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EN SAN FERNANDO

BOLETÍN ROA
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DE CATALUNYA

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SPANISH SPACE PROGRAM, CICYT ref:ESP2001-4534-PE

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PE: Puertos del Estado.
UIB: Universidad de las Islas Baleares.
UCM: Universidad Complutense de Madrid.
CNES: Centre National d'Etudes Spatiales.
OCA-GEMINI: Observatoire de la Côte d'Azur

Índice general

ABSTRACT

A Spanish with French support, Geoid Determination/JASON-1 Absolute Altimeter Calibration campaign has been made on June 10-17, 2003, in the area of Ibiza island in the NW Mediterranean Sea. The Universidad Politécnica de Cataluña, Real Instituto y Observatorio de la Armada en San Fernando, Instituto Cartográfico de Cataluña, Observatoire de la Côte d'Azur-CERGA/GRGS, Puertos del Estado, Universidad Complutense de Madrid and Universidad de las Islas Baleares have participated with support of the Spanish Navy, CNES and Noveltis in that camnpaign. A more complete description of the campaign data processing and results, can be seen in the Marine Geodesy, vol. 27, December 2004, by J.J. Martinez Benjamin, J.M. Davila, J. Garate, P. Bonnefond et al., 'Ibiza Absolute Calibration Experiment: Survey and Preliminary Results'. The IBIZA 2003 campaign has been made with funding from a Project R+D+I of the Spanish Space Program of the Ministery of Science and Technology, CICYT ref:ESP2001-4534-PE.

1. INTRODUCTION

Since many years, space borne radar altimeters have brought a powerful contribution in monitoring the dynamic sea surface topography, and in understanding better the ocean circulation and its impact on the earth system. Today, altimetric satellites are observing the whole oceans, measuring the sea surface height with a rms precision of 3-4 cm at 1 Hz sampling, as demonstrated by TOPEX/POSEIDON, launched in 1992, by Jason-1, launched in 2001 and by ENVISAT, launched in 2002. Such a high level error budget was achieved thanks to the tremendous improvements which have been obtained in radar performances as well as in precise orbit determination. Indeed, applications of altimetry in oceanography and geodesy requires very precise measurements of the satellite-sea level range, along with appropriate environmental corrections, but also an accurate knowledge of the satellite position with respect to the Earth reference.

The CNES/NASA Jason-1 project has already equipped two main NASA and CNES devoted calibration sites: at the Senetosa Cape in Corsica for the French side (Bonnefond et al., 2003b), and on the Harvest Oil platform off the Californian coast for the USA side (Haines et al., 2003). Other sites are already equipped, or in installation phase for in situ measurements mainly using tide gauges, in order to help the verification of altimeter range measurements. This is the case for Bass Strait, Tasmania (Australia) (Watson et al.,2003), Lake Eire (USA) (Shum et al.,2003), Lampedusa (Menard et al., 1994) and Ibiza/ Cape of Begur (Spain) Martinez Benjamin et al.,2000) using a GPS buoy (Born et. al. 1994; Kruizinga, 1997).

The combination of space and in-situ data is essential to the calibration and the validation of altimetric data. Measuring the sea level with in-situ tide-gage and GPS recorders provides an efficient way to control the long term stability of the altimeter radars. An additional objective is to take advantage of this integrated in-situ and satellite observation network, plus ocean models, to study in more details the ocean circulation and the related mass and energy transport in this region of the Western Mediterranean Sea.

Space borne radar altimeter data is a key data for these three objectives. Nonetheless, the satellites repetitivity sets the problem of the under resolution of the ocean meso-scale phenomena for time below the repetitivity (called aliasing problem).

The Western Mediterranean is quite complex from a dynamic point of view. It is very close to some particular features as the Algerian Currents or the Alboran Sea. But this part is itself a region with important circulation. There is a zone of special circulation in the so-called Balearic Sea, or portion of water between the Balearic Islands and the Northeast coast of Spain. The Atlantic waters enter the Sardinian Channel, although part of it does not enter the Eastern Basin through the Straits of Sicily. This part of the water does not circulate in a normal geostrophic pattern due to interaction with other currents. It goes on around the Tyrrhenian Sea, leaves through the Corsica Channel and joins the Corsica Current to form an important cyclonic gyre, the Northern Mediterranean Current also known as Ligurian-Provençal-Catalan Current.

Ibiza and the area around is a region of great interest for altimetric data calibration and inferred geodetic and ocean applications because the site is already instrumented and geodetically well surveyed since many years. Moreover altimetric satellites are passing close making easier the comparison with in-situ data). On an oceanographic point of view, the Balearic Sea circulation is very active and is characterised by an intense eddy activity and a strong seasonal variability.

Geodetic Characteristics of the Ibiza Island Area

The Western Mediterranean is quite a complex area fordifferent 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 adifficult 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.

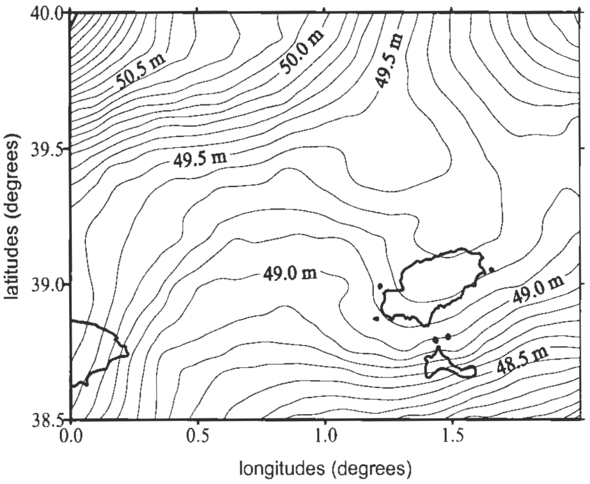


Fig. 1: Level lines of the gravimetric geoid. Contour interval: 10 cm.

There are some results for the local/regional gravimetric geoid, which have been built up using different techniques such as least squares collocation (LSC) and spectral methodology. 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 a variation range around the Island of about one meter , from 48,5 m to 49,5 m. The isolines of one of this geoid are depicted in Fig.1. When gravimetric geoids are compared to each other they show a good match, with only small discrepancies found to the South of Ibiza Island.

2. ALTIMETER CALIBRATION METHODS

A description of the principles involved in the altimeter calibration methodology is given. In the Spanish campaigns, ocean surveying with GPS catamaran and/or wave-rider GPS buoys has been mainly oriented to:

- The direct estimation of the instrumental bias of the radar altimeter on board the satellite.

In this direct calibration method the instantaneous SSH derived from the JASON-1 altimeter measurements, that is, the difference between the satellite orbit height (h_{orbit}) and the altimeter measurement (h_{alt}) which represents the raw range corrected basically of the media delays, troposphere and ionosphere, the sea state bias and the instrumental delay:

$$SSH_{JASON} = h_{orbit} - h_{alt} \quad with \ h_{alt} = h_{true} + BIAS$$

is compared with the same magnitude SSH_{GPS}, which can be considered a 'true' measurement of the instantaneous sea level, estimated from the measurements of the GPS buoys placed underneath the ascending T/P satellite ground track. By this comparison the bias of the altimeter is obtained:

$$BIAS = SSH_{GPS} - SSH_{JASON}$$

The direct calibration supposes the straight comparison of the altimeter and the buoy simultaneous sea surface heights at the same point, and is also called single point calibration. If BIAS>0 the meaning is that the altimeter is measuring too long thus h_{alt} is larger than h_{true}. If BIAS<0 the meaning is that the altimeter is measuring too short thus h_{alt} is smaller than h_{true}.

The single point calibration has been successfully performed in the calibration campaigns and has the advantage of needed neither geoid nor tidal modelling (is a direct comparison of measurements). The drawback is the fact that as the error in the estimation of the range bias decreases with the root square of the number of monitorized overflights, a major number of single point performances gives more reliable and accurate bias computation. Thus, it is desirable systematic performances of single point calibrations in order to minimize the error of the final range bias estimation. Unfortunately, this means continuous economic and manpower efforts that can not be performed during an undefined time.

Then the direct overflight (Fig.2) is most accurate with the sea level independently measured by the GPS buoy directly underneath the satellite altimeter.

For GPS buoy the following instrumentation are required:

-calibration bath for fully equipped buoy to determine the waterline in undisturbed local sea water.
-boat.
-buoy.
-GPS receiver and antenna (data collection rate at 1/s for about one hour before and after the overflight).
-reference GPS site (1/s).
-meteorological data (surface pressure, temperature, humidity and wind speed) at the time of overflight.
-possible laser tracking of the satellite.

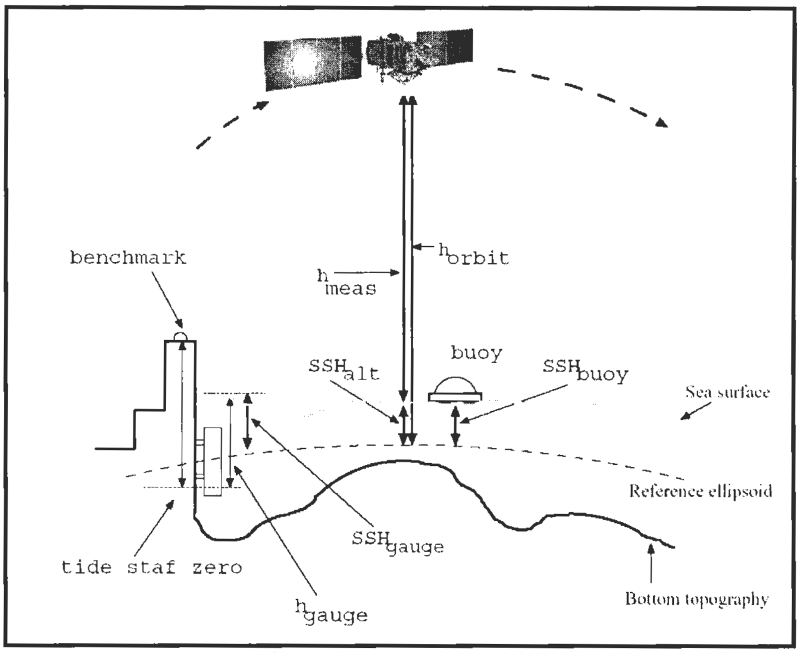


Fig. 2: Direct and indirect altimeter calibration/validation schema

-More interesting is the GPS determination of the instantaneous marine sea level in view of the Mean Sea Surface (MSS). If we consider a nominal Jason-1 ground track and a +/-1km exterior and interior strip, after correcting all the measurements for tides (models) and environmental corrections it is computed the MSS for each location in the strip as the MSS_ALT(X,Y) given by altimetry, where X and Y are the along track and cross track coordinates.The shape of the MSS is very well known along the strip but no the absolute height of the MSS with respect the center of the Earth because the altimeter measurements are biased.
If MSS_TRUTH is the best estimate of the real MSS,
$MSS\_TRUTH(X,Y)=MSS\_ALT(X,Y)+MSS\_BIAS$

It is needed to determine the MSS_BIAS using independent measurements, by example, using GPS buoys or GPS catamaran to estimate MSS_BIAS with mapping,
$MSS\_BIAS(X,Y)=MSS\_GPS(X,Y)-MSS\_ALT(X,Y)=SSH\_GPS(X,Y)-Delta\_Tide-MSS\_ALT(X,Y)$
where SSH_GPS is the instantaneous sea surface height measured by the GPS buoy/catamaran at the (X,Y) points of the strip and Delta_Tide is the tide gauge measurement minus a long term mean tide gauge measurement.

The MSS_BIAS is computed by,
$MSS\_BIAS=[SUM\ i=1,N\ of\ MSS\_BIAS(i)]/N$

The indirect calibration is really the reverse of MSS mapping but the MSS_BIAS has been taken into account. If an altimetric satellite crosses the strip at location (X_s,Y_s), the calculated instantaneous sea surface height SSH_CALC is
$SSH\_CALC(X_s,Y_s)=MSS\_TRUTH(X_s,Y_s) + DELTA\_TIDE$ *(at time of overflight)*
Delta_Tide calculated the same way as before except is it compute at the time the satellite flies over the strip.

The altimeter bias is then calculated according to,
$Altimeter\_Bias=SSH\_CALC(X_s,Y_s) -SSH\_ALT(X_s,Y_s)$
where SSH_ALT(X_s,Y_s) is the instantaneous sea surface height calculated by the altimeter measurement made by the satellite crossing the strip.

Then the indirect overflight is less accurate. Satellite altimeter passes close to a tide gauge (about 15 km) and sea level from tide gauge needs to be mapped (geoid and tide) to foot print of the altimeter.The mapping of the geoid can be achieved by surveying along the satellite ground track with a GPS catamaran or GPS buoy (observe each location about 1 hour at 1/s rate). This height is then corrected to the geoid by removing the tide derived from repeat track analysis. Using this method one assumes that the dynamic topography close to the coast is close to 0.

3. IBIZA 2003 CAMPAIGN

The Jason-1 project has set up a CALVAL Plan organizing calibration and validation activities during the validation phase of Jason-1 (T0 →T0+6 months) and during the operational phase (after T0+6 month). Amongst the studies concerning the verification of the altimetric system components, some of them are devoted to the altimeter sea level measurement assessment by comparing space-derived measurements to in situ ones.
The CNES/NASA Jason-1 project has already equipped two devoted calibration sites: at the Senetosa Cape in Corsica for the French side, and on the Harvest Oil platform off the Californian coast for the USA side.
Other sites are already equipped, or are in installation phase for in situ measurements using mainly tide gauges, and other instruments to help the altimeter range measurements verification. This is the case for:

- Bass Straight, Tasmania (Australia)
- Gavdos Island (Greece)
- Ibiza Island / Cape of Begur on the Costa Brava (Spain)

Fig. 3 gives the potential regions for calibration campaigns around Spain.

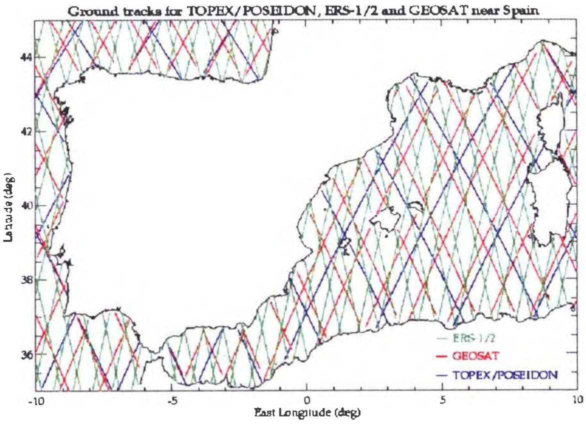


Fig. 3: T/P (Jason-1) and ERS (ENVISAT) ground tracks

A Spanish with French support, Geoid Determination/ JASON-1 Absolute Altimeter Calibration campaign has been made on June 10-17, 2003, in the area of Ibiza island in the NW Mediterranean Sea (Martinez Benjamin et al., 2004), (Fig.4). The Universidad Politecnica de Cataluña, Real Instituto y Observatorio de la Armada en San Fernando, Instituto Cartografico de Cataluña, Observatoire de la Côte d'Azur- GEMINI, Puertos del Estado, Universidad Complutense de Madrid and Universidad de las Islas Baleares-IMEDEA have participated with support of CNES, LEGOS and NOVELTIS in that campaign. This campaign has been based in the experience obtained by three previous campaigns made in March 1999 and July 2000 for TOPEX/POSEIDON and August 2002 for JASON-1 in the Cape of Begur/Llafranc/Palamos area, NE Spain. (Appendix IV)

The determination of the marine geoid by GPS catamaran technique has been one of the main objective of the campaign. This marine geoid will be used to rely the coastal tide gauge data and the off of coast Jason-1 altimeter data. The GPS catamaran has been designed at ICC taking in account the catamaran used in Senetosa/Corsica campaigns (Bonnefond et al., 2003a). Also has been used a GPS buoy with its toroidal design used at the University of Colorado at Boulder. GPS reference stations have been located at Ibiza, San Antonio and Portinatx. Data from tide gauges at Ibiza and San Antonio have been used. A spirit levelling has been made in these two places.

GPS techniques were applied to measure the geoid slope between the locations of the open-ocean altimeter measurements and the coastal tide gauges located at Ibiza and San Antonio harbours. They provide a highly accurate map of the marine geoid in the vicinity of the experiment site. In this case indirect absolute altimeter calibration is possible for any other altimetric satellite crossing the MSS, with the only requirement that tide gauges are operational during the overflight.

A secondary objective has been the Jason-1 absolute altimeter direct calibration made on June 14. The global objective is that Ibiza could be considered in the near future a Permanent Calibration Site as Senetosa and Harvest.

The contribution of the local CalVal experiment IBIZA 2003 has been essentially provide absolute calibration with possible enable separation of error sources using information from multiple in situ sensors as GPS and tide gauges. Naturally the experiment has been highly sensitive to geographically correlated errors. This experiment also applies for global studies that are more statistically significant and less sensitive to geographically correlated errors.

One purpose of this campaign was to integrate for the long term the Ibiza site in the in-situ network deployed in the Mediterranean Sea for calibrating the altimetric missions, completing thus the Senetosa and Macinaggio sites (Corsica, CNES), the Capraia island (Italy), (Fig.5). Another purpose was to describe and to understand better the gradient of the local marine geoid around Ibiza island and the physics of the oceanographic circulation in the western Mediterranean Sea.

The French consortium (POC/Noveltis) disposes of a barotropic ocean model Mog2d. Such a modelling is helpful for providing high frequency dynamics that is not resolved in the altimetric data because of the aliasing problem Starting from the Symphonie model, the french part of the MFSTEP European program, it is necessary to extend the ocean domain in order to well represent the Spanish coasts and the regional ocean and in particular to refine the Mog2d grid model nearby the Ibiza island around the tide gauges locations and more largely in the Balearic Sea. (Fig. 6).

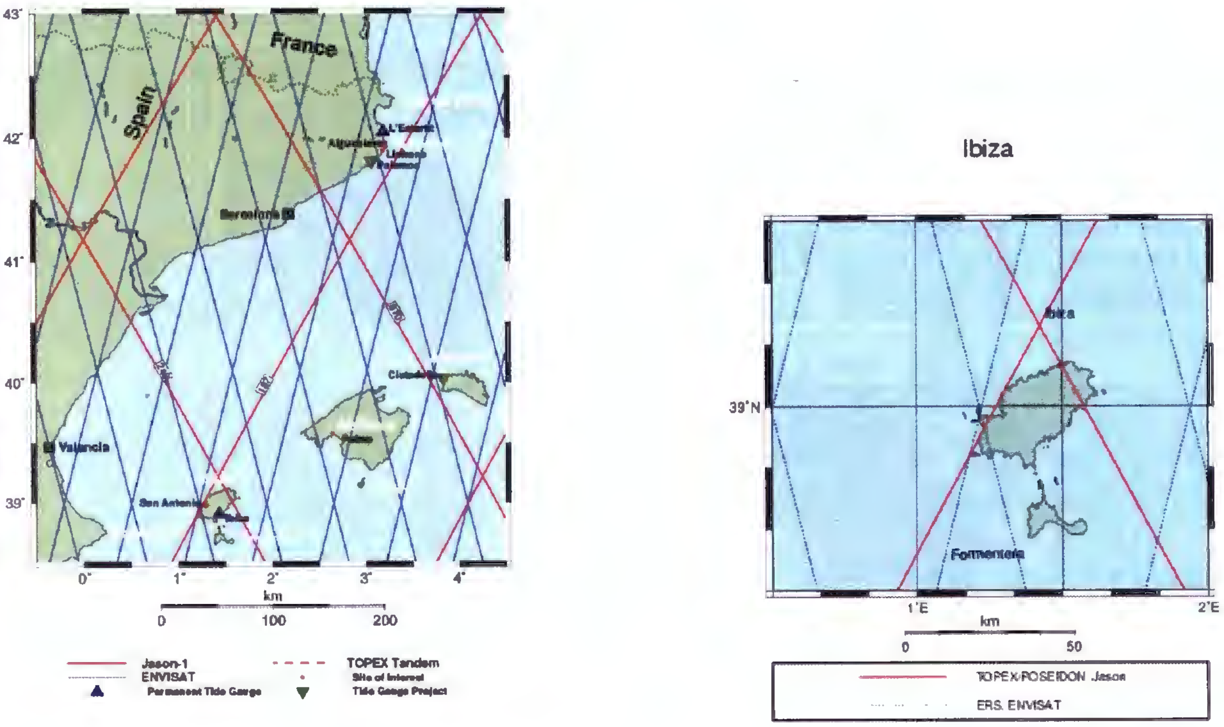


Fig. 4: Jason-1 and ENVISAT ground tracks in the western Mediterranean Sea (left) and around Ibiza island (right)

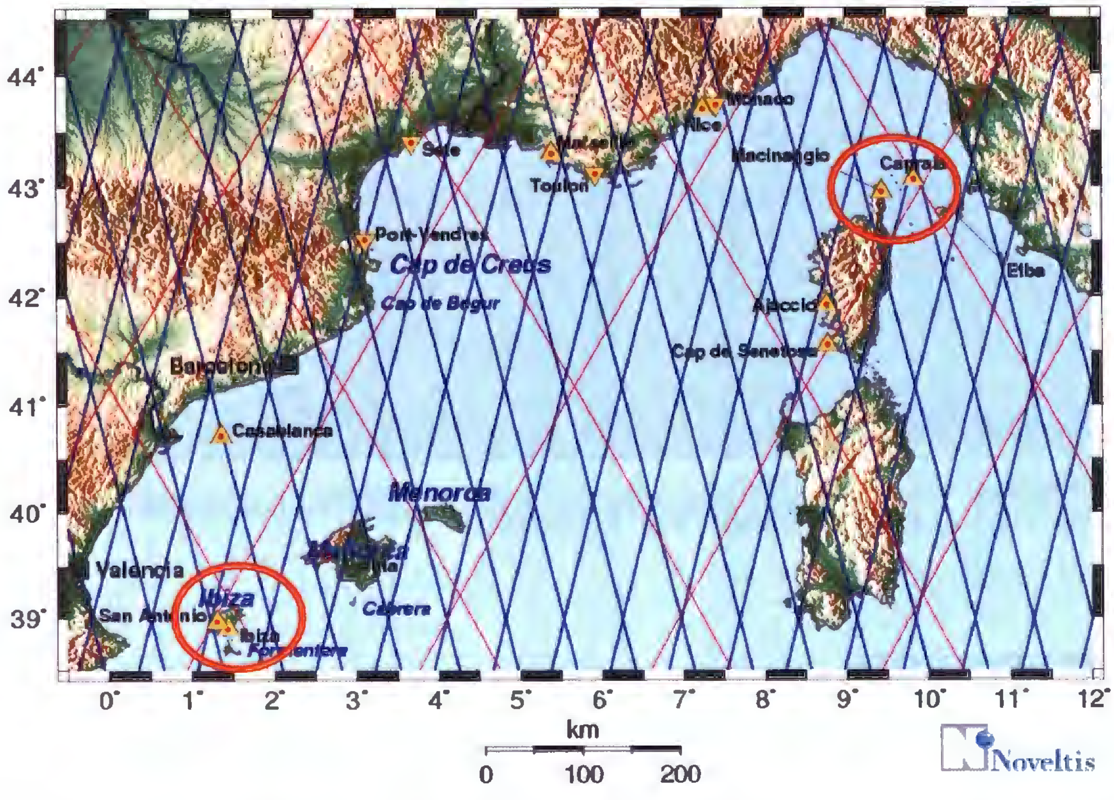


Fig. 5: Jason-1 and ENVISAT satellite passes and the observation network (triangles) sites that are geodetically referred are signalised with a triangle as for Ibiza site.

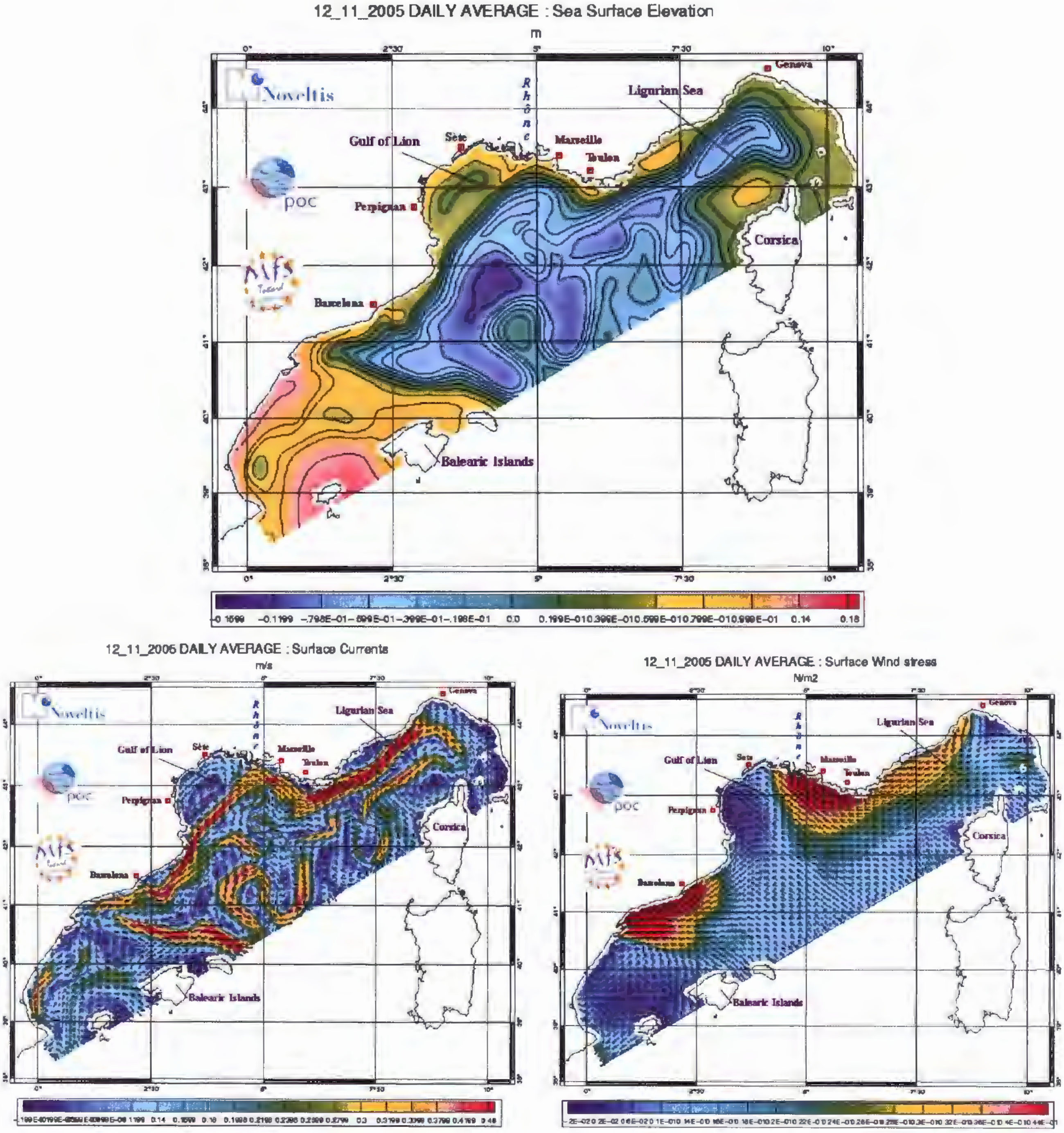


Fig. 6: Daily average of the Sea Surface Elevation computed within the MFSTEP European program (Symphonie model) (above) and two oceanographic characteristics of the region (below)

4. GPS Reference Stations

Five GPS reference stations have been placed at Portinatx, San Antonio and Ibiza (Fig. 7). The distances to the three geographical areas of mapping with the GPS catamaran were in the limit for precise kinematic processing. Two GPS systems were integrated in the GPS catamaran/Patrol Deva and one was integrated in a GPS Buoy. Tables 1 and 2 gives the characteristics of these GPS stations.

Table 1 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*	Portinax (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 lack on 11/06 from 08h09 to end of day

Table 2 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.

Fig. 7: GPS reference stations at Portinatx (left), Ibiza (center) and San Antonio (right)

5. TIDE GAUGES

Tide gauges are installed in the Ibiza (PE) and San Antonio (UIB) harbours (fig. 8a).

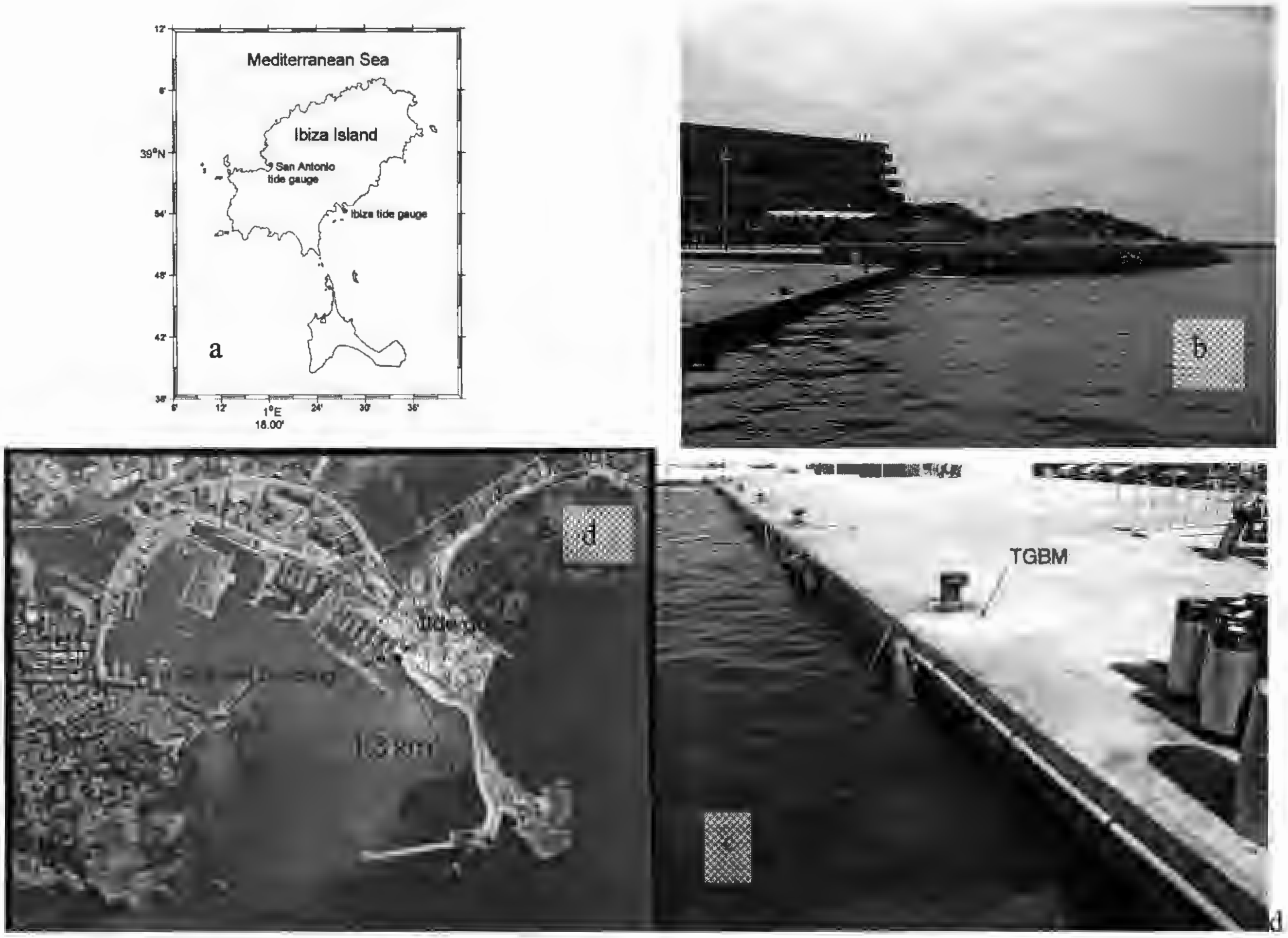


Fig. 8: (a) Location of the Ibiza and San Antonio tide gauges, (b), (c) and (d) detail of the Ibiza tide gauge location and a view from the Quick Bird satellite taken on January 19, 2005.

Puertos del Estado (Spanish harbours) installed the tide gauge station at Ibiza harbour in January 2003 (Fig. 8b,8c,8d and 8e). The station belongs to the REDMAR network, composed at this moment by 21 stations distributed along the whole Spanish waters, including also the Canary islands (http://www.puertos.es). The tide gauge also belongs to the ESEAS (European Sea Level) network. In this case an Aanderaa water level/temperature sensor (3796 A) with compensating unit for atmospheric pressure has been installed at the

Golondrinas pier (Ibiza harbour) (Figure 8). In 2004 a permanent GPS station, funded by the ESEAS – RI EU project, will be collocated with the tide gauge in a building in front of the tide gauge peer. The station coordinates are: 38°54'40.56" N, 1°26'59.46"E.

The position of the pressure sensor with respect to the TGBM (tide gauge bench mark) is –2.679 m (Figure 2, left). The sensor is installed attached to a metallic timber in such a way that is possible to remove it easily from the water for calibration, and locating it again at exactly the same position (Figure 2, right). The tide gauge zero is 0.884 m below the TGBM (a reference employed by the harbour). The Technical University of Catalonia performed an optical levelling of the TGBM during 1-2 July 2003.

The San Antonio tide gauge (Fig. 9) was deployed by the IMEDEA institute by the beginning of 2002 in the framework of the calibration and validation activities for the ENVISAT/European Space Agency (ESA) radar altimeter RA-2. From the beginning of 2003 onwards, the station has been funded by the European Sea Level – RI EU project.

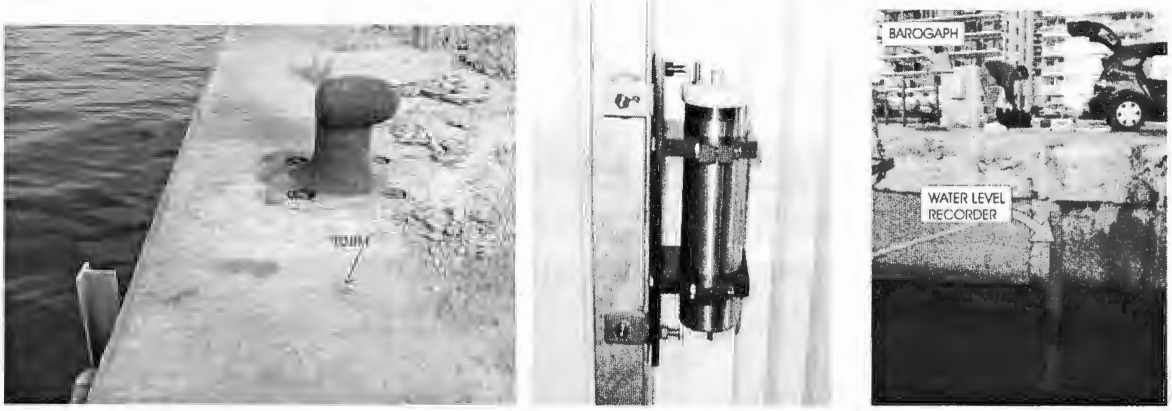


Fig. 9: Place of tide gauge and tide gauge bench mark (TGBM) (left), pressure sensor container attached to the metallic timber (middle) and the iron timber of San Antonio tide gauge with the atmospheric pressure sensor on the docks (right).

The instrument is an Aanderaa WLR 7 complemented with an Aanderaa Air Pressure Sensor 2810 installed on the dock of San Antonio harbour, a few meters away from the tide gauge. The tide gauge was installed in a water depth of about 2 meters (Fig. 10).

Deploying the tide gauge inside San Antonio harbour (Fig. 11), although not exactly located below the satellite track, has clear advantages: the deployment and data recovery is cheaper and easier (as in Ibiza9, the process of vertical referencing is simplified and more accurate, and close atmospheric pressure measurements can be easily obtained. The major disadvantage is the fact that sea level inside the harbour is in some sens corrupted, as compared with open ocean values, by the natural (seiche) oscillations of the harbour bay. However, if the system is designed to resolve the seiche oscillations (i.e. by setting the time sampling to the order of 1 to 2 minutes), they can be filtered out in the post-survey time series analysis, and the values obtained inside the harbour extrapolated to the open sea.

Bottom pressure recorder

Manufacturer:	Aanderaa
Model:	WLR7
Range:	0-700 kPa (60m)
Resolution:	0.001% of range
Calibration Accuracy:	0.02% of actual pressure

Temperature Sensor

Model:	3444
Range:	-3 to +35°C
Accuracy:	±0.1°C

Conductivity cell

Model:	WLR7
Range:	0-77 mmho/cm
Accuracy:	±0.25mmho/cm

Fig. 10: Technical characteristics of the San Antonio pressure tide gauge.

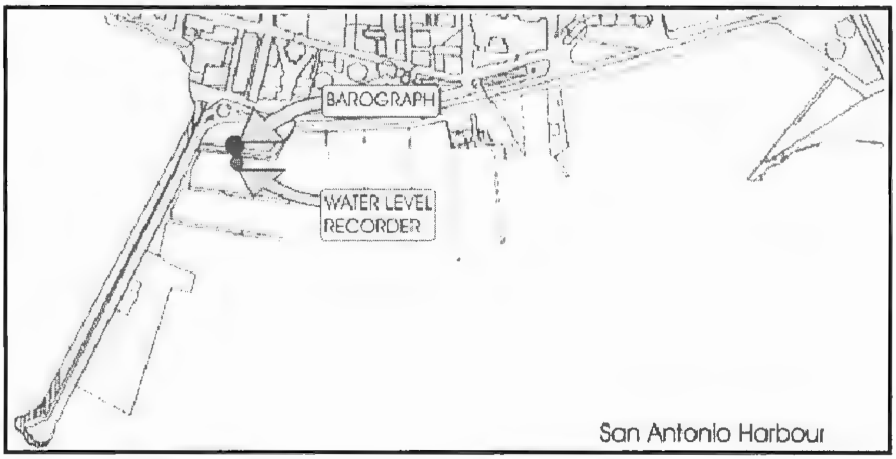


Fig. 11: San Antonio tide gauge location at the harbour.

6. SEA LEVEL DATA PROCESSING

Data from both, Ibiza and San Antonio tide gauges, have been analysed for the period with available data, with the aim of obtaining harmonic constants (table 3) and mean sea levels. This zone presents a very small tide and is characterized as microtidal, that is one of the reasons to select this area for the altimeter calibration and validation.

	San Antonio		**Ibiza**	
Period	From 30/01/2002 to 03/11/2003		From 01/01/03 to 31/12/2003	
Component	**Amplitude (mm)**	**Phase (°)**	**Amplitude (mm)**	**Phase (°)**
O1	22.3	112.15	22.2	108.43
P1	12.4	159.19	12.1	156.94
K1	34.0	156.95	38.4	168.11
M2	19.3	201.85	17.6	215.75
S2	6.5	204.18	5.7	238.70
Factor f	2.18		2.60	

Table 3.- Tidal harmonic constants in San Antonio and in Ibiza.

The tide in the Ibiza harbour area is according to the f factor value, a mixed tide mainly diurnal. Phases in the analysed components shown in the previous table, are also very similar, except for the component S2.

It is very important in the calibration campaign to have the instantaneous sea level data to compare the tide gauge data with GPS data, but the instantaneous sea level is not the same in Ibiza and San Antonio, it depends on the area, so raw data for both tide gauges have been represented to obtain the difference between sea level behaviour in each harbour.

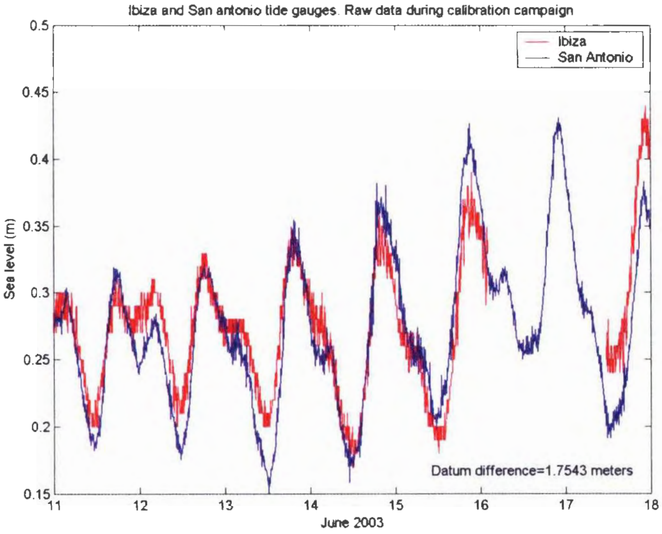


Fig. 12: raw data for both tide gauges during the calibration campaign the mean difference for the period has been subtracted for comparison.

In order to check the quality of the data of both tide gauges, especially during the dates of the campaign, a comparison has been made between both, Ibiza and San Antonio tide gauges (Fig. 12), for the period 24th of May to 20th of September. Data from San Antonio are sampled each 10 minutes. Apart from some important differences in the higher frequency data (Fig. 13, left), due to the different response of each harbour, the daily averaged values show a good agreement for this period (Fig. 13, right).

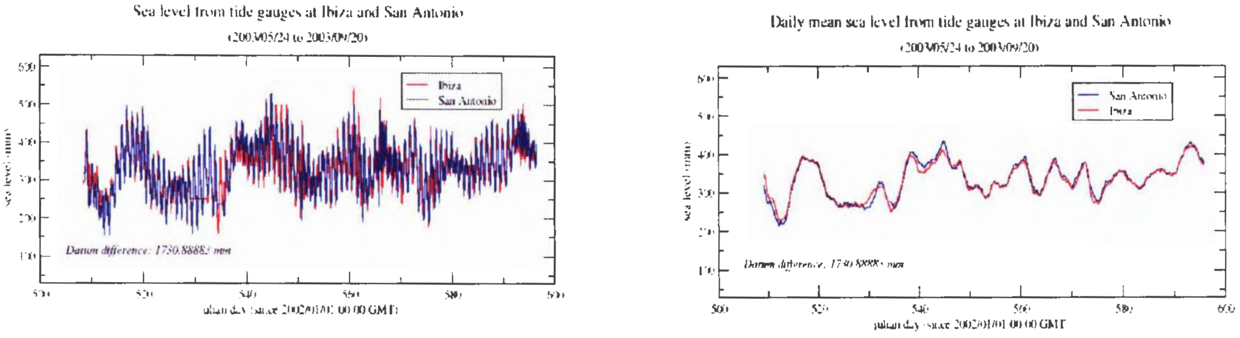


Fig. 13: Comparison between tide gauge data at Ibiza and San Antonio (IMEDEA); the mean difference for the period has been subtracted for comparison. Left: raw data (5 min Ibiza, 10 min San Antonio). Right: daily means applied to raw data.

The quality of monthly mean sea levels have been checked for the whole 2003 year at Ibiza and San Antonio, a comparison was also made with the monthly means obtained for the Valencia station (in the Peninsula coast, in front of Ibiza, fig. 14). The evolution of monthly means are due to a great extent to regional meteorological conditions, so it has to be rather similar between stations not too far away. The annual mean sea level at Ibiza for the 2003 year is 327.8 mm with respect to the tide gauge zero (from a 91% of valid data, the most important gap occurring in January).

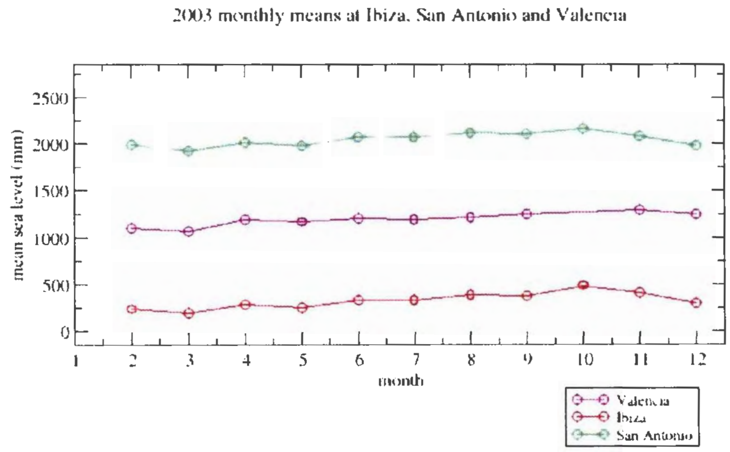
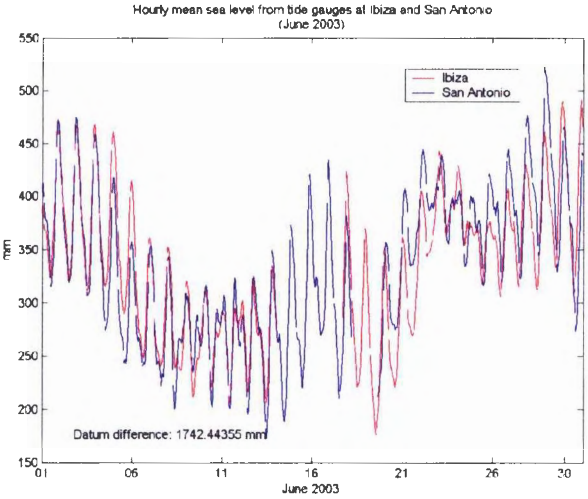


Fig. 14: Monthly means during 2003 in Valencia, Ibiza and San Antonio tide gauges agree reasonably

The calibration campaign in the Ibiza island was realized in June hence data from both tide gauges used in the campaign has been compared for the whole month (fig. 15), and they agree quite well.

Fig. 15: hourly means during June 2003 in Ibiza and San Antonio tide gauges. The mean difference for the period has been subtracted for comparison.



Once the tide gauge data have been checked to know their quality and they show the same behaviour that other tide gauges data in the same area, it can be said that they are good quality data. Then the behaviour of the tide in the calibration and validation area, is known, and tide gauge data are ready to calculate the correction for the altimeter data.

Application of tide gauges to the altimeter calibration campaigns.

The role of the tide gauge measurement in the Ibiza campaign has three main components:

-Calibration of the GPS buoy. Before and/or after calibration campaigns the GPS buoy is deployed at tide gauge locations to make direct comparisons of sea level determination.By floating the GPS buoy near the tide gauge one can find out is there are systematic errors in the GPS derived water measurement. For this it is assumed that there are no errors in the tide gauges, which is not necessarly true, but we have handmade water level measurements to compare and to look at if they matched well.

-Mean Sea Surface Mapping MSS during GPS catamaran campaign. The GPS catamaran measure the instantaneous sea level and we need to correct this measurement for the ocean tide and inverted barometer correction which is measured by the tide gauge. We can only do it if it is known the long term mean sea level at the tide gauge. Normally it is needed a tide gauge record of 18 years to determine this mean sea level well. GPS buoy measurements also provide the sea height variations due to waves.

-Using the same method described before it is then possible to do altimeter calibration for other times when there is an overflight of JASON-1 (or any other altimeter satellite) and no GPS catamaran or GPS buoys are in the water. Basically the MSS mapping provides a reference to which one can reference the new altimeter measurement. The tide gauge would then provide the time variable part of sea level. This is a cheap way of calibration and only a tide gauge on shore would be required. In a way the tide gauge would be the calibration instrument.

This method is the Indirect Absolute Calibration because a mapping is involved to map the tide gauge measurement to the ground track of the satellite. One important assumption is that the tides at the ground track of the satellite are the same as at the tide gauge but probably is not true. However one can make this error small by positioning the tide gauge close to the satellite ground track. This error is also reduced because the tides in the western Mediterranean are not big.

In fact the tide gauges have:
-advantages: works whatever the weather and 24 hours a day, few months of autonomy, no regular manpower needed except for getting data and geodetically linked to global network (ITRF).
-disadvantages: not close to altimetric measurement and possible drift of measurements which can be not linear.

7. LEVELLING

The difference of height between the tide gauges and GPS points was observed and calculated in three levelling itineraries:

a) San Antonio tide gauge - GPS in Nautical Club San Antonio
b) Ibiza tide gauge - GPS in El Corso Hotel
c) Ibiza tide gauge - GPS in Nautical Club Ibiza

The spirit levelling took place 1-2 of July 2003 and 3-4 of December 2004 by an equipment of the Technical University of Catalonia

It was used the classical high precision automatic level Zeiss-Ni1 (with parallel plate micrometer), for itineraries a) and b), and an automatic digital level Leica wild NA2002 for c) (Fig. 16). The method of observation in all the cases was double run levelling with observation in the middle point to avoid systematic errors.

Fig . 16: Level Nil (left) and Digital Level NA2002 (right)

In order to detect bounder and accidental each line was observed twice by the double run method and the observation of control points were used. The loop misclosures in any case exceeded 1 mm.

In the first leveling, three points were taken as control points corresponding to the top of the fire hydrant (Fig. 17b) located next to the pier 5 of the Club Naútic Sant Antoni, to nail in bollard nº 15 (Fig. 17a)), and a nail in bollard between berth 268 and 269 (Fig. 17c).

a b

Fig. 17: Control points: bollard n° 15, fire hydrant and bollard between 268 and 269

In the second leveling the control point was established in the milestone ZMT n°47 (Fig. 18 right)). The geopoint and the tide gauge are represented in the Fig. 18 left.

Fig. 18: Geopoint with tide gauge (left) and ZMT n° 47 (right)

In the last one, the first control point was the mark NGZ 426 placed on the wall of the building of the offices of the Club Nautic. Other control points were established on the terraces. On the top of the building the heights in some marks were observed: the CGCCT mark, Corner of the base of GPS, Base antenna of GPS, and the corner of the building aligned on nail NGZ-426.

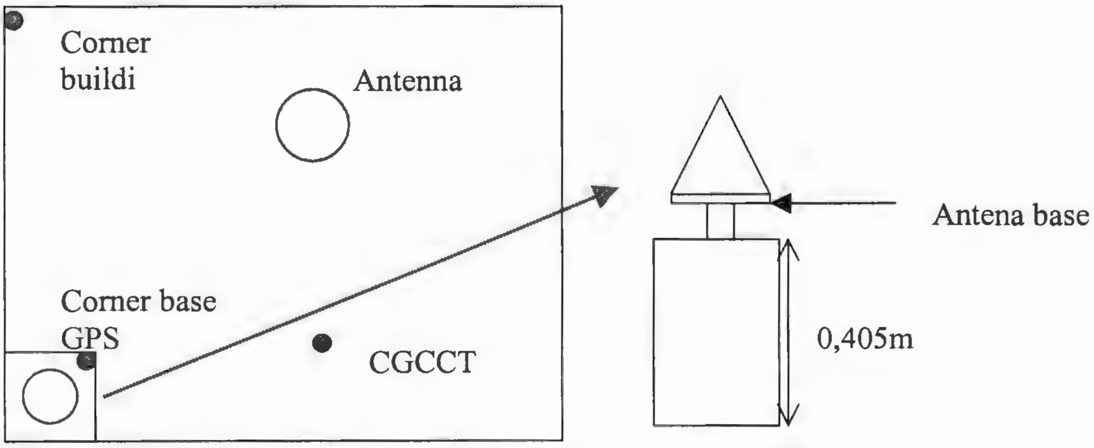


Fig. 19: Position of points on Nautical Club building (left) and detail of antenna GPS (right)

The results are shown in the tables 4-5-6, where the height of the control points and the GPS stations are referenced to the top of tide gauge (Fig. 19).

Table4. Final heights of San Antonio tide gauge - GPS in San Antonio Nautical Club itinerary

Point	**Height (m)**
Tide gauge	0,0000
Bollard 15	1,4660 ± 0.0008
Bollard 268-269	1,0129 ± 0.0008
Fire hydrant	2,6817 ± 0.0008
GPS station	8,2431 ± 0.0008

Table 5. Final heights of Ibiza tide gauge - GPS in El Corso Hotel itinerary

Point	**Heigh (m)**
Tide gauge	0,0000
Geopoint	0,0001 ± 0.0008
ZMT nº 47	3,1868 ± 0.0008
GPS Trimble station	10,5805 ± 0.0008
GPS Leica station	10,5631 ± 0.0008

Table6. Final heights of Ibiza tide gauge - GPS in Ibiza Nautical Club itinerary

Point	**Height (m)**
Tide gauge Ibiza	0,0000
Geopoint NGZ426	0,8942 ±0.001
GPS antenna (base)	10,2566 ±0.001
GPS antenna (south corner on top)	10,1452 ±0.001
CGCCT point	9.4252 ±0.001

The above schedules show the reference plane (Fig. 20 and Fig. 21) taken as origin of heights.

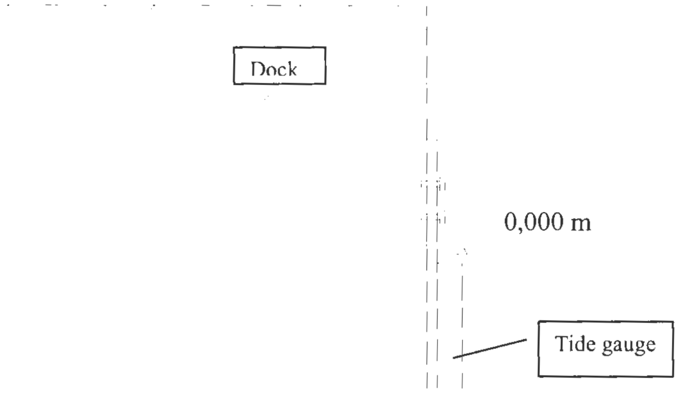


Fig. 20: Height reference in Tide gauge of San Antonio

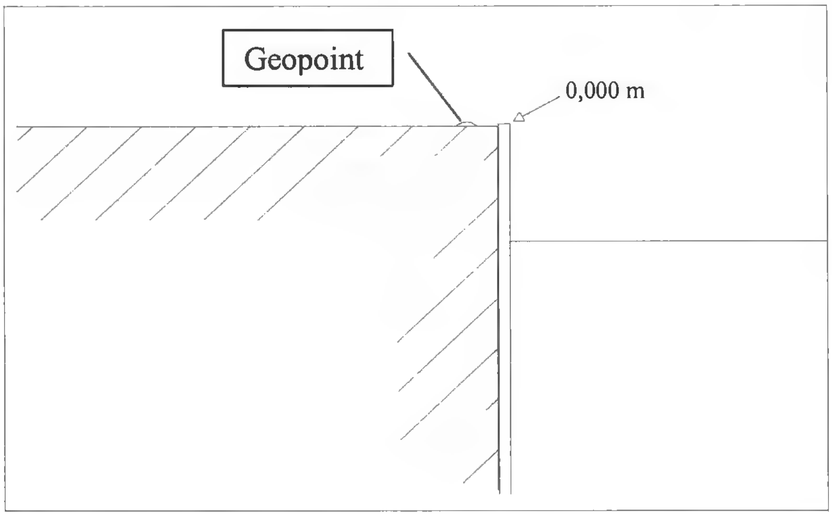


Fig. 21. Height reference in Tide gauge for second and third levelling itineraries in Ibiza

A levelling made on December 3, 2004 allowed to make a levelling (Fig. 22) with the Digital Level NA2002 between the TGBM (Tide Gauge Bench Mark) near the Ibiza tide gauge and the GPS station placed in the roof of the Director's building of Marina de Botafoch (Fig. 23). The CGPS belongs to Puertos del Estado.

Fig. 22: GPS at the Ibiza Direction building in the Puerto Deportivo de Marina de Botafoch and tide gauge

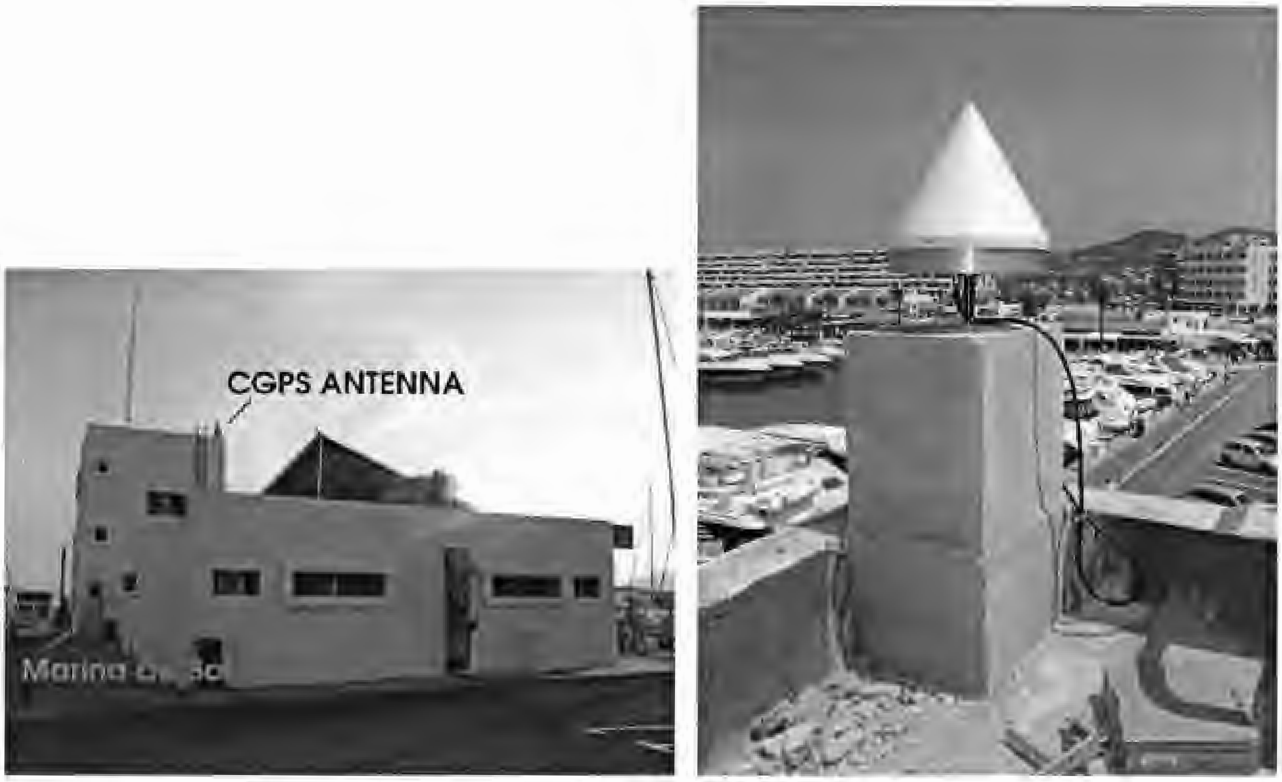


Fig. 23: Location of the GPS in the Director's building at Marina de Botafoch in Ibiza

8. GEODETIC MARKERS

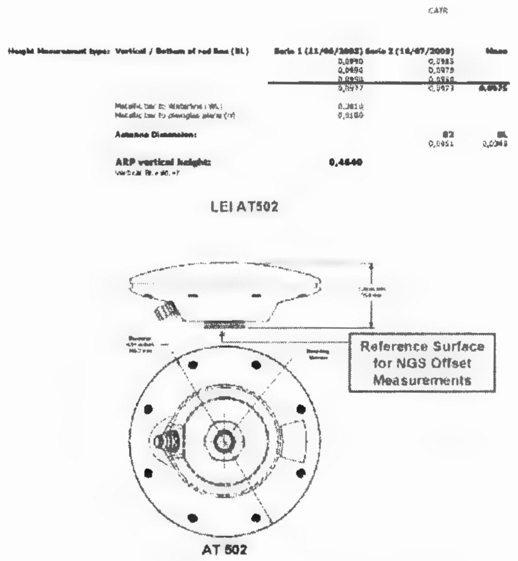


Fig. 24: GPS at the right on the Catamaran (CATR)

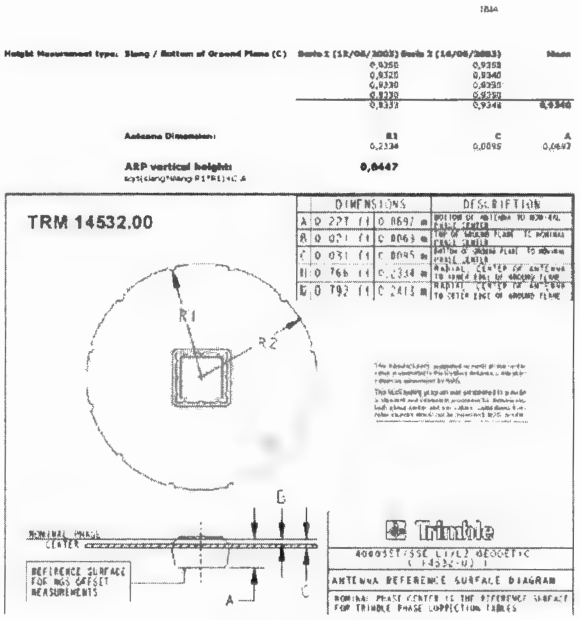
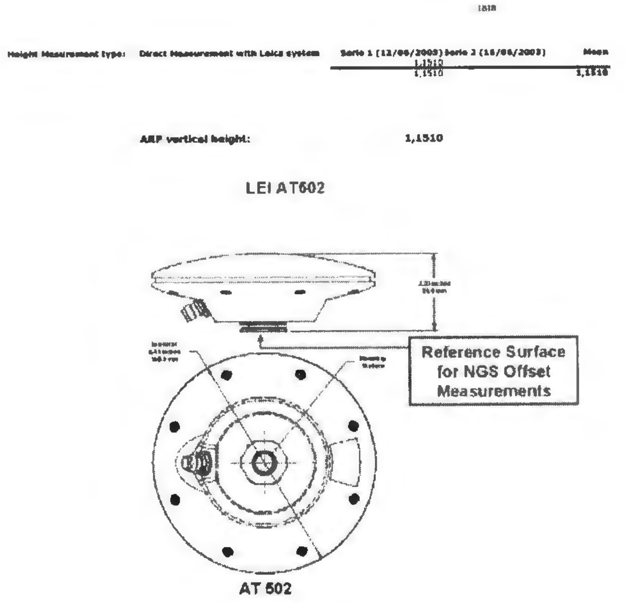


Fig. 25: IBIA antenna at Ibiza hotel El Corso (IBIA)



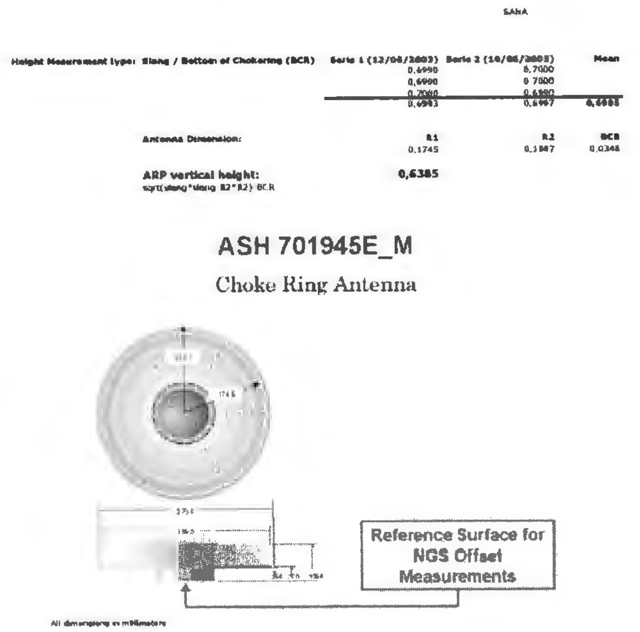
IBIB

Height Measurement type:	Direct Measurement with Leica system	Serie 1 (12/06/2003)	Serie 2 (16/06/2003)	Mean
		1,1510		
		1,1510		1,1510

ARP vertical height: 1,1510

LEI AT602

Fig. 26: GPS antenna at Portinatx



SANA

Height Measurement type:	Slang / Bottom of Chokering (BCR)	Serie 1 (12/06/2003)	Serie 2 (16/06/2003)	Mean
		0,6990	0,7000	
		0,6990	0,7000	
		0,7000	0,6990	
		0,6993	0,6997	0,6995

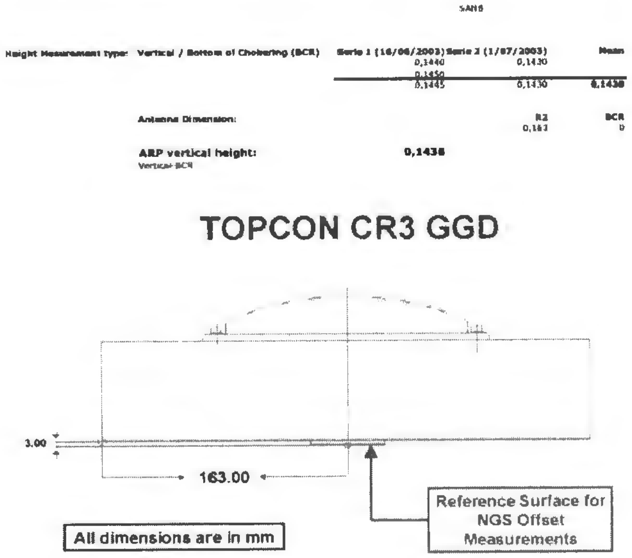
Antenna Dimension:	R1	R2	BCR
	0,1745	0,1847	0,0348

ARP vertical height: 0,6385
sqrt(slang*slang-R2*R2)-BCR

ASH 701945E_M

Choke Ring Antenna

Fig. 27: GPS antenna at the roof of San Antonio Nautical Club (SANA)



SANB

Height Measurement type:	Vertical / Bottom of Chokering (BCR)	Serie 1 (16/06/2003)	Serie 2 (1/07/2003)	Mean
		0,1440	0,1430	
		0,1450		
		0,1445	0,1430	0,1438

Antenna Dimension:	R2	BCR
	0,163	0

ARP vertical height: 0,1438
Vertical-BCR

TOPCON CR3 GGD

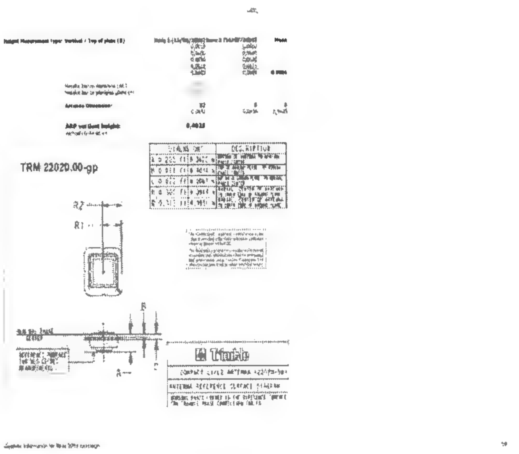
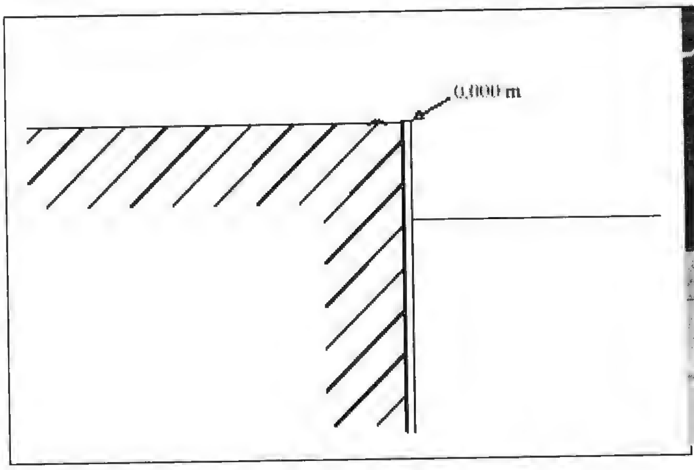
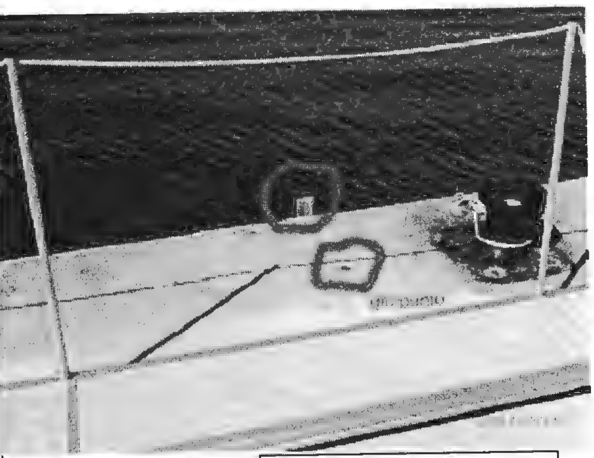


Fig. 28: GPS antenna at the roof of the San Antonio Nautical Club

Ibiza Tide Gauge

Reference	Height	Total
Pressure Sensor	-0,8840	
Reference Point (top of metallic bar)	0,0000	
IBIA	10,5805	**11,4645**
IBIB	10,5631	**11,4471**
IBIC (geopunto)	0,0001	**0,8841**





Reference	Height	Total
Pressure Sensor	-1,9980	
Reference Point (top of second metallic bar)	0,0000	
SANA	8,2431	**10,2411**
SANB	8,2320	**10,2300**

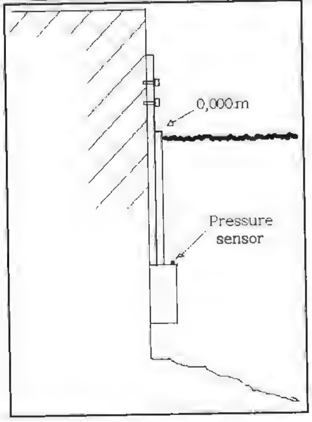


Fig. 29: Ibiza tide gauge

San Antonio Tide Gauge

Reference	**Height**	**Total**
Pressure Sensor	-1,9980	
Reference Point (top of second metallic bar)	0,0000	
SANA	8,2431	**10,2411**
SANB	8,2320	**10,2300**

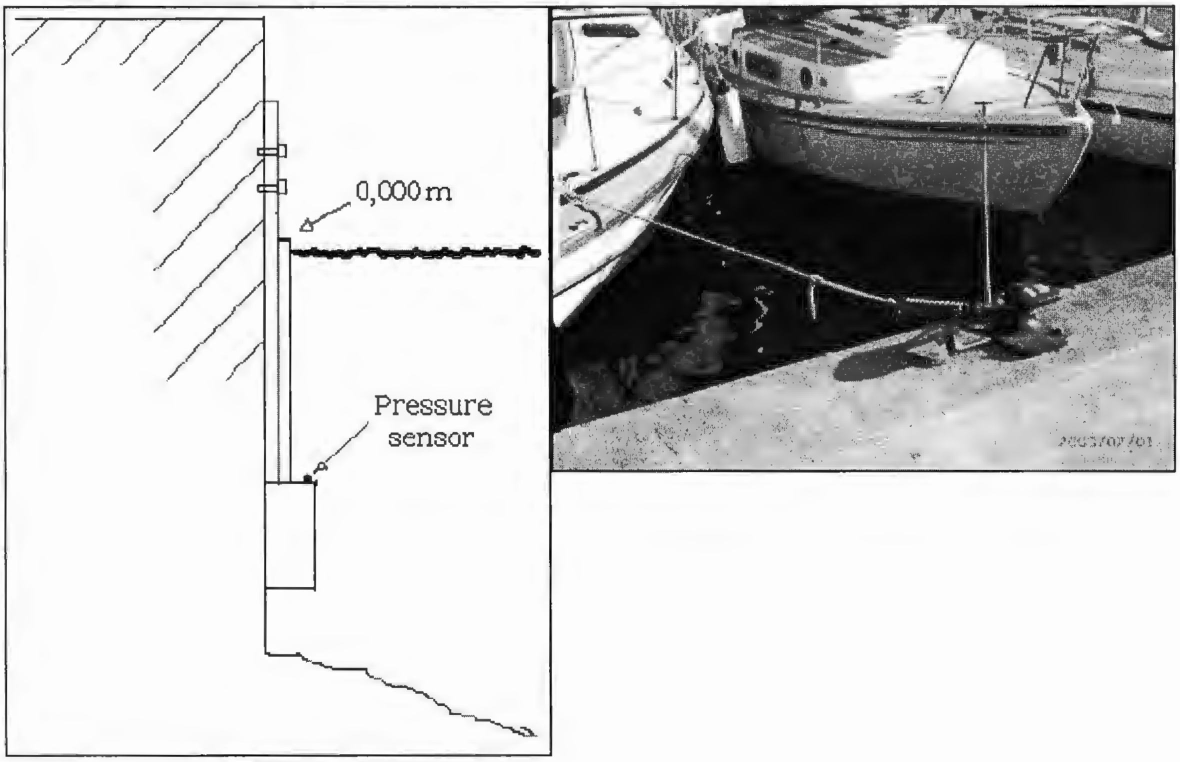


Fig. 30: San Antonio tide gauge

9. GPS BUOYS

The toroidal GPS buoy used in the Ibiza calibration campaign was designed and performed at the ICC (Fig. 31) based on the original design of the University of Colorado at Boulder. The objectives of this light wave-rider GPS buoy were to provide instantaneous geocentric sea level measurements at different JASÓN-1 subtrack points.

The design was based on the requirements described below:
-The dome of the buoy must protect the GPS antenna from the sea water and from any eventual accident.
-The dome must be of a kind of material that allows the reception of the GPS signals with a minimum disturbance.
-The buoy must be not very large and heavy to facilitate the transport and its manipulation.
-The buoy must be constructed in such a way that it was possible to use it again in future altimeter campaigns.
-The cable connection between the antenna inside the dome and the receiver outside must minimize the interferences with the free movement of the buoy in the water and also the delay of the electronic signal to arrive to the receiver.
-The buoy must be an stable structure which guaranties: first, a constant distance between the top of the choke ring antenna and the free waterline mark; second, the antenna phae center must be always perpendicular to the free waterline; third, it must assure not deformation of its structure even in bad sea conditions with big waves.

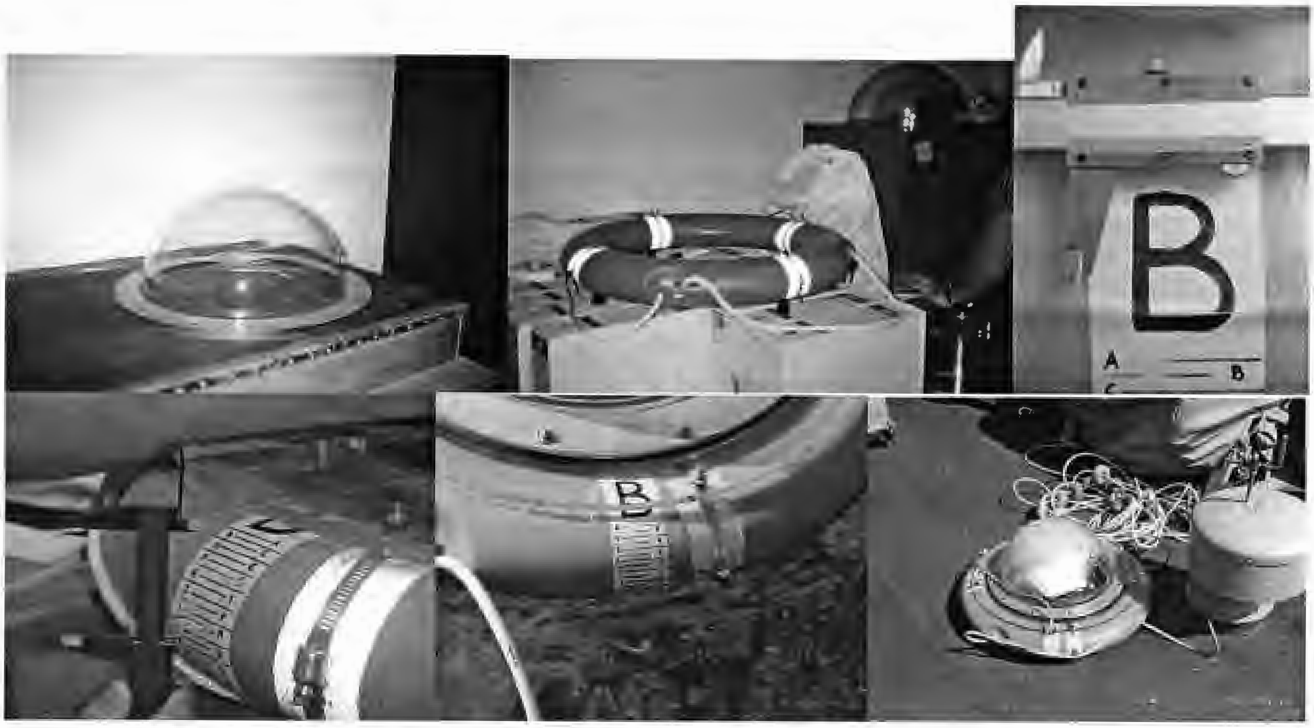


Fig. 31: Sequence of ensambling the wave-rider GPS buoy used in the 2000 experiment, calibration and the buoy on board of the boat.

With respect the absolute direct altimeter calibration, the GPS buoys have:
- advantages: very close to altimetric measurements, geodetic link at the time of overflight (differential GPS) and no drift in the data acquisition.
- disadvantages: need on site manpower, difficult to realize with bad weather conditions or during night and measurements sensible to sea state (tilt of the antenna) and necessity of several GPS campaigns to be the results statistically significant.

10. GPS CATAMARAN

A Catamaran (Fig. 32) equipped with two GPS antennas to perform continuous sea level measurements at a convenient velocity was builded at the Cartographic Institute of Catalonia using two very stable wind-surf boards and a metallic structure, made by one Spanish company located in Valls (Tarragona), on which the antennas have been fixed following the Senetosa design (Bonnefond et al., 2003a).It arrived to Ibiza inside a van carrying also a great part of the instruments to be used in the campaign, by a ship making Barcelona-Ibiza. Two radomes for protection were placed above the two GPS antennas, a Trimble (CATL), and a Leica (CATR), (Fig. 33). 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. This system presents a good stability and allows to be tracked by a boat, in this campaign the Patrol DEVA P29 (Fig. 34) from the Spanish Navy at a convenient speed without stopping GPS data acquisition. Instantaneous sea level measurements were made in the harbours of San Antonio and Ibiza while DEVA was pulling the catamaran near the GPS buoy, with a Trimble antenna and receiver, and the tide gauge. Measurements at three geographical areas around the Ibiza island at the North, SW and SE covering wide areas that include JASON ascending and descending groundtrack, in order to determine the local geoid slope of the marine geoid and in consequence allowing to determine the sea level from offshore to the area where altimetric measurements are not corrupted.

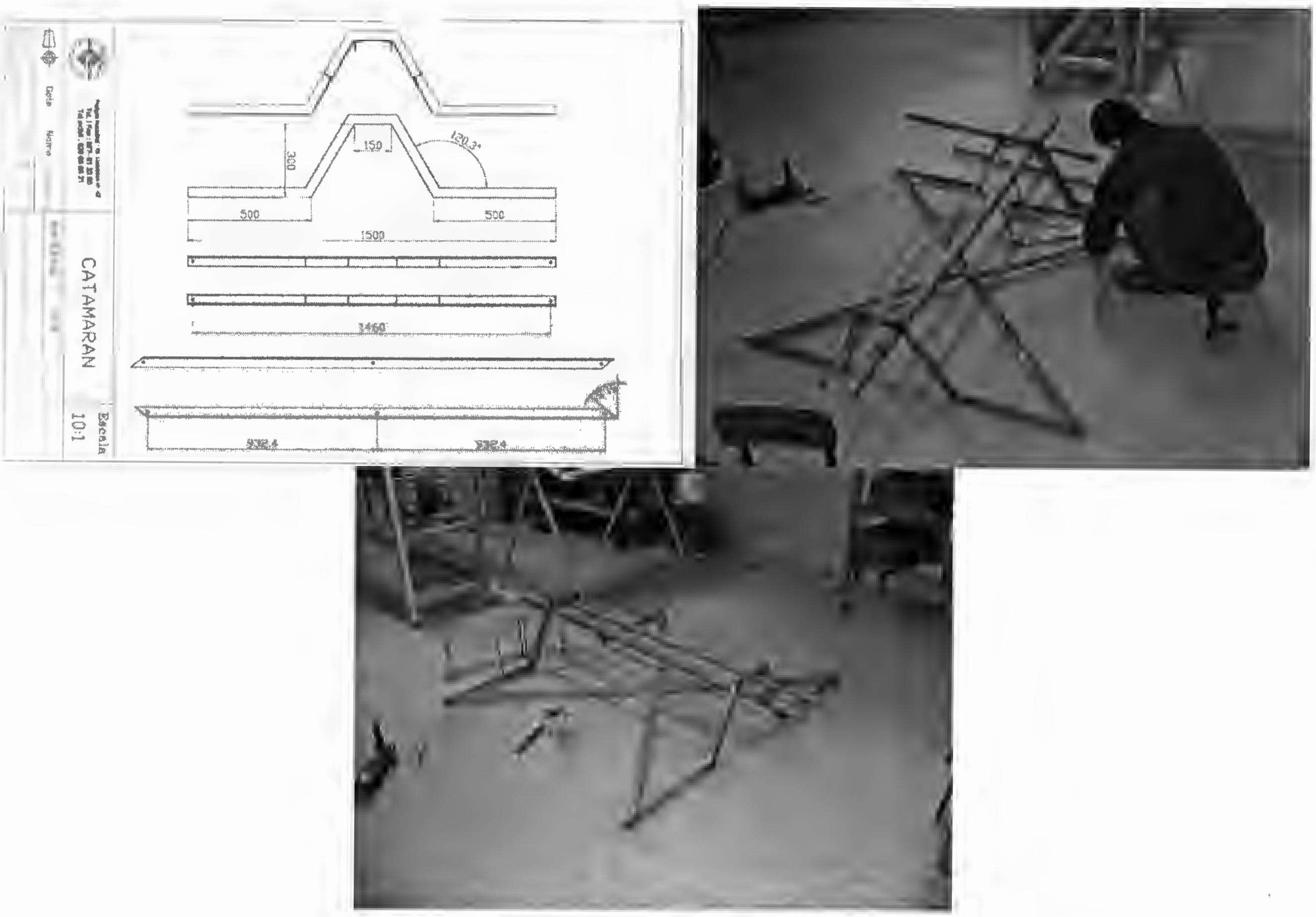


Fig. 32: Building the Catamaran metallic structure at ICC

Fig. 33: Implementing the GPS antennas at San Antonio harbour

Fig. 34: Set of pictures showing the design and use of the GPS catamaran

11. STATIC GPS PROCESSING

The GPS data processing can be divided into two parts: first we need 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 will define the datum for the kinematic processing of the GPS catamaran and buoy data but will be also used to determine the absolute sea level heights derived from tide gauges data.

Reference Station Analysis

OCA-GEMINI Solution

The reference stations are processed using the GAMIT (King and Bock, 2000) and GLOBK (Herring, 2002a) suites developed at the Massachusetts Institute of Technology. Details on the GAMIT/GLOBK processing and standards can be found in Watson et al. (2003).

The GPS station processing has been carried out in two stages: we have used the GAMIT "Relax" mode for the reference stations (SANA, SANB) with antenna-compatible IGS standards and the GAMIT "Baseline" mode for the others (IBIA, IBIB, and PORT).

For the two reference stations processed in the GAMIT "Relax" mode, a regional network based on the most accurate GPS stations of the EUREF network has been chosen (Fig. 35)): Ajaccio and Grasse (France) - Cagliari, Matera and Medicina (Italy) - Ebre and San-Fernando (Spain) - Wettzell (Germany). With six daily solutions the weighted root mean square (wrms) values for SANA and SANB were 3.8 mm and 2.4 mm.

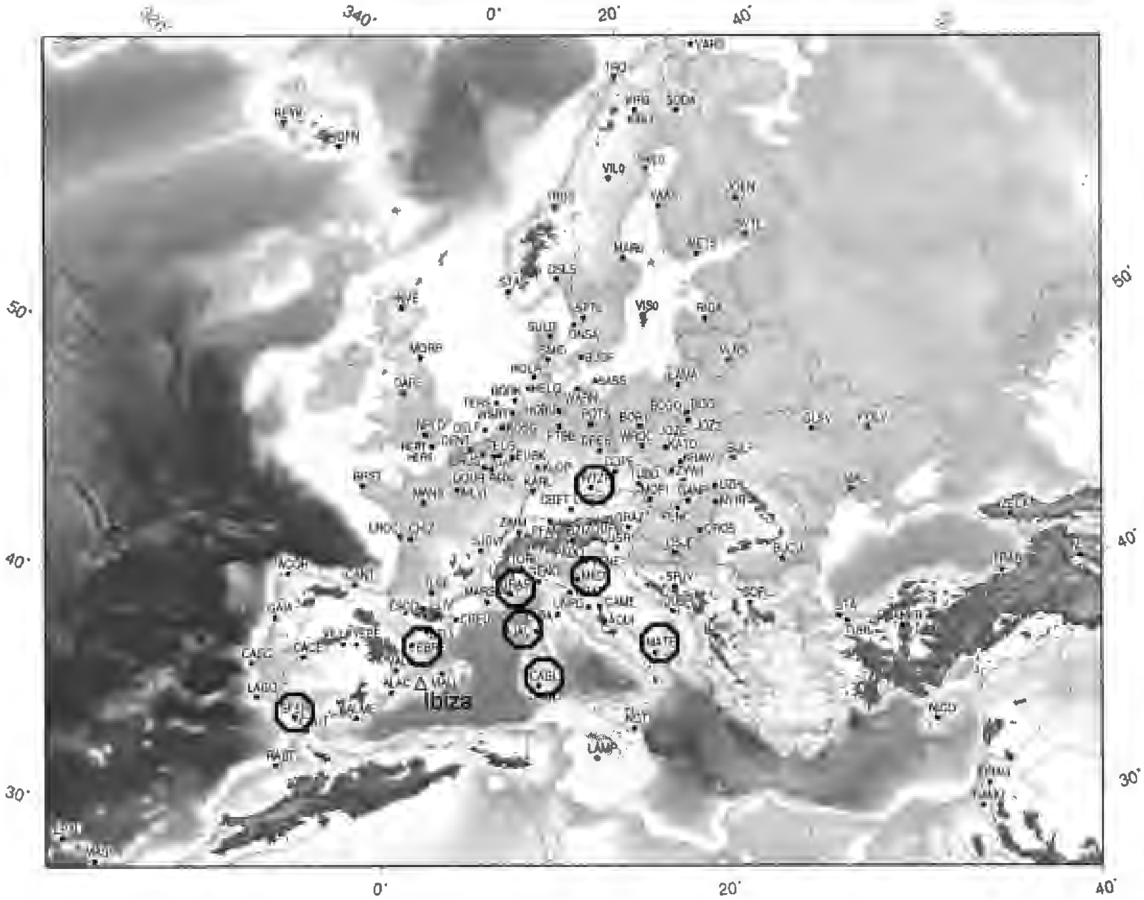


Fig. 35: Network used for the GAMIT Relax mode for SANA and SANB determination (from Mar. Geod., 2004)

SANA and SANB were then fixed and the three other stations determined using the GAMIT "Baseline" mode to reduce the impact of the heterogeneous antenna types. With four daily solutions the weighted root mean square values for IBIA, IBIB and PORT were 5.0 mm, 3.5 mm and 18.2 mm. The large rms for PORT is due to a linear trend that remains unexplained at the time of writing. However, because this station is not used as reference station either for kinematic or for tide gauges absolute positioning, the poor determination will have a very small impact.

In order to estimate the quality of the local network used during this campaign we have compared the height differences with the optical levelling (Tables 4 and 5). The very good agreement (Table 8) for the reference station (2 mm) and the relatively good agreement between the other stations (5 mm for IBIA-IBIB) make us confident as to the quality of the Ibiza network. Cartesian coordinates of the GPS stations are given in Table 9 at the epoch 2003.456 as well as their heights above GRS80 ellipsoid (semi major axis of 6378137 m and an inverse flattening of 298.257222101).

ICC Solution

The Cartographic Institute of Catalonia estimated the coordinates of the 5 GPS stations placed in Ibiza (IBIA, IBIB, SANA and SANB) using Bernese v4.2 software. The strategy followed by ICC involved computing, for every session, baselines from 3 GPS permanent stations of the European Reference Frame network (EUREF). These stations were Mallorca (MALL), Observatori de l'Ebre (EBRE) and Alacant (ALAC) to each Ibiza station.

The reference system used has been ITRF2000 epoch 2003.45. Software used for computing static baselines is Bernese v4.2. The coordinates of EBRE, MALL and ALAC stations have been obtained from weekly solution published by EUREF, which correspond to the week of data collection (file Eur12227.snx). These coordinates are:

For ALAC	X = 5009051.1991	Y = -42072.2259	Z = 3935057.7019	(m)
For MALL	X = 4919369.4626	Y = 225499.8332	Z = 4039849.7957	(m)
For EBRE	X = 4833520.1639	Y = 41537.0769	Z = 4147461.5125	(m)

For ALAC, antenna phase centre used (TRM29659.0) are 0.110 m for L1 and 0.128 m for L2. No phase centre variations were available. Antenna height is 3.305 m.
For MALL, antenna phase centre used (TRM29659.0) are 0.110 m for L1 and 0.128 m for L2. No phase centre variations were available. Antenna height is 0.000 m.
For EBRE, antenna phase centre used (TRM29659.0) are 0.110 m for L1 and 0.128 m for L2. No phase centre variations were available. Antenna height is 0.000 m.

Coordinates for the 5 GPS Ibiza stations were obtained as a result of a network adjustment (using GeoTeX software, developed by ICC) combining all baselines computed by Bernese software and fixing EUREF stations coordinates.
As stated before, the height differences between station pairs SANA-SANB and IBIA-IBIB were also determined by leveling, and results were in good agreement The comparison of the GPS height component obtained in the ICC computation with differences obtained by leveling can be observed in Table 8.

ROA Solution

San Fernando Naval Observatory (ROA) analysed the data files produced by the static GPS station deployed at San Antonio, Ibiza and Portinatx, by using the GIPSY-OASIS II software, developed by the Jet Propulsion Laboratory (JPL). The strategy used was the precise point positioning approach (PPP). In such strategy orbits, polar motion, earth orientation parameters, and satellite clocks behavior files are issued by the JPL. The non-fiducial approach has been chosen. Each station's daily data file is processed independently from the rest of the

set of the station data files. Once the solution has been obtained in the non fiducial reference frame, a Helmert seven parameters transformation is applied in order to align it with the ITRF2000 reference frame. Transformation parameters are also issued by the JPL analysis center. In such a way the solution errors are to the same order of magnitude of a conventional network analysis approach. Ambiguities have not been fixed.
Comparison

The differences in planimetry are below 3-4 mm, but a 29 mm offset was detected in height for the ICC solution (Table 7). Although the reason for the offset is not clear, it may be due to the fact that the reference frames used in the ICC and GEMINI solution were not exactly the same. As mentioned before, ICC used the EUREF combined weekly solution for week 1222 (Eur12227.snx file), while GEMINI used the primary combination of all solutions also published by EUREF (ITRF2000_EUROPE.SSC file). Comparing the station coordinates used by GEMINI of these two files (transformed to epoch 2003.45), some height differences were found. For example, SFER station showed a height discrepancy of 30 mm, EBRE 12 mm and CAGL 16 mm. A possible explanation may be the high constraints (1 mm level) that EUREF applies to some fiducial stations (WTZR, MATE...) in its weekly combined solution, possibly creating an internal inconsistency within the overall frame. Comparison with leveling of the solutions is shown in Table 8.

Table 7 Height differences for GPS stations between ICC, ROA and GEMINI solutions

Markers	**GEMINI-ICC (m)**	**GEMINI-ICC – mean (m)**	**GEMINI-ROA (m)**
IBIA	0.028	-0.001	0.004
IBIB	0.033	0.004	0.011
PORT	0.025	-0.004	0.012
SANA	0.028	-0.001	-0.002
SANB	0.032	0.003	0.001
	mean = 0.029		

Table 8 Height differences between GPS results and leveling

Marker1->Marker2	**δH GPS (m)**			**δH Leveling (m)**	**Difference Leveling – GPS (m)**		
	GEMINI	ICC	ROA		GEMINI	ICC	ROA
SANA-SANB	-0.013	-0.017	-0.016	-0.011	+0.002	+0.006	+0.005
IBIA-IBIB	-0.012	-0.017	-0.019	-0.017	-0.005	0.000	+0.002

As the altimetry satellite orbits are computed in the ITRF2000 reference frame, for the catamaran trajectory computations the IRTF2000 realization was used (GEMINI solution, Table 5) instead of using the EUREF realization (ICC solution)

Table 9 Cartesian coordinates and heights above GRS80 ellipsoid at epoch 2003.456

Marker	**X (m)**	**Y (m)**	**Z (m)**	**H (m)**
SANA	4 963 596.226	112 798.208	3 990 492.996	57.438
SANB	4 963 597.316	112 793.093	3 990 491.772	57.425
PORT	4 953 996.022	130 706.294	4 001 814.258	76.430
IBIA	4 968 004.124	125 818.741	3 984 658.110	60.311
IBIB	4 968 002.892	125 818.607	3 984 659.621	60.299

12. KINEMATIC GPS PROCESSING

The kinematic solutions are based on high rate GPS data (1 Hz). The mobile receivers (Catamaran and buoy) ellipsoidal heights are solved relative to the coordinates of the reference stations chosen in the previous section (OCA-GEMINI solution). This processing was carried out independently by ICC (POSGPS Software) and

OCA-GEMINI (TRACK software).

OCA-GEMINI Solution

The kinematic solution has been processed using TRACK software developed at MIT (Herring 2002b). Details of the TRACK processing and standards can be found in Watson et al. (2003). In order to reduce the impact of distance in the kinematic GPS processing, SANA, IBIB and PORT were chosen as reference stations (fixed) and CATL and CATR were processed independently. IBIB has been chosen instead of IBIA because it was equipped with the same antenna/receiver as CATR. However, there were large data gaps for the Leica receiver (CATR) and also lots of satellite lost, so the solution was very difficult to process and results were very uncertain because of too few fixed ambiguities. We then decided to use only the CATL solution for processing the GPS sea level map.

ICC Solution

For computing GPS kinematic sessions ICC used POSGPS v4.02 software, from Applanix. The computation of each trajectory was done in three steps: a forward filtering (positive in time), a backward filtering (negative in time) and a final combination of the two previous processes (smoothing), assigning weights at each epoch according to certain quality parameters. This software also has the ability to combine different solutions computed from several GPS permanent stations.

In this way, two preliminary quality controls for the estimated trajectory can be done:

1. Differences between the forward filtering process solution and the backward filtering process solution (nearly independent),
2. Agreement between all trajectories computed using different GPS reference stations.

The strategy adopted in the kinematic processes was the following: for each kinematic receiver (buoy or catamaran), a set of trajectories was computed from 3 or 4 different GPS permanent stations (IBIA, IBIB, PORT, SANA or SANB). The two best trajectories (determined by the quality controls explained before) were combined to obtain a final solution. The combination uses weights that the software assigns to each one, depending on some internal quality parameters (number of satellites, ambiguities fixed, distance from rover to reference station, standard deviation...).

13. CONCLUSIONS

The main objective was to test the value of Ibiza Island as a possible permanent calibration site in the Western Mediterranean Sea, to complement to the Corsica/Senetosa site. Results from the 2003 campaign, with a technical contribution on the design of the GPS buoy and GPS catamaran, indicate the convenience of including this site in the network of altimeter calibration sites.

However, this will need the carrying out of a few more optimised campaigns with very high geodetic quality GPS equipment deployed at more suitable sites in order to avoid the long distances of about 20/30 km GPS-area of mapping - limiting the possibilities of the kinematic analysis to process the huge amount of GPS data.

Levelling the marine sea surface using a GPS catamaran proved to be useful in defining the geoid gradient between the coast and offshore area. It allowed to acquire a comprehensive GPS sea level data set, dense enough in time and space, to map the local marine geoid.

A complete description of the IBIZA 2003 data processing, analysis and results, can be seen in Marine Geodesy, vol. 27, December 2004, pp. 657-681, from J.J. Martinez Benjamin, J.M. Davila, J. Garate, P. Bonnefond et al., 'Ibiza Absolute Calibration Experiment: Survey and Preliminary Results'

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APPENDIX I

PLANNING

Previous days

Meetings at the ICC preparing the logistics of the Ibiza campaign (Jose, Jorge, Yves, Eric, Miquel Angel, Julia, Marta, Miriam, Ana, Sergio, Amparo, Maria Isabel, Josep, Marina, Juan Jose)
Preparation logistics Patrol Deva and permission from the Spanish Navy (Jose, Jorge)
Preparation of the GPS catamaran and the GPS buoy at the ICC (Miquel Angel)
Preparatory visit to Ibiza at the locations of Ibiza, San Antonio and Portinatx (Juan Jose)
Go to rent the van in Barcelona (Juan Jose, Jaime)

Monday 9 June

15:00 Arrival to Ibiza and renting a car (Juan Jose, Amparo)
15:00 Go to ICC to load the van with all the instruments for the campaign (Jaime, Marta, Miriam, Ana)
17:30 Load the van in the Transmediterranea ship Barcelona-Ibiza (Jaime)
18:00 Pascal arrives to Ibiza airport and rendez-vous with Juan Jose and Amparo
18:20 Arrival to El Corso hotel in Ibiza. Visit to the tide gauge in the harbor. Selection of the place for the GPS reference station. Discussion about how to make the levelling (Pascal, Amparo, Juan Jose)
19:20 Pascal and Juan Jose travel to San Antonio and arrival to the hotel Es Pla.
20:00 In Barcelona board in the ship to go to Ibiza (Jaime)
20:30 Inspecting the San Antonio harbor, the location of the tide gauge and the Club Nautico and its TOPCON GPS reference station in the roof.Looking for the place of the other GPS refernce station carried from Grasse by Pascal.
22:15 Arrival to the El Corso of Miriam and Ana after flying from Barcelona to Ibiza.

Tuesday 10 June

6:00 Arrival to Ibiza harbor of the Transmediterranea ship with the van and the naterial (Jaime)
7:00 Arrival of the van to the El Corso hotel (Jaime)
10:00 Arrival of Pascal and Juan Jose to El Corso. Waiting the hotel Director for permission to the GPS installation. The permission is given.
12:30 Arrival to El Corso hotel of Sergio after flying from Barcelona to Ibiza.
12:35 The GPS Reference station is installed. It is composed of two GPS antennas and receivers and are located in the roof at a level of a first floor room. Visit the tide gauge in the Ibiza harbor very close to the hotel.
16:30 Travel to Portinatx to install a GPS reference station. Proof to see how to unload data into the PC. (Pascal, Jaime, Ana, Amparo, Juan Jose).
17:00 Arrival to Portinatx. Installation on the roof of one first floor room of a GPS reference station.
19:00 Arrival to Ibiza. Geometric Levelling (Miriam, Ana, Sergio, Amparo)
21:00 Pascal and Juan Jose travel to San Antonio. Rendez-vous with Jose, Jorge and Cristina that have arrived from San Fernando. First visit at night to the Patrullera Deva in the harbor.
? Installation of the GPS reference station in the roof of the Club Nautico de San Antonio(Pascal)

Wednesday 11 June

9:15 Arrival of Miriam, Ana, Sergio, Amparo and Jaime to San Antonio
9:20 Visit to the San Antonio tide gauge
10:00 Levelling from the GPS reference station to the tide gauge (only one way).
10:30 Arrival to San Antonio of Begoña and Damia.
11:00 Work redistribution Build the GPS catamaran. Build the GPS buoy. Buy the PCMCIA memory card for one GPS data recorder. Waiting in the Club Nautico of product manager GPS de Topcon to receive information about the use of the equipment.
12:00 Test to see how to unload file data from the receiver with the software provided by Topcon. As a PC was available data was registered directly. A change in the interval between data was made because the PC memory was big enough to allow it. In order to get more manageable files, it was decided to introduce the option "copy directly in rinex" and change the file every 6 hours, with names sequently ordered.
13:00 Trip to Ibiza (Pascal and al.) to buy material for the GPS buoy radome and come back to San Antonio.
16:15 Preparation and installation of the equipment in the GPS catamaran and the GPS buoy in the San Antonio harbour. Phone contacts with Miquel Angel (All)
17:45 Departure of DEVA
19:45 Arrival of Deva to San Antonio harbour.
20:00 Repair of the GPS buoy (Sergio, Myriam, Ana, Amparo, Jaime).
20:05 Begoña returns to Ibiza to check next day the Ibiza tidegauge.
21:30 Meeting in the Es Pla hotel. General discussion and distribution of the work for the next days to the participants of the campaign. (All).
24:00 Trip to Portinatx to unload the data from the Leica. No data was registered that day since 10 a.m. (Gema, Sergio, Amparo, Jaime, Ana)

Thursday 12 June

2:10 Arrival to Ibiza. Computation and validation of the levelling data from 11 June (Amparo, Ana).
8:00 Set to 1s. the GPS data recorder in Portinatx. Control the GPS antenna each 2 hours. Control the GPS data recorder each 30 minutes. (Jaime)
8:20 Arrival to the San Antonio harbour. Equipment installation on DEVA (Jose, Jorge, Pascal, Juan Jose, Amparo).
8:30 First departure with the GPS buoy in the zodiac for about 30 minutes. It was interrupted, so the corresponding data file was very short. (Cristina)
9:15 Amparo explains to Pascal how to use the Leica receiver on board DEVA; after that she returns to land.
9:20 Levelling in San Antonio from the Club Nautico to the tide gauge in order to close the ring started the day before. The first result provides a great error value (11 cm), probably due to some error taking data, so it was repeated. The error with new measurements is quite lower (1 cm) but is still above the desirable. (Sergio, Gema, Amparo, Ana)
12:30 Measurement of the height of antenna (Astech, Topcon) in San Antonio (taken in three points till the nail under the tripod) (Ana, Amparo).
16:00 Vigilance of the zodiac and GPS buoy during the afternoon (Gema, Cristina)
17:30 Arrival to Ibiza and computation of the levelling (Ana, Sergio, Amparo)
19:30 Levelling reference station-Ibiza tidegauge (Sergio, Ana, Amparo)
22:15 Registration of data with the GPS buoy during the last while of measurements while DEVA describes circles coming into the San Antonio harbour (Cristina)
22:30 Implementation of one receiver in the nail of the Ibiza tidegauge to initiate a short session of observations (Sergio, Ana, Amparo)
23:50 Save the data to the PC and set the GPS data recorder to 30 seconds in Portinatx (Jaime)

Friday 13 June

6:20 Amparo leaves Ibiza to travel to Madrid
8:00 Set to 1s the GPS data recorder in Portinatx. Control the GPS antenna each 2 hours. Control the GPS data recorder each 30 minutes (Jaime)
8:00 Ibiza GPS reference stations initiating operation (Sergio, Ana)
8:10 Departure with the GPS buoy in the zodiac in San Antonio. The GPS is registering during 1 hour – 1 hour and a half. When the buoy is taking in tow it is submerged into the sea and water comes into. Because of this, it is brought till a point close to the tidegauge on board. All the time the GPS is registering. In that point the GPS receiver is left until the battery was finished, around 15 minutes. Since water had come into the buoy, it is opened and after one hour it is mounted again. Even with some water inside the GPS was working normally. The battery of the PC was finished so it is not possible to unload the data so it was made vigilance of the zodiac and buoy meanwhile data unloading was performed in the hotel (Cristina, Gema)
10:30 Control of the GPS reference stations in Ibiza all day. (Sergio, Ana)
21:30 Trip to Portinatx and after to San Antonio (Sergio, Ana, Jaime)
22:45 Meeting of all participants in land and sea in Es Pla hotel in San Antonio. Downloading the GPS data collected in the day to personal computers (Jorge et al.)
24:00 Save the data to the PC and set the GPS data recorder to 30 s. in Portinatx(Jaime)

Saturday 14 June

7:40 Jose, Jorge, Pascal, Cristina and Juan Jose leave Es Pla hotel. The DEVA planning is changed after Spanish Navy permission to stay the night of 14 in Ibiza harbour instead San Antonio harbour, one day before original planning.
8:00 Set to 1s the GPS data recorder in Portinatx. Control the GPS antenna each 2 hours. Control the GPS data recorder each 30 minutes (Jaime)
8:00 Ibiza GPS reference stations initiating operations (Sergio, Ana)
8:15 Departure with the GPS buoy in the zodiac while DEVA is making circles in San Antonio harbour near the zodiac. Vigilance from land of operations (Gema). Cristina is on board of DEVA with the GPS buoy.
9:30 Arrival of Marta to El Corso hotel.
10:00 Control of the GPS reference stations in Ibiza all day (Marta, Ana, Sergio)
10:00 Vigilance of the reference stations in San Antonio. They were checked every one hour and a half. All the times they were working in order, registering data every one s. and between seven to nine satellites were each time visibles (Gema, Cristina)
12:00 Sergio leaves Ibiza to flight to Barcelona.
19:30 DEVA is making circles in Ibiza harbour near the zodiac with the GPS buoy.
20:15 Jose, Jorge, Pascal and Juan Jose stays the night at the Roca y Mar hotel. Cristina is located in El Corso.
21:00 Meeting of all participants at the El Corso. Downloading the GPS data collected during the day to personal computers. Validation of the quality of the data (Jorge, Marta)

Sunday 15 June

6:00 Ana travels to Portinatx to be there all day controlling the GPS reference station.
7:00 Set to 1s the GPS data recorder in Portinatx.
8:00 Departure of DEVA from the Ibiza harbour. DEVA is making cicles in Ibiza harbour near the zodiac with the GPS buoy. (Cristina)
8:30 Control of the GPS reference stations in Ibiza all day (Marta, Ana)
8:30 Vigilance of the reference stations in San Antonio. They were checked every one hour and a half. All the times they were working in order, registering data every one s and between seven to nine satellites were each time visibles. (Gema)
19:00 DEVA is making circles in Ibiza harbour near the zodiac with the GPS buoy.
20:00 Jose, Jorge, Pascal and Juan Jose are located in El Corso hotel. Downloading the GPS data to personal computers. Validation of the quality of data (Jorge, Marta)

Monday 16 June

7:15 Take down the GPS of Portinatx. Load the instruments in the van and go to Ibiza (Jaime)
8:00 Go on board of DEVA with the buoy and the catamaran
10:00 Control and checking of the reference stations in Ibiza
10:30 Control of the buoy near the tide gauge in Ibiza.
11:00 Go to San Antonio to download and save the Topcon data from the PC to zip disks. Dismountain the other GPS reference station at the Club Nautico (Pascal, Gema).
12:00 Pascal leaves Ibiza to flight to Nice.
16:00 Measurements with the catamaran and buoy near the Ibiza tide gauge.
20:00 Dismountain the catamaran
21:30 Official dinner of the participants with the DEVA crew in El Faro restaurant of Ibiza center

Tuesday 17 June

8:00 Go to Portinatx to leave the hotel (Jaime)
8:15 Go to Ibiza harbour (Jose, Jorge, Cristina, Juan Jose)
9:30 DEVA departure with direction to Palma de Mallorca-Menorca.
11:00 Set out the instruments and load the van.
12:00 Gema leaves Ibiza flying to Madrid.
18:00 Go on board the Transmediterranea ship with the van direction Barcelona (Jaime)
23:00 Marta and Anna leaves Ibiza direction Barcelona.

Wednesday 18 June

5:30 Arrival of the van to Barcelona with its instrumentation. Go to the ICC to return them and return the van to the rent a car office (Jaime)
9:00 Jose, Jorge and Cristina leave Ibiza direction San Fernando.
11:00 Juan Jose return the car in Ibiza airport to the rent a car office. He leaves Ibiza direction Barcelona.

APPENDIX II

"JASÓN-1" R/A CALIBRATION. 2003 IBIZA CAMPAING. "DEVA" PATROL ACTIVITIES (11-17/07/2003)

11 JUNE 2003.

DAY/TIME (B)	DEVA DISTANCE METER	COURSE	SPEED	REMARKS
11 June 2003.				"Deva" moored in San Antonio. Between 08:00 and 17:00 people on land preparing catamarán, buoy, etc and checking GPS receivers at San Antonio, Ibiza and Portinaxt.
17:00B	13481.5			On board P. Bonnefond; J. Gárate; J. Martín Davila; J.J. Martínez Benjamín, A. Núñez, G. Rodríguez, S. González. Ship departures from San Antonio to perform tests of Catamarán, Buoy, etc, in "San Antonio" bay08:30 Abordo P. Bonnefond; JJ Mtnez. Benjamín; J. Gárate; J. Martín Davila.
17:45	482.8		4.0	Speed 4 kn. Catamaran on water.
17:50	483.2		5.0	Speed 5 kn.
17:55	483.6		6.0	Speed 6 kn.
18:00	484.1		7.0	Speed 7.0 kn.
18:05	484.9		8.0	Speed 8.0 kn.
18:11	485.5		9.0	Speed 9.0 kn.
18:45	490.1		2.0	Speed 2.0. Some problems withy buoy.
19:17	490.5			Stop tests. Catamaran on board. Course to San Antonio port.
19:50	13491.5		0.0	Ship moored at San Antonio port. Total miles on the day: 10.4 (19.26 km) in 3 hours.

12 JUNE 2003.

DAY/TIME (B)	DEVA DISTANCE METER	COURSE	SPEED	REMARKS
12 June 2003				"Deva" moored in San Antonio port.
08:30B	13491.9		0	On board : P. Bonnefond; JJ Mtnez. Benjamín; J. Gárate; J. Martín Davila. Ship ready to go ashore.

09:07		280		Catamarán on water in San Antonio bay. Zodiac picks Amparo Núñez on board.
09:22	492.6	110	8.0	Start rings. Zodiac+buoy in the vicinities of "Deva" outside pier (about 500m).
09:27	493.2		8.0	End first ring.
09:33	493.9		8.0	End second ring.
09:38	494.7		8.0	End third ring.
09:44	495.3		8.0	End 4th ring.
09:49	495.5		8.0	Zodiac picks A. Nuñez on land. Course to S187 area, located SW San Antonio on land track number 187. Zodiac and GPS buoy stay at San Antonio port.
09:55	496.0	295	8.0	Speed increases to 10 kn. Starts transit to S187 area, towing the catamaran..
11:16	510.2	210	8.0	Starts zone S187, on point 4.
11:40	513.5	210	8.0	On point #3.
12:03	514.9			On point #2.
12:20	518.6	210		On point#1. Turn port to course 115 (line 1-8).
12:29		031	8.0	Starts new line (points 8-5)
12:48	522.5	032	8.0	On point #7.
13:07	525.3	032	8.0	On point #6.
13:29	528.0	040	8.0	On Point #5. Turn starboard to course 120 (line5-12).
13:34	528.4	120	8.0	Course 120.
13:37				Turn to course 215.
13:39	529.3	215	8.0	Starts line points #12 to #9.
13:58	531.9	215	8.0	On point #11 (on point 11 the ship is 500 yards port side the line).
14:20	535.1	205	8.0	On point #10.
14:42	537.8	205	8.0	On point #9. Turn port to course 115 (line 9-16).
14:52	539.1	110	8.0	Turn port 028.
14:53	539.6	028	8.0	On point #16. Starts line #16-#13.
15:12	541.9	032	8.0	On point #15.
15:30	544.0	032	8.0	On point #14.
15:50	547.2			On point #13. Turn port to course 300 to start traversal line 13-4.
15:52				Starts line 13-4.
16:15	550.5	295	8.0	On point 4.
16:16	550.7	150	8.0	Starts diagonal #4-#14.
16:47	554.9	155	8.0	On point #14.
16:49	555.3	310	8.0	Start traversal line #14-#3.
17:10	558.9	140	8.0	On point #3. Starts diagonal 3-15.
17:15				Speed 6 knots during a short period an then 8 knots.
17:49	563.4	300	8.0	On point #15.
17:55	564.5	302	8.0	Starts traversal line 15-2.
18:16	567.2	300	8.0	On point 2.
18:21	567.6	145	8.0	Starts diagonal 2-16. Course 145.
18:52	572.0	145	8.0	On point 16. Turn starboard to course 298.
18:56	572.7	298	8.0	Starts traversal line 16-1.
19:23	576.0	298		On point 1. Turn starboard to course 051.
19:29	576.6	051	8.0	Starts diagonal 1-13.

19:55	580.5	051		Speed down to recover the catamaran and to modify the catamaran towing rope and antenna cables (merged).
20:17	581.6	053	8.0	Again on diagonal line 1-13.
20:57	586.9	053	8.0	On point 13. End area S187. Starts transit to ESA tide gauge (38°52´30´´N; 001°11´42´´E (vicinities Vedra island).
21:25	591.3	040	8.0	Ring around tide gauge.
21:28				Speed 10 kn. Link with zodiac via radio: the buoy has been deployed.
21:36	591.6	000	10	Course 000 to San Antonio harbour.
22:49	603.6	118	8.0	Start rings on San Antonio harbour.
22:54	604.3		8.0	End first ring.
22:58	604.7		8.0	End second ring.
22:59			4.0	Speed 4 kn.
23:03			6.0	Speed 6.0 kn.
23:07	605.5		8.0	End third ring. Stop rings to embark catamaran.
23:20	605.9		8.0	Catamaran on board.
23:45	13606.6		0.0	At San Antonio peer. Total nautical miles on June 12th: 114.7 (212.4 km) in 15h 15m.

13 JUNE 2003.

DAY/TIME (B)	DEVA DISTANCE METER	COURSE	SPEED	REMARKS
13 June 203				"Deva" moored in San Antonio port.
08:25B	13606.7		0	Ship ready to go ashore.
08:30				On board : P. Bonnefond; J. Gárate; J. Martín Davila.
08:47	607.0	280	8.0	Catamarán on water in San Antonio bay. Zodiac with GPS buoy.
08:51	607.1		8.0	Start rings. Zodiac+buoy in the vicinities outside pier(about 300 m).
08:53	607.2		5.0	5 knots.
08:55	607.4		0.0	Speed 0 knots. Ship is too close to pier.
09:08	608.0		8.0	Speed 8 knots. Starts rings again.
09:11	608.3		8.0	End first ring.
09:16	608.8		8.0	End second ring.
09:21	609.4		8.0	End third ring.
09:25	609.9		8.0	End 4th ring.
09:26	609.9		10.0	Course 315 to zone N187 (N San Antonio centered on 187 JASON land track).
10:41	622.7	030	8.0	Starts zone N187 on point 1; line 1-4.
11:01	625.5	030	8.0	On point #2.
11:22	628.1	030	8.0	On point #3.
11:42	630.8	030	8.0	On point#4. Turn port to course 130 (line 4-5).

11:58	632.9	130	8.0	On point 5. Turn starboard to course 215. Starts new line (points 5-8)
12:17	635.6	215	8.0	On point #6.
12:36	638.3	210	8.0	On point #7.
12:57	641.0	210	8.0	On Point #8. Turn port to course 120 (line8-9).
13:06	642.3	025	8.0	Turn port to course 035. Starts line 9-12.
13:27	644.9	030	8.0	On point #10.
13:45	677.6	030	8.0	On point #11.
14:06	650.3	034	8.0	On point #12. Turn starboard to course 120 (line 12-13).
14:15	651.7	125	8.0	Turn starboard course 210. Starts line 13-16.
14:36	654.3	209	8.0	On point #14.
14:55	657.0	209	8.0	On point #15.
15:16	659.6	209	8.0	On. point #16. Finish zone N187. Turn starboard to zone N248.
15:28	661.4	333	8.0	On point #1; zone N248. Starts line 1-4.
15:49	663.1	330	8.0	On point 2.
16:10	666.8	331	8.0	On point 3.
16:30	669.6	331	8.0	On point #4. Turn starboard to course 060. Stars line 4-5.
16:40	670.7		8.0	On point 5. Turn starboard to course 157. Starts line 5-8.
17:00	673.5	155	8.0	On point #6.
17:20	676.2	155	8.0	On point 7.
17:39	678.8	155	10.0	On point 8. Ends works on area N248. Turn starboard to course 235 to San Antonio harbour. Speed 10 knots.
19:00	692.3		0.0	At San Antonio harbour. ZodiaC BY p. "Deva" to change buoy Trimble GPS receiver because Cristina can't retrieve the data.
19:13	693.4		8.0	Starts 1st ring.
19:16	693.7		8.0	Ends 1st ring.
19:19	697.2		8.0	Ends 2nd ring.
19:22	697.8		8.0	Ends 3rd ring.
19:26	697.9			Ends 4th ring.
19:29	695.3		8.0	Ends 5th ring. Stop activities.
19:43	696.0		8.0	Catamaran on board.
20:00	13696.7			Deva at San Antonio. Total nautical miles on June 13th: 90.1 (166.87 km) in 11h 30m.

14 JUNE 2003.

DAY/TIME (B)	DEVA DISTANCE METER	COURSE	SPEED	REMARKS
14 June 2003				"Deva" moored in San Antonio port.
08:30 B				P. Bonnefond; J. Gárate; J. Martín Davila and J.J. Martínez Benjamín on board.

09:25	13696.7		0	“Deva” ready to go ashore.
09:39	696.9	330	7.0	Catamarán on water in San Antonio bay. Zodiac with GPS buoy.
09:52			0.0	Pascal Bonnefond on water till 10:10 to measure catamarán heights.
10:10			0.0	Increase speed to 8.0 kn. Between 10:10 and 10:27 ship stops while Trimble catamaran GPS receiver is changed.
10:27	697.8		8.0	Speed 8 knots. Start rings. Zodiac+buoy in the vicinities outside pier (300 m).
10:35	698.7		7.0?	End first ring.
10:42	699.6		7.0?	End second ring.
10:48	700.4		7.0?	End third ring. Ship stops to embark buoy and Zodiac on board. Cristina Garcia on Board.
10:52	700.5		7.0?	Speed increases to 10 kn., course to area N248 to complete the data acquisition.
12:15	713.7	050	10.0	Starts zone N248, line 1-9, Course 050; speed 8 kn.
12:34	716.2	325	9.0?	On point 9. Turn port to course 324. Starts line 9-12.
12:54	719.0	327	9.0?	On point #10.
13:13	721.7	328	9.0?	On point#11.
13:32	724.3	328	9.0?	On point 12. Turn starboard to course 060. Starts line 12-13.
13:41	725.5	152	9.0?	On point #13. Turn starboard to course 150. Starts line 13-16.
14:01	728.1	155	9.0?	On point #14.
14:40	731.2	155	9.0?	On Point #15.
14.44	733.7	158	9.0?	On point 16. Turn port to course 310. Starts line 16-17.
15:23	739.0	307	0.0	On point #17. Zodiac on the water. Buoy cover is broken but it still floats, so starts data acquisition on buoy. Starts direct Calibration phase.
16:10	739		0.0	End of direct calibration. Zodiac on board.
16:27			10.0	Speed 10 kn. Starts line 17-16 from a point located in the mid way between 17 and 16.
16:44	743.5		9.0?	On point #16. Turn port to course 130 to Ibiza Harbour.
19:13	768.8		8.0	Zodiac on the water to deploy buoy. Speed 8. Start ring in the vicinities of Ibiza harbour.
19:17	769.1		8.0	Ends 1st ring.
19:21	769.6		8.0	Ends 2nd ring.
19:24	769.9		8.0	Ends 3rd ring.
19:28	770.2		8.0	Ends 4th ring.
19:31	770.6		8.0	Ends 5th ring.
19:34	771.2		8.0	Ends 6th ring.
19:38	771.7		8.0	Ends 7th ring.
19:42	772.2		8.0	Ends 8th ring. Stop activities. Course to Ibiza port.
20:25	13773.7		0.0	Moored at Ibiza port. Total miles during day: 77.0 (142.6 km), in 11 hours.

15 JUNE 2003.

DAY/TIME (B)	DEVA DISTANCE METER	COURSE	SPEED	REMARKS
15 June 2003				"Deva" moored at Ibiza port.
08:00B				P. Bonnefond; J. Gárate and J. Martín Davila on board.
08:25	13773.7		0	Ship ready to go ashore.
08:40	774.0	330	7.0	Catamarán on water in Ibiza port.
09:14	774.9		8.0	Speed 8 knots. "Deva" start rings. Zodiac+buoy in the vicinities outside pier (about 300 m).
09:20	775.4		8.0	End first ring.
09:30	776.4		8.0	End second ring.
09:34	776.8		8.0	End third ring.
09:40	777.8		8.0	End fourth ring.
09:55	778.6		0.0	Ship stops to embark buoy and Zodiac on board. Cristina Garcia on Board.
10:00	778.7		10.0	Speed increases to 10 kn., course to area S248 to start data acquisition.
10:47	785.8	150	8.0	Starts zone S248, line 4-1, Course 153; speed 8 kn.
11:06	788.4	155	8.0	On point 3.
11:26	791.1	152	8.0	On point #2.
11:46	793.9	155	8.0	On point# 1. Turn port to course 330, to start line 8-5.
11:55	795.1	330	8.0	On point #8. Starts line 8-5, Course 330; speed 8 kn.
12:15	797.7	330	8.0	On point 7.
12:37	800.7	327	8.0	On point #6.
12:54	803.1	330	8.0	On point#5. Turn starboard 153 to start line 12-9.
13:04	804.5	160	8.0	0n point 12. Starts line 12-9. Course 153, speed 8 kn.
13:24	807.2	155	8.0	On point #11.
13:43	809.9	153	8.0	On point #10.
14:03	812.5	153	8.0	On Point #9. Turn port to course 330 to start line 16-13.
14.10	813.7	310	8.0	On point# 16. Starts line 16-13.
14:35	817.0	332	8.0	On point #15.
14:52	819.2	330	8.0	On point #14.
15:11	821.8	330	8.0	0n point #13. Turn port to course 235. Starts line 13-4.
15.36	825.1	235	8.0	On point# 4. Turn starboard. Starts line 4-14. Course 106. Speed 8.
16:03	829.7	101	8.0	On point #14. Starts line 14-3. Course 235.
16:36	831.4	241	8.0	On point #3. Turn starboard to course 101. Starts line 3-15.

17:10	837.7	102	8.0	On point #15. Turn starboard to course 240. Starts line 15-2.
17:36	841.4	240	8.0	On point #2. Turn starboard to course 101. Starts line #2-#16.
18:11	845.9	103	8.0	On point #16. Turn starboard to course 240. Starts line 16-1.
18:36	849.3	240	8.0	On point #1. Turn starboard to course 354. Starts line #1-#13.
19:39	858.1	354	8.0	On point #13. Turn starboard to course 240. Starts line 13-4. Speed 10 Kn.
20:00	861.4	242	10.0	On point #4. Turn starboard to course 101. End of the area S248. Course 074 to Ibiza harbour.
20:37	867.0	270	1.4	Zodiac and GPS buoy on the water, outside Ibiza harbour.
20:43	867.9		8.0	Speed 8 Kn. (Start rings. Zodiac+buoy in the vicinities outside pier).
20:48	868.4		8.0	Ends 1st ring.
20:50	868.8		8.0	Ends 2nd ring.
20:54	869.2			Low speed.
21:05	869.6			Catamaran on board.
21:11	869.9	325	4.0	Course to mooring site at Ibiza port.
21:40	13870.2		0.0	"Deva" moored at Ibiza port. Total miles during day: 96.5 (178. km), in 13 hours.

16 JUNE 2003.

DAY/TIME (B)	DEVA DISTANCE METER	COURSE	SPEED	REMARKS
16 June 2003				"Deva" moored at Ibiza port.
08:00B				P. Bonnefond; J. Gárate and J. Martín Davila on board.
08:15B	13870.2			"Deva" ready to go ashore.
08:32	870.5			Catamaran on water in Ibiza port. Zodiac with GPS buoy on the water. Simultaneous data acquisition on Buoy and catamaran inside Ibiza harbour at speed 0 kn.
08:53	870.9	290	700	Zodiac picks GPS buoy from the water inside the harbour without stop data acquisition and moves it outside the harbour in the vicinities of the pier.
09:00	871.4	100	8.0	Speed 8 knots. Comienzan curvas de evolución en exteriores Bahía de Ibiza. Zodiac+boya en proximidades parte exterior del muelle (Unos 300 m). (Start rings. Zodiac+buoy in the vicinities outside pier).
09:04	871.8		8.0	End first ring.
09:09	872.3		8.0	End second ring.
09:14	872.8		8.0	End third ring.
09:18	873.2		8.0	End fourth ring.

09:22	873.6		8.0	End fifth ring.
09:26	874.0		8.0	End sixth ring.
09:30	874.4		8.0	End seventh.
09:37	875.2			Ship decreases speed, to unhook catamaran from the ship.
09:57	875.3			Zodiac tows catamaran for simultaneous data acquisition of GPS buoy an catamaran in the vicinities of Ibiza tide gauge.
10:14	875.4			Ship course to Ibiza port.
10:25	875.9		0	Ship moored at Ibiza. Catamaran and GPS buoy continue GPS data acquisition at IBIZA tide gauge. It is tried to measure the height of catamaran GPS antennas above sea level, but finally it's not possible due to some sea waves inside the harbour introduce too much noise.
11:45	875.9			Ship goes ashore.
12:15	876.6	315		Catamaran on board. Zodiac on board too. Course outside Ibiza harbour to GPS buoy measurements at #7 on S248 area.
13:43	887.7	290	8.0	Zodiac on #7. GPS buoy on the water. Starts data acquisition.
14:16	888.6	325	8.0	Zodiac by the ship. Course to #17.
14:44	890.6	060	8.0	Zodiac and GPS buoy on the water on #17. Starts data acquisition.
1522	890.9	310	8.0	Zodiac by the ship. Course to #6.
15:37	892.2	335	8.0	Zodiac and GPS buoy on #6. Starts data acquisition.
16:11	892.6	090		End of GPS measurements with GPS buoy. Zodiac on board. Course to Ibiza harbour.
17:40	13903.4		0.0	At Ibiza. Total miles during day: 33.3 (61.5 km) in 8 hours. End of the "Deva" campaign. Continues GPS measurements at Ibiza tide gauge.

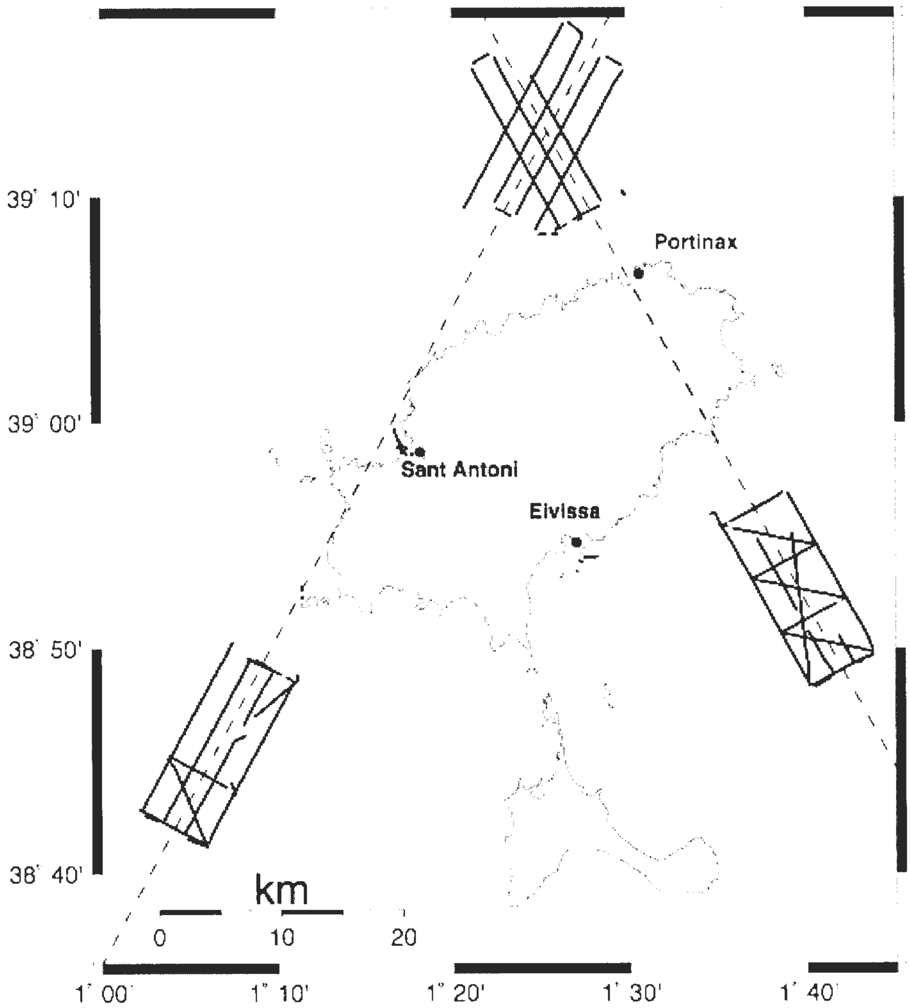


Fig. 36: Patrol P-29 groundtracks. GPS data collected (gray) and kept (black), (from Mar. Geod., 2004)

APPENDIX III

GALLERY OF SOME PHOTOS OF THE CAMPAIGN

Fig. 37: Catamaran and zodiac at the San Antonio harbour

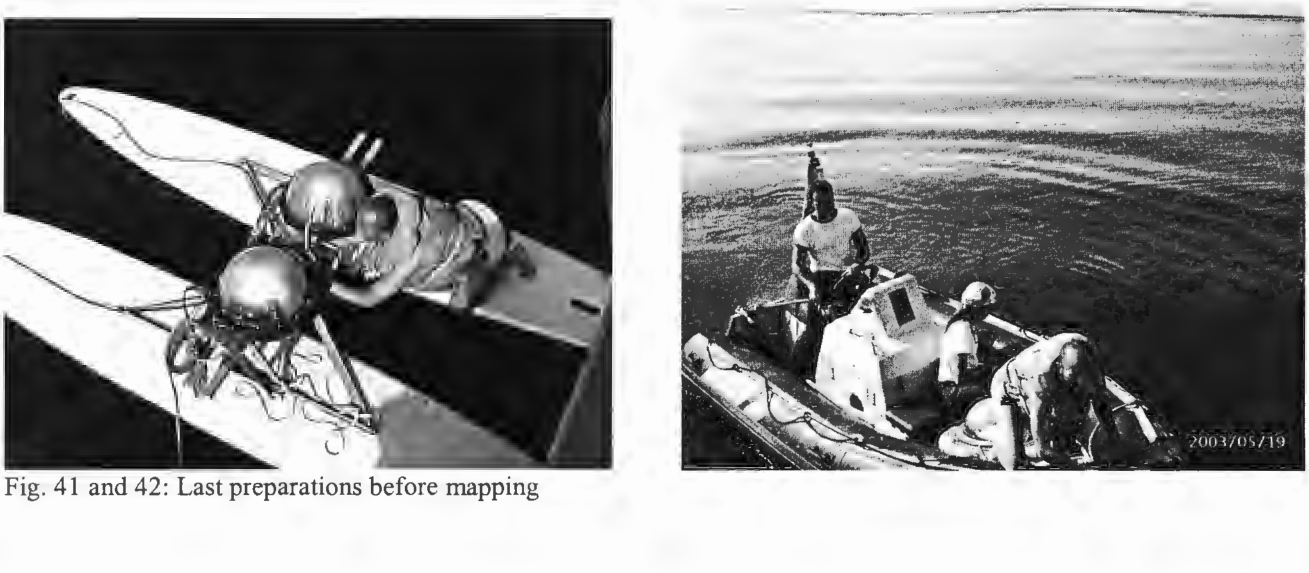
Fig. 38: The zodiac from the Spanish Navy

2003/05/19

Fig. 39: Preparations for the first mapping at San Antonio

2003/05/19

Fig. 40: GPS buoy calibration at San Antonio harbour



2003/05/19

Fig. 41 and 42: Last preparations before mapping


Fig. 43: GPS catamaran prepared for mapping

Fig. 44: Mapping at San Antonio harbour

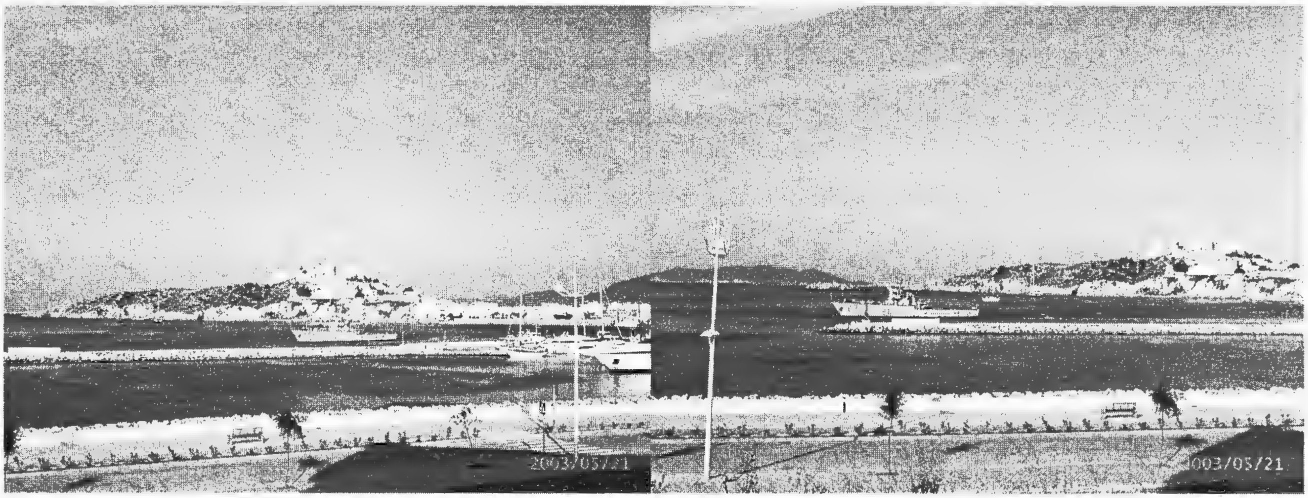


Fig. 45 and 46: Patrol DEVA towing the GPS catamaran leaving Ibiza harbour

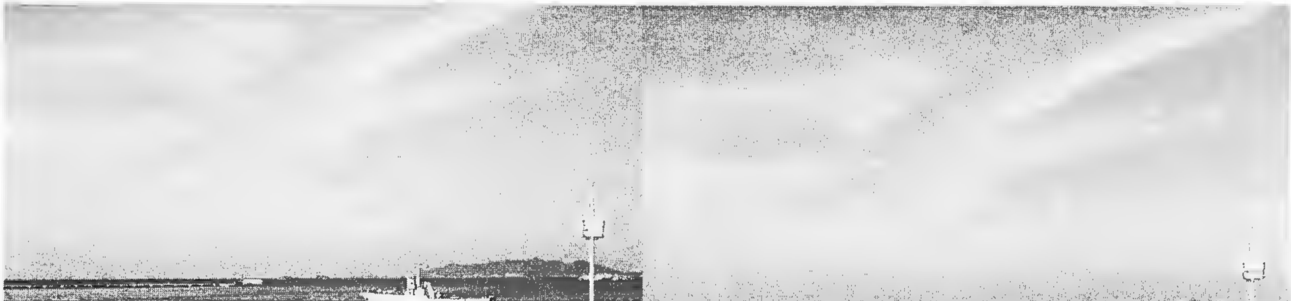


Fig. 47 and 48: Patrol DEVA towing the GPS catamaran leaving Ibiza harbour

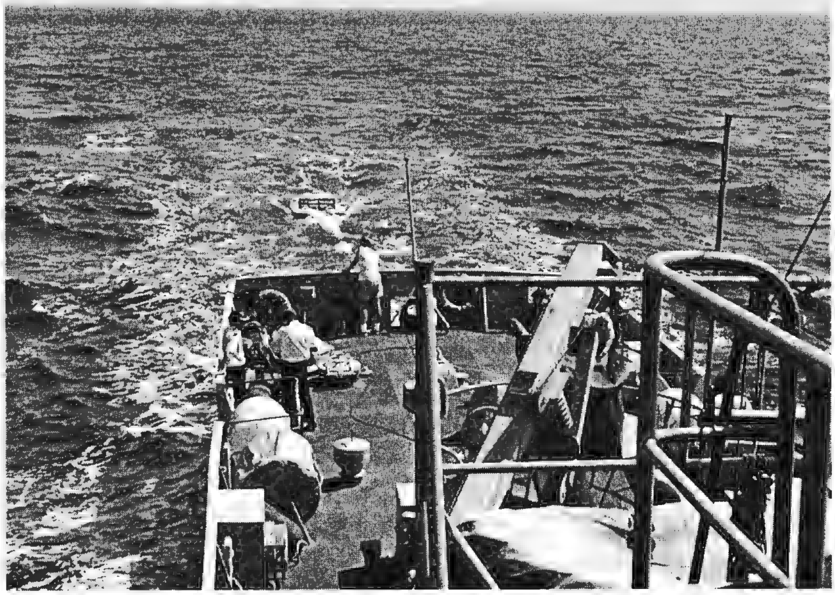


Fig. 49: Mapping out Ibiza island

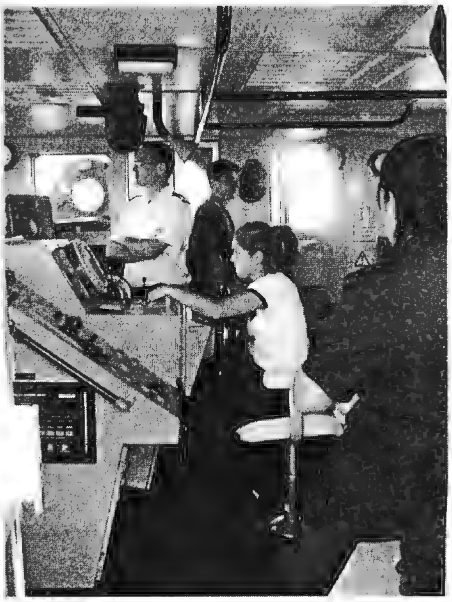


Fig. 50: Controlling the Patrol P-29

Fig. 51: Supervision of the GPS catamaran

Fig. 52: Mapping near Vedra (right) and Sa Galera (left) islands

Fig. 53: Verification of good GPS receiver data from catamaran

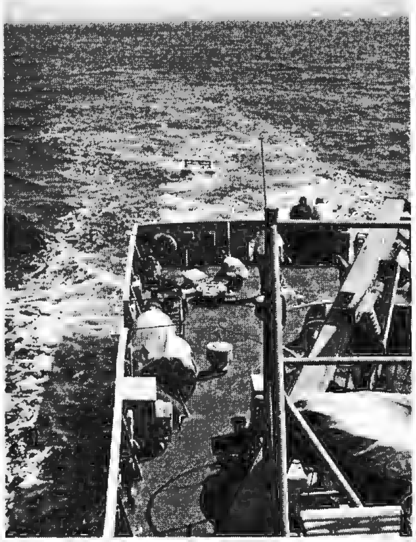


Fig. 54: Mapping the MSS for Indirect Calibration

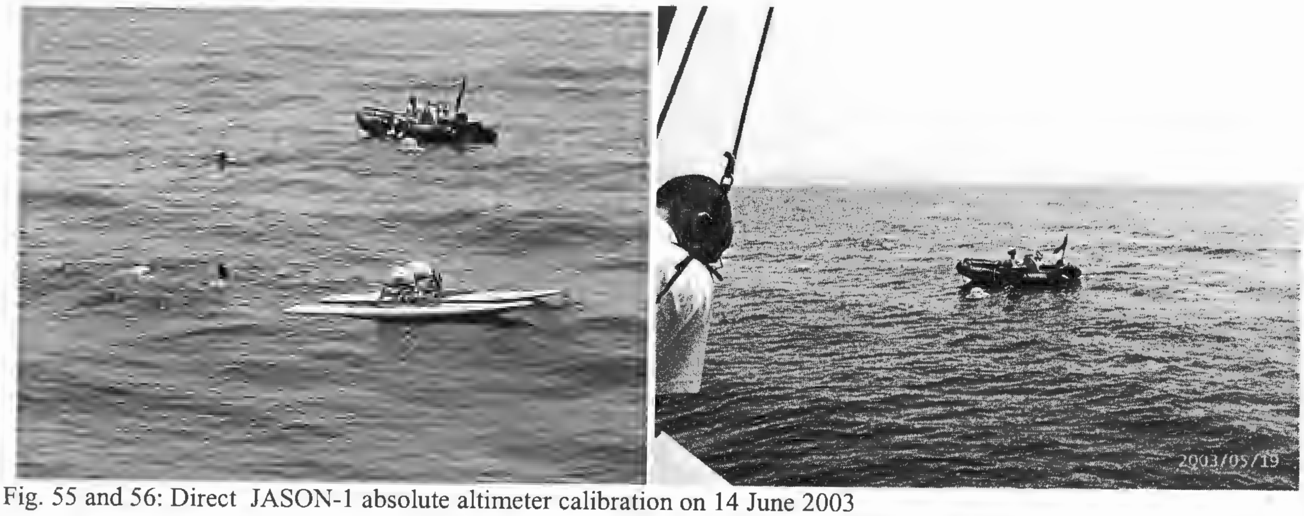


Fig. 55 and 56: Direct JASON-1 absolute altimeter calibration on 14 June 2003

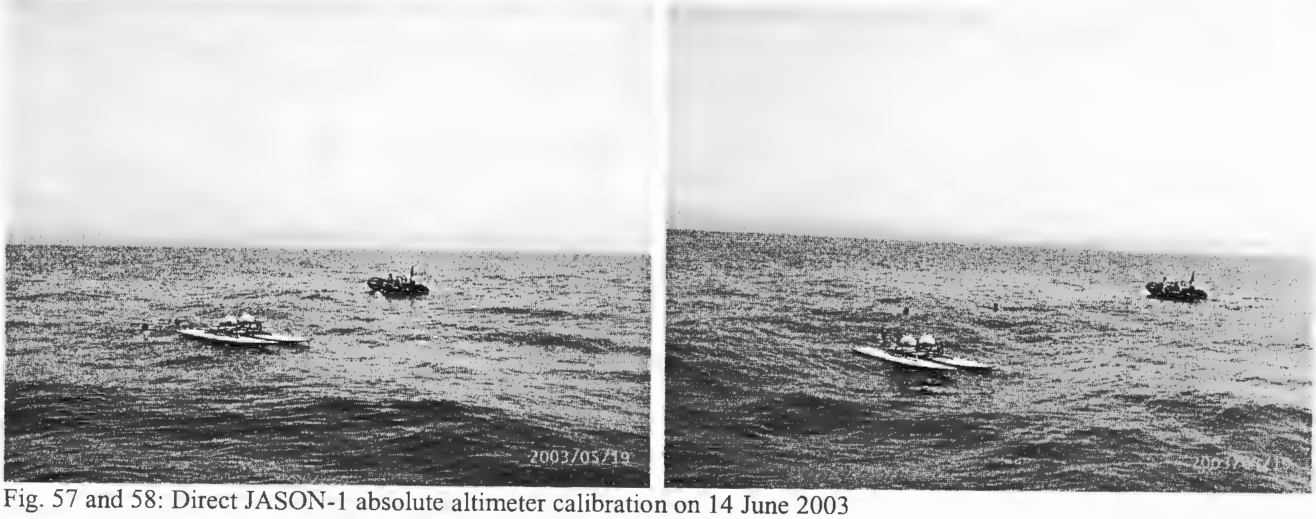


Fig. 57 and 58: Direct JASON-1 absolute altimeter calibration on 14 June 2003

Fig. 59: Coming back to Ibiza

Fig. 60: The 'Calibration Team'

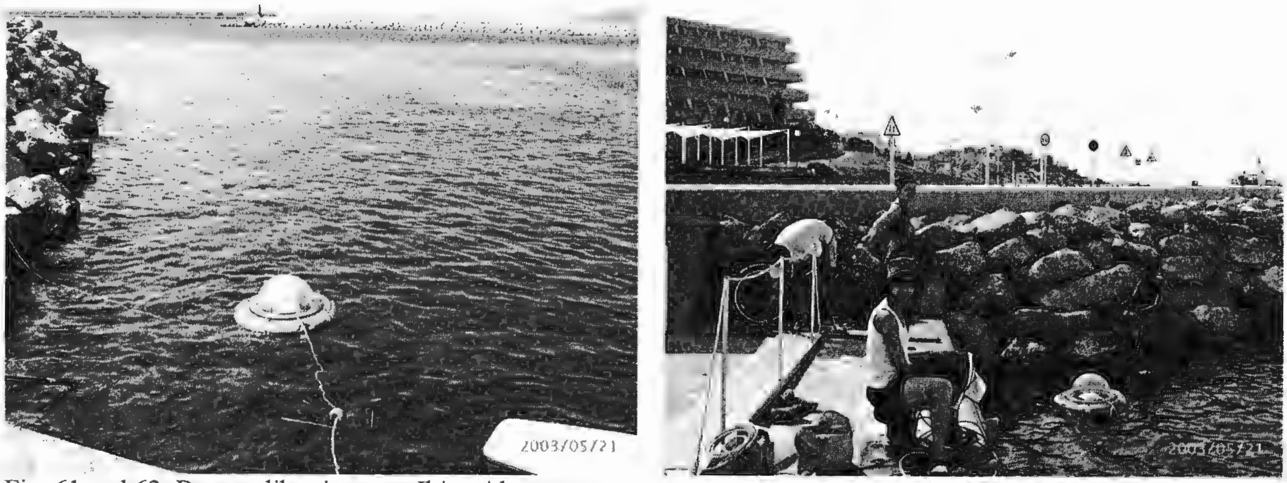


Fig. 61 and 62: Buoy calibration near Ibiza tide gauge

Fig. 63 and 64:GPS measurements at the Ibiza tide gauge location

Fig. 65 and 66: Measurements at the Ibiza tide gauge location in Marina de Botafoch

Fig. 73 and 74: Official dinner at the end of the campaign

Fig. 75 and 76: Official dinner –2

Fig. 77 and 78: Official dinner – 3

APPENDIX IV

Cape of Begur Calibration Campaigns

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A.1.- Introduction

Previous to the Ibiza campaign in 2003, three campaigns have been conducted on 16th-19th March 1999, on 4th-7th July 2000 [Martinez-Garcia et al., 2002] and on 25-28th August 2002 at Begur Cape leaded by the Technical University of Catalonia (UPC). See figure 10.
Those experimences have been developed in the frame of two Spanish National Research and Developement Projects in Space Research referenced as ESP1997-1816-C04-03 and ESP2001-4534-PE.

In all these three experiences the GPS buoys were used to perform radar altimeter calibrations by means of two techniques. First, the single point calibration deploying the buoys under the satellite ground track at the overflight. The second one, the so called indirect method, that provides the absolute sea surface to compare with the altimeter measurement by correcting the precise pre-estimated mean sea surface along the satellite ground track with the sea level anomaly corresponding to the overflight instant. This sea level anomalies are provided by the near tide gauge placed at l'Estartit (few kilometers far from Begur Cape).

Appart of the absolute calibration of the TOPEX side-B altimeter (March 1999, with the support of JPL, and July 2000) and of Poseidon-2 altimeter (August 2002), the mapping of the marine geoid in the area of 2 kilometers wide along the satellite ground track was performed during the 2002 campaign.

A. 2.- Distribution of the calibration site at Begur Cape

The instrumentation consists on the reference station at the coast and the GPS buoys. The near tide gauge is only used when performing the indirect method. The reference station close to the satellite ground track is needed in order to achieve kinematic buoy solutions within centimeter accuracy level, which is the typical error assumed for the range measurement of the altimeter [Fu and Cazenave, 2001].

In all the campaigns, the buoy solution has been computed by using a differential kinematic strategy with short baselines, assuming common atmosphere corrections (ionosphere and specially troposphere) between the fix receiver and the rover. The mean value of the baselines is of 14.3 km and 14.9 km in 1999 and in 2000, respectively, and of 22.4 km in 2002. Previously, the coordinates of the fiducial site at the coast (triangles in Fig. 79) have been fixed by computing the free-network solution [Zumberge, 1997] that involves several permanent IGS-ITRF stations of the ICC in Catalonia (squares in Fig.79).

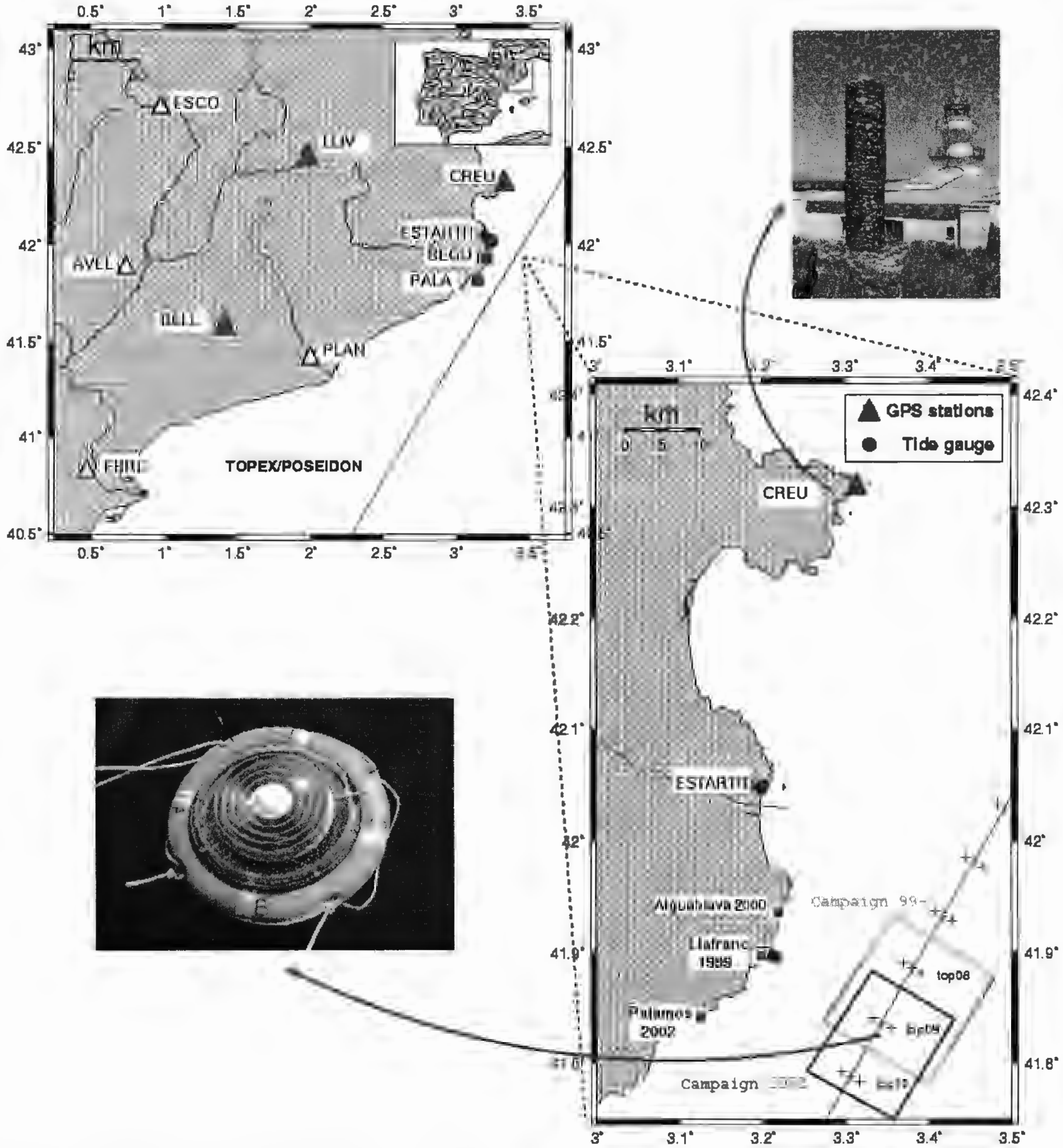


Fig. 79: General distribution of the calibration site of Begur. The GPS network of the ICC in Catalonia and the calibration area offshore Begur Cape indicating the surveying points on both the 1999-2000 and the 2002 campaigns. It is represented the nominal T/P ground track in the center and the parallel internal and the external ground tracks for the mapping of the sea surface.

Apart of the tide gauge at l'Estartit, two ancilliary sensors were temporally installed at Llafranc harbor in 1999 (Fig.79) in order to study the spatial and temporal variability of the tides in that area from the simultaneous records.

In the 1999 and the 2000 campaigns the direct estimation of the altimeter bias was realized during the overflight of the TOPEX/POSEIDON onto a point marked as TOP-08 and in the 2002 campaign the overflight occurred onto TOP-11, in fig.1. Overflight times have an uncertainty of about 10 sec.

A.2.1.- The GPS buoys

The toroidal GPS buoy used in the three experiments (Fig. 80) was performed at the ICC based on the original design of the Colorado University [Born et al., 1994].

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.

In order to check the design at its accuracy a test of the design was performed during the 1999 campaign at Llafranc harbor. It consisted on comparing the SSH derived from the GPS buoy observables with the SSH derived from the geo-referenced water height records of the tide gauges installed at the jetty. Assuming no errors in the tide gauges, it was observed no drifts neither systematic biases between both measurements. In the three campaigns, the same kind of wave-raider buoy with the same antenna and receiver has been used.

Fig. 80: Sequence of ensambling the wave-rider GPS buoy used in the 2000 experiment.

A.2.2.- Reference station at the coast

The (temporal) fiducial station at the coast used for the kinematic solution of the buoy has been placed at Llafranc during the 1999 campaign, at Begur Cape (Aiguablava) during the 2000 campaign and at Palamos during the 2002 campaign (Fig.87). These reference stations were working continuously along the campaigns at 30 Hz sampling rate and at 1 Hz during the direct calibration and during the sea surface mapping. Both the buoy and the fiducial station have been equipped with TurboRogue receivers with DORNE-Margolin T antennas (common antenna phase center offset).

A.2.3.- The tide gauge

Apart from l'Estartit permanent tide gauge, two additional gauges were installed at Llafranc harbor (27.1 km baseline) for the 1999 campaign (sea level record from March until May 1999): a float based tide gauge (Thalimedes) and a common Aanderaa pressure sensor (Fig.81).

The advantage of using l'Estartit record is the continuity and the length of its time series (the record valid for all the three campaigns). Comparing technologies, the Aanderaa pressure sensor and the Thalimedes tide gauges give more accurate and higher sampling rate measurements (1 meas/min at millimeter accuracy) than the old float tide gauge with a recording drum at l'Estartit (1 measurement every 2 hour with centimeter level accuracy). The gauges at Llafranc were provided with a display and storing unit that made easier the data monitoring and the automatic data transmission. Contrary, the gauges at Llafranc were temporal installations because the economic expense and the impossible fixed location at the harbor along the year.

Tide gauge	Device	Time span	Sampling rate
Estartit	Float with recording drum	04.01.92 - 31.12.02	2 hours
Llafranc Thalimedes	Float OTT with shaft encoder	10.03.99 - 14.05.99	1 min
Llafranc Aanderaa	Pressure sensor	11.03.99 - 10.04.99	1 min

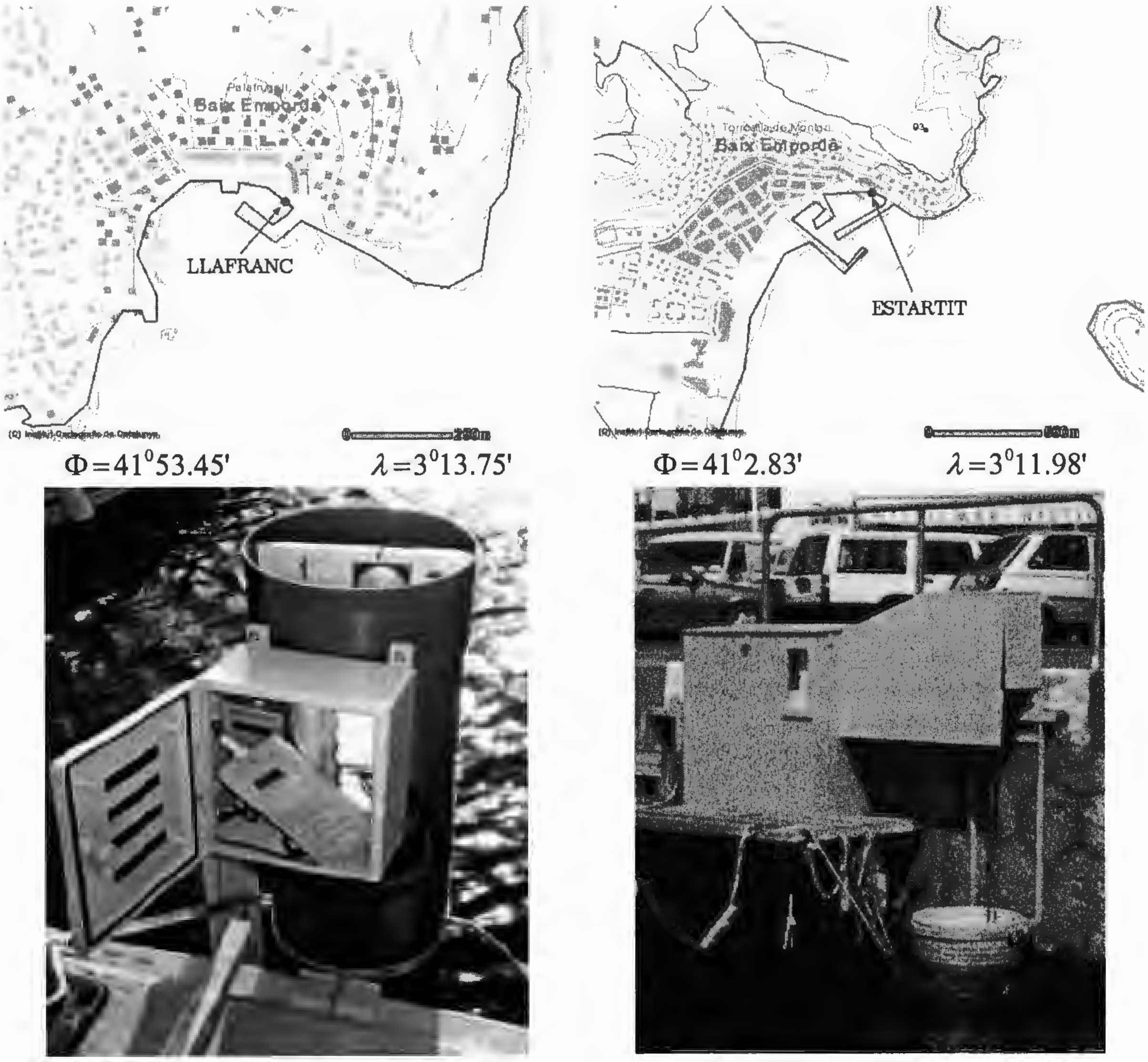


Fig. 81: Tide gauge installations at l'Estartit harbor (right) and at Llafranc harbor in 1999 (left), the location at the harbor jetty (ICC map server), the coordinates of their benchmanks and time span.

A.3.- GPS data processing

The GPS data have been processed with the GIPSY/OASIS-II software (JPL). In the three campaigns the GPS data processing has been split in two parts

1st.- Positioning of the reference station at the coast near the calibration area (free-network solution).

2nd.- Differential positioning of the buoy respect to the reference (fiducial) site off the coast (differential kinematic solution).

A.3.1.- Free-network solution

A regional network (baselines between 200 km and 20 km) involving permanent IGS-ITRF stations and the temporal station at the coast have been used processed obtaining the daily free-network solution [Zumberge, 1999].

The inputs of the data processing are the 30 sec/obs of sampling rate LC observables, the precise IGS orbits and clocks and the apriori ITRF coordinates of the network stations. The solution consists on the 24-hours averaged geocentric coordinates (WGS84) of all the sites estimated as constant parameters, and the station clock delays and the WZTD at every site stochastically estimated using a Kalman-type filter. The WZTD have been considered as a random-walk variable with 1.7 $cm/\sqrt{s}$ of drift and the station clock delay as a white-noise variable with 3 10^5 s of steady-state sigma.

The stochastic solution has the same sampling rate than satellite IGS clock biases. No interpolation has been before or after the Kalman filtering as an error in the clock interpolation of only few microseconds supposes centimeter level error in the satellite along track position and meter level error in the network solution.

Some features in this data processing are listed below:

The basic observable is the carrier phase ionosphere-free combination LC while the pseudo-ranges PC are only used for cleaning and modeling the receiver clock corrections. The data noise assumed is 100 m for code and 1 cm for carrier phase.

Both station coordinates and clocks are solved simultaneously. Receiver clock is modeled by a cubic adjustment.

The elevation cut-off angle is attached at 15°.

The troposphere is modeled with an apriori hydrostatic wet model from Saastamoinen [Saastamoinen, 1973] and a Niell mapping function [Niell, 1996]. No horizontal gradients of the WZTD have been estimated.

The geophysical corrections adopted the classical standarts in GIPSY being the solid Earth tides response modeled as the simple quadrupole [Williams, 1970], the ocean loading following the Pagiatakis model [Pagiatakis 1982, 1988] and the pole tide following the expression of [Yoder, 1984].

The repeatabilities of the daily solutions is at millimetre level (rms). An indicator of the internal consistency of the data processing is the repeatability of the network solutionevery 24-hours East-North-Vertical (ENV) computed coordinates respect to an averaged solution, which is shown in table 10. Every daily solution has been translated into a common reference frame (usually the one corresponding to the overflight date), then a mean solution is computed and finally every single solution is compared with this averaged coordinates of the network (single solutions minus averaged solution).
In table 11 the averaged coordinates of the fiducial sites selected at every campaign are displayed with the

corresponding estimated formal errors, which are significant in order to compare qualitatively the accuracy of the computed coordinates.

Network computations		Repeatabilities of the daily solutions (mm)								
	Time span	East coordinate			North coordinate			Vertical coordinate		
Stations	(day/month year)	min	max	rms	min	max	rms	min	max	rms
BELL-CREU-LLAF	15/03 - 18/03 1999	0.1	1.7	0.9	0.0	1.4	0.7	0.4	3.4	1.5
BELL-CREU-LLIV-BEGU	04/07 - 07/07 2000	0.2	2.2	0.9	0.1	3.4	1.1	0.3	6.1	2.2
CREU-BELL-PALA	19/08 - 01/09 2002	0.0	1.2	0.6	0.0	1.0	0.4	0.0	4.1	1.4

Table 10: Summary of the network computed at every campaign indicating the stations involved and the time span of the complete data set. The absolute mean values of the repeatabilities in the East, North and Vertical components (minimum and maximum amounts in mm) and the corresponding mean rms are displayed. At every campaign the repeatabilities of the 24-hours network solution have been computed respect to an averaged solution (the mean of all the daily solutions).

Campaign	Fiducial site	Averaged coordinates Coordinates (m)	σ_{x_i} (mm)	σ_{3D} (mm)
1999	LLAF	x = 4747506.25	1.00	1.42
		y = 265052.74	0.66	
		z = 4236909.86	0.78	
2000	BEGU	x = 4744149.53	2.08	5.48
		y = 266587.25	0.58	
		z = 4240551.12	1.84	
2002	PALA	x = 4751007.53	1.17	1.63
		y = 258635.31	0.47	
		z = 4233392.15	1.04	

Table 11: Summary of the fiducial site at the coast (temporal station only used during the campaign), their mean coordinates (mean along the time span of the campaign) and the associated formal errors.

A.3.2.- Differential kinematic positioning

A 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. The surveying of the sea surface has been done at the overflight point in all the campaigns, and along several TOPEX/POSEIDON ground track points only during the 2000 campaign. In both cases centimeter level accuracy is required for the computed buoy coordinates.

The inputs for this strategy are:

the simultaneous code and phase observables from the reference site and from the buoy receiver at 1 Hz,

the wet zenith tropospheric delay and the receiver clock delay of the reference site, both at 5 min/obs sampling rate (The troposphere and the reference clock are linearly interpolated before the Kalman-type filtering achieving the sampling rate of the solution stochastic parameters. That is, from 5 min/obs to 10 sec/obs),

the precise IGS satellite orbits at 5 min/obs (which are also interpolated at the sampling rate of the solution stochastic parameters before the Kalman-type filtering) and

the apriori ITRF coordinates of the reference station, weighted at millimeter, and the approximate coordinates of the GPS buoy, with weighting sigmas of 100 m in 1999 and in 2002 campaigns and with weighting sigmas of 10 km in the 2000 experiment.

The wet zenith tropospheric delay computed at the reference station is assimilated to be the same at the buoy because the short baseline. This assumption is better as the shorter baseline between the buoy and the station at the coast is.

The solution consist on the several time dependent parameters and several constant parameters which are:

the geocentric coordinates of the buoy and the satellite and buoy clocks all at 10 Hz (variable parameters), the phase breaks or phase ambiguity biases, and the averaged geocentric coordinates of the reference station along all the time span (constant parameters).

The variable parameters have been estimated by a Kalman-type filter, that has considered the buoy coordinates as stochastic radom walk variables with 10 $m/\sqrt{s}$ of drift and the satellite clock delays as stochastic white noise parameters with 3 10^5 s of steady-state sigmas.The stochastic solution also estimates the phase biases as white noise parameters with steady-state sigmas equivalent to 300 s.

The reason to choose a sampling rate of 1 obs every 10 sec for the buoy coordinates is because the sea level does not change so much along this time interval and for saving CPU computational time in the inverse LSQ (Least-Square-Solution) solution.

Regarding the constant parameters, the process computes the variation of the coordinates of the reference station respect to the apriori given values. As the apriori sigmas are very small, the coordinate variations are vanish and the reference station coordinates can be considered as fixed values. Then the reason to include the reference station in the epoch-by-epoch LSQ problem is to improve the stability of the final solution.

Some interesting features in the data processing must be denoted:

The basic observable is the L_C combination, using the P_C combination for data cleaning and for a first fixing of the carrier phase ambiguities. The assumed data noise is 1 cm for carrier phase and 1 m for code.

Both station clocks and buoy coordinates are solved simultaneously.

The elevation cut-off angle is attached at 10^0 instead of 15^0. In conditions of calmed sea, the sea surface is almost flat and no multipath of the signal from the emitting satellite is produced by reflection onto the sea surface or waves.

The geocentric coordinates of the buoy are converted to sea surface height by correcting the ellipsoidal heights of the antenna phase center and the water zero level offsets.

A.4.- Calibration results

A.4.1.- Range validation. Direct Calibration

The SSH measured by the altimeter at the overflight is compared with the same magnitude derived from the buoy solution. Thus the range bias is computed by the methodology below:

1st.- The straight average of the estimated SSH_{GPS} along a ≈ 5 min time window centered at the overflight instant and the rms respect to the mean value are computed.

2nd.- The LSQ adjust of the SSHalt along a $\approx$20-observations window centered at the overflight instant and the rms of the window respect to the adjust are computed. They are M-DGR products for the T/P and I-GDR products for the Jason-1.

3rd.- The averaged SSH_{GPS} and the adjusted SSH_{alt} at the overflight are subtracted in order to compute the SSH_{BIAS}. Thus $SSH_{BIAS} = SSH_{GPS} - SSH_{alt}$ and $rms_{BIAS} = \sqrt{rms_{GPS}^{2} + rms_{alt}^{2}}$

In table 12 the straight averages of the estimated SSH_{GPS} are collected with their corresponding rms. The LSQ adjust of the SSH_{alt} provides with the altimeter measurement of the instantaneous sea surface at the overflight instant. The associated rms for these measurement are 4.03 cm for the TOPEX Alt-B [Fu and Cazenave, 2001] and 8.34 cm for Jason-1, in agreement with [Haines et al., 2003].

Campaign	Overflight (UTC time)	Cycle	SSH_{GPS} (m)	SSH_{alt} (m)	SHH_{BIAS} (cm)	Altimeter product
1999	18/03 at 08:45:41	T/P 239	49.12 ± 0.319	49.05 ± 0.04	6.50 ± 32.10	M-GDR TOPEX-B
			49.09 ± 0.323	49.05 ± 0.04	3.70 ± 32.60	
2000	07/07 at 07:34:47	T/P 287	49.24 ± 0.074	49.21 ± 0.04	+3.43 ± 7.96	M-GDR TOPEX-B
2002	28/08 at 15:37:07	J 23	49.29 ± 0.061	49.18 ± 0.08	+10.52 ± 10.35	I-GDR Jason-1

Table 12: SSH_{BIAS} estimation by single point experiments over point TOP-08 for TOPEX-B and over point TOP-11 for Jason-1 radar instruments. The two values in 1999 corresponds to both similar GPS buoys used simultaneously at that campaign (UPCB and JPLB buoys, respectively).

The most scattered SSH_{GPS} estimations (higher rms) corresponds to 1999, mainly due to the SA, that was turned off on 2nd May 2000. Both the rms values in 2000 and in 2002 experiments present similar order of magnitude. Also, as the baseline is longer in 2002 than in 2000 or 1999, it is expected that the common tropospheres assumption is less realistic in the last campaign than in the others, which supposes less accurate vertical coordinate estimation in 2002 than in 2000 or 1999.

The first plots in Fig.82, Fig.83 and Fig.84 show the SSH computed from the buoy observables and their straight average along a window centered at the overflight instant. The second plots present a detail of the overflight showing the altimeter measurements (TOPEX ellipsoid), their corresponding linear adjust around the overflight instant and the measurement of the sea level derived from the buoy.

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, 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).

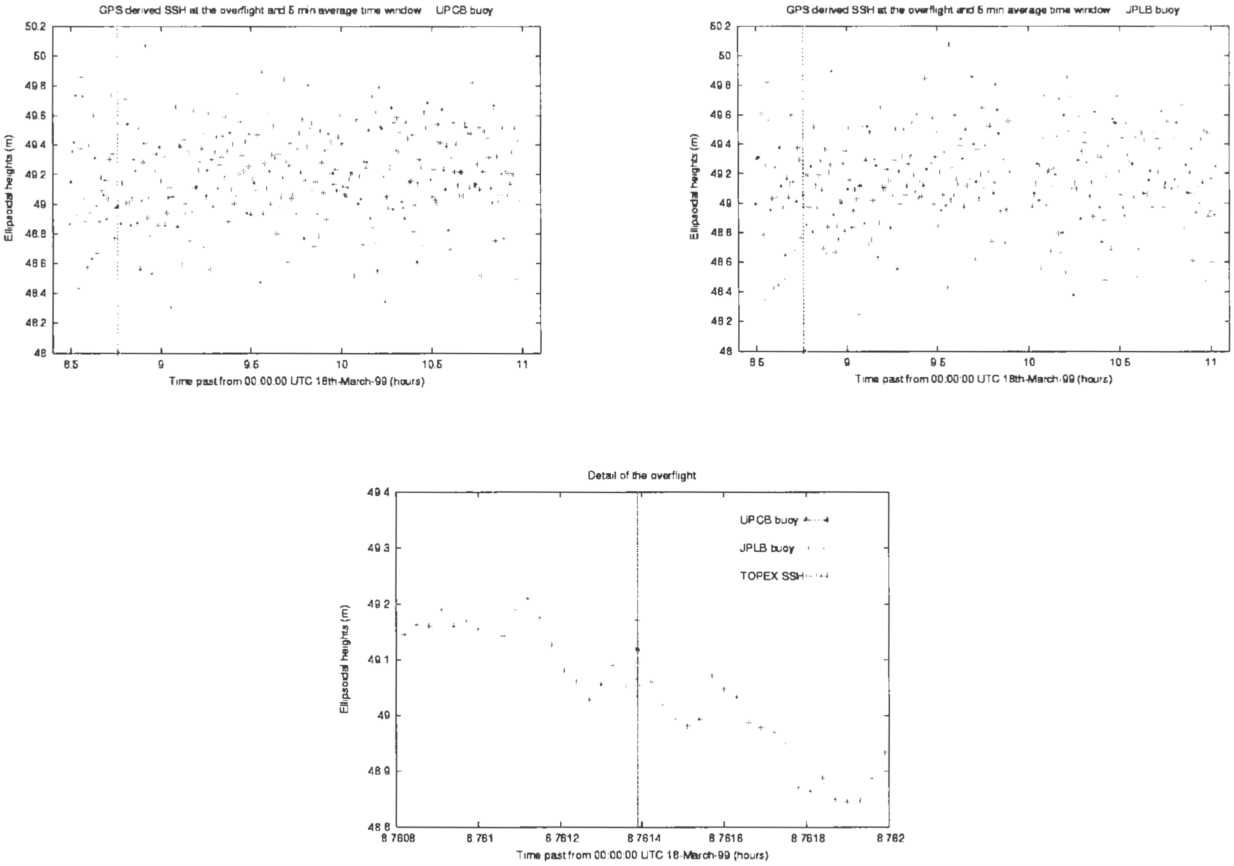


Fig. 82: Campaign 1999, TOPEX-B single point calibration over point TOP-08 ($\Phi = 41.885 \quad \lambda = 3.380$) using both the JPLB and the UPCB buoys.

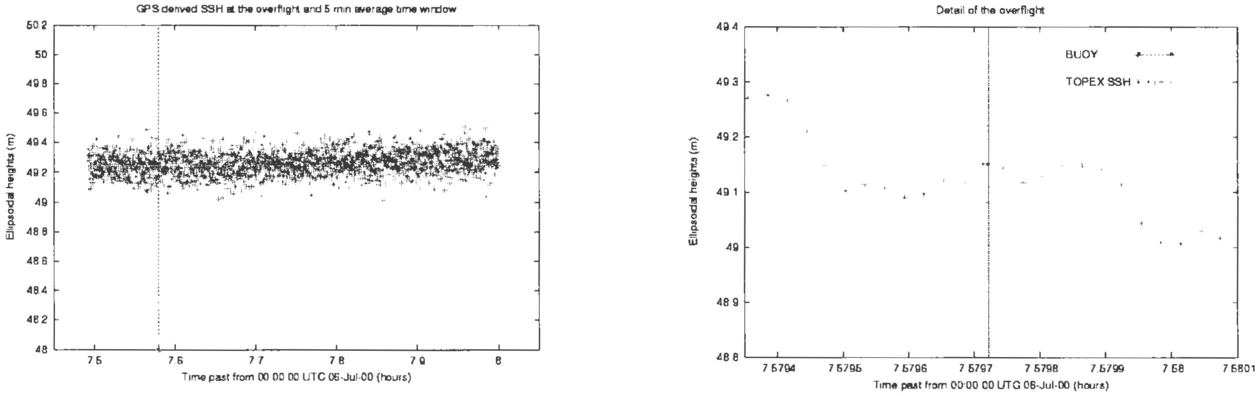


Fig. 83: Campaign 2000, TOPEX-B single point calibration over point TOP-08 ($\Phi = 41.885 \quad \lambda = 3.380$)

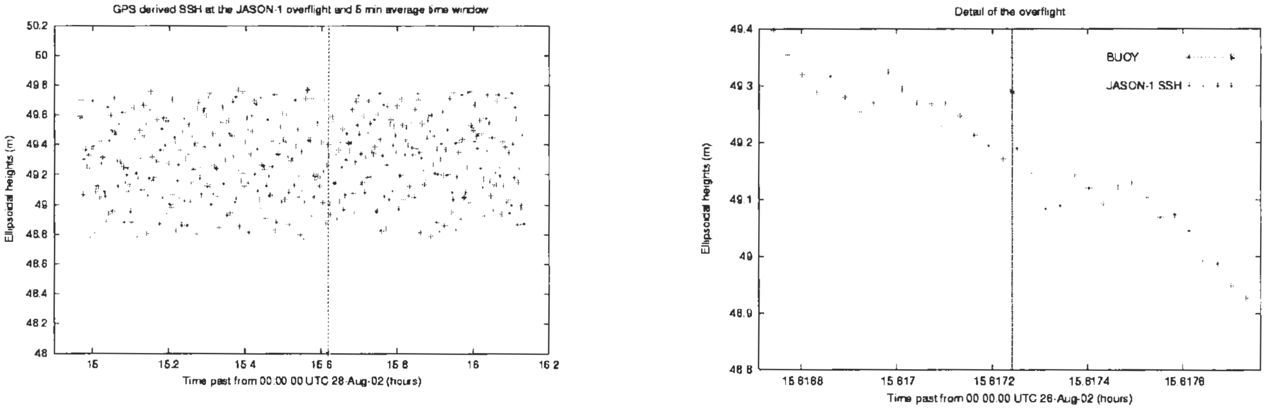


Fig. 84: Campaign 2002, Jason-1 single point calibration over point JAS-11 ($\Phi = 41.740 \quad \lambda = 3.268$).

A.4.2.- Significant Wave Height validation

The significant wave height (SWH) computed from GPS as described in the section before is compared with the simultaneous radar altimeter measurement. Table 13 shows very good agreement between both measurements, thus GPS measurements are very accurate descriptors of SWH because it is the stardard deviation from the mean value of the sea surface.

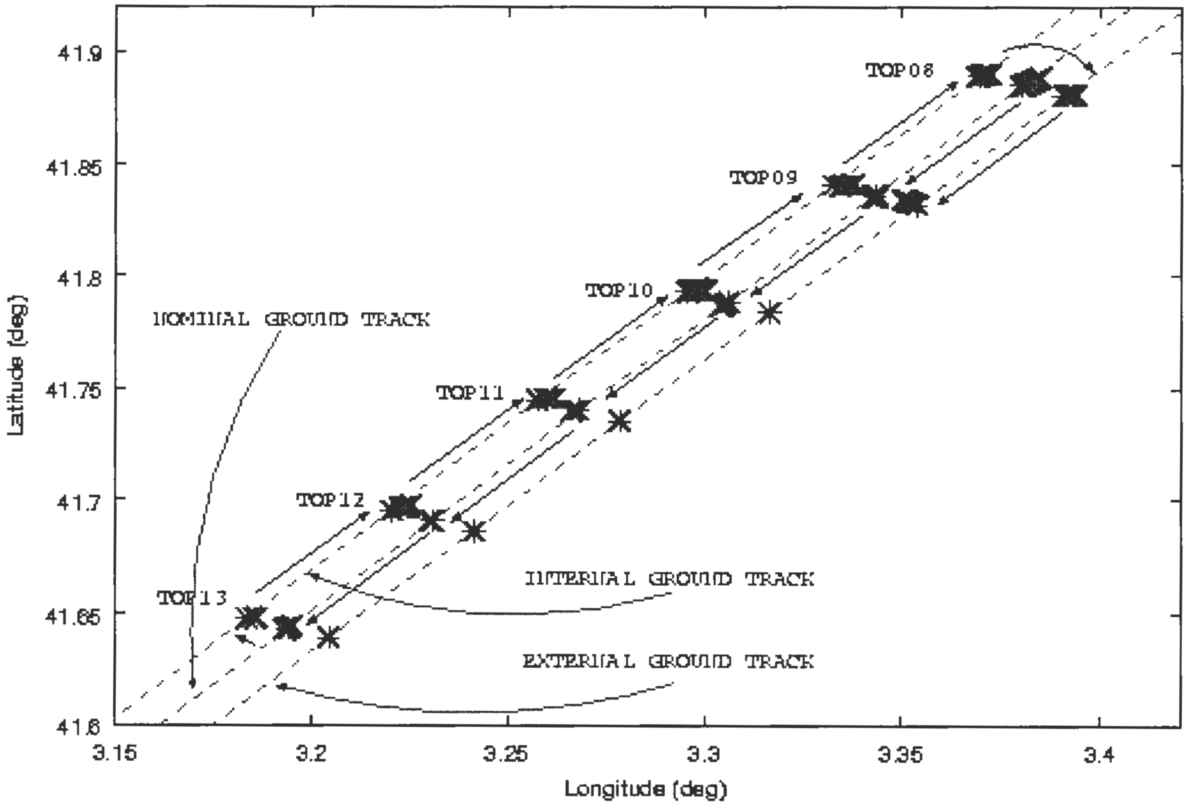
Campaign	SWH_{GPS} (cm)	SWH_{alt} (cm)	Wind speed (km/h)
1999 UPCB	128.0	130.0	31.0
1999 JPLB	129.0	130.0	31.0
2000	21.0	20.0	17.0
2002	27.5	28.0	10.0

Table 13: Significant Wave Heights at the overflight and the in-situ wind speed. The estimated accuracy in the SWH_{alt} *measurements is of 20 cm [Fu and Cazenave, 2001].*

A.4.3.- Indirect calibration and mss mapping

In the 2000 campaign the area along the TOPEX/POSEIDON ground track was surveyed in order to compute a precise local mean sea surface profile and to perform the indirect calibration. The surveying session on 6th July 2000 is summarized in Fig. 85.

The schedule of the surveying session started at point TOP08 (in order to perform the direct calibration during the overflight) and continued along the nominal ground track of the TOPEX/POSEIDON satellite (central track) until point TOP13. After that the inner and outer the parallel ground tracks were also surveyed: from point INT13 to point INT08 and, unfortunately, only points EXT08 and EXT09 of the external ground track. During the 2002 campaign, only the points TOP-9, TOP-10 and TOP-11 were surveyed.



	Latitude	Longitude
TOP08	41.885001	3.380001
TOP09	41.836012	3.343010
TOP10	41.788120	3.306002
TOP11	41.740120	3.268014
TOP12	41.691030	3.231110
TOP13	41.643011	3.194006
INT13	41.647417	3.183532
INT12	41.695484	3.220576
INT11	41.744412	3.257513
INT10	41.792569	3.295626
INT09	41.840476	3.332546
INT08	41.889405	3.369483
EXT08	41.880594	3.390515
EXT09	41.831523	3.353452

Fig. 85: Surveying schedule and buoy tracking on 6th July 2000. The surveyed points are displayed in chronological order and denoted as TOP if they belong to the nominal ground track and as INT or EXT if belong to the inner and outer parallel ground tracks, respectively.

The buoy solution at every point (shown in Fig. 86, plot above) is smoothed using a running average filter. After that, the smoothed instantaneous SSHs are corrected by subtracting the simultaneous values of the SLAs (Fig. 86, plot below). The result is the absolute mss at every surveying point that, which is the most important issue, is time independent. Also, the table included Fig.94 shows the estimated mean formal error of the vertical component at every surveyed point, which helps to give a qualitative idea about the better estimates along the session on 6th July 2000.

Point	Time span **(min)**	σ_{SHH} **(cm)**
TOP08	30.45	3.89
TOP09	19.32	4.52
TOP10	15.47	3.01
TOP11	16.94	5.41
TOP12	8.90	5.39
TOP13	12.47	4.69
INT13	4.74	5.07
INT12	9.97	5.25
INT11	8.95	4.93
INT10	10.97	4.76
INT09	18.82	4.58
INT08	9.97	3.94
EXT08	9.97	4.05
EXT09	11.97	3.75

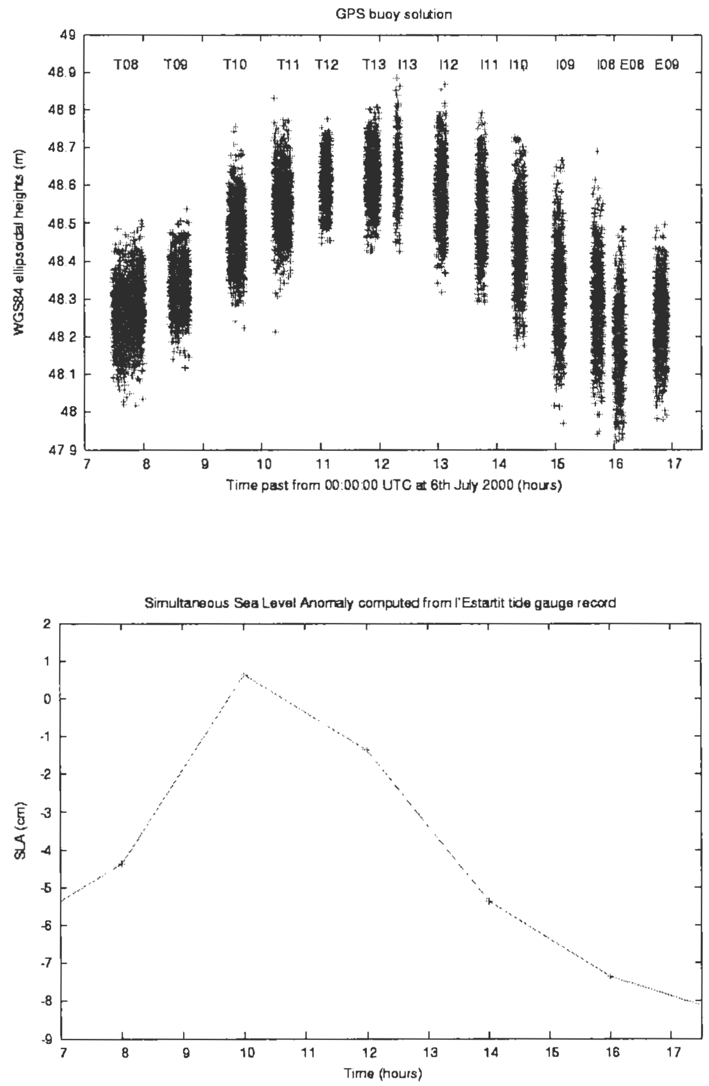


Fig. 86: Above, the GPS hight rate solution for the buoy 6th July 2000. The plot shows the WGS84 ellipsoidal heights (SSH_{GPS} computed at every single point as function of time). Below, the simultaneous SLA computed from the tide gauge long-term record at l'Estartit.

The time independent mss points allow to recover the instantaneous SSH at those locations always that is necessary, because it is only needed to add the SLA value that corresponds to the desired instant. This is the core of the methodology used in the indirect calibration: at every pass of the satellite over Begur Cape, it is possible to compare the SSH derived from the altimeter (M-GDR for TOPEX-B in 2000 and I-GDR for Jason-1 in 2002) with the simultaneously SSH derived from the mean absolute surface that we have computed along the satellite ground track (mss at every surveyed point corrected by the SLA that is simultaneous to the overflight instant).
As it has been commented before, the term 'indirect' relates to the fact that it is not necessary to have a GPS buoy under the satellite during every pass.

The clear advantage is that, in this way, at every single pass we can simulate such many overflights as surveying points we have, obtaining their corresponding single values of the range SSH_{BIAS}. The average of this single point biases gives a mean altimeter bias that is more accurate than a unique observation point with one buoy as in the direct calibration technique. In this document, only a single pass has been monitored with the indirect technique for the TOPEX/POSEIDON and for the Jason-1 altimeters that corresponds to the campaigns in 2000 and in 2002, respectively. Results are summarized in table 14, thus for the TOPEX side-B altimeter the mean bias (for only the cycle 287) results of +2.13 cm with 6.55 cm of rms. In the same table, the mean altimeter bias for the Jason-1 results +10.12 with 6.23 cm of rms (only J-23 pass). The bias computed by this technique are closer to the values given in the literature and their associated rms have decreasing respect to the values obtained in the single point calibrations or direct methods where the buoy is physically present

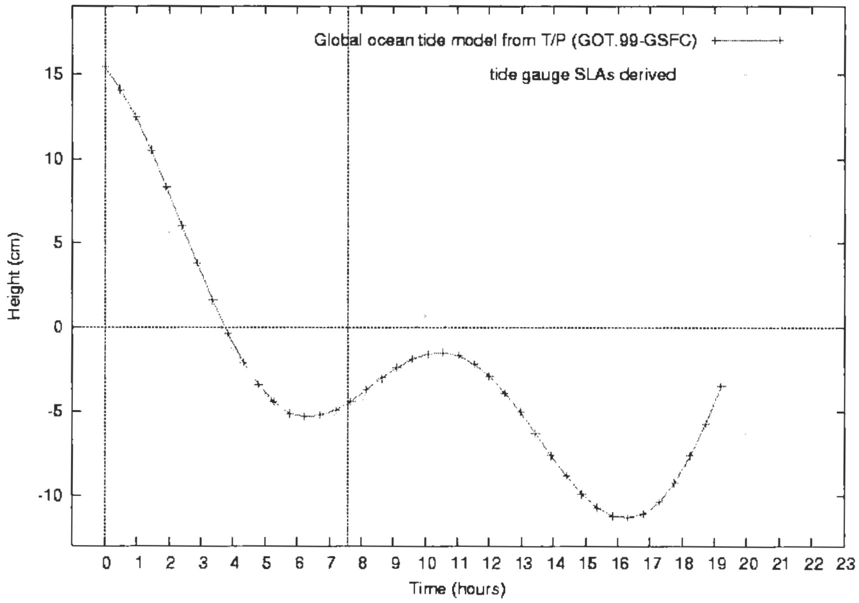
Campaign	Cycle	# averaged points	SHH_{BIAS} (cm)	Altimeter product
2000	T/P 287	6	+ 2.13 ± 6.55	M-DGR TOPEX-B
2002	J 23	4	+10.12 ± 6.23	I-DGR Jason-1

Table 14: SSH_{BIAS} estimation by the indirect method for TOPEX-B and Jason-1 radar instruments in only one pass.

As a remark, it is necessary to apply accurate SLAs to the buoy solution in Fig. 94 in order to obtain an accurate absolute mss at the surveying points. In order to test the accuracy of the SLAs applied to the buoy heights when the mapping of the sea surface, a comparison between l'Estartit tide gauge SLAs and the GOT99-GSFC tide estimates at point TOP08 is given is Fig 95. Both profiles agree reasonably with differences ranging at 1 and 5 cm maximum along a surveying period of 20 hours at 6th July 2000.

The statistics included in Fig. 87 show mean difference between time the series of the GOT99-GSFC model and the tide gauge derived SLAs of -1.34 cm (GOT99 model below the tide gauge) with an rms of 3.22 cm. For this comparison, the tide gauge record has been linearly interpolated from its original sampling rate (1 observation every 2 hours) to the sampling rate of the model, which is 1 observation every 30 min.

It is worthy to remember that the GOT99-GSFC is a long wavelength model of tides, which has low spatial resolution. Anyways, the comparison with the SLAs at the tide gauge location is highly significant and shows, in general, a good agreement.



GOT.00 GSFC model vs Estartit from 0h to 19h on 6th July 2000		
Mean differences (cm)	rms(cm)	#epochs compared
-1.34	3.22	47

Fig. 87: The tide gauge SLAs at l'Estartit and the estimates of the GOT99-GSFC model at the calibration area. Statistics of the epoch-by-epoch comparison. Differences are tide gauge record minus model. The instant of the overflight of the satellite is also plotted showing very good agreement.

Fig. 88 gives some pictures taken during the TOPEX/POSEIDON calibration campaigns in the area of Cape of Begur.

Fig.88: Images of the TOPEX-POSEIDON calibration campaigns developed in 1999 (above) and in 2000 (below).

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