An original approach to compute Satellite Laser Range biases

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Abstract

Although they are permanently calibrated, the Satellite Laser Ranging (SLR) stations can present residual systematic errors, the well-known "range biases". These biases must be considered in any SLR data processing. Indeed, they are strongly correlated with the Up component of the station positions. Thus, if they are not computed together with these positions, they can induce jumps in these latter and consequently damage the global scale factor of the underlying Terrestrial Reference Frame with respect to any given reference.

On the other hand, estimating range biases together with station positions is not so easy, due to the previously mentioned correlations. In this paper, we describe a new approach to derive range bias values together with station positions: the so-called "temporal de-correlation" approach. This method consists in computing station range biases per satellite over a "long" period of time (determined by instrumental changes) together with weekly station position time series in order to significantly reduce the correlations.

Introduction

This paper comprises four parts. First, we provide general considerations about the Satellite Laser Ranging (SLR) technique range biases. Second, we demonstrate the strength of our temporal de-correlation approach through numerical illustrations based on simulations. Then, we analyze the first results produced by this method which has already been used for CALVAL (CALibration/VALidation) experiments and for a SLR data analysis carried out over 12 years. Finally, we describe the recent method improvements, provide the results of this new approach, and produce some conclusions and prospects.

1. General considerations

Fig. 1 shows the Grasse SLR station (7835) Up component time series computed in ITRF2000 without considering any range bias. We can clearly detect a jump in these time series and the epoch of this jump (September 1997) corresponds to a modification of the detection system of the station. This detection system modification has certainly modified the station detection and, as a consequence, its associated systematic errors. As shown by this example, a great attention must be paid to the SLR biases.

As shown on Fig. 2, the International Laser Ranging Service (ILRS) monitors these range biases. Indeed, among all the quality criteria used to qualify the tracking stations, two are directly linked to these biases: the short and long-term bias stabilities.

- The short-term stability is computed as the standard deviation about the mean of the pass-by-pass range biases.

- The long-term stability is the standard deviation of the monthly range bias estimates.

Regarding the data analysis, the situation does not seem to be so clear. Indeed, there are various strategies used to take into account these range biases: not to take biases into account, to correct a priori data with estimated bias values, to compute weekly range biases, etc. This paper aims to describe a method close to the instrumental evolutions of the considered stations. This method allows us to derive range biases by taking into account the problems linked to the simultaneous computation of these latter and station positions.

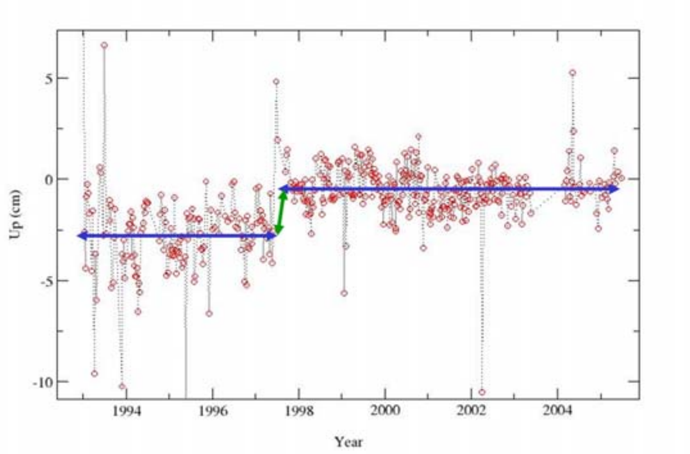

Figure 1. *Up component time series (in cm) of Grasse SLR station (7835) in ITRF2000. No range bias has been estimated nor applied during this computation.*

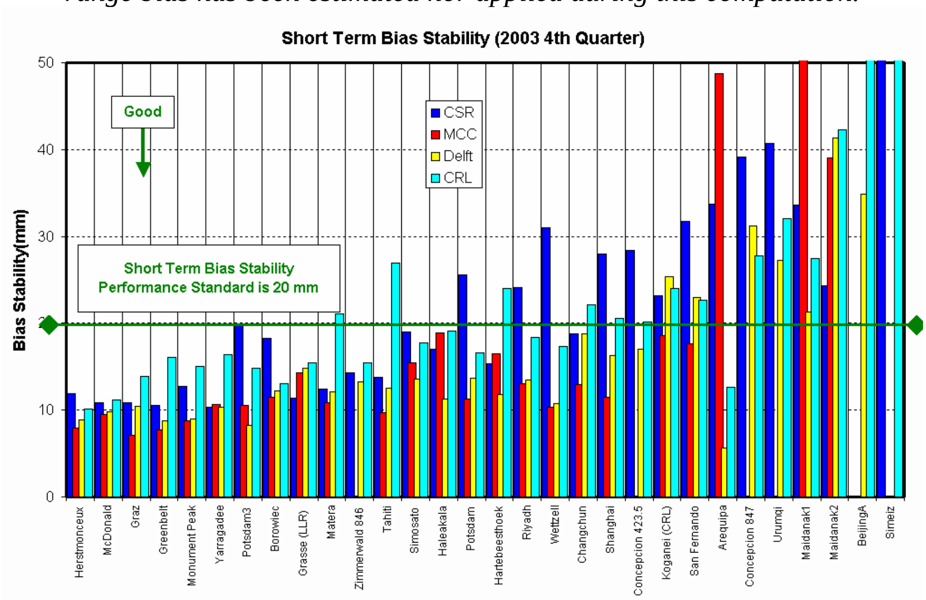

Figure 2. *Example of short-term range bias stabilities provided by ILRS for 2003.* Source: http://ilrs.gsfc.nasa.gov.

2. Numerical illustrations

The simulations provided here aims to evidence the impact of range biases on any SLR data processing results. Fig. 3 shows the global simulation scheme. The first step consists in estimating the two LAGEOS satellite orbits. Then, these orbits are used with SLR measurements together with ITRF2000 [Altamimi et al., 2002], a model of atmospheric loading effects, and some range bias values to derive, on one hand, simulated range measurements and, on other hand, the partial derivatives of these simulated data with respect to station positions and, eventually, to range biases.

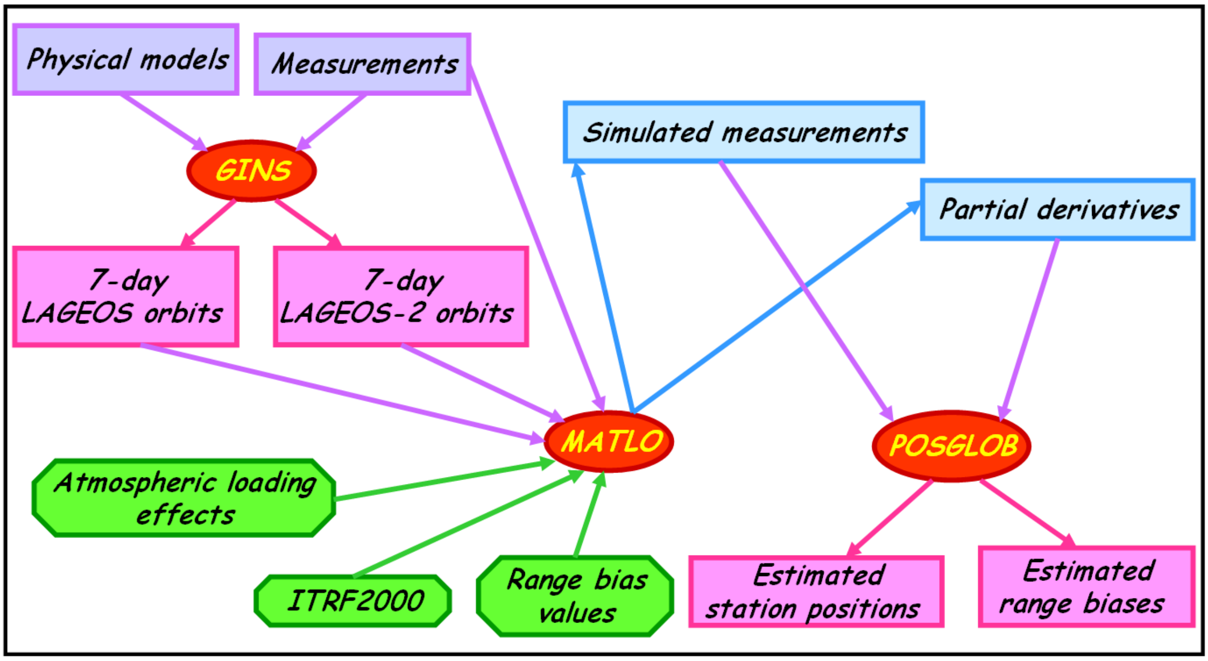

Figure 3. *Simulation method.*

Real orbital arcs and real SLR measurement epochs are used in order to get the most realistic simulations. Atmospheric loading effects are derived from the European Center for Medium-range Weather Forecasts (ECMWF, http://www.ecmwf.int/) pressure grids. As these loading signals are not modeled in the a priori values used, estimated station position time series must evidence them.

For the first simulation (cf. Fig. 4), range biases are applied in simulated measurements but they are not estimated with the Yarragadee SLR station (7090) position time series. The results clearly show that the range biases make a great impact on the Up component time series. Indeed, the time series is completely biased (the mean difference value almost reaches the centimeter level) and is no more stable (the RMS value of the differences is near 5 mm, while the horizontal component RMS values of differences are only at the millimeter level). Thus, range biases must be

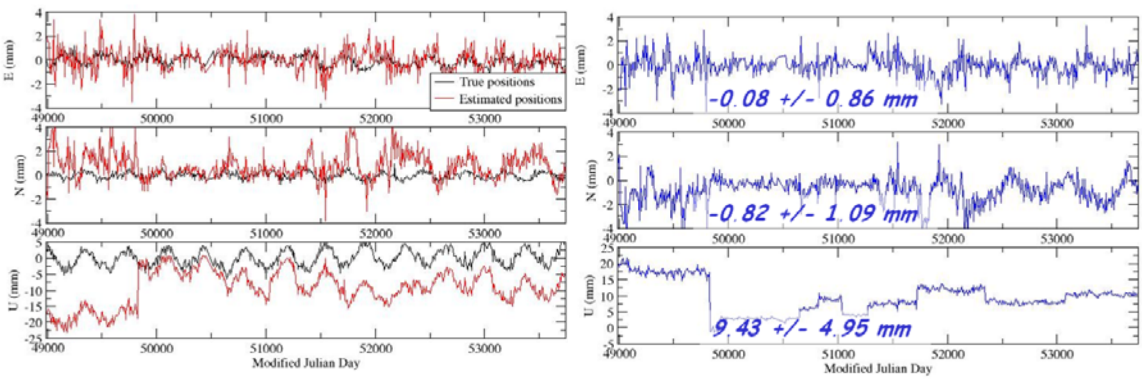

Figure 4. *Results of the first simulation carried out for the Yarragadee SLR station (7090). Values are provided in mm for the three positioning components East, North, and Up. Graphs on the left: black (resp. red) curves correspond to the position time series computed without any bias in simulated measurements (resp. the time series computed with biases applied in simulated measurements). Graphs on the right: differences between red and black curves. Numerical values correspond to the mean and the RMS values.*

estimated together with station positions.

In a second simulation, range biases are applied in simulated measurements and weekly range biases are estimated with the Yarragadee SLR station weekly position time series.

The results shown on Fig. 5 are clearly improved in comparison with those shown on Fig.4. Indeed, the mean value of the Up component differences is divided by 23 and the RMS value by 3.5. Furthermore, the values are also improved for the horizontal components (the difference RMS values are almost divided by 2), proof that range biases can also make an impact (of course lower than the one on the vertical component) on these components. But,

- we can notice large correlations between estimated bias and Up component values (96% on the average);
- spurious signals clearly appear in the weekly estimated biases, even if these latter have made the piece-wise behavior of the Up component time series disappearing.

Thus, range biases must be estimated over a longer period. For the third and last simulation (see the results on Fig. 6), range biases are still applied in simulated

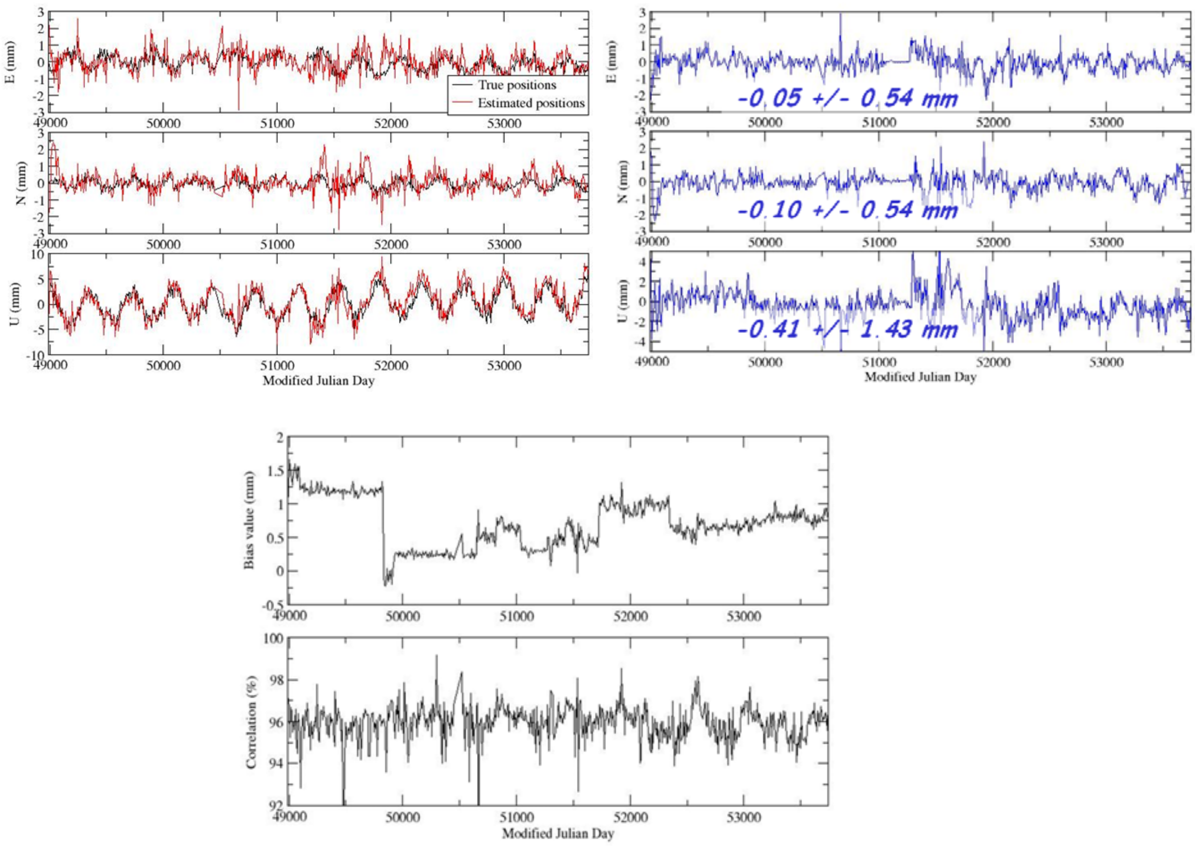

Figure 5. *Results of the second simulation carried out for the Yarragadee SLR station (7090). Values are provided in mm for the three positioning components East, North, and Up. Graphs on the top left: black (resp. red) curves correspond to the position time series computed without any bias in simulated measurements (resp. the time series computed together with weekly range biases with biases applied in simulated measurements). Graphs on the top right: differences between red and black curves. Numerical values correspond to the mean and the RMS values. Graphs below: weekly computed range biases and correlations between bias and Up component estimated values.*

measurements but range biases are now estimated over “long” periods together with the weekly Yarragadee SLR station position time series. The produced results are very satisfying. Indeed, the differences are quite negligible (the mean and the RMS values are below 0.5 mm). Moreover, estimating range biases per satellite allows us to take into account the possible constant signature effects. The correlations have decreased but they are still large (86% on the average).

This approach (that we have called the “temporal de-correlation method”) is the most satisfying one. Moreover, it is fully justified from an instrumental point of view. Indeed, the range biases are directly linked to the tracking instrumentation and we can suppose (at least for the most stable stations) that these instrumentations do not change all the time. As a result, the range biases can be supposed constant over given time intervals.

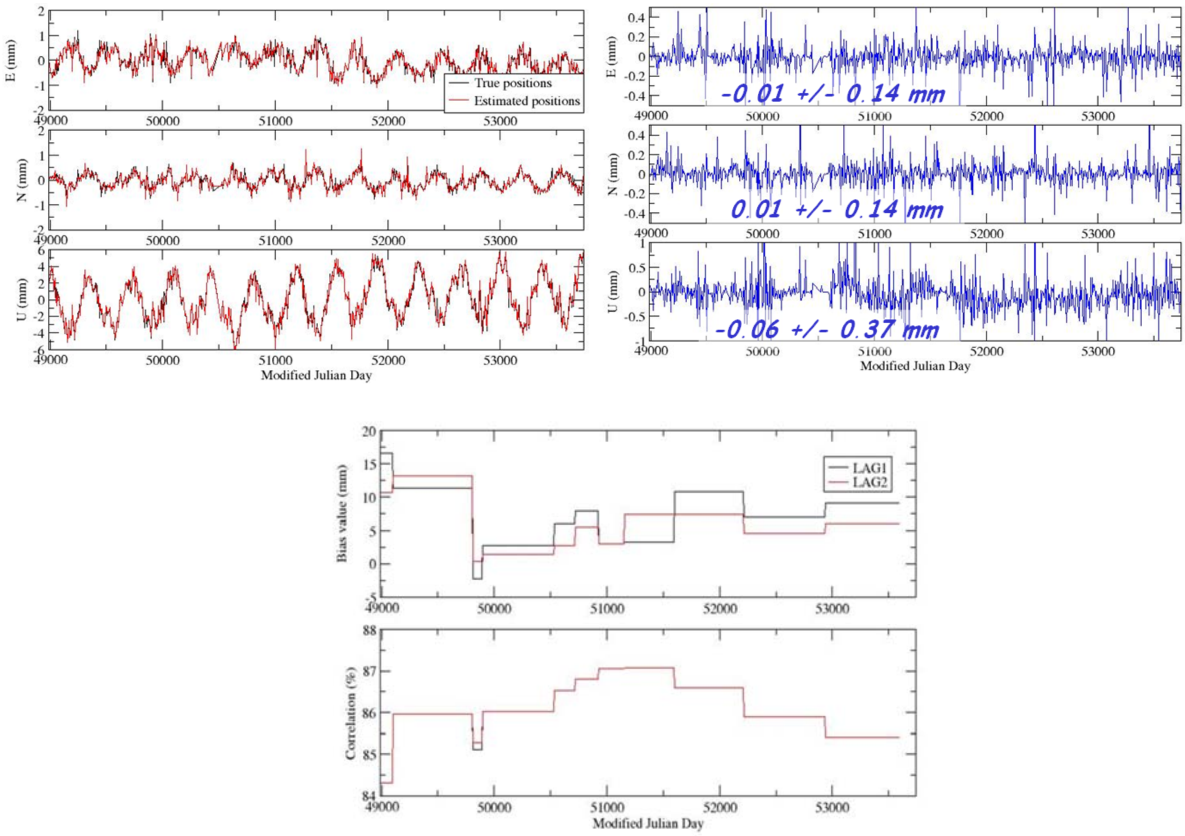

Figure 6. *Results of the third simulation carried out for the Yarragadee SLR station (7090). Values are provided in mm for the three positioning components East, North, and Up. Graphs on the top left: black (resp. red) curves correspond to the position time series computed without any bias in simulated measurements (resp. the time series computed together with the “long-period” range biases with biases applied in simulated measurements). Graphs on the top right: differences between red and black curves. Numerical values correspond to the mean and the RMS values. Graphs below: “long-period” computed range biases per satellite and correlations between bias and Up component estimated values.*

3. First results of the temporal de-correlation method

3.1. CALVAL experiment

These experiments were carried out with the French Transportable Laser Ranging System (FTLRS, see [Nicolas, 2000]) in Corsica in 2002 [Exertier et al., 2004] (and, more recently, in 2005) and in Crete in 2003 [Berio et al., 2004]. As an illustration of the use of our temporal de-correlation method, here is the example of the GAVDOS project, e.g. of the Crete campaign carried out in 2003. During such campaign, the FLTRS aims to calibrate the satellite altimeter (see Fig. 7) with the help of a short-arc technique [Bonnefond et al., 1995]. Thus, we need the most accurate positioning for this transportable station as well as an exhaustive knowledge of its error budget and, in particular, an accurate estimate of its range bias.

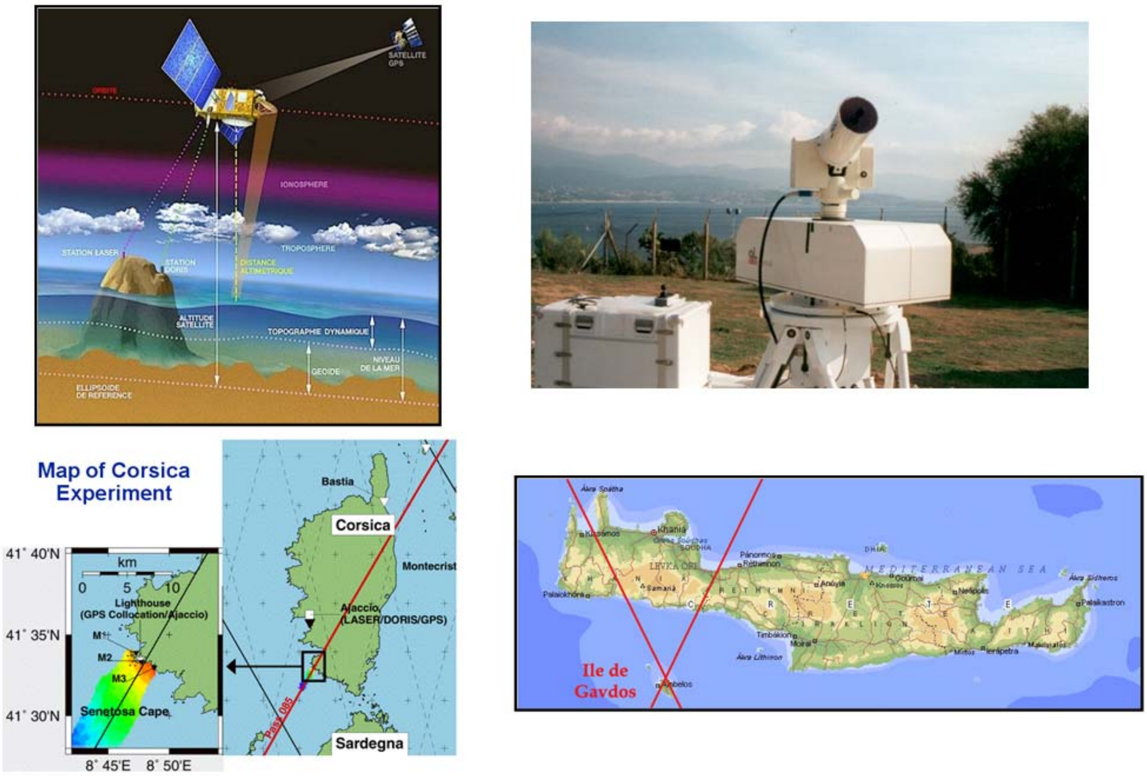

Figure 7. *CALVAL experiments with the FTLRS in Corsica and in Crete.*

Regarding the number of normal points collected on the two LAGEOS satellites by the FTRLS during this campaign (see Tab. 1), it is clear that we need to use the four satellite data to compute the FTLRS positioning. To do so, we have carried out two kinds of computations:

1. the FTLRS position and the range biases per satellite are computed over the whole period of time;
2. we compute weekly FTLRS positions together with range biases per satellite which are computed over the whole period of time (temporal de-correlation approach).

Satellite	Number of normal points
LAGEOS-1	108
LAGEOS-2	315
STARLETTE	2 902
STELLA	1 479

Table 1. *Number of normal points collected by the FTLRS during the Crete campaign carried out in 2003.*

In the both computations, the FTRLS positions are computed with respect to the ITRF2000 position [Altamimi et al., 2002] corrected for the solid Earth tides and the solid Earth pole tide in agreement with [McCarthy, 1996]. With the first method, the mean FTLRS position is directly computed, while, with the second approach, the mean FTLRS position is provided as the weighted mean value of the weekly estimated positions. The results produced by these two methods are summarized in Table 2.

The horizontal component estimated values are left unchanged between both approaches. And, the correlation is strongly decreased with the temporal de-correlation method. We can also notice a transfer between the biases and the Up components (the value is close to 1 cm) between both methods. Only the results of the second method are retained and, as a result, the mean FTLRS range bias value is -13,8 mm. [Nicolas et al. 2002] provides - 5 mm. This difference is explained. Indeed, during the whole campaign, the internal and external FTLRS calibrations exhibited a constant 1-cm difference.

Method	East	North	Up	BLAG1	BLAG2	BSTE	BSTA	Corr.
Method 1	2,5	-5,9	0,3	-19,7	-20,6	-28,3	-22,4	0,93
Method 2	1,6	-5,8	12,5	-9,6	-9,7	-20,2	-15,7	0,57
Absolute differences	0,9	0,1	12,2	10,1	10,9	8,1	6,7	.

Table 2*. Results (in mm) produced by the two methods studied to compute the FTLRS mean position and range bias during the Crete campaign carried out in 2003. The FTLRS mean positions are provided in the ENU local frame. BXXXX corresponds to the FTLRS bias computed for the satellite XXXX and corr. is the maximum value of the correlations between the estimated FTLRS range bias values per satellite and its Up component positioning values.*

Finally, we can see differences between the bias estimated values per satellite (both LAGEOS satellites versus STELLA and STARLETTE satellites). These differences could be explained by a radial constant error of 1 cm found for STELLA [Bonnefond, 2006] and by the fact that the signature effects depend on satellite and on detection system [Nicolas, 2000].

3.2. 12-year SLR data analysis

The temporal de-correlation method has also been applied over 5-month running windows in the framework of a 12-year SLR LAGEOS satellite data analysis (see [Coulot et al., 2005] and [Coulot, 2005] for more details).

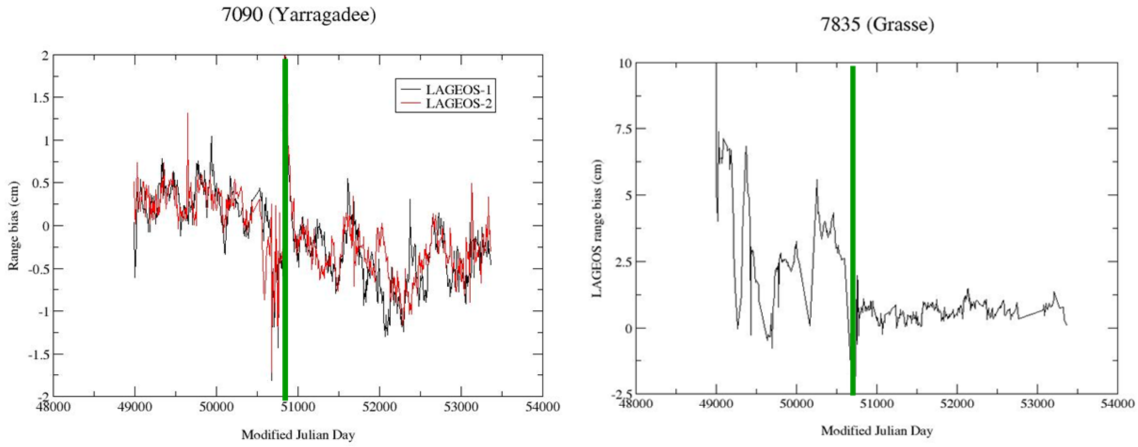

Figure 8. *Bias (in cm) time series with a 5-month sampling computed for the Yarragadee (on the left) and the Grasse (on the right) SLR stations during the 12-year SLR LAGEOS satellite data analysis.*

Fig. 8 provides two examples of bias time series computed during this study. Regarding the Yarragadee (7090) SLR station results, we can first notice that the bias values per satellite are very close: the RMS of the difference is 0.03 mm! A jump is clearly detected in the two time series. And, the epoch of this jump (January 1998) in fact corresponds to a detection system change.

Regarding the Grasse (7835) SLR station results, a jump is also detected in September 1997 and this jump corresponds to the detection system change previously mentioned in section 1 (cf. Fig. 1). We can finally notice the great stabilization of the range biases after this discontinuity. Indeed, the bias RMS value after this latter is 3.0 mm whereas this value is 20.5 mm before the jump!

4. Method improvement

4.1. New approach

Up to now, the limits of the time interval over which biases are supposed to be constant were not rigorously determined. As previously mentioned, range biases are directly linked to SLR instruments. Thus, biases are now supposed to be constant

9. Time and Frequency Standards
9.01.01 Frequency Standard
Type : Rubidium disciplined by GPS
Model : XL-DC 151-358-108-2
Manufacturer : TrueTime
Short Term Stab. [e-12]: 10
Long Term Stab. [e-12]: 3
Time Reference : GPS
Synchronization : GPS Epoch
Accuracy [ns]: <100
Date Installed : 2000-06-29
Date Removed : (yyyy-mm-dd)

8.01 Calibration Type : PRE+POST
Target Location : EXTERNAL
Target Type : CORNER CUBE
Target Structure : CONCRETE PIER
Target Distance [m]: 150.4229
Date Measured : 1998-08
Accuracy (mm) [mm]: 2
Verification : Local Tie Survey Comparison
Return-rate Controlled : YES
Mode of Operation : FEW PHOTON
Average Cal Interval [min]: 75
Single Shot RMS [mm]: 4.5
Edit Criterion 1st Chain : ITERATIVE 3.0 SIGMA
Edit Criterion 2nd Chain : N.A.
Application of Cal Data : AVERAGE
Date Installed : 1992-07-20
Date Removed : (yyyy-mm-dd)
Additional Information : (multiple lines)

6.01.01 Primary Chain
Signal Processing : CFD
Manufacturer : Tennelec
Model : TC454
Date Installed : 1993-04-23
Date Removed : (yyyy-mm-dd)
Amplitude Measurement : YES
Return-rate Controlled: YES
Mode of Operation : Few to Multi Photons

6.02.02 Secondary Chain
Signal Processing : CFD
Manufacturer : Tennelec
Model : TC454
Date Installed : 1998-08-13
Date Removed : (yyyy-mm-dd)
Amplitude Measurement : YES
Return-rate Controlled: YES
Mode of Operation : Single to Multi Photons

Figure 9. *Examples of instrumental change epochs found in the log file of the Yarragadee SLR station (7090).*

between two instrumental changes. We use station log files to determine these changes. Fig. 9 shows examples of instrumental change epochs used for the Yarragadee station (7090). Examples of so computed biases per satellite are provided in [Coulot et al., 2007].

4.2. Results

Fig. 10 compares the results produced with our improved temporal de-correlation method with those produced without considering any range bias during the data processing. Results are satisfying. Indeed, for instance, the scale factor time series is

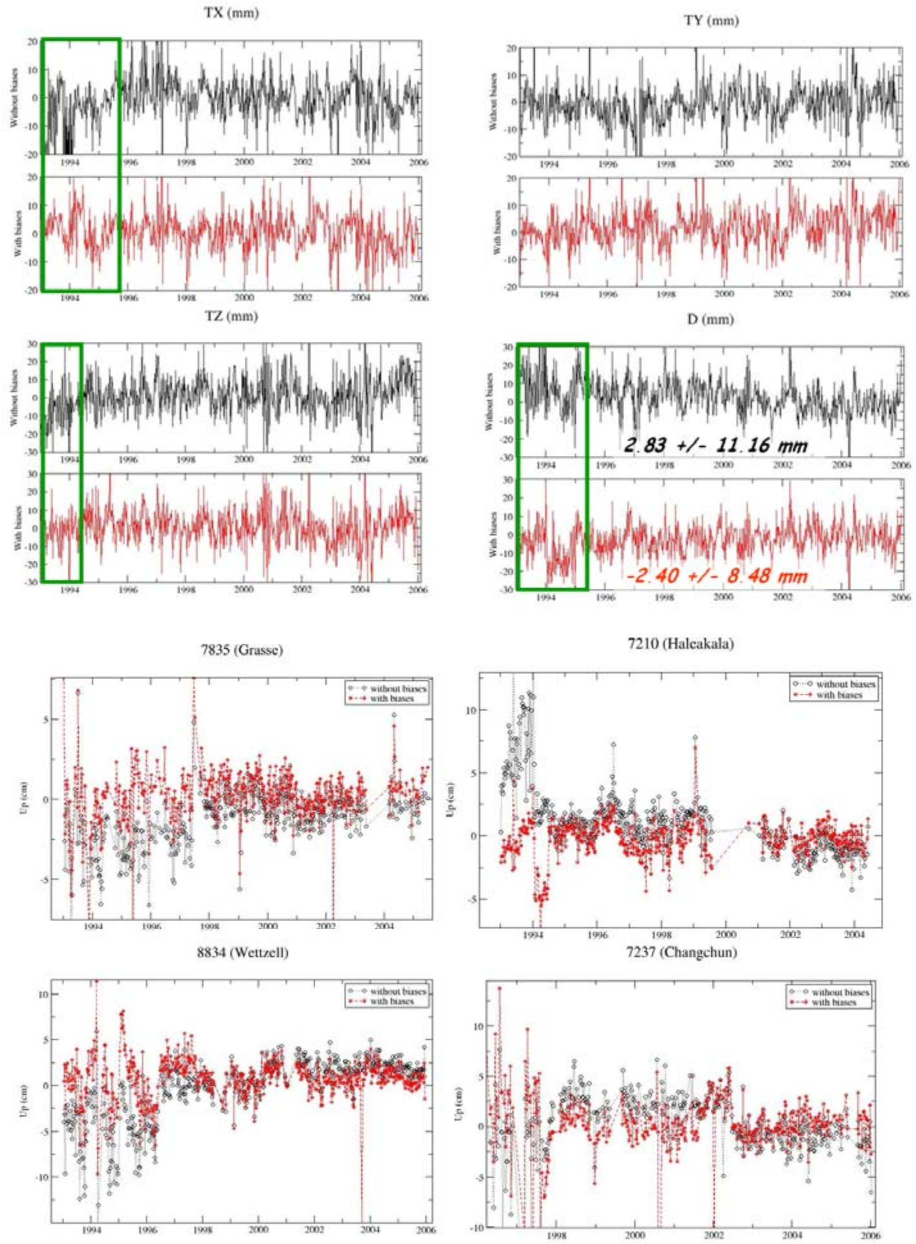

Figure 10. *Translation and scale factor parameters (in mm) computed between the weekly Terrestrial Reference Frames and ITRF2000 and four station Up component time series computed in ITRF2000 (in cm). Black (resp. red) curves correspond to the computation carried out without considering any bias (resp. the computation for which our improved temporal de-correlation method has been applied).*

more stable (RMS value of 8.5 mm to be compared with the 11.2 mm value provided by the computation carried out without bias). Moreover, the drift exhibited by the black scale factor time series disappears when our approach is used. Finally, the station time series are clearly more stable even if some discontinuities are still detected.

5. Conclusions and prospects

The two approaches ("running windows" or "instrumental change epochs") produce very satisfying results. They could be coupled to detect jumps which are not clearly linked to reported instrumental evolutions. Furthermore, it would allow us to rigorously apply the method to "poor quality stations", e.g.. stations for which biases are not stable.

Our method takes into account the correlation between station position Up components and range biases. We should also pay attention to the correlations with the possible radial orbital errors in the framework of a semi-dynamical approach (see [Coulot et al., 2007]). It would thus require a global estimation of all parameters for the whole network involved.

References

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