# A NEW SOFTWARE FOR THE QUALITY CHECK OF GPS PERMANENT STATIONS DATA

Valerio BAIOCCHI*, Mattia CRESPI*, Grazia PIETRANTONIO**
*DITS-Area di Geodesia e Geomatica, Università di Roma "La Sapienza" – Via Eudossiana 18, 00184 ROMA, tel. +390644585097, fax +390644585515, e-mail:: mattia.crespi@uniroma1.it
**DITS-Area di Geodesia e Geomatica, Università di Roma "La Sapienza" – Via Eudossiana 18, 00184 ROMA, now at:
Istituto Nazionale di Geofisica e Vulcanologia – Via di Vigna Murata 605, 00143 ROMA, tel. +390651860266, fax +39065140303, e-mail: pietrantonio@ingv.it

## Introduction

Data quality check of GPS permanent stations is a crucial topic for all the applications where their observations can be employed, both in post-processing (geodesy, surveying, meteorology) and in real-time (navigation, precise positioning in RTK mode).

Therefore it's necessary to have analysis tools able to characterize data quality both from the point of view of the site where the station is installed (multipath and electromagnetic interferences) and from the point of view of the receiver precision.

Presently the most used software to perform these investigations is TEQC, a freeware package distributed by UNAVCO. This software, although rich of options, results inadequate in characterizing the receiver, since it investigates only the multipath on code observations and only in terms of amplitude. Moreover, all softwares for GPS data processing base the estimation of relevant parameters (coordinates, ambiguities, tropospheric delays) on the least squares method, for which the correct definition of the functional and the stochastic model is crucial; nevertheless, they consider code and phase observations as temporally uncorrelated, reaching an overestimation of parameter precisions.

We implemented a new software (PERMGPS-QC), currently still in beta version, devoted to define the stochastic properties of GPS permanent station observations and to investigate multipath characteristics. Our software correctly estimates observation precisions and it individuates mean amplitude and significant frequencies of the multipath.

PERMGPS-QC (fig. 1), implemented in C language, has been tested on simulated and real data, achieving meaningful results; the same data have been also processed with TEQC software (2002 Mar. 14 release) and results have been compared.

## 1 - Preliminary cycle-slip detection and parameter estimation

The input of the software is constituted by 2 RINEX files (related to 2 consecutive days) collected by a permanent station. The software performs a separate elaboration for each satellite, supposing that the observations are available on both frequencies.

The cycle-slips detection is the first step and is performed by checking the values of the ambiguity of the wide-lane combination ($N_W = N_{L1}-N_{L2}$). The signal corresponding to this ambiguity has a frequency $f_W$ = 347.82 MHz and therefore a wavelength $l_W$ = 86.2 cm, notably superior to those of L1 and L2 (about 19 cm and 24 cm respectively), what allows for an easier detection. Once found the sets of epochs with constant initial phase ambiguities, the software estimates unknown parameters (pseudorange ρ and ionospheric delay I epoch by epoch , initial phase ambiguities of L1 and L2) by a simple least-squares approach for each of this sets. In this first estimation we adopt a stochastic model given by a diagonal covariance matrix (temporally uncorrelated observations) and we assume that observable precisions are independent from satellite elevations.

**2 - Confirmation of cycle-slips presence**

At this point of the elaboration the program has a first estimation, epoch by epoch, of the parameters r, I and, for each set of epochs, of $N_{L1}$, $N_{L2}$ based on the presence of the suspicious cycle-slips previously found. In fact some of the suspicious cycle-slips could be not caused by a real loss of contact with the satellite, but by a high noise causing some spurious oscillations of the initial phase ambiguity. To assess their effective presence, the software analyses the trend of the ionospheric delay. The ionospheric delay, especially to our latitudes, shows a regular behaviour which may be modelled by a parabolic trend in the time and, since the loss of contact with the satellite cannot modify its regularity, if meaningful variations are visible in this trend, we are induced to exclude the presence of a cycle-slip. We can consider the ionospheric delay as a function of the time according to the relationship:

$$I = at^2 + bt + c$$

For each suspicious cycle-slip, the software performs three least squares estimation of parameters a, b, c on three different intervals, each constituted by n epochs: the first interval is constituted by n/2 epochs preceding the cycle-slip and n/2 epochs following it, the second and the third intervals are adjacent to the previous one (see fig. 2). The purpose of these estimations is the calculation of the variances of unit weight, since they are index of the goodness of the adopted model. Then the program, in order to verify the regularity of the ionospheric delay

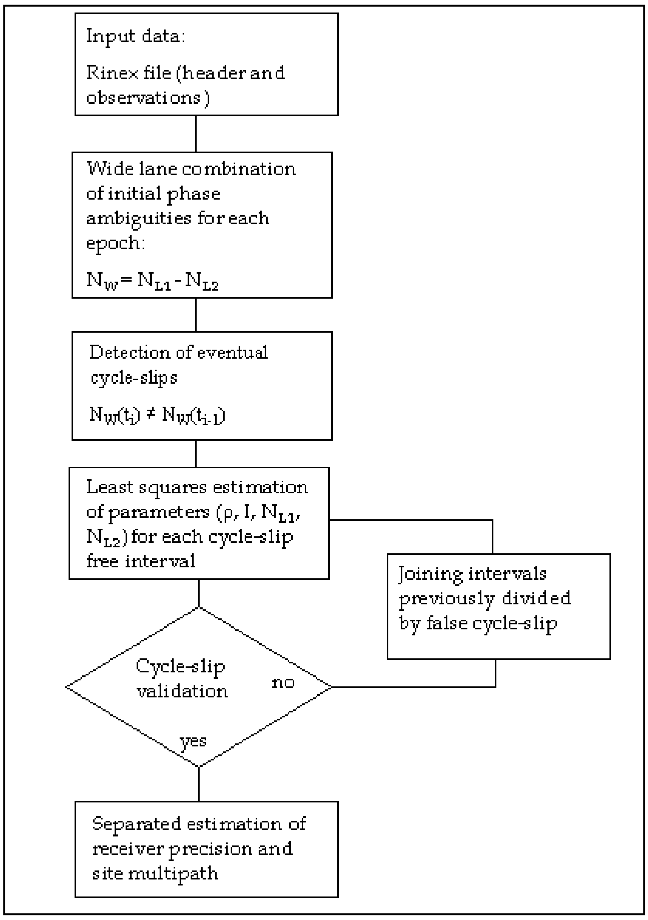


*Fig.1 – Flow chart of* PERMGPS-QC *software*

trend compares the variance of unit weight $s_0$ relative to the interval containing the suspicted cycle-slip with the average of the variances $s_m$ of the adjacent intervals. This is performed by a chi-square test on the model; the hypothesis is:

$$s_0 = s_m$$

If the test is not verified, the presence of the cycle-slip is excluded and the program

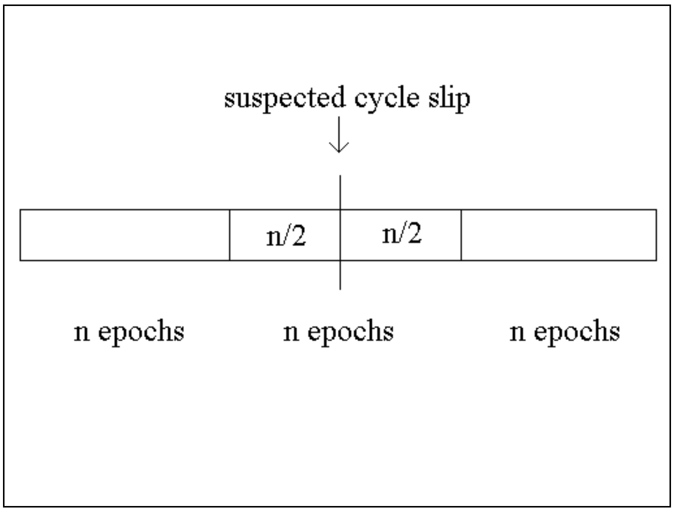


*Fig.2 – Sketch of cycle slip validation procedure*

performs again the least-squares estimation of all the parameters putting together the intervals previously separated by the false cycle-slip, otherwise the cycle-slip is confirmed.

**3 - The receiver precision**

Once found the actual cycle-slips, we perform definitive estimations of the parameters and consequently of the residuals for each observable.

In our functional model the residuals represent the sum of the value of the error due to the multipath and to the electronics of the receiver. Therefore, the analysis of the residuals ($U_1$,$U_2$) can give relevant information both on the characteristics of the multipath (MP) and on the stochastic properties of the receiver noise. To estimate the noise of the receiver it is necessary to remove the multipath component. This is possible since multipath is a systematic effect related to the site and to the particular satellite configuration of each observation epoch; therefore, since each satellite configuration repeats every day with an advance of about four minutes and our data are relative to a permanent station, it is possible to eliminate multipath effects on the residuals differentiating the residuals related to the same configuration:

$$U_1 = MP + v_1$$
$$U_2 = MP + v_2$$
$$U_2 - U_1 = MP + v_2 - MP - v_1 = v_2 - v_1 = \Delta v$$

where $v_1$,$v_2$ are the receiver errors.

Therefore the single difference in time of the residuals is free from multipath and may be used for receiver precision estimation. Once found all the differences, the software verifies by a test that they are not affected by bias and only contain the stochastic effect of the receiver noise. The positive result of the test confirms the constancy of the behavior of the receiver, considering that there are not systematic effects with a one-day period for the receiver. At this point, under the two hypothesis of constant behavior of the receiver (previously verified) and of null temporal correlations among the observables collected in two consecutive days (well known from literature and also verified), we can estimate the precision of each observable. Finally the covariance functions of the residuals are computed under the hypothesis of a second order stationary stochastic process (Barzaghi, Sansò 1983) .

**4 - Multipath**

If we sum, instead of subtracting, the residuals related to the same satellite configuration in two consecutive days, we can get the root mean square of multipath:

$$U_2 + U_1 = MP + v_2 + MP + v_1 = 2MP + v_2 + v_1$$

$$\sigma^2_{U1+U2} = 4\sigma^2_{MP} + 2\sigma^2_{V}$$

The program checks, as before, that in the series of the sum of the residuals there are not other systematic effects. Subsequently, the program individuates the characteristic frequencies of the multipath. This is important especially for short survey (for example, during a RTK survey). In fact, if the observation interval is lower than the period of the multipath, the average of multipath is not zero and so measures are affected by a sistematic error. So the software estimates the power spectrum of the series of residual differences and sums using the Lomb periodogram (Lomb, 1976) since comparing them it is possible to underline the frequencies of the receiver noise (high, $10^{-1}$,$10^{0}$ Hz) and of the multipath (low, $10^{-3}$,$10^{-2}$) Hz It has to be underlined that in TEQC software the whole residual is attributed to the multipath on code measurements and therefore it is impossible to characterize the receiver precision and to evaluate multipath on phase measurements. Moreover, TEQC does not perform any spectral analysis on the multipath.

**5 - Software tests**

First we performed tests of the software with simulated data, achieving good results:

- simulation with "clean" data (without noise and multipath)
- simulation with data affected by a known noise (gaussian noise, temporally uncorrelated) and without multipath.

Then we performed some tests with real data coming from our permanent station MOSE, Rome equipped with a Trimble 4000 SSI receiver; the most significant ones are:

- processing of 24 (+24) hours data, (sampling rate 30 s) and comparison with software TEQC
- processing of 1 (+1) hour (sampling rate 1 s).

In the first case (see tab.1), the estimated sqms are of the order of some tenth of mm for phase observations and from some centimeters to few decimeters for code observations, underlining in such case a noisier behavior for P2 code (obtained by cross-correlation among the two codes in order to remove the military code Y) in comparison to C/A. Multipath mean values are lower than a millimeter for phase observations, while they are about 0.1- 0.2 m for C/A code and about 0.2- 0.4 m for P2.

| | C/A | P2 | L1 | L2 |
|---|---|---|---|---|
| $\sigma_V$ (*m*) | 0.05 | 0.20 | 0.0003 | 0.0002 |
| $\sigma_{MP}$(*m*) | 0.12 | 0.26 | 0.0005 | 0.0004 |

*Tab.1- Processing of 24 (+24) hours data: estimated sqms and multipath mean values (sat 13) estimated by PERMGPS-QC*

As regards the power spectrum, for all the observables the dominant frequency of the multipath is about 0.03Hz (period about 15 minutes). About the correlation functions, the behaviors are again different for phase and code measurements: the first ones, and P2 code, do not show significant correlations for lag time longer than 30 seconds, while C/A code results significantly correlated and it seems also that a periodic phenomenon, hard to be explained, remains in the differences of the residuals.

As regards the comparison with TEQC, it is important to underline the inconsistence of the different values of multipath in 2 consecutive days; such values result in some cases similar, in others significantly different from the ones estimated by PERMGPS-QC (tabs. 1 and 2).

| | 1st day | 2nd day |
|---|---|---|
| $\sigma_{MP}$(C/A) (*m*) | 0.22 | 0.41 |
| $\sigma_{MP}$(P2) (*m*) | 0.83 | 0.91 |

*Tab.2- Processing of 24 (+24) hours data: multipath mean values (sat 13) estimated by TEQC*

In the second case, it has to be highlighted that significant periodicities (due to the multipath) are evident at about 100 seconds. Moreover covariance functions confirm the substantial uncorrelation for L1, L2 and P2 observations and the significant correlation for C/A. It has been shown besides that, in presence of critical data (malfunction of the receiver), the software TEQC attributes its cause to a sudden (unrealistic) increase of the multipath, while it is dealing with an increase of the noise, as correctly highlighted by our software.

In the appendix we reported graphics related to the processing of 24 (+24) hours data.

**6 - Conclusions and future perspectives**

We implemented a new software (PERMGPS-QC) for the quality check of GPS permanent station data, allowing both an investigation on the receiver (estimation of observable precisions and correlations) and on the multipath (mean amplitude and frequency). The new software, implemented in C language, was tested on simulated and real data, comparing the results with those achieved by the software TEQC. We clearly put in evidence the inconsistence of the results of TEQC, due to the hypothesis of coincidence of the code noise with the multipath: in fact, also data of consecutive days sometimes show different values of multipath. Presently the software PERMGPS-QC is still in beta version and in the next future will be investigated the iterative procedure for outliers detection and observation variance estimation and the effect of elevation dependent observation precisions in order to assess the package and to make it available to the GPS community.

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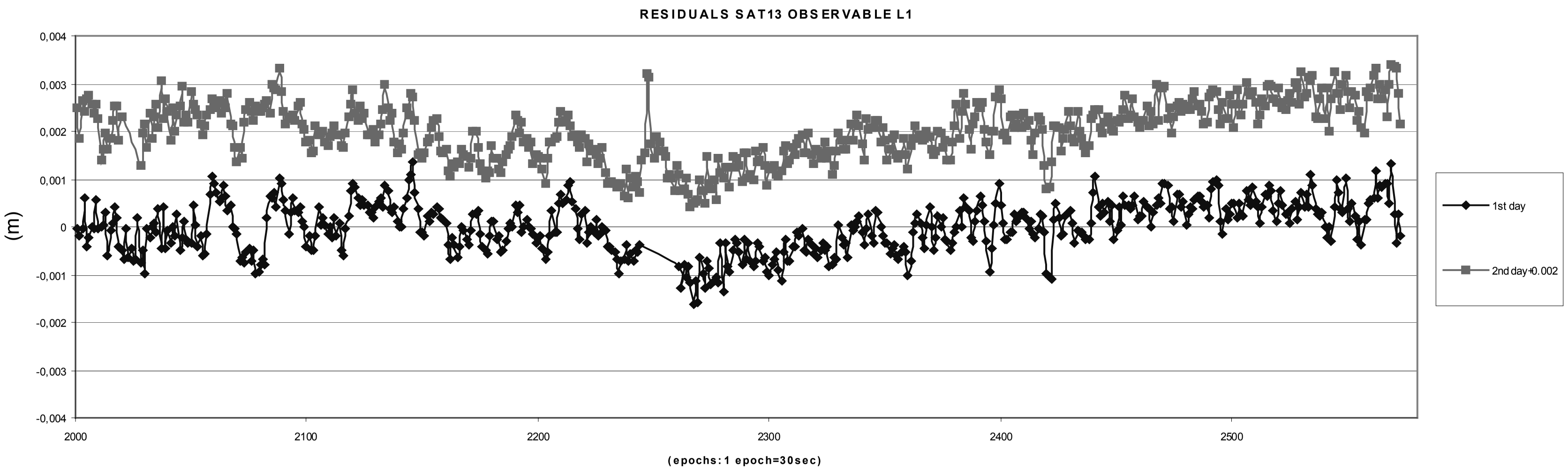
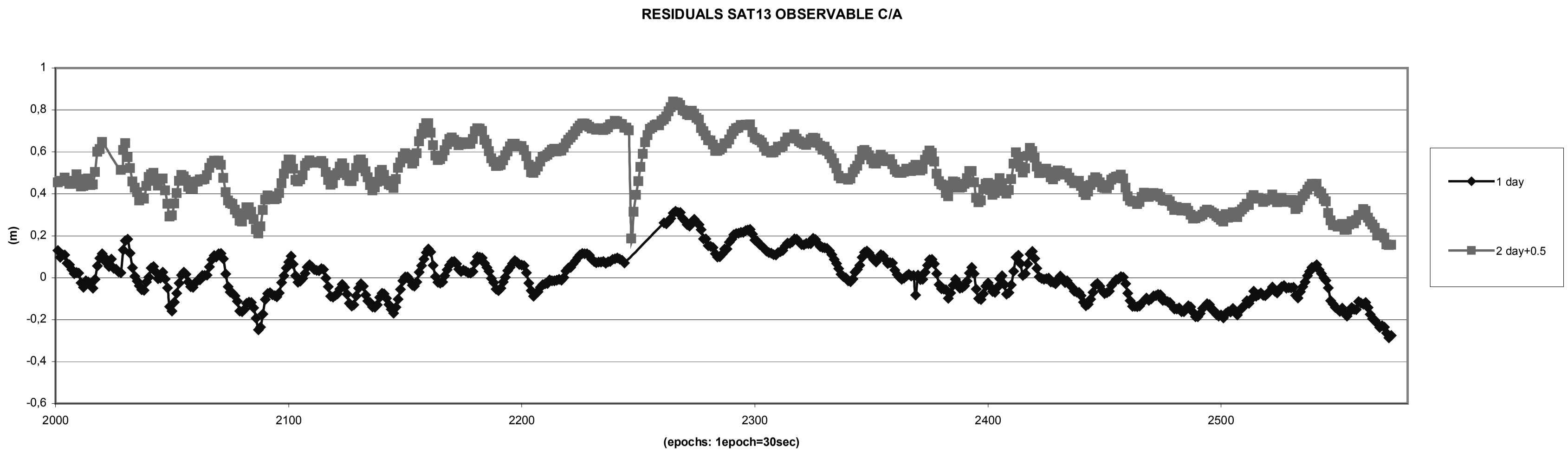
# *APPENDIX*

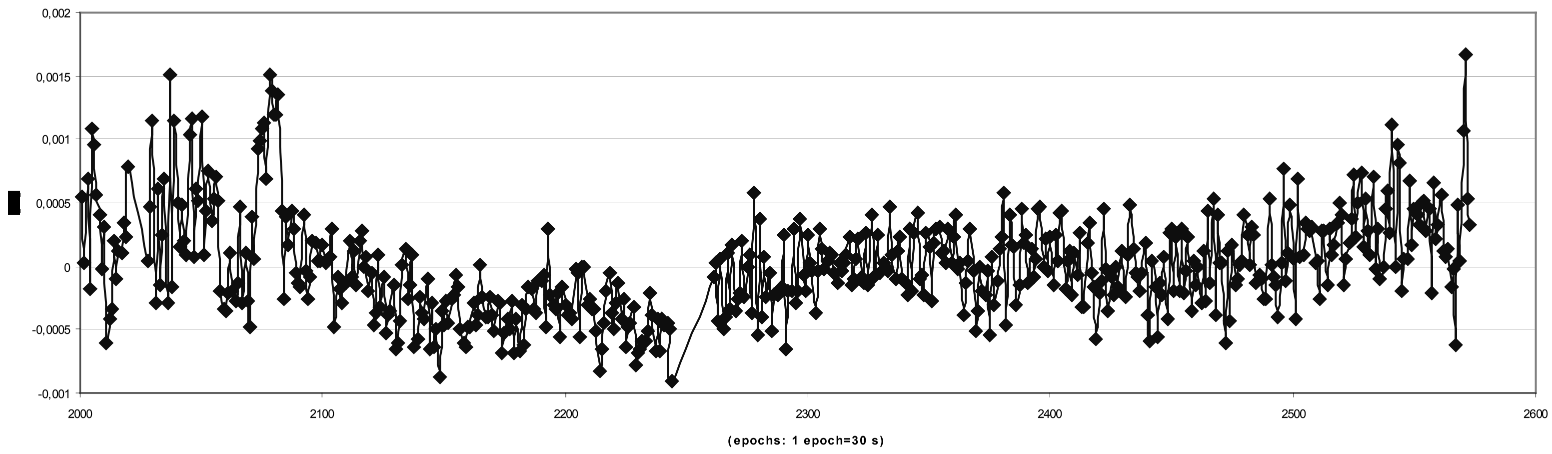


RESIDUALS SAT13 OBSERVABLE L1
(m)
0,004
0,003
0,002
0,001
0
-0,001
-0,002
-0,003
-0,004
2000
2100
2200
2300
2400
2500
(epochs: 1 epoch=30sec)
1st day
2nd day+0.002

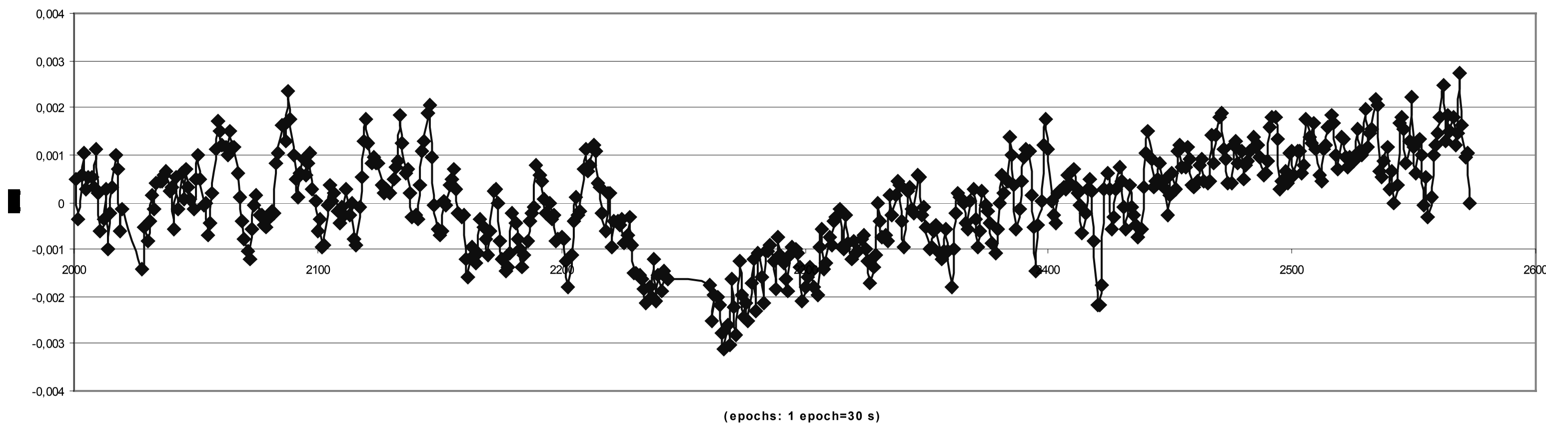



RESIDUALS SAT13 OBSERVABLE C/A
(m)
1
0,8
0,6
0,4
0,2
0
-0,2
-0,4
-0,6
2000
2100
2200
2300
2400
2500
(epochs: 1epoch=30sec)
1 day
2 day+0.5

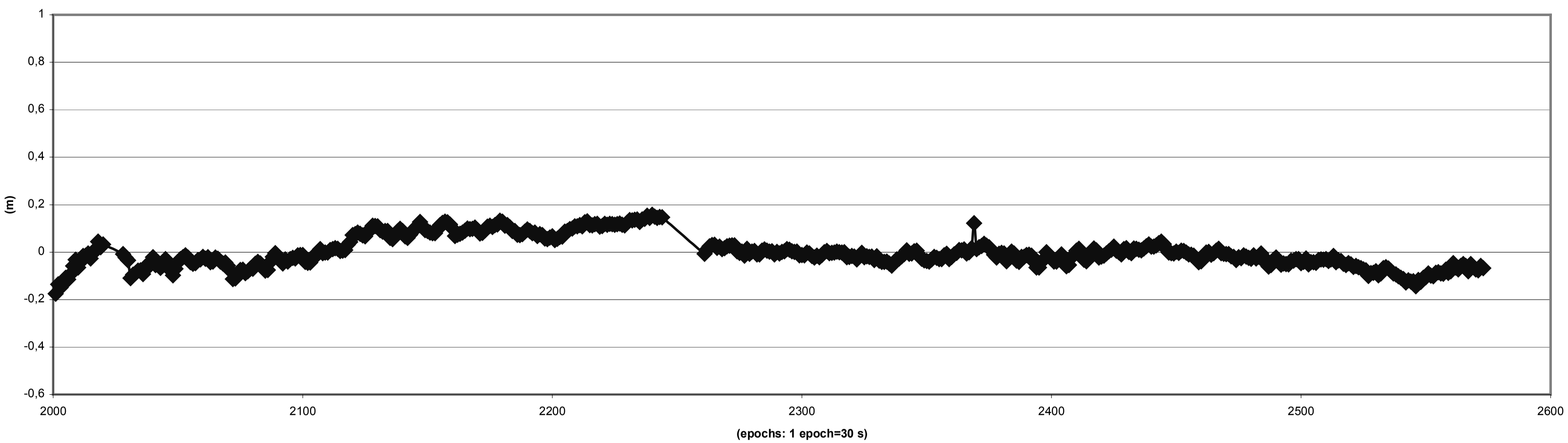
DIFFERENCE OF RESIDUALS SAT13 OBSERVABLE L1



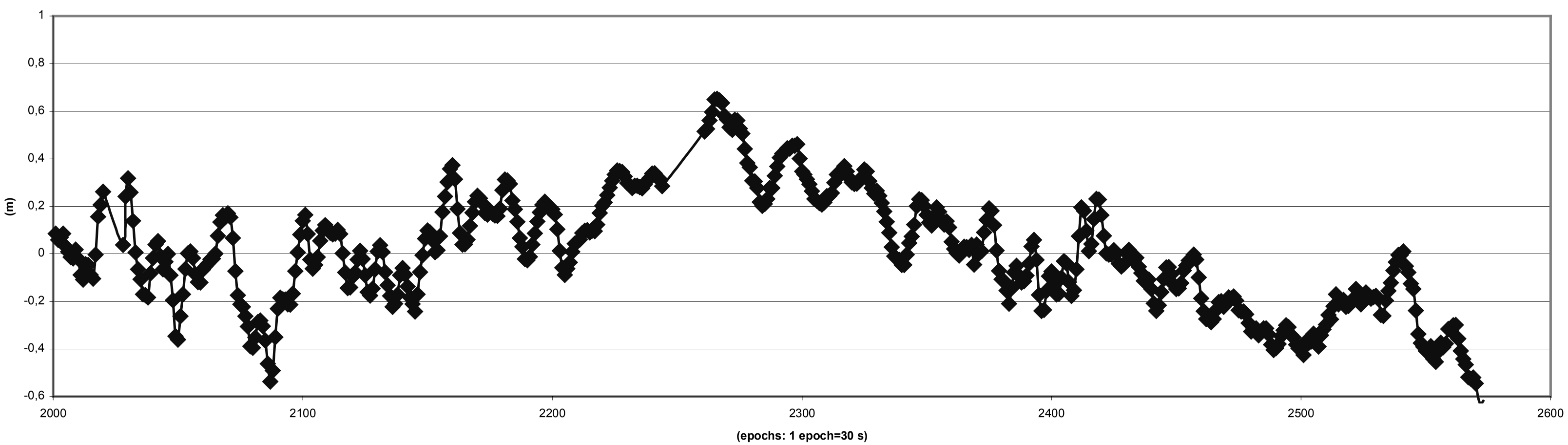

SUM OF RESIDUALS SAT13 OBSERVABLE L1



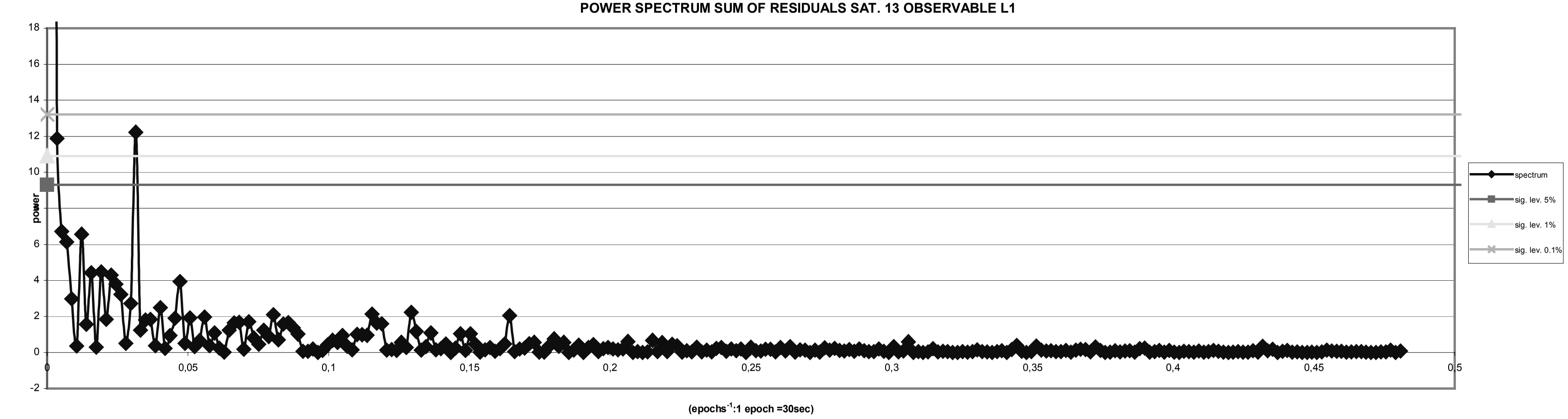
## DIFFERENCE OF RESIDUALS SAT13 OBSERVABLE C/A



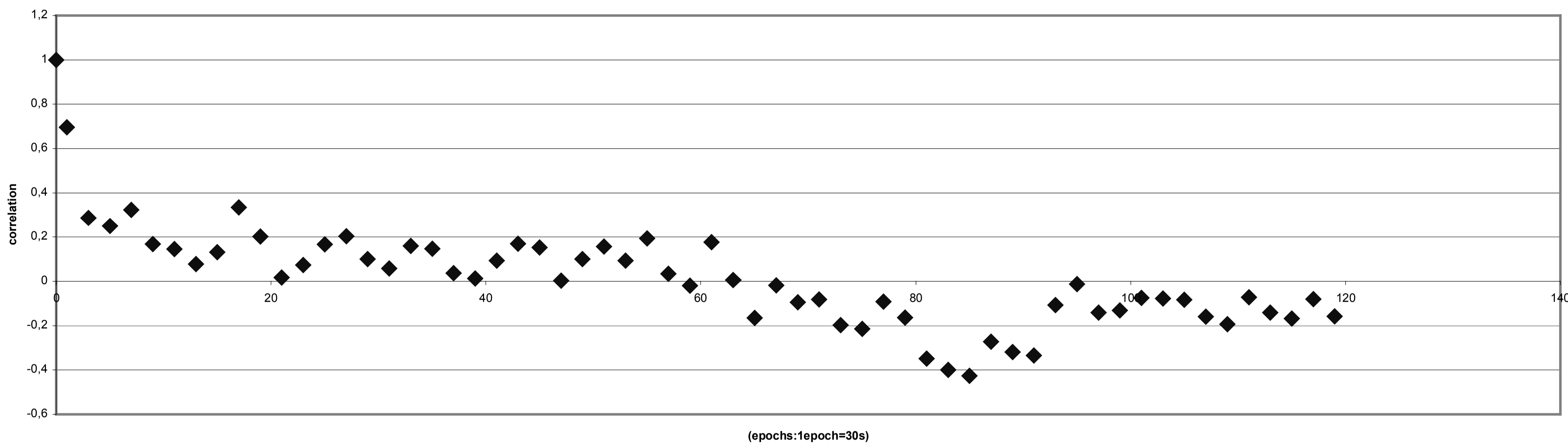

## SUM OF RESIDUALS SAT13 OBSERVABLE C/A



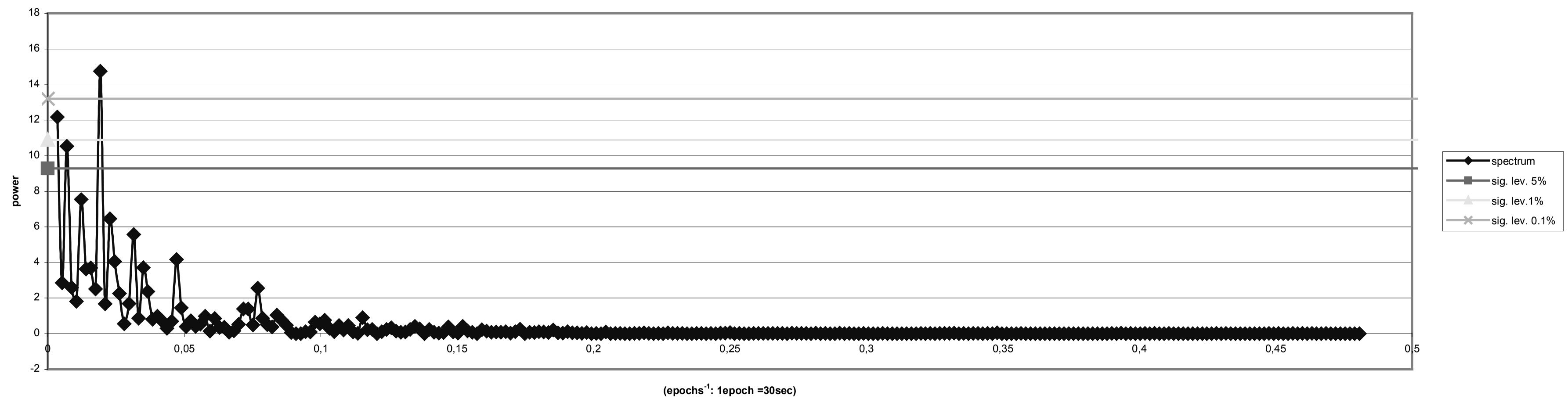
POWER SPECTRUM SUM OF RESIDUALS SAT. 13 OBSERVABLE L1




AUTOCORRELATION FUNCTION RESIDUALS SAT13 OBSERVABLE L1



POWER SPECTRUM SUM OF RESIDUALS SAT13 OBSERVABLE C/A




AUTOCORRELATION FUNCTION RESIDUALS SAT13 OBSERVABLE C/A