Calibration of Radar Altimeters in the Corsica Area: Recent Improvements in view of Jason-1 mission

Y. Ménard (CNES), E. Jeansou (SILOGIC) and A. Orsoni (IGN)
Centre National d'Etudes Spatiales, Toulouse, France

P. Exertier, P. Bonnefond, O. Laurain and F. Barlier
Observatoire de la Côte d'Azur - CERGA, Grasse, France

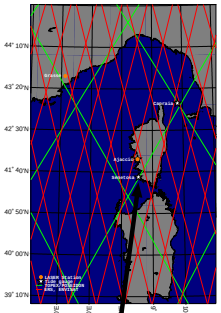
B. Haines (JPL), *Pasadena, California, USA*
D.G. Kubitschek (CCAR), *Boulder, Colorado, USA*

bonnefond@obs-azur.fr

Abstract

Since two years, we have developed a double geodetic site in Corsica (Western Mediterranean), in view of establishing a semi-permanent base for the purpose of absolute altimeter calibration experiments.
A first campaign has been carried out between 1996 - 1997 [*Exertier et al.*, 1998]. A fundamental geodetic point has been established, thanks to the FTLR, GPS, and DORIS systems (Aspretto, Marine Base, Ajaccio), in addition to a dedicated tide gauge site for the TOPEX/Poseidon (T/P) ground track number 85, which is located at the Senetosa Cap (40 km south Ajaccio). Uncertainties on the geoid altitudes at Senetosa have lead to a calibration value of 5.6 ±0.7 cm for T/P. In view of the Jason-1 mission, and thanks to a GPS-buoys experiment, which was conducted in May 1998, the Senetosa site has been greatly improved.
The experiment is briefly described. First results of measurements of sea levels from the tide gauges and buoys are given; comparisons are at the level of 0.7-1.5 cm rms, which is very encouraging for preparing the calibration of Jason-1 mission.

Configuration in Corsica



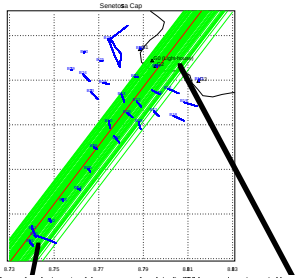


Figure 1. T/P ground tracks (green) and the mean ground track (red). GPS buoys trajectories are in blue. Geodetic points are represented by triangles.

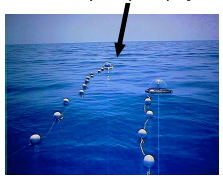


Figure 2. GPS buoys: Turbo-rogue (left) and SERCEL (right).

Figure 3. Turbo-rogue GPS on G_1.

General overview of the calibration site

Description

Corsica has been chosen to be a semi-permanent calibration site for radar altimeters of present and future altimetric missions. It is composed of mainly 2 segments.
- Ajaccio: a geodetic site for satellite tracking (SLR, DORIS). A permanent GPS station and a numeric tide gauge are planned to be installed in a next future.
- Senetosa: a tide gauges site located close to TOPEX/Poseidon ground track (N° 85)

Brief History

- Sept. 1996 to Feb. 1997: Calibration experiment using French Transportable Laser Ranging System at Ajaccio and two tide gauges (one at Ajaccio and the other at Senetosa).
- May 1998: Installation of two others tide gauges at Senetosa. Geodetic operations (GPS, leveling, see Tables 1 and 2). GPS Buoys experiment for geoid slopes determination.

GPS Buoys Experiment

Calibration results from the first campaign (1996-97) have shown that the geoid gradient in the Senetosa area should be very high. Then, it has been decided to improve this site by:
- Installing 2 other tide gauges in both sides of T/P ground tracks (see Figure 1).
- determining the geoid slopes using a GPS buoys technique. In order to compare the GPS receivers precision/accuracy, 3 GPS receivers type have been used: Turbo-rogue (JPL), Ashtech (IGN) and SERCEL (DSNP).

Table 1. Geodetic points heights references

Tide gauges / GPS Buoys	Geodetic points
M_1	G_1
M_2	G_2
M_3	G_3
SERCEL GPS Buoy	G_4
ASHTECH GPS Buoy	G_5
Turbo-rogue GPS Buoy	G_6

G_1 is located very in G_6

Table 2. GPS geographic coordinates of geodetic sites (ITRF 96 epoch)

Point GPS	λ (deg)	ν (deg)	h (m)
G_1	8.7513 (8.45) 2.9457	41.5746 (41.44) 0.2722	69.5961
G_2	8.7566 (8.57) 2.9363	41.5619 (41.26) 0.2510	52.7514
G_3	8.7599 (8.48) 2.9361	41.5743 (41.31) 0.1648	59.3138
G_4	8.8168 (9.04) 2.9321	41.5499 (38.19) 0.1561	59.5477
G_5	8.7568 (9.16) 2.9316	41.5175 (5.44) 756	85.3514

Result obtained with Geodyn II (old software). Transformation in geographic coordinates with current ellipsoid (GRS80) (a = 6378137 m; 1/f = 298.2572236).

GPS Buoys experiment results

1- GPS Buoys Heights determination

Instantaneous GPS Heights

- GPS heights have been processed from RINEX files of all the receivers using Ashtech Software (PRISM-PNAV Vers. 2.4). GPS orbits are from navigation message. Ionospheric correction from dual-frequency, and ambiguities solved.
- SERCEL data have also been processed using DSNP software (3SPack).
- Turbo-rogue data have also been processed using Gipsy/Oasis II [Webb and Zumberge, 1995]. Rather than explicitly differencing the observations, GOAIII solves for clocks of the participants (white-noise resetes with one reference clock fixed). In the final step, we use the ionospheric-contraint bias fixing technique [Blewitt et al., 1989], which does involve formation of double differences.

Filtered GPS Heights

- All GPS heights have been filtered using Vondrak filter [Vondrak, 1977], with a 60 second period. It means that all signals with period higher than 60 s are kept. An example of filtered data is given in Figure 4.
- GPS heights from GOAII software (Turbo-rogue data) have also been filtered by a boxcar filter of 60 s.

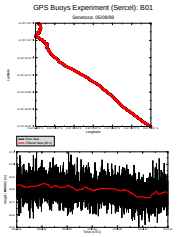


Figure 4. GPS heights from SERCEL data.
Red lines correspond to filtered heights using Vondrak filter.

Comparisons

- All GPS heights (filtered or not) have been compared for common sessions (different receivers).
- Comparisons of software solutions have also been performed.

Results are given in Table 3. An example of differences between common sessions and 2 different receivers is presented in Figure 5.

Table 3. GPS height differences per receiver and by mode; units are in centimeter

Data*	n	min	max	mean	std dev	comment
Raw	13458	-49.82	48.12	0.24	9.91	Turbo-rogue - SERCEL
Filtered	13458	-8.75	8.69	0.23	1.66	Turbo-rogue - SERCEL
Raw	14551	-13.79	22.14	-1.46	4.17	Turbo-rogue - ASHTECH
Filtered	14551	-3.18	2.93	-1.45	0.82	Turbo-rogue - ASHTECH
Raw	13722	-33.64	20.19	-1.84	2.46	SERCEL - SERCEL (DSNP)
Filtered	13722	-9.81	4.83	-1.84	0.57	SERCEL - SERCEL (DSNP)
Raw	20133	-49.99	32.88	-0.75	3.91	Turbo-rogue - Turbo-rogue (GOA II)
Filtered	20133	-10.19	9.88	-0.78	1.19	Turbo-rogue - Turbo-rogue (GOA II)

*Raw: Vondrak with 60 s period has been applied for all the comparisons.
*Software: 3SPACK from Sercel and SERCEL Navigation Processing.
*Software: Gipsy/Oasis II.
When no other information is in bracket, comes from Ajaccio's software (PRISM-PNAV) is used.

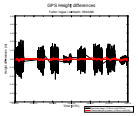


Figure 5. Differences between Turbo-rogue and A sketch GPS heights on the 05/10/98 session.

2- Tides correction for GPS Buoys Heights

- The GPS heights have been corrected from tides variations using mean tides variations computed with the three tide gauges (M_1, M_2 and M_3; see Tables 5 and 6). An independant determination has been performed by B. Haines with Turbo-rogue data (GPS heights, filter, tides correction): differences are presented in Table 4.
- The Tide gauges time series are illustrated in Figure 6.
- An example, of this correction is given in Figure 7.

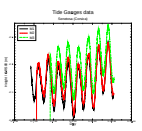


Figure 6. Tide gauges heights time series.

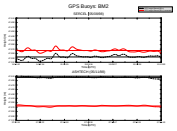


Figure 7. Tide correction for 2 GPS sessions, Red lines for corrected heights.

Table 4. GPS height differences (corrected between A. Orsoni and B. Haines solutions; units are in centimeter

Data	n	min	max	mean	std dev	comment
Raw	2104	-47.31	12.81	-1.47	4.01	Turbo-rogue (A_1-Orsoni) - Turbo-rogue (B_1-Haines*)
Filtered	2104	-12.24	3.81	-1.47	2.41	Turbo-rogue (A_1-Orsoni) - Turbo-rogue (B_1-Haines*)

*Raw: Vondrak with 60 s period. Corrections for tides from B. Haines (based on the average of the 3 tide gauges data).
*Raw: ~ 1 Hz Boxcar ~ 60 (A_1 for one hour). Corrections for tides from B. Haines (based on the average of the 3 tide gauges data).

Table 5. Mean of tide gauges heights and data from 05/10/98 (Hour 0) to 05/11/98 (Hour 0), from M_1, M_2 and M_3

	M_1	M_2	M_3
Mean sea (CNES) (m)	1794.6 (794)	1794.6 (7558	1794.6 (7591
Mean height (m)	47.147	47.483	47.463
Reference epoch: day 129 (05/08/98) at 20:00			

Table 6. Corrections applied to GPS heights (computed from M_1, M_2 and M_3; units are in centimeter

n	min	max	mean	std dev	comment
75187	-13.79	18.63	1.17	4.55	Mean for
75187	0.64	1.81	1.48	0.23	Standard Deviation of mean for

3- Comparisons with Tide gauges

- Differences between GPS heights and tide gauges heights have been computed at each GPS data using linear interpolation between tide gauges data. Results of the average differences for all receivers at each tide gauges location are given in Table 7. Figure 8 gives an example of such differences for M_1 tide gauge.

Figure 9 shows GPS heights and M_1 tide gauges data for a GPS session.

Table 7. GPS Height - Tide gauges; ALL receivers; units are in centimeter

Data	n	min	max	mean	std dev	comment
Raw	1482	-5.33	12.49	1.82	1.59	All receivers M1
Filtered	1482	-0.33	5.39	1.82	0.64	All receivers M1
Raw	1932	-6.28	10.54	1.88	2.51	All receivers M2
Filtered	1932	-0.38	3.79	1.88	1.04	All receivers M2
Raw	3723	-6.81	7.61	4.38	1.61	All receivers M3
Filtered	3723	-2.21	4.48	4.38	0.54	All receivers M3

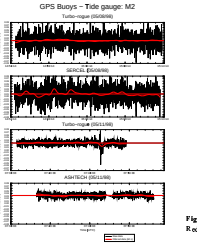


Figure 8. Differences between GPS and tide gauges heights at M_1 location.
Red lines for filtered GPS heights.

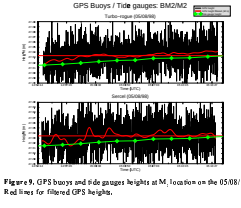


Figure 9. GPS buoys and tide gauges heights at M_1 location on the 05/08/98.
Red lines for filtered GPS heights.

4- Geoid Height differences

Figure 10 illustrates the altitude differences. Where G refers to Geoid and E refers to Ellipsoid.
$h_{G1} = h_{E1} - h_{1G}$
$h_{G2} = h_{E2} - h_{2G}$
The differences above are only true if the geoid slope is not very different at the location of point 1 and 2. Indeed, to compute such differences h_{ij} need to be parallel to h_{iG}. So if the slopes at 1 and 2 are not too much different the error is the same and disappear when computing differences.
- $\delta h_{1,\,GPS} = (h_{1E} - h_{1G})$: geoid height difference between points 1 and 2.
- $\delta h_{1,\,GPS} = (h_{1E} - h_{1G})$: deduced from GPS heights.
- $\delta h_{1,\,levelling} = (h_{1E} - h_{1G})$: measured by leveling.

So: $\delta h_{1,\,GPS} = \delta h_{1,\,GPS} - \delta h_{1,\,levelling}$

During the experiment geodetic points heights near each tide gauges have been measured by GPS and heights difference between M_1 and M_2 has been measured by leveling. Results are given in Table 9.

Figure 10. Scheme of altitude differences

Table 8. Mean of GPS heights for all receivers and sessions at M_1, M_2 and M_3

	M_1	M_2	M_3
Mean height (m)	47.148	47.483	47.463
Standard deviation (m)	0.016	0.017	0.016

Using mean of filtered data, with tide corrections.

Table 9. Comparisons of geoid height differences computed from GPS buoys, tide gauges and leveling; units are in centimeter

	GPS Buoys*	Tide gauges†	Leveling
M_1 - M_2	-3.83	-3.74	-3.59
M_1 - M_3	-5.23	-4.67	
M_2 - M_3	-1.39	-0.46	

*computed from Table 8.
†computed from Table 5.

5- Map of GPS Buoys Heights

Figure 11 illustrates the sea heights obtained with all GPS filtered heights corrected from tides. Interpolations for gridding have been limited to 2.8 km distance with a grid spacing of 50 m.

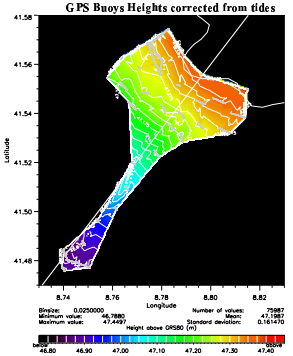


Figure 11. Map of GPS Buoys heights (filtered and corrected from tides).
The white line represents T/P mean ground track. Gray lines correspond to individual GPS buoys data.

Discussion

First, we want to emphasize how intensive the survey was and how rich the data set is. It is probably the first time that a site has been successfully surveyed so much with dual-redundant pelagic GPS, and complemented it with terrestrial GPS, 3 simultaneous tide gauges, and local leveling. The results look great so far too. Getting down to 1-2 cm with kinematic GPS is a real challenge (repeatability or precision is one thing, but establishing agreement with tide gauges takes this a step further since it is a rigorous test of accuracy).

GPS Buoys preliminary results

- Comparisons of receivers/softwares: differences are at the level of 1-2 cm rms with mean differences below 1 cm. The main signal appears to be biases by GPS session may be due to solving technique (ionospheric bias, ambiguities, ...)
- Comparisons with tide gauges (Table 7): GPS heights appear to be always higher than for tide gauges (~1.4 cm). The mean difference could be due in part to the presence of the radome on one antenna (while the fiducial site had none). Multipath could also contribute. Differences of mean biases between (M_1,M_2) and M_3 have to be investigated (tide gauges biases).
- Sea heights have then be determined with a precision better than 1-2 cm rms, showing an along-track slope of 60 cm over 10 km and across-track gradient which can reach ~5 cm between M2 and M3 (~3 km).

Future Plans

- Use of the sea heights grid to link T/P measurements and tide gauges ones in order to perform altimeter calibration.
- Densification of the GPS Buoys heights if necessary.
- New calibration campaign using FTLRS at Ajaccio in 1999.

References

Exertier, P., P. Bonnefond, O. Laurain, F. Pierron, and F. Barlier, New French Transportable Laser Ranging System: positioning, collocation and altimeter calibration experiments results, submitted to Journal of Geodesy, 1998.

Blewitt, G., Carrier phase ambiguity resolution for the Global positioning system applied to geodetic baselines up to 2000 km, J. Geophys. Res. 94(B8), 10187-10203, 1989.

Vondrak, J., Problem of smoothing observational data II. Bull. Astron. Inst. Czech, vol. 28, pp. 84-89, 1977.

Webb, F. and J. Zumberge, An Introduction to Gipsy/Oasis II, Precision software for the analysis of data from the global positioning system, JPL D-11088, 1995.