# Absolute calibration of Jason satellite radar altimeters at Gavdos Cal/Val facility using independent techniques

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## ABSTRACT

The Gavdos calibration facility for satellite radar altimeters has been operational as of 2004. The island is located along repeating ground tracks of Jason-1 and Jason-2 satellites (crossover point for passes No.109 ascending and No.018 descending and adjacent to Envisat), and because of its small size, both altimeter and radiometer measurements are not significantly contaminated by land. This makes Gavdos an ideal place for the calibration of satellite altimeters. In this work, three different techniques have been applied for calibrating the Jason altimeter measurements at Gavdos Cal/Val facility. These are: (i) The conventional: In-situ observations made by tide gauges, GNSS receivers, meteorological and other sensors in conjunction with precise geoid models are applied for determining the altimeter bias; (ii) The MSS: instead of the geoid, the mean sea level, provided by the CLS10_MSS model, is used as a reference surface for estimating the bias; and (iii) Microwave transponder measurements are implemented and examined over the cross over point on land to produce the altimeter bias as well. This paper presents the results regarding these calibration techniques.

**Keywords:** satellite radar altimeter, calibration, Jason

## 1. INTRODUCTION

Satellite altimetry might be considered as a powerful alternative technique for monitoring sea-level changes, and thus, global climate changes. To this end, several altimetric satellite missions have been launched, i.e., Jason 1&2, ERS, Envisat, CryoSat-2, while others are scheduled to be launched, i.e., Sentinel-3, SARAL/AltiKa, HY-2, etc.

Nevertheless, the expected operational period of these missions does not regularly exceed 5 years (i.e., ERS-1 from July 1991 to June 1996); even if some missions have been extremely successful providing data for more than 10 years (i.e., TOPEX/Poseidon from August 1992 to January 2006, Jason-1 from December 2001 to 2009). Therefore, to interconnect measurements from these missions, but also to obtain results of homogenous quality and rigorous reliability, the scientific community requests that calibration and validation of the satellite altimetric missions is made.

Calibration and validation of altimetric missions is the process of quantitatively defining and comparing the altimetric system’s measurements, i.e., sea state bias, wet tropospheric path delay, marine geoid, tides, geographically correlated errors, etc., with known and controlled signal inputs, determined by independent means. Improper treatment of measurement errors might lead to erroneous conclusions regarding not only the sea-surface heights but also all the ancillary measurements made by the satellite. Thus, dedicated research infrastructures, together with distributed tide gauges are employed in order to ensure the reliability of altimeter’s measurements by consistently and reliably determining (i) the absolute altimeter biases and drifts for each of these various satellite altimeters, and (ii) the relative biases among missions.

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In the world, there exist four permanent sites for providing absolute calibration of satellite altimeters. Two of them exist in Europe: Gavdos, in Crete, Greece and Corsica in France (operated by CNES); one in the Harvest Oil Platform, California, USA (operated by the Jet Propulsion Laboratory, NASA) and one in Bass Strait, Tasmania, Australia (operated by the University of Tasmania). The main objective of these sites is to calibrate the sea-surface height and ancillary measurements made by the satellite as it passes overhead the site, by using observations from tide gauges, GPS receivers, and other sensors directly placed under the satellite ground tracks on the earth's surface. Nevertheless, calibration results depend on the local conditions, standards and specifications applied, duration of measurements and geographical location of the calibration sites.

This paper presents the calibration methodology conducted at the Gavdos Cal/Val facility along with the extracted calibration results for the Jason-2 satellite mission employing three different techniques: (i) In-situ observations made by tide gauges, GPS receivers, meteorological and other sensors in conjunction with the precise geoid models to estimate absolute satellite biases, (ii) an alternative technique, where the reference surface for the calibration process is a mean sea surface model provided by the CLS10_MSS, and (iii) Microwave transponder measurements. The rest of this paper provides insights to the basic calibration theory and provides an explanation of the terms that are necessary to understand how calibration is performed (Section 2). It also contains a small description of the Gavdos infrastructure (Section 3).

## 2. SATELLITE ALTIMETRY CALIBRATION PRINCIPLES

The satellite altimeter emits signals towards the Earth, and, subsequently, receives the echo from the sea surface after the signal's reflection. The wavelength of this signal depends on the altimetric mission, e.g., Jason-2 uses the C- and Ku-bands, Cryosat-2 applies the Ku-band, and the AltiKa will use the Ka-band. Given the altitude and the range of the satellite, the Sea Surface Height (SSH) at each measured point, *k*, of the satellite's track is obtained by:

$$SSH(k) = Altitude(k) - Range(k) \tag{1}$$

where "altitude" is the satellite's height above the reference ellipsoid, and "range" is the distance between the altimeter and the sea surface.

Nevertheless, there are several error sources infiltrating eqn (1), such as the atmosphere delays (ionosphere, wet and dry components of the troposphere) and the sea state bias (SSB). These need to be corrected for because they are mainly influencing the accurate determination of the range measurement, thus, leading to inaccurate estimation of the SSH. Accordingly, a more accurate estimation of SSH may be written as:

$$SSH'(k) = Altitude(k) - Range(k) + Corrections(k) \tag{2}$$

where:

$$Corrections(k) = Iono(k) + Dry\_tropo(k) + Wet\_tropo(k) + SSB(k) \tag{3}$$

Values for the corrections are contained in the satellite's data log file, called the Geophysical Data Record (GDR). Besides the above corrections, to be applied in the range measurements, one should take into account the effect of land contamination in the satellite measurements. As the satellite approaches the coastline, the quality of the measurements for both the radiometer (about 25 km footprint) and the altimeter (about 5 km footprint) deteriorates; thus, complicating the calibration/validation process.

For the calibration process using in-situ measurements, the Sea Level Anomaly (SLA) needs to be determined at the satellite's measuring location. The SLA is obtained by subtraction of the Mean Sea Surface (MSS) from the SSH at each measured point of the satellite's track:

$$SLA(k) = SSH'(k) - MSS(k) \tag{4}$$

The MSS at any point *k* is given as the geoid height, *N*, above ellipsoid, plus the Mean Dynamic Topography (MDT) at this point. Thus, Eqn. (4) might be replaced by:

$$SLA(k) = SSH'(k) - N(k) - MDT(k) \tag{5}$$

In order to provide absolute calibration results, one should estimate the SLA at each point *k* of the satellite's track by independent means. The latter requires that a tide gauge (or GPS buoys) is deployed exactly under the satellite's ground-track on the ocean surface as the satellite flies over. In the case of Gavdos, the basic calibration principle is portrayed by Fig. 1. The SLA at the calibration site location is extracted through the following:

$$SLA(t_0) = SSH(t_0) - N(t_0) - MDT(t_0) \tag{6}$$

Nevertheless, the $SSH(t_0)$ has to be corrected for the tide effects on the height determination using GPS:

$$SSH'(t_0) = SSH(t_0) + solid\ earth\ tide(t_0) + pole\ tide(t_0) + ocean\ tide(t_0) \tag{7}$$

leading to:

$$SLA(t_0) = SSH'(t_0) - N(t_0) - MDT(t_0) \tag{8}$$

Therefore, the estimated absolute bias for the altimetric measurements of the Jason-2 satellite is computed as:

$$Absolute\ Bias = SLA(t) - SLA(t_0) \tag{9}$$

Accurate determination of the parameters introduced through Eqns 1-9 is crucial for the validity and reliability of the absolute bias estimation.

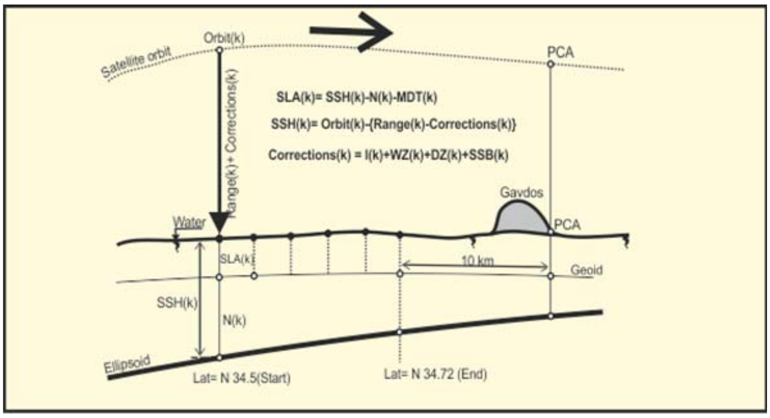

Fig. 1. The principle for the calibration of Jason satellites at the Gavdos facility. Black dots correspond to each satellite measurement on the sea surface, while white dots are referred to the underlying geoid height.

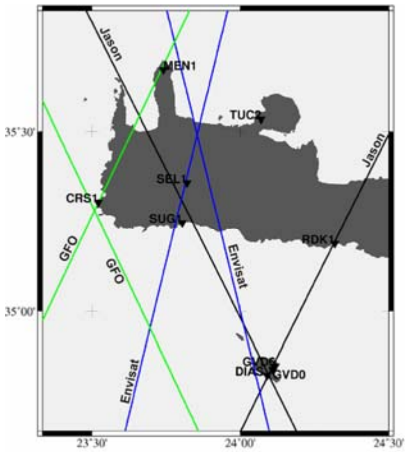

Fig. 2.The continuously-operating geodetic arrays (GVD0, GVD6, RDK1, CRS1, TUC2, SUG1, SEL1, MEN1) over western Crete, along with the repeating ground tracks of the GFO, Envisat and Jason altimetry missions.

# 3. THE GAVDOS INFRASTRUCTURE

The Gavdos island is located along a repeating ground track of Jason-1 and Jason-2 satellites (crossover point for passes No.109 ascending and No.018 descending and adjacent to Envisat), and because of its small size, both altimeter and radiometer measurements are not significantly contaminated by land. This makes Gavdos an ideal place for the calibration of satellite altimeters (see Fig. 2). Additionally, Gavdos site might be characterized as the only calibration site in the world in which altimeter's calibration might be performed for both ascending and descending satellite passes using the same infrastructure.

The infrastructure of the facility is at three different locations on the island of Gavdos, i.e., in the harbor, at the central facility on the main land of the island and at the cross-over facility. It includes all the necessary equipment, e.g., tide gauges, permanent GPS satellite receivers, meteorological and oceanographic instruments, a DORIS satellite beacon, an electronic transponder, communications systems for the transmission of data, etc., in order to provide an accurate estimation of the absolute altimetric bias (Fig. 3a and Fig. 3b).

Figure 3a

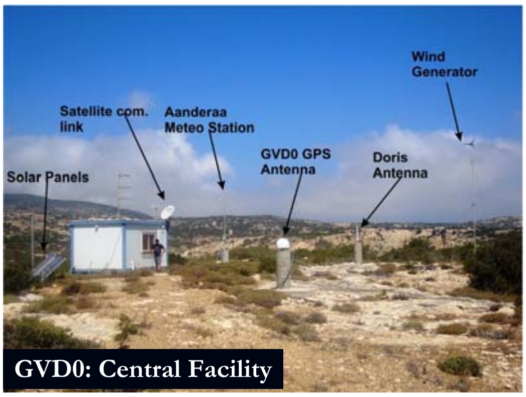

Figure 3b

Fig. 3. The basic infrastructure of Gavdos, located at the "Karave" harbor and at the central facility.

To extent and strengthen the applicability of Gavdos operations for satellite calibration, similar facilities have been deployed on the mainland of west Crete (Greece), namely at Crysoskalitissa (CRS1) and Rodakino (RDK1) sites. At these sites, tide gauges (and seismographs in some locations) are collocated with continuously operating GPS receivers (Fig. 4a and Fig. 4b).

Figure 4a

Figure 4b

Figure 4.The CRS1 site on the west Crete (Fig. 4a) and the RDK1 site on the central south Crete (Fig. 4b).

The above mentioned infrastructure is continuously interconnected and tied with other TUC's GNSS arrays, such as two sites located inside the University campus (i.e., the TUC1 and TUC2), along with another three GNSS sites installed in the North-South axis of Crete in cooperation with the North Carolina State University, USA (Fig. 2).

## 4. CALIBRATION METHODOLOGY

### 4.1 Conventional Methodology

A standardized methodology for the estimation of Jason's altimeter bias has been developed and adopted by all calibration sites of Gavdos (Greece), Corsica (France) and Harvest platform (USA). Despite the local characteristics of each calibration site, altimetric and radiometric measurements can be modeled and evaluated based on certain and agreed upon criteria. Regarding local characteristics, the Harvest calibration site happens to be located exactly under the Jason-2 ground track, so the sea-surface level can be unambiguously determined for the bias estimation, using the local tide gauges collocated with the GPS. In the case of Gavdos facility, the ground tracks of Jason are close to the calibration site (circa 500-2000m), thus the procedure for the bias estimation becomes more delegate and complicated. Accordingly, the terms Point of Closest Approach (PCA) and relative Time of Closest Approach (TCA) were introduced to estimate the location and time when the satellite is closest to the Gavdos calibration site [1]. Based on the PCA and TCA terms the range corrections (see Eq. 3) will now be applied.

Specifically, for satellite Pass No. 109, the ionosphere correction, to be applied at a particular measuring point --where t=0-- is calculated as the average value of the ionospheric correction values, supplied by the GDR, in the window from t1= −21sec to t2=−1sec. A minus sign signifies previous value to the satellite measuring point by so many seconds. The dry troposphere correction values are obtained as an interpolated value at the satellite measuring point, using a linear fit from time t1= −5sec up to time t2=+2 sec. Similarly, and in order to avoid land contamination on the satellite radiometer measurements, a linear model is applied on the wet troposphere delays (given by the GDR), covering a region from time t1= −15sec up to time t2=−5 sec. Finally for the sea-state bias, a cubic polynomial has been applied in the area between t1= −10sec up to t2=−1sec.

Likewise for Pass 018 (descending pass), the correction values have been determined employing the same procedure but with opposite signs in the application region. Nevertheless, in order to avoid the effect of land contamination in the correction values the signs of the time ranges were changed from minus (-) to plus (+), i.e., for the ionospheric corrections the time range was set to t1= +1sec and t2=+21 sec after the satellite measuring point. Consequently, the corrected SSH at any measured point ($k$) of the satellite is calculated using Eq.3.

Accurate determination of the SLA (Eq.5) requires precise determination of both the geoid and the MDT at each point of interest ($k$). The determination of the geoid, in the area surrounding Gavdos, has been performed in 2003 using a variety of sensors and techniques. The application of different geoid models revealed that the area south of Gavdos for both satellite passes (No. 018 and No.109) can be safely used for satellite calibration. Accordingly, the geoid heights above ellipsoid have been evaluated in order to correspond exactly under the satellite pass. The final geoid heights have been calculated based on a newly compiled gravity database, which comprises refined topography and bathymetry models for the evaluation of terrain effects [2] and considers the EGM2008 geopotential model [3] as reference. Specifically, the "remove-compute-restore" methodology has been employed for the evaluation of the final geoid heights along the ground track of Jason-2. The prediction of residual geoid heights has been based on the least-squares collocation optimal estimation method [4, 5]. Regarding the determination of the MDT values at each measured point ($k$) of the satellite altimeter a well-known and widely accepted MDT model namely the RioMed CNES-CLS09_v1.1 has been employed.

Absolute bias estimation (Eq. 9) requires, also, the determination of the SLA at the tide gauge location (Eq. 8). The geoid height at the calibration site is known with high accuracy and, thus, to determine the altimeter's absolute bias, through Eq. 9, one has to determine the SSH ($k_0$) and refer both SSH's to the same reference system.

The SSH at the calibration site is determined from (i) the GPS processing of the collocated GPS receiver with the tide gauges and by taking into account the various height offsets (distance between tide gauge and GPS antenna reference points) and (ii) the raw tide gauge measurements. Notwithstanding, the GPS height determination is considered as the most critical element in Eq. 6. In this work, two different software been employed for the determination of GPS coordinates of the reference calibration point in Gavdos, namely: GAMIT [6] and Bernese [7]. The processing results are loosely constrained Cartesian coordinates for stations, satellite orbit parameters, as well as their mutual dependencies. The coordinates of the GPS network and the corresponding uncertainties are given in Tables 1 & 2, while the site velocities in the ITRF2005 reference frame are given in Table 3. Details regarding the methodology applied for the GPS processing are provided elsewhere [1].

Table 1. The ITRF2005 Geodetic Coordinates of the TUC-Net sites (Reference Epoch 2009.0).

| Site | Latitude (Deg Min Sec) | Longitude (Deg Min Sec) | Ellipsoidal Height (m) | East Sigma (mm) | North Sigma (mm) | Height Sigma (mm) | Processing Interval (years) |
|---|---|---|---|---|---|---|---|
| CRS1 | N35 18 12.650629 | E23 31 17.262685 | 21.2045 | 0.078 | 0.074 | 0.336 | 2008.1872-2010.3603 |
| GVD0 | N34 50 18.580135 | E24 6 31.906600 | 123.8773 | 0.049 | 0.047 | 0.188 | 2007.0589-2010.5247 |
| GVD5 | N34 50 54.349114 | E24 7 7.049527 | 21.0740 | 0.175 | 0.168 | 0.768 | 2007.0562-2009.5301 |
| GVD6 | N34 50 54.198511 | E24 7 6.926227 | 20.2236 | 0.150 | 0.156 | 0.706 | 2007.6726-2009.3685 |
| GVD7 | N34 50 52.746519 | E24 7 11.203951 | 20.1457 | 0.364 | 0.349 | 1.527 | 2009.3712-2010.5247 |
| IMS1 | N35 22 12.549670 | E24 28 20.981252 | 35.9294 | 2.584 | 2.605 | 10.948 | 2010.1904-2010.5247 |
| RDK1 | N35 11 15.377273 | E24 19 6.538186 | 25.5504 | 0.265 | 0.258 | 1.199 | 2009.1767-2010.5247 |
| TUC2 | N35 31 59.484446 | E24 4 14.013630 | 160.8997 | 0.047 | 0.045 | 0.178 | 2007.0014-2010.5247 |

Table 2. The Cartesian coordinates of the stations in the TUC- Net.

| Site | X (m) | Y(m) | Z(m) |
|---|---|---|---|
| CRS1 | 4778073.8381 | 2079694.1286 | 3665411.0777 |
| GVD0 | 4783636.3443 | 2140712.0414 | 3623246.2377 |
| GVD5 | 4782619.7492 | 2141235.2186 | 3624092.1537 |
| GVD6 | 4782622.8126 | 2141233.1581 | 3624087.8591 |
| GVD7 | 4782601.6814 | 2141342.7663 | 3624051.0939 |
| IMS1 | 4739016.0051 | 2156947.1389 | 3671450.8552 |
| RDK1 | 4755448.4243 | 2149014.3483 | 3654911.3206 |
| TUC2 | 4744543.7929 | 2119411.9354 | 3686258.8066 |

Table 3. The XYZ (ITRF2005) velocities of the TUC-Net sites (Reference Epoch 2009.0).

| Site | Lat (Deg) | Long (Deg) | Vx (mm/yr) | Vy (mm/yr) | Vz (mm/yr) |
|---|---|---|---|---|---|
| CRS1 | 35.3035 | 23.5215 | 4.742±0.347 | 10.380±0.189 | -7.630±0.270 |
| GVD0 | 34.8385 | 24.1089 | 3.444±0.144 | 10.522±0.080 | -9.802±0.111 |
| GVD5 | 34.8484 | 24.1186 | 6.127±0.547 | 10.975±0.293 | -8.356±0.547 |
| GVD6 | 34.8484 | 24.1186 | 3.024±0.807 | 8.540±0.428 | -14.006±0.625 |
| GVD7 | 34.8480 | 24.1198 | 4.471±1.137 | 11.443±0.588 | -10.378±0.858 |
| IMS1 | 35.3702 | 24.4725 | 5.651±6.240 | 8.012±3.375 | -19.882±4.872 |
| RDK1 | 35.1876 | 24.3185 | 2.084±0.930 | 9.835±0.500 | -9.493±0.710 |
| TUC2 | 35.5332 | 24.0706 | 3.618±0.130 | 10.103±0.072 | -9.581±0.102 |

Accordingly, the altimeter's absolute bias was determined using the calibration region (12 to 21 km south of Gavdos) for Pass No. 109 and (8 to 18 km south of Gavdos) for Pass No. 018.

### 4.2 The Mean Sea Surface Methodology

Accurate determination of the SSH and, thus, accurate estimation of the altimeter's absolute bias might be characterized a simple process in the cases where the geoid undulations are well known and/or well modeled. Unfortunately, this is not the case for Pass No. 018, south of Gavdos. A major tectonic trench and close to subduction zone exists south of Gavdos (Fig. 5). Thus, the geoid undulations have to be closely examined to map fine details at that region.

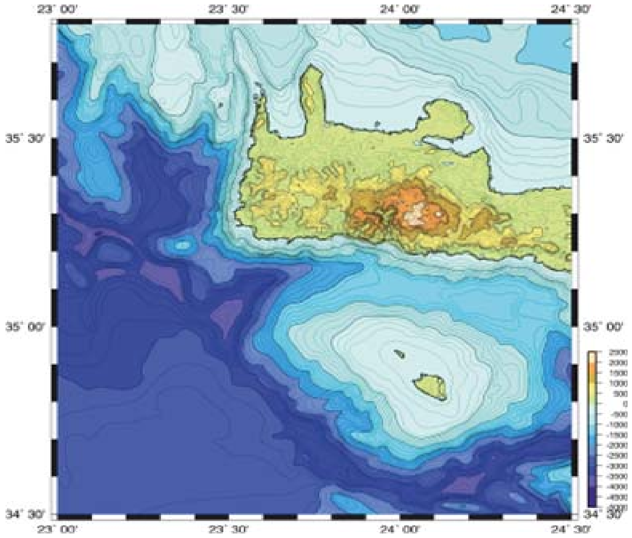

Fig. 5. The Gavdos bathymetric map (personal communication Dr. S. Alexandri, Hellenic Centre for Marine Research).

Thus, in order to be able to cross check the given geoid undulations over that area and ensure the reliability of calibration results for Pass 018, an alternative technique based on the MSS as a reference surface has been chosen for the determination of the SSH difference between two dates (Fig. 6). The calibration procedure presented in the OSTST/Jason-2 Product Handbook (2009) has been followed in this case.

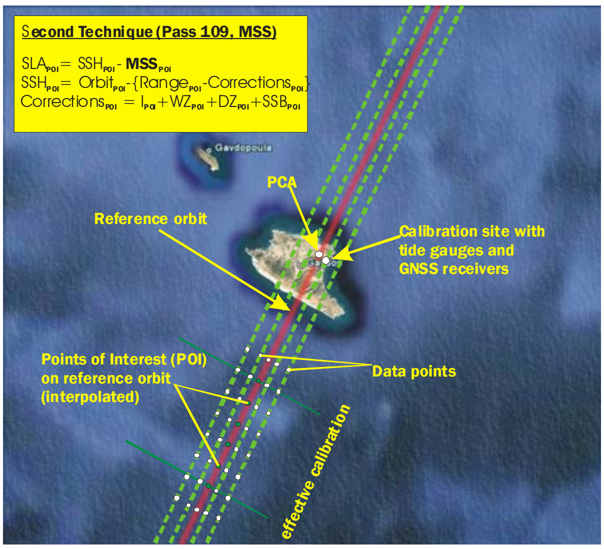

Fig. 6.The basic procedure for estimating Jason-2 bias through the MSS_CLS_10 technique.

Initially, a reference track has been established as the average of the satellite measurement points over the 58 cycles of Pass No. 109 and over the 40 cycles of Pass No. 018. This has been necessary because for a given satellite pass, each cycle has different latitude - longitude measuring points as the satellite is drifted by ± 1 km from cycle to cycle. The latter motion with respect to the reference track, introduces a cross-track geoid gradient on different cycles.

Accordingly, for every cycle and for every measured point, $k$, the SLA($k$) has been calculated as the difference between the corrected SSH($k$) (Eq. 7) and the MSS($k$) as provided by the CLS_10 MSS model. Similarly, the SLA($k_0$) has been determined using, again, the CLS10_MSS model. The determined absolute bias for each cycle has been, finally, interpolated to the reference track using a 3rd order polynomial. The Jason-2 altimeter bias for cycles 2-60 has been estimated using the same area as in the conventional methodology (12 to 21 km south of Gavdos) for Pass No. 109 and (8 to 18 km south of Gavdos) for Pass No. 018.

### 4.3 Transponder Calibration

The dedicated microwave transponders set up in Gavdos may also serve as an alternative and independent technique for altimeter's calibration. A microwave transponder receives, amplifies and retransmits, with minimal distortion, the satellite's radar altimeter pulse which is emitted and recorded again on-board the satellite. Consequently, a transponder deployed accurately beneath a satellite's pass mirrors the radar echo, thus, providing us a well-defined point of reflection. The measure of the pulse's two-way travel-time yields the range between satellite and transponder.

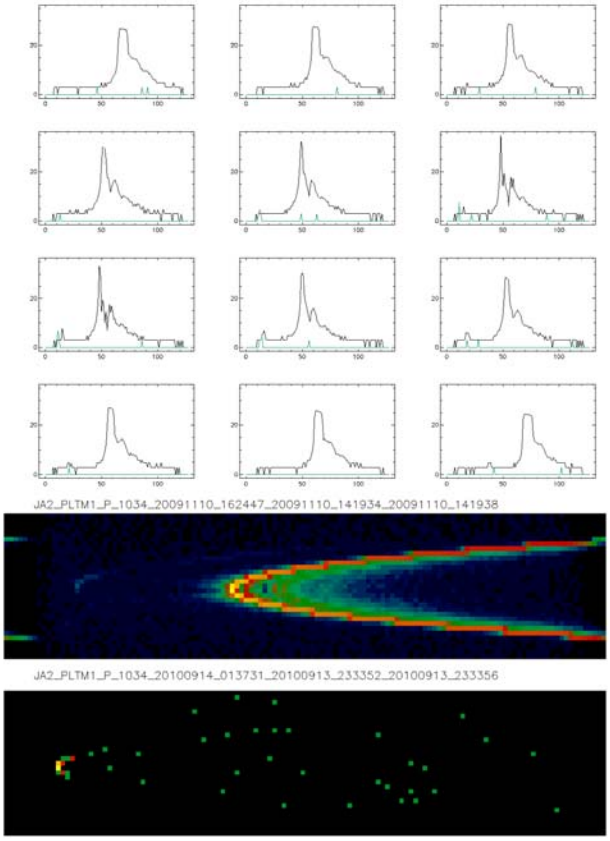

Fig. 7. The above depicts the 1-Hz calibration data of Jason-2 during the transponder experiment carried out on 2010/09/13 23:33:53, over Pass No. 18. This campaign has been in coordination with CNES, France.

The transponder has been at the DIAS site, the crossing point of the Jason satellite's ground tracks on Gavdos. Collaboration with CNES (France) has been established and agreed to switch the Jason satellite to calibration mode in order the satellite will be able to see the transponder, located at 200-m above sea level on Gavdos. Transponder calibration has been tested in late 2009, but regular calibration has been carried out as of 1 Jan 2010 over Pass No. 18.

Fig. 7 shows the transponder calibration data as seen by the Jason satellite on 13 September 2010. This picture shows a comparison between two calibration overflights in Gavdos. In the subplots above the colored transponder signature, successful calibrations are given in black solid lines; while the unsuccessful ones are shown in flat green lines. The upper 12 sub-plots show a series of the so called elementary calibrations. In these sub-plots, the x-axis is a bin number. There are 128 bins with a separation of 3.125 ns each, thus providing a measure of the travel time for the radar pulse. From the bin number, the distance between the satellite and the transponder can then be derived. The range window is preset in a way that at the closest approach, the transponder signature is expected at bin number 46. The y-axis is the power of the return echo. High power means high reflectivity, i.e., the amplified transponder signal; low power means earth surface reflections, etc. The black line shows a clear transponder echo. The 5 out of the 12 plots show the moment of the closest approach, with the highest return power at the lowest bin number. There are commonly 20-Hz and 1-Hz data provided by the altimeter in the regular modes.

Please note that the transponder signature can easily be identified and analyzed as a parabolic curve. The actual distance between the satellite and the transponder deduced from the radar pulse's travel time is then corrected for the propagation effects from the dry and wet part of the troposphere and of the ionosphere. Geophysical corrections, e.g., solid Earth and tides affecting the range have to be applied as well. The horizontal offset of the satellite's ground track from the transponder position can be determined from the satellite orbit. Calibration results for the transponder experiment are being processed at the moment and will be soon published.

## 5. RESULTS

The absolute bias for Jason-2 has been determined using both the conventional and the MSS_CLS_10 procedure over Pass No. 109 and Pass No. 018 in Gavdos calibration site.

Regarding Pass No. 109, the bias has been estimated in the area from 12 to 21 km (on the south part of the Pass 109 groundtracks) using cycles 2 to 60. The mean altimeter bias has been determined to be +169.95±5.14 mm in the Ku-band with the conventional technique. The alternative CLS10_MSS technique for the same area (12 to 21 km south of Pass 109 groundtracks) and for the same GDR data, gave an altimeter bias equal to 131.58±1.86 mm. However, Cycle 27 has been characterized as an outlier (large sigma0 values) and excluded from processing. Fig. 8 shows the altimeter bias for every cycle over Pass No. 109, employing the conventional technique.

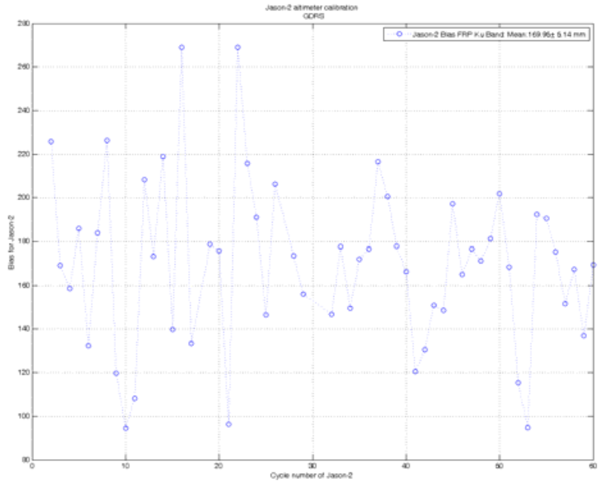

Fig. 8. The Jason-2 absolute bias, for Pass No. 109, Cycles 2-60, using the conventional calibration technique.

For Pass No. 018, the bias has been estimated in the area from 8 to 18 km (on the south part of the Pass 018 groundtracks), employing cycles 1 to 40. Thus, the mean altimeter bias has been determined to be +168.54±6.21 mm in the Ku-band, with the conventional technique. The alternative CLS10_MSS technique for the same area (8 to 18 km south of Pass 109 groundtracks) and for the same GDR data, has estimated the altimeter bias to be 137.47±5.84 mm. We should mention that Cycles 3 and 32 have been identified as outliers (large sigma0 values) and excluded from further processing. Additionally, all cycles from Cycle 41 and thereafter have been excluded from the analysis, because the transponder calibration experiment on Pass No. 018 does not produce GDR over the sea surface. Fig. 9 depicts the altimeter bias for every cycle over Pass No. 018 with the conventional technique.

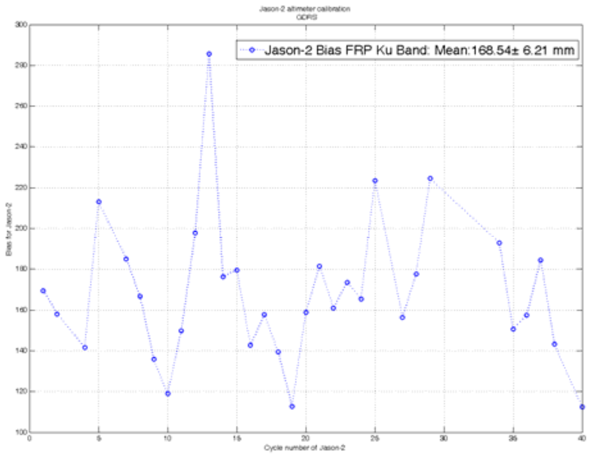

Fig. 9. The Jason-2 absolute bias for Pass No. 018, Cycles 1-40.

## 6. CONCLUSIONS

The analysis conducted thus far at Gavdos Cal/Val facility gives that the conventional technique gives the most accurate and reliable results for Pass 109 and No. 18. Additionally, the preliminary results with the CLS10_MSS technique indicate the results obtained give a comparison of Jason- 2 with the TOPEX/Poseidon. By the time of this writing a new model for the MSS, i.e., MSS_CNES_CLS_10, has been released. Future plans include the transponder calibration experiment along with a GPS buoy placed underneath the overflown satellite and along the ground tracks at about 20 km south of Gavdos.

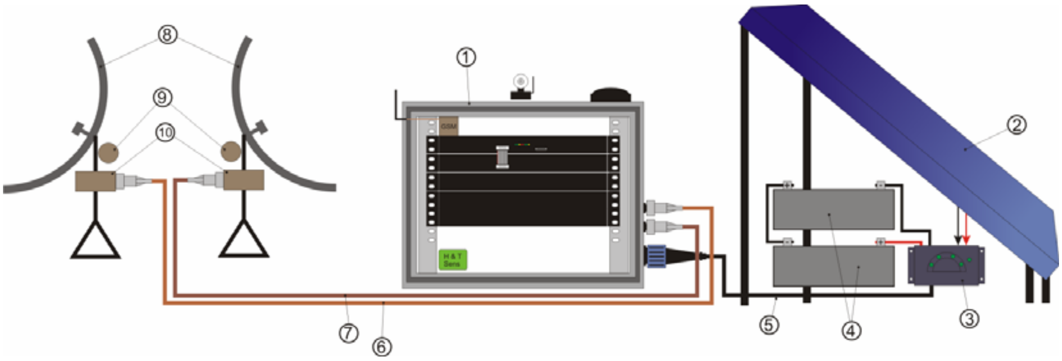

Fig. 10. A diagram of the major components of the transponder under development.

In the future plans a new transponder is being developed by the Technical University of Crete for calibrating new altimetric satellites. This transponder has a central frequency of 13.575 GHz with a bandwidth of 350 MHz. Its polarization is circular to avoid any misalignment effects of its antennas with the satellite orbit in the ascending and descending passes. It will be mobile, to be easily transferred to other locations, and modular to operate with other frequencies and satellites. It will be capable for recording incoming & outgoing signals and will be controlled remotely through a control computer using communication links. This transponder will be operational in 2010.

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