Theodolite Survey of the Dome from the AO9 Monument
August 2001

The Gregorian dome was surveyed from the AO9 monument at the base of the main reflector in August 2001. The following is an edited and reformatted version of the notes about the survey results originally written up by Phil Perillat, as retreived on 2011 September 15.

- `http://www.naic.edu/~phil/optics/surveyaug01/ao9surveyaug01.html`
- `http://www.naic.edu/~phil/optics/surveyaug01/ao9surveyROaug01.html`

Note: The two sections, Origin=AO9 and Origin=Reflector, are extremely similar in presentation and wording, but differ in the crucial numbers calculated. The reader is urged to be cautious.

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1 Survey Results, Origin = AO9

The dome position was surveyed from the AO9 monument on 9 Aug 2001 starting at about 10 pm. This section shows the results using AO9 as the origin. See Section 2 for the results relative to the center of the reflector. The dome was moved through the following positions:

1. A za strip from 2° to 19.6° in 1° za steps at an azimuth of 242.87° (pointing at tower 8).
2. A za strip from 19.6° to 1.09° in 1° za steps at an azimuth of 302.87°.
3. An azimuth swing from an azimuth of 242.87° to 602.87° in 30° steps with the dome at 19.6° za.
4. An azimuth swing from an azimuth of 602.87° to 242.87° in 60° steps with the dome at 10° za.

1.1 Differences between the encoder and theodolite (az,za) positions → Platform offset from AO9.

The dome and azimuth were positioned using the az, za encoders with no model corrections included. The theodolite vertical is determined by gravity while the theodolite azimuth is arbitrary. To calibrate the theodolite azimuth I used:

`TheodAzCorrection= mean(EncoderAz-theodoliteAz)`

The average was done over the two azimuth swings. The correction was then added to the theodolite azimuth encoder values. The position differences (Theodolite−Encoder) are shown in Figures 1 and 2. (`processing:survey/010809/pltazzadif.pro`)

The azimuth rotates about the main bearing. The bearing is offset relative to the AO9 monument where the theodolite was positioned. This offset causes a 1 azimuth term in the differences of the measured azimuth positions. The difference was computed as TheodoliteZa−encoderZa (and similar for az values). The peak of the sine wave has the theodolite angle greater than the encoder angle. For this to occur the distance from AO9 to the dome must be greater than the distance from the main bearing to the dome. So the platform is displaced along the direction of the peak. To compute the horizontal distance I generated a circle and then offset by 0.01 inch steps from 0 to 5 inches. I then computed the differences in the two circles. The offset distance corresponding to 88″ was 2.23 inches. Projecting this along the phase direction of 6° gives the offsets of the platform relative to AO9:

Radial offset of platform	dx offset (east positive)	dy offset (north positive)
2.23 inches	0.2 inches	2.2 inches

The platform offset will create a pointing error. The raw pointing errors that were used to build model 13 (Jan 2002; see Figure 3) agree with the measured translation:

Pointing error (amplitude,phase)	Offset error (amplitude,phase)
za: 98″, 185° az: 98″, 94°	za: 88″, 5° az: 88″, 277°

The pointing error is the direction you must move the telescope to correct for the pointing offset. It is 180 degrees from the direction of the motion and the amplitudes are within 10%. (`processing: survey/010809/reduc/cmpao9offsets.pro`)

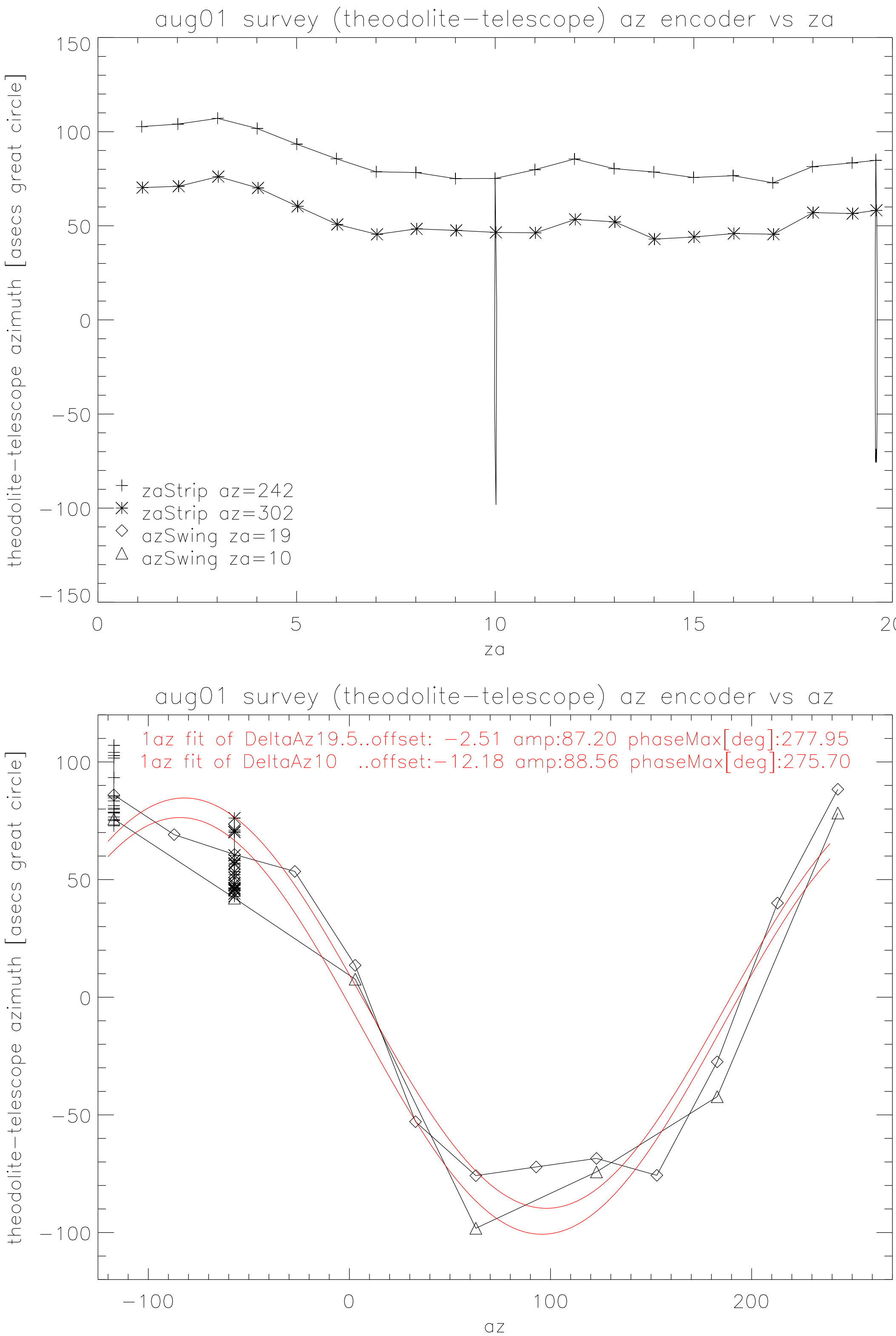

Figure 1: Position differences (Theodolite−Encoder) plotted versus za (top) and azimuth (bottom). These are great circle azimuth (the difference has been multiplied by the sine of the zenith angle). The bottom plot contains a sine fit to the 1az term for both of the spins. The offset, amplitude, and phase of the peak are printed.

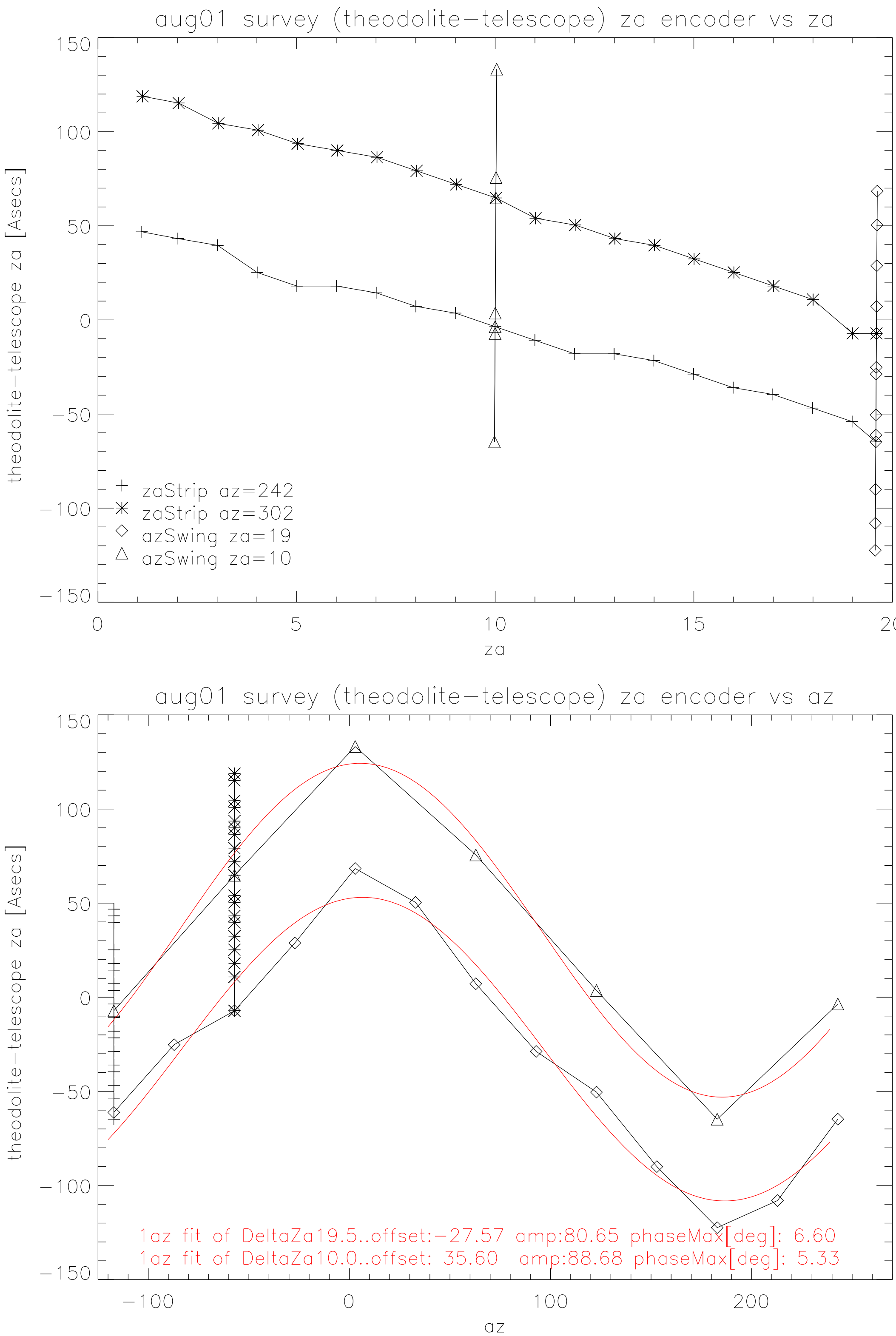

Figure 2: Zenith angle differences (Theodolite−Encoder) versus za (top) and azimuth (bottom). The bottom plot also contains a fit to the 1az terms of the swings. The amplitude for the az swing at 19.5° is 80″ instead of 88″ for the other 3 fits. Looking at the fit in Figure 2, the peak to peak excursion is closer to an amplitude of 88″ so the sine wave probably got messed up a bit.

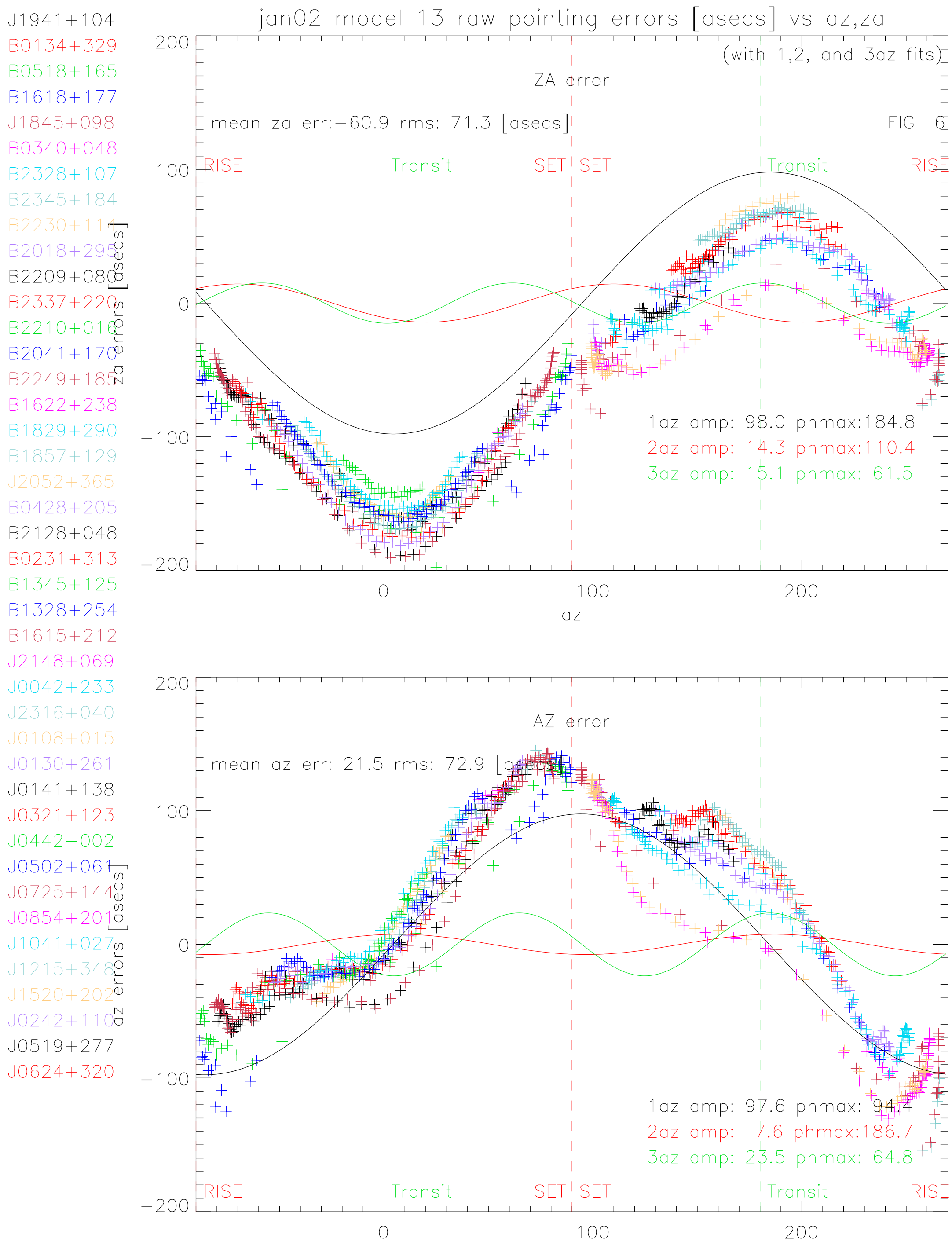

Figure 3: Raw pointing errors that were used to build model 13 (Jan 2002)

1.2 The pitch, roll, and focus errors versus az and za

The directions of the pitch, roll, and focus errors are defined as:

- Positive pitch error: the uphill portion of the dome is to high (far from the dish).
- Positive roll error: looking uphill, the right side of the dome is too low (close to the dish)
- Positive focus error: the dome is too far away from the reflector.

Figure 4 shows the pitch, roll, and focus errors versus azimuth and zenith angle, and Figures 5– 7 plot their absolute values. You can see the two za strips plus the two azimuth swings. For pitch and roll 1 tick mark is 0.03°. For focus 1 tick mark in 0.3 inches. The angle is set so that 180° from pointing up is 50% of the maximum error. The za values of 19.6 and 10 at azimuth of 242.87° were repeated three times (twice with the azimuth spin and once with the za strip). The points 19.6 and 10 za at azimuth of 302.87° were repeated twice. These pitch values vary by about 8% max. The roll values lie on top of each other. The focus error varies by up to 14%.

Figure 8 shows the motion of the platform about 1256.35 feet as measured by the distomats while the survey was being taken. The maximum motion was 0.2 inches so the platform was relatively stable during the measurements. (`processing:survey/010809/reduc/pltprf.pro`)

1.3 Fitting the pitch, roll, and focus.

The pitch, roll, and focus measurements were fit to a cubic in (za-10) degrees and 1, 2, and 3 az terms in azimuth. Figures 9–12 show the fits in az, za.

Figure 9 shows the pitch data (black) and the fit (red), which is good except for the bump at za of 8°, 1°, and za $\geq$ 19. Figure 10 shows the roll data (black) and fit (red), which is pretty good. A different fit was used for focus (Figure 11): it used $(za - 10)$ for the za variable. It was 3rd order in $(za - 10)$ for the za part. The az terms had 1a, 3az, and $\sin(za - 10) \times [\cos(3az) + \sin(3az)]$. Figure 12 shows the azimuth terms of the fits (1az,2az,3az) as well as the fit coefficients.

The rms for the fits are: pitch 0.013°, roll 0.0085°, and focus 0.1 inches. The 1az term of 0.02° for pitch may be from the horizontal offset of the platform. This offset should not give a roll term so I don't know where the 0.035° 1az roll term is coming from. When the tilt sensors were run on 04 Aug 2001 the 1az term was 0.003 for these tiedown positions. The 3az term for pitch and roll is similar to what we measured back in Feb 2000 and what the tilt sensor measured in 04 Aug 2001. The fit to focus is what will be used to compute the focus error over the entire dish (since the tilt sensors don't measure focus). (`processing:survey/010809/reduc/pltfit.pro`)

The fit data will eventually be used to connect the pitch and roll of the theodolite to the pitch and roll as measured by the tilt sensors. We can get a complete sampling of az, za with the tilt sensors to help us with the model. We use the theodolite data to remove any offsets that the tilt sensors have.

To Do: Do some more tilt sensor azimuth swings to make sure that the platform is not tilted. The tiedown encoders were changed back in Sep 2001 (lightning) and we should verify that the tiedowns were set back to the same values.

(`processing:survey/010809/reduc/doit.pro` for initial analysis.)

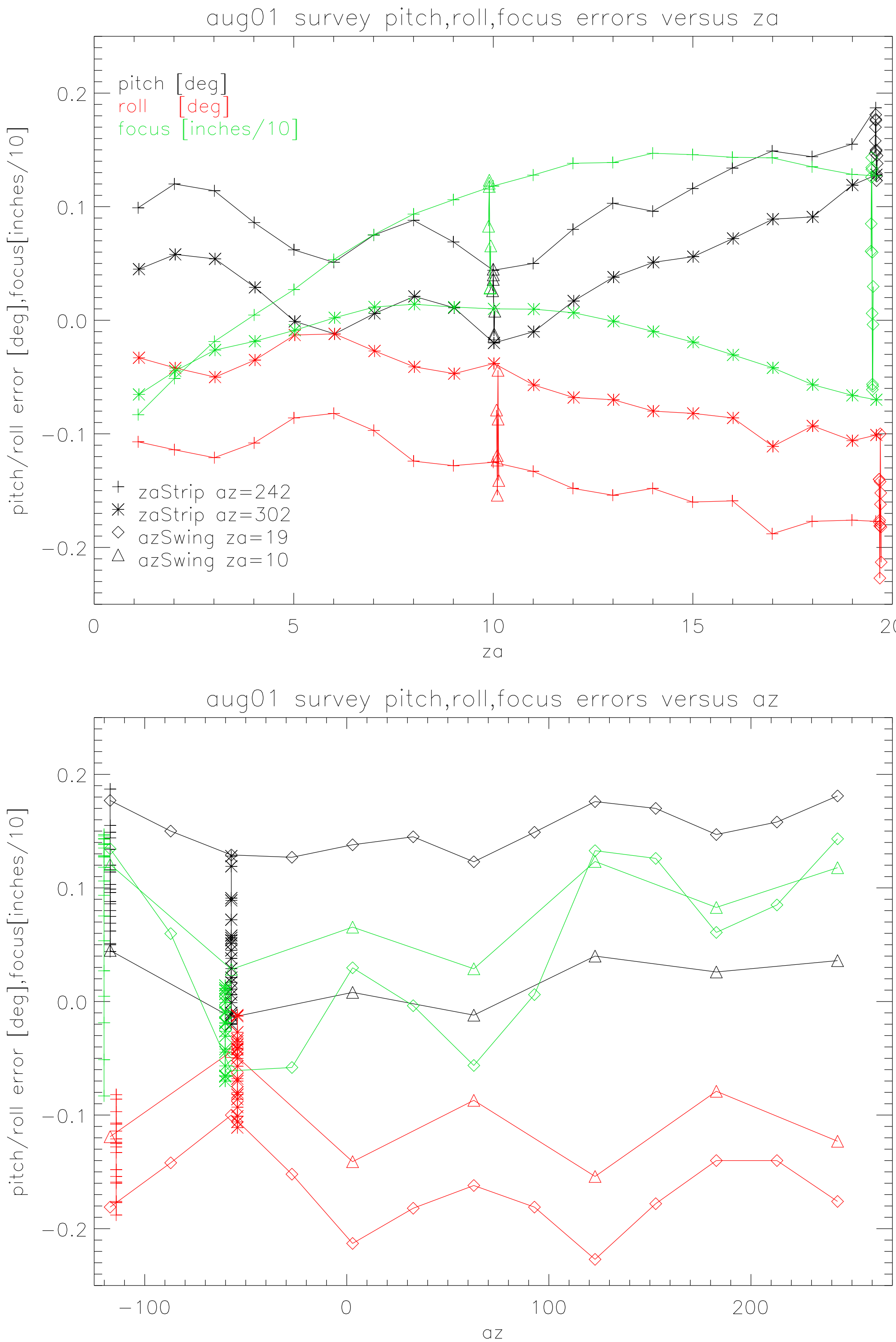

Figure 4: Top: Pitch, roll, focus errors versus za. Black is pitch, red is roll, and green is focus. The vertical axis is degrees for pitch and roll, and inches/10 for focus (0.1 = 1 inch). The za strips and azimuth spins are plotted with different symbols. Bottom: The same errors plotted versus azimuth angle.

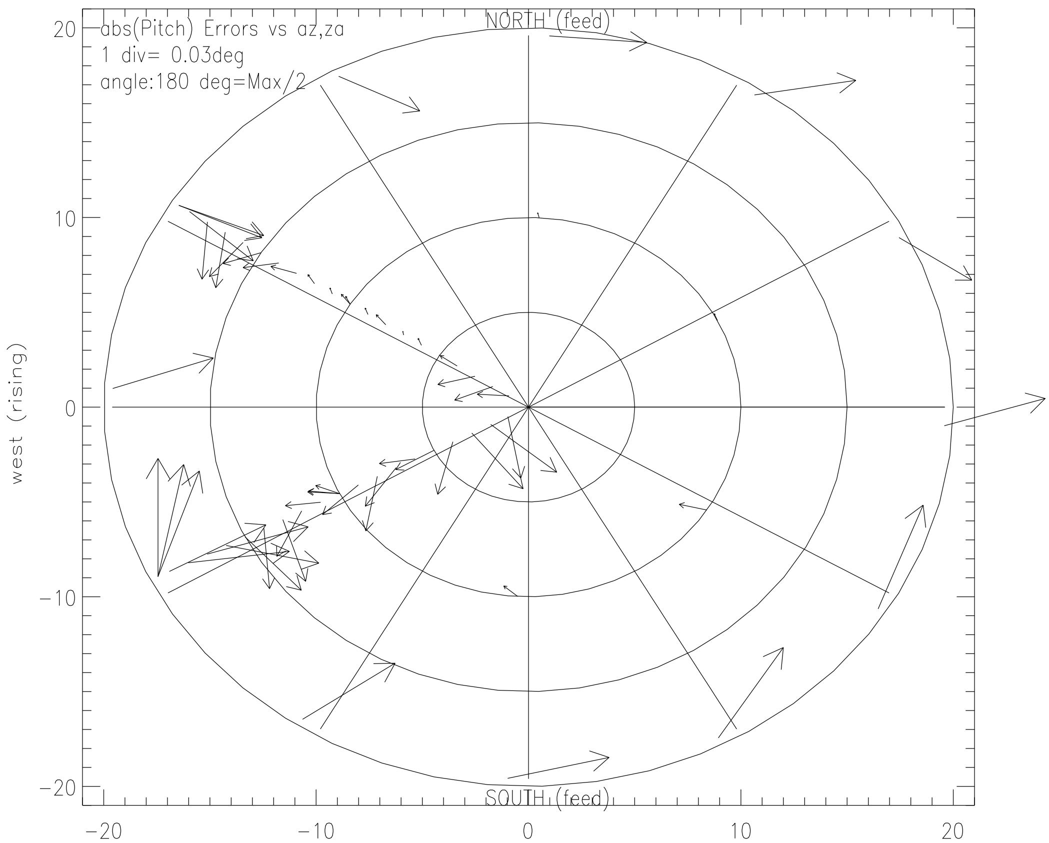

Figure 5: Absolute value of the pitch errors versus azimuth and zenith angle. See text for details.

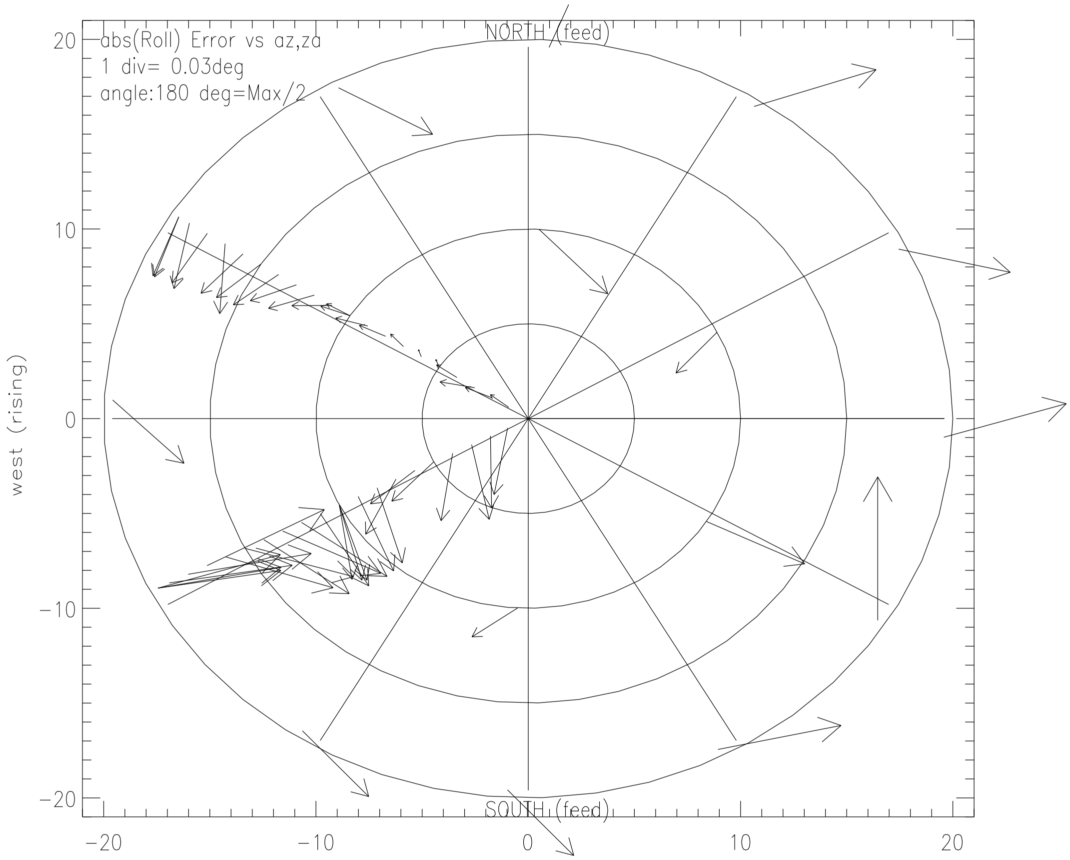

Figure 6: Absolute value of the roll errors versus azimuth and zenith angle. See text for details.

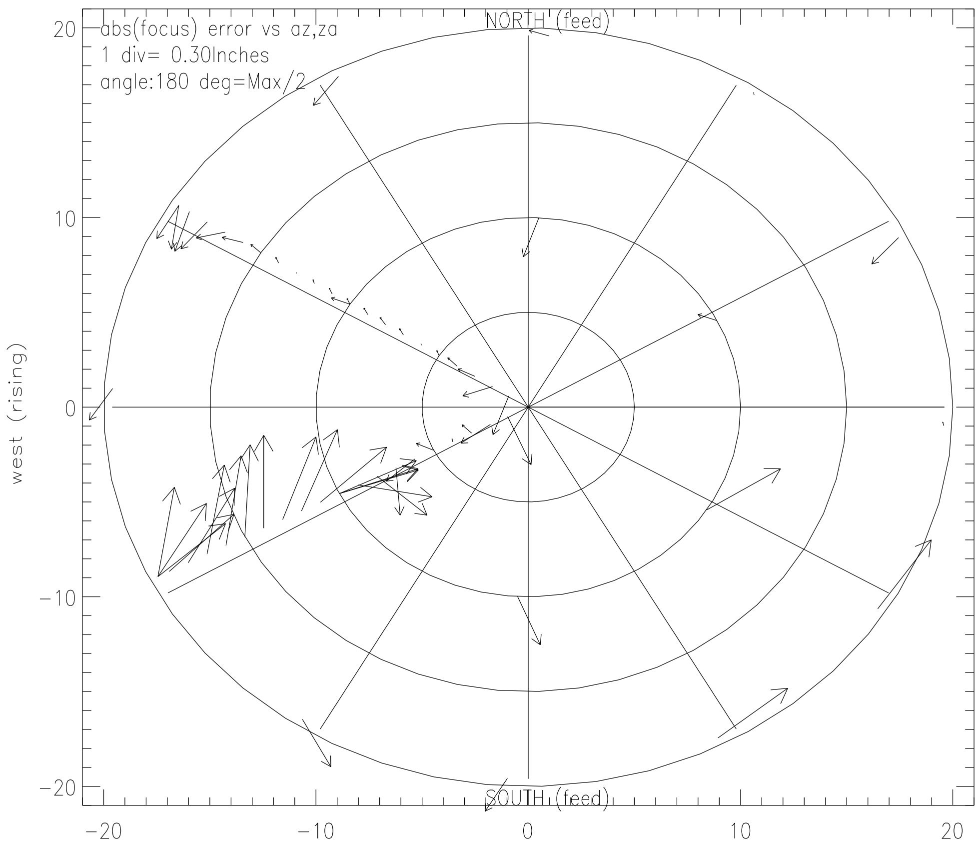

Figure 7: Absolute value of the focus errors versus azimuth and zenith angle. See text for details.

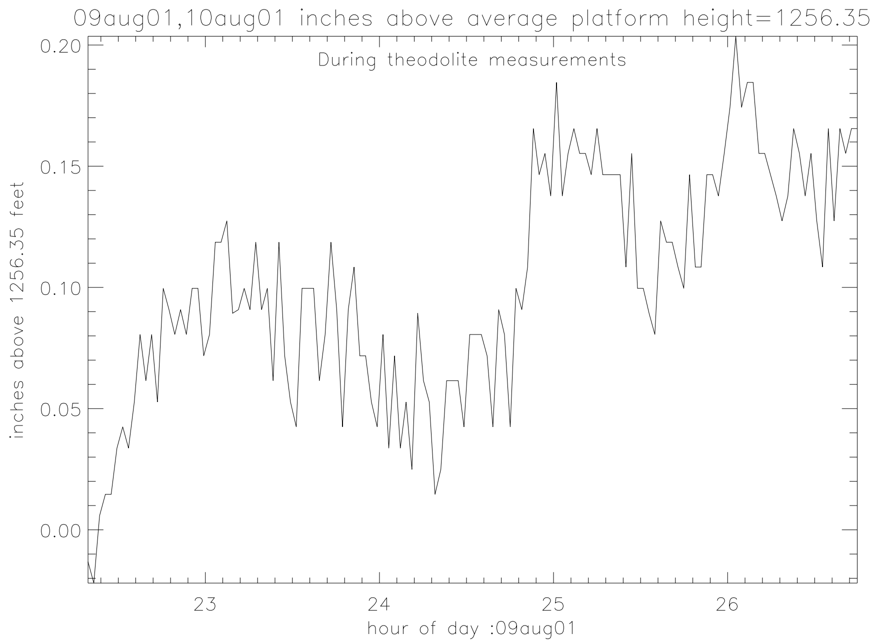

Figure 8: The motion of the platform about 1256.35 feet as measured by the distomats while the survey was being taken. The maximum motion was 0.2 inches.

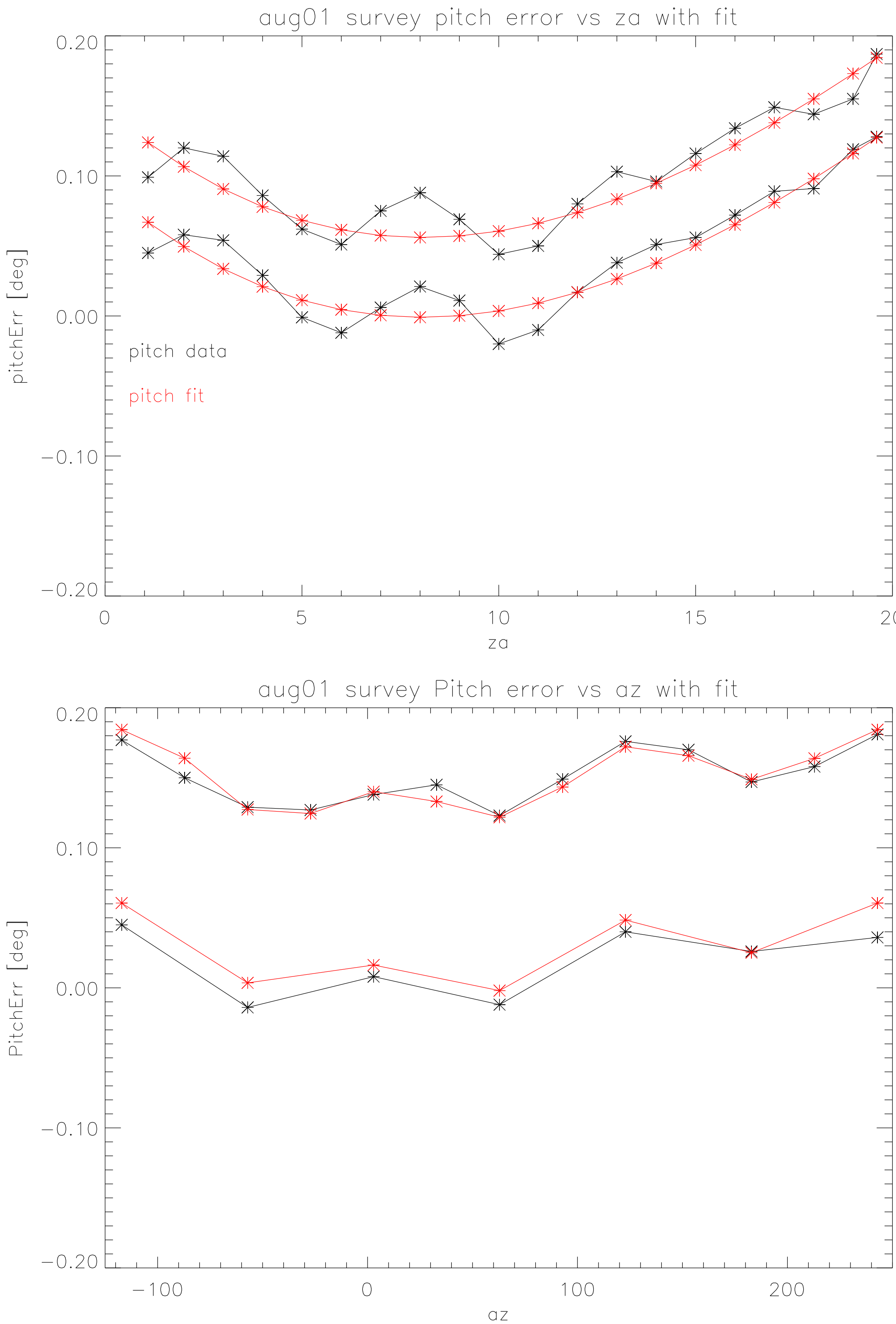

Figure 9: Pitch data (black) and fit (red). See §1.3.

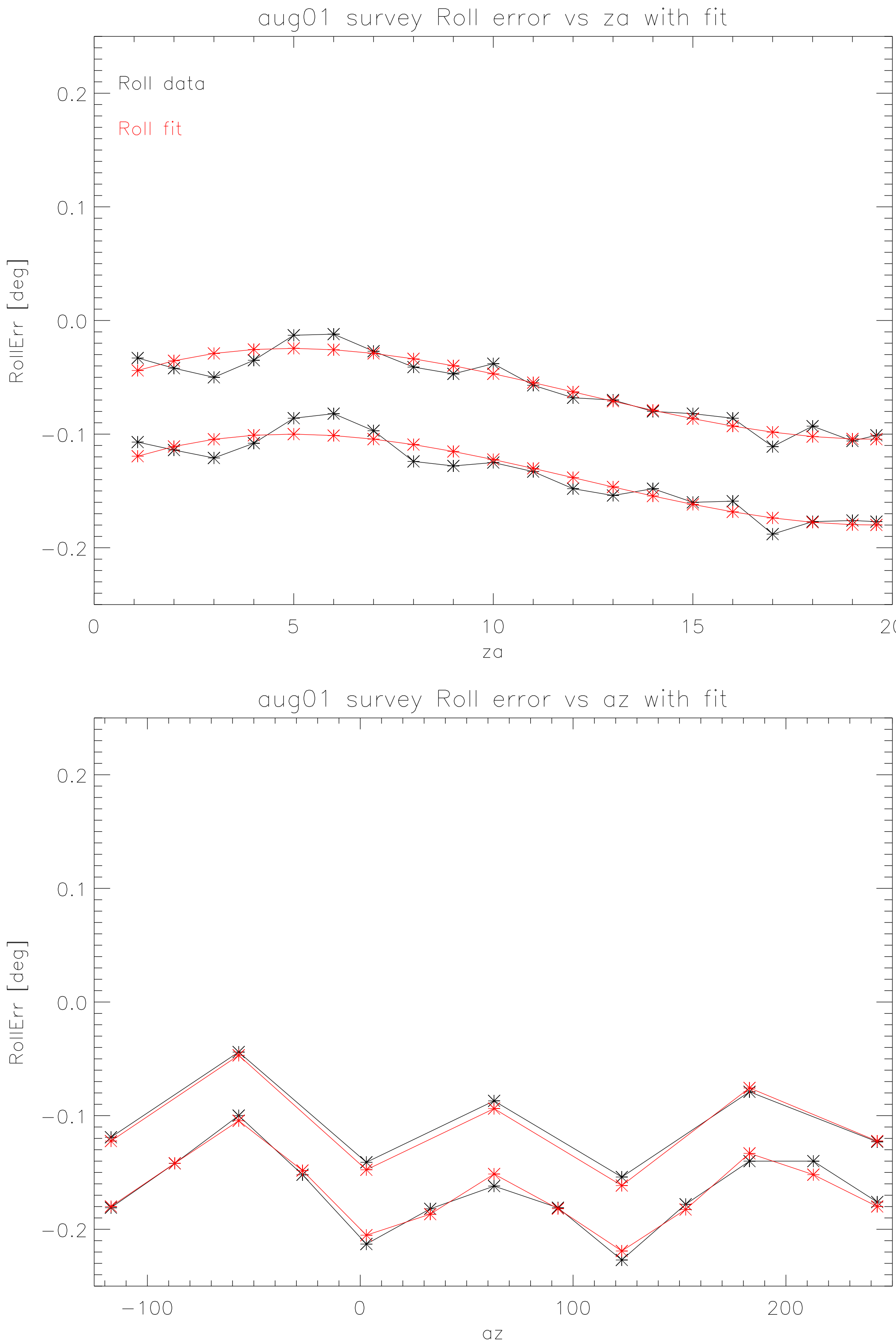

Figure 10: Roll data (black) and the fit (red). See §1.3.

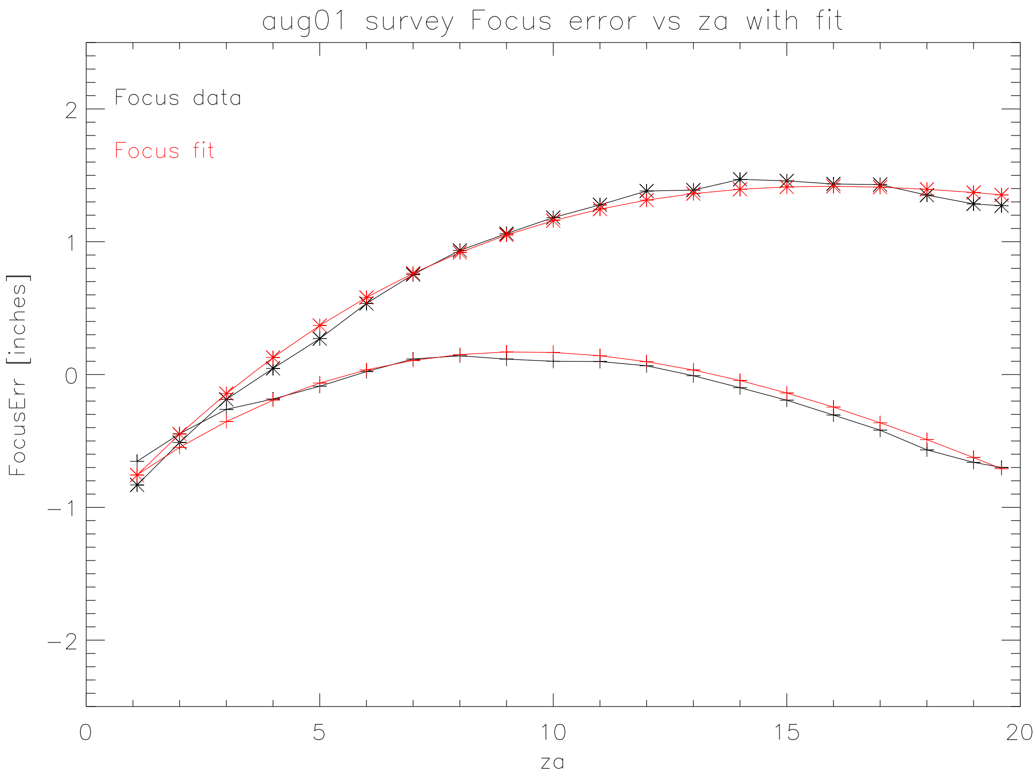

Figure 11: Focus data (black) and the fit (red) in $(za - 10)$. See §1.3.

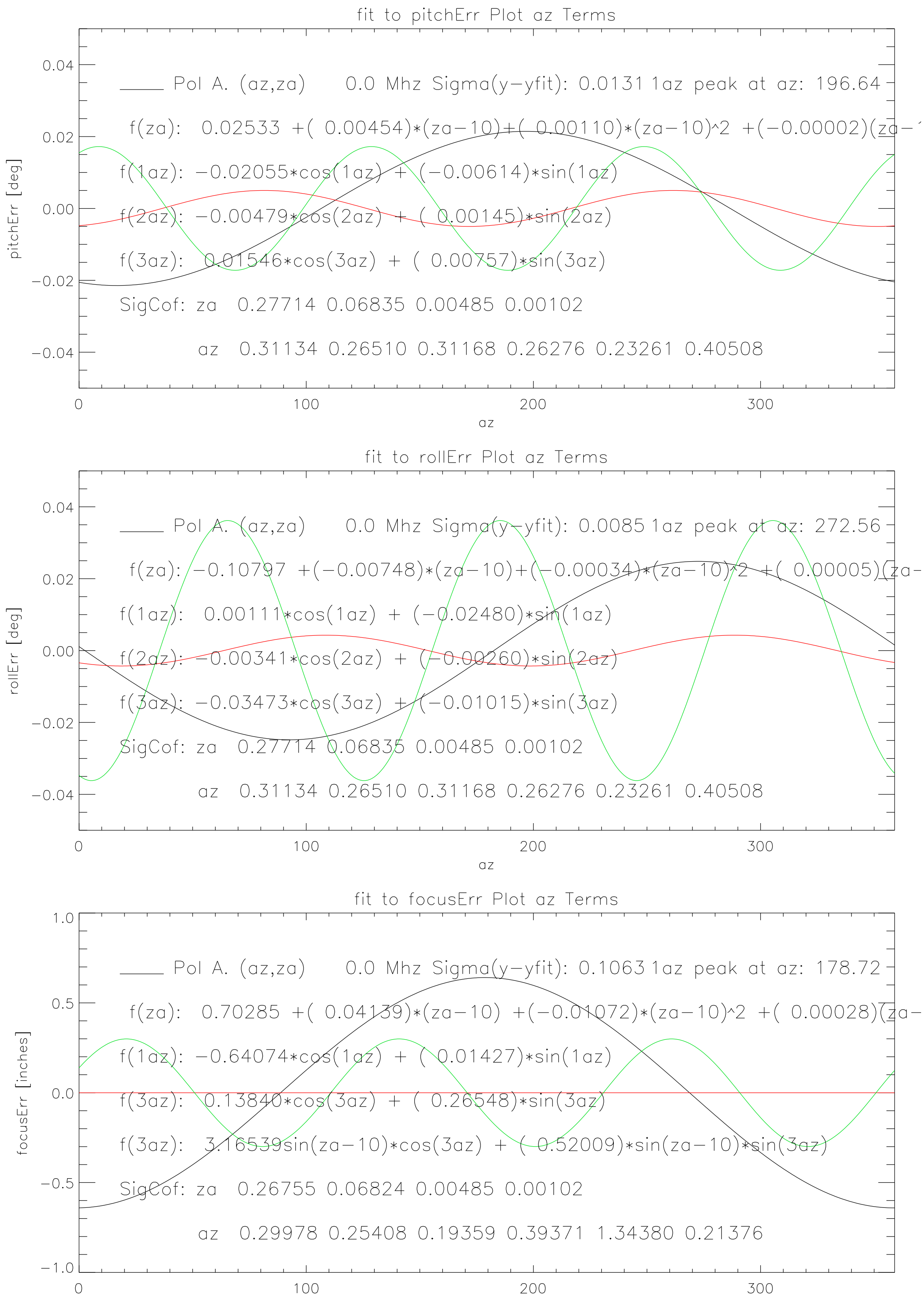

Figure 12: The azimuth terms of the fits (1az,2az,3az) as well as the fit coefficients. See §1.3.

2 Survey Results, Origin = Reflector

The dome position was surveyed from the AO9 monument on 9 Aug 2001 starting at about 10 pm. This section shows the results using AO9 as the origin. See Section 2 for the results relative to the center of the reflector. The dome was moved through the following positions:

1. A za strip from 2° to 19.6° in 1° za steps at an azimuth of 242.87° (pointing at tower 8).
2. A za strip from 19.6° to 1.09° in 1° za steps at an azimuth of 302.87°.
3. An azimuth swing from an azimuth of 242.87° to 602.87° in 30° steps with the dome at 19.6° za.
4. An azimuth swing from an azimuth of 602.87° to 242.87° in 60° steps with the dome at 10° za.

2.1 Differences between the encoder and theodolite (az,za) positions → Platform offset from AO9.

The dome and azimuth were positioned using the az, za encoders with no model corrections included. The theodolite vertical is determined by gravity while the theodolite azimuth is arbitrary. To calibrate the theodolite azimuth I used:

```
TheodAzCorrection= mean(EncoderAz-theodoliteAz)
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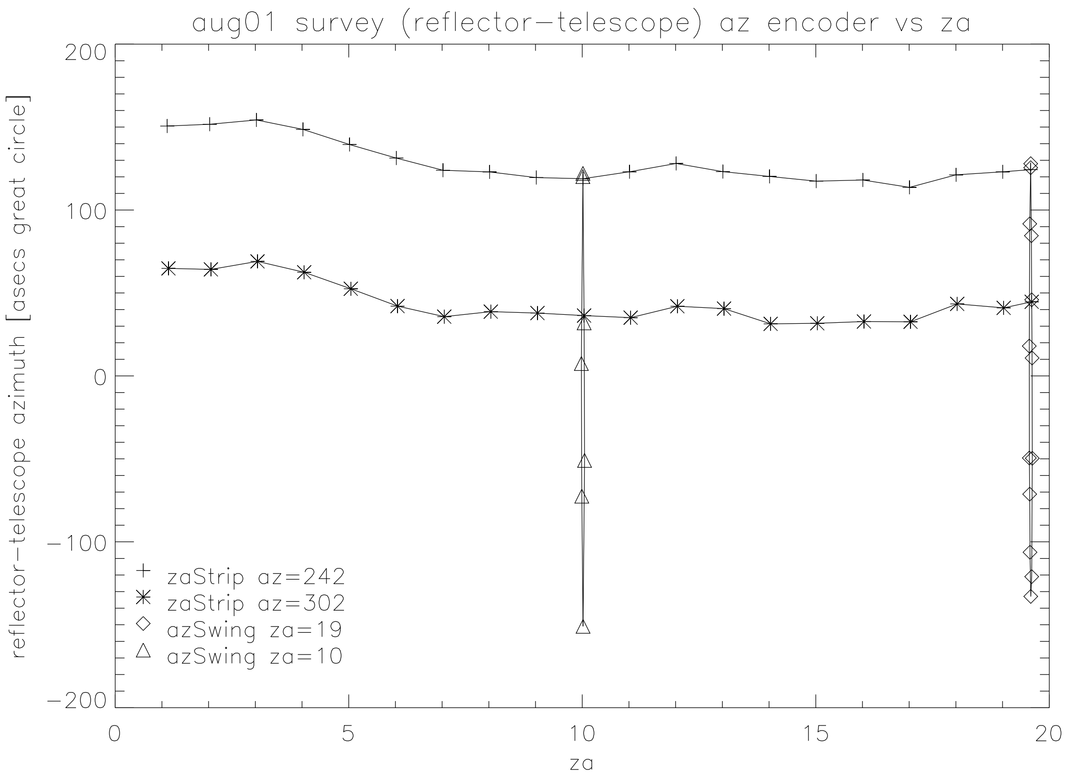
The average was done over the two azimuth swings and then the correction was added to the theodolite azimuth encoder values. The theodolite positions were then translated to the center of the reflector (offset 0.69 inches south, 1.34 inches east of AO9). The offset was measured using the photogrametry data and a survey of some of the optical targets. The position differences (Reflector−Encoder) are shown in Figures 13 and 14. (`processing:survey/010809/reducR/pltazzadif.pro`)

The azimuth rotates about the main bearing. The bearing is offset relative to AO9 where the theodolite was positioned. AO9 is then offset from the center of the reflector. The combined offsets create a 1 azimuth term in the differences of the measured azimuth positions (Reflector−Encoder). The difference was computed as ReflectorZa−encoderZa (and similar for az values). The peak of the sine wave has the Reflector angle greater than the Encoder angle. For this to occur the distance from the center of the reflector to the dome must be greater than the distance from the main bearing to the dome. So the platform is displaced along the direction of the peak. To compute the horizontal distance I generated a circle and then offset by 0.01 inch steps from 0 to 5 inches. I then computed the differences in the two circles. The offset distance corresponding to 123″ was 3.09 inches. Projecting this along the phase direction of 339° gives the offsets of the platform relative to the reflector:

Radial offset of platform	dx offset (east positive)	dy offset (north positive)
3.09 inches	−1.11 inches	2.88 inches

The platform offset relative to the reflector will create a pointing error. The raw pointing errors that were used to build model 13 (Jan 2002; see Figure 15[1]) do not agree with the measured translation:

[1] Figure 15 is identical to Figure 3, but repeated for completeness.



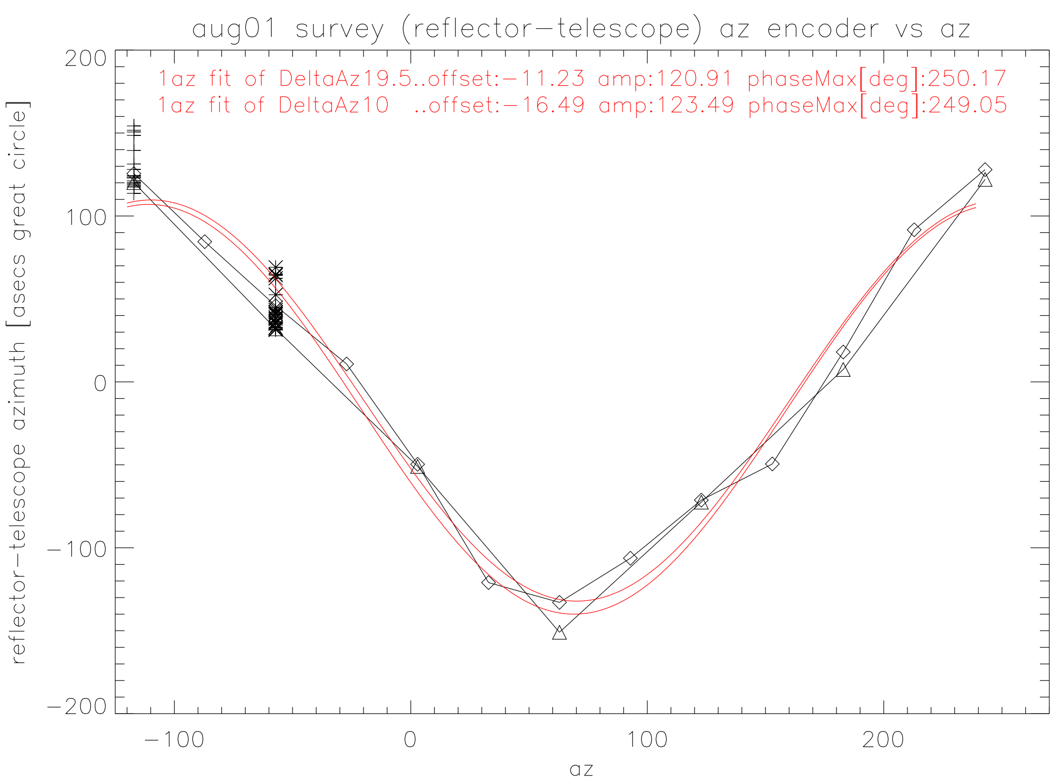
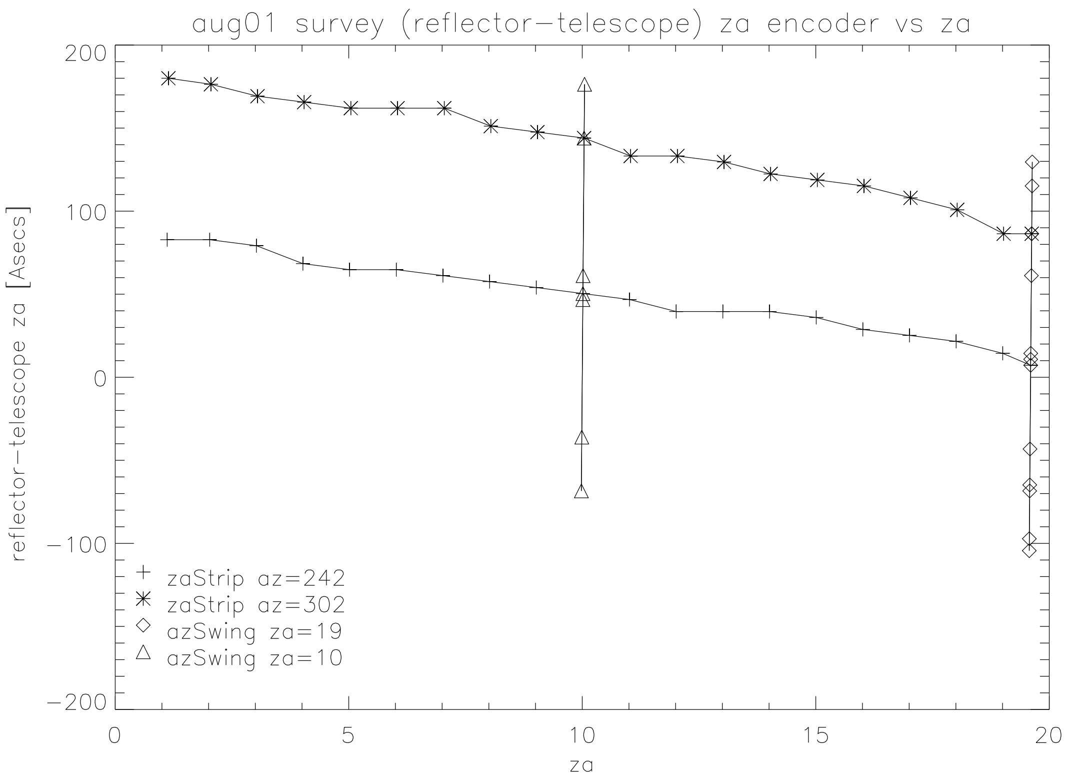


Figure 13: Azimuth differences (Reflector−Encoder) plotted versus za (top) and azimuth (bottom). These are great circle azimuth (the difference has been multiplied by the sine of the zenith angle). The bottom plot contains a sine fit to the 1az term for both of the spins. The offset, amplitude, and phase of the peak are printed.



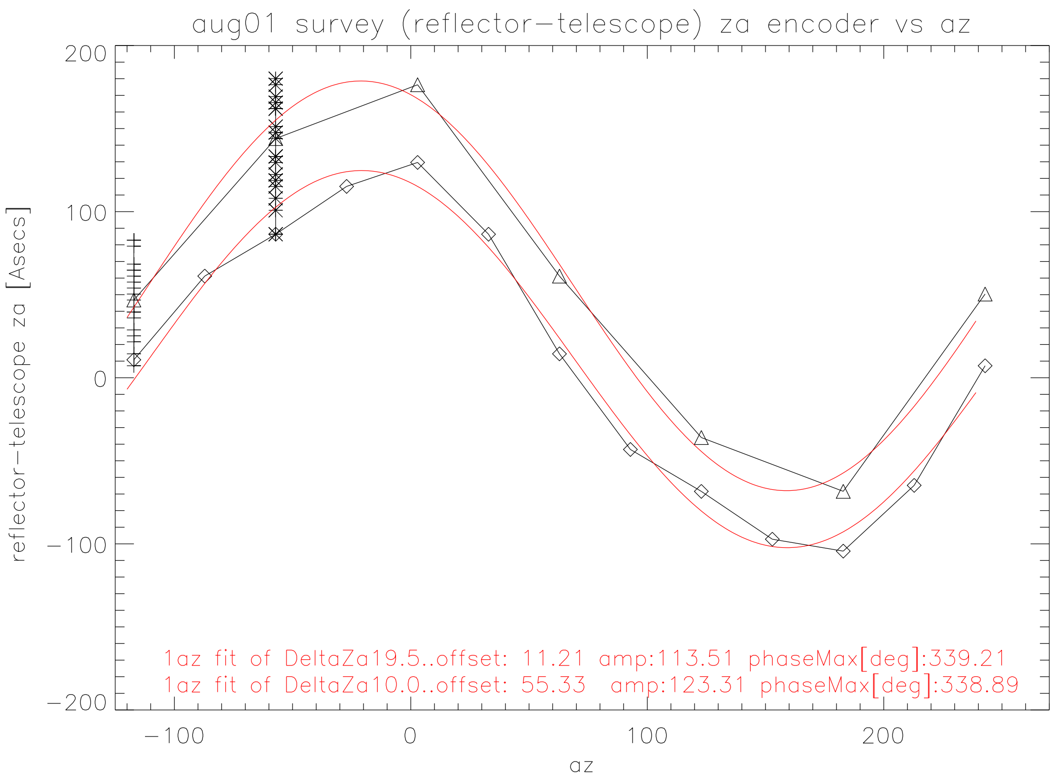


Figure 14: Zenith angle differences (Theodolite−Encoder) versus za (top) and azimuth (bottom). The bottom plot also contains a fit to the 1az terms of the swings. The amplitude for the az swing at 19.5° is 114″ instead of 122″ for the other 3 fits.

Pointing error (amplitude,phase)	Offset error (amplitude,phase)
za: 98″, 185°	za: 122″, 339°
az: 98″, 94°	az: 122″, 249°

The pointing error is the direction you must move the telescope to correct for the pointing offset. It is 180° from the actual motion. The pointing errors agree a lot better with the offset of the platform relative to just AO9. (`processing:survey/010809/reducR/cmpao9offsets.pro`)

2.2 The pitch, roll, and focus errors versus az and za

The directions of the pitch, roll, and focus errors are defined as:

- Positive pitch error: the uphill portion of the dome is to high (far from the dish).
- Positive roll error: looking uphill, the right side of the dome is too low (close to the dish)
- Positive focus error: the dome is too far away from the reflector.

Figure 16 shows the pitch, roll, and focus errors versus azimuth and zenith angle, and Figures 17–19 plot their absolute values. You can see the two za strips plus the two azimuth swings. For pitch and roll 1 tick mark is 0.03°. For focus 1 tick mark in 0.3 inches. The angle is set so that 180° from pointing up is 50% of the maximum error. The za values of 19.6 and 10 at azimuth of 242.87° were repeated three times (twice with the azimuth spin and once with the za strip). The points 19.6 and 10 za at azimuth of 302.87° were repeated twice. These pitch values vary by about 8% max. The roll values lie on top of each other. The focus error varies by up to 14%.

Figure 20 shows the motion of the platform about 1256.35 feet as measured by the distomats while the survey was being taken. The maximum motion was 0.2 inches so using 1256.35 feet as the average value will not create large errors. (`processing:survey/010809/reducR/pltprf.pro`)

2.3 Fitting the pitch, roll, and focus.

The pitch, roll, and focus measurements were fit to a cubic in (za-10) degrees and 1, 2, and 3 az terms in azimuth. Figures 21–24 show the fits in az, za.

Figures 21 and 22 have the pitch and roll data (black) and fits (red). These fits are pretty good. A different fit was used for focus (Figure 23): it used $(za - 10)$ for the za variable. It was 3rd order in $(za - 10)$ for the za part. The az terms had 1a, 3az, and $\sin(za - 10) \times [\cos(3az) + \sin(3az)]$. Figure 24 shows the azimuth terms of the fits (1az,2az,3az) as well as the fit coefficients.

The rms for the fits are: pitch 0.013°, roll 0.0085°, and focus 0.13 inches. The 1az term of 0.028° for pitch may be from the horizontal offset of the platform. This offset should not give a roll term so I don't know where the 0.035° 1az roll term is coming from. When the tilt sensors were run on 04 Aug 2001 the 1az term was 0.003 for these tiedown positions. The 3az term for pitch and roll is similar to what we measured back in Feb 2000 and what the tilt sensor measured in 04 Aug 2001. The fit to focus is what will be used to compute the focus error over the entire dish (since the tilt sensors don't measure focus). (`processing:survey/010809/reducR/pltfit.pro`)

These data will be used to connect the pitch and roll centered on the reflector to the pitch and roll as measured by the tilt sensors. We can get a complete sampling of az, za with the tilt sensors to help us with the model. We use the the reflector based data to remove any offsets that the tilt sensors have. (`processing:survey/010809/reducR/doit.pro` for initial analysis.)

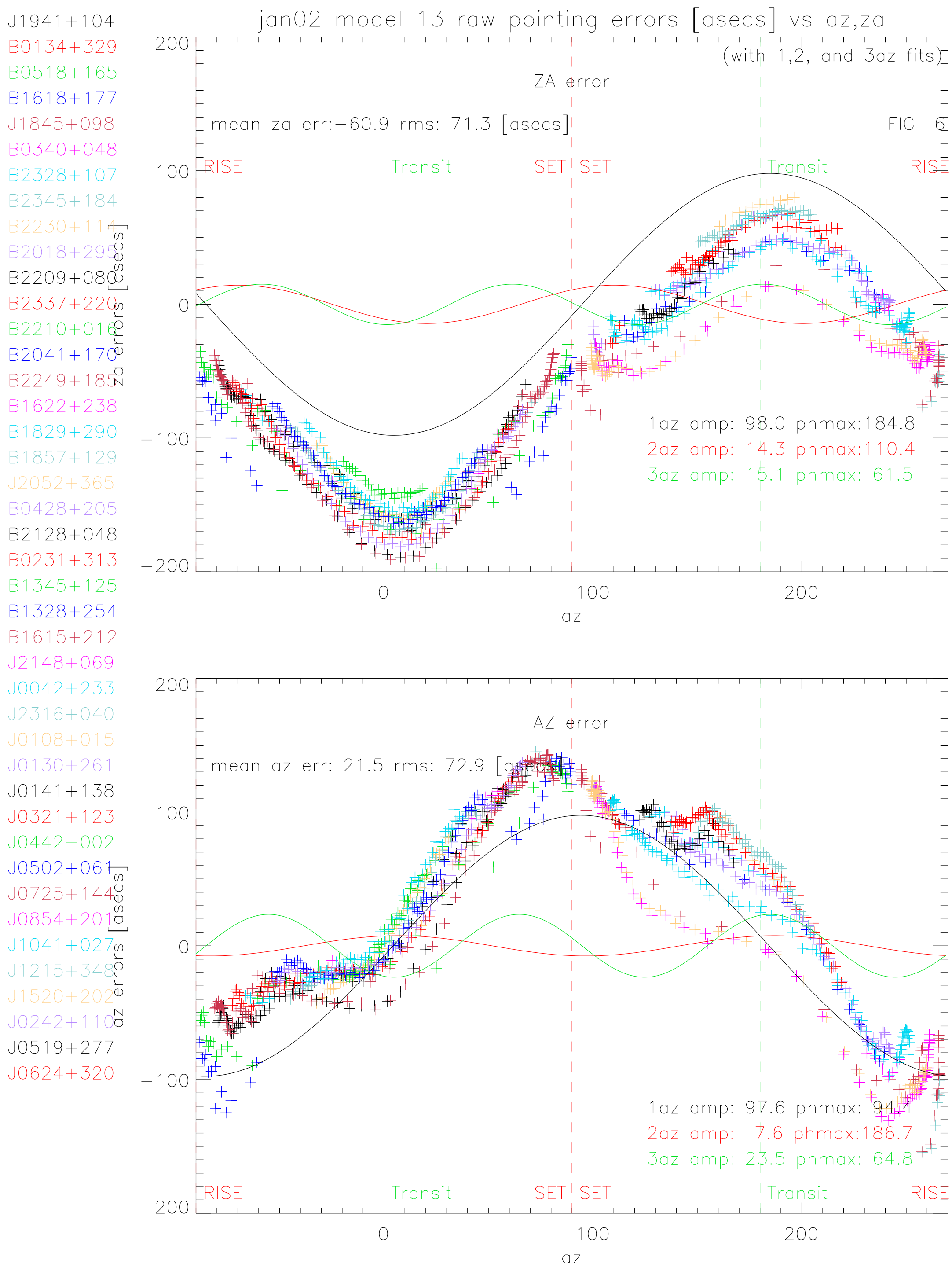
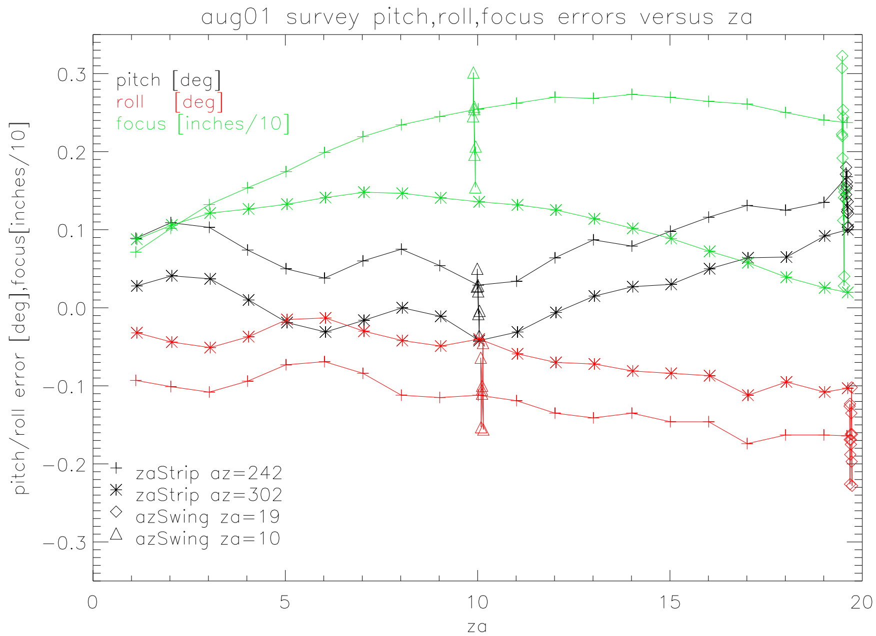


Figure 15: Raw pointing errors that were used to build model 13 (Jan 2002). Note, this figure is identical to Figure 3.



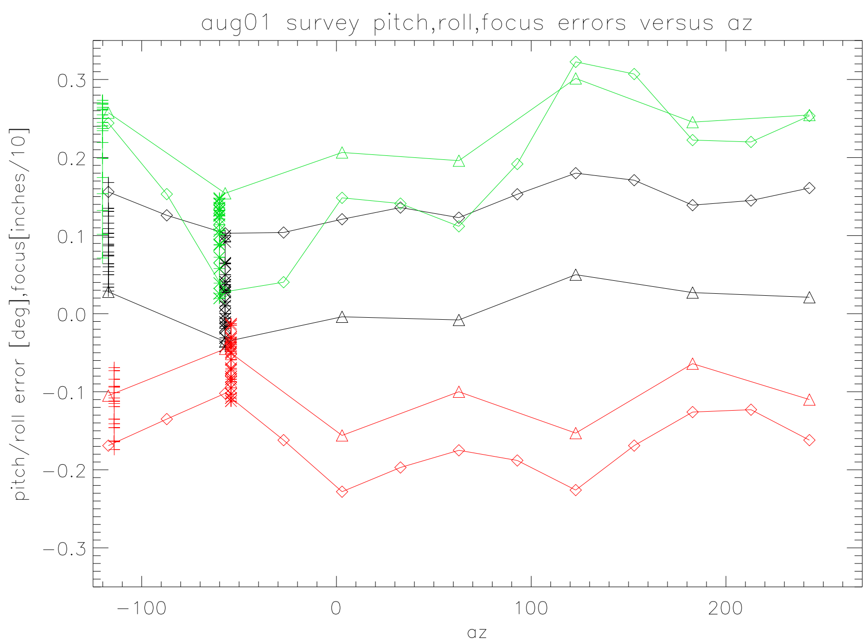


Figure 16: Top: Pitch, roll, focus errors versus za. Black is pitch, red is roll, and green is focus. The vertical axis is degrees for pitch and roll, and inches/10 for focus (0.1 = 1 inch). The za strips and azimuth spins are plotted with different symbols. The measured radius of curvature for the reflector was used (869.781 feet). Bottom: The same errors plotted versus azimuth angle.

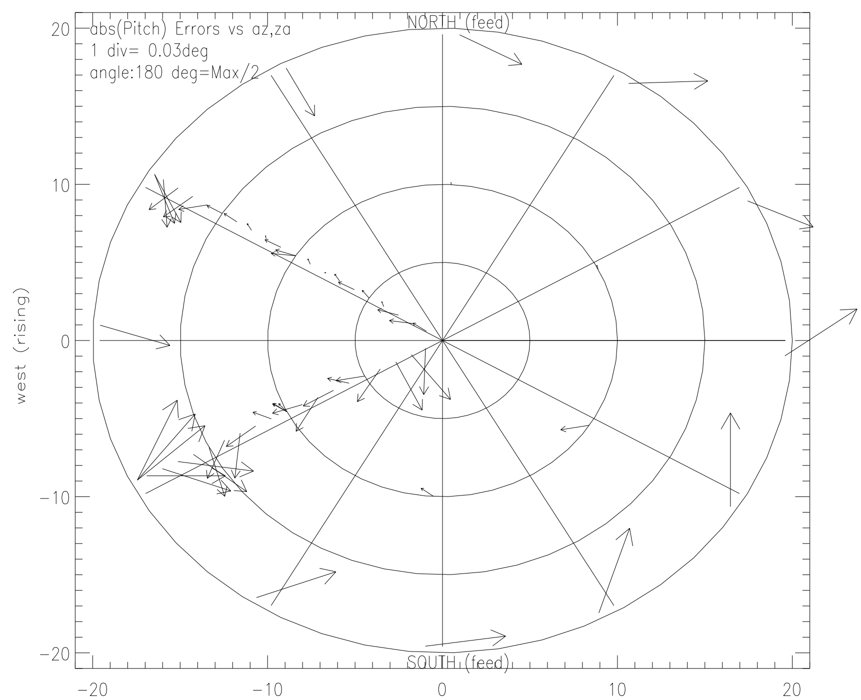


Figure 17: Absolute value of the pitch errors versus azimuth and zenith angle. See text for details.

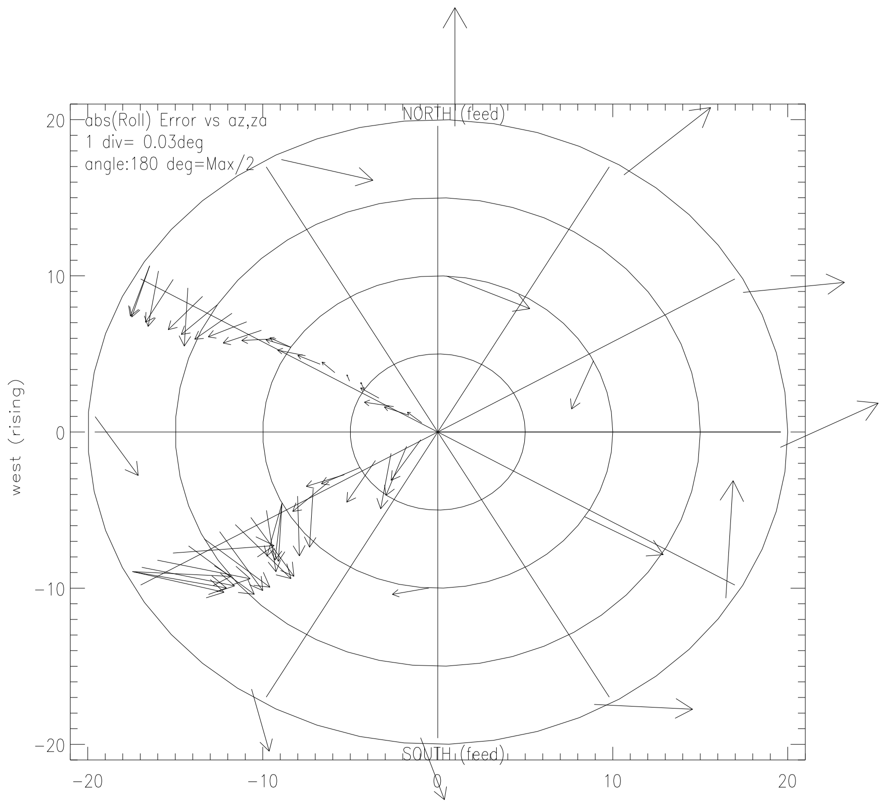


Figure 18: Absolute value of the roll errors versus azimuth and zenith angle. See text for details.

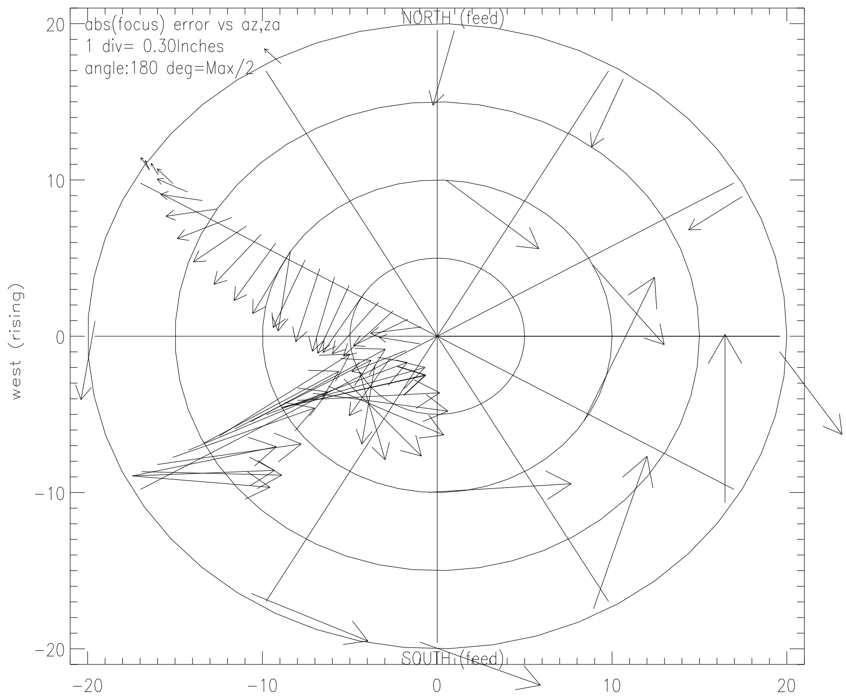


Figure 19: Absolute value of the focus errors versus azimuth and zenith angle. See text for details.

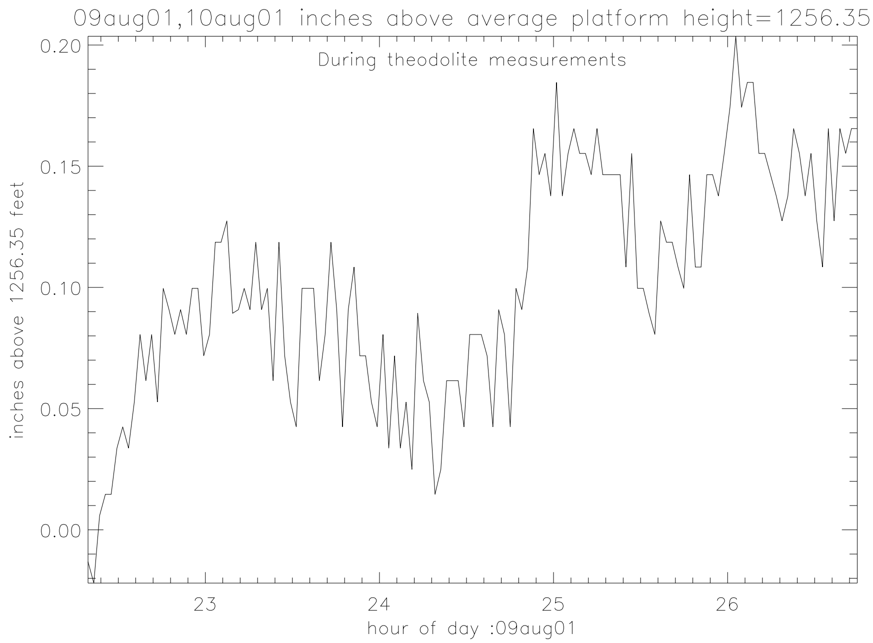


Figure 20: The motion of the platform about 1256.35 feet as measured by the distomats while the survey was being taken. The maximum motion was 0.2 inches.

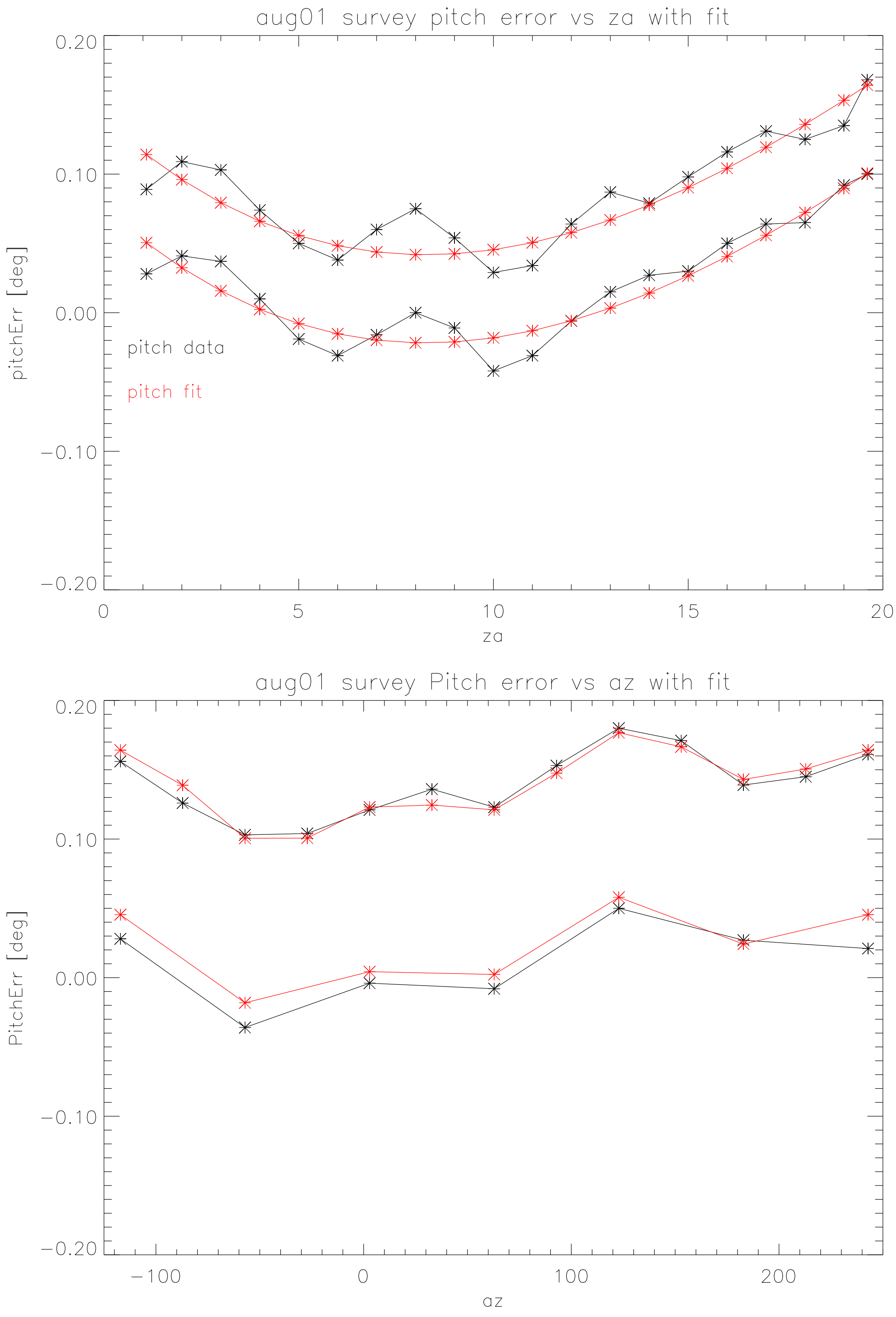


Figure 21: Pitch data (black) and fit (red). See §2.3.

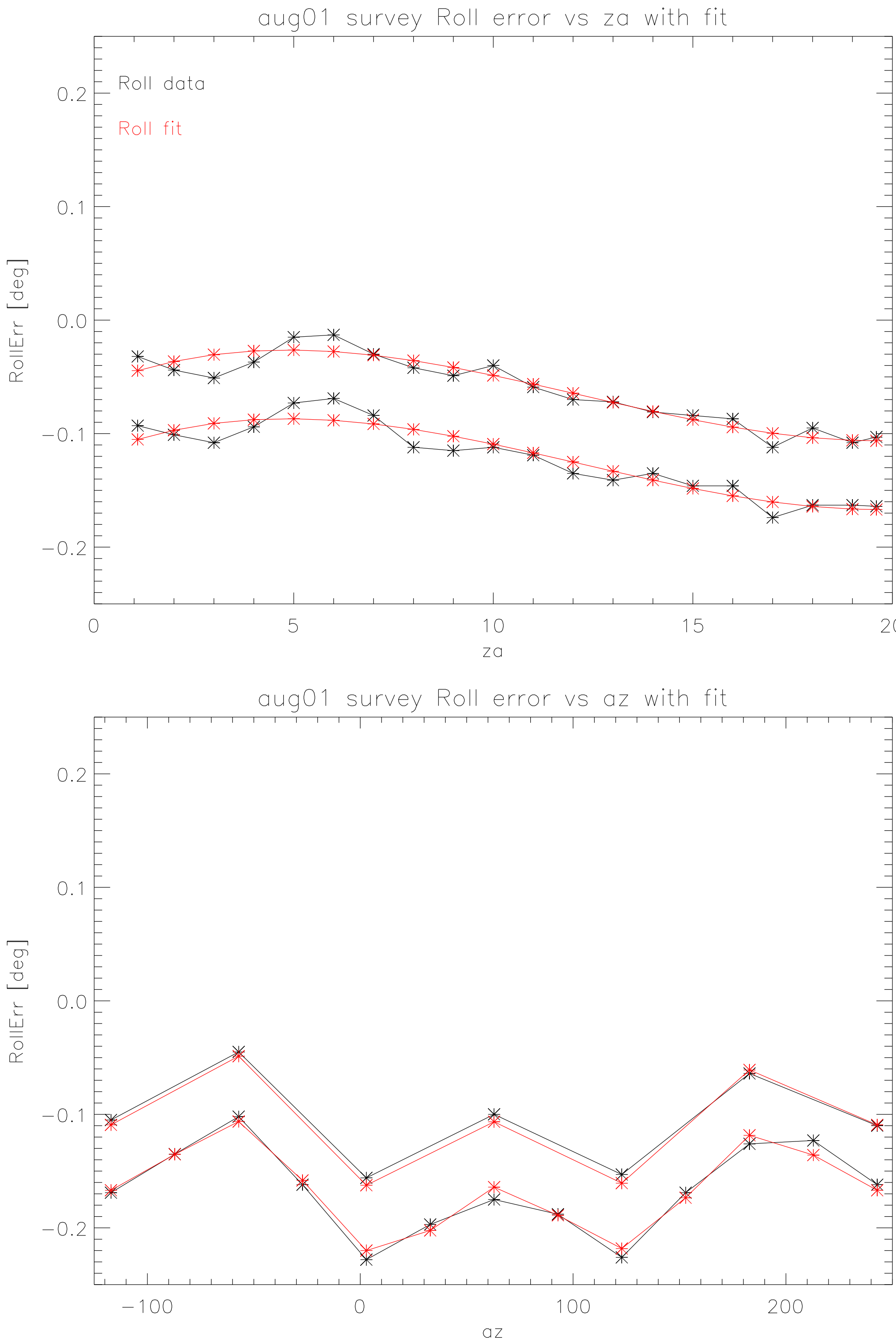


Figure 22: Roll data (black) and the fit (red). See §2.3.

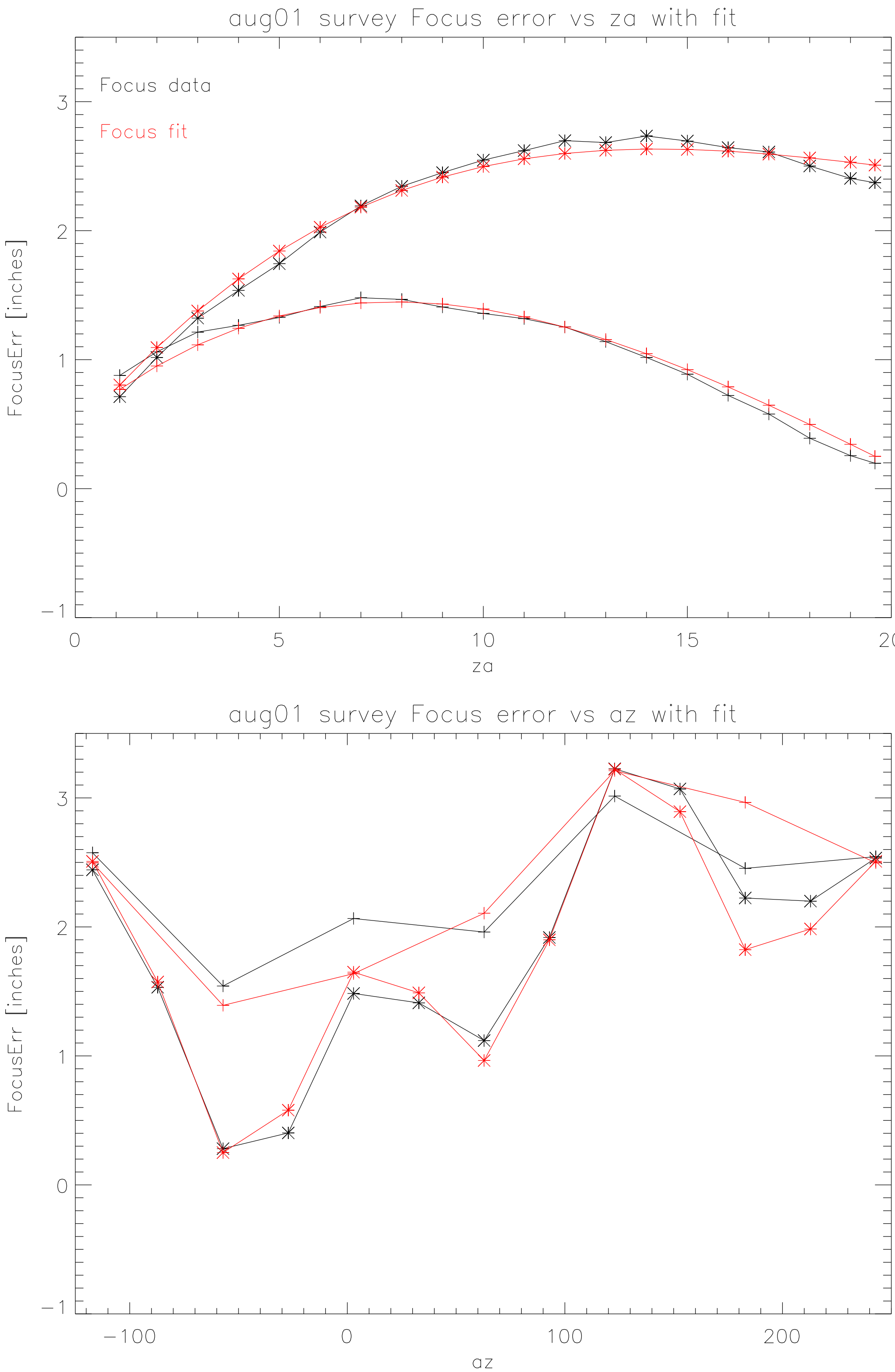


Figure 23: Focus data (black) and the fit (red) in $(za - 10)$. See §2.3.

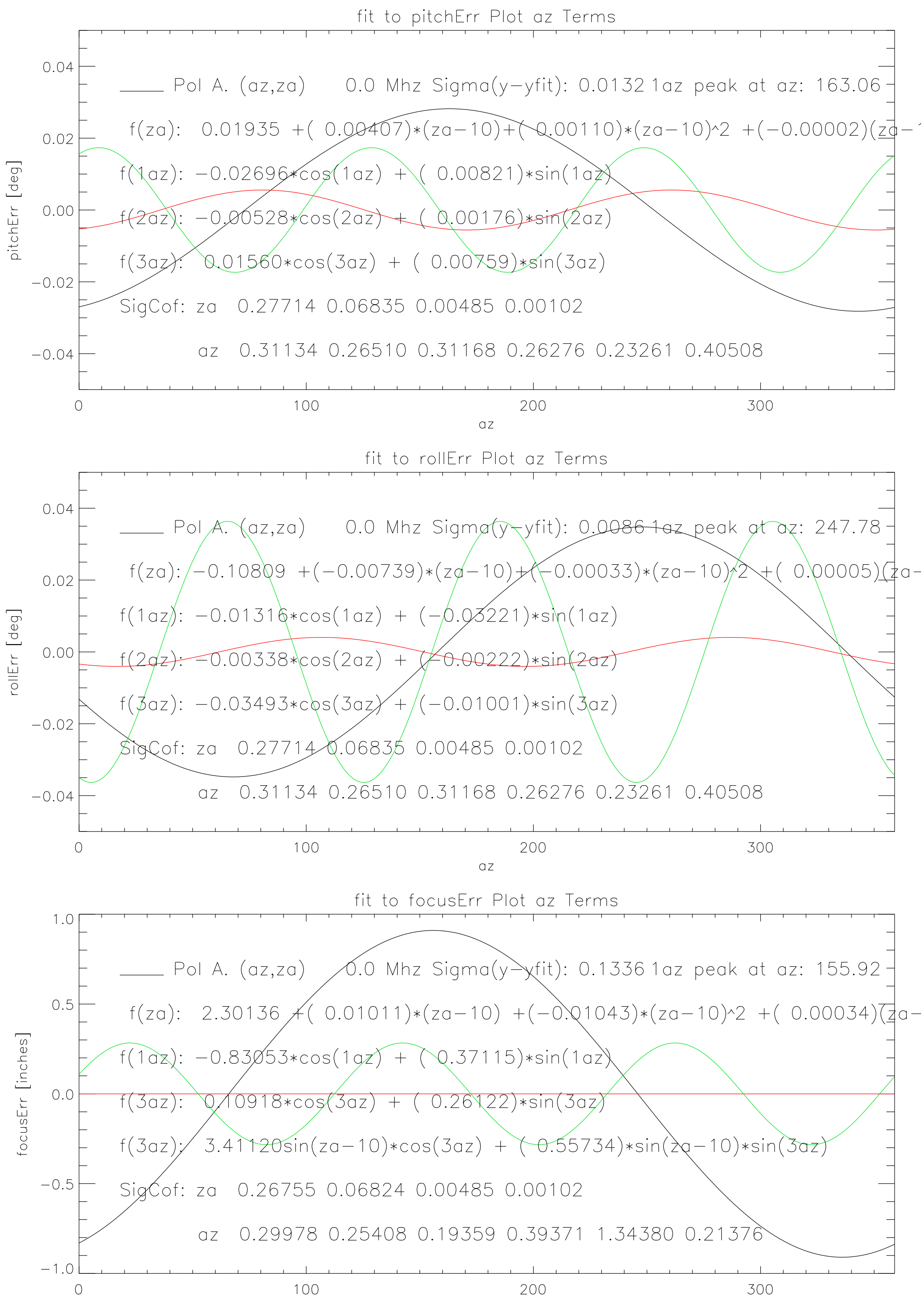


Figure 24: The azimuth terms of the fits (1az,2az,3az) as well as the fit coefficients. See §2.3.