Jason-1 Precision Orbit Determination: Status and Assessment

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Precision Orbit Determination Validation Goals

The principal goals for this POD validation effort are:

(1) Validate the CNES orbits in preparation for routine production of the precise orbits for the Geophysical Data Records. Since direct observation of the orbit error is not possible, we make a number of tests that together should provide a sufficiently robust indication of the level of orbit error. These tests are discussed later in this poster.

(2) Investigate the performance of the tracking systems. The DORIS and GPS receivers are both improved designs over that carried by TOPEX/POSEIDON. The new generation DORIS receiver on Jason-1 provides a dramatic improvement in the fits. The RMS of the DORIS observations on T/P averages 0.46 mm/s compared to 0.37 mm/s on Jason-1 (ignoring the stations affected by the SAA; see discussion below). The improved LRA design on Jason-1 supports mm-level satellite laser ranging accuracy. The RMS of the SLR data on T/P averages 2.2 cm (even after routinely estimating several biases to accommodate the LRA effects) compared to 1.6 cm on Jason-1 (estimating only 2 biases that are unrelated to the LRA). The RMS of the laser range biases for the high elevation SLR passes is only 10 mm for our SLR/DORIS-based orbits.

(3) Verify performance of the reference system used for POD. We find that the ITRF2000 coordinates are an important improvement in the overall POD performance. Only a few sites required additional adjustment; these were sites that were too new to have good estimates in ITRF2000. Some of these were determined from Lageos-1 and Lageos-2, but in other cases, Jason-1 proved to be able to determine equally accurate coordinates. Coordinates provided by IGN for the newer DORIS beacons not in ITRF2000 also proved to be very reliable.

(4) Investigate possible POD improvements. Areas where improvement might be obtained are in the force modeling, the empirical parameterization employed and in the methods for combining and weighting the multiple tracking data types.

DORIS Performance on Jason-1

Considerable analysis has been devoted to the apparent anomalous performance of the DORIS receiver on Jason-1 whenever the satellite is in the area of the South Atlantic Anomaly (SAA). It seems reasonable to suppose that the higher radiation in this area is having an effect on the onboard oscillator. The exact cause is still being investigated, but it appears to be growing steadily worse with time. This anomaly has very profound effects on station positioning with DORIS, and other posters should have more detailed information about this. Here we will review the impact on POD.

Figure 1 shows the DORIS RMS from the fits to Cycle 19 of Jason-1. Also plotted are the T/P fits for the matching cycle. It is clear that for a few sites (names indicated in red) the RMS on Jason-1 is significantly worse than on T/P, whereas for most of the stations, the RMS is better. All the indicated sites are in the vicinity of the SAA. Figure 1 also indicates the RMS for the case where a single, global frequency drift parameter is included along with the pass-by-pass frequency offset and troposphere scale parameter usually estimated in the orbit determination process. It was at one time speculated (when the effect in the earlier cycles was not so large) that the apparent large frequency change that occurred during the exposure to the SAA might be accommodated with an additional frequency drift parameter. In some cases, the RMS is reduced considerably, but the resulting RMS is still worse than for T/P. Orbit comparisons indicated that while this could improve the fits for these stations, the effect on the orbit was insignificant (and usually slightly worse). Even when a bias drift term was estimated for every pass, the RMS did not reduce very much, while the orbit results degraded. Analysis of the residuals in the pass indicates that the SAA effect is generally not well characterized by a simple linear trend.

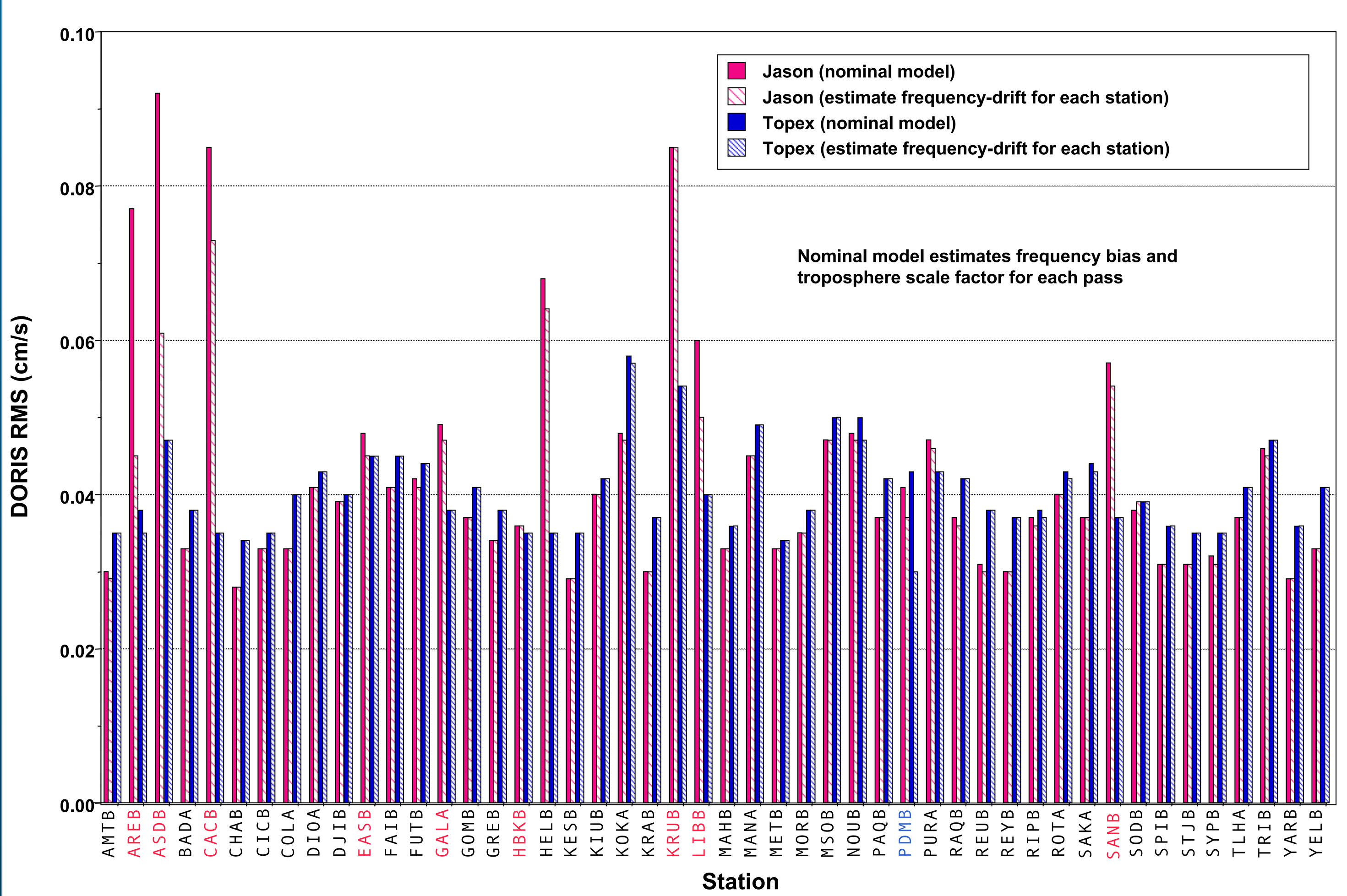

Figure 1. The RMS for each DORIS beacon from Jason-1 Cycle 19 and T/P Cycle 362 using the nominal observation parameterization. Next to this is the RMS after adding a single global frequency drift parameter for each beacon. The stations highlighted in red are worse on Jason-1 than on T/P.

An interesting discovery from this analysis: The station at Ponta Delgada (PDMB) appears to have a real frequency drift that is considerably larger than any other beacon in the network. Estimating just a single frequency drift term significantly reduced its RMS for T/P. For every other beacon, there was either no improvement at all or very little. This indicates that the assumption that the frequency drift is sufficiently small during a pass to ignore it is generally valid, except at PDMB. It is recommended that a frequency drift term be included for any beacon that exhibits a real drift of this magnitude to achieve the best results.

Orbit Accuracy Tests

In the following tables, we present some evaluations of the various orbits provided 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. It should be noted that crossovers are insensitive to any orbit error that is common to ascending and descending tracks, including any miscentering in the Earth-fixed frame. To detect significant miscentering in the Earth-fixed frame, we compared all orbits to the CSR SLR/DORIS orbits. These orbits use the same modeling and tracking data as T/P, and this model has demonstrated to be accurate and robust on T/P.

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 frames). We did not explicitly compare all the orbits in the inertial frame, but rather relied on the mean crossover as an indicator of this. We did verify with some experiments that the correlation was very strong between the crossover mean 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, although it is possible that some part of the mean may also originate from the altimeter data itself.

CNES (SLR/DORIS)

	Crossover (CSR)		Crossover (SLR/DORIS)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	14	64.6	14	4	3	1	3
9	2	59.7	7	60.6	17	3	5	6	3
10	-6	62.5	-3	66.3	27	2	2	8	5
11	-11	63.1	-8	61.4	14	0	-3	10	7
12	-9	56.5	-7	56.5	12	0	-4	7	-7
13	-3	62.4	12	63.2	17	0	-3	8	-12
14	-7	59.8	6	59.7	14	-1	-7	3	3
15	-4	58.0	8	58.0	16	-1	-5	2	3
16	-7	62.0	10	62.9	15	-1	-3	-4	1
17	4	60.4	21	63.8	14	-1	-2	-1	4
18	-5	59.2	7	56.8	12	0	-2	-5	1
19	7	61.9	18	63.3	13	-1	2	-3	2
20	8	61.4	14	61.7	12	-1	3	4	5
Mean	-2	60.7	8	61.4	15	0	-1	3	1

CNES (GPS-DYNAMIC)

	Crossover (CSR)		Crossover (GPS-DYN)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	5	63.1	13	4	6	-1	-3
9	2	59.7	-8	59.6	17	3	7	6	5
10	-6	62.5	-10	59.8	19	2	2	7	9
11	-11	63.1	-22	65.8	15	0	-3	8	7
12	-9	56.5	-33	67.0	17	0	-2	4	-2
13	-3	62.4	-3	61.9	16	0	-3	3	-5
14	-7	59.8	-14	60.5	20	-1	-5	1	23
15	-4	58.0	-5	57.8	16	-1	-3	-2	11
16	-7	62.0	14	62.8	16	-1	-3	-7	8
17	4	60.4	26	66.1	15	-1	0	-5	-7
18	-5	59.2	-8	57.0	14	-1	0	-9	-11
19	7	61.9	10	62.1	14	-1	6	-6	6
20	8	61.4	5	60.2	13	-1	7	1	8
Mean	-2	60.7	-3	61.8	16	0	1	0	4

CNES (GPS-ELFE)

	Crossover (CSR)		Crossover (GPS-ELFE)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	11	63.4	16	4	5	-2	2
9	2	59.7	-6	60.8	17	3	1	-4	2
10	-6	62.5	-10	60.9	17	2	-3	3	8
11	-11	63.1	-24	68.5	19	0	1	1	9
12	-9	56.5	-38	70.0	21	0	0	1	0
13	-3	62.4	-3	63.0	19	0	5	9	-5
14	-7	59.8	-12	61.8	23	-1	2	-1	24
15	-4	58.0	-6	58.8	19	-1	6	-1	10
16	-7	62.0	15	63.4	19	-1	3	-5	8
17	4	60.4	26	66.2	20	-1	5	4	-5
18	-5	59.2	-8	56.5	16	-1	1	-1	-10
19	7	61.9	10	63.0	17	-1	4	-2	8
20	8	61.4	5	61.7	16	-1	4	-2	5
Mean	-2	60.7	-3	62.9	18	0	3	0	4

Table 1. CNES orbits based on SLR/DORIS, GPS using a dynamic approach similar to SLR/DORIS, and GPS using a form of relaxed-dynamics approach (ELFE). The orbits based on SLR/DORIS appear to perform betterm both in terms of the crossover RMS and in the centering. The orbits where the mean crossover is large also, as expected, have a large crossover RMS.

NASA (SLR/DORIS)

	Crossover (CSR)		Crossover (NASA)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	10	62.8	9	1	2	-2	3
9	2	59.7	2	60.0	14	0	1	0	0
10	-6	62.5	-3	60.7	10	0	1	2	0
11	-11	63.1	-11	62.6	9	1	-1	1	4
12	-9	56.5	-13	57.8	13	1	0	4	1
13	-3	62.4	2	61.6	12	1	-3	2	-4
14	-7	59.8	-4	58.3	9	1	-3	2	1
15	-4	58.0	3	57.5	8	0	-1	1	0
16	-7	62.0	-4	61.2	9	1	2	0	1
17	4	60.4	8	61.0	10	1	2	1	2
18	-5	59.2	-4	58.2	16	3	5	-5	-3
19	7	61.9	10	63.2	12	1	6	-1	-1
20	8	61.4	7	61.7	9	0	3	2	1
Mean	-2	60.7	0	60.5	11	1	1	1	0

NASA (GPS)

	Crossover (CSR)		Crossover (NASA GPS)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	22	65.4	18	1	0	-1	-2
9	2	59.7	2	58.2	14	0	0	-4	2
10	-6	62.5	9	60.2	21	0	0	-4	5
11	-11	63.1	-15	63.5	17	1	0	-2	9
12	-9	56.5	-25	61.8	16	1	-1	5	3
14	-7	59.8	-19	63.5	21	1	0	-6	14
15	-4	58.0	-5	58.0	17	0	-1	-3	3
16	-7	62.0	-2	62.6	17	1	7	0	10
Mean	-5	60.5	-4	61.6	17	1	1	-2	5

Table 2. NASA orbits based on SLR/DORIS and on GPS. The SLR/DORIS orbits agree very well with the CSR orbits, as would be expected due to the deliberate use of similar models and methods. There are a few cycles where the miscentering for the GPS-only orbits is significant, which is reflected in the crossover RMS.

JPL (GPS-Reduced Dynamic)

	Crossover (CSR)		Crossover (JPL)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	6	60.8	15	1	2	2	3
9	2	59.7	5	57.8	15	1	2	-3	2
10	-6	62.5	3	59.1	18	0	-1	1	3
11	-11	63.1	-3	60.3	17	1	2	3	9
12	-9	56.5	-12	56.6	12	1	0	6	-3
13	-3	62.4	6	60.9	18	0	2	13	-2
14	-7	59.8	-6	57.8	12	0	0	1	-2
15	-4	58.0	-7	57.8	14	0	2	3	-8
16	-7	62.0	-10	62.0	12	0	5	2	-5
17	4	60.4	-5	57.8	13	0	7	8	-3
18	-5	59.2	-2	55.2	15	1	4	4	-6
19	7	61.9	7	59.1	13	1	5	3	-4
20	8	61.4	7	59.5	13	1	4	7	2
Mean	-2	60.7	-1	58.8	14	0	3	4	-1

JPL/IGN (GPS/DORIS)

	Crossover (CSR)		Crossover (JPL/IGN)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	9	60.8	14	1	2	2	7
9	2	59.7	3	57.7	15	1	3	-1	7
10	-6	62.5	-1	59.0	18	0	1	3	6
11	-11	63.1	-10	61.8	16	1	1	4	11
12	-9	56.5	-14	57.2	14	1	2	9	4
13	-3	62.4	-1	60.9	18	1	6	14	1
14	-7	59.8	-12	59.2	13	0	-1	5	6
15	-4	58.0	-11	58.4	16	0	0	6	2
16	-7	62.0	-15	63.0	15	0	5	7	8
17	4	60.4	-9	57.9	16	0	6	12	8
18	-5	59.2	-6	56.7	17	1	8	5	4
19	7	61.9	6	59.6	15	1	6	6	6
20	8	61.4	2	58.0	16	1	6	10	11
Mean	-2	60.7	-5	59.2	16	0	3	6	6

Table 3. JPL orbits using GPS and a reduced-dynamics approach, and JPL/IGN orbits based on GPS and DORIS combined. Both sets of orbits show a reduced crossover RMS relative to the nominal CSR orbits. The centering of the reduced-dynamics orbits from JPL is generally good. The centering of the GPS/DORIS orbits from JPL/IGN shows more scatter. It is unclear why both orbits show a 13-14 mm difference in the Y centering for Cycle 13. This cycle gave some groups trouble, so there may be something in the GPS data that is causing this (or the CSR orbit is really miscentered).

DEOS (SLR/DORIS)

	Crossover (CSR)		Crossover (DEOS)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	20	68.7	15	1	-1	-2	0
9	2	59.7	13	61.7	15	0	-3	-2	0
10	-6	62.5	0	61.5	14	0	0	4	-1
11	-11	63.1	-9	64.1	14	1	2	5	6
12	-9	56.5	-7	56.2	19	1	6	6	-3
13	-3	62.4	-4	63.6	14	1	4	2	-4
14	-7	59.8	2	60.3	14	1	2	-1	7
15	-4	58.0	4	58.9	10	0	-1	-3	0
16	-7	62.0	5	62.6	13	0	-3	-3	2
17	4	60.4	20	64.2	16	1	-4	-4	3
18	-5	59.2	6	58.8	17	2	1	-10	-4
19	7	61.9	18	64.4	16	0	0	-3	-3
20	8	61.4	19	65.2	13	0	-4	2	-5
Mean	-2	60.7	7	62.3	15	1	0	-1	0

DEOS (SLR/DORIS - GRIM5C1)

	Crossover (CSR)		Crossover (GRIM5C1)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	22	68.1	17	-1	-1	-3	0
9	2	59.7	13	60.4	17	-2	-4	-2	-1
10	-6	62.5	-2	60.5	16	-2	-1	4	0
11	-11	63.1	-10	64.2	16	-1	1	5	9
12	-9	56.5	-10	56.8	22	-1	5	6	-3
13	-3	62.4	-6	64.0	16	-1	3	2	-4
14	-7	59.8	2	59.7	15	-1	1	0	8
15	-4	58.0	4	58.3	13	-2	-2	-2	1
16	-7	62.0	6	62.4	16	-2	-3	-3	2
17	4	60.4	20	63.2	18	-1	-4	-5	1
18	-5	59.2	7	58.5	21	0	1	-11	-6
19	7	61.9	20	63.5	18	-2	0	-4	-2
20	8	61.4	20	64.4	16	-2	-4	1	-7
Mean	-2	60.7	7	61.8	17	-1	-1	-1	0

Table 4. DEOS orbits based on SLR/DORIS, using the nominal gravity model (JGM3) and an alternative model (GRIM5C1). Some reduction in the crossover RMS is achieved with GRIM5C1. The orbits are generally well centered in the Earth-fixed frame but some orbits have considerable crossover means, indicating poor centering in the inertial frame (which is reflected in higher crossover RMS).

CSR (SLR/DORIS - GRIM5C1 gravity model)

	Crossover (CSR)		Crossover (GRIM5C1)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	6	62.1	10	-2	-1	-1	1
9	2	59.7	4	59.0	9	-2	-1	-1	0
10	-6	62.5	-7	61.4	10	-2	-1	-1	0
11	-11	63.1	-15	63.8	9	-2	-1	-1	2
12	-9	56.5	-11	56.8	9	-2	-1	0	2
13	-3	62.4	-5	63.7	9	-2	-1	0	1
14	-7	59.8	-5	59.3	9	-2	-1	-1	0
15	-4	58.0	-4	57.4	9	-2	-1	-1	-1
16	-7	62.0	-5	61.1	10	-2	-1	-1	-1
17	4	60.4	4	58.9	9	-2	-1	-1	-2
18	-5	59.2	-4	57.5	9	-2	0	-1	-2
19	7	61.9	9	60.9	9	-2	0	-1	-2
20	8	61.4	10	61.1	9	-2	-1	-1	-1
Mean	-2	60.7	-2	60.2	9	-2	-1	-1	0

CSR (SLR/DORIS - Preliminary GRACE gravity model)

	Crossover (CSR)		Crossover (GRACE)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	-2	62.1	12	0	0	8	3
9	2	59.7	-1	59.0	10	0	1	8	-1
10	-6	62.5	-6	61.7	10	0	1	8	-3
11	-11	63.1	-16	64.3	10	0	1	8	2
12	-9	56.5	-10	56.2	10	0	1	8	1
13	-3	62.4	-4	63.1	10	0	1	9	-1
14	-7	59.8	-4	58.8	11	0	1	8	-1
15	-4	58.0	-4	57.1	10	0	1	8	-4
16	-7	62.0	-7	61.3	11	0	1	8	-4
17	4	60.4	1	58.5	10	0	1	8	-3
18	-5	59.2	-9	58.2	11	0	2	9	-1
19	7	61.9	6	60.2	10	0	1	8	-3
20	8	61.4	6	60.7	11	0	0	8	-1
Mean	-2	60.7	-4	60.1	10	0	1	8	-1

Table 5. CSR orbits based on SLR/DORIS but using two alternative gravity models; GRIM5C1, the same as shown in Table 4, and a preliminary GRACE gravity model recently developed. In both cases there is a modest decrease in the crossover RMS, but not as much as seen in the GPS-based orbits shown in Table 3. Some orbit improvement can be expected from a better gravity model but the gravity model is likely not one of the 'tall poles' in the orbit error budget anymore. The mean radial difference of 2 mm in the GRIM5C1 orbits is curious (also seen in the DEOS orbits), The mean Y difference in the GRACE orbits is likely geographically correlated error resulting from the GRACE model, which contains no information from any other satellite. On the other hand, it could be, at least in part, geographically correlated error due to JGM3.

CSR (GPS/SLR/DORIS)

	Crossover (SLR/DORIS)		Crossover (GPS/SLR/DORIS)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	5	60.5	14	0	7	7	2
9	2	59.7	3	58.7	14	1	6	3	0
10	-6	62.5	-4	58.8	17	0	3	4	1
11	-11	63.1	-13	61.8	13	0	4	6	7
12	-9	56.5	-14	56.1	11	0	2	9	1
14	-7	59.8	-7	58.7	13	0	-5	0	5
15	-4	58.0	-6	57.9	15	0	-6	1	-5
16	-7	62.0	-8	59.6	13	0	-4	1	-1
17	4	60.4	4	58.9	13	0	-2	8	-1
19	7	61.9	9	59.7	14	0	5	6	-3
20	8	61.4	7	57.9	13	1	7	13	2
Mean	-2	60.7	-2	59.0	14	0	1	5	1

Table 6. CSR orbits determined use the combination of GPS, SLR and DORIS. There is a significant reduction in the crossover RMS while the centering remains good. The larger crossover biases in Cycles 11 and 12 seem persistent among many of the orbits, so it may be at least partly due to the altimeter data.

CSR (DORIS-only)

	Crossover (CSR)		Crossover (DORIS-only)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	12	63.7	6	0	0	0	0
9	2	59.7	6	60.1	6	0	0	0	-3
10	-6	62.5	-4	61.5	7	0	-1	0	-3
11	-11	63.1	-16	65.1	7	0	0	0	1
12	-9	56.5	-12	56.7	7	0	0	0	-5
13	-3	62.4	5	63.0	11	0	0	0	-12
14	-7	59.8	-6	59.7	8	0	0	-1	3
15	-4	58.0	-6	58.2	7	0	0	0	-3
16	-7	62.0	-5	62.2	5	0	0	0	1
17	4	60.4	3	60.3	5	0	1	0	-1
18	-5	59.2	-7	59.9	8	0	1	0	-4
19	7	61.9	11	62.7	9	0	1	-1	-9
20	8	61.4	9	61.3	7	0	-1	0	-8
Mean	-2	60.7	-1	61.1	7	0	0	0	-3

CSR (SLR-only)

	Crossover (CSR)		Crossover (SLR-only)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
8	5	62.5	0	63.2	7	0	0	0	1
9	2	59.7	-2	60.7	6	0	0	0	3
10	-6	62.5	-3	65.3	10	0	1	0	-3
11	-11	63.1	-3	63.1	9	0	-1	0	-3
12	-9	56.5	-7	59.2	9	0	0	0	0
13	-3	62.4	10	79.9	31	0	3	1	-6
14	-7	59.8	-5	61.0	7	0	0	0	-5
15	-4	58.0	5	60.0	11	1	0	0	4
16	-7	62.0	-6	63.9	14	-1	2	2	-5
17	4	60.4	6	62.8	10	0	-1	-1	-6
18	-5	59.2	-7	61.1	10	-1	-2	0	-6
19	7	61.9	7	68.4	22	1	-2	-1	2
20	8	61.4	7	62.4	7	-1	1	0	-5
Mean	-2	60.7	0	63.9	12	0	0	0	-2

Table 7. CSR orbits using SLR only and DORIS only. Neither is as good as the orbits based on both, demonstrating that each system provides important orbit information. The SLR-only orbits are more consistently centered, as would be expected, but sometimes the tracking is not sufficient to compete with the much more dense DORIS tracking.

Conclusions

The orbits examined here, whether based on SLR, DORIS, GPS or some combination, generally perform well. Some differences are significant, however. The CNES orbits based on SLR/DORIS outperform their orbits produced with GPS only, in terms of crossover RMS and orbit centering. Including SLR and DORIS would likely improve the results. A few of the CNES orbits exhibited a larger than normal radial bias. A few NASA GPS and DEOS SLR/DORIS orbits were significantly miscentered.

The GPS orbits from JPL, the GPS/DORIS orbits from JPL/IGN and the GPS/SLR/DORIS orbits from CSR appear to perform the best overall, indicating the contribution that GPS can make to the orbit accuracy.

The gravity model tests indicate that some improvement is possible, although it is unlikely that the gravity model is a major contributor to the orbit error. Some geographically correlated orbit error may remain, however, and we can expect the GRACE models to eliminate this.

Although the individual orbit tests were not shown here, variations in the parameterization for the CSR ten-day arcs fit to SLR/DORIS did not lead to anything consistently better. A higher level of parameterization can be supported by the GPS tracking, but the orbit centering can suffer. This can be offset by including SLR tracking to constrain orbit centering better. Variations in weighting the DORIS data relative to the SLR in the SLR/DORIS combinations also did not lead consistently better results. The current weighting still seems optimal (using ITRF2000), but it is not especially sensitive to even a factor of 2 change. The GPS weighting also did not seem to be especially sensitive (see poster by Choi et al.)

It may be reasonable to claim that the radial orbit accuracy for Jason-1 is closer to 1 cm than to 2 cm. This can be inferred by examining the high elevation SLR passes for the DORIS-only orbits. The RMS of the range biases (which, when withheld from the orbit solution, are a strong and direct measure of the radial orbit accuracy) was only 1.4 cm, suggesting a radial orbit accuracy at the same level. Since the orbits with SLR included are more accurate than the DORIS-only orbits, the radial orbit accuracy should be even better. Most centers produced orbits equal to or better than the DORIS-only orbits in terms of crossover variance, suggesting that some of the best orbits may be approaching 1 cm.

At this level, centering the orbit at the mm level becomes important; otherwise the radial orbit error will be dominated by the miscentering. Miscentering in Z or in the equatorial plane can lead to artifacts in sea level analyses. This makes the contribution of SLR to orbit centering increasingly important.

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