Global altimeter SWH data set, Version 4, October 2008

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INTRODUCTION

Altimeter SWH measurements are presently available almost continuously over a 16-year time period from the six altimeter missions ERS-1&2, TOPEX-Poseidon, GEOSAT Follow-ON (GFO), Jason-1 and ENVISAT . Each altimeter data product has specific characteristics (format, flags), and in order to facilitate the access to SWH altimeter measurements and the use of this long time series, data were extracted from the original products, screened according to quality flag values, corrected and gathered into homogeneous daily data files.

DATA

The altimeter data are the Geophysical Data Records (GDR), or equivalent, distributed by the space agencies, as summarized in Table 1.

Satellite	Product	Cycles	Time Period	Comments
ERS1	OPR	83 to 156	14-04-1992 to 02-06-1996	Phases C an G only
ERS2	OPR	1 to 137	15-05-1995 to 30-06-2008	
ENVISAT	GDR	9 to 70	27-09-2002 to 04-08-2008	
TOPEX Poseidon	M-GDR	1 to 481	25-09-1992 to 08-10-2005	End of mission
Jason-1	GDR	1 to 232	15-01-2002 to 03-05-2008	Version *b*
GEOSAT FO	GDR	37 to 219	07-01-2000 to 23-07-2008	

ERS-1 data are the ESA Radar altimeter Ocean Product (OPR) described in Cersat (1996), for phase C (April 14, 1992 - December 20, 1993) and phase G (March 24, 1995 – June 6, 1996). The ERS-1 phases A - B (August 1, 1991 to March 30, 1992), D (December 23, 1993 to April 10, 1994) and E - F (April 10, 1994 to March 21, 1995) are not available in the OPR format; the re-processing is still going on.

ERS-2 data are the OPR (Cersat 1996), for the whole mission, going on since May 15, 1995. After June 22, 2003 the ERS-2 coverage has been seriously reduced due to the failure of the on-board tape recorder.

TOPEX Poseidon are the Merged Geophysical Data Record (M-GDR) described in AVISO (1996), over the whole mission, from September 25, 1992 to October 9, 2005.
Jason are the Jason GDR (Picot et al. 2003) from cycle 1 (January 15, 2002) to cycle 209 (September 18, 2007). The Jason GDR processing is version *b* for the whole data set.

GEOSAT Follow On are the GDR (NOO 2002), distributed by John Lillibridge (NOAA/NESDIS/ORA), from cycle 37 (January 7, 2000) to cycle 202 (October 8, 2007).

ENVISAT are the ESA RA-2 GDR product available from the end of cycle 9 (September 27, 2002) to cycle 60 (August 20, 2007) and described in ESA (2002).

DATA SCREENING

Altimeter SWH measurements are extracted from the various products and selected according to the specific quality flags described in the dedicated user guides.
The following flags and conditions are tested, according to the altimeter.

For ERS: swh zero and default values; number of averaged 20 Hz measurements larger than 16; measurement confidence data (mcd) flag bits 0, 7 and 8.

For TOPEX: swh zero and default values; swh_Pts_Avg equal to 8; AGC_Pts_Avg equal to 16; Geo_Bad_1 bits 1 and 3; Geo_Bad_2 bit 0.

For Poseidon: above TOPEX flags and Alt_Bad_1 bits 2-5; Alt_Bad_2 bits 2-5.

For GFO: 1 Hz quality flag bits 0, 4, 6, 7, 9, 10, 19-21; noaa_flag<3; nval_swh=10; swh_std/swh<0.2

For Jason: qual_1Hz_alt_data flag;; swh_numval_ku larger than 18; surface_type 0 or 1; swh_rms_ku>0; swh_ku>0.

For ENVISAT: product quality flag; swh mean and std zero and default values; mcd bit 16; alt_surface_type 0 or 1; num_18Hz_ku_ocean_swh larger than 18; ku_ocean_retracking_quality flag: ku_ocean_backscatter_coef zero and default values; abs(off_nadir_angle_wvform)<1000;

Specific tests are also performed for Jason-1 and ENVISAT, based on the ratio of SWH standard deviation to SWH mean values, established during the validation (Queffeulou 2004).

Above quality flags and tests are not sufficient to discard all the erroneous SWH data. Spurious measurements are still observed: some are located in the vicinity of the coast where some 'land' can be within the altimeter footprint (some land data are also not flagged), or in areas of high scattering resulting in so-called sigma0 blooms (Mitchum et al. 2004). Some other individual spurious measurements (corresponding mainly to high values of SWH) are not explained. Consequently the data are filtered to eliminate these measurements. The screening is based on the analysis of the differences between successive along track SWH measurements. For each pass (half orbit) mean value and standard deviation of differences of SWH measurements from pairs of consecutive points are estimated. At 1 second along track sample, two consecutive points are separated by about 6 or 7 km. A range is then defined by the mean value of the differences plus or minus 3 times the standard deviation (4 times for GFO). Individual data for which the differences with the neighbouring measurements are outside this range are then discarded. Specific thresholds are also used at the beginning or at the end of continuous along track series i.e. corresponding to over land passes or to flagged data series. The whole data set from the six altimeter missions were processed in this way. The number of discarded data is low. Only a few measurements per pass, when it happens. All of them appear to be erroneous measurements.

ICE & LAND MASK

Individual altimeter data contaminated by sea ice or land were further eliminated using ice and land masks.
The ice mask is build using the Polar Sea Ice concentration product freely available at CERSAT data centre. Ftp address to get this product is
ftp://ftp.ifremer.fr/ifremer/cersat/products/gridded/psi-concentration

The earth mask is build using the Land-Sea Mask available at USGS from the Global Land 1-KM AVHRR Project (http://edcsns17.cr.usgs.gov/1KM).

DATA CORRECTION

Comparisons with buoy data (Queffeulou 2003,2004) show that the altimeter SWH estimate is in general in agreement with the in-situ data, with standard deviations of differences of the order of 0.30 m, but tends to slightly overestimate low SWH and to underestimate high SWH. Correction to SWH were then established. These corrections, in general linear, correspond to a few percent of SWH.
A correction was also estimated for the TOPEX SWH drift between 1996 and 1999. For GFO the correction was established for the global oceans through TOPEX and ERS-2 comparisons. For ENVISAT and Jason, SWH corrections were obtained from an update (Queffeulou 2006) of buoy comparison results of Queffeulou (2004).
Updated validation results are given in the annexe I.

Details of corrections are given hereunder:

ERS-1

For swh<=2.87 swh_cor = poly3(swh), with:
a0 = 0.3815; a1 = 0.8692; a2 = 0.0746; a3 = -0.0062

For swh>2.87 swh_cor = 1.2510 x swh – 0.2458

ERS-2
swh_cor = 1.0642 x swh + 0.0006

TOPEX
Side-A(up to cycle 235):
swh_cor = 1.0539 x swh - 0.0766 + dh
with:
dh = 0 for cycle < 98
dh = poly3(98) - poly3(cycle) for 98 <= cycle <= 235
with a0 = 0.0864 ; a1= -6.0426×10^{-4} ; a2 = -7.7894×10^{-6} ; a3 = 6.9624×10^{-8}

Side-B (after cycle 235):
swh_cor = 1.0237 x swh - 0.0476

GEOSAT FO
swh_cor = 1.0625 x swh + 0.0754

POSEIDON
swh_cor = 0.9914 x swh – 0.0103

JASON-1
swh_cor = 1.0429 x swh + 0.0266 version *a*

swh_cor = 1.0250 x swh + 0.0588 version *b*

ENVISAT
swh_cor = 1.0585 x swh - 0.1935

DATA FILE NAME, STRUCTURE, FORMAT…

One data file per day, in netcdf format.

Parameters:
1 time in day since 1 january 1900
2 latitude
3 longitude
4 10 m wind speed
5 Ku-band backscatter coefficient
6 Ku-band Significant Wave Height (1 second average)
7 Ku-band Significant Wave Height standard deviation
8 corrected Ku-band Significant Wave Height
9 satellite altimeter index:
  1: ERS-1
  2: ERS-2
  3 :ENVISAT
  4 :TOPEX
  5 :Poseidon
  6 :Jason-1
  7 :GEOSAT Follow-On
10 cycle number
11 pass number (relative orbit number within a cycle): half revolution for TOPEX, Poseidon, Jason and GFO ; revolution for ERS and ENVISAT

Note:
for ENVISAT cycles 15 to 24, the GDR pass number is erroneously incremented within the cycle. To recover the true pass number:
for Ascending pass true_pass_number=(pass_number+1) / 2
for Descending pass true_pass_number=pass_number / 2

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ANNEXE I : UPDATED VALIDATION RESULTS

To test altimeter SWH corrections, global monthly mean values of SWH from the various altimeters are compared. Altimeter SWH measurements are collected over the whole oceans, between the extreme latitudes of the TOPEX and Jason orbits (i.e. between 66.15° South and 66.15° North). Monthly mean values of SWH are then computed, when the data number over the month is larger than 600000.

Figure 1 shows the time series of monthly mean SWH for the GDR data of the various altimeters. There are large biases between the altimeter SWH mean values, reaching for instance 50 cm between ERS-1 and TOPEX. A trend is also observed on the TOPEX data between 1996 and January 1999. This has been discussed in details in Queffeulou 1999, 2004 and 2006, and corrections were proposed.

Figure 2 shows the time series obtained when using the corrected measurements, based on corrections given in the above "Data Correction" chapter. Differences and trends are significantly reduced. There are still some slight biases which are analysed hereunder.
Note that some anomaly occurs on the GFO data near the end of the time series (May, June and September 2007). Indeed since September 26, 2006, due to power limitation, the GFO altimeter has been power cycled so that it is off during eclipse periods (cf http://gfo.bmpcoe.org/Gfo/Exec_col/Exec_col.htm). This reduces the measurement sampling, so that GFO mean values of swh are not estimated from the globat data set, for theses time periods(i.e. the data number threshold of 600000 is not high enough and has to be increase maybe to 800000 or 900000...)

Figures 3, 4 and 5 show the biases of the altimeter monthly corrected SWH mean values, relative to TOPEX, GFO and ENVISAT, respectively. Reference altimeter SWH is also reported on the graphs, in dm.

Mean value (bias) and standard deviation of differences corresponding to the various curves in Figures 3 to 5, were estimated, and are given in Table 1, with the corresponding time periods.
For TOPEX the upper limit of time period was set to April 2005 for comparison: for the last 5 months (May September 2005) of the time series in Figure 3 it seems that the TOPEX SWH bias drops down, relative to ENVISAT, GFO and Jason. This will have to be investigated further.
For GFO the upper limit of time period was set to January 2007: after that time anomalies are observed on GFO SWH (cf above).
ERS-2 and Jason comparison (curve not shown here) was performed over the time period from January 2002 to June 2003.

The standard deviations for the various pairs of altimeters spread over a relatively narrow range, from 2.17 cm to 3.65 cm. The absolute values of biases cover a larger range, from 0.69 cm (TOPEX - GFO) to 14.85 cm (ERS2-Jason) .

Table 1 Mean value (bias) and standard deviation (std) of monthly corrected SWH differences.

Altimeter pair	Time period	Bias (cm)	Std (cm)
TOPEX - GFO	Jan 2000 Apr 2005	-0.69	3.15
- Jason	Jan 2002 Apr 2005	-7.92	3.12
- ERS2	Jan. 2000 June 2003	7.25	2.79
- ENVISAT	Oct 2002 Apr 2005	3.55	3.58
ENVISAT - GFO	Oct 2002 Jan 2007	-4.05	3.30
- Jason	Oct 2002 Aug 2007	-11.68	3.65
- ERS2	Oct 2002 Jun 2003	2.98	3.00
- TOPEX	Oct 2002 Apr 2005	-3.55	3.58
GFO - Jason	Jan 2002 Jan 2007	-7.58	2.17
- ERS2	Jan 2000 Jun 2003	8.05	2.31
- ENVISAT	Oct 2002 Jan 2007	4.05	3.30
- TOPEX	Jan 2000 Apr 2005	0.69	3.15
ERS2 - Jason	Jan 2002 Jun 2003	-14.85	3.42

Combining results given in Table 1 enables to estimate, for the each of the five altimeters, a total of four values of bias relative to the other altimeters. These four values are given in Table2, together with the average. For each pair of altimeters the four bias values are consistent. The averages could be considered as estimates of the observed biases. These values are reported in Figure 6, taking TOPEX as the reference. There is good consistency, and the biases could be approximated as:

ERS2 - TOPEX SWH = -7 cm
ENVISAT- TOPEX SWH = -3.7 cm
GFO - TOPEX SWH = 0.6 cm
Jason - TOPEX SWH = 8 cm

Table 2 Biasses obtained in combining results of Table 1. The average value is given in the last column.

TOPEX –ENVISAT	3.36	3.76	4.27	3.55	**3.7**
TOPEX – Jason	-8.13	-8.27	-7.60	-7.92	**-8.0**
TOPEX – ERS2	6.53	7.36	6.93	7.25	**7.0**
TOPEX – GFO	-0.34	-0.80	-0.50	-0.69	**-0.6**
ERS2 – ENVISAT	-3.70	-2.98	-4.00	-3.17	**-3.5**
ERS2 – Jason	-15.17	-14.66	-15.63	-14.85	**-15.1**
ERS2 - GFO	-7.94	-7.03	-7.27	-8.05	**-7.6**
Jason – ENVISAT	11.47	11.68	11.63	11.87	**11.7**
Jason – GFO	7.23	7.63	7.58	6.80	**7.3**
ENVISAT – GFO	-4.24	-4.05	-4.24	-5.07	**-4.4**

Summary and Conclusion

For calibration purpose corrections to GDR altimeter SWH measurements were proposed in previous studies (Queffeulou 2004 and 2006). These corrections are based on comparisons between buoy and altimeter measurements, and on cross-altimeter comparisons. These corrections are generally linearly dependent on SWH.
Investigating the altimeter monthly SWH mean values over the global Oceans, over several years, it appears that there are significant differences between the various altimeter GDR data. When correcting the GDR altimeter data these differences are significantly reduced.
After correction, some biases still remained. These biases were estimated on average, relatively to TOPEX , as equal to: –7 cm for ERS-2; -3.7 cm for ENVISAT; 0.6 cm for GFO ; 8 cm for Jason.
These biases were estimated globally, and assumed to be independent of SWH level (which is presumably not true) .
These biases could be applied in order to homogenise the data set, if needed.

Note that the uncertainty on buoy SWH estimate is much larger than the observed biases (significant differences have also been observed between the various buoy networks like NDBC, MEDS, Norwegian or European).
TOPEX bias has been observed to increase during the 5 last month of the mission (May to September 2005)- to be confirmed.

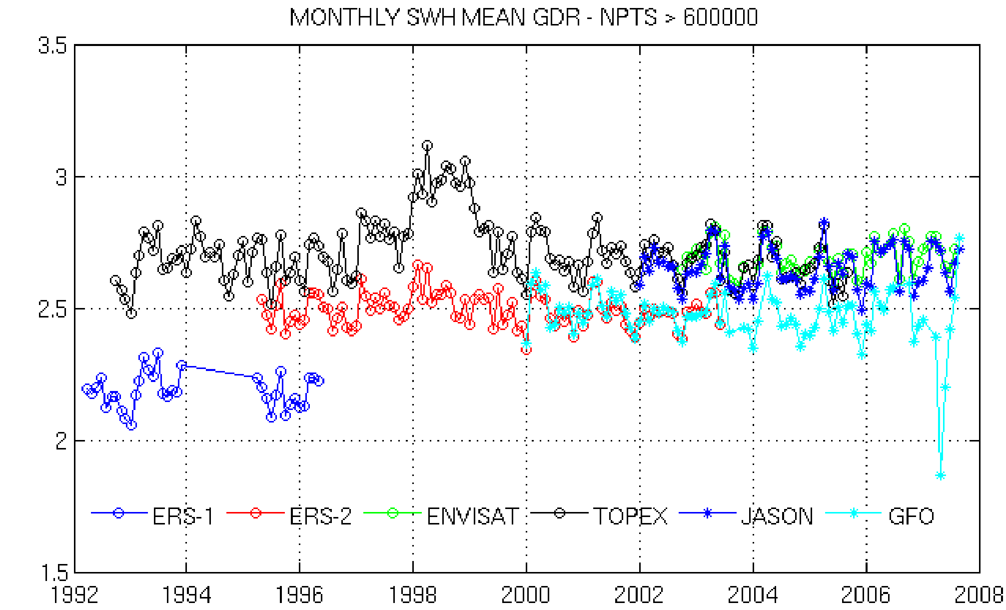
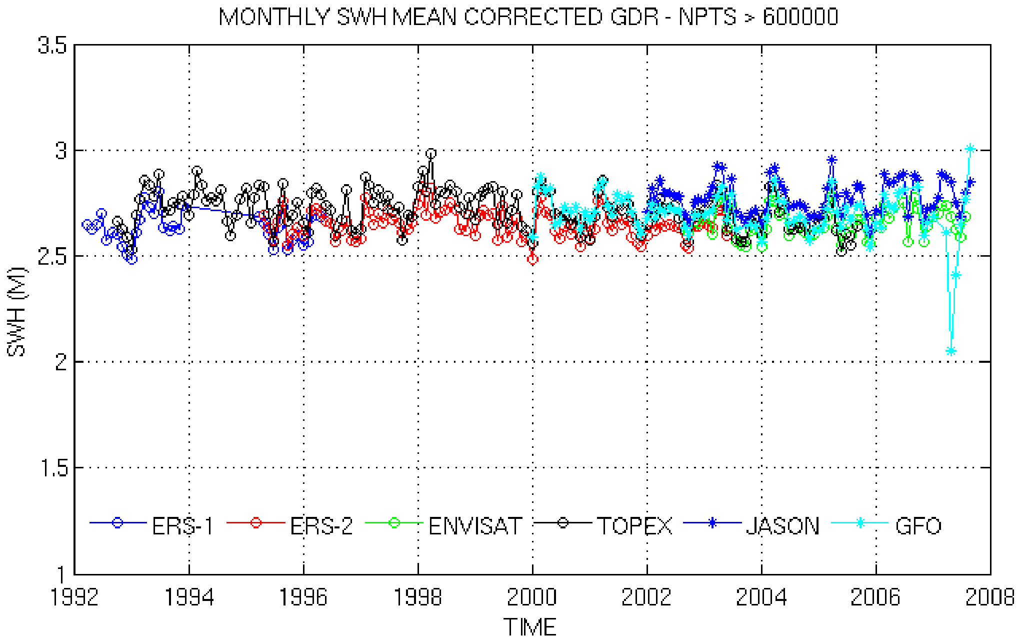


Figure 1 Global Oceans (66.15° N – 66.15° S) monthly SWH mean values from the various altimeters.



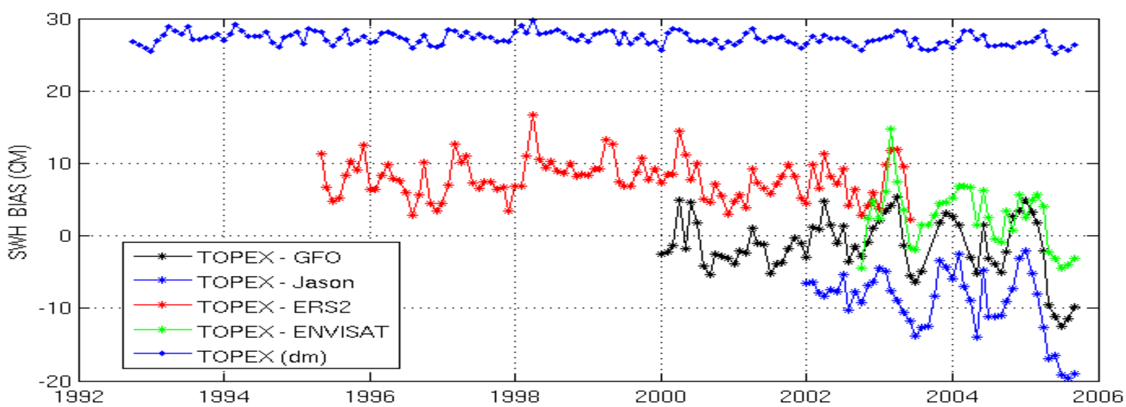


Figure 3 SWH bias relative to TOPEX, monthly mean of corrected values. Monthly TOPEX SWH also shown in dm.

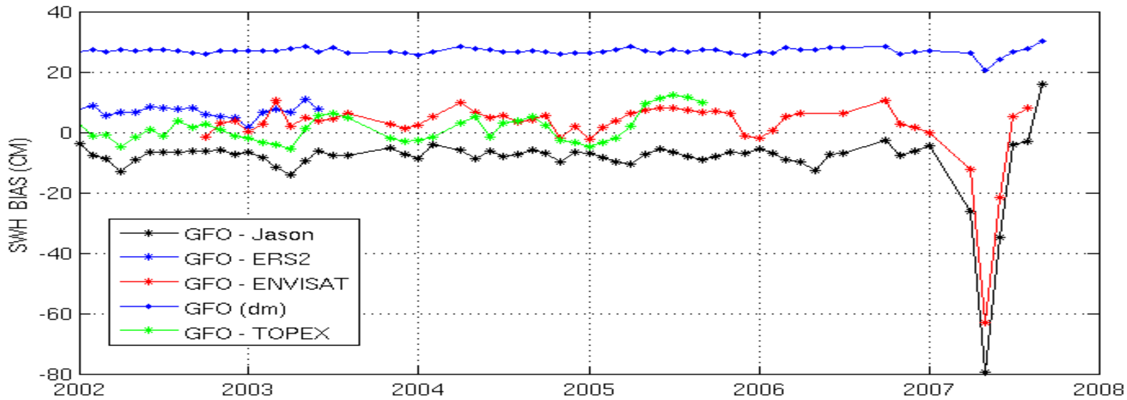


Figure 4 SWH bias relative to GFO, monthly mean of corrected values. Monthly GFO SWH also shown in dm.

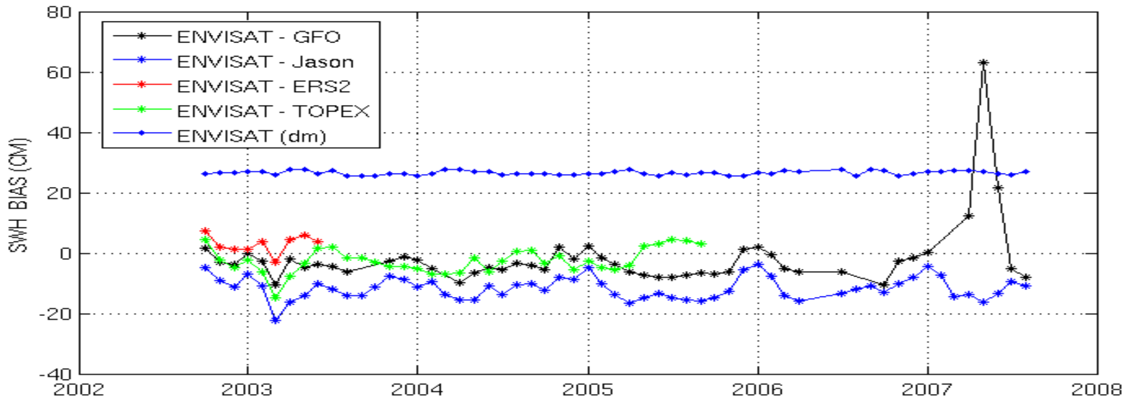


Figure 5 SWH bias relative to ENVISAT, monthly mean of corrected values. Monthly ENVISAT SWH also shown in dm.

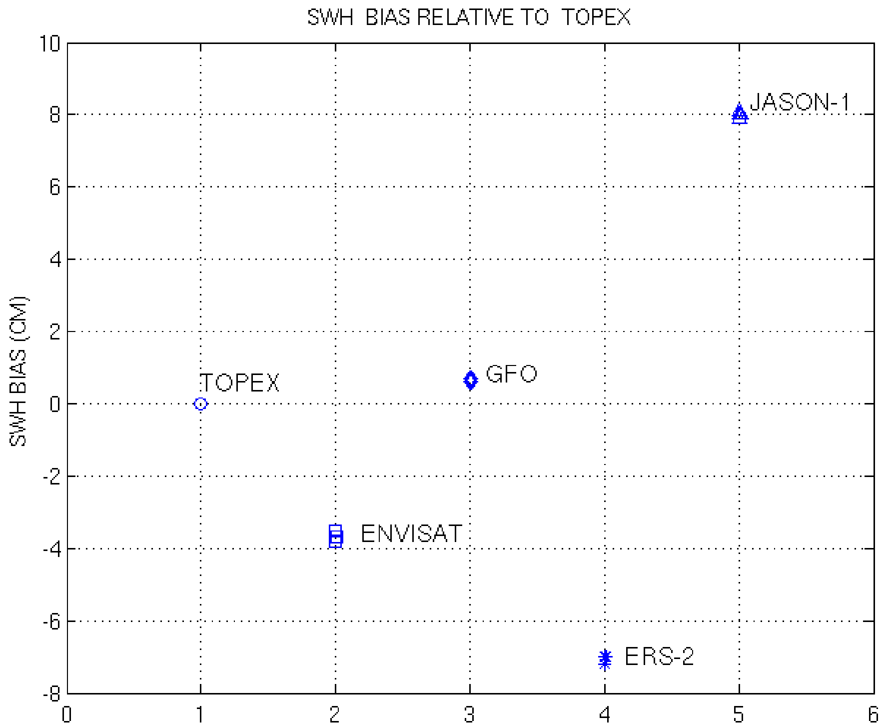


Figure 6 Representation of the altimeter SWH biases of Table 2 (average values given in the last column), when TOPEX is taken as reference.