FTLRS POSITIONING FOR THE EU/NASA ALTIMETER CALIBRATION PROJECT GAVDOS

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Abstract

The Eastern Mediterranean area is one of great interest for its intense tectonic activity as well as for its regional oceanography. Recent observations convincingly demonstrated the importance of the area for regional meteorological and climatologic changes. GPS monitors tectonics, while tide gauges record the variations in Mean Sea Level (MSL). Monitoring tide gauge locations with continuous GPS on the other hand, will remove the uncertainties introduced by local tectonics, that contaminate the observed sea level variations. Such a global tide gauge network with long historical records is already used to calibrate satellite altimeters (e.g. on TOPEX/POSEIDON, GFO, JASON-1, ENVISAT, etc.), at present, a common IOC-GLOSS-IGS effort --TIGA. Crete hosts two of the oldest tide gauges in the regional network, at Souda Bay and Heraklion. We recently completed the instrumentation of a third, state-of-the-art MSL monitoring facility in southwestern Crete, on the isle of Gavdos, the southernmost European parcel of land. Our project –GAVDOS, further expands the regional tide gauge network to the south, and contributes to TIGA and MedGLOSS. This presentation focuses on the altimeter calibration aspect of the facility, in particular, its application to the JASON-1 mission. Another component of the project is the repeated occupation of the older tide gauges at Souda Bay and Heraklion, and their tie to the new facility. The Gavdos facility is situated under a ground-track crossing point of the original T/P and present JASON-1 orbits, allowing two calibration observations per cycle. It is an ideal site if the tectonic motions are monitored precisely and continuously. The facility hosts in addition to the two tide gauges, multiple GPS receivers, a DORIS beacon for positioning and orbit control, a transponder for direct calibration and it is visited periodically by Water Vapor Radiometers and solar spectrometers. At frequent intervals we also deploy GPS-laden buoys and conduct airborne surveys with gravimeters and laser profiling lidars for a high resolution and increased accuracy of the geoid and an independent observation of the local Sea Surface Topography (SST). The French Transportable Laser Ranging System (FTLRS) completed recently a co-location campaign at the Chania, Crete base site, which has a long GPS record since 1997. The FTLRS occupation provides us with an absolute SLR-derived position in the ITRF2000 frame, the ability to compare with the GPS-derived position, and improved orbit control over the site during the campaign. This will ensure the best possible and most reliable results from the project. We will present our latest estimates of the FTLRS position and the GPS-derived velocity vectors for the site, and other relevant results.

Introduction

Seal level change has become one of the hottest research topics in the past decade. The advent of remote sensing techniques from space (altimetry) provides frequent synoptic pictures of the state of Earth's oceans at regular interval. The TOPEX/POSEIDON mission was the first to do this in a very precise and routine fashion since mid-1992. This was followed by Jason-1, launched in time to allow for a comfortable overlap of the two missions. Since any instrument is characterized by systematic and random errors usually different from any other instrument even of the same type, it is prudent, and absolutely necessary in a case as this, to verify that past, current and future altimeter instruments, all measure sea level using the same "yard-stick", the same standard. This is ensured by calibration of the instruments before launch as well as while in space. It is also a matter of continuous monitoring of instrument performance, since electronic and mechanical systems age with time, and they do not necessarily perform equally throughout their lifetime [Mitchum, 1998]. Satellite Laser Ranging (SLR) was initially used to measure precisely the distance to the satellite when over-flying a laser site, to compare with the observed altimeter radar range. As altimeters became more precise though and science requirements more stringent, the primary role was taken by a global network of tide gauges, and the role of SLR has become that of a provider of a locally ultra-precise orbit. SLR is also used to determine the position of the experiment site in the same reference frame as it is used in computing the satellite orbits, ITRF2000 [Altamimi et al., 2002].

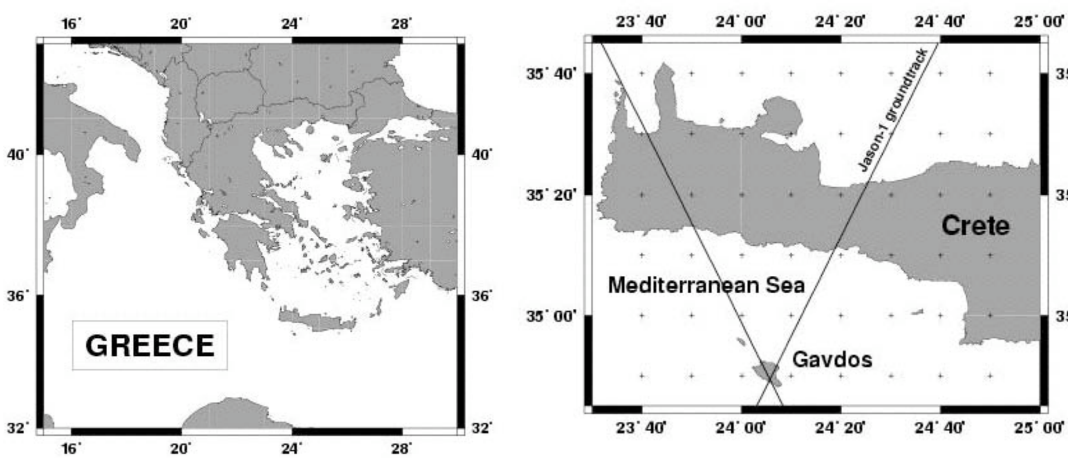

Figure 1. The location of the island of Gavdos, south of Crete and the Jason-1 groundtracks.

The GAVDOS project goals are the absolute calibration of altimeter missions and in particular, of the TOPEX/POSEIDON (T/P) and Jason-1 systems, and the continuous monitoring of these instruments for bias drifts or other temporal changes. Naturally, the continuous tide gauge and positioning of the tide gauge with GPS, provides also an independent measurement of local/regional sea level, in an area void of other such observations (Figure 1). Due to a fortuitous coincidence the Jason-1 groundtracks cross exactly over the tiny island of Gavdos south of Crete, Greece. This makes it a perfect regional calibration site, due to its small expanse, open sea location, small tides, fairly well known local geophysics and proximity to mainland. JCET in collaboration with the

Tech. University of Crete at Chania (TUC), and several other European institutes, submitted a proposal to establish an altimeter calibration and sea level monitoring site on Gavdos. The project was funded jointly by the European Union (EU), the National Aeronautics and Space Administration (NASA), and the Swiss Federal Government, and enjoys the participation of many institutes from Europe, and JCET group from the USA [Pavlis et al., 2004].

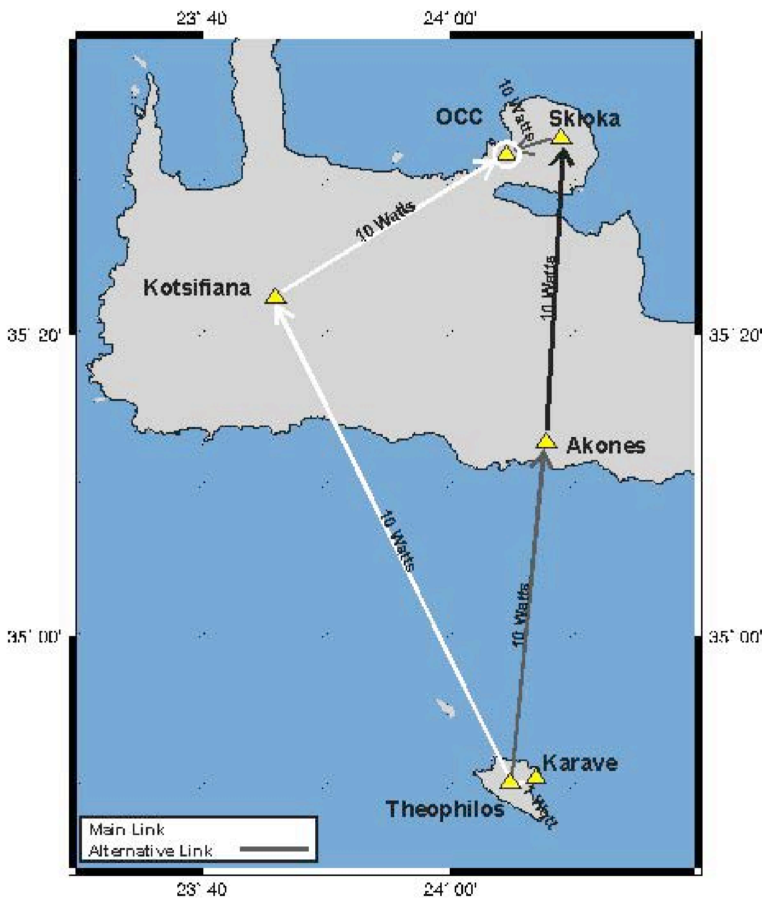

Figure 2. The regional GAVDOS network of sites: (a) OCC, the Operations Control center at the TUC campus, (b) the Karave tide gauge and GPS site on Gavdos, and (c) the Theofilos control and communications site on Gavdos, with the back-up GPS and DORIS beacon. The lines between sites indicate the possible communications links (and power) between the various sites for data access and instrument control operations.

Figure 2 illustrates the various sites that comprise the regional network and gives a brief description for the function of each of them. For a more detailed description of the project and its initial results, consult [*ibid.*]. This contribution will focus on the discussion of the deployment of the French Transportable Laser Ranging System (FTLRS—Figure 3), the positioning results from the six-month 2003-deployment at OCC, and a comparison to results obtained with GPS over the same time-period [Nicolas et al., 2001]. In addition to these, we will discuss in detail the pre- and post- campaign local surveys of the FTLRS deployment pad and calibration target, using precise GPS techniques.

SLR Positioning at OCC

Reference frame consistency, especially in the vertical, is of primary importance for an altimeter calibration and sea level monitoring project. Local orbital improvement over the calibration site, is also highly recommended during these experiments. Since the Gavdos site is fairly far away from permanent SLR tracking sites (Matera, Italy and Graz, Austria are the closest two), we opted to include a short-term campaign with a transportable system visiting the oldest site of the GAVDOS network, the OCC at TUC. This established a SLR collocation with one of the GPS network sites that has the longest observational record. The deployment of FTLRS at TUC (Figure 4) lasted from March to October 2003, with data primarily collected during two periods, April-June and Sept.-October, avoiding the high temperature mid-summer months. The data, promptly submitted to the ILRS data centers, were analysed by various Analysis Centers, including OCA/CERGA and JCET/NASA. The system tracked a number of SLR target satellites, with emphasis placed on the two altimeter-carrying missions, T/P and Jason-1. The distribution of the acquired passes and Normal Point (NP) data is shown in Figure 5.

Figure 3. FTLRS deployment at the TUC campus, the ranging system on the pad.

For precise positioning of the system, two different approaches were used by OCA and JCET, both leading to essentially the same results, given the differences in the amount and distribution of the data used. JCET used the LAGEOS and LAGEOS 2 tracking exclusively, while OCA supplemented that data with data from lower altitude targets, such as Starlette and Stella.

Figure 4. FTLRS at the TUC campus, the system and the facility as seen from OCC.

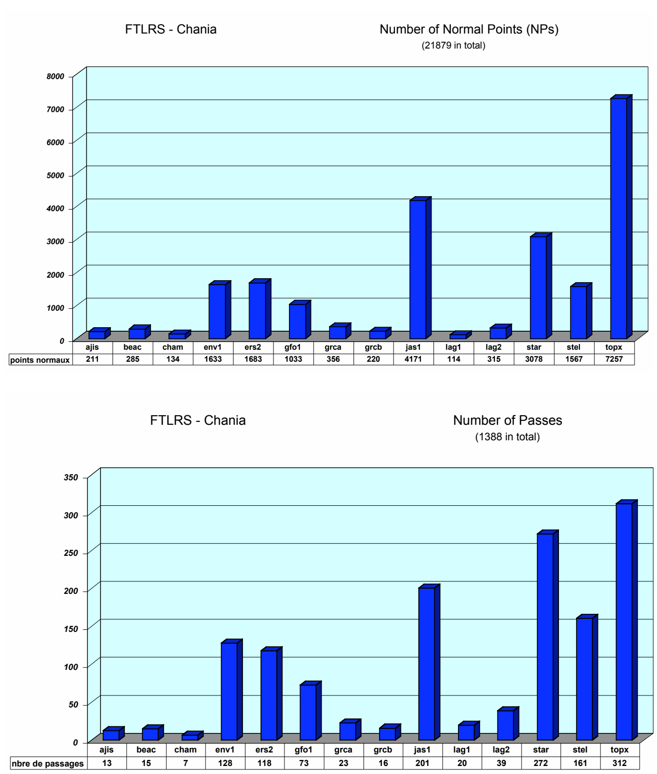

Figure 5. FTLRS-acquired SLR data during 2003: normal point data (top) and number of passes (bottom), at TUC, Chania, Crete, Greece.

At JCET we used a dynamic technique and data taken only on the two geodetic targets, LAGEOS 1 and 2, [Pavlis, 2002, 2003]. Separate solutions were done for the small data set of Spring 2003, as well as the entire set of data, using a fixed velocity vector relative to stable Europe, derived from many years of GPS observations at TUC1: 35.7 mm/yr at an azimuth of 226° [Pavlis, et al., 2002]. The position of FTLRS was determined in a quasi-ITRF2000 frame, realized by constraining the rest of the SLR sites' positions and velocities to their ITRF2000 values.

At OCA, the technique of SLR data reduction was based on their short-arc methodology with end-arc-overlaps [Bonnefond et al., 1995], using data taken on the two LAGEOS spacecraft (s/c) and additionally, on the low altitude geodetic satellites Starlette and Stella. The OCA analysis allowed for the estimation of measurement biases for each target satellite, assuming the biases stable over the entire campaign, with a strategy that minimized the correlation between the height component and the estimated biases. The JCET analysis made no use of low altitude satellites and since JCET's preliminary analysis did not indicate the existence of biases, we did not allow for such parameters in the final solution. The bias recovered from the OCA analysis is at the level of 10 mm, as opposed to an expected level of about 5 mm. The Cartesian positions from SLR, along with those obtained by GPS, are shown in Table 1 for both, the JCET and the OCA analyses. The results are in excellent agreement within techniques as well as across techniques, with only exception the Z-component values between the JCET and OCA SLR solutions and the corresponding GPS estimates.

Table 1. FTLRS Position vector derived from SLR and GPS data

Site and Epoch	X [m]	Y [m]	Z [m]
SLR0 1st part 1997.0 *(JCET SLR)*	4744552.665 ±0.021	2119414.416 ±0.022	3686245.086 ±0.019
SLR0 all data 1997.0 *(JCET SLR)*	4744552.665 ±0.006	2119414.426 ±0.006	3686245.095 ±0.006
SLR0 all data 2003.7 *(JCET SLR)*	4744552.558 ±0.006	2119414.553 ±0.006	3686245.158 ±0.006
SLR0 2003.7 *(JCET GPS)*	4744552.558 ±0.005	2119414.553 ±0.005	3686245.135 ±0.008
SLR0 4 S/C 2003.7 *(OCA SLR)*	4744552.564 ±0.006	2119414.553 ±0.006	3686245.139 ±0.006
SLR0 2003.7 *(OCA GPS)*	4744552.561 ±0.005	2119414.555 ±0.005	3686245.138 ±0.008

The discrepancy with GPS of some 20 mm may be due to the fact that the GPS values are simply averaged between the daily estimates from pre- and post-deployment solutions, while for the JCET SLR reductions, the GPS-derived velocity vector was used in the analysis. OCA also averaged their position estimates over the campaign period, making no use of an underlying velocity vector as JCET did. It should also be noted that both, JCET and OCA, used the same GPS processing software, the GAMIT suite, [King and Bock, 2000]. These issues are being investigated, as the SLR data taken on the other targets during the campaign are analysed and alternative estimates at JCET, allowing for biases are explored.

Local Surveys

The reference marker on the concrete pad that was built at the Chania campus of TUC for the FTLRS deployment, was surveyed with GPS prior to the deployment in early 2003, and a couple of months after the cease of operations, in early 2004. The setup of the GPS instruments and antennae was different on different days in 2003, and this is indicated in Figures 6 and 7. A single setup was used in 2004.

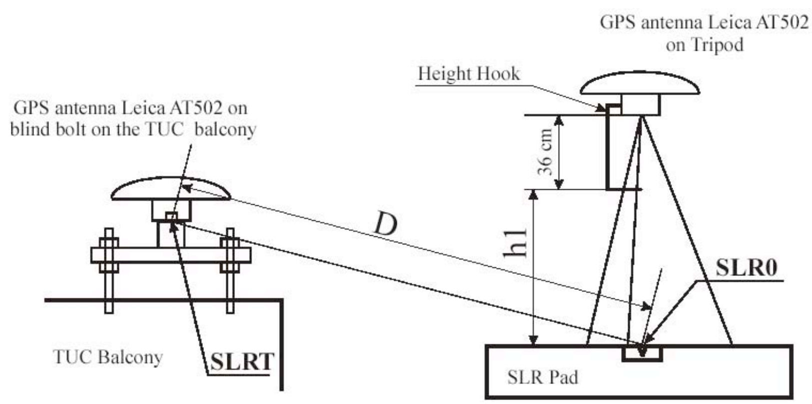

Figure 6. Local survey setup of GPS instruments and antennae on DOY 71-74, 2003.

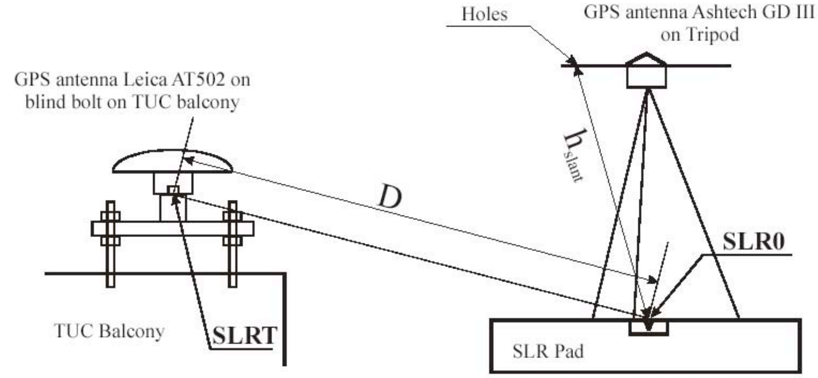

Figure 7. Local survey setup of GPS instruments and antennae on DOY 80-81, 2003.

The results from 2003 are slightly noisier and they are sparser compared to those from 2004. The changes indicated in each coordinate are consistent with changes expected due to tectonic activity in the area. The SLR calibration target was surveyed only in 2003.

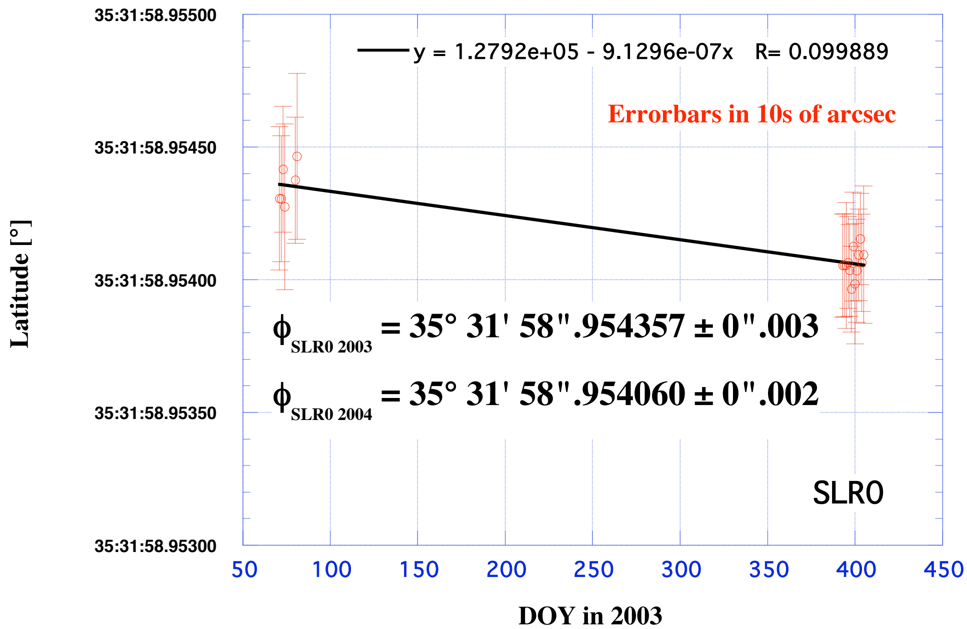

Figure 8. GPS-derived latitude estimates of the SLR marker “SLR0”, in 2003 and 2004.

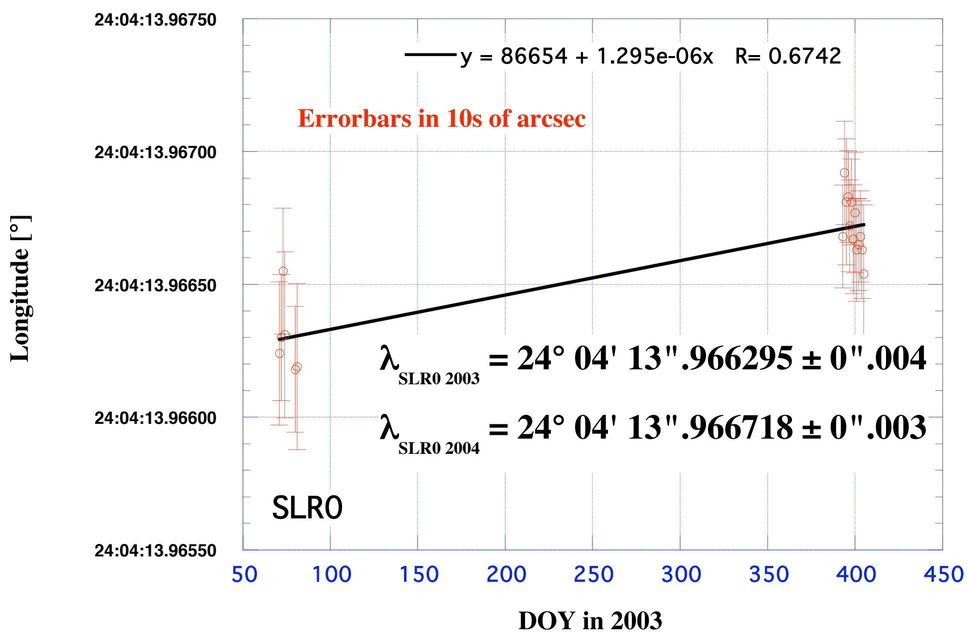

Figure 9. GPS-derived longitude estimates of the SLR marker “SLR0”, in 2003 and 2004.

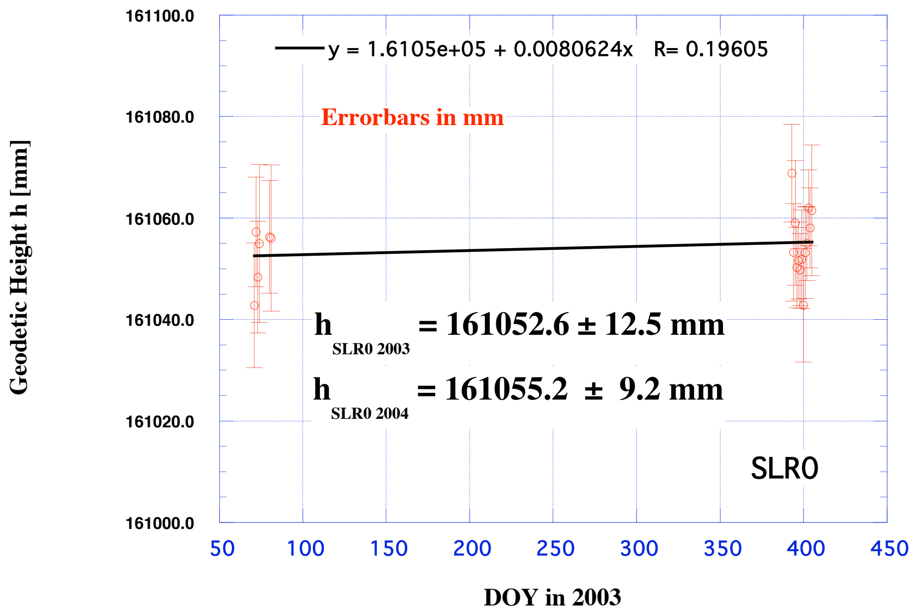

Figure 10. GPS-derived height estimates of the SLR marker "SLR0", in 2003 and 2004.

Figures 8 through 10 show the results of the two surveys of the SLR marker, SLR0, in 2003 and 2004. Figures 11 through 13 show the 2003 survey results for the SLR calibration target.

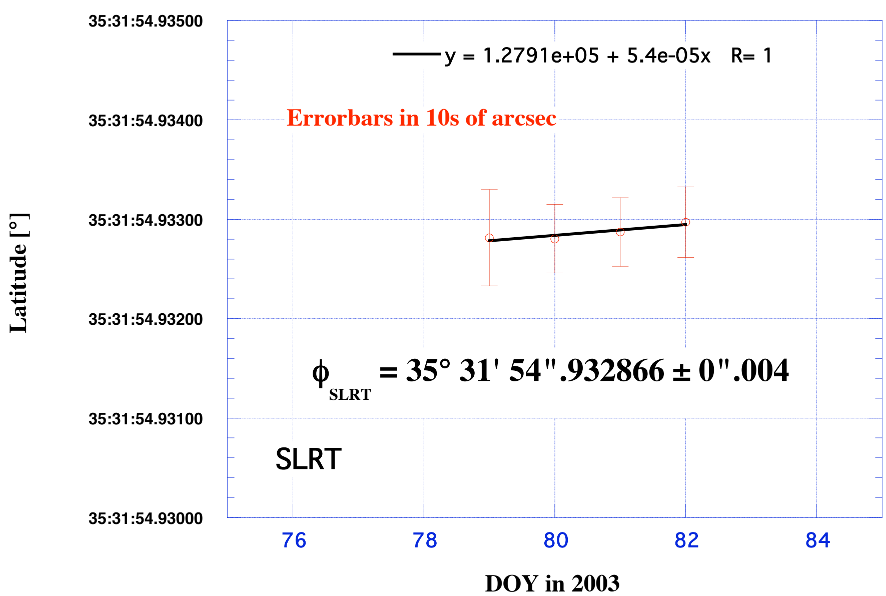

Figure 11. GPS-derived latitude estimates of the SLR calibration target "SLRT".

The results for the calibration target indicate some systematic change over the four days of observations, however, the magnitude of these changes is at the two millimeters per day level and they are well within the accuracy range for such surveys.

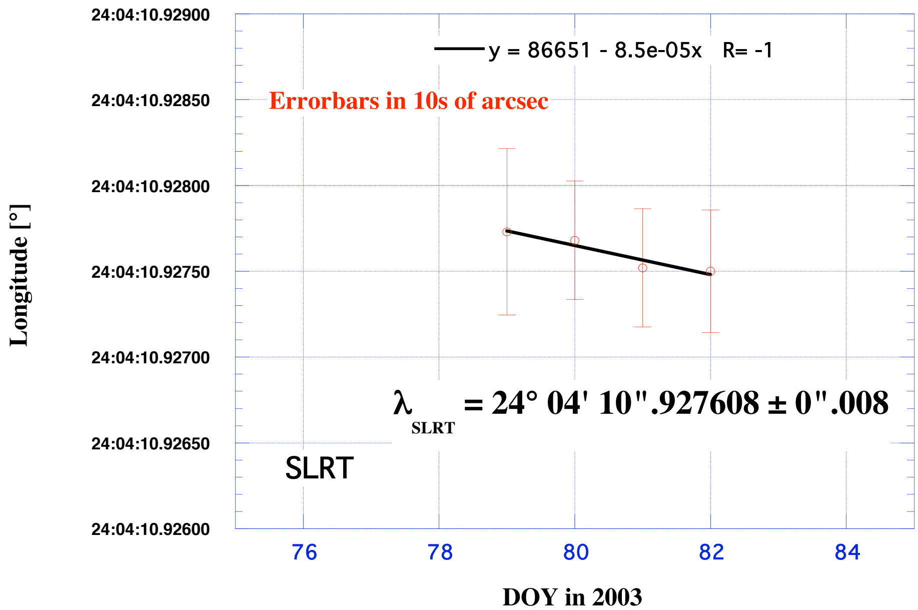

Figure 12. GPS-derived longitude estimates of the SLR calibration target "SLRT".

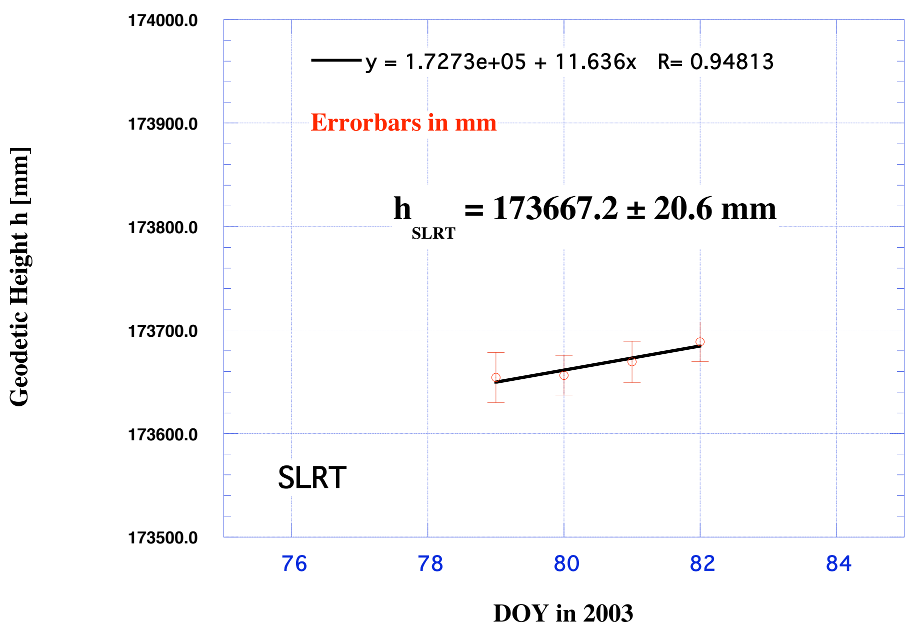

Figure 13. GPS-derived height estimates of the SLR calibration target "SLRT".

The spread of the height estimates for the calibration target (Figure 13) are slightly more disturbing, not so much for their size, in that sense they are consistent with the height estimates for SLR0 during the same period (cf. Figure 10, 2003 results), but rather for the very systematic nature of the change. This seems to be more related to the fact that the target was placed at the corner of a three-story building. It will be interesting to compare these results with average daily temperatures over these four days.

Figure 14. The Theofilos control site, with the GPS and DORIS (insert) pillars.

The regional network data of the continuously operating GPS receivers have been consistently analyzed with GAMIT and with the establishment of an ITRF2000-consistent absolute position at OCC/TUC, we can now propagate these absolute coordinates throughout the network. In the next step we plan to generate a similar absolute position based on the DORIS data from the Theofilos site (Figure 14), and compare these coordinates to those obtained from the GPS and SLR combination.

Summary

We discussed the recent deployment of the French Transportable Laser Ranging System at Chania, Crete, Greece, in the realm of the GAVDOS altimeter calibration and sea level monitoring project. The SLR data provide an absolute, ITRF2000-consistent position for one of the older project sites, with the longest GPS record. We can now propagate the absolute position of OCC/TUC to all sites linked to it via the continuously operating GPS network. This campaign has demonstrated that with the proper planning, mobile SLR systems can provide solid positioning support in a very short time for such projects. The success of this effort convinced us to plan to repeat the campaign in the future in order to control any long-term changes in the tectonic behavior of the region, and to further improve the quality with which the absolute locations of the regional network are known.

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