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GAVDOS: A satellite radar altimeter calibration and sea-level monitoring site on the island of Gavdos, Crete

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Abstract

An absolute sea-level monitoring and altimeter calibration permanent facility has been established on the island of Gavdos, Crete, Greece. The facility has been selected for various reasons, in particular because it is under a crossing point of the ground tracks of TOPEX/Poseidon and Jason–1, and adjacent to an ENVISAT pass. The island is also far from the mainland at a location where tides are small.

Keywords: Calibration/validation, radar altimetry, sea level, Jason–1, ENVISAT, GPS

1. Introduction

This paper describes the objectives, current status and future plans for the establishment of the GAVDOS calibration facility for satellite altimeter missions. GAVDOS is an infrastructure research project. Its first objective is the establishment of an absolute sea level monitoring and altimeter calibration facility on the isle of Gavdos, south of Crete, Greece. The calibration facility is under a crossing point of the ground-tracks of TOPEX/ Poseidon (T/P) and Jason–1, and adjacent to an ENVISAT pass. The location of the Gavdos island is shown in Figure 1.

The site has been chosen because

- the small island is far from the main land, with relatively low topography, and rather simple coastal circulation
- the surrounding geoid is known from *in situ* measurements and will be further improved using airborne measurements
- the local tides are small
- calibration can be made from the island, twice per cycle, on ascending and descending tracks
- the cross-over information can be used to remove possible biases dependent on the direction of the satellite pass

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- it is possible to locate an altimeter transponder precisely under the crossing point for an additional, independent and innovative direct way of calibration.

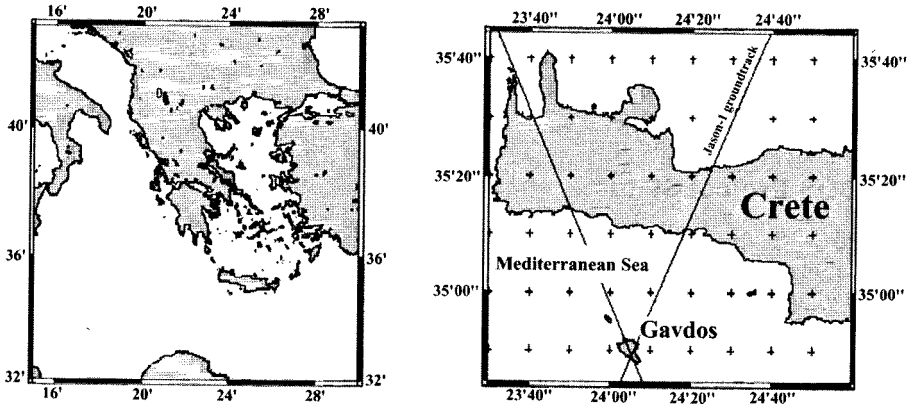

Figure 1 The location of Gavdos island and the Jason–1 ground tracks.

The purpose of such a permanent facility is

- to conduct comparative laser distance measurements between the facility and satellite radar altimeters, such as TOPEX/Poseidon, Jason–1, ENVISAT, etc.
- to ensure the unbiased establishment of the mean sea level, as realised by the globally distributed altimeter measurements
- to consistently and reliably monitor any radar altimeter errors (either systematic or random)
- to cross-calibrate different satellite altimeter missions, on a common and long-term basis. Our challenge is to meet the 1-cm accuracy level needed for the Jason–1 data products.

The second objective is to monitor deformations of the Earth's surface at the tide gauges in the area as a contribution to the EuroGLOSS (Global Sea Level System) (Baker *et al.*, 1997). This objective will be achieved by:

- monitoring horizontal and vertical land deformation using GPS (Global Positioning System) permanent arrays on Gavdos and on Crete, collocated with tide gauges
- determining, independently of GPS, the local tectonics by operating a DORIS beacon (Doppler Orbitography by Radio-positioning Integrated on Satellite)
- by monitoring local sea-level variations with a regional network of tide gauges, and with auxiliary sensors (meteorological, oceanographic, Sea Surface Topography from scanning airborne lasers, etc.).

The third objective is the development of a detailed regional geoid and Sea Surface Topography (SST) model, which is required for referencing the altimeter measurements over the calibration facility and for studying the regional sea current circulation.

Finally, the fourth objective is to involve this project in other European and international programmes, and in particular, the European Union Cluster on Operational Forecasting, EuroGLOSS, WEGENER (Working Group for Earthquake Research), the IGS (Interna-

tional GPS Service for Geodynamics), and the TIGA (GPS Tide Gauge Benchmark Monitoring Pilot Project). Using this calibration experiment, the influence of potential error sources resulting, e.g. from the orbital modelling, instrument malfunction and deterioration, etc., decreases significantly. The site is also designed to be used for other altimeter missions, such as European ERS–2, and the US Geosat Follow-On (GFO) missions. The deployment of altimeter transponders at the site shows great promise in additionally making the facility the calibration site of the European ENVISAT altimeter.

2. GAVDOS Project Status

At the time of this presentation, significant progress in the construction of equipment facilities, preparation of infrastructure for data transmission and processing, and in preliminary analysis of geodetic and gravimetric data has been made. Three locations for installing equipment have been chosen (see Figure 2) for the needs of the permanent facility.

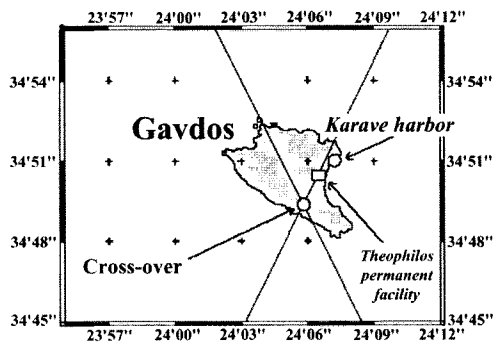

Figure 2 Location of the measurement facilities on the Gavdos island

The Theophilos Station, shown in Figure 3, is the central facility at Gavdos. It has been constructed on an area of approximately 4000 m^2. The following instruments have been installed at this site:

- A GPS receiver on a concrete pillar on stable limestone bedrock
- A weather station, measuring wind speed & direction, solar radiation, ambient temperature and humidity and barometric pressure
- A demultiplexer & multiplexer
- A UHF radio modem link.

The multiplexer output, containing the combined data stream (GPS, meteorological station and tide-gauge data) is interfaced to a radio modem. This radio modem will transmit the collected data via a repeater to the mainland of Crete.

A 12V battery bank powers all devices at Theophilos. A solar charger is used to charge the battery bank from a photovoltaic source consisting of eight SM55 modules (Siemens) having a maximum output power capability of 440 Watt (under 1 $kW m^{-2}$ irradiance), placed at 60° tilt and facing south. The estimated average daily energy production during winter is 45 Ah, while the daily energy requirements have been estimated to be approxi-

mately 25 Ah. The solar panels' energy production is stochastic and the power system design has been based on monthly mean irradiation values of previous years. Power over-sizing has been incorporated in the system design method in order to compensate both the variable energy production and future additional energy requirements (Markvart, 1994). The battery bank consists of three batteries (Gel electrolyte) with a nominal capacity of 210 Ah, resulting in a total nominal capacity of 630 Ah. A gas generator has been installed as a backup power supply for a PC. At this stage, there is no absolute gravity station at this facility.

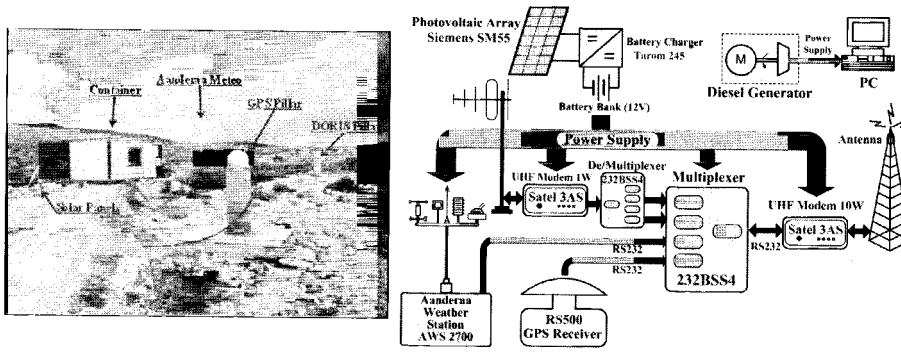

Figure 3 The Theophilos station and the design of various installations

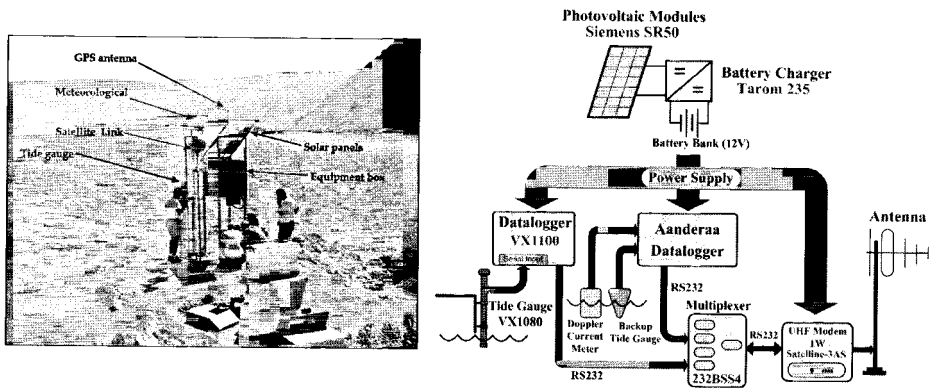

Figure 4 The Karave station and the design of various installations

The Karave station and the instrument functionality are shown in Figure 4. The following instruments have been installed at Karave station:

- A data-logger to store the acoustic tide-gauge sensor measurements. Precision levelling of the tide gauge marks has been carried out to several geodetic benchmarks in the area
- A back-up tide gauge (Pressure), a Doppler Current Meter and a datalogger
- The combined data stream is transferred to a low power (1 watt) radio modem and then transmitted to the Theophilos permanent facility

- A solar charger to charge a 12-volt battery bank from a Photovoltaic power source in order to cover the data-acquisition units and radio modem power requirements
- A stand alone wave and sea level recorder at a distance of about one mile offshore of Karave port at 10 m water depth.

The main acoustic tide-gauge was installed by experts who have worked for similar installations for NOAA/USA and the United Nations all over the world. This gauge is tracking measurements on its own by measuring in the calibration tube and self-corrects for temperature variations in the measuring air-column. Control levelling is carried out at least twice per year and definitely after any changes on the system/environment. The back-up tide gauge measures differential pressure in a single channel with an accuracy of ±0.2% of the range (tides in the area are of the order of 40cm). Being a back-up gauge no precise datum control is planned at this early stage of the project. However, plans include implementing the method proposed by Smith *et al.* (1991) for its collocation.

The Dias station is at the crossover point. It is located about 3.5km away south from the Theophilos site. It has a concrete base of 1.5×2.0m for the installation of an altimeter signal transponder (Fu and Cazenave, 2000).

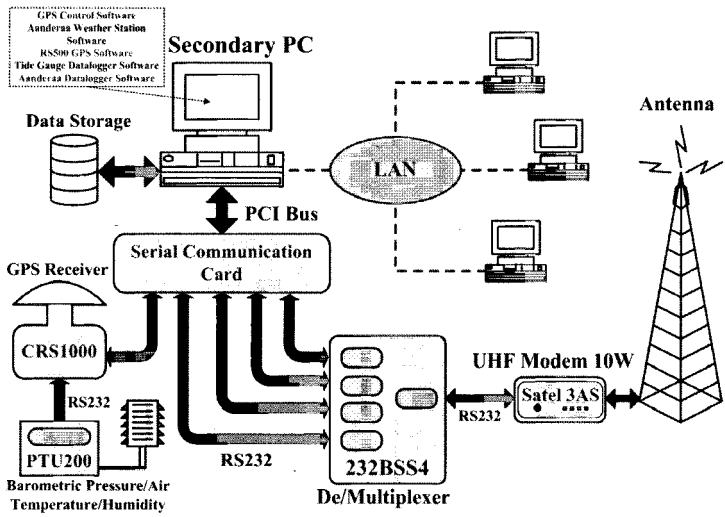

Figure 5 The equipment setup at the Operations Control Station in TUC, Crete.

An Operations Control Center (OCC) has been established at the Technical University of Crete (TUC) (Figure 5). A radio modem at OCC communicates with a repeater station and finally with the facility on Gavdos. A central computer (called COSMOS) and a back-up computer are in regular operation at the OCC. A GPS receiver with a meteorological station is also in continuous operation. The web site for the GAVDOS Project can be found at http://www.gavdos.tuc.gr. All results from the project are disseminated through the official Web site via a public and a restricted area (Data Center). Data are planned to be disseminated to the European Sea Level Service and MedGLOSS. The total amount of data transmitted from Gavdos to TUC (Crete) every day is estimated to

be about 1.1MB. An overhead of 30% of that must be anticipated to account for the "Error Correction" functions.

Existing software packages cannot be used for GPS data collection in this project because there are no open-source software packages that can work with operational GPS receivers, while the cost of commercial software packages is significantly high. A software package is under development, in order to detect and automatically identify any failure signals in real-time, thus improving the accuracy, reliability and integrity of the GPS positioning. It is designed to confirm the existence of failures or changes of small magnitude, and to locate the origin of the failure in order to monitor and control the quality of GPS data for deformation and/or critical real-time applications. The Python 2.2.2 programming language was chosen because it is standard, object-oriented and available for almost all existing computer platforms. As a relational database management system a PostgreSQL 7.3 was chosen because it is regarded as a reliable and mature non-commercial RDBMS and also supports a wide range of built-in data types and embeds an extensive set of data processing functions. GPS data have been processed using precise orbital information (GAMIT, 2000), retrieved from IGS Analysis Centers. Preliminary results are presented in Table 1.

A set of Digital Topographical Maps (DTM) and Digital Depth Maps (DDM) has been constructed. The DDM represents a gridded model of the bathymetry of the area around Gavdos (Lat =N33°–37° and Lon=E21°–29°). This is to provide a first depth model for the region. Additionally, ship-borne depth soundings from the GEODAS database (US National Geological Survey) have been acquired. The validated global DDM together with the depth soundings from GEODAS will be a mesh of depths with grid spacing better than 0.75' and probably close to 0.25' (1.25 and 0.5 km respectively). A 1 km-dense grid of topographic heights for the inland Crete and Gavdos is also available (data from the Global Land 1-km Base Elevation, GLOBE Project, 2002). The final mesh of topographic heights will be close to or better than 500 m level (0.25').

Table 1 Preliminary WGS84 coordinates of geodetic sites involved (latitude, longitude and height with their root-mean-square (RMS) errors). Reference epoch is 2002.3

Site	Latitude	Longitude	Ellipsoid Height
TUC1	35º 31' 54.96212"± 5.6cm	24º 4' 11.02585" ± 2.30cm	177.758cm ±3cm
SBTG	35º 29' 14.93260" ±1.60cm	24º 4' 57.09439" ±3.37cm	24.156 m ±4.60cm
GVD0	34º 50' 18.58134" ±5.63cm	24º 6' 31.90211" ± 8.52cm	124.649 m ±8.15cm
GVD1	34º 50' 18.71625" ±1.69cm	24º 6' 31.75722" ±3.56cm	122.385 ±5.27cm
GVD2	34º 50' 54.34317" ±2.62cm	24º 7' 6.97096" ±0.20cm	17.131 ±3.33cm
GVD3	34º 50' 17.44219" ±0.19cm	24º 5' 27.43621" ±0.28cm	256.146 ±0.84cm
GVD4	34º 50' 54.36821" ±0.22cm	24º 7' 7.44944" ±0.37cm	16.724 ±1.01cm

Further, four cruises of the Institute of Crete of Marine Biology research vessel, Philia, have taken place to collect Conductivity-Temperature-Depth profiles from 25 stations around Gavdos and on a 5-mile grid.

3. Future Plans

Along the lines of this research project, the transponder equipment has been tested in-house at the Space Research Institute of the Austrian Academy of Sciences, Graz (SRISG) and found in a satisfactory operation state. Further measurements will also be made to ENVISAT, ERS–2 and Jason–1 satellites in the vicinity of SRISG to ensure that the transponder can manage signals from these altimeters successfully and to check if some modifications are required for changing over to the Jason–1 frequencies (provided that the specifications of the equipment are within the bandwidth of the transponder's amplifier). Later, the transponder is to be installed permanently at the crossover point on Gavdos. It is expected that with the deployment of altimeter transponder will enable us to measure direct distances to the satellite with a ≈ 5 mm precision.

A site for setting up the French Transportable Satellite Laser Ranging (FTLRS) station for this GAVDOS project has been chosen on Crete, on the Technical University of Crete campus. Calibration results from Gavdos will be compared with those from the French Western Mediterranean site at Corsica and the NASA/JPL site at Harvest Platform, California, USA. The permanent facility is expected to become fully operational in 2003.

Acknowledgements

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