GEODETIC CGPS IMPLEMENTATION AT BARCELONA, L'ESTARTIT AND IBIZA HARBOURS FOR SEA LEVEL MONITORING

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ABSTRACT

Sea level is an environmental variable which is widely recognised as being important in many scientific disciplines as a control parameter for coastal dynamical processes or climate processes in the coupled atmosphereocean systems, as well as engineering applications. A major source of sea-level data are the national networks of coastal tide gauges, in Spain belonging to different institutions as the Instituto Geográfico Nacional (IGN), Puertos del Estado (PE), Instituto Hidrográfico de la Marina (IHM), Ports de la Generalitat, etc.

L'Estartit floating tide gauge was set up in 1990. Data are taken in graphics registers from each two hours the mean value is recorded in an electronic support. L'Estartit tide gauge series provides good quality information about the changes in the sea heights at centimeter level, that is the magnitude of the common tides in the Mediterranean. This data has been used to compute the Mean Sea Surface MSS using GPS Buoys along an ascending track of Topex/Poseidon (July 2000) and Jason-1 (August 2002).

Puertos del Estado (Spanish Harbours) installed the tide gauge station at Ibiza harbour in January 2003. 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. The tide gauge also belongs to the ESEAS (European Sea Level) network. The main objective of the altimeter calibration campaign IBIZA2003 was to check the value of Ibiza Island as a permanent calibration site in the western Mediterranean Sea, to complement the Corsica site in the network of Mediterranean altimeter calibration sites, Corsica, Gavdos and Ibiza.

In the framework of the Spanish Space Project ref:ESP2005-05829, the instrumentation of sea level measurements has been improved by providing a radar tide gauge a Datamar 3000C device and a Thales Navigation Internet-Enabled GPS Continuous Geodetic Reference Station (iCGRS) with a choke ring antenna complementing the actual infrastructure at the Barcelona harbour from Puerto de Barcelona and Puertos del Estado.

Satellite Altimetry is the only feasible way to measure global sea level rise. The mean sea level has been rising at an increasing rate of about 1.7 mm/yr in the period 1870-2000, and about 3.1 mm/yr since 1992.

Keywords: altimetry, calibration, tide gauges, GPS

1 Introduction

Altimeter calibration, Figure 1, is essential to obtain an absolute measure of sea level, as are knowing the instrument's drifts and bias. It is the best way to estimate the global sea level rise. Specially designed tidegauges are necessary to improve the quality of altimetric data, preferably near the satellite track. Further, due to systematic differences a month instruments onboard different satellites, several in-situ calibrations are essentials to tie their systematic differences.



Fig.1: Global sea level rise from satellite altimetry

The main technique for positioning moving platforms with GPS, both in post-processing (offline), and in real time, is the kinematic method. It uses the geometric strength of simultaneous observations of several satellites made with a suitable receiver, to determine the instantaneous position of any vehicle, without the need to have a realistic model of the dynamics of the platform, something usually difficult to model mathematically. Since high accuracy can be obtained in this way with GPS, this approach is universally used today. The static method is used when GPS is used to find the position of a fixed site, and that position is treated as constant (after correcting for small site displacements, such as the earth tide).

Tide gauges measure sea level relative to land. Good tidal models exits for the western Mediterranean. They are critically dependent on accurate bathymetric information, which has improved recently. Long-term sea level change has been quantified recently using a decadal data records from Topex/Poseidon and ERS-1/ERS-2 and using long term (several decades to 100 years) tide gauge records.

A major source of sea-level data are the national networks of coastal tide gauges, in Spain belonging to different institutions as the Instituto Geográfico Nacional (IGN), Puertos del Estado (PE), Instituto Hidrográfico de la Marina (IHM), etc.

2 Altimeter calibration sites

The 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., [1], and on the Harvest Oil platform off the Californian coast for the USA side Haines et al., [2]. 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. [9], Gavdos Island (Greece), Pavlis, Mertikas et al. [5], Lake Eire (USA), Shum et al. [6] and Ibiza, Cape of Begur, (Spain), Martinez-Benjamin et al. [3,4].

The two Spanish areas for altimeter calibration have been the Ibiza island and Cape of Begur . Figure 2



Fig.2: Altimeter calibration sites in the western Mediterranean (image cortesy of Eric Jeansou from Noveltis)

Three preliminary campaigns for TOPEX/POSEIDON (T/P) were made in March 1999 and July 2000 and for JASON-1 in August 2002, in the NW Mediterranean Sea at the Begur Cape area using GPS Buoys provided with a TRIMBLE DORNE MARGOLIN antenna and connected to the receiver on the boat by a coaxial watertight cable.

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: First, positioning of the reference station at the coast near the calibration area (free-network solution) and, second, differential positioning of the buoy respect to the reference (fiducial) site off the coast (differential kinematic solution). 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 area of calibration is showed in Figure 3.



Fig 3: General distribution of 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.

The GPS observables from a network consisted of three permanent ICC stations (Bellmunt de la Segarra, BELL,; Creus Cape, CREU, and Llivia, LLIV), and the temporal site in the coast (station at Begur Cape, BEGU) was processed following a free-network solution strategy with the GIPSY-OASIS II software developed by JPL.

The toroidal GPS buoy used in the three experiments was performed at the ICC based on the original design of the Colorado University, improving the stability and minimaxing the distance between the sea surface and the center of phase of the antenna. The buoy was provided with a TRIMBLE DORNE MARGOLIN antenna and connected to the receiver on the boat by a coaxial watertight cable.

The design was based on the requirements described below:

a) The dome of the buoy must protect the GPS antenna from the sea water and from any eventual accident.b) The dome must be of a kind of material that allows the reception of the GPS signals with a minimum disturbance. c)The buoy must be not very large and heavy to facilitate the transport and its manipulation.d) The buoy must be constructed in such a way that it was possible to use it again in future altimeter campaigns. e)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.f)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.

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.

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 IBIZA 2003 campaign and its logistics has made a contribution to the development of GPS, tide gauges and altimetry applications in oceanography and geodesy providing the means for an on-going calibration system for radar altimetry. It has required an in depth involvement in the field campaign, in the processing of collected data and in the analysis of results. It has showed the uselfullness of Ibiza as a complementary calibration site to Corsica permanent calibration site

In June 2003, one campaign for the calibration and validation of the altimeter data was done in the Ibiza Island. GPS stations, one GPS buoy, one GPS catamaran and two tide gauges were utilized in this campaign. Tide gauges were installed in the Ibiza and San Antonio harbour.

In the table 1 are diplayed the Jason-1 SSH biases from calibration studies: GDR-B (includes a new POE orbit and improved Jason Microwave Radiometer JMR calibration) reduces the geographically correlated errors for Jason-1, leading to more coherent results from local and regional studies.

Site	GDR-A (mm)	GDR-B (mm)	# of cycles	Reference
Harvesť	+141.8 ±6.3	+97.4 ±7.4	108 / 29	Haines et al.
Corsica'	+107.9 ±6.7	+86.3 ±8.6	84/21	Bonnefond et al.
Bass Strait	+152.3 ±7.7	+105.0 ±8.3	18 / 18	Watson et al.
Gavdos	+131.0 ±15	NA	20 / NA	Pavlis et al.
Ibiza	+120.5 ±4.4	NA	33 / NA	Martínez-Benjamín et al.
Regional	+100.0 ±1.0	91.0 ±8.0	21/21	Jan et al.

"Biases given at the 2002.0 reference epoch

2.1 L'Estartit calibration site

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). L'Estartit tide gauge is a classical floating tide gauge set up in l'Estartit harbour. Data are taken in graphics registers, from which a data each two hours is recorded in electronic support. This two hour data are interpolated to one hour data to do a good harmonic analysis of the astronomical tide. Tide gauge is controlled each week to get correct and accuracy data and the tide gauge maintenance has the same periodicity. A quality control to ensure the self-consistency of the records has been made. The tide gauge heights are geo-referenced to a benchmark of the Cartographic Institute of Catalonia (ICC). The coordinates of this geodetic mark have been calculated in 1999 by a precise leveling survey in order to connect the benchmark to the local EUREF subnetwork that includes the permanent GPS IGS-ITRF station at Cap de Creus. On 5 June 2008 the float tide gauge has been located near the old location in the l'Estartit harbour. The Figure 4 shows its location. The longitude, latitude and height are 3.2060021; 42.0533614; 50.491.



Fig. 4: New location of l'Estartit float tide gauge.

2.2 Ibiza calibration site

Puertos del Estado (Spanish harbours) installed a new tide gauge station at Ibiza harbour between 2002 and 2003. The station, Figure 5, belongs to the REDMAR network, composed at this moment by 21 stations distributed along the whole Spanish waters, including also the Canary islands (<u>http://www.puertos.es</u>). Figure 6 shows the levelling made at Marina de Botafoch harbour.



Fig. 5: Location of Ibiza harbour pressure tide gauge



Fig. 6: Location of Ibiza harbour pressure tide gauge

2.3 Barcelona calibration site

A Radar tide gauge DATAMAR 3000C device, provided by GEONICA S.L. is ready to be installed at Barcelona harbour. This modern installation will work in a parallel way to the Puertos del Estado radar tide gauge MIROS active since 2006, belonging to REDMAR tide gauge network. The goal is the real time monitoring of sea level and the generation of historical series for their further study. Figure 7 shows the two radar tide gauges and Figure 8 shows the infrastructure.

The DATAMAR 3000C tide gauge unit is powered by internal batteries to be recharged by an optional solar panel or by the mains 220 / 110 V - 50/60 Hz. In the case of mains failure, the internal batteries will allow the unit to still continue to work during several days, depending on the power drain conditions and sensors installed.

In order to assure a high accuracy of the internal clock, very important for tide data intercomparison, the TIDE-GAUGE recorder incorporates a GPS receiver for automatic clock synchronization. This allows a time accuracy in the order of 40 nanoseconds, suffering only a short but constant synchronization delay of some milliseconds. It is intended that the overall system will constitute a CGPS station of the TIGA (GPS Tide Gauge Benchmark Monitoring) network.



Fig. 7: The radar DATAMAR 300C tide gauges to be installed (UPC) and the operational radar tide gauge MIROS (REDMAR network from Puertos del Estado)



Fig. 8: Expected location of the two radar tide gauges DATAMAR 3000C (UPC-3) and MIROS (Puertos del Estado-2) at the Barcelona harbour and the two GPS reference stations at the Barcelona harbour (Puerto de Barcelona) and at the Cartographic Institute of Catalonia (UPC).

3 Sea Level Monitoring by Airborne LIDAR

An airborne calibration campaign with a Partenavia P-68 (ICC) carrying an Optech Lidar ALTM-3025 (ICC) was made on June 16, 2007, overflying l'Estartit harbour (about 6 km wide by 50 km long) and mapping with observe lidar strips of about 800 m. wide.

The validation of this new technology LIDAR may be useful to fill coastal areas where satellite radar altimeters are not measuring due to the large footprint and the resulting gaps of about 20-40 km within the coastline. Measurements with a GPS Buoy were made during the experience and a GPS reference station was installed in Aiguablava. A DSM of l'Estartit harbour area was derived in the first results from the campaign. On October 12, 2007, another LIDAR campaign was made at night with a Cessna Caravan 208B. Figures 9, 10 and 11.



Fig. 9: Aiguablava GPS station and GPS Buoy



Fig. 10: The Partenavia P-68 and the Cessna Caravan 208B of th Cartographic Institute of Catalonia.



Fig. 11: The two tracks of the 16 June and 12 October, 2007, and the LIDAR Optech ALTM 3025.

4 Sea Level Monitoring by Spaceborne Laser (ICESat/GLAS)

ICESat, Schutz et al. [7], Urban et al. [8] was launched on June 13, 2003. at 60 km altitude with a 94° inclination. Its primary mission was to detect polar ice changes. Other objective areas were :sea ice, land, vegetation, cloud & aerosols and oceans. The main instrument is GLAS with 3 redundant lasers L1/L2/L3. The footprint spacing is about 165 m along-track, with a size of about 70 m. ICESat has pointed to targets Ibiza and l'Estartit for three campaigns: L3g (Oct/Nov 2006), L3h (Apr/May 2007) and L3i (Oct/Nov 2007). In the Figure 11 it is showed the ICESat tracks after focusing the Ibiza and l'Estartit harbours. Figure 12 shows some tracks at Ibiza and l'Estartit sites.



Fig. 12: The ICESat/GLAS observation tracks over Ibiza island and l'Estartit. The dots mean the reference tracks

The main objective is the validation of the airborne LIDAR technology for the determination of sea level in support to the marine altimeter calibration made with GPS Buoys/Catamaran. In order to test the potential of Lidar to connect sea level measurements from tide gauges in the coast with altimetry measurements offshore, a lidar airborne campaign was made flying underneath the track of the ICESat laser altimeter near the l'Estartit harbour on October 12, 2007.

The ICESat laser altimeter delivers ellipsoidal heights and can be used over land to calibrate the lidar instrument onboard the Cessna Caravan 2083 airplane (ICC). The calibrated airborne lidar can then be used over ocean to detect the sea surface height. Currently no radar altimeter is able to get closer to the coast than about 15-20 km at least, however, significant shallow water tides and ocean dynamics, e.g. Kelvin waves, takes place at the coast, where it can be observed by tide gauges if available.

Altimetry cannot observe these phenomena, but a lidar system could be used to connect the two different measurement systems. Since the airborne lidar is affected by tilts and biases, a calibration should take place over land, and only ICESat altimetry currently delivers sound land elevations as opposed to much less accurate radar altimeters over land. The investigations is related to the point that the coastal sea level can be observed with GPS buoys, and may be lidar airborne campaigns, Braun.

4 Summary

The main objective will be the estimation from the time series of sea level change in the areas of Barcelona, l'Estartit and Ibiza for sea level monitoring and altimeter calibration. It is intended that the overall systems will constitute a CGPS station of the TIGA (GPS Tide Gauge Benchmark Monitoring) network. The TIGA network of tidegauges collocated with GPS and MET units provides near real-time and long-term data of sea level.

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