Calibration and Validation of DORIS Orbits for Jason-1

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Jason-1 Precision Orbit Determination and DORIS

Our goal was to assess the quality of the various orbits for Jason-1, particularly those including DORIS, and evaluate the contribution of the various tracking systems. Jason-1 supports SLR, DORIS and GPS tracking, so a variety of orbit determination choices are available. Various institutions have used combinations of this tracking to produce precise orbits, which enable us to gain some insight into the orbit error characteristics. We can also use the altimeter data, in crossover form, as an independent check on some components of the orbit error (note that crossovers are insensitive to any orbit error that is common to ascending and descending tracks, including any miscentering in the Earth-fixed frame).

We noted that the medium precision orbits (MOE) placed on the Jason-1 IGDRs are of surprisingly good quality in many cases, as shown in Table 1. The orbits for T/P, on the other hand, are sometimes less accurate than usual, which is something to keep in mind during these Topex/Jason cross-calibration efforts. Figure 1 illustrates how the bias between Jason-1 and T/P becomes more consistent for ascending and descending tracks as the orbit accuracy is improved.

	Jason		TOPEX	
Jason Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)
3	-1.3	14.9	---	---
4	-1.6	14.1	---	---
5	0.9	15.6	---	---
6	8.6	24.1	---	---
7	9.2	34.8	---	---
8	2.8	15.7	-2.1	25.4
9	-0.3	15.2	-0.7	35.0
10	-1.1	19.4	-7.8	54.4
11	0.9	16.6	-2.8	61.6
12	9.3	26.6	5.9	33.5
Avg	2.7	19.7	-1.5	42.0

1 - Cycle 3, Passes 3-254 only because of OMM in Pass 1
2 - TOPEX Cycles 346-350 are GDR with POE

Table 1. Comparison of MOE orbits for Jason-1 and T/P with precise orbits computed by CSR using SLR and DORIS. The MOE orbits on Jason-1 appear to be competitive with the precise orbits in some cases.

Figure 1. For cycle 8, a preliminary orbit based on GPS data did not appear to be as well-centered as a later precise orbit, leading to a significant discrepancy in the relative bias between Jason-1 and T/P for ascending and descending tracks. Using a more precise orbit, the discrepancy disappeared. For cycle 9, the SLR-only orbit was nearly as good as the combined SLR/DORIS orbit, so the bias discrepancy was fairly small. For cycle 10, a more precise orbit than the MOE considerably reduced the discrepancy, although it was not removed entirely.

In the following tables, we present some detailed evaluations of the various orbits submitted for comparison. We chose several statistics which capture much of the overall orbit error characteristics. The altimeter crossover rms is an obvious measure, which has the advantage of being independent of all the tracking. As noted earlier, the centering of the orbit in the inertial frame is also important for altimeter analyses. The Z-shift impacts studies of mean sea level, while miscentering of the orbit in the inertial frame within the equatorial plane create erroneous offsets between the ascending and descending passes (the Z-shift is the same in the inertial and Earth-fixed frame). We did not explicitly compare all the orbits in the inertial and Earth-fixed frame, but rather relied on the mean crossover as an indicator of this. We did verify this with some experiments that the correlation was very strong between the crossover bias and the miscentering of an orbit in its inertial X and/or Y components; where the mean crossover is at the few mm level, the orbit is probably well centered in inertial space. We also can investigate orbit quality and consistency by intercomparing orbits. In this case, the number of possible combinations was unreasonable, and we chose to adopt our SLR/DORIS orbit as a standard for comparison. We believe our orbit is sufficiently accurate and unbiased to identify significant anomalies. Since our orbit appeared to be in good agreement with most orbits, we will assume that it is well centered in all three directions (X, Y and Z) in the Earth-fixed frame (also based on past performance on T/P). In addition, our orbit was produced with models exactly matching those we use for T/P (except those specific to each satellite), to provide a measure of orbit improvement relative to the standard T/P models. In each of the tables, our crossover statistics are included for reference.

CNES (SLR/DORIS)

Cycle	Crossover (CSR) Mean (mm)	RMS (mm)	Crossover (CNES) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
3	-9	65	-2	64	12	2	-1	-2
4	-4	63	1	64	14	2	0	-2
5	-3	64	1	63	14	-3	-3	1
6	-2	65	-3	63	17	4	0	2
7	3	71	-3	77	32	3	0	4
8	6	68	10	68	14	4	4	6
9	5	68	5	68	17	3	6	7
10	-3	68	-2	73	27	2	2	8
Mean	-1	66	1	68	19	3	0	2	4

CNES (GPS - DYN)

Cycle	Crossover (CSR) Mean (mm)	RMS (mm)	Crossover (CNES) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
3	-9	65	-14	66	26	-2	-18	-15	-8
4	-4	63	8	66	18	2	-2	-3	-17
5	-3	64	18	70	25	3	-1	-6	-17
6	-2	65	11	71	23	5	0	-3	-21
7	3	71	11	74	29	4	6	-1	13
8	6	68	4	68	14	4	4	5	0
9	5	68	-3	67	18	3	8	5	7
10	-3	68	-7	64	19	2	2	2	12
Mean	-1	66	3	68	21	3	0	-2	-2

CNES (GPS - ELFE)

Cycle	Crossover (CSR) Mean (mm)	RMS (mm)	Crossover (CNES) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
5	-3	64	18	69	25	3	9	-5	-14
6	-2	65	12	67	25	3	4	-3	11
7	3	71	11	68	29	4	-3	1	11
8	6	68	8	68	16	4	5	-2	5
9	5	68	-2	67	17	3	2	-4	-6
10	-3	68	-14	64	19	2	-3	-3	1
Mean	1	67	7	67	22	3	2	-2	1

Table 2. CNES orbits based on SLR/DORIS and on GPS using dynamic and 'reduced-dynamic' (ELFE) approaches. The crossover mean is larger for the ELFE approach, and the scatter in the centering is quite large with the GPS-based solutions. There is also a few mm in the mean radial difference in all the CNES orbits which is not seen in any other case. This is a concern, since this can have an effect when linking the T/P and Jason-1 sea level time series, unless this is removed through the relative altimeter bias.

DEOS

Cycle	Crossover (CSR) Mean (mm)	RMS (mm)	Crossover (DEOS) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
3	-9	65	-4	66	17	0	-4	4	-11
4	-4	63	5	64	17	0	-4	4	-9
5	-3	64	6	65	20	0	1	1	-4
6	-2	65	7	67	19	1	1	9	-4
7	3	71	3	76	27	2	2	7	-13
8	6	68	16	72	17	2	-2	3	-8
9	5	68	5	68	16	1	-5	0	-4
10	-3	68	-2	65	17	0	-3	10	-9
Mean	-1	66	4	67	19	1	-2	6	-8

Table 6. DEOS orbits based on SLR/DORIS. There appears to be a systematic bias in the X-, Y- and Z-components.

CSR (DORIS only)

Cycle	Crossover (SLR/DORIS) Mean (mm)	RMS (mm)	Crossover (DORIS only) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
3	-9	65	-8	64	9	0	0	0	-10
4	-4	63	-3	64	8	0	-1	0	-8
5	-3	64	2	64	8	0	0	0	-8
6	-2	65	-3	67	15	-1	1	1	-17
7	3	71	-2	72	13	0	1	1	-9
8	6	68	8	68	10	0	0	0	-14
9	5	68	5	68	7	0	-1	0	-5
10	-3	68	-2	65	14	0	-1	1	-5
Mean	-1	66	0	66	11	0	0	0	-9

Table 7. CSR orbits based on DORIS only. There appears to be a systematic bias in the centering in this case, also. The coherence with the DEOS orbits suggests that the DORIS data must be weighted heavily more than SLR in the DEOS case.

JPL (GPS)

Cycle	Crossover (CSR) Mean (mm)	RMS (mm)	Crossover (JPL) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
8	6	68	-1	66	10	1	1	6	10	5
9	5	68	3	66	16	0	10	5	6
10	-3	68	8	65	21	0	6	4	4
Mean	3	68	3	66	18	0	7	8	5

Table 3. JPL orbits using GPS and a 'reduced-dynamic' approach. The crossover rms is consistently smaller. The earlier cycles from JPL were not representative of the later processing, and so they were excluded. There appears to be a significant bias in the X and Y Earth-fixed centering.

NASA (SLR/DORIS)

Cycle	Crossover (CSR) Mean (mm)	RMS (mm)	Crossover (NASA) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
3	-9	65	-6	64	7	-1	0	0	-3
4	-4	63	-1	63	8	-1	0	-2	0
5	-3	64	3	63	11	0	1	0	-4
6	-2	65	-2	65	10	-1	3	1	-6
7	3	71	-2	75	23	1	3	1	-4
8	6	68	7	67	9	1	2	2	-4
9	5	68	9	69	13	0	1	1	-2
10	-3	68	-2	67	12	0	1	2	-11
Mean	-1	66	1	67	12	0	2	-1	-5

Table 4. GSFC orbits using SLR/DORIS. The GSFC models were specifically chosen to match those used at CSR to ensure a high level of internal agreement.

JPL/IGN (DORIS)

Cycle	Crossover (CSR) Mean (mm)	RMS (mm)	Crossover (CNES) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
3	-9	65	-9	64	7	-1	-1	3	1	20
4	-4	63	0	63	17	-1	1	2	24
5	-3	64	-2	64	17	0	0	0	18
6	-2	65	-10	67	17	1	5	4	20
7	3	71	-13	66	24	1	-3	6	18
8	6	68	-2	68	20	0	3	4	24
9	5	68	-7	67	22	-1	-1	2	24
10	-3	68	-14	66	21	-1	-2	4	24
Mean	-1	66	-7	65	19	0	1	2	20

JPL/IGN (DORIS+GPS)

Cycle	Crossover (CSR) Mean (mm)	RMS (mm)	Crossover (CNES) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
8	6	68	0	66	16	1	1	6	12
9	5	68	3	66	16	1	1	5	10
10	-3	68	-2	64	20	-1	0	4	11
Mean	3	68	-1	65	17	0	1	5	11

Table 5. JPL/IGN orbits using DORIS and DORIS+GPS. The crossover RMS is very good on average. The orbit centering is considerably worse with DORIS only. There is a systematic bias in the Z-component for both cases.

CSR (SLR only)

Cycle	Crossover (SLR/DORIS) Mean (mm)	RMS (mm)	Crossover (SLR only) Mean (mm)	RMS (mm)	Radial Diff RMS (mm)	X Mean (mm)	Y Mean (mm)	Z Mean (mm)
3	-9	65	-8	68	21	0	-3	-1	-4
4	-4	63	-7	64	18	0	1	-1	0
5	-3	64	-6	67	12	1	1	0	5
6	-2	65	-3	71	11	1	1	0	5
7	3	71	6	74	16	0	1	1	10
8	6	68	3	68	7	0	0	0	3
9	5	68	4	68	14	0	-1	1	2
10	-3	68	-4	71	21	1	-1	2	6
Mean	-1	66	0	69	13	0	0	0	4

Table 8. CSR orbits based on SLR only. While not as accurate as the other cases, the results are still very good. Predictably, the orbit appears to be well centered in Z.

Comparing the results among the various institutions, we note that most of the orbits have a mean X and Y that agrees with the CSR orbits within 2 mm, and within 5 mm for Z. Some orbit solutions, however, exhibit either significant biases or scatter in the centering, especially in Z. Almost all orbit solutions have a mean crossover of only 1 mm, although the cycle to cycle average is usually several mm. The radial bias in the CNES orbits is distinct from all other orbit solutions. The DORIS-only orbits for Jason-1 are very competitive with the other orbits, with only some weakness in the Z-centering.

DORIS Anomaly on Jason-1

Analysis of the post-fit residuals, in which the residuals are mapped into an apparent station coordinate error (station navigation), suggested that several stations have significant height or horizontal position errors. However, these did not correlate with the DORIS residual analysis from Topex/Poseidon. Figure 2 indicates which stations appeared to be the most affected. One might speculate about a correlation with the ionosphere and the geomagnetic equator, illustrated in Figure 3. The locations of the affected stations are strongly correlated with the latitudinal variations of the geomagnetic equator. It is curious, though, that not all stations in the vicinity of the geomagnetic equator are affected. Also, it is unclear why the one station, SAKA, also seems to be affected (in our analysis). It could simply be an anomaly, or an example of a related phenomenon (scintillation, for example?).

Figure 2. Apparently anomalous DORIS stations indicated by large blue circles.

Figure 3. Geomagnetic equator

The station at Arequipa (AREB) seems to be particularly affected by the anomaly (Figure 4). The station coordinates provided by H. Fagard (2002) appear to work very well for T/P. Yet the residuals from AREB are generally worse on Jason-1 than on T/P, in spite of the general trend that the fits on Jason-1 are considerably better overall than for T/P (Table 9).

Figure 4. The DORIS residuals for AREB from Jason-1 and T/P. Not only are the residuals from AREB much larger than normal for Jason-1, they are larger than the residuals on T/P. There is also some indication of a trend towards an increase in the RMS.

Topex/Poseidon Cycle	DORIS RMS (mm/s)	Jason-1 Cycle	DORIS RMS (mm/s)
344	0.462	1	0.367
345	0.458	2	0.364
346	0.456	3	0.366
347	0.466	4	0.370
348	0.468	5	0.377
349	0.455	6	0.371
350	0.459	7	0.382
351	0.463	8	0.369
352	0.449	9	0.381
353	0.461	10	0.381
Average	0.460		0.373

Table 9. The DORIS receiver on Jason-1 has considerably lower noise than the receiver on T/P, as indicated by the much better residual RMS.

Conclusions:

Nearly all of the orbits produced for Jason-1, whether based on GPS, SLR, DORIS or some combination, appear to be performing at a comparable level. If we believe that the T/P orbit accuracy is approaching the 2 cm level, it appears that the Jason-1 orbits are of a similar quality (as demonstrated by the fact that the RMS difference between the various orbits is generally less than 2 cm). The altimeter crossovers are an independent test which is particularly helpful in identifying orbit miscentering in inertial space in the equatorial plane. Crossovers are insensitive to any displacement of the orbit in the Earth-fixed frame, so the various orbit comparisons are important for testing this component of the orbit error. In general, in spite of the variety of techniques, the accuracies of the various orbits examined appear to be fairly uniform, and most orbits demonstrated consistent centering and good radial accuracy.

These results are preliminary, and it is anticipated that experience with the Jason-1 DORIS and GPS receivers will allow additional improvement of the orbit determination techniques and models. One of the challenges is to understand the curious behavior of the DORIS data for some beacons. The orbits do not seem to be significantly affected, but perhaps the orbits would be even better if the anomaly was not present.