Tilt Results (I)

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1 Introduction

Earlier studies have shown the presence of thermal distortion of the antennas. Tiltmeters have been suggested as a technique to monitor and correct any such distortion.

Before this scheme can be implemented we need to calibrate the tiltmeters and determine the systematic effects—tilts which may depend on the azimuth and elevation.

We also plan to use the tiltmeters to expedite the determination of the antenna pointing model.

This note addresses these issues.

2 Tiltmeter Setup

The configuration of the two tiltmeters is that one is mounted on the elevation axis near the elevation encoder, another on the azimuth bearing. They are in the same vertical plane, normal to the elevation axis. As suggested by G. Nelson and M. Kesteven in 1988, the purpose of this is to get some information about thermal distortion.

The data collected by the dataset go through the ACC as part of the general monitor scheme.

3 The Experimental Data

We made many tests during the period from the end of August to November. The main purpose of the tests was to calibrate the tiltmeters mounted on the antenna # 2 and to get the azimuth tilt parameters of the pointing model. This involved:

— Azimuth scans at fixed elevation at different stations.

— Elevation scans at fixed azimuth at different stations.

In addition, data were collected during 17 days of operation; the antenna was completely stationary during two of these days.

Finally, azimuth scans at fixed elevation to test the "off-station" stability.

4 Azimuth Data Analysis

4.1 Pointing Model Parameter

We expect the tilt to have an azimuthal dependance of the form:

$$y = a + b \times cos(az) + c \times sin(az)$$

where b,c are related to the antenna pointing model parameters a_x and a_y.

$$b = a_x$$

$$c = a_y + \arctan(B/R_{\oplus})$$

where B is antenna distance from station 35, $R_{\oplus}$ is the radius of the earth.

After processing the data, we have plotted the graph of the fitting curves and residuals of fitting. From the graph attached to this note, you can see that they fit quite well and the RMS is small. The fitting equations are:

For 23th August (Station 13),

$$y = -31.1 \pm 0.16 + (6.4 \pm 0.22)cos(az) + (55.7 \pm 0.25)sin(az)$$

$$RMS = 2.4\ arcseconds$$

For 28th August (station 13),

$$y = -27 \pm 0.53 + (5.9 \pm 0.86)cos(az) + (58.4 \pm 0.64)sin(az)$$

$$RMS = 11.1\ arcseconds$$

For 1th September (station 16),

$$y = -22.5 \pm 0.65 + (2.2 \pm 0.95)cos(az) + (51.7 \pm 0.9)sin(az)$$

$$RMS = 8.1\ arcseconds$$

For 26th September (station 16),

$$y = -22.55 + 2.03cos(az) + 52.37sin(az)$$

$$RMS = 6.6\ arcseconds$$

We note from the data that there exist some suspect data points. We believe these to be associated with the acceleration transients of the antenna when the antenna starts or stops. If these bad readings are discarded, the fitting is better and the RMS is less. The results are listed below:

For 23th August (station 13),

$$y = -31.1 \pm 0.12 + (6.4 \pm 0.15)cos(az) + (55.7 \pm 0.18)sin(az)$$

$$RMS = 1.7\ arcseconds$$

For 28th August (station 13),

$$y = -27 \pm 0.11 + (5.9 \pm 0.18)cos(az) + (58.4 \pm 0.14)sin(az)$$

$$RMS = 2.4\ arcseconds$$

For 1th September (station 16),

$$y = -22.5 \pm 0.18 + (2.2 \pm 0.26)cos(az) + (51.7 \pm 0.25)sin(az)$$

$$RMS = 2.2 \ arcseconds$$

For 26th September (station 16),

$$y = -22.55 \pm 0.15 + (2.03 \pm 0.22)cos(az) + (52.37 \pm 0.21)sin(az)$$

$$RMS = 2.01 \ arcseconds$$

We compare the results with these got by means of astronomical observing. The results are listed in the Table 1.

date	stn	*Obs.*		predict	*test predict*		*obs. pointing*	
		cos(az)	sin(az)	sin(az)	a_x	a_y	a_x	a_y
23/8	13	6	56	55	6	1	23	6
1/9	16	2	52	47	2	5	11	7
29/9	6	0	93	92	0	1	-5	-4
15/10	31	1	6	7	1	-1	-5	13
26/10	21	-2	66	41	-2	25	-16	24
	34	-20	-3	0	-20	-3	-27	-6
2/11	11	6	84	75	6	9	7	19

Table 1. The Tilt and Astronomical Results of a_x and a_y

There are differences between these results. We believe that the error of astronomical results is much bigger than that of the tilt results as the astronomical calibration test observes only a few radio sources after reconfiguration. They seem to in rough agreement.

4.2 Analysis of Residuals

We also plotted the fitting residuals vs azimuth. It is clear from Figure 1 and Figure 2 that the fitting residuals for 23th August (station 13) are similar to the residuals for 1th September (station 16). We have tested this, as shown in Figure 3, where we have plotted the 23th August data (t_1) against the 1th September data (t_2). A least squares fitting and line of regression yield:

$$t_2 = (0.76 \pm 0.11)t_1 + 0.24 \pm 0.19$$

$$R^2 = 0.57$$

The coefficient of t_1 to t_2 is quite large, close to 1.0. The coefficient of correlation is 0.57 and also is quite large. This indicates that there is something in common between the two tests, although two different stations were involved. We suggest that the fitting residual is partially contributed by the azimuth bearing.

It is also the case that this effect is common to the two tiltmeters on the antenna. In Figure 4 we show the difference between the two tiltmeters (Δt) for the two days. The Δt plot has a "non-noisy" appearance, although of modest results ($5''$ peak-to-peak); however there appears to be no correlation between the two days ($R^2 = 0.$).

The data for 26th September (station 16), after the "off-station" experiments , confirm this. The least squares fitting and line of regression against 23th August yield:

$$t_2 = (0.75 \pm 0.11)t_1 + 0.66 \pm 0.19$$

$$R^2 = 0.57$$

The least squares fitting and line regression for the difference reading of 23th August vs 26th September yield:

$$\Delta t_2 = (0.57 \pm 0.16)\Delta t_1 + 0.11 \pm 0.27$$

$$R^2 = 0.26$$

5 Elevation Calibration

In order to get some information about the elevation effects, we carried out elevation scans at fixed azimuth in some tests. We noticed from the data that the readings of the tiltmeters change and the difference between the two tiltmeters changes with the elevation angle as well.

We used the least squares fitting method to fit these data. Suppose there exists a linear relation between the elevation of the antenna and the tilts,

$$y = a + b \times el$$

where a, b are constants. a indicates the zero offset of the tilt, which is not important. What we are more concerned is the b in the formula. The results are as listed in the table. For more information, see the graphs attached.

	23 Aug.		*28 Aug.*	
AZ	b	rms(arcsec)	b	rms(arcsec)
0			0.08	4.3
90			0.05	0.7
180	0.05	1.0	0.06	1.3
270			0.05	1.1
0-270			0.07	5.1

Table 2. The Difference Tilt (Δt) Fitting Parameter

The tiltmeter in the pedestal room (P-tilt) shows no elevation dependance.

6 Thermal Distortion

As mentioned above, the configuration of the two tiltmeters is mainly used to get some information about the thermal distortion. The two tiltmeters are in the same vertical plane. The one on the azimuth bearing is in the pedestal cabin, which is air-conditioned. The other is mounted on the elevation axis, exposed to ambient air. That means that the temperature of the one in the cabin is constant, while the other changes with the air temperature.

We expect the difference reading of the two tiltmeters Δt to change with temperature, because the alidade structure deforms when the temperature changes. Examining the data for 17 days of the factor due to elevation, we averaged the Δt over half hour intervals. The Δt vs time and temperature vs time are plotted. See the graphs attached.

In order to get some information about temperature vs Δt, we also used the least squares fitting and the line of regression methods to process the data. We expect there exists a linear relation between the temperature (T) and the Δt,

$$\Delta t = a + b \times T$$

where a, b are constants. a indicates the zero offset of the Δt, which is not important. What we are more concerned is the b, which show the ratio of Δt to temperature. The results are as listed in the table.

	26 Aug.	27 Aug.	28 Aug.	29 Aug.	30 Aug.	31 Aug.
b	-0.75	-0.52	-0.96	-0.21	0.77	-0.32
R^2	0.73	0.48	0.85	0.06	0.71	0.18
	1/Sep.	2 Sep.	3 Sep.	4 Sep.	5 Sep.	17 Sep.
b	-0.64	0.59	0.58	-0.69	-1.22	-1.2
R^2	0.35	0.36	0.4	0.77	0.82	0.91
	18 Sep.	19 Sep.	20 Sep.	22 Sep.	23 Sep.	
b	-1.56	-1.1	-1.18	-1.85	-0.7	
R^2	0.87	0.89	0.9	0.83	0.37	

Table 3. The Δt vs Temperature

Table 3 summarises the Δt vs temperature relation over the 17 days period. The results are not clear since the antenna was in use for much of this time.

On September 19 and September 20 the antenna was completely stationary and the plots are quite similar, with a mean relation:

$$\Delta t = -1.14\, T \; arcseconds/C^{\circ}$$

7 Wind Factor

We got some data about wind during the system test period. We hope that they can give us some rough idea of wind effect on the antenna. The E-tilt and P-tilt vs time and RMS of E-tilt vs time are plotted. The graphs attached show:

1. P-tilt changes slightly due to wind.
2. E-tilt changes a lot.

The wind force on antenna is also plotted. The plots indicate that tilt and wind force are correlated. From the plots we also notice that strong wind ($v > 40KM/h$) can deform the antenna by as much as 10 arcseconds, but normally it is only 5 to 6 arcseconds (peak-to-peak) when the wind speed is in the range from 20 km/h to 40 km/h. The RMS of the tilt during the windy period is as large as more than 3 arcseconds.

8 Off-station Analysis

On 17th September the antenna was moved to an off-station for a couple of hours. During the period we did the following tests:

– Azimuth scans at fixed elevation.

– Parked unmoved for a couple of hours.

We use the least squares fitting technique to process the data and plot the fitting curves and the residuals of fitting in Figure 5. The fitting equation is:

$$y = -5.18 \pm 0.73 + (-165.1 \pm 1.80)cos(az) + (257.1 \pm 0.69)sin(az)$$

$$RMS = 12.4\; arcseconds$$

From the above formula we notice that a, b and c have a big standard variation. From Figure 5 we find that there is a big difference, about 40 arcseconds, between the antenna clockwise and counter-clockwise, in contrast to the much smaller (10″) difference observed in the "on-station" test. We attribute much of this to the movement, the deformation of the rail and the wind force.

We got the data when the antenna was stationary in off-station. The E-tilt and P-tilt are plotted in Figure 6. From Figure 6 we can find that E-tilt changes almost 12 arcseconds when the wind speed is more than 40 Km/h. In Figure 7 the E-tilt and P-tilt are plotted when the antenna was at the station. We notice from Figure 7 that the maximum change of E-tilt is only 4.5 arcseconds, compared to the 6 or 7 arcseconds change of E-tilt when the antenna at off-station. So the displacement of the antenna is easily changed by wind when the antenna is at off-station. We suggest the reason is that the antenna structure is much stiffer on station than at off-station on the rail.

We conclude that the "off-station" solution is not a viable one.

9 Discussion

9.1 Pointing Model

The Australia Telescopes are frequently moved on the rail, from station to station, to meet the configuration requirements of the astronomers. The time used for calibration is very limited. So there is not enough time to observe many astronomical radio sources to get an accurate pointing model. This problem will be more serious when the AT works at the mm wavelengths. The pointing accuracy of AT should be within a few arcseconds. That means that need a more accurate pointing model to correct the pointing errors.

From these tests we recommend the above method, which uses the least squares fitting technique to fit the readings of the tiltmeters in the azimuth scan, to get the a_x and a_y parameters of the pointing model.

The results are reliable and trustworthy; this scheme reduces the number of parameters in the pointing model from the present 7 to 5. So you can use less calibration time to get a more accurate pointing model.

9.2 Thermal Distortion

The structural distortion is a very complicated issue. The temperature, wind, antenna structure, displacement of the antenna, all contribute. We have used the weather station air temperature as the tiltmeter temperature probe has not yet been connected.

The data for 19th September and 20th September when the antenna was stationary are all consistent with a tilt-temperature coefficient of about $1.1''/C^{\circ}$.

It is a matter of some concern that the data from the other days show no such clear picture. Further studies are needed to locate the source of this problem: Changing temperature in the pedestal room? Antenna motion?

In particular, we noticed that the reading of the tiltmeter in the pedestal (P-tilt) drifted even if the antenna was parked. That means that the reference for thermal distortion changes with time.

9.3 Hysteresis?

From Figure 1 we also noticed that there is about 6 arcseconds difference between the readings for clockwise and counter-clockwise azimuth scans. This exists in all our experiments after correcting for the elevation factor. These tests were made at elevation of 88 degrees, and appeard to demonstrate hysteresis of antenna at the 5 arcseconds level. Subsequent tests (report # 2) show that the effect is an artefact of data gathering, and we find no hysteresis.

9.4 Tiltmeter's Stability

We notice from the test that the readings of the tiltmeters change even if the antenna is fixed. The readings show a peak to peak difference of order 2 arcseconds. We should pay more attention to this problem. Using tiltmeter for on-line correction needs the tiltmeter to be more stable. Is this caused by the noise of electronics or the instability of the tiltmeter itself?

9.5 Wind Factor

Wind issue is a very important factor contributing to the pointing accuracy. Its effect on the pointing accuracy will become obviously very important when the antenna works at the mm wavelengths.

The results we have got show that there is as large as 10 arcseconds tilt caused by the wind when strong wind occurs. We suggest that pay more attention to this problem.

9.6 Others

At present we have just installed two tiltmeters on the antenna, one on the top of the alidade near elevation axis, another on the bearing of azimuth in the cabin. That only give us some information in one plane. Should we install another one on the top of the alidade near the elevation axis vertical to the one which had been installed? If do this, we will have the tilts of the antenna in the x and y plane. So we can get more information about the deformations of the alidade caused by the temperature and wind.

10 Conclusions

10.1 Azimuth

1. Main effect existed in the two tiltmeters' readings, strong sinusoidal dependence on Azimuth, corresponds to tilt of azimuth axis with repect to gravity.

   — Partly related to the station (distance from the reference station 35).

   — Partly related to the station specifics (the 4 piers not co-planar with station 35).

   This effect is included in the pointing model (parameters a_x,a_y).

2. Additional tilt as a function of azimuth, not easily modelled, —apparently related to the antenna, and not the station since the effect is the same at two different stations.

10.2 Elevation

1. Small tilt dependence on Elevation, $5''$ from $12°$ to $90°$.

2. Shows up on the reading of tiltmeter on the elevation axis (E-tilt) only.

   This means that the alidade changes with elevation. This effect is probably included in pointing model (associated with Δ parameter c_e-d_z).

10.3 Thermal Distorsion

- A significant correlation is shown when antenna is stationary:

$$\Delta t = 1.14 \times T \; arcseconds/C^{\circ}$$

10.4 Wind Effect

- The deformation caused by the wind is 5 to 6 arcseconds (peak-to-peak) when the wind speed is in the range from 20 KM/h to 40 KM/h. This is in agreement with the consultant engineer's analysis reference [1].

References

[1] Cooper,D.N, Guoth, N. and Evans, R.J., *The Australia Telescope Antennas: Structural, Mechanical and Servo Mechanism Features*, IREECON '85

TILT & FITTING CURVE vs AZIMUTH

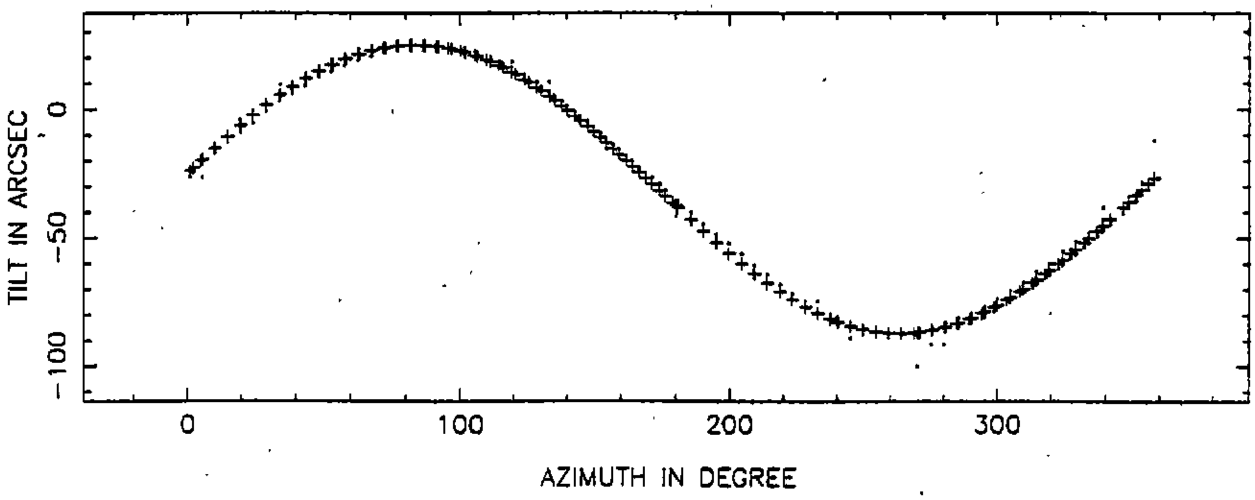
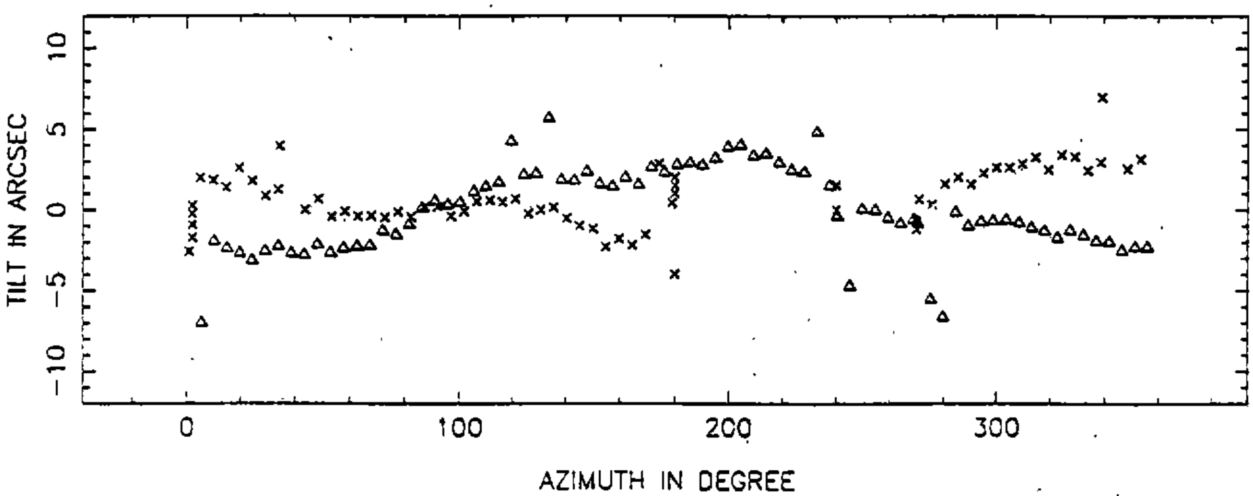
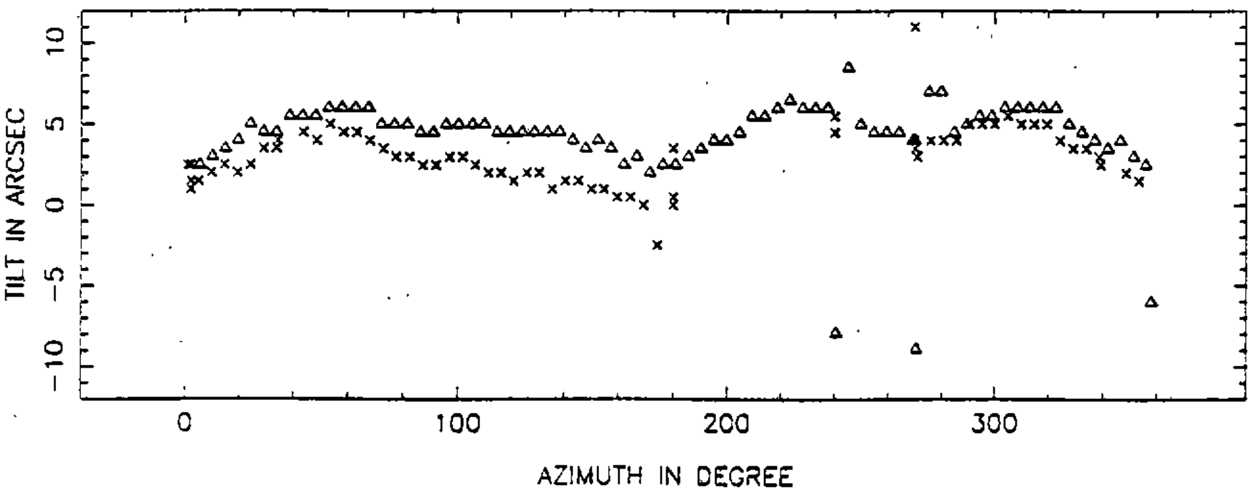


Fig. 1 FITTING ERRORS vs AZIMUTH



DIFF TILT vs AZIMUTH



THE CALIBRATION FILE USED IS: 23aug.cab
THE ELEVATION IS FIXED AT 88.0 DEGREES
THE MODEL FOR TILT vs AZIMUTH IS:

$$y = -31.11 + (6.40)\cos(AZ) + (55.68)\sin(AZ)$$

THE FITTING ERROR RMS: 2.57 arcsec

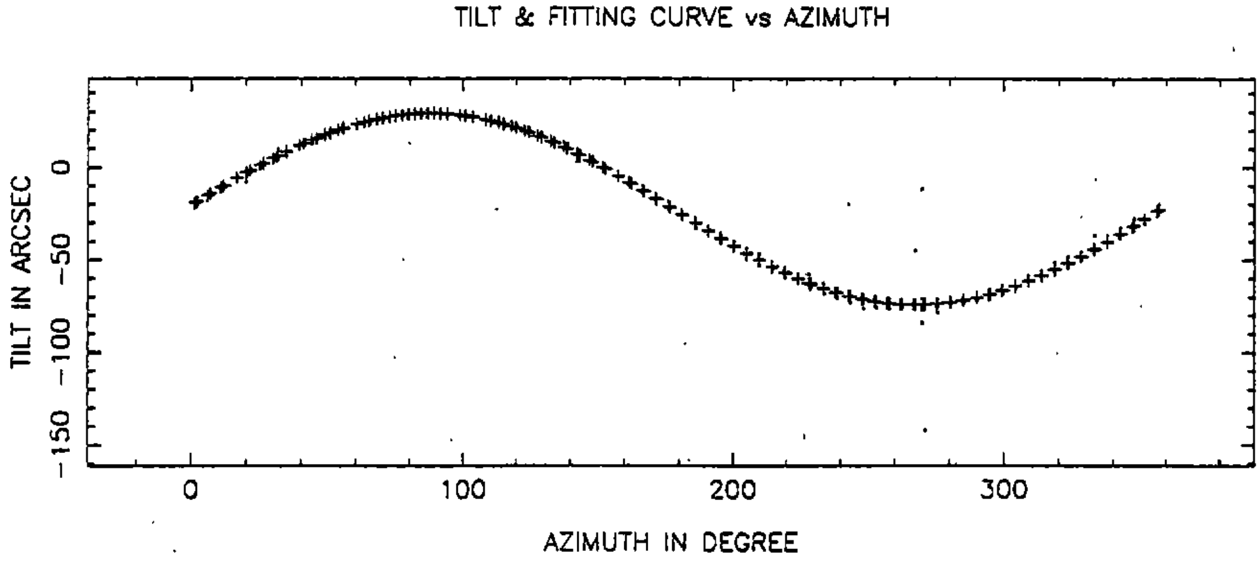
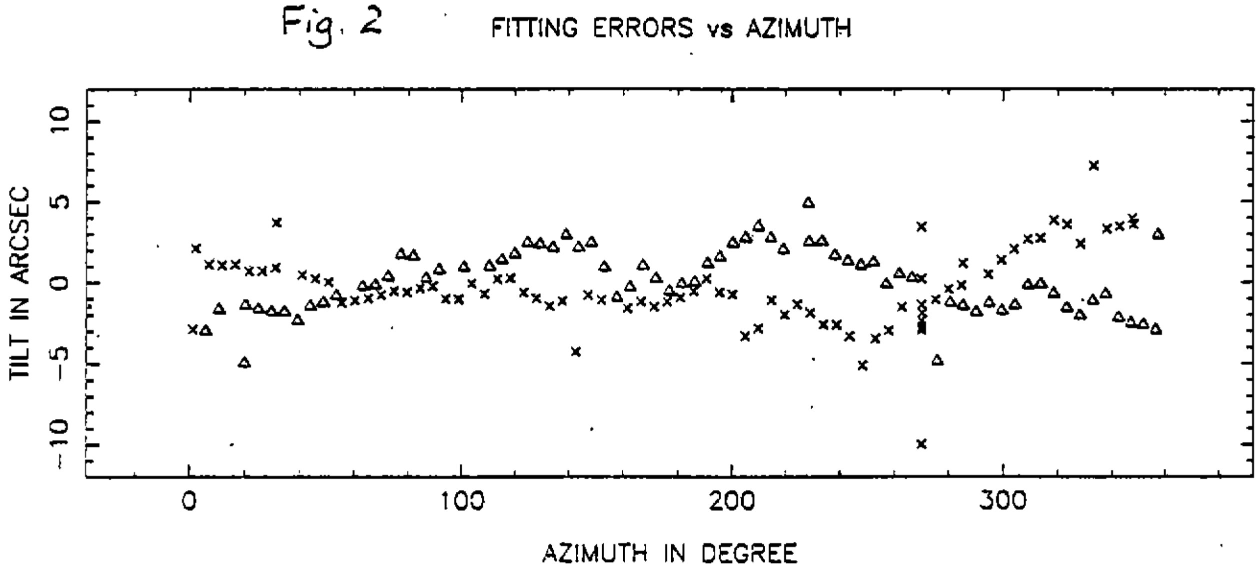
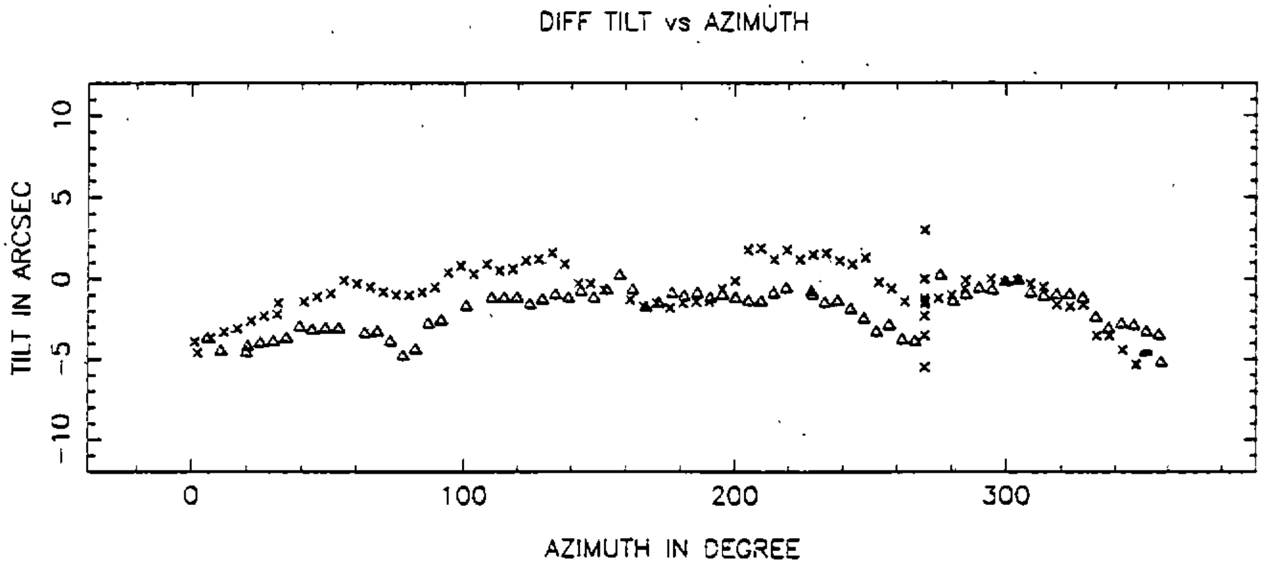


Fig. 2



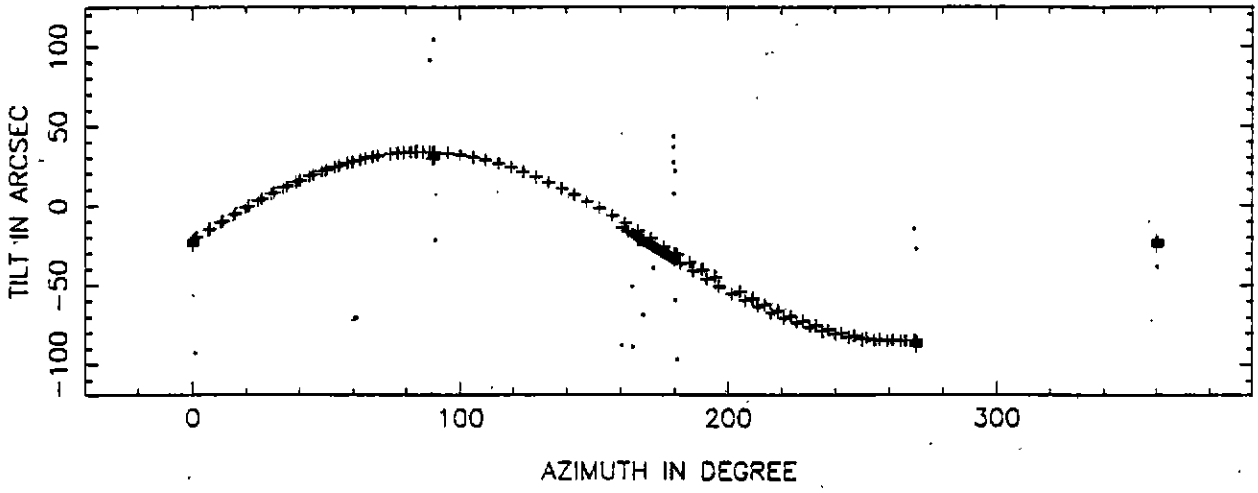


THE CALIBRATION FILE USED IS: 1sept.cao
THE ELEVATION IS FIXED AT 88.0 DEGREES
THE MODEL FOR TILT vs AZIMUTH IS:

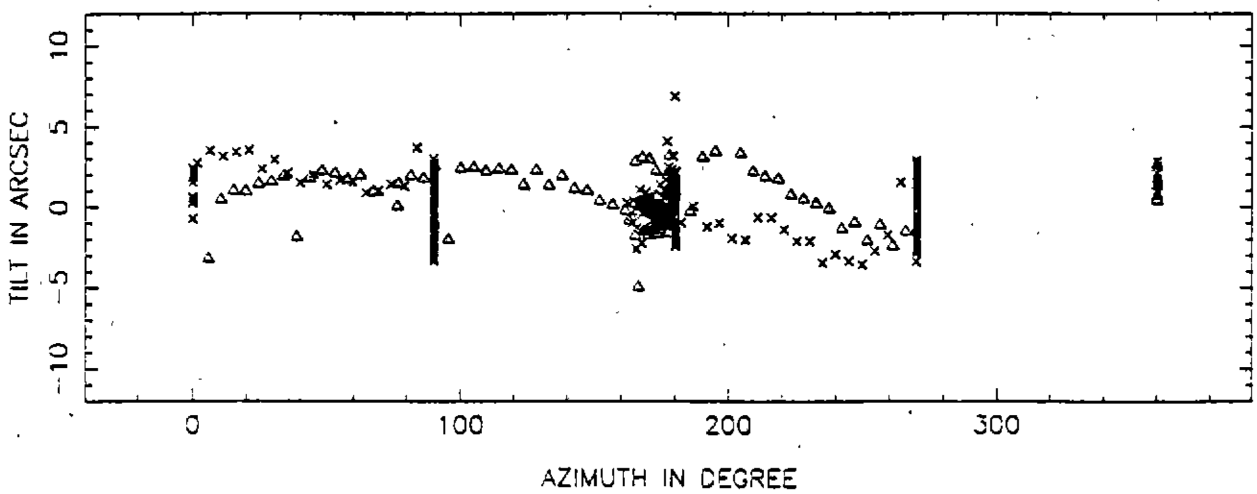
$$y = -22.53 - (2.21)\cos(AZ) + (51.70)\sin(AZ)$$

THE FITTING ERROR RMS: 8.05 arcsec

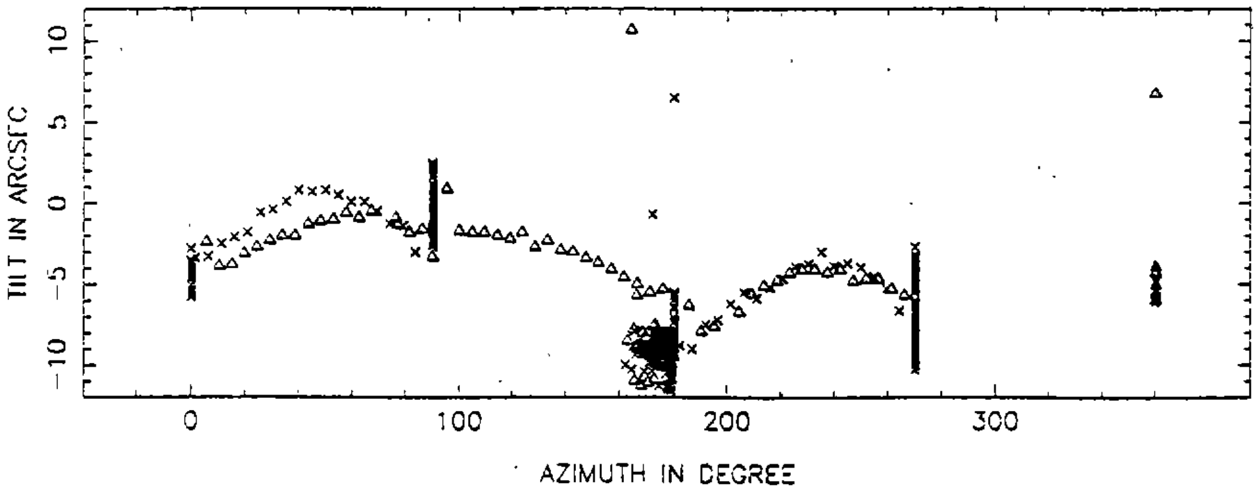
TILT & FITTING CURVE vs AZIMUTH



FITTING ERRORS vs AZIMUTH



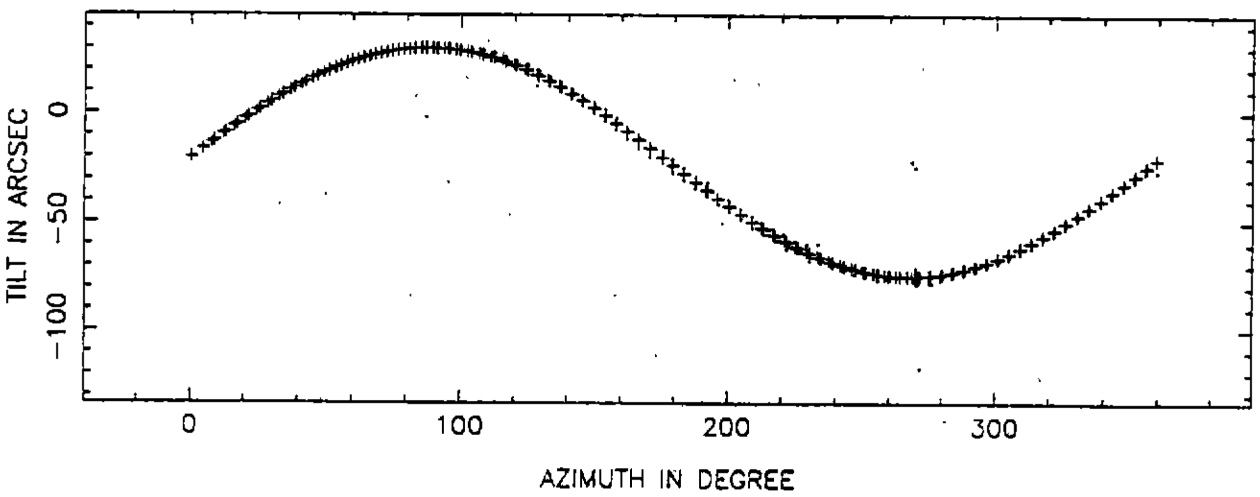
DIFF TILT vs AZIMUTH



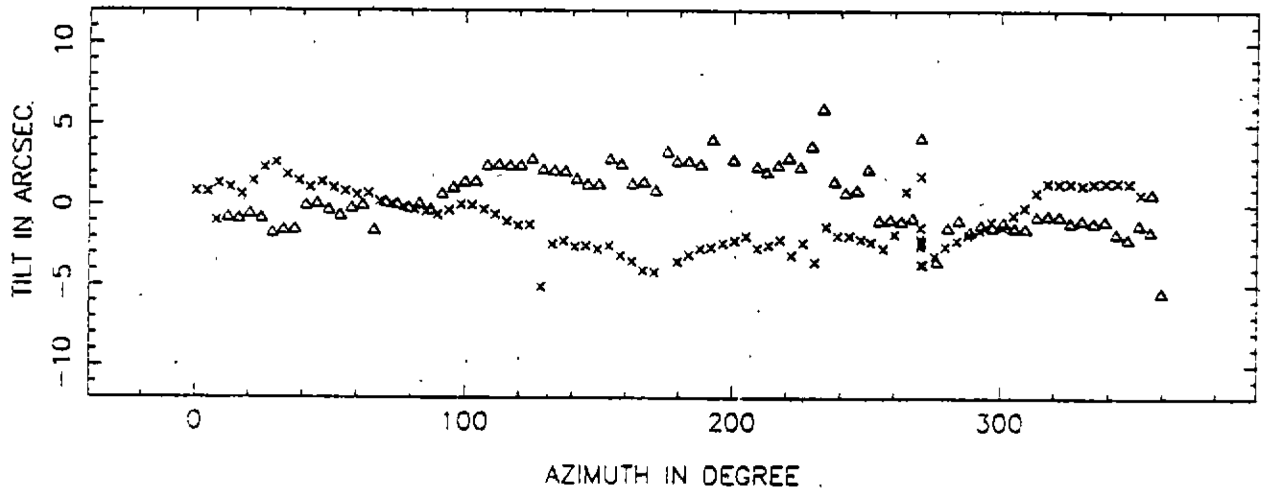
THE CALIBRATION FILE USED IS: 28aug.cab
THE MODEL FOR TILT vs AZIMUTH IS:
y = −30.72 − (4.35)cos(AZ) + (59.20)sin(AZ) + (0.06)EL
THE FITTING ERROR RMS: 10.93 arcsec
THE MODEL OF CALIBRATION ELEVATION EFFECT IS:
y = 5.15 + (−0.07)EL

DUHONG 3-SEP-1992 11:

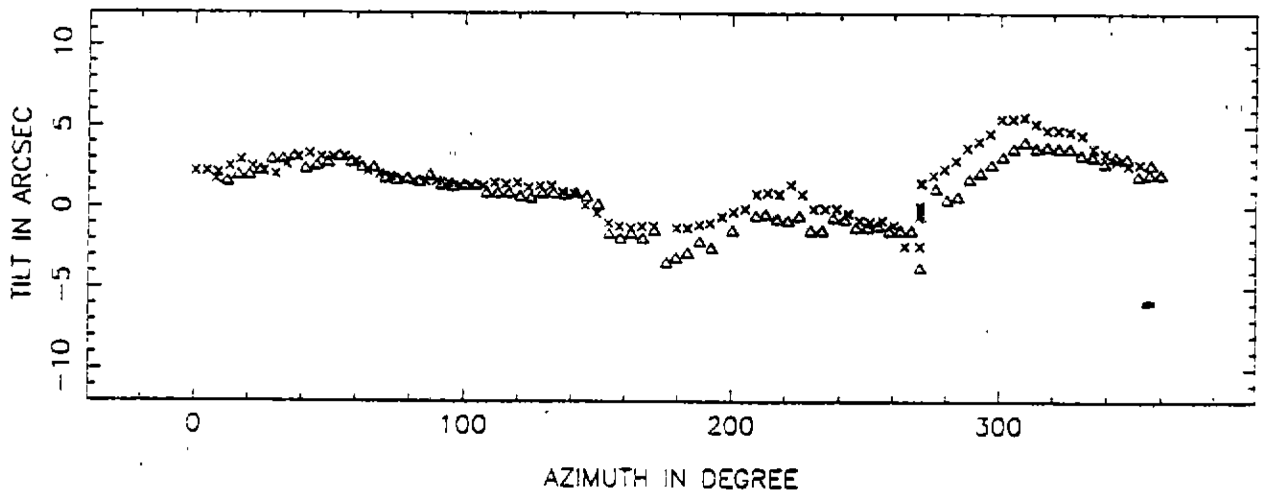
TILT & FITTING CURVE vs AZIMUTH



FITTING ERRORS vs AZIMUTH



DIFF TILT vs AZIMUTH



THE CALIBRATION FILE USED IS: 26sept.cab
THE MODEL FOR TILT vs AZIMUTH IS:
y = -22.55 + (2.03)cos(AZ) + (52.37)sin(AZ)
THE FITTING ERROR RMS: 6.52 arcsec
THE MODEL OF CALIBRATION ELEVATION EFFECT IS:
y = 0.00 + (0.00)EL

STATION 16

DUHONG 26-SEP-1992 14:

Fig. 3 THE FIRST FITTING ERROR vs THE SECOND FITTING ERROR

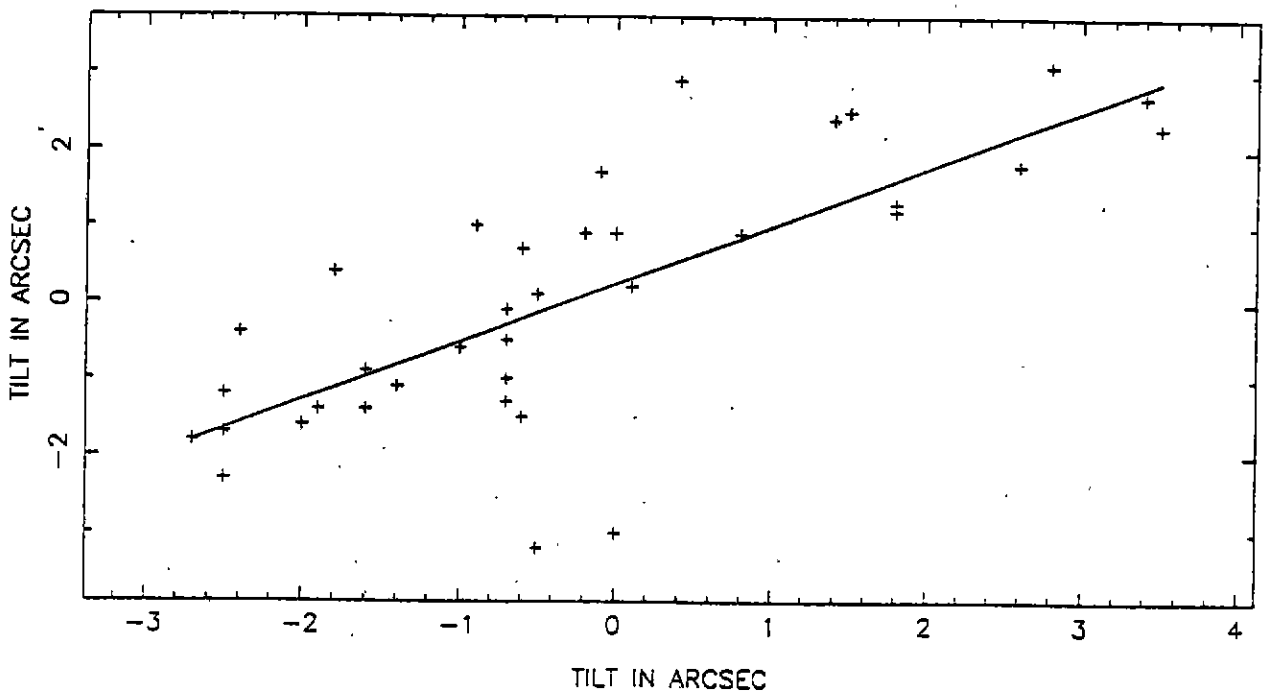
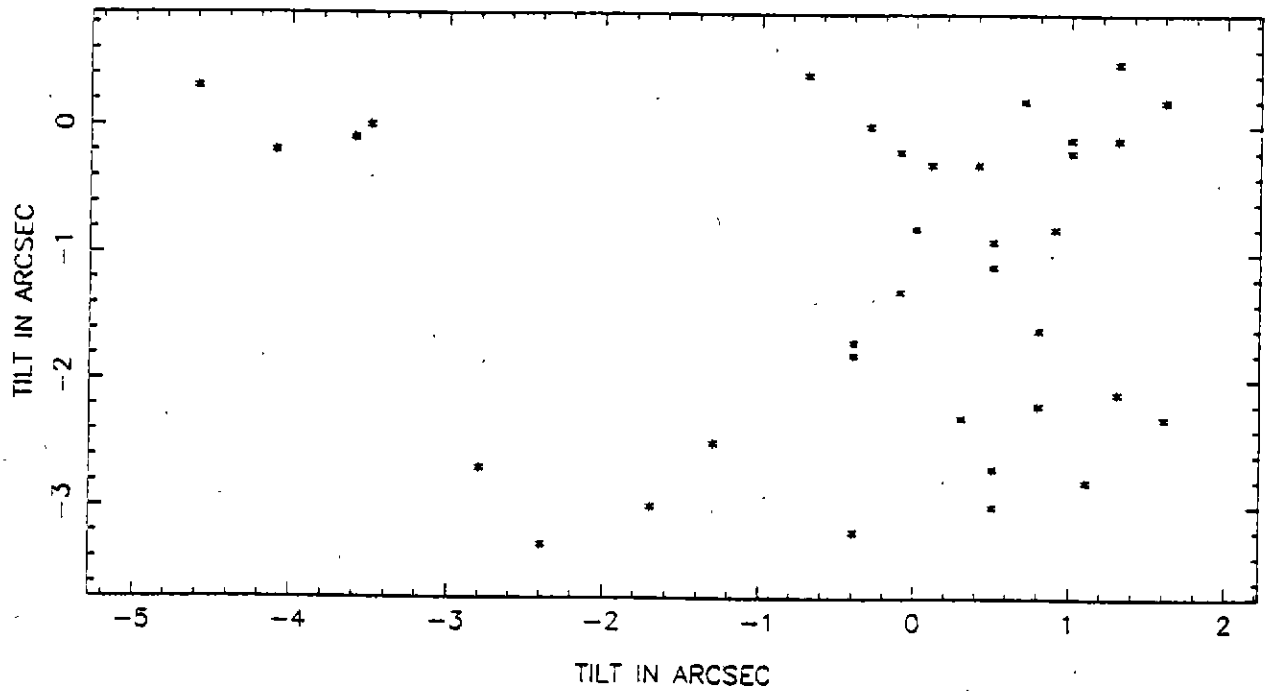


Fig. 4 THE FIRST DIFF TILT vs THE SECOND DIFF TILT



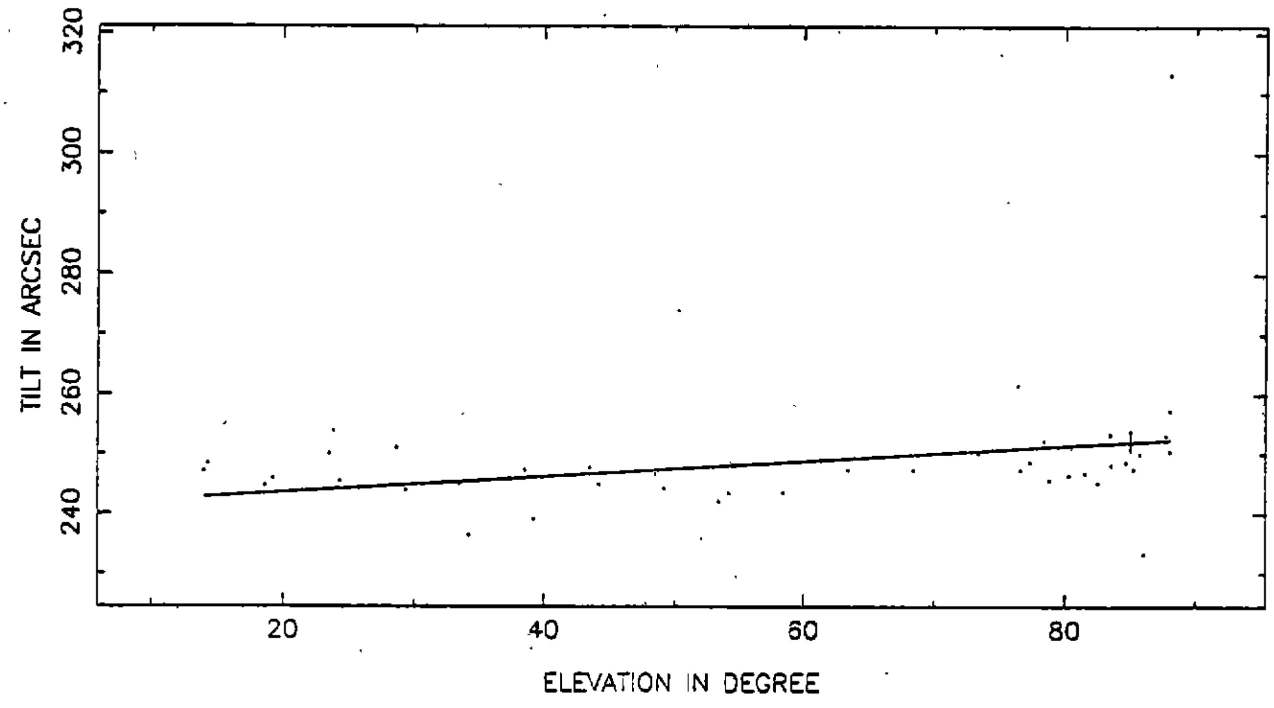
THE ONE FILE USED IS: 23augd.cao (STATION 13)
THE ANOTHER FILE USED IS: 1septd.cab (STATION 16)
THE MODE OF FITTING TILT vs TILT IS:

tilt2 = 0.24 + (0.76)tilt1

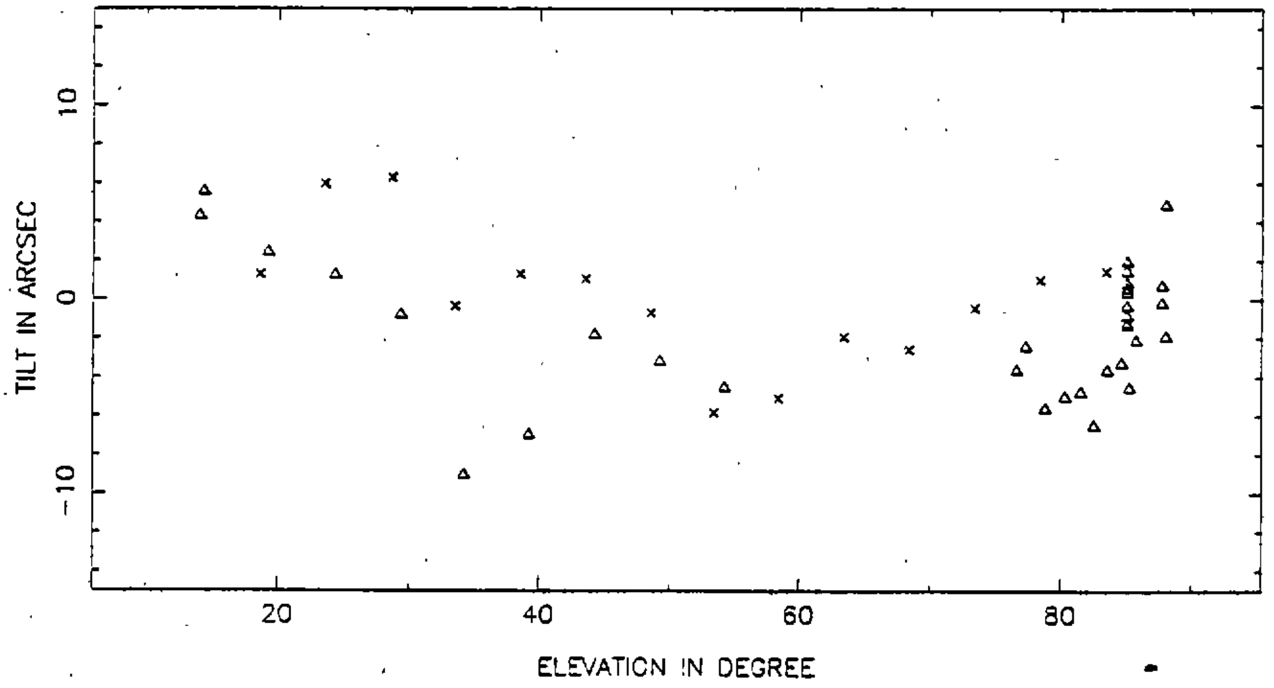
$R^2 = 0.57$

DUHONG 3-SEP-1992 14:

TILT & FITTING CURVE vs ELEVATION



TILT FITTING RESIDUAL ERROR vs ELEVATION



THE CALIBRATION FILE USED IS: 17sept.ccb

THE AZIMUTH IS FIXED IN 90.0 DEGREES
THE MODEL FOR DIFF TILT vs ELEVATION IS:

y = 240.99+ (0.13)EL

THE TILT FITTING RESIDUL ERROR IN RMS: 9.5 arcsec

TILT & FITTING CURVE vs AZIMUTH

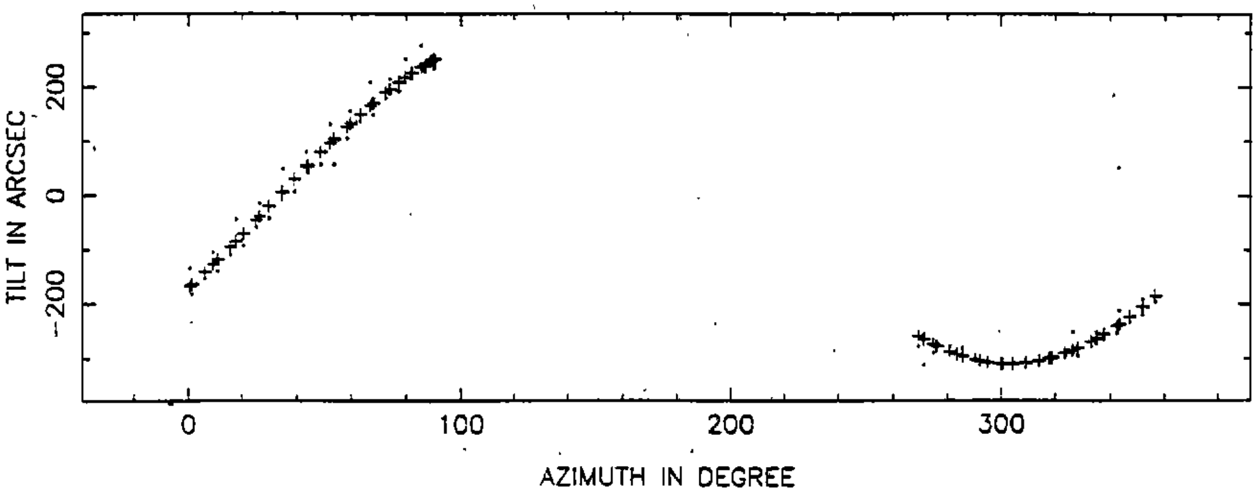
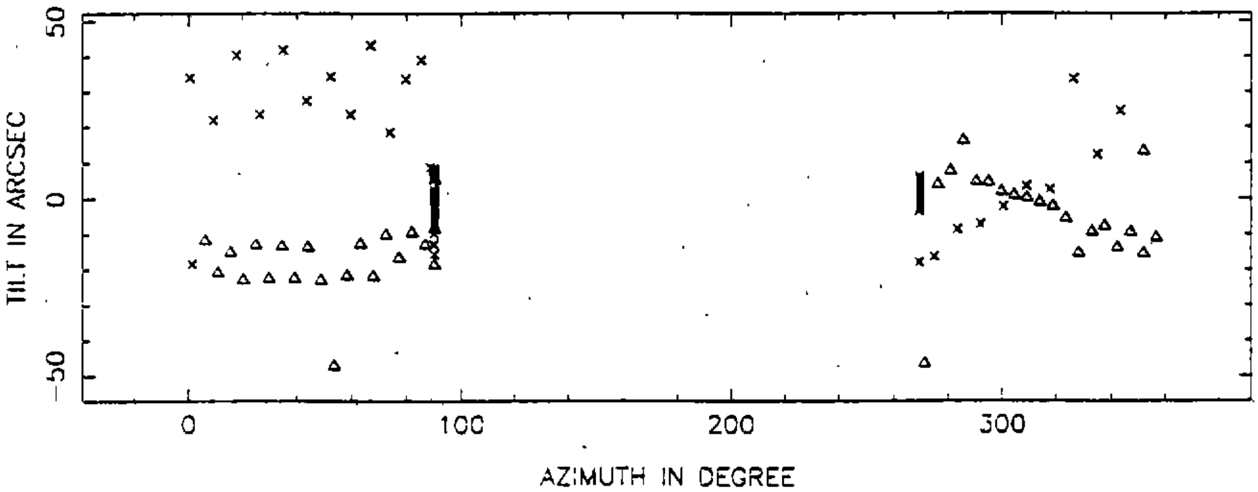
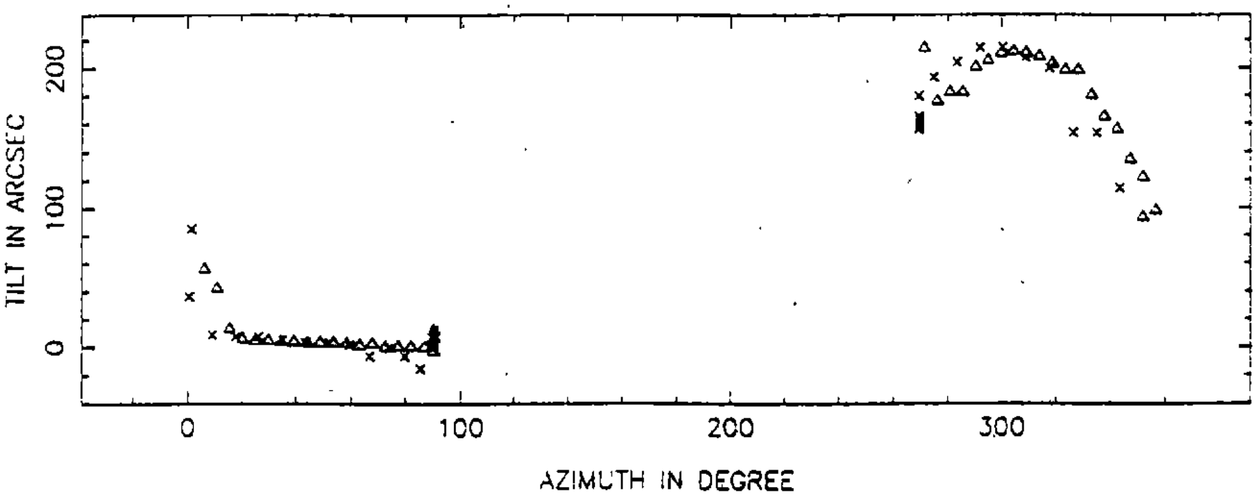


Fig. 5 FITTING ERRORS vs AZIMUTH



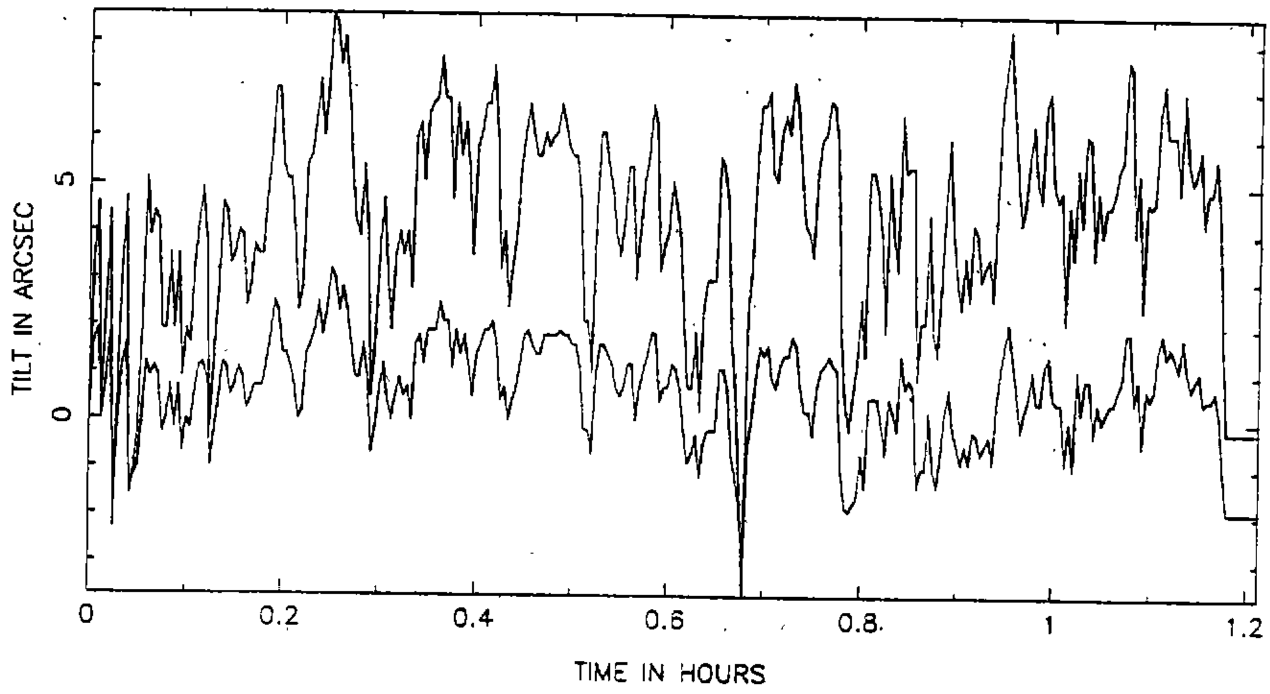
DIFF TILT vs AZIMUTH



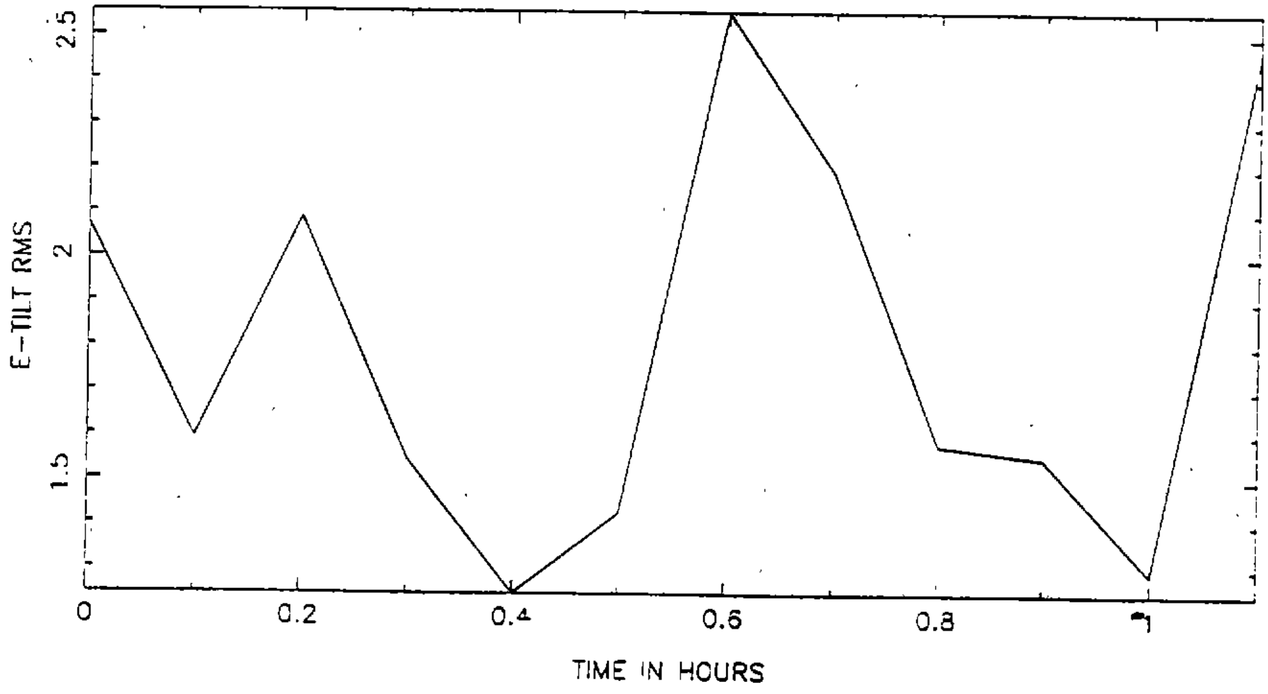
THE CALIBRATION FILE USED IS: 17sept.cab
THE MODEL FOR TILT vs AZIMUTH IS:
y = −5.18 − (−165.10)cos(AZ) + (257.10)sin(AZ)
THE FITTING ERROR RMS: 12.41 arcsec
THE MODEL OF CALIBRATION ELEVATION EFFECT IS:
y = 0.00 + (0.00)EL

DUHONG 1−OCT−1992 15:

Fig 6 E–TILT & P–TILT vs TIME



E–TILT RMS vs TIME



THE TIME STARTS AT 17–SEP–1992 8:57:58.3

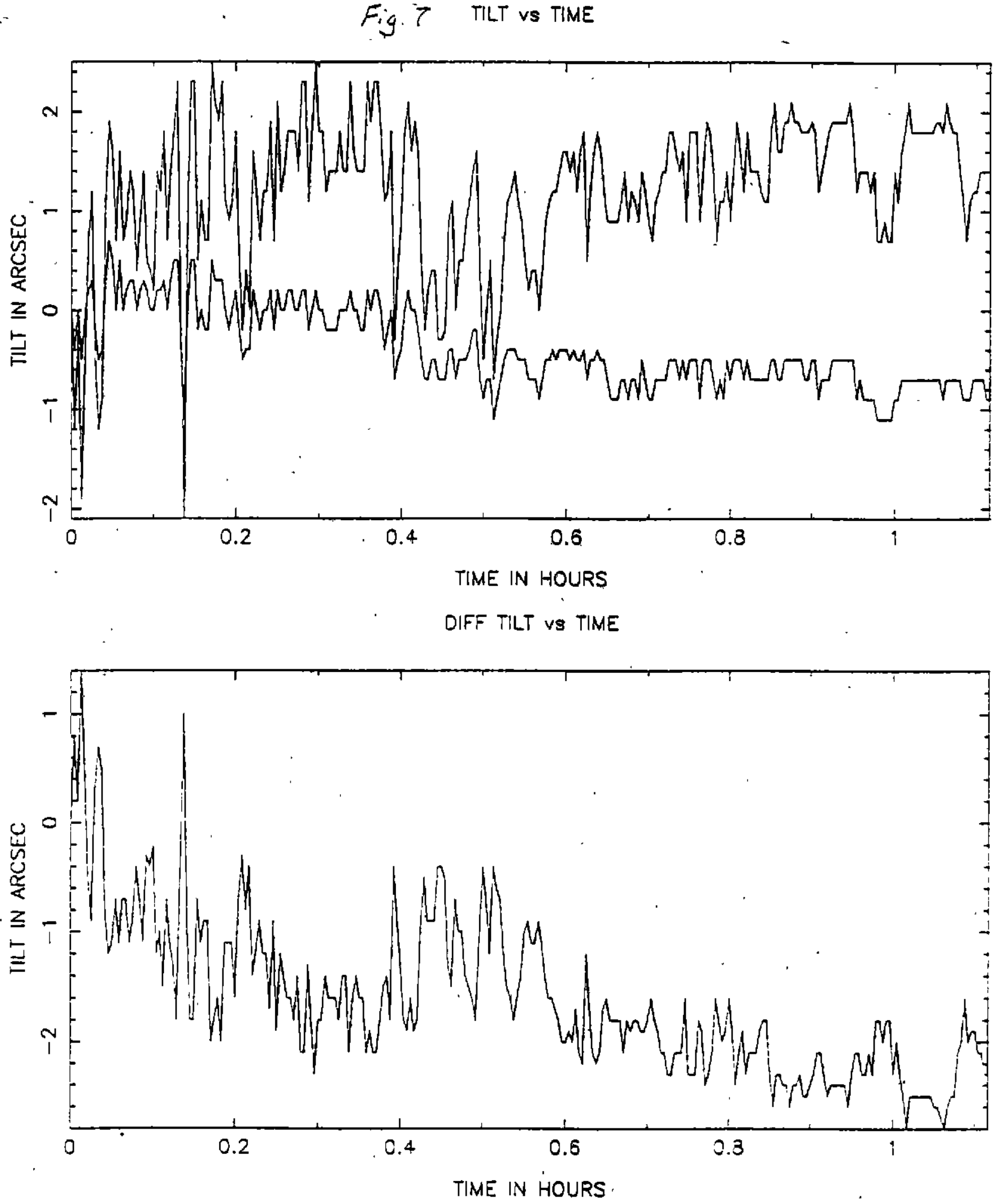
THE DATA FILE IS: 17sept.st
THE MEAN AND RMS OF TILT IS:
Mean is: 4.29 ARCSECS, RMS is: 2.09

THE MEAN AND RMS OF DIFF TILT IS:
Mean is: –3.66 ARCSECS, RMS is: 1.23

OFF STATION

DUHONG 23–SEP–1992 09:

Fig. 7



THE TIME STARTS AT 17-SEP-1992 15:52:59.3

THE DATA FILE IS: 17sept.s
THE MEAN AND RMS OF TILT IS:
Mean is: 1.20 ARCSECS, RMS is: 0.74
THE MEAN AND RMS OF DIFF TILT IS:
Mean is: -1.61 ARCSECS, RMS is: 0.73

on station

DUHCNG 22-SEP-1992 12: