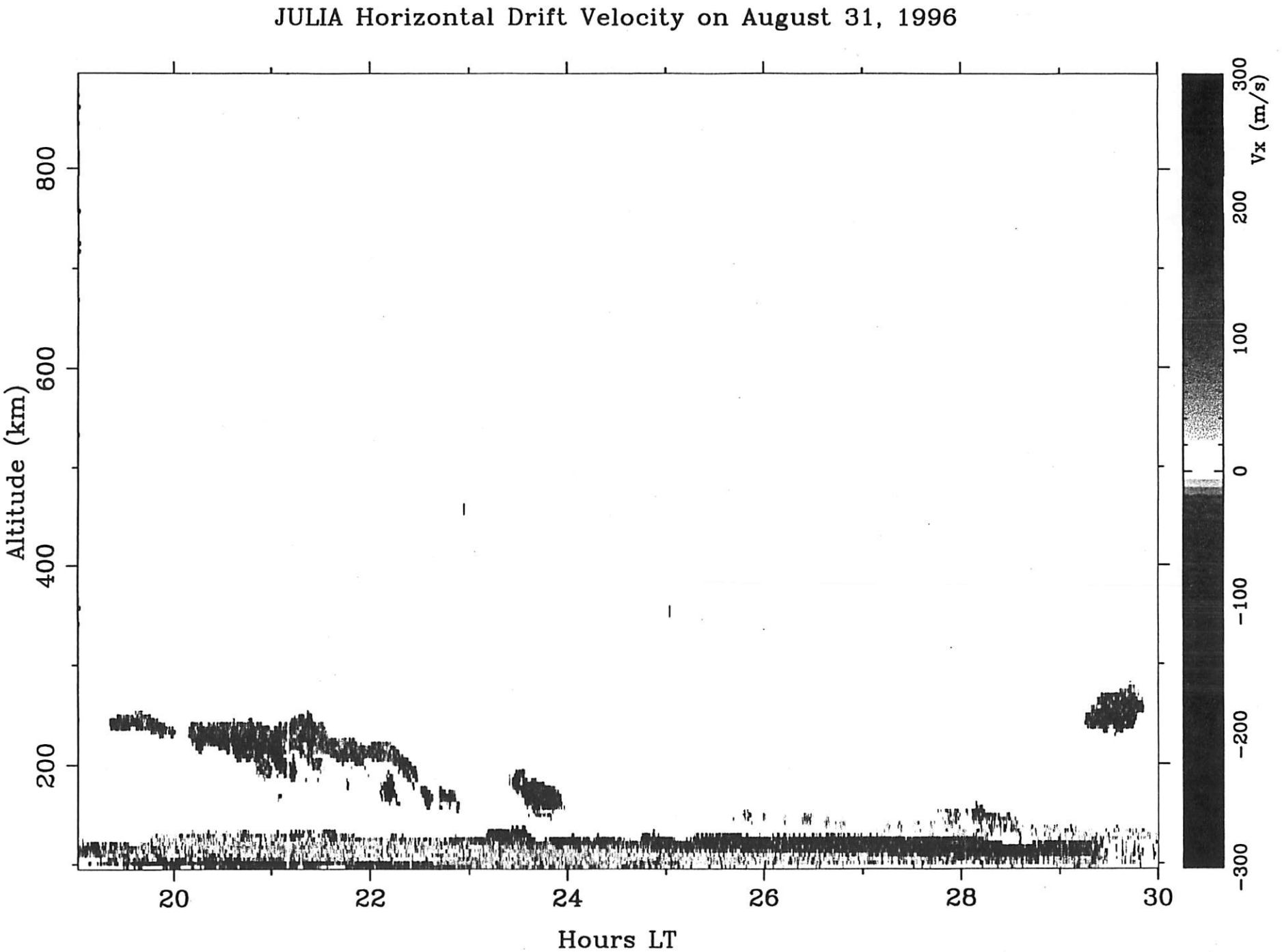


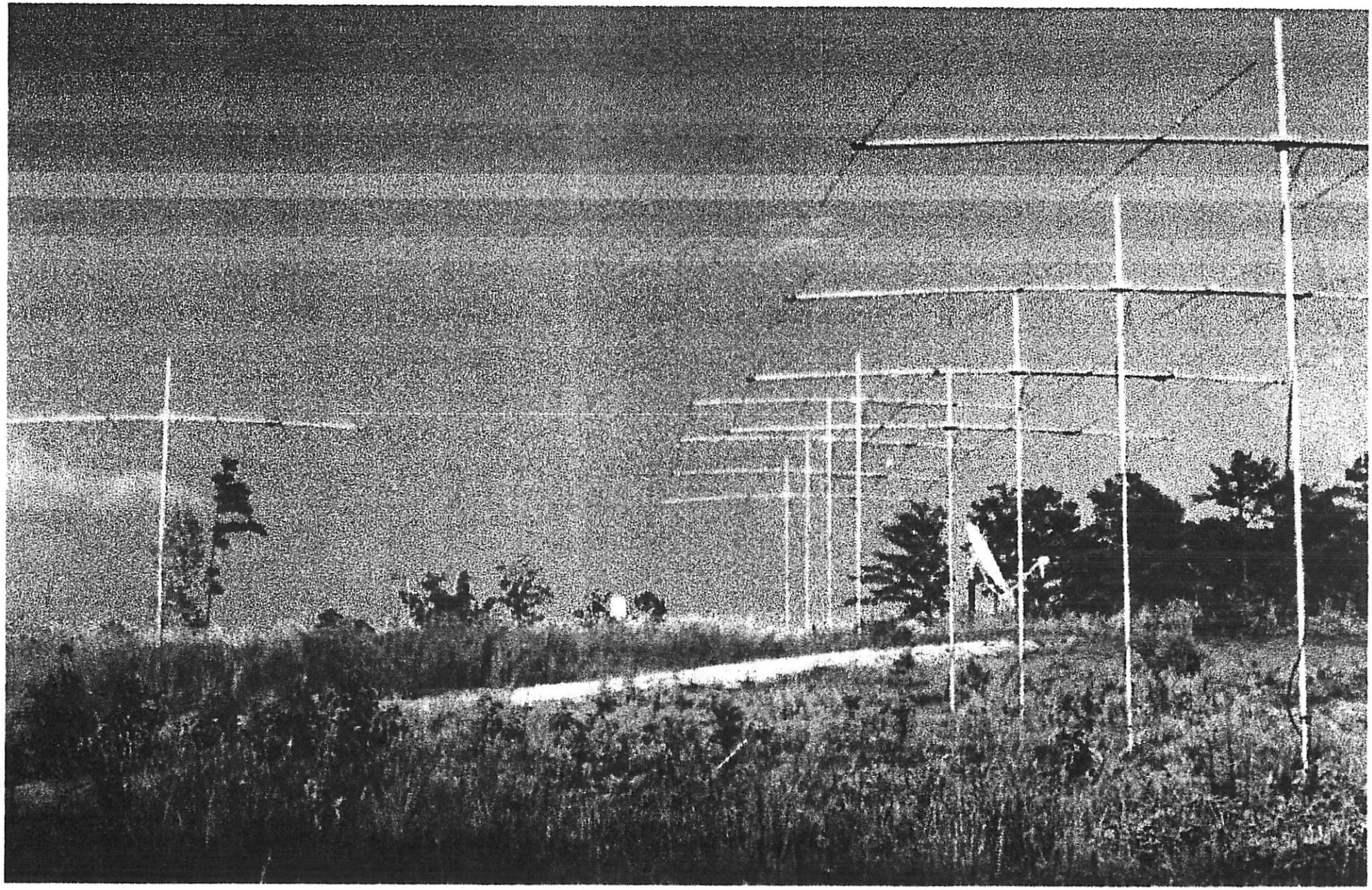
DIP EQUATOR

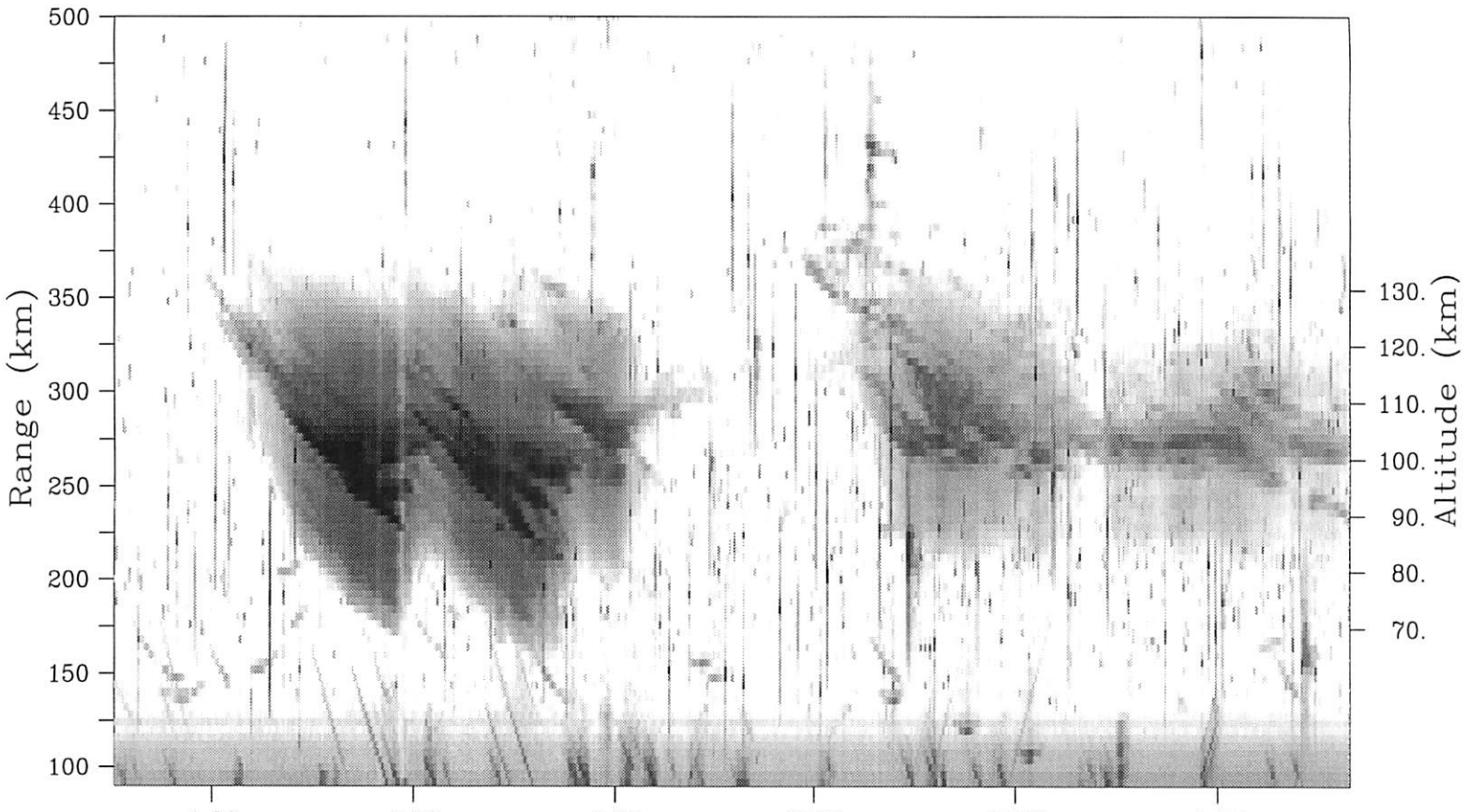
~500 KM N

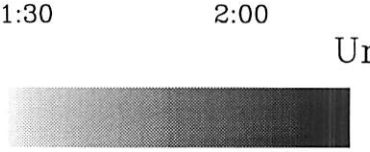


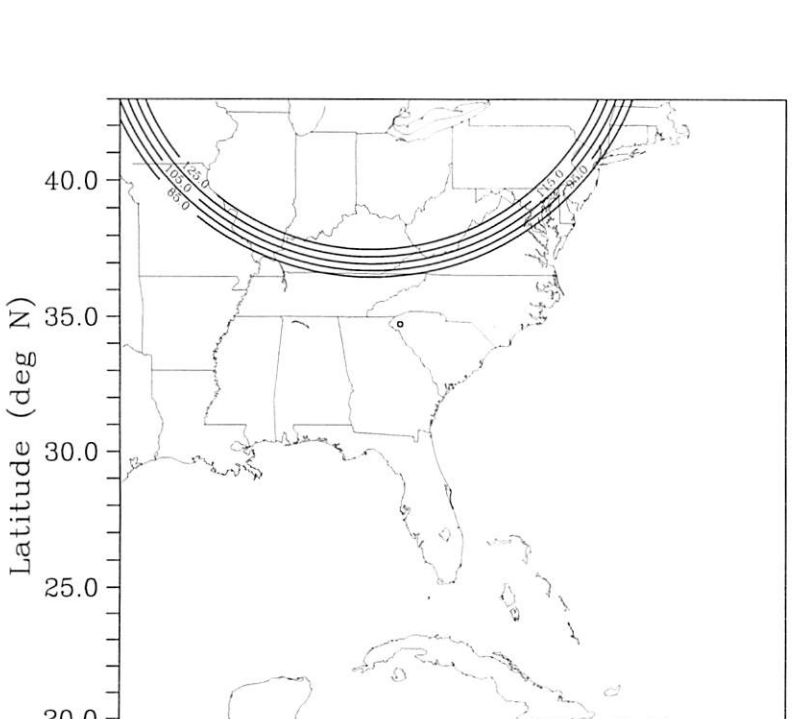


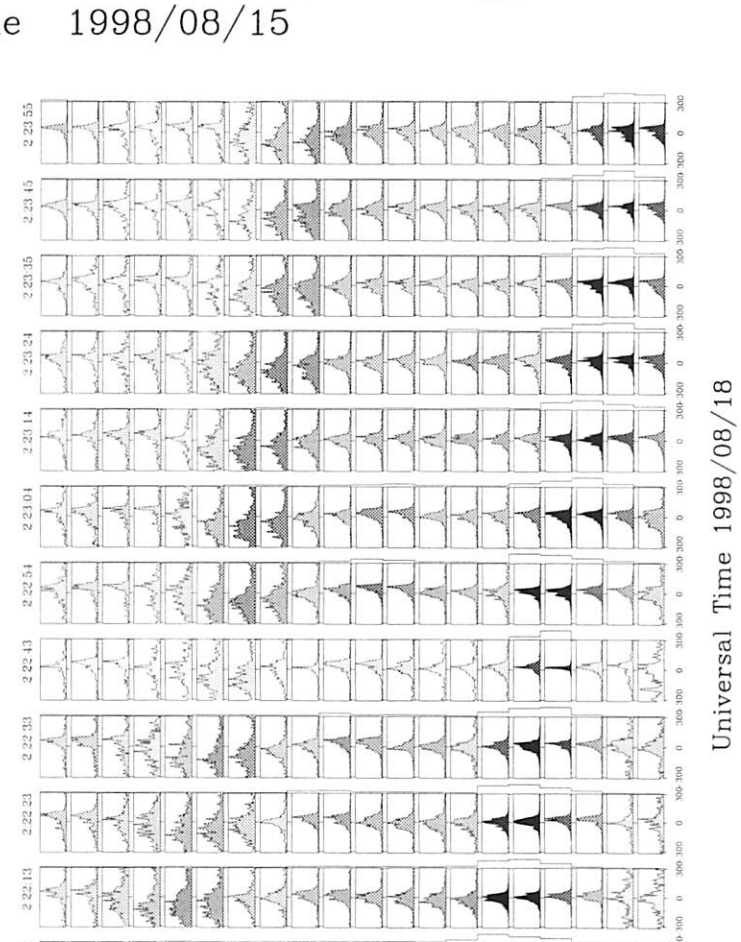

JULIA Horizontal Drift Velocity on August 31, 1996
Altitude (km)
800
600
400
200
20
22
24
26
28
30
Hours LT
Vx (m/s)
300
200
100
0
−100
−200
−300

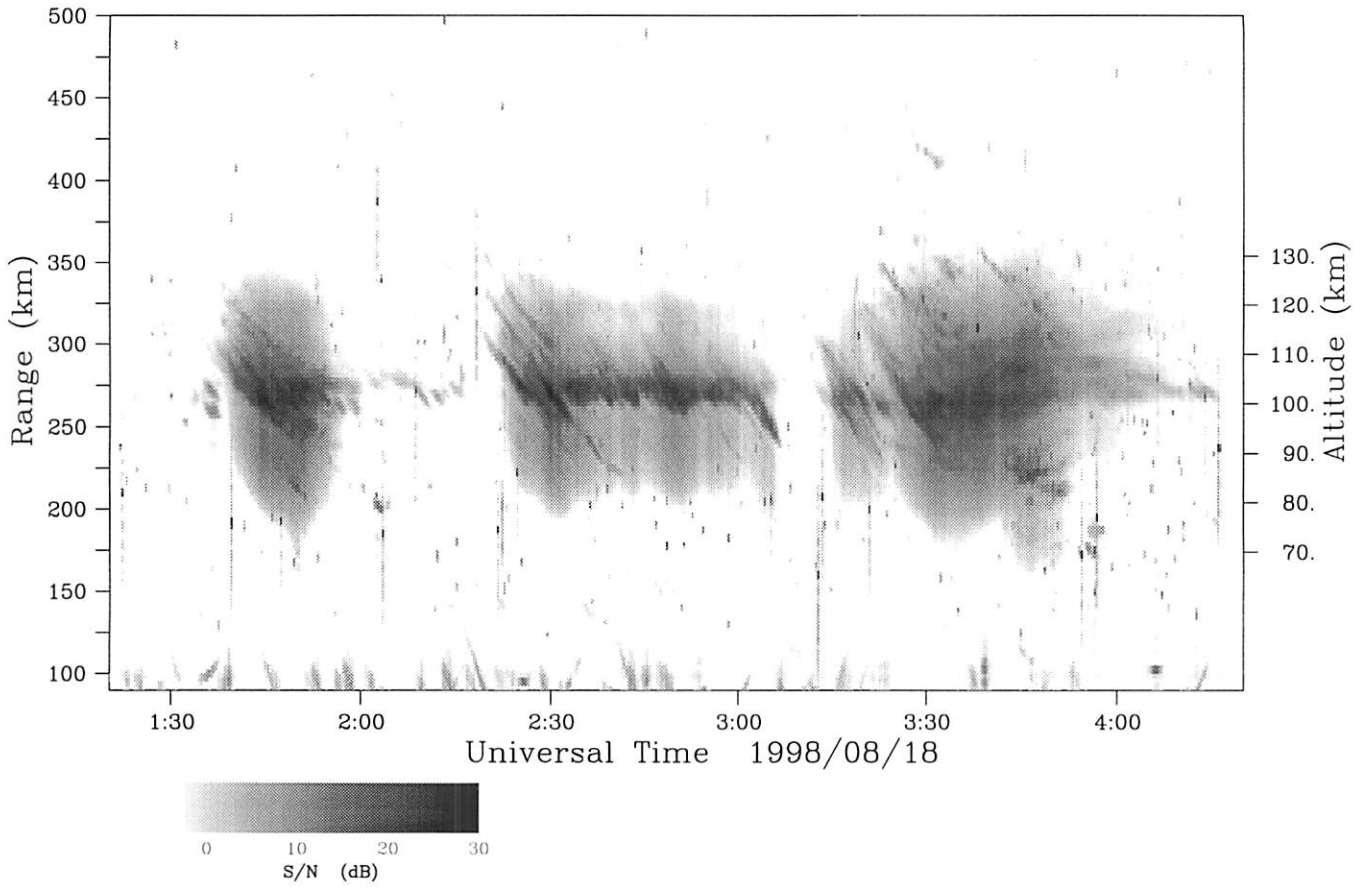


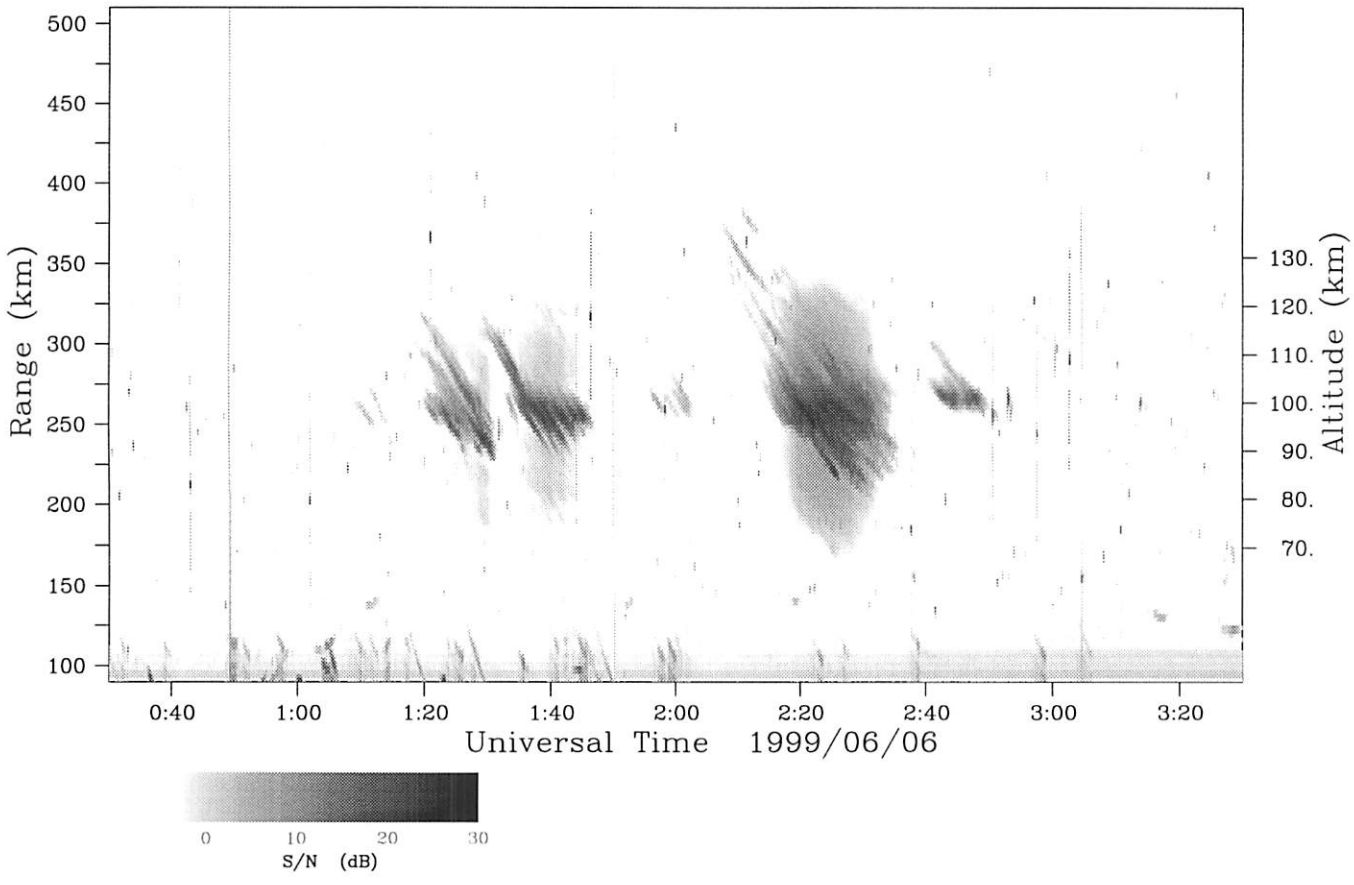

Range (km)
Altitude (km)
Universal Time 1998/08/15
1:30
2:00
2:30
3:00
3:30
4:00

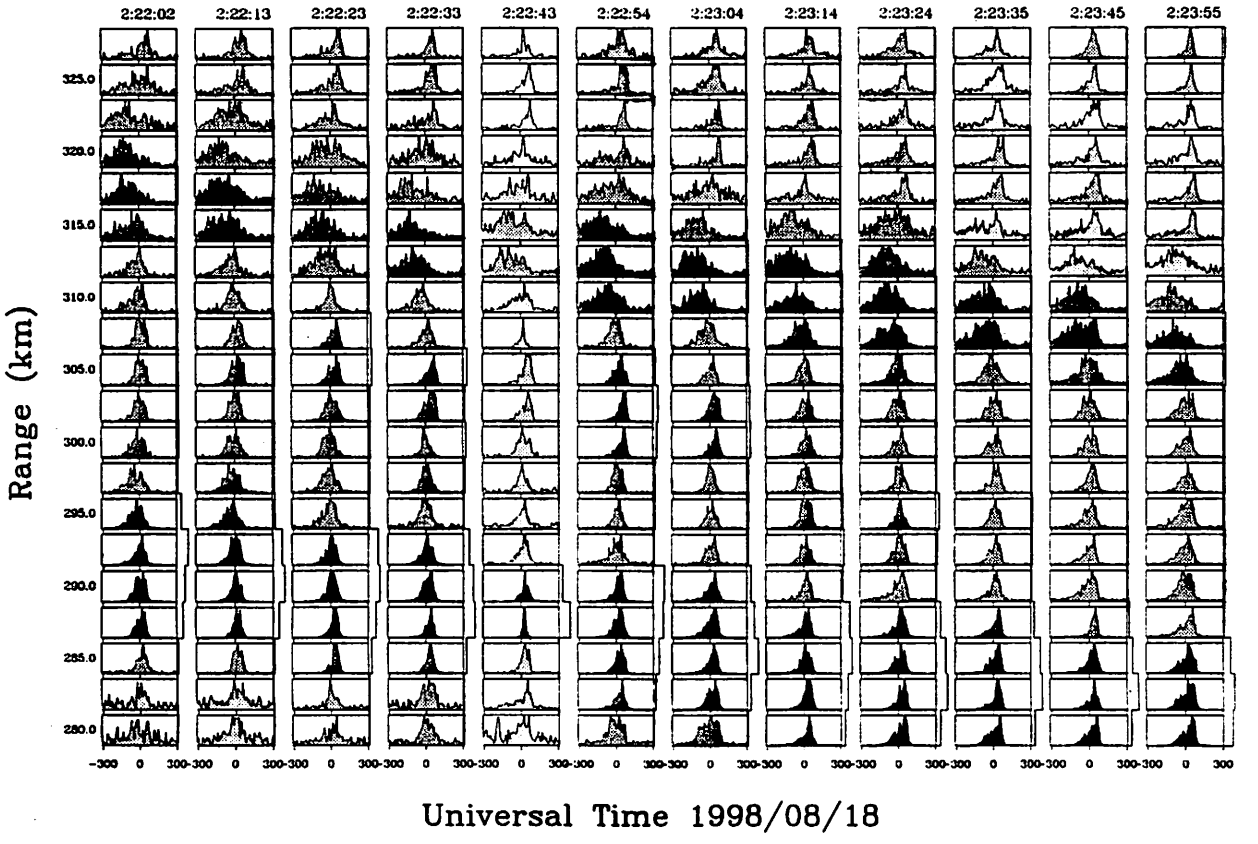

S/N (dB)

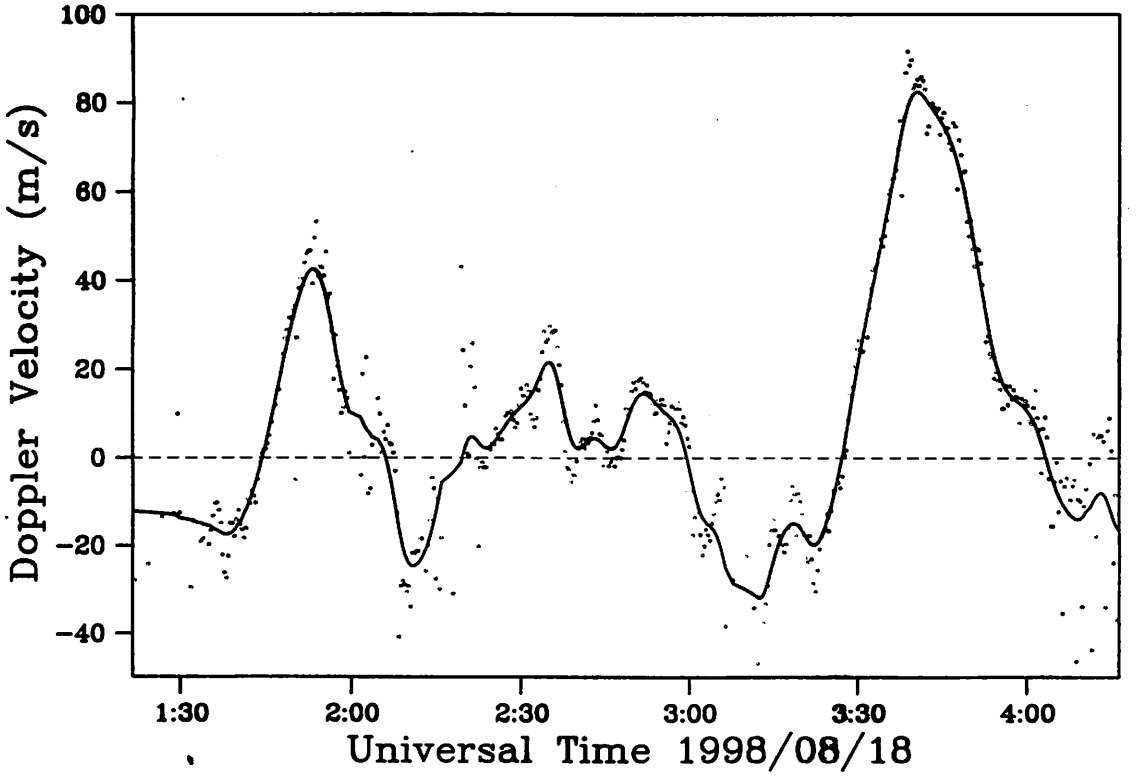

Latitude (deg N)
Longitude (deg E)

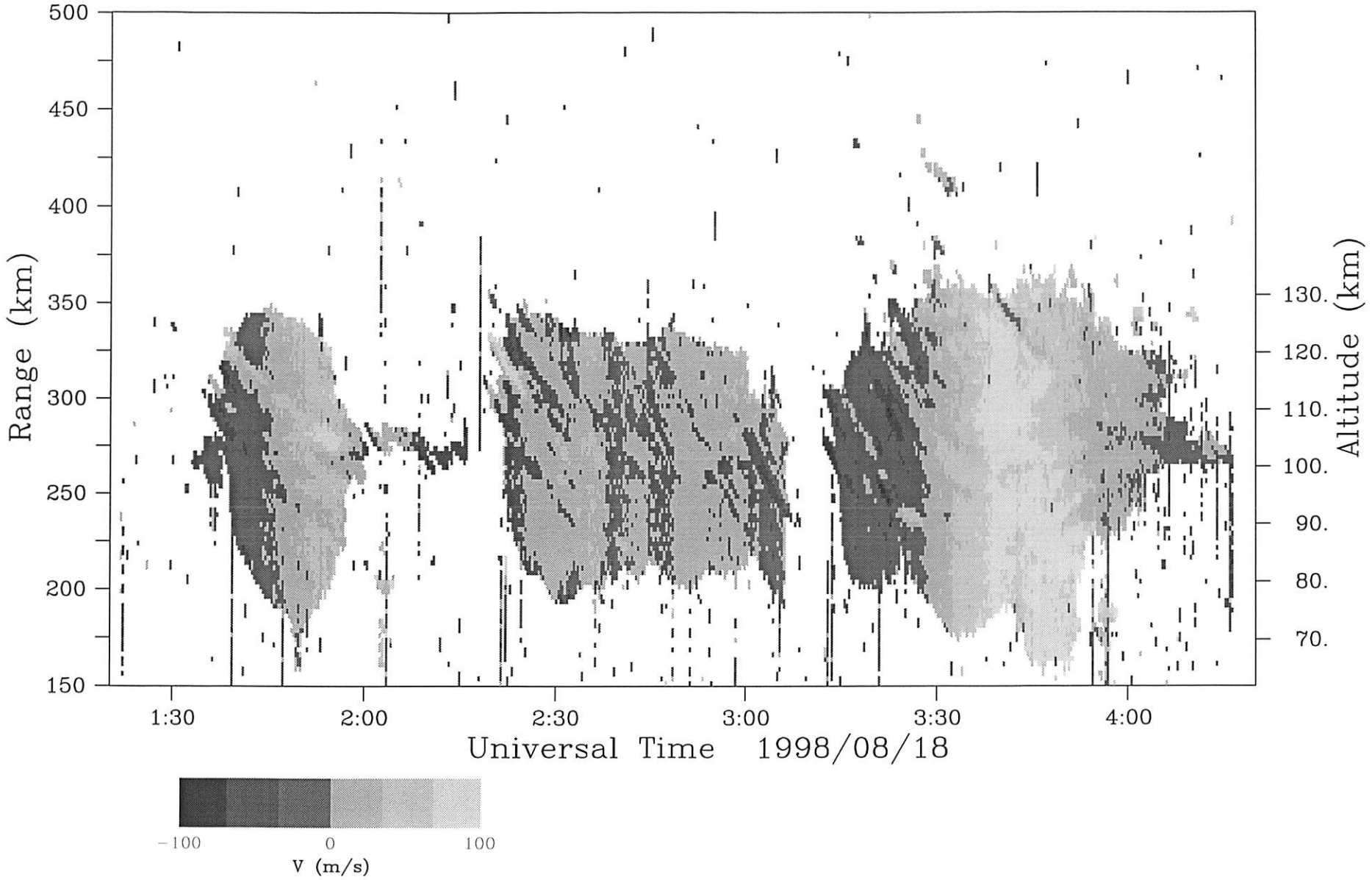

Universal Time 1998/08/18
Range (km)

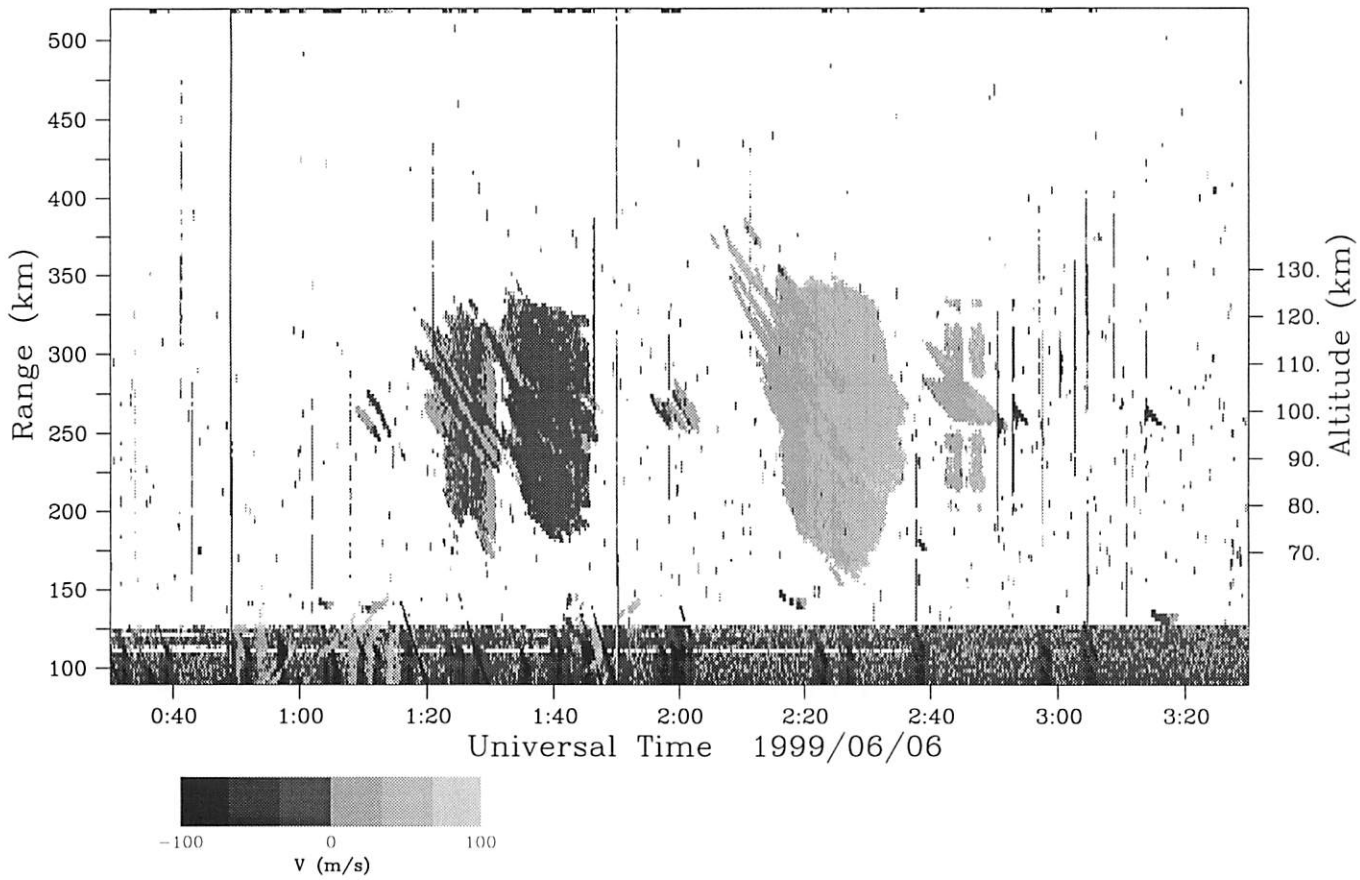

Range (km)
500
450
400
350
300
250
200
150
100
Altitude (km)
130.
120.
110.
100.
90.
80.
70.
1:30
2:00
2:30
3:00
3:30
4:00
Universal Time 1998/08/18
0
10
20
30
S/N (dB)

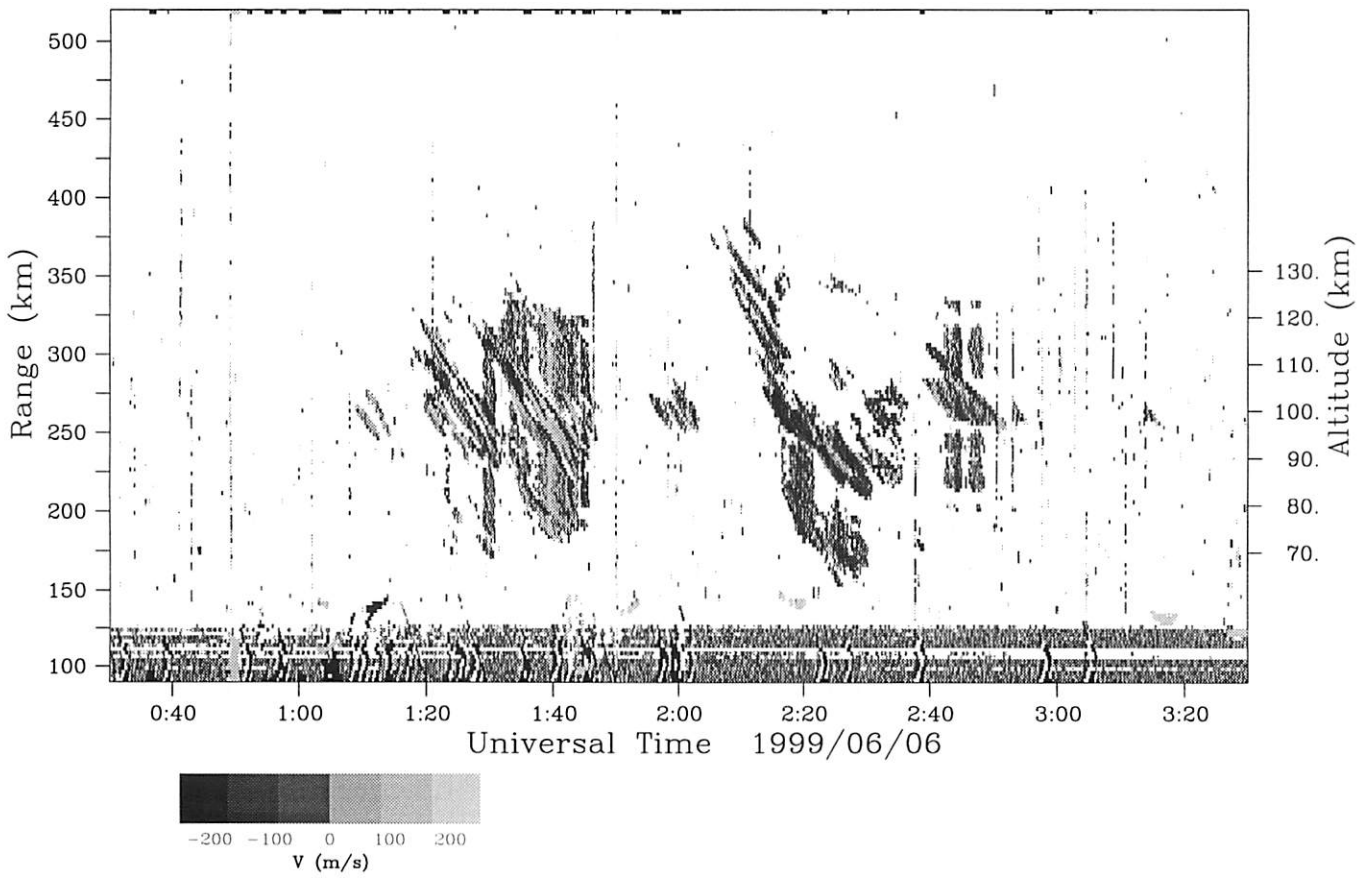

Range (km)
500
450
400
350
300
250
200
150
100
Altitude (km)
130.
120.
110.
100.
90.
80.
70.
0:40
1:00
1:20
1:40
2:00
2:20
2:40
3:00
3:20
Universal Time 1999/06/06
0
10
20
30
S/N (dB)


2:22:02
2:22:13
2:22:23
2:22:33
2:22:43
2:22:54
2:23:04
2:23:14
2:23:24
2:23:35
2:23:45
2:23:55
Range (km)
325.0
320.0
315.0
310.0
305.0
300.0
295.0
290.0
285.0
280.0
Universal Time 1998/08/18

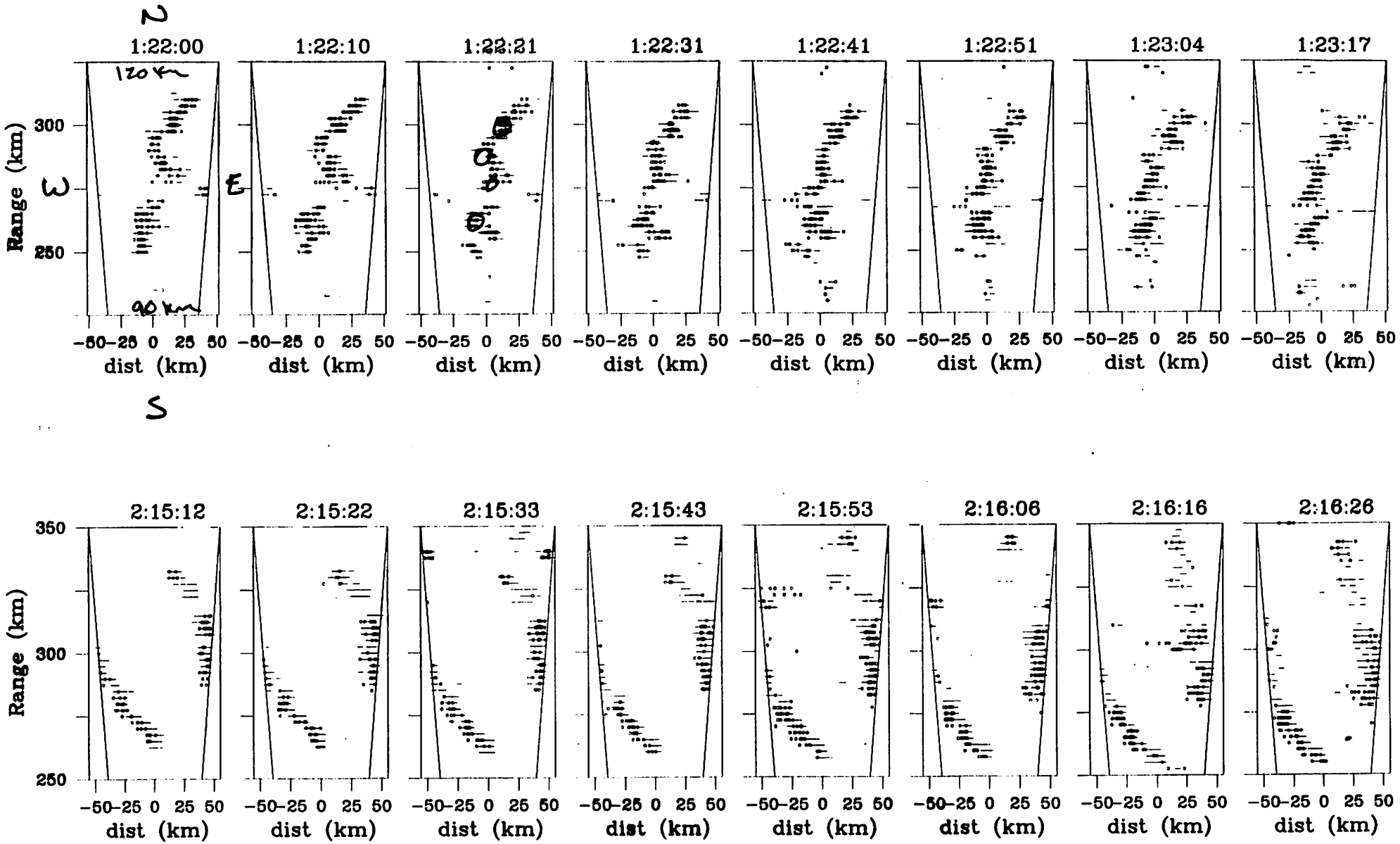

Doppler Velocity (m/s)
100
80
60
40
20
0
-20
-40
1:30
2:00
2:30
3:00
3:30
4:00
Universal Time 1998/08/18


500
450
400
350
300
250
200
150
Range (km)
130.
120.
110.
100.
90.
80.
70.
Altitude (km)
1:30
2:00
2:30
3:00
3:30
4:00
Universal Time 1998/08/18
−100
0
100
V (m/s)


Range (km)
500
450
400
350
300
250
200
150
100
Altitude (km)
130.
120.
110.
100.
90.
80.
70.
0:40
1:00
1:20
1:40
2:00
2:20
2:40
3:00
3:20
Universal Time 1999/06/06
−100
0
100
V (m/s)


Range (km)
500
450
400
350
300
250
200
150
100
Altitude (km)
130.
120.
110.
100.
90.
80.
70.
0:40
1:00
1:20
1:40
2:00
2:20
2:40
3:00
3:20
Universal Time 1999/06/06
−200
−100
0
100
200
V (m/s)

JUNE 6 1999


N
1:22:00
1:22:10
1:22:21
1:22:31
1:22:41
1:22:51
1:23:04
1:23:17
120 km
90 km
W
E
S
Range (km)
300
250
-50 -25 0 25 50
dist (km)
2:15:12
2:15:22
2:15:33
2:15:43
2:15:53
2:16:06
2:16:16
2:16:26
350
300
250

Conclusions

- CS radar imaging is permitting us to resolve, at long last, certain fundamental problems in ESF
- Low power radar at the electrojet can recover information usually reserved by ISR
- Equatorial electrojet irregularities serve as tracers of neutral winds/waves in lower thermosphere
- Midlatitude E region irregularities surprisingly regular, intense, dynamic, and intricate