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FRENCH TRANSPORTABLE LASER RANGING STATION: POSITIONING CAMPAIGNS FOR SATELLITE ALTIMETER CALIBRATION MISSIONS IN OCCIDENTAL MEDITERRANEAN SEA

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ABSTRACT

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, in the Mediterranean area, of radars on board altimetric satellite. It has been developed for altimetric and oceanographic missions such as TOPEX/Poseidon (T/P, 1992), Jason-1 (2001), Envisat (2002) and Jason-2 (2008). The FTLRS was deployed there during laser campaigns, on 2002 and 2005, and recently on 2008. Here, we present the analysis results of the SLR data acquired by the FTLRS during 2002 and 2005 campaigns mainly on the low Earth geodetic satellites: Starlette and Stella (altitude of 800 km).
The paper describes the different steps of the laser data processing. The average arcs RMS obtained are about 1-2 cm for Lageos-1&-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 proposed.

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

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 (Exertier at 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 et al., 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 (as LAGEOS-1 & -2 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 last mission of the FTLRS in occidental Mediterranean Sea was in Ajaccio for the third time in 2008 (Deleflie et al., 2011) 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). The analysis results are taken from (Gourine et al., 2008).

SATELLITE LASER RANGING (SLR) TECHNIQUE

Satellite Laser Ranging (SLR) is a pulse-echo measuring technique, which uses lasers to measure ranges from ground station (telescope) to satellite borne retro-reflectors (Figure 1.a). Because the events of sending and receiving a pulse can be registered within a few picoseconds, SLR determines the position of the ground station and of the satellite within a few millimeters. SLR is a dynamical measuring technique since the target at the satellite is moving in an orbit through the gravitational field of Earth. SLR is due to the use of optical wavelengths dependent on clear sky and the absence of clouds during the satellite passes.

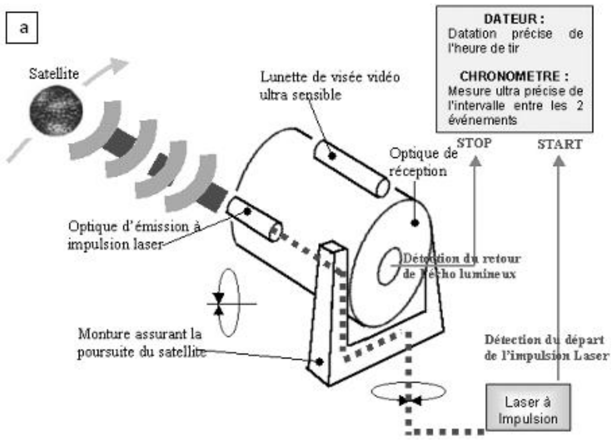


Figure 1: Satellite Laser Ranging (SLR). (a) Principle of the SLR measurement (b) Orbits of principle SLR satellites.

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 figure 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 Topex/Poseidon (T/P), Jason-1, ERS, etc., this technique occupies an essential and complementary place for other space techniques such as GPS, DORIS and VLBI.

ALTIMETER CALIBRATION

The success of altimetry missions is at origin of precise studies of sea level evolution. Besides the great interest which deals with geodetic studies of the geoid (equipotential surface of Earth's gravity field closest to the mean sea level prolonged under the continents), one is concerned more and more about the phenomena that affect our planet as global warming, etc.. Thus, the accurate altimetric measurements of the ocean surface can provide an element of answer: under the influence of heat, water tends to dilate thus causing a rise in its level.

This rise in sea level can have important economic consequences because great part of the population lives in coastal regions. The measurements on T/P for two decades, permit the estimation of this augmentation of about 1mm/year and for the Mediterranean Sea, it is about 1cm/year. Moreover, these measurements allow the study of ocean circulation (dynamic topography) and natural phenomena such as the Gulf Stream and El Niño.
From these different scientific interests was born the need to ensure the accuracy of the altimetric measurement. Therefore, compensate the bias and the drift of altimeters that degrade and affect these measurements, becomes a priority in the altimetry missions. In recent decades, successive missions calibration. Indeed, the absolute calibration was used in the past for many missions, for example:

- Seasat in Bermuda (1978);
- ERS-1 in Venice (1991);
- TOPEX / Poseidon in Lampedusa (1993);
- TOPEX / Poseidon and Jason-1 on the Harvest platform (since 1992);
- TOPEX / Poseidon, Jason-1 and ENVISAT in Corsica (since 1998).

The principle of absolute calibration based on the calculation of the bias on the height of the sea which is calculated as the difference between a sea level measured by the radar altimeter on board and that recorded by local sensors (tide gauges, GPS buoy, ...). By convention, a negative bias means that the altimeter measures too long. However, a positive bias means that the altimeter measurement is too short (*Bonnefond et al.*, 2003). In 2002 and 2005, SLR campaigns were performed under two specific tasks of the SLUM for altimetry calibration. Since few years, the last calibration campaign was effectuated on 2008. This later is not considered in the paper.

SATELLITE ALTIMETRY

In satellite altimetry, an orbiting satellite emits electromagnetic waves to the ocean surface of the Earth. It then records the time of arrival and the characteristics of the reflected signals (Figure 2).
The height or vertical distance of the satellite from the sea surface, the instantaneous surface of the sea, the significant wave height, the wind speed and other geophysical parameters can be determined from these measurements.
Dedicated calibration sites (such as Ajaccio site) measure environmental conditions that underlie the formation of the sea surface height, observe crustal deformation in the region, the conditions of the wind, waves, troposphere and ionosphere and subsequently permit a separation of the various potential errors of the altimeter. For example, the altimeter of TOPEX / Poseidon reach an accuracy of 3.5 cm, those of JASON-1 & -2 have an accuracy of 2.5cm and 2cm, respectively. Accurate estimates of the orbit, as the satellite overflies the site, are also critical. Dedicated calibration sites are commonly located along a

repeating ground track of altimetric satellites, and additionally where the altimeter and radiometer footprints do not experience significant land intrusion.

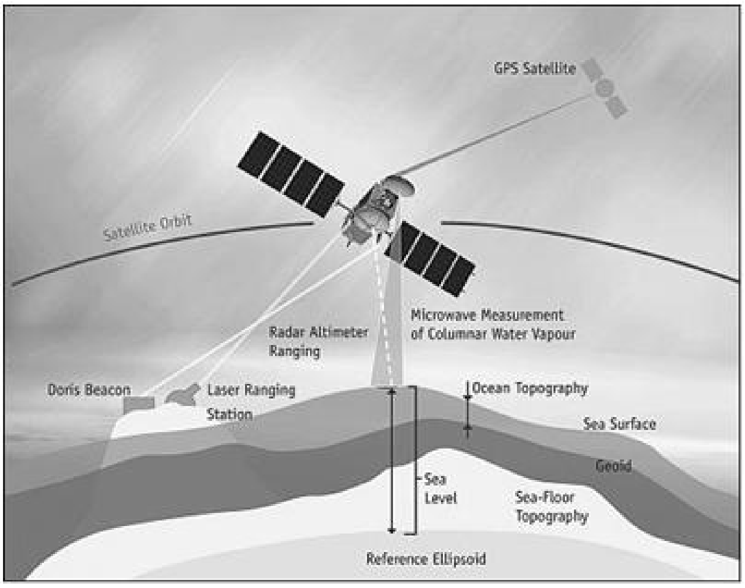


Figure 2: Principle of altimetry measurement (*image credit*: EUMETSAT)

FTLRS DESCRIPTION

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), figure (3). 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. 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., 2002) and (*Nicolas* et al., 2000), they mainly concern:

- 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.

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 (Nicolas et al., 2002).

Table 1: Summary of FTLRS characteristics

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	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

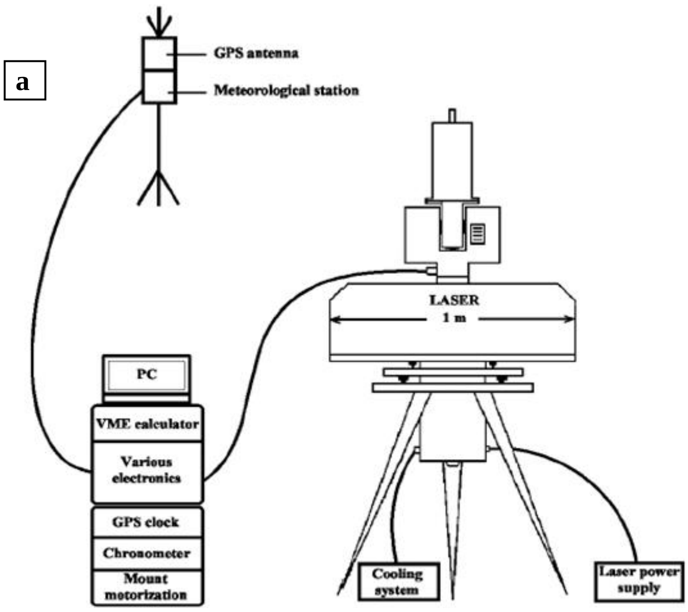


Figure 3: French Transportable Laser Ranging Station. (a) Main components of FTLRS (b) Photo of FTLRS during the Corsica campaign (on left, one can distinguish the meteorological station and GPS antenna).

FTLRS POSITIONING EXPERIENCES IN CORSICA

Figure 4 shows the geographic site of the Corsica area.The TOPEX/Poseidon and Jason-1 ground tracks pass over the Senetosa Cape which is the dedicated site for altimeter calibration where the *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.

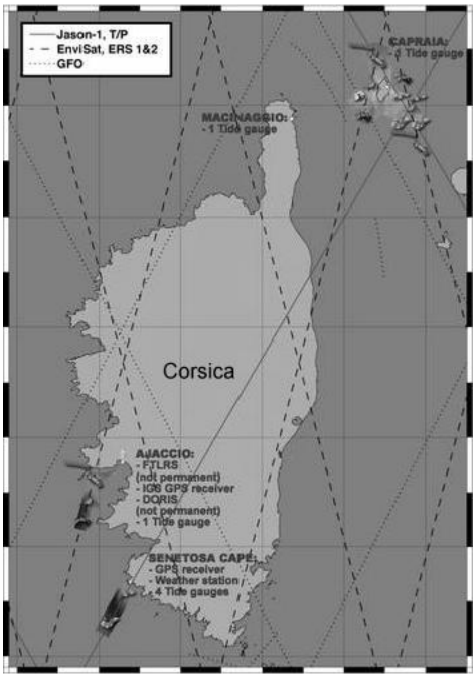


Figure 4: Ajaccio Site in Corsica, with ground track of oceanographic satellites (Jason-1, T/P, Envisat, ERS1&2, GFO)

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 (see 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, form the great part of the basis of our computation.

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 positioning is based on a multi-satellite semi-dynamical approach (Exertier et al., 2004). First, the 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 *(Geodesy by Simultaneous Numerical Integration)* software assuming dynamical models and reference frame. 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. The estimation of station coordinates is performed using the MATLO *(MAThematics for Localization and Orbitography)* (Coulot, 2005) software.

The orbit quality is given by the RMS of orbit residuals after adjustment. 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&-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 (Reigber et al., 2005) for the 2002 and 2005 positioning.

Table 3: Average weighted RMS (in mm) of the range residuals after orbit fits according to Grim5-c1 (Grim) and Eigen-Grace03s (Eigen) gravity field models

	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 signatures 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 (Coulot, 2005). To reach the intrinsic accuracy of SLR technique, the data processing strategy must guarantee a correct estimation of the biases. (Exertier et al., 2004) have developed a specific method, called *temporal decorrelation*, decreasing the correlation between biases and vertical coordinates at level of 0.5.

Table 4 gives, for the two campaigns, the values of the FTLRS bias and of the coordinate updates ($\delta\varphi$, $\delta\lambda$, δh) relative to absolute coordinates published by (Exertier et al., 2004). Concerning the bias, one can note that the global mean

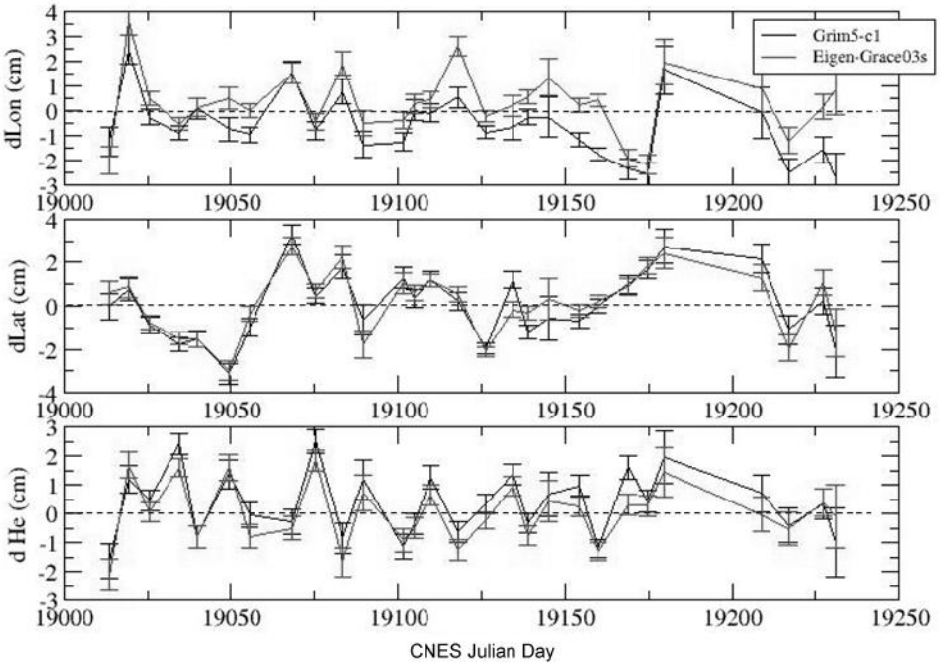
(-5 mm) is very close to the value which had been determined previously (–7±2 mm, ibid). We know that this value did not change since the first technological tests made in 2001 (Pierron et al., 2004). The differences between the 2002 and the 2005 solutions, in terms of geographical coordinates, are very small and are at the level of residual errors of the ITRF2005 velocities (Altamimi et al., 2007). By consequence, differences between 2002 and 2005 coordinates are at level of the tectonic movement and show that the point is locally stable.

Table 4. Range bias per satellite and differences (in mm) between our solution and FTLRS coordinates (*Exertier et al.*, 2004), for the two campaigns 2002 and 2005. The terms LAG, STAR and STEL correspond to LAGEOS-1&-2, Starlette and Stella, respectively.

	Mean LAG	STAR	STEL	Mean STAR & STEL	¢¨	¢*λ*	δ*h*	*3D*
2002	-6	-13	-13	-13±0.7	-0.8± 0.7	+1.6± 0.7	+0.2±0.8	+1.8± 1.3
2005	+4	-6	-4	-5 ± 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

Figure 5 represents the coordinate update time series with their standard deviations, according to both 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).

2002



2005

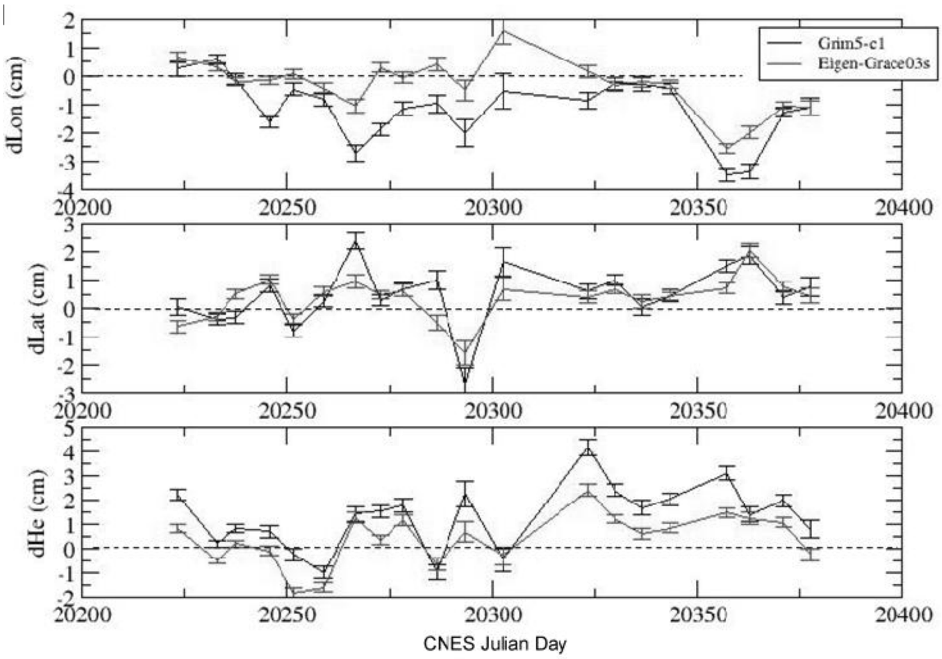


Figure 5: Time series of geographic coordinate updates of the FTLRS according to 2002 and 2005 campaigns

The results of this work were used successfully in a study of analysis of Jason-1 laser residuals using the precise orbits from both CNES and JPL (Bonnefond et al., 2006).

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:

- **Contribution to the International Terrestrial Reference Frame (ITRF) densification in North of Africa**

Until today, there is no point of ITRF (*International Terrestrial Reference Frame*) 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:

- improve of the ITRF quality in term of configuration and also to allow to Algerian researchers to participate in the ITRF observations and processing 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 transformation between the different used systems.

- **Study of geophysical and geodynamical phenomena**

SLR technique, thanks to long periods measurements of stations positions, contributes to observation and study of geophysical and geodynamical phenomenon (geological movements such as 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.

- **Satellite altimetry**

SLR allows precise tracking of oceanographic satellites. Thereby, it plays an important role in satellite altimetry missions (ERS-1, T/P, Jason-1 & -2, etc.) dedicated to monitor the evolution of the mean level of Mediterranean sea, phenomenon that interests Algeria, in priority (Figure 6). This priority is justified by the important population concentration 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 Algerian geodetic system.

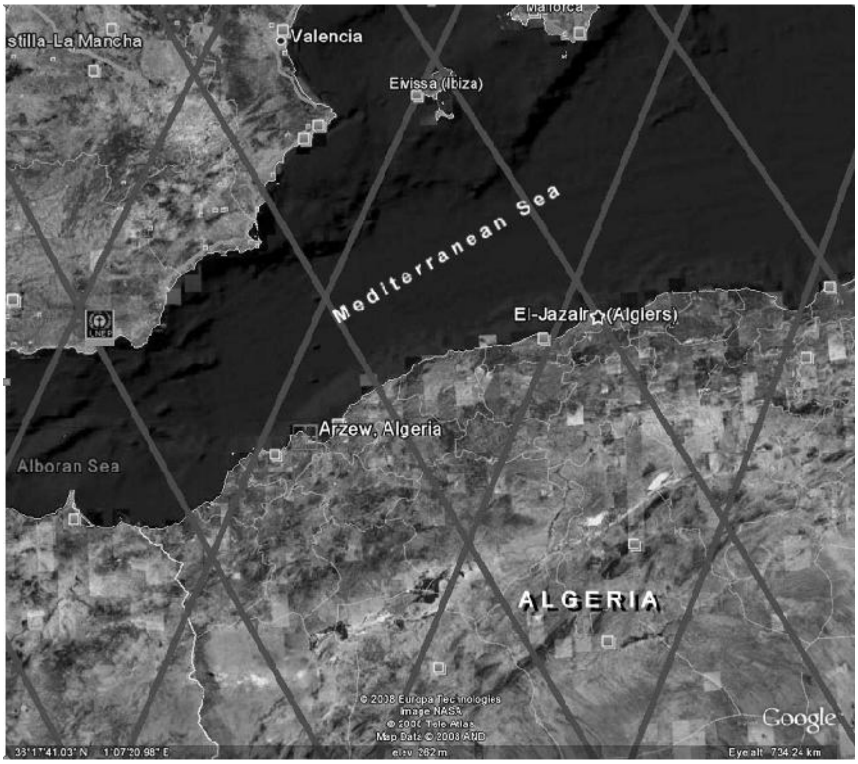


Figure 6: Ground tracks of Jason-1 satellite over occidental Mediterranean Sea and West of Algeria.

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 Satellite Altimeter Calibration 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 and satellite altimetry. As first step to concretize this idea, it is necessary to strength the scientific cooperation between Algerian and French research centers notably between ASAL/CTS-Algeria and OCA/GEMINI-France.

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