Inclusion of an Axis-offset to Cambridge telescope data within e-MERLIN

e-MERLIN memo

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1. Introduction and motivation

In order to assess the phase referencing capabilities of the e-MERLIN array a series of long multi-phase calibrator observations have been undertaken. These observations have utilised a collection of 4 nearby vlbi phase calibrators around the polar cap region. During the analysis of these observations delay variations as a function of elevation angle have been noted on the Cambridge antenna. These elevation dependent delay errors have been diagnosed and attributed to an erroneous axis-offset of 0.0metres being applied to this antenna. The correct axis-offset value for Cambridge as measured by MAN is 1.503mm.

2. Effect and solution

The resultant effect of this erroneous axis offset is a cos(elev) dependent delay term being included in the data. In the process of standard e-MERLIN data reduction the time (and hence elevation) dependent delay is calibrated on an antenna basis using all calibration source scans. The result of this is that the delay values calibrated for nearby (similar elevation) calibrations source will correctly determine the delay on target fields. However a small residual error due to the axis offset remaining which is a function of the elevation differences between target and phase reference sources. This effect can be seen in the following figures.

Severity of the effect:

- For high elevation target sources the residual cos(elevation) dependent delay difference between target and phase is small and only effects the Cm data.
- Lower target elevations scans, and more distant target/phase calibrator scans will be more severely affected with the potential result of a loss of phase coherence on CM data.
- All non-Cm baselines are unaffected
- If target based phase self-calibration is possible (true for ALL L-band data and many C-band observations) phase residual error arising from these delay differences can be calibrated correctly.
- In the most extreme cases, faint target source with complex structure on CM baseline lengths (typically C-band) with low elevation observations (ie. Low declination) the initial phase coherence following initial delay and phase calibration can in some cases result in poor starting models for self-calibration. This can then have an effect on the resultant image reliability.

Corrections:

- Data observed Post 16th Feb 2015 have the correct axis offset applied in the online observing system. This can be checked by as a value of 1.503m should be applied and visible in the Antenna tables appended to these data.

- Pre- 16th Feb 2015 data are unlikely to have this correction applied online. These data can be corrected during offline processing using the AIPS task 'CLCOR'. The terms and inputs required for correction are listed below along with plots of the size of these corrections.

3. Observations and data set parameters

Observation	Start (UT)	Stop (UT)	Freq Ch1, IF1 (GHz)	Correlator set-up	Antennas	CM Offset	Sources	Notes
13 Jan 2015	0/12:16:44	01/11:00:00	4.8165	4*128MHz	KN, DE, PI, CM	NO	1927+739, 1803+784, 2007+777, 1749+7006	Lower culmination
16 Feb 2015	0/13:03:55	1/12:02:00	4.8165	4*128MHz	MKII, KN, DE, PI, CM	YES – 1503mm	1927+739, 1803+784, 2007+777, 1749+7006	Lower culmination
04 Mar 2015	0/01:02:17	01/01:02:00	4.8165	4*128MHz		YES – 1503mm	1927+739, 1803+784, 2007+777, 1749+7006	**Being processed**
01-04 Mar 2013					KN, De, Da, PI, CM		3C84	Long 3 day run **See last section only**

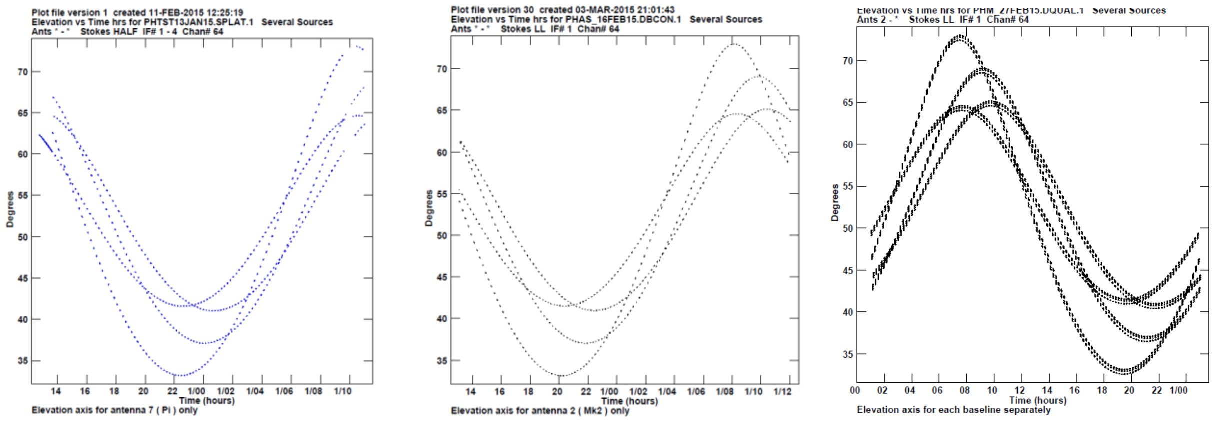

Figure 1: Elevation vs Time of observation. Left = 13Jan 2015, Middle = 16 Feb 2015, Right = 27 Feb 2015

4. Data processing steps applied

The basic data for all data followed these processing steps. **Note that CLCOR was only run on data observed before 16 Feb 2015 where the online axis-offset for Cambridge was not set.**

Data loaded, uvfixed, averaged (to 128chan/IF/pol), and concatenate data using pipeline – standard procedure.

1. STANDARD Data edited to remove time off source between scans.
2. CLCOR run on data to apply axis offset for CM. – **ONLY DATA BEFORE 16th February 2015**
   - `Task 'clcor';optyp 'anax';clcorprm = 1.503, 0;anten = 9;go clcor`

`Produce new CL table (CL2) including phase/delay/rate corrections for CM. Also edit AN table to include offset(see figure 3 and 4)`

3. FRING – fit for delay and phase only (no RATE)

- `Calsour '';bchan 10;echan 110;refant 7;docal 100;gainu 0`
- `Solint 10;`
- `Aparm 3 0 0 0 1 0 2.5 0`
- `Dparm 3 100 0 1 0 0 0 0 1 0`

`Produces SN1 (containing DELAY & Phase information)`

4. CLCAL – SN1 + CL2 = CL3
   - `Calsour '1927+739';opcode 'CALP';INTERPOL 'AMBG'`
   - `Snver 1;inver 1;gainver 2;gainuse 3`
5. BPASS – Bandpass on 1927+739 assuming flat spectra 2Jy)
6. CALIB – correct for Amplitude variations (using 1927+739 – assume flat spectrum 2Jy source)
   - `Calsour '1927+739' '';docal 100;gainu 0;doband 1;bpver 0`
   - `Solmode 'A&P';soltyp 'L1'`
   - Solint = -1
   - Aparm 4 0 0 0 1 0 (Note APARM(1) = 3 used for data set 2015Jan13 due to sparse number of antenna)

Produces SN2 – time/IF based gain correction (see figure 6-8)

7. CLCAL – SN2 + CL3 = CL4
   - `tget clcal;snver 2;inver 2;gainver 3;gainu 4`
8. CALIB – Phase only corrections (Using 1927+739) → Phase calibrate on one source.
   - tget calib
   - `Calsour '1927+739' '';docal 100;gainu 0;doband 1;bpver 0`
   - `Solmode 'P';soltyp 'L1'`
   - Solint = 0.5
   - Aparm 3 0 0 0 1 0
9. CLCAL – SN3 + CL4 = CL5
   - `tget clcal;snver 3;inver 3;gainver 4;gainu 5`
10. Derive Phase solutions for all source following correction to 1927+739
    - tget calib
    - `Calsour '*ALL*' '';docal 100;gainu 0;doband 1;bpver 0`
    - `Solmode 'P';soltyp 'L1'`
    - Solint = 0.5
    - Aparm 3 0 0 0 1 0

Solutions from this final SN table are plotted in figures below.

5. Plots and results

5.1. Effect of the inclusion of CM axis offset via CLCOR (13Jan 2015 only)

Application of CLCOR to correct for the antenna axis offset on CM of 1503mm creates a new CL table that is appended to the data and needs to be applied during all further calibration steps. This CL table (#2) includes delay, rate and phase (derived from rate) corrections calculated from the axis-offset. These corrections are plotted below for information.

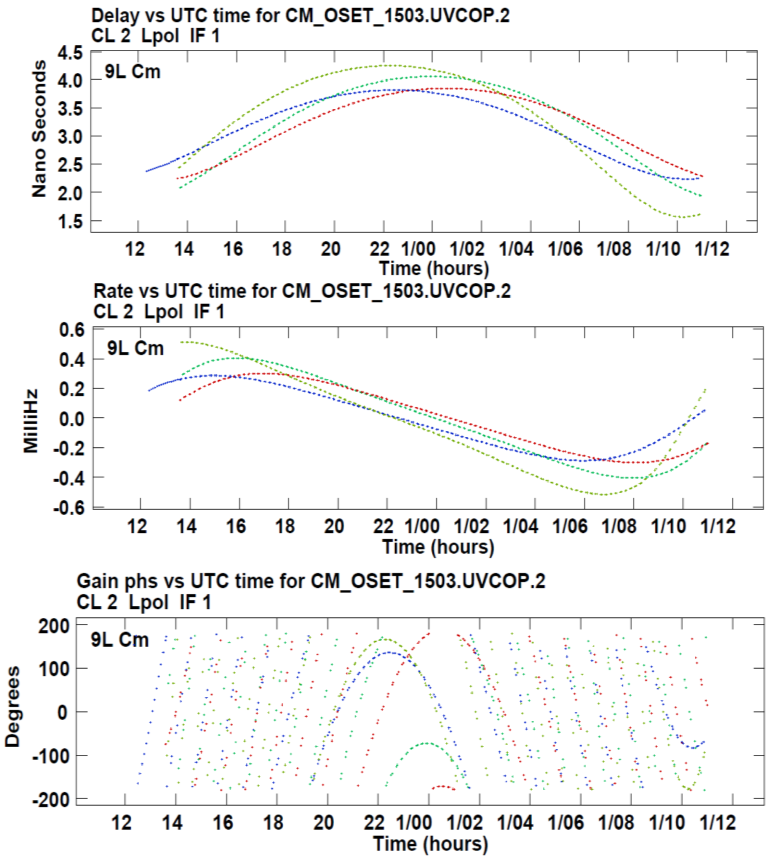

Figure 3: Delay, Rate and Phase corrections vs UT calculated by CLCOR for a 1503mm axis offset on CM. Different colours represent each of the 4 sources used in the observation (Date from 2015 Jan 13 observation).

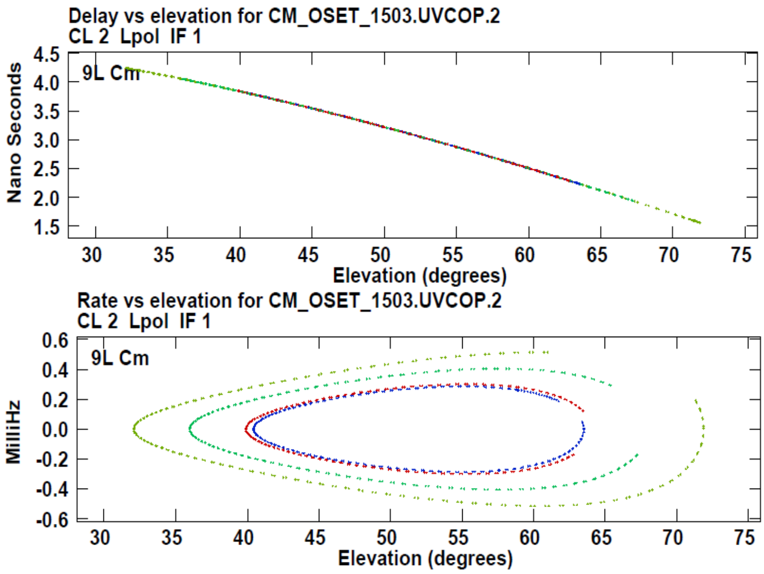

Figure 3: Delay and Rate corrections vs source elevation. Different colours represent each of the 4 sources used in the observation (Date from 2015 Jan 13 observation).

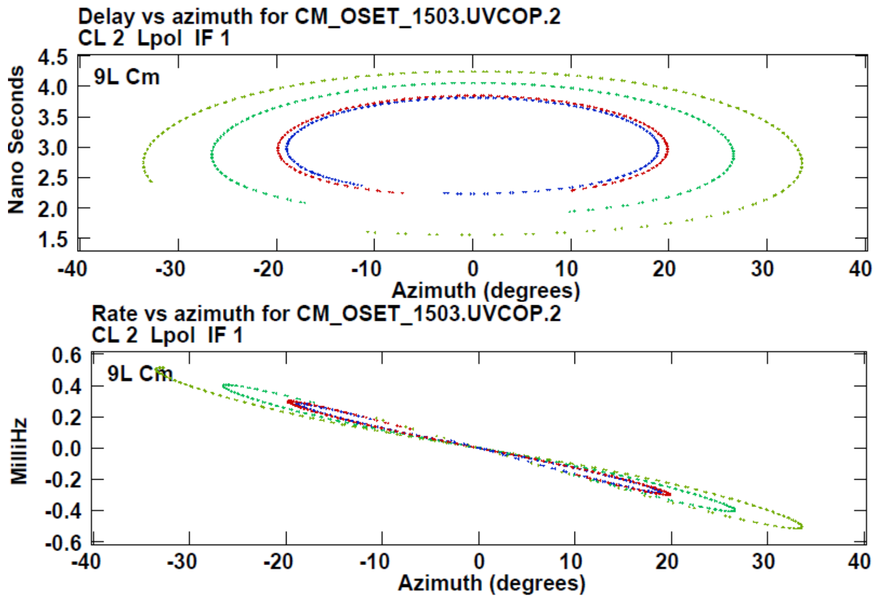

Figure 4: Delay and Rate vs Azimuth. Different colours represent each of the 4 sources used in the observation (Date from 2015 Jan 13 observation).

5.2. Derived CM Delay before and after axis offset correction (13Jan 2015 only).

On all e-MERLIN data observed prior to 16 Feb 2015 an incorrect value (0.0m) of the CM axis offset was applied. The result of this is that all data observed prior to this date will have an elevation depended delay term. This is evident in the derived delay corrections as plotted in Figure 6Figure 6 . This delay correction follows a COS(Elevation) term and will result in the values of delay derived on a calibrator source being different to the true delay value for a target source in an adjacent scan, due to the differing elevation of the two sources.

In order to correct this effect off-line the AIPS task ‘CLCOR’ (see above) can be used to insert the telescope axis-offset for CM and derive delay, rate/phase corrections accordingly. If this is applied to the data prior to fring fitting the delay vs elevation term is significantly reduced. However, it should be noted that some smaller (few 100s picosecond) elevation dependent delay remains. This value is small and appears to a different sense when the axis offset correction is applied online (see section 5.3 below).

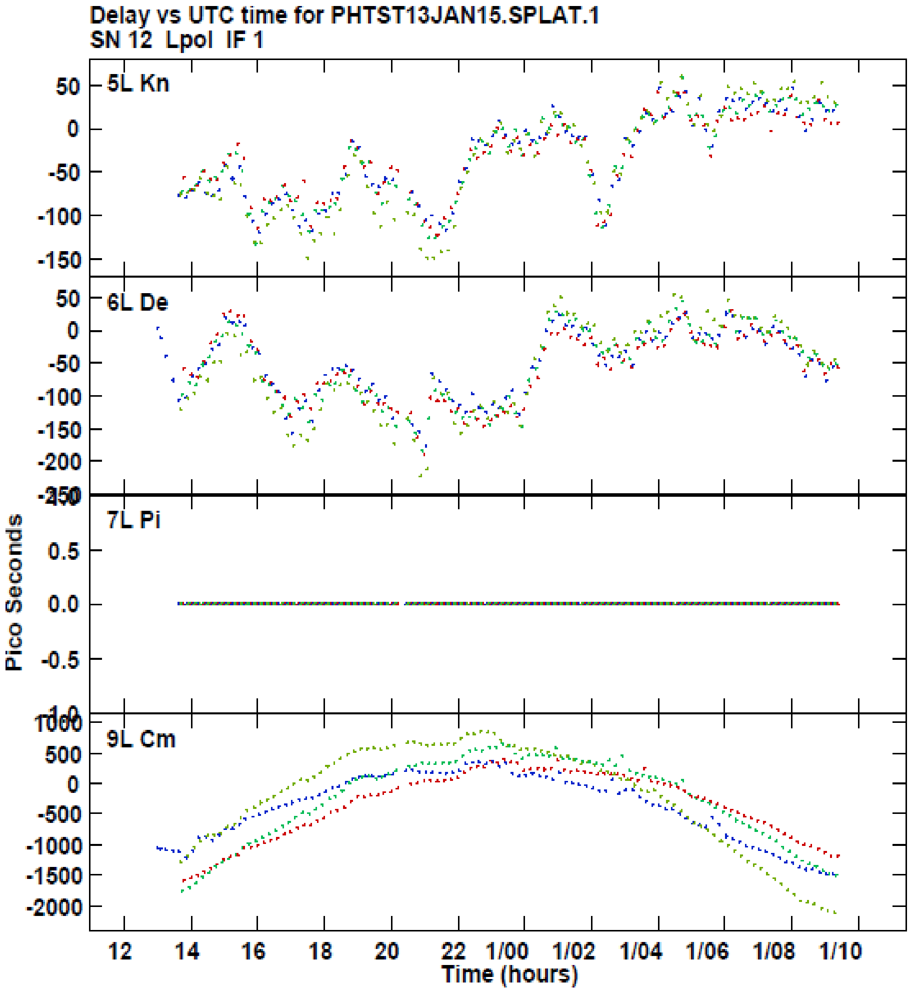

Figure 6: BEFORE Delay vs UT calculated from data. NO AXIS OFFSET APPLIED (13Jan 2015)

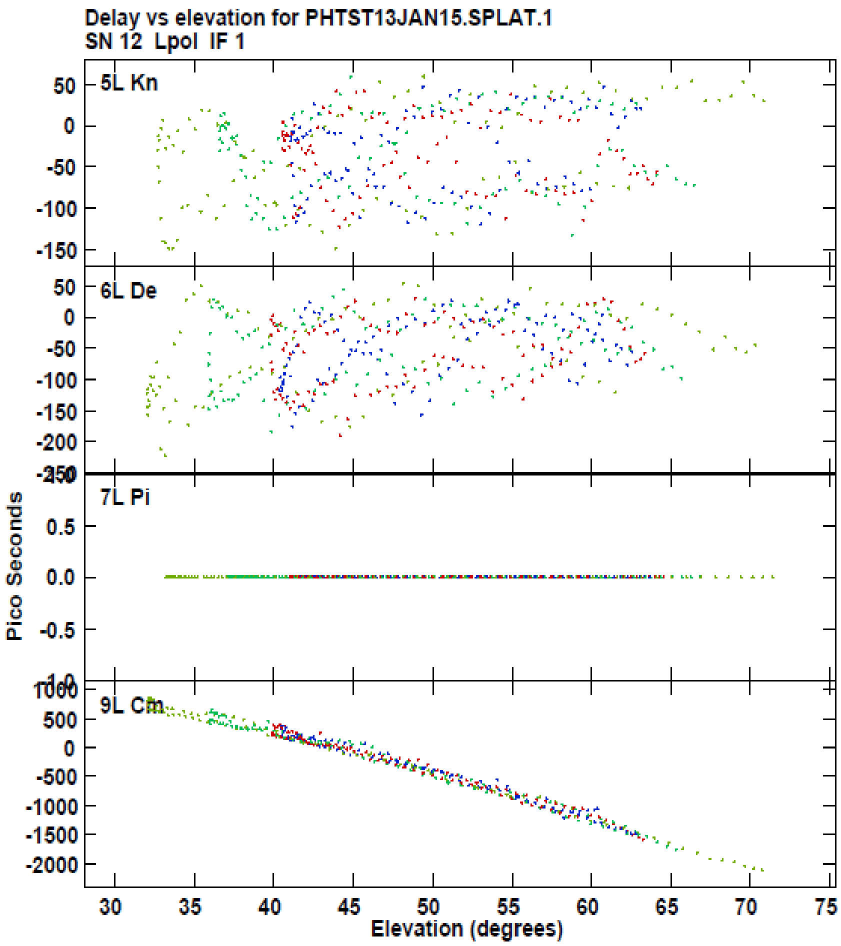

Figure 6: BEFORE Delay vs Elevation calculated from data - no axis offset applied (13 Jan 2015)

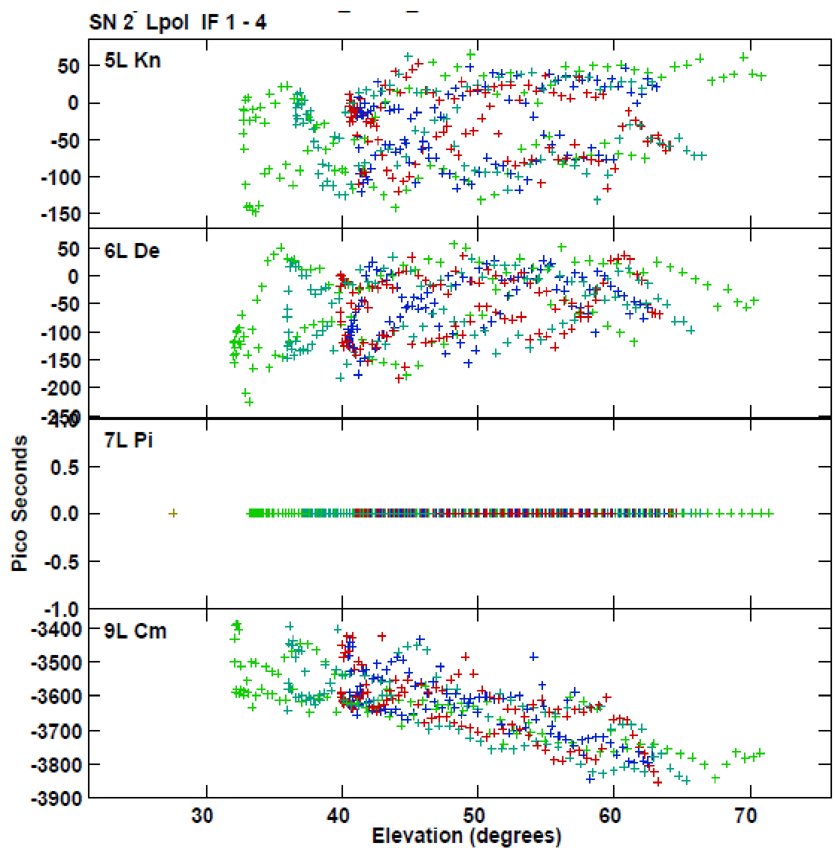

Figure 8: AFTER. Delay (LL) vs Elevation calculated from source - AXIS Offset applied in CLCOR (13 Jan 2015).

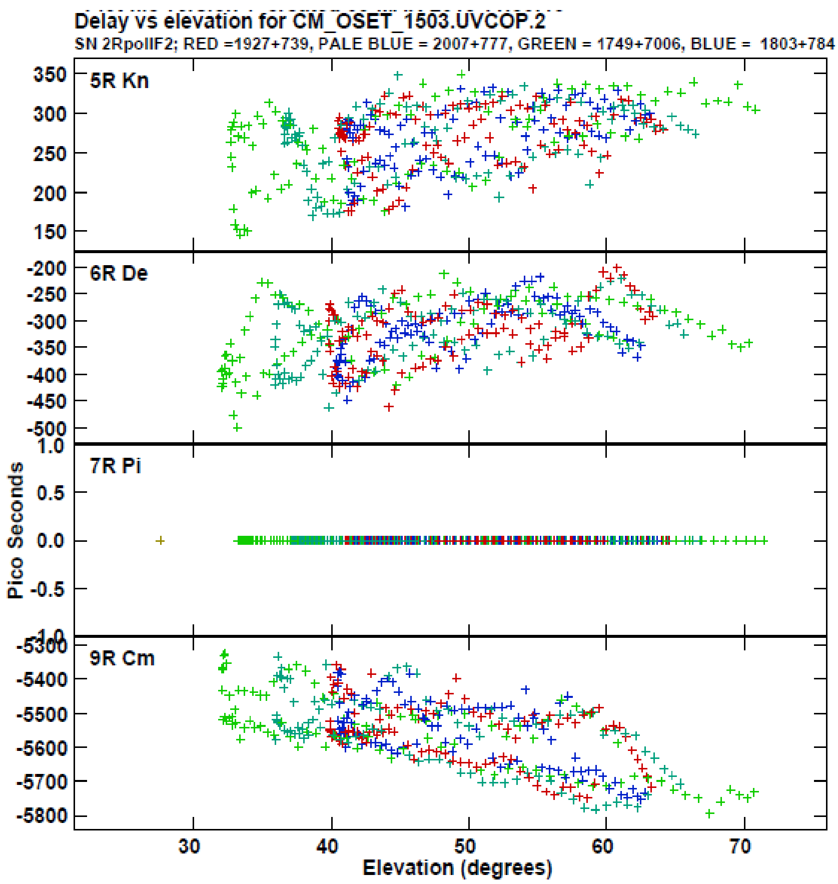

Figure 8: AFTER. Delay (RR) vs elevation calculated from data - AXIS OFFSET applies in CLCOR (13 Jan 2015).

5.3. Delay calculated with online correction for axis offset

Following 16 Feb 2015 the axis offset for CM has been applied within the online system. The following plots (Figure 9) show the delay calculated from multiple sources (same as section above).

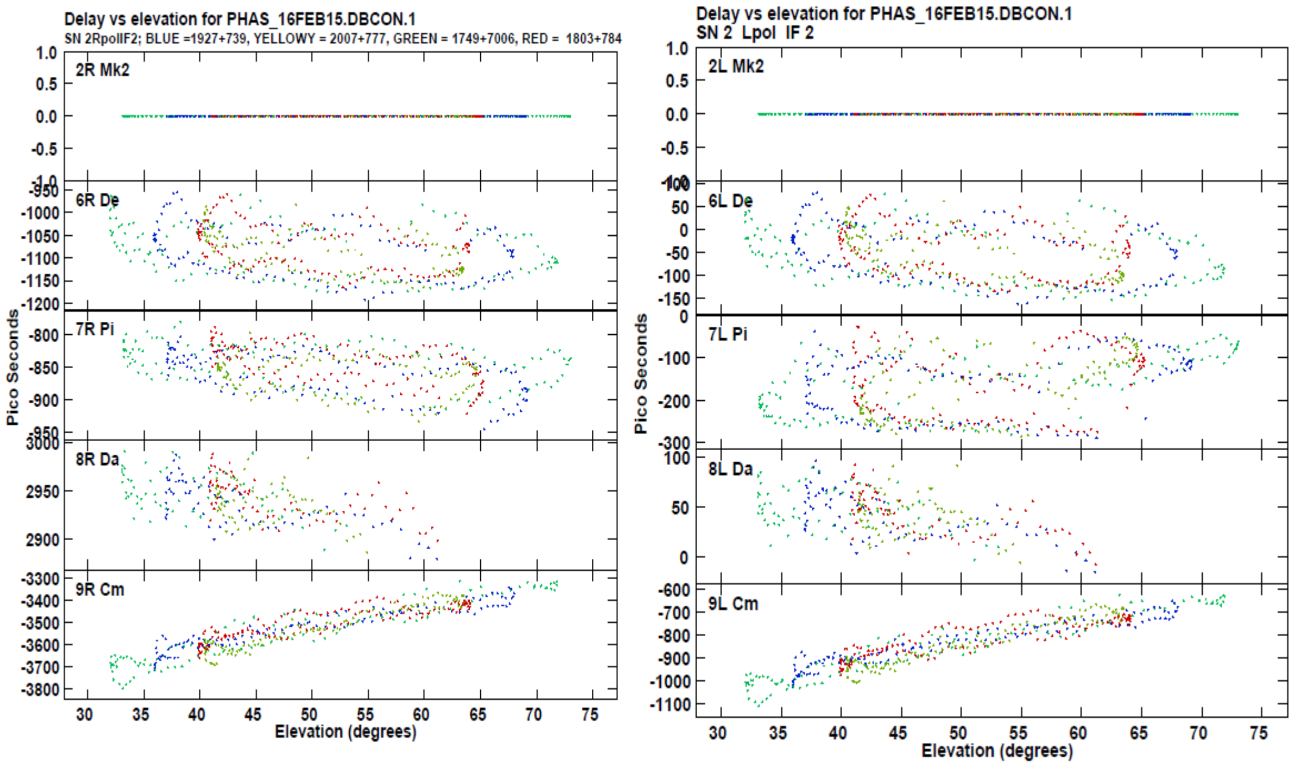

Figure 9: Delay vs Elevation with axis offset applied online. Data 16 Feb 2015.

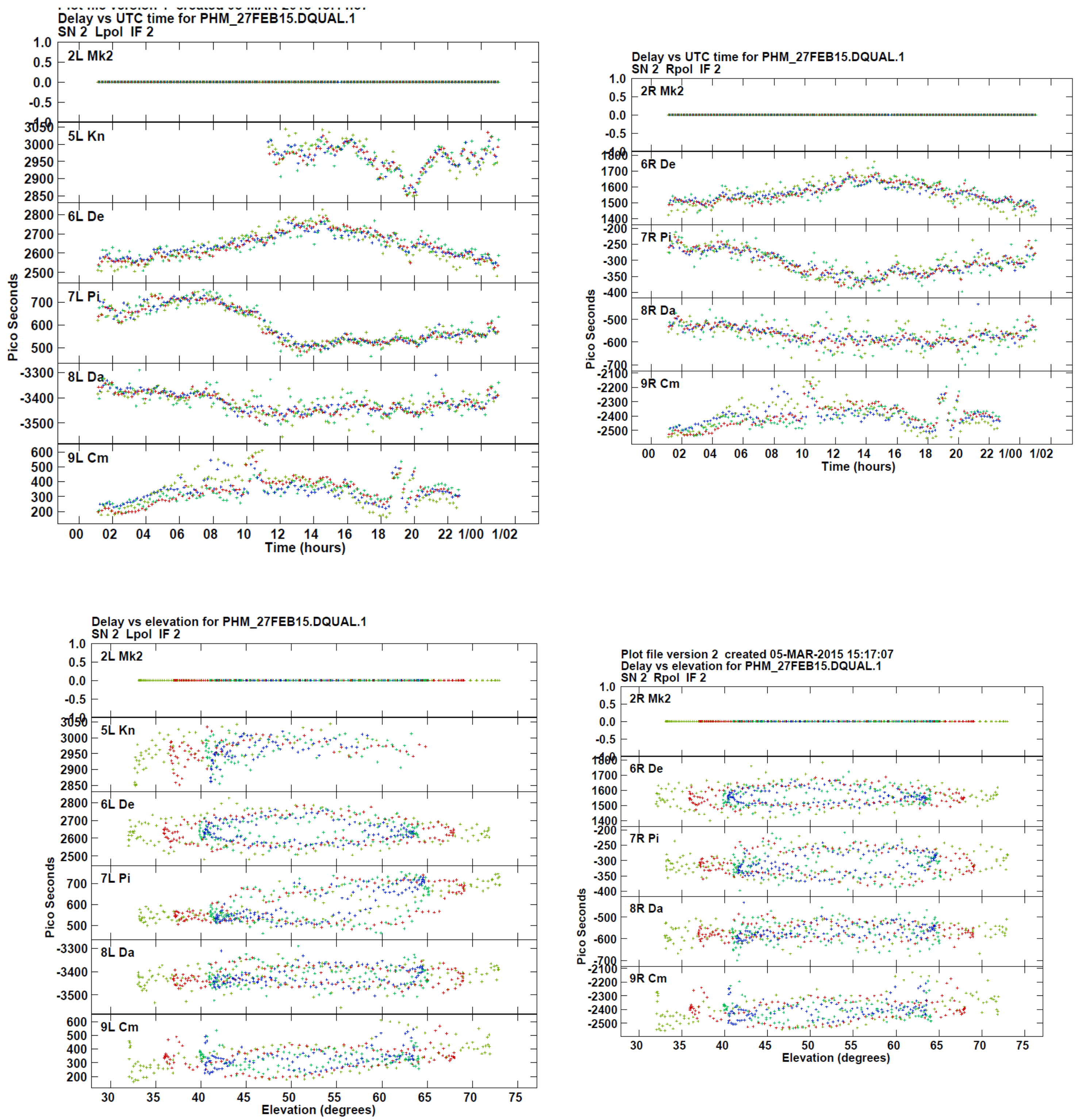

Figure 10: 2015 Feb 27 calculated delay as a function of time and elevation. Left-hand side LL-pol, Right-hand side RR-pol (Axis offset applied online).

5.4.Phase stability following application of axis offset

Following the application of delay, phase, amplitude and bandpass solutions based on a single calibrator source (1927+738) as described in section 4 the resultant phase corrections for all of the remaining target sources were derived. These residual phase corrections derived by calib demonstrate the phase stability of the individual telescopes (relative to the chosen reference antenna). Prior to the inclusion of the CM axis offset CM data were not found to be phase stable.

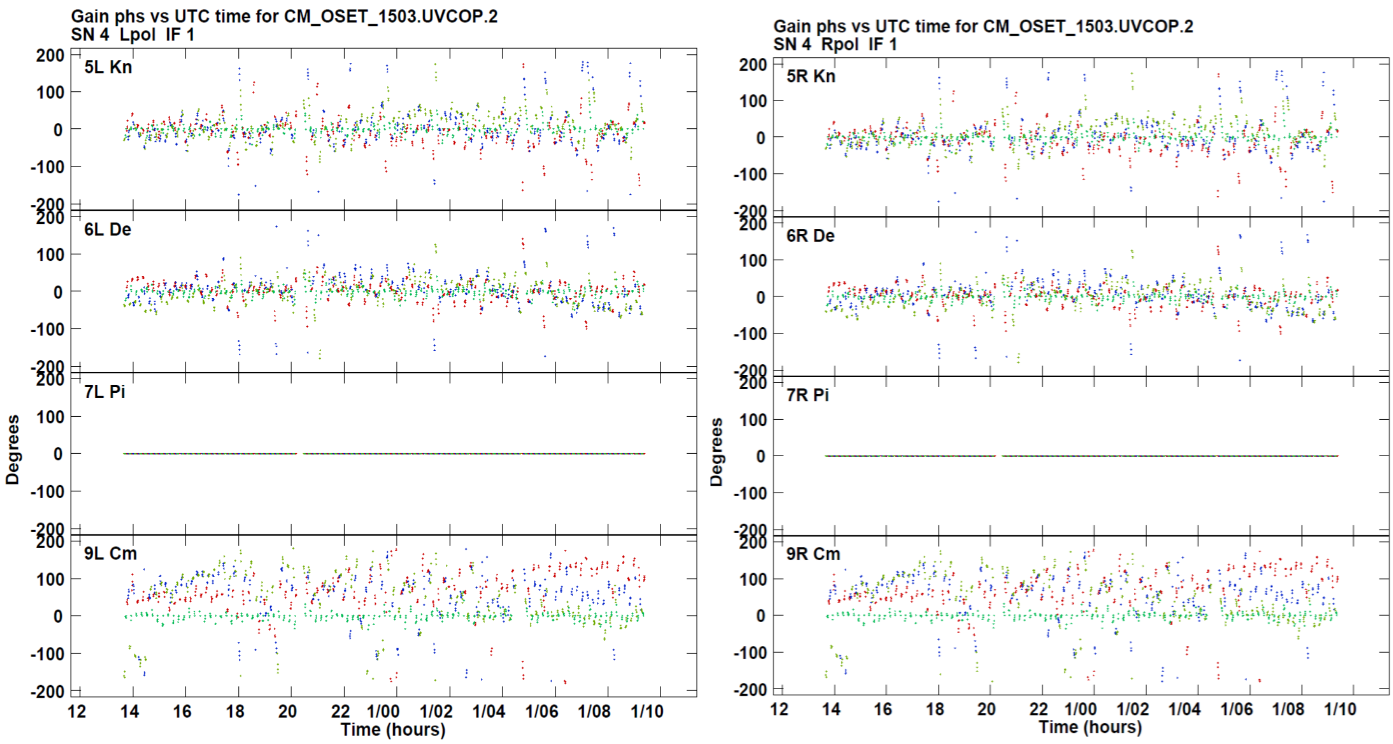

Figure 11: 13 Jan 2015 - Phase solutions (SN) for all sources following delay/bandpass/amplitude/phase correction on 1927+738 (BLUE source).

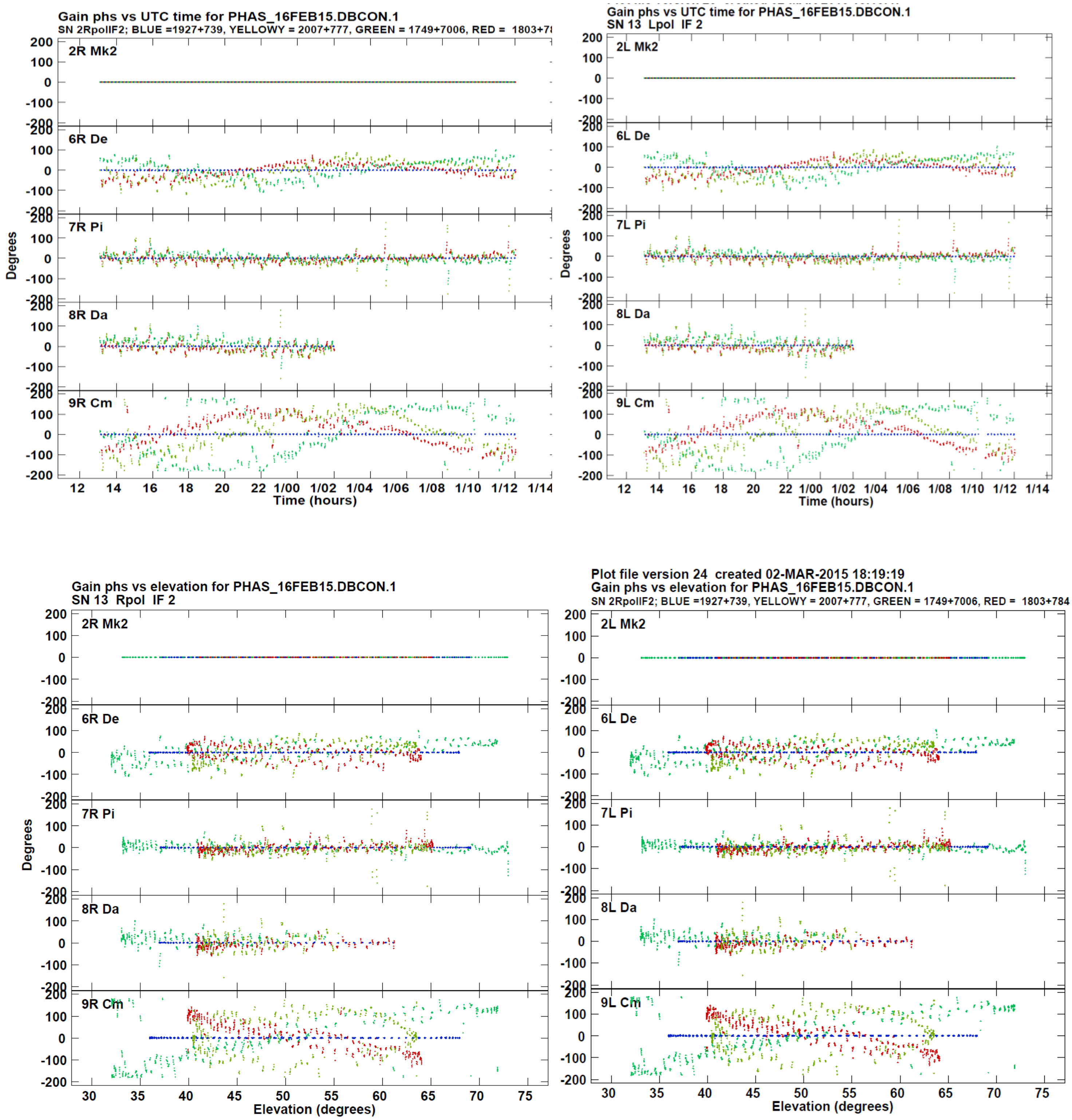

Figure 12: 16 Feb 2015 (ONLINE Cm axis offset applied) - Phase solutions (SN) for all sources following delay/bandpass /amplitude/phase correction on 1927+738 (BLUE source).

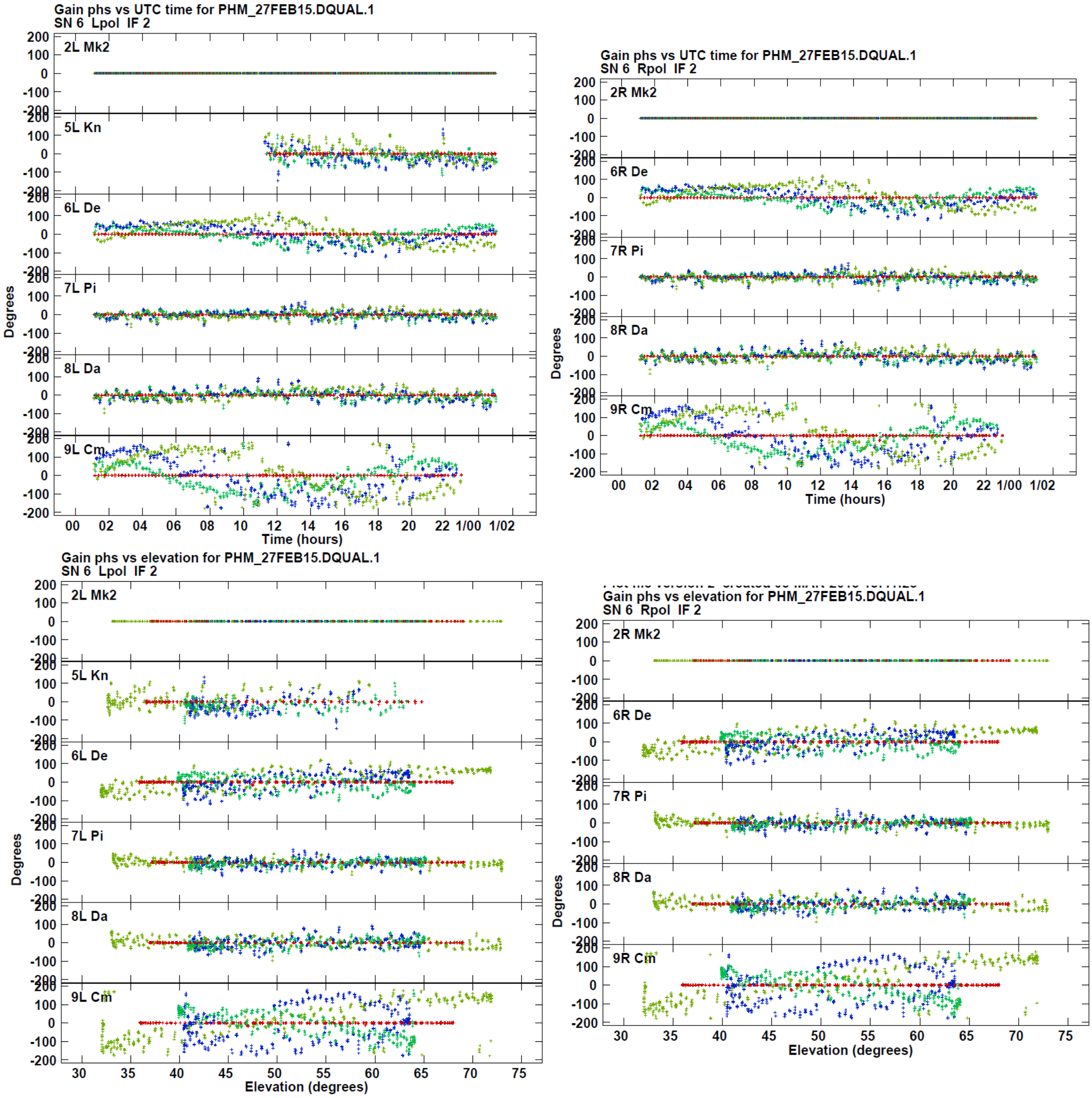

Figure 14: 27 Feb 2015. Phase corrections for all sources derived following application of calibration (using 1927). (axis offset applied online)

5.5. Long observations of 3C84 – 1-4 Mar 2013

Dataset comprises a long run of 3 continuous days on 3C84.

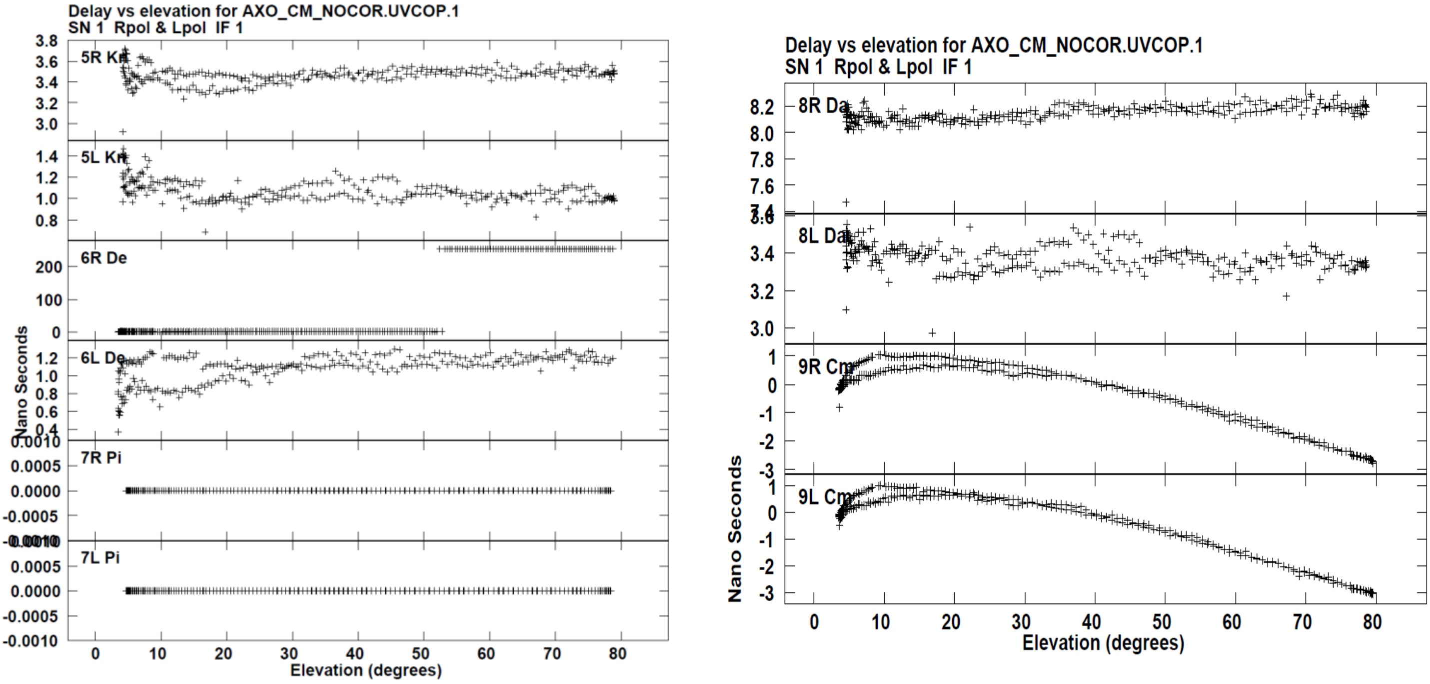

Figure 18: 1-4 Mar 2013 Day 1 of run only. 3C84 Delay with no CM axis offset applied.

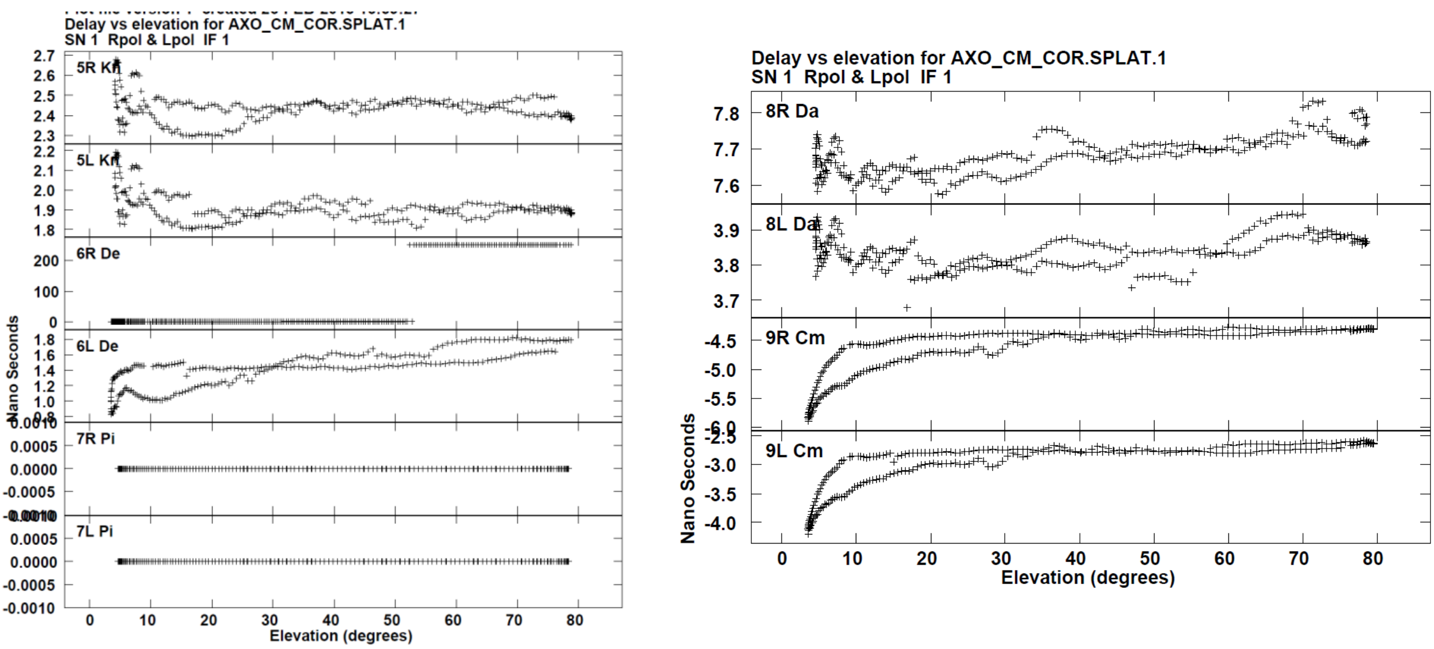

Figure 19: 1-4 Mar 2013 Delays calculated for 1st day of run following CLCOR application of CM offset axis.