A European radar altimeter calibration and sea-level monitoring site for Jason-1 and ENVISAT at the island of Gavdos, Crete, Greece

Mertikas, Stelios, Pavlis, Erricos, Drakopoulos, Panos, Palamartchouk, Kirill

Stelios P. Mertikas, Erricos C. Pavlis, Panos Drakopoulos, Kirill Palamartchouk, "A European radar altimeter calibration and sea-level monitoring site for Jason-1 and ENVISAT at the island of Gavdos, Crete, Greece," Proc. SPIE 4880, Remote Sensing of the Ocean and Sea Ice 2002, (14 February 2003); doi: 10.1117/12.462517

SPIE.

Event: International Symposium on Remote Sensing, 2002, Crete, Greece

A European radar altimeter calibration and sea-level monitoring site for Jason-1 and ENVISAT at the island of Gavdos, Crete, Greece

Stelios P. Mertikas[a], Erricos C. Pavlis[b],
Panos Drakopoulos[c, d], and Kirill Palamartchouk[a]

[a]Technical University of Crete, Geodesy and Geomatics Lab, EL 73100, Crete, Greece
[b]Joint Center for Earth Systems Technology, University of Maryland Baltimore County, Interdisciplinary Science Group, Baltimore, USA
[c]Institute of Marine Biology of Crete, Department of Oceanography, Heraklion, Greece
[d]Technological Education Institute of Athens, Lab of Optical Instrumentation, Athens, Greece

ABSTRACT

An absolute sea level monitoring and altimeter calibration permanent facility is being established on the isle of Gavdos, south of the island of Crete, Greece. This calibration facility has been chosen because Gavdos is under a crossing point of the ground-tracks of TOPEX/Poseidon and Jason-1, and adjacent to an ENVISAT pass.

Satellite altimeter missions will be evaluated at that site using external measurements from tide gauges, GPS, a DORIS beacon, meteorological sensors, wave height sensors, airborne campaigns for gravity and sea surface topography, water vapor radiometry, solar atmospheric spectrometry, GPS buoys, altimeter transponder, Satellite Laser Ranging, etc. The mean sea level and the earth's tectonic deformation field in the region will be also determined accurately.

The GAVDOS project has started in December 2001 and has been in the context of an international calibration/validation effort of the Jason-1 Science Working Team.

This paper describes the objectives, current status and future plans for the establishment of the GAVDOS calibration facility for satellite altimeter missions.

Keywords: Calibration/validation, Radar altimetry, Sea level, Jason-1, TOPEX/Poseidon, ENVISAT, Geoid, Tides, DORIS, GPS

1. OBJECTIVES

This paper describes the objectives, current status and future plans for the establishment of the GAVDOS calibration facility for satellite altimeter missions.

GAVDOS is a research for infrastructure 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 Fig. 1.

The site has been chosen because (1) the small island is far from the main land, with relatively small topography, and rather simple sea current circulation; (2) the surrounding geoid is known from in situ measurements and will be further improved using airborne measurements; (3) the local tides are small; (4) calibration can be made from the isle, twice per cycle (every 5 days instead of 10 days), on ascending and descending tracks; and (5) the cross-over information can be used to remove possible biases dependent on the direction of the satellite pass.

E-mail: mertikas@mred.tuc.gr

Remote Sensing of the Ocean and Sea Ice 2002, Charles R. Bostater, Jr., Rosalia Santoleri, Editors, Proceedings of SPIE Vol. 4880 (2003) © 2003 SPIE · 0277-786X/03/$15.00

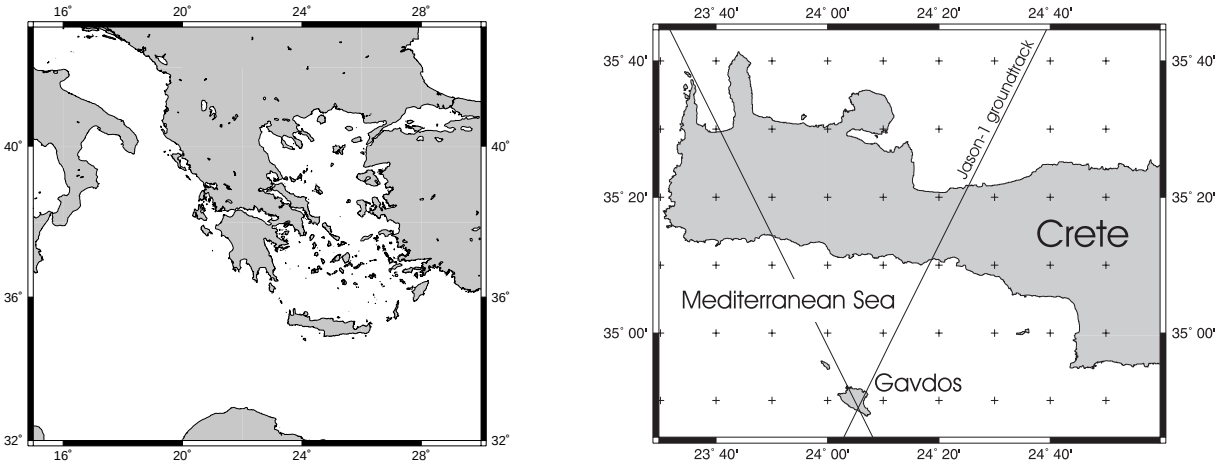

Figure 1. The location of Gavdos island and the Jason-1 ground tracks.

The purpose of such a permanent facility is (1) to conduct comparative laser distance measurements between the facility and satellite radar altimeters, such as TOPEX/Poseidon, Jason-1, ENVISAT, etc; (2) to ensure the unbiased establishment of the mean sea level, as realized by the globally distributed altimeter measurements; (3) to monitor consistently and reliably any radar altimeter errors (either systematic or random); and (4) to cross-calibrate different satellite altimeter missions and each one of them, 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 European Sea-level Observing System (EOSS). This objective will be achieved by: (1) monitoring horizontal and vertical land deformation using GPS (Global Positioning System) permanent arrays on Gavdos and on Crete, collocated with tide gauges; (2) determining, independently of GPS, the local tectonics by operating a DORIS beacon (Doppler Orbitography by Radio-positioning Integrated on Satellite); and (3) by monitoring local sea-level variations with a regional network of tide gauges, and with auxiliary sensors (meteorological, oceanographic, Sea Surface Topography, etc.).

The third objective is the development of a detailed regional geoid and Sea Surface Topography (SST) model. These models are 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 programs, and in particular, the European Union Cluster on Operational Forecasting, Euro-GLOSS (Global Sea Level Observing System), WEGENER (Working Group for Earthquake Research), the IGS (International 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 modeling, instrument malfunction and deterioration, etc., is decreased significantly. The site is designed to be used also 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 holds great promise in making the facility the calibration site of the European ENVISAT altimeter, as well.

Eastern Mediterranean is a natural laboratory for applied geophysics. In the past Crete was visited by transportable laser systems, and was a part of GPS campaigns in the area. As the international scientific community has moved towards permanent geodetic arrays and away from expensive, hard to move systems (like the Satellite Laser Ranging—SLR and Very Long Baseline Interferometry—VLBI), Eastern Mediterranean has been left void of any positioning systems.

Intense seismicity in the area around the facility and large tectonic motions require that land deformation needs to be monitored with dense local networks, operating permanently and continuously. Also the Gavdos

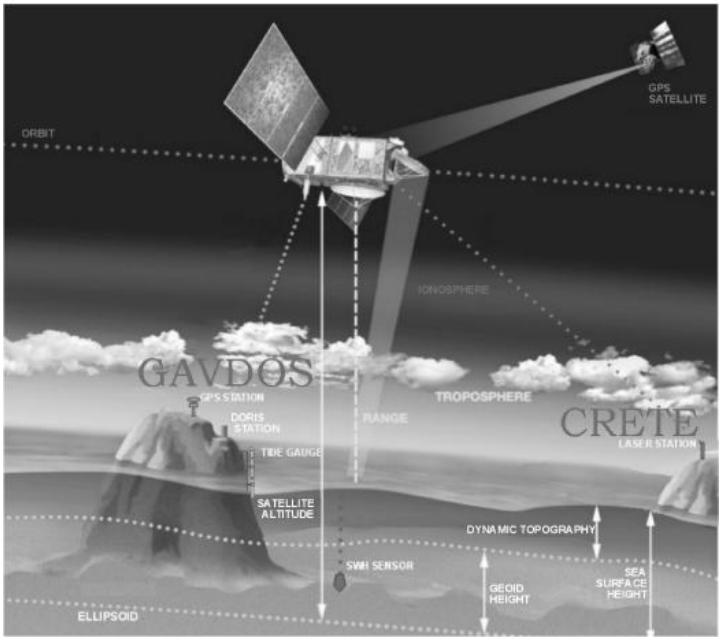

Figure 2. The Gavdos permanent calibration facility for satellite radar altimeters (after AVISO, http://www.jason.oceanjobs.com).

location is close to the Cretan Arc straits and considering the evidence of East Mediterranean transients occurring in the past, a sea level station on the island will serve as a long-term climate monitoring station. These requirements become an absolute necessity when the ultimate goal is the monitoring of the sea level and the calibration of the satellite altimeter missions.

The GAVDOS project contributes directly in this vein through monitoring of the tectonic signals at the existing tide gauges in the area (one at Souda Bay and one at Heraklion Harbor, Crete) and the establishment of a new absolute sea-level monitoring site at Gavdos.

This permanent facility will not only create a dedicated observatory on the fringes of the Hellenic trench, it will also expand its utility to sea-level monitoring and altimeter calibration of a number of current and future oceanographic missions.

2. JASON-1 MISSION AND GOALS

The T/P mission has made significant progress in the understanding and modeling of ocean circulation and consequently on its climatic impact. It has also made essential contributions in monitoring the global mean sea level, and the study of tides, marine meteorology, geophysics, and geodesy. The exceptional results obtained from the T/P mission and the need for longer time series has brought up the follow-on mission of Jason-1.

Early in 1993, CNES (France) and NASA (USA) started a new cooperation on this Jason-1. The main motivation was to provide the same level of performance as T/P, offering the capability to pursue the mission under the same conditions. The success of the T/P mission was due primarily to an appropriate optimization of the system: instruments, satellite, and orbital parameters were all specifically selected to fulfill the objectives of the mission.

The Jason-1 satellite was successfully launched on 7 December 2001 [2]. *Cycle 1* for Jason-1 is dated on 15 January 2001. Jason-1 is expected to have the same performance, and fly over the same ground tracks as the T/P mission, at least in the beginning.

During the assessment and the verification phase of the Jason-1 mission (first 6 to 8 months), all ground-processing algorithms and all critical output quantities and associated errors will be verified and calibrated. This will be done through statistical analysis and by comparison with external measurements, including direct distance measurements at the cross-over point by means of the Rutherford Appleton Laboratories "signal transponder" that the Austrian Partner (SRISG) will deploy. The calibration/verification accuracy will be compatible with error budget specifications (Table 1, after [1]).

Table 1. Jason-1 Error Budget.

Source of Error	**Error Budget (cm)**
Altimeter noise	1.5
Ionosphere	0.5
Electromagnetic Bias	1.0
Tracker Bias	0.2
Skewness	0.2
Dry Troposphere	0.7
Wet Troposphere	1.0
Altimeter range Root-Sum-Square	**2.25**
RMS Orbit	1.0
Total RSS Sea Surface Height	**2.5**
Significant Wave Height	25.0
Wind Speed	1.5 m/s
Sigma 0	0.5 dB

The parameters to be verified include altimetric range and associated corrections, orbit, wind speed and significant wave height (SWH). In addition to the biases, the calibration process will provide an estimation of the individual drifts of the system components. Instrument calibrations will be monitored at least weekly throughout the life of the mission. Today, there are two dedicated calibration and validation sites for Jason-1. One is at the Harvest oil platform, off the coast of California operated by the USA and the other is on the island of Corsica operated by CNES (France). There are two more calibration/Validation sites ready for deployment, one at the Bass Strait, Tasmania, Australia and this permanent site on Gavdos.

During the first 3 months of the verification phase, T/P and Jason-1 have been be separated by only 1 minute along the same flight path. This formation-flying configuration will enable an optimum cross-calibration/validation of the two data sets.

Adequate calibration and drifts will be provided to users to support connection of previous (T/P) and future (Jason-2) time series with those of Jason-1. Following this preliminary cross calibration phase, T/P will be moved to an interleaving ground track in order to increase space-time sampling and thus offer new opportunities for scientific issues. The T/P satellite is scheduled to transfer orbit on the 2nd week of August 2002 (interleaving orbit). The orbit transfer will be completed on the 2nd week of September, 2002.

The Operational Sensor Data Record (OSDR) and the Interim Geophysical Data Records (IGDR) for Jason-1 are accessible through the AVISO ftp sites (i.e., http://www.jason.oceanobs.com).

3. GAVDOS PROJECT STATUS

At the time of this presentation, a 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.

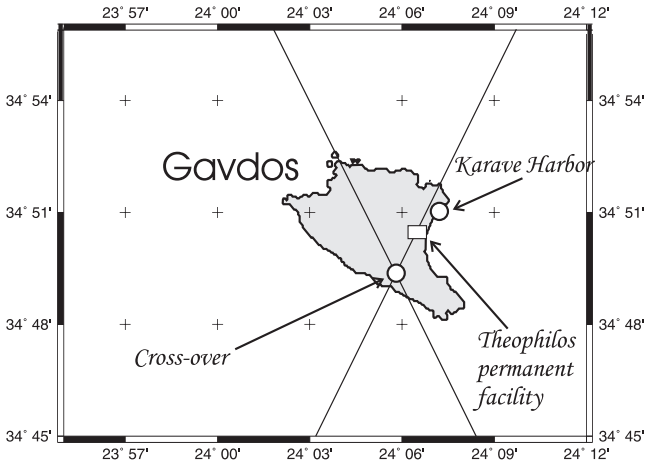

Figure 3. Location of the measurement facilities on the Gavdos island.

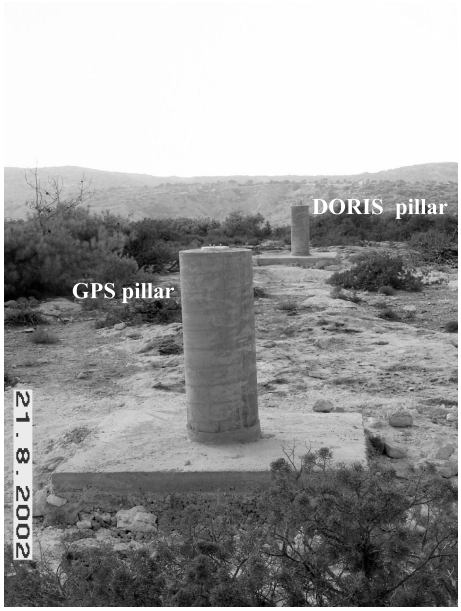

Figure 4. GPS and DORIS pillars at the main facility in Theophilos site.

Reconnaissance during several field trips to Gavdos has been carried as of early 2002. Three locations for installing equipment have been chosen (see Fig. 3) for the needs of the Gavdos permanent facility. The main facility, named *Theophilos*, is located on stable ground about 3 km away from the harbor. There, the GPS permanent station, the DORIS beacon along with the principal weather station and the main communication and control facility are being built (Fig. 4). Procedures for buying a piece of land at the Theophilos site have been initiated by the Technical University of Crete (TUC) and for the needs of this project.

The second site is on the *Karave* harbor of Gavdos. A pressure tide gauge and a wave height sensor (at a 10 m depth) have been installed in May 2002. Also, in August 2002, an acoustic tide gauge (main tide gauge), a pressure back-up tide gauge, a Doppler water current sensor, the meteorological station, the GPS receiver for time-tagging and the satellite link for data collection and retransmission through Meteosat have also been installed (Fig. 5). High precision leveling of the tide gauge marks has been carried out to several bench marks

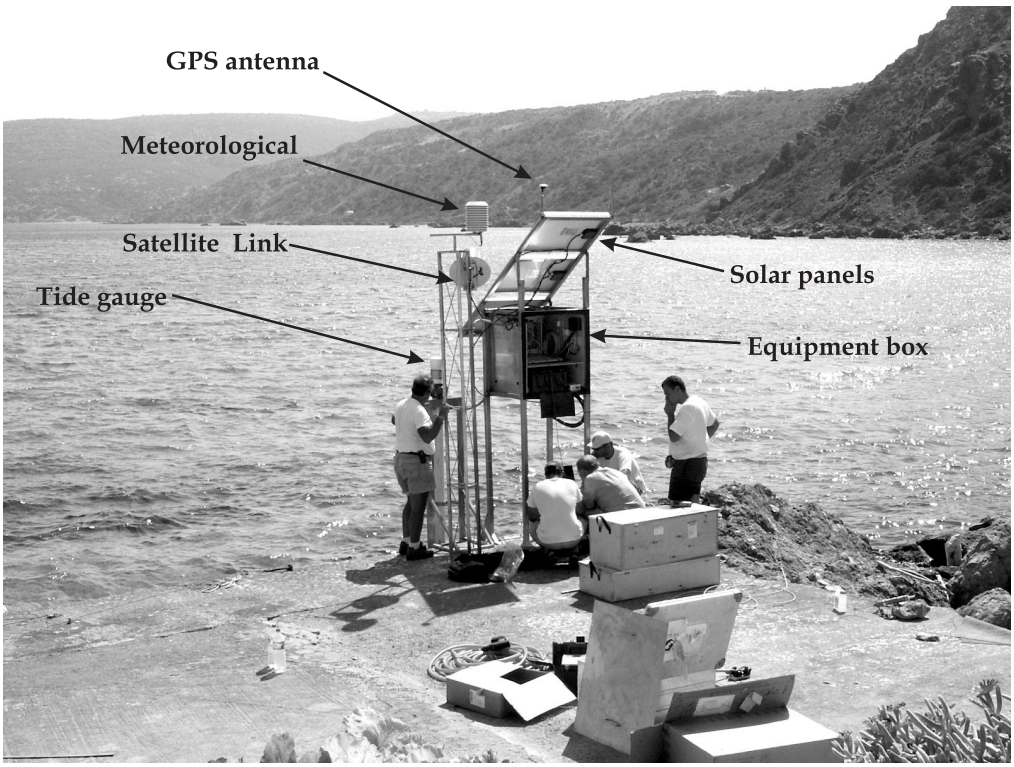

Figure 5. The Karave site with the two tide gauges, the meteorological station, the GPS receiver for time-tagging and the satellite link for data collection and retransmission through Meteosat.

in the area around the Karave harbor.

Finally, a third site is also established on Gavdos at the cross-over point of the ground tracks of Jason-1. This site was named *Dias* and it is the location where the transponder will be deployed. Installation plans, construction diagrams, data flows for controlling all equipment from TUC trough a UHF link have been completed. An *Operations Control Center* has also been established at the Technical University of Crete. There, a main computer has been prepared for data archiving, processing and equipment control via a UHF radio telecommunication link. A web site for the GAVDOS Project, with public and restricted areas, has also been constructed (http://www.gavdos.tuc.gr).

An analysis of the data since 1997 for the permanent GPS station, named TUC1, (located in the TUC campus) and using the GEODYN and GAMIT [3] software, produced a very high precision position and horizontal velocity vector for that site. The results obtained are compatible with those of the SLR at a nearby site (i.e., Roumeli, Crete) made over more than a decade ago (about 3-4 cm horizontal tectonic motion of Crete). Two recent GPS surveys have also been carried out to collocate the Souda Bay tide gauge (SBTG, about 6 km from TUC) with the permanent station of TUC1. One survey took place from November 24 to December 12, 2001 (intermittent 19 days), and the second one from April 12 to April 20, 2002 (9 days). Based on the results of processing the data, we have a good geodetic position for that SBTG site, as well.

Preliminary GPS measurements have been made at the Theophilos (GVD1) and at the Karave (GVD2) sites in Gavdos. Data from these surveys have been processed together with the set of global IGS stations using the GAMIT software. Coordinates of the sites are presented in the Table 2.

Eight local geoid solutions have been computed by the Aristotle University of Thessaloniki, Greece for the Gavdos region. Altimetry and sea as well as terrestrial gravimetric data have been used for the determination

Table 2. ITRF2000 Coordinates of primary geodetic marks and the mark on the tide gauge at the Souda Bay in Crete, (Epoch 2002.27, April, 2002).

Mark name	X (m)	Y (m)	Z (m)
TUC1 (Crete)	4744660.9783	2119381.8419	3686155.1790
GVD1 (Gavdos)	4783634.5832	2140707.2476	3623248.9672
GVD2 (Gavdos)	4782617.7068	2141232.1173	3624089.7503
SBTG (Tige Gauge in Souda Bay, Crete)	4746688.7618	2121559.4445	3682051.1494

of an accurate geoid solution using the "remove-compute-restore" technique. The accuracy of the produced preliminary geoid may be of the order ±5 cm for the region of Crete.

The differences between the altimetric and the gravimetric solutions show a discrepancy of about ±40 cm mainly due to the absence of the Sea-Surface-Topography signal in the gravimetric solutions and the limited accuracy of the gravity data. Maps of these results have been produced.

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.=33°–37° and Lon.=21°–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 ($0.25'$).

Further, two cruises of the IMBC research vessel, *Philia*, have taken place to collect Conductivity-Temperature-Depth profiles from 25 stations around the Gavdos island on a 5-mile grid.

4. 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 stated a satisfactory operation. Some measurements will also be made to ERS-2 and Jason-1 satellites in the vicinity of the SRISG to ensure that the transponder can manage the signals of ERS-2 successfully and to check if some modifications are required for changing the Jason-1 frequencies (provided that the specifications of the equipment are within the bandwidth of the transponder amplifier). Later, the transponder is to be installed permanently at the cross-over point on Gavdos island. 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.

An airborne laser campaign as well as a gravity campaign are planned in 2003. The Swiss Federal Office of Topography will provide the Twin Otter aircraft for these airborne gravimetric surveys. The airborne gravimeter will be provided by the University of Bergen, Norway.

Verification of the radar altimeter measurements with GPS buoy experiments will take place. The GPS buoys will be placed under the satellite ground tracks to provide in situ SST data.

Absolute calibration tests for the satellite laser ranging system have been carried out in Corsica. A site for setting up the French transportable SLR and for this GAVDOS project has been chosen in Crete near the Technical University of Crete. Calibration results from Gavdos will be compared with those from the French Western Mediterranean site at Corsica.

The first priority now is installing the permanent GPS and DORIS equipment on Gavdos island and establishing radio data links between all sites on Gavdos with the Control Operations Center at the Technical University of Crete.

Of great importance for the GAVDOS Project is developing automated data analysis and an expert system that can collect data from the tide gauges, meteorological sensors, SLR, GPS, DORIS, etc. It is anticipated that that system will be able to process these data in order to get precise satellite trajectories, precise site coordinates, establish correlations between main parameters in long- and short-term scales, and generate alarms when in case of strange data or obvious malfunction.

ACKNOWLEDGMENTS

The GAVDOS Project is funded by the European Union (contract EVR1-CT-2001-40019), The Swiss Federal Government and, the National Aeronautics and Space Administration (NASA, USA).

The following institutes comprise the GAVDOS Consortium: *TUC*: Technical University of Crete, Greece (Co-ordinator); *JCET*: Joint Center for Earth Systems Technology, NASA & University of Maryland, Baltimore County, USA; *AUTH*: Aristotle University of Thessaloniki, Greece; *IMBC*: Department of Oceanography, Institute of Marine Biology of Crete, Greece; *SRISG*: Space Research Institute, Austrian Academy of Science, Austria; *KMS*: Department of Geodynamics, National Survey and Cadastre, Denmark; *ETHZ*: Swiss Federal Institute of Technology, Geodesy and Geodynamics Lab, Switzerland; *OCA-CERGA*: Observatoire de la Cote d'Azur, France; *HNHS*: Hellenic Navy Hydrographic Service (support partner), Greece; *UIB*: University of Bergen (support partner), Norway.

REFERENCES

1. Y. Menard and B. Haines, "Jason-1 CALVAL plan", CNES, JPL, April 2, 2001. Ref: TP2-J0-PL-974-CN.
2. Y. Menard, "Jason-1 & TOPEX/POSEIDON Science Working Team Meeting", Minutes, CNES and NASA, 10-12 June 2002, Biarritz, France, Ref: TP2-J0-CR-2156-CNES.
3. "Documentation for the GAMIT GPS analysis software", Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Scripps Institution of Oceanography, University of California at San Diego, Release 10.0. 6 December 2000.
4. AVISO: http://www.jason.oceanjobs.com.