The Updated 2014 Gravity Model

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1. Introduction

After finishing the replacement of the sub-reflector actuators in 2013, AutoOOF measurements were made during one night (2013.11.24) to produce an updated Zernike-gravity model for the active surface (2014winterV1). After this model was adopted as the default, several observing programs (W-band, Q-band, and even Ka-band) reported issues. In particular, there were multiple cases where the beam became peanut shape in the elevation direction (seen in peak scans at W-band), consistent with a strong "coma" effect. Also, using the 2014winterV1 gravity model, the AutoOOF solutions typically had rms errors of 300-500 µm, instead of the 180-280 µm errors measured using the previous model, 2010winterV1. After reverting back to the 2010winterV1 model, the AutoOOF errors were improved, and we no longer obtained peanut shape beams for W-band. However, the 2010 model is outdated and is not necessarily optimal for the updated actuators. To derive an improved gravity model, we used all the AutoOOF measurements taken after the completion of the replacement of the actuators in the fall of 2013. By using the results of AutoOOFs taken throughout an entire winter season, we obtained a more representative model then that based the gravity model on only one night's data, where the thermal conditions may have been atypical.

2. Procedure

A GBTIDL script (processAO, a copy of which is included as a Wiki attachment) found 121 AutoOOF results that were taken from 2013.11.24 through the fall of 2014. The output of the script is a table with rows for each AutoOOF observation and columns that give the AutoOOF results plus other ancillary information like the antenna's elevation. We eliminated 12 of the AutoOOFs that were obviously very divergent from the 106 remaining observations. The 5th order thermal solutions from the AutoOOF measurements were used since, traditionally, gravity models only goes to the 5th order; plus we found no evidence for gravitational effects for 6th order results. The processAO script summed the thermal Zernikes of the AutoOOF fits and the gravity Zernikes used at the time of the observations. The sum of the thermal and gravity coefficients removes any systematic deficiencies in the assumed gravity model at the time of the observing and allows us to analyze three separate sets of data (2013.11.24 data, data with the 2010winterV1 gravity model, and data with the 2014winterV1 gravity model) as a single data set.

3. Results

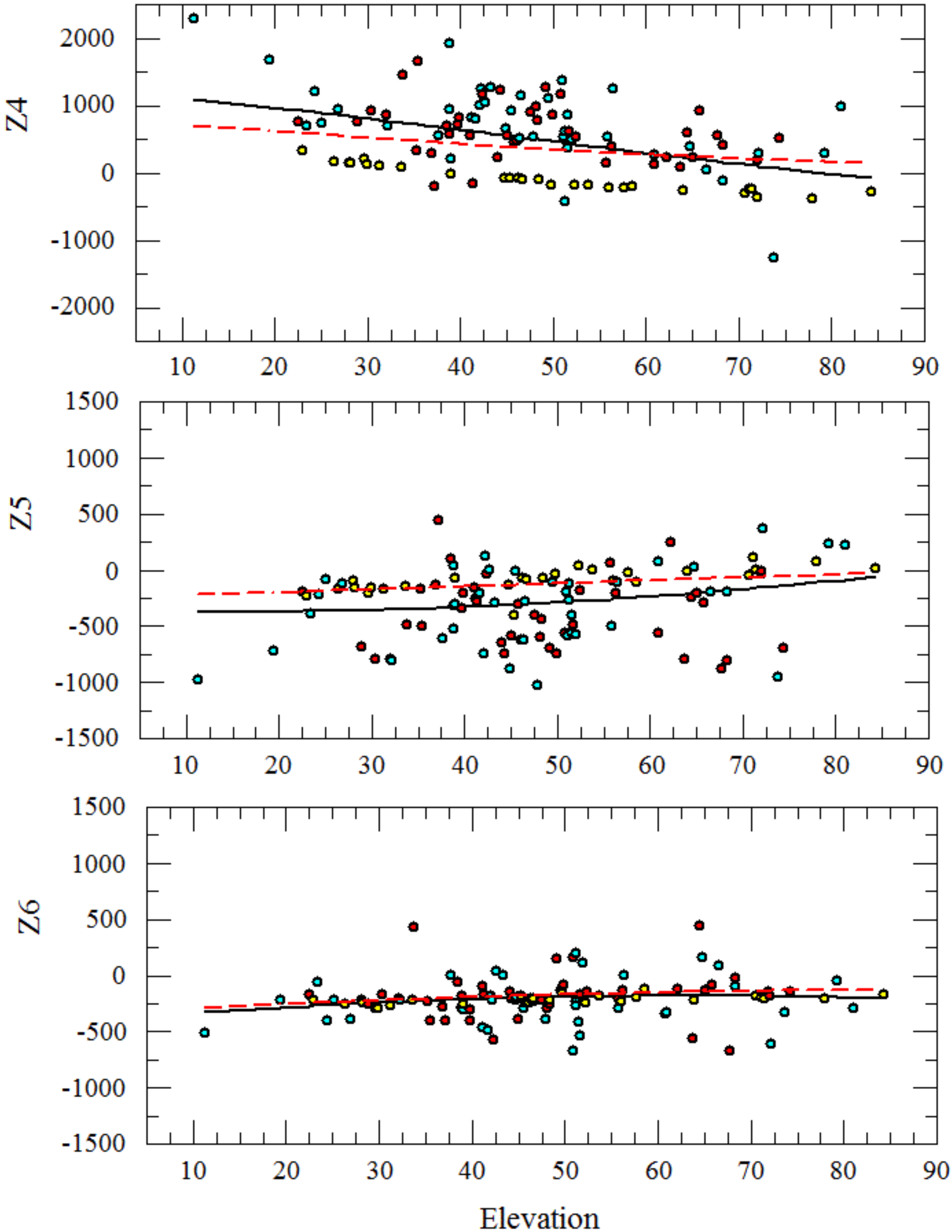
The results for each Zernike coefficient (Z4-Z21 using the GBT definition of Zernikes) were plotted as a function of elevation and are shown in the plots below. The yellow points are the 2014.11.24 data from which the 2014winter gravity model was derived. The red points are from solutions that used the Winter2010V1 gravity model, and the blue points are solutions using the Winter2014V1 gravity model. We find no systematic differences between the gravity+thermal results using the 2010 and 2014 gravity models (i.e., the AutoOOFs provided "thermal" solutions that compensated for deficiencies in the input gravity model). This demonstrates that all sets of data are valid and can be combined for the analysis. The dashed-red line shows the 2010 gravity model, while the yellow points represent the 2014winterV1 gravity model. The black solid lines show the best fits based on all the data. The trends in the data as a function of elevation represent the effects of gravity, while the scatter about the trend shows the variation of the thermal effects. A key result is that the Z4 yellow points are systematically offset from the rest of the Z4 data. This may suggest that these data were not taken in typical thermal conditions, and the associated 2014winter gravity model introduced a significant offset for the Z4 coefficient. This offset is suspected to account for the strong "coma-like" effect that produced peanut shape beams in the elevation direction using the 2014winter gravity model.

We propose using the coefficients based on the best fit to the data (solid black lines in plots) as the updated gravity model (2014FallV1, Table 1). This model is based on fitting solutions for each Zernike (x) using the relationship $Z_x = A_x*\sin(el) + B_x*\cos(el) + C_x$, where el is elevation. Table 1 gives the coefficients and formal errors from the fits (all values in µm). A series of F-test imply that the Z5, 6, 7, 8, 10, 14, 15, 16, 17, and 18 are statistically consistent with these terms being independent of gravity (i.e., constant with elevation). The gravity-dependence of Z4, 11, 12, 13, 19, and 20 is as well fit by a straight line as by the above function. Only Z9 and 21 have a statistically significant non-linear shape as a function of elevation.

TABLE 1:

Z	A	B	C	σ_A	σ_B	σ_C	rms
4	-697.71	697.91	550.68	905.87	775.82	1137.56	517.55
5	-148.22	-482.95	136.07	540.74	463.11	679.05	308.94
6	319.46	154.68	-535.72	319.70	273.80	401.46	182.65
7	-554.68	-327.02	632.92	378.25	323.95	475.00	216.11
8	-65.60	53.89	108.34	268.56	230.01	337.25	153.44
9	588.39	1305.77	-1063.37	341.03	292.07	428.25	194.84
10	932.92	542.64	-1119.48	481.14	412.07	604.20	274.89
11	136.83	923.46	-288.13	329.68	282.35	414.01	188.36
12	-532.04	-177.33	440.51	238.51	204.27	299.52	136.27
13	360.71	62.38	-94.13	160.01	137.04	200.94	91.42
14	-38.56	15.16	-160.13	188.20	161.18	236.34	107.52
15	-622.70	-414.96	744.87	288.93	247.45	362.83	165.07
16	121.80	-38.60	16.58	293.75	251.58	368.89	167.83
17	-210.31	-198.02	203.98	161.70	138.48	203.05	92.38
18	71.68	3.62	-266.29	142.96	122.44	179.53	81.68
19	579.23	-51.98	-392.41	178.29	152.70	223.89	101.86
20	243.95	-121.70	-6.45	194.88	166.91	244.73	111.34
21	593.36	1065.48	-1287.78	304.57	260.84	382.46	174.01

PTCS/PN76


Z4
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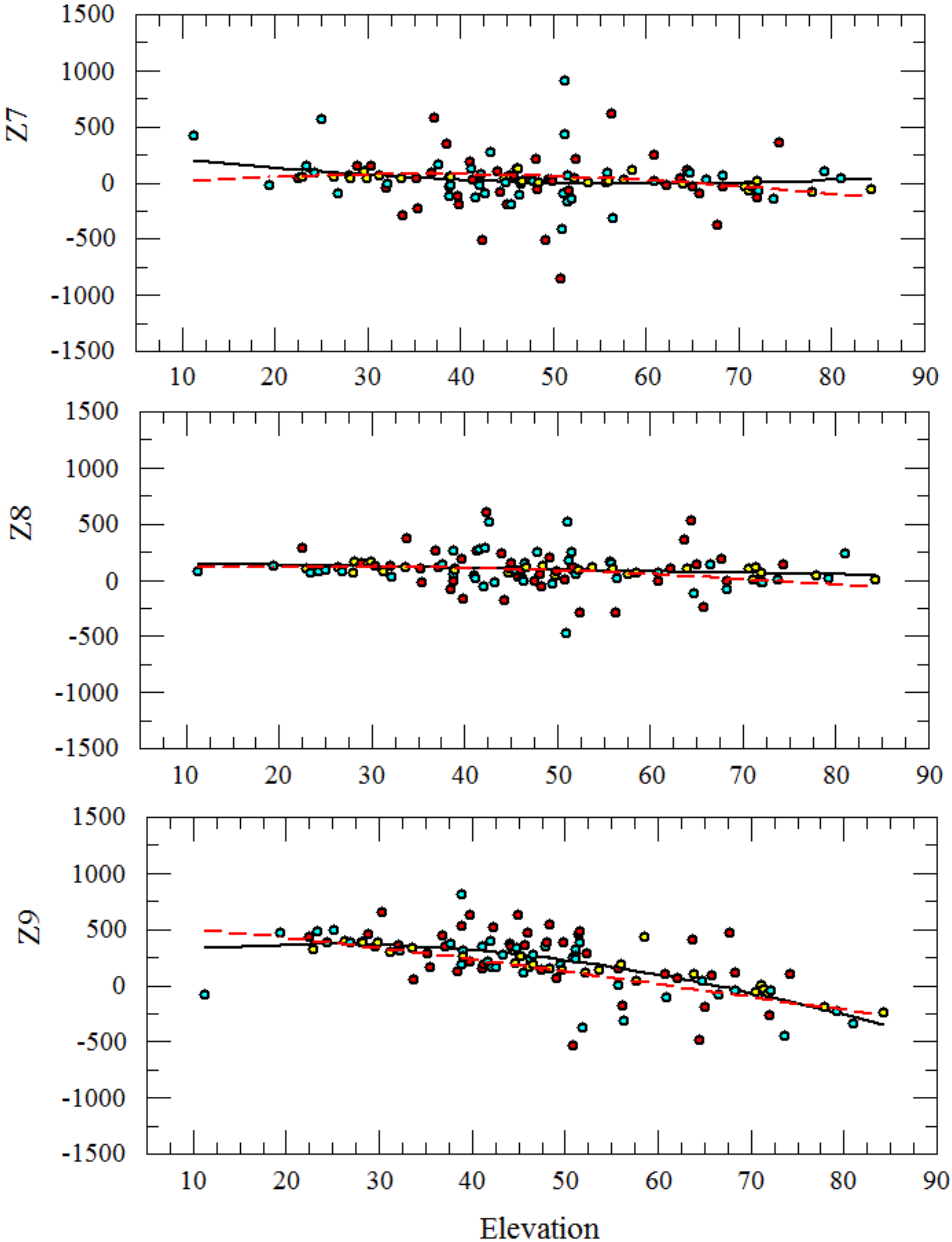
1000
0
-1000
-2000
10
20
30
40
50
60
70
80
90
Z5
1500
1000
500
0
-500
-1000
-1500
Z6
Elevation



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Z8
Z9
1500
1000
500
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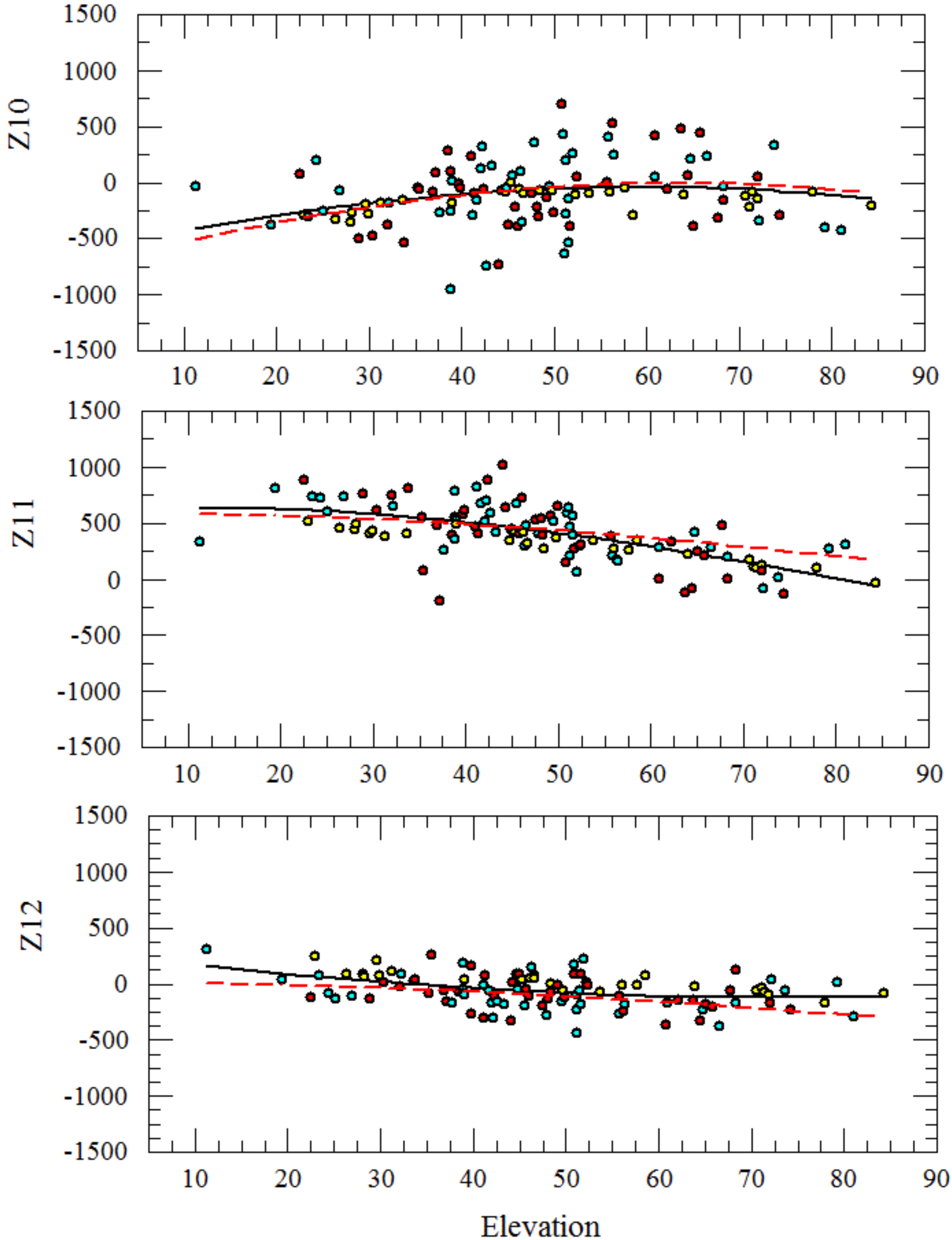
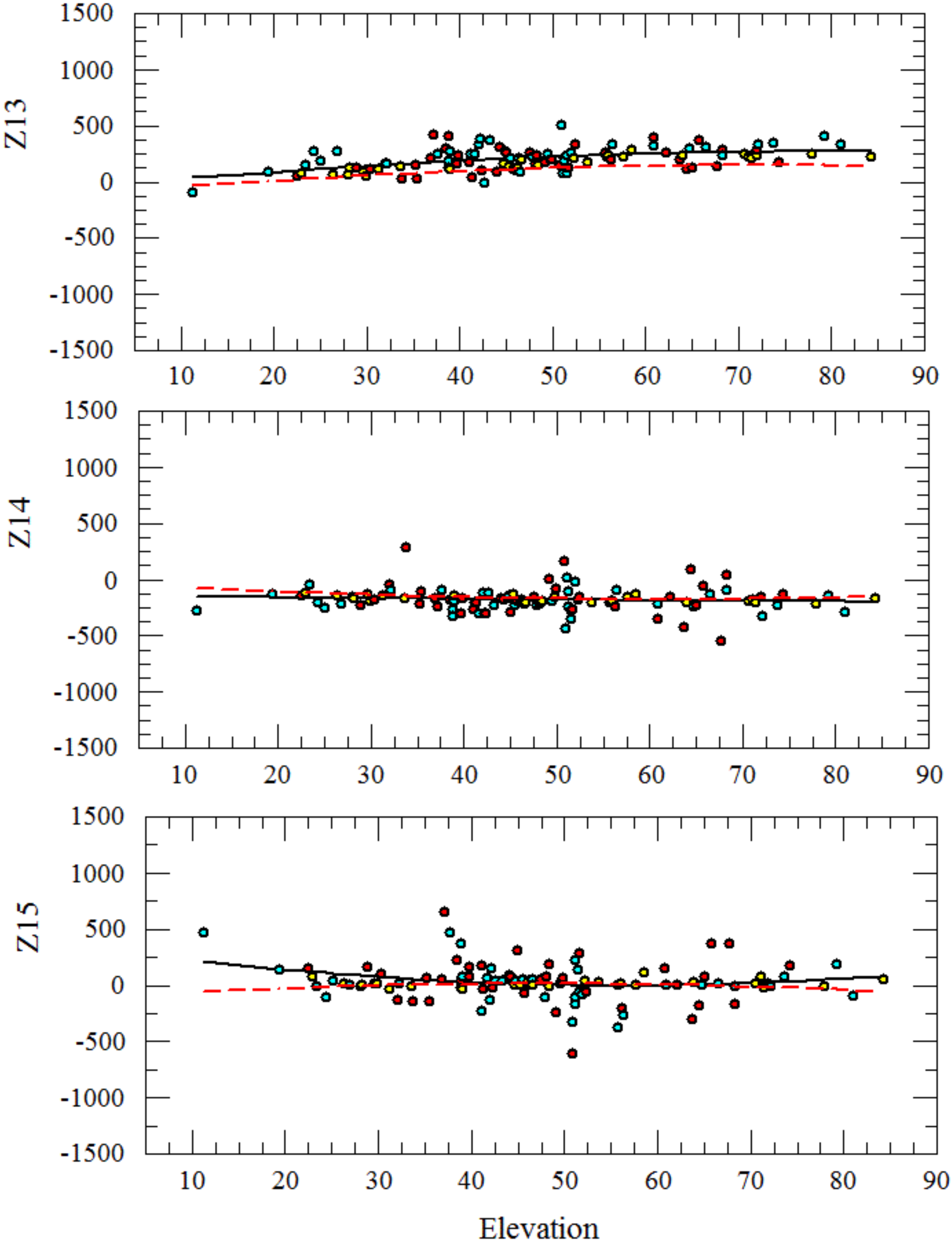
-500
-1000
-1500
10
20
30
40
50
60
70
80
90
Elevation

PTCS/PN76



Z10
1500
1000
500
0
-500
-1000
-1500
10
20
30
40
50
60
70
80
90
Z11
1500
1000
500
0
-500
-1000
-1500
10
20
30
40
50
60
70
80
90
Z12
1500
1000
500
0
-500
-1000
-1500
10
20
30
40
50
60
70
80
90
Elevation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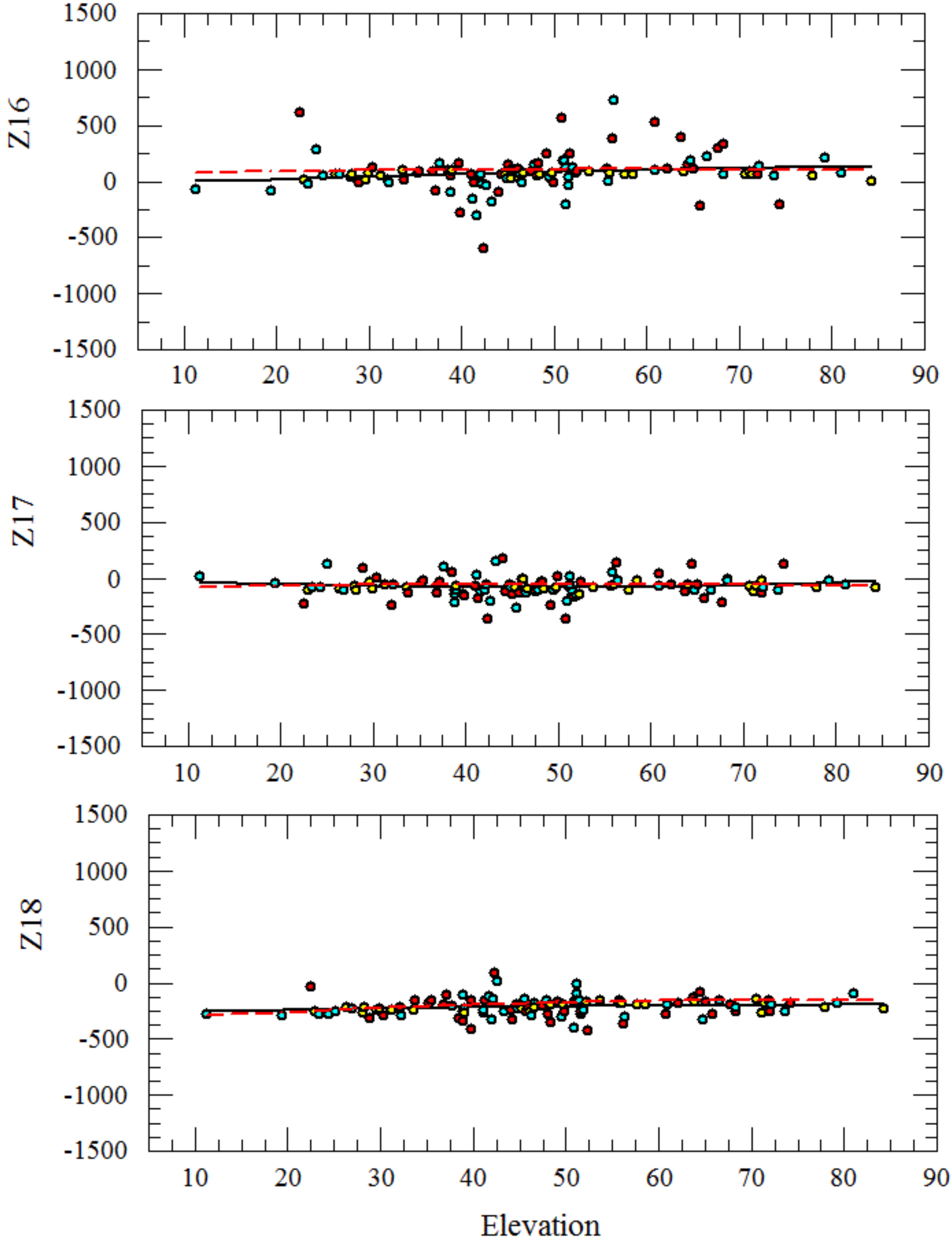
500
0
-500
-1000
-1500
Z13
Z14
Z15
10
20
30
40
50
60
70
80
90
Elevation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Z17
Z18
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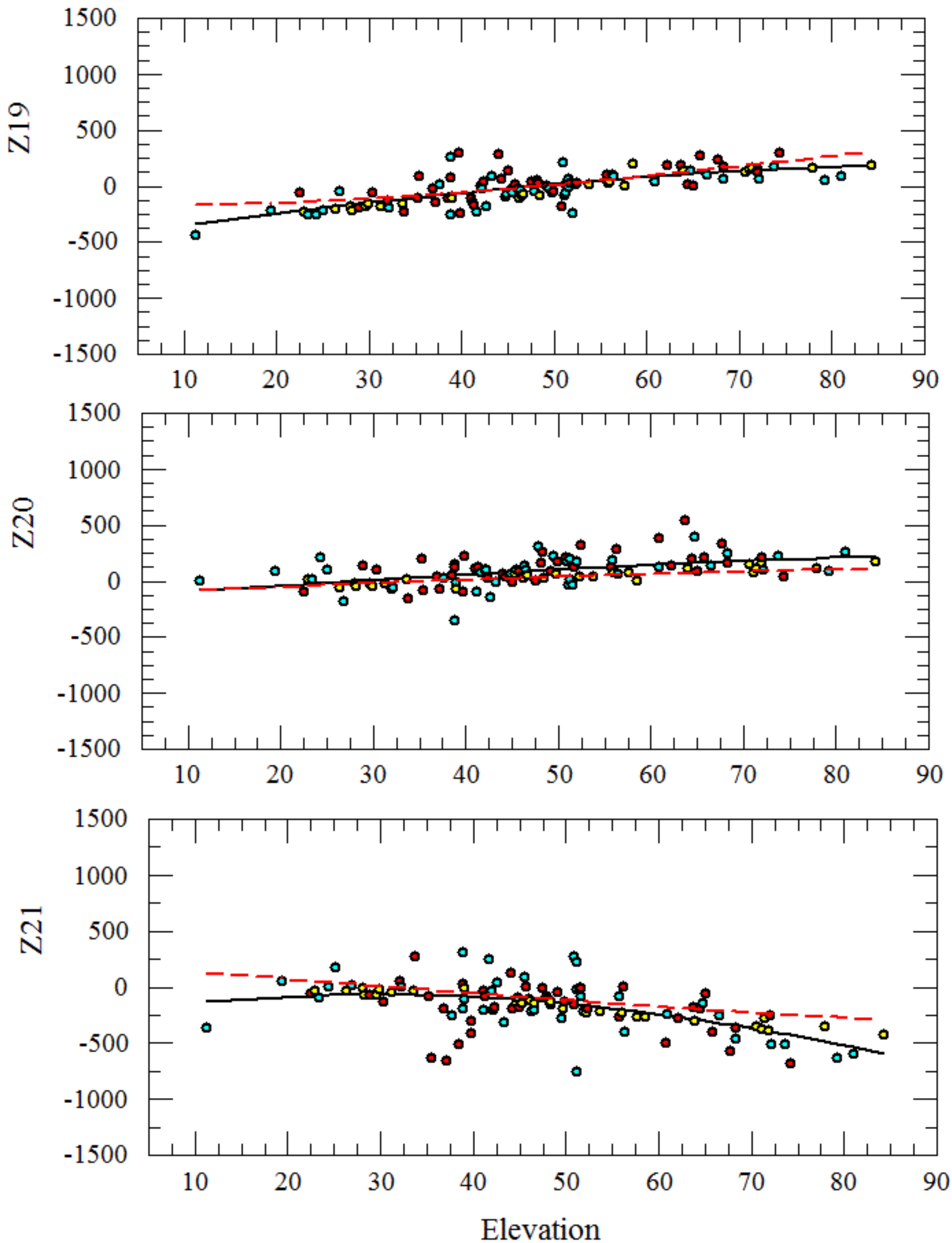
1000
500
0
-500
-1000
-1500
10
20
30
40
50
60
70
80
90
Elevation


Z19
Z20
Z21
1500
1000
500
0
-500
-1000
-1500
10
20
30
40
50
60
70
80
90
Elevation

For completeness, we show the solutions based on using the mean value for C and zeros for A and B for cases where no shape is detected in the fits (Table 2), but we proposed to use the full solutions given in Table 1 as the initial model for the upcoming season.

TABLE 2:

Z	A	B	C	σ_A	σ_B	σ_C	rms
4	-697.71	697.91	550.68	905.87	775.82	1137.56	517.55
5	0.0	0.0	-282.34	----	----	314.38	314.38
6	0.0	0.0	-206.22	----	----	182.95	182.95
7	0.0	0.0	23.06	----	----	217.58	217.58
8	0.0	0.0	95.99	----	----	153.50	153.50
9	588.39	1305.77	-1063.37	341.03	292.07	428.25	194.84
10	0.0	0.0	-98.51	----	----	280.25	280.25
11	136.83	923.46	-288.13	329.68	282.35	414.01	188.36
12	-532.04	-177.33	440.51	238.51	204.27	299.52	136.27
13	360.71	62.38	-94.13	160.01	137.04	200.94	91.42
14	0.0	0.0	-178.06	----	----	106.93	106.93
15	0.0	0.0	29.32	----	----	168.00	168.00
16	0.0	0.0	79.20	----	----	168.57	168.57
17	0.0	0.0	-75.06	----	----	92.41	92.41
18	0.0	0.0	-212.43	----	----	81.72	81.72
19	579.23	-51.98	-392.41	178.29	152.70	223.89	101.86
20	243.95	-121.70	-6.45	194.88	166.91	244.73	111.34
21	593.36	1065.48	-1287.78	304.57	260.84	382.46	174.01

4. Discussion and Concluding Remarks

The AutoOOF measurements from last season were used to derive a new gravity model (2104FallV1). The high-order Zernike terms tend to show a low dispersion that may suggest these terms are relatively insensitive to thermal effects. The terms that have the largest thermal scatter are Z4, Z5, and Z10. The Z4 term appears particularly sensitive to varying conditions with an rms scatter of more than 500 µm. If the thermal variations primarily only effect the lower order terms, it may be possible to speed up the derivation of the thermal Zernikes by taking short daisy, circle, or spiral scans instead of the full, time-consuming maps currently used by AutoOOF. Currently, the AutoOOF procedure takes 30minutes to complete at W-band, and users only do it every 4hrs or more given the large overhead. The shortened AutoOOF procedure may only take 5-10 minutes, and could be done every 45min-1hr. In some cases the AutoOOFs also would replace our current practice of using AutoPeakFocus. The faster cadence could mean we'll have better surfaces, with higher efficiencies, with a significant reduction in overhead to almost the same level as is needed to refine pointing and focus.

The rational for fitting the Zernike's with Equation (1) is the theoretical expectation that the GBT surface deformations will follow "Hooke's law" (Nikolic et al., PTCS PN 47.1). Based on the empirical data, we may be able to model gravity better with a simpler fit for many of the coefficients (e.g., Table 2).

The quality of the proposed gravity model (2014FallV1) should be verified by making gain curve measurements at Q-band to test whether the measured aperture efficiency remains constant with elevation. We should also check the AutoOOF solutions to verify that the residual rms values are of order 200 µm.