Memo: high SNR, 1 Gps VLBI experiments in 2004–2006

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1 Experiments

In 2004–2006 18 VLBI experiments were carried in 1024 megabit per second recording mode were carried out. The list of experiments is presented in table 1

$04MAY12XA	7	!	rd0403	1252	5	Ny On Wf Wz Kk
$05JAN19XA	7	!	rd0501	2441	6	Ag Wf Ny On Wz Kk
$05FEB08XA	7	!	rd0502	2967	7	Ag Wf Ny On Wz Kk Gk
$05MAR30XA	5	!	rd0503	2698	7	Ag Wf Ny On Wz Kk Gk
$05APR06XA	6	!	rd0504	1444	6	Gk Wf Ny On Kk Wz
$05MAY18XA	6	!	rd0505	2054	6	Ag Ny Wf Zc Kk Gk
$05JUN21XA	6	!	rd0506	3022	7	Gk Wf Wf Ny On Ag Kk
$05JUL12XA	4	!	rd0507	3175	7	Gk Wf Ny On Ag Kk Zc
$05AUG17XA	6	!	rd0508	2975	7	Gk Wf Ny On Ag Kk Wz
$05NOV15XA	5	!	rd0509	3224	7	Gk Wf Ny On Ag Wz Kk
$05DEC07XA	5	!	rd0510	3178	7	Ag Wf Ny On Gk Kk Wz
$06JAN25XA	5	!	rd0601	1419	5	Ag Wf Ny Wz Kk
$06MAR29XA	5	!	rd0602	2365	6	On Wf Ny Ag Wz Kk
$06APR26XA	5	!	rd0603	2199	6	Ag Wf On Ny Wz Kk
$06JUN28XA	5	!	rd0604	2735	6	Ag Wf Ny On Kk Wz
$06JUL19XA	5	!	rd0605	1828	5	Ny Wf On Wz Kk
$06SEP19XA	5	!	rd0607	2430	5	Ny Wf On Wz Kk
$06OCT04XA	6	!	rd0608	2627	5	Ny Wf On Wz Kk

The principal investigator of these experiments was Nancy Vandenberg. She scheduled these experiments in such a way that the minimal SNR was around 80 at X-band and 60 at S-band. The achieved signal to noise ratio for these experiments was within 20% of the goal, as it seen in figures 1.

Two factors contributed to delay in analysis of these experiments: 1) the principal investigator did not take lead in efforts to process experiments; 2) the Haystack correlator delayed the data release for as long as one year(!) instead of usual 2–3 weeks turnaround.

These experiments were analyzed using a traditional approach. This means that the group delay and fringe phases at the reference frequency were computed by an undocumented algorithm implemented in the computer program Fourfit. Ionosphere free linear combinations of group delay at X-band and S-band was used as observables. The data were re-edited and re-weighted using ELIM and UPWEI algorithms.

2 Solutions

Global solution showed that the wrms of postfit residuals are at a level of 10–20 ps an show a clear seasonal pattern. Winter residuals are in a range of 11-13 ps, summer residuals are in a range of 15–18 ps as it seen in figure 2.

In order to evaluate systematic errors, three global solutions were made: one with 18 high SNR RD experiments, the second with 18 R1 experiments chosen at dates within 1–3 days to RD experiments, and the third with 18 RDV experiments from December 2003 through September 2006.

Solutions were made using the following way. First, additive re-weighting parameters that make χ^2/ndf close to 1 were computed. Second, pre_hs solution with all sessions from 1979.08.03 through 2006.11.23, except 18 RD, 18 R1, and 18 RDV sessions was computed. The setup of this solution is similar to the setup of 2007a solution, except modeling harmonic variations in the Earth orientation parameters: a better empirical expansion of the harmonic variations in the Earth rotation was used in the pre_hs solution: `heo1_20061210`. The expansion `heo_20061210` was produced by a LSQ fit of VLBI observations from 1984.01.04 through 2006.11.21. Third, three solutions were made with the so-called input combined global matrix computed in the pre_hs solutions: solution hs_rd with 18 RD sessions, solution hs_r1 with 18 R1 sessions, and solution hs_rv with 18 RDV sessions. This mean that each of these solutions is equivalent to a global solution with all experiments as in pre_hs + 18 other experiments. Fourth, differences in polar motion and UT1 between the estimates of these parameters from solutions hs_rd, hs_r1, hs_rv and USNO Finals EOP series were computed. Statistics of these differences as well as statistics of adjustments of nutation delay offsets with respect to the `heo_20061210` expansion are shown in table 1.

Table 1: wrms of differences between 18 EOP estimates from three different VLBI solutions. The first three rows show the differences with respect to USNO Finals. The last two rows show the differences with respect to the empirical model of harmonic variations in the Earth rotation heo_20061210 which was derived from analysis of VLBI data for the period [1984.0, 2006.9]. Units: nrad.

Experiment	R&D	R1	RDV
X pole	0.55	0.24	0.25
Y pole	0.39	0.13	0.27
UT1	0.43	0.24	0.37
$\Delta\psi \sin \varepsilon_0$	0.64	0.24	0.30
$\Delta\varepsilon$	0.66	0.32	0.26

Since GPS almost entirely contributes to the USNO Finals polar motion, these differences can be considered as differences between VLBI and GPS results. The UT1 from USNO Finals is based on VLBI results from these experiments, with applying smoothing.

Three baseline type of solutions were made with identical control file, but different session list: RD, R1 and RDV. Site positions were estimated at each experiment individually. The baseline length repeatabilities computed at each of these solutions are shown in plot 6. The dependence of baseline length repeatability on baseline length L was fitted to the model $\sqrt{A^2 + (B * L)^2}$. Using the ecoffifients A and B the baseline length repeatability to common baseline lenghts was computed. The results are shown in table 2.

3 Phase delay ambiguity resolution

There was an attempt to resolve phase delay ambiguities. They were not fully successful. At some baseline phase delay ambiguities can be reliably resolved — figure 7, at other baselines they cannot be reliably resolved — figure 8, at some baseline reliability of phase delay ambiguity resolution is questionable: — figure 9.

Table 2: Extrapolation of baseline length repeatability in mm for three solutions at baseline lengths 1000 km, 5000 km and 10000 km.

Length	R&D	R1	RDV
1 000 km	2.0	1.2	1.9
5 000 km	5.2	6.2	4.7
10 000 km	10.0	12.4	8.9

Although phase delay ambiguities were resolved for all 1 Gbps sessions, for the majority of experiments phase delay ambiguities resolution procedure raised a flag of possible errors in phase delay ambiguities. The rms scatter of the phase delay ambiguity resolution function should be less than 0.10–0.15 for reliable phase delay ambiguity resolution. For many baselines this function was of 1.35–1.50, as it is seen at plot 10.

4 Conclusion

Analysis of ∼40 000 observations of 1 Gps experiment showed mixed results. The differences of the estimates of polar motion with respect to the GPS series **have a scatter of a factor of 2 greater** than the scatter of the reference solutions. The differences of the estimates of nutation angles with respect to the global solution **have a scatter of the factor 2–2.5 greater** than scatter of the reference R1 solution. The baseline length readabilities from 18 RD experiments are **20% smaller** than the repeatabilities from 18 R1 experiments, and **10% greater** than the repeatabilities from 18 RDV experiments. Since the R1 and RD network were different, at present we cannot determine whether 20% baseline length repeatability reduction is caused by a 4-fold bandwidth increase or it is caused by change of the network.

Analysis of high SNR RD experiments confirmed that increase of the bandwidth alone without a significant revision of observing and analysis strategies does not provide an automatic improvement in the accuracy of estimates of baseline lengths and the Earth orientation parameters. Surprisingly, **a factor of two degradation of accuracy of EOP estimates was revealed**. It should be noted that an attempt to use 1 Gps recording mode in the min03 experiment resulted in **a factor of 2.5 increase of UT1 errors**. This a serious problem. Without solving this problem 1 Gps and higher bits rate **cannot be recommended** for using in experiments dedicated for the Earth orientation parameter estimation.

Phase delay ambiguity resolution is not reliable. Phase delay solutions do no have a practical value.

It was found that instrumental errors is still a significant factor which affects 1 Gbs experiments. Without reducing the level of instrumental errors observations at 1 Gbs mode is not warranted. Reducing instrumental errors should have a precedence over development of 2 Gbs and 4 Gps systems.

5 Recommendations

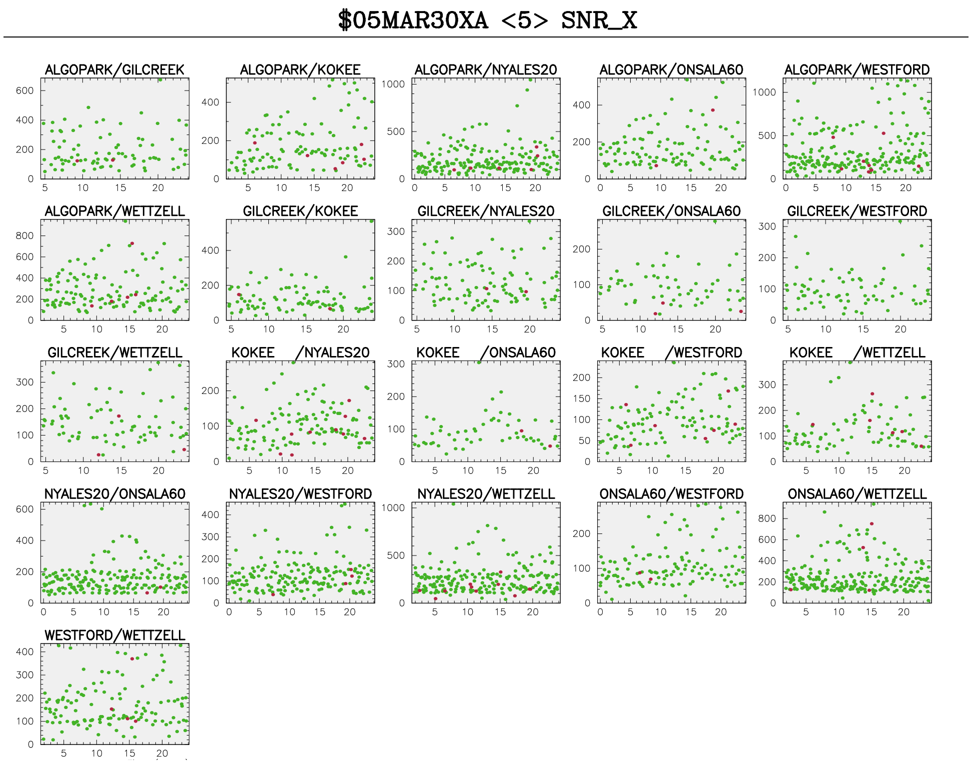
There is no sense to continue observing high SNR experiments **without** changes in analysis strategy.

In depth analysis of experiments is desirable. This should include amplitude analysis, revision of algorithms for group and phase delay computation, applying correction for spurious signals in phase calibration and other enhancements.

In order to perform advanced analysus, the Field System computer program should be upgraded, in order to make it feasible to export system temperature and antenna gain curves into analysis software.

The differences in fringe phases and group delays recorded in 256 Mbs, 512 Mbs, 1024 Mbz should be investigated in depth with a goal of identifing systematic errors which affect estimates of the Earth Orientation Parameters.

Figure 1: Signal to noise ratio at the X-band (up) and S-band (down)



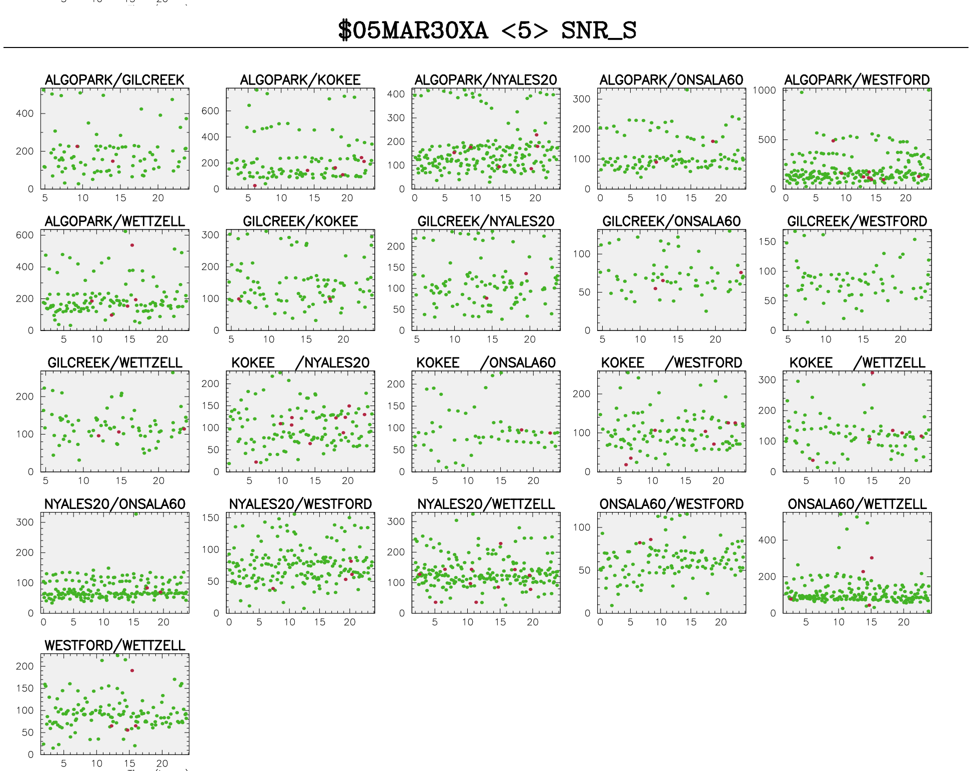


Figure 2: Wrms of postfit residuals in ps as a function of time

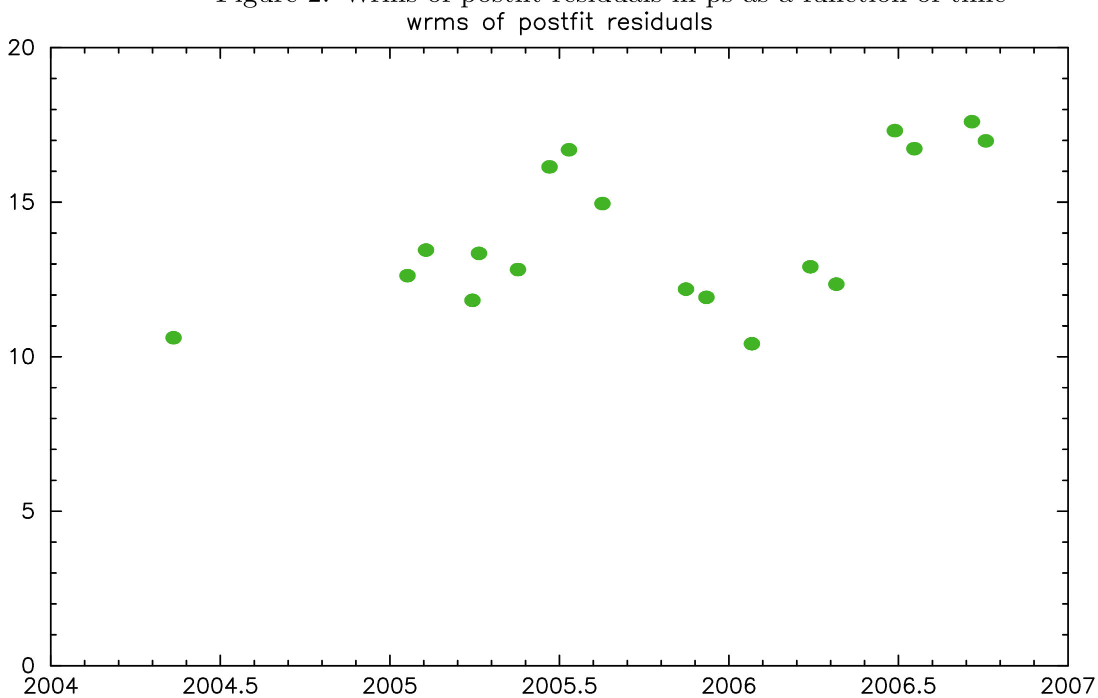


Figure 3: Corrections to daily offsets of $\Delta\varepsilon$ with respect to the empirical expansion heo_20061210. The first plot shows offsets from high SNR RD experiments, wrms = 0.64 nrad. The second plot shows offsets from R1 experiments, wrms = 0.24 nrad

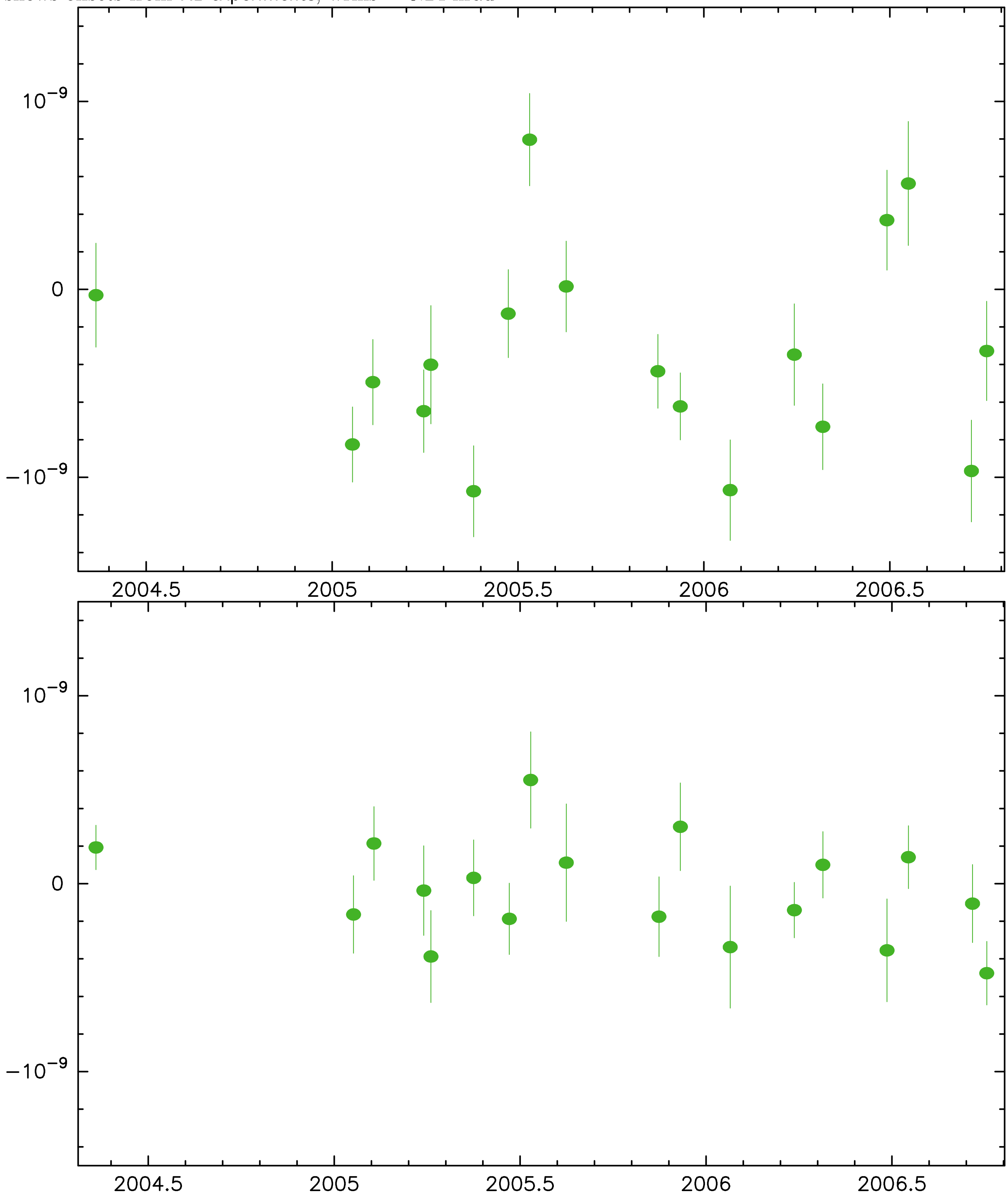


Figure 4: Differences in Xpole coordinate between USNO Finals (GPS) and high SNR RD experiments (upper plot), and R1 experiments, lower plot.

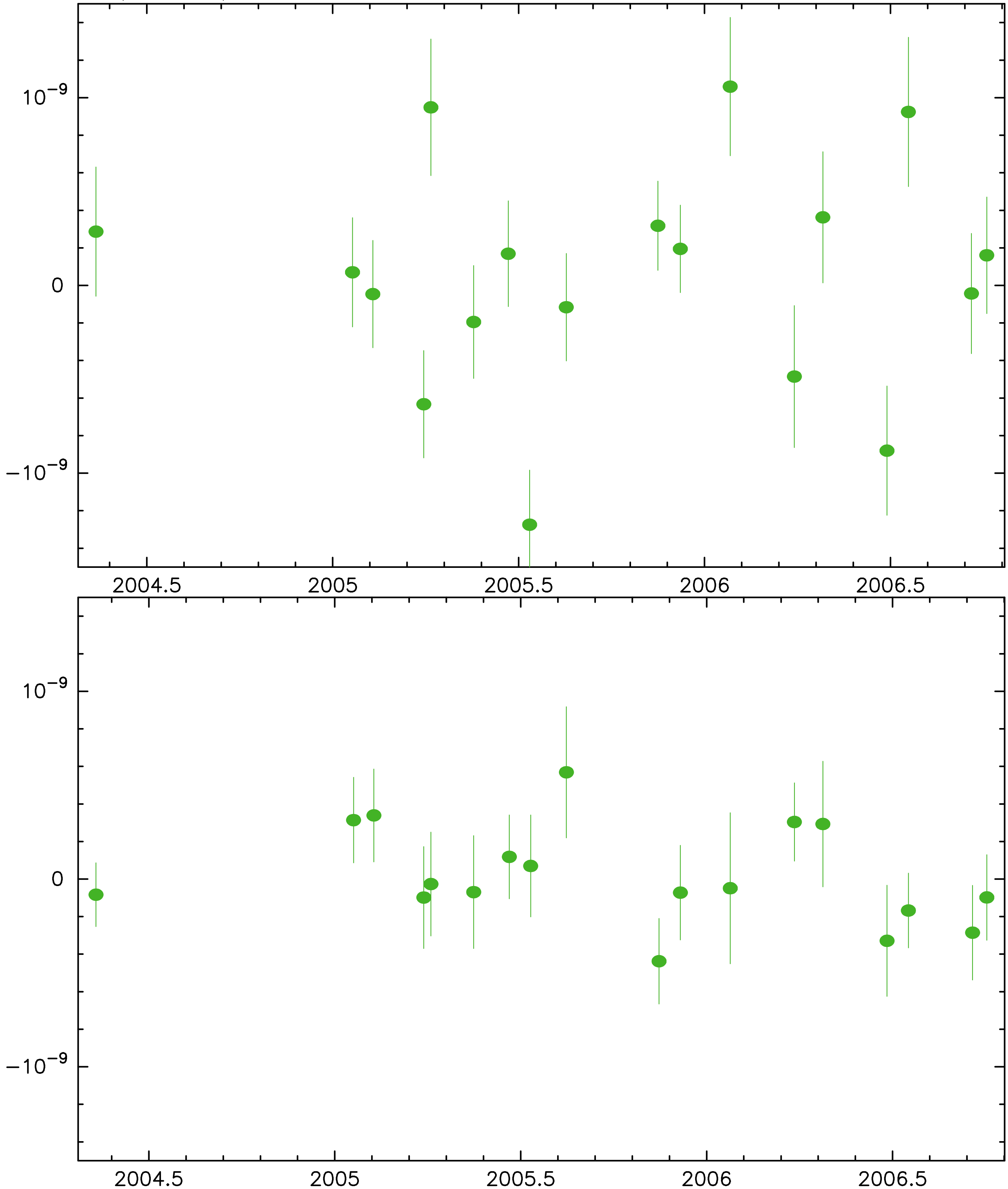


Figure 5: Differences in UT1 angles between USNO Finals (GPS) and high SNR RD experiments (upper plot), and R1 experiments, lower plot.

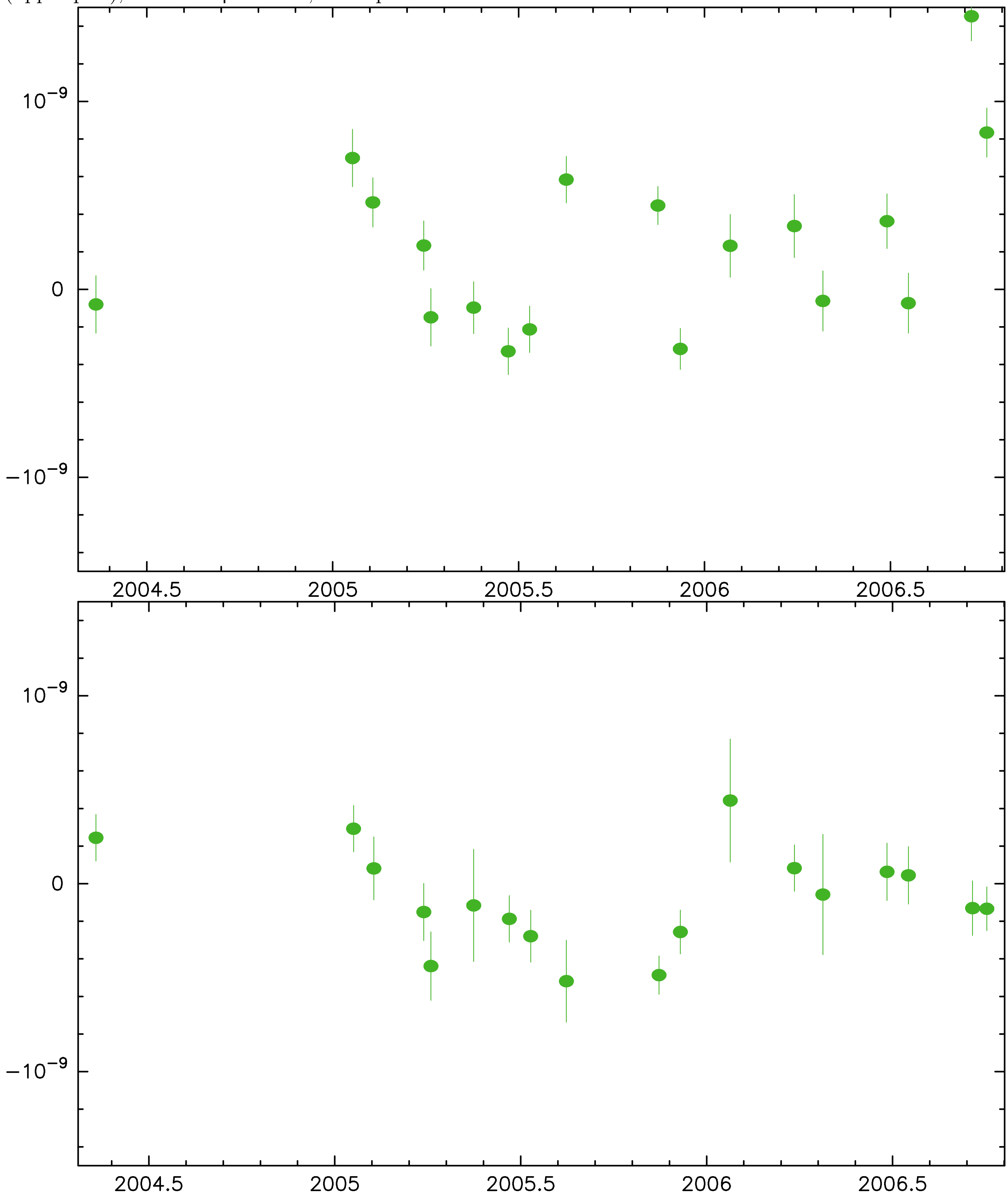


Figure 6: Baseline length repeatability in mm for baselines from the **high SNR RD experiments**, from **R1 experiments** and from **RDV experiments**.

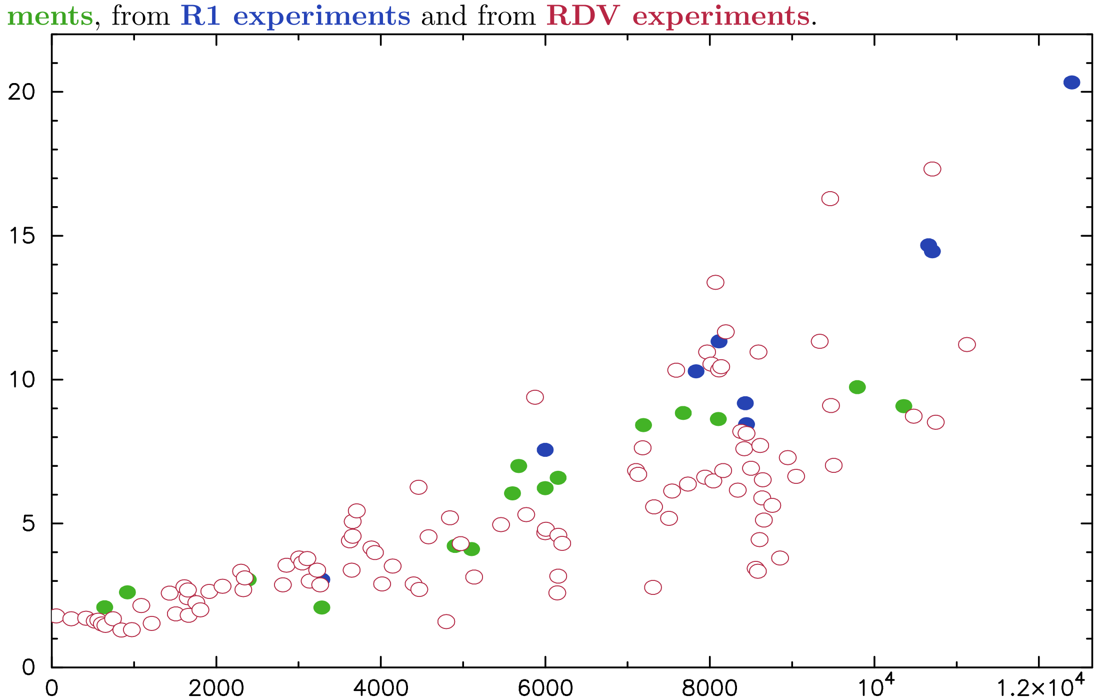
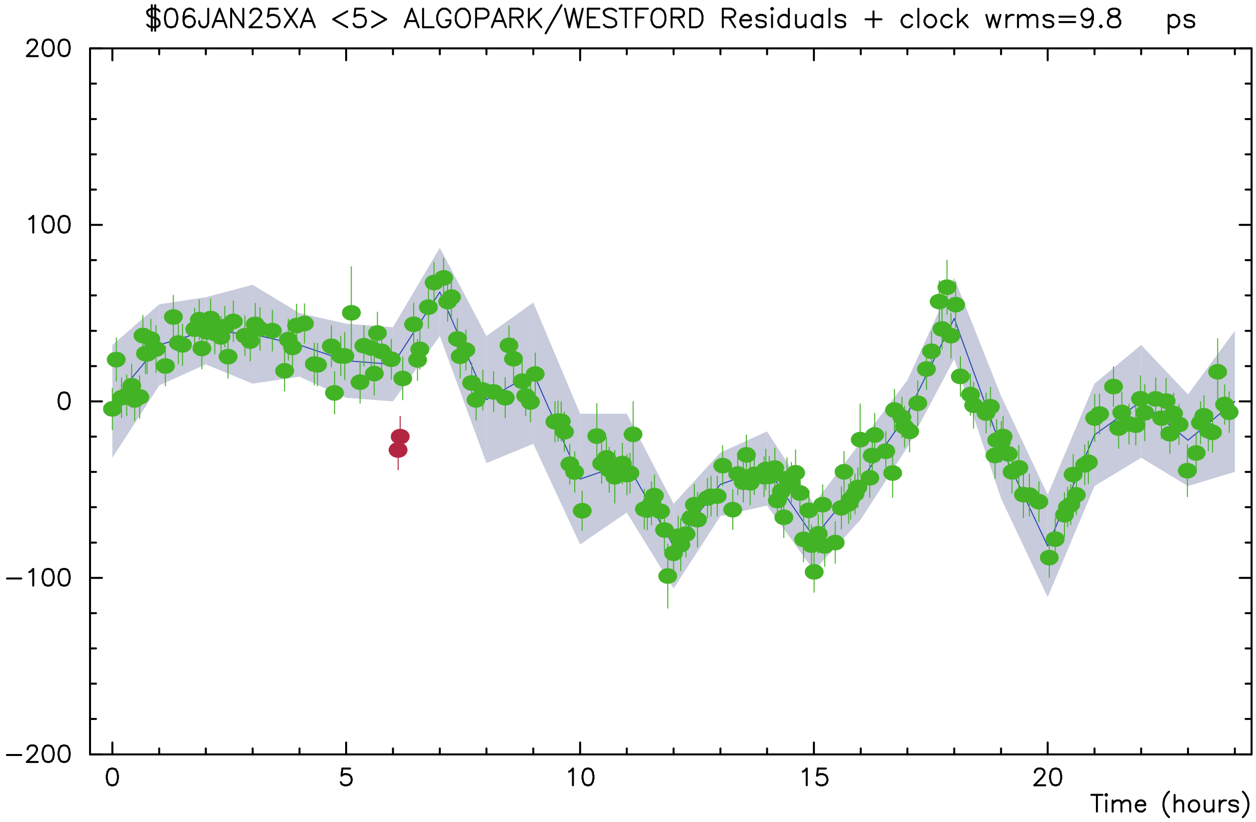


Figure 7: Group delay residuals(up) and phase delay residuals from the group delay solution (down). Group delay ambiguities are reliably resolved.



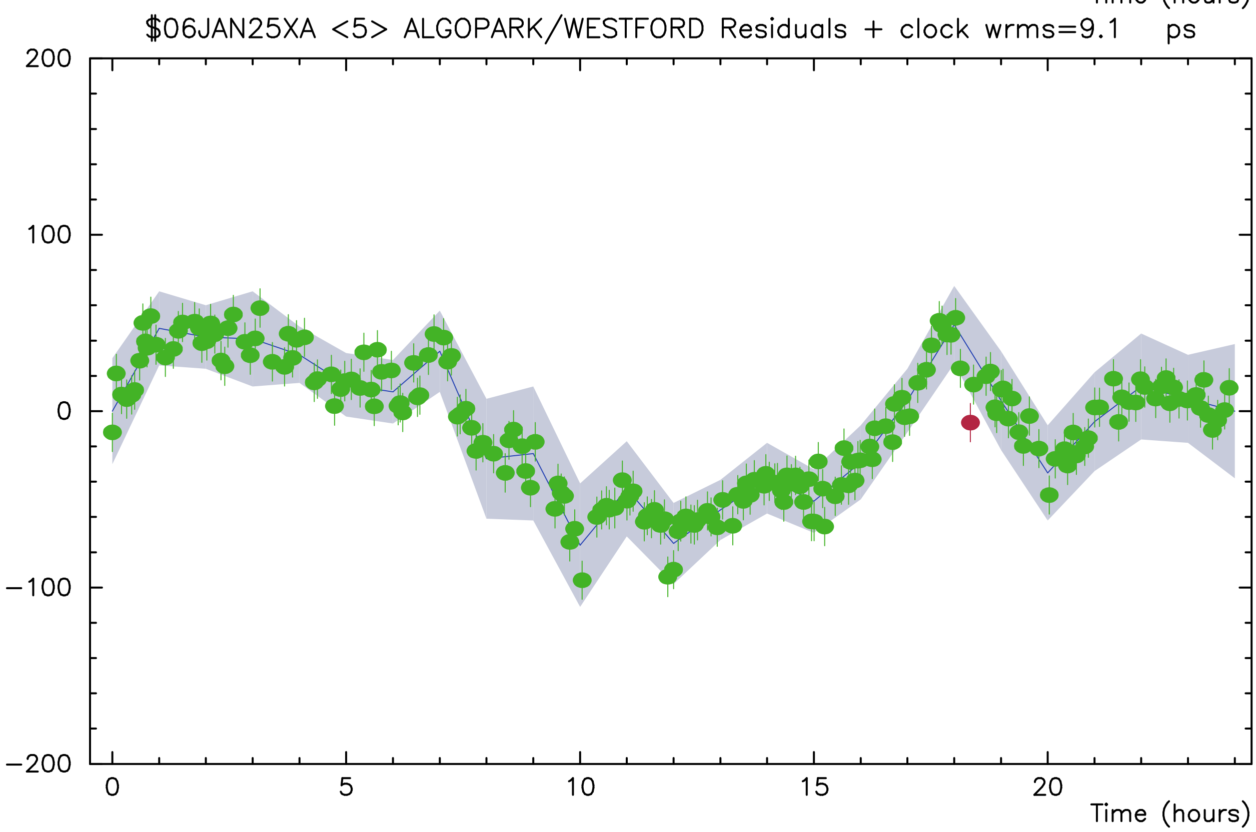
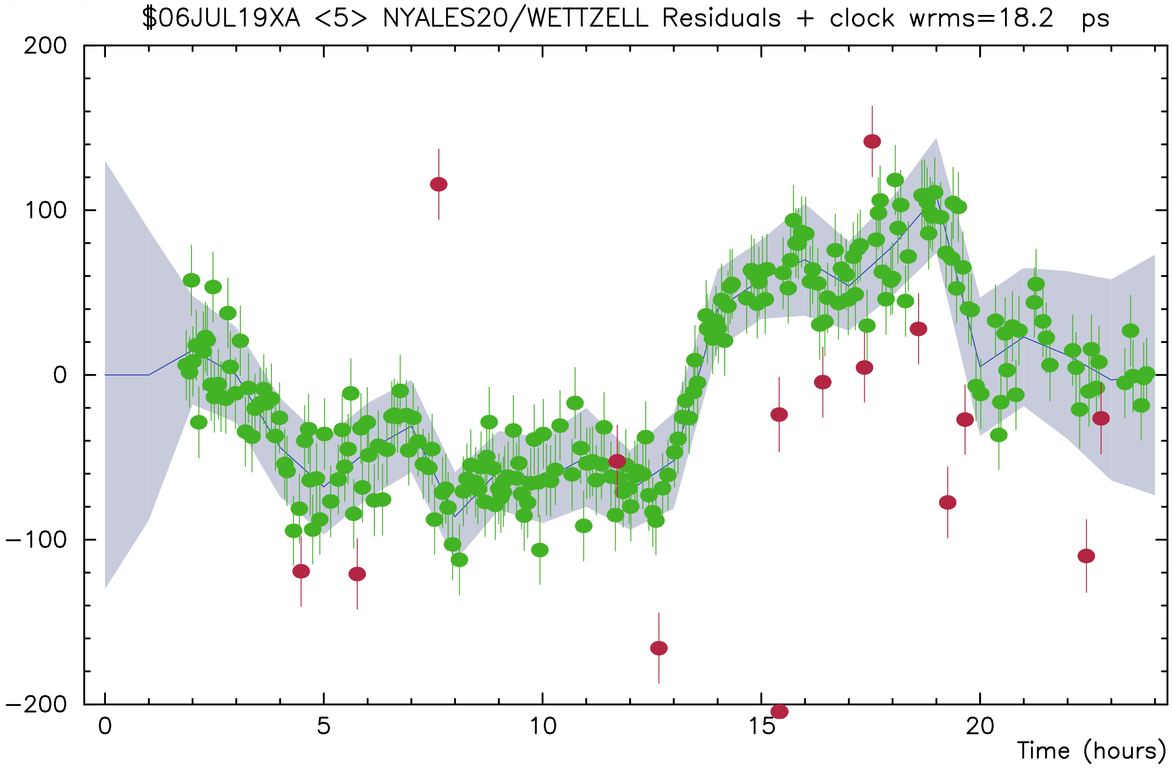


Figure 8: Group delay residuals(up) and phase delay residuals from the group delay solution (down). Group delay ambiguities are not resolved.



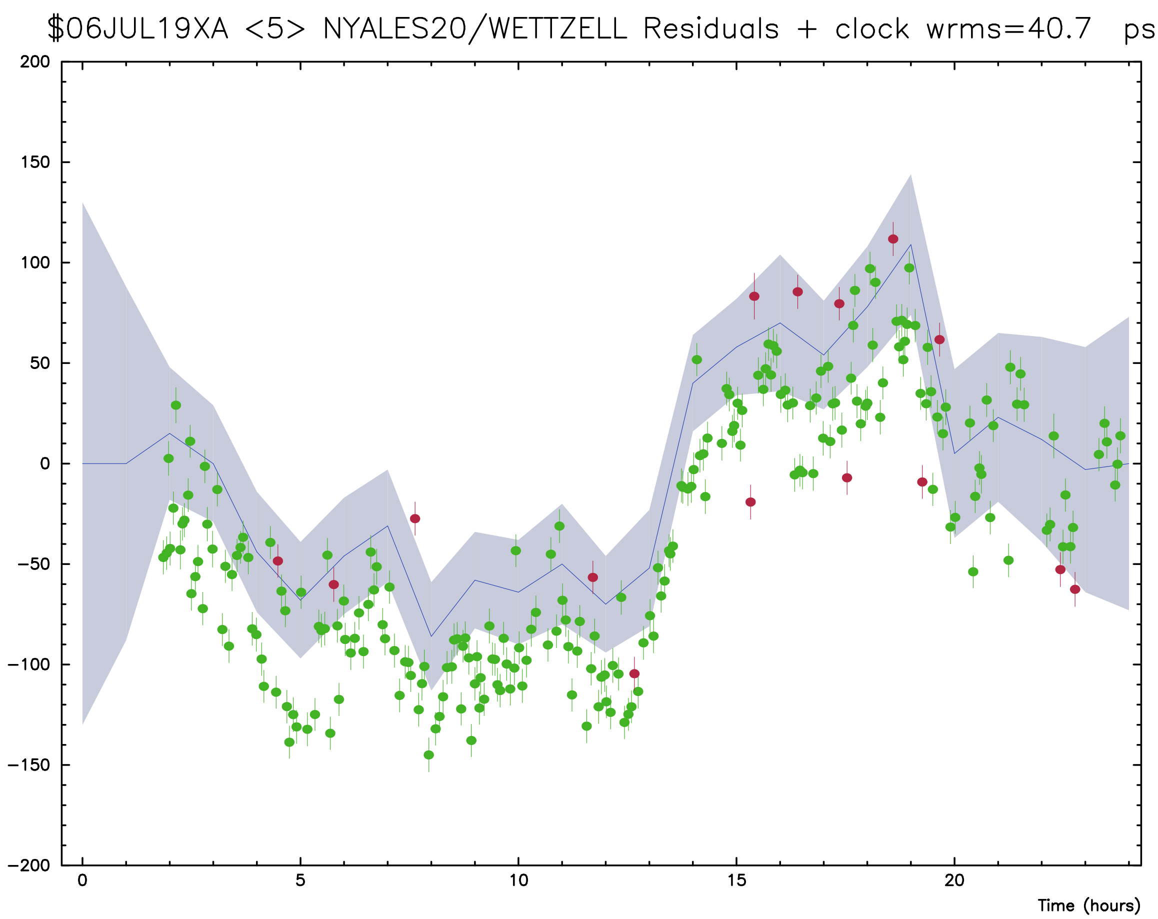


Figure 9: Group delay residuals(up) and phase delay residuals from the group delay solution (down). Group delay ambiguities are resolved. but their reliability is questionable.

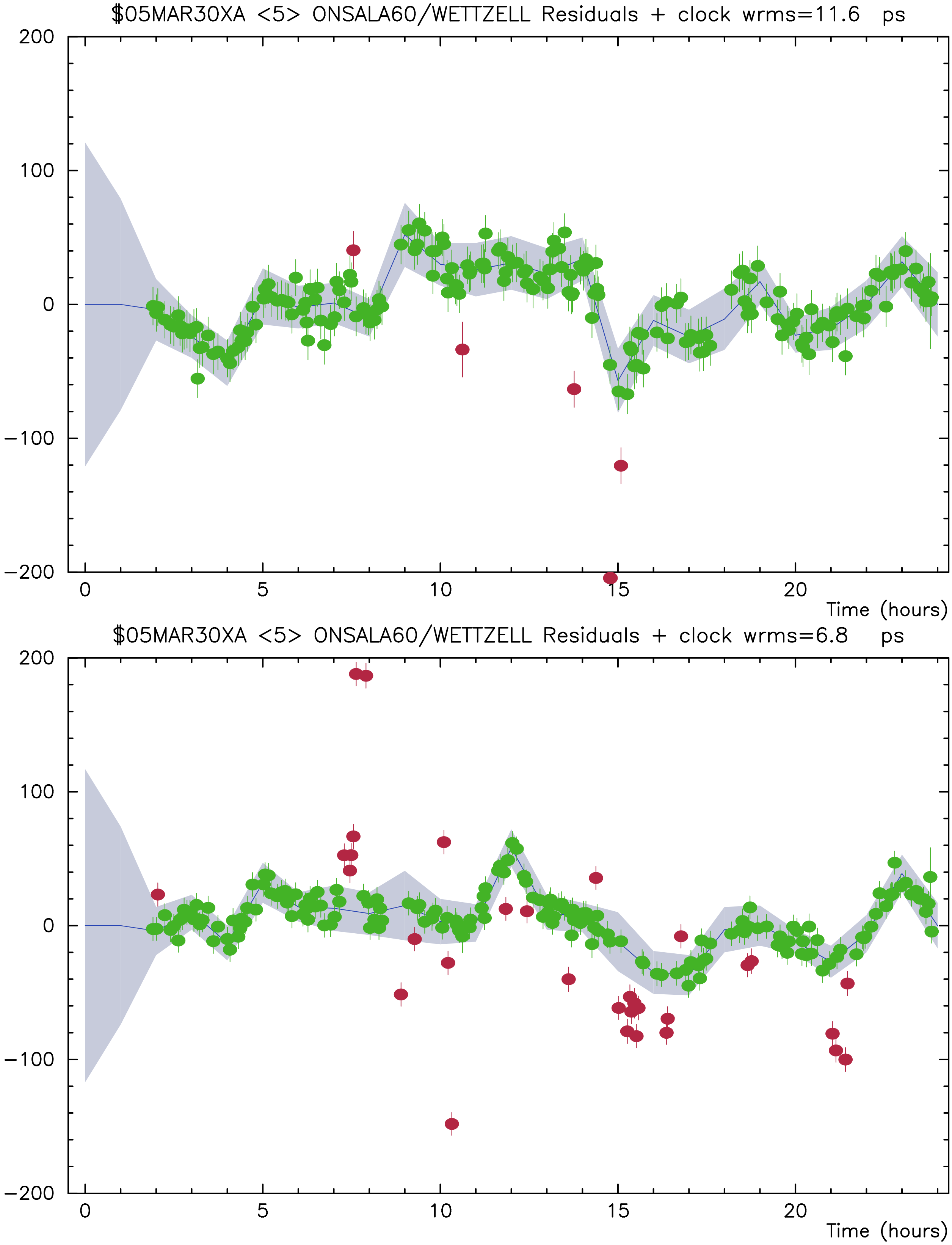


Figure 10: Phase delay ambiguity resolution function. Example of reliable phase delay ambiguity resolution function (lower plot) and unreliable function (upper plot).