Calibration Altimeter Sites at Cape of Begur and Ibiza Island

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ABSTRACT

The three Begur experiments have been conducted on March, 16-19, 1999, which was the first altimeter calibration ever developed in Spain and the first Alt-B altimeter calibration made in the Mediterranean Sea; on July, 4-7, 2000, and on August, 25-28, 2002.

Direct absolute altimeter calibration, estimating the TOPEX Alt-B bias, was made from direct overflights using GPS buoys. This method does not require any modelling of geoid and tidal error. Other main objective of the campaigns was to map with GPS buoys the Mean Sea Surface, MSS, along an ascending T/P groundtrack about 15-20 km from the coast, using coastal tide gauge measurements. This method requires geographical mapping of geoid and ocean tides which reduces the accuracy of the bias estimate by a factor of two. Indirect absolute altimeter calibration is possible for any satellite crossing the MSS, with the only requirement that tide gauges are operational during the overflight.

In the framework of the JASON-1 CNES/NASA mission, a campaign was conducted on June 9-17, 2003, in the Absolute Calibration Site of the Island of Ibiza. The objective was to determine the local marine geoid slope under the ascending (187) and descending (248) Jason-1 ground tracks, in order to allow a better extrapolation of the open-ocean altimetric data with on-shore tide gauge locations, and thereby improve the overall precision of the calibration process. We present preliminary results on Jason-1 altimeter calibration using the derived marine geoid: from this analysis the altimeter bias is estimated to be 120 ±5 mm.

Key words: Altimetry, Calibration, Geoid, GPS, Tide gauges, GPS Buoys, Catamaran.

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1. INTRODUCTION

Satellite radar altimetry plays a critical role in monitoring the global oceans for scientific uses as well as navigation. The extreme accuracy of Jason-1 (Menard et al. 2003) and Topex/Poseidon, and the additional global coverage of the European satellite Envisat, have created significant advances in oceans and climate studies. Published examples include estimating heat storage in the oceans, detecting interannual waves around Antartica or interannual changes in the Mediterranean, relating physical and biological processes in the oceans, predicting changes in the rotation of the Earth and measuring the rate of change of global mean sea level. In addition precise tidal models were developed for the deep ocean all using T/P (Shum. et al. 1997), and there are further developments, especially in shallow coastal waters. These tidal models are used for Precise Orbit Determination, Earth Rotation predictions, and to better understand energy dissipation in the Earth-Moon system.

The radar altimeter measures the instantaneous distance to the sea surface, as well as wind and waveheight. Jason-1, joint mission of NASA and CNES launched in December 2001 has been measuring in Ku band (13.575 GHz) and C band (5.3 GHz), Topex/Poseidon launched in August 1992 measuring at 13.6 GHz and 5.3 GHz respectively and Envisat, mission from the European Space Agency ESA, launched in March 2002 measuring the RA-2 at 13.575 GHz and 3.2 GHz.

Altimeter calibration is essential to obtain an absolute measure of sea level, as are known the instrument's drifts and bias. Specially designed tide gauges are necessary to improve the quality of altimetric data, preferably near the satellite track. Further, due to systematic differences among instruments onboard different satellites, several in-situ calibrations are essential to tie their systematic differences.

During the last years, complementary altimetric missions have notably permitted to compare instruments: relative calibrations have been achieved, global statistics and results show the power of such a technique. However, through these missions, problems have been discovered both in the algorithms and the instruments: the SPTR and USO drift corrections for ERS, the oscillator drift corrections for TOPEX/Poseidon and more recently in the JMR wet path delay correction for Jason-1. This has reinforced the interest of absolute calibration campaigns to detect such problems in near-real time. Beyond the calibration of the altimeters, the calibration sites also are very useful in assessing the various components of the altimetric systems, even if it is only a single-point verification. The calibration sites are often equipped with a complete system of in-situ instruments which have the capability of very accurate estimation of the environmental parameters interfering in the altimetric measurement: sea state, sea level, troposphere and ionosphere effects, reference frame stability, etc. Nevertheless, absolute calibration of radar altimeters at the centimeter level or less is one of the most difficult challenges in Space Geodesy. Indeed, the realization of the closure equation - to compare terrestrial sea level measurements with sea heights deduced from satellite altimetry - requires a very specific area where several kind of quantities (sea level, terrestrial positioning, orbit, etc.) have to be precisely and simultaneously measured at each overflight of the altimeter satellite. This leads to perform, with a very high accuracy, comparisons between the used techniques (in situ and space ones) in a homogeneous geocentric reference frame. The global error budget of the absolute calibration experiment is thus very difficult to achieve, because of all kinds of possible systematic errors. The main absolute calibration experiments realized in the recent past (Ménard et al. 1994; Christensen et al. 1994; Francis, 1992) showed this difficulty clearly. As a consequence of the increased precision of the satellite altimetry technique (instrumentation, orbit, and corrections) over the last ten years, requirements are now at the centimeter level and even less for the altimeter bias determination. This makes absolute calibration a field campaign which can be very expensive economically, but remains strictly necessary for a given oceanographic mission and especially for a series of successive missions (over several decades).

Thus, the experiment requires a site which is just under the altimeter satellite ground track and is offshore in order to avoid land perturbations on the radar echos that implies a rapid decreasing of the tracking precision. A classical configuration uses a very small island as in Lampedusa (Italy) for the TOPEX/Poseidon (T/P) calibration experiment (Ménard et al. 1994), or a dedicated or existing artificial offshore structure such as the Venice tower (for ERS mission) or the oil Harvest platform (T/P) (Francis, 1992; Christensen et al. 1994, Born et al. 1994). However in such situations, the cost appeared to be very high, mainly due to structure deployments or distances from economic facilities (airport, harbor, etc). Other calibration sites are Bass Strait, Tasmania (Australia) (Watson et al. 2004), Corsica Island (France) (Bonnefond et al. 2003b), Gavdos Island (Greece) (Pavlis et al. 2002), Lake Erie (USA) (Shum et al. 2003) and Ibiza Island / Cape of Begur (Spain) (Martinez Benjamin et al. 2004, 2000a, 2000b; Martinez Garcia et al. 2000).

The on-site absolute calibration of the TOPEX side-B altimeter on board the TOPEX/POSEIDON satellite was the purpose of two calibration campaigns in the NW Mediterranean Sea near Begur Cape in 1999 and 2000. The campaign on 15th-18th March 1999 was focused in the direct calibration estimating the instrument bias (Martinez Benjamin et al. 2000). The campaign on 4th-7th July 2000 consisted in the mapping of the mean sea surface MSS along the T/P ground track with GPS buoys, basically oriented to perform the indirect altimeter calibration and consolidating the results of the 1999 campaign (Martinez Garcia et al. 2000). The MSS provides a reference for the altimetric measurement and the tide gauge with the temporal part of the sea level. A third campaign for Jason-1 altimeter calibration was made on 25th-28th August, 2002.

The absolute calibration site in Ibiza has been chosen following technical and economical requirements. In opposition to classical configuration explained above, Ibiza island is a too large area to do not affect altimetric measurements in terms of radar echoes and wet troposphere corrections (due to land contamination). This implies to preferably use altimetric data measured far from the coast

(5-10 km); on the other hand, above 20 km, the sea level departs from the one measured by coastal tide gauges due to a possible differential behavior of oceanic effects between coast and full sea. Therefore it is necessary to account for geoid height differences along this distance.

A Spanish JASON-1 calibration campaign, IBIZA 2003, was carried out in June 9-17, 2003 in the area of Ibiza Island in the NW Mediterranean Sea. The objective of the campaign was to map the instantaneous sea level/local geoid gradient in three areas around Ibiza: at the crossing point of an ascending and descending JASON-1 tracks located to the north of the island, and along these tracks to the SE and SW of the Island. The campaign was based on the experience gained from three previous campaigns in the region of Cape Begur.

2. ELEMENTS OF THE BEGUR CALIBRATION CAMPAIGNS

A. The Tide Gauges

Apart from the in-situ measurements of the SSH made by the GPS buoys, two tide gauges were used in the first campaign. A gauge based in a pressure sensor (AANDERAA) and another one based on a float-operated shaft encoded with and integrated data logger (Thalimedes) were installed at Llafranc harbour. Both tide gauges were referred to a geodetic benchmark provided with a GPS receiver at the harbour jetty and also they were periodically calibrated for monitoring the agreement between their measurements.

With respect the monument and instrumentation of the l'Estartit tide gauge, the installation is a traditional floating gauge placed in the inner wall of l'Estartit harbour (Fig. 1).

Figure 1. L'Estartit tide gauge.

It provides sea level measurements every 2 hours. The accuracy of the height measurements is about 2 mm. The advantages of using l'Estartit records are the good quality, the continuity and the length of their time series. The tide gauge heights are geo-referenced to a benchmark in the adjacent jetty identified as number 314 094 002 in the Cartographic Institute of Catalonia (ICC) classification:

UTM coordinates are X= 517199.76m, Y=4655985.52m and Z=+1.72m from the zero reference height of the tide gauge. The coordinates of this geodetic mark have been calculated in 1999 by a precise levelling survey in order to connect the benchmark to the local EUREF sub-network that includes the permanent GPS IGS-IRTF station at Creus Cape, CREU. By carrying out a series of episodic GPS surveying campaigns it would be possible to detect any vertical land movement of the benchmark.

B. The reference GPS stations

For the differential positioning of the buoy, a coastal reference station is necessary as close as possible to the calibration area. This fiducial site does not have a fixed location along all the three campaigns so, it has been necessary a previous computation of its accurate coordinates. For this purpose a network consisted of three permanent ICC stations has been considered. These sites, belonging to the IGS network, are used to compute the coordinates of the fiducial station and the media parameters at the site.

The GPS data have been processed with the GIPSY/OASIS-II software (GPS Inferred Positioning SYstem and Orbit Analysis and SImulation Software) developed at the Jet Propulsion Laboratory (JPL). In the three campaigns the GPS data processing has been split into two parts:

- Positioning of the reference station at the coast near the calibration area (free-network solution).
  The GPS observables from a network consisted of three permanent ICC stations (Bellmunt de la Segarra, BELL,; Creus Cape, CREU, and Llivia, LLIV), and the temporal site in the coast (station at Begur Cape, BEGU) have been processed following a free-network solution strategy (Zumberge et al. 1997) with the GIPSY-OASIS II software developed by JPL.
  This strategy provides sub-centimeter accuracy station coordinates estimated as constant parameters, the station clock delays and the Wet Zenith Tropospheric Delay (WZTD) at every site estimated as stochastic parameters.
- Differential positioning of the buoy respect to the reference (fiducial) site off the coast (differential kinematic solution). The differential kinematic positioning has been performed using as reference station the nearest site at the coast and considering the GPS buoy as a rover receiver.

C. The GPS buoys

The GPS buoys used in the calibration campaigns were designed and built at the Cartographic Institute of Catalonia using an original design from the University of Colorado at Boulder improving the stability and minimizing the distance between the sea surface and the center of phase of the antenna. The models follows some functional requirements as to offer protection to the GPS antenna against the sea water, bad sea conditions and any eventual accident. The radome must allow the GPS signal reception with a minimum disturbance. The small size and manoeuvrability and the stable and recyclable structure for future calibration campaigns was considered.

In the 1999 campaign two buoys were used simultaneously in the direct calibration. In the 2000 and 2002 campaigns an improved prototype was used. That buoy was more stable to the tilt and also the protection of the antenna against the sea water was more efficient by including some technical improvements in the radome sealing. The buoy was provided with a TRIMBLE DORNE MARGOLIN antenna and connected to the receiver on the boat by a coaxial watertight cable.

3. CALIBRATION RESULTS AT BEGUR CAPE CAMPAIGNS

The altimeter bias estimation by single point experiments over points (Fig. 2) top-08 for Topex alt-B and over point top-11 for Jason-1 are showed in table 1 (Martinez Garcia, 2004).

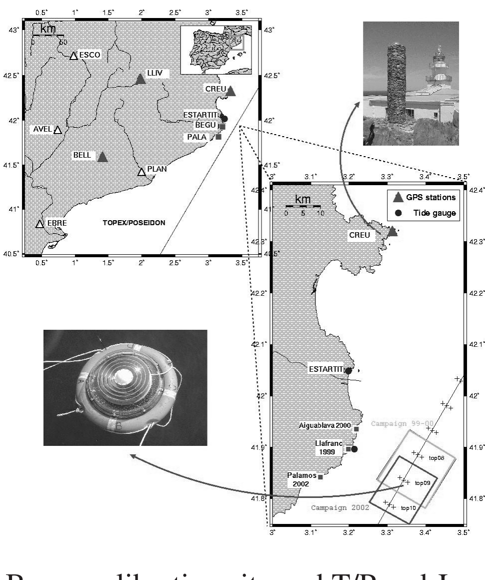

Figure 2. Cape of Begur calibration site and T/P and Jason-1 nominal track.

Table 1. Altimeter BIAS estimation by single point experiments over point TOP-08 for TOPEX-B and over point TOP-11 for Jason-1. The two values in 1999 corresponds to both similar GPS buoys used simultaneously at that campaign (UPCB and JPLB buoys, respectively).

Campaign	Overflight	Cycle	SSHGPS (m)	SSHalt (m)	BIAS (cm)	Altimeter product
1999	18/03 at 08:45:41	T/P 239	49.118 +/- 0.32	49.052 +/- 0.04	+6.5 +/- 32.1	M-GDR Topex-B
			49.090 +/- 0.32	49.053 +/- 0.04	+3.7 +/- 32.6	
2000	07/07 at 07:34:47	T/P 287	49.243 +/- 0.07	49.209 +/- 0.04	+3.43 +/- 7.96	M-GDR Topex-B
2002	28/08 at 15:37:07	J 23	49.289 +/- 0.06	49.184 +/- 0.08	+10.52 +/- 10.35	I-GDR

Results of the point calibrations are in agreement with the official values obtained in single point experiments with buoys, which range is several centimeters. Thus, for the TOPEX side-B single calibration, the range bias was estimated in +6.5 cm with 32.1 cm of rms and +3.7 cm with 32.6 cm of rms in 1999 (Selective Availability still on) and in +3.43 cm with 7.9 cm of rms in 2000, and for the Jason-1 in +10.52 cm with 10.35 cm of rms in 2002.

Results of the TOPEX side-B altimeter computed in both, 1999 and 2000 experiments, are in agreement with the official values given at (Bonnefond et al. 2003) and (Haines et al. 2003) where more than 100 cycles of the TOPEX/POSEIDON mission have been monitored at Senetosa (Corsica) and Harvest (USA), respectively, computing positive final biases of few mm by a straight average of all the single direct calibrations. Our computations also agree in the sign, with resulting positive biases that means that the altimeter measurement is longer than the true distance between the satellite and the ocean surface (altimeter measurement below the true sea surface).

4. IBIZA ISLAND CALIBRATION CAMPAIGN

The Western Mediterranean is quite a complex area for different reasons: due to the presence of several islands, coastal lines, shallow waters and a peculiar hydrologic equilibrium due to its proximity to the Atlantic water exchange area. This makes the estimation of the gravity field and the geoid slope quite a difficult task. Presently there are several global models accounting for free air gravity anomalies (GAS), but their fits are not good enough to make accurate determinations.

There are some results for the local/regional gravimetric geoid, which have been built up using different techniques such as least squares collocation (LSC), spectral methodology and fast Fourier transform (Rodriguez Velasco et al. 2000). In all cases, the classical remove-restore technique has been employed, taking into account the long wavelength part of the gravity field by means of coefficients sets of the geopotential EGM96 model and the topography effect or contribution of high frequencies to the gravity field. The result is a fairly smooth surface, with variation range around the Island of about one meter, from 48,5 m to 49,5 m.

Within the framework of a project comprising part of the Spanish Space Program related to the JASON-1 CNES/NASA mission, a campaign was conducted on June 9-17, 2003, in the Absolute Calibration Site of the island of Ibiza. The objective was to determine the local marine geoid slope under the ascending (187) and descending (248) Jason-1 ground tracks, in order to allow a better extrapolation of the open-ocean altimetric data with on-shore tide gauge locations, and thereby improve the overall precision of the calibration process (Fig. 3). The marine geoid will be used to relate the coastal tide gauge data from Ibiza and San Antonio harbours to off-shore altimetric data. The map obtained will be used to validate and filter altimetric data in the vicinity of the island and to correct the altimeter data from the geoid slope before comparison with tide gauge. A direct altimeter absolute calibration was also made (on June 14) with the catamaran and the GPS buoy near the crossover point located to the north of the island.

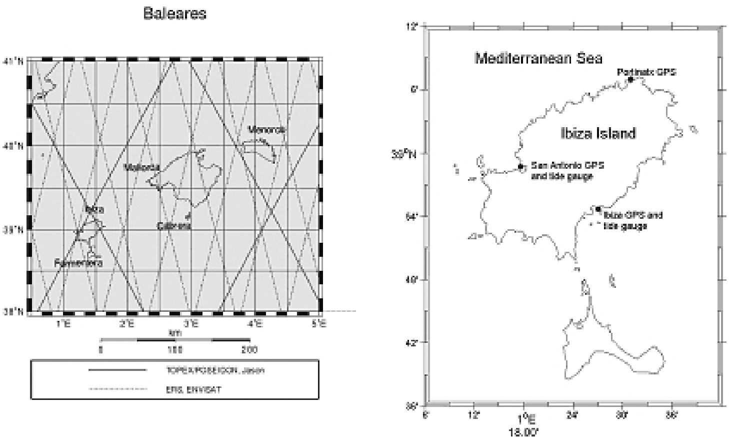

Figure 3. Ibiza calibration site and GPS Reference Stations/Tide Gauges locations.

A major component of the campaign was a newly designed, calibrated GPS catamaran, to perform continuous sea level measurements, built up at ICC, following the original design from Senetosa experiences (Bonnefond et al. 2003a). Two radomes for protection were placed above the two GPS antennas, a Trimble (CATL), and a Leica (CATR). Two GPS receivers, Trimble and Leica, were used aboard the Deva and linked to the antennas of the catamaran by cables independent of the towing rope at a distance about 30 m. It was towed by the Spanish Navy Patrol Deva (Fig. 4). The objective was to provide instantaneous geocentric sea-level measurements with the instantaneous nearby GPS data obtained with the catamaran (an optical levelling was carried out in both harbours).

Figure 4. GPS Catamaran and Patrol Deva from the Spanish Navy towing the GPS Catamaran leaving Ibiza harbour.

Five GPS reference stations were deployed on Ibiza Island: one in Portinatx, two in San Antonio and two in Ibiza (see Fig. 1 and Tables 1 and 2). An additional Trimble antenna and receiver were also installed in Ibiza harbour for a few hours (on 06/16/2004). For IBIA, SANA and SANB stations, the raw data set covered 6 days (11-16 June 2003), whereas for IBIB and PORT stations it covered only 5 days. The sample rate was fixed to 30 seconds except during the Catamaran/Buoy measurements, when it was set to 1 second (Tables 2 and 3).

Table 2. Location and time of observation for each GPS station.

Marker Name	Location	From	To
IBIA	Ibiza (hotel roof)	11/06 18h58	16/06 24h00
IBIB	Ibiza (hotel roof)	12/06 08h29	16/06 24h00
SANA	San Antonio (nautical club roof)	11/06 12h49	16/06 07h53
SANB	San Antonio (nautical club roof)	11/06 13h24	16/06 07h32
PORT*	Portinatx (room roof)	10/06 15h49	15/06 24h00
Buoy	Ibiza, San Antonio, Calibration (North)	11/06 15h33	16/06 07h37
CATR	Ibiza, San Antonio, Calibration (North)	11/06 15h34	16/06 07h37
CATL	Ibiza, San Antonio, Calibration (North)	12/06 08h24	16/06 09h48

*Data lacking on 11/06 from 08h09 to end of day

Table 3. Antenna height, type of antenna and type of receiver for each GPS station.

Marker Name	ARP Height	Antenna Type	Receiver Type
IBIA	0.8447	TRIMBLE: 4000 ST/SST	ASHTECH: XII Z-12
IBIB	1.1510	LEICA: AT502	LEICA: SR530 3.02
SANA	0.6385	ASHTECH: Choke Ring	ASHTECH: iCGRS Z-12
SANB	0.1438	TOPCON choke ring antenna CR-3	TOPCON: LEGACY-E L1/L2
PORT	0.9510	LEICA: AT502	LEICA: SR530 3.02
Buoy*	-0.0078	TRIMBLE: Compact L1/L2	TRIMBLE: 4000SSI
CATR*	0.4640	LEICA: AT502	LEICA: SR530 3.02
CATL*	0.4025	TRIMBLE: Compact L1/L2	TRIMBLE: 4000SSI

*Height relative to the water line.

5. CALIBRATION RESULTS AT IBIZA ISLAND

The Fig. 5 shows the GPS data collected in the specific geographical areas around Ibiza island.

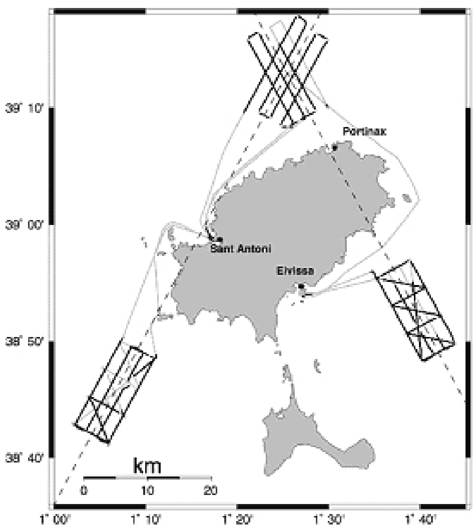

Figure 5. GPS data collected (gray) and kept (black). Dashed lines represent the Jason-1 passes: ascending N°187 (South West – North East) and descending N°248 (North West –. South East).

The GPS data processing can be divided into two parts: first we needed very accurate absolute positions (particularly in the vertical component) in a global reference frame coherent with the one commonly used for T/P and Jason-1 mission (ITRF2000). Secondly, these reference stations defined the datum for the kinematic processing of the GPS catamaran and buoy data but we also used them to determine the absolute sea level heights derived from tide gauges data. The detailed description of the Ibiza campaign GPS and Sea Height data processing can be seen in (Martinez Benjamin et al. 2004).

The bias found at San Antonio is very close to that found at other calibration sites notably the Corsica one where the geographically correlated errors should be comparable (orbit, sea state,..): +138 ± 7 mm at Harvest (Haines et al. 2003), +120 ± 7 mm at Corsica (Bonnefond et al. 2003b) and +131 ± 11 mm at Bass Strait (Watson et al. 2003).

6. CONCLUSIONS

The main objective was to test the value of Ibiza Island and Cape of Begur as possible permanent altimeter calibration sites in the western Mediterranean Sea, to complement to the Corsica/Senetosa site. They can help to control the geographically correlated errors that are significant at single sites. Results from the Cape of Begur and Ibiza island campaigns indicate the convenience of including these sites in the network of altimeter calibration sites. It is suggested that together with other calibration programs they might contribute to a better characterization and understanding of the altimeter bias.

The direct point calibration (buoy placed at the nadir satellite during overflight) has been successfully performed in the four campaigns giving single estimations of the Jason-1 and Topex altimeter range bias ranging at centimeter level. A technical contribution has been made on the design of the GPS buoy and GPS catamaran.

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