A PERMANENT INFRASTRUCTURE IN CRETE FOR THE CALIBRATION OF SENTINEL-3, CRYOSAT-2 AND JASON MISSIONS WITH A TRANSPONDER

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ABSTRACT

A new prototype microwave transponder has been developed and delivered in 2011 by the Technical University of Crete to serve as an alternative and independent technique for calibration of, mainly, European altimetric missions. Calibration of the transponder itself has been conducted at the Compact Payload Test Range facilities in the European Space Agency in 2012. This work will present the preparatory steps taken, and the procedures to be followed for the establishment of a permanent calibration site for Sentinel-3 in the south west of Crete, Greece, using the developed transponder. This ground infrastructure, along with other permanent facilities in Crete, may be used for the calibration of other Ku-band altimetric missions such Jason-2, Cryosat-2, etc.

1. INTRODUCTION

Precise measurements of the surface topography of the ocean, and of continental waters are made through satellite altimetry missions all over the globe. An orbiting satellite emits electromagnetic waves to the surface of the Earth, it records the reflected signals and their time of arrival and estimates the range between the satellite and the earth surface. In conjunction with a precise satellite orbit, that could be determined by, for example, Satellite Laser Ranging, the instantaneous surface of the water (and/or earth surface) is then determined with respect to the center of mass of the earth, accurately.

The range bias is one of the main parameter that needs to be calibrated and monitored in satellite altimetry. The main contributor to any systematic error is the delay induced by the altimeter elements that are excluded from internal calibration (e.g., antenna group delay, waveguides, part of the duplexer).

The external calibration of an altimeter mission is the process of deriving the error in the measurement of the system, using known and controlled signal inputs [1]. The operational principle of the altimeter's delay using a microwave transponder is presented in Section 2. In Section 3, the technical characteristics of the Technical University of Crete transponder along with its internal calibration are provided. Section 4 presents the field work conducted for the selection of the permanent infrastructure's location. Section 5 provides the facility's main characteristics in terms of instrumentation and infrastructure are given. Finally, Section 6 s ummarises the finding of this work and describe future plans for the establishment of the Sentinel-3 altimeter calibration site.

2. TRANSPONDER CAL/VAL EXPERIMENTS

Determination of the altimeter's absolute range bias is, mainly, accomplished using dedicated permanent calibration facilities that accurately measure the sea-surface height as the satellite flies over them.

The idea for incorporating land based transponders was initially introduced in [2]. A microwave transponder is an electronic equipment which receives the pulsed radar signal, transmitted by the altimeter of the over-passing satellite and actively amplifies and retransmits the signal towards the spacecraft, where it is recorded. The time delay of the signal is measured, from which the absolute range between the transponder and the satellite can be deduced. The main advantage of this technique, compared to the conventional sea-surface calibration, stands for the fact that no ocean dynamics errors are involved in satellite altimeter's calibration.

However, in the world, only few transponders have been built and implemented for this reason. The ESA's premises in Svalbard, Norway host a transponder developed by RAL, UK in 1987 that has been used mainly for the Cryosat-2 calibration [3,4]. The Gavdos Cal/Val facility in Greece hosted the Austrian Academy

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of Sciences transponder and that transponder has been effectively used for the calibration of Envisat [5] and Jason-2 [6] missions. There has been another transponder placed in Rome, Italy which was used for the Envisat sigma-0 calibration [7].

3. THE TUC'S TRANSPONDER

The majority of these transponders have been built more than one or two decades ago. This entails that their electronics are aging, and is difficult to adjust to and follow the recent technological advances in satellite altimetry measurements.

Along these lines, the Geodesy and Geomatics Engineering Lab at the Technical University of Crete in Greece developed (2011) a new Ku-band microwave transponder.

Its operational central frequency is in the range of 13.5-13.8GHz, while Tab.1 presents its radio-frequency characteristics.

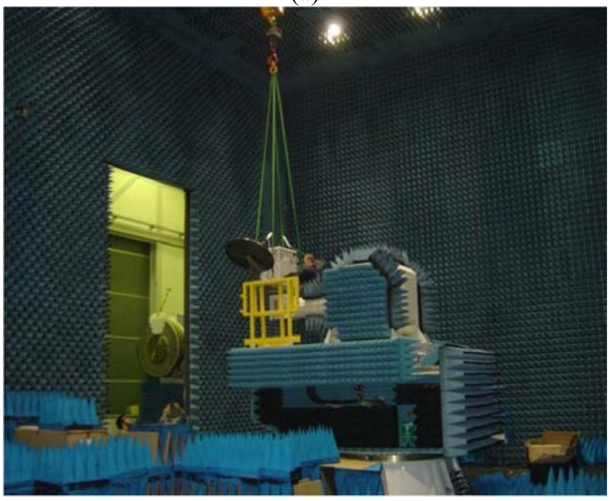
Description	Specification
Frequency	13.575GHz
Bandwidth	350 MHz
Gain stability	0.5 dB
Receiver noise figure	< 8 dB
Internal electronics Gain	0.5 dB
Antenna diameter	90 cm

Table 1. The TUC's transponder Radio Frequency characteristics

TUC's transponder is mobile, allowing calibration at different locations but also modular for operating in other frequencies, provided that some parts are modified. It is capable of recording the incoming and outgoing signals, while it can be controlled and operated remotely. The transponder frequency has been selected to be compatible with past, current and future European as well as international altimetry missions that operate in this microwave range (i.e., Jason series, Cryosat-2, Sentinel-3). Additionally, it is equipped with a Global Navigation Satellite System receiver and appropriate meteorological sensors to provide precise time-tagging, as well as the atmospheric delay corrections during transponder calibration. This is of importance for the accurate determination of the altimetric range because the atmosphere affects the altimetric measurements [8]. Furthermore, this prototype transponder is the only microwave transponder that incorporates circularly polarized antennas. The latter, allows performing calibration experiments on different satellite missions at the same location, approaching from different directions, providing that the satellite ground track is in a range of 3-5 km away from the transponder location.

This transponder has been characterized for 4 months (March-July 2012) at the Compact Payload Test Range facilities in ESA/ESTEC, the Netherlands (Fig. 1).

(a)



(b)

Figure 1. The Technical University of Crete transponder (a) and its characterization procedures at the CPTR facilities at ESTEC/ESA.

Based on these characterization results the transponder's internal path delay is accurately known. Moreover, during these characterization tests, the transponder's reference point as well as other parameters have been established (Fig. 2).

The transponder has already been used for the calibration of several Cryosat-2 passes (10-May, 8-June and 3-August 2013) over the SLR2 site (35° 32.084΄N, 24° 04.061΄E) in North West Crete, Greece, and a clear response has been captured on the satellite's data (Fig. 3).

Figure 2. Transponder reference points

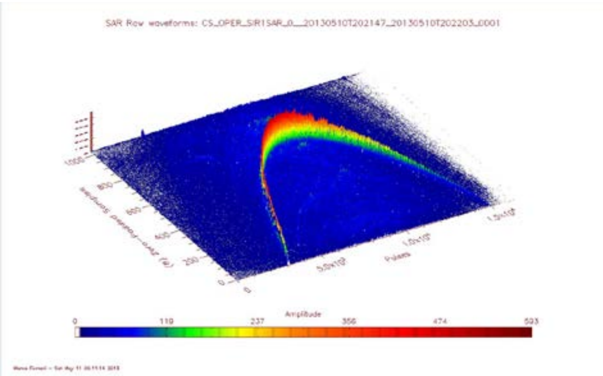


Figure 3. Cryosat-2 SAR raw waveforms using the transponder at the SLR2 site in Crete, Greece, on 10-May-2013.

More campaigns are scheduled, while data analysis for the altimeter bias estimation is on-going.

4. THE SENTINEL-3 CALIBRATION SITE

In 2011, the selection of a potential location for the establishment of a permanent facility to be used to calibrate both Sentinel-3A and -3B satellites, and possibly other altimeter missions, was initiated. A reconnaissance survey took place in September 2011 around the originally planed cross-over point between 3A and 3B tracks (see Fig. 4), for the evaluation of two different candidate sites at the Chrysoskalitissa (CRS2) and Kefala (KFL2) areas in West Crete.

The CRS2 site (35° 20.518΄N, 23° 32.342΄E, Fig. 5) is very close to the sea (~200m) and about 300m from the originally Sentinels-3 cross-over point. Its height is at about the sea level (+50m), while the existence of a water reservoir (~1km to the south) raised significant concerns regarding its reflectance interference during the transponder experiment.

The KFL2 site (35° 20.782΄N, 23° 33.851΄E , Fig. 6) is 3km away from the sea with an altitude of about 600m. The existence of mobile telephony antennas and the distance (~1km) from the Sentinel-3 crossover point were the main reasons why this site has not been selected.

Figure 4. The originally planned Sentinel-3 ground tracks over Crete (S3A=grey, S3B=purple).

Figure 5. Reconnaissance survey at the CRS2 location

Figure 6. The KFL2 site on top of the mountains.

By moving the Sentinel-3 ground tracks 20 km to the East (Fig. 7), it has been possible to generate in Crete mainland a triple cross-over point between Sentinel-3A,

-3B and Jason-2&3 (and also Jason-CS, as it will most likely fly over the same Jason-series tracks). This criterion was used to finally define and freeze the ground tracks for Sentinel-3 mission..

Figure 7. A triple cross-over point for Sentinel-3A (red), -3B (purple) and Jason series (yellow) exist at the CDN2 site in western Crete.

The CDN2 (35° 20.729΄N, 23° 46.577΄E) site is exactly under Jason, 100m east of Sentinel-3A and 300m west of Sentinel-3B ground tracks. The CNES team will verify the satellite signal observed using Jason-2 around the CDN2 candidate.

5. THE CDN2 SITE INFRASTRUCTURE

Summarizing, a permanent Sentinel-3 altimeter calibration site must fulfill the following requirements:

- It should be under, or in the proximity of the ground tracks of Sentinel-3A (and or Sentinel-3B) and preferably of both satellites;
- The echo from the transponder observed at the calibration location must be stronger and distinguishable from its surrounding returns;
- To accomplish calibration for other missions (Jason-2, Jason-3 and Jason-CS), using the same location, the distance between the site and the other satellites' ground tracks must be less than 500-1000m;
- Locations with high vegetation should be avoided;
- Metallic infrastructures at the altimeter calibration site should be avoided to deter any unwanted signal interference.

The following instrumentation will be installed as minimum:

- A permanent Global Navigation Satellite System (GNSS) continuously operating reference station capable to track satellite systems including GPS, GLONASS and Galileo (Fig. 8);
- Meteorological sensors to monitor air pressure, temperature, humidity and wind speed;
- The microwave transponder.

Figure 8.The GNSS receiver next to the transponder at the SLR2 site in west Crete. A similar infrastructure is to be constructed at the CDN2 site.

In order to ensure continuous and uninterrupted operation of this instrumentation a hybrid power supply system will be designed and implemented. This system will be comprised of solar panels, wind generator, and back-up batteries because no permanent power supply occurs in an area of 2km away from the CDN2 site.

A low-power local field computer for instrument operation, operations control, data archival and transmission will be also installed. Transmission is to be accomplished through an adequate communications link system to allow instrument remote operation and data handling. The system will rely on mobile telephony networks (GPRS, GSM) and on satellite communications links. The latter will be selected carefully because most of the communications satellites operate in the Ku-band, thus interference during transponder operation should be avoided. At least three operating satellite links with good dowlinhk and uplink capabilities exist in the region and final choice is underway.

One of the most critical subjects during the design of a calibration site should be the infrastructure's security. All the instrumentation along with the rest of the infrastructure should be well protected. To this end, an effort to protect the CDN2 calibration site using non-metallic fence will be made. Nonetheless, if metallic fences are prescribed by the location and site conditions and settings, then all measures for avoiding any signal return will be taken.

Moreover, the transponder has to be protected from strong winds and weather conditions in general at this mountainous location (altitude ~900m). For example, a wooden shack (Fig. 2&8) has been constructed to house the transponder during the calibration campaigns performed at the SLR2 site in northwest Crete. Taking into account the extreme weather conditions that prevail in the CDN2 area, another protection shack may be selected. In such case, either dielectric covers or a moving roof will be constructed to ensure that no metallic items are close to the instrument during its operation.

The rest of the instruments will be protected using either weather-proof boxes (Fig. 9) or a container with appropriate covers to avoid/reduce any satellite echoes by their metallic parts.

Figure 9. The SEL1 permanent GNSS site at Petra Seli, south west Crete, where water-proof box has been used for receiver and batteries housing.

Fig. 10 illustrates an indicative spatial distribution of the necessary and ancillary instrumentation to be constructed at the CDN2 Sentinel-3 altimeter calibration site.

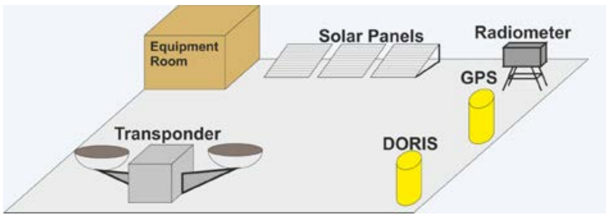


Figure 10. The CDN2 facility infrastructure layout.

Besides the instrumentation and infrastructure, the preparatory steps taken for the establishment of the CDN2 site involve also the development of appropriate software for data archival and transmission and for the determination of the transponder's precise positioning.

The GNSS receiver data in conjunction with the meteorological sensors will be processed with appropriate scientific software (e.g., GIPSY/OASIS, GAMIT, Bernese) to derive a) the precise location and tectonic movement of the transponder's reference point in an earth-fixed earth-rotating reference frame, and b) the altimeter signal delays caused by the wet troposphere and the ionosphere.

These delays are vital inputs in the transponder methodology employed for the determination of the satellite altimeter bias. For example, during the Cryosat-2 calibration campaign with the transponder performed on 10-May-2013 20:21:40 UTC, the range of the wet zenith troposphere delays as computed by a G NSS station (TUC3) next to the transponder (Fig. 8) was about 3cm for the 17 hours of the receiver's operation (Fig. 11).

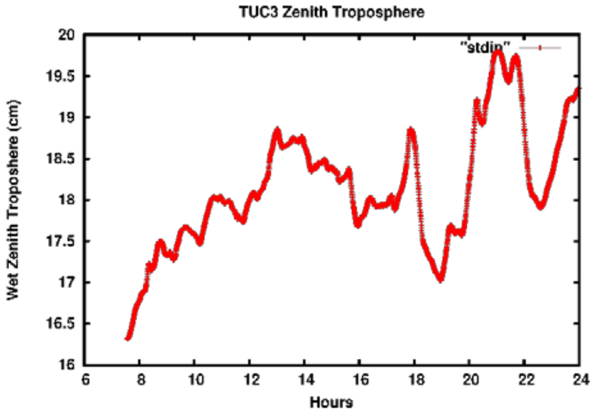


Figure 11. The wet tropospheric delays with respect to time as determined by GNSS data analysis for the 10-May-2013, 20:21:40 UTC Cryosat-2 pass over the SLR2 site. The TUC3 GNSS station was installed 6 meters away from the transponder.

6. CONCLUSIONS – FUTURE PLANS

Calibration and validation of the satellite altimeter range measurements is one of the essential parameters needed to reach the desired accuracy for the sea-surface topography mission. An alternative technique to accomplish this task, using an active transponder has been shortly presented.

The procedure followed, the prerequisites and problems encountered regarding the selection of the site to serve as the permanent Sentinel-3 altimeter calibration site has been described. The proposed instrumentation and infrastructures along with preparatory steps taken for the establishment of this site were also provided.

The operational performance of the Technical University of Crete transponder and for the estimation of the Cryosat-2 altimeter bias has been demonstrated. Moreover, the need for integration of dedicated GNSS data processing for the determination of the wet troposphere and ionosphere delays has been presented.

The Sentinel-3 altimeter calibration site is expected to be fully operational early 2014, that is about one year prior to the Sentinel-3A launch. During this period, calibration campaigns for the Jason-2 and Cryosat-2 altimetry mission will be performed to test the transponder's operational capabilities in real-field conditions. These campaigns will aim at: a) delivering altimeter calibration values for these satellites, b) getting familiarised with the remote operation procedures to be followed, and 3) identifying potential upgrades necessary for improving the transponder's performance.

The transponder is to be upgraded, improved, and characterised before its final deployment and support for Sentinel-3A commissioning phase in 2015.

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