Limits to the AT Antenna Pointing Precision
(I) - Tiltmeter Tests

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Abstract

This document describes a series of tiltmeter experiments that were undertaken at the Mopra radiotelescope and the Compact Array at Narrabri. The objective was to determine some of the factors which ultimately limit the pointing accuracy of these antennas.

1 Introduction

Rarely does a telescope point in the direction defined by its indicator dials — zero-point offsets, non-linearities and distortions all conspire to introduce a pointing error which varies with direction and possibly with time. Most telescopes therefore include in their control system a *pointing model*, an algorithm which accounts for the imperfections and corrects the pointing.

The control systems in the AT antennas currently use a ten-parameter model (Kesteven and Calabretta,1986); our standard practice is to determine the value of these parameters from observations: we measure the pointing error in a number of directions and then find the pointing model which best fits the data. The accuracy of the fit would be improved if the number of free parameters were reduced - if we could measure some parameters directly. The orientation of the azimuth axis is a clear candidate in this context, as it can be measured with tiltmeters attached to the azimuth platform.

The antenna at Mopra is of the *wheel-on-track* design; irregularities in the track will appear as pointing problems which are not easily accounted for with a pointing model. These also can be probed with tiltmeter measurements.

The experiments undertaken made use of tiltmeters to investigate these claims. We find that the Mopra antenna has a number of low-level problems which set the limits on the ultimate pointing accuracy. The Narrabri antennas seem better in this regard.

2 Experiment Design

The experiments were directed towards the following questions:

1. Are there significant irregularities in the Mopra azimuth track or Narrabri slewing rings?
2. Is the Mopra track horizontal?

3. Can we shed any light on the anomalous "cedz" question? (Is there any evidence of rotation of the elevation bearing block as the antenna tips in elevation?).

These questions lead to the following trials:

- Place the tiltmeters on the elevation bearing block; rotate the antenna in azimuth.
- With the same tiltmeter placement, rotate the antenna in elevation, from zenith to horizon.
- Place the tiltmeters in the vertex room, as close to the azimuth axis as possible; rotate in azimuth.

Our initial experiments were conservative, as we were concerned about the response of the tiltmeters to antenna motion; our strategy was to drive the antenna to a new position, then stop the motors. This placed a serious overhead in the data-taking, of 10-20 seconds per point.

In the later series of tests we drove the antenna continuously at 5 degrees/minute in azimuth. The noise level in the data is indeed higher than in the initial series, but it is adequate to provide 1 arcsec rms when the data is averaged into 1-degree (az) bins.

The antenna is slewed through 360 degrees azimuth, in both clockwise (CW) and counterclock wise (CCW) directions; this provides some indication of problems such as hysteresis and drift. (Drift is to be expected, given that the observations were largely taken during the day, and we know that the Narrabri antennas deform at the rate of 1.5 arcsec/°C with temperature changes). An ideosyncrasy in the antenna control system prevented us driving the antenna in one continuous 360 degree sweep; the data is segmented, in 90 degree steps, with concomitant tiltmeter disturbances at each motor start/stop. Substantial effort was required in the analysis to blend the different sectors - the tiltmeters were clearly affected at each transition. Some residual trace is evident in the final results, as the data show "steps" between different sectors.

The control system kept the antenna's optical axis at a fixed elevation (89.5 degrees); we zeroed the pointing model parameters for these experiments to prevent the control system from providing a correction for the azimuth axis tilt.

3 Hardware

3.1 The Tiltmeters

The tiltmeters are Schaevitz model No. LSOC-1, accurate to about 1 arcsec.

A tiltmeter mounting plate was built, with four tiltmeters aligned along orthogonal axes. The tiltmeters are arranged in pairs, back-to-back in order to provide substantial immunity to thermal drifts. In all our experiments one pair of tiltmeters was aligned parallel to the antenna's elevation axis.

3.2 Data Logging

The tiltmeter output is a DC signal in the range -5 to +5 volts; the scaling is approximately 10000 arcsec/volt. We calibrated the tiltmeters on the antenna: clamp the assembly to the vertex room floor, then tip the antenna through a small angle (in elevation).

A PC notebook with a PCMCIA analog-to-digital data logger card sampled the tiltmeter signals every second; the data was timestamped and stored to file. A companion task on the control system computer logged the antenna position and drive status at 10 second intervals.

4 Analysis

The data reduction was largely an case of merging the data, first combining the data from the paired tiltmeters, and then combining the CW and CCW data.

The sequence is illustrated in figure 1 which shows the results of a run taken at Narrabri. The first four plots (1a to 1d) show the traces from the four tiltmeters; Units 1 and 2 are oriented at right angles to the Elevation axis, units 3 and 4 parallel.

The next four plots (1e to 1h) show the sum and differences for each pair; in effect they show the real tilt (cycling through +/- 100 arcsecs), and the thermal drift and noise (around 1 arcsec). The difference plots also confirm that the calibration of the tiltmeters is correct - there is no trace of the cycling.

The next four plots (1i to 1l) show the mean and difference of the CW and the CCW passes. At this stage in the processing we correct for drift - we need to allow for the small systematic changes to the structure which occurred during the run. The obvious symptom is that the measured tilt at the start of the run differs from the tilt at the half-way point, and from the end point, all at azimuth 270 degrees. A linear trend was sufficient to realign the two passes, although the difference plots (1j and 1l) show that some non-linearity at the 1 arcsec level is present.

The mean plots (1i and 1k) are our best estimate of the tilt as a function of azimuth; we assume (in the control system) that this data can be related to a tilt in the aziumth axis. The residuals after removing the best fitting axis tilt are shown in the last two plots (1m and 1n). The last two plots show our best estimate of the azimuth irregularities and indicate the quality of the azimuth slewing ring.

(Figure 1 is discussed in greater detail in Appendix A, as a number of interesting features are present).

5 Results

5.1 Mopra

1. The tiltmeters placed on the elevation bearing block, and aligned normal to the elevation axis show that the block rocks back-and-forth with azimuth. See figs 3a, 3b This motion will affect the elevation encoder zero-point.
2. Exactly the same action is seen in the vertex room (fig 4a). In other words, the encoder zero-point shifts are faithfully tracked (as they should be) by the control system, and there are no other problems.
3. The bearing block tiltmeters which were aligned parallel to the elevation axis also show significant action (figs. 3c and 3d). Although we have not tested this point, it seems that the two bearing blocks move independently, since the vertex room tiltmeters are quite uncorrelated with the bearing block units (fig. 4c).
4. The vertex room tiltmeter data (all four tiltmeters) cannot be usefully related to a single azimuth axis tilt (the parameters *ax* and *ay* of the pointing model). A serious pointing model for Mopra could probbaly benefit by providing separate (*ax*,*ay*) for elevation and for azimuth.
5. The vertex room data place a lower limit on the achievable global pointing accuracy: until the pointing model is reworked to accomodate the track errors (figs. 4a and 4c) it will not be possible to do better than 5 arcsecs (rms). The reference pointing strategy will temper the agony, but not remedy the situation, as the track errors are of high frequency, and objects only a few degrees apart will have uncorrelated pointing errors.

6. Hysteresis is evident in the data; it amounts to about +/-2.5 arcsec in elevation. The Narrabri data taken under identical conditions do not show this problem. We have yet to test whether this is related to the relatively high slew rate (5 degrees/minute), or whether it is still preent when sidereal tracking is underway.

7. The bearing block tiltmeters show no movement (< 1 arcsec) as the antenna is tipped in elevation.

5.2 Narrabri

Most of the Mopra experiments were repeated at Narrabri, on just one antenna (CA03). The main conclusion is that this antenna is in better shape, as few of the Mopra effects are seen. The residual tilts, after allowing for the azimuth axis tilt are about 0.8 arcsec (rms).

The residuals do appear smooth and stable, so a reworked control system could possibly reduce this component even further.

It is tempting to generalise that all the narrabri antennas are likely to perform as well as CA03 - after all, they were built identically.

The experiments are simple, so the other antennas can easily be checked.

6 Discussion

The Mopra data show that the azimuth track is uneven, with tilt excursions of +/- 5 arcsecs, corresponding to a surface uneveness of +/- 0.2 mm.

The structural analysis of the four-wheel antenna base is complicated; the following simple picture is a starting point:

We have two A-frames which support the elevation bearings, with substantial cross-links between the two frames. If a wheel is raised at a bump in the track it will rotate its A-frame about the elevation axis. This will rotate the zero-point of the elevation encoder (if the wheel is attached to the A-frame which carries the encoder). It will also move the top of the frame horizontally by an amount roughly equal to the bump height. Thus we can expect to see azimuth errors (equivalent to zero-point shifts of the azimuth encoder) whenever any of the wheels is displaced vertically as the antenna slews in azimuth.

The A-frames also show significant movement in the direction parallel to the elevation axis; the two frames appear to move independently, and the elevation axis itself seems to remain largely horizontal.

In summary, the Mopra antenna has low level structural deformations which are complicated and which seem difficult to model satisfactorily; the overall pointing accuracy is unlikely to better 5 arcsecs (rms).

7 Conclusions and Recommendations

1. The Mopra track is uneven with repeatable fine structure at the 0.2 mm level. It would be worth cleaning the track as a first step. This might remove the fine structure, leaving a simpler error function to model.

2. Since the worst deflection occurs at the STOW position, perhaps a different stow location should be tried.

3. Some thought should be given to reworking the control system pointing machinery, allowing the option to include an azimuth error function (polynomial or tabular).
4. The pointing model has two parameters, the azimuth axis tilt (ax,ay); it seems likely that at Mopra the track is so close to horizontal that these terms are not needed. However, the track shape, and the elastic response of the antenna base may lead us to use the functional form provided by (ax,ay), albeit with separate parameter values for azimuth and for elevation.
5. The azimuth slew test is valuable disgnostic of the slewing ring at narrabri, and these tests should be repeated every year or so.

Appendix A - CA03 data

The antenna was located at station 29 for this experiment. The data were collected during the day, in two separate experiments.

The mean plots (1i and 1k) are very well fitted by a single tilt of the azimuth axis, tipped 33 arcsecs in the N-S plane, and 107 arcsecs in the E-W plane.

The azimuth axis tilt. All the stations are meant to be coplanar with station 35, at the western end of the track. At station 29 we expect to find an East-West tilt of 11 arcsecs. The pointing model assumes tilts of 94 arcsec (E-W) and 26 arcsec (N-S) relative to station 35; this would imply a tiltmeter result of 105 arcsec (E-W) and 26 arcsec (N-S) in fair agreement with our data. An examination of the pointing history at station 29 shows that the large tilt is associated with the station, not the antenna.

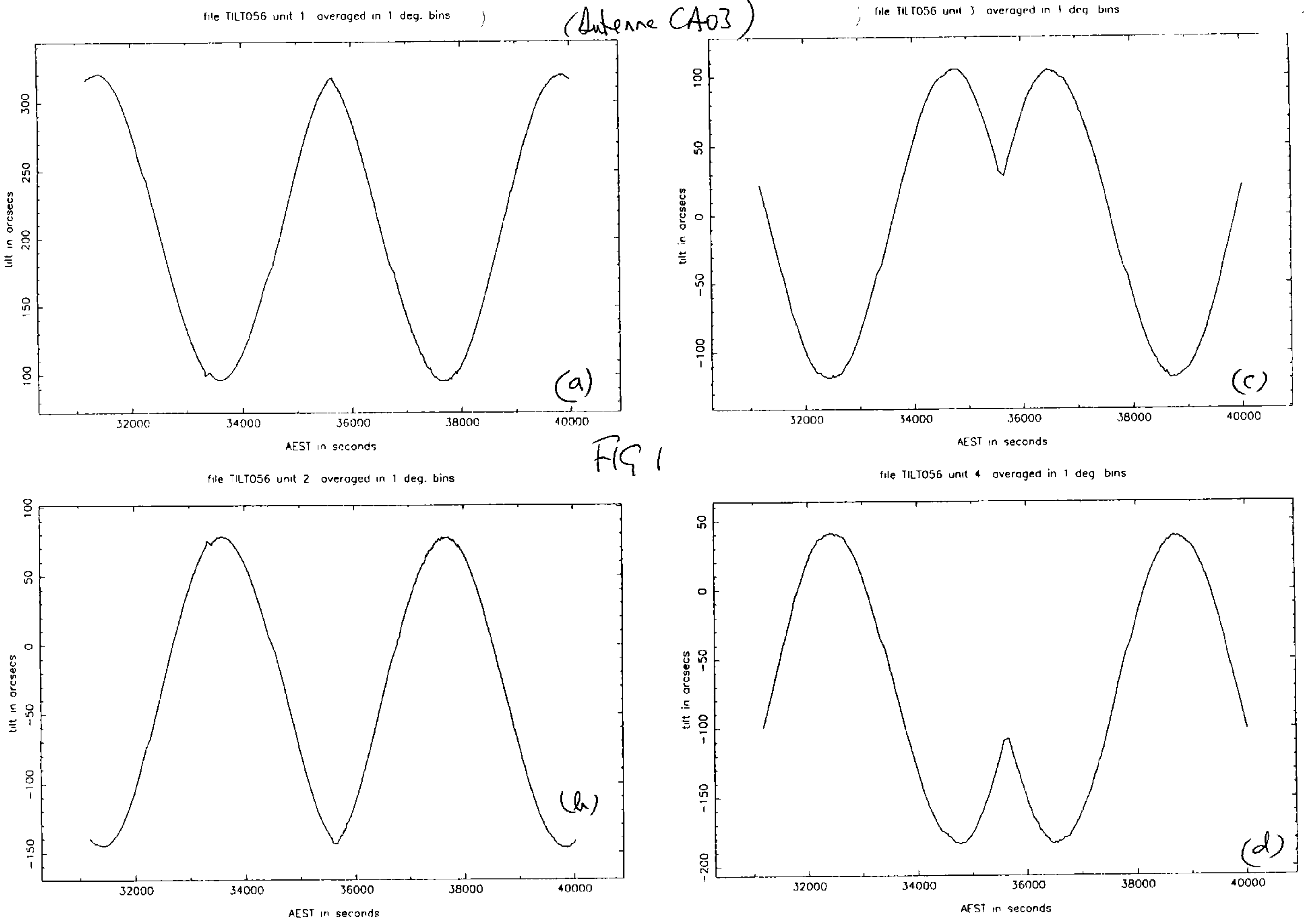
References

Kesteven, M. J., Calebretta, M. R., *Calibration Notes, I — Antenna Errors*, ATNF technical report, AT/25.1.1/029, 1986.

Figure Captions

figure 1	The full analysis cycle, Narrabri (CA03).
1a-d	raw data, tiltmeters 1 to 4
1e-f	sum and difference, tiltmeters 1 and 2
1g-h	sum and difference, tiltmeters 3 and 4
1i	tilt vs azimuth, as seen by tiltmeters 1 and 2
1j	difference between the two az. passes, units 1 and 2
1k-l	tilt and difference, units 3 and 4
1m	residual tilt after removing the best-fit axis tilt, units 1 and 2
1n	residual tilt, units 3 and 4
figure 2	Sum and difference in the residual tilts, at narrabri.
2a-b	units 1 and 2
2c-d	units 3 and 4
Figure 3	Sum and difference in the residual tilts at Mopra, comparing the elevation bearing block and the vertex room. Note the excellent agreement in the tiltmeters aligned normal to the El. axis, and the total lack of agreement in the tiltmeters aligned parallel to the El. axis
Figure 4	Sum and difference in the residual tilts, for two Mopra experiments, one day apart

NARRABRI
(Antenne CA03)



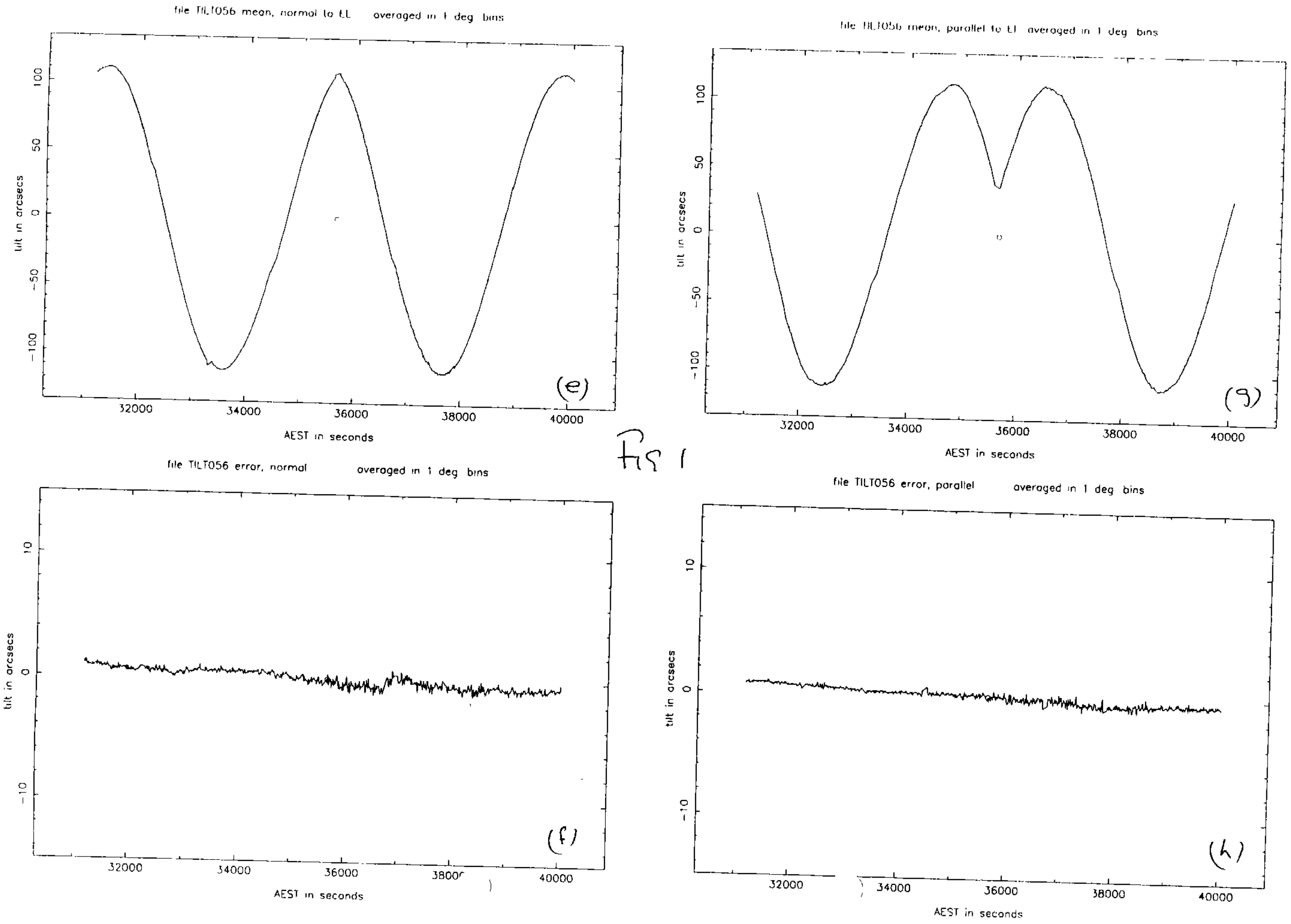
file TILT056 unit 1 averaged in 1 deg. bins

file TILT056 unit 3 averaged in 1 deg bins

file TILT056 unit 2 averaged in 1 deg. bins

file TILT056 unit 4 averaged in 1 deg bins

FIG 1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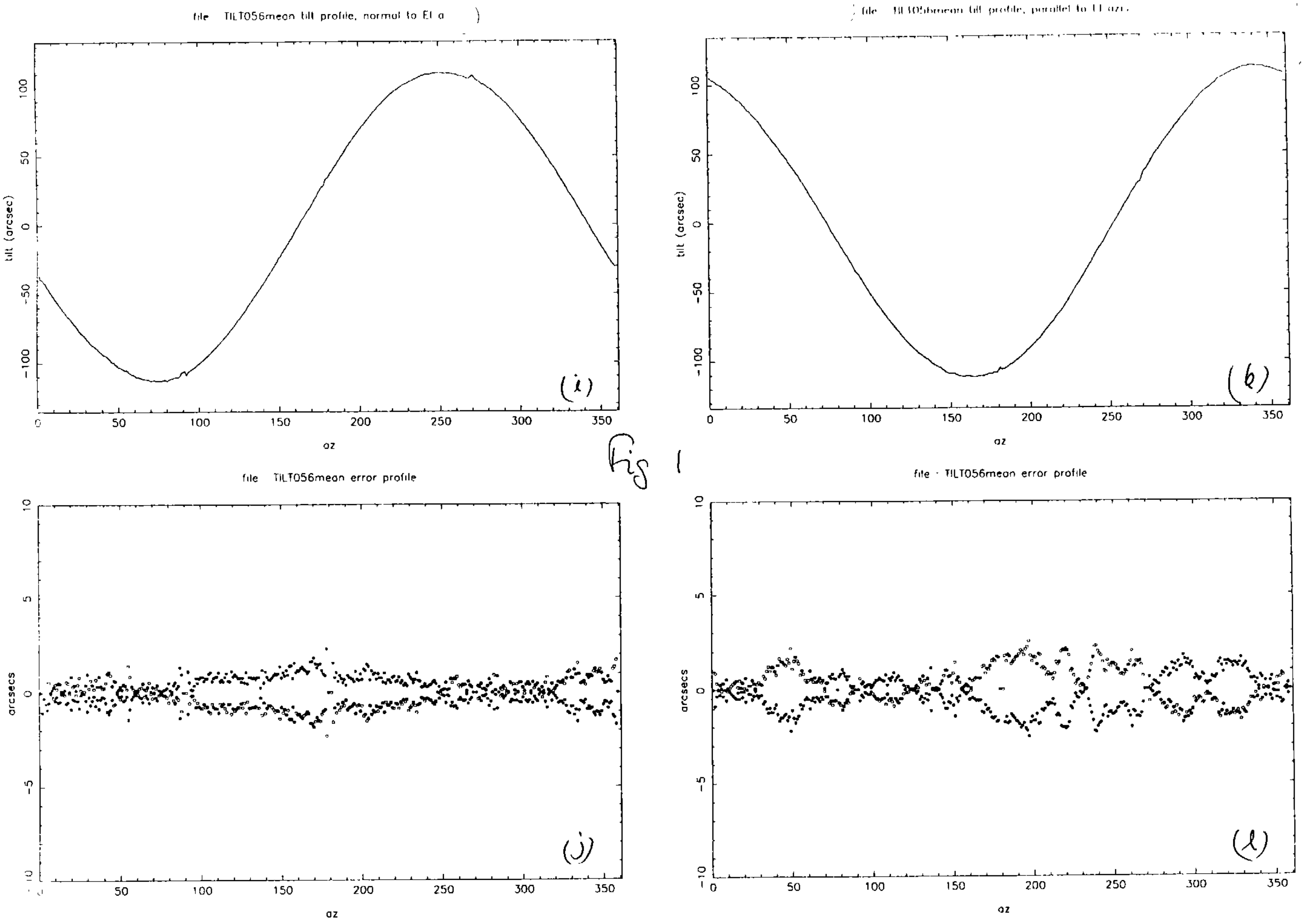
50
0
-50
-100
32000
34000
36000
38000
40000
AEST in seconds
(e)
file TILT056 mean, parallel to EL averaged in 1 deg bins
tilt in arcsecs
(g)
file TILT056 error, normal averaged in 1 deg bins
10
0
-10
(f)
file TILT056 error, parallel averaged in 1 deg bins
(h)

Fig 1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tilt (arcsec)
100
50
0
-50
-100
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(i)
file TILT056mean tilt profile, parallel to El azi.
tilt (arcsec)
100
50
0
-50
-100
0
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100
150
200
250
300
350
az
(b)
file TILT056mean error profile
arcsecs
10
5
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-5
-10
50
100
150
200
250
300
350
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(j)
file · TILT056mean error profile
arcsecs
10
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0
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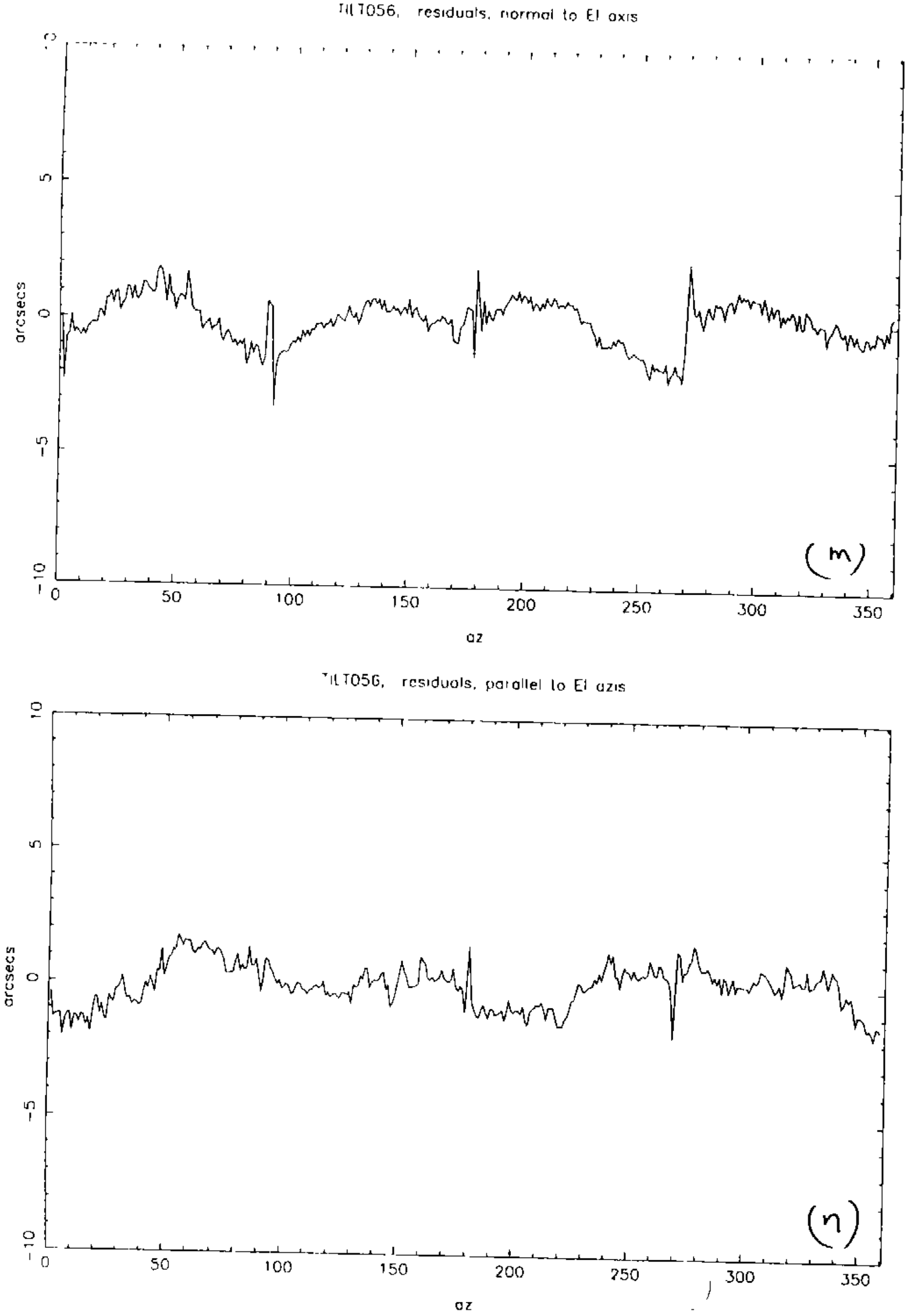
Fig 1



TILT056, residuals, normal to El axis

TILT056, residuals, parallel to El azis

Fig 1

Narrabri

NARRABRI

MEAN OF TWO SEPARATE DAYS

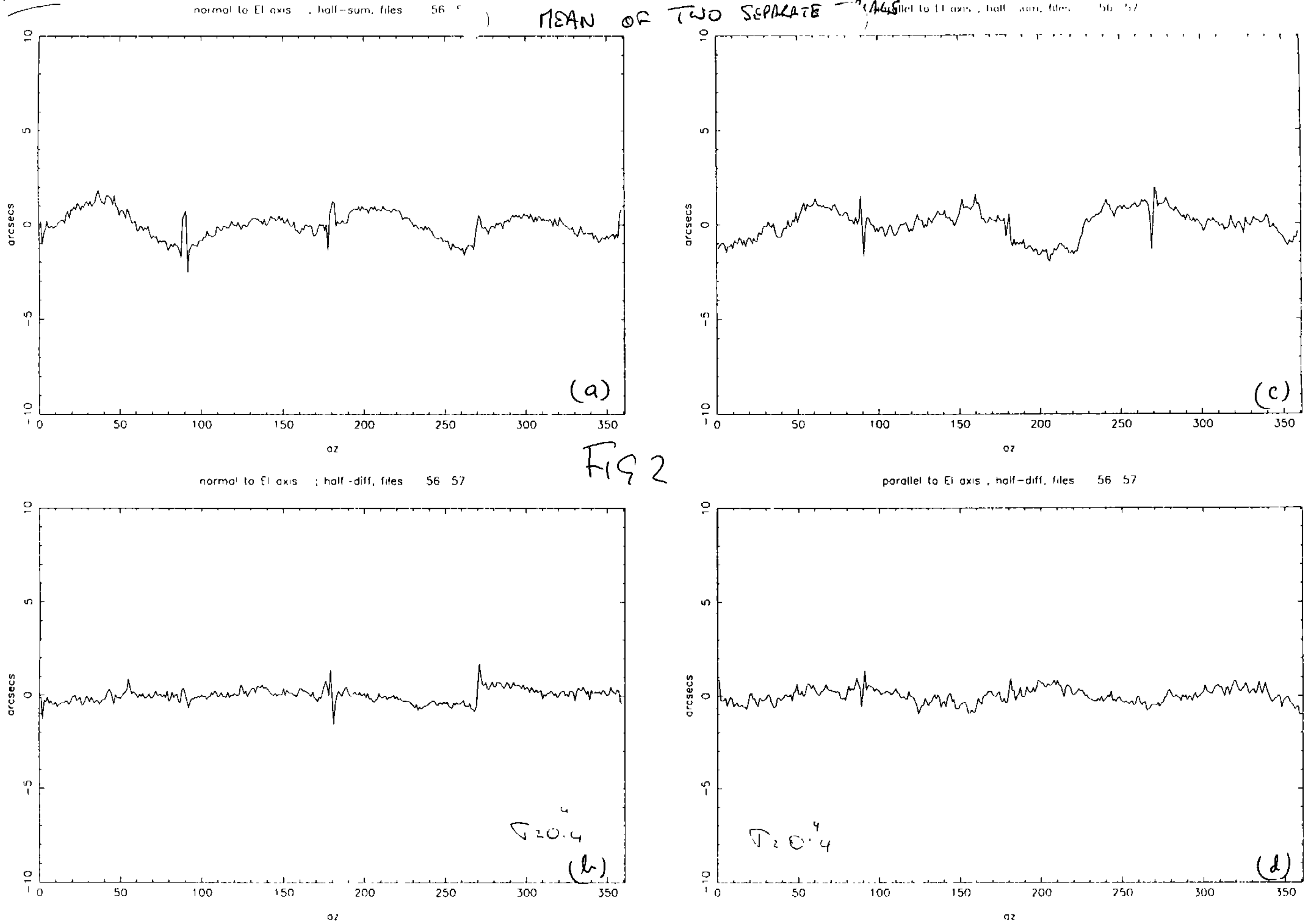


FIG 2

MOPRA.
COMPARISON & BEARING BLOCK VERTEX ROOM

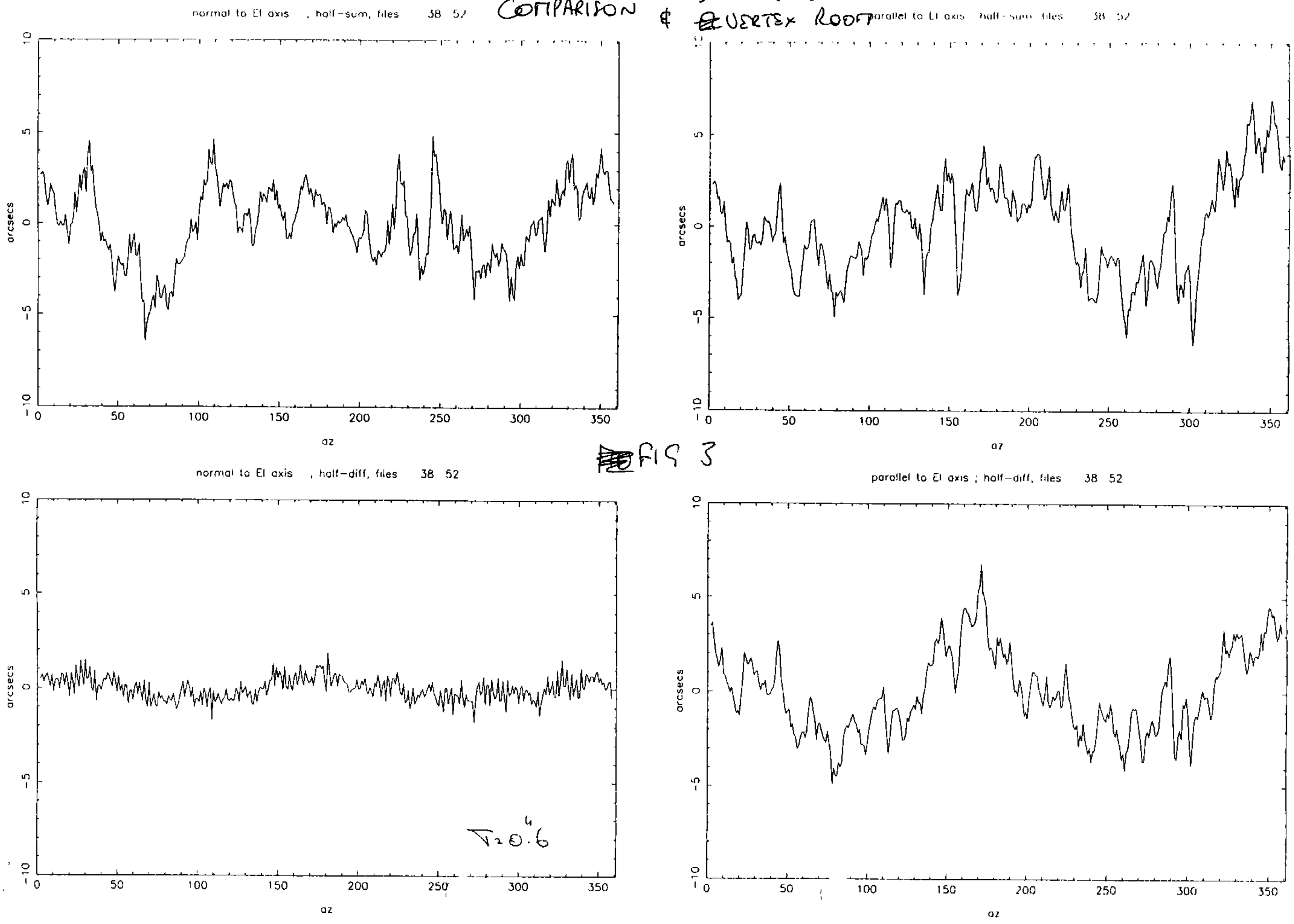


FIG 3

MOPRA

STABILITY OF THE POL [illegible]

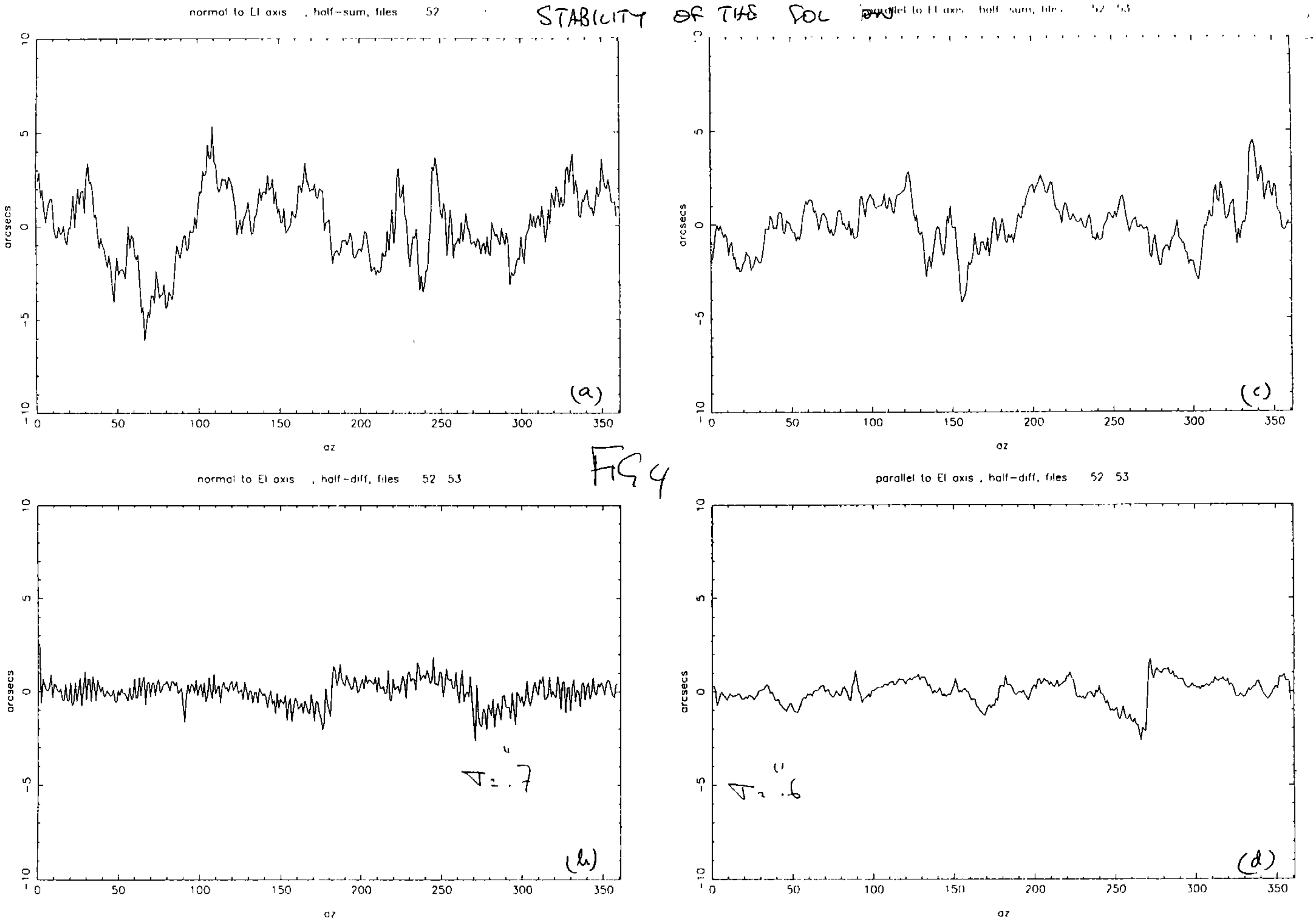


FIG 4