Measuring MLT Winds by Tracking Meteor Trails with Incoherent Scatter Radar

A New Method Observes Rapidly Changing Winds Exceeding 500km/Hr

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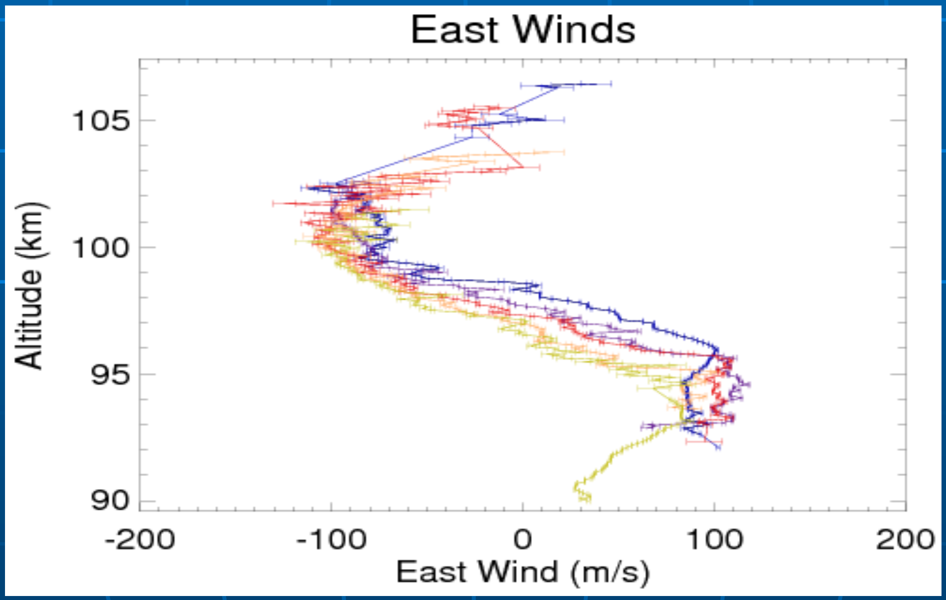


Research supported by the NSF Aeronomy, DOE/NSF & CEDAR Grants

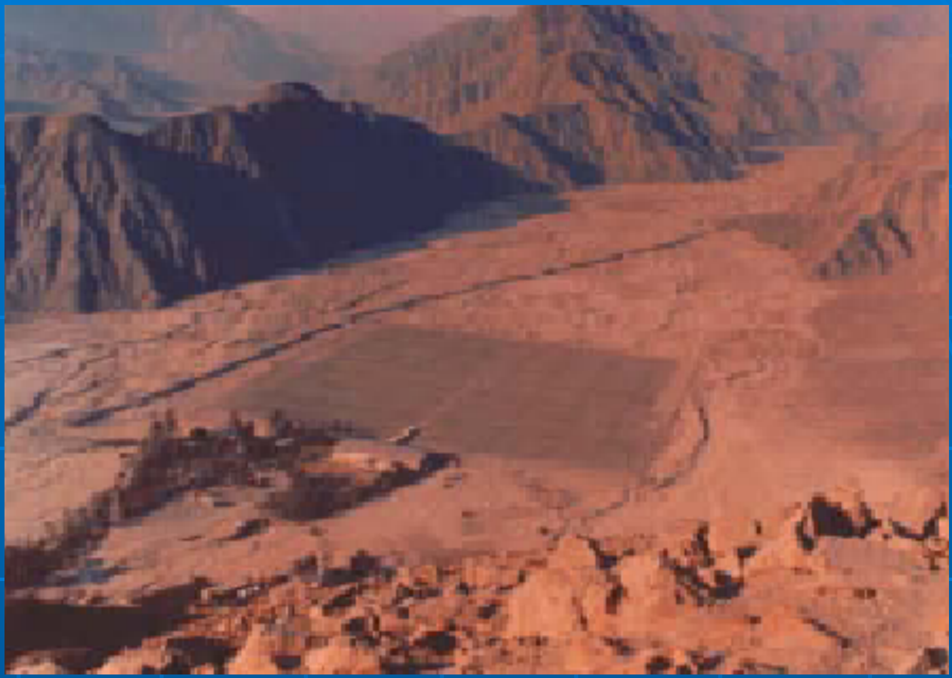
BOSTON UNIVERSITY

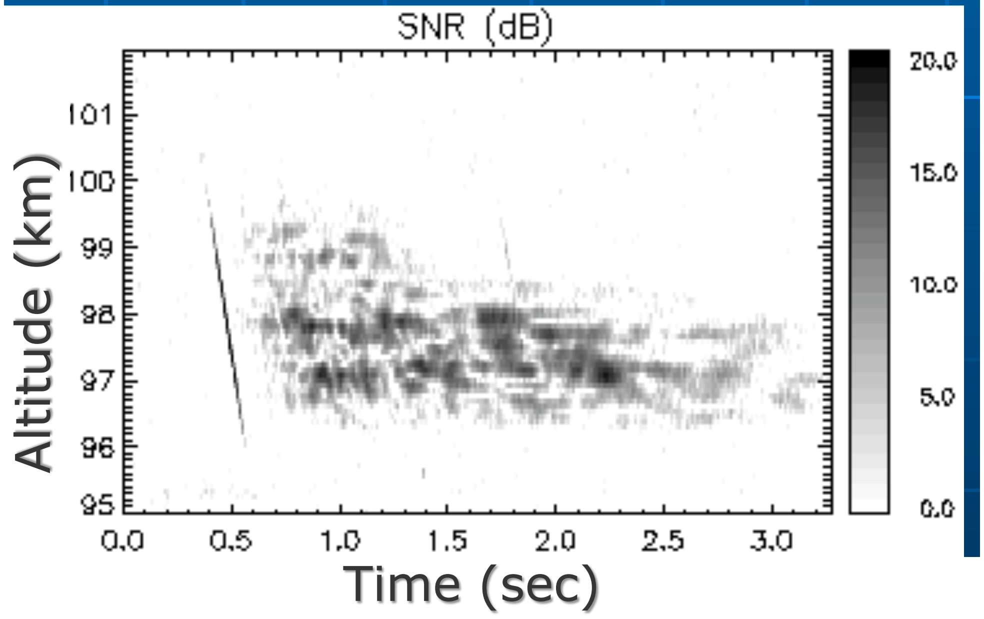
CEDAR Workshop 2009

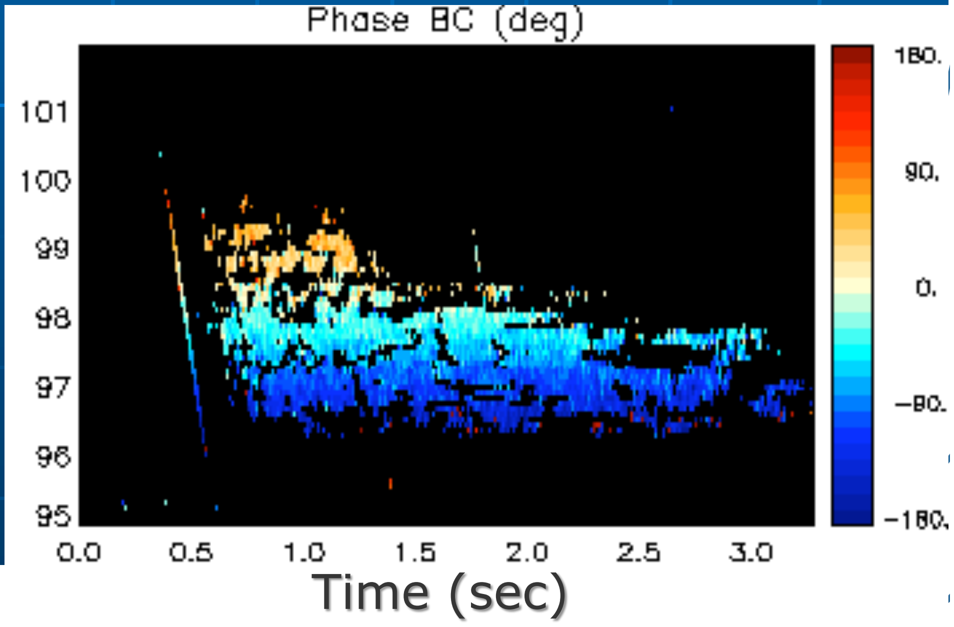
Overview

- Background:
  - Winds in the MLT
  - Observations of Specular Meteor trails by Large (HPLA) Radars
- Method: Use Phase interferometry from Trails
- Result: Accurate Wind measurments
  - km resolution
  - 10 minute resolution

HPLA RADAR – Jicamarca Radio Observatory





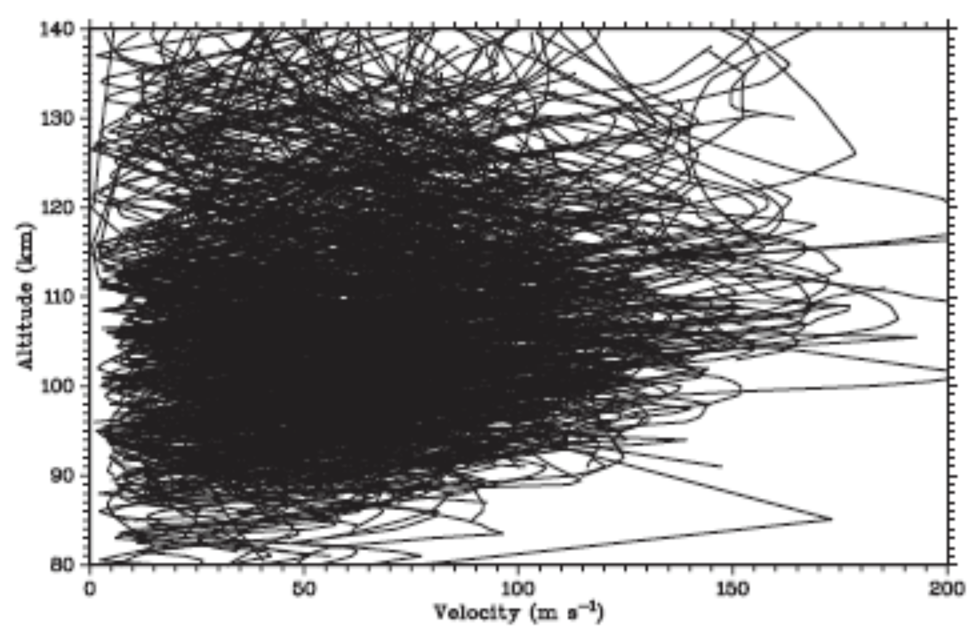


Winds in the Lower Thermosphere

- Specular Radar measurements
- LIDAR measurements
- 400 Rocket launches to measure winds

Specular Meteor Radar

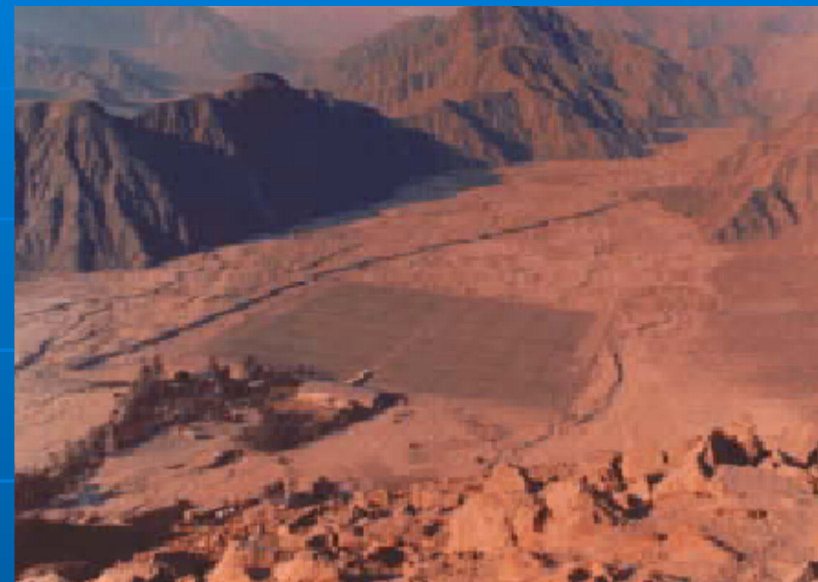
Rocket Wind Speeds

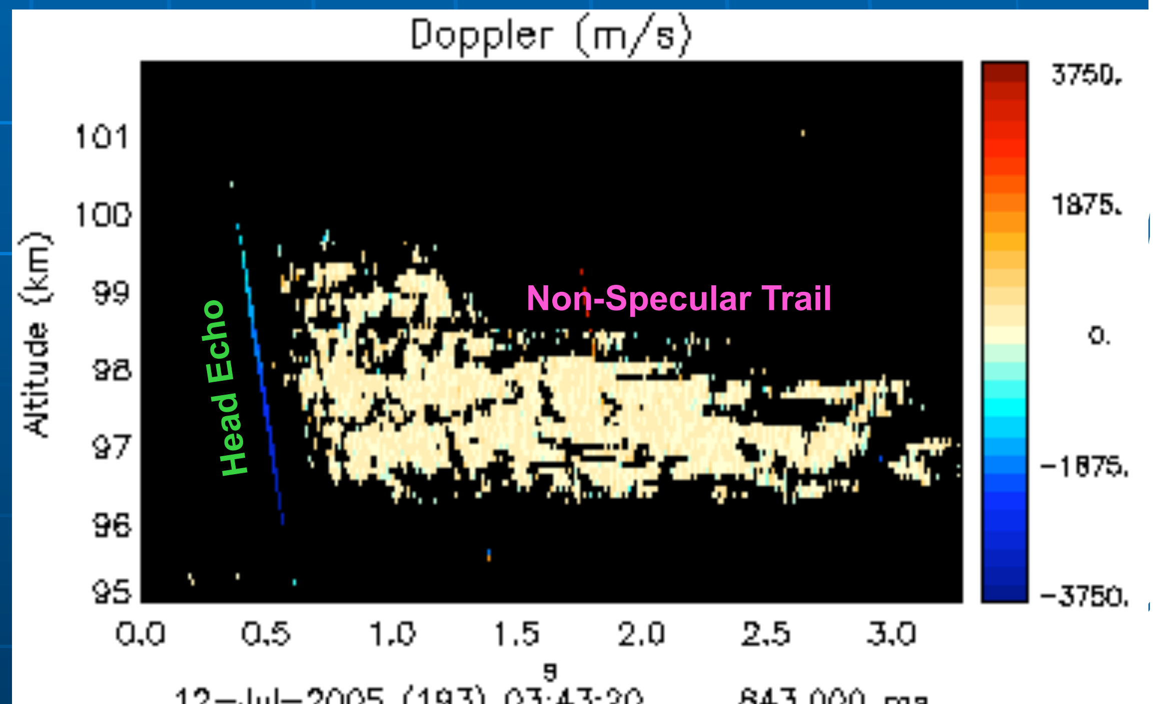


Larsen, M. F., J. Geophys. Res., 2002

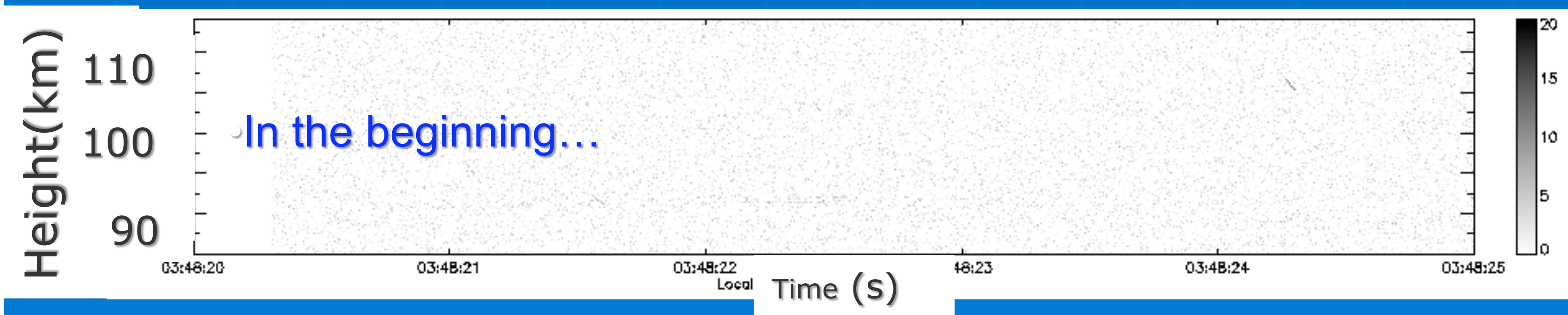
Background: HPLA Meteor Radar Science

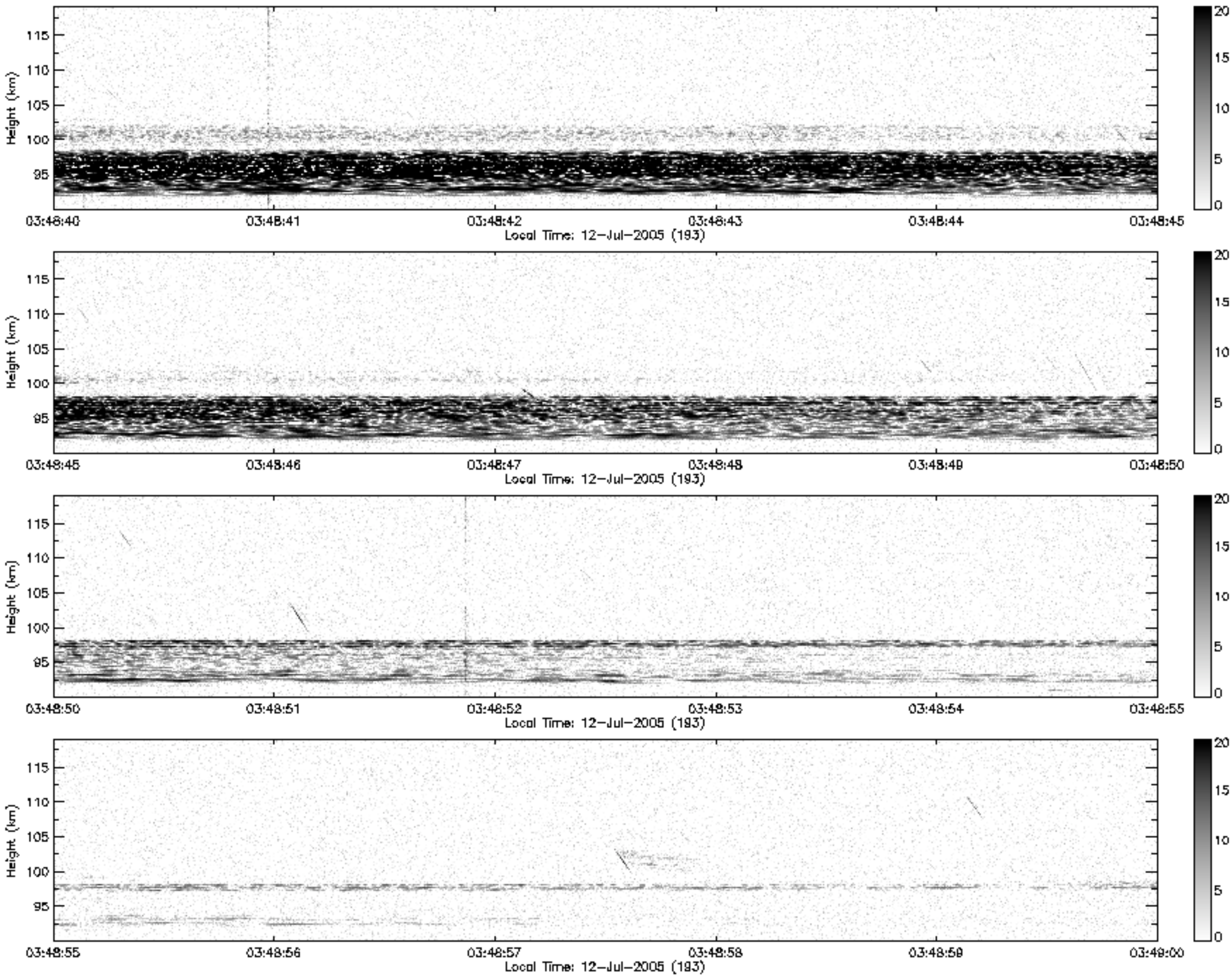
- Meteor enters Atmosphere
- Slam into air molecules
- Heat, ablate & ionize
- Create plasma trail
- Reflections from leading edge of plasma form head echoes
- Trail cools and expands
- Diffusion begins
- Waves and Turbulence develop:
  - In a limited range of altitudes
  - Reflections from plasma waves creates non-specular trails



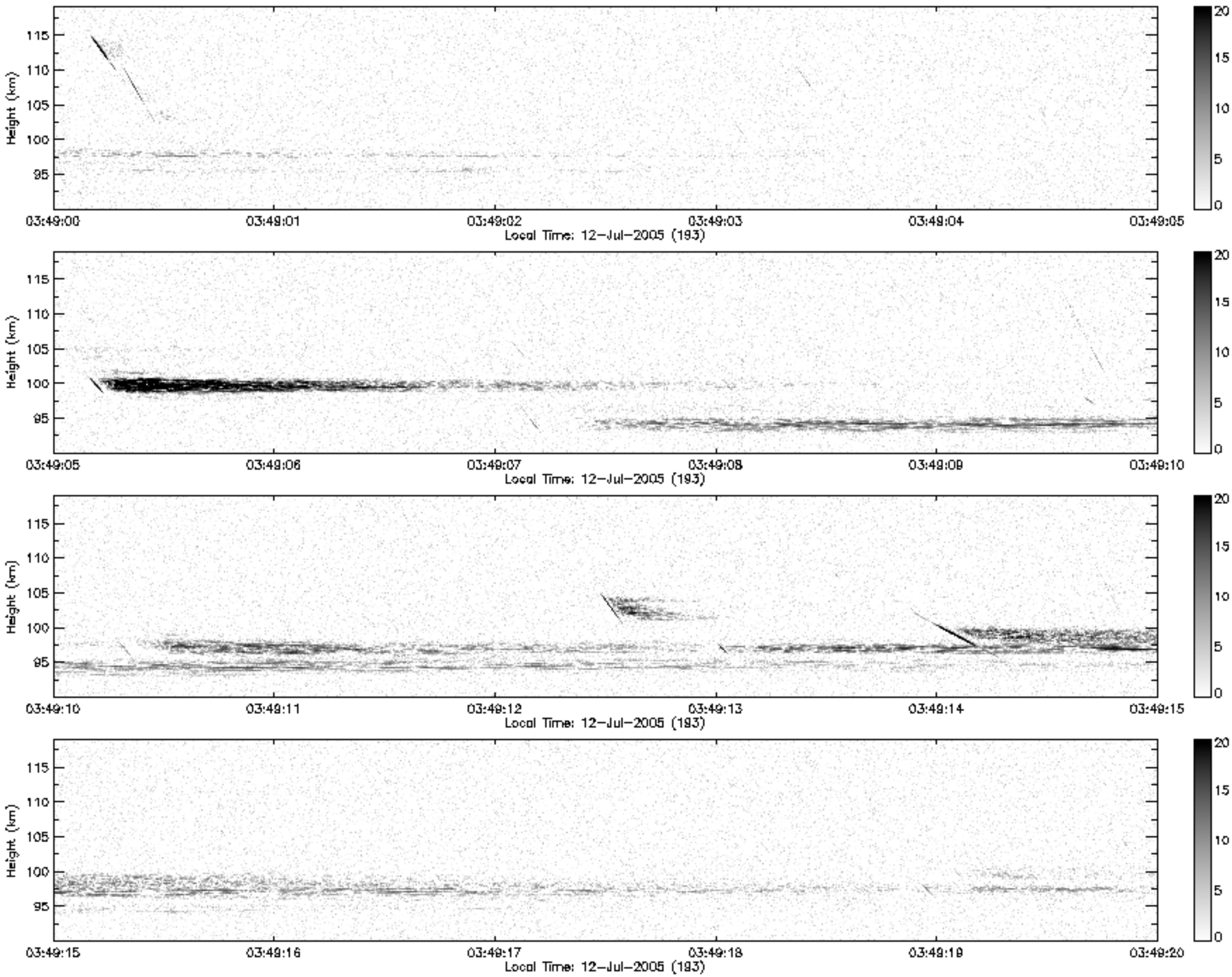


Data from JRO: My first 20 seconds

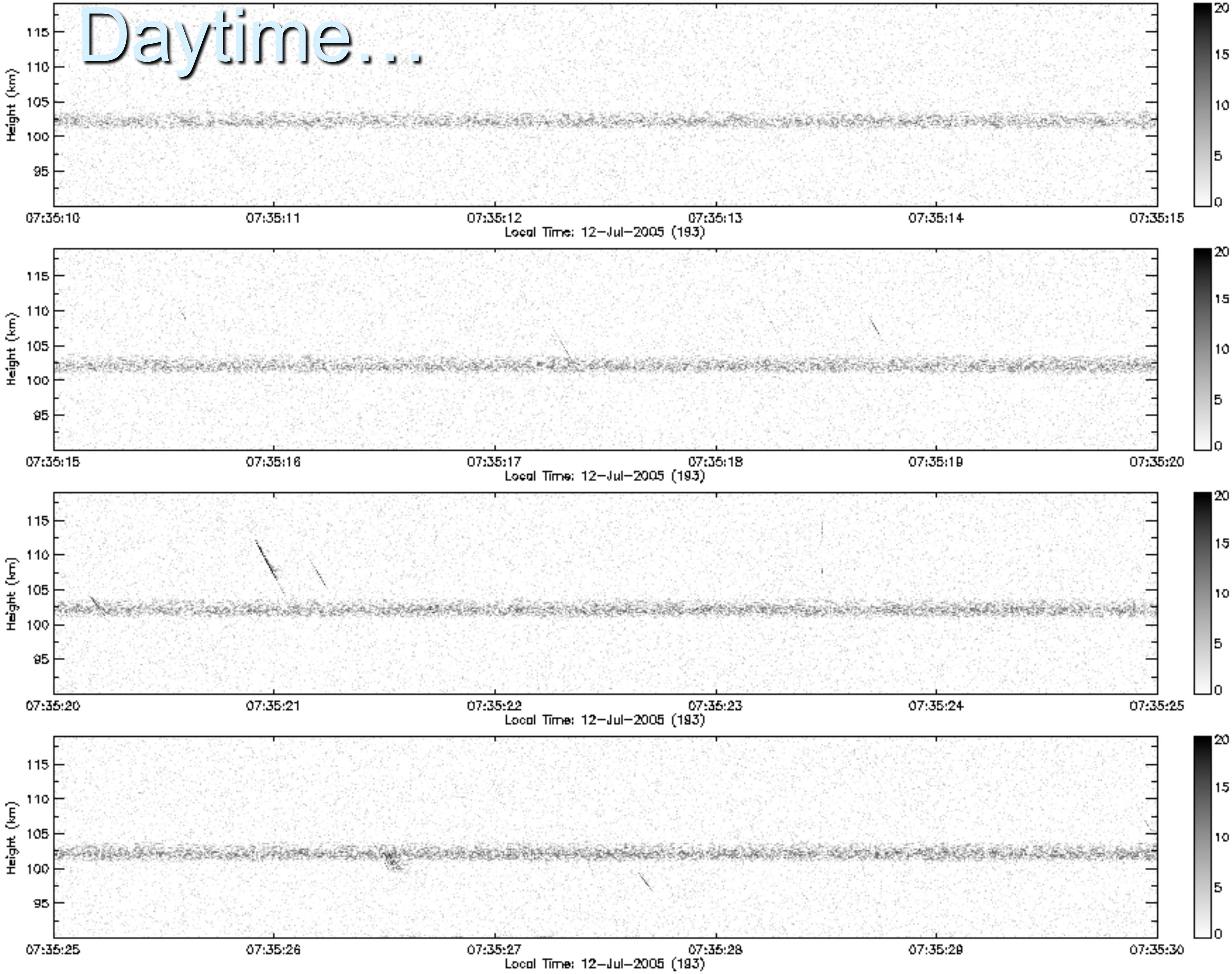


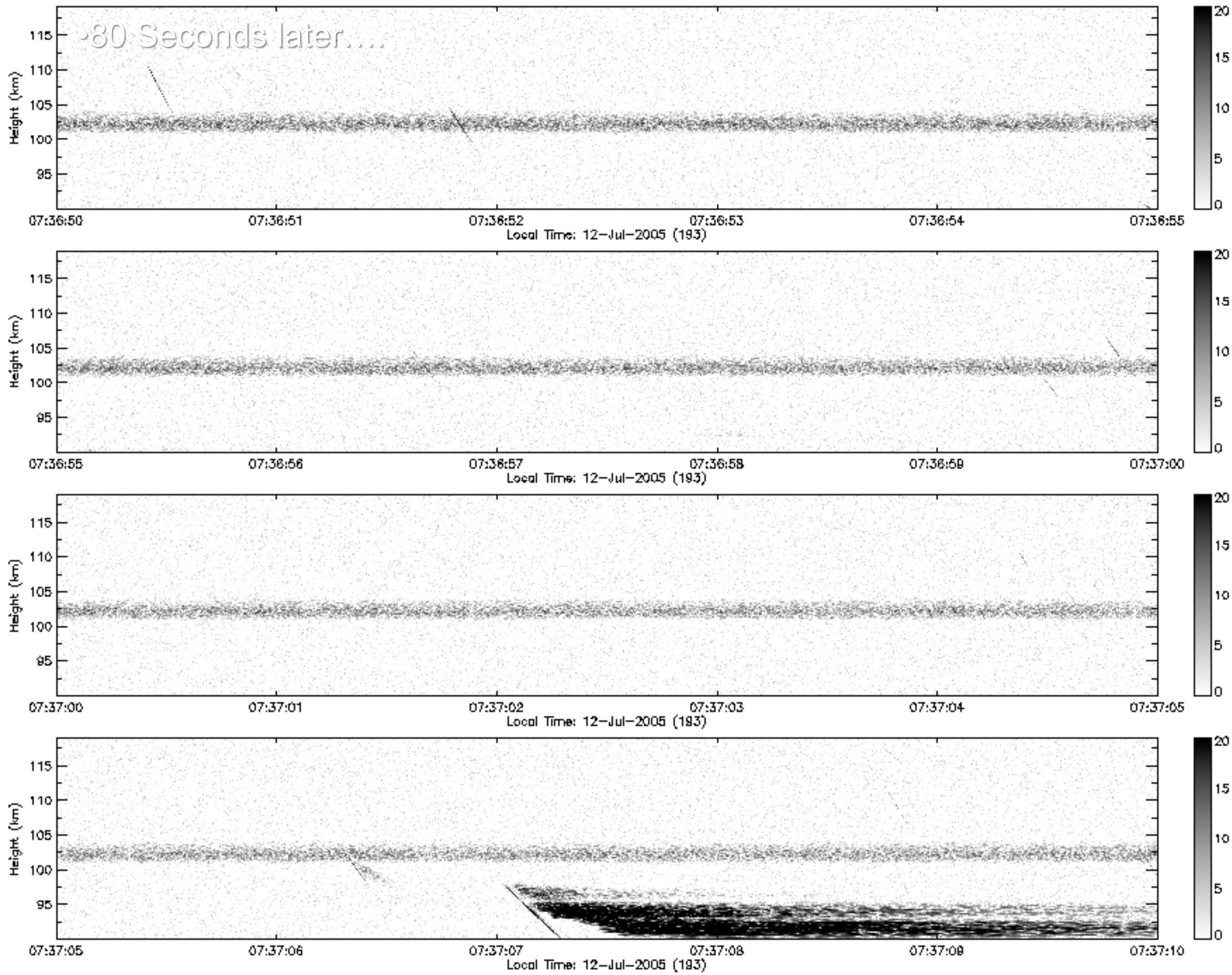


Height (km)
115
110
105
100
95
03:48:40
03:48:41
03:48:42
03:48:43
03:48:44
03:48:45
Local Time: 12-Jul-2005 (193)
20
15
10
5
0
03:48:45
03:48:46
03:48:47
03:48:48
03:48:49
03:48:50
03:48:50
03:48:51
03:48:52
03:48:53
03:48:54
03:48:55
03:48:55
03:48:56
03:48:57
03:48:58
03:48:59
03:49:00

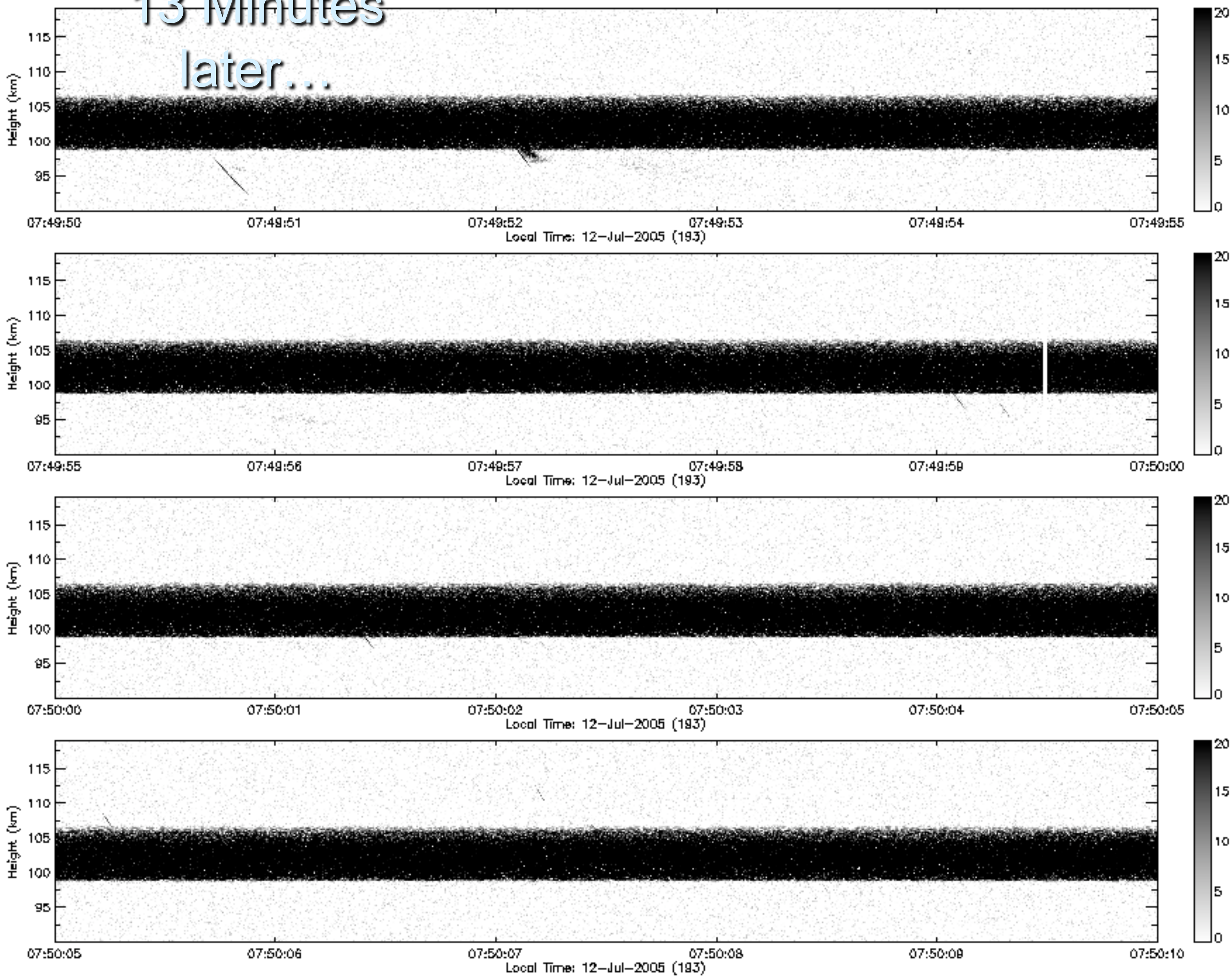

Height (km)
115
110
105
100
95
03:49:00
03:49:01
03:49:02
03:49:03
03:49:04
03:49:05
Local Time: 12-Jul-2005 (193)
20
15
10
5
0
03:49:06
03:49:07
03:49:08
03:49:09
03:49:10
03:49:11
03:49:12
03:49:13
03:49:14
03:49:15
03:49:16
03:49:17
03:49:18
03:49:19
03:49:20

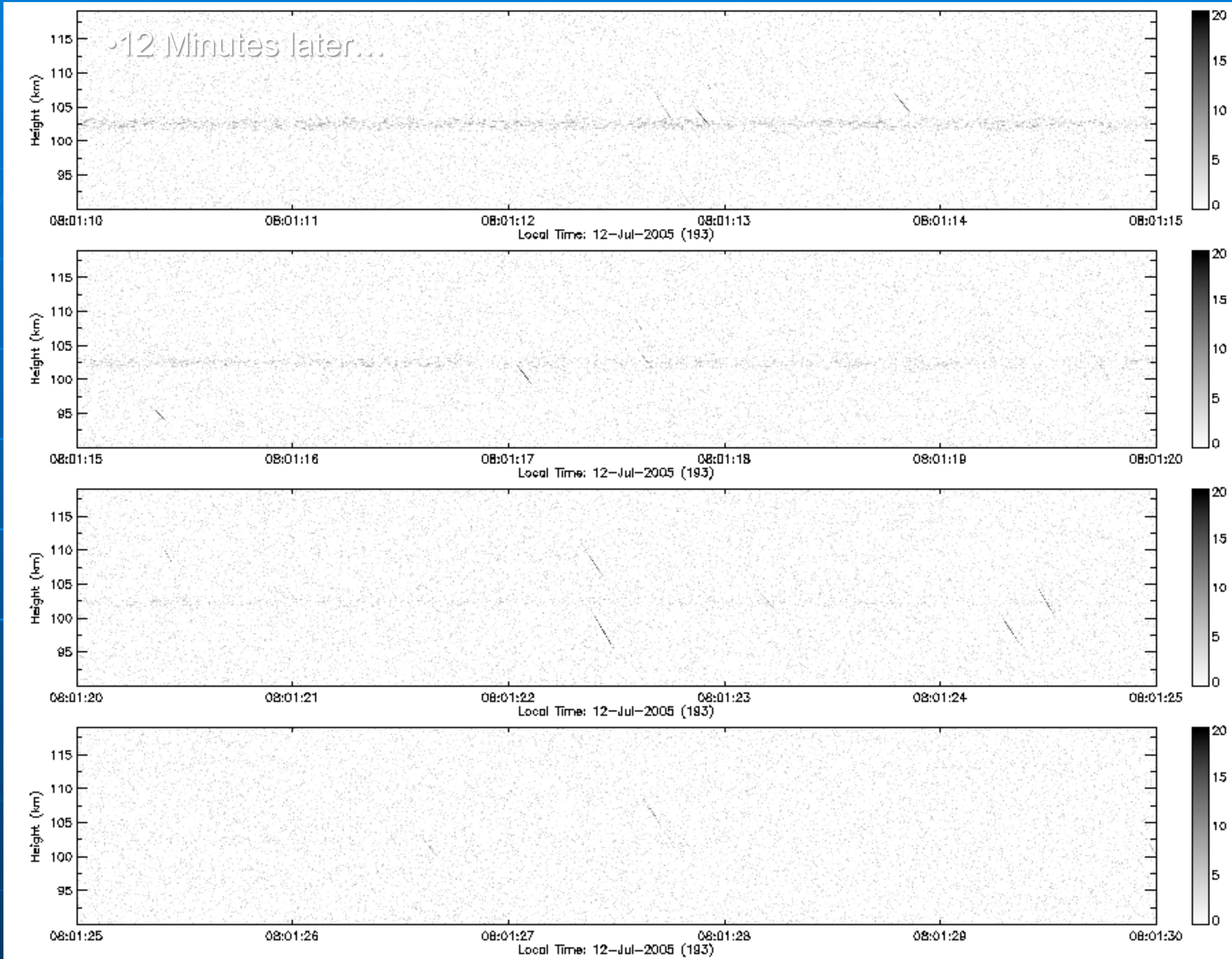
Daytime…


Height (km)
115
110
105
100
95
07:35:10
07:35:11
07:35:12
07:35:13
07:35:14
07:35:15
Local Time: 12-Jul-2005 (193)
20
15
10
5
0
07:35:16
07:35:17
07:35:18
07:35:19
07:35:20
07:35:21
07:35:22
07:35:23
07:35:24
07:35:25
07:35:26
07:35:27
07:35:28
07:35:29
07:35:30


•80 Seconds later….
Height (km)
Local Time: 12–Jul–2005 (193)
07:36:50
07:36:51
07:36:52
07:36:53
07:36:54
07:36:55
07:36:56
07:36:57
07:36:58
07:36:59
07:37:00
07:37:01
07:37:02
07:37:03
07:37:04
07:37:05
07:37:06
07:37:07
07:37:08
07:37:09
07:37:10

13 Minutes later…

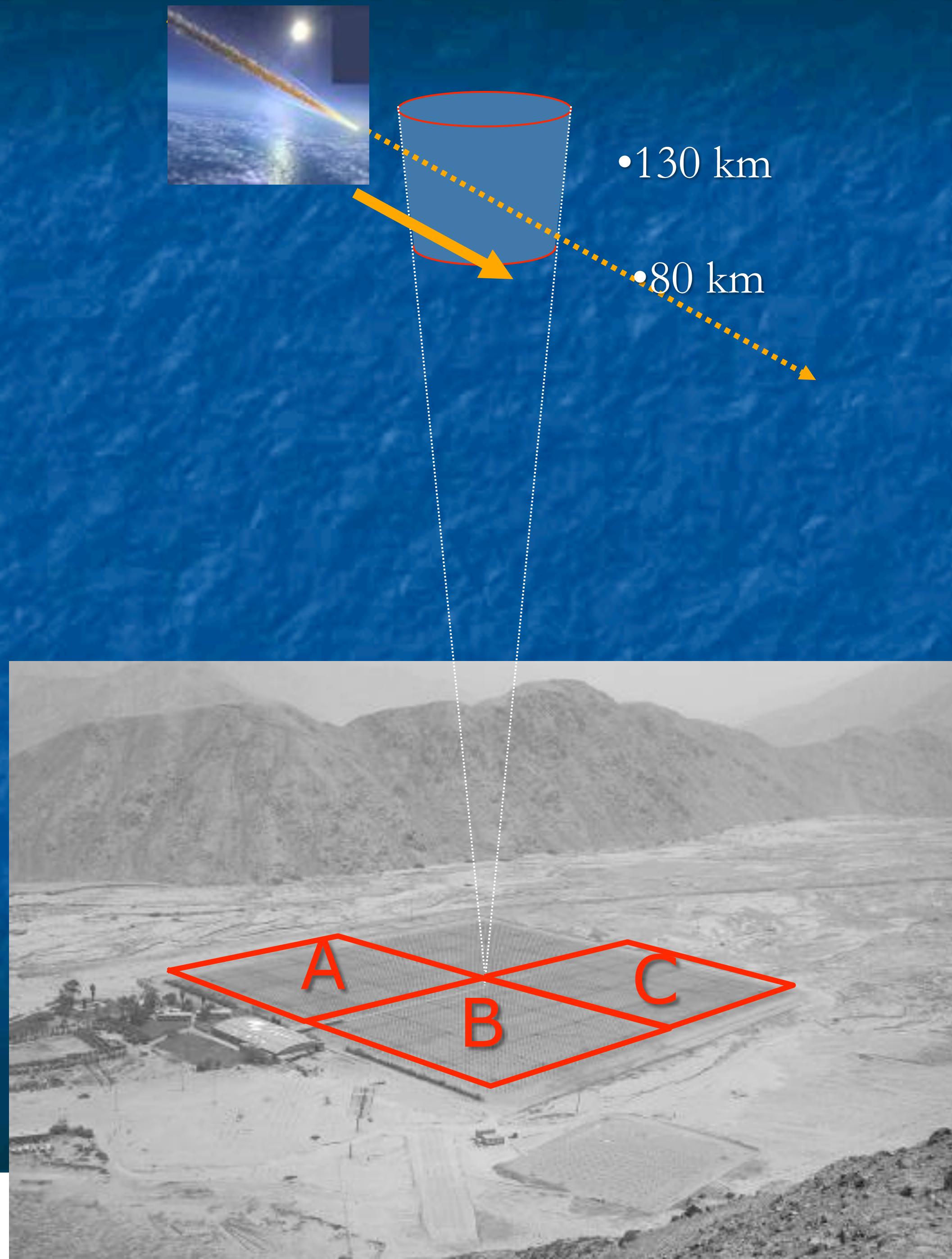




•12 Minutes later…
Height (km)
115
110
105
100
95
08:01:10
08:01:11
08:01:12
08:01:13
08:01:14
08:01:15
Local Time: 12–Jul–2005 (193)
20
15
10
5
0
08:01:16
08:01:17
08:01:18
08:01:19
08:01:20
08:01:21
08:01:22
08:01:23
08:01:24
08:01:25
08:01:26
08:01:27
08:01:28
08:01:29
08:01:30

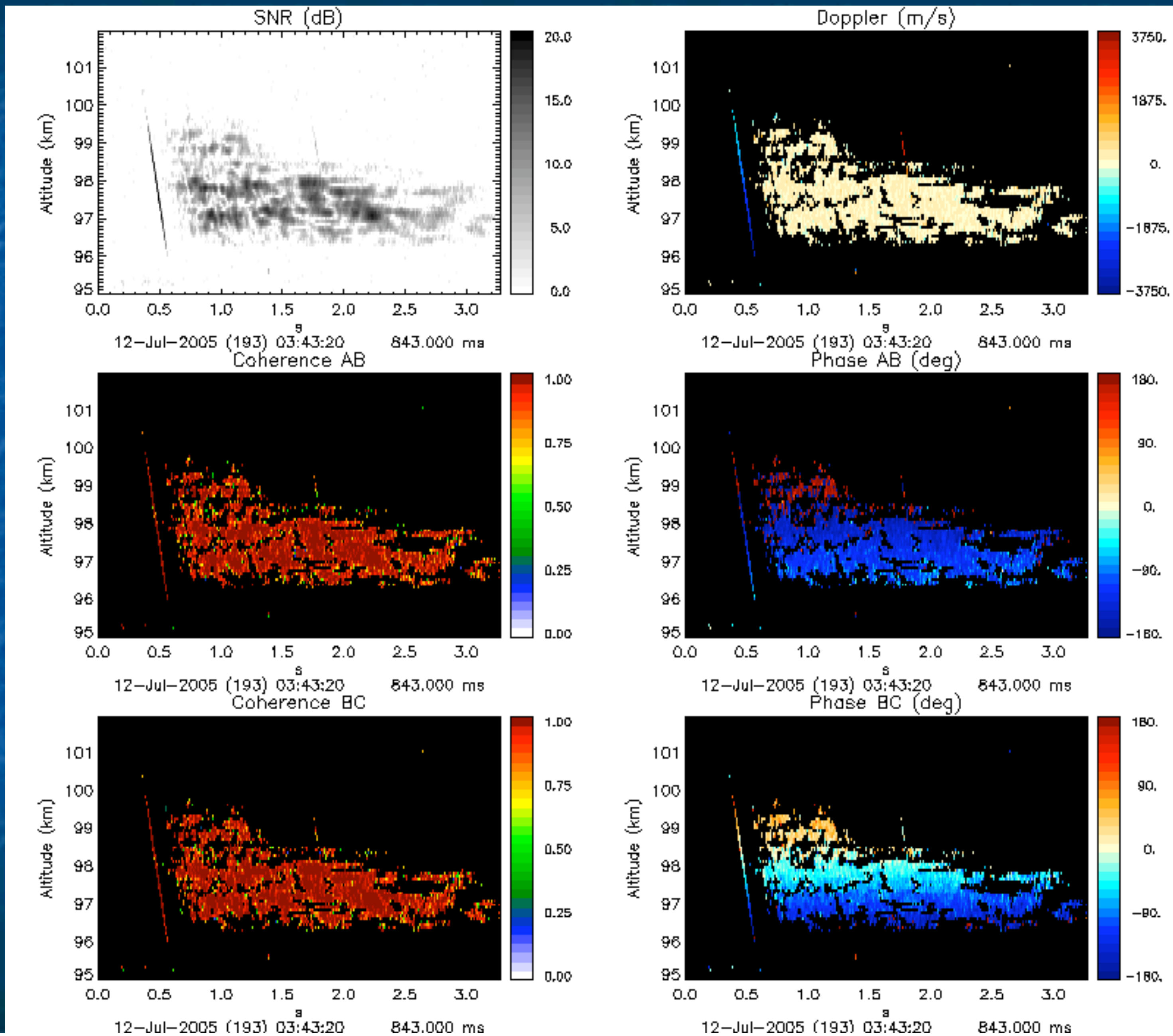
JRO 50MHz Radar Observations

- Antenna:
  - 300m x 300m
  - 18,432 dipoles
  - Peak power: 2 MW
  - Frequency: 50 MHz
- *A truely High-Power Large-Aperture Radar (HPLA)*
- **Interferometer**

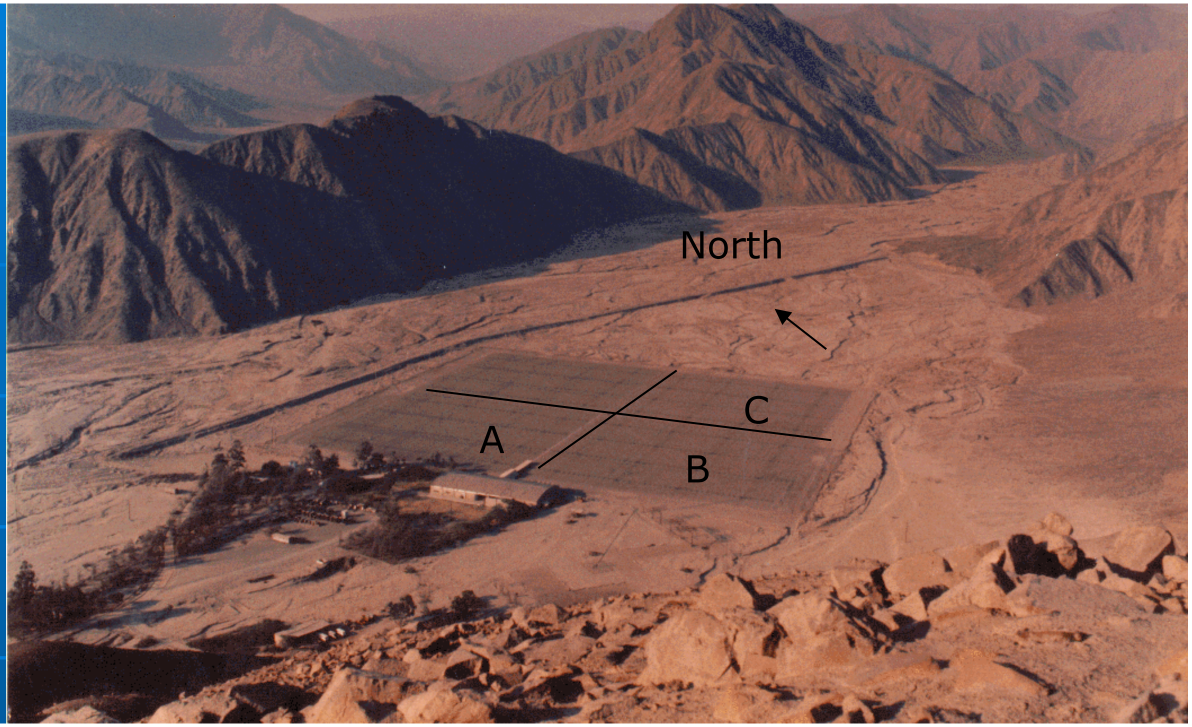


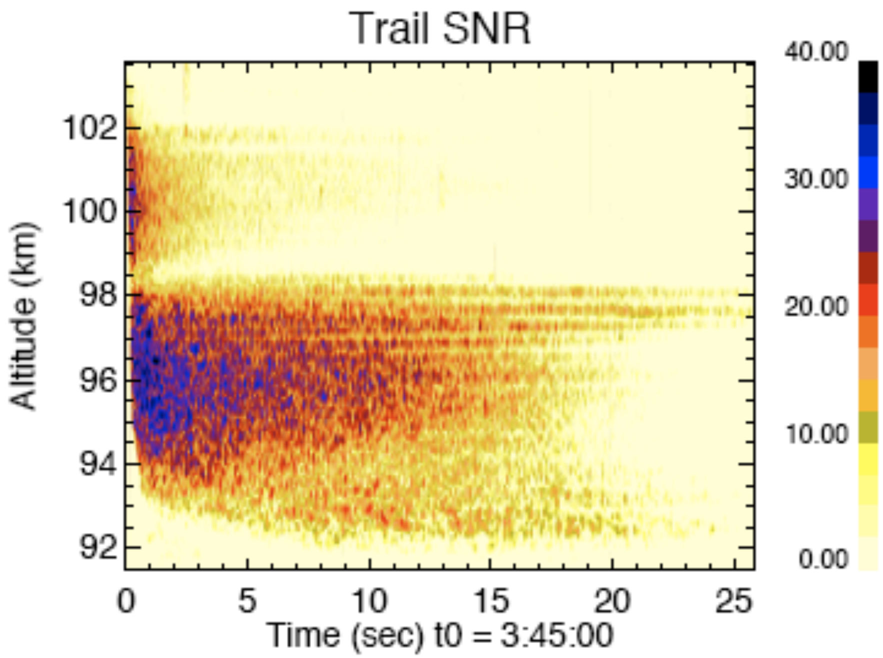
•Not to scale

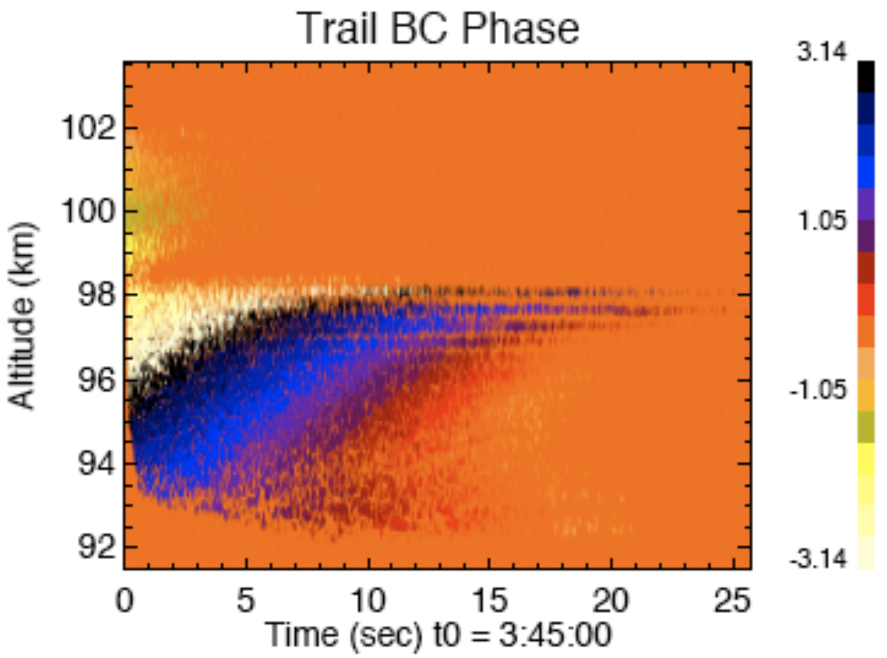
SNR, Doppler, and Phase



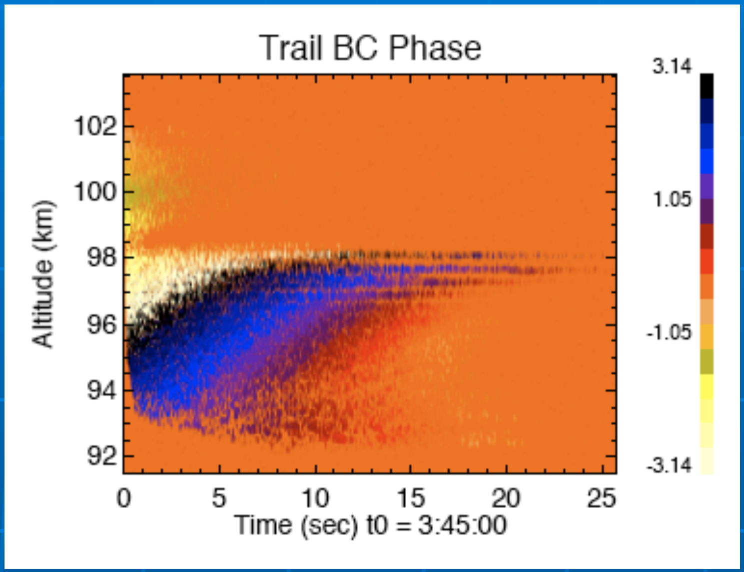
Jicamarca Trail Interferometry

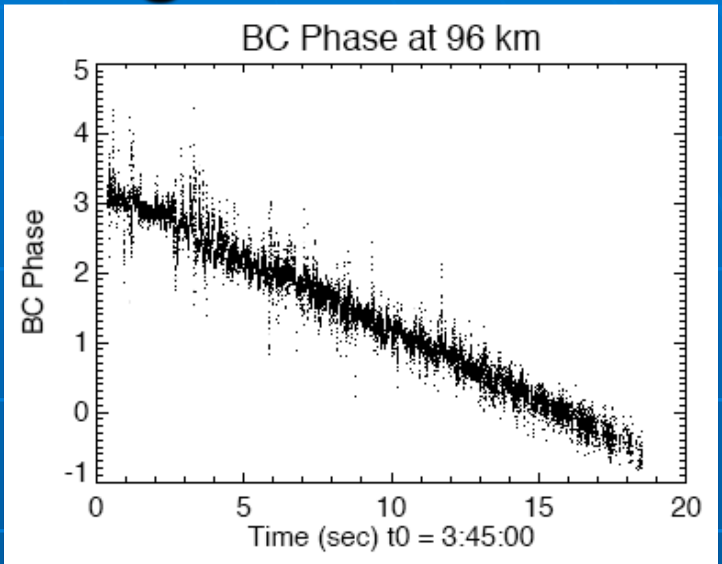




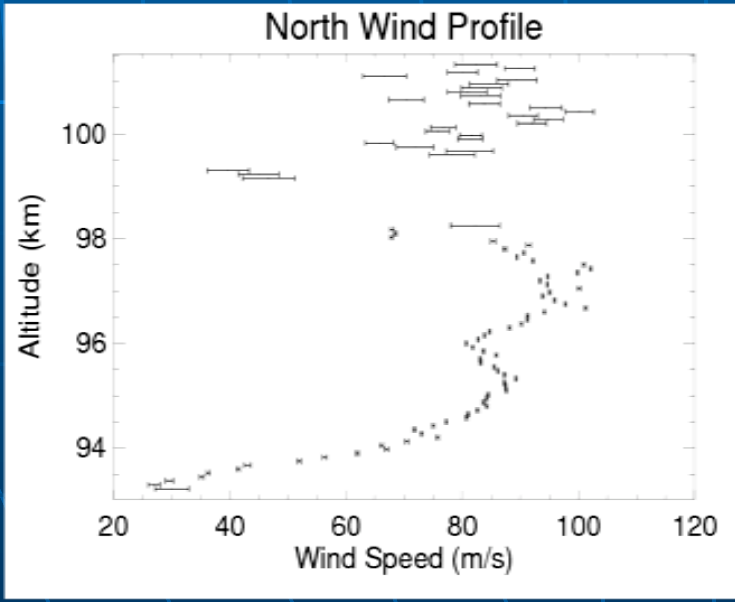


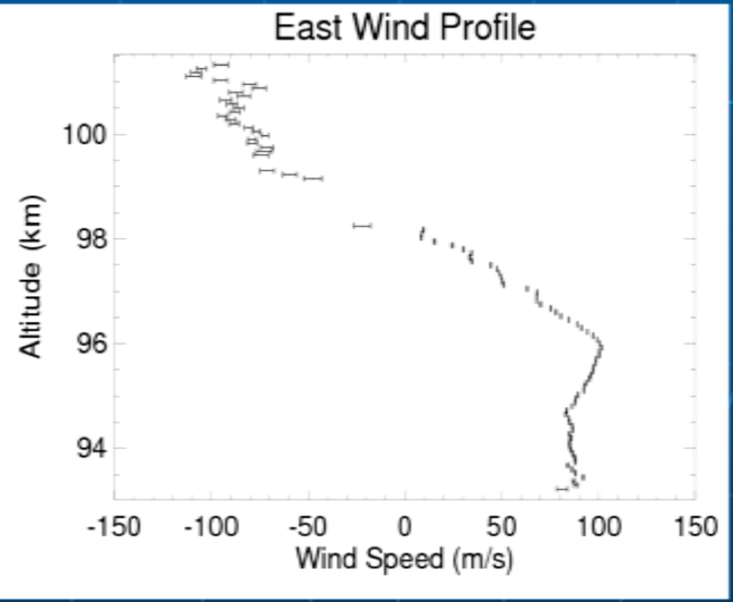
Trail Phase at Single Altitude



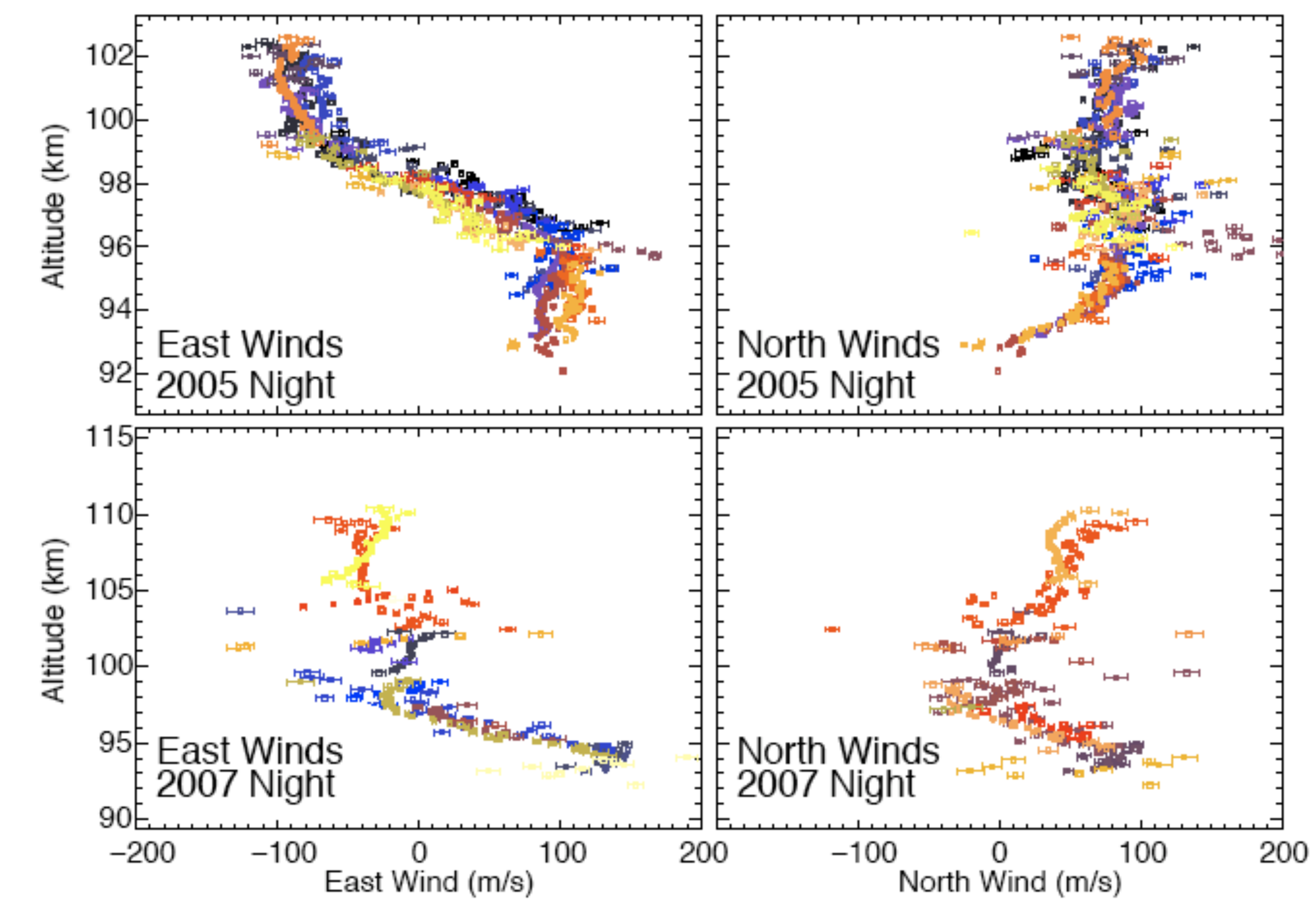


Winds from all altitudes

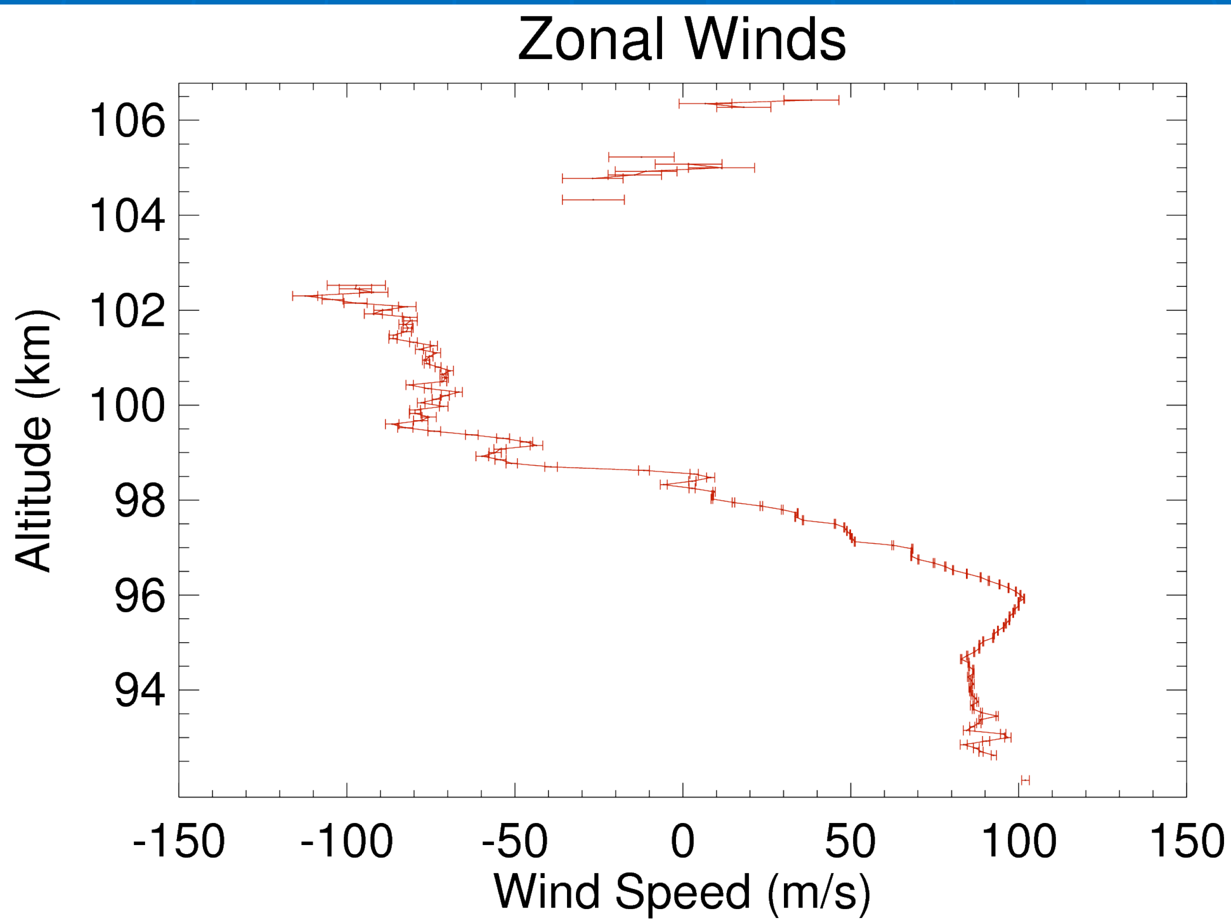




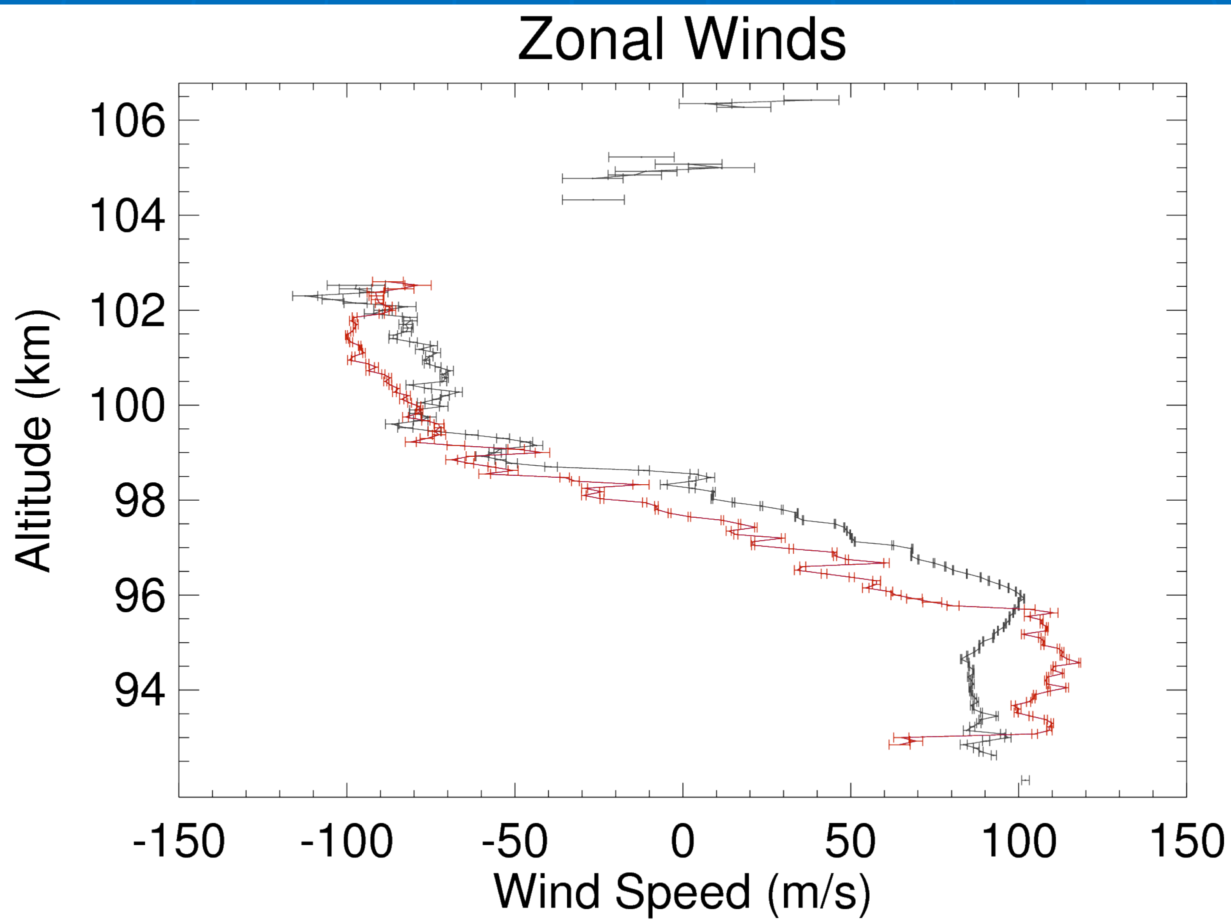
Wind Profiles from many trails



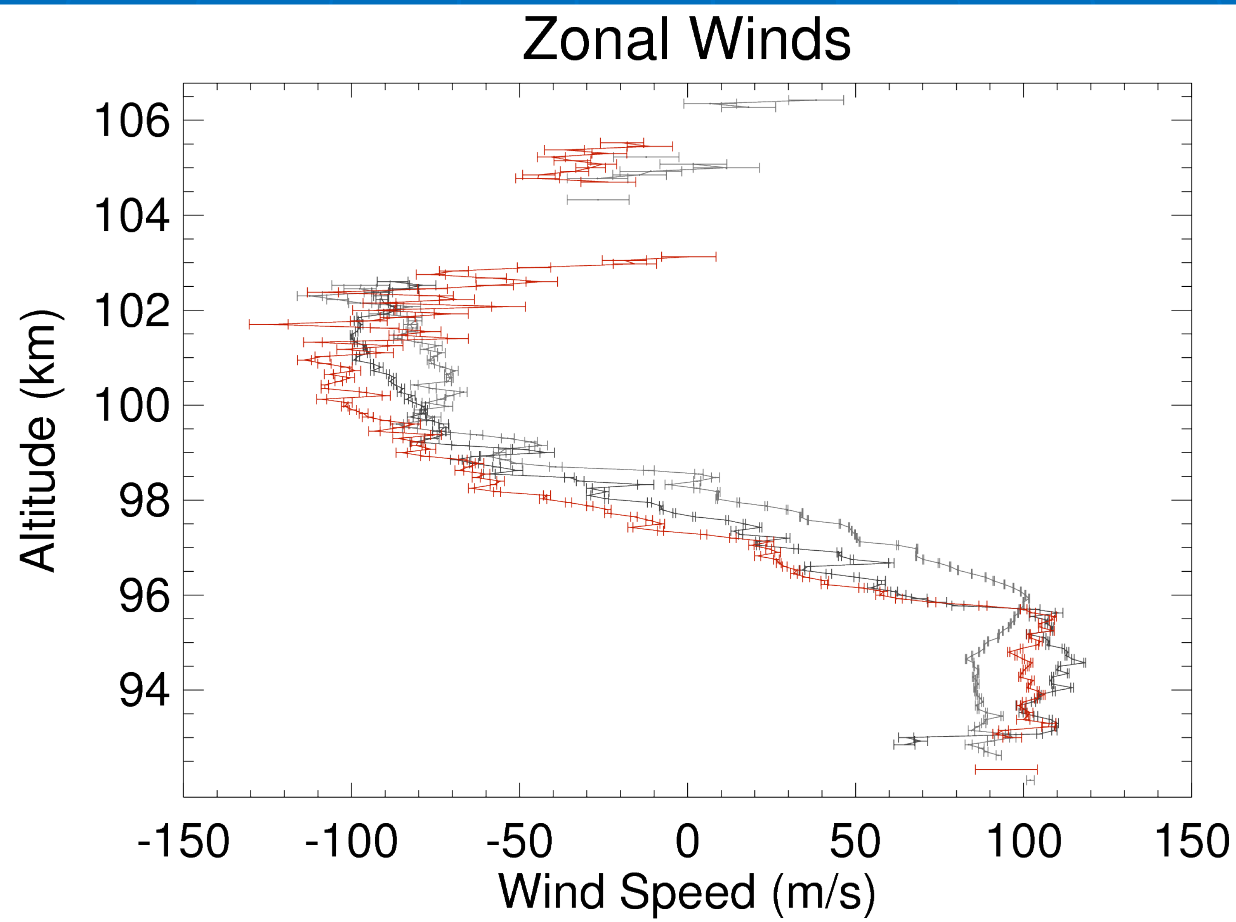
Zonal Winds from 15 min of data



Zonal Winds from 15 min of data



Zonal Winds from 15 min of data



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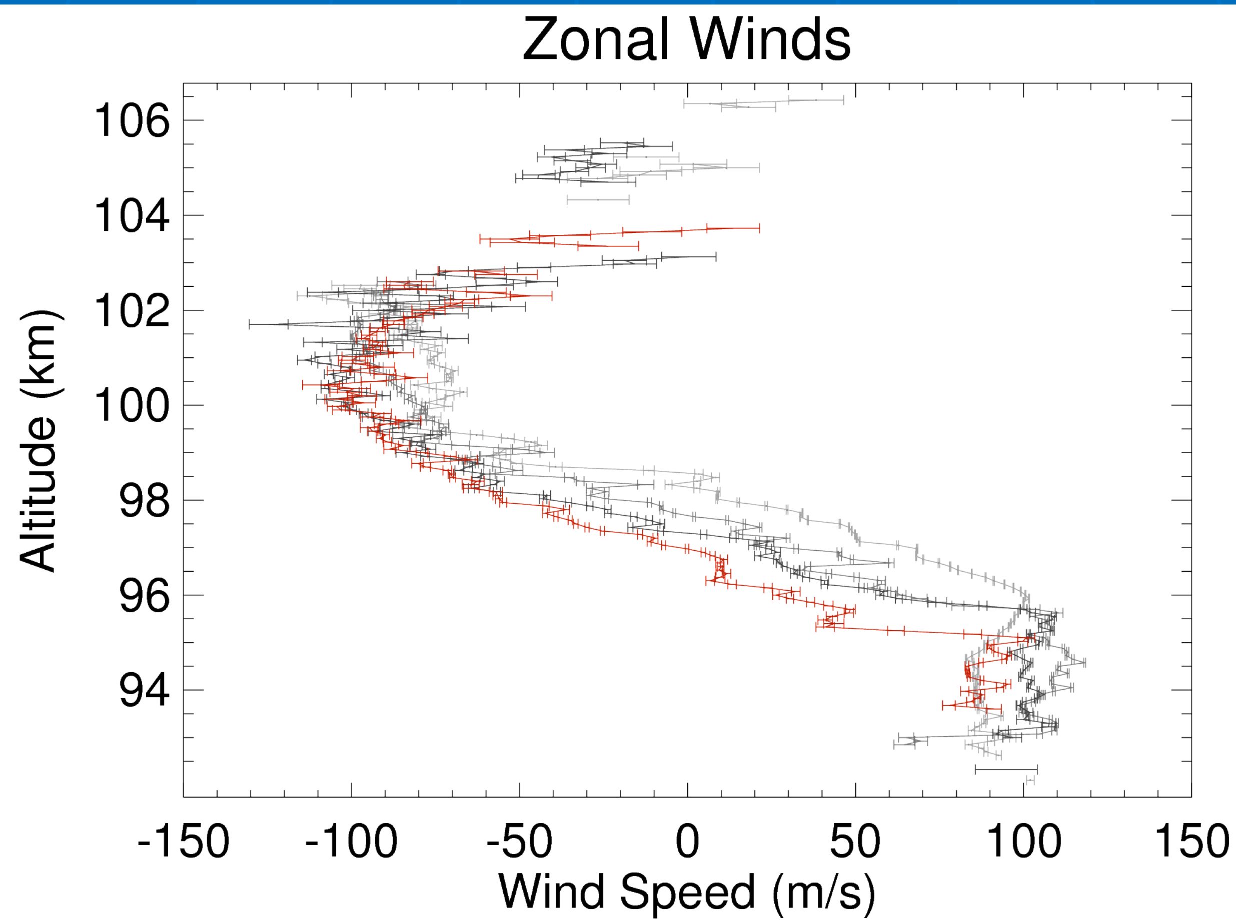
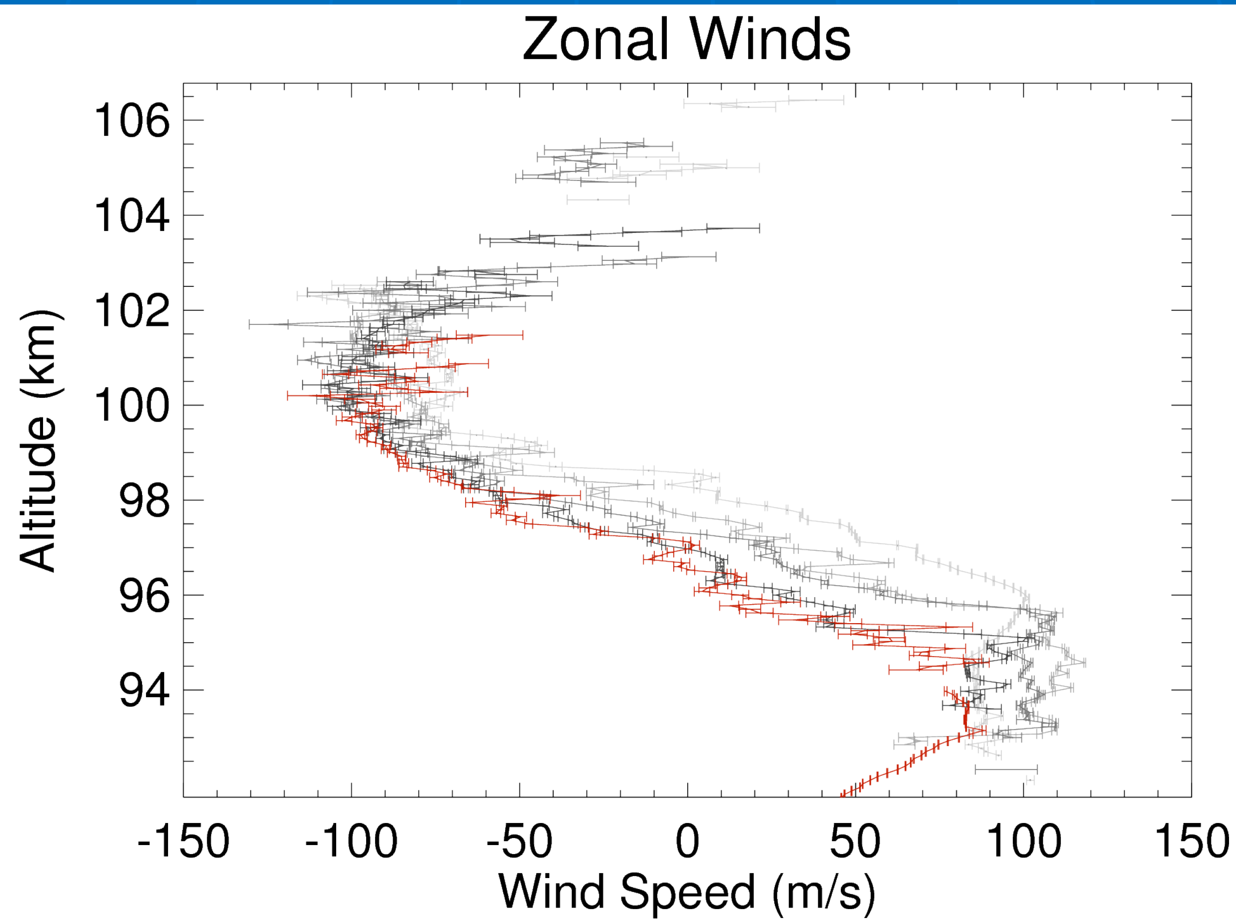
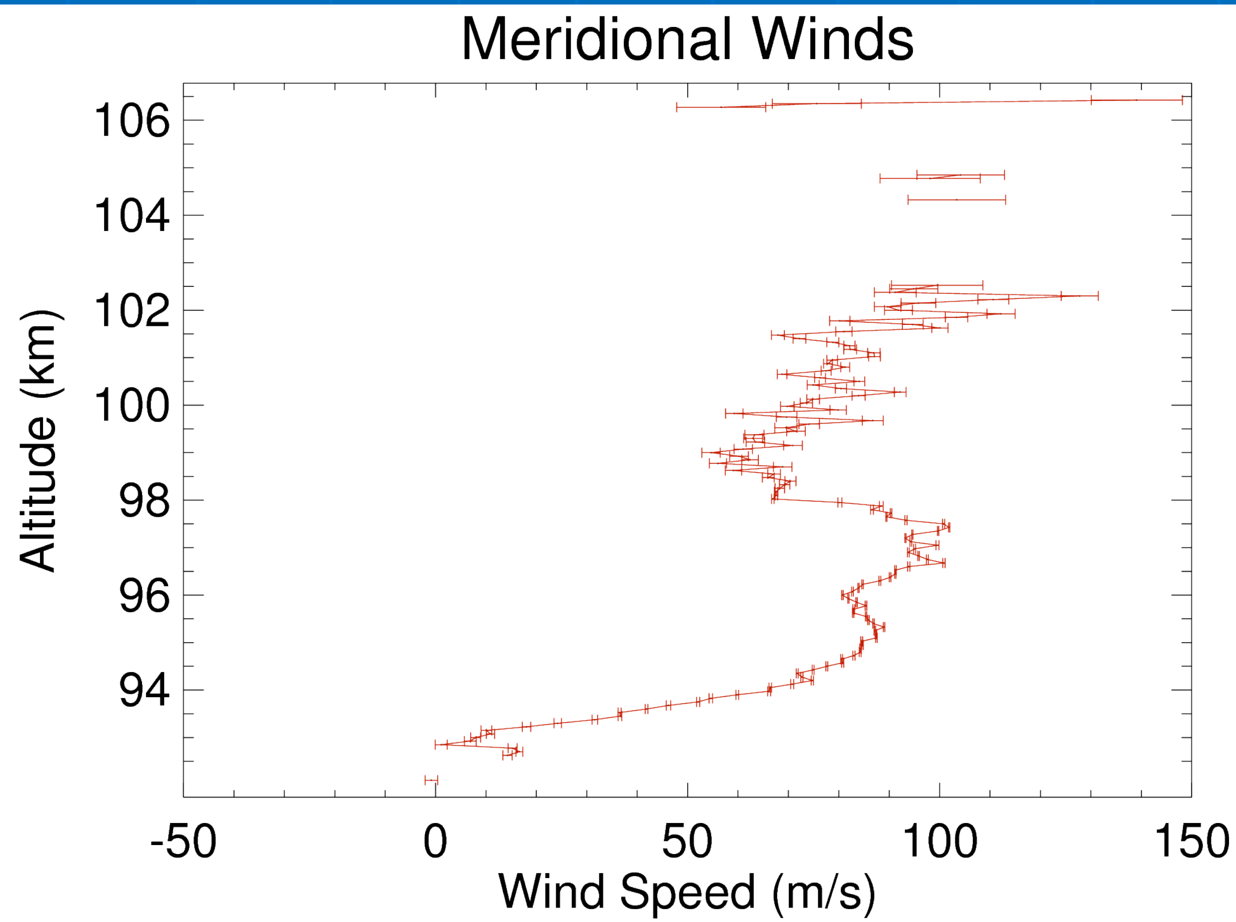


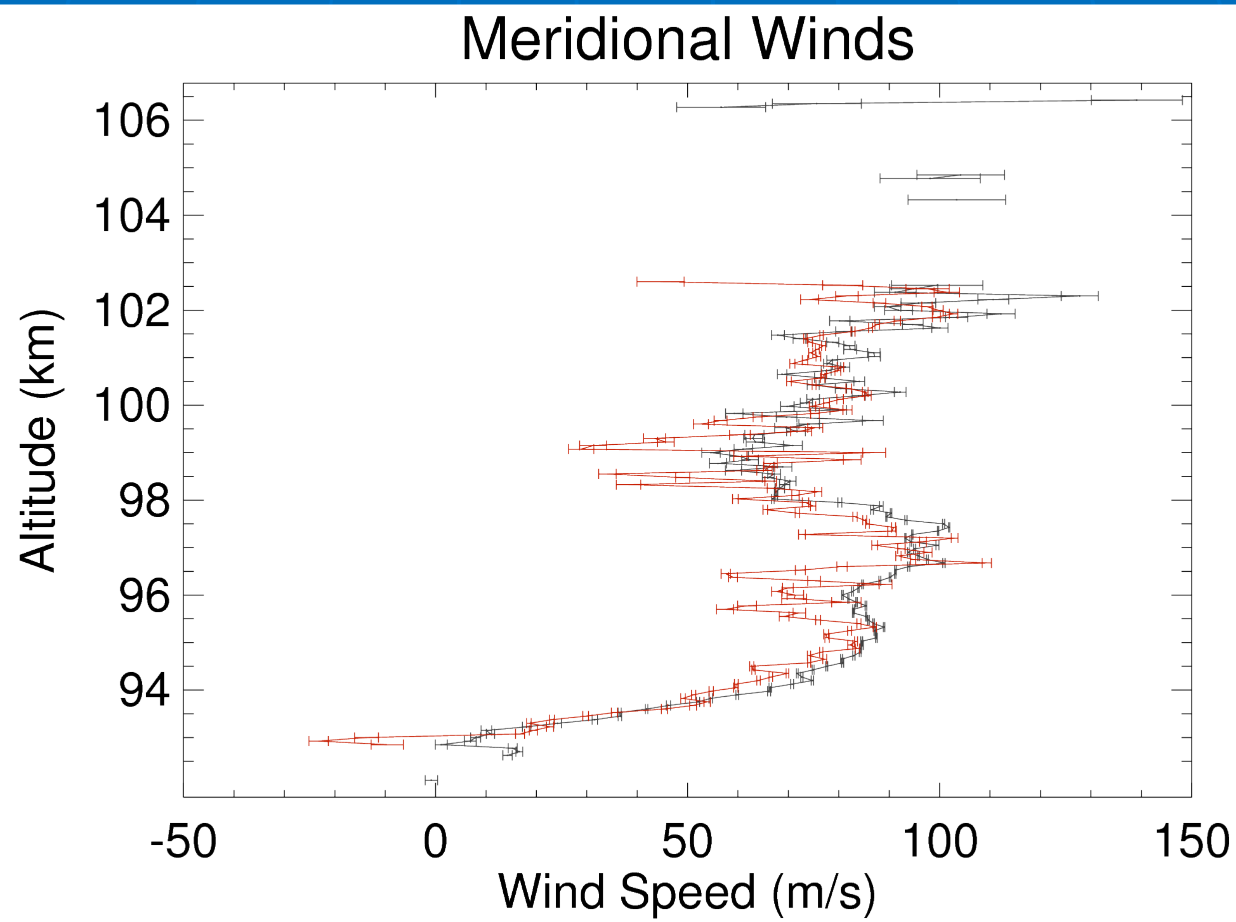
Zonal Winds from 15 min of data



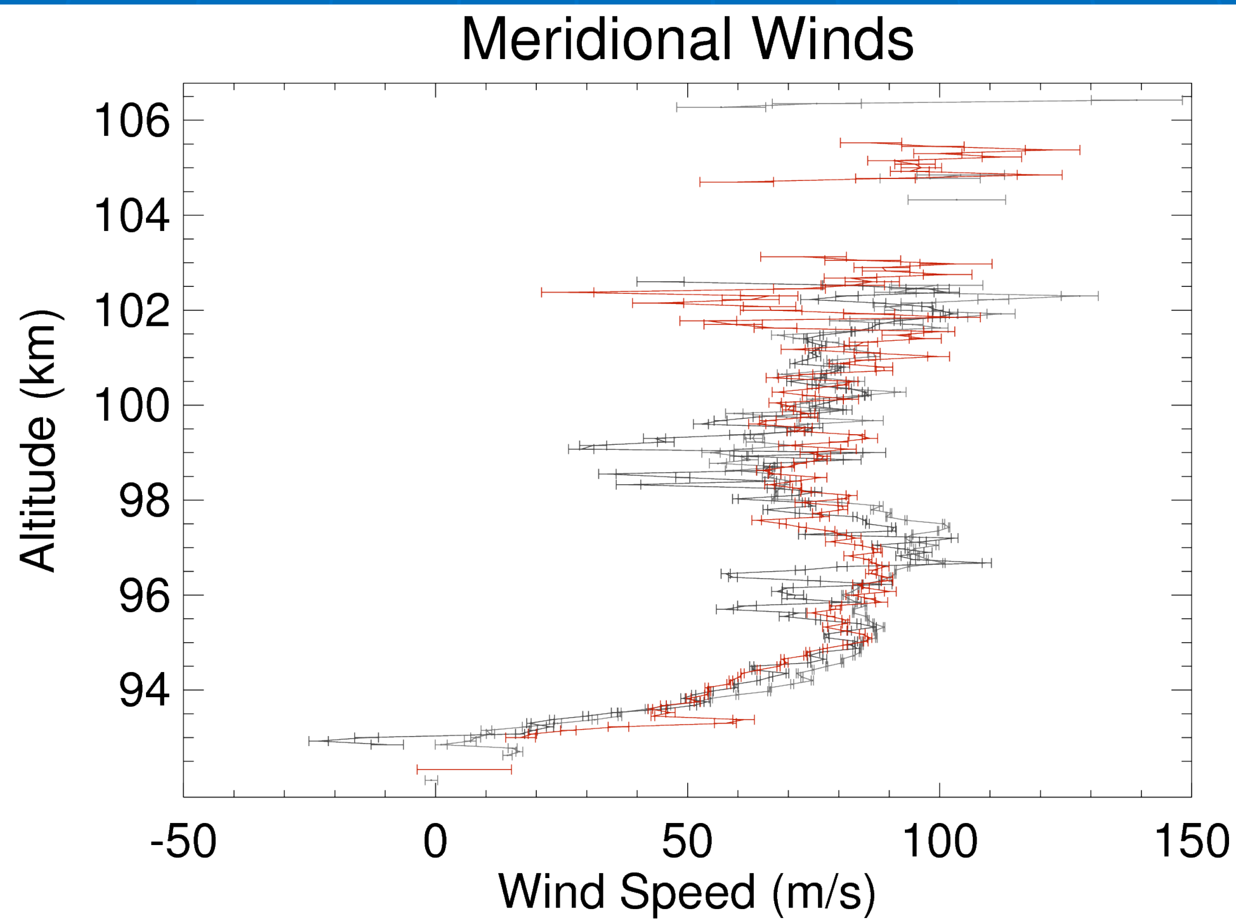
Meridional Winds from 15 min of data



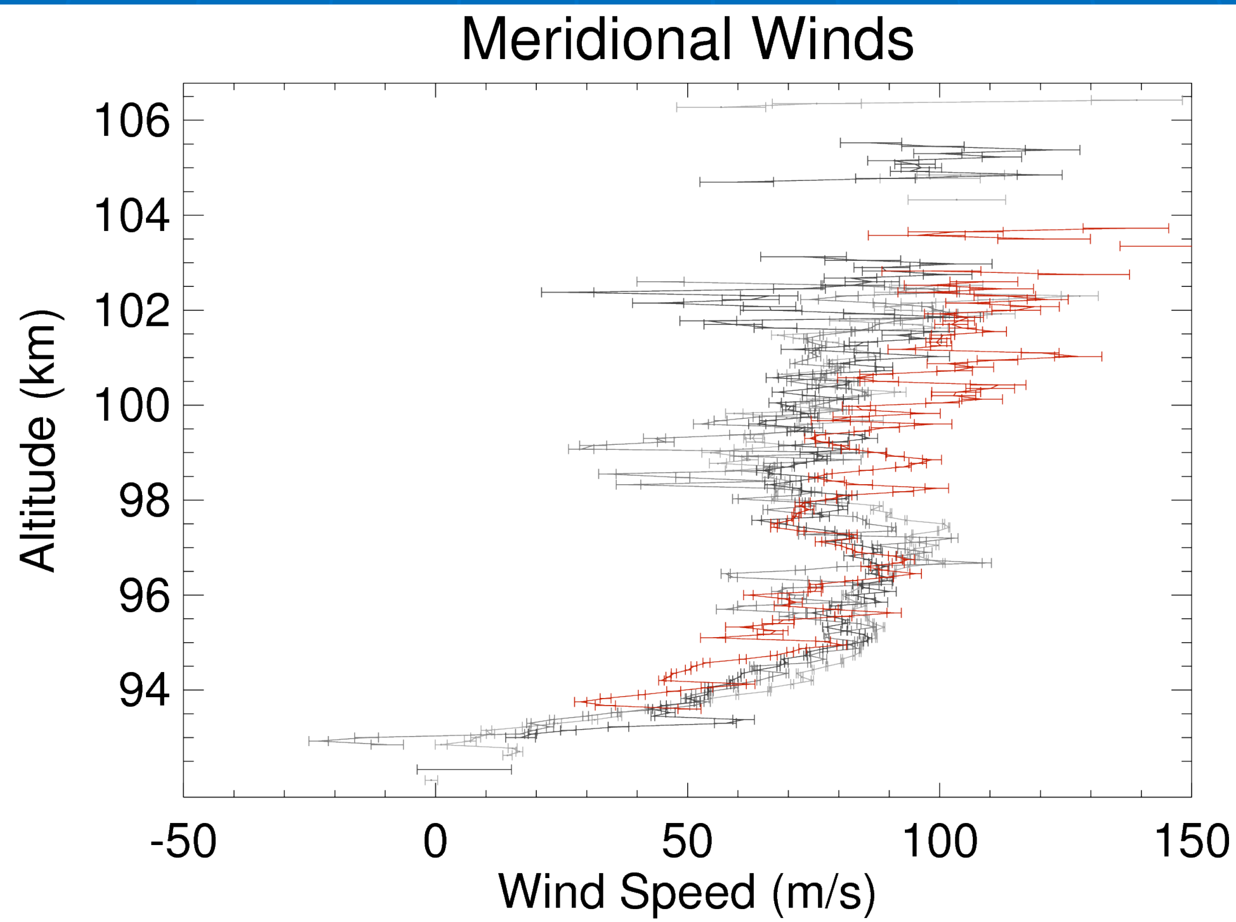
Meridional Winds from 15 min of data



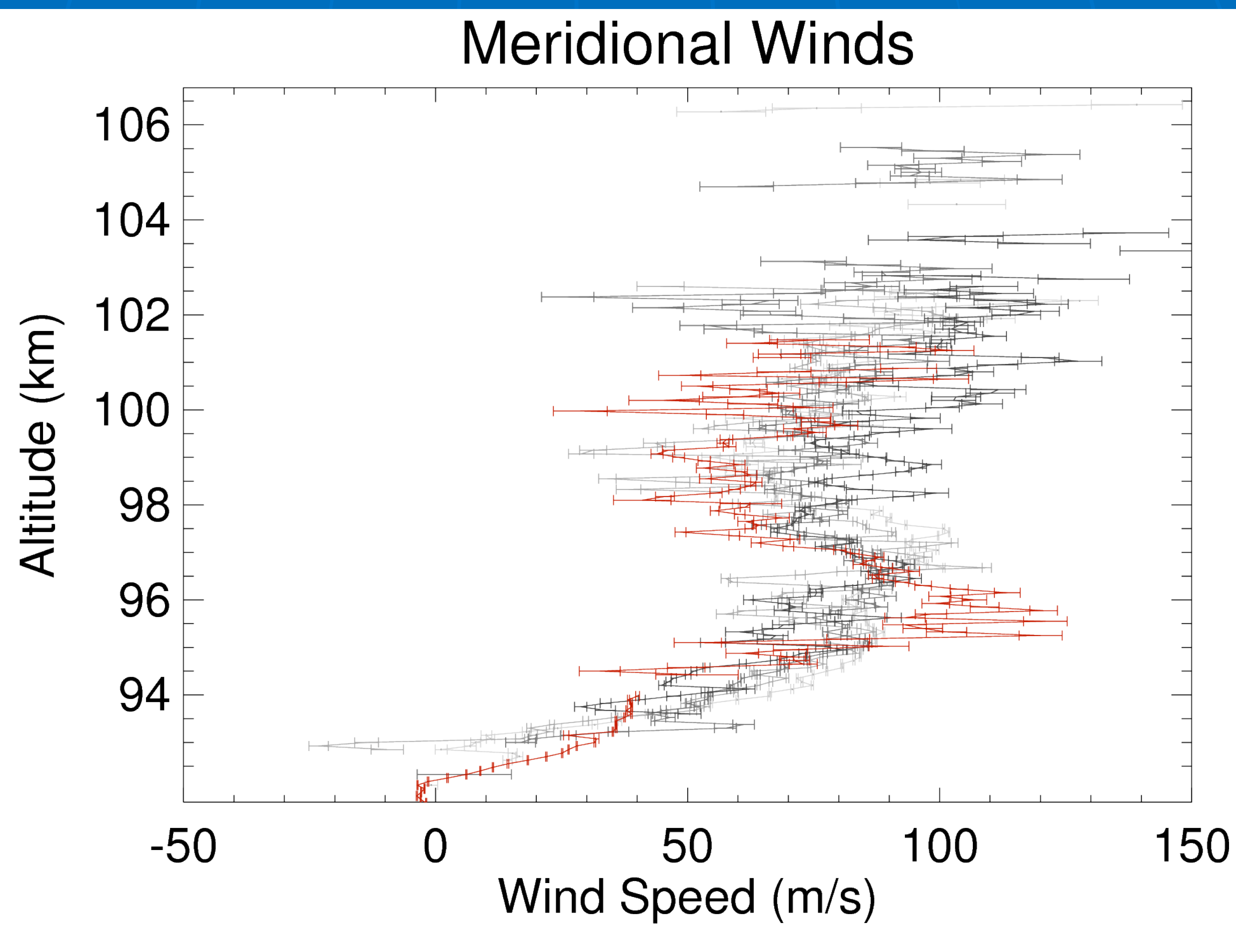
Meridional Winds from 15 min of data



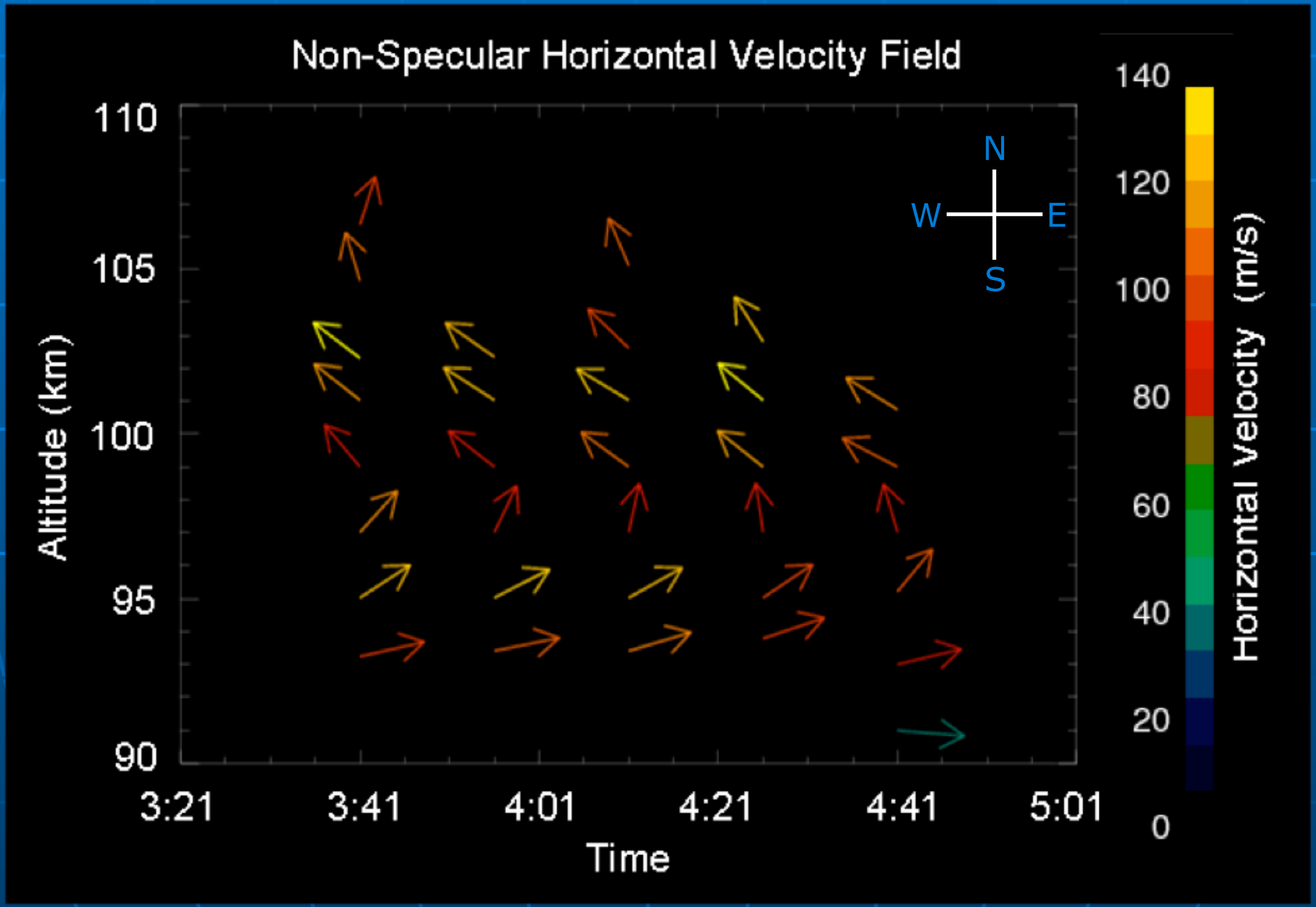
Meridional Winds from 15 min of data



Meridional Winds from 15 min of data

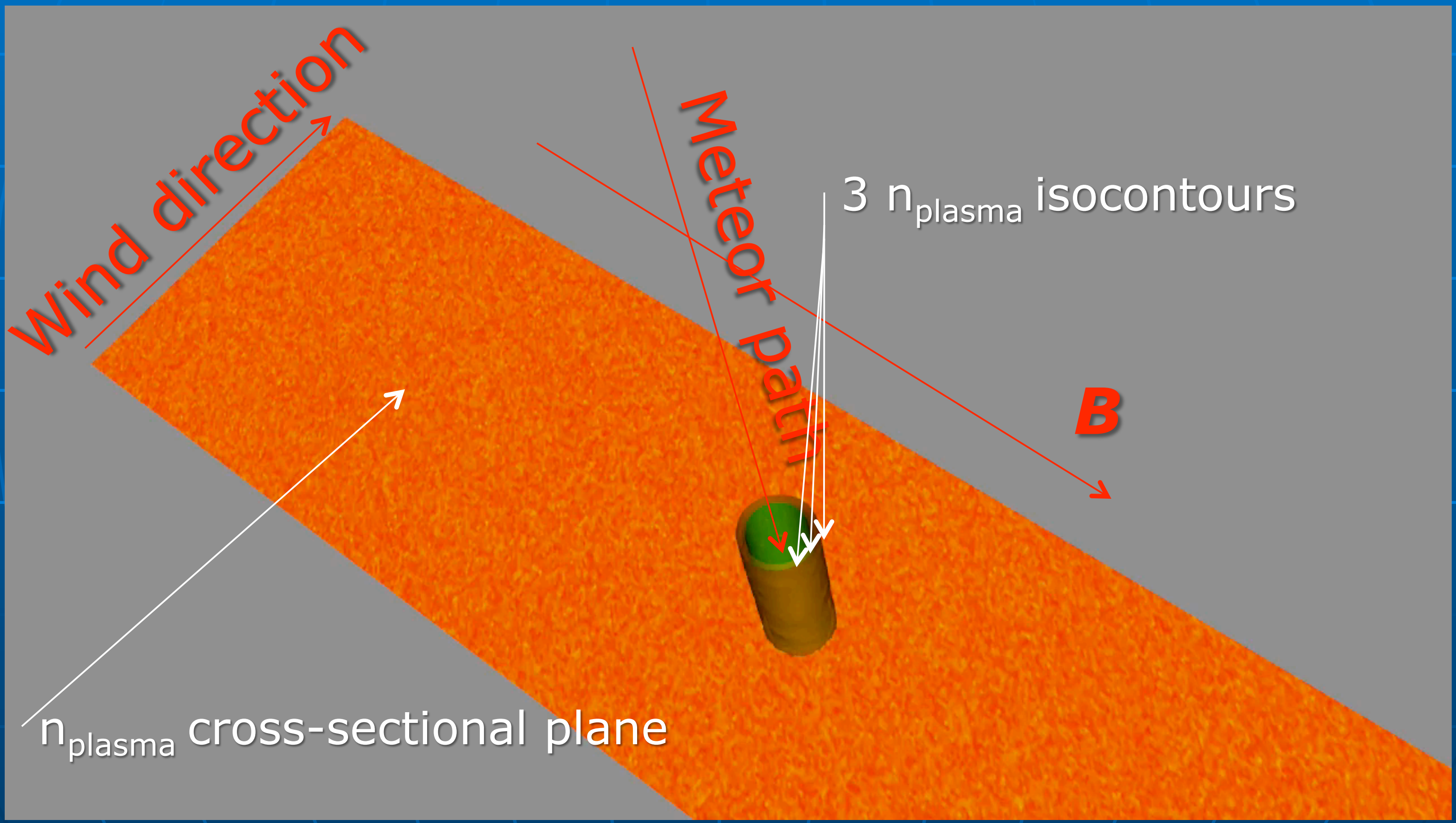


Wind fields



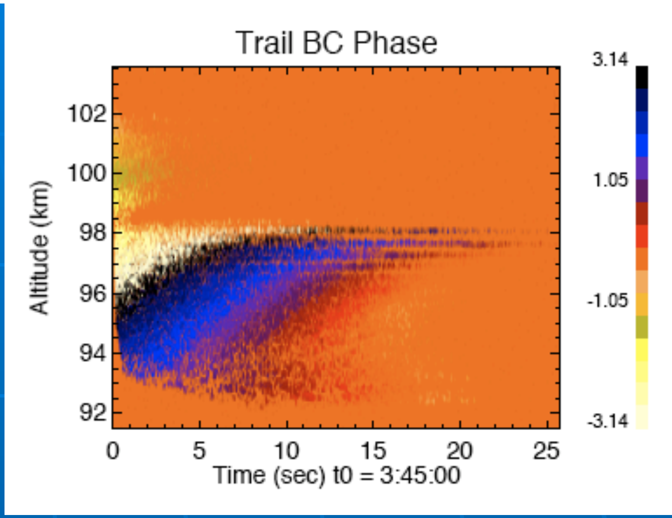
Non-Specular Horizontal Velocity Field
110
105
100
95
90
Altitude (km)
3:21
3:41
4:01
4:21
4:41
5:01
Time
N
W
E
S
140
120
100
80
60
40
20
0
Horizontal Velocity (m/s)

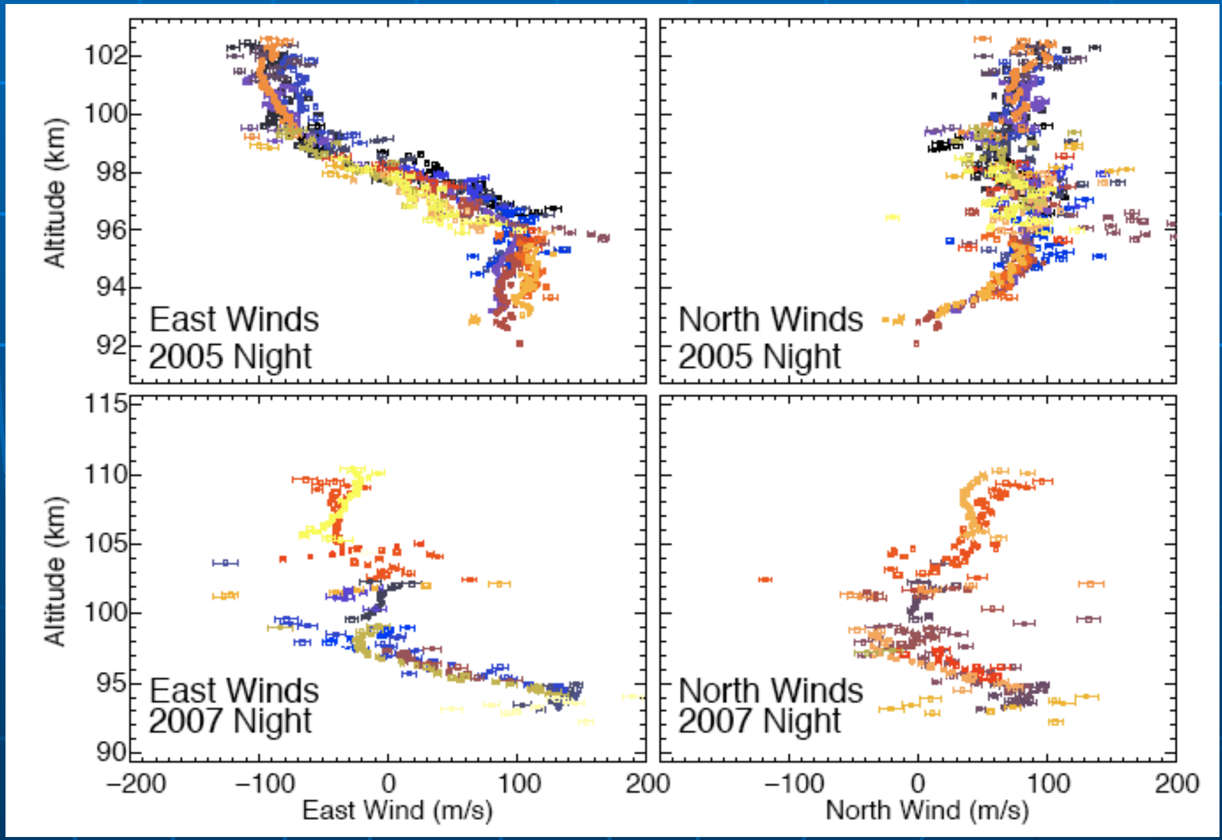
Particle in Cell Simulations of Meteor Plasma



Conclusions

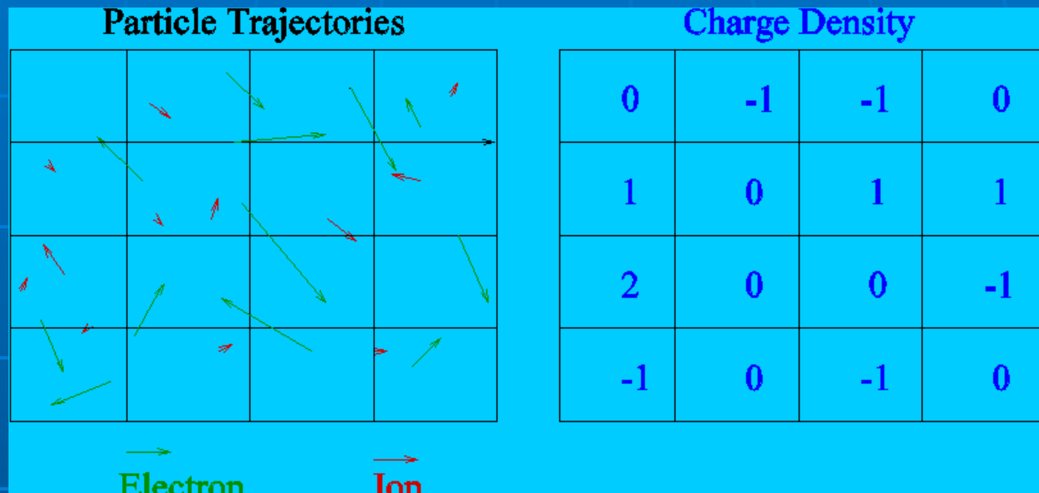
- New Tool to Monitor Winds
- High Spatial and Time Resolution
- Low and Mid-latitudes
- Publications:
  - GRL, May ’09
  - Physics Today, June ‘09





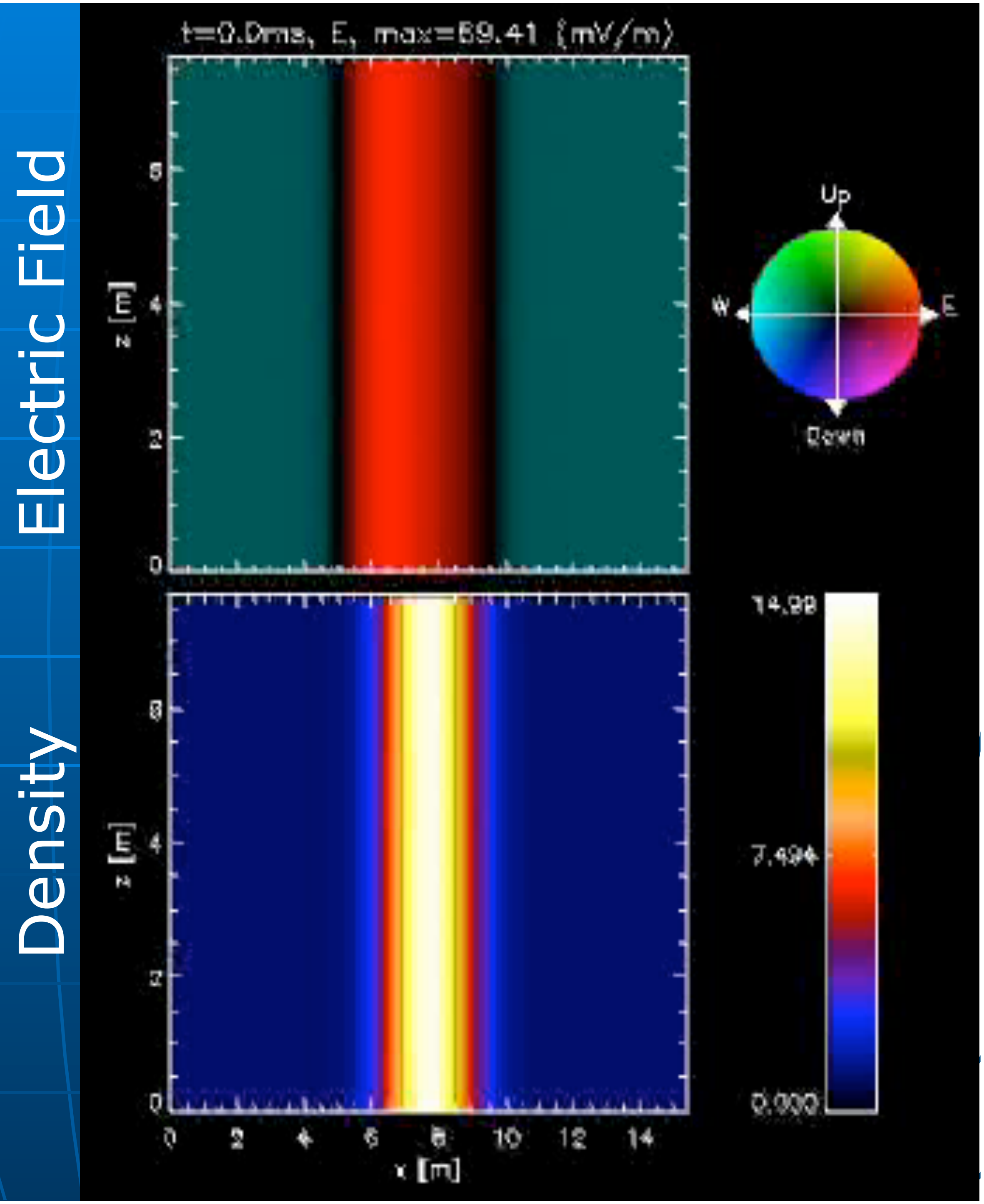
Simulation Method: Particle-In-Cell

1. Gather to determine charge density, r



2. Calculate Electric field: $\vec{\nabla} \bullet \vec{E} = \rho / \varepsilon_0$
3. Update velocities: $\dfrac{d\vec{v}_i}{dt} = \dfrac{q_i}{m_i}\left[E(\vec{x}_i, t) + \vec{v}_i \times B(\vec{x}_i, t)\right]$
4. Update Positions: $\dfrac{d\vec{x}_i}{dt} = \vec{v}_i$
5. Collide particles with neutrals
6. Go to Step 1

Meteor Plasma Simulation in 2D



3D Meteor Simulations