Positioning of the French Transportable Laser Ranging System (FTLRS) in Corsica over the 2002 and 2005 Campaigns

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SUMMARY

The geodetic site of Ajaccio in Corsica is the main calibration site of satellite altimeters in the Mediterranean area. It has been developed for oceanographic missions such as TOPEX/Poseidon (T/P, 1992), Jason-1 (2001) and Envisat (2002). The French Transportable Laser Ranging System (FTLRS) can be deployed there during an absolute calibration campaign. The role of the FTLRS is to provide accurate tracking (range measurements) of the spacecraft altitude when passing above the *in situ* instruments (tide gauges, notably) and, at the same time, to ensure an absolute geocentric positioning to be tied to the tide gauge reference points. The first absolute calibration campaign has been carried out in Ajaccio, from January to September 2002; a second one has been carried out from May to October 2005. The goal is to detect a possible drift in the altimeter bias that could be detected at the 1 mm/yr level, or less if possible, between this two periods. To detect such a drift however, we have to be confident in the positioning of the sea surface height by *in situ* instruments at least at the same level of accuracy.

Here, we present the computation of the two sets of geocentric coordinates from the FTLRS range data acquired in 2002 and in 2005 mainly on the low Earth geodetic satellites Starlette and Stella. The paper describes the different steps of the processing, notably in order to avoid correlations between the FTLRS range bias, the coordinates and the expected accuracy of computed orbits. Finally, a few mm accuracy is reached for the double positioning of the FTLRS in 2002 and in 2005. The tectonic velocity being deduced from both set of coordinates is compared to GPS permanent measurements to the level of less than 1 mm/yr.

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1. INTRODUCTION

The Observatoire de la Côte d'Azur (OCA, France) is involved since many years in oceanographic satellite missions such as TOPEX/Poseidon (T/P, 1992), Jason-1 (launched in December 2001), ERS-1 and -2 (1990's), and EnviSat (2002), particularly in the calibration of the satellite altimeters and in orbit validation activities (CAL/VAL experiments). The objective of the calibration process is to estimate and monitor the vertical displacement of the site, the absolute level of the geoid, the sea level observed both by radar altimetry and *in situ* instruments, and the altitude of the spacecraft. The goal is to reach a level of accuracy of 1 mm in the estimation of the altimeter bias and to monitor its possible drift to the 1 mm/yr level and less, if possible. Although measurements are made locally, the calibration process is computed in a global (geocentric) reference frame. In the Mediterranean area, the geodetic site of Corsica (including Ajaccio and Senetosa) is the main site dedicated to this type of experiments (Bonnefond et al., 2003).

The Satellite Laser Ranging (SLR) plays a key role both in the determination of the orbit of oceanographic satellites (in particular for the calibration passes) and of the geocentric positioning of the site (Exertier et al., 2004). In issue of collaboration between CNES, IGN, INSU and OCA, the French Transportable Laser Ranging System (FTLRS) has been developed specifically for realizing geodetic campaigns. This highly mobile system, with a weight of 300 kg and a telescope of 13 cm diameter, is the smallest operational SLR station in the world (Nicolas, 2000). If its great mobility is its main advantage that confers it campaigns on dedicated sites, its indispensable miniaturization could constitute a disadvantage. In particular, its small telescope makes difficult the reception of laser pulse echoes from high orbiting satellites (like LAGEOS geodynamical satellites at an altitude of 6000 km) particularly at elevations lower than 40 degrees (Coulot, 2005). Therefore, to compute highly accurate geocentric coordinates the difficulty lies in using range data of low Earth orbiting geodetic satellites (like Starlette and Stella, at an altitude of 800 km). As a consequence of their lower altitude, the accuracy of their orbit determination is more sensitive to remaining uncertainties in the dynamical models. The error budget of the geocentric positioning then is affected notably by introducing correlations between the satellite geocentric altitude and the adjusted terrestrial coordinates (Exertier et al., 2004).

Operational since 1996, the FTLRS has participated to several absolute calibration campaigns in the framework of the T/P and Jason-1 CNES and NASA missions : in Ajaccio in 2002 (Exertier et al., 2004), in Crete (at Chania University) in 2003 (Pavlis et al., 2004), and for the second time in Ajaccio in 2005. The present article deals with the absolute positioning of the FTLRS in Ajaccio (Corsica) for the two SLR tracking campaigns made in 2002 (from January to September) and in 2005 (from May to October). The objective in realizing these two campaigns is to detect a possible drift in the altimeter bias that could be detected at the 1 mm/yr level, or less if possible. To detect such a drift however, we have to be confident in the monitoring of the sea surface height by *in situ* instruments at least at the same level of accuracy. Thus, the question should be : are we able to maintain an absolute positioning of the calibration to a few mm level (accuracy) from 2002 to 2005 with the FLTRS ?

The work methodology comprises two main steps :

a. the orbit computation of the different tracked satellites is performed by the GINS software (GRGS, Toulouse), based on a purely dynamical approach, see section 3,

b. the estimation of the station coordinate updates and of the FTLRS range bias is performed using the MATLO software (OCA, Grasse), which can also determine orbit correction via simply cinematical assumptions, see section 4 and discussion.

Finally, the results of the two SLR campaigns in Corsica are presented and discussed.

2. DESCRIPTION OF THE CORSICA CAMPAIGNS

The geographic configuration of the Corsica area is shown in Figure 1. Effectively, the TOPEX/Poseidon and Jason-1 ground tracks pass over the Senetosa Cape which is the dedicated site for altimeter calibration where in situ instruments (tide gauges, GPS, and a meteorological station) have been installed permanently.

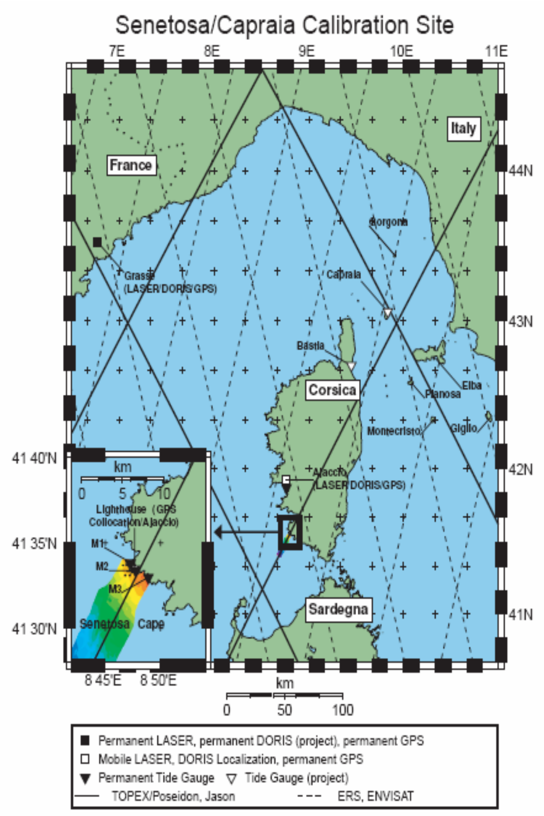

Figure 1: Ajaccio Site in Corsica

The naval base at Aspretto (Ajaccio) is used since 1996 as a semi-permanent site where the FTLRS can be deployed for several month campaigns assuring security and local facilities.

During the two campaigns, the laser tracking has been done both on oceanographic and geodetic satellites. The LAGEOS-1 & -2, due to their high altitude, are difficult to reach as it is shown by the low number of normal points collected on these satellites (Table 1). The only measurements available on these two satellites are not enough to perform a 3D geocentric positioning at the level of less than 1 cm. On the other hand, the data acquired on low Earth satellites, mainly Starlette and Stella (see Table 1), form the great part of the basis of our computation.

Satellite	2002 Campaign	2005 Campaign
LAGEOS-1	301	377
LAGEOS-2	323	235
Starlette	3413	5294
Stella	1731	2069

Table 1. Number of normal points collected by the FTLRS during the 2002 and 2005 campaigns in Ajaccio.

Figure 2 represents the geographical distribution of the FTLRS range data that have been acquired on LAGEOS-1 and Starlette during approximately 5-6 months (2005). Through this figure one can note the following points, which are reinforced by values given in Table 1:

- few measurements on LAGEOS satellites, particularly at low elevation, and a non regularly distribution of these data over the Ajaccio site,
- ten times more range data on Starlette, relative to LAGEOS, but a factor of five concerning Stella which satellite is even more difficult to track due to its polar inclination. We note an homogeneous distribution of the range data over the site.

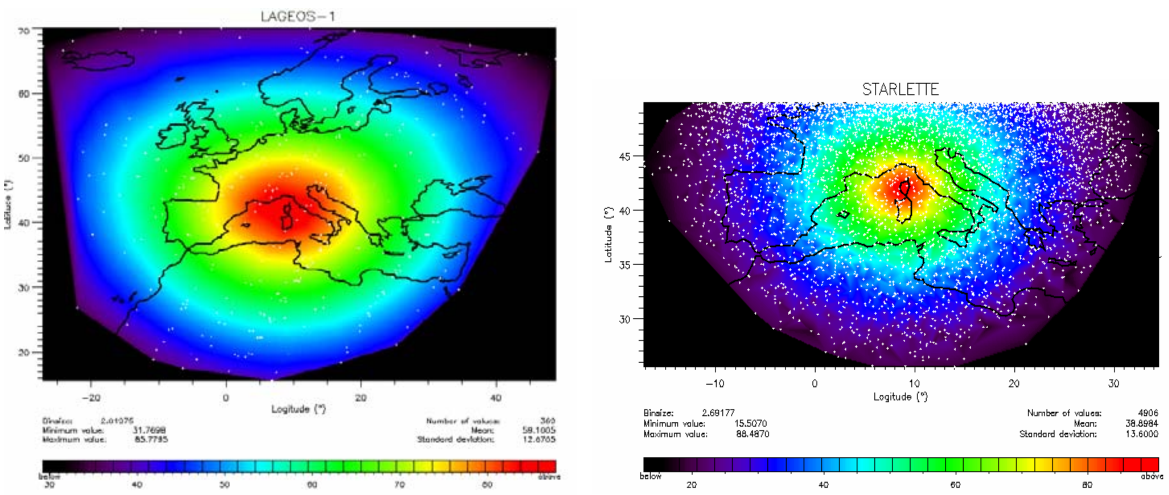

Figure 2: Maps of the range data distribution during the 2005 campaign (5 months) above Ajaccio, Corsica for LAGEOS-1 and Starlette, respectively at left and right.

3. ORBIT COMPUTATION AND MODELS

The precise orbit determination is realized with fixed dynamical models (except gravity field) and reference frame (GINS software, see Table 2), that is to say the same models and frame are used to compute all the orbits. A subset of SLR fixed stations, which are well distributed on the Earth, is used as the reference frame for the orbitography. Of course, the FTLRS range data are not included in the orbit computation.

The quality of an absolute positioning is directly linked to the accuracy of the orbits used (in addition to the data accuracy itself). For this reason high geodetic satellites (LAGEOS-1 and -2) are used primarily by geodesists to compute Earth Orientation Parameters and station coordinates (for the SLR network). In fact, these satellites have the advantage of being less sensitive to remaining uncertainties in the dynamical models than Starlette and Stella are. It concerns gravitational and non gravitational effects. But since few years, global Earth gravity field models have greatly improved the accuracy of their coefficients notably thanks to the recent GRACE mission. As a consequence, empirical coefficients can be estimated along the orbit with more consistency than before; their role is to compensate part of the unknown non gravitational forces (constant and periodic).

Model	Designation
Gravity field model	*GRIM5-C1* or *EIGEN-GRACE03S*
Atmospheric pressure	*ECMWF*
Solar activity	*File acsol2*
Atmospheric density	*DTM-94bis*
Ocean tides	*FES-2002*
Planets	*DE403 bdlf.ad.ibm*
Terrestrial reference frame	*ITRF2000*
Earth Orientation Parameters	*EOP-C04*

Table 2: Physical models used for the orbit computation

In order to quantitatively evaluate this improvement, we computed Starlette and Stella orbit fits independently with two Earth gravity field models, GRIM5-C1 and EIGEN-GRACE03S (Gruber et al., 2000; Reigber et al., 2005), from the same data set (range data acquired by the SLR network during the 2005 campaign period). The goal was to highlight the effect of the gravity field model on the quality of the orbits (and of all the adjusted parameters and coefficients), and then to quantify the differences in term of absolute positioning. To illustrate this as a geometrical effect, the radial orbit differences between the two solutions of the Starlette orbits have been projected on the Earth’s surface along the satellite ground tracks (Figure 3).

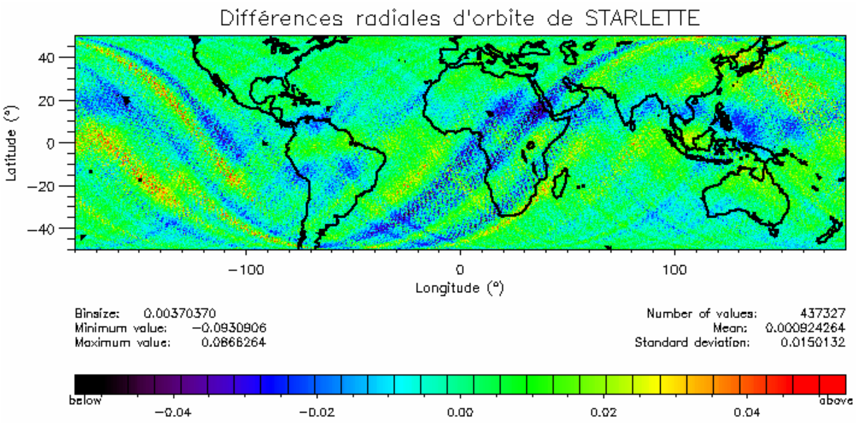

Figure 3. Mean radial orbit differences (in m) geographically correlated obtained from two solutions of the Starlette orbits (32 arcs of 5 days during the 2005 campaign); two different Earth gravity models (GRIM5-C1 and EIGEN-GRACE03S) have been used.

The plot (Figure 3) has been obtained from five months of Starlette orbit differences, that corresponds to 32 arcs of 5 days each. After a preliminary rejection of recovered arc portions, the standard deviation of the radial orbit differences is of 15 mm (for example, it is of 5 mm for LAGEOS orbit differences obtained in the same conditions). The Mediterranean area seems to be less affected by a permanent effect.

	2002 campaign		2005 campaign	
Satellite	GRIM5-C1	EIGEN-GRACE03S	GRIM5-C1	EIGEN-GRACE03S
LAGEOS-1	13	-	11	11
LAGEOS-2	10	-	10	09
Starlette	23	18	23	18
Stella	23	19	21	16

Table 3: Average weighted rms (in mm) of the range residuals after orbit fits of the satellites used for the FTLRS positioning

Another criteria to evaluate the orbit quality is given by the rms of orbit residuals after fit. Table 3 gives these rms for the four used satellites: all arcs of 2002 and 2005 periods for the two considered solutions. As expected, the orbits of the LAGEOS-1 and -2 are more precise (2 times) than those of Starlette and Stella, and they are also less affected by the change of the gravity field model. Based on these tests and other recent results concerning the assimilation of GRACE data into Earth models, we have adopted the EIGEN-GRACE03S gravity model for the 2002 and 2005 positioning. Finally, one can expect a permanent signature of around ±3 mm in the estimation of the altitude of Ajaccio (FTLRS) even if we compute orbits with this recent gravity model.

4. POSITIONING OF FTLRS STATION

First, orbits are computed as precisely as possible without the FTLRS tracking data. Then, the normal matrices are established and the FTLRS parameters (coordinate updates and range bias) are solved through a weighted least-squares adjustment. It is important to keep in mind that LAGEOS range data represent about 10 per cent of the Starlette and Stella ones (Table 1). Thus, we cannot expect realistic results (coordinates and range bias) from only using the LAGEOS data sets (see also Figure 2).

	mean LAGEOS	Starlette	Stella	mean Starlette & Stella	$\Delta\varphi$	$\Delta\lambda$	Δh
2002	-6	-13	-13	-13. ± 0.7	+0.5 ± 0.7	+2.7 ± 0.7	-1.2 ± 0.8
2005	+4	-6	-4	-5. ± 0.8	+4.1 ± 0.4	-2.9 ± 0.4	+4.0 ± 0.4

Table 4. Range bias per satellite and differences (in mm) between our solution and FTLRS coordinates (Exertier et al., 2004), for the two FTLRS campaigns 2002 and 2005.

SLR technique is known as the most accurate technique for positioning, more especially in the vertical direction. However, SLR measurements present biases which are mainly due to inaccurate internal calibration of stations and, to a lesser level, to satellite signatures (which also depend on the power of the emitted laser pulses). The estimate of both vertical positioning and SLR range biases is strongly correlated generally (correlation greater than 0.9). But Exertier et al. (2004) have developed a specific method, called *temporal decorrelation*, decreasing the correlation between biases and vertical coordinates at the level of 0.5. The main idea consists to solve for coordinates every 7 days, while bias (per satellite) is solved for as a unique value for the entire studied period.

Table 4 and 5 give, respectively for the two periods, the values of the FTLRS bias and of the coordinate updates relative to absolute coordinates published before (Exertier et al., 2004). Concerning the bias, one can note that the global mean (-5 mm) is very close to the value which had been determined previously (–7±2 mm, ibid). We know that this value did not change since the first technological tests made in 2001 (Pierron and al., 2004). Concerning the coordinate updates, which are estimated relatively to the Exertier et al. (2004) solution (velocities from the permanent GPS receiver at Ajaccio), the values for 2002 and 2005 are at 3 mm level in average.

Because coordinate updates are fitted every 7 days, while the range bias is once for all, we call "stability" the following quantities: $\sigma\varphi, \sigma_\lambda$ and σ_h for each geographical coordinate update φ, λ and h over each observation period:

$$\sigma_\varphi = \sqrt{\frac{\sum_{i=1}^{n}(\varphi_i - \overline{\varphi})}{n-1}}$$

and similarly for σ_λ and σ_h. Then, the total "stability" σ of the geographical position is given by:

$$\sigma=\sqrt{\frac{\sigma_\varphi^2+\sigma_\lambda^2+\sigma_h^2}{3}}$$

We have 28 and 20 7-days solutions, respectively for the 2002 and 2005 campaigns.

Campaign	Number	$\sigma\varphi$ *(mm)*	σ_λ *(mm)*	σ_h *(mm)*	σ *(mm)*
2002	28	14.6	13.1	10.5	12.9
2005	20	7.5	12.3	10.5	10.3

Table 5. "Stability" of 7-days solutions of FTLRS geographical coordinates for each campaign (2002 and 2005).

5. DISCUSSION

As a result, the more surprising effect is the variation of the adjusted values of the FTLRS range bias between 2002 and 2005 (increase of +10 mm on the global mean for all satellites). Considering however the remaining correlation between the range bias and the altitude coordinate update during the global fit (coefficient of around 0.5), we also have to look at the variation of the altitude update: at –1.2±0.8 mm in 2002 and at +4.0±0.4 mm in 2005 which explains most of the bias variations.

Nevertheless, the new set of coordinates (from all 2002 and 2005 data sets) along with the -5 mm mean range bias have been used for validating the latest Jason-1 precise orbits and the mean of the SLR residuals for the FTLRS do not show any differences for the 2002 and 2005 campaign (close to 0 for both).

For future campaigns, and parallel to the technological progress of the FTLRS instrumentation (according to Nicolas et al., 2002), ideas were discussed between the OCA and the different French partners for planning the development of a new telescope of 25 cm diameter. This will permit to greatly improve the tracking particularly at mean and low elevations, as for high geodetic targets as for satellites equipped with small laser retro-reflectors. Thus, this will contribute to the importance of the role of SLR technique for altimeter calibration missions as for space geodesy and so in the realization of the ITRF.

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