Satellite Laser Ranging Mobile Station : Presentation and Geodetic Applications

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ملخّص : يقدّم المقال محطة قياس البعد الليزري الفائقة التحرّك (FTLRS) وتجاربها في المواقع الجغرافية بكورسيكا (فرنسا). عمل موّقع في إطار التعاون في مجال الجيوديزيا الفضائية بين مركز التقنيات الفضائية (CTS ، الجزائر) و مرصد ساحل أزور (GEMINI / OCA) Côte d'Azur ، فرنسا). يعّد الموقع الجيوديزي لأجاسيو بكورسيكا من أهم مواقع المعايرة بالنسبة لقياس إرتفاع القمر الصناعي في منطقة البحر الأبيض المتوسط . تقدّم في مهام قياس الإرتفاع مثل TOPEX/Poseidon (T/P, 1992), Jason-1 (2001) et Envisat (2002) غُرض هناك FTLRS خلال الحملتين الليزريتين ، في 2002 و 2005 . نقدّم حساب مجموعتي الإحداثيات المركزية الأرضية من معطيات FTLRS المحصّل عليها من الحملتين خصوصاً في الأقمار الصناعية الجيوديزية الأرضية المنخفضة : Starlette و Stella (ارتفاع يقدّر بــ 800 كلم). يلخّص المقال المراحل المختلفة لمعالجة المعطيات الليزرية . يقدّر معدّل الأقواس RMS تقريبا بــ 1-2 سم بالنسبة للأقمار الصناعية Lageos-1, Lageos-2 Starlette و Stella ؛ تبيّن بأنّ أحسن نتائج مدار القمر الصناعي و المواقع المركزية الأرضية قد تمّ الحصول عليها من نموذج الجاذبية Eigen- Grace03s . يكون فرق المواقع 3D المطلق ، بين 2002 و 2005 ، تقريبا بــ 7.7 ملم (i.e., 2.6 mm / yr) أقل من الأخطاء الباقية لسرعة ITRF2005 (تقريبا بــ 4.3 ملم/yr). أخيراً ، تمّ قبول بعض الإقتراحات للإستعمال FTLRS في الجزائر في التطبيقات الجيوديزية.

الكلمات الأساسية : محطة قياس البعد الليزري الفائقة التحرّك المواقع ، إستقرار ، قياس البعد الليزري للقمر صناعي ، نموذج حقل الجاذبية الأرضية.

Résumé : Le présent travail est souscrit dans le cadre de coopération dans le domaine de la géodésie spatiale entre le Centre des Techniques Spatiales (CTS, Algérie) et l'Observatoire de la Côte d'Azur (GEMINI / OCA, France). L'article présente la station de Télémétrie laser ultra mobile (FTLRS) et ses expériences de positionnement géographique en Corse (France). Le site géodésique d'Ajaccio en Corse est le site principal du calibrage d'altimètres du satellite dans la région méditerranéenne. Il a été développé pour les missions altimétriques tel que TOPEX / Poseidon (T/P, 1992), Jason-1 (2001) et Envisat (2002). Le FTLRS a été déployé là pendant deux campagnes laser, en 2002 et 2005. Ici, nous présentons le calcul des deux ensembles de coordonnées géocentriques des données FTLRS acquises principalement dans les deux campagnes sur les satellites géodésiques Terrestres basses: Starlette et Stella (altitude de 800 km).

L'article résume les différentes étapes du traitement des données laser. La moyenne des arcs RMS obtenu est environ de 1-2 centimètre pour les satellites Lageos-1, Lageos-2, Starlette et Stella; il est indiqué que les meilleurs résultats des orbitographies du satellite et de positionnement géocentrique sont obtenus avec le modèle de gravité Eigen-Grace03s. La différence du positionnement 3D absolu du FTLRS, entre 2002 et 2005, d'environ 7.7 mm (i.e., 2.6 mm / yr) est moins que les erreurs résiduelles de vélocité ITRF2005 (d'environ 4.3 mm/yr). Finalement, quelques suggestions de l'usage de FTLRS en Algérie pour les applications géodésiques sont faites.

Mots-clés : station de Télémétrie laser ultra mobile (FTLRS), Positionnement, Stabilité, télémétrie Laser du Satellite, modèle du champ de gravité terrestre.

Abstract : The present work is subscribed in the framework of cooperation in space geodesy domain between the Centre des Techniques Spatiales (CTS, Algeria) and the observatory of the Azure coast (GEMINI/OCA, France). The paper deals with the presentation of the French Transportable Laser Ranging Station (FTLRS) and its experiences of geographic positioning at Corsica (France). The geodetic site of Ajaccio in Corsica is the main calibration site of satellite altimeters in the Mediterranean area. It has been developed for altimetric missions such as TOPEX/Poseidon (T/P, 1992), Jason-1 (2001) and Envisat (2002). The FTLRS was deployed there during two laser campaigns, at 2002 and 2005. Here, we present the computation of the two sets of geocentric coordinates from the FTLRS range data acquired in the two campaigns mainly on the low Earth geodetic satellites: Starlette and Stella (altitude of 800 km).

The paper summarizes the different steps of the laser data processing. The average arcs RMS (Root Mean Square) obtained are about 1-2 cm for Lageos-1, Lageos-2, Starlette and Stella satellites; it is showed that best results of satellite orbits determination and geocentric positioning are obtained with Eigen-Grace03s gravity model.

The difference of FTLRS absolute 3D positioning, between 2002 and 2005, of about 7.7 mm (i.e., 2.6 mm/yr) is less than residual errors of ITRF2005 velocities (of about 4.3 mm/yr). Finally, some suggestions of the use of FTLRS in Algeria for geodetic applications are made.

Key words : French Transportable Laser Ranging Station (FTLRS), Positioning, Stability, Satellite Laser Ranging (SLR), Earth gravity field model.

1. Introduction

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 [2]. 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 [3]. 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 (as LAGEOS geodynamical satellites at an altitude of 6000 km) particularly at elevations lower than 40 degrees [1].

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 [2].

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 [2], in Crete (at Chania University) in 2003 [6], and for the second time in Ajaccio in 2005.

The present article deals with the description of FTLRS experiences carried out in Ajaccio (Corsica), during SLR tracking campaigns made in 2002 (from January to September) and in 2005 (from May to October).

2. Satellite Laser Ranging (SLR) Technique

The SLR technique is based on ultra precise timing (approximately 30 Pico seconds) of round trip of flight of ultra short pulses of light from a station on the ground (Telescope) to a satellite equipped with retro-reflectors (made up of cube corners). This provides instantaneous range measurements of millimeter level precision, which can be accumulated to provide accurate measurement of orbits and a host of important scientific data.

The telescopes laser are equipped with motorized tracking systems, precise and fast so as to be able to track the satellites of which speed can reach 7 km/s. The only information collected by these instruments is the distance telescope satellite and the precise moment of the measurement, fig.1.(a) [3].

However, the technique is tributary of the methodology and of the need of technicians specialized for its implementation. The contribution of the SLR measurements, gathered these last years, on the geodetic satellites, see fig.(1.b) : Starlette, Stella, Ajisai, Etalon, Lageos, etc, was important in the improvement of the terrestrial gravity field model (first model coefficients and their variations), for orbitography, positioning and space oceanography.

Among the space geodesy techniques, SLR technique does not seem to be the most precise one with the best temporal resolution. However, it is most exact on long term, which confers to it a unique place for observation of slowly variable phenomena (e.g. postglacial rebound), and for the realization of a stable geocentric terrestrial reference frame. By providing an absolute scale factor via the determination of the gravitational constant (GM), and its contribution in the calibration of the radar altimeters of the French organisations CNES, IGN, and OCA have developed a new concept of satellite laser ranging (SLR) system called the French Transportable Laser Ranging Station (FTLRS), fig. (2).

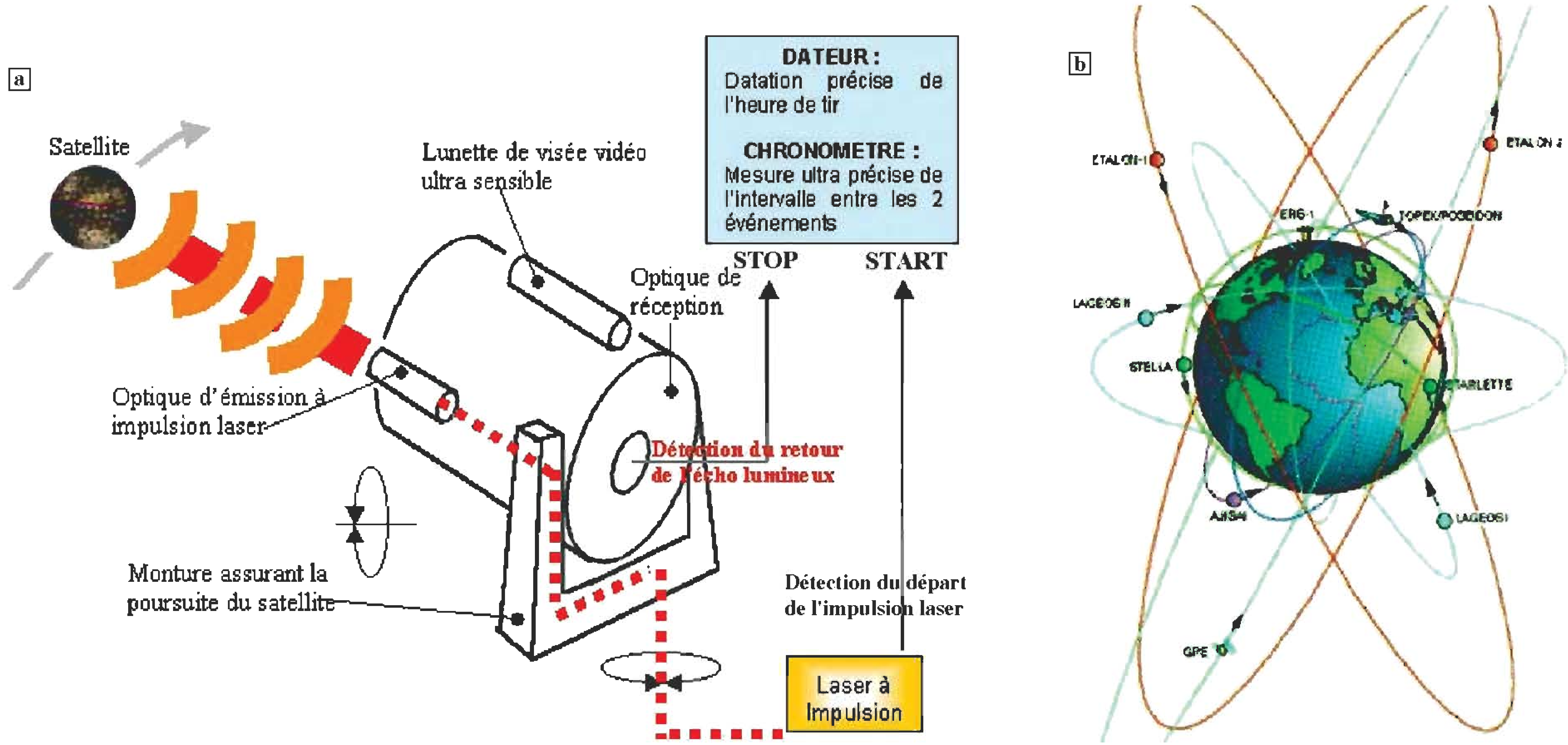

Fig. 1 Satellite Laser Ranging (SLR). **(a)** Principle of the SLR measurement [3] **(b)** Orbits of principle SLR satellites.

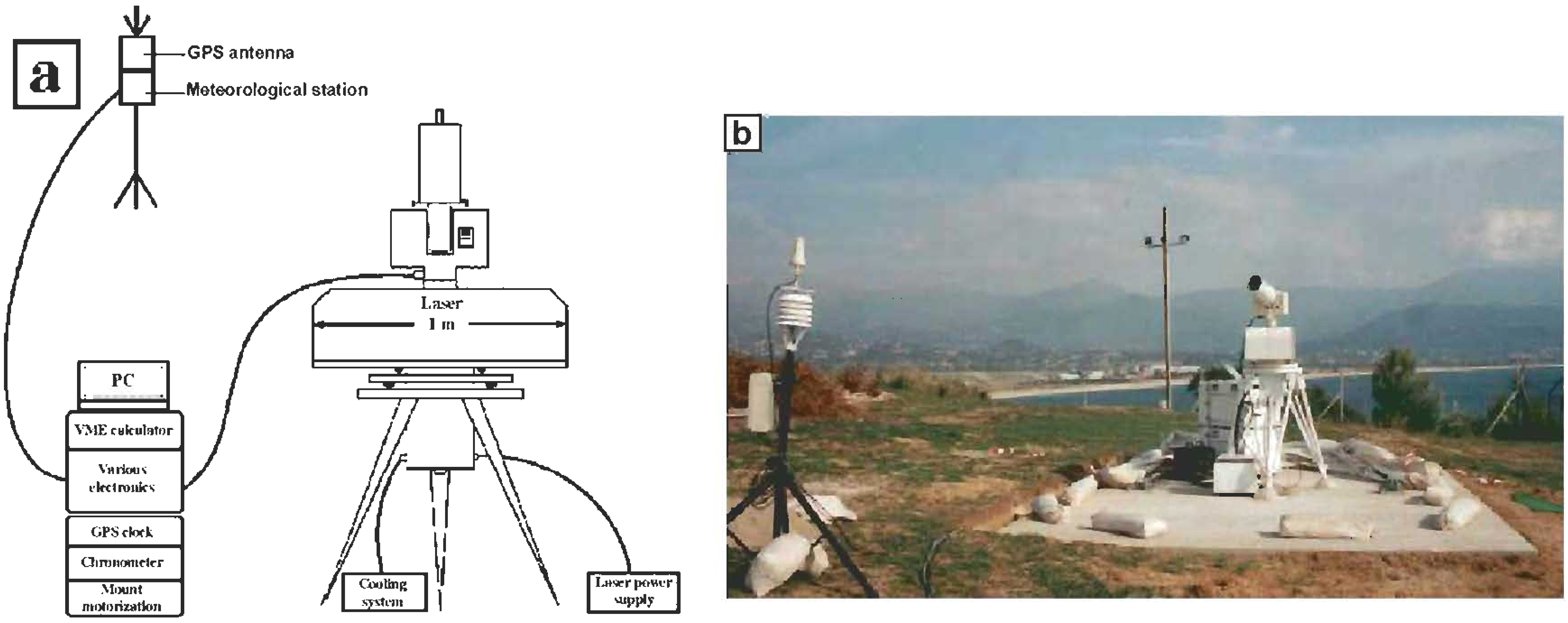

Fig. 2 French Transportable Laser Ranging Station. **(a)** Main components of FTLRS **(b)** Photo of FTLRS during the Corsica campaign (on left, the meteorological station and GPS antenna).

The idea was to realise a very small SLR station (telescope of 13 cm diameter, weight 300 kg), that is easily transportable, for example to make measurements in oceanic zones such as islands or offshore platforms. The technical description of the instrument is described in the table 1.

Table 1. Summary of FTLRS characteristics [3].

Total weight :	300 kg (8 containers <55kg)
Laser :	Nd:YAG doubled in frequency, λ=532 nm (green), 50 mJ by impulse, 10Hz, impulse width of 35 ps
Detector :	Photodiode with avalanche in Geiger mode
Telescope :	13 cm diameter , 2 kg
Climatic Conditions of use :	0 to +35°C, until 95% of humidity
Calibration :	External target, target on the outlet side of the telescope
Error of pointing :	≤10'' rms
System of chronometer :	Standford SR620, Rubidium controlled on GPS

The main objectives are to participate in space oceanography, centimetric calibration of radar altimeters, precise positioning and geodynamics. To reach this performance, many major improvements have been carried out on the FTLRS. According to Pierron et al. [7] and Nicolas [3], they mainly concern :
Topex/Poseidon, Jason-1, ERS, etc., this technique occupies an essential and complementary place for other space techniques.

3. FTLRS Description

- Laser configuration (wavelength, pulse width, cooling, stability, reliability in hard environments);
- Detection package with new optical configuration and C-SPAD (Compensated Single Photon Avalanche Diode) detector;
- Start detection with permanent laser monitoring;
- New GPS steered rubidium clock;
- Software improvement.

The success of all these upgrades has been confirmed at the level of few millimetres by the analysis of a collocation experiment performed at the Grasse observatory between the three laser instruments (autumn 2001) and the evaluation of data set from the 2002 Corsica campaign [4].

4. FTLRS Experiences in Corsica

The geographic configuration of the Corsica area is shown in Fig.3. 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. 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 2). 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 2), form the great part of the basis of our computation.

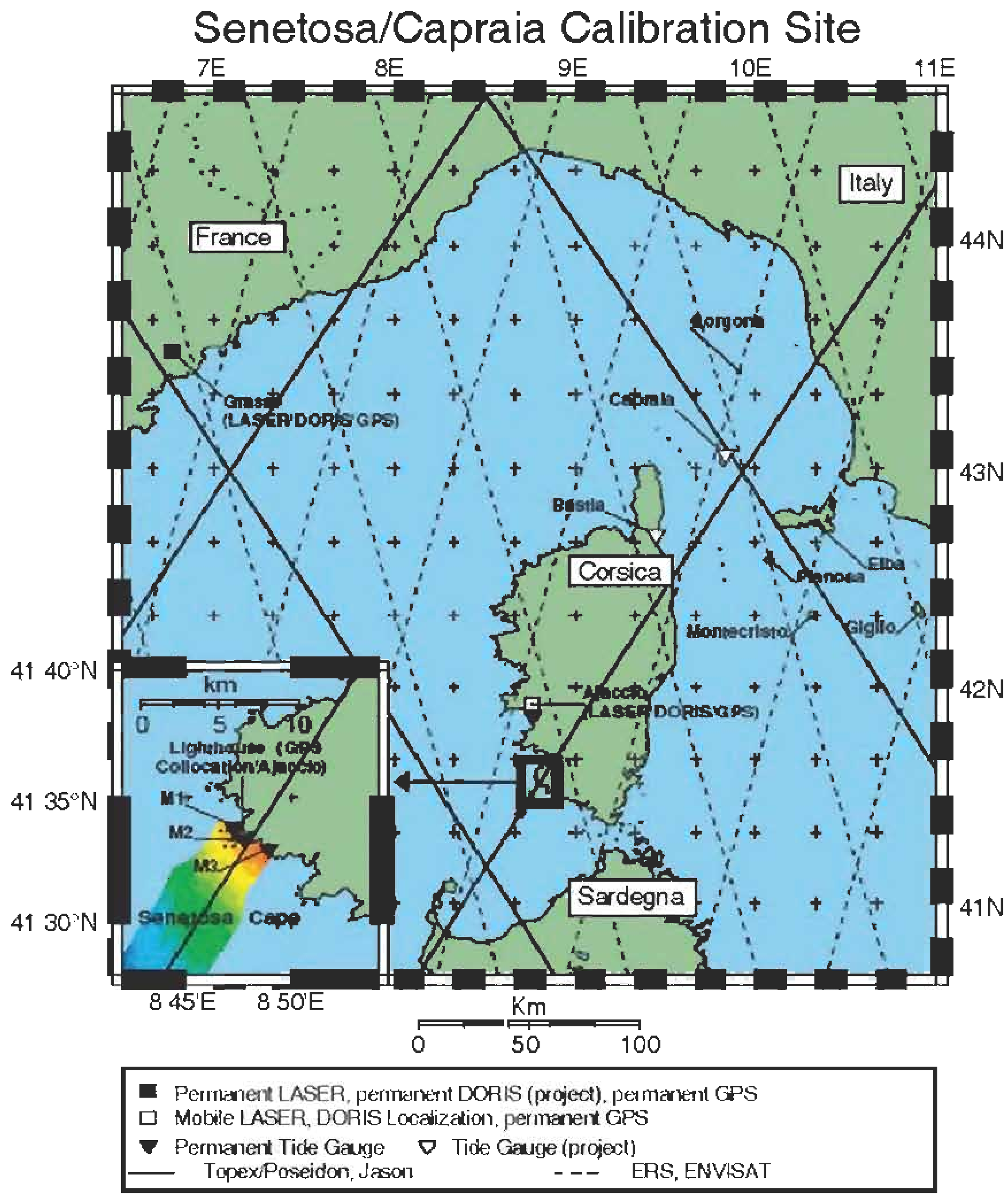

Fig. 3 Ajaccio Site in Corsica.

Table 2. Number of normal points collected by FTLRS during 2002 and 2005 campaigns.

Satellite	2002 Campaign	2005 Campaign
LAGEOS-1	301	377
LAGEOS-2	323	235
Starlette	3413	5294
Stella	1731	2069
Total	5768	7975

The adopted methodology to determinate the FTLRS geographic position, at Ajaccio site, is based on a multi-satellite semi-dynamical approach [2]. First, orbits are computed as precisely as possible (especially for the lower altitude satellites) without the FTLRS tracking data. Then, the normal matrices are established and the FTLRS parameters (coordinate updates and range biases) are solved through a weighted least-squares adjustment.
The precise orbit determination is performed by GINS *(Géodésie par Intégration Numérique; Geodesy by Simultaneous Numerical Integration,* in English) software (GRGS, Toulouse) assuming the following dynamical models and reference frame listed bellow (see Table 3). A subset of SLR fixed stations from the International Laser Ranging Service (ILRS) network, 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.

Table 3. Some dynamical models used for the orbit computation.

Model	Designation
Gravity field model	GRIM5-C1 or EIGEN-GRACE03S
Atmospheric pressure	ECMWF
Solar activity	ACSOL2
Atmospheric density	DTM-94
Ocean tides	FES-2002
Planets	DE403
Terrestrial reference frame	ITRF2000
Earth Orientation Parameters	EOPC04

The orbit quality is given by the rms of orbit residuals after fit. Table 4 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 Lageos-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.

Table 4. Average weighted rms (in mm) of the range residuals after orbit fits of the satellites used for the FTLRS positioning.

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

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 satellite ignatures and to inaccurate internal calibration of tracking instruments. These biases pose problems because they are strongly correlated with the vertical component of the station position (correlation greater than 0.9).

However, this component is important for the geodynamical studies since it holds ⅔ amplitude of signals acting on the station motion [1]. To reach the intrinsic accuracy of SLR technique, the data processing strategy must gua-rantee a correct estimation of the biases. Exertier et al. [2] have developed a specific method, called *temporal decorrelation*, decreasing the correlation between biases and vertical coordinates at level of 0.5.

The estimation of station coordinates updates and of the FTLRS range bias is performed using the MATLO *(MAThématiques pour la Localisation et l'Orbitographie; MAThematics for Localization and Orbitography,* in English) software (OCA, Grasse) [1]. For both campaigns, the initial coordinates used in the adjustment are the published ones by Exertier et al. [2]. These later correspond to the 2002 epoch. The FTLRS coordinates of the first campaign were recalculated with respect to the published position, which was corrected from plate tectonics (ITRF2000 velocities) at Ajaccio.

Table 5 gives, for the two periods 2002 and 2005, the range bias per satellite and the geographic coordinate updates. 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, [2]). We know that this value did not change since the first technological tests made in 2001 [8]. The differences between the 2002 and the 2005 solutions, in terms of geographical coordinates, are very small and are at the level of residual errors of the ITRF2005 velocities. By consequence, differences between 2002 and 2005 coordinates are at level of the tectonic movement and show that the point is locally stable.

Table 5. Range bias per satellite and geographic coordinate updates (in **mm**) of the FTLRS, for the two campaigns 2002 and 2005.

	Mean Lageos	Starlette	Stella	Mean Starlette & Stella	$\Delta\varphi$	$\Delta\lambda$	Δh	3D
2002	-6	-13	-13	-13.0 ± 0.7	-0.8 ±0.7	+1.6±0.7	+0.2±0.8	+1.8±1.3
2005	+4	-6	-4	-5.0 ± 0.8	+4.1±0.4	-2.9± 0.4	+4.0±0.4	+6.4±0.7
2005–2002					+4.9	−4.5	+3.8	+7.7

The fig. 3 represents the coordinate update time series with their standard deviations, according to the two gravity field models during the two observation campaigns. Statistically, the estimates of coordinate updates with the Eigen-Grace03s model are better than those with the Grim5-c1 model. Indeed, we have reduced the weighted mean of the geographical position from about 7.7±1.3 mm to 1.8±1.3 mm (in 2002) and from about 16.8 ±1.0 mm to 6.4 ±0.7 mm (in 2005).

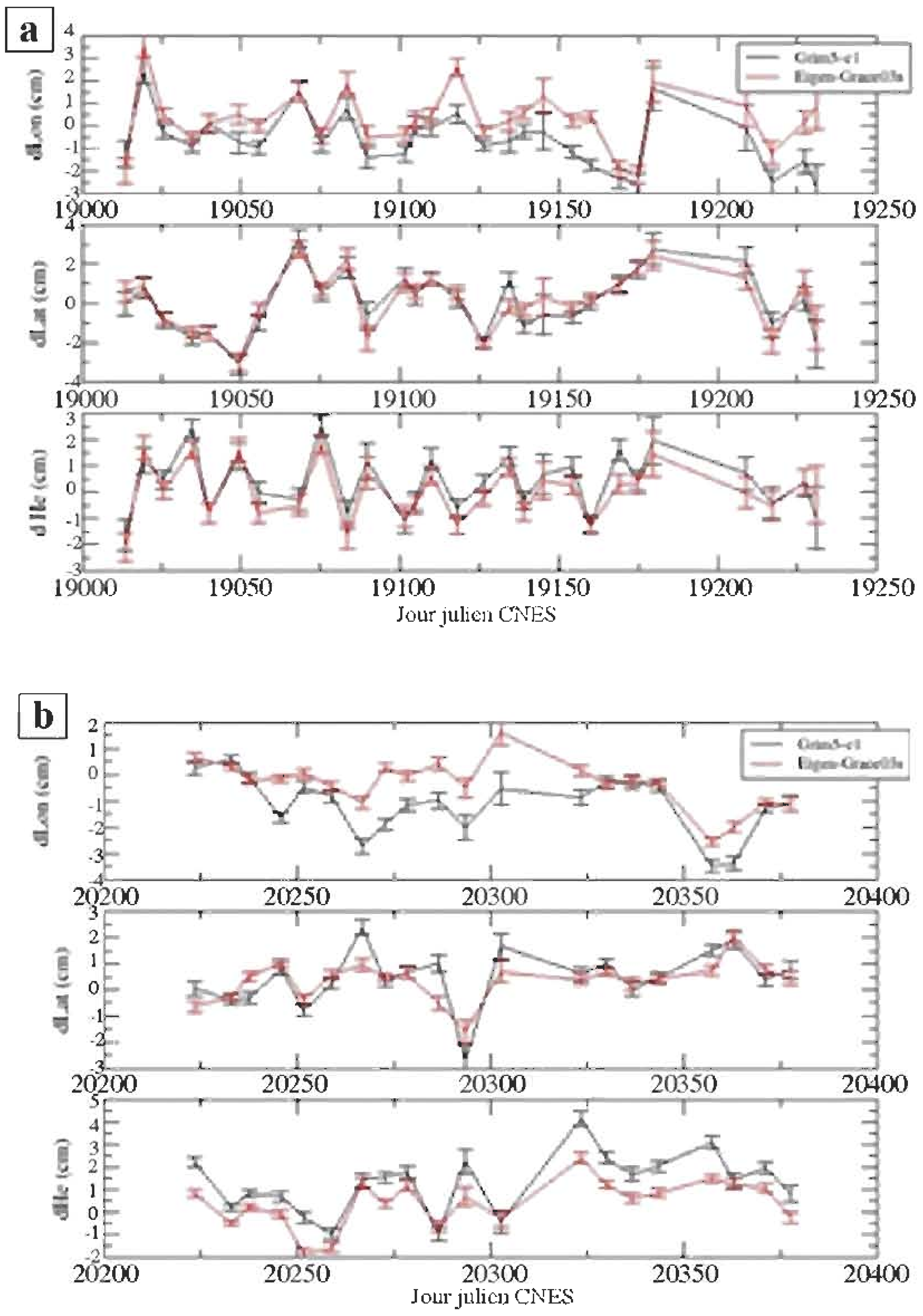

Fig. 3 Coordinate updates time series of the FTLRS (a) 2002 campaign (b) 2005 campaign.

5. Some suggestions of the use of the FTLRS in Algeria for geodetic applications

We propose some suggestions of the use of the FTLRS in Algeria, as following :
Until today, there is no point of ITRF network on the Algerian territory (and even on the North of Africa), where the interest of deploying the FTLRS in our country in view to :

a. Contribution to the International Terrestrial Reference Frame (ITRF) densification in North of Africa

- improve of the ITRF quality in term of configuration and also to allow to Algerian researchers to participate in ITRF observations programs.
- its extension to the national territory for the revaluation of the Algerian geodetic system (Nord Sahara 1959) in order to validate its quality and to facilitate the utilization of space techniques, notably the possibility of passage between the different systems used.

b. Study of geophysical and geodynamical phenomena

SLR technique, by measure for long periods of stations positions, contributes to observation and study of geophysical and geodynamical phenomenon (geological movements, notably the plates tectonic). It contributes also to the study of movements of Geocentre and terrestrial pole. In addition, considering insufficiencies of the national cartography relative to the seismic risks, the contribution of this space technique in deformation monitoring of the North of Algeria will have a positive impact on all works and projects relative to the study of seismic risk in Algeria.

c. Space oceanography

SLR allows precise tracking of oceanographic satellites. Thereby, it plays an important role in space altimetry missions (ERS-1, TOPEX/Poseidon, Jason-1, …) dedicated to monitor the evolution of the mean level of Mediterranean sea, phenomenon that interest Algeria, in priority. This priority is justified by the important population density on coastal zones (as, in Algiers, Oran, Annaba,..). Another advantage of this system is its contribution in the determination of an absolute altimetric reference (geodetic fixing of SLR stations to the tide gauges) which constitutes capital information for representation of the third dimension of the National geodetic system.

d. ALSAT Tracking

Installation of Laser retro-reflectors on future Algerian satellites (ALSAT generations), permits to allow making measurements by FTLRS for the orbital monitoring.

6. Conclusion

The FTLRS system confirms its place, as a unique highly mobile SLR system designed to participate to tracking campaigns on dedicated sites. According to the results obtained from the Corsica experiences, the FTLRS has demonstrated successful performance in the absolute geographic positioning as well as in CAL/VAL missions. 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. Finally, the idea to deploy this laser mobile station in Algeria is very interesting and fruitful for national geodetic applications as contribution of ITRF densification in North of Africa, geodynamics studies, space altimetry and ALSAT tracking.

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