SMART-R during DYNAMO: a Technique to Diagnose Elevation Angle Errors

R.A. Rilling, C. Schumacher
National Center for Atmospheric Research, Boulder, CO USA, rilling@ucar.edu
Texas A&M University, College Station, TX USA, cschu@tamu.edu

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Introduction

Mobile and transportable radars are increasingly in use for observations during field experiments. These radars can be quickly moved to regions of interest, and sometimes even operated while in motion. Not all mobile radars are fitted with automatic systems for platform leveling. Additionally, limited options for site selection, and a total lack of site preparation, can result in situations where shifting of the platform may occur during operation. This paper presents one unique option for diagnosing the extent of platform shift and off-level for one radar during a field deployment. The technique requires only a single scan volume, and can be applied to any radar where a sufficiently well-defined bright band can be observed by a series of elevation tilts.

This bright band (BB) level check has been applied to data from the Shared Mobile Atmospheric Research and Teaching Radar (SMART-R) which was deployed during DYNAMO (Dynamics of the Madden-Julian Oscillation experiment, 2011, Indian Ocean). SMART-R was located on a sandy spit on an atoll in the Maldives with water on three sides. The radar lost level early in its deployment when the front left tire sank slightly, but the problem was not diagnosed until about mid-project. A contributing factor to the lack of early diagnosis was a wall of complete blockage at low elevations to the west of the radar, and wide-open ocean to the east. Fliegel (2011) was able to estimate the extent of the off-level and the direction of maximum error through single-radar analysis of echo top heights. Fliegel's analysis used the comprehensive set of radar echoes, but could not adequately address the time history of the off-level error. Additionally, the DYNAMO radar science community determined that there was an elevation bias error with SMART-R, but there was large uncertainty concerning the size of this bias and whether the bias was the same at all elevation tilts (e.g., an elevation encoder error or software conversion factor might show different biases at different elevations).

For constant elevation angle scanning, the bright band appears as a circle of high reflectivity, with that circle centered on the radar (this assumes that there is no actual tilt to the atmospheric melting level). As the radar elevation angle increases, the apparent diameter of the circle decreases. If the radar platform is off-level, the bright band becomes slightly elliptical, and the ellipse is no longer centered on the radar. If the height of the bright band is known, an independent elevation bias can be determined for each elevation angle. When the height of the bright band is only approximately known, using different heights with a process of minimization will lead to a “best guess” for any corrections.

Procedure

The general process is as follows:

- Using summary images for S-Pol (which was located a few km from SMART-R), 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 BB
- SMART-R data were smoothed using a 5x5 (azimuth x range) median filter
- A polynomial fit was made to reflectivity data through the BB for each radial, and the gate of maximum reflectivity was determined as a function of azimuth
- Using the azimuthally-dependent range to the center of the BB, along with the S-Pol determined (or an estimated) BB height, the apparent elevation angles to the BB were found
- Original, uncorrected elevation angles were compared to the apparent elevation angles, and a true correction to the original elevation angle was computed.

The last step in the outline assumes the following equation for the elevation error applies to each elevation scan:

Eapparent – **E**original = b1 * cos(azimuth – b2) + b3

E is an elevation angle
b1 is the amplitude of the off-level angle
b2 is the direction of maximum off-level
b3 is the elevation bias

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).

The Bright Band Cases

A good case study of a bright band would include extensive stratiform precipitation 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	weak BB
20111222 20:34	high tilts, only; half circle

Times are in UTC. Only cases for 24-Oct, 23-Nov and 21-Dec have been analyzed and reported here.

Reflectivity plots at 15° elevation for the BB case of 23-Nov-2011 are shown in Figure 1. Panels show the original reflectivity, smoothed reflectivity, and the polynomial fit to the reflectivity for the BB region.

Bright band locations were analytically determined for the various elevation scans. Figure 2 shows the determined gate number for the relevant 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 3 shows the apparent elevation angle of BB, determined from BB range (Fig. 2) and either the known or approximated BB height. The lighter, smoothed lines show the lines of best fit after outliers are removed.

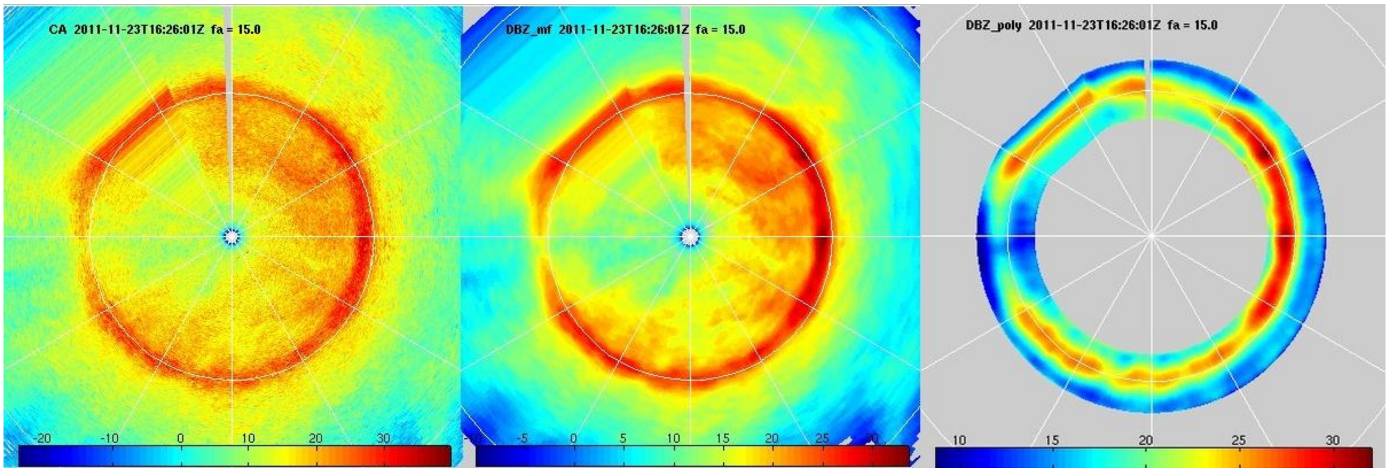

Figure 1: Original reflectivity for SMART-R showing a bright band, left panel. Other panels show progressively smoothed reflectivity. Note that color bars are self-scaling. Smeared beams in the NW wedge are an artifact of the plotting process, and are missing data that were not included in the analysis.

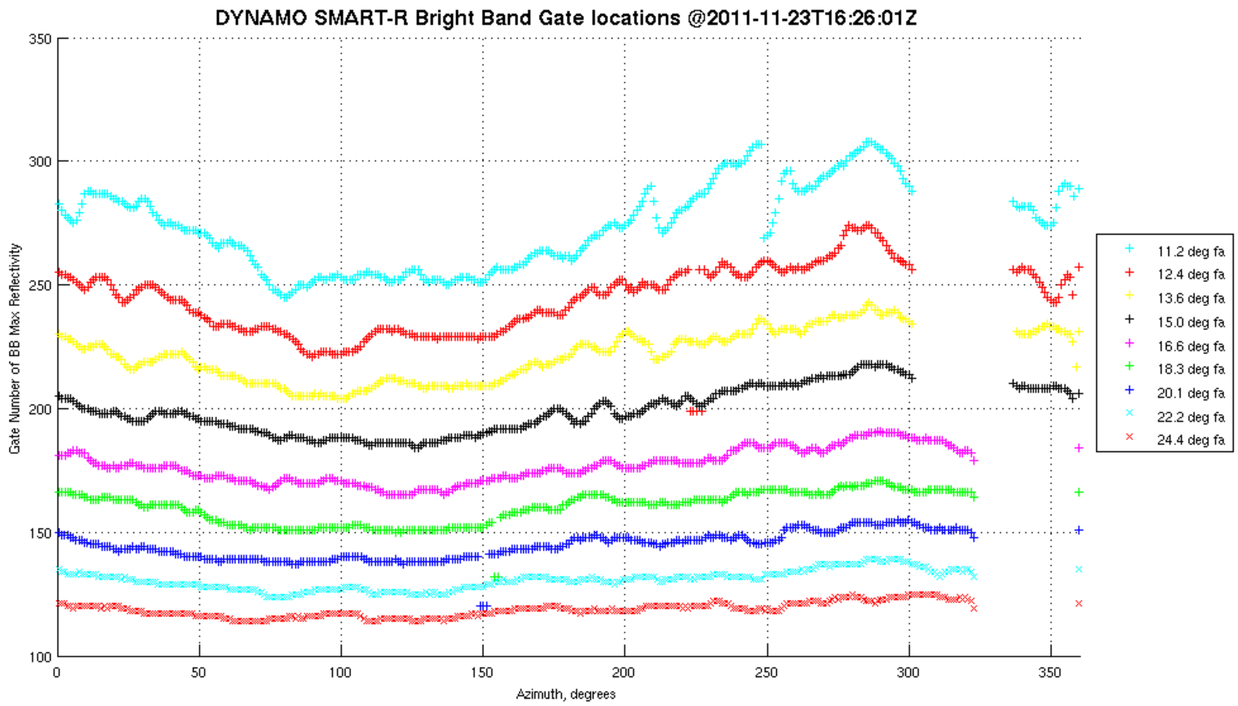

Figure 2. Determined bright band gate locations from fit of polynomial to smoothed radar data.

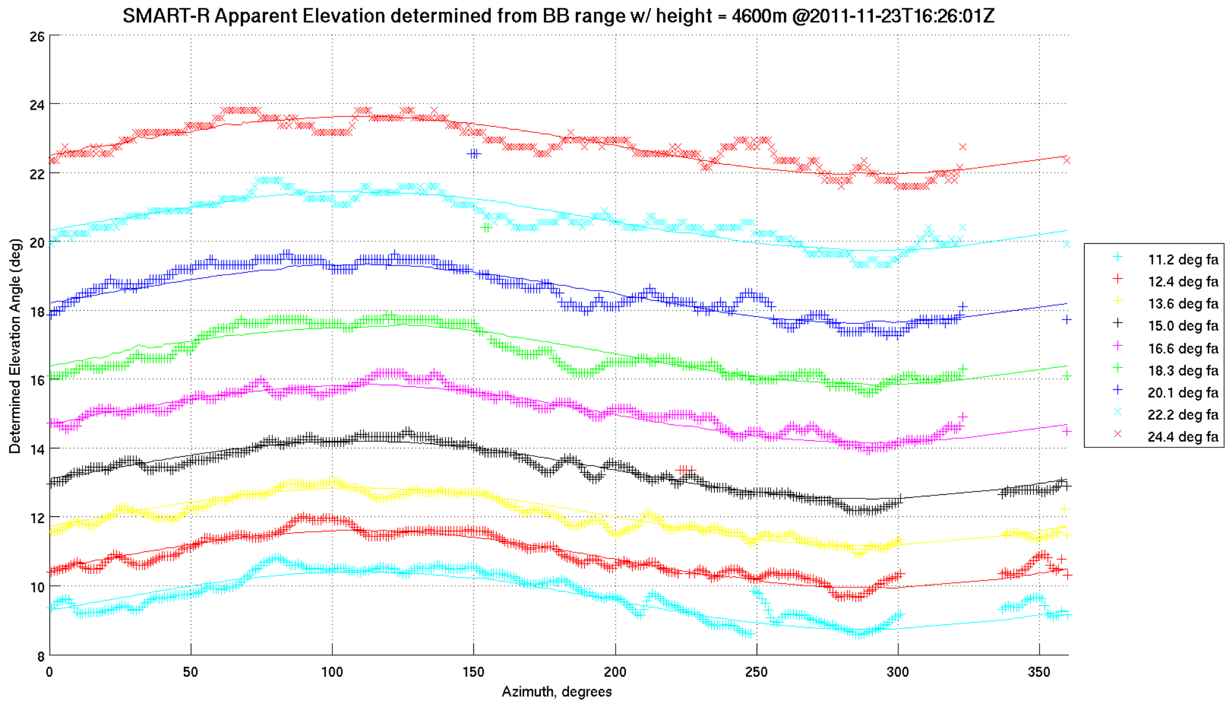

Figure 3. Apparent elevation angles determined from known BB height and range to BB. Figure also shows lines of best fit (using a common set of coefficients).

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. Table 1 shows a set of analyses for the 2011-11-23 case, 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 stable, and likely the most correct. (Similar tables have been produced for the other bright band cases, but are not presented here).

Summarizing for the three cases, we have the following coefficients:

20111024	.86	271.7	1.51	
20111123	.84	289.4	1.47	(avg of two best BB)
20111221	.64	288.4	1.54	(avg of two best BB)

Simply averaging the three cases results in the following approximate equation:

$$\mathbf{E}\text{correc} = \mathbf{E}\text{orig} - [\, 0.78 * \cos(\text{azimuth} - 283) + 1.5 \,]$$

With the exception of the bias term, this compares extremely closely to the original Fliegel equation of:

$$\mathbf{E}\text{correc} = \mathbf{E}\text{orig} - [\, 0.75 * \cos(\text{azimuth} - 285) \,]$$

The current analysis shows that there might be a small change of the off-level with time, but any differences are considered to be small, likely within the error bounds of the process, and therefore, inconclusive.

Further Implications

Following the suggestion of the DYNAMO radar science group, and after this initial bright band analysis, a simple measurement was made of the SMART-R dish during level pointing. That measurement was conducted by Schumacher and several students from a class at Texas A&M University, using a plumb bob. The group concluded that the SMART-R dish pointed low by approximately 1.25°, based upon this physical measurement. The time history of this elevation bias has not been determined.

An initial reflectivity comparison of SMART-R to the nearby S-Pol radar had been performed both in the field and prior to the DYNAMO Science Workshop of March, 2013. SMART-R was also compared to the TRMM-PR satellite by Fliegel. These comparisons initially led to the conclusion that SMART-R was "running hot", and the reflectivity was adjusted downward by 8 dB. Now, since we have concluded that SMART-R is pointing high by 1.5°, another reflectivity comparison must be performed. Initial, unpublished results by the authors indicate that the original 8 dB correction should only be approximately a 4 dB correction (this work will continue).

Conclusion

A conceptually simple technique for evaluating off-level and elevation bias of a radar system is presented. The technique has been applied in post-analysis to the SMART-R radar as deployed in DYNAMO. The single-volume scan technique is shown to be functionally equivalent to a full-project analysis of all radar data, and may even be able to show small changes in radar off-level or elevation bias over time. This technique might be particularly valuable in verifying radar pointing accuracy during short deployments when other pointing checks may not have been made.

Acknowledgements

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References

Fliegel, J.M., 2011: Quality control and census of SMART-R observations from the DYNAMO/CINDY2011 field campaign. Thesis, Office of Graduate Studies of Texas A&M University.

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)

Table 1: Analysis of bright band for 2011-11-23 case. Table shows the determined b1, b2, and b3 coefficients (here, referred to as "betas") for each elevation tilt, assuming different heights of the BB. Standard deviation analysis suggests using corrections for bb_heights 4600 or 4650 (statisically, these are pretty much the same results)

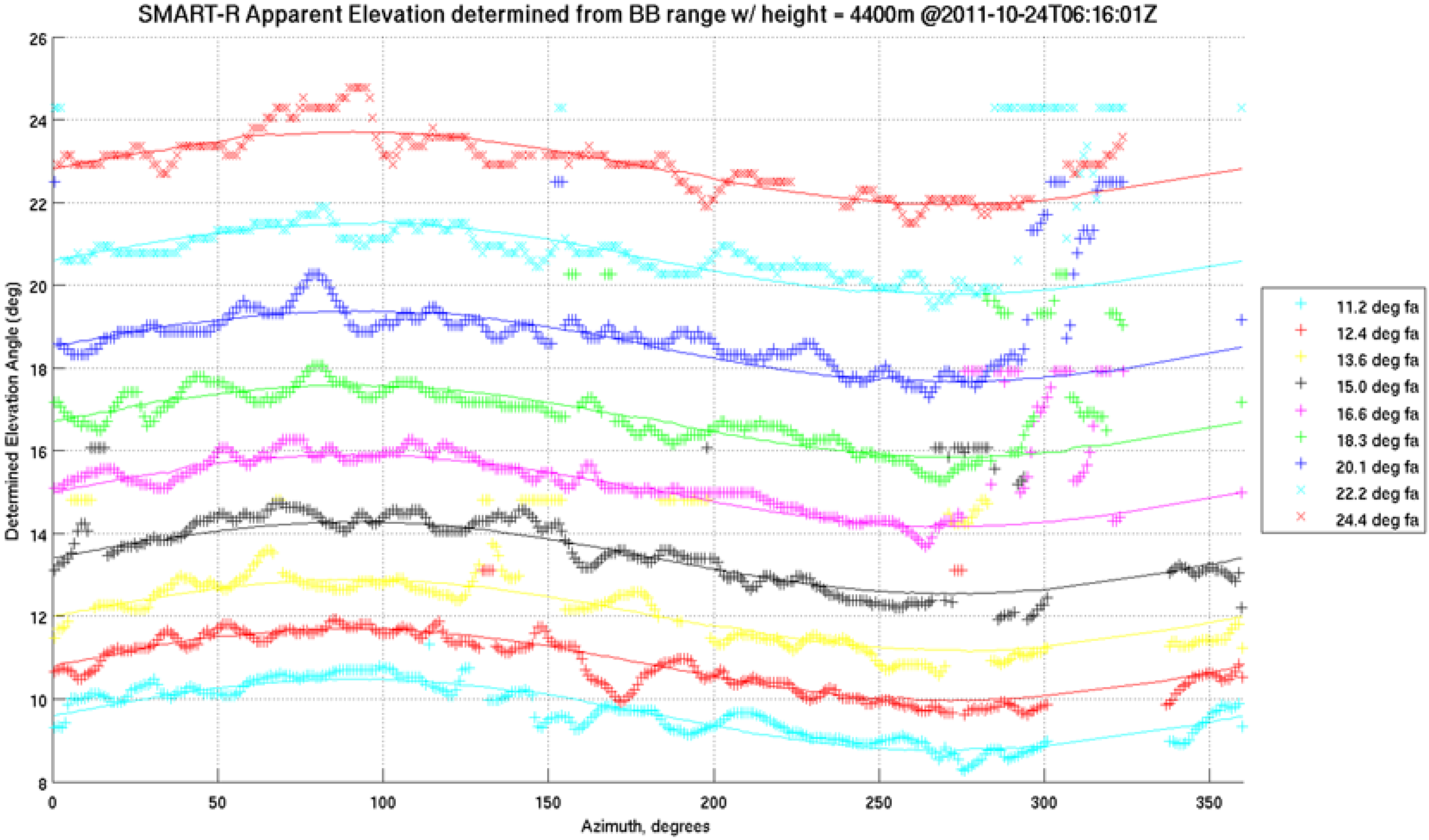

Figure 4. Similar to Fig. 3, but for the 2011-10-24 case. Data for this day are noisier, as evidenced by points between about 290 and 360 degrees. The analysis technique first fits a cosine curve to the aggregate of all the points, then eliminates those points that are more than 1.5 degrees from the 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.

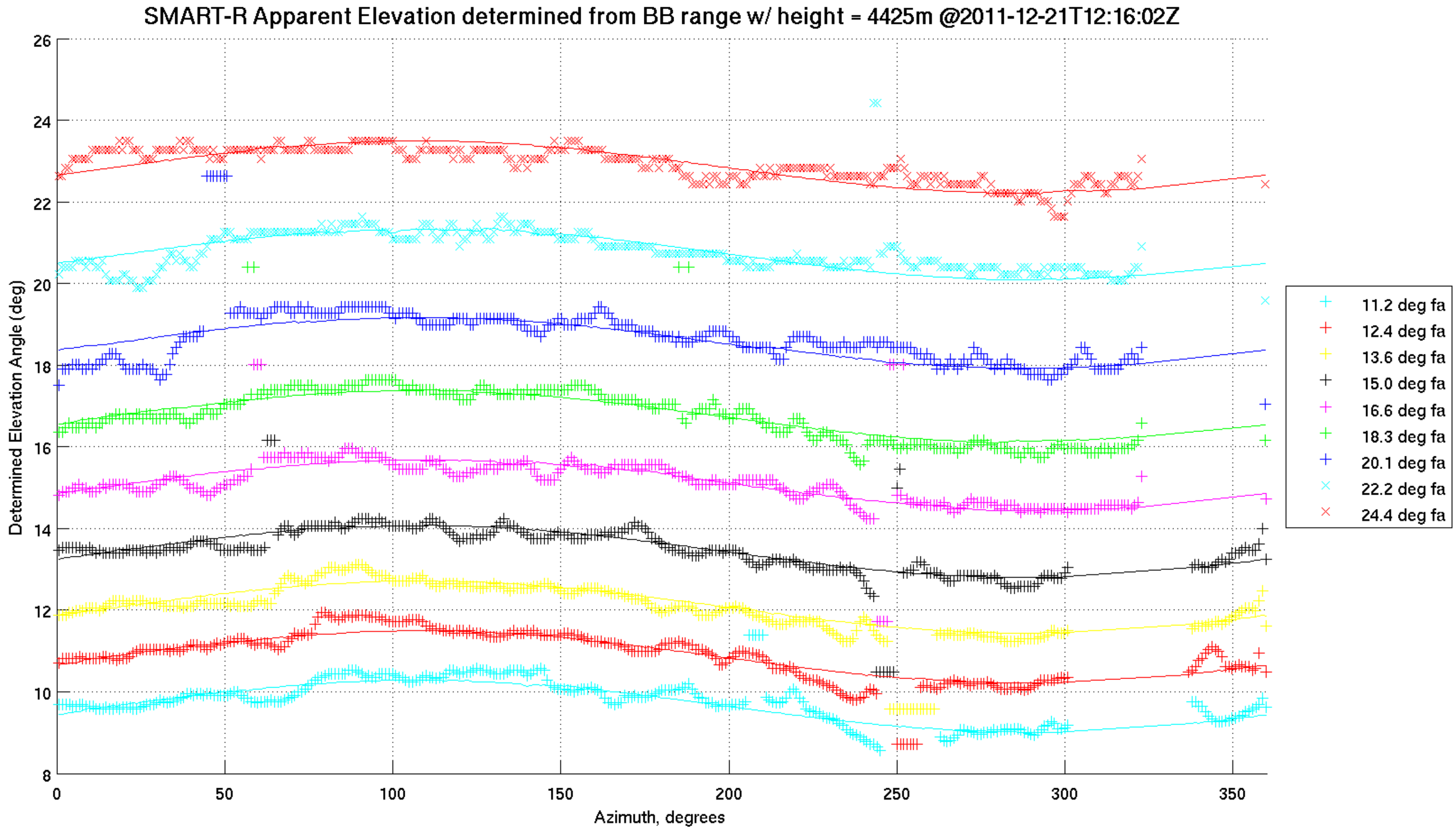

Figure 5. Similar to Fig. 3, but for the 2011-12-21 case.