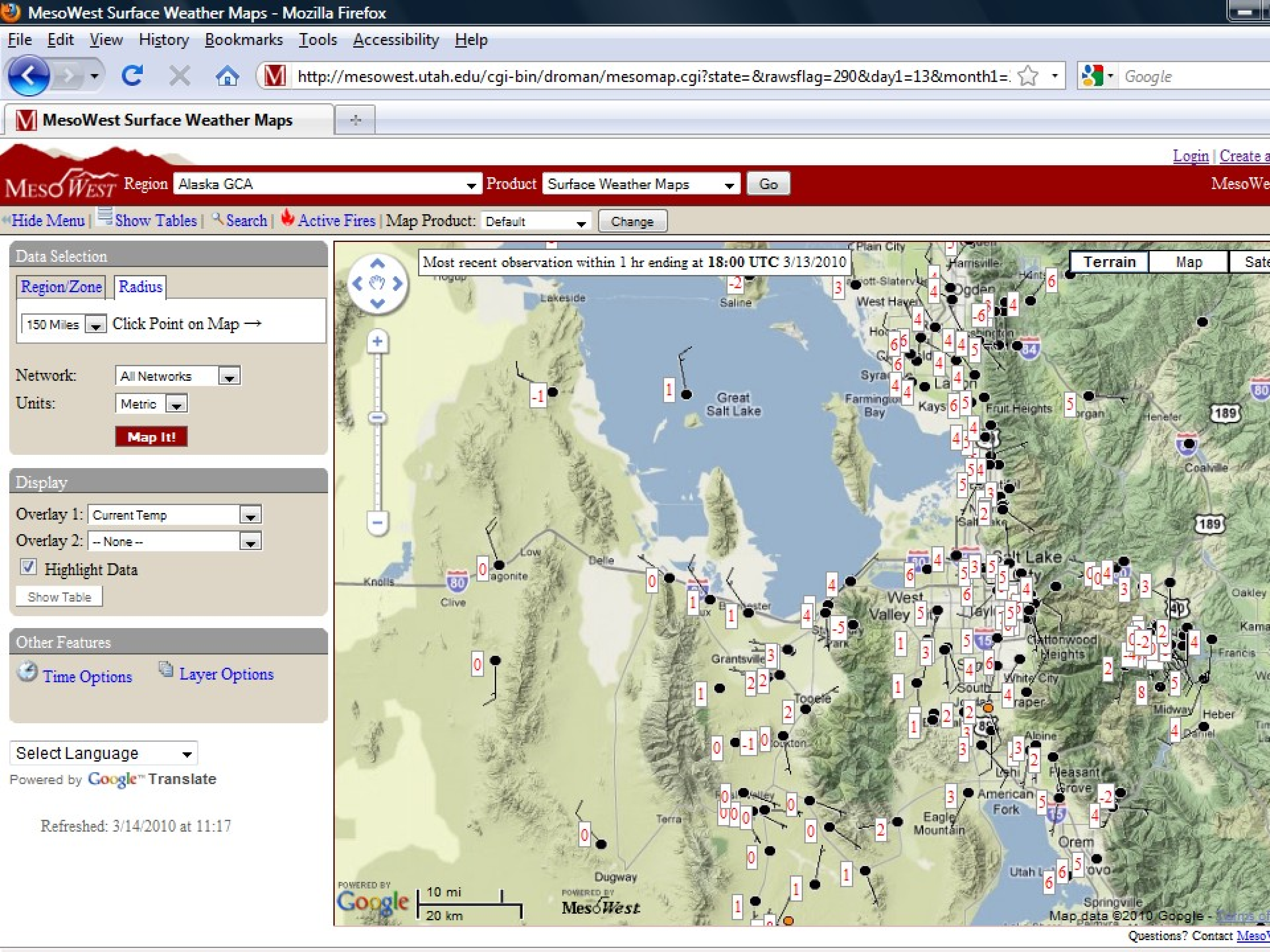
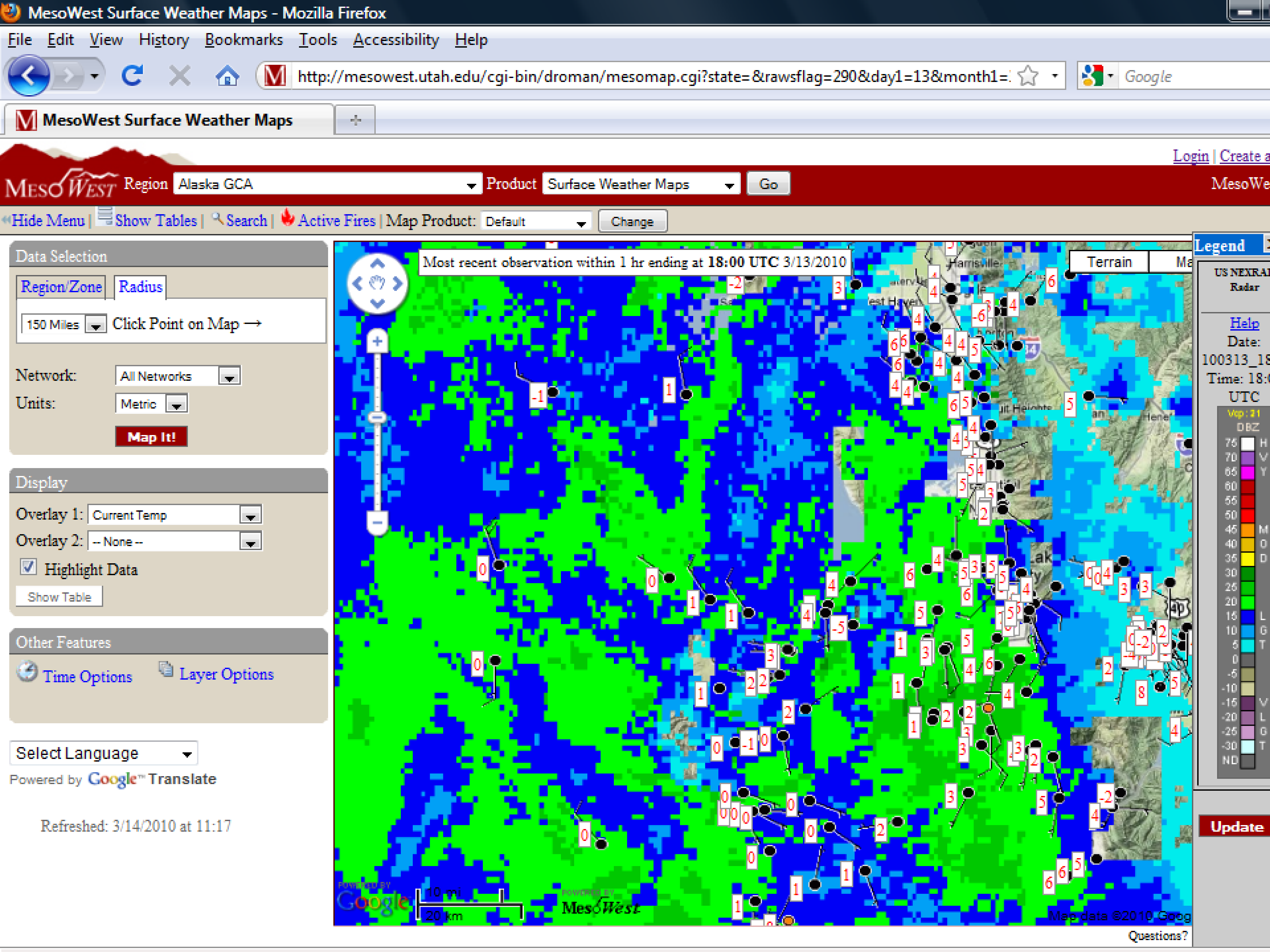
Active Remote Sensing of the PBL

- Immersed vs. remote sensors
- Active vs. passive sensors
- RADAR- radio detection and ranging
  - WSR-88D
  - TDWR
  - wind profiler

- SODAR- sonic detecting and ranging
  - minisodar
  - RASS


Central, AK - September 23, 1999


MesoWest Surface Weather Maps - Mozilla Firefox
File Edit View History Bookmarks Tools Accessibility Help
http://mesowest.utah.edu/cgi-bin/droman/mesomap.cgi?state=&rawsflag=290&day1=13&month1=
Google
MesoWest Surface Weather Maps
Login | Create a
MesoWest Region Alaska GCA Product Surface Weather Maps Go
Hide Menu | Show Tables | Search | Active Fires | Map Product: Default Change
Data Selection
Region/Zone Radius
150 Miles Click Point on Map →
Network: All Networks
Units: Metric
Map It!
Display
Overlay 1: Current Temp
Overlay 2: -- None --
Highlight Data
Show Table
Other Features
Time Options
Layer Options
Select Language
Powered by Google Translate
Refreshed: 3/14/2010 at 11:17
Most recent observation within 1 hr ending at 18:00 UTC 3/13/2010
Terrain
Map
Great Salt Lake
Ogden
Salt Lake City
West Valley
Tooele
Grantsville
Farmington Bay
Fruit Heights
Coalville
Cottonwood Heights
Heber
Midway
American Fork
Eagle Mountain
Orem
Provo
Utah Lake
Springville
Pleasant Grove
Alpine
Dugway
Knolls
Clive
Delle
Saline
Lakeside
West Haven
Harrisville
Oakley
Kamas
Francis
Henefer
Draper
South Jordan
Lehi
10 mi
20 km
POWERED BY Google
POWERED BY MesoWest
Map data ©2010 Google
Questions? Contact MesoW

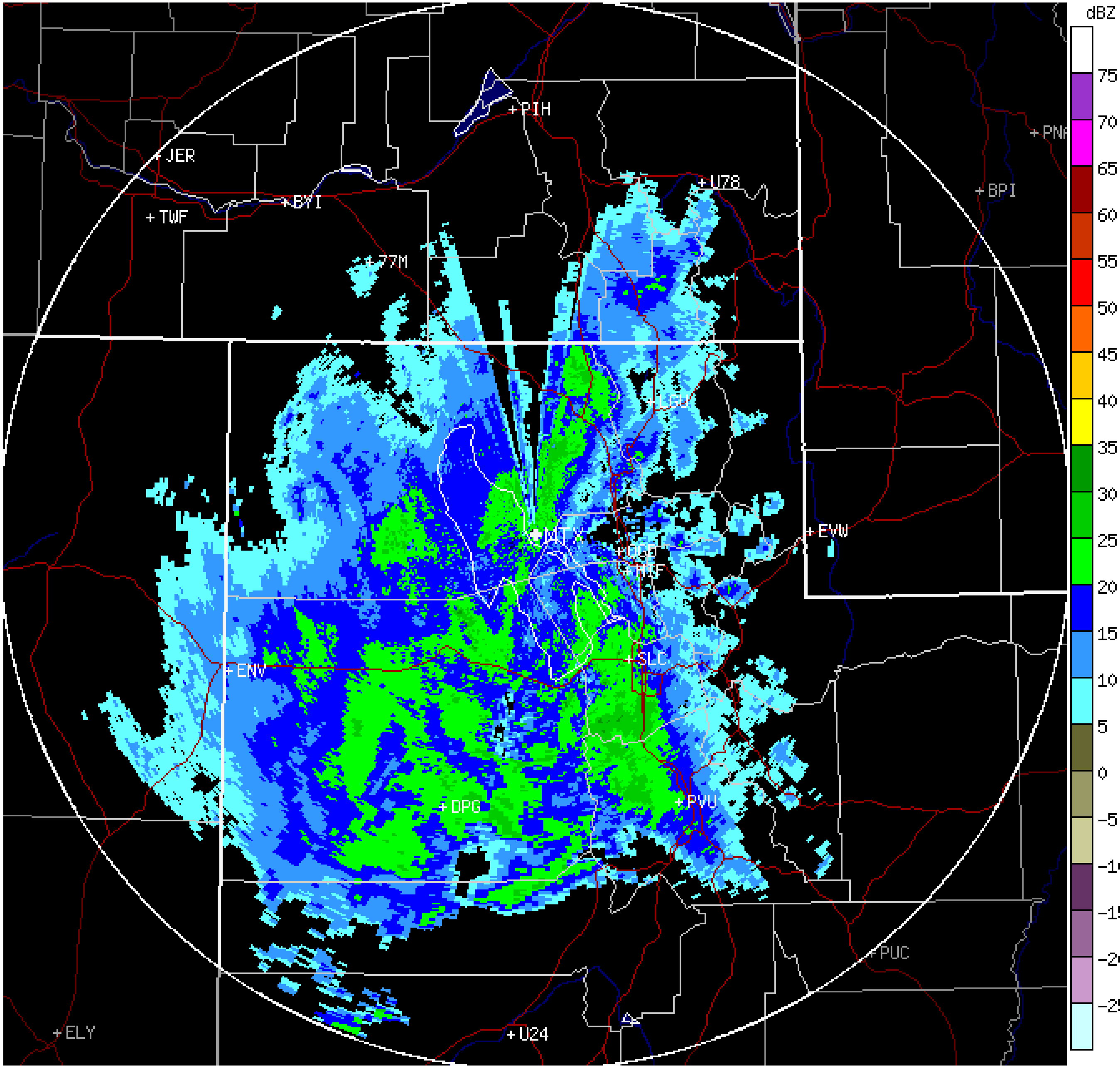

MesoWest Surface Weather Maps - Mozilla Firefox
File Edit View History Bookmarks Tools Accessibility Help
http://mesowest.utah.edu/cgi-bin/droman/mesomap.cgi?state=&rawsflag=290&day1=13&month1=
MesoWest Surface Weather Maps
Login | Create
Region Alaska GCA
Product Surface Weather Maps
Go
Hide Menu | Show Tables | Search | Active Fires | Map Product: Default
Change
Data Selection
Region/Zone
Radius
150 Miles
Click Point on Map →
Network: All Networks
Units: Metric
Map It!
Display
Overlay 1: Current Temp
Overlay 2: -- None --
Highlight Data
Show Table
Other Features
Time Options
Layer Options
Select Language
Powered by Google Translate
Refreshed: 3/14/2010 at 11:17
Most recent observation within 1 hr ending at 18:00 UTC 3/13/2010
Terrain
Legend
US NEXRAD Radar
Help
Date:
Time:
UTC
DBZ
Update
Questions?

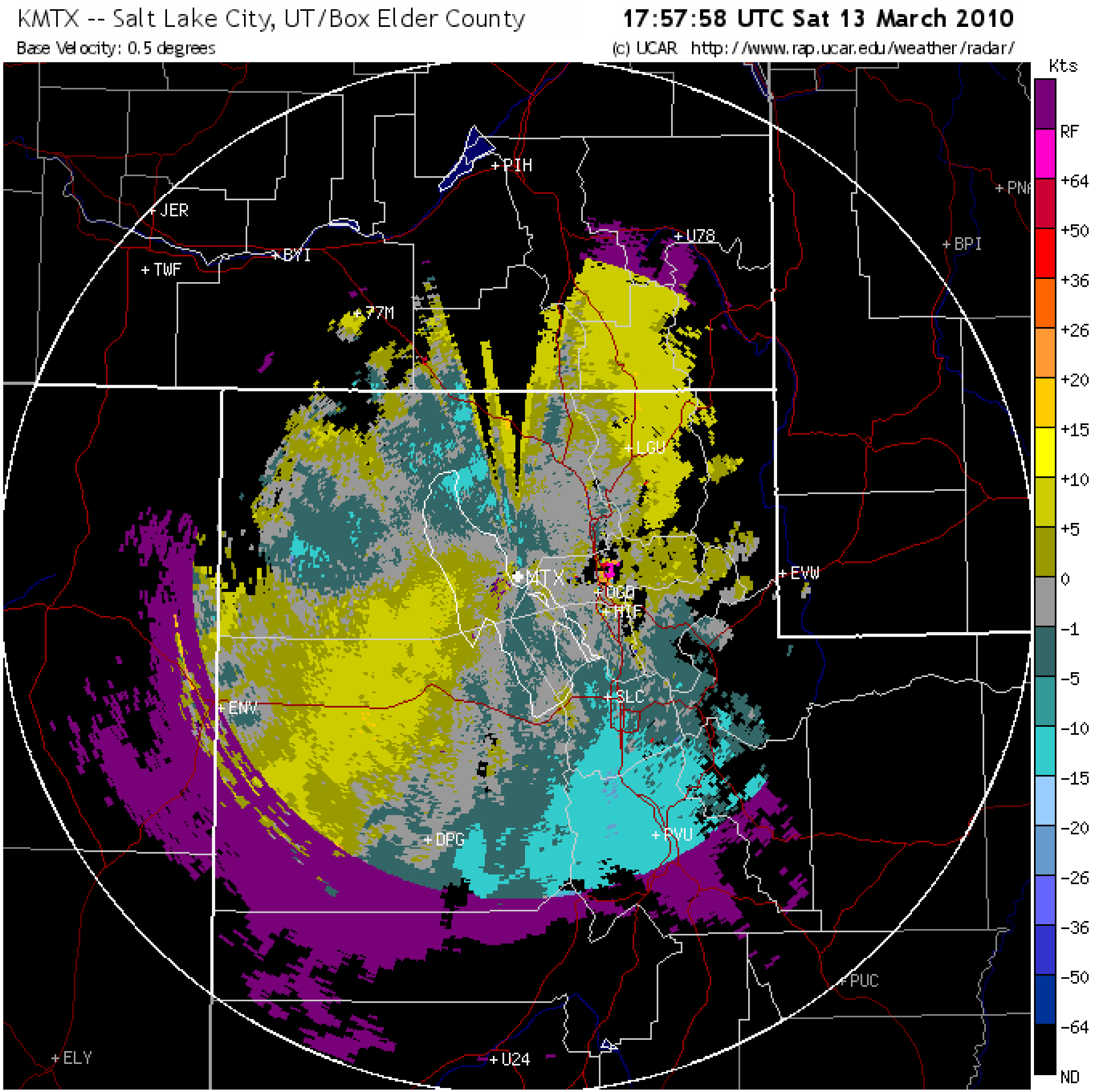
KMTX -- Salt Lake City, UT/Box Elder County

17:57:58 UTC Sat 13 March 2010

Base Reflectivity: 0.5 degrees, Precip Mode

(c) UCAR http://www.rap.ucar.edu/weather/radar/




KMTX -- Salt Lake City, UT/Box Elder County
17:57:58 UTC Sat 13 March 2010
Base Velocity: 0.5 degrees
(c) UCAR http://www.rap.ucar.edu/weather/radar/
Kts
RF
+64
+50
+36
+26
+20
+15
+10
+5
0
-1
-5
-10
-15
-20
-26
-36
-50
-64
ND
PIH
JER
BYI
TWF
U78
PNA
BPI
77M
LGU
MTX
OGD
HIF
EVW
SLC
ENV
DPG
PVU
PUC
ELY
U24

RADAR Training: Warning Decision Training Branch

- http://www.wdtb.noaa.gov/
- http://www.wdtb.noaa.gov/courses/dloc/outline.html

Fundamental Characteristics of EM radiation

- Frequency (wavelength)
- Amplitude
- Polarization (dual pol radar)
  - Most radiation randomly oriented in nature
  - Can be generated with a preferred orientation
  - If all targets spheres, then there would be no advantage for polarimetric techniques

EM radiation

- Speed of light = frequency * wavelength = 3×10^8 m/s
- Commercial power: 60 Hz; 5000 km
- Visible light: 6×10^{14} Hz; .5 micron
- WSR-88D: 2.85 GHz; 10 cm
- Radar wind profiler: 404 MHz; ~ 70 cm
- Speed of sound ~ 300 m/s
- minisodar; 4000 Hz; ~8 cm

Refractivity

- Radiation travels slower through media
- Sharp changes in the density of media can cause the radiation to bend up or down
- If changes in refractivity occur on very small scales relative to wavelength, then radiation backscattered towards radar (principle used by profilers & sodars)

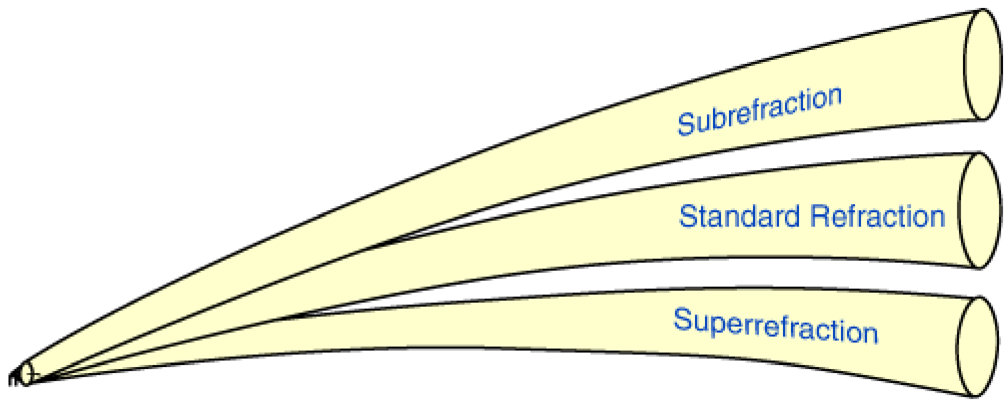
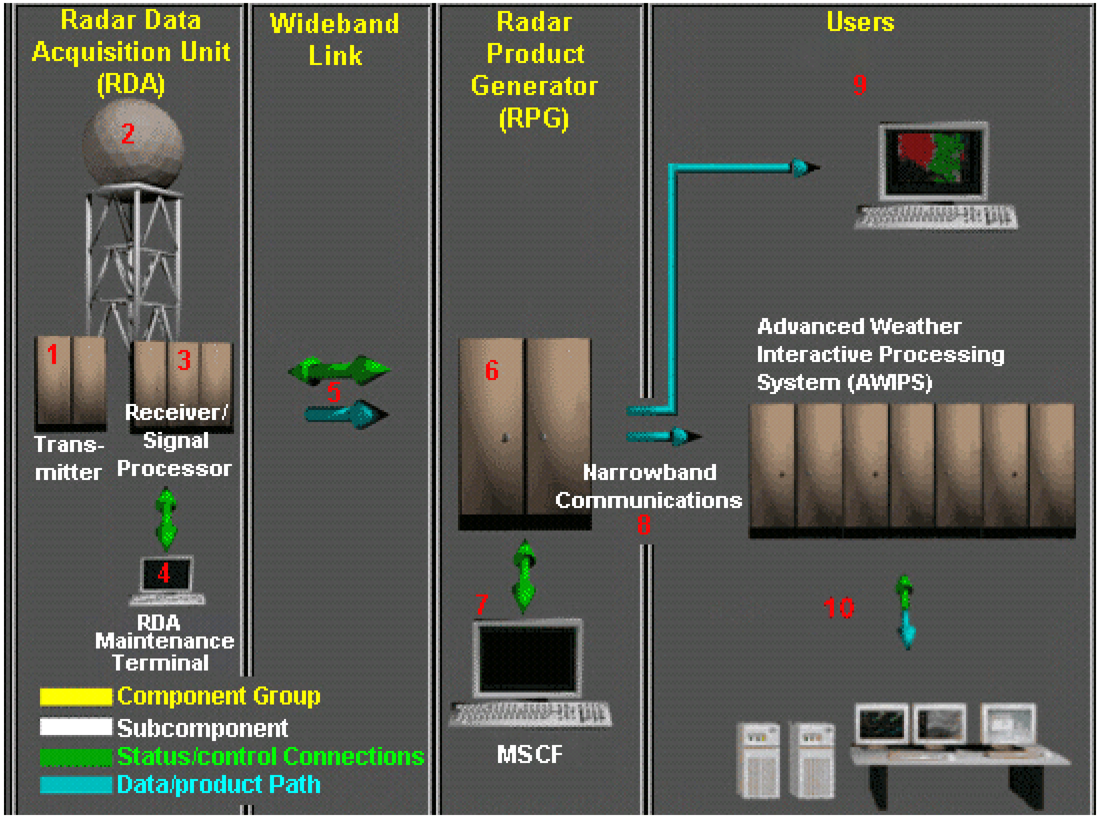


Figure 10

Figure 10. Beam propagation paths for various atmospheric reflective index conditions.

WSR-88D



See http://www.wdtb.noaa.gov/courses/dloc/topic2/ic52_content.html

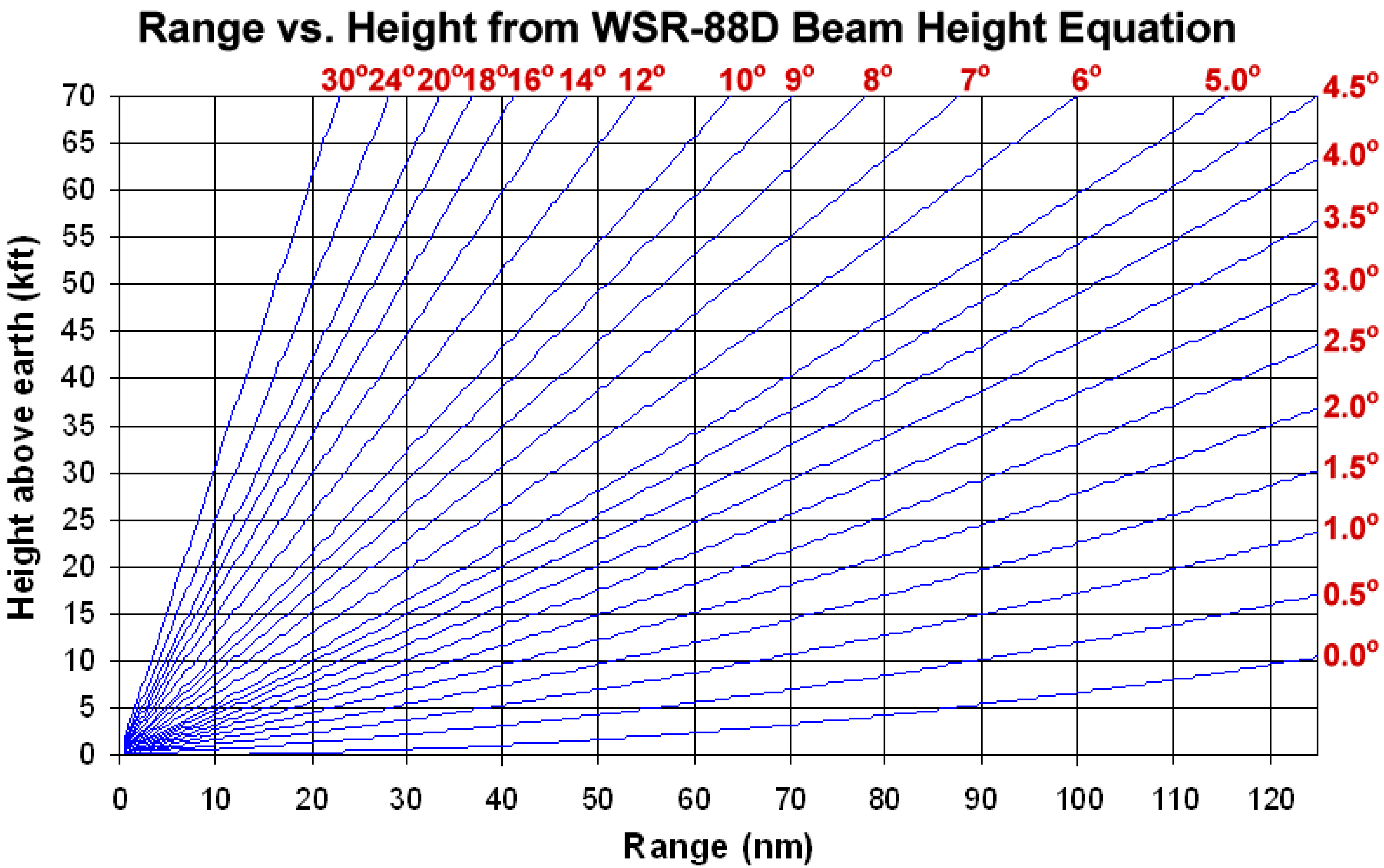


Figure 11. Beam centerline height for various ranges as a function of elevation angle assuming standard refractive conditions. These curves are derived from the WSR-88D Beam Height Equation, Equation 12.

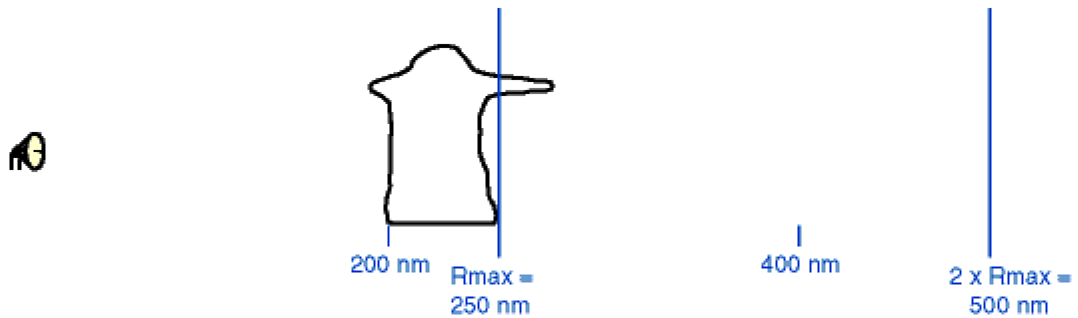


Figure 6

Figure 6. Example of a single target lying within R_{max}. The pulse travels out and interacts with leading edge of target located at 200 nm range. The pulse conti
on away from the radar while a small fraction of the energy backscattered toward the radar arrives before the second pulse is transmitted.

Backscattering

$$P_r = \frac{P_t g^2 \lambda^2 \sigma_t}{64\pi^3 r^4}$$

Large targets (birds)

- D > 10 wavelength

$$\sigma_t \propto D^2$$

Intermediate (10 wavelength > D > .1 wavelength) complicated; Mie regime

Small targets (D < .1 wavelength); Rayleigh regime

$$\sigma_t \propto D^6$$

Radar measures returned power; we assume comes from reflectivity of spherical raindrops

$$z_e = \frac{P_r r^2 c_r}{l}$$

Effective radar reflectivity varies over 10 orders of magnitude; so use log reflectivity; Z_e

Table 4: dBZ and Z values

dBZ	$Z(mm^6m^{-3})$	dBZ	$Z(mm^6m^{-3})$
-32	0.000631	30	1,000
-28	0.001585	41	12,589
-10	0.1	46	39,810
0	1	50	100,000
5	3.162	57	501.187
18	63.1	95	3,162,277,660

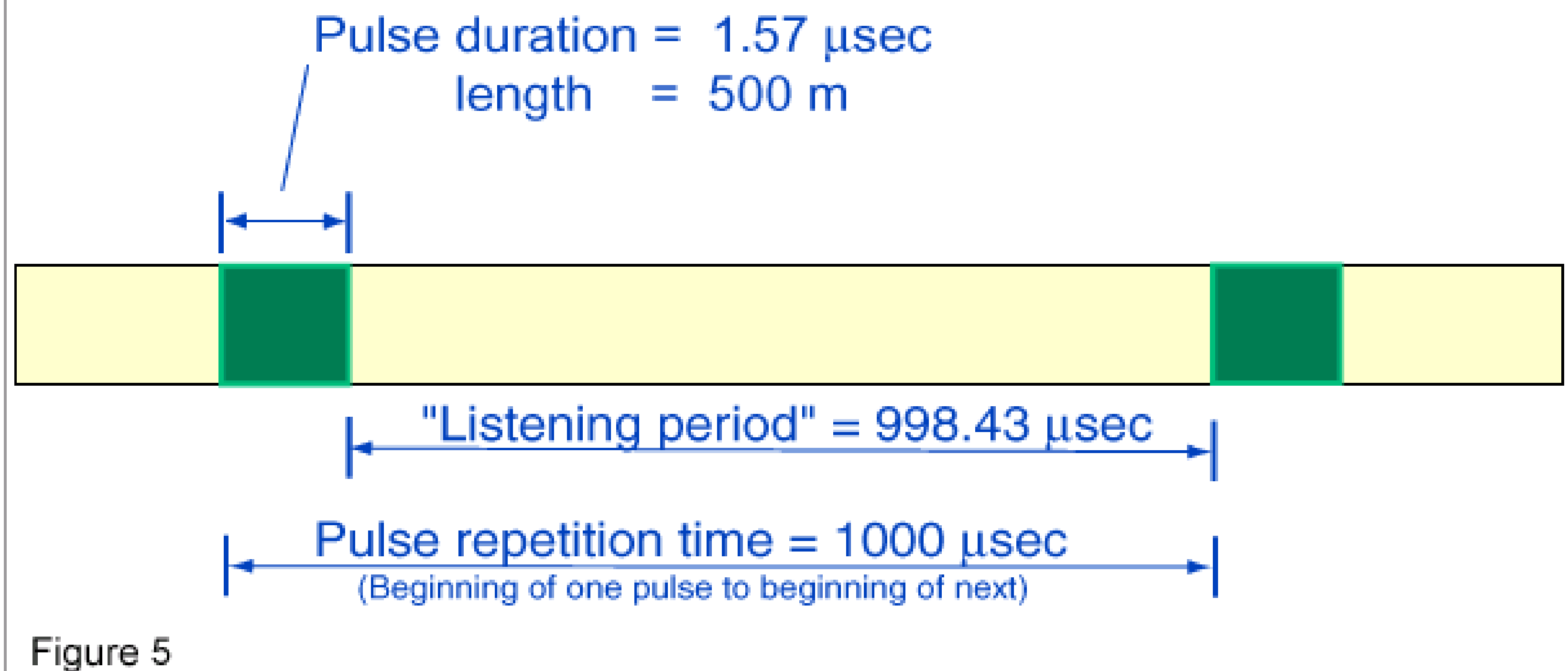


Figure 5. Example of pulse duration, t, and listening period, τ. Time is along the x axis and, when multiplied by the speed of light, c, yields the actual physical length of the pulse, H.

Close

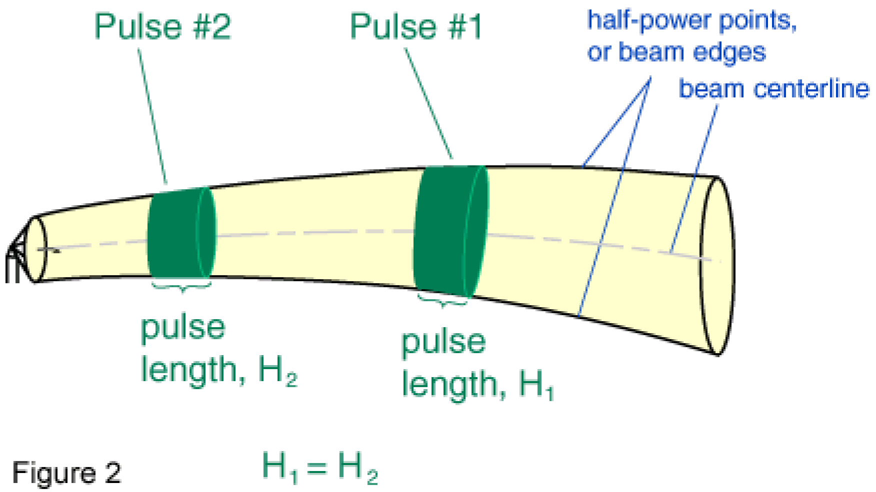
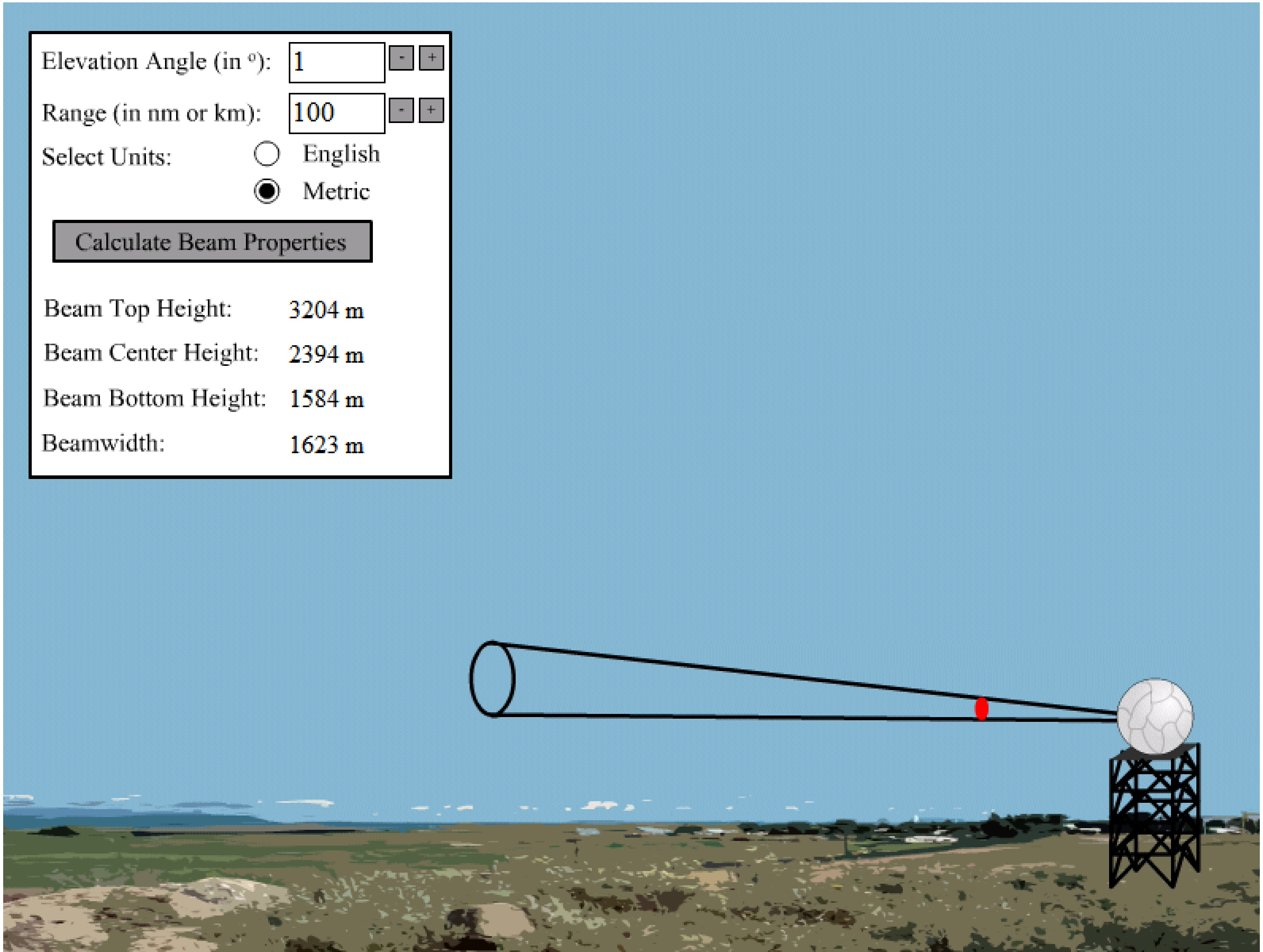


Figure 2. Radar "beam" geometry and pulse volumes. Pulse 1 has a greater volume than pulse 2 even though both pulses have the pulse length, H.

http://www.wdtb.noaa.gov/tools/misc/beamwidth/index.htm



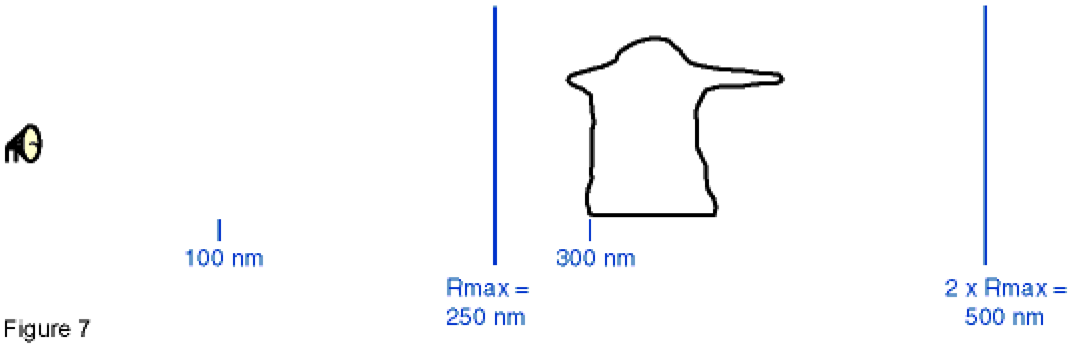


Figure 7. Example of a single target lying beyond R_{max}. The pulse interacts with the leading edge of a target at a range of 300 nm. The first pulse continues to travel away from radar while a small amount of backscattered energy from it has reached a range of 100 nm just as the next pulse is transmitted.

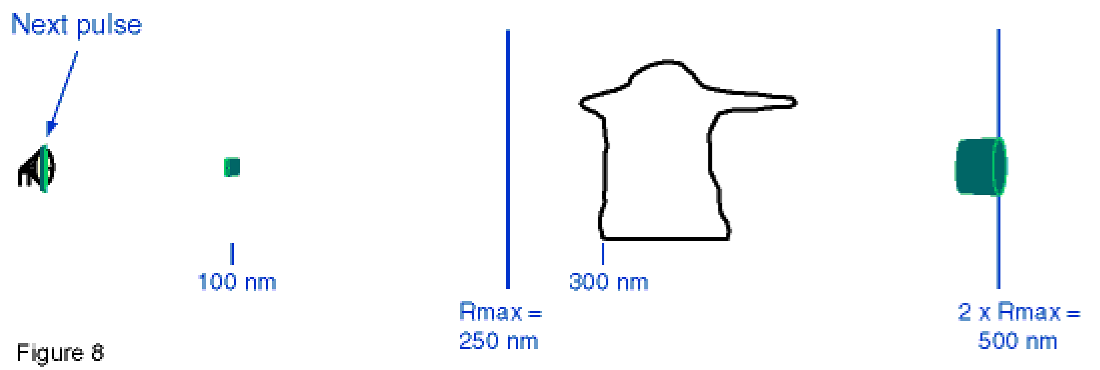
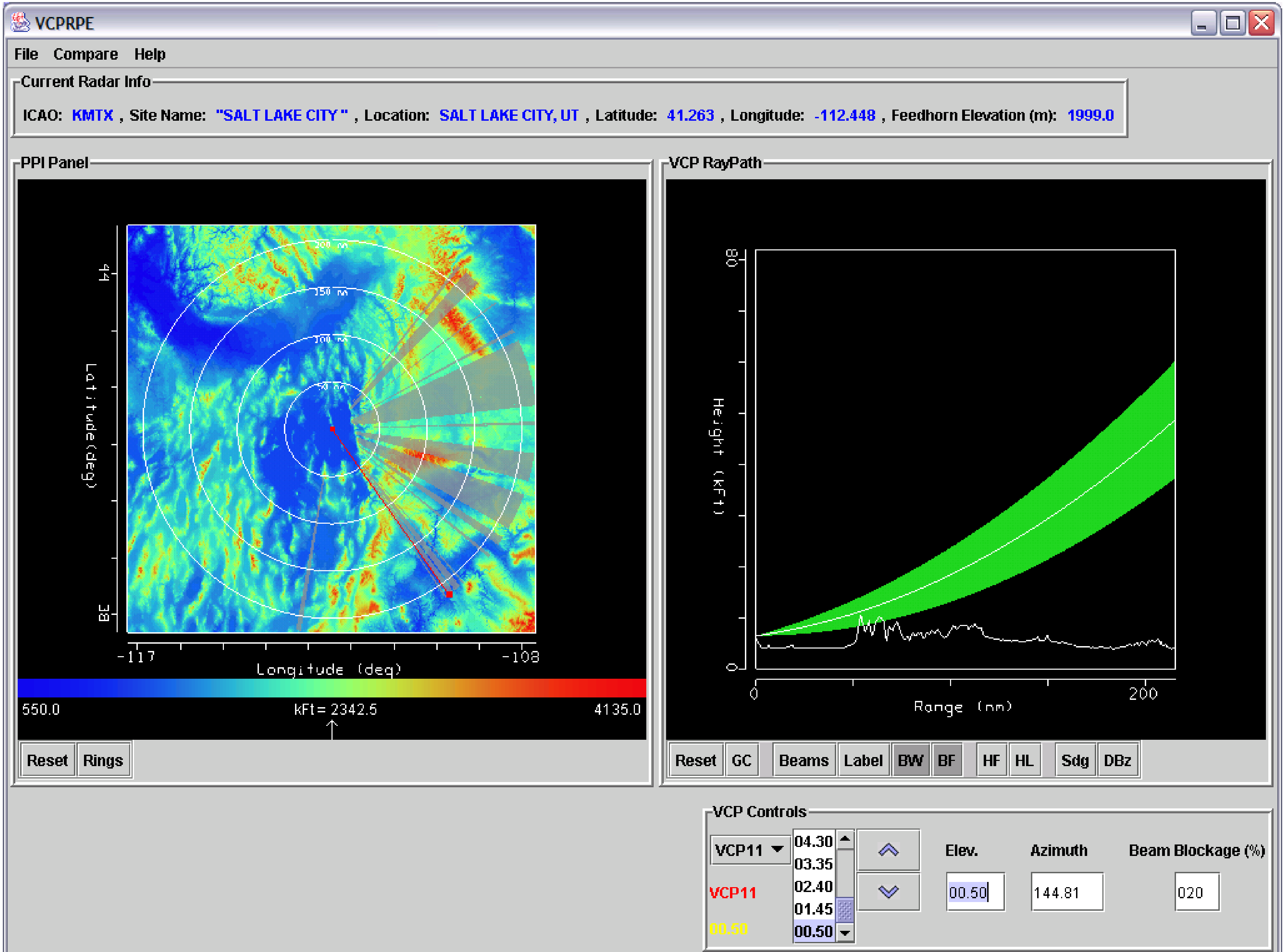
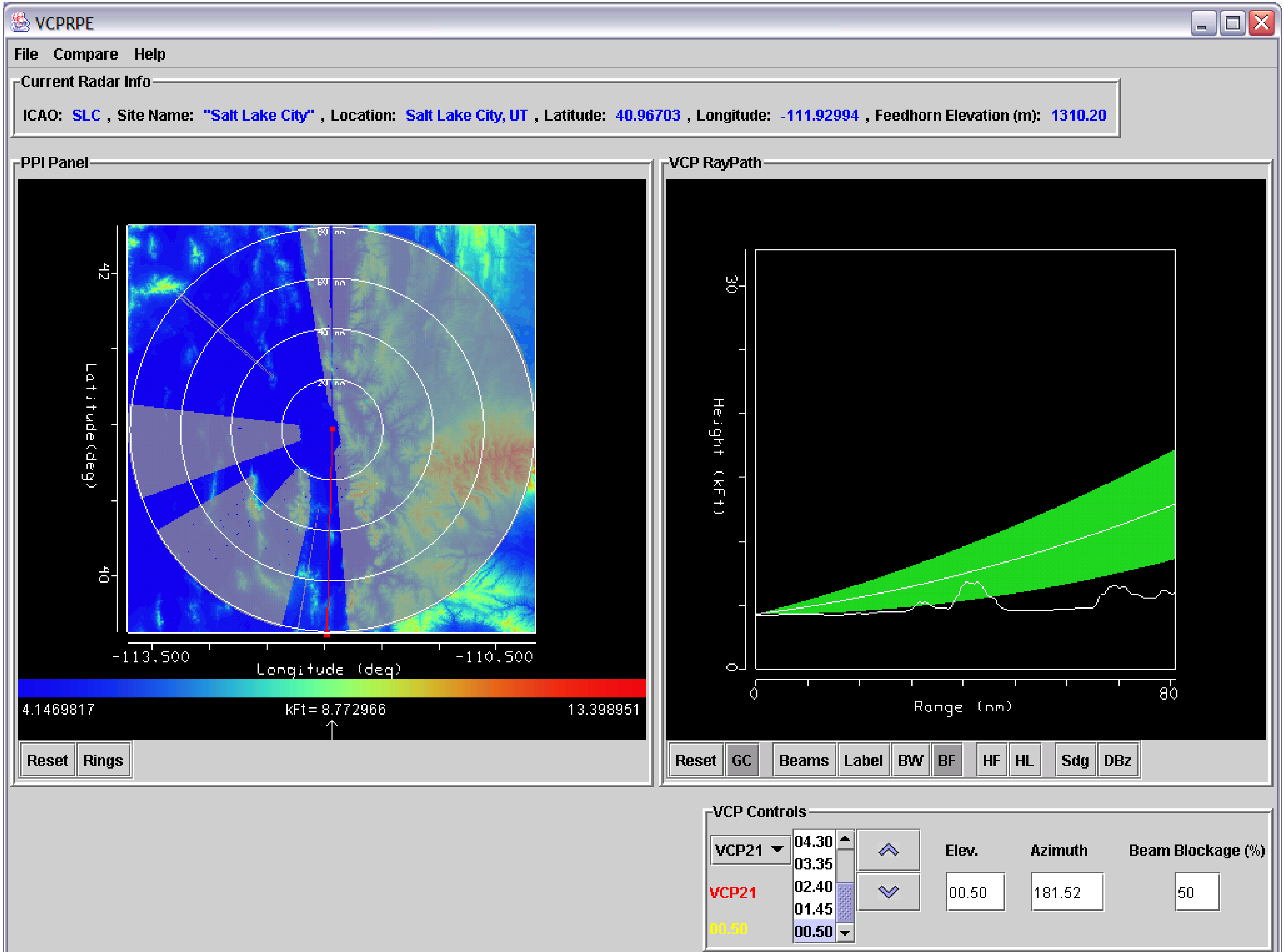


Figure 8. Example of a single target lying beyond R_{max}. Backscattered energy from the first pulse returns to the radar from its 600 nm round trip while the next pulse has reached a range of only 100 nm. The radar interprets the backscattered energy as coming from the second pulse (not the first pulse), and incorrectly places the target at 50 nm range.


VCPRPE
File Compare Help
Current Radar Info
ICAO: KMTX , Site Name: "SALT LAKE CITY " , Location: SALT LAKE CITY, UT , Latitude: 41.263 , Longitude: -112.448 , Feedhorn Elevation (m): 1999.0
PPI Panel
Latitude(deg)
44
38
-117
-108
Longitude (deg)
550.0
kFt= 2342.5
4135.0
Reset Rings
VCP RayPath
Height (kFt)
80
0
Range (nm)
200
Reset GC Beams Label BW BF HF HL Sdg DBz
VCP Controls
VCP11
VCP11
00.50
04.30
03.35
02.40
01.45
00.50
Elev.
Azimuth
Beam Blockage (%)
00.50
144.81
020


VCPRPE
File
Compare
Help
Current Radar Info
ICAO: SLC , Site Name: "Salt Lake City" , Location: Salt Lake City, UT , Latitude: 40.96703 , Longitude: -111.92994 , Feedhorn Elevation (m): 1310.20
PPI Panel
Latitude (deg)
42
40
-113.500
-110.500
Longitude (deg)
4.1469817
kFt= 8.772966
13.398951
Reset
Rings
VCP RayPath
Height (kFt)
30
0
0
80
Range (nm)
Reset
GC
Beams
Label
BW
BF
HF
HL
Sdg
DBz
VCP Controls
VCP21
VCP21
00.50
04.30
03.35
02.40
01.45
00.50
Elev.
Azimuth
Beam Blockage (%)
00.50
181.52
50

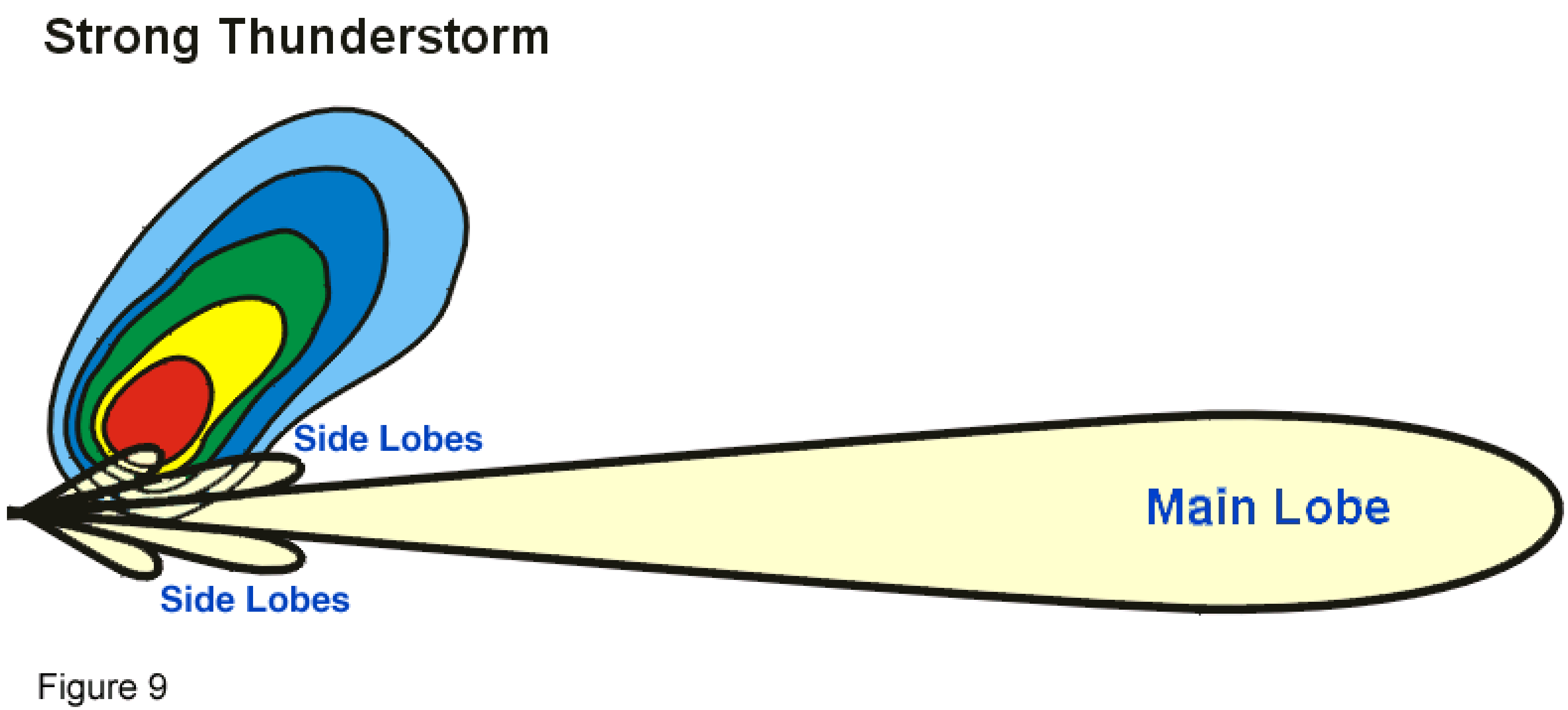


Figure 9. Example of sidelobe contamination. A strong reflectivity gradient results in side lobes interacting with a target while the main lobe does not.

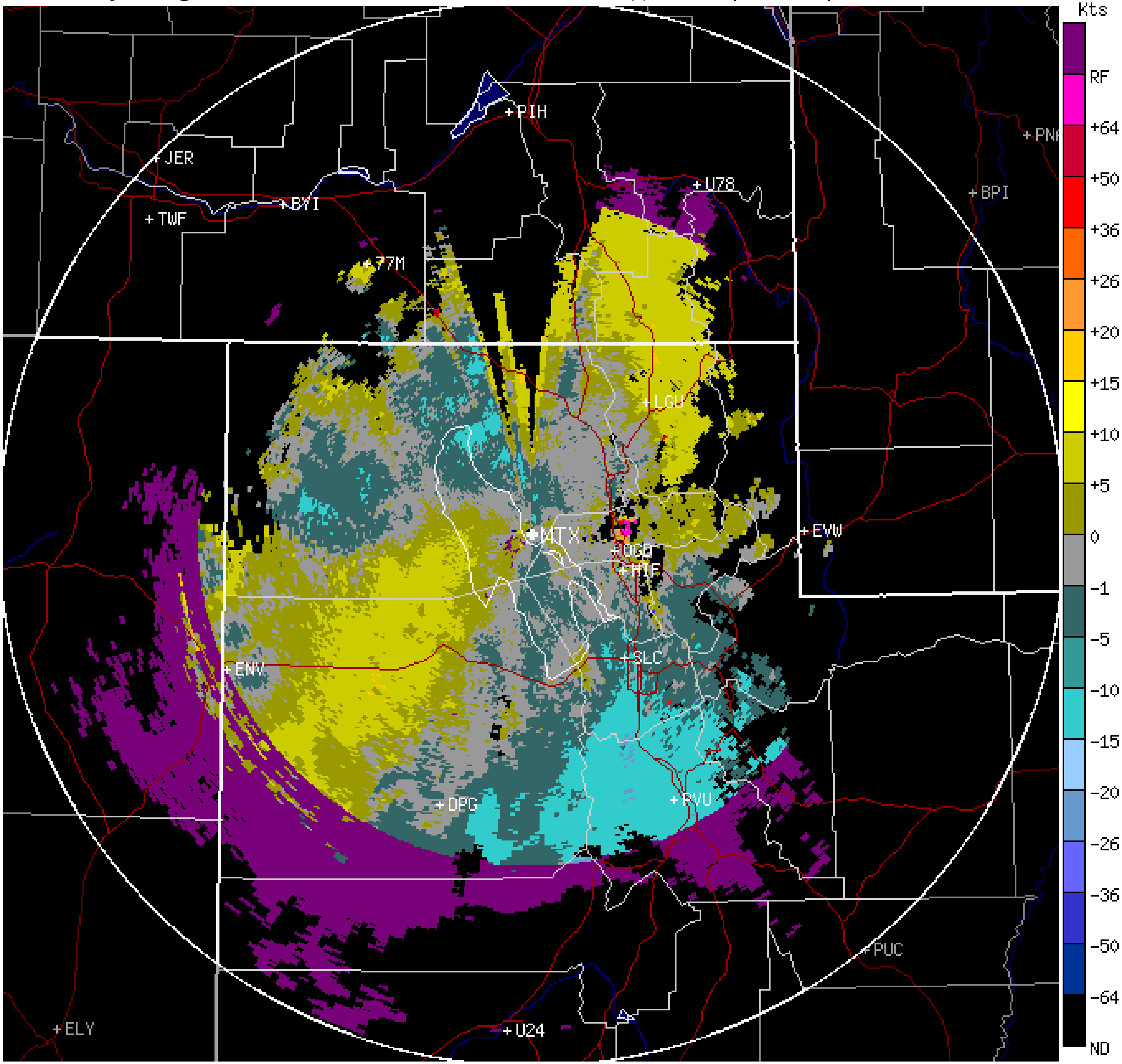
-

KMTX -- Salt Lake City, UT/Box Elder County

17:57:58 UTC Sat 13 March 2010

Base Velocity: 0.5 degrees

(c) UCAR http://www.rap.ucar.edu/weather/radar/



Radial velocity

- Distance traveled to stationary target:

  $2r = ct$

- Distance when target moving towards

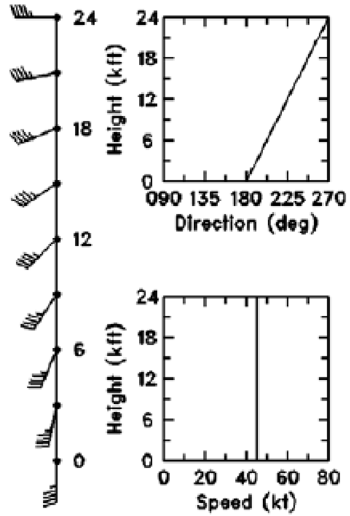
  $2v_rt$ less

- Distance when target moving away

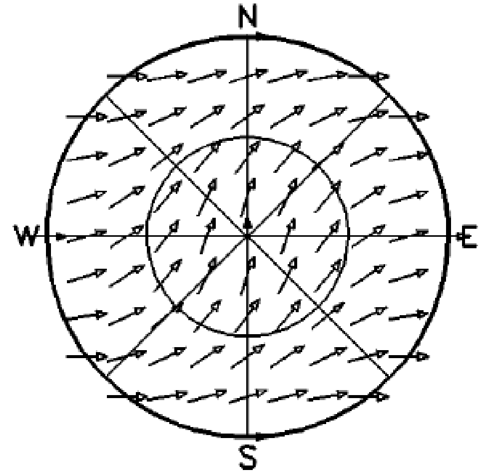
  $2v_rt$ more

- Target appears stationary when object moving perpendicular to radar
- Doppler shift of frequency due to object motion toward/away radar

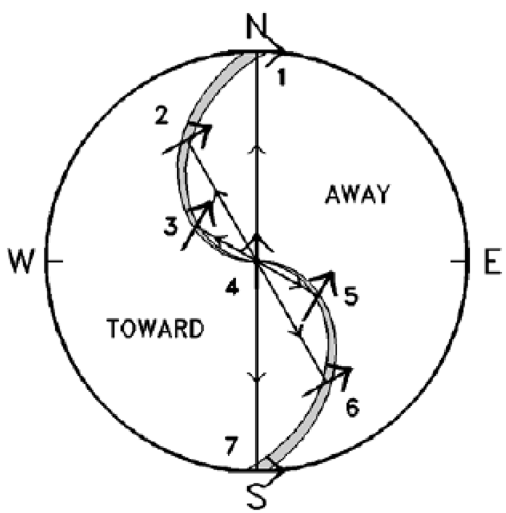
  $2v_r/$ wavelength



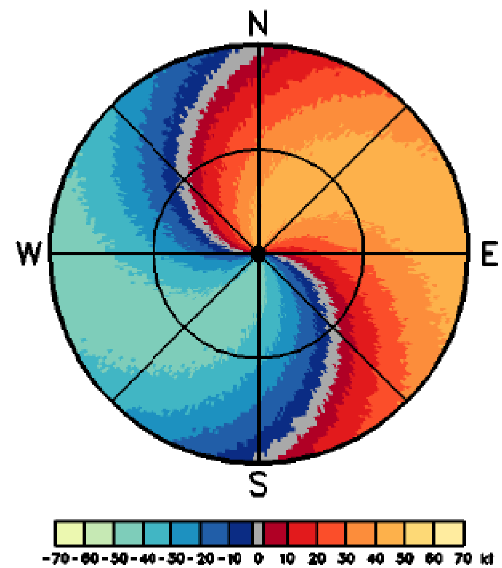
(a) Wind profile



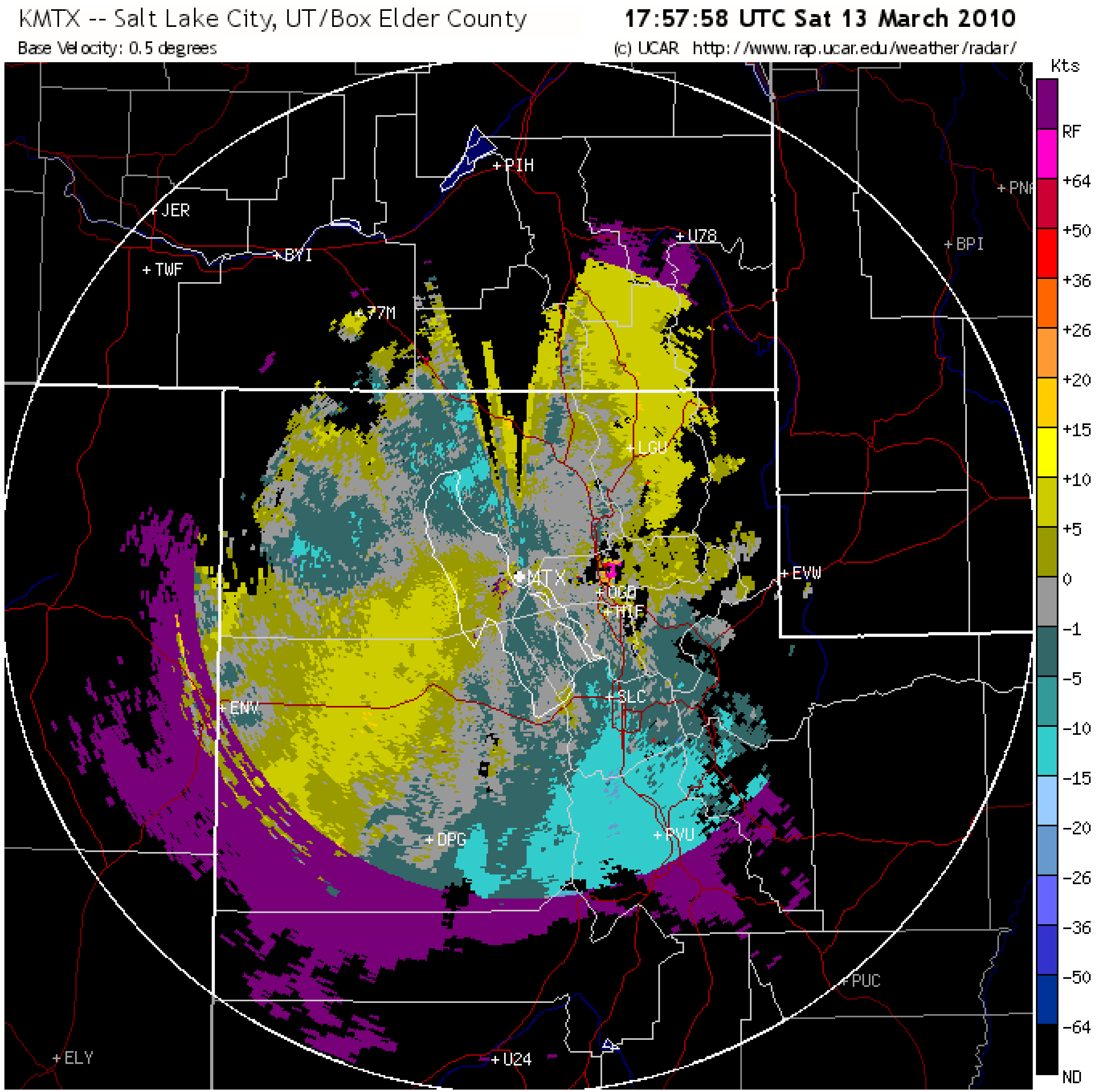
(b) Winds on PPI surface



(c) Interpretation of display



(d) Doppler velocity display


KMTX -- Salt Lake City, UT/Box Elder County
17:57:58 UTC Sat 13 March 2010
Base Velocity: 0.5 degrees
(c) UCAR http://www.rap.ucar.edu/weather/radar/
Kts
RF
+64
+50
+36
+26
+20
+15
+10
+5
0
-1
-5
-10
-15
-20
-26
-36
-50
-64
ND
PIH
JER
BYI
TWF
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PVU
PUC
ELY
U24

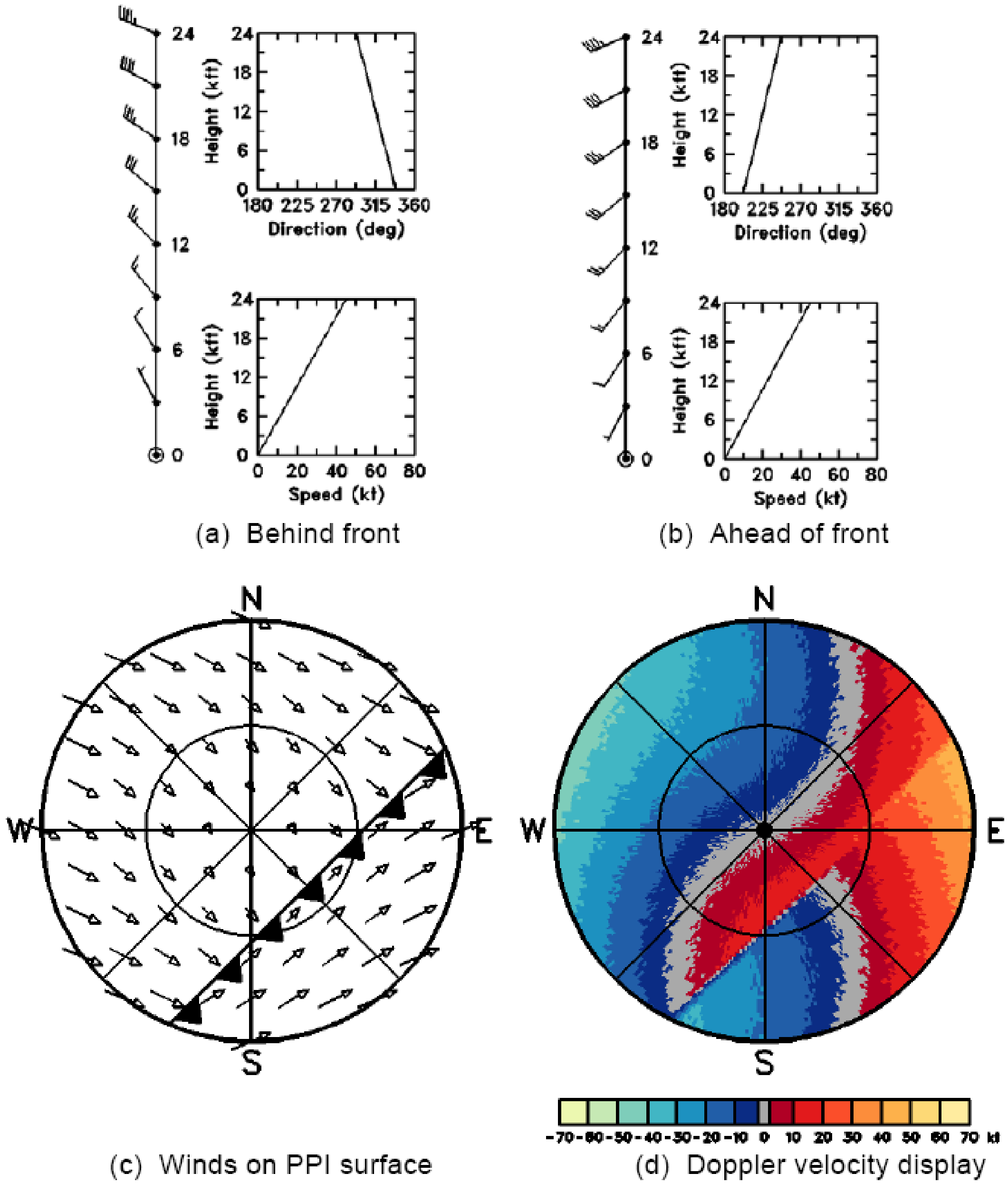


Figure 6-3
Frontal Discontinuity

Doppler dilemma

- Limited by how much frequency shift can be unambiguously detected by radar settings
  - If want to see high winds, then can’t detect far away from radar
  - If want to see far away from radar, then can only detect light winds
  - Otherwise range folding

Doppler dilemna

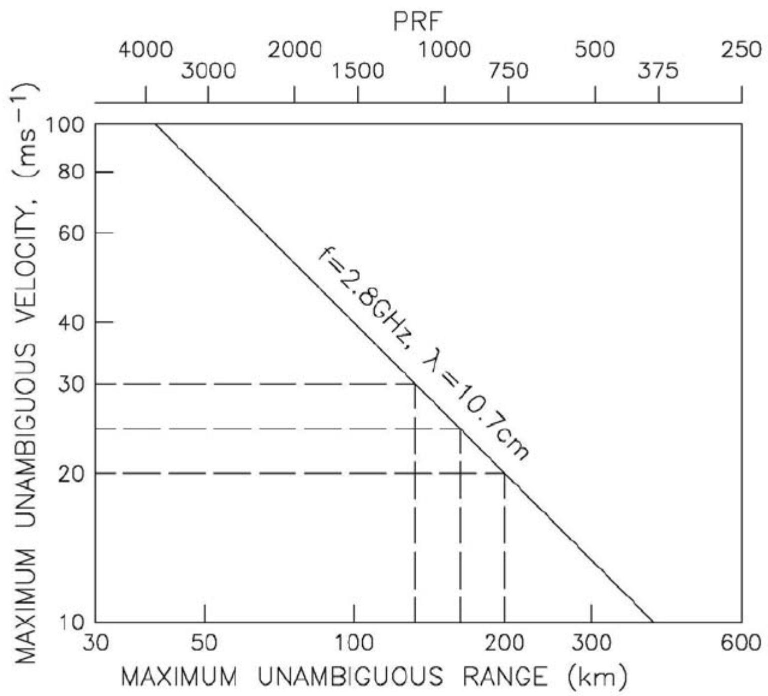


Figure 2-3
Unambiguous Range-Velocity Relationship for the WSR-88D

Dashed lines are for unambiguous velocities of 30, 25, and 20 ms^{-1} with associated unambiguous ranges of 134, 160, and 200 km.

National Weather Service
NOAA PROFILER NETWORK

About NPN Profilers

Typical NPN Profiler Site Equipped With RASS.
(Use mouse to identify specific components.)

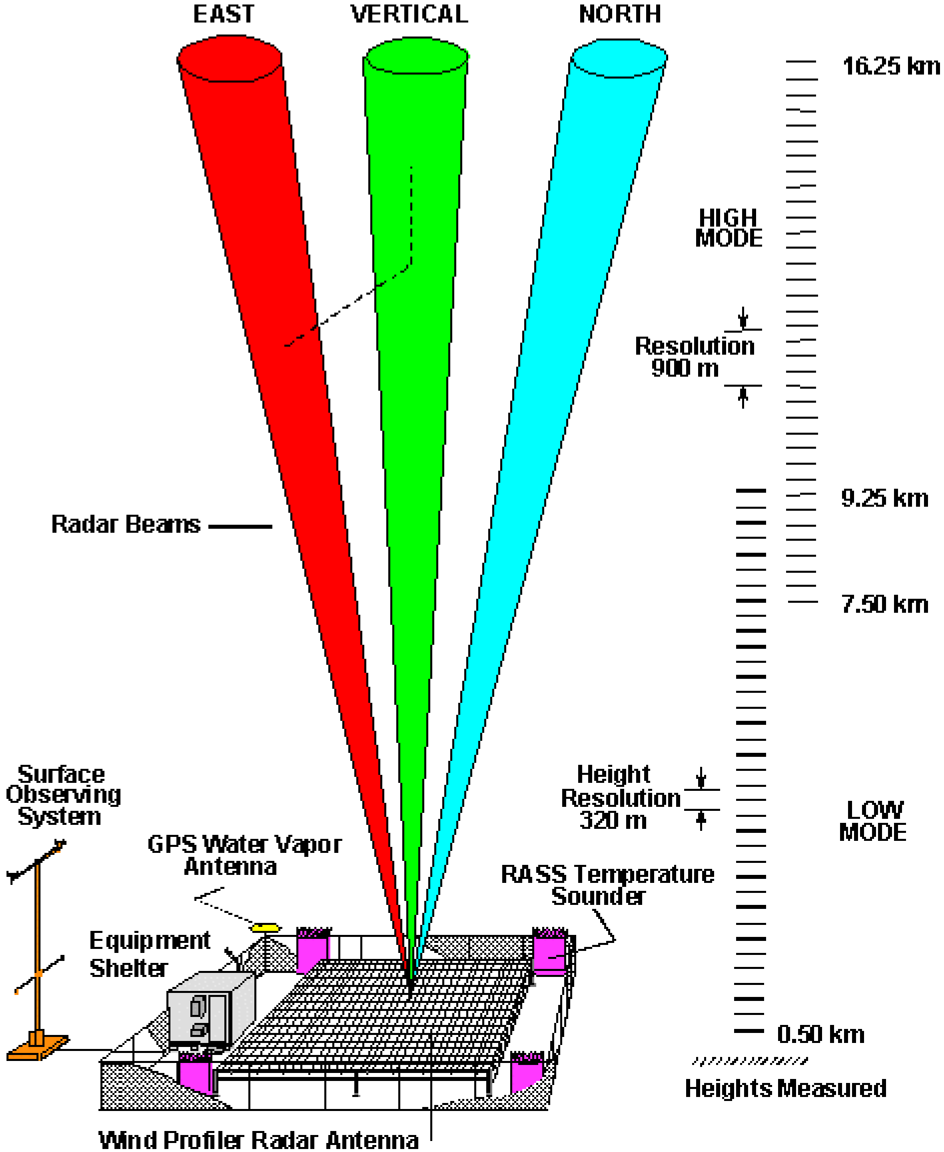
Wind profilers are specifically designed to measure vertical profiles of horizontal wind speed and direction from near the surface to above the tropopause. Data from this network are distributed in real-time to government and university atmospheric researchers, private meteorologists, the National Centers for Environmental Prediction, the Storm Prediction Center, all National Weather Service (NWS) Forecast Offices, and foreign agencies responsible for weather prediction.

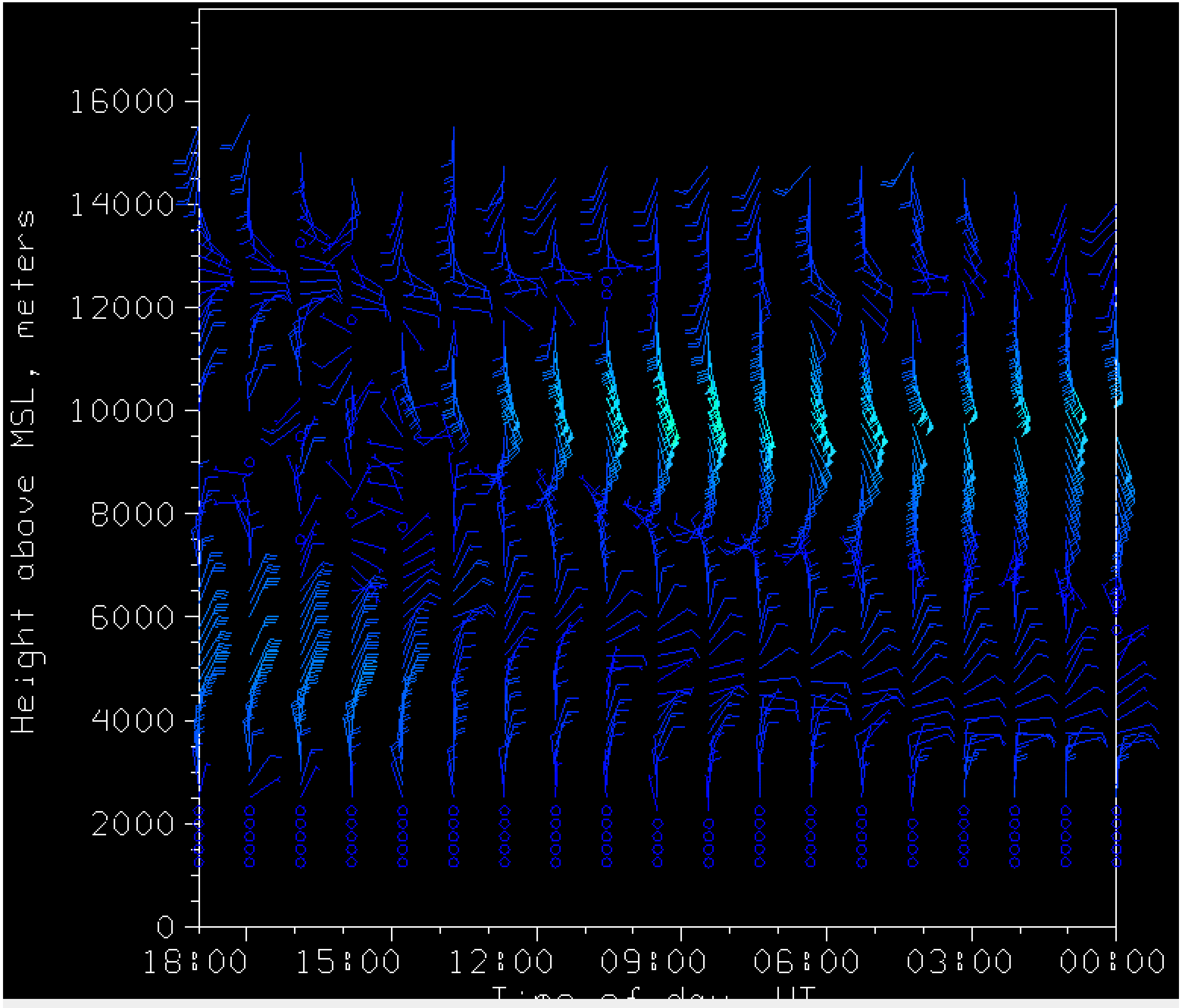
The NOAA Profiler Network (**NPN**) was first deployed in 1990-1992 and has operated continuously ever since. The original network consisted of (31) 404 MHz profiler sites located in the central United States and one site in Alaska. Since January of 2000, there are (32) 404 MHz profilers in the central United States and three 449 MHz profilers in Alaska. See Site Location Information (HTML), Site Location Information (TEXT), or Site Map for more information about NPN site locations.

Wind NPN profilers are designed to operate reliably and unattended in nearly all weather conditions. To achieve th reliability, they have a minimum number of moving parts; therefor a fixed beam antenna is used. Obtaining wind pro consistently to the tropopause in nearly all weather conditions requires the use of a relatively long wavelength radar Typical NWS weather radars that have been operational for the past 30 years operate with wavelengths of 10 cm o and require cloud or precipitation particles to act as reflectors. 404 MHz Wind profilers are relatively low-power, hig sensitive clear-air radars, operating at a wavelength of 74 centimeters. The radars detect fluctuations in the atmos density, caused by turbulent mixing of volumes of air with slightly different temperature and moisture content. The

NOAA Profilers

- operate continuously, alternating sampling modes every 1 minute between a low or high mode
- switch beam positions (eastward, northward, or vertical) every 2 minutes.
- Each mode contains 36 range gates (sampling heights), spaced every 250 m in the vertical.
- The low mode samples the lower atmosphere, beginning at 500 m above ground level (AGL) and continues to 9.25 km AGL
- The high mode slightly overlaps the top of the low mode, beginning at 7.5 km AGL and extends to a maximum height of 16.25 km AGL
- Data collected over 6 minute period, averaged into hourly averages


EAST
VERTICAL
NORTH
16.25 km
HIGH MODE
Resolution 900 m
9.25 km
7.50 km
Radar Beams
Surface Observing System
GPS Water Vapor Antenna
Height Resolution 320 m
LOW MODE
RASS Temperature Sounder
Equipment Shelter
0.50 km
Heights Measured
Wind Profiler Radar Antenna



Height above MSL, meters
16000
14000
12000
10000
8000
6000
4000
2000
0
18:00
15:00
12:00
09:00
06:00
03:00
00:00

Wind profilers

- Conventional weather radars detect reflections from hydrometeors rather than the air itself
- Wind profiling radars depend on the scattering of electromagnetic energy by minor irregularities in the index of refraction, which is related to the speed at which electromagnetic energy propagates through the atmosphere
- When an electromagnetic wave encounters a refractive index irregularity, a minute amount of energy is scattered in all directions.
- Backscattering, scattering of energy toward its point of origin, occurs preferentially from irregularities of a size on the order of one-half the wavelength of the incident wave
- Because the refractive index fluctuations are carried by the wind, they can be used as tracers.
- These irregularities exist in a size range of a few centimeters to many meters, most wind profilers operate at frequencies well below those of conventional weather radars.

Limitations

- ground clutter
- radio frequency interference (RFI)
- migrating birds
- atmospheric echoes in radar sidelobes
- performance of wind profiler is limited by its sensitivity, which improves with higher transmitted power levels and larger antennae
- The returned signal strength is also a function of the refractive index structure parameter, which tends to decrease with height and is dependent on meteorological conditions; if small, returned power may not be strong enough to make a meaningful measurement of the wind

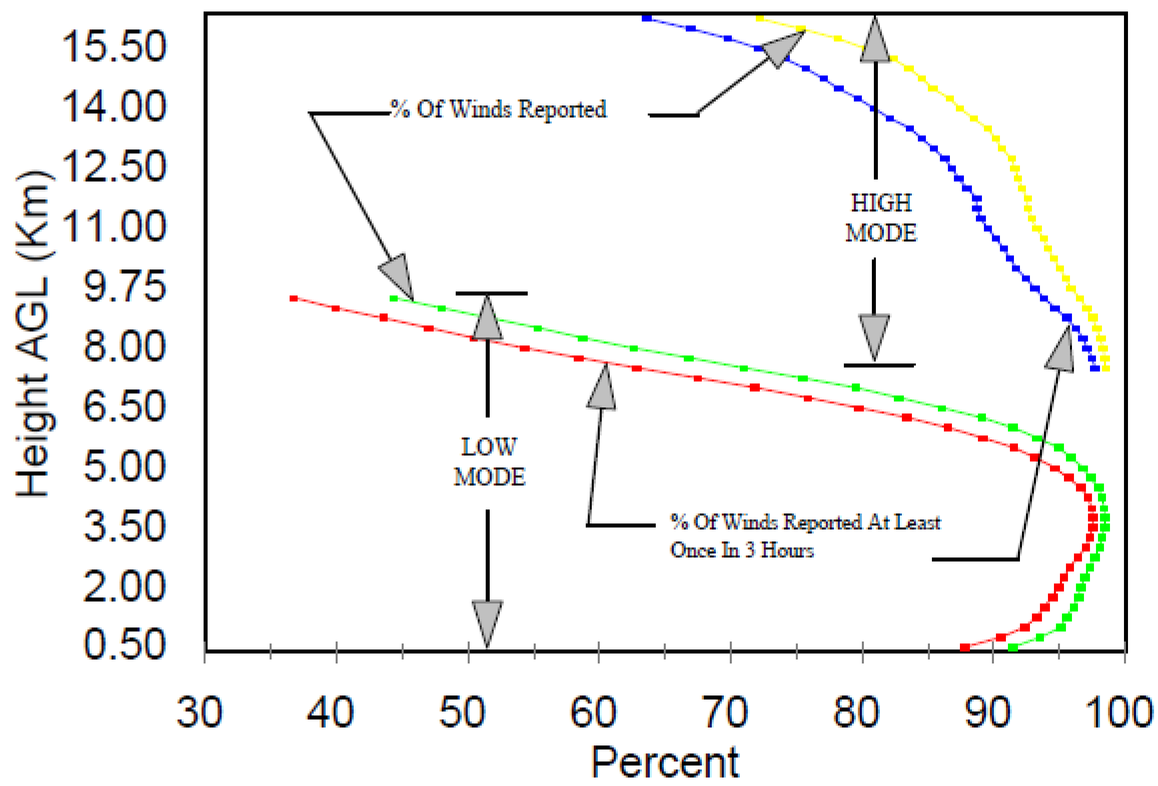
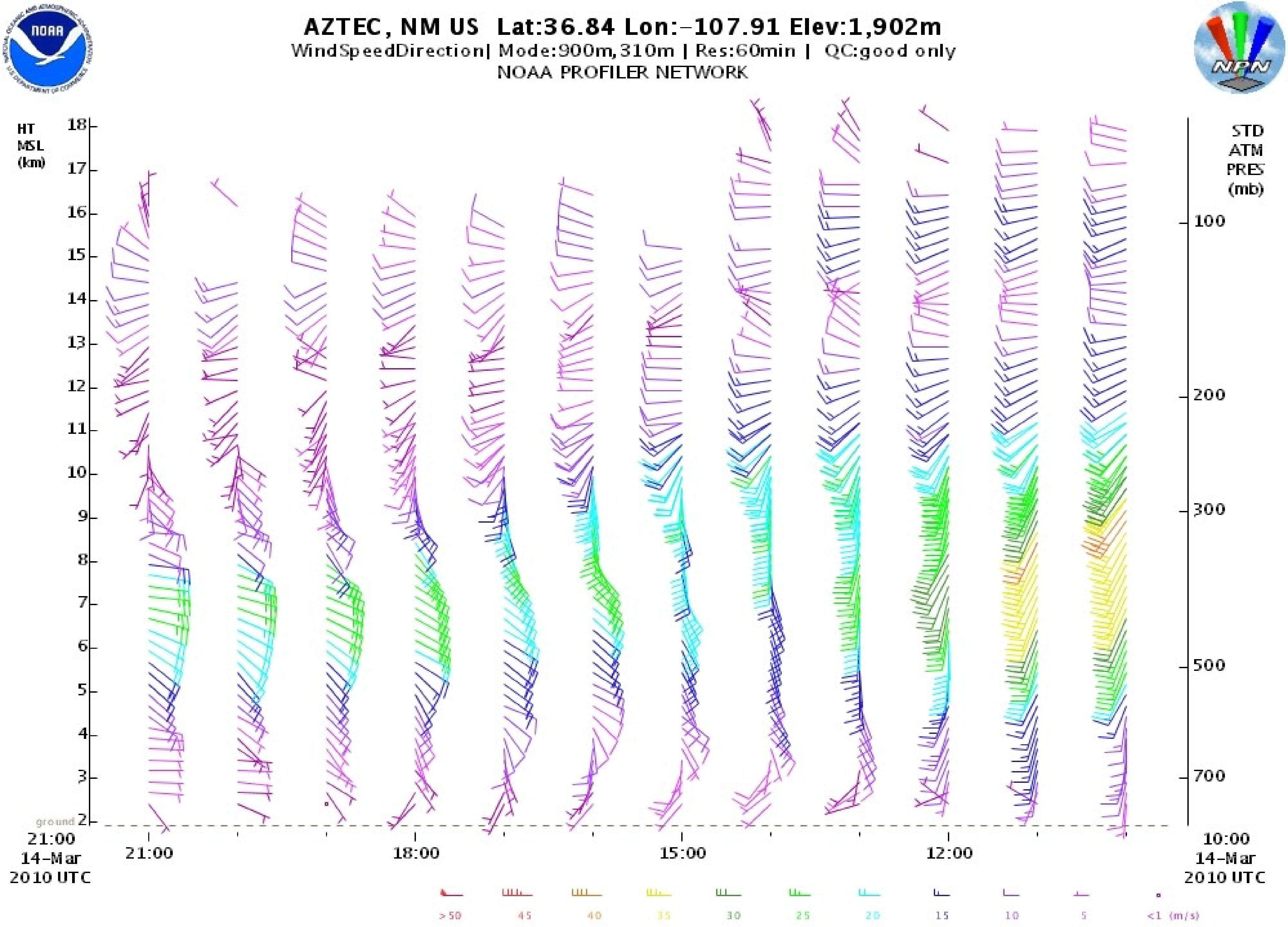


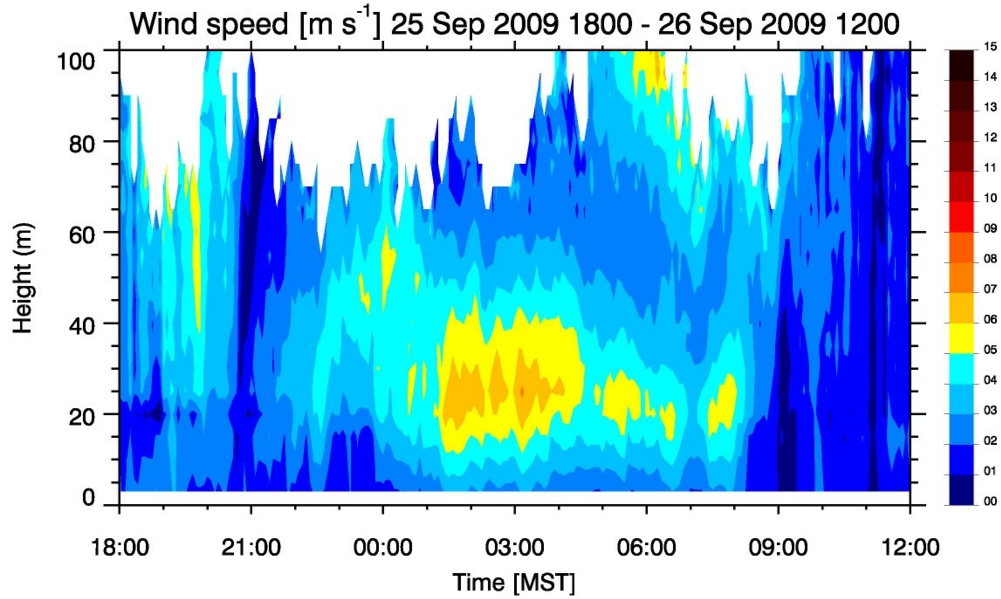
Figure 2-2. Percentage of time hourly winds were derived and passed quality control, as a function of height. Data were averaged over 29 of the national network profilers from June 1992 through May 1994. The top pair of curves is for the high mode, and the bottom pair is for the low mode (see Fig. 2-1).


AZTEC, NM US Lat:36.84 Lon:-107.91 Elev:1,902m
WindSpeedDirection| Mode:900m,310m | Res:60min | QC:good only
NOAA PROFILER NETWORK
NOAA
NPN
HT MSL (km)
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
ground 2
STD ATM PRES (mb)
100
200
300
500
700
21:00 14-Mar 2010 UTC
21:00
18:00
15:00
12:00
10:00 14-Mar 2010 UTC
>50
45
40
35
30
25
20
15
10
5
<1 (m/s)

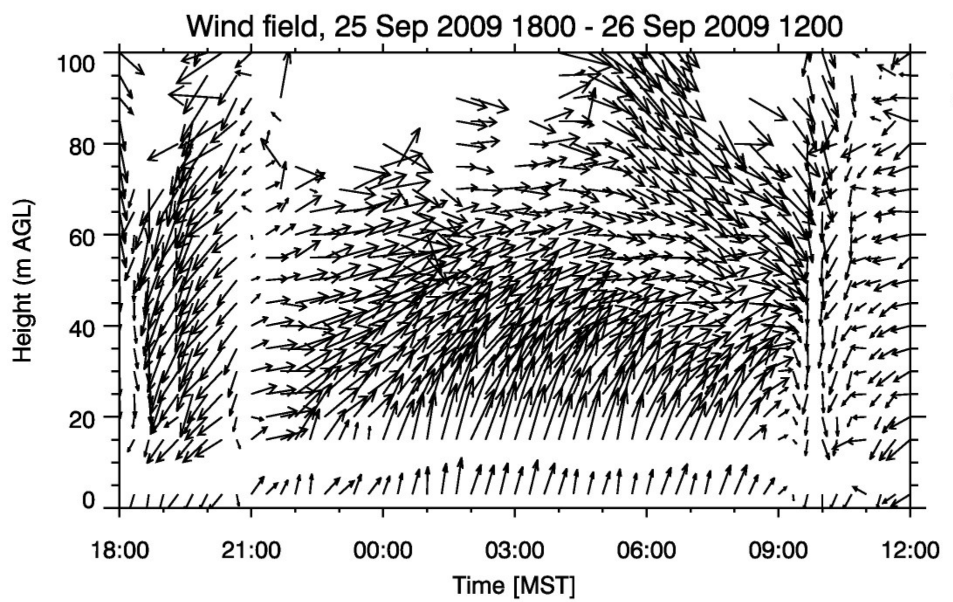

ASC

miniSoDAR

- emits high frequency (4500 Hz) pulses of amplified acoustic energy within the threshold of human hearing
- samples atmospheric echo from pulse, which contains information used to produce three-dimensional wind and turbulence profiles
- 5-m increments beginning at 15 m to max altitude of 250 m
- acoustic antenna is array of 32 speakers used to both transmit and receive acoustic signals
- speaker array is electrically steered to generate three independent beams
- received signal is product of interaction of transmitted acoustic pulse with small-scale atmospheric temperature and moisture fluctuations
- frequency of received signal is directly proportional to radial motion of scattering volume
- radial motions as determined from Doppler shift from 3 independent beams is combined to produce vertical profile of horizontal wind field



Wind speed [m s^{-1}] 25 Sep 2009 1800 - 26 Sep 2009 1200
Height (m)
Time [MST]
0
20
40
60
80
100
18:00
21:00
00:00
03:00
06:00
09:00
12:00
00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15



Wind field, 25 Sep 2009 1800 - 26 Sep 2009 1200
Height (m AGL)
Time [MST]
0
20
40
60
80
100
18:00
21:00
00:00
03:00
06:00
09:00
12:00

Limitations

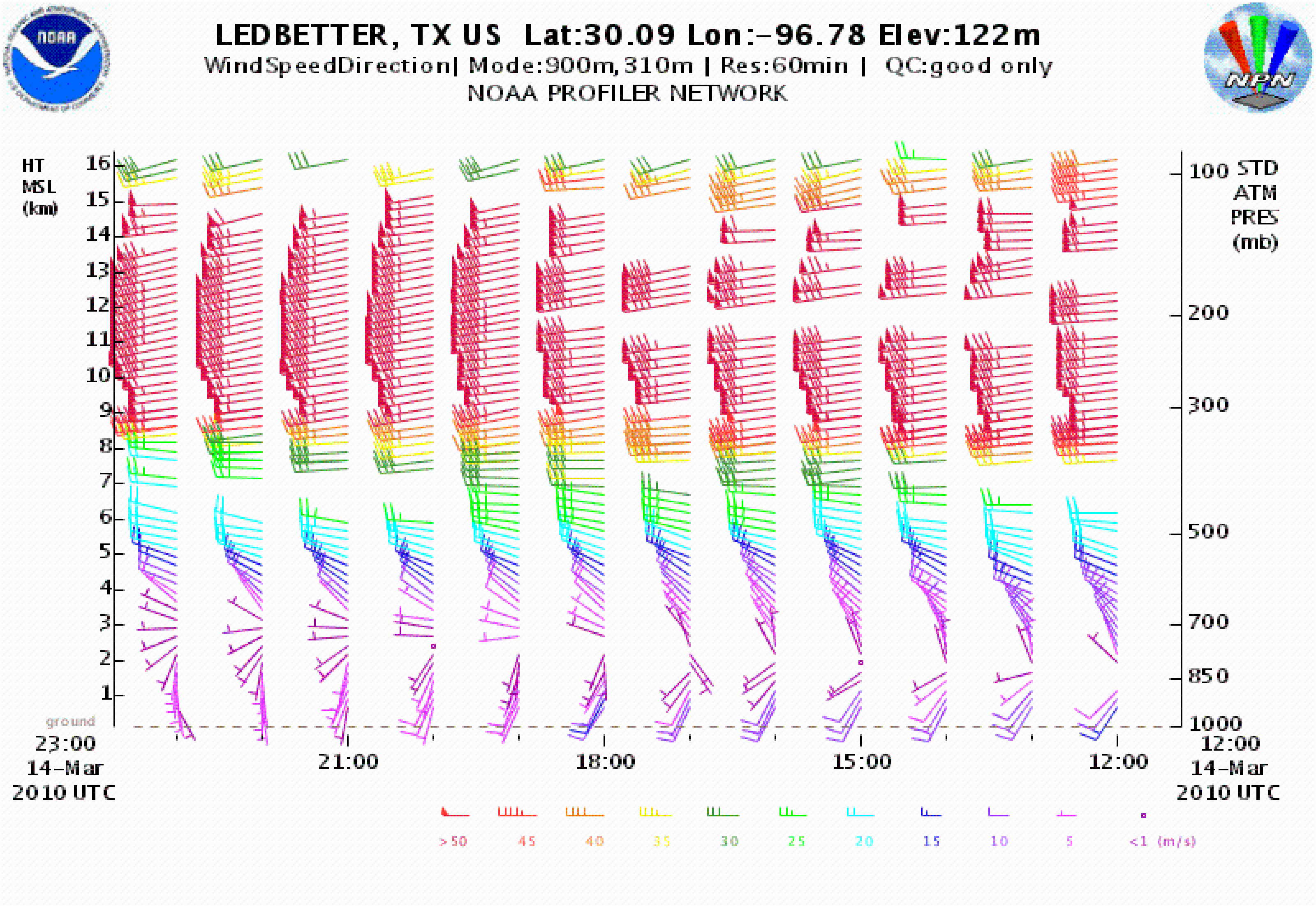
- vertical range of sodars is approximately 0.2 to 2 kilometers (km)
- vertical range is a function of frequency, power output, atmospheric stability, turbulence, and noise environment
- Due to attenuation characteristics of the atmosphere, high power, lower frequency sodars penetrate higher
- Strong winds blow acoustic pulses away from receiver

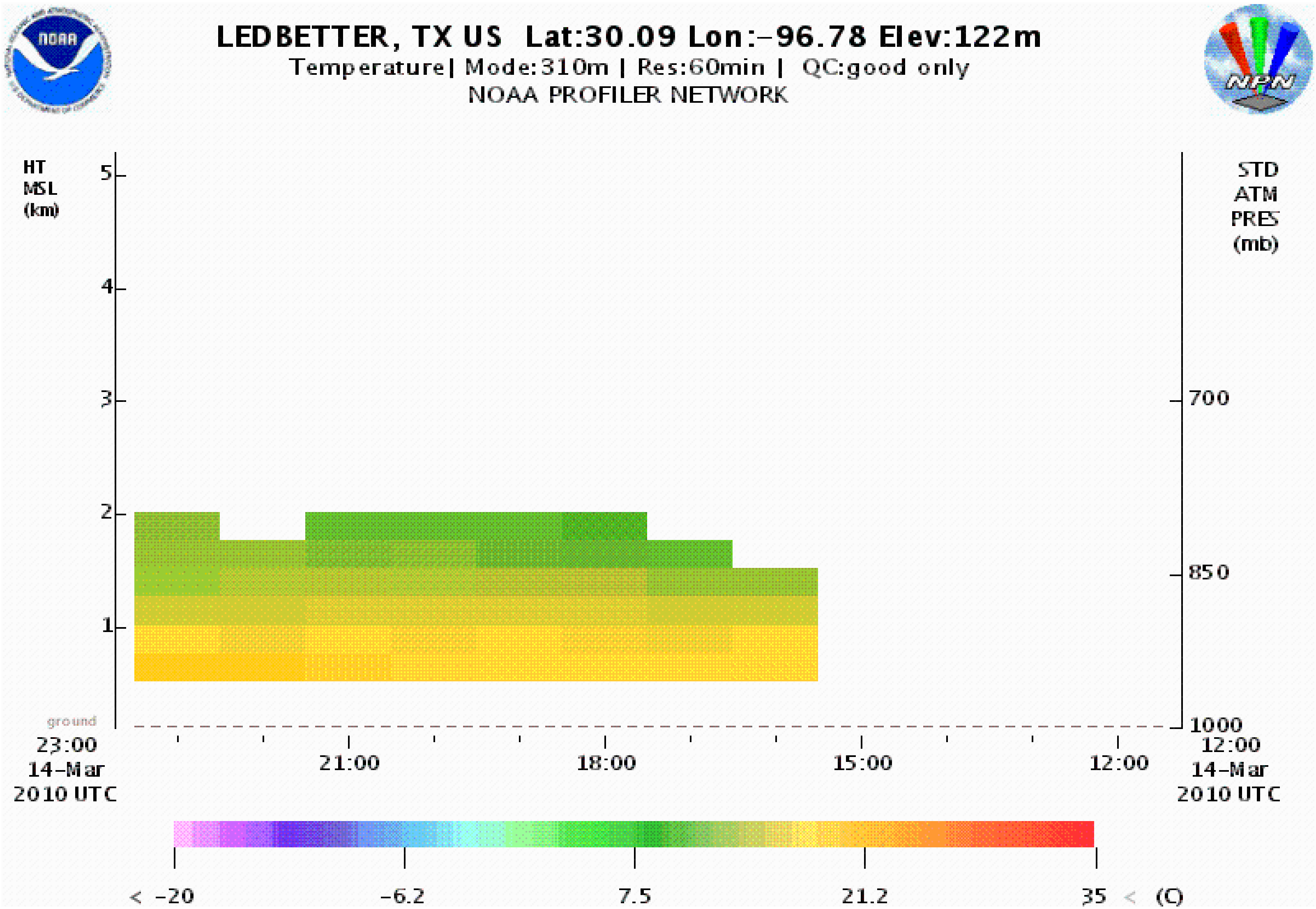
RASS- **radio acoustic sounding system**

- measures the atmospheric lapse rate using backscattering of radio waves from an acoustic wave front to measure the speed of sound as a function of height
- compression of air by an acoustic wave creates partial reflection of the transmitted radar signal
- from speed of sound, temperature of air can be computed
- acoustic subsystems must be added to the radar wind profiler to generate the sound signals and to perform signal processing
- three or four vertically pointing acoustic sources are placed around the radar wind profiler's antenna
- The acoustic sources are used to transmit sound into the vertical beam of the radar, and are usually encased in noise suppression enclosures to minimize nuisance effects that may bother people in the vicinity of the instrument

RASS

- usually performed with a 60 to 100 meter pulse length
- Because of atmospheric attenuation of the acoustic signals at the RASS frequencies, the altitude range that can be sampled is usually 0.1 to 1.5 km, depending on atmospheric conditions
- high wind velocities tend to limit RASS altitude coverage to a few hundred meters because the acoustic signals are blown out of the radar beam


LEDBETTER, TX US Lat:30.09 Lon:-96.78 Elev:122m
WindSpeedDirection| Mode:900m,310m | Res:60min | QC:good only
NOAA PROFILER NETWORK
HT MSL (km)
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
ground
23:00 14-Mar 2010 UTC
21:00
18:00
15:00
12:00
12:00 14-Mar 2010 UTC
STD ATM PRES (mb)
100
200
300
500
700
850
1000
>50
45
40
35
30
25
20
15
10
5
<1 (m/s)


LEDBETTER, TX US Lat:30.09 Lon:-96.78 Elev:122m
Temperature| Mode:310m | Res:60min | QC:good only
NOAA PROFILER NETWORK
HT MSL (km)
5
4
3
2
1
ground
STD ATM PRES (mb)
700
850
1000
23:00 14-Mar 2010 UTC
21:00
18:00
15:00
12:00
12:00 14-Mar 2010 UTC
< -20
-6.2
7.5
21.2
35 <
(C)