H-maser i74 acts like good wine!

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ABSTRACT

After making more than 182 Millions of measurements, one per second over an almost uninterrupted period of 5.8 years, of the Time Interval difference between the 1PPS (one peak per second) delivered by our Timing GPS receiver (single frequency) and the 1PPS delivered by the primary frequency Standard of the VLBI station of Medicina, i.e. our i74 Hydrogen Maser, it can be estimated that its ***Frequency Drift has been reduced by a factor of 4*** along its life until now. The overall reliability of the machine has been almost perfect, not having undergone any downtime. We have only applied some frequency retuning (less than once per year) in order to keep the station Clock Offset within the optimal values suggested by the VLBI Correlator people. It can be noted that we have generally preferred to avoid any time resynchronization to limit the intrinsic uncertainty associated with such operations. Of course the previous result assumes that the GPS chain has been kept within the same level of Frequency Drift over that period of time, so that the improvement is substantially related only to the "aging" of the H-Maser itself. This hypothesis is very well funded being the GPS a military/civil navigation system, operationally granted for public use and accurately monitored worldwide by all metrological Institutes.

We, as Italians who love to eat *good slow food,* are used to compare any product that improves with time to "**good wine**", that is to say the only one that does not transform into bad vinegar.

How to fit the VLBI station Clock Offset (CO)

We have already described in detail the configuration of our measuring setup [1], designed to satisfy not only the minimum requirements needed to speed up the fringe search operation at the VLBI correlator, but also suitable for extracting more info from it. In particular it can be shown that the second order term in fitting the CO data over time is independent from the choice of the initial point of the fit or the number of points used to compute the fit (apart from an obvious reduction of its statistical uncertainty, when the input data set is made by experimental points following the same parabolic slope). This last means that if the “aging” of the H-Maser changes with time (that is to say, its frequency drift changes), the evolution over time of this parameter can be monitored by computing successive different second order fits of the CO. The amount of data of each batch of data shall be chosen in order to follow the time scale evolution expected for the atomic standard under consideration: form our experience we have chosen batch periods of about three months each. Even after the analysis we present here, this choice represents a good compromise between the typical instabilities of the measurements itself (mainly due to the GPS over very short time periods) and the typical “aging” of the H-Maser. As a matter of facts, it is very well known that this last is mainly related to the aging of the Temperature sensor that controls the temperature (and then the dimension) of the microwave cavity where the Hydrogen atoms are stimulated to emit, under the maser action, the characteristic line at 1.4 GHz, correspondent to the quantum energy step from the first excited state of the atom to its ground state.

Believe it or not, the cavity temperature has to be kept constant over the years of operation of the H-Maser at the level of just fractions of milli Kelvins. This figure comes out when one takes into account the shielding factors of the many temperature passive and active shields surrounding the microwave cavity, the temperature expansion coefficient of the material of which this last is made of and finally of the “pushing factor” of its resonant dimensions on the final sinusoidal frequency delivered to the following electronic receiver. By the way remember that the usage of the microwave cavity is compulsory needed for acting as an amplifying resonator of the extremely weak signal coming out from the maser process (*= coherent disexcitation of quasi-free hydrogen atoms contained in the bulb moreover kept under extremely clean vacuum*).

The i74 data set collected at the Medicina T&F lab

In Fig. 1 you can see the overall pattern of the CO over the last 5.8 years, as measured in our laboratory. The plot shows the experimental points as diamonds over the thin EXCEL fit of the second order. At a glance is evident the very high reliability of our system by noting that missing data (no diamonds but only the thin fit) are extremely few. From our history records, we can confirm that these last were related to suspensions of data taking, by our own will, and not due to a downtime of the H-Maser. Also from so many fit plots we have the experimental evidence that the second order fits approximate the data extremely well being their correlation coefficients made by from two to four nines (0.99 - 0.9999).

The EXCEL program (see Fig. 2) is intended to analyze the accumulated data in order to extract the past evolution parameters of the i74 H-Maser but also to predict what can be expected for the CO in the far future. It is pretty evident that, being the data shape an almost perfect parabola, one can choose the operating parameters in such a way to keep the CO with the sign (lead/lag) and absolute value within the desired range suggested by the Correlator people.

As it is well known, the H-Maser is ***NOT*** a primary atomic time standard, also because it utilizes an electronic synthesizer to *linearly* set the final output signal frequency. In order to set such synthesizer, our strategy is to compute the two linear (first order) fits that best match: one the past parabola data and the second, the expected future parabolic data set. The simple difference, between those last two values, can be applied as the algebraic sum to the old frequency settings of the synthesizer as the best estimate applicable to it in order to get the wanted future trend.

[In the old H-Maser models that figure had to be first transformed into machine units by converting the thumbwheel units of the synthesizer into frequency increments of the output signal]. Nowadays it is sufficient to update the so called *value of DDS* in the H-Maser settings.

With this procedure we are confident to predict the best estimate of the future behavior of the CO, because we utilize the most recently evaluated operating parameters of the H-Maser (second order fit), together with the new synthesizer settings that best match past records with future expectations.

Fig.3 shows the evolution of the second order term over the life of the i74 H-maser located in the T&F lab of Medicina. **It started from 9.4 E-16 s/s^2 at the delivery time (May 2013) in Medicina to the present value of 2.3 E-16 s/s^2**. As explained in the abstract, the improvement in these figures can be totally assigned to our H-Maser but their absolute values rely more specifically on the choice of the Department of Defence (DoD in USA) to closely track UTC, as they claim to have done since the operational start of the system. It must be remembered here that the H-Maser acts, in this measuring configuration also as a “flying wheel”, so we can be confident against outliers.

Each of the following pages (from fig 3 to fig 25) reports the second order fit of each consecutive, (approximately) 3 months periods, from to 15/05/2013 to 31/12/2018.

Here we report the typical appearance of the Excel file, that we use for making the computations:

- the first four RED columns are dedicated to the input data;
- the other red figures are input quantities that you can modify at your will to fit past data;
- the top left box reports all the two fit results, with the associated statistical parameters;
- the top right green box allows to input (in red) the expected future behavior;
- the brown box below shows the new synthesizer settings to be assigned to the DDS;
- all data are in seconds, sec/sec, s/s^2, except for the selection of the rows that are in hours. Just for completeness row 7 reports the above parameters in: per day units.

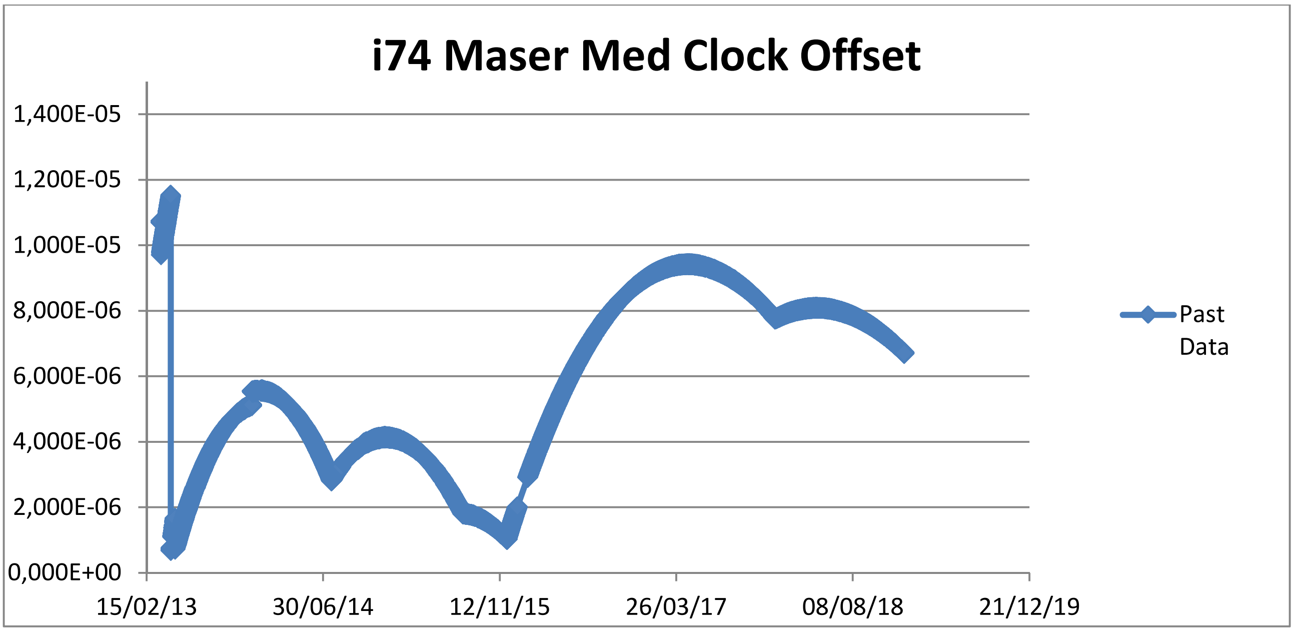


Fig.1 The total data set of the Clock Offset measurements over more than 5 years.

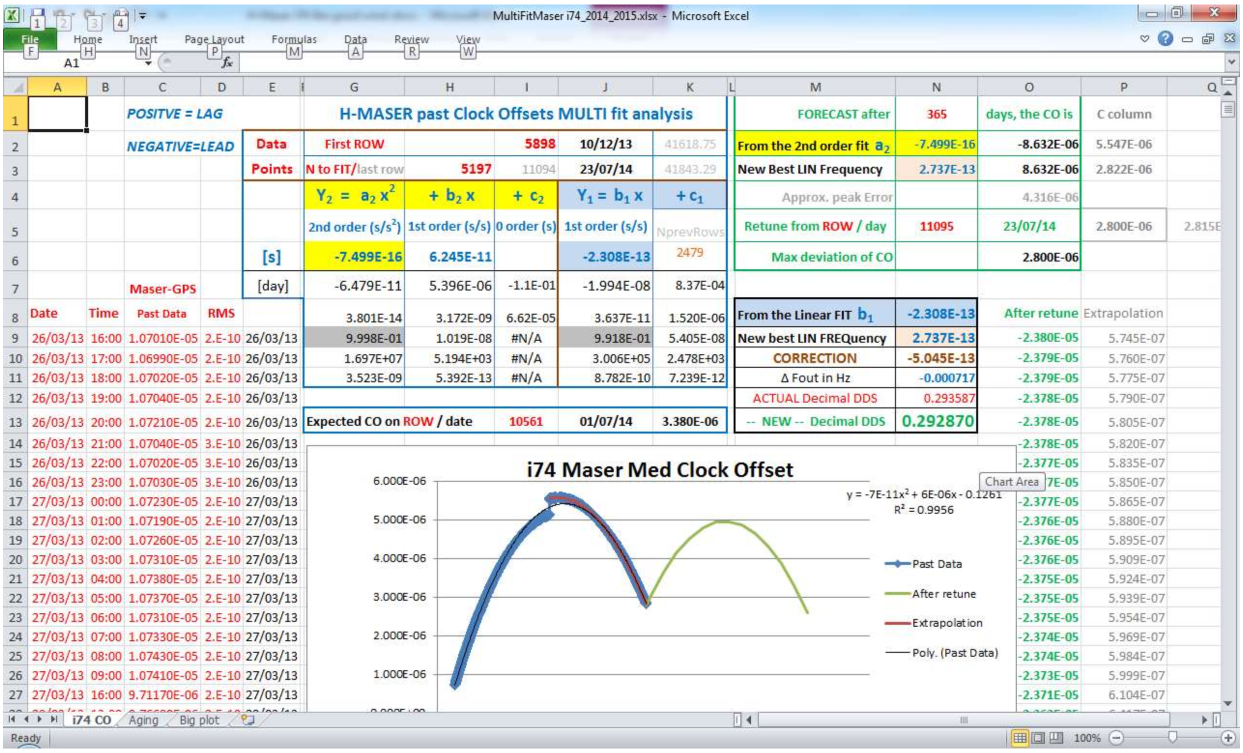


Fig 2. How the EXCEL program looks like. The (yellow) G6 cell hosts the II order term.

	BATCH DA	A	2nd order (s/s^2)
1	15/05/2013	13/08/2013	-9,4086E-16
2	14/08/2013	10/12/2013	-8,6333E-16
3	10/12/2013	18/03/2014	-8,0956E-16
4	18/03/2014	23/07/2014	-7,6420E-16
5	23/07/2014	30/10/2014	-6,4037E-16
6	30/10/2014	28/01/2015	-6,5352E-16
7	28/01/2015	29/04/2015	-5,6434E-16
8	30/04/2015	30/07/2015	-4,9360E-16
9	30/07/2015	02/12/2015	-4,9538E-16
10	03/12/2015	01/04/2016	-4,3558E-16
11	01/04/2016	02/07/2016	-4,3344E-16
12	03/07/2016	05/10/2016	-3,8729E-16
13	06/10/2016	05/01/2017	-3,4720E-16
14	06/01/2017	05/04/2017	-3,2529E-16
15	06/04/2017	10/07/2017	-3,5424E-16
16	11/07/2017	15/10/2017	-2,9258E-16
17	16/10/2017	30/12/2017	-3,1549E-16
18	01/01/2018	31/03/2018	-2,9485E-16
19	01/04/2018	30/06/2018	-2,9522E-16
20	01/07/2018	30/09/2018	-2,5122E-16
21	01/10/2018	31/12/2018	-2,3840E-16

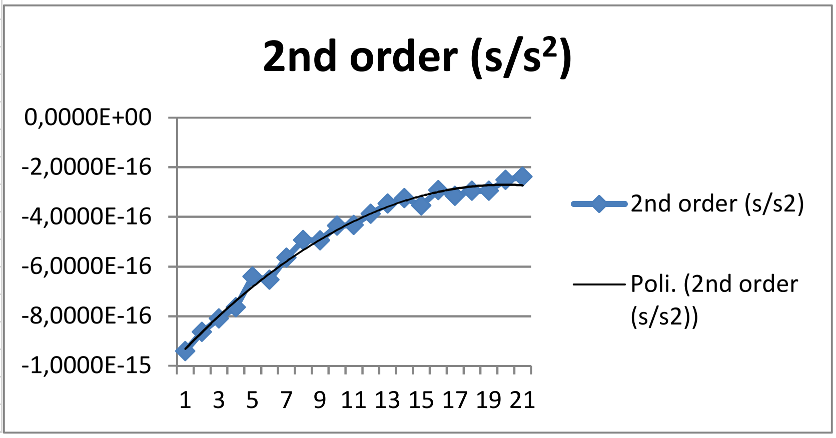


Fig 3. Graph of the evolution over 5 years of the II order coefficient (freq. drift)

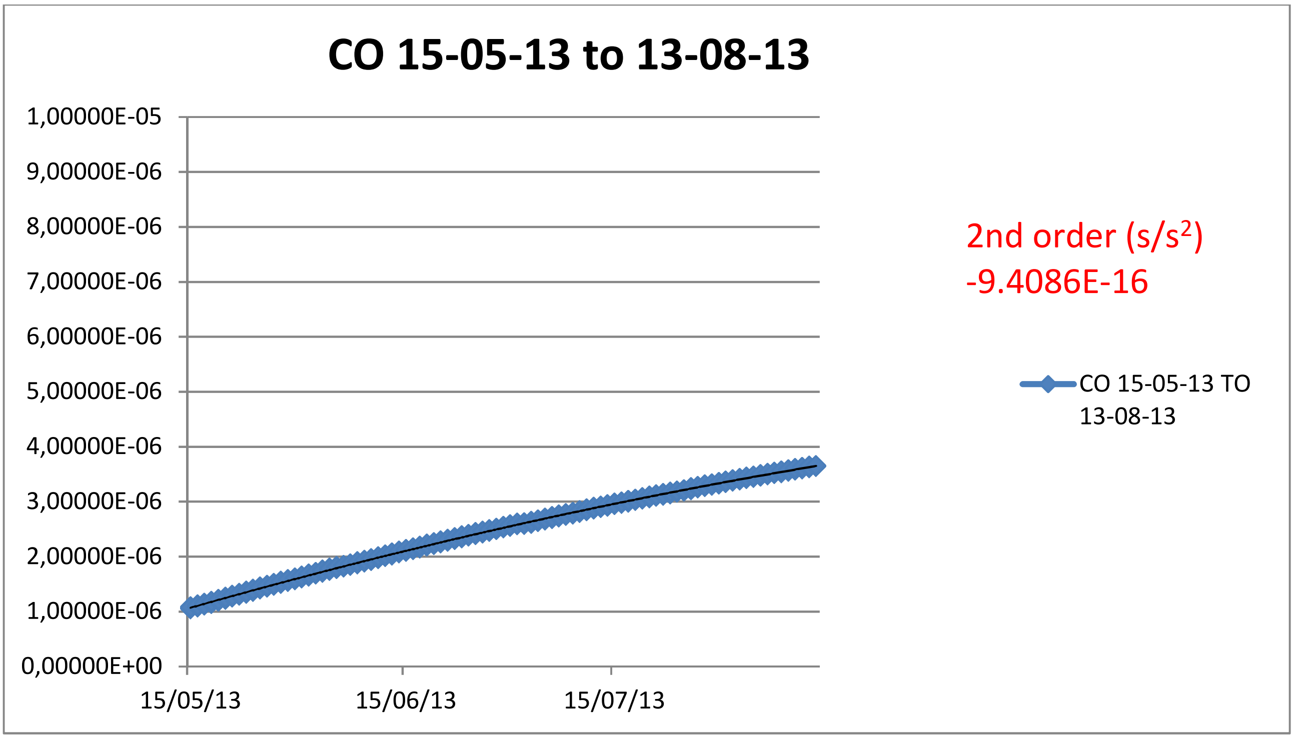
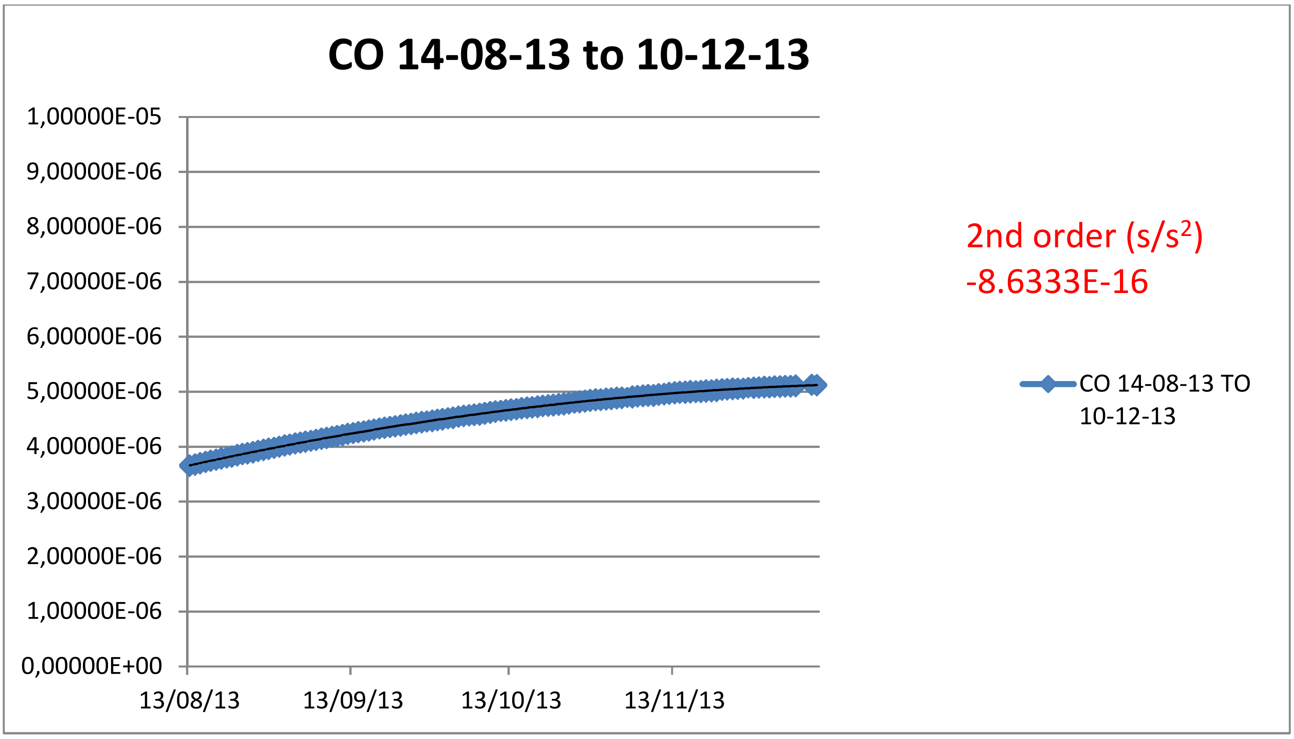


Fig 4. Successive data batches, each 3 months long (approximately)



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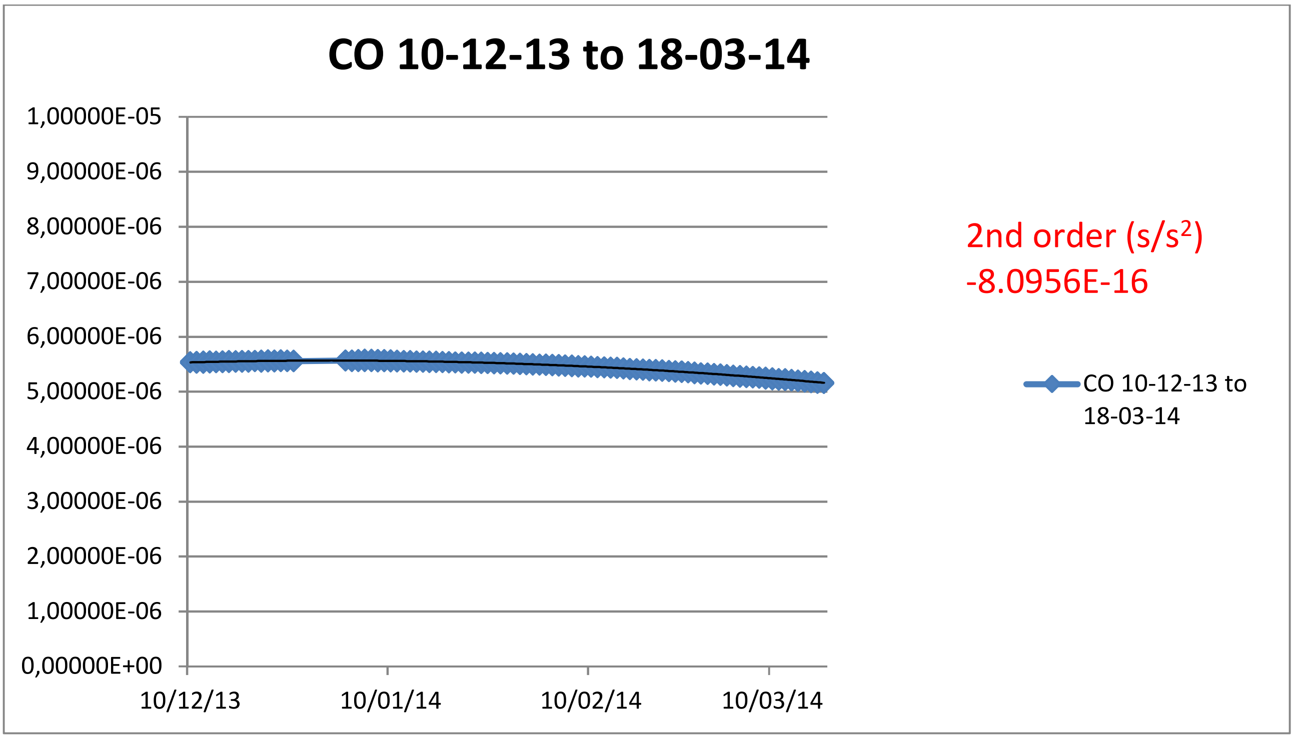

Fig 6. Successive data batches, each 3 months long (approximately)

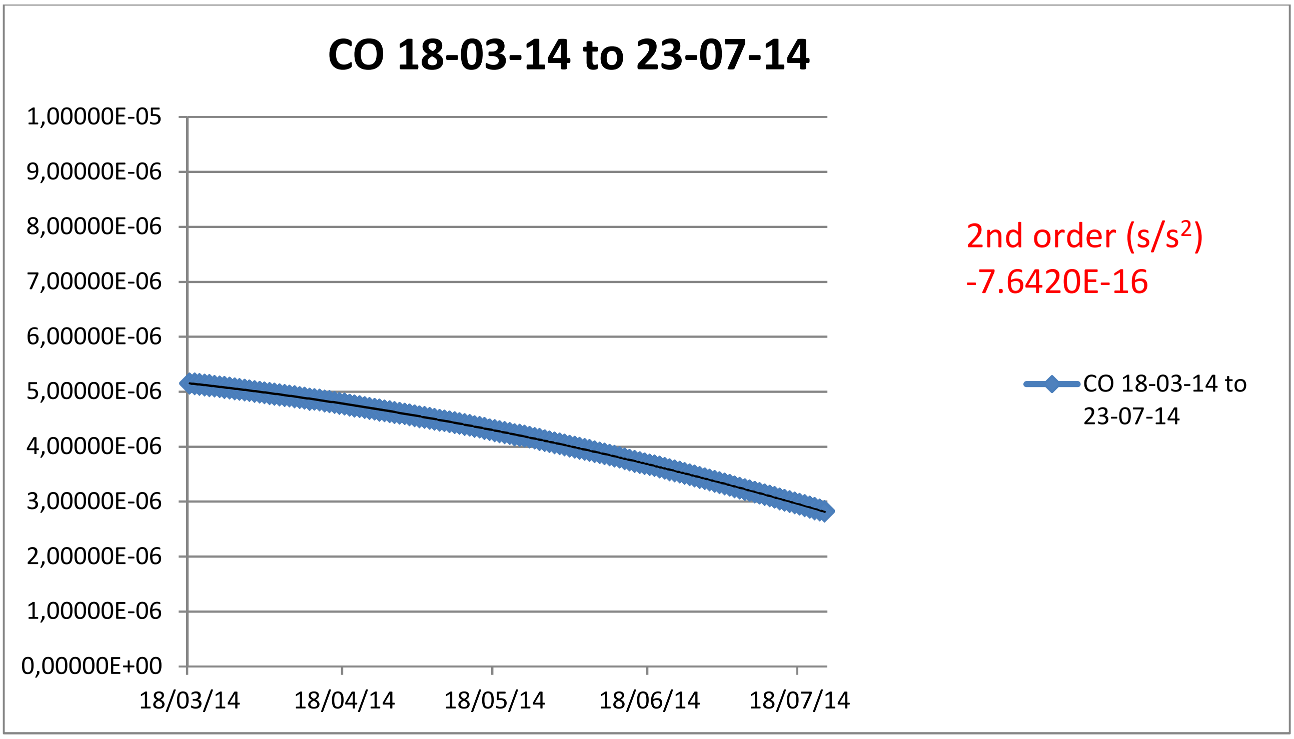

Fig 7. Successive data batches, each 3 months long (approximately)

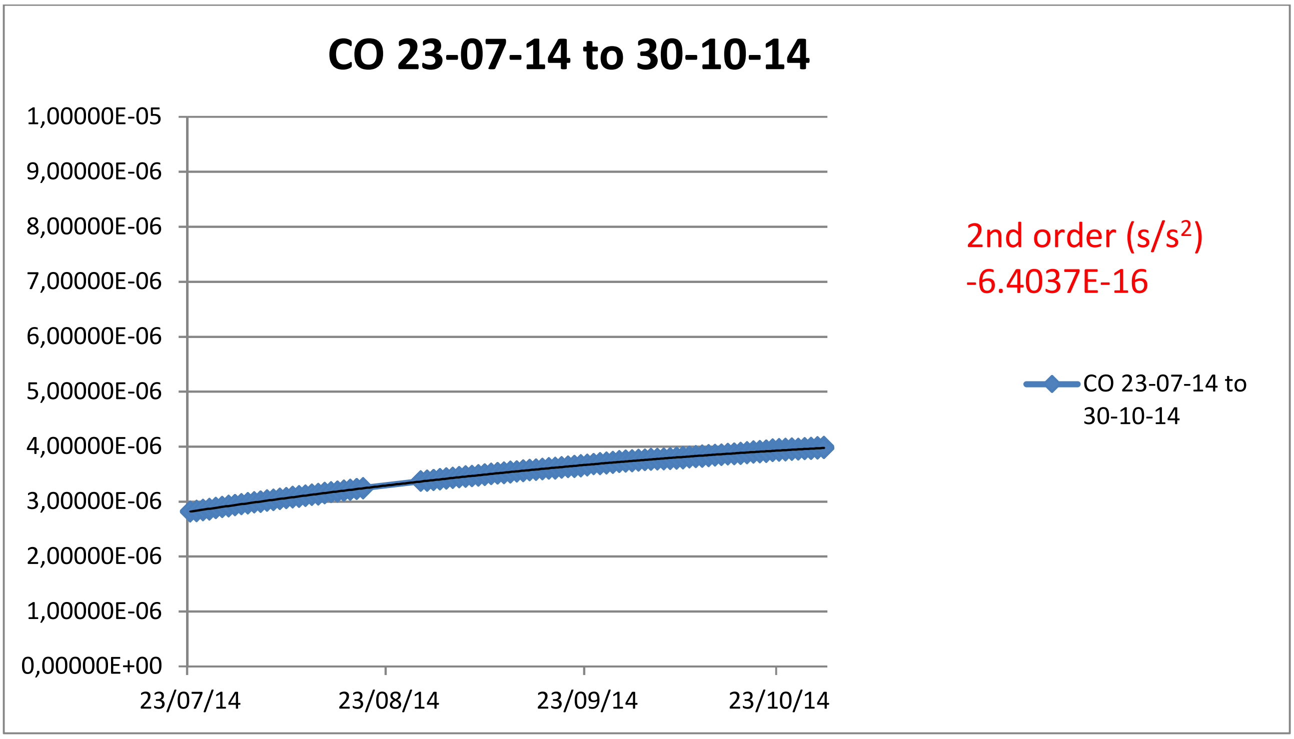

Fig 8. Successive data batches, each 3 months long (approximately)

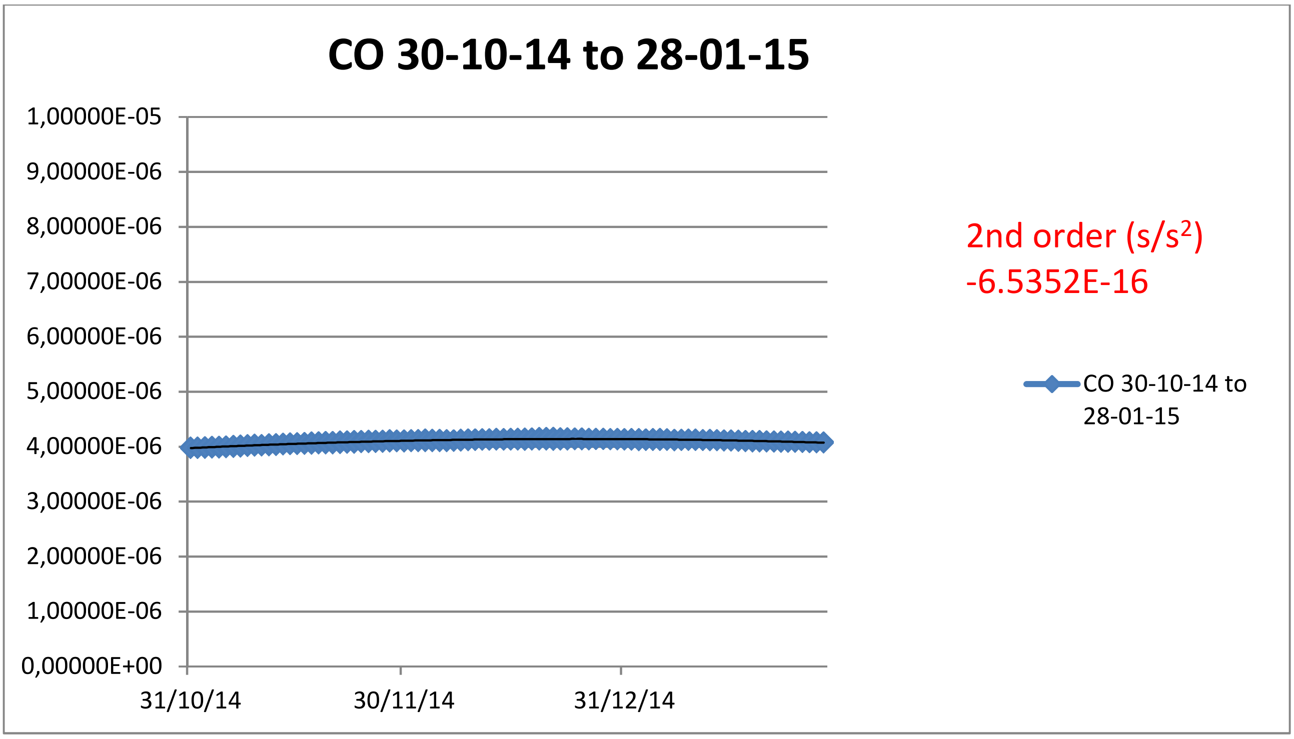

Fig 9. Successive data batches, each 3 months long (approximately)

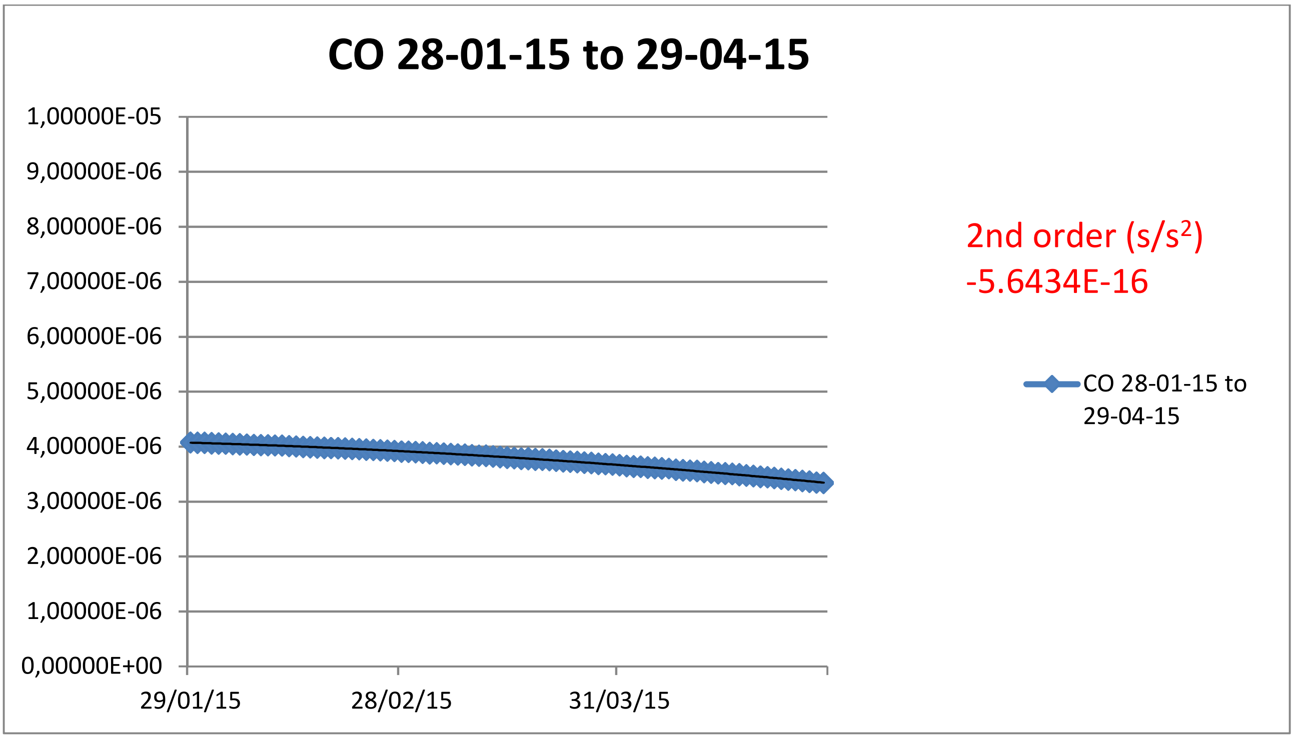

Fig 10. Successive data batches, each 3 months long (approximately)

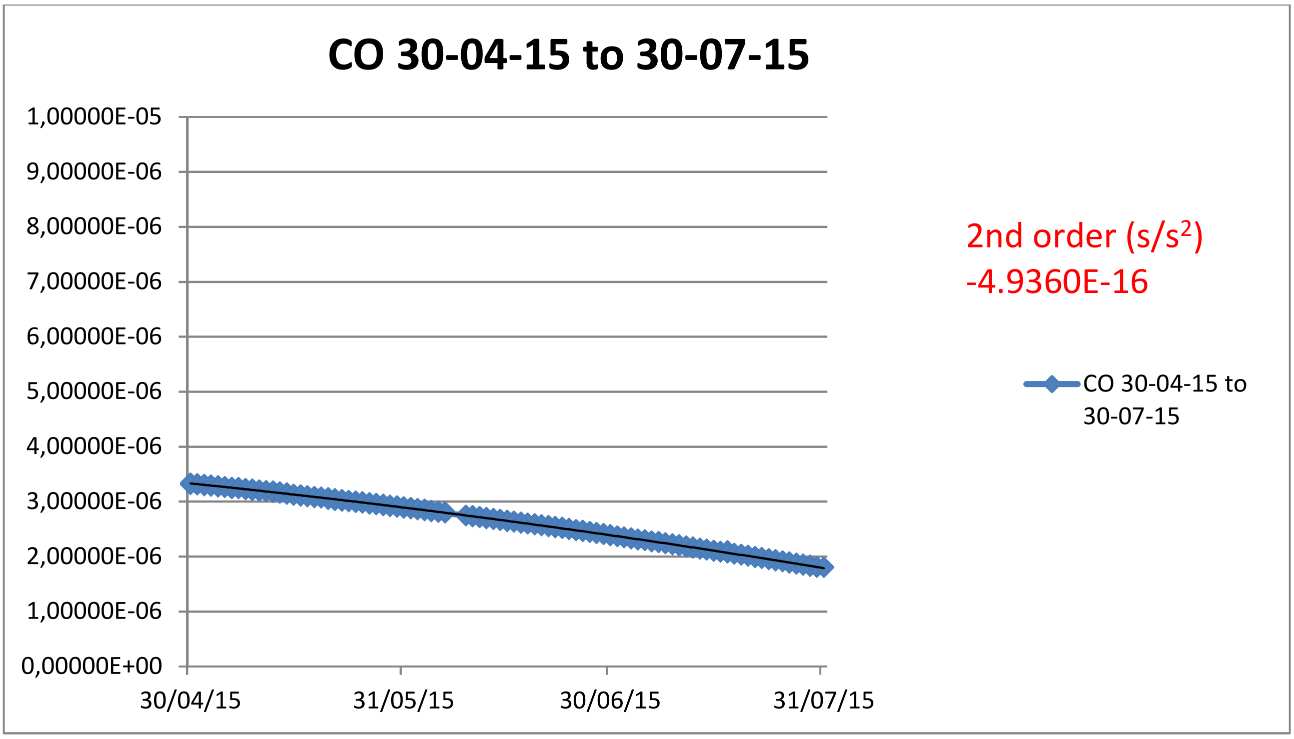

Fig 11. Successive data batches, each 3 months long (approximately)

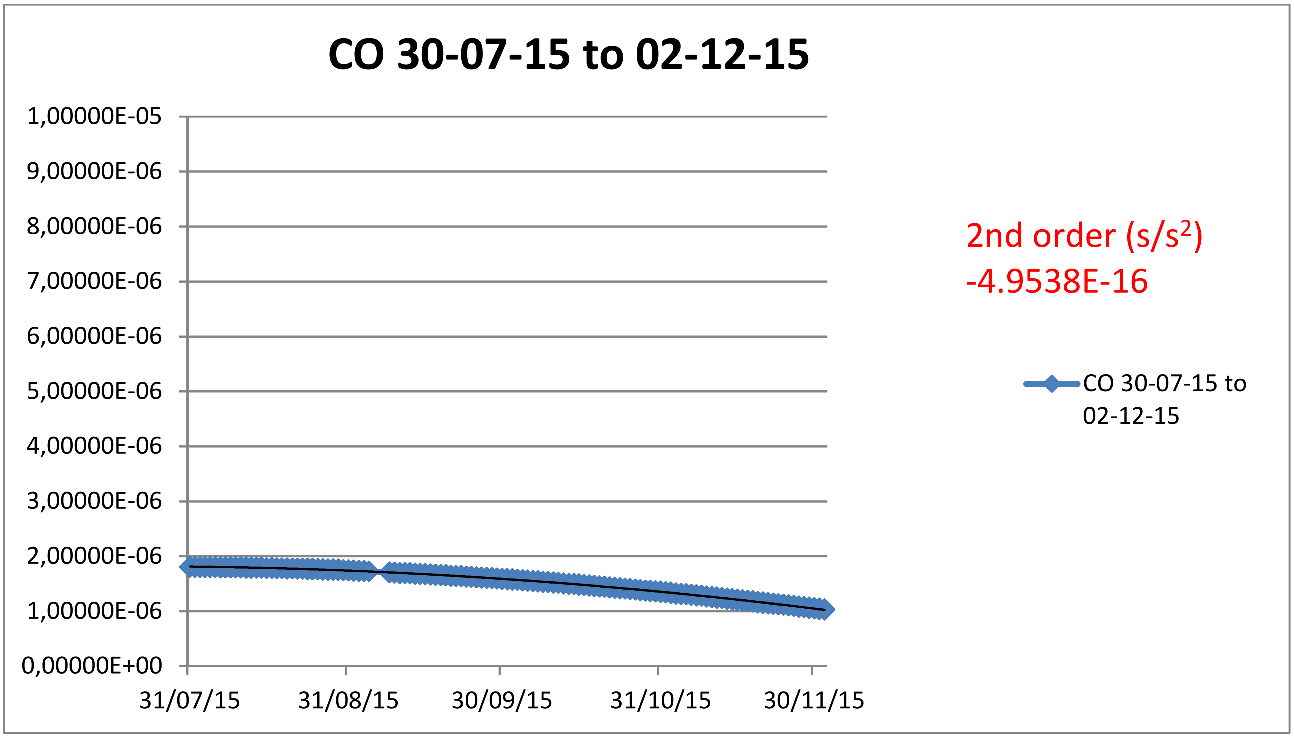

Fig 12. Successive data batches, each 3 months long (approximately)

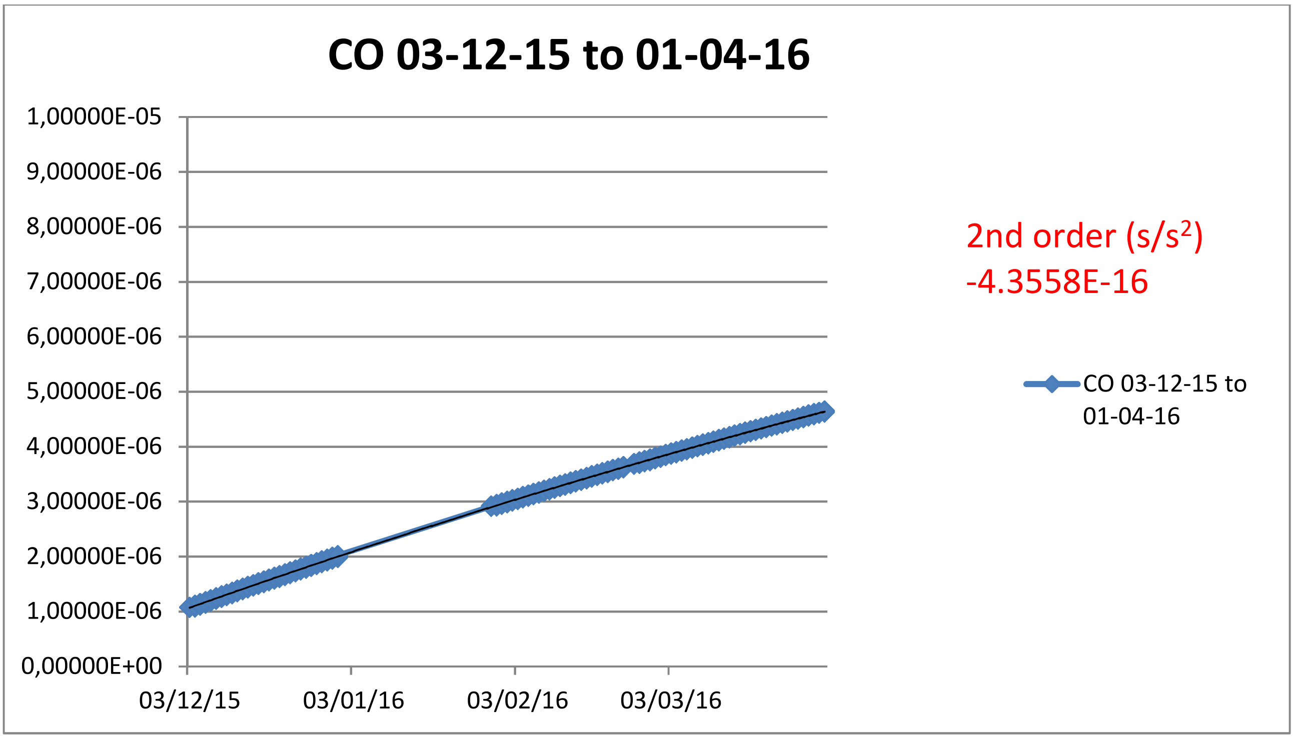

Fig 13. Successive data batches, each 3 months long (approximately)

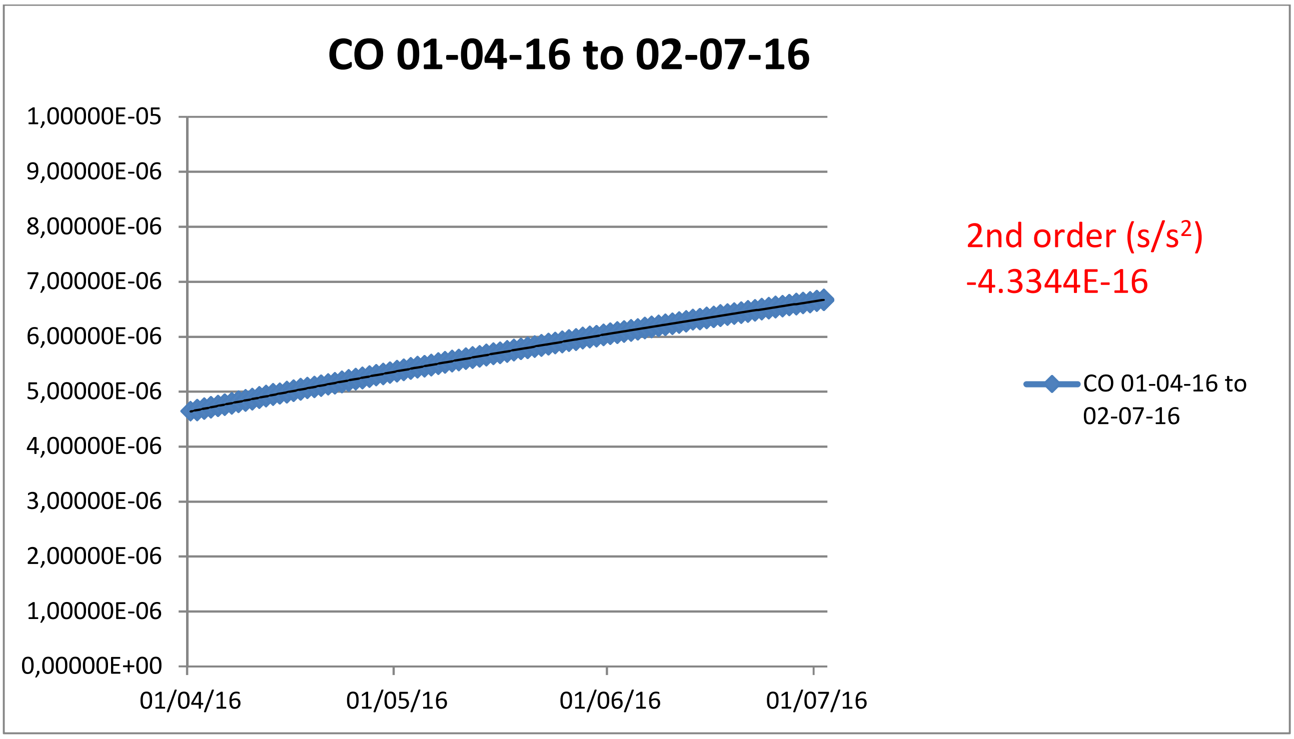

Fig 14. Successive data batches, each 3 months long (approximately)

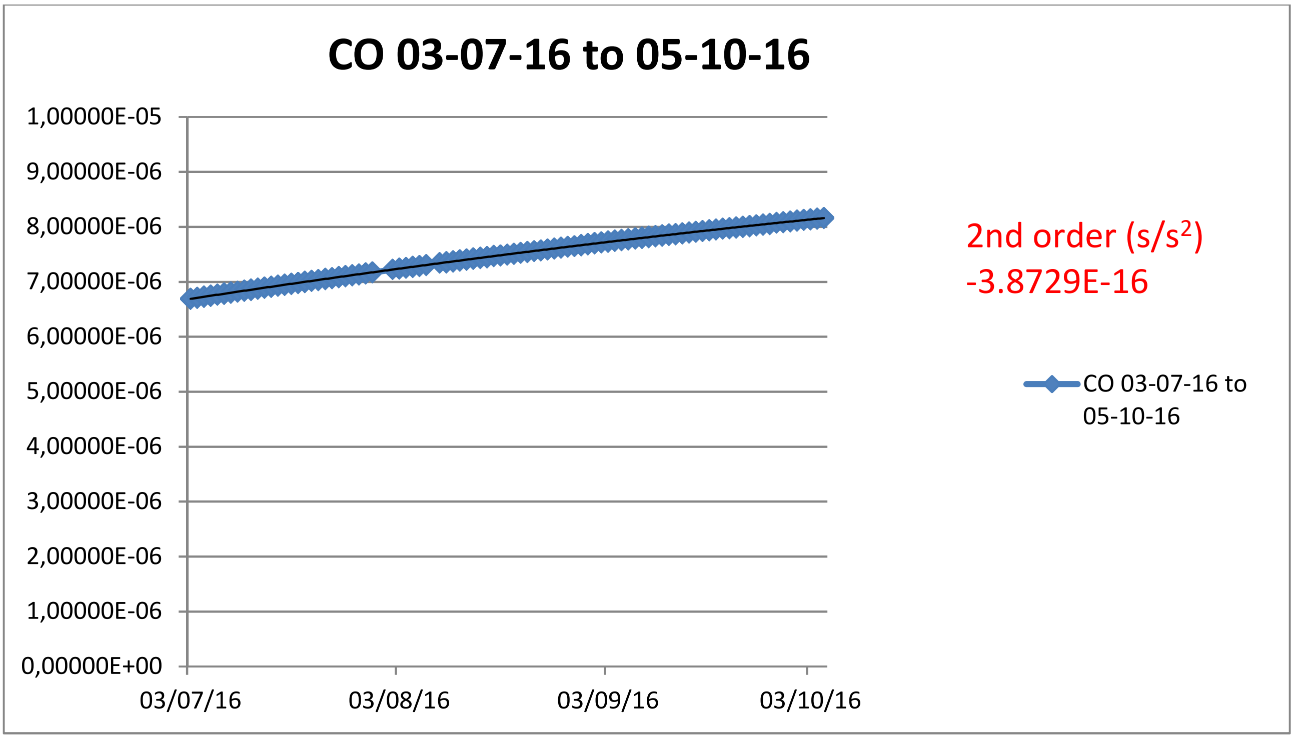

Fig 15. Successive data batches, each 3 months long (approximately)

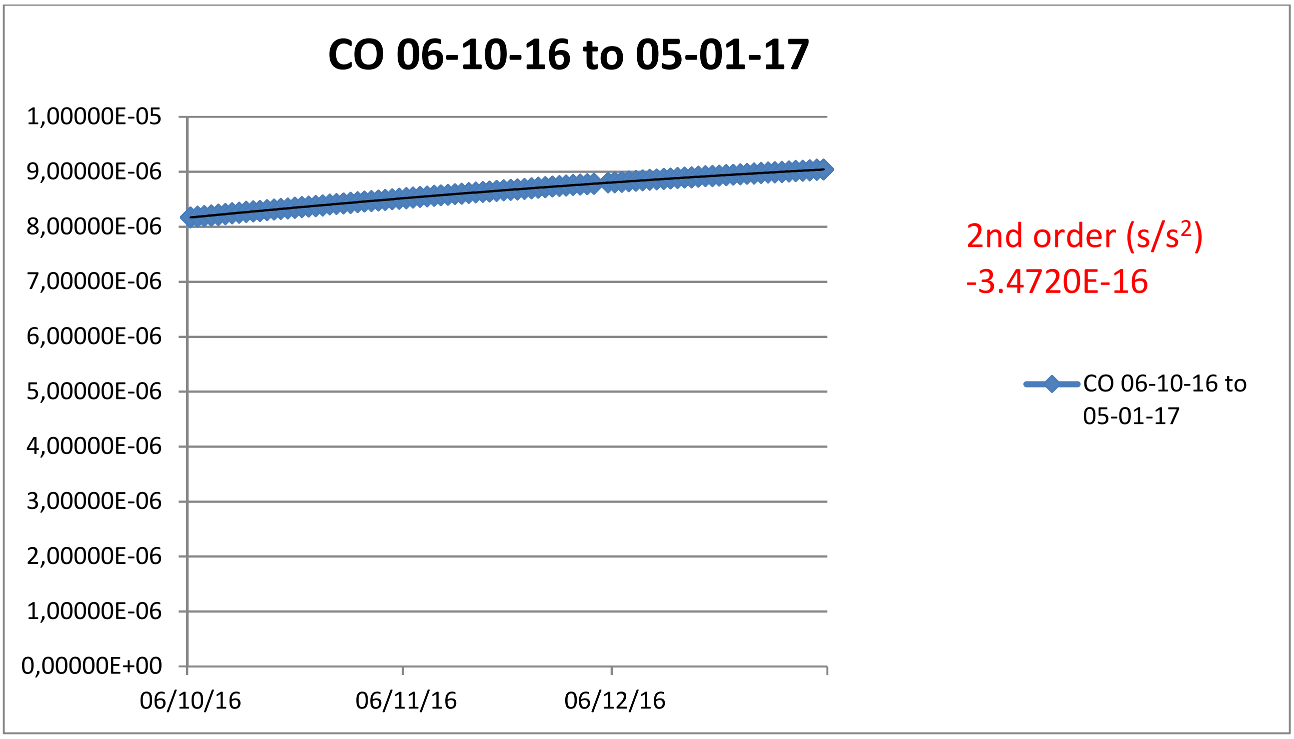

Fig 16. Successive data batches, each 3 months long (approximately)

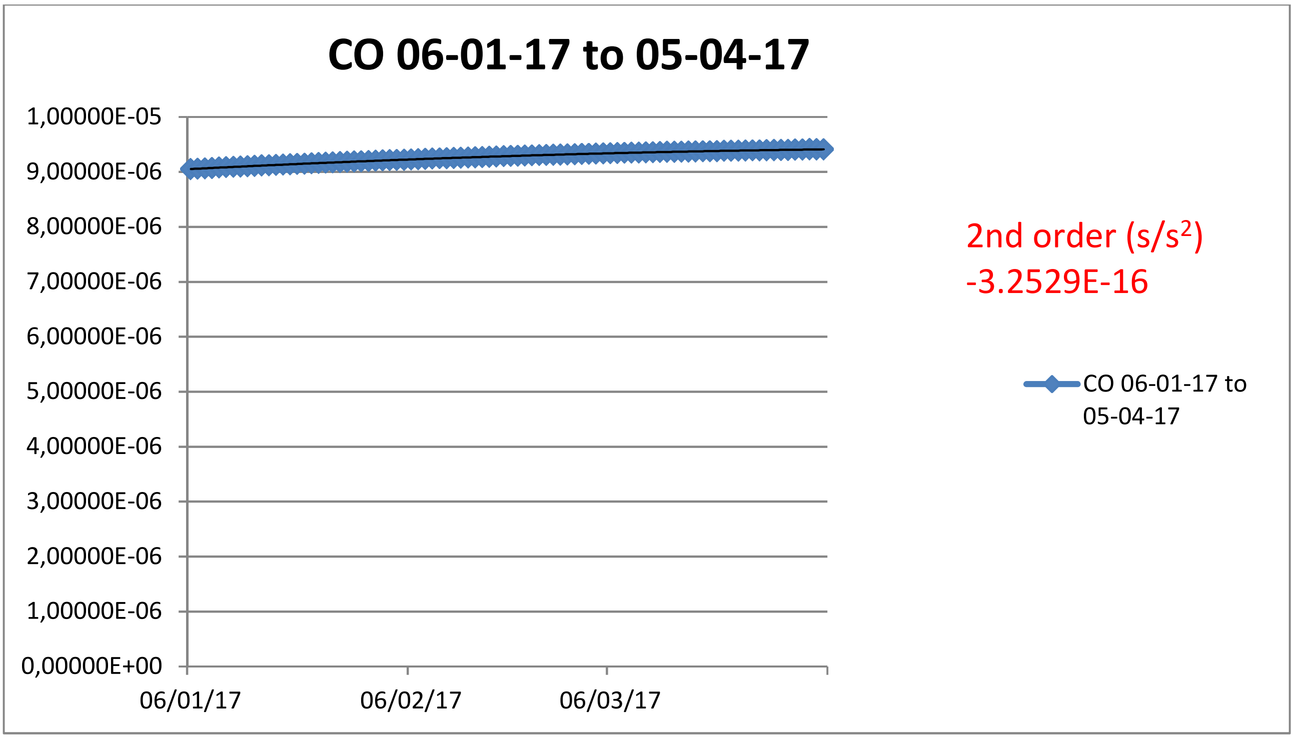

Fig 17. Successive data batches, each 3 months long (approximately)

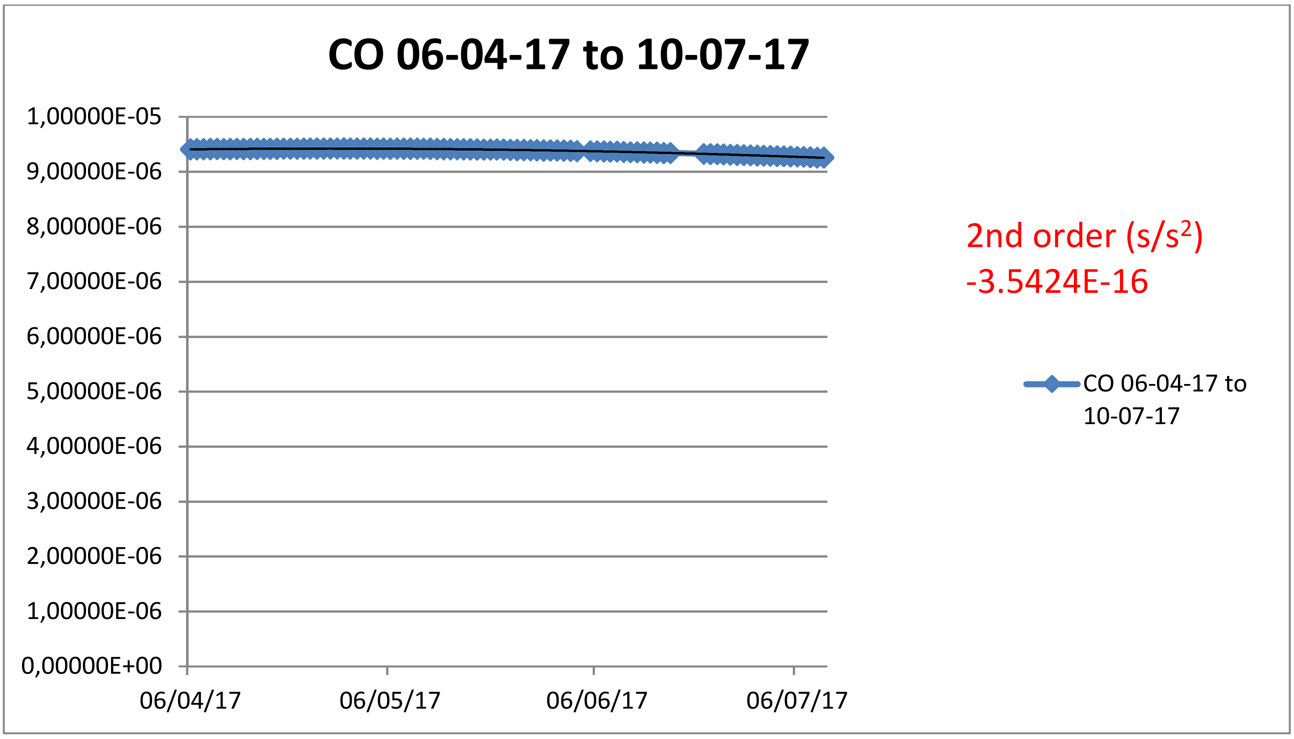

Fig 18. Successive data batches, each 3 months long (approximately)

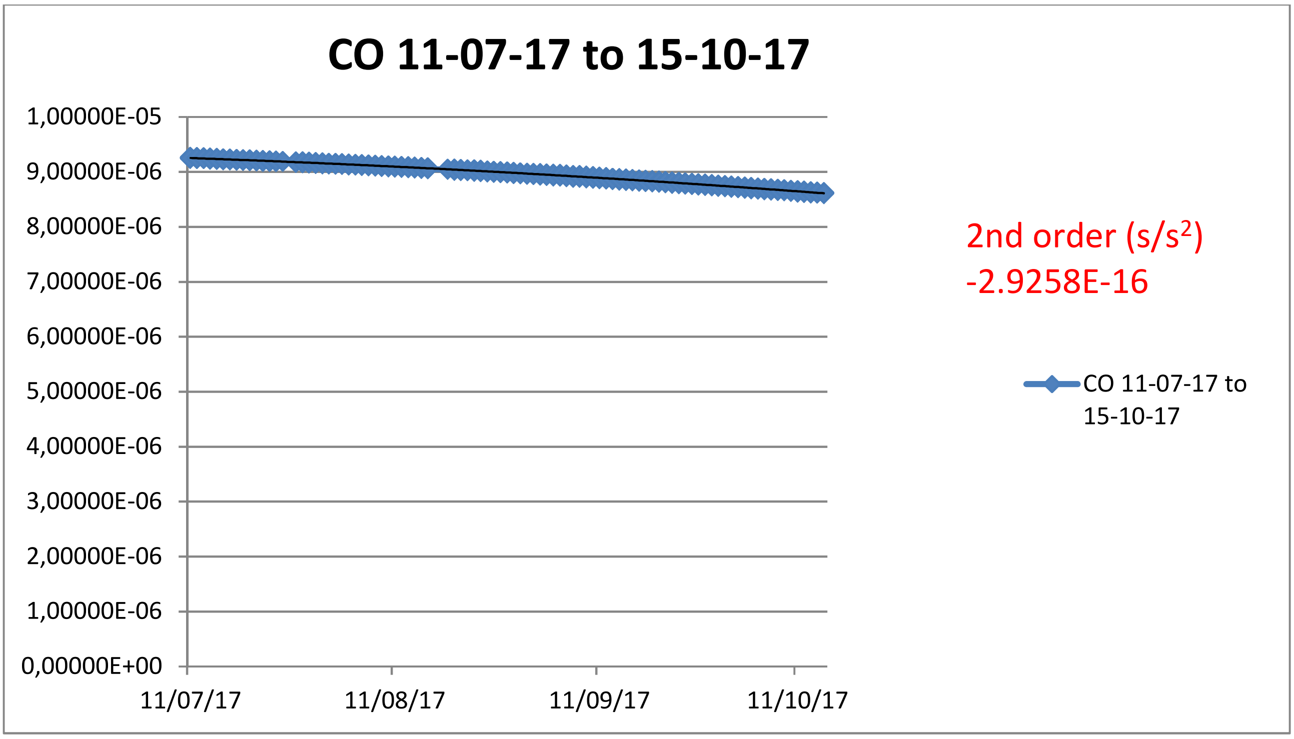

Fig 19. Successive data batches, each 3 months long (approximately)

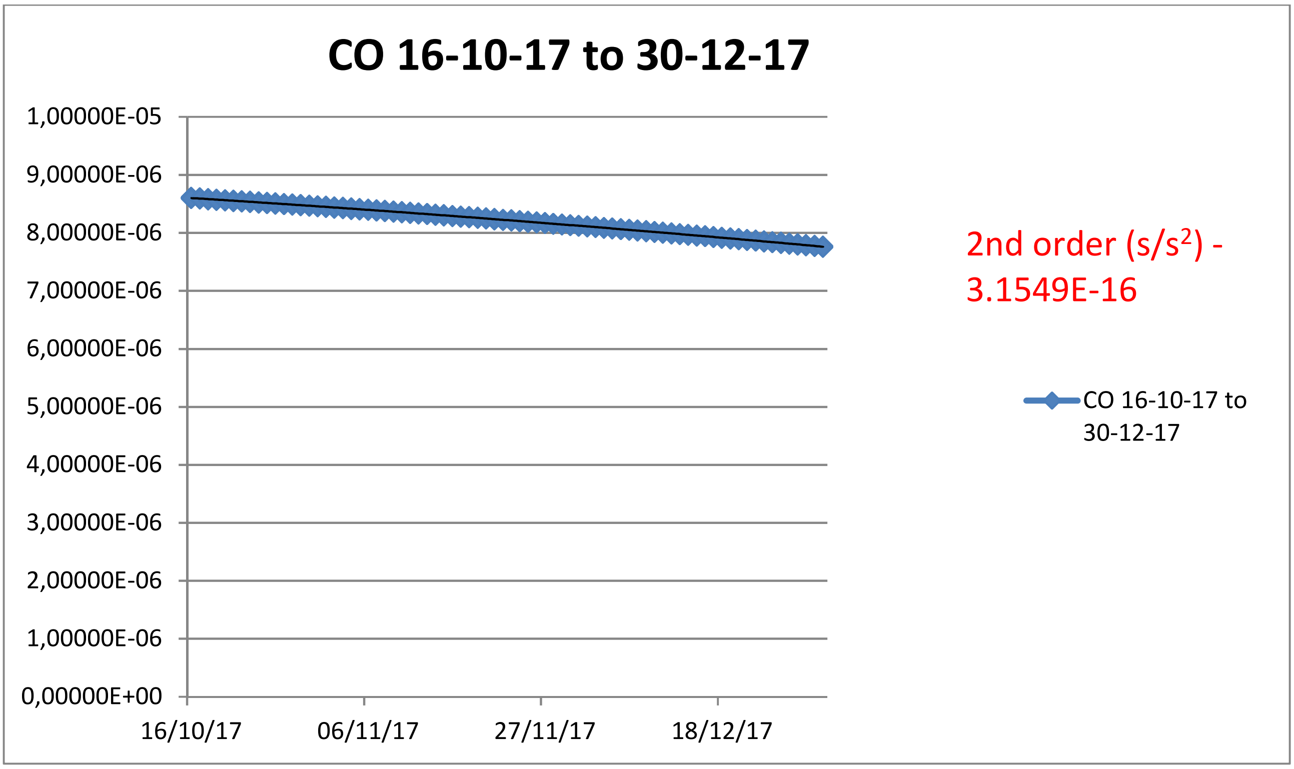

Fig 20. Successive data batches, each 3 months long (approximately)

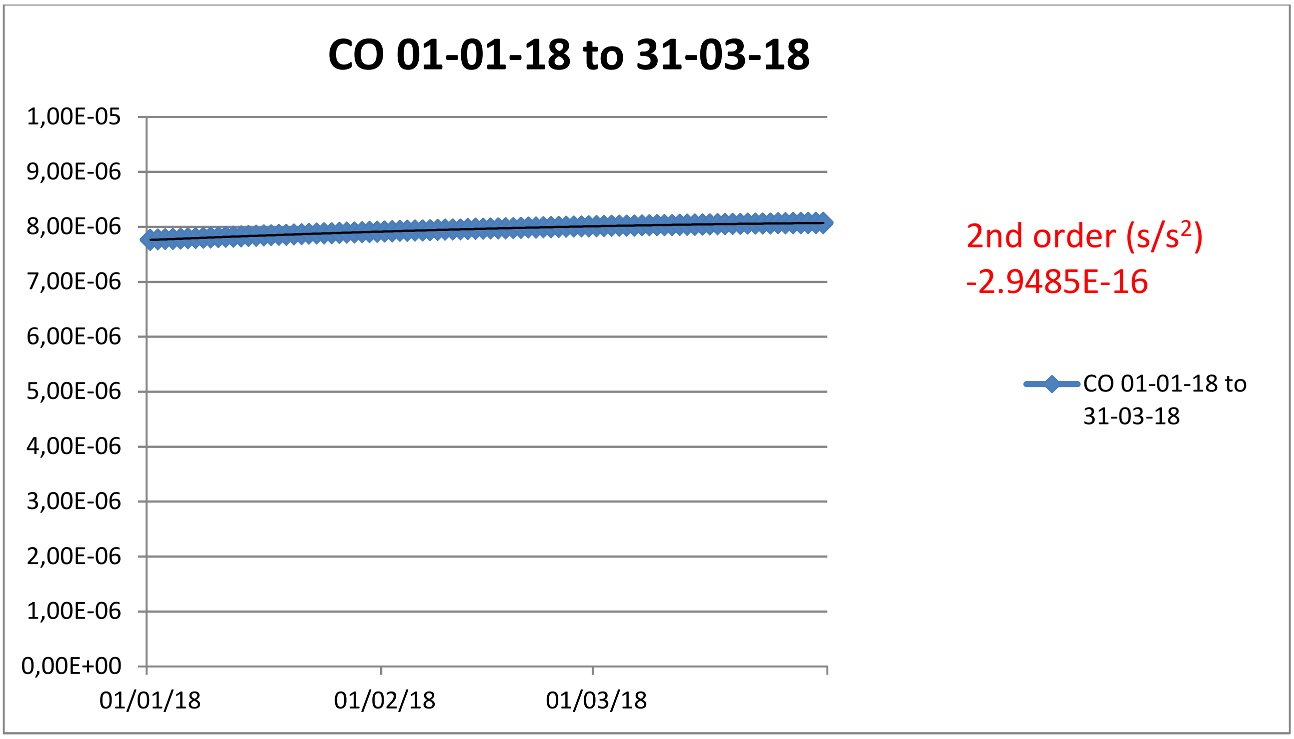

Fig 21. Successive data batches, each 3 months long (approximately)

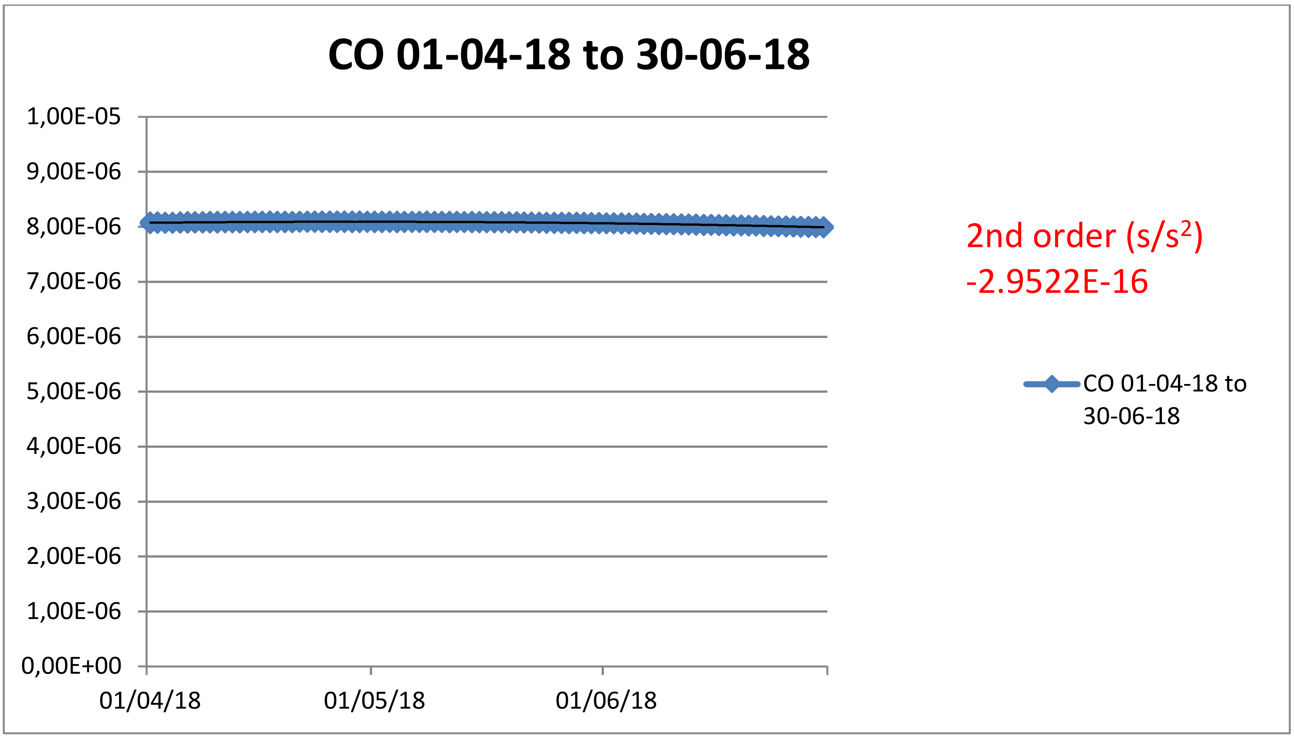

Fig 22. Successive data batches, each 3 months long (approximately)

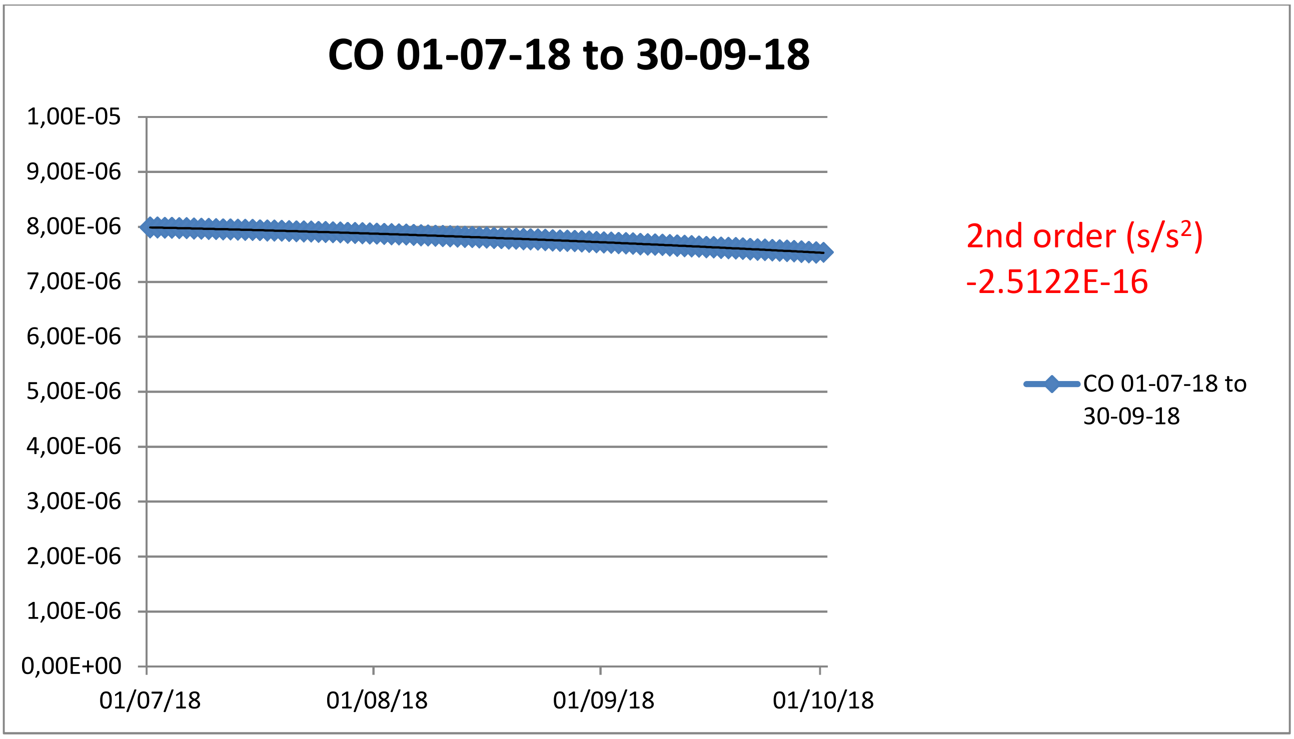

Fig 23. Successive data batches, each 3 months long (approximately)

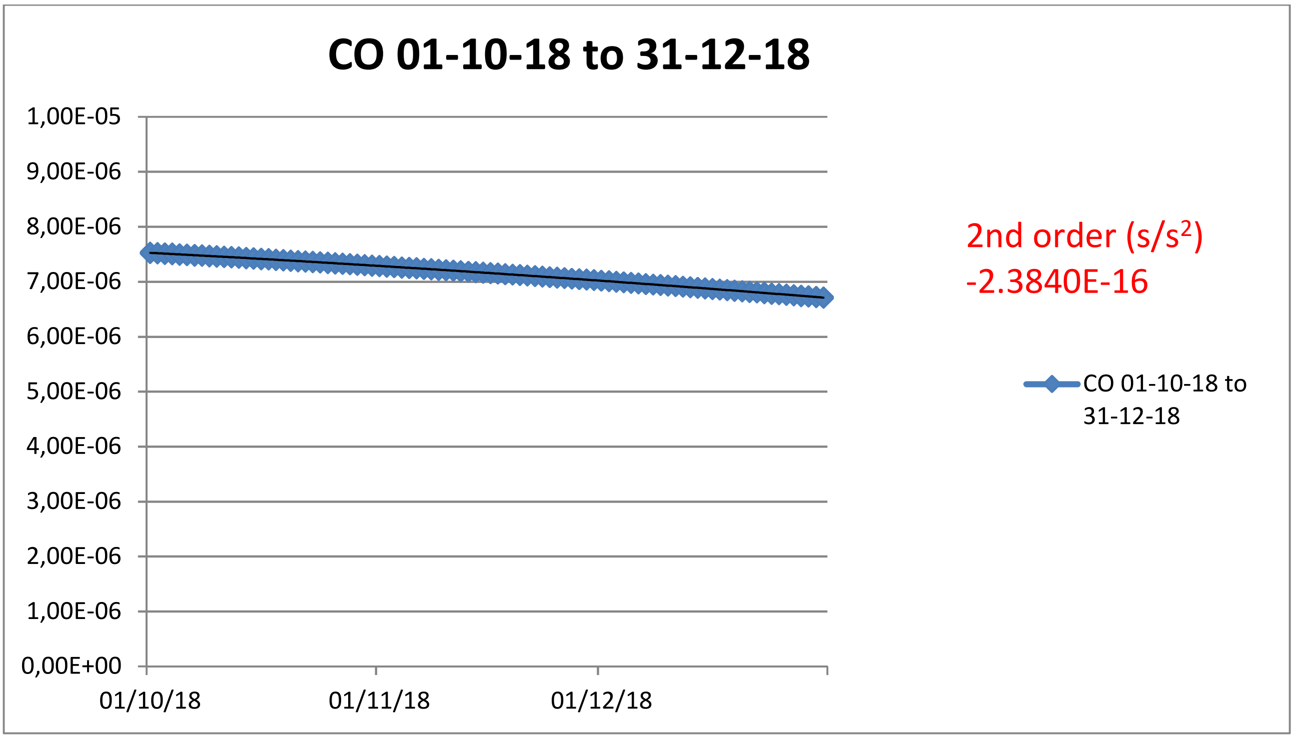

Fig 24. Successive data batches, each 3 months long (approximately)

Reference

[1] R. Ambrosini, M. Roma, C. Bortolotti, “Hardware/Software configuration of the Time & Frequency laboratory at the Medicina Observatory”, Rapporto Interno IRA 517-18.pdf

Acknowledgements

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