Corsica: a multi-mission absolute calibration site

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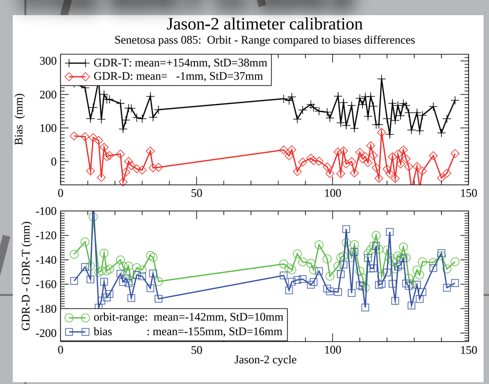
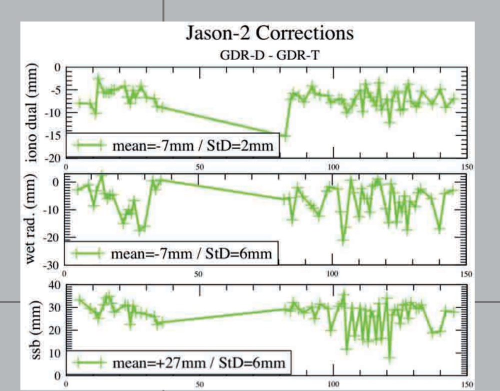
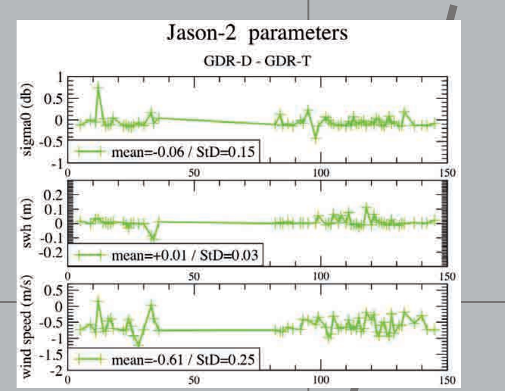
Analysis of the Jason-2 GDR-D Products

From GDR-T to GDR-D







Jason-2 GDR-D minus Jason-2 GDR-T corrections and biases differences in mm (except for Sigma0, Significant Wave Height and wind speed)

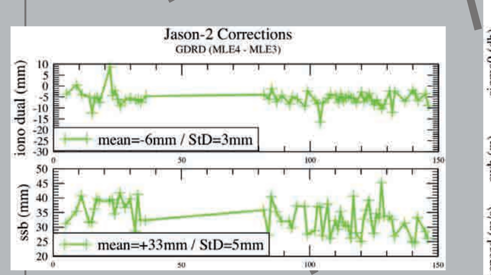
	Mean	σ
Corrections		
Wet troposphere (AMR)	-7	6
Ionosphere (dual frq.)	-7	2
Sea State Bias	+27	6
Total	**+13**	
Environmental parameters		
Sigma0 (dB)	-0.06	0.15
SWH (m)	+0.01	0.03
Wind speed (m/s)	-0.61	0.25
Biases		
Absolute biases	-155	16
Orbit - range	-142	10

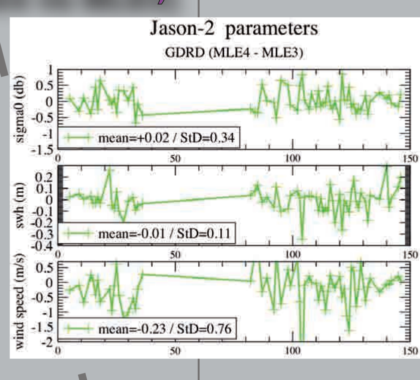
~-156 expected from instrumental errors:
24.71 – 180.92 = **-156.21 mm**
- wrong altimeter PRF applied in the ground segment on Jason 2 (truncation effect)
- antenna internal Path Delay reference error

Differences comes mainly from:
- MQE fit regional differences: ~4 mm
- GDR-D – GDR-T orbit differences: ~3 mm
- pseudo datation bias: ~4 mm
=> ~3 mm remains unexplained, waiting for the complete set for better averaging

Since the launch of the Jason-2 satellite on 20th of June 2008, the GDR (Geophysical Data Record) data were distributed in version T. The OSTST community requested (during the OSTST meetings of 2009, 2010, and 2011) several modifications in order to correct for some problems in the GDR-T and to improve several standards: a complete description of the evolutions included in GDR-D standards is available in the Jason-2 User Handbook document (http://www.aviso.oceanobs.com/fileadmin/documents/data/tools/hdbk_j2.pdf). Apart from the models improvements, some instrumental errors were discovered by the CNES project team that affected the range and then biased the SSH by about 156 mm (see insert under the table at right). The reprocessing in the so-called GDR-D standards is now on going and cycles 1-36 / 82-146 are currently released: this analysis is based on this set and compared to the previous GDR-T product. **The main result is that with the GDR-D products the SSH is now close to be unbiased** (see "TOPEX/Poseidon, Jason-1 and Jason-2 absolute SSH biases" subsection). Concerning, the corrections one of the major improvement is the SSB that were updated (Tran et al., 2010) and the differences is +27 mm when compare to GDR-T. Another very important improvement lies to the wet tropospheric correction (Brown et al., 2010) that permits to reduce the contamination in the coastal areas (Bonnefond et al., 2012). The last improvement that enter in the absolute bias closure equation is the ionospheric correction that was biased by ~8 mm. From our analysis, the GDR-D are fully conform to the expected changes. There is only ~3 mm that remains unexplained from the corrected instrumental errors but probably due to the incomplete set. Apart from the SSH, users will expect some few changes in the SWH (~1 cm at Corsica site while close to zero from global average) but more important changes on the wind speed (-0.61 m/s at Corsica site compared to ~-0.5 m/s from global studies).

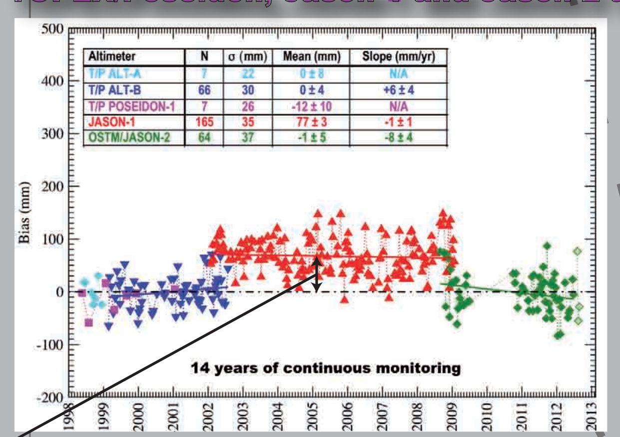
Impact of the retracking (MLE4 vs MLE3)





In the GDR-D products both MLE4 and MLE3 retracking are available (as well as ICE1). We thus have performed a comparative studies showing that **while the SSH is almost unbiased when using MLE4 (-1 ±5 mm) it is biased by about 22 mm when using MLE3.** This difference is mainly due to the SSB correction. Apart from the SSH, users will expect some few changes in the SWH (~1 cm at Corsica site) but more important changes on the wind speed (-0.23 m/s at Corsica site). Moreover, we have performed a study on the altimeter land contamination comparable to the one performed in Bonnefond et al. (2012) and presented in this poster: results presented in **Figure 9** (bottom right of the poster) **clearly show an opposite behavior of the retracked range when approaching the coast (<10 km)**. As typical sea surface slopes of 1–10 microradians lead to currents at the level of 0.1–1.0 m/s at mid latitude, the estimated slope due to land contamination (8 microradians) can produce artificial current of ~0.8 m/s in the coastal areas (<10 km).

TOPEX/Poseidon, Jason-1 and Jason-2 absolute SSH biases



-78 mm (Jason-2 – Jason-1) to be compared to instrumental errors discovered by CNES project team:
117.02 + 3.16 – 180.92 = **-60.74 mm**
- wrong altimeter internal path delay value used on Jason-1
- wrong altimeter PRF applied in the ground segment on Jason-1 (truncation effect)
- antenna internal Path Delay reference error

-78 mm is reduced to -68 mm when improving SSB and wet radiometer correction for Jason-1

Abstract

In collaboration with the CNES and NASA oceanographic projects (T/P and Jason), the OCA developed a verification site in Corsica since 1996 and operational since 1998.

Now, Corsica is, like the Harvest platform (NASA side), an operating calibration site able to support a continuous monitoring with a high level of accuracy: a 'point calibration' which yields instantaneous bias estimates with a 10-day repeatability of around 30 mm (standard deviation) and mean errors of 3-4 mm (standard error). For a 35-day repeatability (ERS, Envisat), due to a smaller time series, the standard error is about the double (~7 mm).

In-situ calibration of altimetric height (SSH for ocean surfaces) is usually done at the vertical of a dedicated CAL/VAL site, by direct comparison of the altimetric data with in-situ data. Adding the GPS buoy sea level measurements to the "traditional" tide gauges ones, it offers the great opportunity to perform a cross control that is of importance to insure the required accuracy and stability. This configuration leads to handle the differences compare to the altimetric measurement system at the global scale: the Geographically Correlated Errors at regional (orbit, sea state bias, atmospheric corrections...) and local scales (geodetic systematic errors, land contamination for the instruments, e.g. the radiometer).

Our CAL/VAL activities are thus focused not only on the very important continuity between past, present and future missions but also on the reliability between offshore and coastal altimetric measurement. With the recent extension of the Corsica site (Capraia in 2004 and Ajaccio in 2005) and the ESA support, we are now able to perform absolute altimeter calibration for ERS-2, Envisat, HY-2A and SARAL/Altika in a next future with the same standards and precision than for T/P and Jason missions. The upcoming Sentinel-3 mission will naturally be included in our CAL/VAL activities but will require with some extension of the local geoids. This will permit to improve the essential link between all these long time series of sea level observation.

Results

Altimeter Bias Determination

The calibration principle is to compute the difference between the sea surface height (ssh) measured by the altimeter and the ssh recorded by the tide gauge. These two ssh are located at two distant points. The link between the two ssh is partly the geoid slope from offshore altimetric measurement to tide gauges locations. The situation of the Corsica calibration sites implies to take it into account. This slope can reach 6 cm/km (at Senetosa Cape) and specific GPS campaigns have been realized in order to determine a geoid map of about 20 km long and 5 km wide centered on the satellites ground tracks. The calibration process as well as the geoid map determination have been described in detail in Bonnefond et al. (2003a and 2003b respectively) and illustrated in Figure 1.

In this study, the calibration process has been applied in the same way to TOPEX/Poseidon, Jason-1&2 and ERS-2/Envisat satellites and for the Cape Senetosa and Ajaccio sites. The tide gauges series used in this analysis are illustrated in Figure 2 where our longer time series is from the M3 location at Senetosa and spans from May 1998 to now.

The presented altimeter biases are derived from Senetosa (TOPEX/Poseidon and Jason-1&2) and Ajaccio (ERS-2 and Envisat) tide gauges.

For TOPEX/Poseidon the altimetric data used are the MGDR, while it is the GDR-C for Jason-1 and Envisat, and the OPR-2 for ERS-2. For Jason-2 both GDR-T and GDR-D (see top left insert) are analyzed. For Envisat due to the lost of S-Band after cycle 065, the GIM model has been used for the ionospheric correction for homogeneity of the series. For the others, the atmospheric corrections come from on board instruments (radiometer and altimeter). The mean altimeter biases for each satellite are given in Figure 3. Note that all the biases are corrected from the land contaminations described hereafter (radiometer and altimeter).

GPS "BY-PRODUCTS": Wet Troposphere

The wet tropospheric correction (path delay with a negative sign) is an important source of geographically correlated bias. Indeed, it is mainly linked to radiometer land contamination, with differences existing between calibration sites depending on the distance from the coast and the orientation of the satellite approach to the land. This contamination for the Envisat descending pass (#130) overflying Ajaccio site is illustrated in Figure 4b. Compared to the case of T/P and Jason 1&2 overflight (ascending pass #85) at Senetosa where the impact can reach 10-15 mm (Figure 4a), the bias induced by the MWR land contamination is at the level of few mm. Details on the land contamination and the technical description of the various radiometers are given in Bonnefond et al. (2010a, 2010b and 2011).

The bias induced by the land contamination can also be evaluated by comparisons with the wet tropospheric correction determined from in situ GPS data. The GDR-C data from both JMR and AMR exhibit a bias compared to GPS, while delays from the JMR and AMR using the Enhanced Path Delay (EPD) product developed by Brown (2010) agree with GPS at the millimeter level (Table 1) in an averaged sense. The long time series of JMR vs. GPS comparisons at the Corsica site (more than five years beginning 2003) also permits monitoring of drifts in the path delay measurements. The use of the EPD products also shows an improvement in term of stability (Table 1) and the estimated drift for JMR is negligible (+0.5 mm/yr), as the associated standard error is at the same level. The comparisons of the wet troposphere correction derived from the MWR with GPS reveal a very small bias of about +6 mm, close to the one observed from the comparison with ECMWF (~+4 mm at the end of the interpolation area, Figure 4b). The observed drift of 1 mm/yr in the comparisons with GPS is at the same level than associated standard error and so not statistically significant (this is mainly due to the 35-day repetitivity for Envisat lower than the 10-day ones for the Jason satellites).

Investigations of errors in the wet tropospheric corrections are of particular importance for coastal applications of satellite altimetry. Such studies can characterize the impact of radiometer land contamination on the Sea Surface Height determination.

GPS BUOY "BY-PRODUCTS": Significant Wave Height

Since 2000, a GPS buoy is also used in the calibration process at Senetosa. GPS buoy measurements also provide the sea height variations due to waves. Because GPS buoy is drifting during the calibration pass (about 1 hour of measurement centered on Time of Closest Approach), filtered sea height is removed to avoid sea height variations due to geoid slope. Standard deviation on the GPS buoy sea height residuals is then computed (σ_{shr}). GPS buoy measurements have also their internal error which have been estimated during quasi-static session to be at the level of 2.6cm (σ_{gps}). The standard deviation on the GPS buoy sea height residuals is then the root square sum of σ_{gps} and σ_{wave} (where σ_{wave} is the standard deviation of GPS buoy measurements due to waves). SWH (or $H_{1/3}$) is then deduced from the formula:

$SWH_{buoy} = 4.\sigma_{wave}$.

Current error budget of GDRs (Bonnefond et al., 2011) for SWH is 10% or 40 cm (which ever is greater) with a goal of 5% (or 25 cm). From Figure 5 and Table 2, the comparisons between SWH from altimetry and SWH from GPS buoy measurements show that the error on SWH is far better than what is expected from GDRs and very close to the goal. With a correlation of ~87 %, whatever the satellite, the GPS buoy appears to be a valuable tool to validate SWH from altimetry. However, it is difficult to validate it over the full range of SWH due to too harsh sea-state conditions to ensure safe navigation for high values of SWH but also due to strong tilts of the SWH buoy that lead to lots of losses of lock.

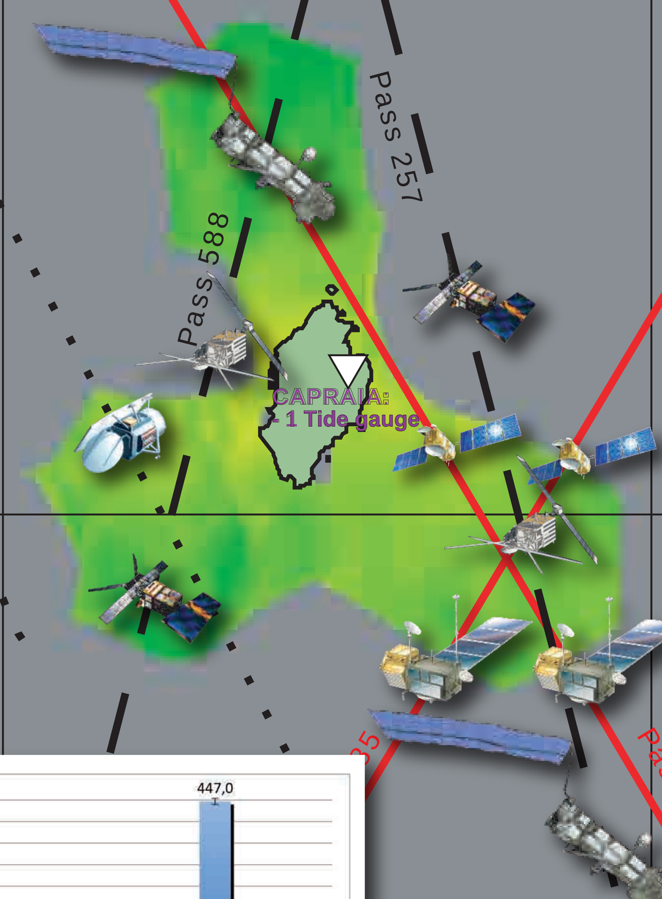
Altimeter land contamination (details in Bonnefond et al., 2012)

Typical footprint values are provided in Table 3 and illustrated in Figure 6. It clearly appears that up to several kilometers off nadir, all backscattered signals can corrupt waveforms and consequently range estimation. Analyzing the behavior of Sea Surface Height due to the altimeter land contamination is not obvious because of the height variations from one cycle to another due to tides and ocean dynamics that are higher in magnitude than the expecting error itself. Moreover, as the satellite is moving from ocean to the coast (or the reverse) the geoid signal will also affect the Sea Surface Height variations up to several centimeters per kilometer. The Corsica calibration site process is then perfectly designed for such a study as we correct for the geoid slope and the deduced cycle-by-cycle altimeter bias is implicitly corrected from tides and ocean dynamics thanks to the differences between altimetric and tide gauges heights. Moreover, even if the cycle-by-cycle altimeter bias is the result of the mean of all the high-rate entering the surfaces mapped with the Catamaran-GPS, the individual high-rate are saved and can be stacked over a long period to be able to extract any persistent behavior as a function of distance to the coast. Figure 7 illustrates this for T/P, Jason 1&2 and Envisat. Results at Senetosa (Table 4) clearly show a drop of the Sea Surface Heights for T/P and Jason satellites when approaching the coast but while the estimated slope is very small for T/P (~2mm/km) it is about four times bigger for Jason 1&2 (~8 mm/km). Figure 8 illustrates what happens when Jason 2 is approaching the coast with a clear modification of the shape of the waveforms. Far off the coasts, waveforms conform to the Brown model which is the model usually used to retrack the ocean waveforms. From 10 km offshore, the slope of the trailing edge is slightly modifying. The echo becomes more "peaky" due to weaker land backscattered signals and consequently, the estimates provided by the retracking algorithm are potentially altered.

Thanks to a large number of GPS buoy deployments at Senetosa since 2000 and Ajaccio since 2008 (respectively 98 and 12) and notably at different locations for Jason 2, we have derived mean values of the altimeter bias at offshore locations where the altimeter should not be affected by land contamination. The results presented in Figure 7 are in good agreement with the general shape of the high-rate biases and the lower values of the biases deduced from the GPS buoy for T/P and Jason 1&2 at 10 km clearly shows that, even at 10 km, the land contamination affects the range. At Ajaccio, the location where the GPS buoy is deployed is the only one far enough from any land to avoid contamination and the mean value of the GPS buoy biases is also in good agreement with the shape of the tide gauges high-rate biases.

Conclusion

Capitalizing on dedicated instrumentation, a coastal calibration site such as Corsica can yield results that strengthen the important link between open-ocean and coastal measurements in the context of the altimetric error budget.



MACINAGGIO: - 1 Tide gauge

AJACCIO: - FTLRS (not permanent) - IGS GPS receiver - DORIS (not permanent) - 1 Tide gauge

SENETOSA CAPE: - GPS receiver - Weather station - 4 Tide gauges

Pass 130

SARAL/AltiKa (EnviSat ground track)

Sentinel-3A

Pass 085

HY-2A

Claude Gaillemin's house

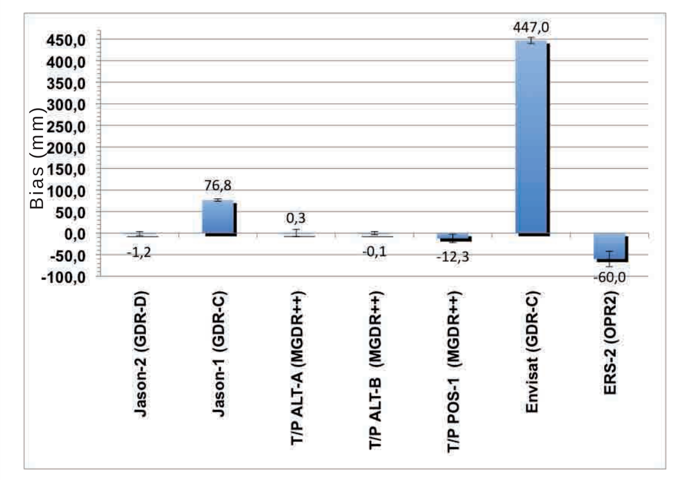


Figure 3. Absolute biases determined from Senetosa site for TOPEX/Poseidon, Jason-1 and Jason-2 as well as from Ajaccio site for Envisat and ERS-2.

Table 1. Radiometers minus GPS wet troposphere

Instrument	Mean (mm)	σ^* (mm)	Drift (mm/yr)	Formal error (mm/yr)
JMR - GPS	+18	12	+0.8	0.8
JMR/EPD** - GPS	0	11	+0.5	0.7
AMR - GPS	+12	14	-0.1	1.7
AMR/EPD** - GPS	+1	14	-0.1	1.6
MWR*** - GPS	+6	15	+1	1

* σ is the standard deviation.
** Enhanced Path Delay (EPD) for AMR (Advanced Microwave Radiometer) onboard Jason-2 and JMR (Jason-1 Microwave Radiometer) onboard Jason-1.
*** MicroWave Radiometer onboard EnviSat

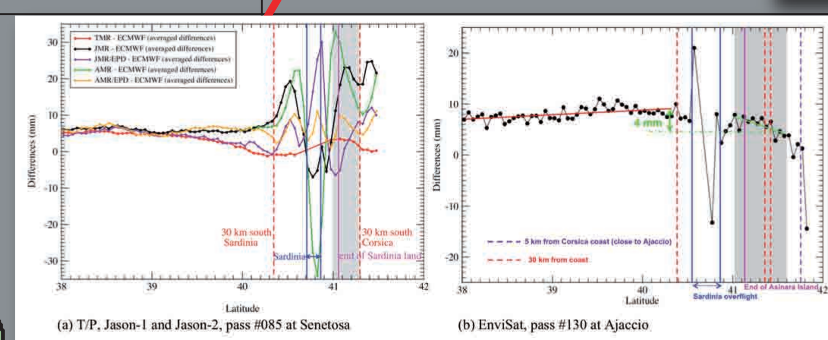


Figure 4. Comparison of averaged differences (every 5 km) between wet tropospheric correction from radiometers and ECMWF model at Senetosa (a) and Ajaccio (b). The dashed red lines correspond to a 30 km distance from the coast. The blue plain lines correspond to Sardinia overflight. The pink plain line corresponds to the end of the small Asinara Island. The grey area indicates the interpolation area for the calibration process.

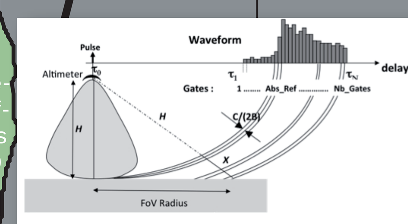


Figure 6. Schematic representation of a pulse-limited altimeter short pulse propagating from the altimeter to the sea surface. See Table 3 footnotes for explanations of notations.

Table 3. Total footprint radii for past, current and future (italic) missions

Instrument (satellite)	FoV radius[a] (m)	Surface (km^2)	x^b (m)	Last gate	Abs. Ref. gate	B (MHz)	H (altitude, km)
POSEIDON-1(TOPEX/Poseidon)	6116	118	14.0	62	32	320	1336
ALT-A&B(TOPEX/Poseidon)	10492	346	41.2	120	32	320	1336
POSEIDON-2&3(Jason-1&2)	9489	283	33.7	104	32	320	1336
RA-2(Envisat)	7550	179	36	122	45	320	790
SIRAL(CryoSat-2)	7979	200	44.0	128	34	320	723
AltiKa(SARAL)	6123	118	23.7	128	52	480	790
SRAL(Sentinel-3)	7885	195	39.4	128	44	320	790

[a] FoV_radius = $\sqrt{((H+x)^2 - H^2)}$ (Field of View).
[b] x = (Nb_Gates – Abs_Ref)*c/(2B), where B is the bandwidth and c is the speed of light.

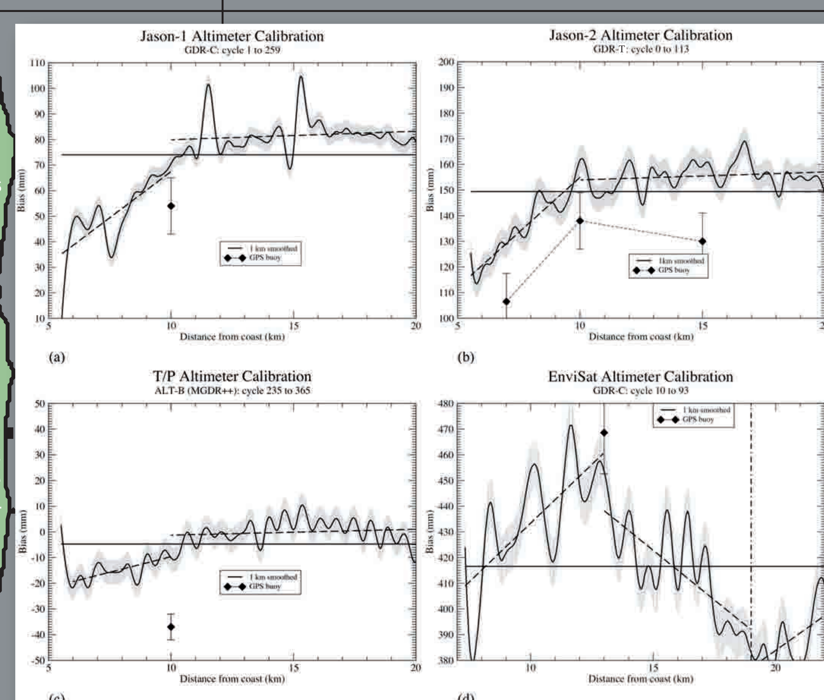


Figure 7. High-rate biases from tide gauges sea level measurements as a function of distance to the coast for: (a) Jason-1, (b) Jason-2, (c) TOPEX/Poseidon at Senetosa, and (d) Envisat at Ajaccio. Black diamonds are the mean values of the biases determined from the GPS buoy sea level measurements with the error bar (standard error). The dashed lines correspond to linear regressions in the different areas described at the beginning of Section 3.1.1; the straight plain black lines correspond to the mean of the whole data and correspond to the classical mean bias computation used at the Corsica calibration site. The vertical thin dash-dot line on (d) corresponds to the Capu di Muro location. The grey shaded areas correspond to the standard deviation of the raw high-rate biases (standard deviation divided by the square root of the number of values over 1 km).

Table 4. Slope in the SSH and bias differences due to the altimeter land contamination (derived from Figure 7)

Site / Instrument	Slope (mm/km)	Bias differences* (mm)
Senetosa (5 km to 10 km)		
ALT-B (TOPEX/Poseidon)	+2.4	+4.6
POSEIDON-2 (Jason-1)	+7.2	+7.6
POSEIDON-3 (Jason-2)	+8.6	+6.1
Ajaccio (RA-2, EnviSat)		~+30
7 km to 13 km	+9.1	
13 km to 19 km	-7.7	
19 km to 22 km	+6.8	

* estimated from the area where altimeter should not be contaminated: 10 km to 20 km at Senetosa and only at 13 km for Ajaccio (see text in the beginning of section 3.1.1 for details).

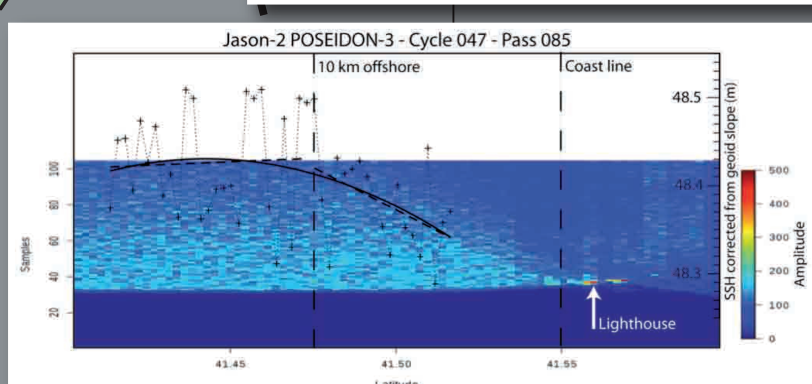


Figure 8. Jason-2 20-Hz waveforms for pass #085 on cycle 047: the waveforms are plotted as latitude (x-axis), gate number (y-axis) and amplitude in FFT power units (color scale). The 20 Hz Sea Surface Heights corrected from geoid slope have been superimposed (crosses). The dashed line corresponds to the linear regression separated at 10 km and the plain line to a quadratic fit over the whole data set.

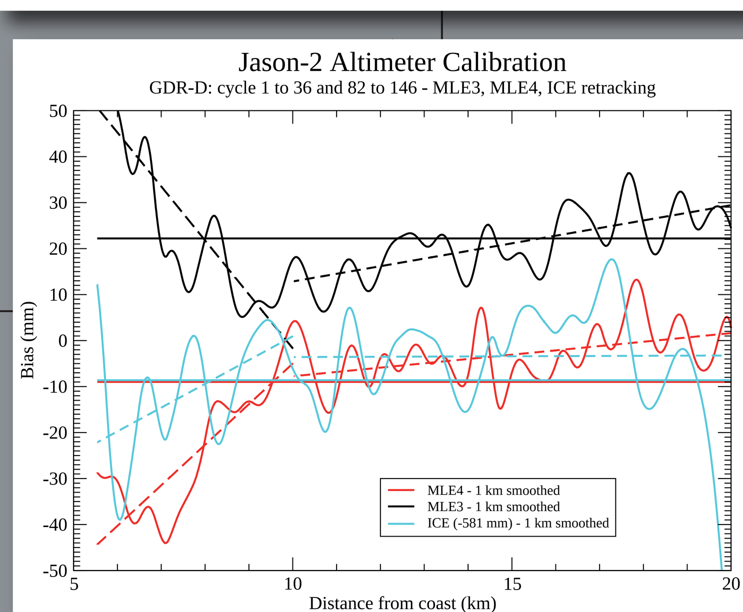


Figure 9. Same study than Figure 7 but using Jason-2 MLE3, MLE4 and ICE retracking in GDR-D products.

Table 4. Slope in the SSH for MLE3, MLE4 and ICE retracking (Jason-2 GDR-D)

Retracking	Distance < 10 km Slope (mm/km)	Distance > 10 km Slope (mm/km)
MLE3	-12.0	+1.6
MLE4	+9.0	+0.8
ICE	+5.6	-1.9

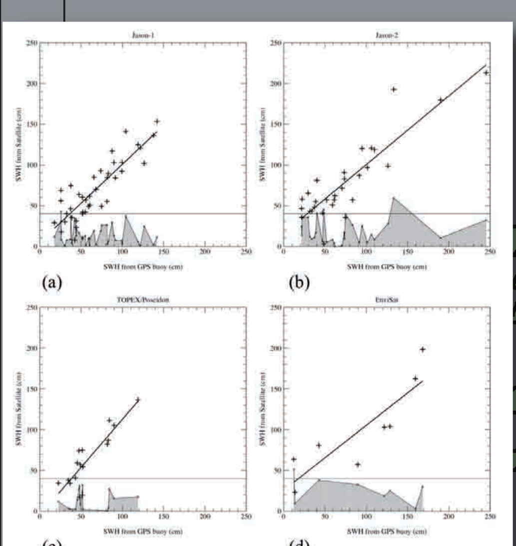


Figure 5. SWH from altimetry as a function of SWH from GPS buoy measurements: (a) Jason-1 (b) Jason-2 (c) TOPEX/Poseidon at Senetosa and (d) EnviSat at Ajaccio. Shaded areas correspond to absolute values of SWH differences. Plain bold lines correspond to linear regressions. The horizontal thin line corresponds to the expected error budget of 40 cm for SWH below 4 m (10 % for SWH above 4 m).

Table 2. SWH from altimetry versus GPS buoy SWH

Satellite	Correlation (%)	Slope	σ (cm)	Mean (cm)	Number
Jason-1	87	1.0	18	14	39
Jason-2	88	0.8	24	18	26
T/P	87	1.2	17	14	16
EnviSat	87	0.8	31	26	8

σ is the standard deviation of SWH differences. Mean value of absolute differences.

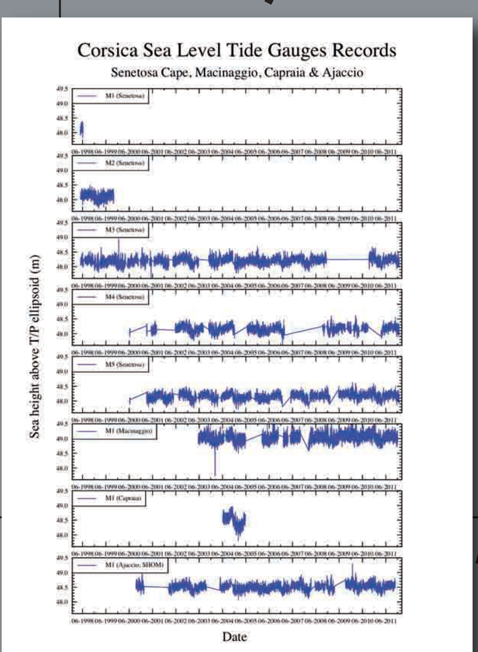


Figure 2. Tide gauges time series in Corsica

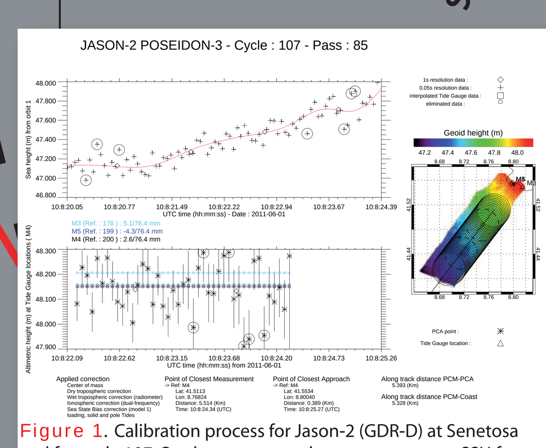


Figure 1. Calibration process for Jason-2 (GDR-D) at Senetosa and for cycle 107. On the upper panel, crosses represent SSH for high-rate data and diamonds for 1 Hz ones. On the lower panel, the altimetric heights are corrected from the geoid height differences at the tide gauges locations. On the map at right, the high-rate and 1 Hz data are plotted at their locations along with their footprint circles deduced from Chelton et al. (1989) formula.

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