CryoSat-2 IGDR SWH assessment update – May, 2013

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SWH data from the CryoSat-2 IGDR data set produced and provided by the *NOAA Laboratory for Satellite Altimetry* (ftp://ibis.grdl.noaa.gov/pub/cs2igdr/) were validated using comparisons with collocated altimeter measurements from Jason-1, Jason-2 and ENVISAT RA-2.
This report is an update of a previous validation (Queffeulou 2012-a). The present data are the LRM and Pseudo LRM data re-processed and available on the *NOAA Laboratory for Satellite Altimetry* ftp site, since January 25, 2013. CryoSat cycle number 11 to 36 were investigated, corresponding to the following time periods for comparison with other altimeters:

Jason-1 28/01/2011 – 02/01/2013
Jason-2 28/01/2011 – 02/01/2013
Envisat 27/02/2011 – 09/03/2012

Before collocation the following CryoSat quality flags were tested:
Bit 4: Land flag: 0 = ocean or lake
Bit 11: Quality of range: 0 = good
Bit 12: Quality of SWH: 0 = good
Bit 13: Quality of backscatter: 0 = good

Data for which the CryoSat swh rms is larger than some threshold are discarded.
This threshold depends on swh value and was defined in Queffeulou 2012-a.

Some negative measurements of SWH are observed from time to time at low SWH.
In a first analysis these data were also discarded. In the proposed SWH correction these data are taken into account (see section SWH correction).

Two types of collocated data set are analysed. The first data set consist in the closest 1 Hz measurements, within a 30 minute time window. To enlarge the comparison data set the time window was then increased up to one hour, and in this case, to filter the time and space geophysical variability, the measurements of each altimeter are averaged over 50 km along track, 25 km each side of the crossing point, adding the condition that almost all along-track measurements are valid (ie number of along track valid measurements larger or equal to 7 and 9 (7) for CryoSat and Jason (Envisat) respectively.

SWH validation

Statistical results, relative to Jason-1, Jason-2 and Envisat GDRs are given in Table 1. Main impact of increasing the time window and averaging over 50 km is to increase the data number and to significantly reduce the standard deviations of differences.

Table 2 gives the statistical results when Jason-1 and Jason-2 and Envisat GDRs are corrected, according to Queffeulou and Croizé-Fillon 2012. The results relative to the 3 altimeters are much more consistent than when the GDR are not corrected. For the LRM data the biases are the same with the 3 altimeters (7 cm for 50 km average) and the standard deviations are almost identical (11 cm – 13 cm). Slopes and intercepts are very close.

Note that results for the Pseudo-LRM data are slightly different from the LRM ones, and less homogeneous relative to the 3 altimeters. But the data number is relatively poor (only 26 or 13 for Envisat), so as the SWH range covered by the data (cf figures).

Table 1: SWH statistical results for collocated data between Crysoat (LRM, left; Pseudo LRM, right) and Jason-1, Jason-2 and Envisat GDRs. Data number (N), mean value (MEAN) and standard deviation (STD) of differences, slope and intercept of the inertial regression line. Results are given for the 1hz, 30 mn (first line) and for the 50 km average, 1 hour (second line) collocated data set.

LRM	Jason-1	Jason-2	ENVISAT
N	3391 5279	4000 6410	1236 2013
MEAN (M)	0.14 0.15	0.13 0.15	0.14 0.14
STD (M)	0.25 0.16	0.24 0.12	0.23 0.11
SLOPE	0.981 0.990	0.974 0.983	1.019 1.015
INTERC. (M)	-0.08 -0.12	-0.05 -0.09	-0.20 -0.19

Pseudo LRM	Jason-1	Jason-2	ENVISAT
N	237 137	254 161	26 13
MEAN (M)	0.15 0.21	0.16 0.21	0.19 0.19
STD (M)	0.26 0.16	0.24 0.12	0.28 0.08
SLOPE	0.988 0.976	0.979 1.003	0.943 0.992
INTERC. (M)	-0.12 -0.11	-0.10 -0.22	-0.03 -0.15

Table 2: as for Table 1, for Jason-1, Jason-2 and Envisat **corrected** GDRs

LRM	Jason-1	Jason-2	ENVISAT
N	3391 5279	4000 6410	1236 2013
MEAN (M)	0.06 0.07	0.06 0.07	0.06 0.07
STD (M)	0.25 0.13	0.24 0.12	0.22 0.11
SLOPE	1.001 1.011	0.988 0.997	1.006 1.009
INTERC. (M)	-0.07 -0.11	-0.02 -0.06	-0.08 -0.10

Pseudo LRM	Jason-1	Jason-2	ENVISAT
N	237 137	254 161	26 13
MEAN (M)	0.08 0.11	0.09 0.12	0.12 0.13
STD (M)	0.26 0.15	0.24 0.12	0.28 0.07
SLOPE	1.009 0.997	0.994 1.018	0.920 0.999
INTERC. (M)	-0.11 -0.09	-0.07 -0.20	0.10 -0.12

Figures 1 to 4 show the comparison scatter-plots for the various data set.

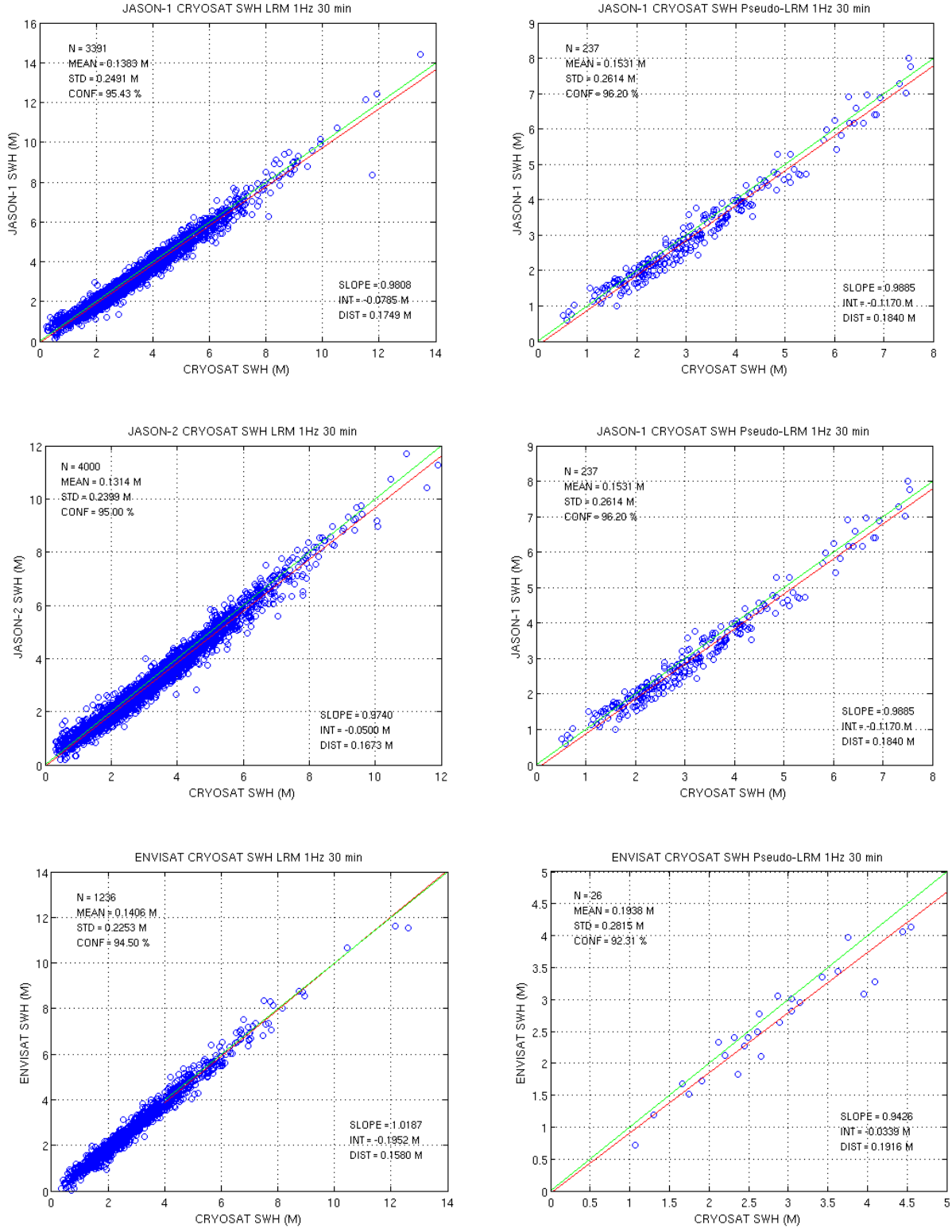

Figure 1: comparison of 1 Hz, 30 mn collocated data between CryoSat LRM (left) or Pseudo-LRM (right) and Jason-1 (top), Jason-2 (middle) and Envisat (bottom) GDR.

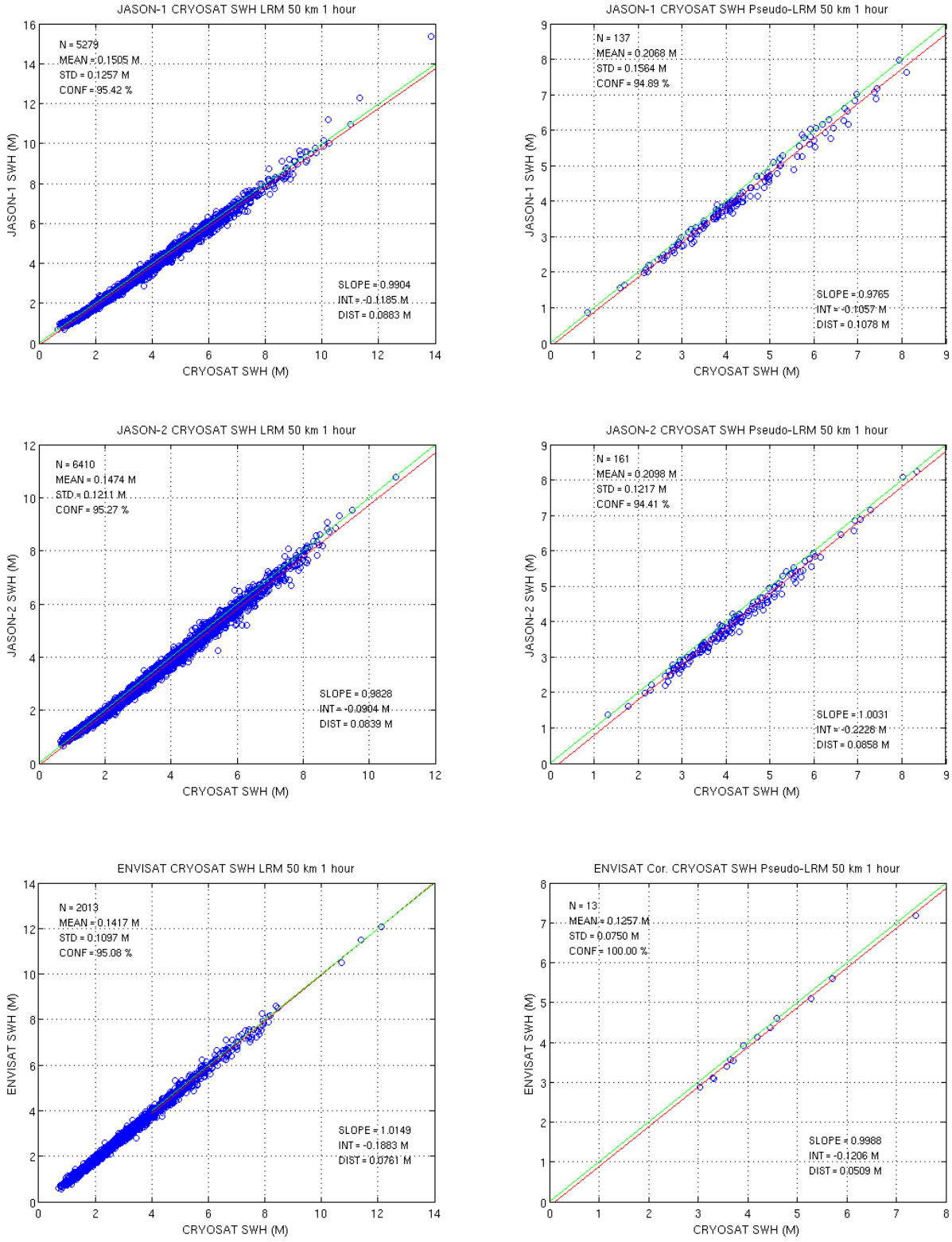

Figure 2: as Figure 1, for 50 km, 1 hour collocated data.

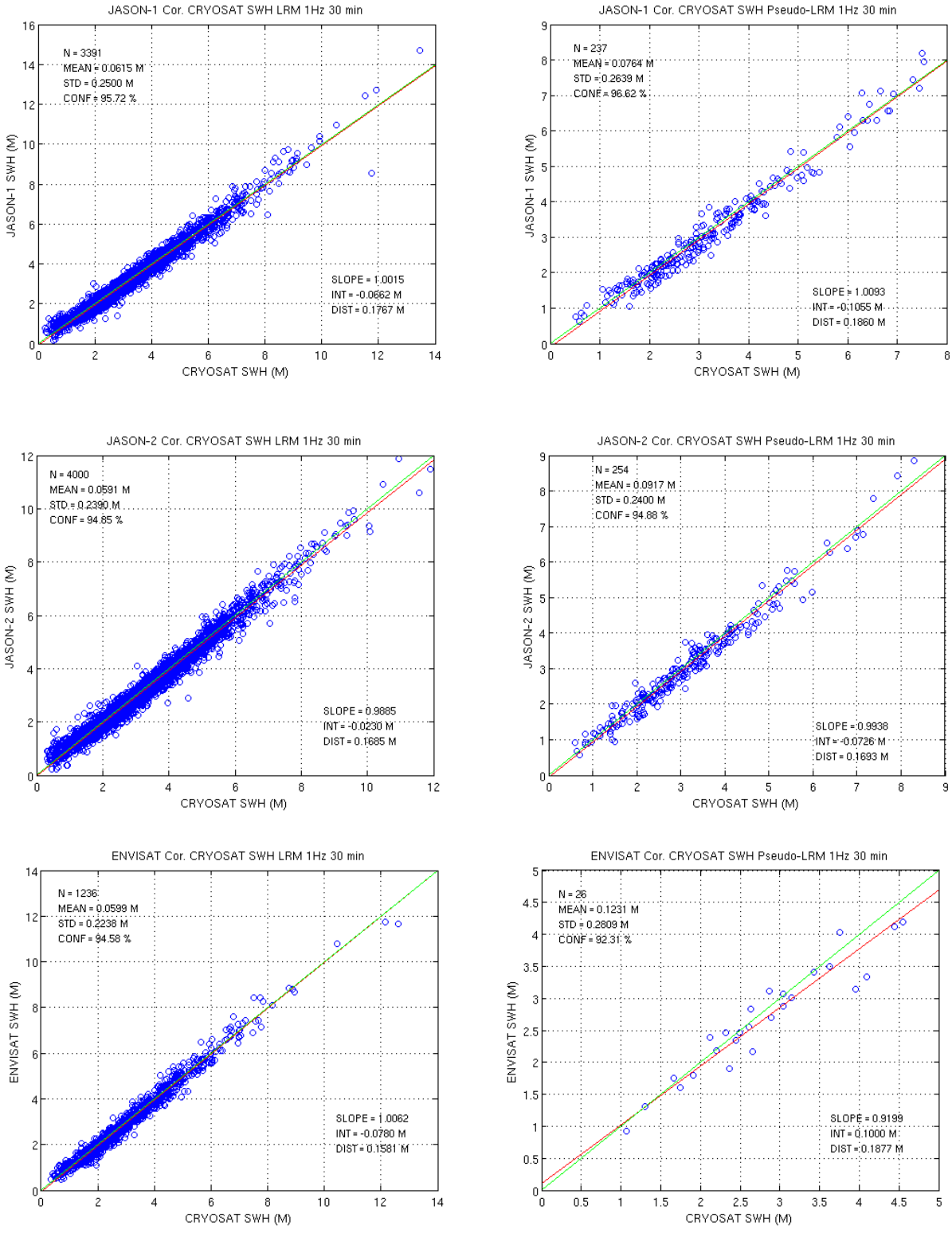

Figure 3: comparison of 1 Hz, 30 mn collocated data between CryoSat LRM (left) or Pseudo-LRM (right) and Jason-1 (top), Jason-2 (middle) and Envisat (bottom) **corrected** GDR.

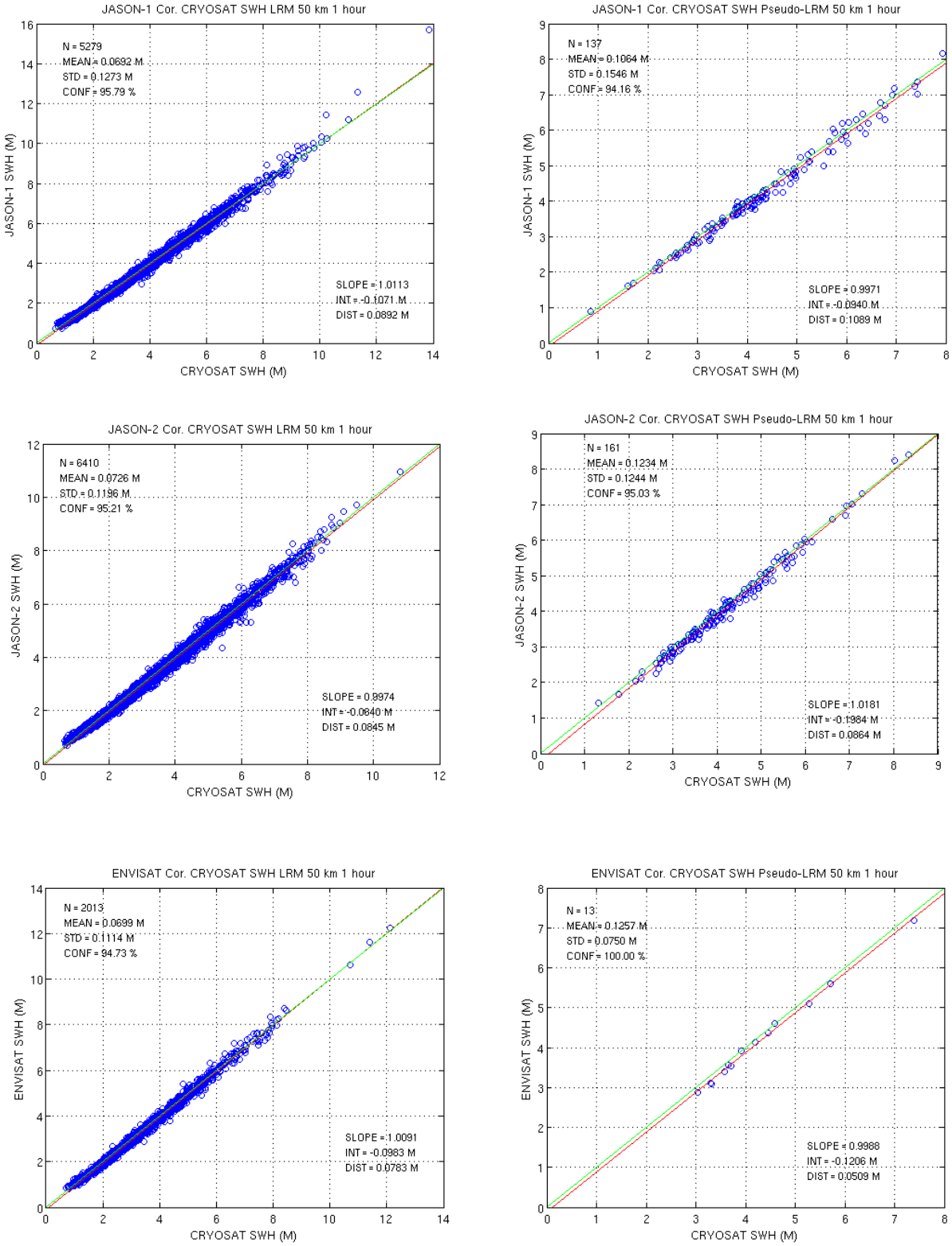

Figure 4: as Figure 3, for 50 km, 1 hour collocated data.

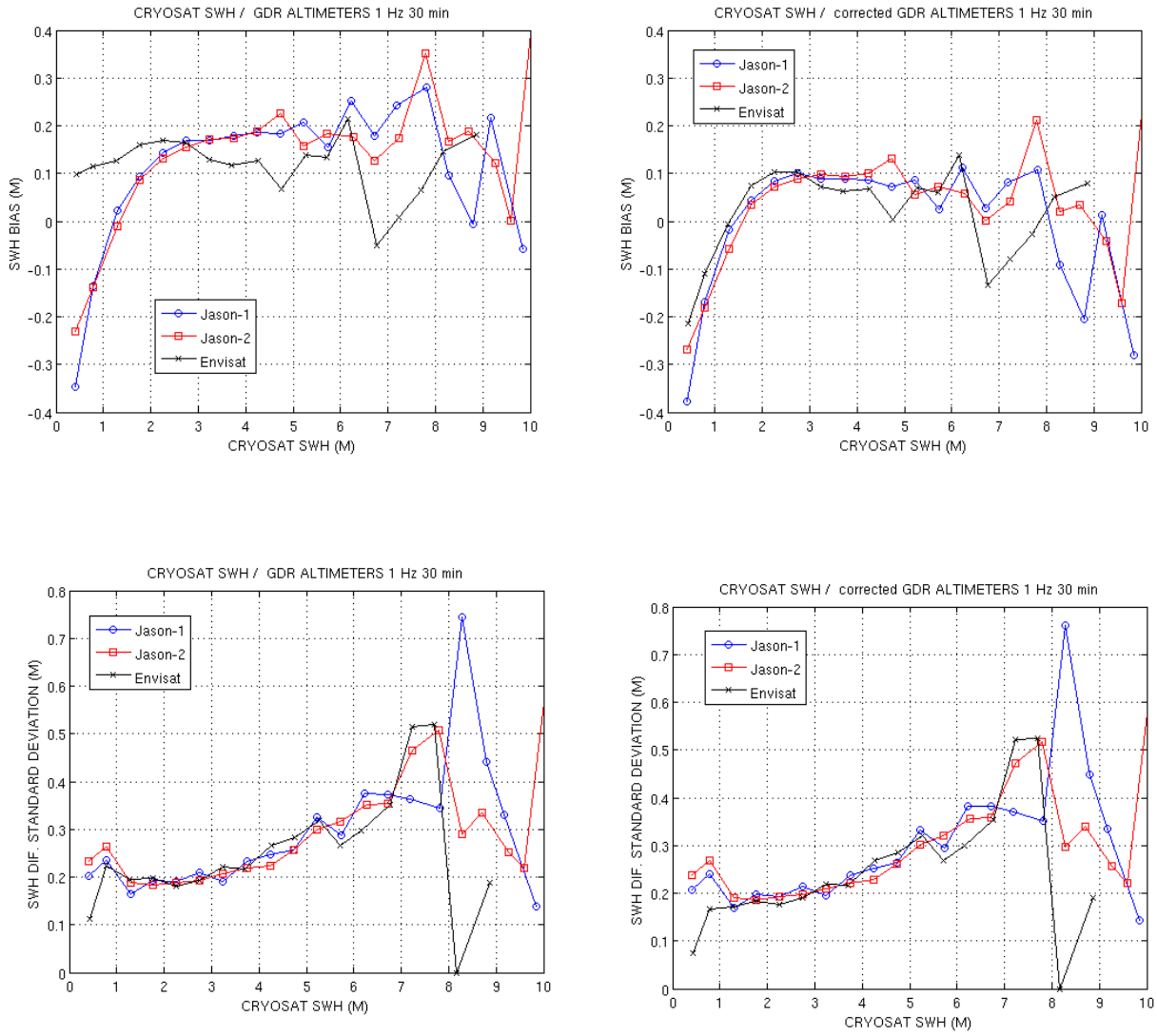

Figure 5: CryoSat SWH bias (top) and SWH difference standard deviation (bottom) as a function of SWH (0.5 m wide bins), relative to Jason-1, Jason-2 and ENVISAT GDR (left) and corrected GDR (right) SWH.

Figure 5 shows the CryoSat SWH bias and SWH difference standard deviation as a function of SWH, for the 1 Hz, 30 mn collocated data set. For the GDR data the bias behaviour is almost the same relative to Jason-1 and Jason-2, but not relative to ENVISAT (top, left). However, once the GDR are corrected (top, right) the behaviour of the CryoSat SWH bias is very consistent relative to the 3 altimeters: a negative bias up to 35 cm is observed for SWH less than 1.5 m; a positive bias, up to 10 cm is observed over the SWH range 1.5 m – 7 m. Note that large spikes for SWH larger than 6-7 m are due to poor data numbers in these ranges.

Indeed the observed differences for ENVISAT in top left are due to the non-linear behaviour of the ENVISAT SWH version 2.1, which is suppressed when applying the SWH correction (Queffeulou and Croizé-Fillon 2012). These results are also a good validation of the proposed corrections for Jason-1, Jason-2 and ENVISAT GDR SWH.

The standard deviation of differences is relatively high (about 20 cm to 40 cm for SWH from 1 m to

7 m), but this is relative to 1 Hz collocated data cells, and could include some geophysical noise. Statistics for 50 km average data leads to much better results, as shown in Figure 6: bias between -10 cm and +10 cm, and standard deviation increasing from 7 cm to 30 cm, over the SWH range 1 m – 9 m.

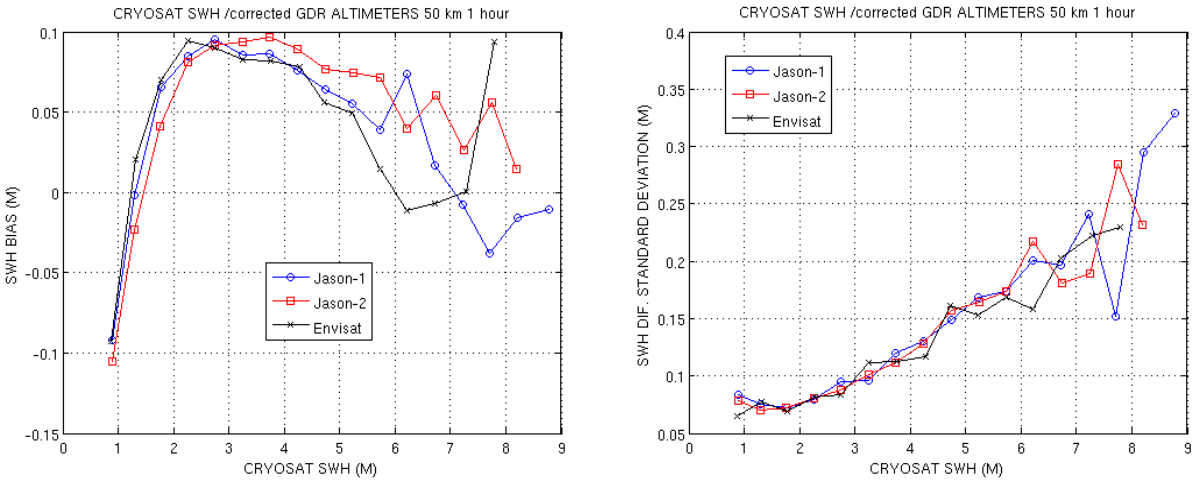

Figure 6: CryoSat SWH bias (left) and SWH difference standard deviation (right) as a function of SWH (0.5 m wide bins), relative to Jason-1, Jason-2 and ENVISAT corrected GDR, for the 50 km, 1 hour collocated data set. Bins with less than 10 data are not plotted.

Proposed SWH correction

Since comparison results are consistent relative to the 3 independent (Jason-1, Jason_2 and Envisat) altimeter corrected GDRs, these data can be gathered to estimate a global correction for CryoSat SWH. The 1 Hz, 30 min data set was selected rather than the 50 km, 1 hour data set, to get more data as possible in the extreme SWH ranges. Figure 7 shows the scatter plot relative to the 3 altimeters, with statistical results: 0.06 m mean bias, 0.24 m standard deviation of differences. Data were binned in 0.25 m wide classes (CryoSat SWH). Plot of the mean values and standard deviations per bin (Figure 8) show that the CryoSat SWH is underestimated at low SWH (under 1 m), and the difference is non linear. A global correction was then estimated by fitting a third order polynomial for SWH less than 5 m, and a linear relation ship for SWH between 3 m and 10 m. The correction is then applied as:

for $h<=2.45$ m; $h\_cor=a_0 + a_1 h + a_2 h^2 + a_3 h^3$
$a_3=-0.0145$; $a_2=0.1546$; $a_1= 0.4712$; $a_0=0.4889$

for $h>2.45$; $h\_cor=a_0 + a_1 h$
$a_1=1.0058$; $a_0=-0.1057$

This correction can be applied to the negative values observed, but will have to be evaluated further at very low swh.

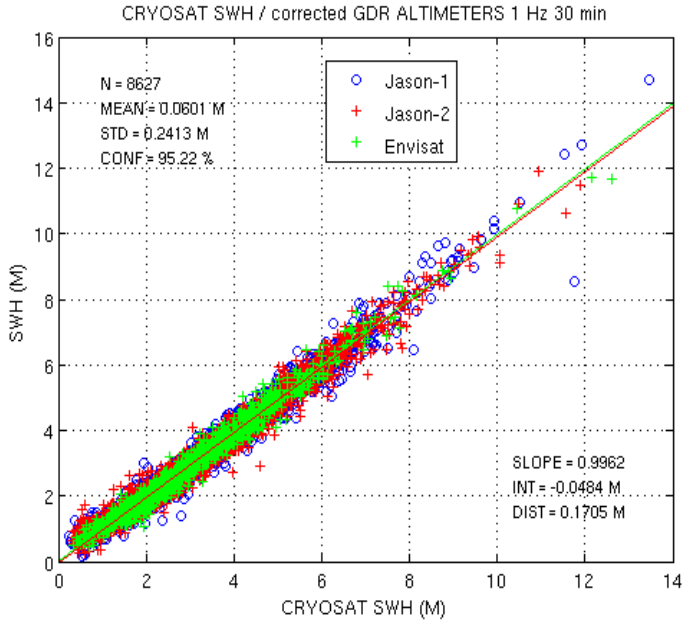

Figure 7: comparison of 1 Hz, 30 mn collocated data between CryoSat LRM and Jason-1, Jason-2 and Envisat **corrected** GDR.

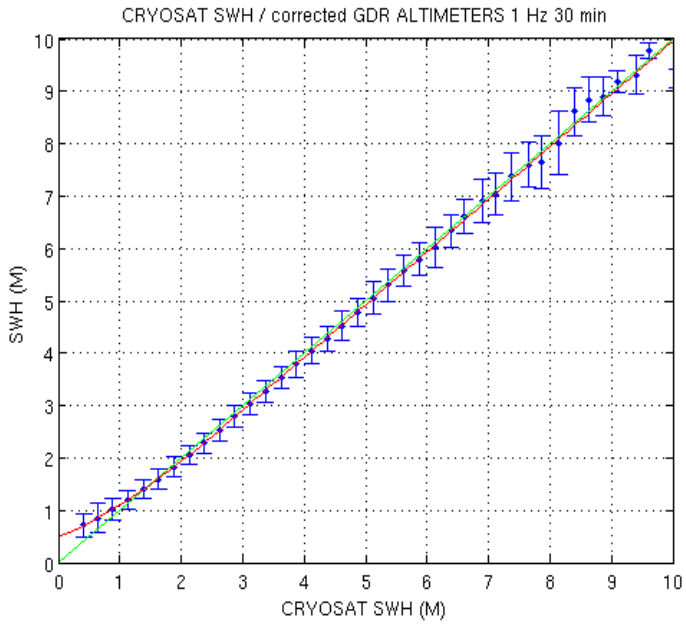

Figure 8: comparison of 1 Hz, 30 mn collocated data between CryoSat LRM and Jason-1, Jason-2 and Envisat **corrected** GDR. Mean values and standard deviations of differences per 0.25 m CryoSat SWH bins. Proposed correction to CryoSat SWH in red.

Sigma0 validation

Sigma0 comparison results are shown in Table 3. Standard deviations observed relative to Jason-1 are higher than for Jason-2 and Envisat, particularly for the 1 Hz, 30 mn data set. There is no significant difference between results for the LRM or the Pseudo-LRM data set (though the number of comparison data is much less for the Pseudo-LRM data set).

Table 3: SWH statistical results for collocated data between Crysoat (LRM, left; Pseudo LRM, right) and Jason-1, Jason-2 and Envisat GDRs. Data number (N), mean value (MEAN) and standard deviation (STD) of differences, slope and intercept of the inertial regression line. Results are given for the 1hz, 30 mn (first line) and for the 50 km average, 1 hour (second line) collocated data set.

LRM	Jason-1	Jason-2	ENVISAT	Pseudo-LRM	Jason-1	Jason-2	ENVISAT
N	3391 5279	4000 6410	1326 2013	N	237 137	254 161	26 13
MEAN (dB)	-2.89 -2.85	-2.53 -2.52	0.05 0.07	MEAN (dB)	-2.88 -2.80	-2.51 -2.50	0.03 0.07
STD (dB)	0.37 0.20	0.23 0.20	0.19 0.16	STD (dB)	0.38 0.18	0.24 0.17	0.13 0.09

The following values could be selected for the CryoSat sigma0 bias, relative to Jason-1,Jason-2 and Envisat GDR (cf figure 9, left side, for 50 km, 1 hour LRM comparisons):

bias/Env= 0.0658 dB (1)
bias/J1= -2.8516 dB (2)
bias/J2= -2.5234 dB (3)

In a previous report (Queffeulou and Croizé-Fillon, 2012) GDR sigma0 were calibrated relative to the ENVISAT ones :

- for Jason-1 : add -2.8165 (4)
- for Jason-2 (version T) : add -2.7678 (5)

Jason-2 GDR are presently in version D. The passage from T to D induces a 0.2024 dB bias (6) – with a 0.03 dB std, estimated on pass by pass sigma0 mean values of differences between T and D version for cycle 1 to 5 (Queffeulou 2012-b).

Using above relations (1) to (6), the CryoSat sigma0 calibration values relative to Envisat, could be:

+0.0658 dB, from direct Envisat / CryoSat comparison
-0.0351 db (-2.8516+2.8165) , from direct Jason-1 / CryoSat comparison
+0.0420 dB (-2.5234+2.7678 -0.2024), from direct Jason-2 / CryoSat comparison

These results show some inconsistency, the bias varying between -0.04 dB and +0.06 dB, but the most important issue is the observed drift of CryoSat sigma0 with time, as shown in figure 10,

comparing the monthly mean values of calibrated sigma0, for data located between 66°N and 66°S in latitude, from Jason-1, Jason-2, Envisat and CryoSat (with no calibration applied to CryoSat sigma0).

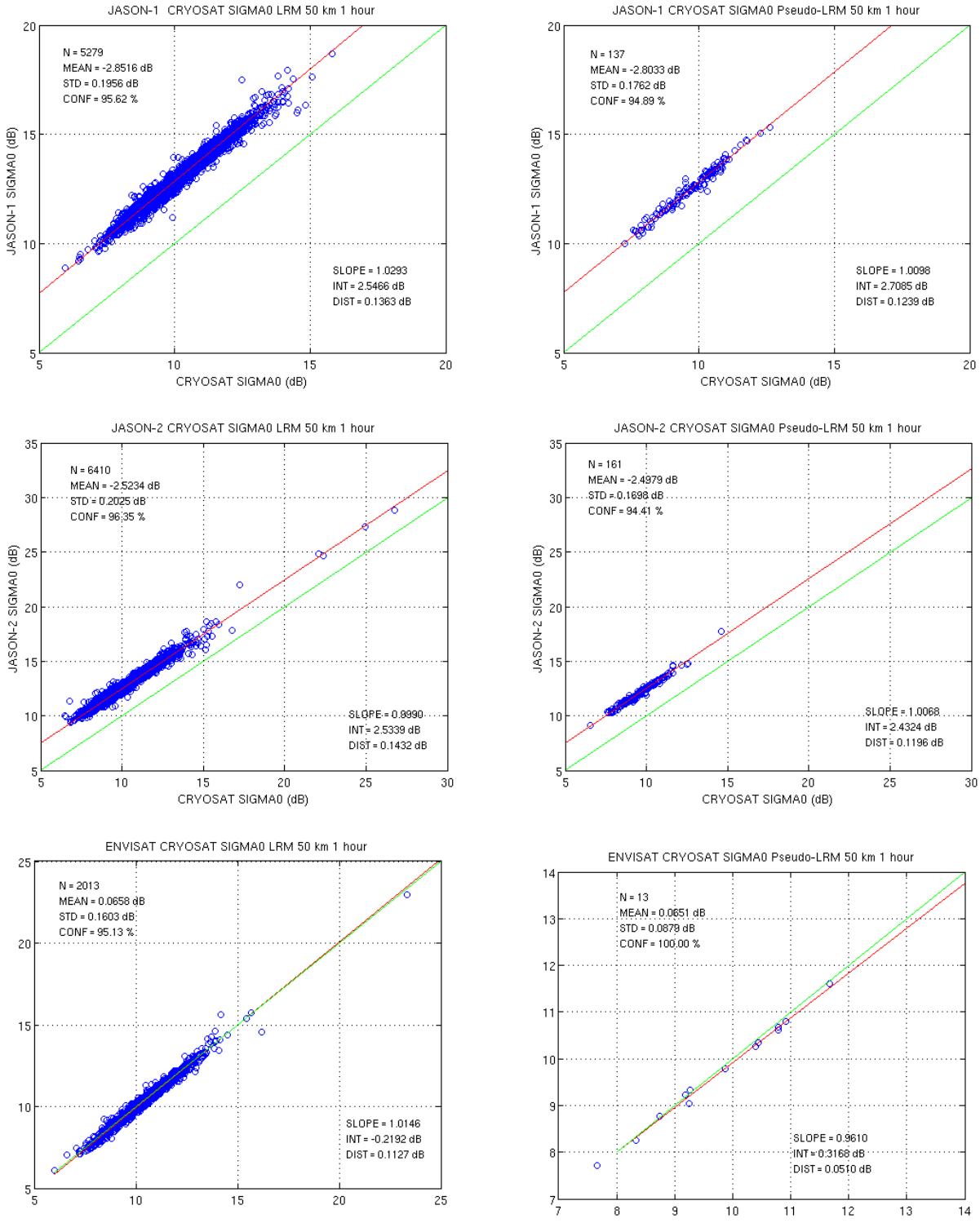

Figure 9: comparison of 50 km, 1 hour collocated sigma0 data between CryoSat LRM (left) or

Pseudo-LRM (right) and Jason-1 (top), Jason-2 (middle) and Envisat (bottom) GDR.

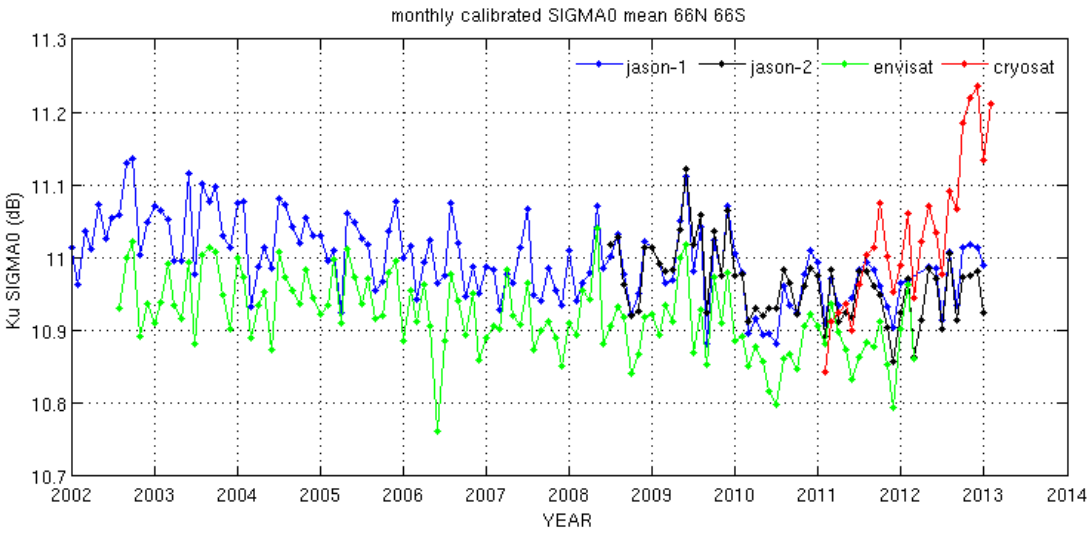

Figure 10: monthly mean values of calibrated sigma0, for measurements located between 66°N and 66°S in latitude.

References

Queffeulou, P. and D. Croizé-Fillon, Global altimeter SWH data set - April 2012. Report available at ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/altimeter_wave_merge__9.0.pdf

Queffeulou P., 2012-a, CryoSat-2 IGDR SWH assessment – January 17, 2012. Report available at ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/cryosat2_igdr_swh_assessment.pdf

Queffeulou, P., 2012-b, Preliminary assessment of Jason-2 GDR version D for SWH and sigma0 data, September 2012. Report available at ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/documentation/J2_versions_D_T.pdf