DCA97MA017
Addendum II to Meteorological Factual Report

Weather Radar Data

Archive Level II doppler weather radar tapes from the White Lake, Michigan (KDTX), Wilmington, Ohio (KILN), and Cleveland, Ohio (KCLE) WSR-88D doppler weather radars were obtained from the National Climatic Data Center in Asheville, North Carolina. The data on the tape were reviewed on a Hewlett Packard X-Station using Motif Interactive Radar Analysis Software (Motif-IRAS).

> Reference : Priegnitz, D.L., 1995 : IRAS: Software to display and analyze WSR-88D radar data, Eleventh International Conference on Interactive Information and Processing for Meteorology, Oceanography, and Hydrology, Boston, American Meteorological Society, 197-199.

Wilmington, Ohio WSR-88D Doppler Weather Radar (KILN). Cross Section *Cincinnati, Ohio (KCVG) (0 nautical miles)* to Accident Site (183 nautical miles). Total distance about 183 nautical miles bearing 016 degrees from KCVG. KILN radar times 1943:45Z to 2059:31Z. Maximum Tops in feet (ft) MSL. Distances in nautical miles (nmi). Beam center (.44 degree elevation angle) at KCVG about 4,600 feet. Beam center at Accident Site about 31,900 feet. Beam width about 4,500 and 18,400 feet respectively.

Time	Echo Observed	Maximum Echo Tops	Maximum Echo Intensity
1943:45	From 5 - 60 nmi	7,000 ft	10 to 15 dBZ
1949:35	From 5 - 65 nmi	7,000 ft	10 to 15 dBZ
1955:24	From 0 - 65 nmi	7,000 ft	10 to 15 dBZ
2001:14	From 0 - 60 nmi	8,000 ft over KCVG (0 to 5 dBZ)	5 to 10 dBZ
2007:03	From 0 - 60 nmi	7,000 ft	10 to 15 dBZ
2012:53	From 0 - 60 nmi	8,000 ft over KCVG (0 to 5 dBZ)	10 to 15 dBZ
2018.43	From 0 - 60 nmi	8,000 ft over KCVG (-5 to 0 dBZ)	5 to 10 dBZ
2024:33	From 10 - 55 nmi	7,000 ft	10 to 15 dBZ
2030:22	From 0 - 50 nmi	8,000 ft over KCVG (5	10 to 15 dBZ

		to 10 dBZ)	
2036:12	From 0 - 65 nmi	17,000 ft at 65 nmi	10 to 15 dBZ
2042:02	From 5 - 60 nmi	7,000 ft	5 to 10 dBZ
2047:52	From 0 - 60 nmi	7,000 ft	10 to 15 dBZ
2053:41	From 0 - 65 nmi & From 75 - 80 nmi	9,000 ft	10 to 15 dBZ
2059:31	From 5 - 70 nmi & 75 nmi & 85nmi	11,000 ft at 85 nmi	10 to 15 dBZ

White Lake, Michigan WSR-88D Doppler Weather Radar (KDTX). Cross Section Accident Site (0 nautical miles) to about 92 nautical miles from KCVG (92 nautical miles) along a 196 degrees radial. Total distance about 92 nautical miles. KDTX radar times 2002:26Z to 2106:48Z. Maximum Tops in feet (ft) MSL. Distances in nautical miles (nmi). Beam center (.44 degree elevation angle) at Accident Site about 4,400 feet. Beam center at a point about 92 nautical miles on a 016 degrees radial from KCVG about 19,300 feet. Beam width about 4,300 and 13,500 feet respectively.

Time	Echo Observed	Maximum Echo Tops	Maximum Echo Intensity
2002:26	From 0 - 35 nmi	21,000 ft	30 to 35 dBZ
2008:18	From 0 - 35 nmi	20,000 ft	25 to 30 dBZ
2014:09	From 0 - 40 nmi	18,000 ft at 5 nmi	25 to 30 dBZ at Accident Site
2020:00	From 0 - 35 nmi	19,000 ft	20 to 25 dBZ
2025:51	From 0 - 30 nmi	18,000 ft at 5 nmi	25 to 30 dBZ at 5 nmi
2031:42	From 0 - 30 nmi	16,000 ft	20 to 25 dBZ at Accident Site
2037:33	From 0 - 25 nmi	15,000 ft at 10 nmi Echo base 2,000 ft and echo tops 12,000 ft at Accident Site	15 to 20 dBZ at Accident Site
2043:24	From 0 - 25 nautical miles	14,000 ft at 5 nmi Echo base 2,000 ft and echo tops 12,000 ft at Accident Site	15 to 20 dBZ at Accident Site
2049:15	From 0 to 20 nmi & 30 nmi	13,000 ft at 5 nmi & 30 nmi Echo base 2,000 ft and echo tops 12,000 ft	10 to 15 dBZ at Accident Site

2055:05	From 0 - 25 nmi	13,000 ft at 5 and 25 nmi Echo base 2,000 ft and echo tops 12,000 ft at Accident Site	5 to 10 dBZ at Accident Site
2100:57	From 0 - 25 nmi	12,000 ft at Accident Site and 25 nmi Echo base 2,000 ft and echo tops 12,000 ft at Accident Site	10 to 15 dBZ at Accident Site
2106:48	From 0 - 25 nmi	12,000 ft at 25 nmi Echo base 2,000 ft and echo tops 8,000 ft at the Accident Site	10 to 15 dBZ at the Accident Site

Cleveland, Ohio WSR-88D Doppler Weather Radar (KCLE). Cross Section Accident Site (0 nautical miles) to about 46 nautical miles from KCVG (137 nautical miles) along a 196 degrees radial from the Accident Site. Total distance about 137 nautical miles. KCLE radar times 2003:22Z to 2113:27Z. Maximum Tops in feet (ft) MSL. Distances in nautical miles (nmi). Beam center (.44 degree elevation angle) at Accident Site about 9,300 feet. Beam center at a point about 46 nautical miles on the 016 degrees radial from KCVG about 33,900 feet. Beam width about 8,400 and 19,200 feet respectively.

Time	Echo Observed	Maximum Echo Tops	Maximum Echo Intensity
2003:22	From 0 - 30 nmi	>24,000 ft Echo base 6,000 ft echo tops 16,000 ft at Accident Site	20 to 25 dBZ at 5 nmi 10 to 15 dBZ at accident site
2009:12	From 0 - 30 nmi & 40 nmi	17,000 ft at 40 nmi Echo base 6,000 ft echo tops 16,000 ft at the Accident Site	20 to 25 dBZ at the Accident Site
2015:02	From 0 - 30 nmi	16,000 ft Echo base 6,000 ft echo tops 16,000 ft at the Accident Site	15 to 20 dBZ at 5 nmi 10 to 15 dBZ at Accident Site
2020:53	From 0 - 25 nmi	>24,000 ft at 5 nmi Echo base 6,000 ft echo tops 16,000 ft at the	20 to 25 dBZ at 5 nmi 10 to 15 dBZ at the Accident Site

		Accident Site	
2026:43	From 0 - 20 nmi	16,000 ft Echo base 6,000 ft echo tops 16,000 ft at the Accident Site	20 to 25 dBZ at the Accident Site
2032:33	From 0 - 15 nmi	16,000 ft Echo base 6,000 ft echo tops 16,000 ft	5 to 10 dBZ at the Accident Site
2038:23	From 0 to 5 nmi & 10 nmi	16,000 ft at 0 to 5 nmi & 10 nmi Echo base 6,000 ft echo tops 16,000 ft at the Accident Site	5 to 10 dBZ at the Accident Site
2044:14	No Echoes		
2050:04	No Echoes		
2055:54	90 nmi	>24,000 ft	5 to 10 dBZ
2101:45	No Echoes		
2107:37	125 nmi	>24,000 ft	10 to 15 dBZ
2113:27	No Echoes		

Attachment 1A .. Plot of track from KCVG to Accident Site.

Attachments 1B and 2 .. KDTX WSR-88D Doppler Weather Radar Plan Position Indicator (PPI) images for 2055:05Z and 2100:57Z. The ground track of Northwest Flight 272 is superimposed (track times 2055:03Z to 2059:40Z; altitudes 5,900 feet descending to 4,000 feet and than climbing to 4,800 feet). Image is blown up 8 times. Weather radar echo intensity values (dBZ) noted by color bar at bottom of image. The elevation angle is .44 degree. Cross = approximate location of accident site. Range ring = 10 kilometers; azimuth radials = 10 degrees. The accident site is located about 185 degrees at 43 nautical miles from KDTX. Northwest Flight 272 reported moderate to severe rime icing upon entering clouds at 4,000 to 5,000 feet. The rate of accumulation was estimated at ½ inch per minute.

Attachments 3 and 4 .. KDTX WSR-88D Doppler Weather Radar Plan Position Indicator (PPI) 4 panel images for 2055:03Z and 2100:57Z. The ground track of Northwest Flight 272 is superimposed (track times 2055:03Z to 2059:40Z; altitudes 5,900 feet descending to 4,000 feet and than climbing to 4,800 feet). Image is blown up 8 times. Weather radar reflectivity values (dBZ) noted by color bar at bottom of images. Cross = approximate location of accident site. The elevation angles are .44, 1.3, 2.3, and 3.2 degrees.

Table Showing Beam Height and Beam Width (KDTX Radar) at the Accident Site as a Function of Elevation Angle

Elevation Angle (degrees)	Beam Height (feet)	Beam Width (feet)
0.44	4,400	4,300
1.3	8,300	4,300
2.3	12,900	4,300
3.2	17,000	4,300

Attachments 5 and 6 .. Aircraft Flight Track Cross Sections for 2055:05Z and 2100:57Z. Northwest Flight 272 ground track (2055:03Z to 2059:58Z ; altitudes 5,900 feet descending to 4,000 feet and than climbing to 4,900 feet). Height in kilometers. Times (hours, minutes, seconds) on horizontal axis. Radar reflectivity values (dBZ) noted by the numbers at the end of the line segments (black). Altitudes in feet noted at the end of the red line segments. Weather radar reflectivity values (dBZ) color coded (see PPI images).

Note: Motif-IRAS allows interrogation of the Aircraft Flight Track Cross Section. Interrogation of a certain point on the Cross Section results in the display of weather radar echo intensity (dBZ) and track time (Motif-IRAS track time). In this report, altitudes of the airplanes are estimated, when necessary, from track data using the Motif-IRAS Aircraft Flight Track Cross Section flight track times.

The 2055:05Z Flight Track Cross Section showed maximum echo tops of about 10,000 feet. The maximum echo intensity was about 11 dBZ with a minimum value of about -3.5 dBZ. Echo tops varied from about 10,000 feet to about 6,000 feet. The 2100:57Z Cross Section showed maximum echo tops still at about 10,000 feet. The maximum echo intensity decreased to about 10.5 dBZ with a minimum value of about -2.0 dBZ.

The following Table details the Maximum Echo Intensity (dBZ), Maximum Echo Height (feet), and Minimum Echo Intensity (dBZ) as a function of the Motif-IRAS track time along the ground track of Northwest Flight 272. KDTX radar times of 2055:05Z and 2100:57Z. Motif-IRAS Aircraft Flight Track Cross Section Program used.

KDTX 2055:05Z

Time (Z)	Maximum Echo Intensity	Maximum Echo Height	Minimum Echo Intensity	Remarks
2055:03	7.5	10,000	-3.5	Minimum Intensity Above 6,000 feet
2055:32	9.0	10,000	-1.5	Minimum Intensity Above

2056:03	9.0	10,000	-3.0	Minimum Intensity Above 6,000 feet
2056:33	10.5	6,000	--	No Echo Above
2057:03	10.0	6,000	--	No Echo Above
2057:33	8.5	6,000	--	No Echo Above
2058:03	6.0	6,000	--	No Echo Above
2058:33	5.5	10,000	-3.0	Minimum Intensity Above 6,000 feet
2059:03	8.0	6,000	--	No Echo Above
2059:33	7.0	10,000	-2.5	Minimum Intensity Above 6,000 feet
2059:57	6.5	10,000	-3.0	Minimum Intensity Above 6,000 feet

Base of echo below 3,000 feet. Maximum intensity 11.0 dBZ at a Motif-IRAS track time of 2055:27Z and 2056:23Z

KDTX 2100:57Z

Time (Z)	Maximum Echo Intensity	Maximum Echo Height	Minimum Echo Intensity	Remarks
2055:03	8.5	10,000	-1.5	Minimum Intensity Above 6,000 feet
2055:33	10.5	10,000	-1.5	Minimum Intensity Above 6,000 feet
205603	8.5	6,000	--	No Echo Above
2056:33	8.5	6,000	--	No Echo Above
2057:03	8.0	6,000	--	No Echo Above
2057:33	8.5	6,000	--	No Echo Above
2058:03	7.5	6,000	--	No Echo Above
2058:33	8.0	6,000	--	No Echo Above
2059:03	9.0	6,000	--	No Echo Above
2059:33	10.0	10,000	-1.5	Minimum Intensity Above 6,000 feet
2059:56	9.5	6,000	--	No Echo Above

Base of echo below 3,000 feet. Maximum intensity 10.5 dBZ at a Motif-IRAS track time of 2055:33Z.

Attachments 7 - 10 .. KDTX PPI Images for 2037:33Z, 2043:24Z, 2049:15Z, and 2055:05Z. COMAIR 3272 ground track plotted. Images for 2037:33Z, 2043:24Z, and 2049:15Z are 2 times blow up; range rings every 10 kilometers; azimuth radials every 10 degrees. Weather radar echo intensity in dBZ indicated by colors defined in color bar at bottom. Center of polar grid at the accident site. Image for 2055:05Z is an 8 times blow up. COMAIR 3272 and Northwest Flight 272 ground track plotted. Range rings every 10 kilometers. Center of polar grid at the accident site. Weather radar echo intensity in dBZ indicated by colors defined by color bar at bottom.

Attachments 11 - 15 .. Four panel KDTX PPI Images for times of 2031:42Z, 2037:33Z, 2043:24Z, 2049:15Z, and 2055:05Z. Elevation angles of 0.44, 1.3, 2.3, and 3.2 degrees. COMAIR 3272 ground track plotted. Range rings every 20 kilometers, 2031:42Z and 2037:33Z images, and every 10 kilometers 2043:24Z, 2049:15Z, and 2055:05Z images. Weather radar echo intensity in dBZ indicated by colors defined by color bar at bottom.

Attachment 16 .. Depicts the KDTX radar beam center height and the beam width as a function of times along COMAIR 3272's ground track.

Attachments 17 - 21 .. COMAIR 3272 Flight Track Cross Sections for 2037:33Z and 2043:24Z (track times of 2035:04Z to 2045:05Z) and 2043:24Z, 2049:15Z, and 2055:05Z (track times of 2045:05Z to 2054:20Z). Weather radar echo intensity values (dBZ) noted at end of black line segments. Altitudes noted at end of red line segments. Times in hours, minutes, seconds. Height in kilometers.

Attachments 22 - 24 .. Cross Sections of weather echoes along COMAIR 3272's ground track for selected time segments. KDTX radar times 2043:24Z, 2049:15Z, and 2055:05Z. Weather radar echo intensity in dBZ indicated by colors defined by color bar at bottom of PPI images. Height in kilometers. Distance in kilometers.

The following Tables relate times, altitudes (feet msl), and weather echo intensity (dBZ) based on the ground track of COMAIR 3272.

KDTX Time 2037:33Z
2034Z to 2040Z No Echoes Track Altitude 21,000 feet to 13,300 feet

KDTX Time 2043:24Z
2040Z to 2042Z No Echoes Track Altitude 13,300 feet to 11,000 feet

Track Time (Z)	Weather Echo Intensity (dBZ) at Track Altitude	Track Altitude (Feet MSL)
2042:06	3.5	11,000
2042:32	5.0	11,000
2043:04	2.0	11,000
2043:36	5.0	11,000
2044:04	7.5	11,000
2044:22	7.0	11,000
2045:05	No Echo	11,000
2045:37	No Echo	11,000
2046:05	No Echo	11,000

KDTX Time 2049:15Z

2046:06	No Echo	11,000
2046:36	No Echo	10,500
2047:05	No Echo	9,700
2047:43	-1.5	8,700
2047:56	-2.0	8,400
2047:59	-0.5	8,400
2048:06	No Echo	8,200
2048:24	-3.0	7,700
2048:38	-2.5	7,400
2048:54	-0.5	7,100
2049:04	-1.5	7,000
2049:21	1.0	7,000
2050:00	-2.0	7,000
2050:11	2.0	7,000
2050:39	-0.5	6,900
2050:48	-0.5	7,000
2051:06	-3.5	7,000
2051:20	-1.5	6,900
2051:36	5.5	6,600
2051:52	5.0	6,400

KDTX Time 2055:05Z

2052:06	4.5	6,200
2052:20	5.0	6,100
2052:38	7.0	5,800
2052:57	8.5	5,400
2053:13	6.5	5,200
2053:25	9.5	4,700
2053:36	9.5	4,500
2053:52	9.0	4,200

2054:02	10.5	4,100
2054:12	10.5	4,000
2054:20	10.5	3,900

The following Tables relate times, altitudes (feet msl), and weather echo intensity (dBZ) based on the ground track of Northwest Flight 272.

KDTX Time 2055:05Z

Time (Z)	Weather Echo Intensity (dBZ) at Track Altitude	Track Altitude (Feet MSL)
2054:54	7.5	6,000
2055:15	10.0	5,600
2055:34	9.0	5,300
2055:47	10.0	5,200
2056:00	9.0	5,000
2056:14	10.0	4,900
2056:39	10.5	4,700
2056:55	10.0	4,600
2057:17	10.0	4,400
2057:37	9.0	4,200
2057:54	7.5	4,100
2058:13	6.0	4,000

KDTX Time 2100:57Z

2058:03	7.5	4,000
2058:12	7.5	4,000
2058:22	8.0	4,000
2058:33	8.0	4,000
2058:42	8.5	4,000
2058:53	8.0	4,100
2059:03	9.0	4,300
2059:12	9.0	4,500
2059:21	8.5	4,600
2059:28	8.5	4,700
2059:39	10.0	4,800
2059:47	10.0	4,900
2059:58	9.5	4,900

The following Tables relate times, altitudes (feet msl), and weather echo intensity (dBZ) based on the ground track of America West Flight 2050 (Cactus 50).

KDTX Time 2043:24Z

2042:50Z to 2046:00Z No Echoes Track Altitude 13,100 feet to 12,000 feet

Time (Z)	Weather Echo Intensity (dBZ) at Track Altitude	Track Altitude (Feet MSL)
2046:06	No Echo	12,000
2046:42	No Echo	11,900
2047:09	-2.0	11,400
2047:47	No Echo	10,700
2048:08	-2.0	10,500
2048:35	-3.0	10,000
2049:05	-3.0	9,400
2049:20	-0.5	9,000
2049:46	-1.5	8,400
2050:16	-1.0	7,700
2050:33	-3.0	7,700
2050:54	-3.5	7,300
2051:24	8.5	6,700
2052:02	13.0	6,100

KDTX Time 2055:05Z

2052:03	8.5	6,100
2052:22	9.5	5,700
2053:03	8.5	4,900
2053:30	9.5	4,200
2053:47	12.0	3,900
2054:15	13.0	3,400
2054:48	11.5	3,100
2055:09	12.5	3,000
2056:06	14.5	2,900
2056:20	15.0	2,700

The following Tables relate times, altitudes (feet msl), and weather echo intensity (dBZ) based on the ground track of Northwest Flight 483.

KDTX Time 2043:24Z

2040:04Z to 2045:36Z No Echoes Track Altitude 12,000 feet to 8,700 feet

Time (Z)	Weather Echo Intensity (dBZ) at Track Altitude	Track Altitude (Feet MSL)
2045:43	-2.5	8,400

2045:58	-0.5	7,900
2046:07	-2.0	7,600

KDTX Time 2049:15Z

2046:48	No Echo	6,900
2047:09	6.0	6,400
2047:40	6.0	5,800
2048:09	2.5	5,100
2048:39	5.5	4,300
2049:19	8.5	3,500
2049:46	12.0	3,300
2050:25	12.0	3,000
2051:04	14.0	3,000
2051:46	15.0	3,000

KDTX Time 2055:05Z

2052:03	13.5	3,000
2052:22	14.5	2,900
2052:54	14.0	2,400

Attachments 25 and 26 .. Flight Track Cross Sections for KDTX times of 2049:15Z and 2055:05Z. America West Flight 2050 (Cactus 50) ground track. Height in kilometers. Time (hours, minutes, seconds) on horizontal axis. Radar reflectivity values (dBZ) noted by the numbers at the end of the line segments (black). Altitudes in feet noted at the end of the red line segments. Weather radar reflectivity values (dBZ) color coded (see PPI images). Cactus 50 reported moderate rime icing with a rate of accumulation estimated at ¼ inch in 5 to 8 minutes.

Attachments 27 - 29 .. Flight Track Cross Sections for KDTX times of 2043:24Z, 2049:15Z, and 2055:05Z. Northwest Flight 483 ground track. Height in kilometers. Time (hours, minutes, seconds) on horizontal axis. Radar reflectivity values (dBZ) noted by the numbers at the end of the line segments (black). Altitudes in feet noted at the end of the red line segments. Weather radar reflectivity values (dBZ) color coded (see PPI images). Northwest Flight 483 did not observe any icing. The Captain noted that " conditions looked like we should have expected icing problems, but none were actually observed."

Attachments 30 - 32 .. KDTX PPI Images for 2043:24Z, 2049:15Z, and 2055:05Z. COMAIR 3272, Northwest Flight 272, Northwest Flight 483, and America West Flight 2050 (Cactus 50) ground tracks plotted. Images are 4 times blow up; range rings every 10 kilometers; azimuth radials every 10 degrees. Elevation angle .44 degree. Weather

radar echo intensity in dBZ indicated by colors defined in color bar at bottom. Center of polar grid at the accident site.

Attachment 33 .. is a plot of Weather Echo Intensity in dBZ as a function of altitude as encountered by COMAIR Flight 3272 (Comair 3272), Northwest Flight 272 (NWA 272), America West Flight 2050 (Cactus 50), and Northwest Flight 483 (NWA 483).

Attachments 34 - 36 .. COMAIR 3272 Track Data.
Attachments 37 - 41 .. Cactus 50 Track Data.
Attachments 42 - 45 .. Northwest Flight 272 Track Data.
Attachments 46 - 49 .. Northwest Flight 483 Track Data.

VIP/DBZ Conversion Table

NWS VIP ... National Weather Service Video Integrator and Processor Level.
WSR-88D LVL ... WSR-88D Doppler Weather Radar Level.
PREC MODE dBZ ... Precipitation Mode dBZ.
RAINFALL .. Rainfall in inches per hour.

NWS VIP	WSR-88D LVL	PREC MODE DBZ	RAINFALL
0	0	<5	
	1	5 to 9	
	2	10 to 14	
1	3	15 to 19	.01 in/hr
Very Light	4	20 to 24	.02 in/hr
	5	25 to 29	.04 in/hr
2	6	30 to 34	.09 in/hr
Light to Moderate	7	35 to 39	.21 in/hr
3	8	40 to 44	.48 in/hr
Strong			
4	9	45 to 49	1.10 in/hr
Very Strong			
5	10	50 to 54	2.49 in/hr
Intense			
6	11	55 to 59	>5.67 in/hr
Extreme	12	60 to 64	
	13	65 to 69	
	14	70 to 74	
	15	GTE 75	

The following relationship from a paper by *Greene and Clark relates LWC to weather radar reflectivity:

$M = 3.44X10^{-3}Z^{4/7}$ where M = LWC in grams per cubic meter and Z = weather radar reflectivity in millimeters to the sixth power per cubic meter (mm^6/m^3). The following Table relates M to weather radar reflectivity in dBZ:

$dBZ = 10 X Log(Z)$
$Z = 10^{dBZ/10}$

Reflectivity (dBZ)	LWC (grams per cubic meter)
<5	<.01
10	.01
15	.02
20	.05
25	.09
30	.18
35	.34
40	.66
45	1.28

An exponential drop-size distribution proposed by Marshall and Palmer (1948) is assumed.

* Vertically Integrated Liquid Water - A New Analysis Tool; Monthly Weather Review; Vol. 100 No. 7; July 1972.

Ice Water Contents (IWC)

Reference: Upper - Level Structure of Oklahoma Tornadic Storms on 2 May 1979. II: Proposed Explanation of "V" Pattern and Internal Warm Region in Infrared Observations; Journal of Atmospheric Science; Heymsfield, Szejwach, Schotz, and Blackmer, Jr; Volume 40; July 1983; pages 1758 - 1759.

The IWC in grams per cubic meter was estimated using the relation $IWC = 0.035Z^{0.505}$ where Z is the radar reflectivity factor in millimeters to the sixth power divided by meters cubed. The relation was derived for air temperatures of -10 to -60 degrees C. It is noted in the above reference that another IWC relation was derived for snow aggregates by Sekhon and Srivastava (1970) using snow size spectra observed at the ground and a truncated exponential distribution. This relation gives IWC only about

70% lower than the above relation at low reflectivities. The following values were determined from the relation IWC = $0.035Z^{0.505}$.

dBZ = 10 X Log(Z)
$Z = 10^{dBZ/10}$

dBZ	IWC
-10	.01
-5	.02
0	.04
5	.06
10	.11
15	.20
20	.36
25	.64

Table from a chart developed at the National Center for Atmospheric Research that relates Weather Radar Reflectivity (dBZ), Drop Size, and Liquid Water Content (LWC). LWC in grams per cubic meter.

Cloud Drops .. Diameter < 40 microns.
Drizzle Drops .. Diameter 40 to 400 microns.
Rain Drops .. Diameter >400 microns.

Valid for monodisperse liquid droplets.

dBZ	LWC=.05 Drop Size	LWC=.1 Drop Size	LWC=.5 Drop Size	LWC=1.0 Drop Size
-10	drizzle	drizzle	drizzle	cloud
0	drizzle	drizzle	drizzle	drizzle
10	rain	drizzle	drizzle	drizzle
20	rain	rain	rain	drizzle
30	rain	rain	rain	rain

Estimates of Liquid Water Content

A moist adiabatic ascent from a cloud base of 1,300 feet (temperature of -4 degrees C, pressure of 940 millibars, saturation mixing ratio = 3.05 grams per kilogram) to an altitude of 11,000 feet (temperature -20 degrees C, pressure 640 millibars, saturation

mixing ratio of 1.25 grams per kilogram) results in the release of about 1.8 grams of water per kilogram of air. Assuming an average air density of 1.0 kilogram per cubic meter, results in an Adiabatic Liquid Water Content (ALWC) of about 1.8 grams per cubic meter. A Liquid Water Content is estimated by multiplying the ALWC by .25 and .33. This yields .5 and .6 gram per cubic meter respectively. At a 640 millibar temperature of -15 degrees C the LWC = .3 and .4 gram per cubic meter. At a 640 millibar temperature of -10 degrees C the LWC = .06 and .07 gram per cubic meter.

The following was obtained from the Forecasters' Guide On Aircraft Icing; Air Weather Service; Scott AFB, Illinois; March 1980:

$LWC = .348(W_0 - W_1)P/T$
As noted in the report, this represents a practical upper limit of the LWC in cumuliform clouds at flight level. The LWC in stratiform clouds averages about 1/2 the value computed for cumuliform clouds.

W_0 = saturation mixing ratio at cloud base (grams per kilogram).
W_1 = saturation mixing ratio at flight level (grams per kilogram).
P = pressure at flight level (millibars).
T = cloud temperature at flight level (degrees Kelvin).

Given: cloud base = 1,300 feet; temperature = -4 degrees C at cloud base; P at cloud base = 940 millibars // W_0 = 3.05 grams per kilogram.

At 11,000 feet; P = 640 millibars; T = -20 degrees C (253.16 degrees Kelvin) // W_1 = 1.25 grams per kilogram.

Therefore, LWC = .8 gram per cubic meter for stratiform conditions and 1.6 grams per cubic meter for cumuliform conditions for an altitude of 11,000 feet.

At 11,000 feet; P = 640 millibars; T = -15 degrees C (258.16 degrees Kelvin) // W_1 = 1.90 grams per kilogram.

Therefore, LWC = .49 gram per cubic meter for stratiform conditions and 0.99 gram per cubic meter for cumuliform conditions for an altitude of 11,000 feet.

At 11,000 feet; P = 640 millibars; T = -10 degrees C (263.16 degrees Kelvin) // W_1 = 2.83 grams per kilogram.

Therefore, LWC = .09 gram per cubic meter for stratiform conditions and 0.19 gram per cubic meter for cumuliform conditions for an altitude of 11,000 feet.

Summary

Weather echo tops at the time of departure of Comair Flight 3272 from KCVG were near 7,000 to 8,000 feet (KILN radar times 1955:24Z and 2001:14Z). Maximum weather radar intensities were 5 to 10 dBZ in the area (LWC .01 gram per cubic meter; IWC .06 to .11 gram per cubic meter). At about 65 nautical miles from KCVG weather echo tops were near 17,000 feet (KILN radar time 2036:12Z; Comair Flight 3272 was at about 21,000 feet at this time). Comair Flight 3272 first encountered weather echoes at 11,000 feet as it approached KDTW (Motif-IRAS track time 2042:06Z). The airplane was in and out of weather echoes from 11,000 feet to about 8,200 feet (Motif-IRAS track time 2048:06Z). The maximum weather echo intensity was 7.5 dBZ (LWC .01 gram per cubic meter; IWC .08 gram per cubic meter) during this time. From about 8,200 feet until 3,900 feet the airplane was continuously in weather echoes. Weather echo intensities of 5 dBZ (LWC .01 gram per cubic meter; IWC .06 gram per cubic meter) or greater were noted from about 6,600 feet (Motif-IRAS track time 2051:36Z) to 3,900 feet (Motif-IRAS track time 2054:20Z). Maximum echo intensities of 10.5 dBZ (LWC .01 gram per cubic meter; IWC 0.12 gram per cubic meter) were noted at 4,100 feet to 3,900 feet (Motif-IRAS track times of 2054:02Z to 2054:20Z).

Weather echo intensities as a function of altitude were plotted for the ground tracks of Comair Flight 3272, Cactus 50 (moderate rime icing), Northwest Flight 272 (moderate to severe rime icing), and Northwest Flight 483 (no icing observed). Review of the plotted data from 7,000 feet to 4,000 feet showed that the weather radar echo intensity values encountered by Comair Flight 3272 fell within an area of reported moderate or greater icing from about 6,000 feet to 4,000 feet (see Attachment 33). The ground tracks of these other airplanes were in the area of accident site. Northwest Flight 272 ground track times 2054:54Z to 2059:58Z; Cactus 50 ground track times 2042:50Z to 2058:34Z; and Northwest Flight 483 ground track times 2039:55Z to 2054:57Z.

Estimates of the LWC varied from .06 gram per cubic meter to 1.6 grams per cubic meter depending on the method and assumptions used to estimate the LWC. Rain and drizzle size drops were possible assuming a monodisperse drop distribution.

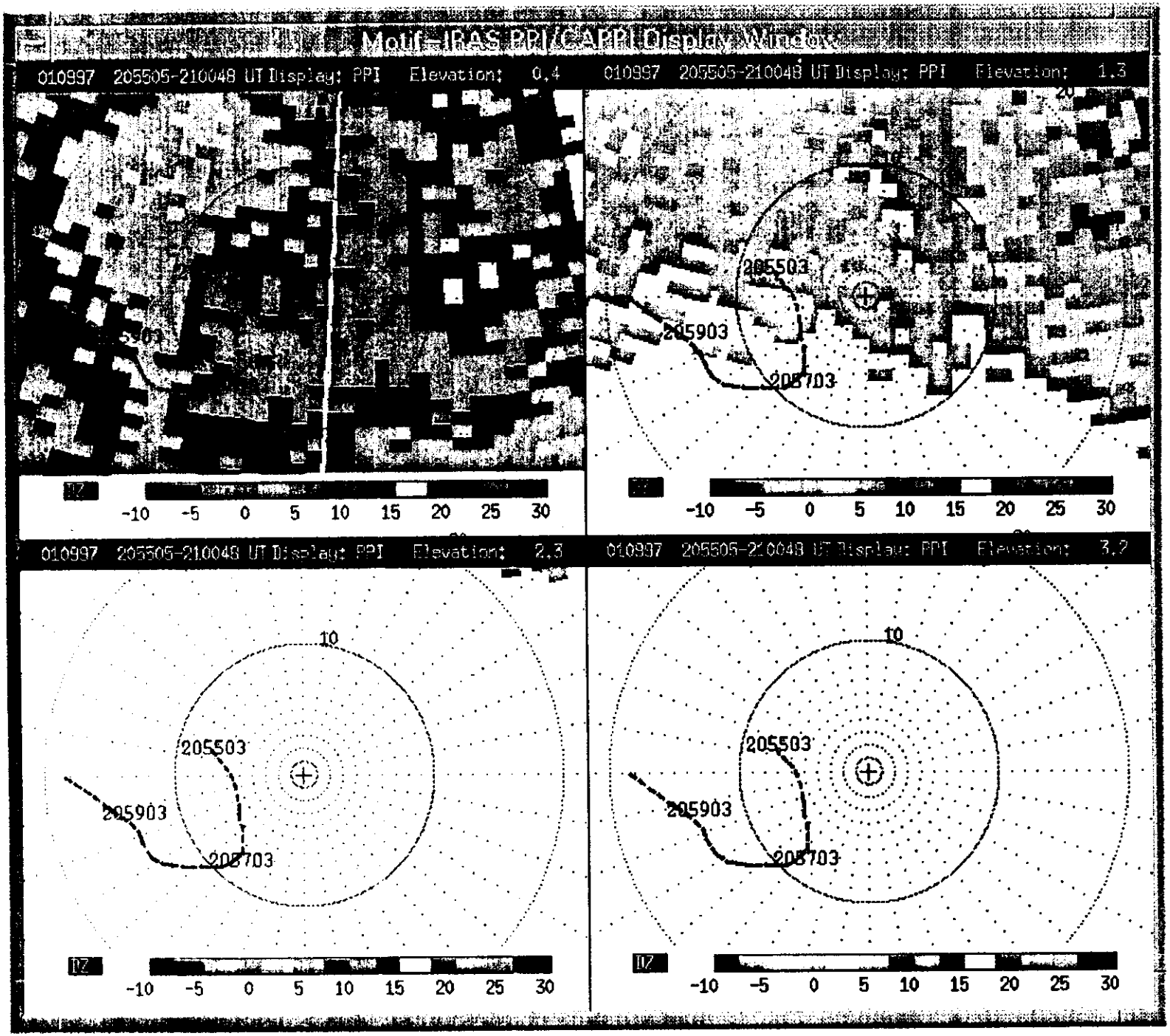
[redacted]

Gregory D. Salottolo
National Resource Specialist
Meteorology
5-20-97

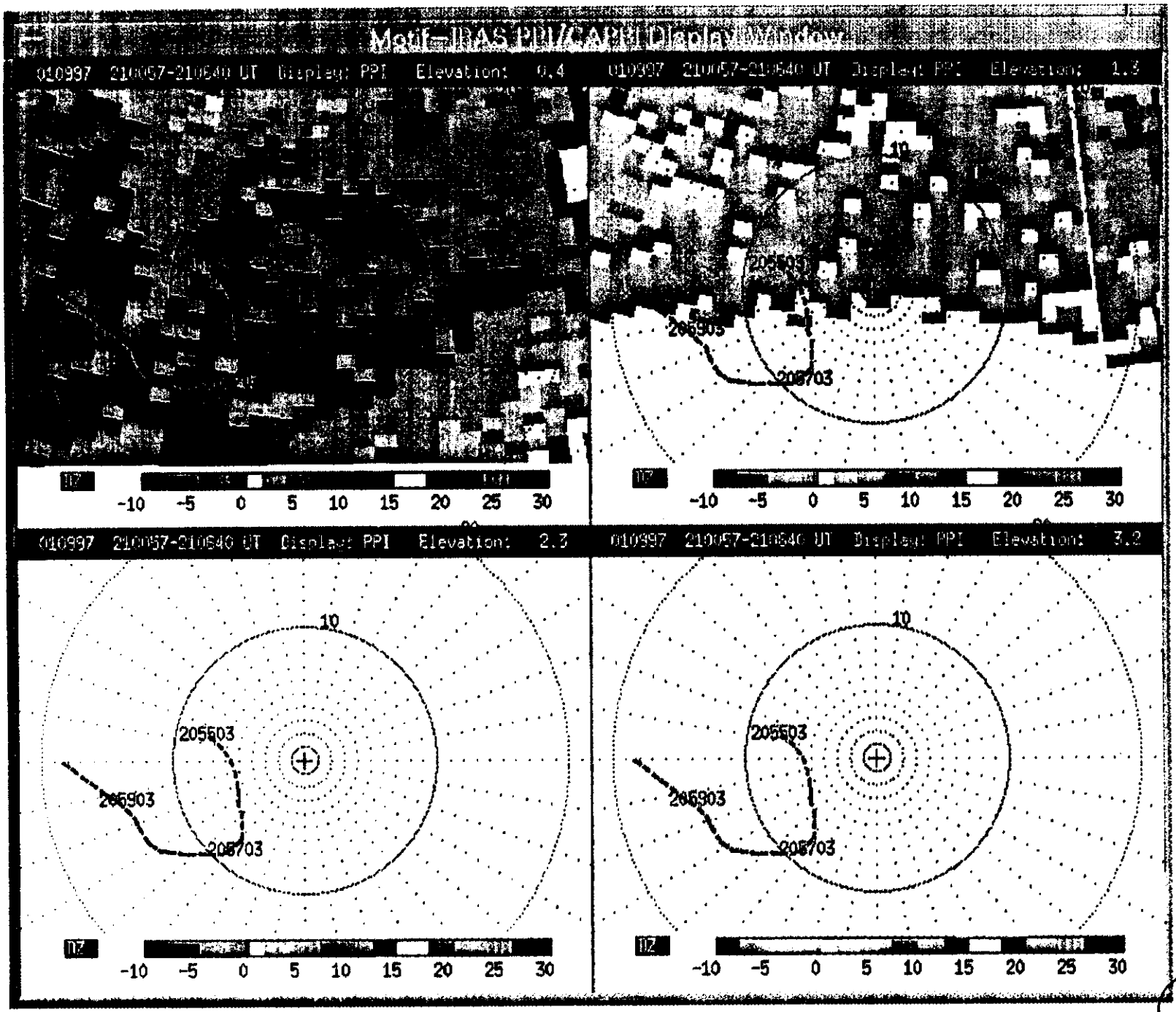
(1B)


Motif - IRAS FRI/CAFRI Display Window
A272 Track
-10
-5
0
5
10
15
20
25
30

(2)


Motif-IRAS PPI/CAPPI Display Windows
010997 205505-210048 UT Display: PPI Elevation: 0.4
010997 205505-210048 UT Display: PPI Elevation: 1.3
205503
205903
205703
DZ
-10 -5 0 5 10 15 20 25 30
010997 205505-210048 UT Display: PPI Elevation: 2.3
010997 205505-210048 UT Display: PPI Elevation: 3.2
10
205503
205903
205703
DZ
-10 -5 0 5 10 15 20 25 30

3


Motif-IRAS PPI/CAPPI Display Window
010997 210057-210640 UT Display: PPI Elevation: 0.4
010997 210057-210640 UT Display: PPI Elevation: 1.8
010997 210057-210640 UT Display: PPI Elevation: 2.3
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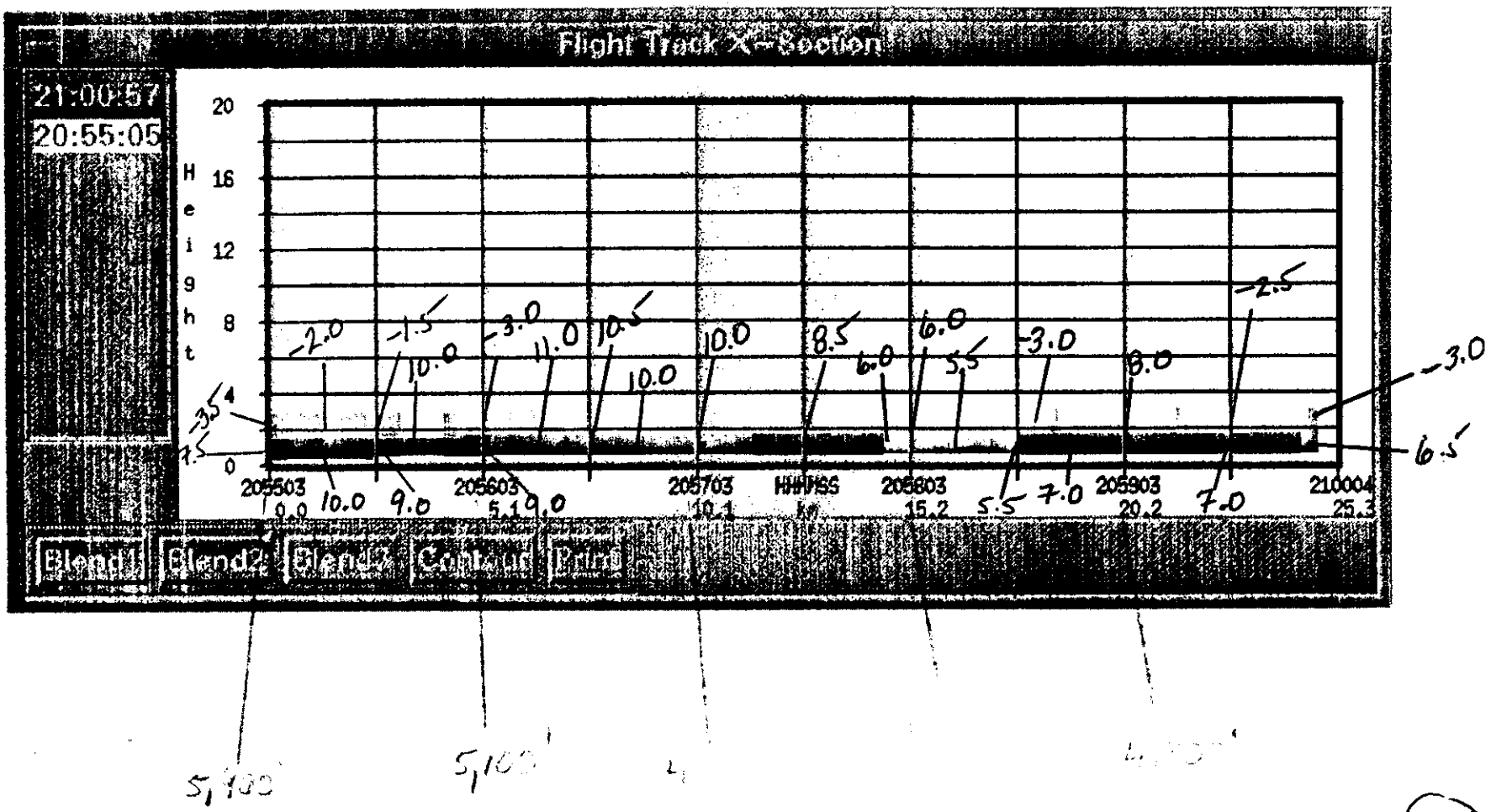
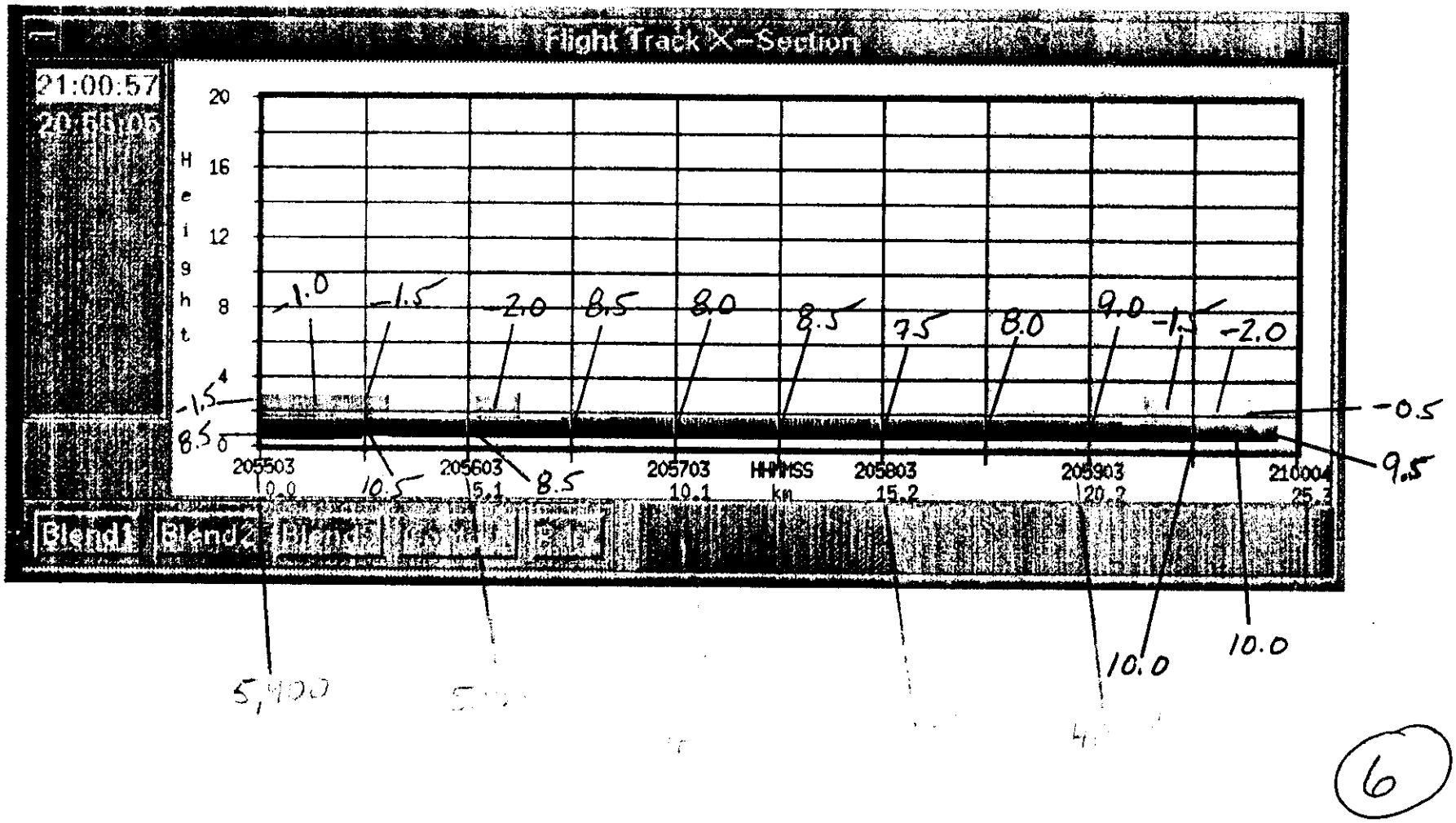
10
205903
205703
DZ
-10 -5 0 5 10 15 20 25 30

NWA 272

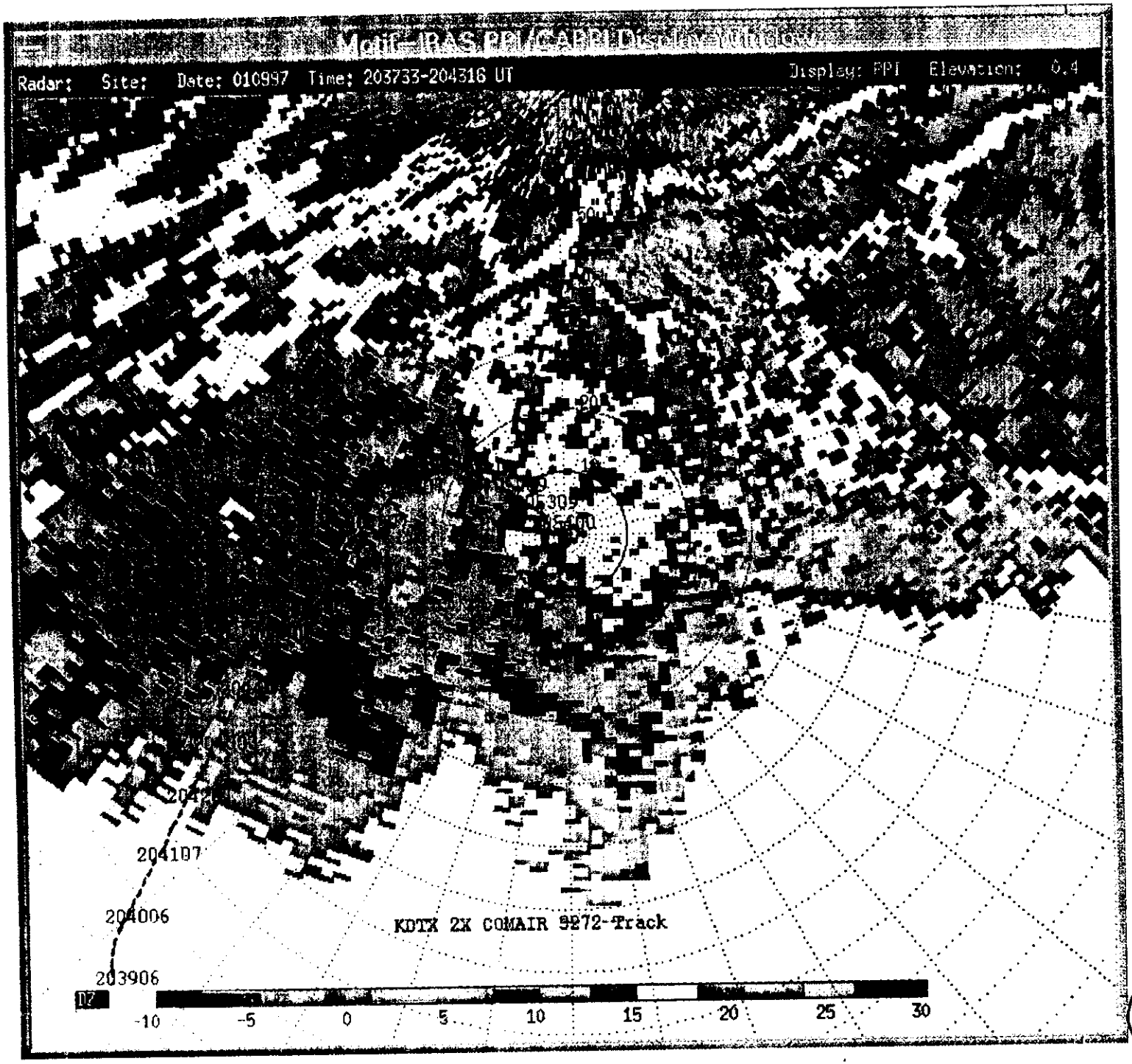

Flight Track X-Section
21:00:57
20:55:05
Height
20
16
12
8
4
0
205503
205603
205703
205803
205903
210004
Blend1
Blend2
Blend3
Control
Print

5

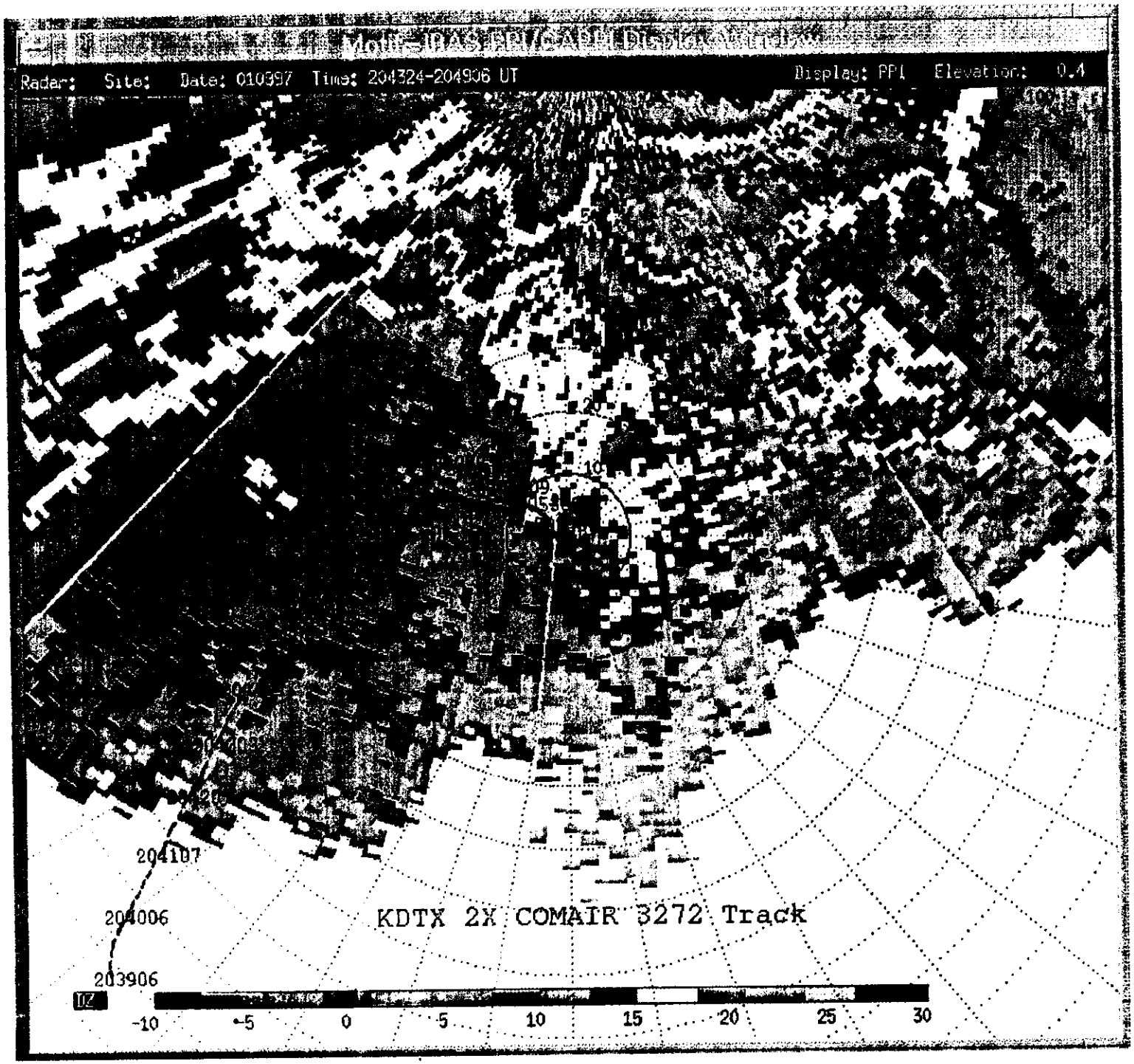
NWA 272

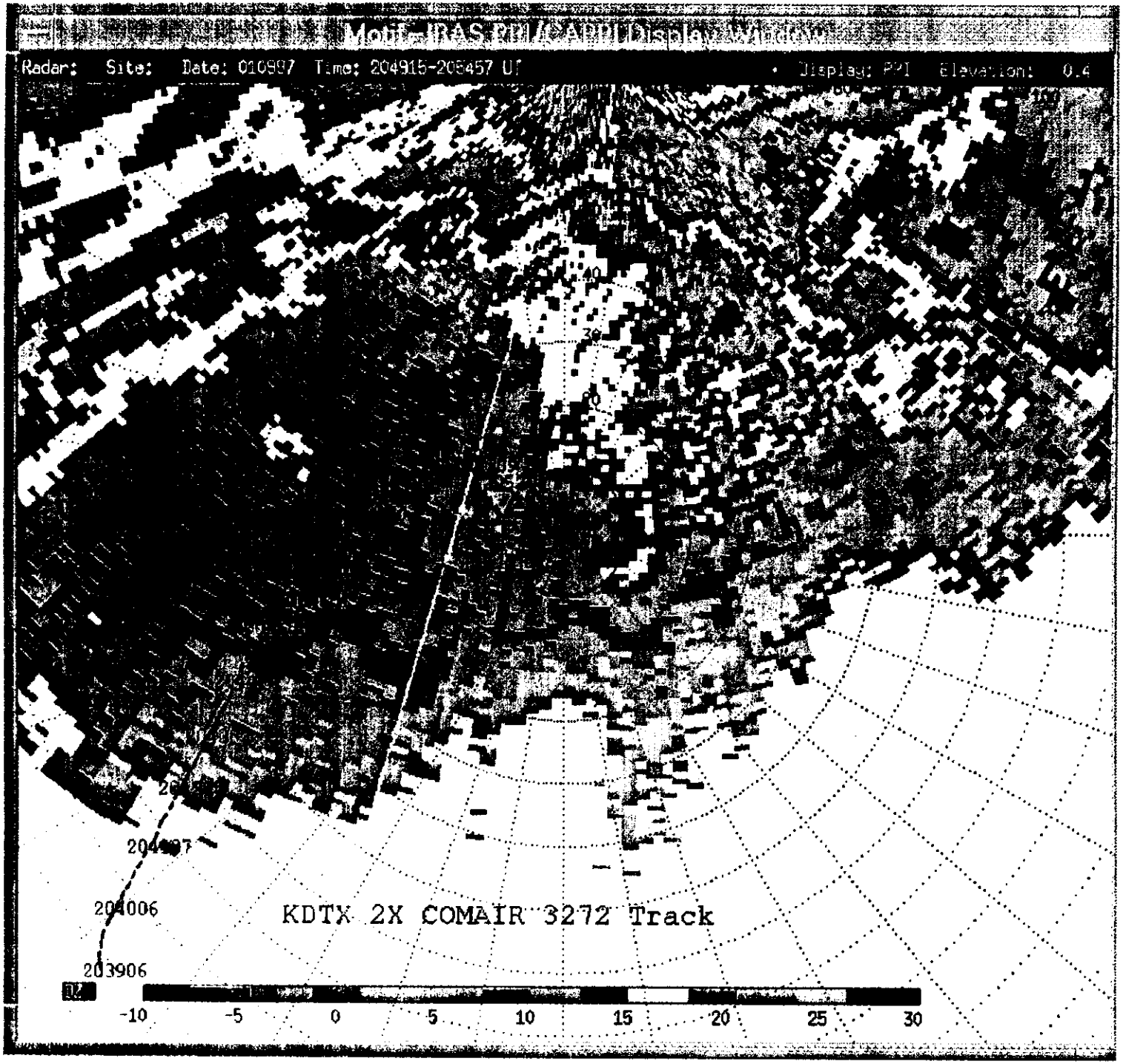

Flight Track X-Section
21:00:57
20:55:05
Height
20
16
12
8
4
0
205503
205603
205703
HHMMSS
205803
205903
210004
km
Blend1
Blend2
Blend3
-1.0
-1.5
-2.0
8.5
8.0
8.5
7.5
8.0
9.0
-1.5
-2.0
-1.5
8.5
-0.5
9.5
10.5
8.5
10.0
10.0
5,900

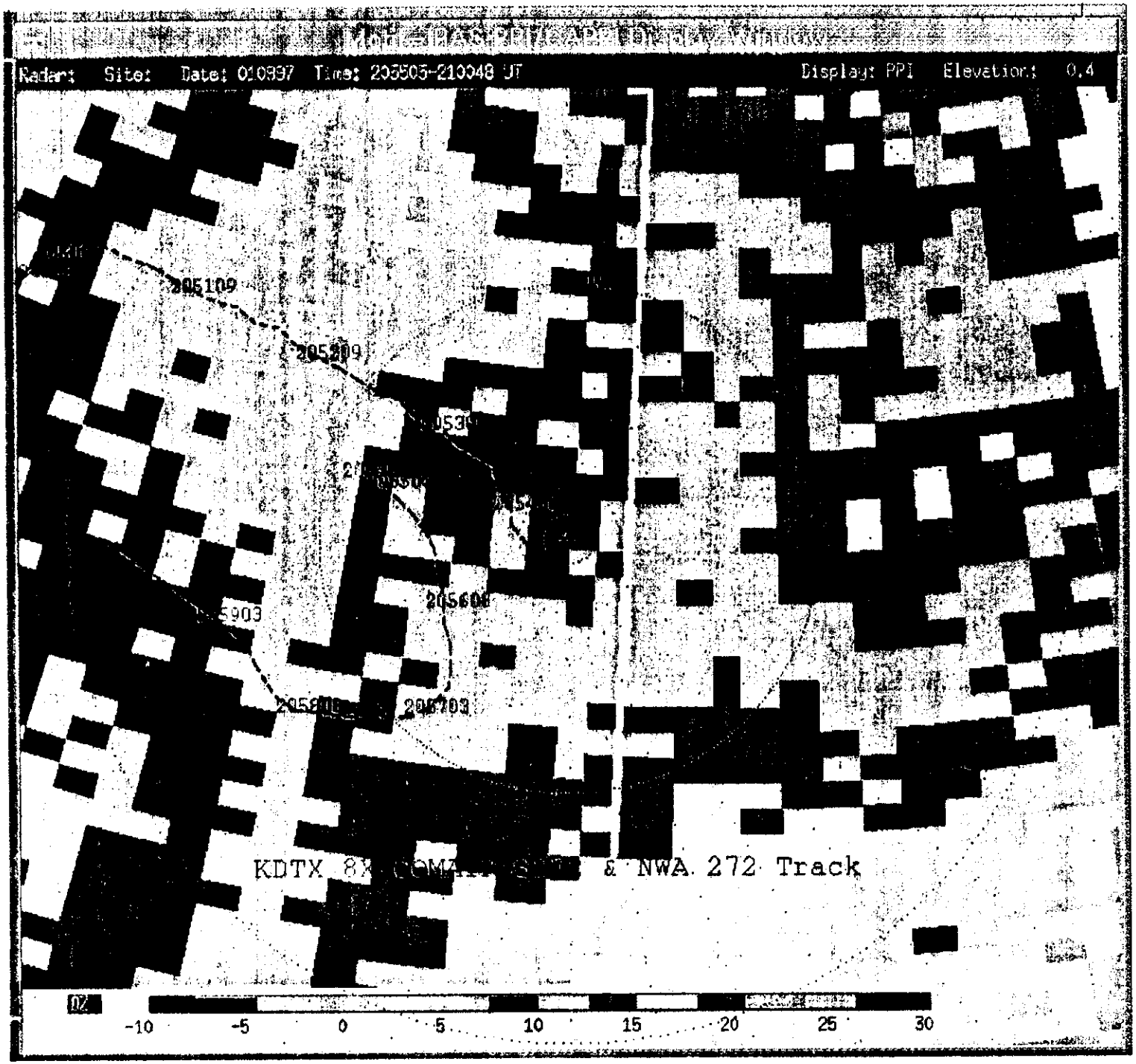
6

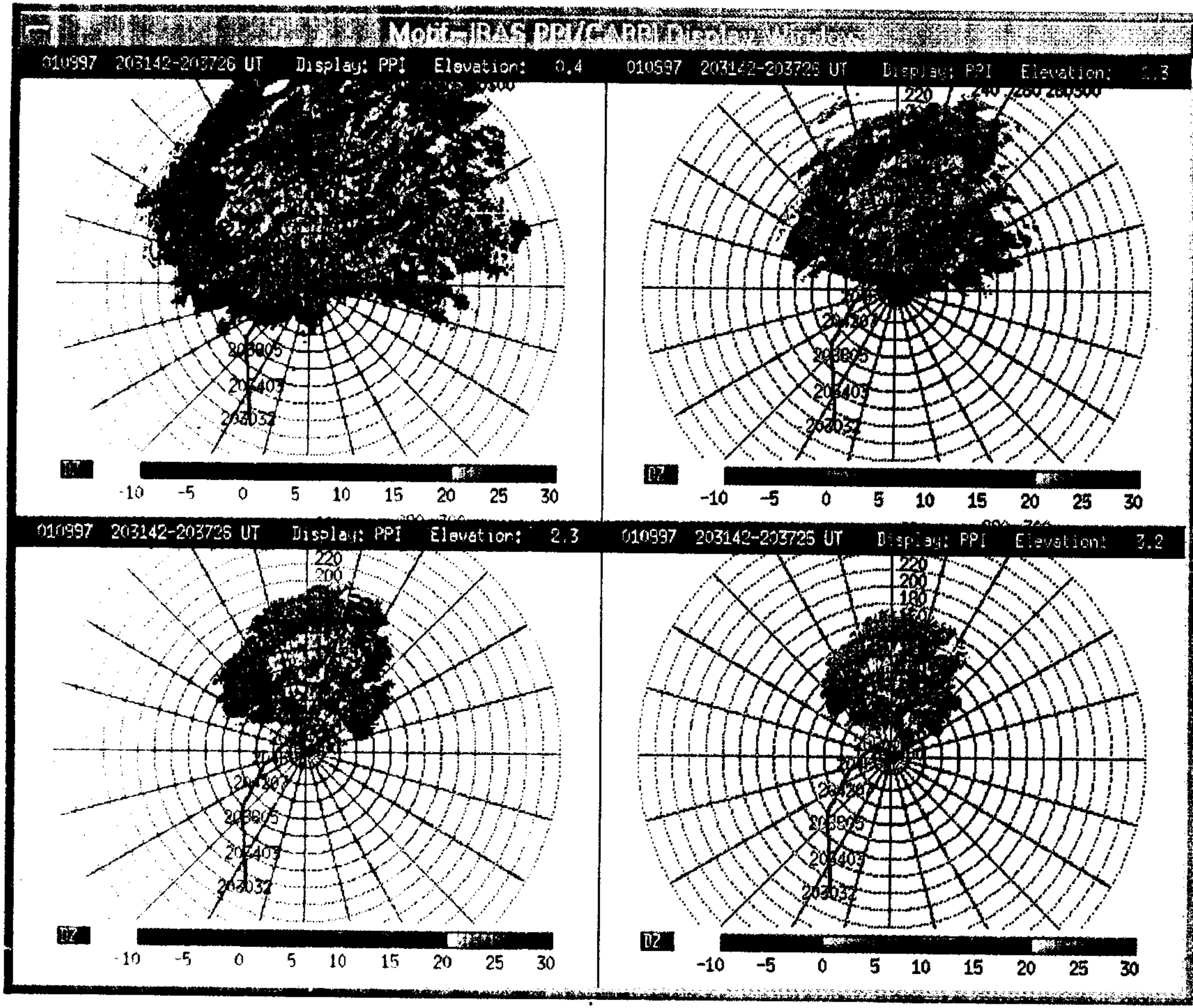

Radar: Site: Date: 010997 Time: 203733-204316 UT
Display: PPI Elevation: 0.4
204107
204006
203906
KDTX 2X COMAIR 9272-Track
DZ
-10
-5
0
5
10
15
20
25
30

7

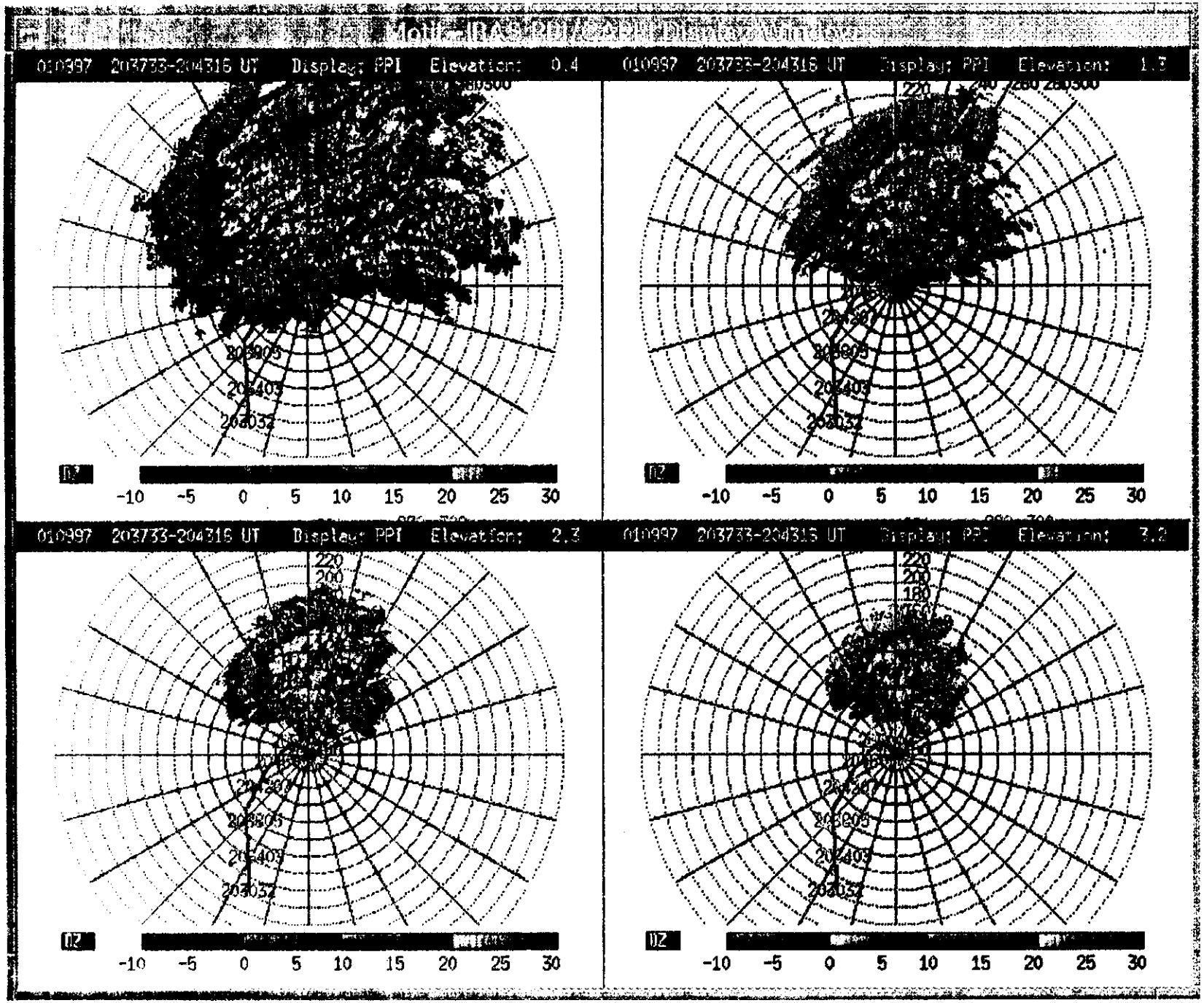

Radar: Site: Date: 010397 Time: 204324-204906 UT
Display: PPI Elevation: 0.4
204107
204006
203906
KDTX 2X COMAIR 3272 Track
DZ
-10 -5 0 5 10 15 20 25 30

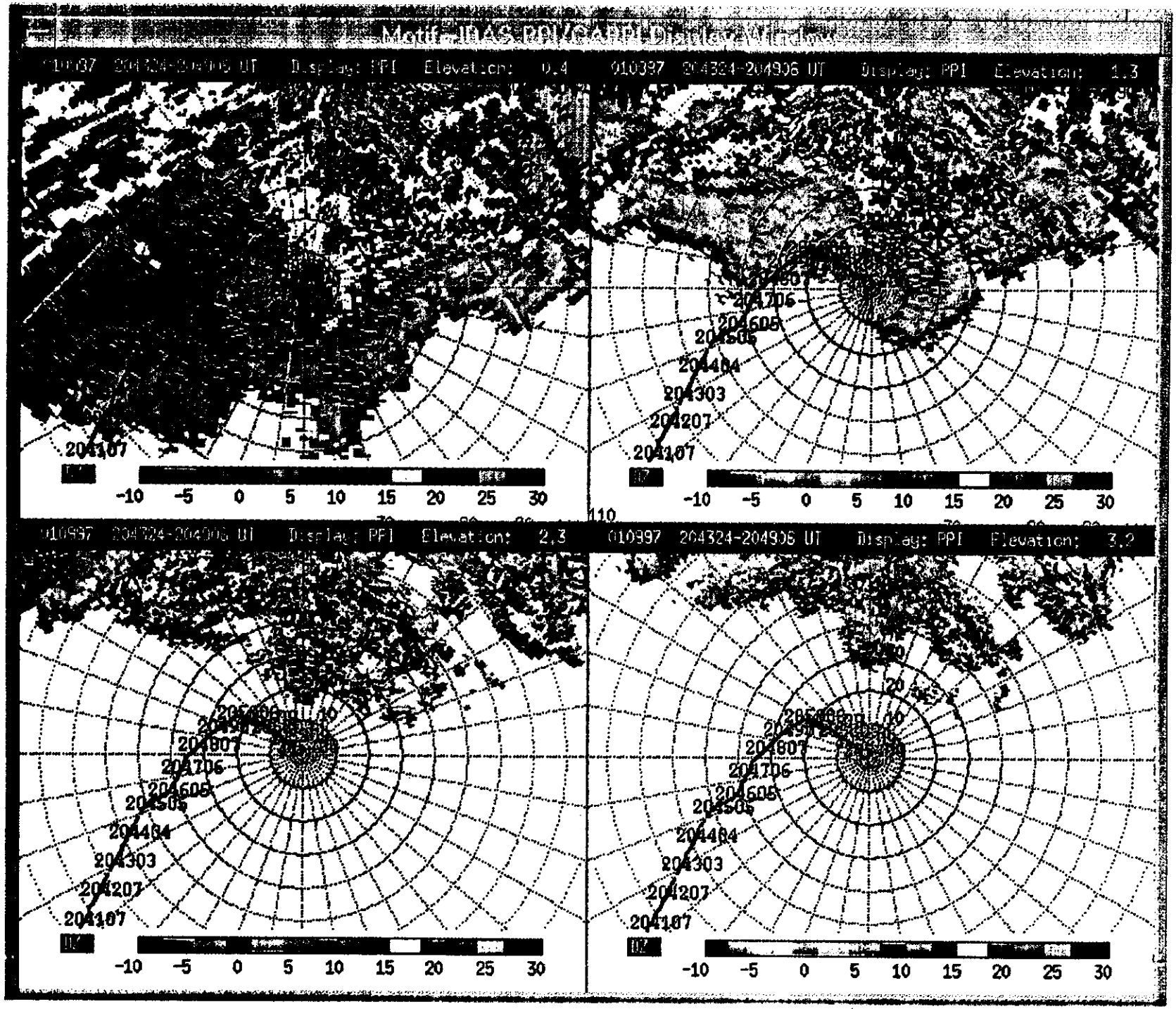

Motif - IRAS RDA/APPI Display Window
Radar: Site: Date: 010997 Time: 204915-205457 UT
Display: PPI Elevation: 0.4
204907
204006
203906
KDTX 2X COMAIR 3272 Track
dBZ
-10
-5
0
5
10
15
20
25
30


Radar: Site: Date: 010897 Time: 205505-210048 UT
Display: PPI Elevation: 0.4
205109
205209
205609
205703
KDTX 8X
& NWA 272 Track
dBZ
-10
-5
0
5
10
15
20
25
30


Mobile-IRAS PPI/CAPPI Display Window
010997 203142-203726 UT Display: PPI Elevation: 0.4
010997 203142-203726 UT Display: PPI Elevation: 1.3
010997 203142-203726 UT Display: PPI Elevation: 2.3
010997 203142-203726 UT Display: PPI Elevation: 3.2
DZ
-10 -5 0 5 10 15 20 25 30

(11)


010997 203733-204316 UT Display: PPI Elevation: 0.4
010997 203733-204316 UT Display: PPI Elevation: 1.3
010997 203733-204316 UT Display: PPI Elevation: 2.3
010997 203733-204316 UT Display: PPI Elevation: 3.2
DZ
-10 -5 0 5 10 15 20 25 30


010397 204324-204906 UT Display: PPI Elevation: 0.4
010397 204324-204906 UT Display: PPI Elevation: 1.3
010997 204324-204906 UT Display: PPI Elevation: 2.3
010997 204324-204906 UT Display: PPI Elevation: 3.2
204107
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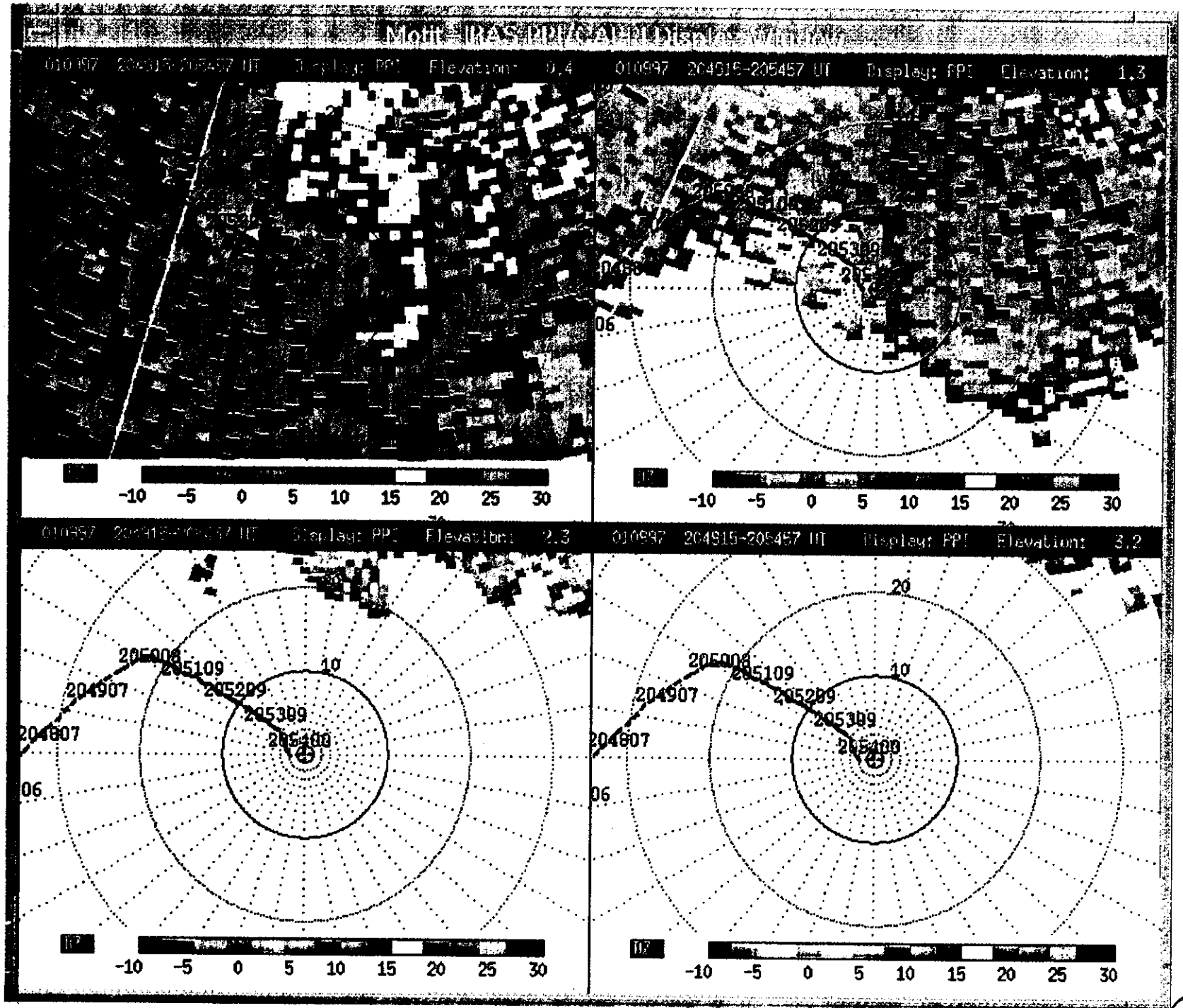
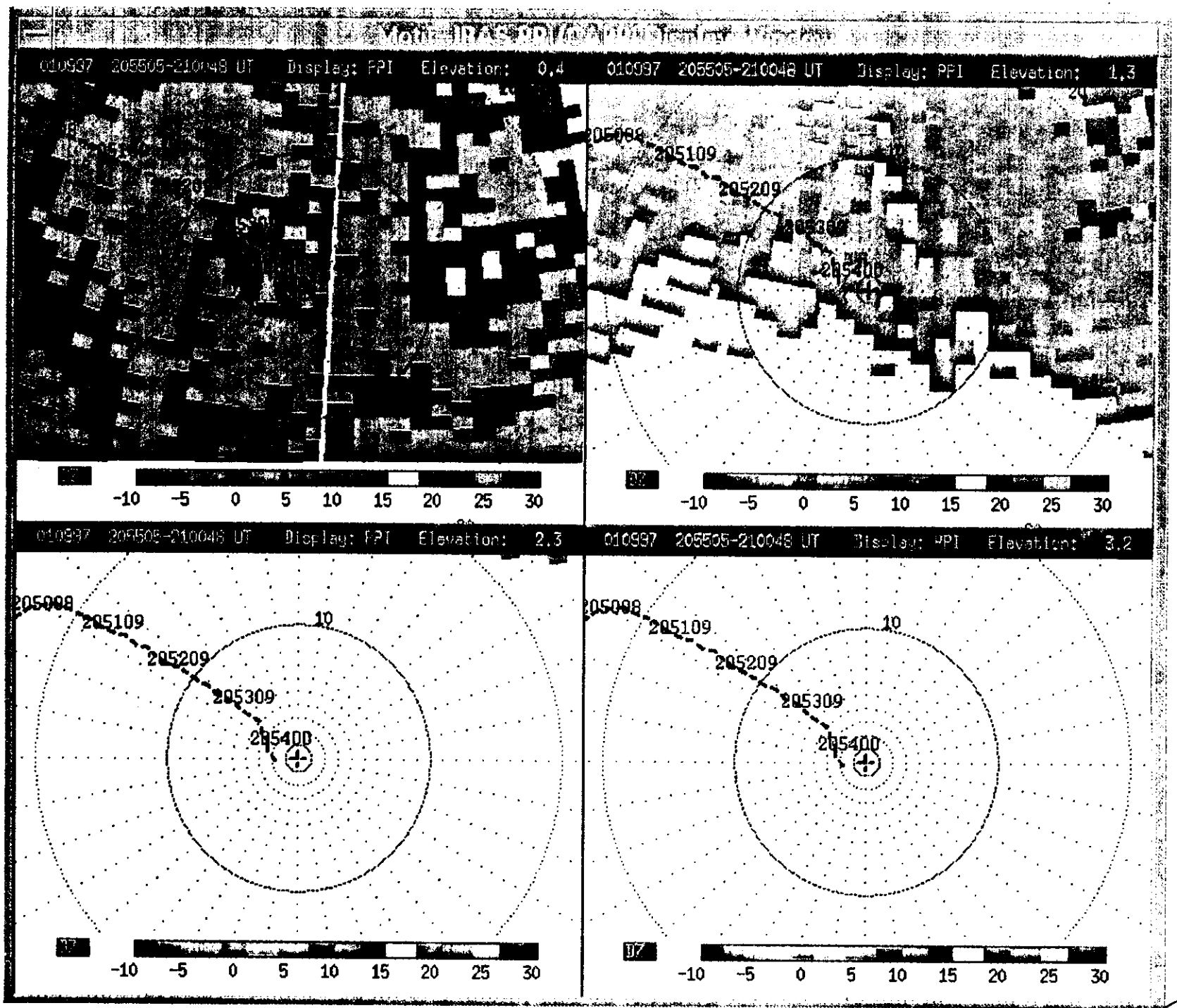
204404
204505
204606
204706
204807
-10 -5 0 5 10 15 20 25 30

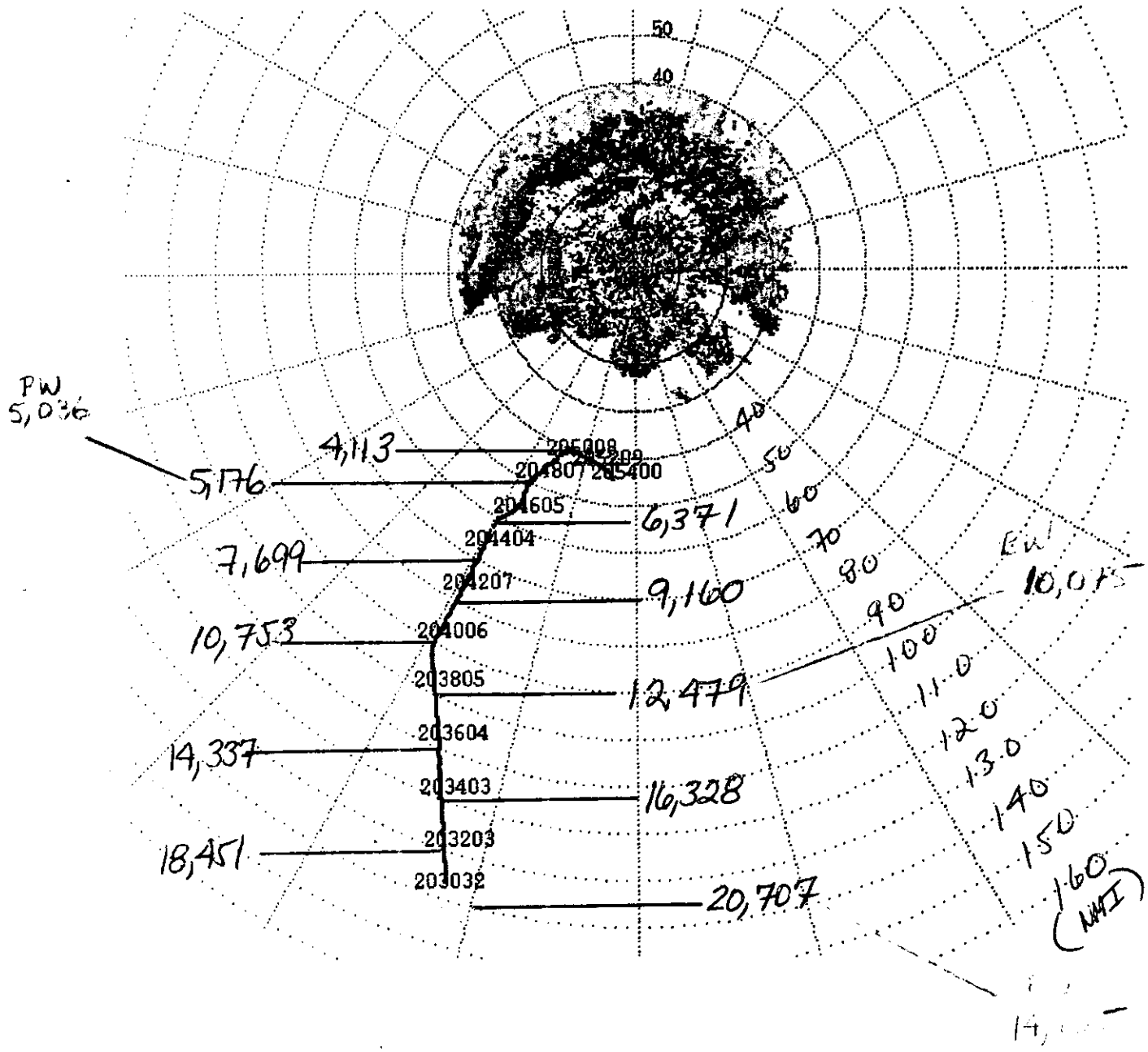

010997 204915-205457 UT Display: PPI Elevation: 0.4
010997 204915-205457 UT Display: PPI Elevation: 1.3
010997 204915-205457 UT Display: PPI Elevation: 2.3
010997 204915-205457 UT Display: PPI Elevation: 3.2
-10 -5 0 5 10 15 20 25 30
205008
205109
204907
205209
205309
204807
205409
10
20
06


010997 205505-210048 UT Display: PPI Elevation: 0.4
010997 205505-210048 UT Display: PPI Elevation: 1.3
010997 205505-210048 UT Display: PPI Elevation: 2.3
010997 205505-210048 UT Display: PPI Elevation: 3.2
205008
205109
205209
205309
205400
10
-10 -5 0 5 10 15 20 25 30

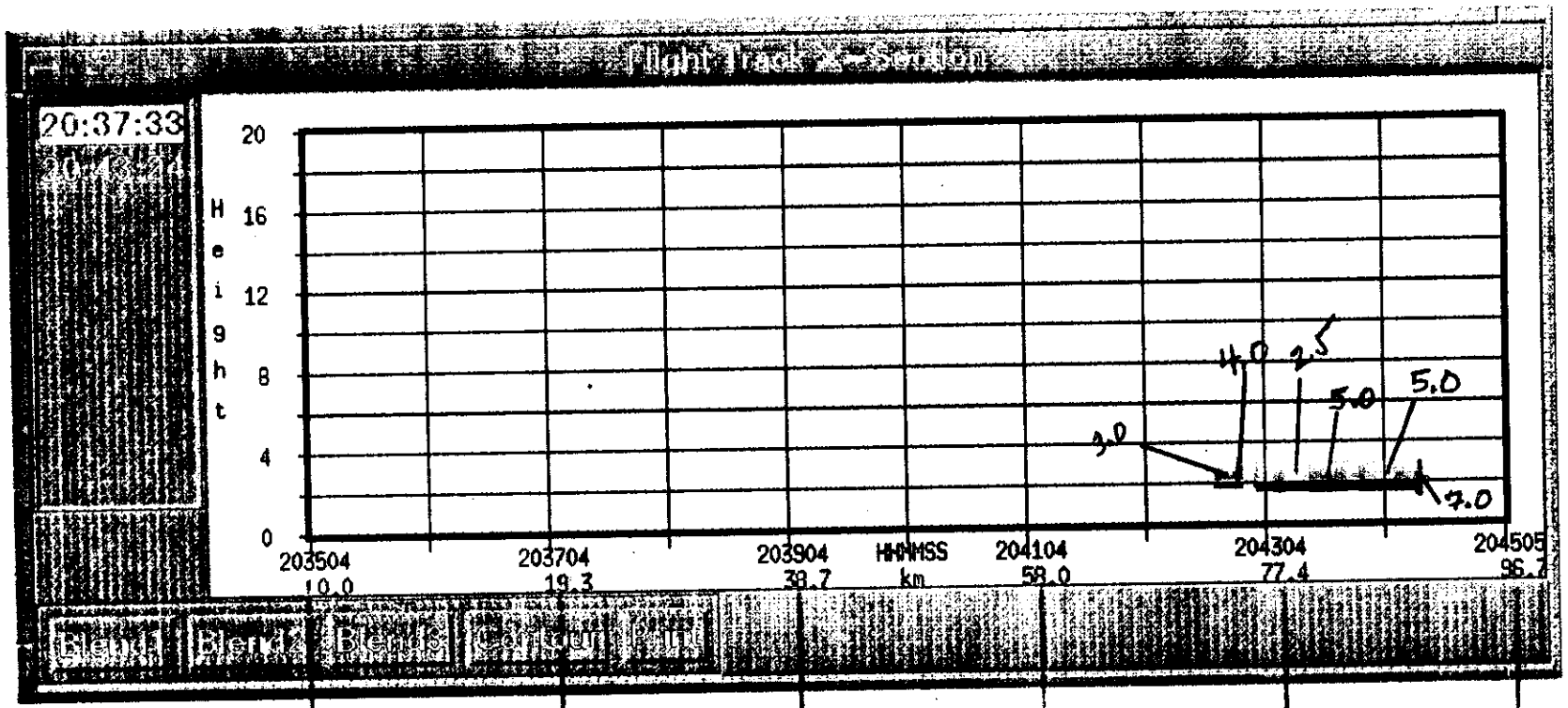
15

KDIX

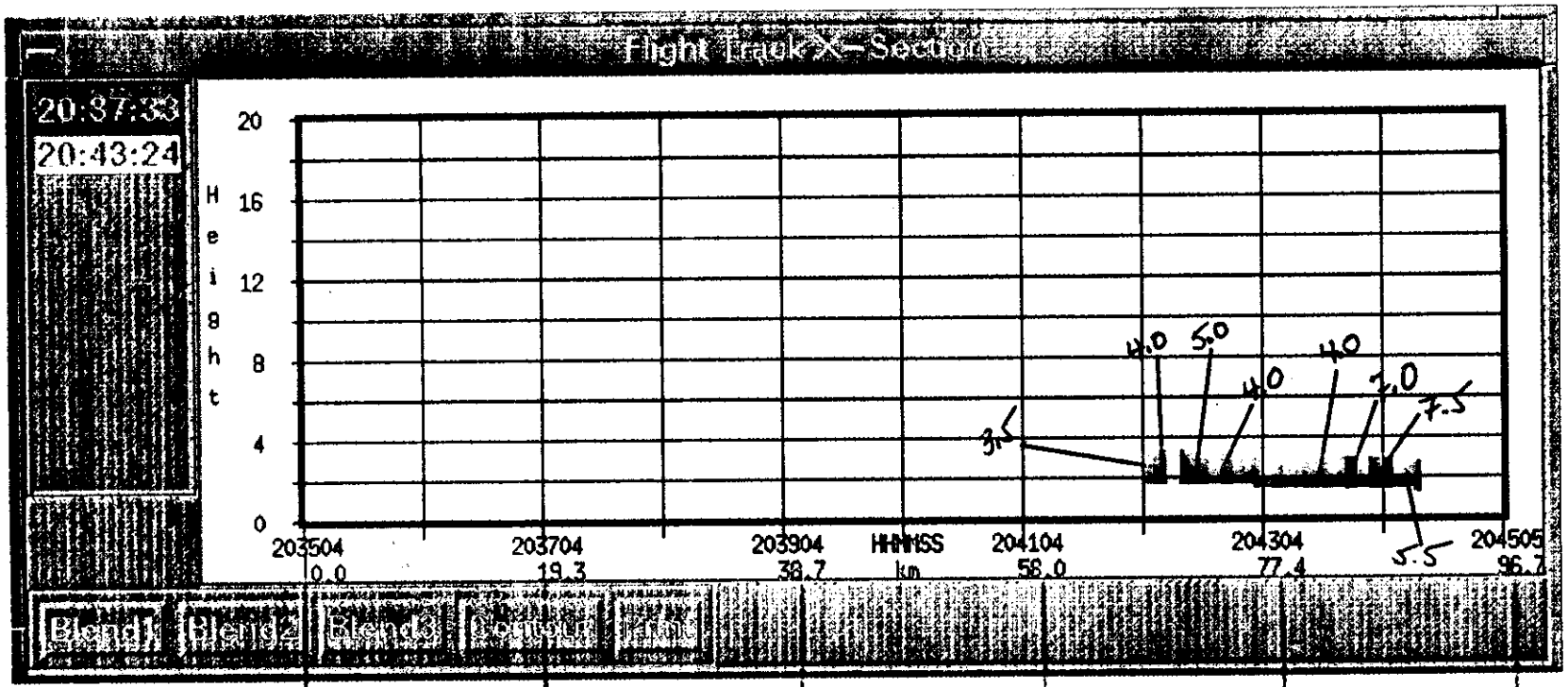
Radar Beam Center (feet msl)



COMAIR 3272

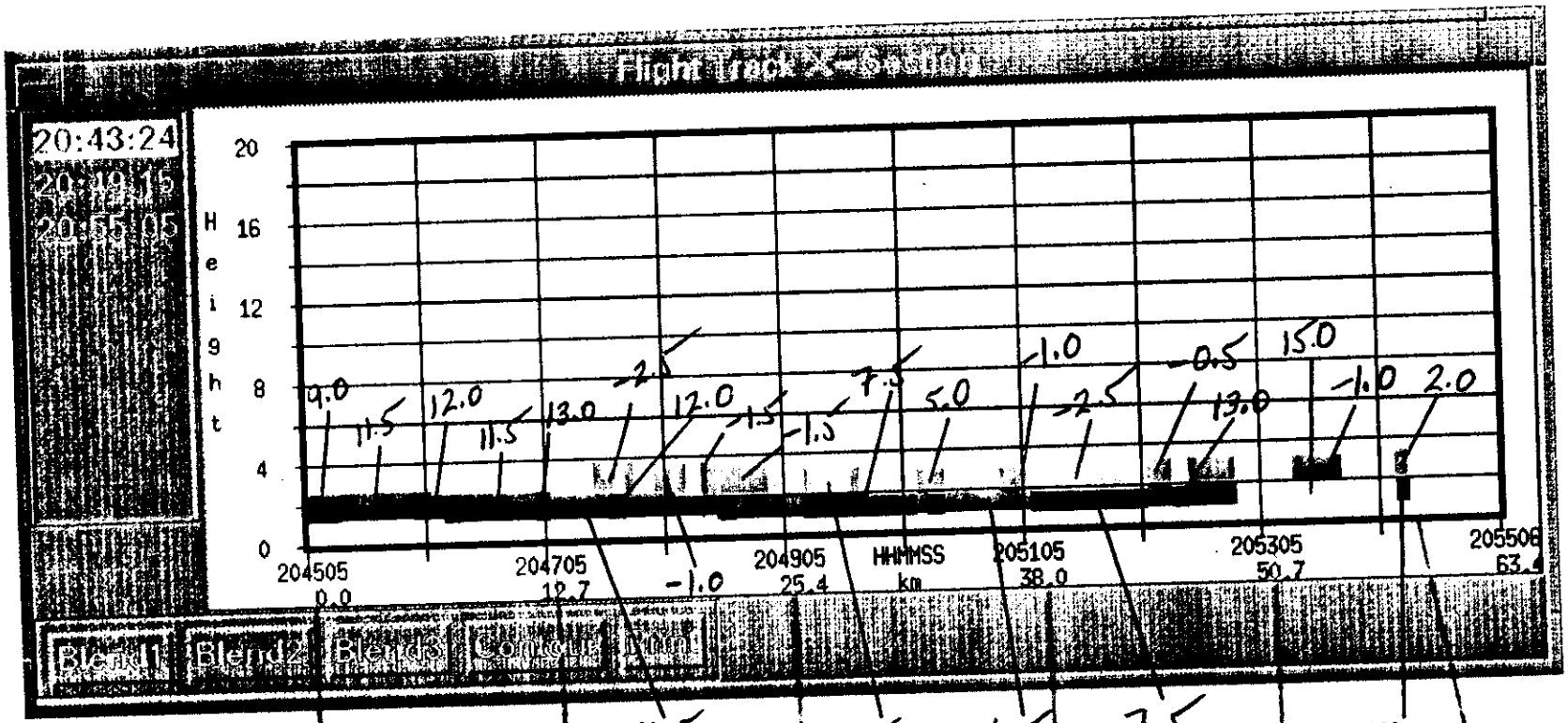

Flight Track - Section
20:37:33
Height
20
16
12
8
4
0
4.0
2.5
5.0
5.0
3.0
7.0
203504
10.0
203704
19.3
203904
38.7
HHMMSS
km
204104
58.0
204304
77.4
204505
96.7
Blend1
Blend2
Blend3
Cartesian
Print

COMAIR 3272

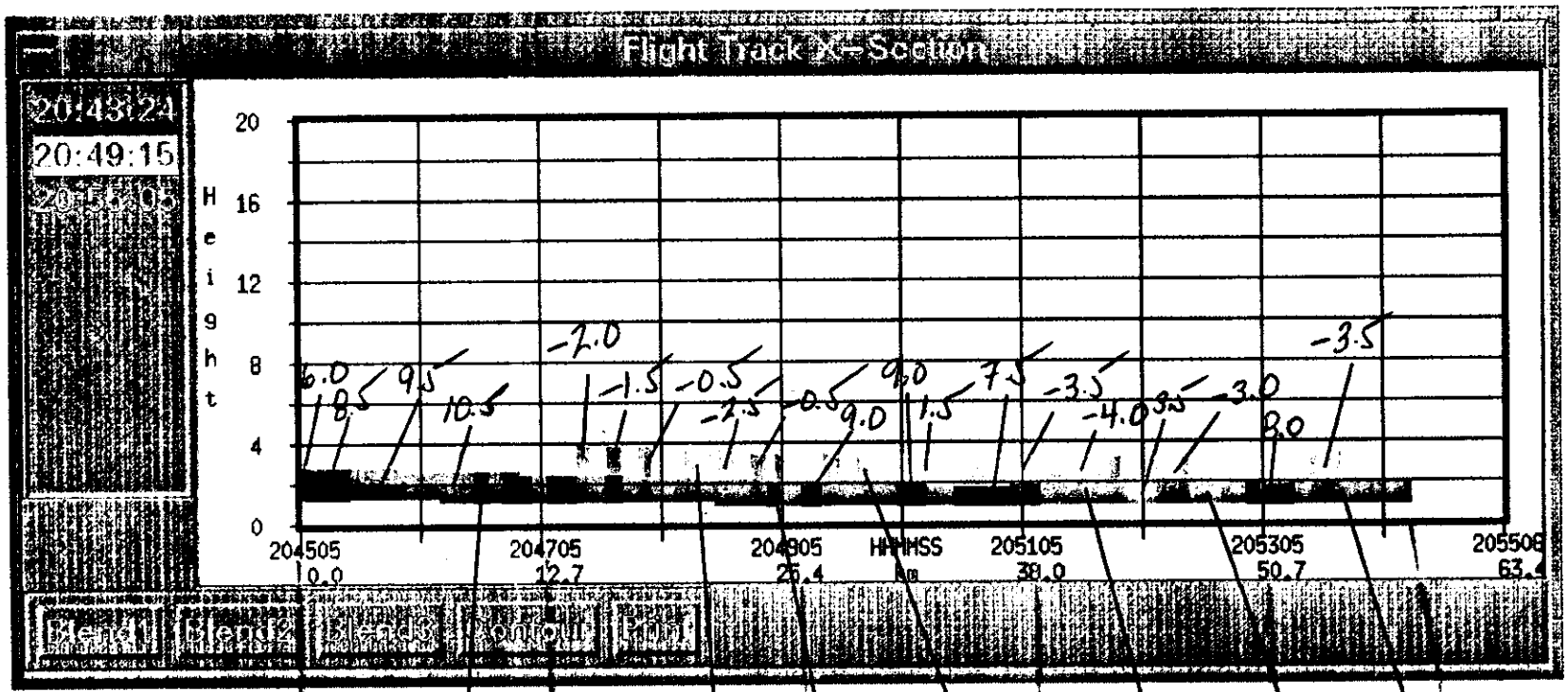


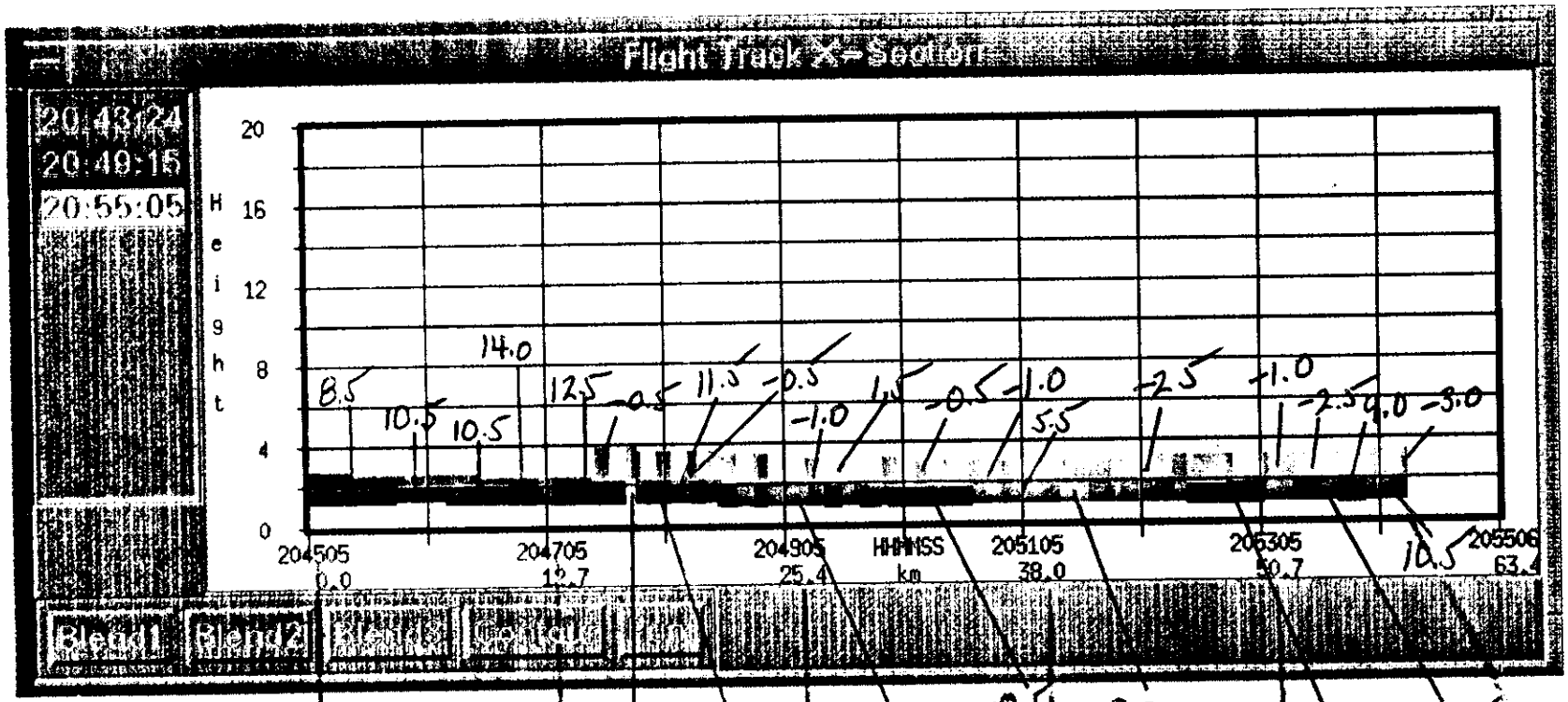
21,000'

COMAIR 3272


Flight Track X-Section
20:43:24
20:19:15
20:55:05
Height
20
16
12
8
4
0
9.0
11.5
12.0
11.5
13.0
2.5
12.0
1.5
1.5
7.5
5.0
1.0
2.5
0.5
13.0
15.0
1.0
2.0
204505
0.0
204705
12.7
-1.0
204905
25.4
HHMMSS
km
205105
38.0
205305
50.7
205506
63.4
Blend1
Blend2
Blend3
Control
Run
11.5
1.5
6.5
7.5
14.0

COMAIR 3272


Flight Track X-Section
20:43:24
20:49:15
Height
20
16
12
8
4
0
204505
0.0
204705
12.7
204905
25.4
HHMMSS
205105
38.0
205305
50.7
205506
63.4
Blend1
Blend2
Blend3
Control
Print
6.0
8.5
9.5
10.5
-2.0
-1.5
-0.5
-2.5
-0.5
9.0
9.0
1.5
7.5
-3.5
-4.0
3.5
-3.0
8.0
-3.5
12.5
-3.0
14.0
-1.0
5.5
3.0
10.0


Flight Track X-Section
20:43:24
20:49:15
20:55:05
Height
20
16
12
8
4
0
204505
0.0
204705
15.7
204905
25.4
HHMMSS
km
205105
38.0
205305
50.7
205506
63.4
Block1
Block2
Block3
8.5
10.5
10.5
14.0
12.5
-0.5
11.5
-0.5
-1.0
1.5
-0.5
-1.0
5.5
-2.5
-1.0
-2.5
-4.0
-3.0
10.5
15.0
12.5
10.5
-0.5
3.0
7.5
9.5

11.0

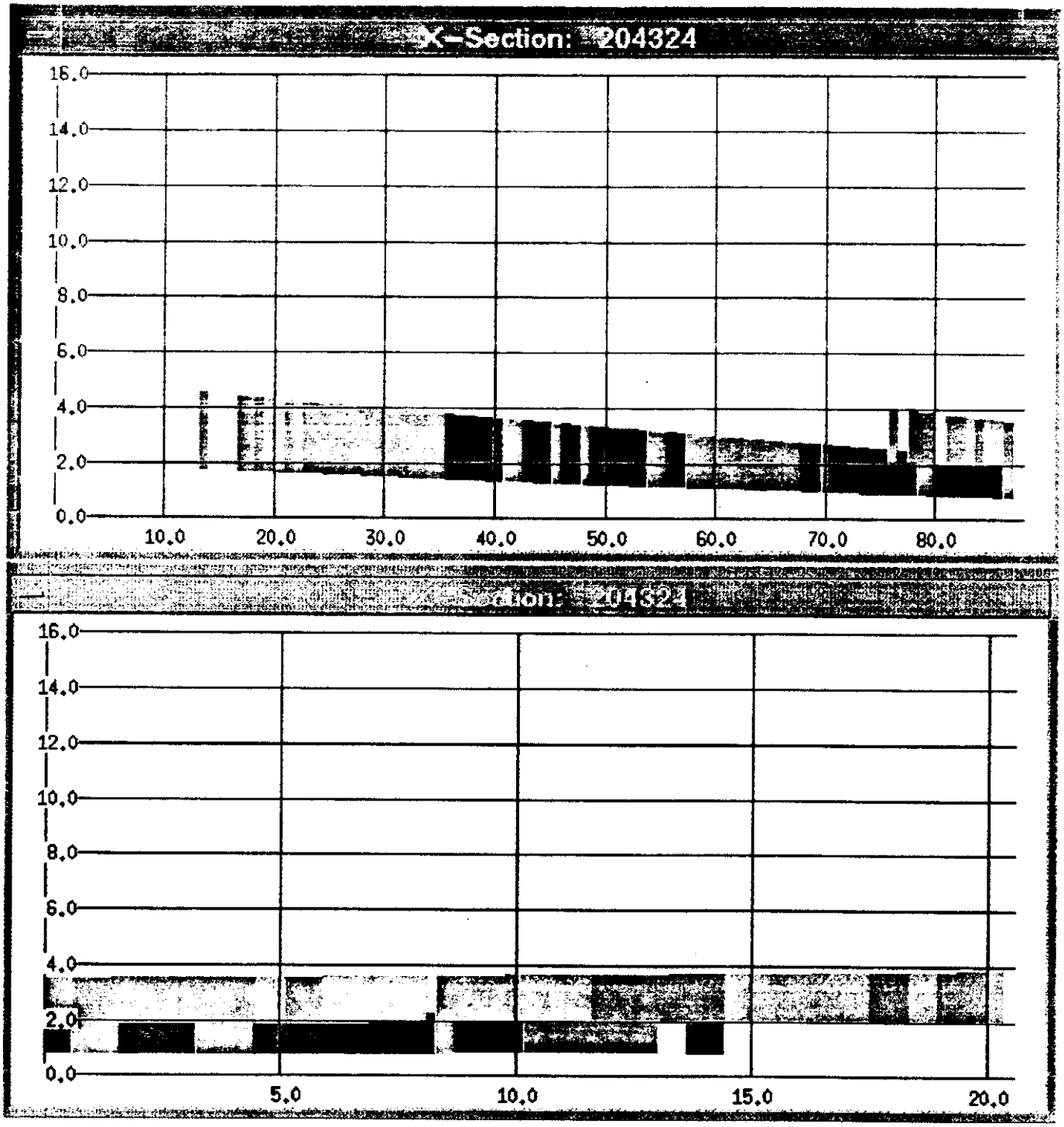
9.7

7

21

COMAIR 3274 TRACK

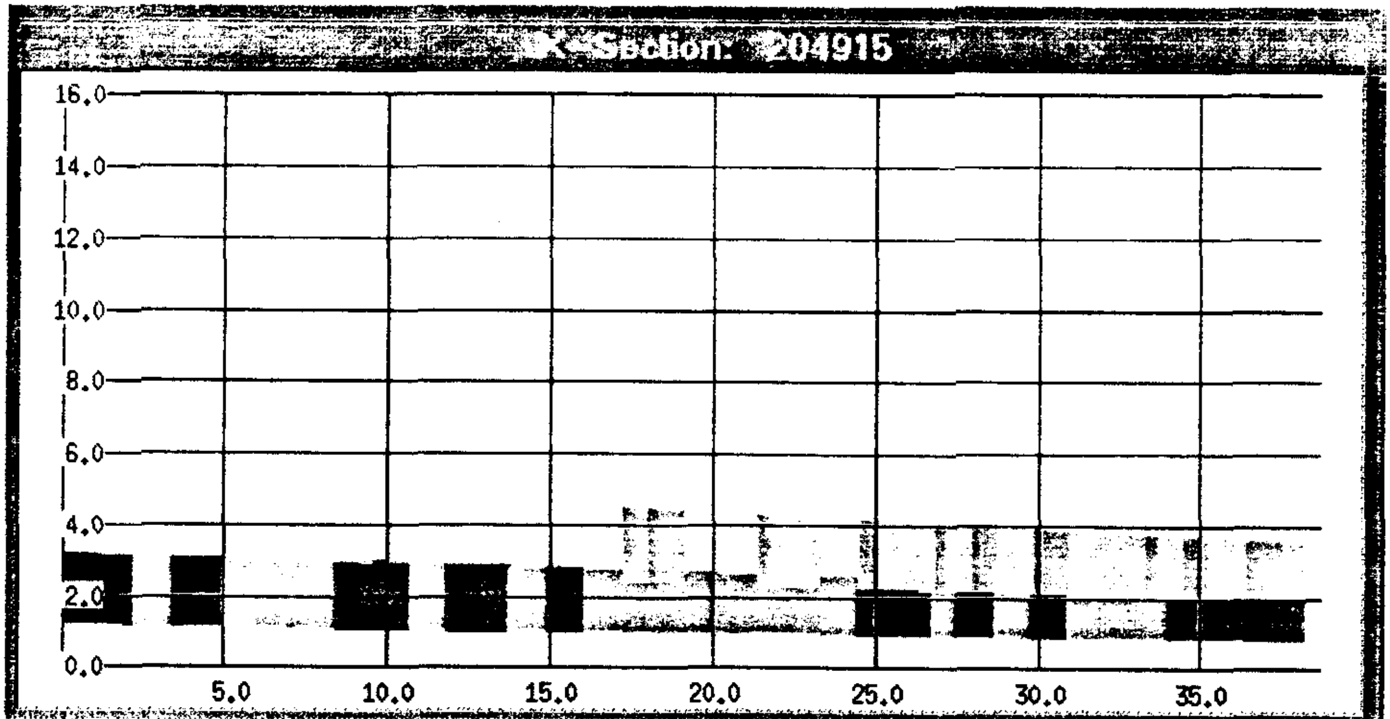
Segment 2040 06Z to 2050:08Z

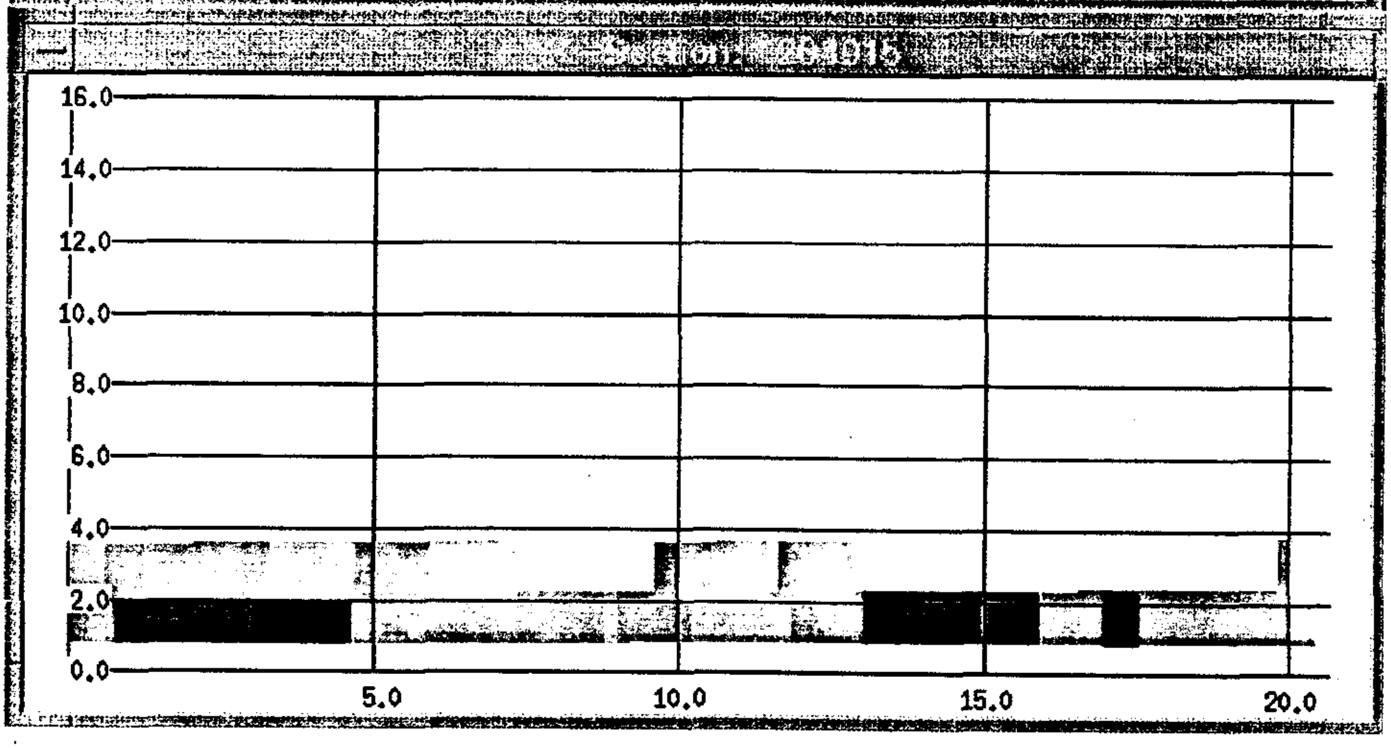


Segment 2050:08Z to Accident Site

22

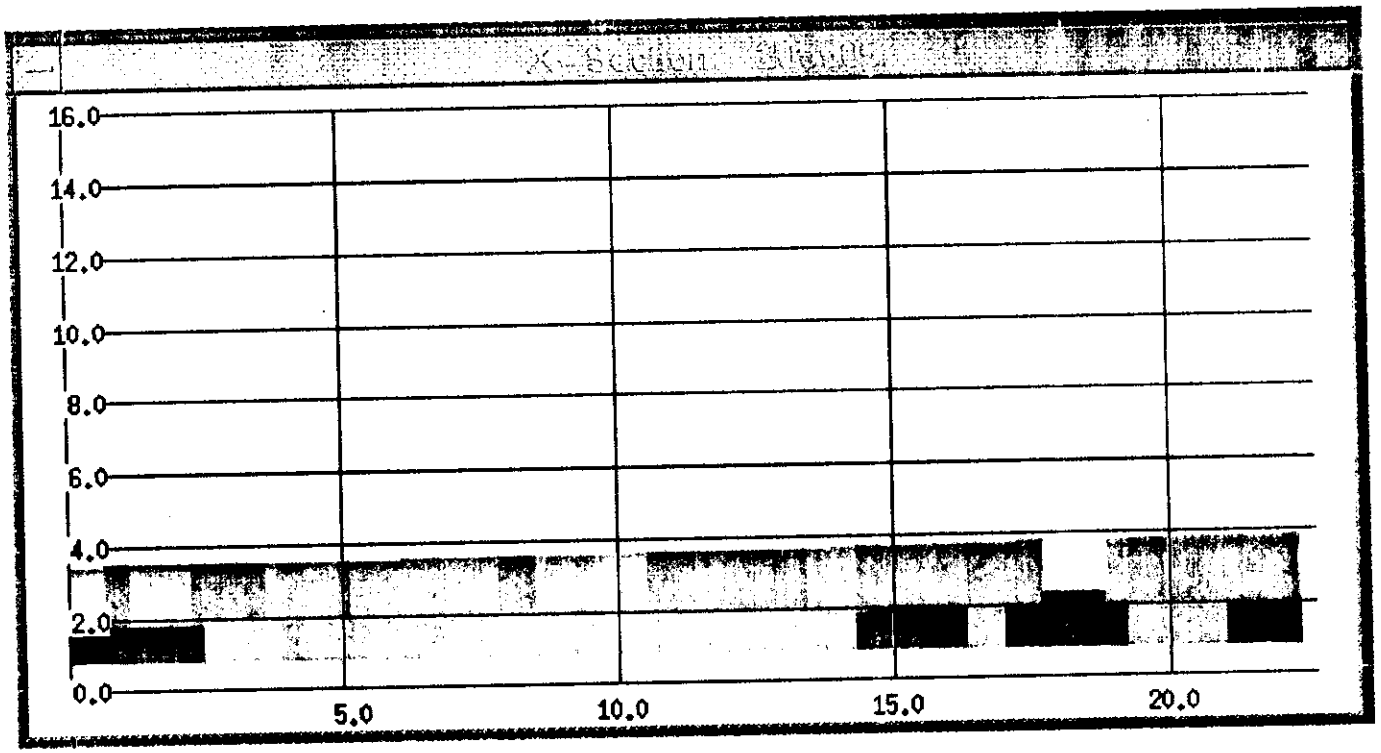
COMAIR 3272 TRACK
Segment 2045 05 to 2050 08





Segment 2050:08 to Accident Site

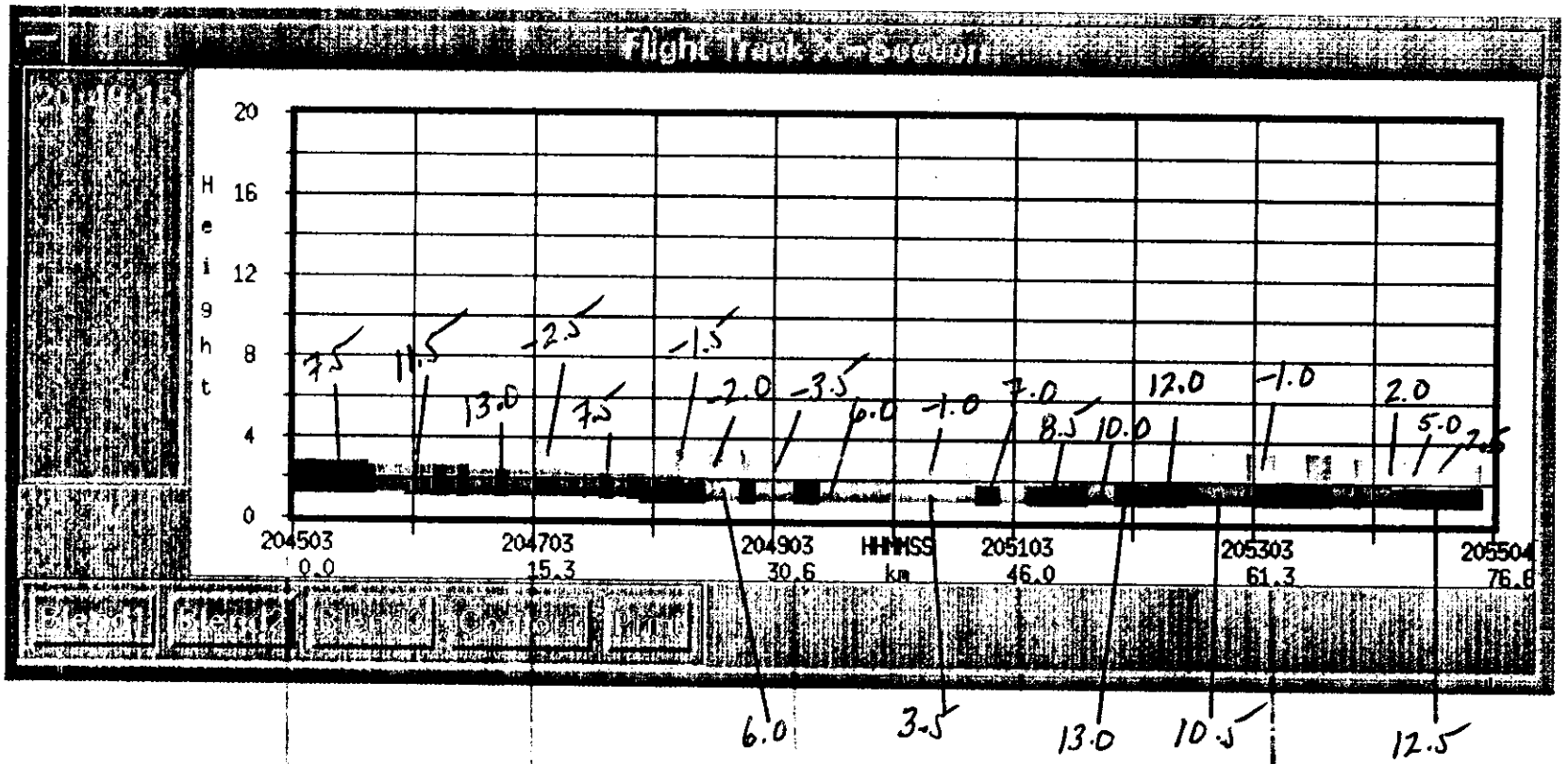
COMAIR 3272 TRACK
Segment 2050:08Z to Accident Site



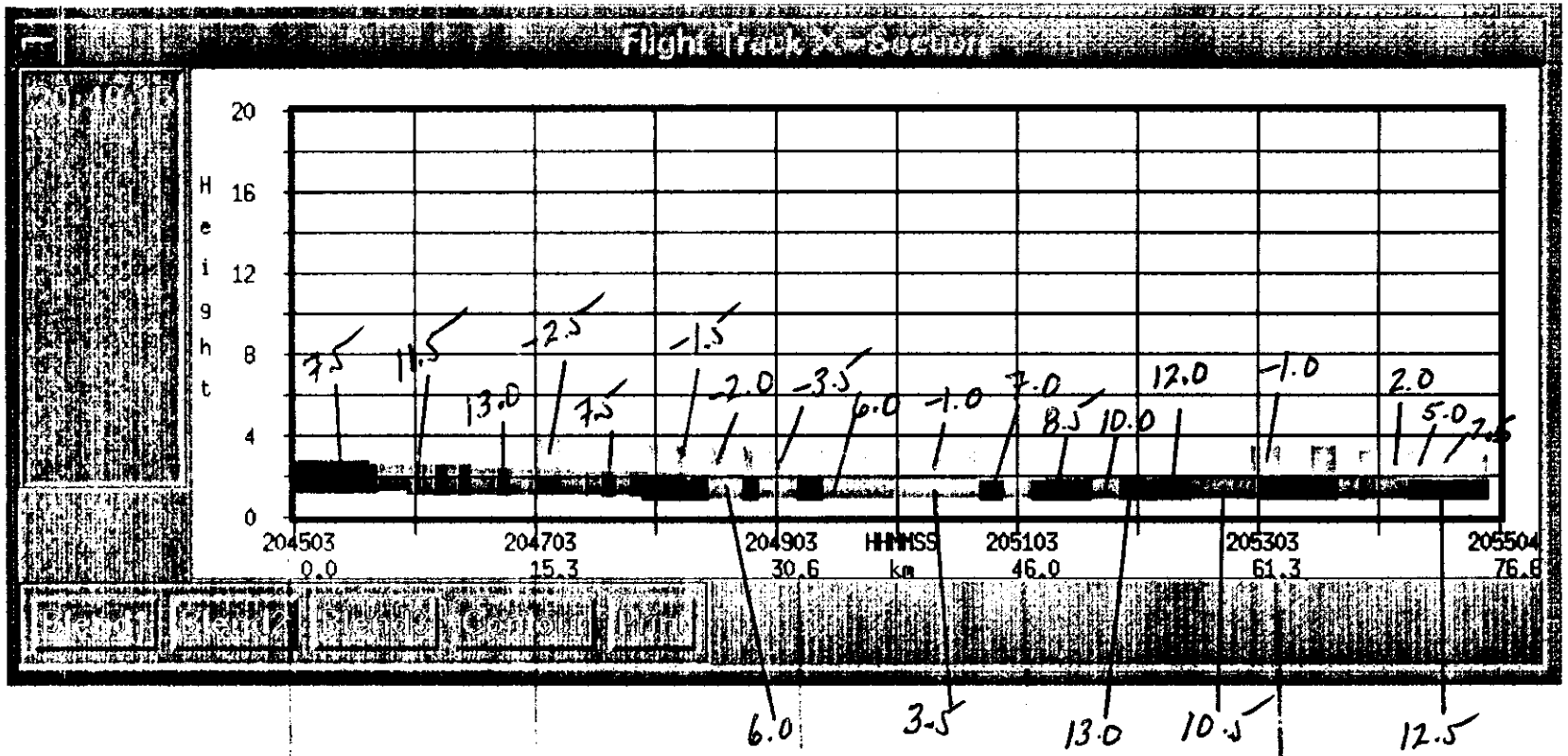
42

24

CACTUS 50


Flight Track X-Section
20040915
Height
20
16
12
8
4
0
204503
0.0
204703
15.3
204903
30.6
HHMMSS
km
205103
46.0
205303
61.3
205504
76.8
Reset
Blend2
Blend3
Control
Print
7.5
11.5
13.0
-2.5
7.5
-1.5
-2.0
-3.5
6.0
-1.0
7.0
8.5
10.0
12.0
-1.0
2.0
5.0
6.0
3.5
13.0
10.5
12.5

CACTUS 50


Flight Track X-Section
Height
20
16
12
8
4
0
204503
0.0
204703
15.3
204903
30.6
HHMMSS
km
205103
46.0
205303
61.3
205504
76.8
7.5
11.5
13.0
2.5
7.5
1.5
2.0
3.5
6.0
1.0
7.0
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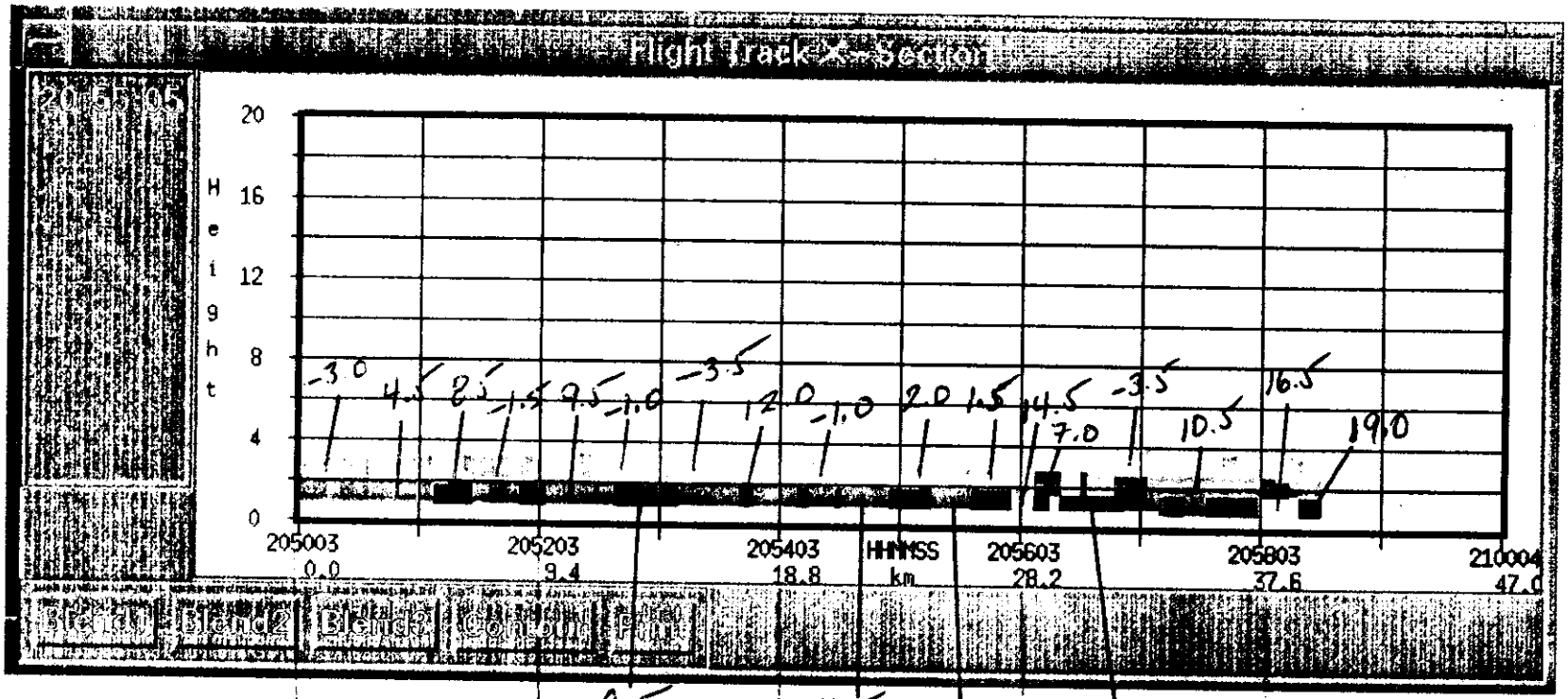
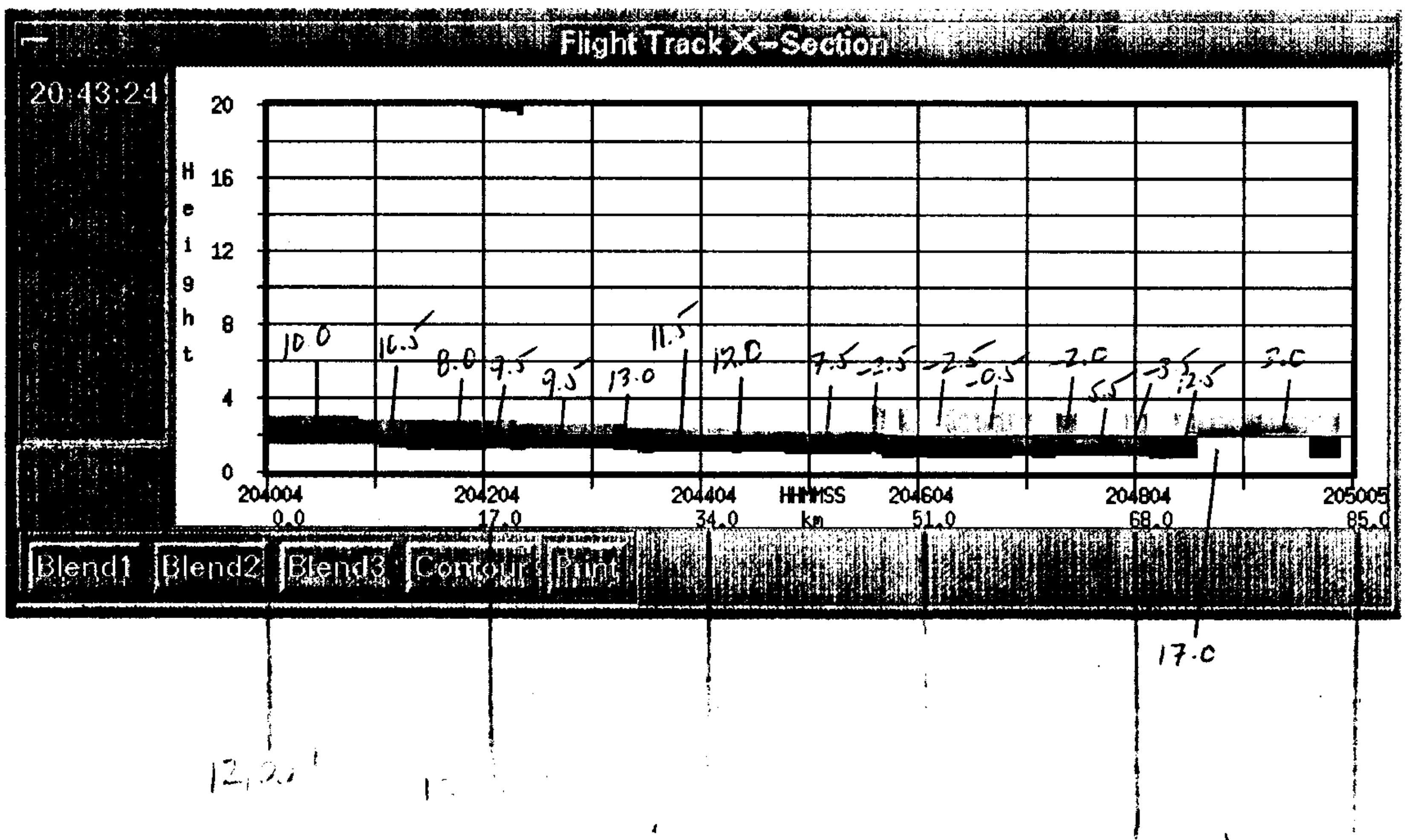
3.5
13.0
10.5
12.5

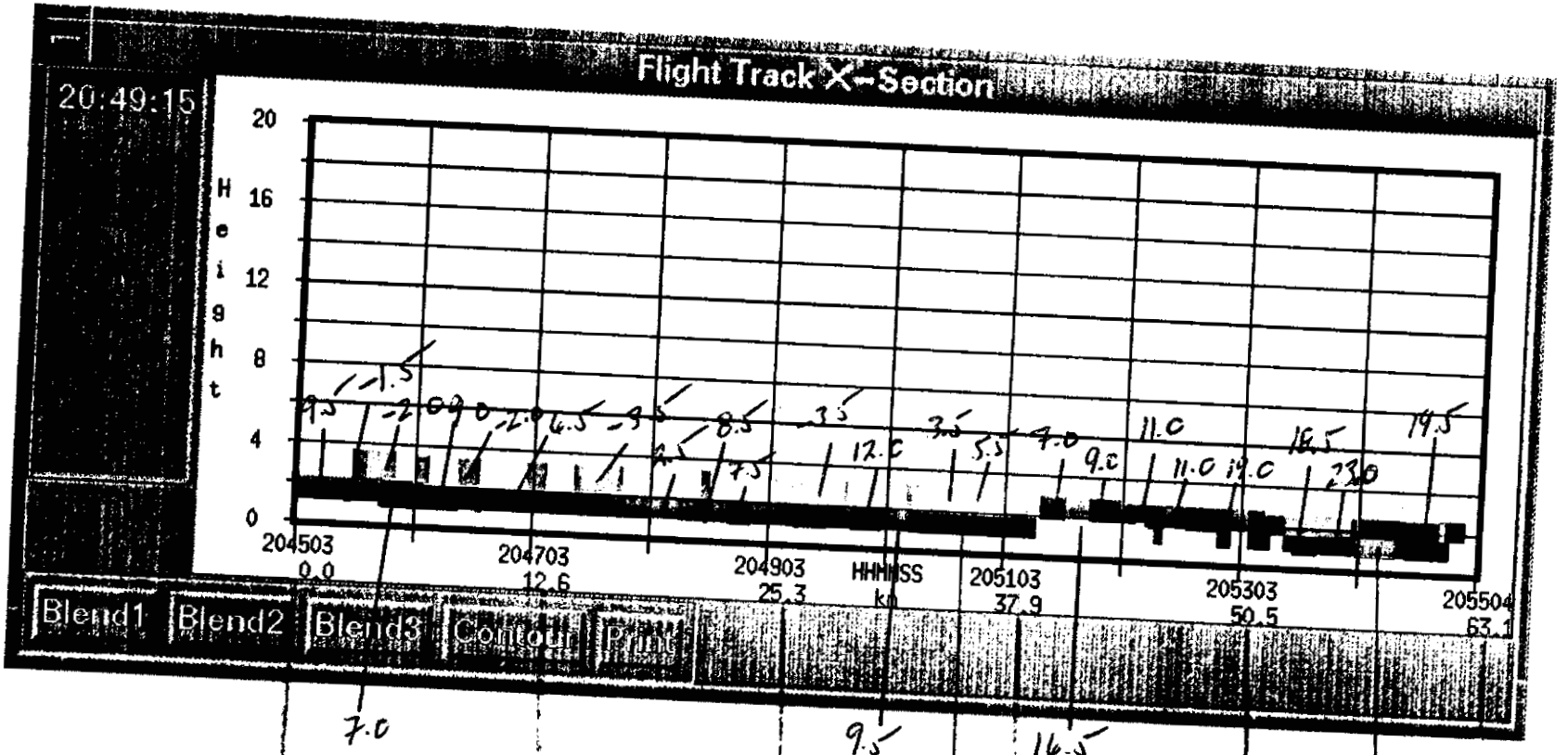
CACTUS 50


Flight Track X-Section
20:55:05
Height
20
16
12
8
4
0
-3.0
4.5
8.5
-1.5
9.5
-1.0
-3.5
12.0
-1.0
2.0
1.5
4.5
7.0
-3.5
10.5
16.5
19.0
205003
0.0
205203
9.4
205403
18.8
HHMMSS
km
205603
28.2
205803
37.6
210004
47.0
Blend1
Blend2
Blend3
Contour
Text
8.5
11.5
11.0
14.0

NWA 483

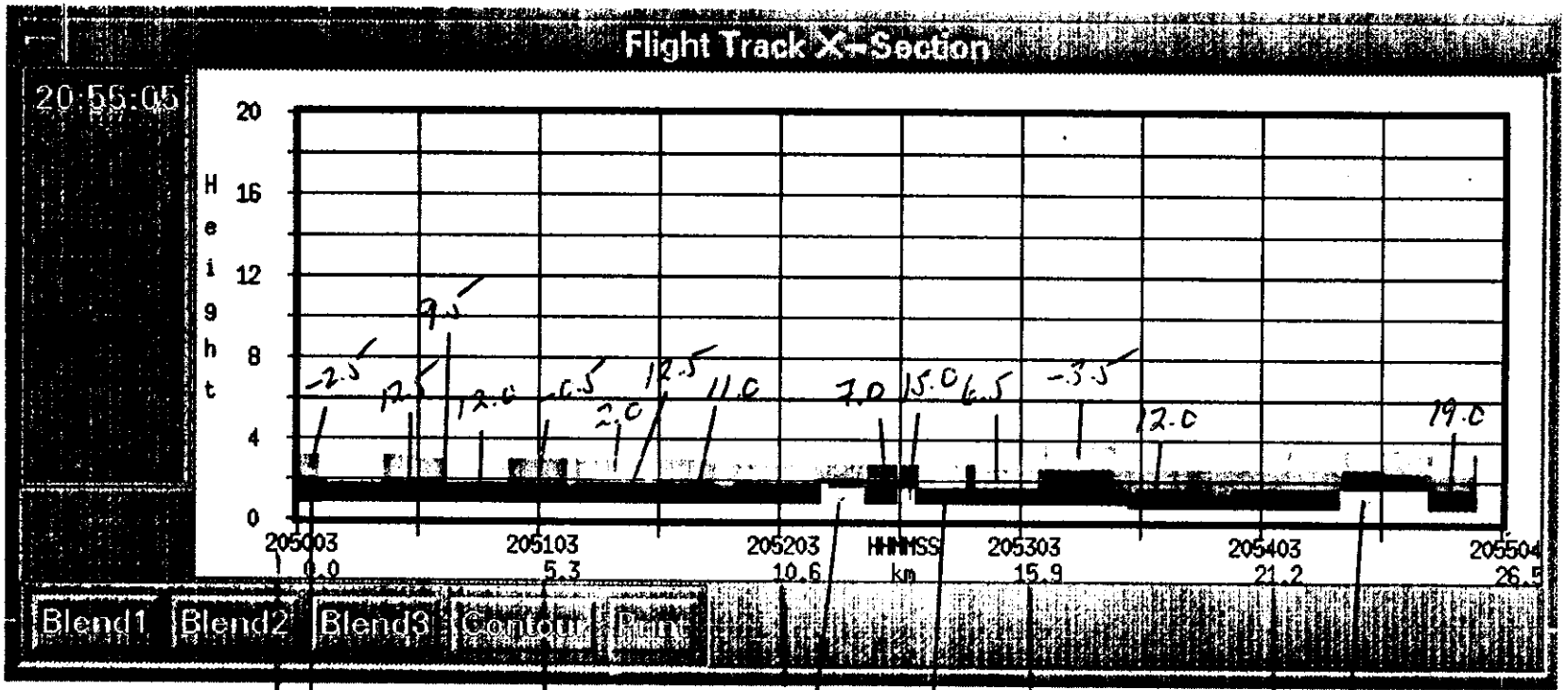

Flight Track X-Section
20:43:24
Height
20
16
12
8
4
0
204004
0.0
204204
17.0
204404
34.0
HHMMSS
km
204604
51.0
204804
68.0
205005
85.0
Blend1
Blend2
Blend3
Contour
Print
10.0
16.5
8.0
9.5
9.5
13.0
11.5
12.0
7.5
17.0

NWA 483



7.0 9.5 13.0 16.5 25.0

NWA 483


Flight Track X-Section
20:55:05
Height
20
16
12
8
4
0
205003
0.0
205103
5.3
205203
10.6
HHMMSS
km
205303
15.9
205403
21.2
205504
26.5
Blend1
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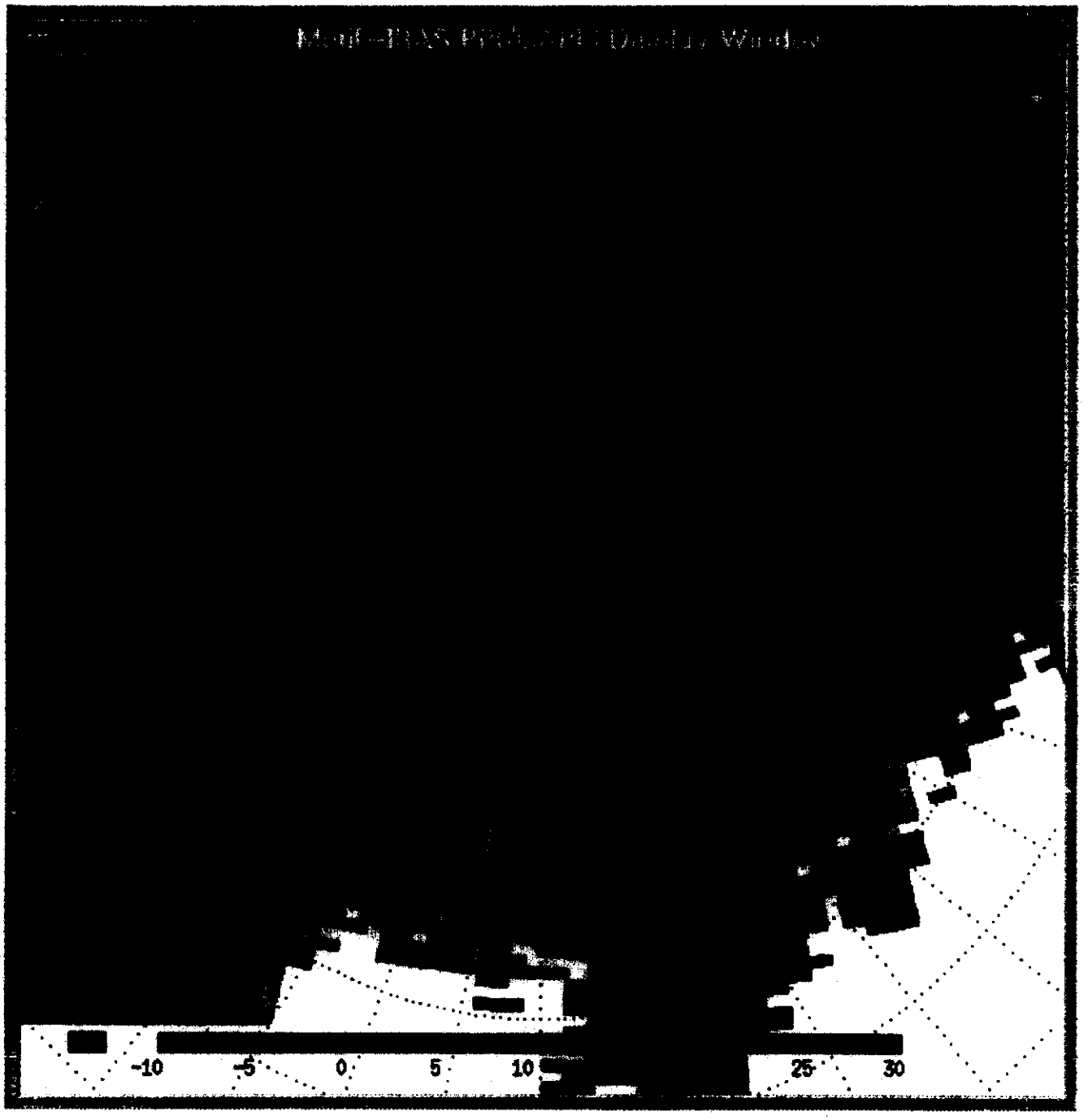
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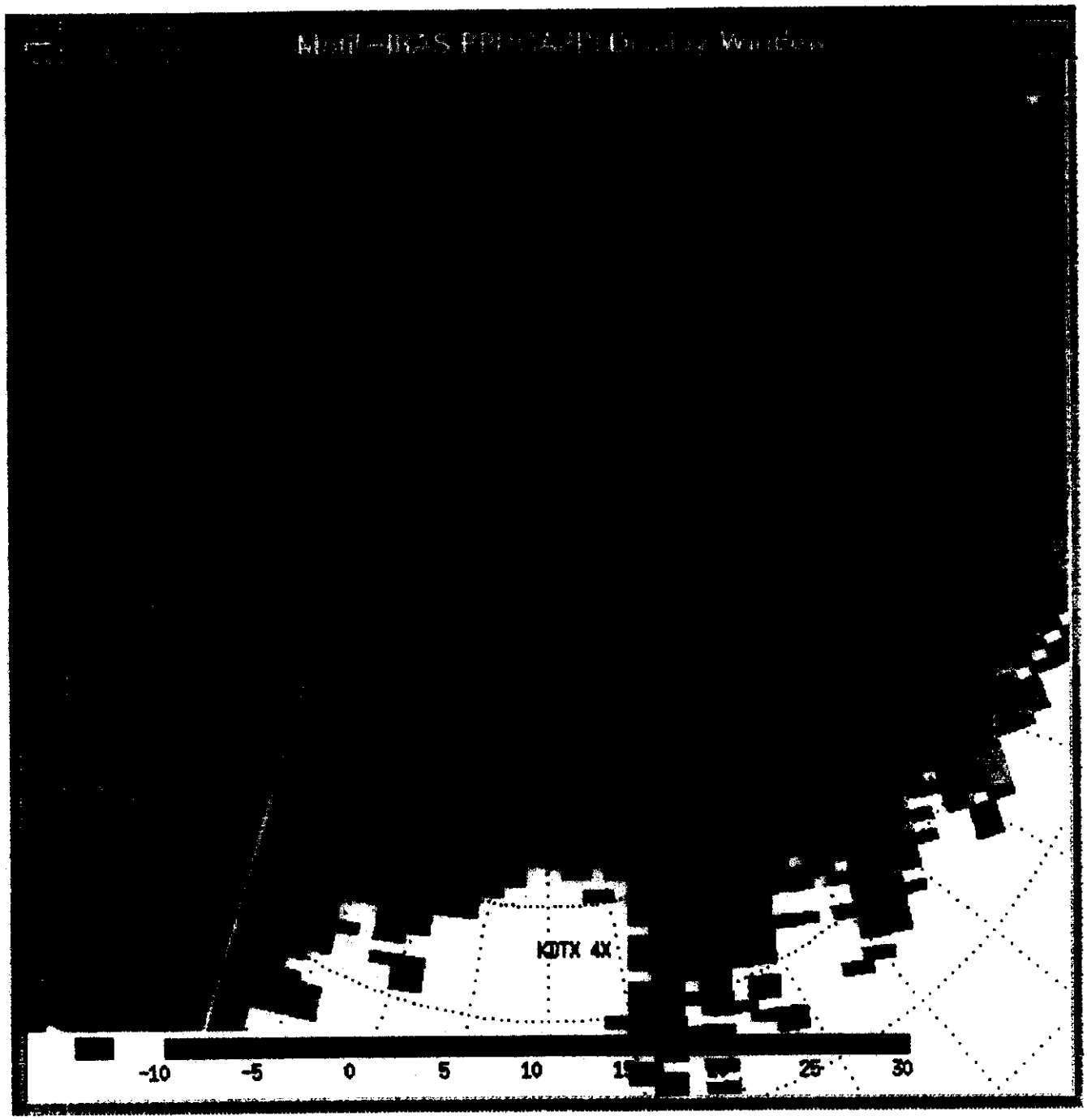
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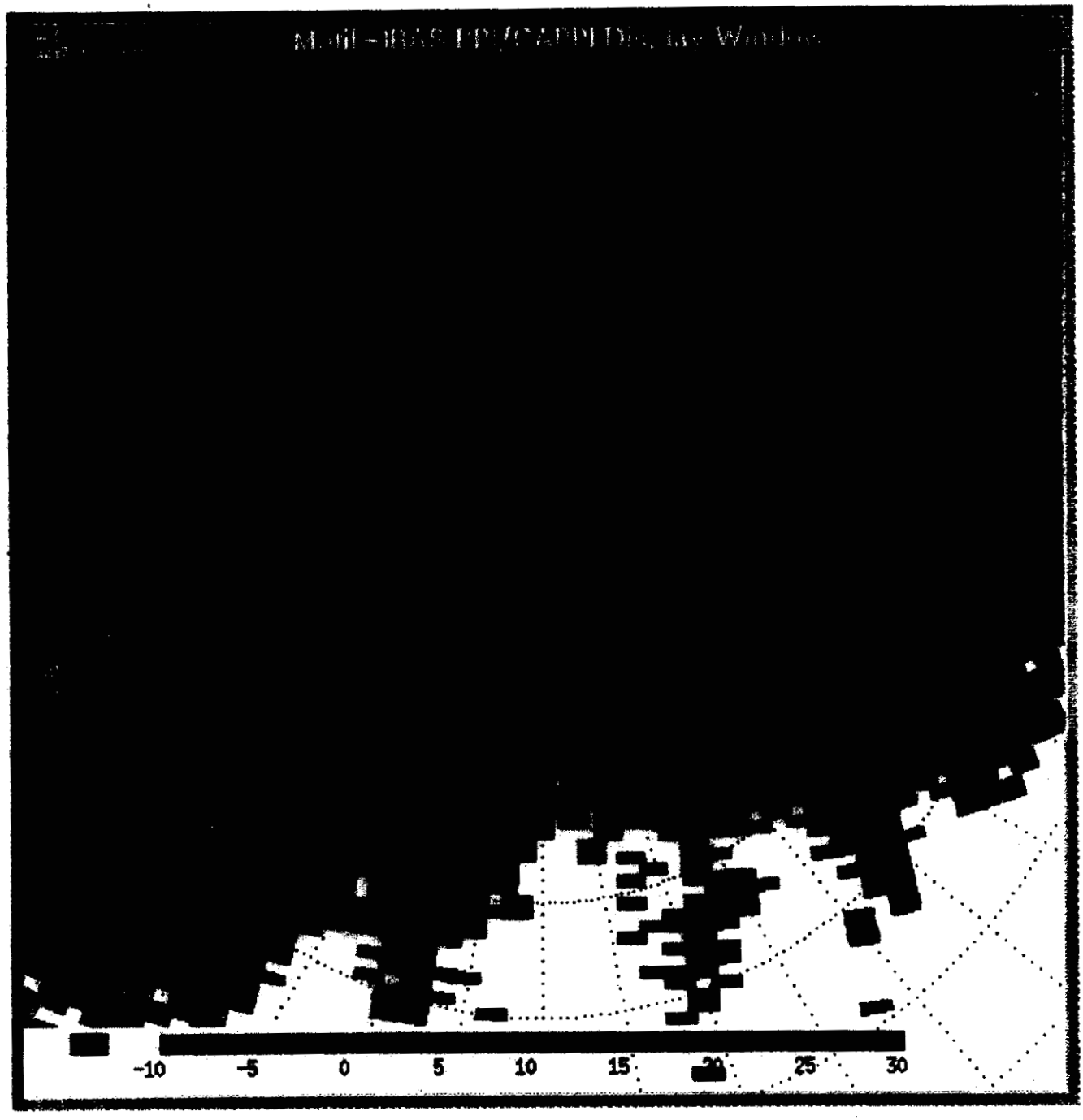
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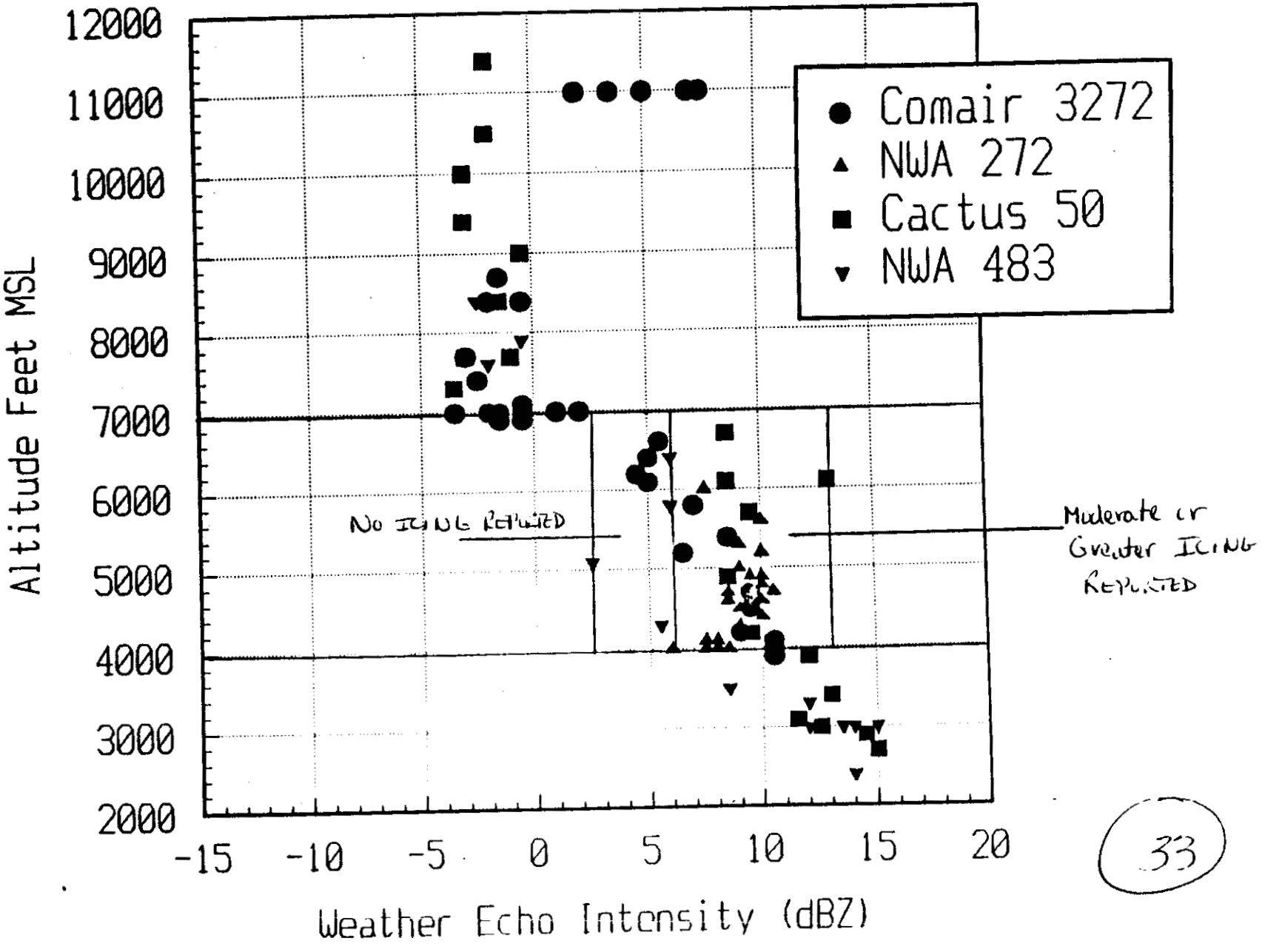
Weather Echo Intensity Encountered by Airplanes



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205430	42.162500	-83.338308	1100
205434	42.164667	-83.335609	1100
205439	42.167833	-83.334034	1000
205444	42.169833	-83.331336	1000
205448	42.172000	-83.329986	900
205453	42.174000	-83.327062	900
205457	42.177167	-83.324362	800