Bright Band Analysis to Diagnose SMART-R Off-Level and Elevation Bias
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Problems have been found with the apparent elevation angle for the SMART-R radar during DYNAMO. Jon Fleigel hypothesized that the radar platform had tilted during early operations, with a downward tilt of approximately .75 degrees in an azimuthal direction of 285 degrees. Work on the part of University of Washington researchers has shown that there is still some unaccounted error associated with the SMART-R elevation angle, and that this error may be as large as 1 to 1.5 degrees.

It is found that analysis of bright band data can be used to accurately diagnose both the SMART-R off-level correction and the elevation bias. The procedure requires careful work, but yields results that are reasonably reproducible. Unfortunately, adequate bright bands were in short supply during DYNAMO, and only three cases are presented here. The cases occurred near 23-Nov-2011 16:34, 24-Oct-2011 06:15 and 21-Dec-2011. In the first two cases, the existence of a nearly full-around bright band was brief; the third case had a less complete, and much weaker BB. Any asymmetry in the SMART-R bright band indicates a tilt to the radar platform, and simple geometry, combined with an S-Pol estimated bright band height, can indicate an absolute elevation angle error in SMART-R . If a particularly precise analysis can be made, there may be better confidence in these results than in the estimates of Fliegel.

The general process is as follows:

- Using summary images for S-Pol in DYNAMO, periods of circular bright band (BB) at high elevation tilts were found.
- BB height was carefully estimated using S-Pol RHI scans. Any tilt to the BB was noted.
- Reflectivity data for high (>11 degrees) SMART-R PPI scans were windowed for the bright band
- SMART-R data were smoothed using a 5x7 (azimuth x range) median filter
- A polynomial fit is made to reflectivity data through the bright band for each radial, and the gate of maximum reflectivity is determined as a function of azimuth
- Using the azimuthally dependent range to the center of the BB, along with the S-Pol determined BB height, the apparent elevation angles to the BB were found
- Original, non-Fliegel corrected elevation angles are compared to the apparent elevation angles, and a true correction to the original elevation angle is computed.

The last step in the outline assumes the following equation applies:

$$E_{apparent} - E_{original} = b1 * \cos(\text{azimuth} - b2) + b3$$

In practice, the diagnosed apparent elevation can be quite noisy and is often complicated by any incompleteness in the BB circle. The coefficients to the equation are therefore found after deletion of outliers using successive approximations to a least-squares fit to the stated function (details available).

Figures are attached and described. The end result of the analysis is:

$$E_{corrected} = E_{original} - [\, 0.85 * \cos(\text{azimuth} - 281) + 1.45 \,]$$

With the exception of the b3 term, these values are not much different from the Fliegel/Schumacher values. Interpretation of the results also shows that the elevation bias is constant for the high tilts, and therefore, the same bias likely applies for the lower tilts. The correction is likely accurate to +/- 0.2 deg.

Reflectivity is also affected by the change in elevation. Preliminary results indicate a correction of as much as +3 or +4 dB may be required (this mitigates the original correction of -8 dB).

Supporting Information

Supporting information can be found on the EOL web site at:

http://www.eol.ucar.edu/projects/dynamo/spol/data_quality/smartr_bb/smartr_bright_band_analysis.html

While the information is more complete, it is less structured and incompletely described.

Bright Band Cases

A good case study of a bright band would include extensive stratiform precip with echoes uniformly distributed fully around the radar and extending through the melting layer. The melting layer should have zero or known tilt. Such cases were extremely rare during DYNAMO. Only one really good case was found, and one other fair case. Several other possible, but likely very marginal, cases were found. All cases had only brief periods of existence. Cases, in time order, are listed.

Date/time	Comments
20110124 06:18	fair case; bb at 4300-4400 m
20111123 16:34	very good case; bb at 4600 m
20111127 21:43	shows promise at high tilts
20111127 22:03	marginal case
20111219 07:33	partial circle only
20111221 11:18	weak bb
20111221 13:03	
20111222 20:34	high tilts, only; half circle

Only cases for 24-Oct and 23-Nov have been analyzed and reported here.

The Best Case: 23-Nov-2011

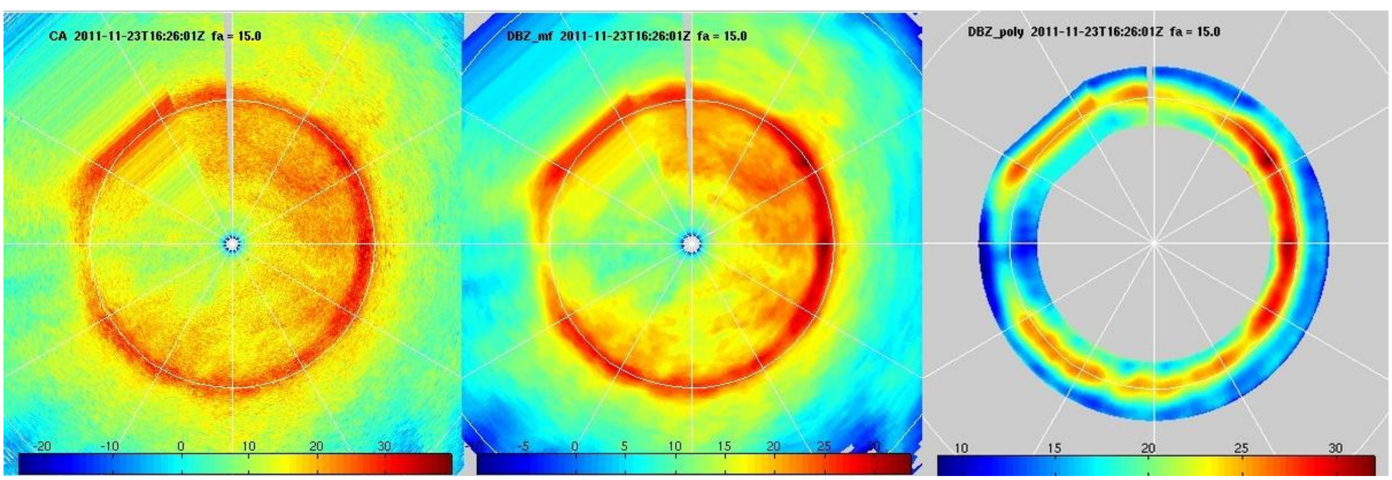

Figure 1: Original reflectivity for SMART-R showing a bright band, left panel. Other panels show progressively smoothed reflectivity. Note that color bars are self-scaling. Smeared beams in the NW wedge are an artifact of the plotting process, and are missing data that were not included in the analysis.

Bright band locations were analytically determined for the various elevation scans. Figure 2 shows determined gate number for the various tilts vs azimuth. Note that the lowest tilts tend to have the greatest noise in the BB determination, while the highest tilts show very little diagnosable difference in BB location, and are therefore less sensitive for this process.

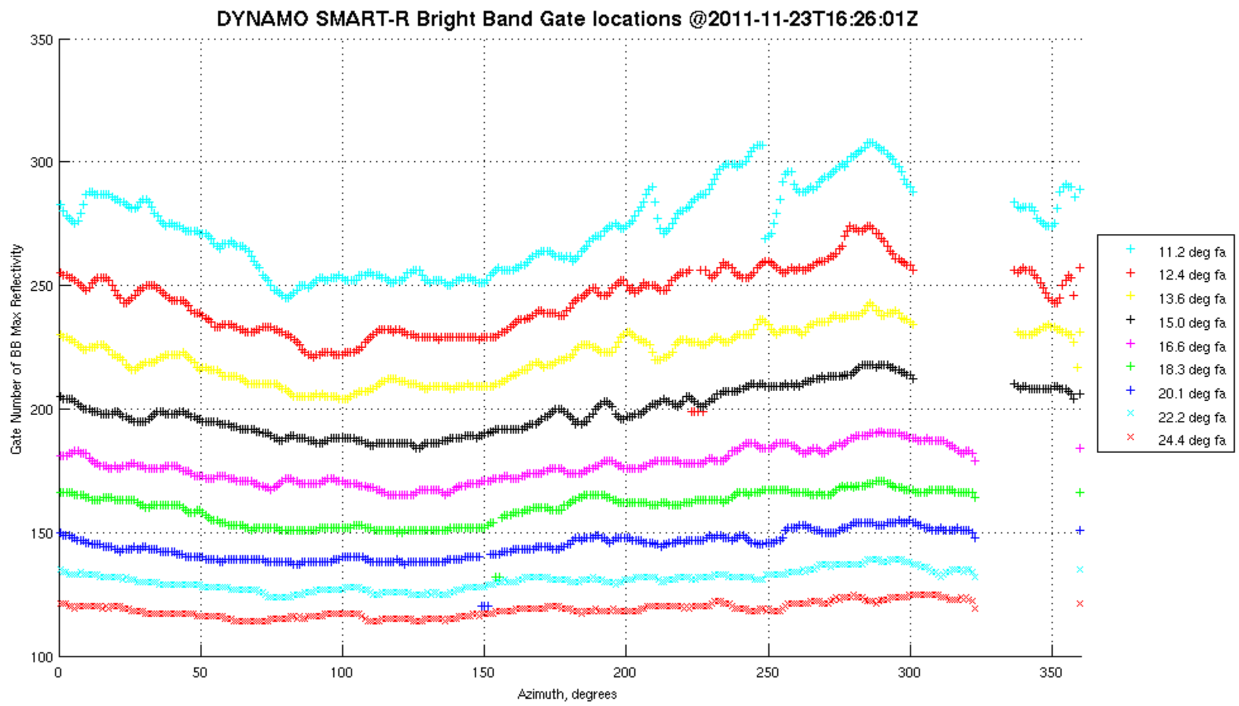

Figure 2.

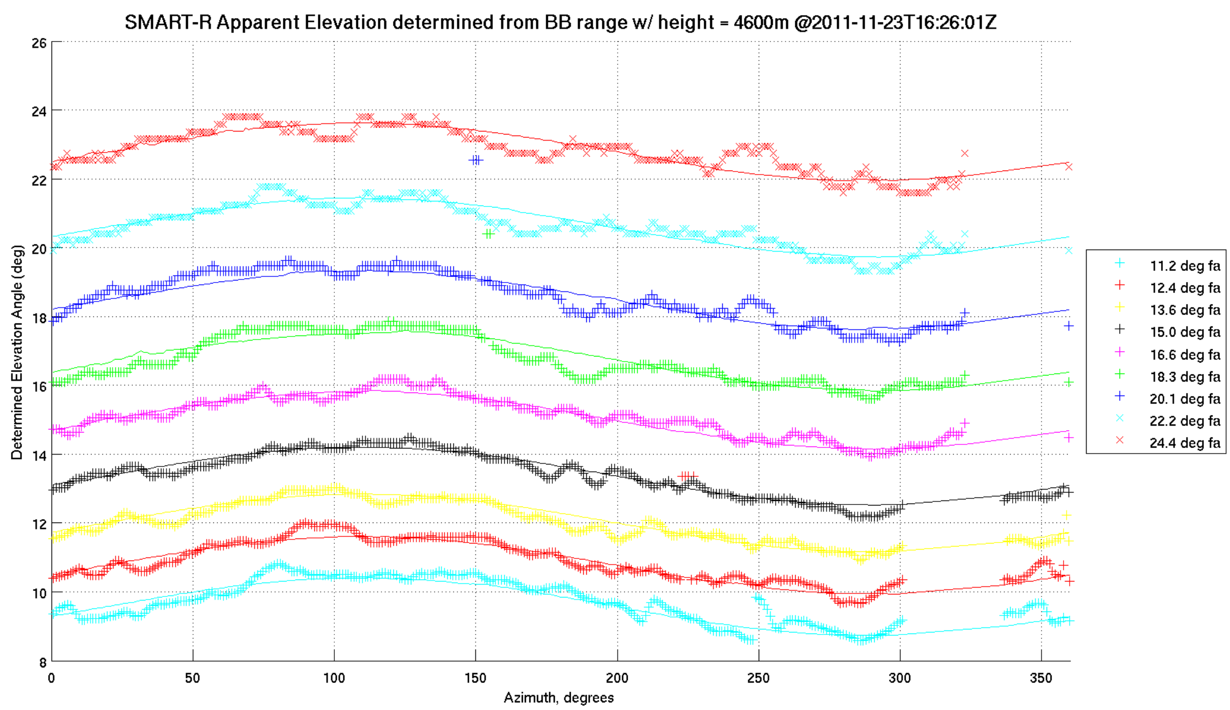

Figure 3. Apparent elevation angles determined from known BB height and range to BB. Figure also shows lines of best fit (using a common set of coefficients).

Variations and Analysis

Figures 2 and 3 pertain to a single case, and a single estimated BB height. As it turns out, the analysis procedure is very sensitive to changes in the estimated height of the BB. The following tables show sets of analyses for different cases with different estimated heights of the BB. Within each set there are separate best-fit coefficients shown for each elevation tilt, and for the aggregate of all tilts. There are also two sets of initial aggregate estimates that are used in the outlier elimination process. Note that the analysis produces non-uniform values for the absolute elevation bias (*vs.* fixed angle) when the BB height is in error; we can therefore easily select the cases where the BB height estimate is most nearly correct.

Further consideration of the standard deviation of the b1 and b3 (beta(1) and beta(3)) suggests that the estimates for 20111123, bb_height = 4600m and for bb_height = 4650m are probably equally valid (an indication of the error bounds on the technique). Comparison of the analysis for 20111123 to that of 20111024 indicates that the azimuth of greatest tilt can be either 289 degrees, or 271 degrees, respectively. The large range in values is not surprising, given the small value of the amplitude, and the flatness of the cosine curve near the max and min values.

An analysis for a weak bright band on 20111221 yields good statistics, with about the same value of elevation bias as the other two days, but with a significantly smaller value of the off-level amplitude, possibly indicating a shift in the platform with time. Off-level amplitude is about 0.64 for 20111221, compared to 0.85 for the other two cases. The tenuous nature of this third BB caused some problems with the analysis, and for that reason, there is a little less confidence in the results for the third case, despite the good statistics.

In the attached tables, we have an assumed correction of the form:

true_elev = orig_elev - { beta(1) * cos(azimuth - beta(2)) + beta(3)}

(the orig_elev is the non-corrected SMART-R elevation, prior to Jon Fliegel's work)

The original Fliegel corrections were:

beta(1)	beta(2)	beta(3)
0.75	285	0.00

BB Analysis for 20111123 ~16:34Z

for bb_height = 4700 m

	beta(1)	beta(2)	beta(3)
1st guess	0.8539	290.7538	1.1987
2nd guess	0.8483	289.8012	1.2071
11.2 deg	0.8709	295.0518	1.2802
12.4 deg	0.8455	289.5133	1.2881
13.6 deg	0.8205	288.7979	1.3508
15.0 deg	0.9352	291.9410	1.3136
16.6 deg	0.8295	293.9027	1.1703
18.3 deg	0.8892	287.2169	1.2145
20.1 deg	0.9263	282.3572	1.0958
22.2 deg	0.8017	288.6839	1.1158
24.4 deg	0.8177	286.8654	1.0706
std_dev	.049		.103
All deg	0.8566	289.5471	1.2122

for bb_height = 4650 m

1st guess	0.8450	290.6707	1.3726
2nd guess	0.8396	289.7147	1.3809
11.2 deg	0.8654	294.8736	1.3887
12.4 deg	0.8362	289.5114	1.4070
13.6 deg	0.8114	288.7973	1.4827
15.0 deg	0.9247	291.9427	1.4611
16.6 deg	0.8201	293.9034	1.3379
18.3 deg	0.8787	287.1875	1.4013
20.1 deg	0.9153	282.3597	1.3048
22.2 deg	0.7918	288.6842	1.3500
24.4 deg	0.7935	287.0792	1.3234
std_dev	.050		.061
All deg	0.8461	289.4882	1.3848

for bb_height = 4600m

	beta(1)	beta(2)	beta(3)
1st guess	0.8361	290.5860	1.5463
2nd guess	0.8310	289.6266	1.5545
11.2 deg	0.8558	294.8698	1.4945
12.4 deg	0.8270	289.5095	1.5259
13.6 deg	0.8022	288.7967	1.6146
15.0 deg	0.9142	291.9444	1.6086
16.6 deg	0.8107	293.9040	1.5053
18.3 deg	0.8683	287.1575	1.5879
20.1 deg	0.9044	282.3622	1.5136
22.2 deg	0.7820	288.6845	1.5839
24.4 deg	0.7726	287.6103	1.5777
std_dev	.051		.047
All deg	0.8359	289.4705	1.5574

for bb_height = 4500
(results in beta(3) steadily increasing!)

1st guess	0.8185	290.4118	1.8931
2nd guess	0.8138	289.4454	1.9012
11.2 deg	0.8399	294.7214	1.7080
12.4 deg	0.8085	289.5055	1.7636
13.6 deg	0.7840	288.7953	1.8781
15.0 deg	0.8933	291.9481	1.9032
16.6 deg	0.7919	293.9054	1.8397
18.3 deg	0.8485	287.3708	1.9590
20.1 deg	0.8826	282.3673	1.9304
22.2 deg	0.7667	289.1378	2.0476
24.4 deg	0.7297	289.3160	2.0795
std_dev	.054		.121
All deg	0.8174	289.5518	1.9014

Standard deviation analysis suggests using corrections for bb_heights 4600 or 4650 (statisically, these are pretty much the same results)

BB Analysis for 20111024 ~06:16Z

for bb_height = 4500 m

	beta(1)	beta(2)	beta(3)
1st guess	0.5224	243.9177	0.7774
2nd guess	0.8694	269.9048	1.1236
11.2 deg	0.8858	269.2202	1.2560
12.4 deg	0.9675	274.4477	1.3266
13.6 deg	1.0513	275.4914	1.3218
15.0 deg	1.1183	273.0068	1.2160
16.6 deg	0.8907	272.3394	1.0984
18.3 deg	0.8441	266.0714	1.1158
20.1 deg	0.7471	275.4912	1.0252
22.2 deg	0.6804	269.5281	0.9808
24.4 deg	0.7930	268.7456	1.0143
std_dev	.141		.134
All deg	0.8928	272.9110	1.1582

(cumulative/average)

for bb_height = 4450 m

1st guess	0.5178	243.9239	0.9644
2nd guess	0.8586	269.7426	1.3053
11.2 deg	0.8715	268.7144	1.3702
12.4 deg	0.9543	273.8061	1.4614
13.6 deg	1.0295	275.5415	1.4690
15.0 deg	1.1117	273.1726	1.3751
16.6 deg	0.8801	272.3394	1.2742
18.3 deg	0.8338	266.0762	1.3118
20.1 deg	0.7279	275.5244	1.2377
22.2 deg	0.6689	270.0558	1.2236
24.4 deg	0.8291	265.3492	1.2305
std_dev	.139		.096
All deg	0.8809	272.1606	1.3327

for bb_height = 4400m

1st guess	0.5133	243.9293	1.1512
2nd guess	0.8479	269.5747	1.4868
11.2 deg	0.8554	267.8824	1.4864
12.4 deg	0.9417	273.5528	1.5870
13.6 deg	1.0175	275.5357	1.6067
15.0 deg	1.1056	273.3457	1.5344
16.6 deg	0.8695	272.3395	1.4499
18.3 deg	0.8182	265.7358	1.5038
20.1 deg	0.7231	275.5585	1.447
22.2 deg	0.6523	270.2187	1.4627
24.4 deg	0.8108	264.4622	1.4933
std_dev	.140		.058
All deg	0.8649	271.6605	1.5097

for bb_height = 4350 m

	beta(1)	beta(2)	beta(3)
1st guess	0.5088	243.9339	1.3377
2nd guess	0.8365	269.3786	1.6676
11.2 deg	0.8401	267.2877	1.6010
12.4 deg	0.9267	272.7031	1.7167
13.6 deg	1.0018	275.6719	1.7468
15.0 deg	1.0961	273.4503	1.6916
16.6 deg	0.8589	272.3395	1.6255
18.3 deg	0.7952	264.4672	1.6882
20.1 deg	0.7185	275.3951	1.6636
22.2 deg	0.6439	270.2109	1.7083
24.4 deg	0.8087	263.5965	1.7371
std_dev	.139		.049
All deg	0.8500	270.9940	1.6859

for bb_height = 4300 m
(this height results in beta(3)
steadily increasing!)

1st guess	0.5042	243.9377	1.5240
2nd guess	0.8229	269.0335	1.8467
11.2 deg	0.8302	267.2838	1.7116
12.4 deg	0.9146	272.4008	1.8424
13.6 deg	0.9877	276.0614	1.8892
15.0 deg	1.0828	273.4537	1.8465
16.6 deg	0.8484	272.3395	1.8009
18.3 deg	0.7810	264.0580	1.8802
20.1 deg	0.7034	274.9712	1.8781
22.2 deg	0.6410	270.9269	1.9514
24.4 deg	0.8047	262.6481	2.0029
std_dev	.136		.084
All deg	0.8371	270.6292	1.8640

(cumulative/average)

Statistically, the 4350 m guess is the best, but shows a large elevation bias angle with a pattern of larger angles on each end. The 4400 guess is very similar. There is little statistical difference between the two. The 4400 m guess is chosen since it better matches elevation bias for the other days.

BB Analysis for 20111221 ~12:16Z

for bb_height = 4350

	beta(1)	beta(2)	beta(3)
1st guess	0.6702	286.3770	1.7588
2nd guess	0.6396	288.5166	1.7698
11.2 deg	0.6584	291.2848	1.6145
12.4 deg	0.7298	283.0433	1.6695
13.6 deg	0.6828	282.7624	1.7512
15.0 deg	0.6169	286.3531	1.7467
16.6 deg	0.5758	290.3174	1.7597
18.3 deg	0.7963	293.2974	1.8347
20.1 deg	0.6401	299.3688	1.7650
22.2 deg	0.5179	292.7950	1.8291
24.4 deg	0.4722	273.2773	1.8578
std_dev	.101		.079
All deg	0.6285	287.8403	1.7570

for bb_height = 4400

1st guess	0.6765	286.5066	1.5772
2nd guess	0.6382	289.0176	1.5838
11.2 deg	0.6644	291.5778	1.5017
12.4 deg	0.7386	283.0302	1.5453
13.6 deg	0.6910	282.7638	1.6134
15.0 deg	0.6244	286.3432	1.5924
16.6 deg	0.5827	290.3608	1.5855
18.3 deg	0.8061	293.2797	1.6407
20.1 deg	0.6494	299.8267	1.5503
22.2 deg	0.5264	293.8975	1.5896
24.4 deg	0.4787	273.2604	1.5850
std_dev	.102		.041
All deg	0.6332	288.3163	1.5758

for bb_height = 4425

1st guess	0.6796	286.5707	1.4864
2nd guess	0.6408	289.1230	1.4927
11.2 deg	0.6683	291.5768	1.4464
12.4 deg	0.7429	283.0237	1.4832
13.6 deg	0.6951	282.7645	1.5445
15.0 deg	0.6282	286.3383	1.5152
16.6 deg	0.5861	290.3822	1.4984
18.3 deg	0.8111	293.2710	1.5436
20.1 deg	0.6546	300.2939	1.4444
22.2 deg	0.5318	295.5324	1.4752
24.4 deg	0.4819	273.2521	1.4484
std_dev	.102		.040
All deg	0.6357	288.6554	1.4860

for bb_height = 4450

	beta(1)	beta(2)	beta(3)
1st guess	0.6828	286.6342	1.3955
2nd guess	0.6433	289.2276	1.4016
11.2 deg	0.6722	291.5759	1.3911
12.4 deg	0.7473	283.0174	1.4211
13.6 deg	0.6992	282.7652	1.4756
15.0 deg	0.6319	286.3334	1.4380
16.6 deg	0.5896	290.4033	1.4112
18.3 deg	0.8160	293.2624	1.4465
20.1 deg	0.6610	301.2098	1.3412
22.2 deg	0.5395	295.8421	1.3552
24.4 deg	0.4907	273.4937	1.3155
std_dev	.101		.053
All deg	0.6397	288.9297	1.3965

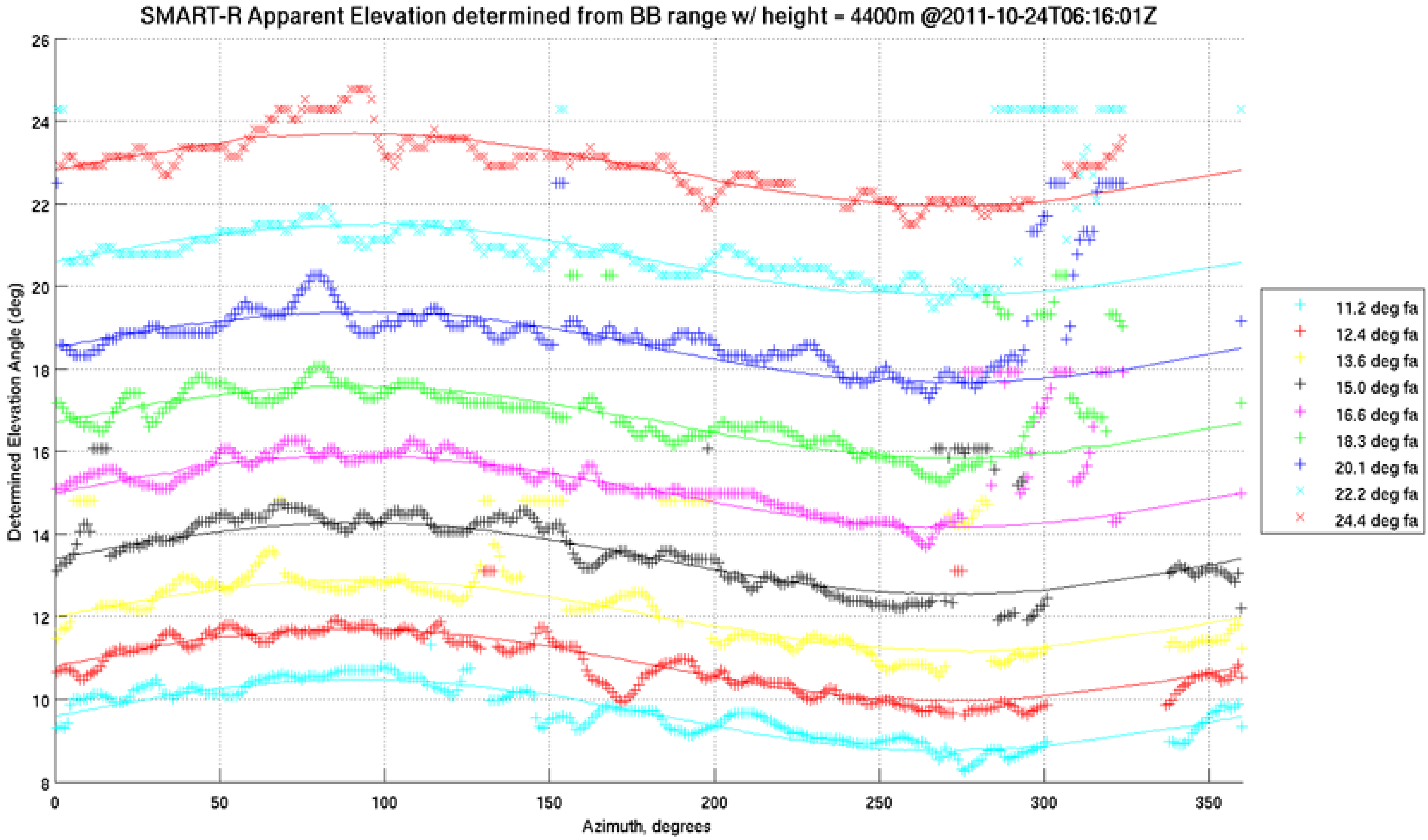

Figure 4. Similar to Fig. 3, but for the 2011-10-24 case. Data for this day are noisier, as evidenced by points between about 290 and 360 degrees. The analysis technique first fits a cosine curve to the aggregate of all the points, then eliminates those points that are more than 1.5 degrees from the line of best fit. The best fit line is then recomputed, and points that are more than 0.75 degrees from that second line are eliminated. A final fit is then computed, and is shown on this plot.

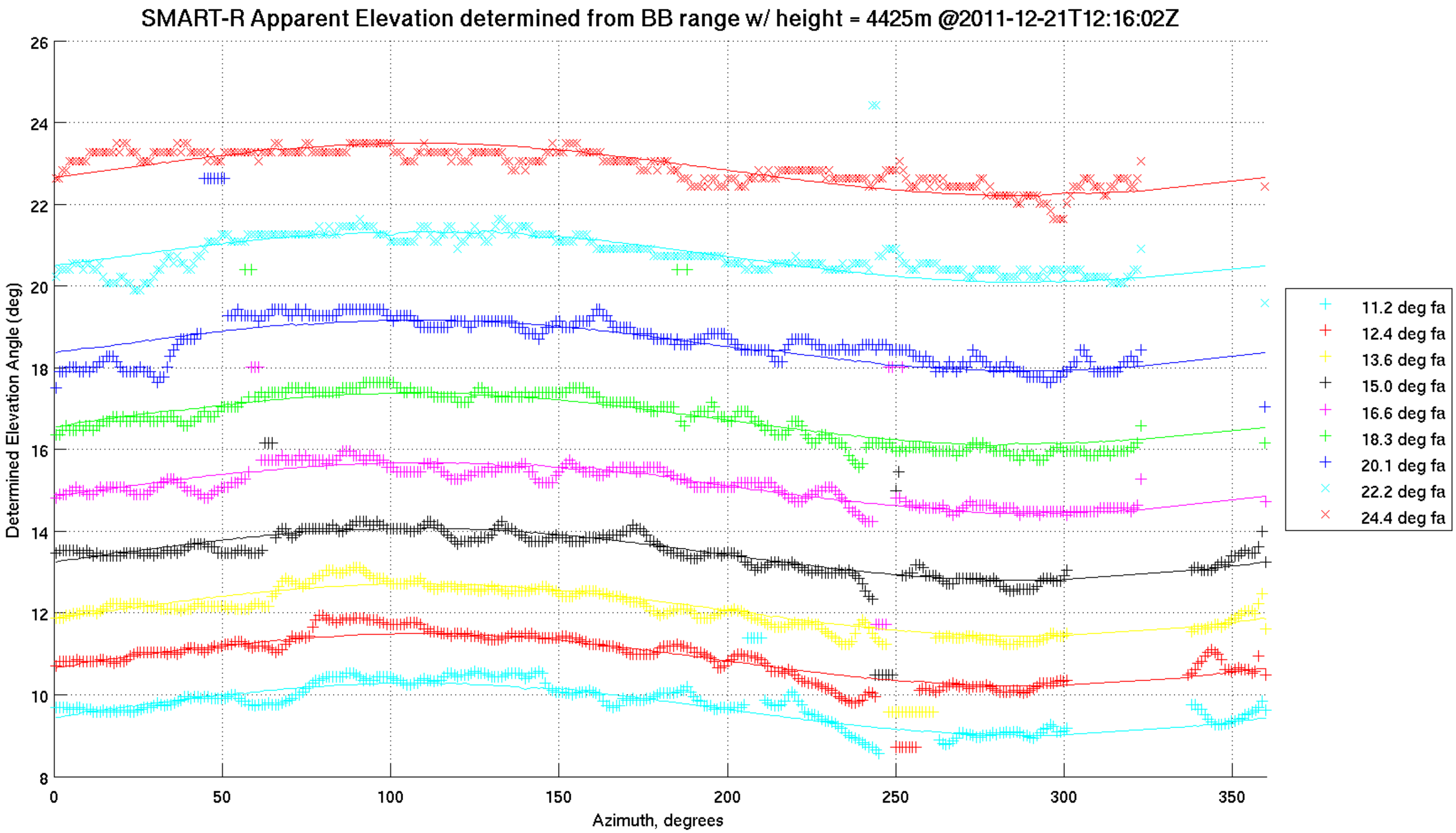

Figure 5. Similar to Fig. 3, but for the 2011-12-21 case.