NCRA internal technical report

Web-based GMRT ONLINE data monitoring tools: II. Monitoring pointing of GMRT antennas

N. G. Kantharia & S. N. Katore

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Abstract

Several online control data monitoring and recording tools are being developed for enabling (1) long term study of these parameters (2) study of individual antenna peculiarities (3) providing a way to detect a problem, study repeatability and subsequently enable its fixing. The details of the tools are described in a separate note (Katore & Kantharia 2012). In this note, we focus on the behaviour of the pointing offsets of the GMRT antennas using the data collected from every pointing run following feed rotation. All the data since October 2010 have been recorded in a computer and plotting routines are provided that the pointing offsets as a function of time and band can be viewed and the basic statistics are made available to the user who could be an astronomer or member of the engineering group. The data examined are from October 2010 to August 2012.

Study of the elevation and azimuth pointing offsets of 30 antenna has resulted in the following preliminary inferences: (1) some antennas show band-dependent pointing offsets in elevation and azimuth. (2) several antennas show an occasional jump in their mean pointing offset by more than a few arcminutes (encoder jump) which then continues to be the pointing correction for the antenna. Most antennas have experienced one such change in the last two years but there are a few antennas which show more than one such change in their pointing over the last two years. (3) The rms on the measurements of elevation pointing offsets is, on the average, smaller than that observed for azimuth pointing offsets.

In this note we present a preliminary analysis of the pointing offset data from October 2010 to August 2012 and end with a short correlation with inputs on the mechanical work done on the antennas from the mechanical group.

Contents

1 Introduction

The control and monitor system (combination of telemetry and the ONLINE programmes) at GMRT records information on several control parameters in the shared memory of the control computer. Tools have been developed to read, record and plot several of these control parameters such as pointing offsets, windmeter readings, antenna base shell temperatures etc from the shared memory. All the recorded data are made available online at http://www.gmrt.ncra.tifr.res.in/ under the heading 'Monitoring Tools'. More details on these tools can be found in the report 'Web-based GMRT ONLINE data monitoring tools: II. Monitoring Wind Speeds at GMRT' by Katore and Kantharia. In this note, we discuss the recording of pointing offsets estimated after a regular grid pointing experiment and discuss the results obtained from examining the data recorded between October 2010 and August 2012 for all the antennas along the azimuth and elevation axes.

The pointing offsets at GMRT are estimated by observing a grid of nine points about a strong calibrator source such as 3C286 along the elevation axis and then along the azimuth axis. About 1 minute of visibility data for each of the nine points spaced by an appropriate offset is collected. The pointing offsets recorded in the earlier pointing experiment are loaded before the procedure is run. The cross-correlation data along the two axes are then separately used to solve for antenna gains. The best-fit gaussian to the beamshape is used to estimate the pointing offsets from the expected position. We have recorded the pointing offsets every time a pointing run is implemented at GMRT in any of the wavebands. In this note, we use these offsets recorded over the last two years to quantify the variation in the pointing offsets seen for each antenna, jumps in the pointing offsets, scatter in the pointing offsets and other quantifiable quantities. This is a preliminary note which tries to understand the data collected since October 2010. These results will help understand the pointing of individual GMRT antennas better and help fix mechanical problems. The development of the tools are ongoing and more utilities to analyse the data will be added in the future versions.

In this note, we summarize the results on the antenna pointing offsets recorded over the last two years. Section 2 and 3 discuss the variation in the azimuth and elevation pointing offsets respectively and section 4 discusses the variation observed for the individual antennas. In the appendix, we present a summary of the different behaviour that is displayed by the variation in the pointing offsets.

2 Azimuth pointing offsets from October 2010 to August 2012

Table 1 and Figures 1 to 5 show the variation of the recorded azimuth pointing offset for the antennas between October 2010 and August 2012 at all wavebands. The offsets show several types of behaviour which can be broadly classified into three main types: (1) large rms ($\geq 10'$) scatter over the mean indicating a large variation in the estimated pointing offsets from experiment to experiment. 12 antennas listed in Table 1 show particularly large scatter : C00, C01, C02, C05, C09, C10, C14, E04, E05, S04, W01, W05. This list includes both an inherently large variation and also scatter due to a discrete jump in the mean value. (2) the difference in the mean values of the pointing offsets at the three wavebands. The 16 antennas for which the mean values of the pointing offsets measured at the three wavebands match within 2' are C04, C06, C08, C10, C11, C12, C13, C14, E02, E06, S01, S02, S03, W01, W03 and W04. The nine antennas for which the mean offsets measured at the three wavebands differ by 5' or more are C01, C02, C05, C09, E04, E05, S04, W02 and W04. (3) jump in the pointing offset by several arcminutes. The 15 antennas (see Figs 1 to 5) which have shown this effect in the last two years are C00, C01, C02, C04, C05, C06, C08, C09, C10, C12, C14, E04, E05, S04, W05. Comparing this list with the antennas listed above in (1) and the figures, it appears that W01 shows a large variation in the measurements and the same was the case fo C02 and C05 before they were corrected by the mechanical group around April 2012 and April 2011 respectively as mentioned in Appendix B.

Additionally some of these antennas show a change in the scatter of the pointing offsets over the two year period. Also noticeable are some good antennas whose mean and rms are well-behaved and antennas which show a sudden improvement in their pointing characteristics probably indicating work by the mechanical group. There are 13 antennas which have shown stable behaviour over the last two years namely C03, C11, C13, E02, E03, E06, S01, S02, S03, S06, W02,W03, W04.

In Figure 13, a table showing the dates and the magnitude of the abrupt change in the pointing offset of the antennas for both the elevation and azimuth axes is given for data between 27 October 2010 to 3 November 2012. The 12 antennas which show small variation over the last two years and no abrupt change in the mean pointing offset are: C03, C11, C13, E02, E03, E06, S01, S02, S03, S06, W03, W06. While no abrupt change in the mean pointing offset is seen for W04, the mean value appears to have gradually changed from $-4'$ in October 2010 to 10' in November 2012.

3 Elevation pointing offsets from October 2010 to August 2012

The behaviour of the elevation pointing offsets are shown in Table 2 and Figs. 6 to 10, 11, 12. The elevation pointing offsets also show a range of behaviours but one important difference between these and azimuth pointing is that the fewer antennas show problems with the elevation offsets with only a few antennas showing sudden jumps, large scatter in the measurements or peculiar behaviour. If we again look for antennas which show one or more of the three problems listed for the azimuth pointing offset as listed in Table 2 then we can draw the following conclusions: (1) There are no antennas which show more than 10' of rms scatter over the mean elevation pointing offset unlike the scatter observed in the azimuth pointing offsets. $\geq 5'$ rms over the mean are recorded for 17 antennas as compared to 19 antennas which show such large scatter for the azimuth pointing offset. (2) The antennas in which the mean elevation pointing offset for the three wavebands differ by 5' or more are C00, C09, C14, S01, S04, W03, W04, W06. The antennas for which the mean offsets match within 2' are C03, C12, E02, E03, W01. The rest of the antennas show a variation in the mean elevation offset with wavebands between 2' and 5'. (3) The 10 antennas which show a sudden jump in the elevation pointing offset by several arcminutes are C02, C06, C08, C14, E03, S04, W02, W04, W05, W06. (4) A fourth effect is noticed in the mean offset values (from Figs. 6 to 10) wherein the mean gradually changes with time. The nine antennas which appear to show this effect are C00, C06, C08, C09, E06, S01, S03, W05, W06.

The 11 antennas which have shown steady behaviour over the last two years are C01, C03, C04, C05, C10, C11, C12, C13, E05, S06, W03.

In Figure 13, a table showing the dates and the magnitude of the abrupt change in the pointing offset of the antennas for both the elevation and azimuth axes is given for data between 27 October 2010 to 3 November 2012. The 12 antennas which show small variation over the last two years and no abrupt change in the mean elevation pointing offset are: C04, C05, C10, C11, C12, C13, E03, E04, S02, S06, W01, W03. While no abrupt change in the mean pointing offset is seen for C01, the mean value appears to have gradually changed from 11' in October 2010 to 18' in November 2012 and for S03 from -4' to 5'. Rest of the antennas have shown one or more abrupt change in their mean pointing offset in the last two years. The seven antennas which have shown stable behaviour in both elevation and azimuth pointing are C11, C13, E03, S02, S03, S06, W03.

Table 1: Azimuth pointing errors - statistics from October 2010 to August 2012

Antenna	1420 MHz		610 MHz		325 MHz		All Frequency	
	mean '	rms '	mean '	rms '	mean '	rms '	mean '	rms '
Central Square								
C00	-45.4	68.1	-46.7	70.2	-51.9	73.6	-48.1	70.8
C01	8.5	13.2	10.0	12.9	4.9	13.2	8.0	13.2
C02	16.0	27.8	18.7	36.8	22.5	45.1	19.3	37.9
C03	-0.7	3.1	-3.1	1.7	-1.3	4.4	-1.9	3.3
C04	-4.8	9.1	-6.2	8.2	-5.8	5.7	-5.7	7.7
C05	-30.8	6.1	-23.6	32.2	-24.8	34.3	-25.7	29.2
C06	-19.8	6.4	-18.4	5.8	-19.6	11.4	-19.1	8.1
C08	21.9	2.8	19.8	4.9	19.5	6.6	20.2	5.2
C09	45.4	73.7	37.1	72.2	47.4	77.0	42.3	74.2
C10	4.3	16.2	3.4	14.9	6.4	22.0	4.6	17.8
C11	-0.3	2.3	0.4	9.3	0.8	12.9	0.4	9.7
C12	2.8	6.0	2.1	8.3	2.8	10.3	2.5	8.6
C13	2.0	1.6	1.9	2.3	-0.9	2.5	1.0	2.6
C14	-4.3	19.6	-2.1	15.3	-3.5	16.8	-3.1	16.8
Eastern arm								
E02	3.8	1.7	5.1	3.1	5.4	3.5	4.9	3.0
E03	-8.6	1.3	-8.2	1.4	-11.3	4.2	-9.3	3.0
E04	60.3	41.7	55.4	41.6	55.4	44.6	56.5	42.6
E05	14.0	46.7	13.5	46.8	7.4	36.0	11.7	43.6
E06	-10.7	4.8	-9.5	4.1	-8.9	2.3	-9.6	3.9
Southern arm								
S01	2.8	4.2	4.1	1.5	4.0	2.9	3.8	2.8
S02	-2.7	6.8	-2.1	1.4	-2.5	6.8	-2.4	5.2
S03	-0.9	1.4	-1.3	3.7	-1.8	4.2	-1.3	3.5
S04	-16.6	27.6	-20.5	48.4	-25.4	56.0	-21.2	47.3
S06	-3.1	5.6	-1.9	1.7	-0.7	1.9	-1.8	3.2
Western arm								
W01	-2.7	11.6	-3.2	14.4	-1.4	18.1	-2.5	15.1
W02	15.5	5.0	17.8	4.6	23.8	6.1	19.2	6.2
W03	-2.3	3.4	-1.8	1.6	-0.9	4.5	-1.6	3.3
W04	-2.2	2.3	-4.3	1.8	-3.0	2.9	-3.4	2.5
W05	46.4	19.9	38.2	27.1	44.9	22.7	42.3	24.5
W06	-1.7	2.9	1.3	2.2	0.4	4.3	0.3	3.4

Table 2: Elevation pointing errors - statistics from October 2010 to August 2012

Antenna	1420 MHz		610 MHz		325 MHz		All Frequency	
	mean ’	rms ’	mean ’	rms ’	mean ’	rms ’	mean ’	rms ’
Central Square								
C00	8.8	6.5	11.5	4.1	16.9	7.4	12.6	6.7
C01	16.3	2.2	15.0	2.2	18.9	3.8	16.5	3.3
C02	-19.1	8.4	-20.8	7.8	-21.4	8.2	-20.6	8.1
C03	-4.7	2.7	-4.0	5.4	-3.2	2.8	-3.9	4.2
C04	9.2	2.7	11.2	1.8	8.6	5.0	9.9	3.6
C05	-5.7	2.2	-3.1	1.9	-2.0	4.0	-3.4	3.1
C06	3.2	5.4	6.4	4.8	4.6	9.2	5.1	6.8
C08	0.2	5.6	3.0	7.9	-0.4	11.5	1.2	9.0
C09	-10.3	2.7	-8.8	4.0	-1.6	9.7	-6.8	7.3
C10	2.8	4.9	4.6	3.1	6.1	7.4	4.7	5.4
C11	8.3	7.7	6.4	6.0	5.8	11.1	6.6	8.4
C12	-0.6	3.8	0.2	4.3	-0.6	6.2	-0.2	4.9
C13	0.6	1.6	3.8	5.2	4.6	2.6	3.3	4.1
C14	-53.3	10.2	-46.6	13.1	-49.6	9.1	-49.1	11.6
Eastern arm								
E02	19.2	2.6	17.6	3.4	17.6	7.6	18.0	5.0
E03	20.1	2.6	19.9	3.1	21.1	8.7	20.3	5.5
E04	-0.2	3.6	1.0	2.5	2.2	2.9	1.1	3.0
E05	-1.1	3.0	1.3	2.6	3.0	3.5	1.3	3.4
E06	6.3	1.9	5.3	5.0	7.9	3.0	6.4	4.0
Southern arm								
S01	39.4	4.0	39.4	4.0	44.9	9.1	41.2	6.6
S02	7.1	1.8	7.1	2.3	10.7	3.3	8.2	3.1
S03	-3.0	2.7	0.0	6.4	0.6	6.1	-0.5	5.8
S04	5.0	4.5	11.8	8.2	7.3	8.2	8.8	8.0
S06	-3.7	2.8	-2.6	2.5	-0.9	9.5	-2.3	5.9
Western arm								
W01	-4.9	2.7	-4.6	5.6	-3.7	6.0	-4.4	5.2
W02	2.2	5.8	3.7	5.6	-0.9	32.8	1.9	19.3
W03	5.5	2.4	8.3	2.4	10.8	2.9	8.5	3.2
W04	0.4	5.7	8.1	4.0	8.4	4.7	6.4	5.7
W05	-5.9	4.6	-6.6	4.4	-4.3	4.8	-5.7	4.7
W06	-11.5	7.1	-9.6	7.2	-5.9	9.7	-8.8	8.3

4 Notes on individual antennas

C00 *Azimuth:* This antenna shows a peak-to-peak scatter in the antenna offset measurements of about 20’. A jump in the mean offset by $\sim 110'$ is noted in mid-April 2012 which then jumps to $\sim 175'$ and settles down there. Around September 2012, the mean offset value has been reset to $\sim 0'$.
Elevation: This antenna shows a relatively large standard deviation about the mean. The scatter seems to have also increased since April 2011 and a sudden change in the pointing offsets is seen in August 2011. Moreover, in particular, the elevation pointing offset

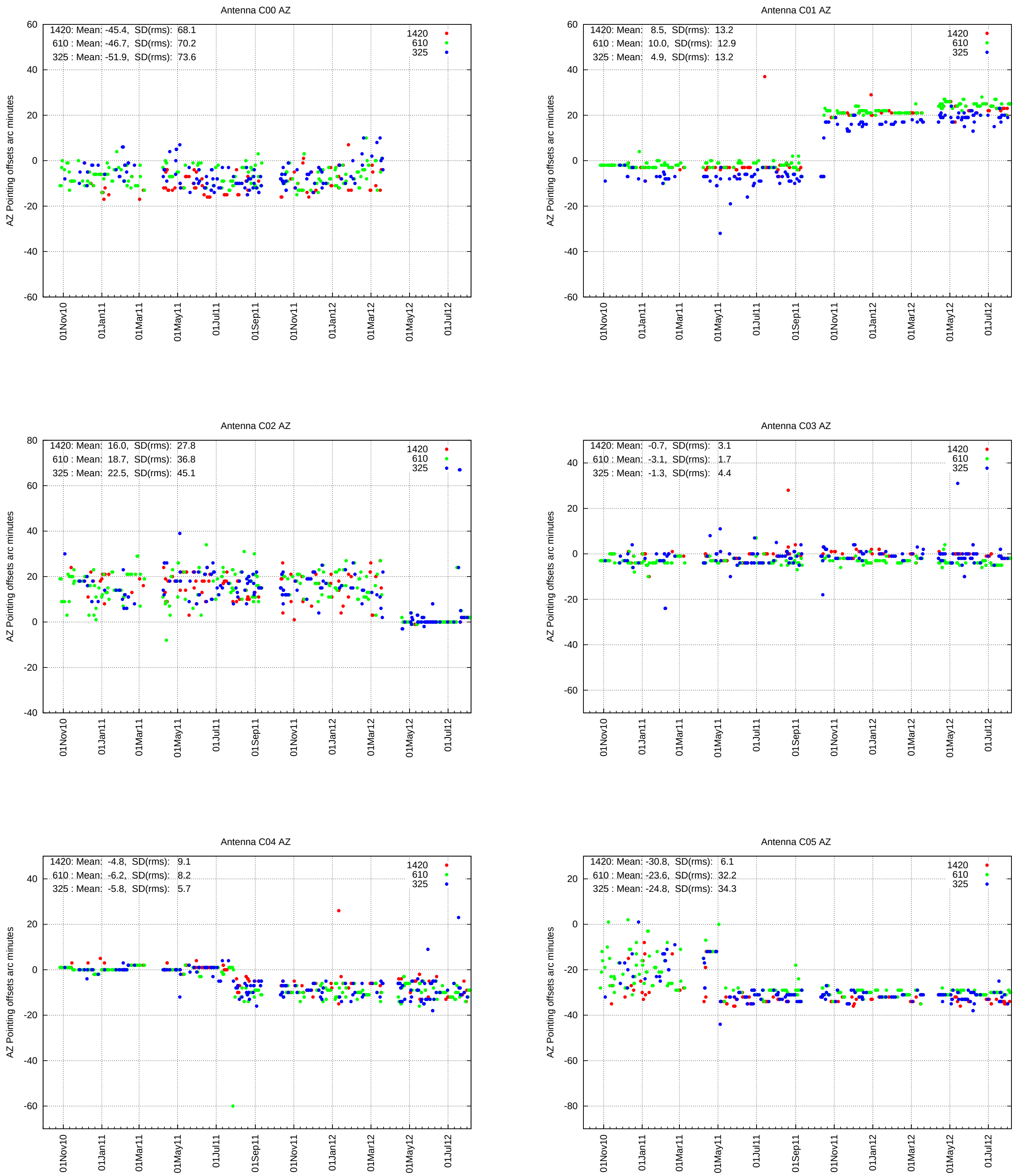

Figure 1: **Azimuth** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

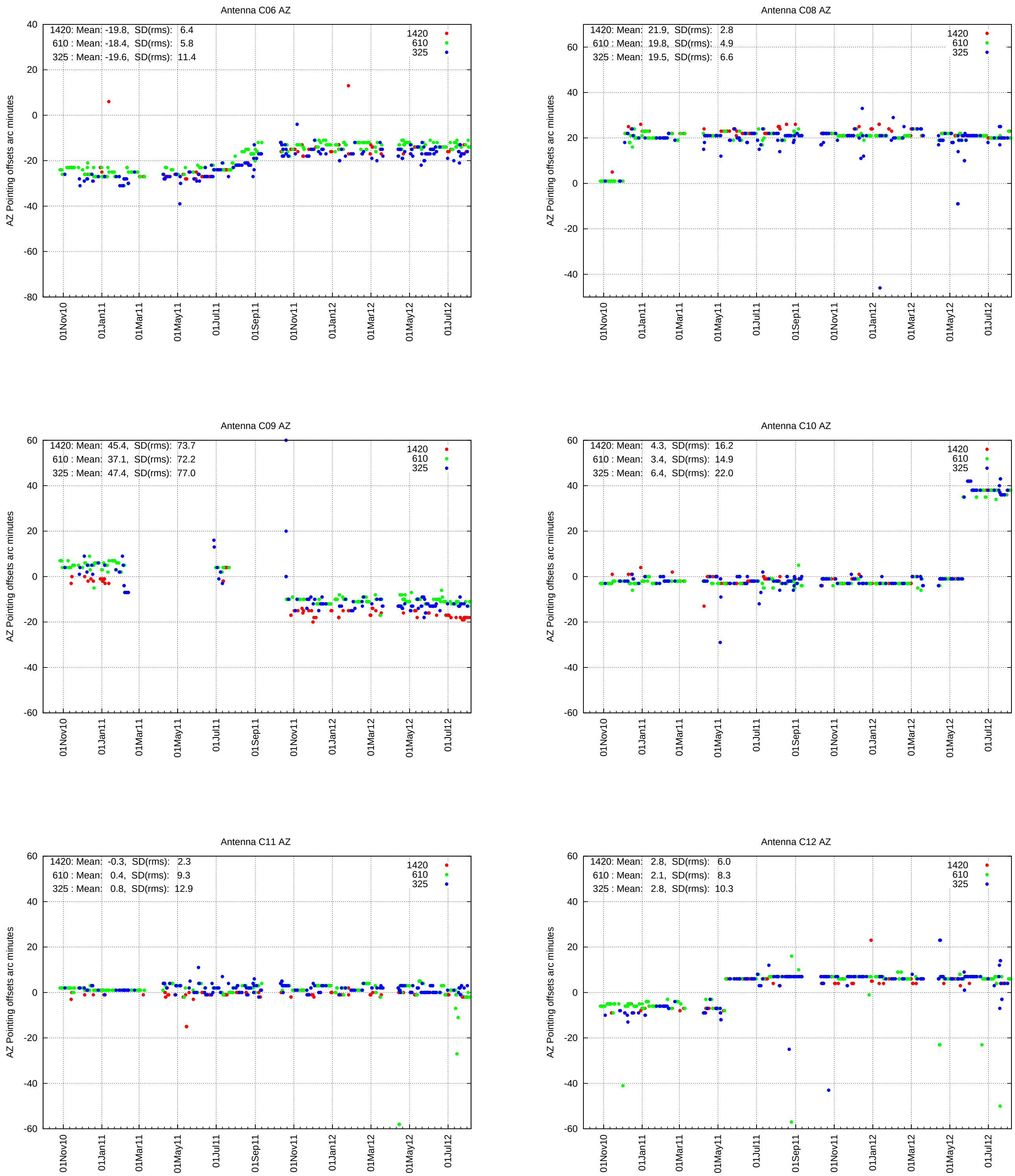

Figure 2: **Azimuth** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

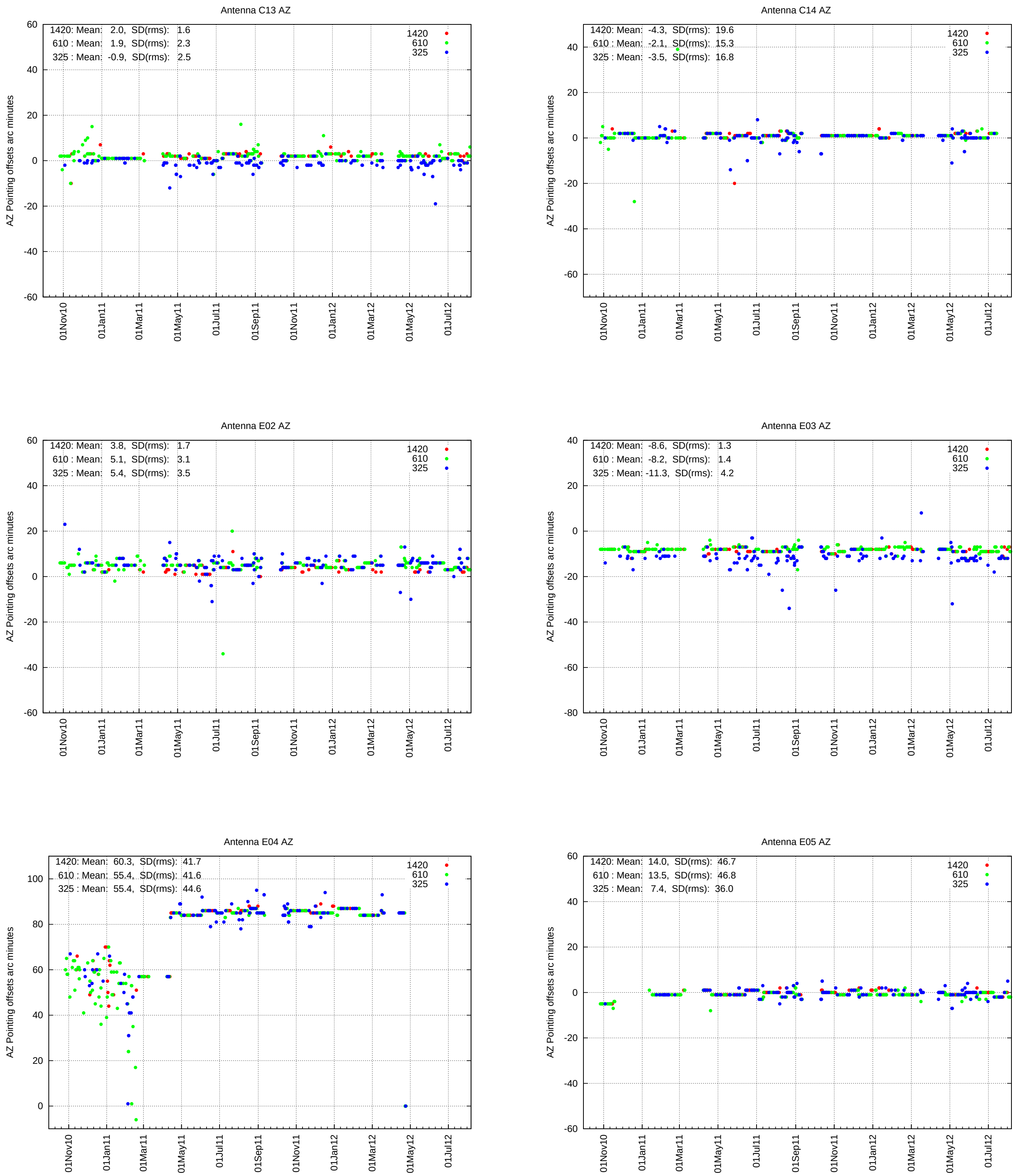

Figure 3: **Azimuth** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

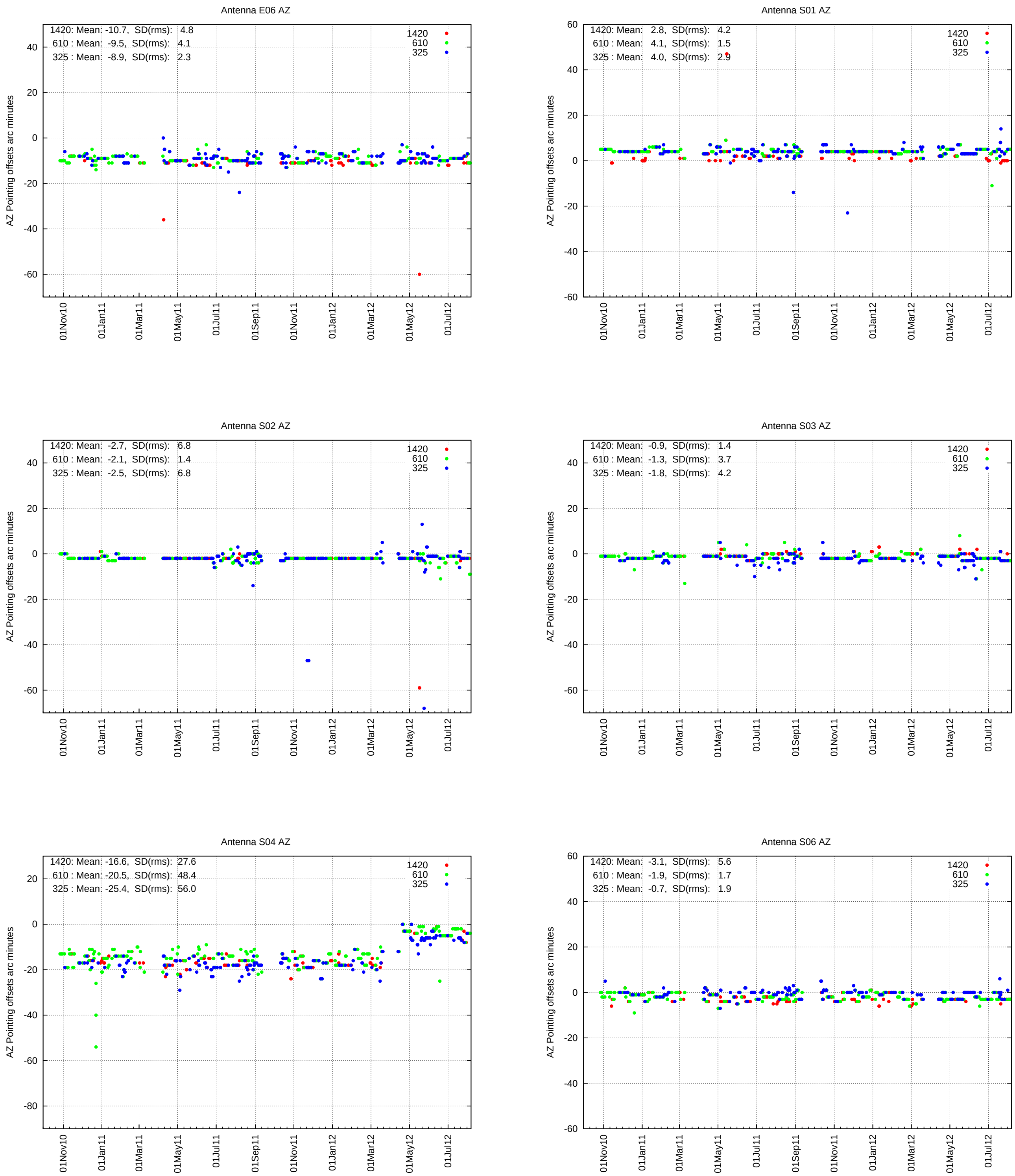

Figure 4: **Azimuth** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

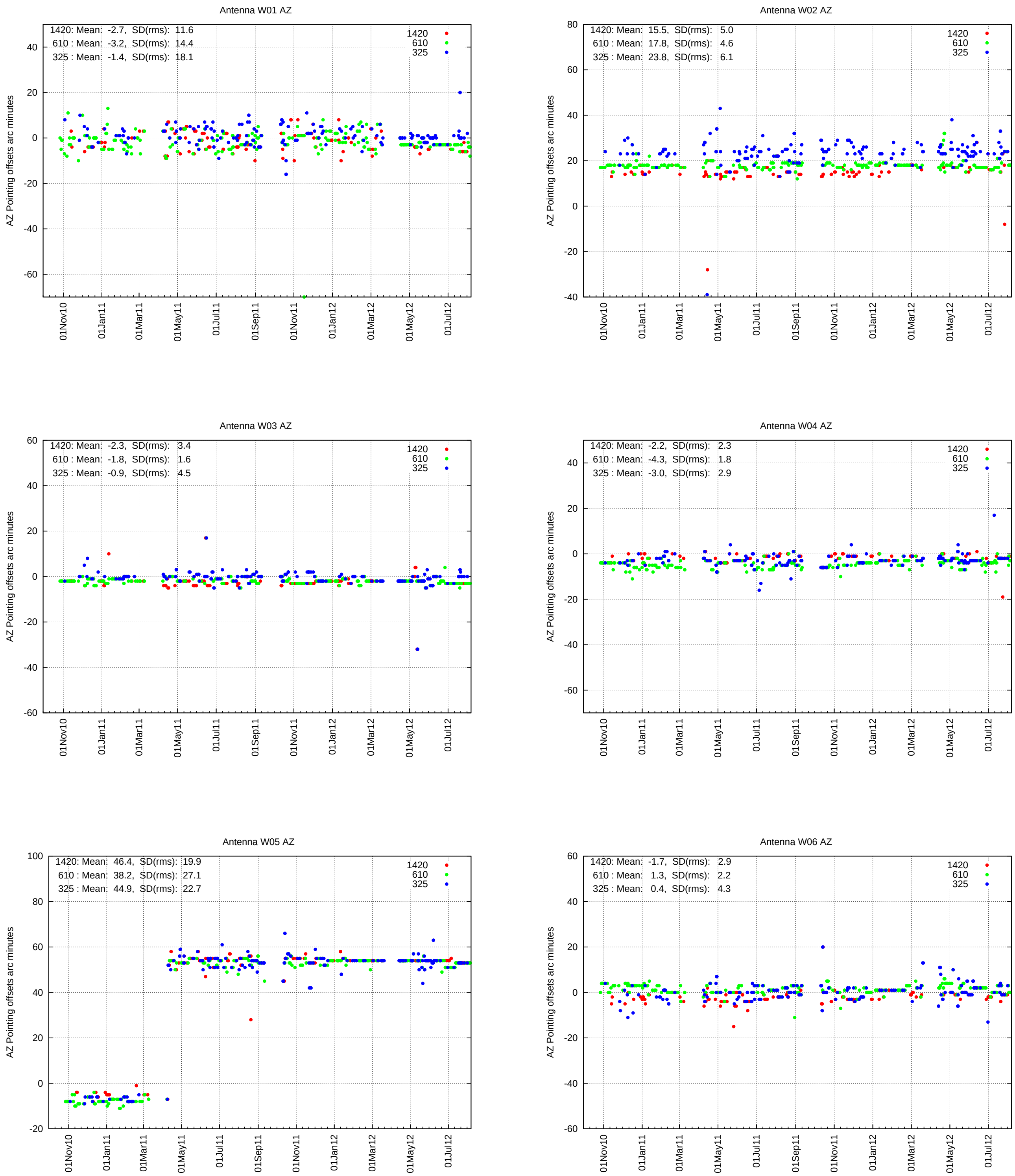

Figure 5: **Azimuth** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

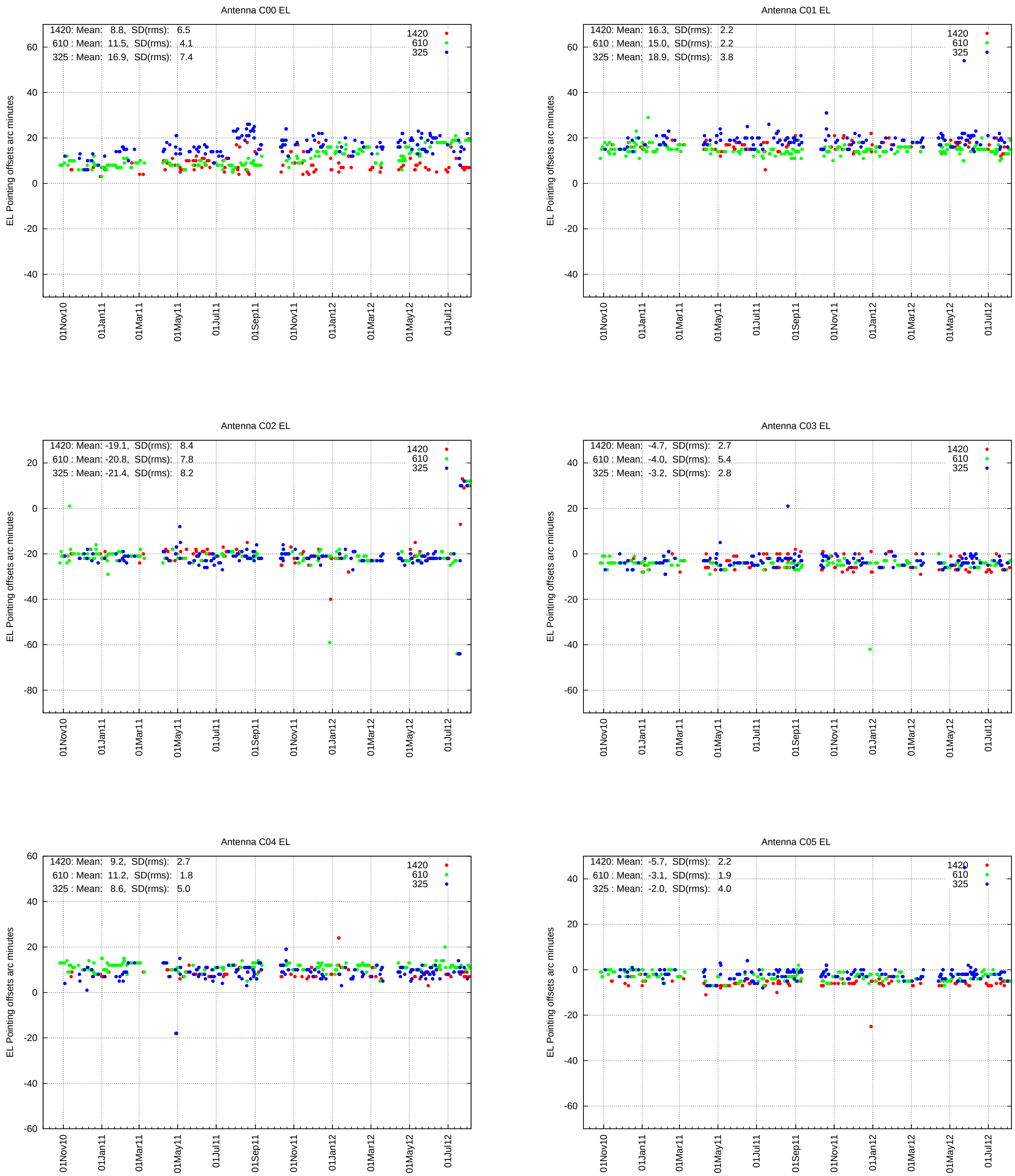

Figure 6: **Elevation** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

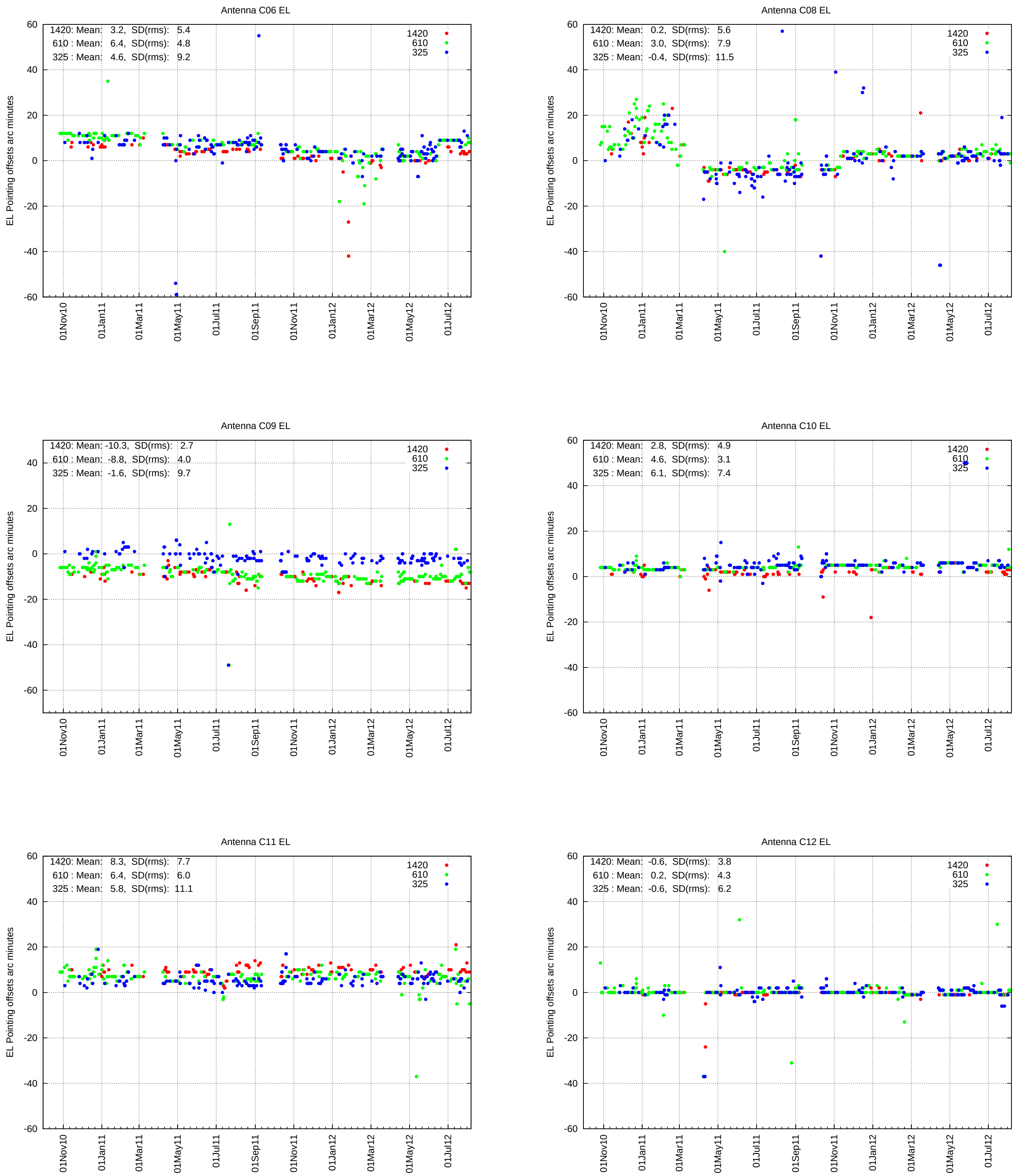

Figure 7: **Elevation** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

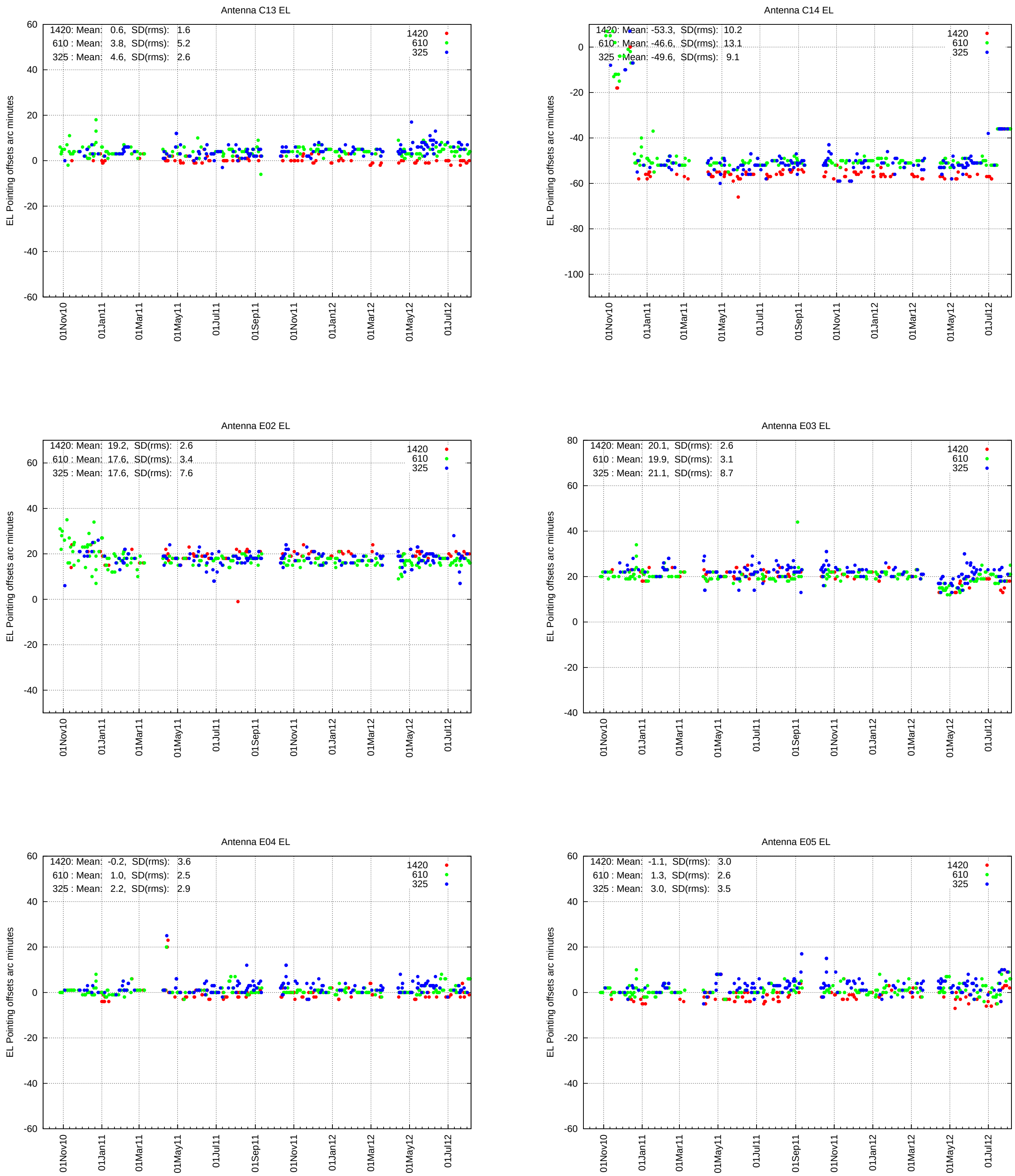

Figure 8: **Elevation** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

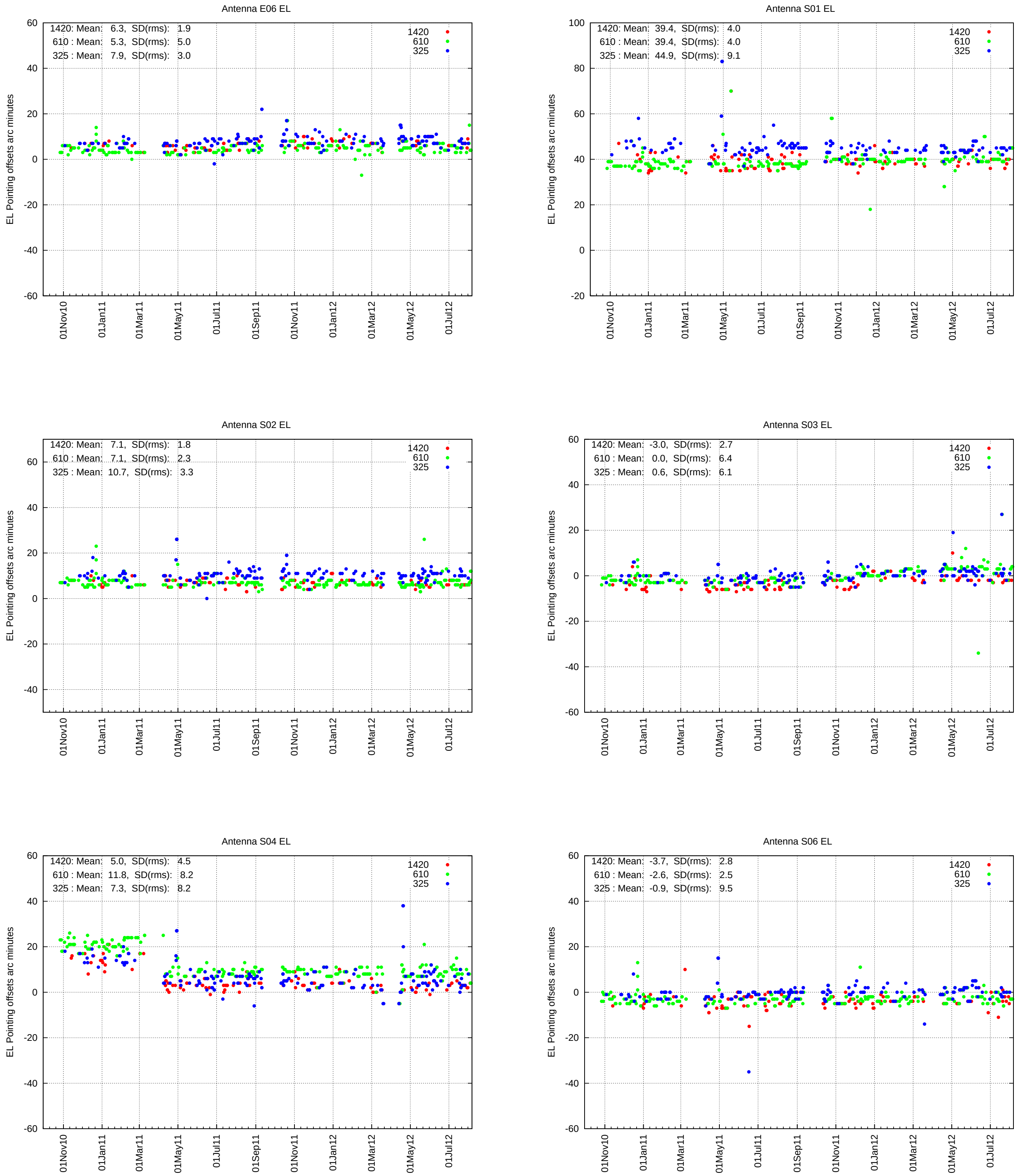

Figure 9: **Elevation** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

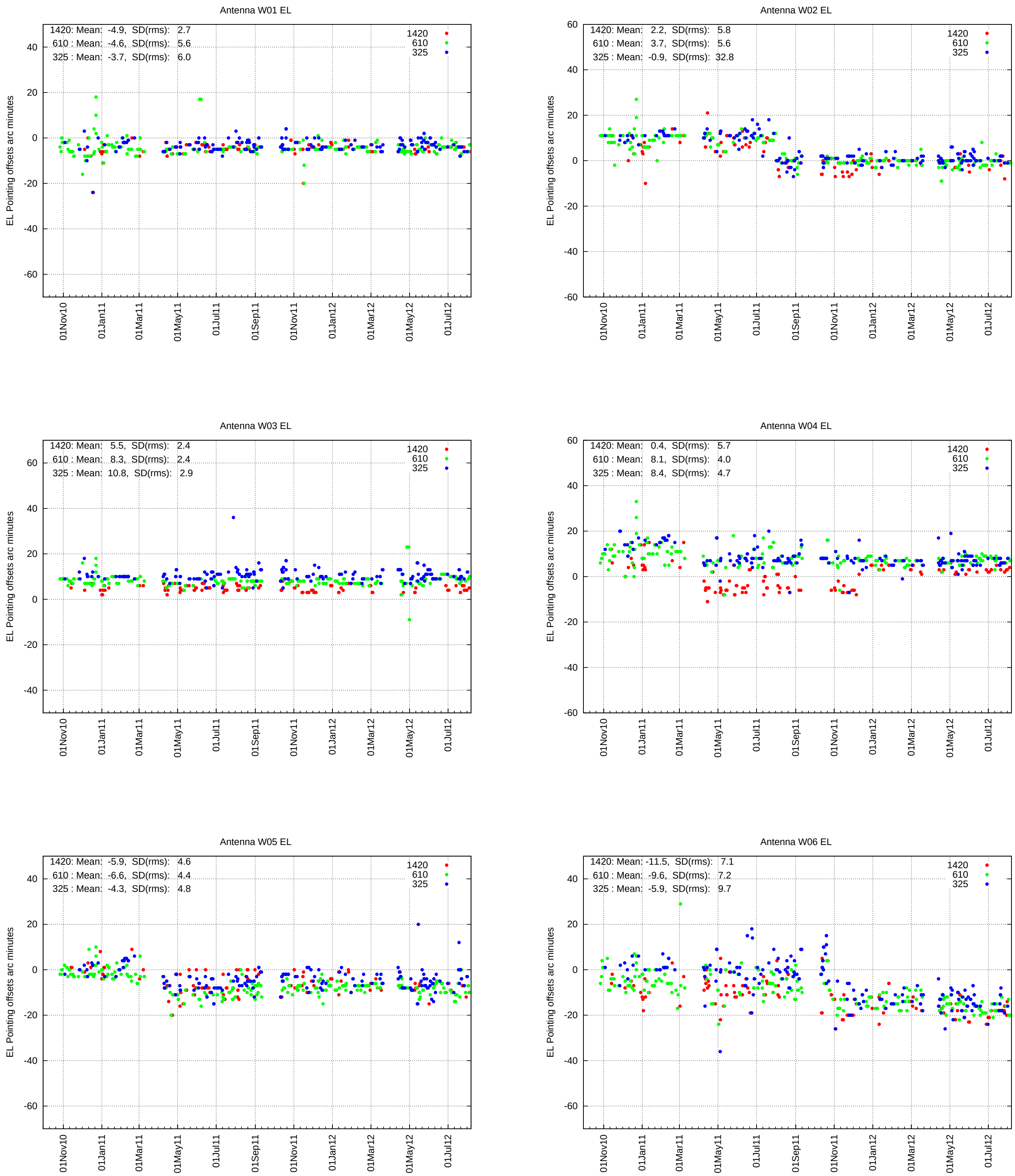

Figure 10: **Elevation** Pointing offsets for different GMRT wavebands from October 2010 till August 2012. Red points are offsets seen at 1420 MHz, green at 610 MHz and blue is for 325 MHz. The scale on the y-axis is same for all the panels.

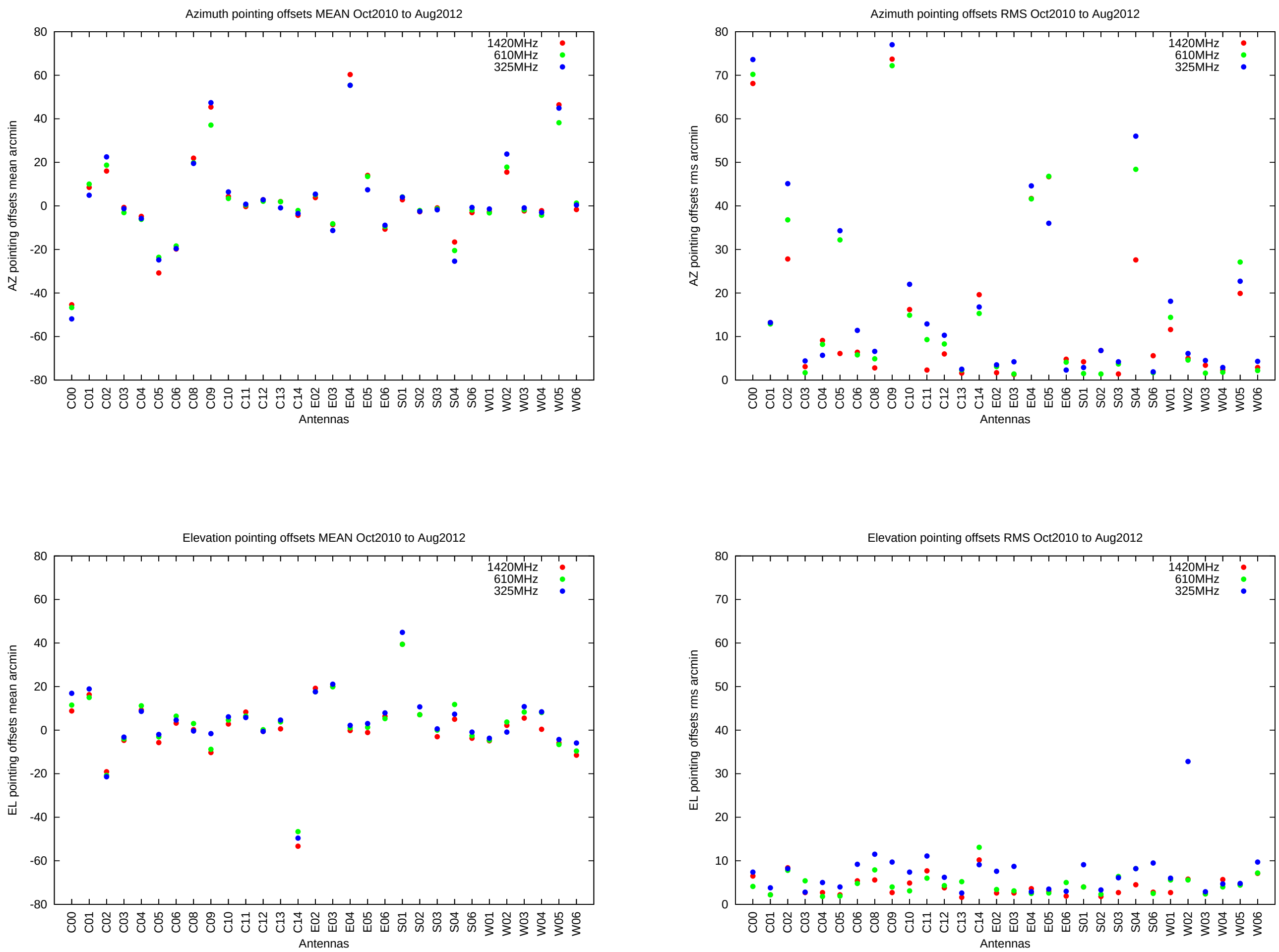

Figure 11: The **mean** and **rms** estimated from the pointing offsets recorded over a two year period from October 2010 to August 2012 for the 30 antennas are shown here. Top panels show the mean and rms of the azimuth pointing offset measurements and the bottom panels shows the same for the elevation pointing offsets. In all the panels, the red symbol is for 1280 MHz data, green symbol is for data recorded at 610 MHz and blue symbol is for data recorded at 325 MHz.

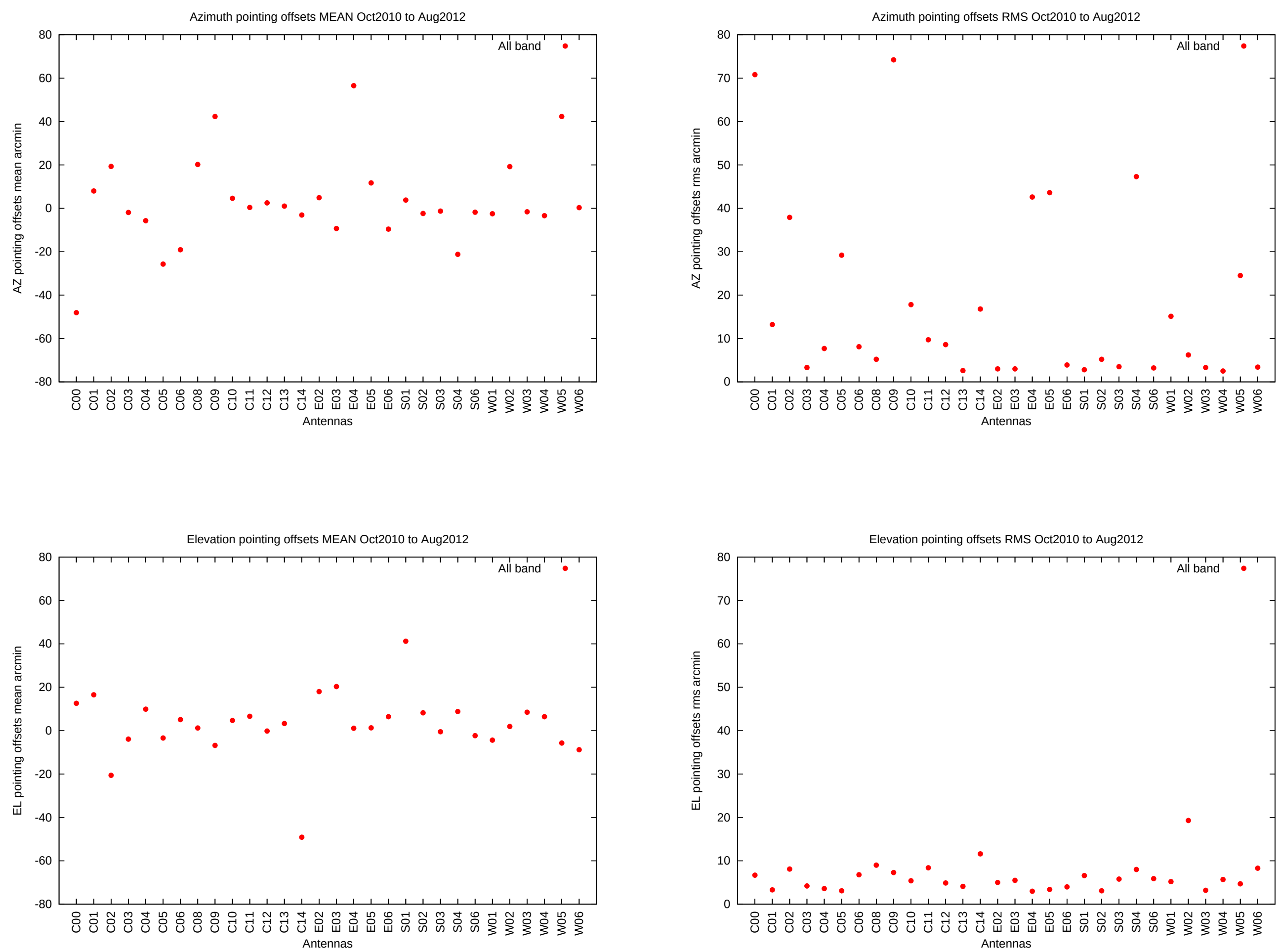

Figure 12: The **mean** and **rms** estimated from the pointing offsets recorded over a two year period from October 2010 to August 2012 for each antenna are shown here. Top panels show the azimuth pointing offsets and the bottom panels show the same for the elevation pointing offsets. The scale on the y-axis for both the plots is similar to enable quick comparison. Note the larger standard deviation on the azimuth pointing offset measurements as compared to the elevation pointing offset measurements. The data from all the bands have been used here.

measured at 610 MHz seems to show a gradual change since October 2011 and a bunch of measurements at 325 MHz seem to be clustered at a different mean offset in August 2011. In short, this antennas is a problem antenna and needs attention.

C01 *Azimuth:* This antenna shows different means for different wavebands in addition to a jump in the mean by about 20' which was recorded in mid-October 2011. The antenna offset oscillates between lower standard deviation (e.g. between January 2012 and March 2012) and larger standard deviation (e.g. between April 2012 to October 2012). The azimuth pointing of this antenna needs to be looked into since it has shown peculiar behaviour in the last two years. *Elevation:* Shows a shift in the mean offset with waveband but otherwise has stable pointing.

C02 *Azimuth:* This antenna shows a peak-to-peak scatter in the azimuth offset measurement of 20' till April 2012 when the scatter appears to reduce to less than 5' and the mean values have been made close to 0'. This is likely due to mechanical measures. *Elevation:* C02 showed a sudden change in the mean offset of magnitude $\sim 45'$ in July 2012.

C03 *Azimuth:* This antenna has well-behaved azimuth offsets which do not change systematically over time. A slight shift in the measured offset with waveband is visible. *Elevation:* C03 is one of the reasonably good antennas in the last two years. As shown in Figure. 13, there appears to have been a change of 5' in its elevation pointing offset in the last two years.

C04 *Azimuth:* This antenna showed well-behaved azimuth pointing offset till around August 2011. The azimuth offsets in August 2011 show two important changes - the scatter in the measurements increases to about 10' and the mean offset changes by about 10'. This antenna demonstrates that the cause of the abrupt change in the mean value and the increased standard deviation of the measurements is likely the same. This antenna needs to be studied and corrected. *Elevation:* C04 has shown stable elevation pointing offset over the last two years.

C05 *Azimuth:* This antenna showed a large peak-to-peak variation of about 20' in the measurements till April 2011. As shown in Fig. 13, this antenna has shown about three jumps in the last two years - the problem was resolved by the mechanical team in April 2011 (private communication), after that the mean value and standard deviation have reduced and no abrupt changes in the mean offset have been recorded. Stable since then. *Elevation:* C05 shows stable offset over the last two years.

C06 *Azimuth:* This antenna shows gradual change from a mean azimuth offset of about $-25'$ to $-15'$ in July-September 2011 before the maintenance break. After maintenance there seems to be no change in the mean value. It will be useful to investigate what can cause such continuous change in the mean azimuth offset of the antenna. *Elevation:* C06 shows a peculiar variation in the elevation pointing offset over the last two years. The mean offset is constant from October 2010 to March 2011 and then the offset seems to show a gradual change till September 2011 when there is a maintenance break. There is an abrupt change in the mean value in October 2011 followed by several outlier measurements in Feb-March 2012. After the maintenance break in March/April 2012, the measured offset appears to be steady till end May 2012 and then the gradual variation in the mean offset is noticed to set in again at all the wavebands. Several small discrete changes in the measured offset values would appears as a gradual change in the mean offset.

C08 *Azimuth:* This antenna recorded a jump in the mean azimuth offset of about 20' in December 2010 but appears to show a stable behaviour after that. *Elevation:* The elevation offset measurements of C08 show a not-so-normal behaviour. It shows a large scatter in the measurements from October 2010 to March 2011. There appears to have been a sudden change in the elevation offset after maintenance break in April 2011 and the scatter in the measurements appear to have reduced since then. Its not clear if this is due to mechanical work on the antenna. However since April 2011 till now a constant mean pointing offset is recorded at all the bands.

C09 *Azimuth:* This antenna has been one of the worst-behaved antennas along azimuth. Several abrupt changes in the mean azimuth pointing by large offsets were recorded between October 2010 and August 2012. First time was in February 2011 when a jump of about 120' was recorded. Another large magnitude change in the mean offset was recorded in early July 2011. The mechanical team made some repairs to the azimuth system of this antenna in July (private communication). And this likely corrected the large mean offset resulting in a variation of about 170' in the mean value recorded in end-July 2011. A jump of similar magnitude in October 2011 was recorded. Since then the antenna has maintained a steady behaviour. *Elevation:* A change in mean pointing offset of about 7' is recorded in August 2011. as seen in Fig. 7. While the 610 and 1420 MHz offsets are similar (means $\sim -10.6'$ and $\sim 11.0'$ respectively), the offsets measured at 325 MHz is different with a mean of -2.7. Otherwise the pointing seems to be stable.

C10 *Azimuth:* This antenna showed a steady behaviour from October 2010 till May 2012 when the mean azimuth offset jumped by about 40' and has been constant since then. *Elevation:* Overall the elevation pointing for C10 shows stable behaviour.

C11 *Azimuth:* This antenna shows steady behaviour for the azimuth pointing offset although the standard deviation of the offset measurements is larger for 325 MHz as compared to 1420 MHz. *Elevation:* The antenna shows reasonably stable behaviour. There appears to be an increased number of outlier measurements since April 2012 but further monitoring data is required to confirm this or to make it a statistically significant effect.

C12 *Azimuth:* This antenna showed a sudden change in its mean pointing offset by about 12' in May 2011. Otherwise the antenna appears to show steady behaviour. *Elevation:* No major problems are visible in the elevation offset over the last two years. The standard deviation of the measurements also seems to be smaller than for example, C11 although there appear to be a larger number of outliers. It would be useful to study this in more detail once other problems are understood and resolved.

C13 *Azimuth:* This antenna shows steady behaviour for the azimuth pointing error with a standard deviation $\leq 2.5'$ over the two years of data recording. *Elevation:*The elevation pointing offset appears to exhibit stable behaviour over the last two years. The three wavebands have different mean pointing offsets which might be indicative of the turrent positioning - feed positioning system.

C14 *Azimuth:*This antenna shows fairly good behaviour till July 2012 when it shows a sudden jump in the mean azimuth offset of about $-75'$. This is followed by another jump in the opposite direction in August 2012 which brings it back to its earlier mean value. *Elevation:* This antenna has shown four abrupt changes in the mean pointing offset over the last two years as listed in Figure. 13, with the last being in August 2012. The magnitude of the variation varies from 10' to 40'. The elevation encoder was replaced by the mechanical team in May 2012 (private communication).

E02 *Azimuth:* E02 shows stable performance for the azimuth pointing offset. *Elevation:* A large scatter in the pointing offset measurements is recorded from October 2010 to December 2010. The scatter has dropped after that and the antenna shows stable pointing behaviour. For completion, we note that E02 had a problem where its mean elevation pointing offset would change when the antenna crossed the local meridian so that offsets were different for before or after transit of a source.

E03 *Azimuth:* E03 is a reasonably stable antenna as regards azimuth pointing offset. The measurements at L band and 610 MHz bands have very good standard deviation $\sim 1.2'$ whereas at 325 MHz, the standard deviation is 4'. For some reason, the pointing offsets measured at 325 MHz show more than double the standard deviation at the other two bands. *Elevation:* In April 2012 (maintenance month), an abrupt change in the pointing by about 5' was recorded at all the wavebands. However around June 2012, the offsets have changed and reverted back to the earlier mean values.

E04 *Azimuth:* This antenna showed a large peak-to-peak scatter of $\sim 30'$ upto March 2011. The mechanical team did some shaft work on it in April 2011 (private communication) which corrected the problem and the scatter came down. However the antenna showed a sudden jump of about 25' in the mean azimuth offset in April 2011. Another sudden change the mean azimuth offset by about 100' was seen around April 2012. This antenna needs to be carefully examined. *Elevation:* No major change is seen in the elevation pointing offset.

E05 *Azimuth:*This antenna showed a sudden change in the mean azimuth pointing offset by about 165' in November 2010 and then another jump by about $-165'$ January 2011. Since then it has maintained a steady behaviour. *Elevation:* As seen in Fig. 8, the antenna appears to show an abrupt change of 10' in the elevation pointing offset in July 2012.

E06 *Azimuth:* This antenna shows a stable mean azimuth pointing offset. *Elevation:* The elevation pointing offset does not show deviant behaviour. Overall, a stable antenna.

S01 *Azimuth:* This antenna shows a stable mean azimuth pointing offset. However a slight shift in the mean azimuth offsets recorded at the three wavebands is noticeable. *Elevation:* The mean pointing offset at 325 MHz is different by more than 5' compared to that recorded for the 610 and 1420 MHz. Also the mean offset recorded at 325 MHz seems to be gradually changing over the last two years whereas it seems to be the same at the other two wavebands.

S02 *Azimuth:* This antenna shows stable mean azimuth pointing offset over the last two years with the standard deviation of 1.4' at 610 MHz. A few deviant points are noticeable. The scatter seems to have increase in two short bursts during the last two years. It will be useful to check the cause of this. *Elevation:* The elevation pointing offset recorded for S02 shows no major problems in the last two years. Occasionally deviant points are recorded. Overall shows stable pointing characteristics.

S03 *Azimuth:* Good pointing stability. The standard deviation recorded at L band is 1.4' over the last two years. *Elevation:* Reasonably good pointing stability. However does seem to have shown a small change in the mean offset in Dec 2011.

S04 *Azimuth:* This antenna showed an abrupt change of about 300' in the mean azimuth pointing offset in April 2012. The scatter on the pointing offsets is quite large and the antenna shows mean azimuth pointing error differing by about 5' at the three wavebands. This antenna needs to be examined. *Elevation:* A sudden change of about 20' in the mean offset was noted in April 2011 after the maintenance break. Since then the antenna has shown stable behaviour. The range of the offset values recorded is large with a standard deviation at 610 and 325 MHz of 8'.

S06 *Azimuth:* A well-behaved antenna. Different mean azimuth pointing offsets for the three wavebands. *Elevation:* No sudden jumps are visible in the offsets and overall the antenna shows stable pointing behaviour.

W01 *Azimuth:* This antenna shows a large standard deviation ($> 10'$) in the azimuth offset measurements. No sudden jumps are seen in the mean azimuth offset. Since April 2012, the scatter in the measurements has been reduced. However the mean offsets for different wavebands appear to be slightly different. *Elevation:* No major problems are recorded for this antenna. The scatter on the measurements has reduced following the maintenance break in April 2011,

W02 *Azimuth:* This antenna shows a standard deviation of $> 5'$ on the measurements. The mean offsets recorded for the 1420, 610 and 325 MHz bands differ by more than 5'. However no abrupt changes in the mean offset are recorded. *Elevation:* A sudden change in the mean elevation pointing offset by about 10' was noted in August 2011. Since then the offset has been stable.

W03 *Azimuth:* This antenna shows stable behaviour in the last two years. *Elevation:* Well behaved elevation pointing offsets with a standard deviation of $\sim 2.5'$ at all the three wavebands.

W04 *Azimuth:* This antenna shows stable pointing. *Elevation:* The elevation pointing offset measurements show a strange behaviour as seen in the Figure. Several abrupt changes in the mean pointing offset are recorded. Since April 2012, the pointing behaviour seems to have stabilised.

W05 *Azimuth:* A sudden jump of about 60' in the mean azimuth pointing offset was seen in April 2011. Since then the mean value of the offset appears to be stable. *Elevation:* The elevation pointing of this antenna also shows strange behaviour. A few abrupt changes in the mean value of the offset are noted in the last two years. The standard deviation at all the wavebands is about 5'.

W06 *Azimuth:* This antenna shows reasonably stable offset behaviour in the last two years. *Elevation:* The elevation pointing of this antenna also shows a strange behaviour in the last two years. Better and stable characteristics are observed since November 2011 after the mechanical team fixed the encoder (private communication).

5 Final remarks

- As shown in Figs. 11, 12, the rms scatter on the measurements of the elevation pointing offset is lower than on the measurements of the azimuth pointing offsets. As listed in the last column of Tables 1 and 2, 12 antennas show a scatter $> 10'$ in the azimuth pointing offset measurements whereas only two antennas show such a large scatter in the elevation pointing offset measurements. Note that this scatter includes measurements at all bands and any abrupt change in the mean offset value. As listed in the Tables, 17 antennas show a $> 5'$ rms scatter in elevation pointing offsets whereas 19 antennas show such standard deviation for azimuth pointing offsets. Out of these, C00, C02, C06, C08, C09, C10, C11, C14, S04, W01 and W02 are common.

- The mean azimuth offsets measured at the three wavebands (L band, 610 MHz, P band) differ by $\geq 5'$ for 9 antennas and the mean elevation offsets differ by $\geq 5'$ for 8 antennas. While mean azimuth pointing offset for 16 antennas match within 2' for the different wavebands; only five antennas show a similar match for the elevation pointing offset. Since the feeds are mounted on a turret which rotates on an axis parallel to the elevation axis, different mean elevation offset values for different wavebands are understandable. However it is difficult to understand the different mean azimuth offsets measured for the different wavebands.

- In the last two years, 17 antennas have shown one or more abrupt change in the mean azimuth pointing offset by several arcminutes and 16 antennas have shown such abrupt change in its elevation pointing offset. Interestingly, the magnitude of the largest changes are $> 100'$ for the mean azimuth pointing offset shown by C00, C02, C09, E05, S04 and W01 whereas the largest change seen in the mean elevation pointing offset is only 40'-50' shown by C14 and S01. C10, C14, E04 and W05 show a change between 40' and 80' in their mean azimuth pointing offset.

- As listed in the table (Fig. 13), there are many antennas which show good pointing behaviour with no change ($\leq 2'$) in the mean pointing offset in the last two years. In elevation, these antennas are: C04, C05, C11, C12, C13, E04, S02, W01, W03. In azimuth, these antennas are: C11, C13, E02, E03, E06, S01, S02, S03, W03, W06. There are a few antennas which show a gradual change ($> 2'$) in the mean pointing offset over the last two years without recording any abrupt change in the mean value. In elevation, these antennas are: C01, C10, E03, S03, S06. In azimuth, such behaviour is displayed by the following antennas: C03, S06, W04. All these antennas show stable pointing behaviour indicating sound mechanical structure and encoder. The seven antennas which display no abrupt change in the pointing along either axes in the last two years are: C11, C13, E03, S02, S03, S06, W03.

- In this report, we have used the online data monitoring tools described in Katore & Kantharia (in preparation) and activated in 2010 to study the behaviour of the antenna pointing offsets over the last two years. Antennas show a range of behaviours ranging from no change to several undesirable changes in the measurements over the last two years. This compilation of results is crucial in characterising the antenna pointing and an important step towards understanding and resolving them.

- As next steps, (1) we plan to derive the next generation pointing model which includes terms which bear direct relation to the mechanical structure of the antenna. The current implementation of the pointing model (Roy & Kulkarni 2009) gives a mathematical fit to the observed pointing data and has been able to help correct the variation in pointing as a function of elevation and azimuth. Howevera a pointing model similar to what was explored before this by Kantharia (2008) and Kantharia, Kulkarni & Nityananda (2009) is required to be able to understand the behaviour in terms of the structural properties of the GMRT antennas. (2) using the results presented in this report, a discussion with the mechanical group will help attack the problematic antennas from both the astronomical and engineering perspectives and generate long term solutions. We note that some of the problematic antennas have already been understood and corrected by the mechanical team. (3) provide more powerful statistical and plotting tools for further characterising of the antenna pointing.

6 Acknowledgements

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7 References

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8 Appendix A - Possible explanation of different features

- *Large scatter in measurements* - Many GMRT antennas show a large standard deviation on the pointing offset measurements. A possible reason for this could be the following: A change in the pointing offset especially elevation pointing offset is noticed when the antenna crosses the local meridian as noticed by several colleagues and shown in Kantharia et al. 2009 and Roy & Kulkarni 2009. The meridian crossing

EL OFFSET JUMPS

ANT	Date	OFFSET (arc-min)
C00	Oct 27, 2010	8
	Sep 9, 2011	17
	Nov 3, 2012	21
C01	Oct 27, 2010	11
	Nov 3, 2012	18
C02	Oct 27, 2010	-24
	Jul 21, 2012	10
	Nov 3, 2012	12
C03	Oct 27, 2010	-4
	Oct 12, 2012	5
	Nov 3, 2012	5
C04	Oct 27, 2010	13
	Nov 3, 2012	13
C05	Oct 27, 2010	-1
	Nov 3, 2012	-3
C06	Oct 27, 2010	12
	Oct 14, 2011	1
	Jun 17, 2012	9
	Nov 3, 2012	10
C08	Oct 27, 2010	7
	Feb 4, 2011	25
	Apr 10, 2011	-5
	Nov 21, 2011	1
	Nov 3, 2012	4
C09	Oct 27, 2010	-6
	Aug 4, 2011	-13
	Oct 11, 2011	-3
	Nov 3, 2012	-10
C10	Oct 27, 2010	4
	Nov 3, 2012	8
C11	Oct 27, 2010	9
	Nov 3, 2012	8
C12	Oct 27, 2010	0
	Nov 3, 2012	1
C13	Oct 27, 2010	6
	Nov 3, 2012	6
C14	Oct 27, 2010	5
	Nov 4, 2010	-8
	Dec 12, 2010	-47
	Jul 15, 2012	-36
	Aug 24, 2012	-53
	Nov 3, 2012	-50

ANT	Date	OFFSET (arc-min)
E02	Oct 27, 2010	31
	Nov 13, 2010	23
	Jan 2, 2011	19
	Nov 3, 2012	17
E03	Oct 27, 2010	20
	Nov 3, 2012	16
E04	Oct 27, 2010	0
	Nov 3, 2012	-2
E05	Oct 27, 2010	0
	Jul 22, 2012	10
	Nov 3, 2012	8
E06	Oct 27, 2010	3
	May 28, 2012	10
	Nov 3, 2012	9
S01	Oct 27, 2010	36
	May 19, 2011	42
	Nov 3, 2012	44
S02	Oct 27, 2010	7
	Nov 3, 2012	6
S03	Oct 27, 2010	-4
	Nov 3, 2012	5
S04	Oct 27, 2010	23
	Apr 9, 2011	4
	Nov 3, 2012	7
S06	Oct 27, 2010	-4
	Nov 3, 2012	0
W01	Oct 27, 2010	-4
	Nov 3, 2012	-5
W02	Oct 27, 2010	11
	Aug 7, 2011	1
	Nov 3, 2012	1
W03	Oct 27, 2010	9
	Nov 3, 2012	10
W04	Oct 27, 2010	6
	Jan 10, 2011	17
	Mar 9, 2011	8
	Nov 24, 2011	-7
	Dec 9, 2011	8
	Nov 3, 2012	6
W05	Oct 27, 2010	-2
	May 1, 2011	-11
	Oct 13, 2011	-3
	Jul 7, 2012	-10
	Nov 3, 2012	3
W06	Oct 27, 2010	-6
	Nov 7, 2011	-17
	Nov 3, 2012	-22

AZ OFFSET JUMPS

ANT	Date	OFFSET (arc-min)
C00	Oct 27, 2010	-11
	Apr 13, 2012	-114
	Apr 20, 2012	-177
	Sep 5, 2012	5
	Nov 3, 2012	4
C01	Oct 27, 2010	-2
	Oct 16, 2011	20
	Nov 3, 2012	26
C02	Oct 27, 2010	19
	Sep 11, 2011	15
	Apr 13, 2012	237
	Apr 19, 2012	2
	Nov 3, 2012	3
C03	Oct 27, 2010	-3
	Nov 3, 2012	2
C04	Oct 27, 2010	1
	Aug 22, 2011	-10
	Nov 3, 2012	-9
C05	Oct 27, 2010	-28
	Feb 3, 2011	-13
	Mar 8, 2011	-28
	May 5, 2011	-34
	Nov 3, 2012	-29
C06	Oct 27, 2010	-24
	Jan 30, 2011	-31
	Aug 25, 2011	-17
	Nov 3, 2012	-18
C08	Oct 27, 2010	1
	Dec 5, 2010	22
	Nov 3, 2012	22
C09	Oct 27, 2010	7
	Feb 7, 2011	-7
	Feb 12, 2011	120
	Jun 30, 2011	4
	Jul 22, 2011	170
	Oct 20, 2011	-10
	Nov 3, 2012	-10
C10	Oct 27, 2010	-3
	May 29, 2012	42
	Nov 3, 2012	37
C11	Oct 27, 2010	2
	Nov 3, 2012	2
C12	Oct 27, 2010	-6
	May 13, 2011	6
	Nov 3, 2012	6
C13	Oct 27, 2010	2
	Nov 3, 2012	2

ANT	Date	OFFSET (arc-min)
C14	Oct 27, 2010	-2
	Nov 18, 2010	2
	Jul 15, 2012	-75
	Aug 13, 2012	-2
	Nov 3, 2012	0
E02	Oct 27, 2010	6
	Nov 3, 2012	5
E03	Oct 27, 2010	-8
	Nov 3, 2012	-9
E04	Oct 27, 2010	60
	Apr 13, 2011	83
	Apr 25, 2012	-21
	Nov 3, 2012	-22
E05	Oct 27, 2010	-5
	Nov 27, 2010	162
	Jan 17, 2011	-1
	Nov 3, 2012	-1
E06	Oct 27, 2010	-10
	Nov 3, 2012	-9
S01	Oct 27, 2010	5
	Nov 3, 2012	4
S02	Oct 27, 2010	0
	Nov 3, 2012	0
S03	Oct 27, 2010	-1
	Nov 3, 2012	-2
S04	Oct 27, 2010	-13
	Mar 3, 2011	-19
	Apr 15, 2012	-320
	Apr 22, 2012	-3
	Nov 3, 2012	-3
S06	Oct 27, 2010	0
	Nov 3, 2012	-3
W01	Oct 27, 2010	0
	Apr 13, 2012	-112
	Apr 16, 2012	0
	Nov 3, 2012	-2
W02	Oct 27, 2010	17
	May 24, 2012	24
	Nov 3, 2012	18
W03	Oct 27, 2010	-2
	Nov 3, 2012	-4
W04	Oct 27, 2010	-4
	Nov 3, 2012	10
W05	Oct 27, 2010	-8
	Apr 10, 2011	52
	Nov 3, 2012	54
W06	Oct 27, 2010	0
	Nov 3, 2012	2

Figure 13: The table in the figure lists the antenna and dates on which these antennas suffered a sudden change in the measured mean offset. The table shows the antenna, dates on which the abrupt change was recorded and the magnitude of the mean offset on that date for both the elevation and azimuth axes. Thus, the difference between this and the previous value of the offset gives the magnitude of the change. These data were recorded between 27 October 2012 to 3 November 2012. All the antennas, thus, show an entry for both these dates which are listed in black and retained as reference values. The good antennas are where both these entries show similar values. The red entries in the table show the sudden changes in the mean offset recorded for the particular antenna.

leads to the elevation of the source decreasing and the elevation motors reversing the motion of the antenna. Most antennas show a change of a few arcminutes due to this reason - however there are antennas which show a large change. Thus, depending on when the pointing procedure was done, this effect can lead to a resultant large scatter in the measurements. The large scatter $> 5' - 10'$ antennas possibly show this jump and need to be examined and fixed.

- *Abrupt change in pointing* Many antennas show a sudden change in the mean pointing offset at a certain epoch as shown in Figs. 1 to 10. This also appears to be associated with a change in the standard deviation of the measurements. Such problems have been fixed by the mechanical team as seen for a few antennas shown in the Figures and is thus understood. Some antennas have shown multiple jumps such as C09 azimuth pointing. This is likely due to a faulty encoder system.

- *Standard deviation- a function of waveband* The standard deviation for each band is given in Table 1 and 2. These are also listed in the top left corner of the figure panels. The different bands show different values - while in many cases the largest deviation is at P band and lowest at L band which is likely due to the different accuracy of measurements, in some cases, the change is not so straightforward and needs to be examined.

- *Small standard deviation* These are good antennas. The low values indicate that they have do not show a change in the pointing of the antenna near 0h hour angle nor any other instability. These should also be studied and compared to the not-so-good antennas to help understand any glaring differences.

9 Appendix B - Correlating with inputs from mechanical group

Here we list some of the antennas where a change recorded in the pointing offset plot correlates with intervention by the mechanical group. This is an example list and not exhaustive. The latter needs to be jointly done by the astronomers working on understanding the antenna pointing and the mechanical engineering team.

- **C05 azimuth:** This antenna showed severe problems in the azimuth pointing offset - ranging from a large change during an observation to a large scatter in the measurements. Around May 2011, the azimuth pointing of the antenna became stable. The mechanical group had done azimuth shaft assembly work in April 2011 which seems to have resolved this problem.

- **C04 azimuth:** The azimuth encoder was installed in July 2011. The antenna showed a sudden change in the mean offset in August 2011 and the scatter on the measurements also seemed to increase after that.

- **C01 azimuth:** The azimuth encoder was replaced in October 2011. which caused the antenna to record a jump in the mean offset at the time.

- **C02,W01 azimuth:** Both the antenna showed a large scatter in the pointing offset measurements. In March 2012, a new azimuth encoded assembly was installed by the mechanical team on both the antennas. Since then, the antenna pointing has improved considerably with the scatter reducing from a peak to peak variation of 15'-20' to less than 5'.

- **C14 elevation:** The pointing offset of this antenna showed a jump of about 50' in July 2012. The elevation encoder was replaced in May 2012 The antenna has shown considerable improvement in its pointing behaviour since July 2012.