

# Tectonics, sea-level monitoring and altimeter calibration with a regional GPS array

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## Abstract

We describe an innovative regional GPS project that makes use of the same array of instruments to address a wide range of scientific problems. The primary application of the array is the precise, continuous monitoring of regional deformation in the area of western Crete, Greece. At the same time the fortuitous coincidence of one island site with a sub-satellite cross-over point of the TOPEX/POSEIDON and JASON-1 missions makes that site an excellent candidate for an altimeter calibration for both missions, as well as many other altimetric missions (ERS-2, GFO, ENVISAT). Our contribution describes the present status of the array, first results from precise connections of the GPS sites with existing tide-gauges and our future plans.

## 1. Introduction

Eastern Mediterranean sea, an area with intense tectonic activity, is of great interest for its regional tectonics and oceanography. This is reflected in the large number of multi-national research projects in the area. Our project was initiated over two years ago and since then it has grown to incorporate several objectives. Although these objectives are of a multi-disciplinary nature, they can be easily addressed simultaneously with the proper deployment of a regional GPS array, and they are:

- Establish a permanent, continuous-tracking GPS array with (minimum) one IGS-class site
- Connection to local tide-gauges with continuous monitoring
- Develop & test algorithms for automatic, real-time detection of motion associated with seismic risk
- Deployment of the array so that it complements local seismic networks
- Collect deformation data to test Hellenic subduction zone models for the area
- Provide fiducial sites with precise geodetic positions for future and on-going projects (mapping, navigation, etc.) in the framework of WEGENER and EUROGLOSS.
- Establish one permanent site on the isle of Gavdos as an altimeter calibration site.

## 2. Project description

As part of a permanent GPS array that we are currently deploying over the west and central part of the island of Crete, we also plan to occupy the two tide-gauge sites at Souda Bay and Heraklion. The first one was positioned with GPS in the past and more recently, by our group as part of the CRETE project (Crete REGIONAL Tectonic Experiment). Intense seismicity in this area and large geodynamic motions require that characterization of the deformation needs to be done with dense local networks, preferably permanent and continuously operating ones. Continuous monitoring at tide-gauge sites has gained importance lately since (a) tectonics contaminate the inferred sea-level variations, and (b) a global network of tide-gauges with long historical records can be used effectively as satellite altimeter calibration sites for current and future missions (e.g. TOPEX/POSEIDON, GFO, JASON-1, ENVISAT). This effort is a jointly sanctioned activity by IOC, GLOSS, and IGS, already underway [Baker et al., 1997; Mitchum, 1997]. The island of Crete hosts two of the oldest tide-gauges in the area with plans to soon upgrade these instruments with state-of-the-art equipment and further expand the network to the south of the island with a new site on the isle of Gavdos. This isle is situated under a groundtrack crossing point of the T/P and JASON orbits. Its location makes it an ideal calibration site if the tectonic motions are monitored precisely and continuously. In addition to the GPS receiver and the tide-gauge, we are also exploring possibilities for additional ancillary instrumentation at this site, such as a DORIS beacon, altimeter transponders, gravimeters, etc..

We present here the first positioning results of the base site at the Technical University of Crete (TUC), Department of Mineral Resources Engineering (MRED), and the results from our Souda Bay campaign during one week in December of 1997.

## 3. The central site of the array

Through an initial seed funding of the Greek Ministry for Research and Technology, TUC/MRED purchased two GPS receivers as a first installment in the development of CRETE. After careful scrutiny of the

available options and pricing, the University picked the Ashtech CGRS Z-12 model. Their decision was also in part based on the evaluation of research-quality equipment by UNAVCO. The equipment was tested and verified at TUC. One of the two receivers was then installed permanently at TUC. This site is referred to as TUC1. The antenna for this base site was installed on the roof of the building housing MRED. Several areas of the roof were examined for multipath contamination of the signals and interference from other, nearby instrumentation. The southwest corner of the building was found to be the most appropriate.

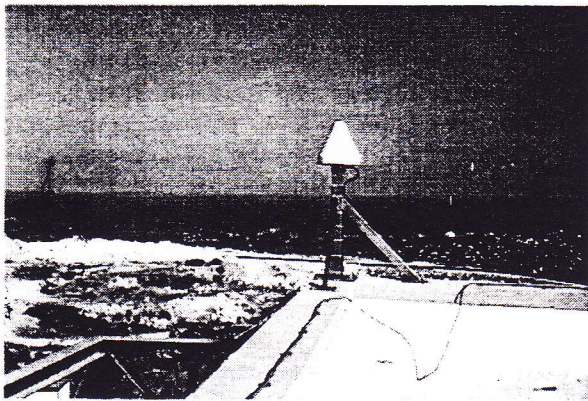


Figure 1. The antenna at the main site TUC1.

The antenna mount was locally manufactured based on specs that were drawn from similar constructions available from UNAVCO's document archive. The result is shown in Fig. 1. The receiver itself is housed within the building in the area of the MRED laboratory and it is connected to an uninterrupted power supply line and a local PC. This particular receiver is running the "BASE" version of the Ashtech OS, while the second receiver can be used optionally as "BASE" or "ROVER", depending on whether the equipment is used in a static, permanent installation or a kinematic survey. One of the future applications of the array is the transmission of DGPS corrections for local users. The receiver pair can communicate in real time via two radio transceivers (Motorola GM 300) equipped with GRM 530 modems for Base-Rover Real-Time Kinematic (RTK) applications with cm-level accuracy. The second receiver is intended for permanent installation at the Souda Bay tide-gauge site. This is pending negotiations between TUC and the Hellenic Navy. An MOU that was recently signed between TUC and the Hellenic Navy Hydrographic Service will pave the way in the finalization of this phase.

#### 4. Operations at TUC

Data archival facility at TUC is based on the CDDIS design. Although the data is currently downloaded from

the receiver on a daily basis, eventually it will be collected in hourly intervals, quality-checked, RINEXed and archived. The quality checking process makes use of UNAVCO's *TEQC* suite. We are contemplating using UNAVCO/UNIDATA's *LDM* s/w for local data management and dissemination when the array becomes operational. At this point however, data from the dedicated TUC archival platform is accessible only via ftp. For the precise analysis of the regional GPS data set and future global solutions, we have installed at TUC, NASA Goddard's *GEODYN/SOLVE* suite of programs. The main package and a number of support utilities are presently operational on a dedicated Sun Ultra 10.

The collected data is currently analyzed as daily solutions for the position of TUC1. These daily solutions are done (post-facto) in point-positioning mode using the precise IGS orbits. Eventually, the ensemble of data from the entire array will be analyzed in weekly solutions using additional GPS data from selected near-by sites. In the future, monthly and annual solutions will be also developed based on definitive IGS products. These solutions will provide the most precise connection of the array to the global ITRF. Finally, the analysis of data from the first few years of operation of the array will be used for the determination of motion vectors at the array sites.

#### 5. Initial positioning experiments

The first time TUC1 operated under the present configuration was in August of 1997. Data were continuously collected until the end of the year with the exception of two short breaks to participate in two regional RTK campaigns. During the third week of December, GPS week 936, the Hellenic Navy granted us a permission to occupy the Souda Bay tide-gauge and collect GPS data. The Souda Bay (SBTG) site is located within the proper of a Naval Base and it is only a short distance (~6 km) from the base site TUC1. Both sites were occupied simultaneously for one week. Our point positioning solutions use the precise IGS orbits (*post facto*), but not the IGS satellite clocks. We use instead the data from a small number of regional IGS sites to create a set of biased doubly differenced ranges (DDR) from phase observations. Based on these DDRs we solve for the array sites' coordinates. The group of surrounding region IGS sites that we selected to use for this preliminary regional analysis are: ANKR, GRAZ, KERK, KITAB, KOSG, MADR, MASP, MATE, METS, POTS, VILA, and WTZR. Not all sites are needed, but since some of them have no data on certain dates, we decided to use redundant sites to account for the missing ones. Additionally, the larger set dilutes the effect of these changes in the geometry of the "reference-frame-defining" network.

For the daily solutions, all of the IGS sites have their coordinates held fixed at the values consistent with the ITRF96 standard set (accounting for tectonic motions). As a result, the solutions obtained for TUC1 and SBTG are essentially (in principle) also consistent with the ITRF96 standard. The level at which this has been achieved is dependent of course on the quality and distribution of the tracking data and the level at which the selected regional network realized the ITRF96 frame. One of the drawbacks in the design of this particular network is the lack of regional IGS sites to the south of the CRETE array. This however may be adequately resolved in the future, as more North African countries join the IGS network.

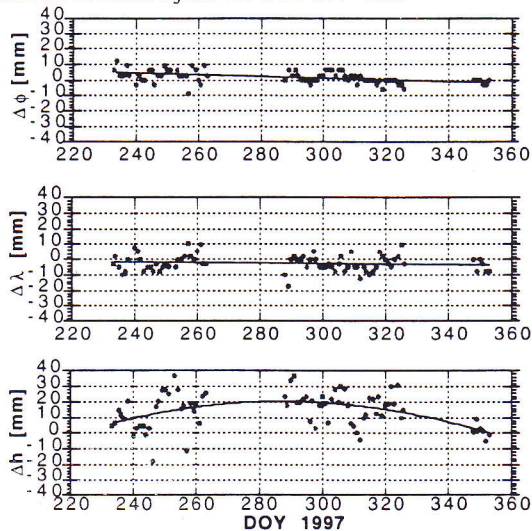


Figure 2. Time series of latitude, longitude and height variations for TUC1 daily solutions during 1997.

The results for TUC1 from the reduction of the 1997 data are displayed in terms of their daily discrepancies from the mean estimate of the geodetic coordinates  $\phi$ ,  $\lambda$  and  $h$  in Figure 2. Similarly, in Figure 3 we have the corresponding variations for the data collected at SBTG during the short occupation of the tide-gauge site in December of 1997. The typical scatter for these estimates is 4 and 5 mm for latitude and longitude, and 10 mm for height. The twice as high scatter for the height is expected, although a slight improvement may be expected in that coordinate when better modeling of the local ocean loading is applied. For the short time period that both sites were simultaneously tracking in December 1997, we also have estimates of the daily variations in the baseline between the two sites. Same-day variations at the two sites are highly correlated due to the extremely short distance separating them and the computation of the baseline removes these common-mode errors. It is not surprising then that the variations exhibited by this baseline length (Fig. 4) are reduced by an order of magnitude when compared to those

exhibited by the coordinates of the two sites (Figs. 2 and 3).

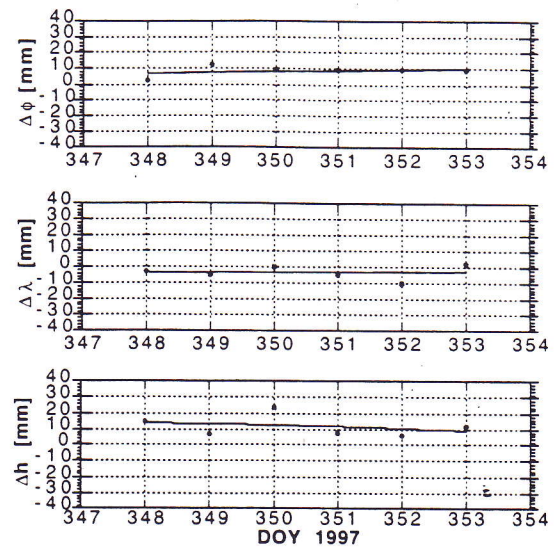


Figure 3. Time series of latitude, longitude and height variations for SBTG daily solutions in December 1997.

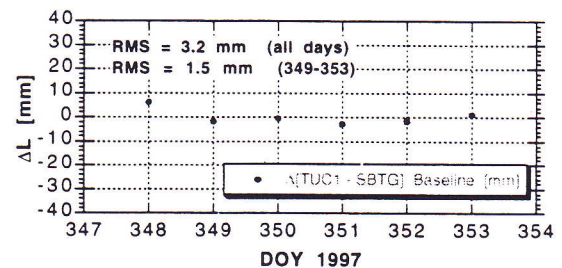


Figure 4. Time series of the TUC1 - SBTG baseline variations for daily solutions in December 1997.

The antenna location at SBTG was not the optimal one and the installation was only temporary. One would therefore expect better and more consistent results when these issues are resolved. The coordinates of the two sites in the ITRF96 frame are given in Table 1.

Table 1. The coordinates of TUC1 and SBTG sites in the ITRF96 frame, based on the 1997 data set.

X	Y	Z
<b>Base Site TUC1:</b>		
4 744 660.921 m	2 119 381.932 m	3 686 155.160 m
±8 mm	±6 mm	±8 mm
<b>Souda Bay Tide Gauge Site SBTG:</b>		
4 746 691.167 m	2 121 560.400 m	3 682 052.994 m
±6 mm	±6 mm	±4 mm

## 6. Tectonics of the area

Locations of future sites for the CRETE array are shown in Figure 5. This area is tectonically very active and there is strong evidence from recent seismic experiments [Giunchi et al. 1996] as well as from studies of historical and geological data [Lambeck, 1995] that there is a ~5 mm/y uplift associated with the south-western tip of the island. In fact the rate of uplift gradually declines as one proceeds in a northeasterly direction, until we reach a "quiet" area at about the middle of the island.

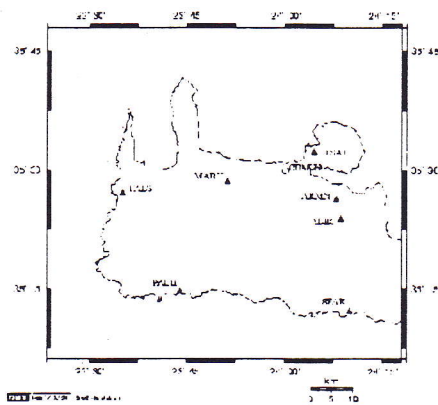


Figure 5. Location of TUC1 and some possible future sites for CRETE in western Crete, Greece.

It is therefore reasonable to say that the island is tilting upwards about an axis that lies near the middle of the island and has NW-SE direction. Tectonics of the area are associated with several, frequent, large and shallow earthquakes that cause a lot of material damages and pose a significant hazard to the islanders and visitors. These constitute the issues that the "tectonic" component of this project addresses.

## 7. Altimeter calibration at Gavdos

One of the newest additions to the utilities of CRETE is the establishment of a permanent altimeter calibration site in the area. The small isle of Gavdos lies some 60-km off the southwest coast of the main island. One of the crossover points of the TOPEX/POSEIDON satellite altimeter groundtrack coincides with that isle. The fact that the isle is rather isolated, the Mediterranean is much quieter than the open ocean, the tides are small and easily observable with regional tide-gauges, and the weather is clear nearly year-round, makes this site a very good candidate.

Considering that the T/P follow-on mission, JASON-1, will follow the same groundtrack, this site can be used to cross-calibrate the two missions as well as any other altimeter in space. The cross-calibration of such systems is one of the most important issues in connection with the sea-level studies on a global basis.

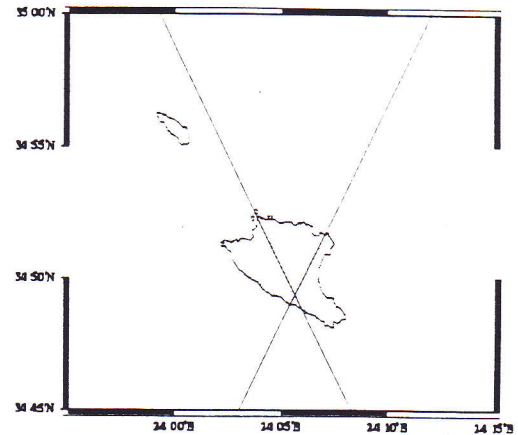


Figure 6. The isle of Gavdos in southwestern Crete, Greece, and the TOPEX/POSEIDON and JASON-1 groundtracks.

## 8. Conclusion

We presented here the first results from a regional permanent GPS array that we are in the process of establishing in southwestern Crete, Greece. In addition to the primary application of monitoring local deformation, the array will cover a number of other applications essential in the creation of an Integrated Global Geodetic Observing System. Successful contributions from CRETE to the areas discussed herein will make this array a truly multidisciplinary project to observe the Earth system in an integrated way.

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