Jason-1 Orbit Improvement by Combining GPS with SLR/DORIS

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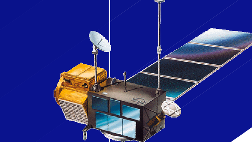


Models:

Table 1. Dynamic Models

Dynamic Models:	
Gravity	JGM-3 truncated to 70 x 70, GM=398600.44150 km^3/sec^2 and Re=6378136.3000 m
Third-Body	JPL DE200
Solid-Earth tide	IERS 96 [*Wahr et al.*, 1981]
Ocean tide	CSR 4.0 + TEG4 resonant tides
Atmospheric Drag	Density Temperature Model(DTM) [*Barlier et al.*, 1978]
Solar Radiation pressure	Mass = 481.0 kg, Simple Box-wing model, Earth shadow model includes: umbra and penumbra
Earth radiation pressure	Albedo and infrared second-degree zonal model
Relativity perturbation	*Ries et al.* [1991]
GPS satellites Orbits	Fixed with the IGS final solution, sp3 files.
Numerical Integration	Krogh-Shampine-Gorden 14th order, fixed step integrator. Arc Length: 30 hours, 6 hours overlapped.

Table 2. Measurement Models

Measurement Models:	
Double-differenced GPS data	Preprocessed using the TEXGAP software developed at CSR. Elevation cutoff: 0 deg. Sampling rate : 30 sec. Ionosphere-free linear combination, Satellite clock biases are eliminated by forming Double-Difference
Troposphere	Mapping function for dry and wet
Ionosphere	Not modeled, but eliminated by L1 and L2 linear combination.
Plate motions	ITRF2000 for GPS stations
Station Coordinates	GPS, SLR and DORIS fixed with ITRF2000 (with a few exceptions)
Rotational Deformation	IERS 96
Tide model	IERS 96, ocean loading included
Earth Orientation Model	IERS
Center of Mass Offset	(X=-94.2 cm, Y=0.0 cm, Z=0.0 cm)
Instrument Phase Center	SLR= (22.9, 59.8, 68.3) cm, DORIS=(22.9, -59.8, 102.7) cm, GPS=(238.91, -21.80, -50.40) cm

Table 3. Experiments processed for this research

Experiments	Estimation strategy
Nominal Orbits	***Common Strategy*** + both X and Z offsets estimated + JGM3 model + all 43* stations were fixed + estimating every 1.8738 hr for Drag and every 5.6214 hr for empirical forces.
Empirical force	Various empirical parameter estimation frequency
Weighting for mixed data types	Various GPS weight with 10 cm for SLR and 2 mm/sec DORIS Various DORIS weight with 10 cm for SLR and 25 cm for GPS
Effect of Station Distribution	Various GPS ground station set with different numbers and different distribution were experimented

Parameterization for Empirical forces:

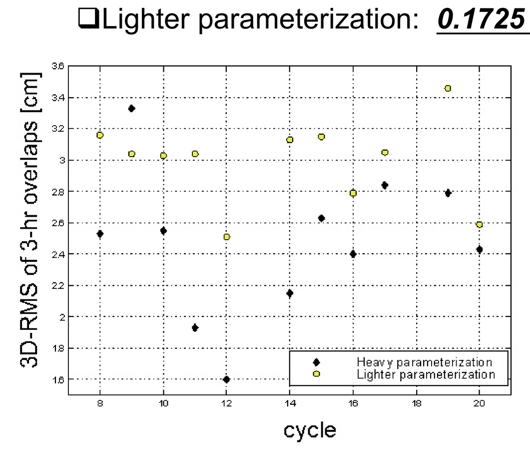
To find an optimal estimation frequency for the empirical forces and drag is very important to obtain a better orbit solution. The errors caused by insufficient surface models can be accommodated in the empirical and drag parameters. The heavier parameterization tends to reduce the orbit fit residual rms, but it doesn't always mean it'll give a better orbit.

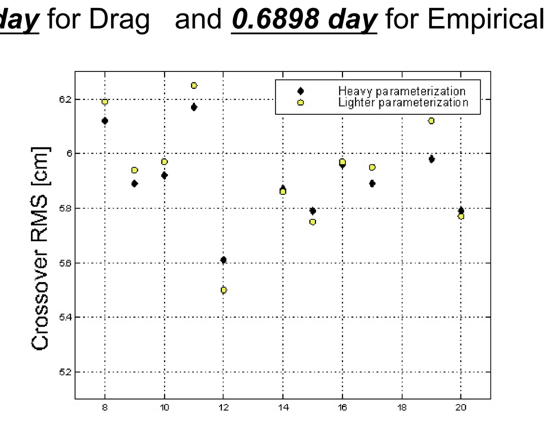
One of the benefits of the GPS data over the SLR/DORIS data for the POD purpose is its dense and homogeneous tracking. With the dense observation set, heavier parameterizations are possible to accommodate the force model errors. How far we can push the parameterization is still a question.

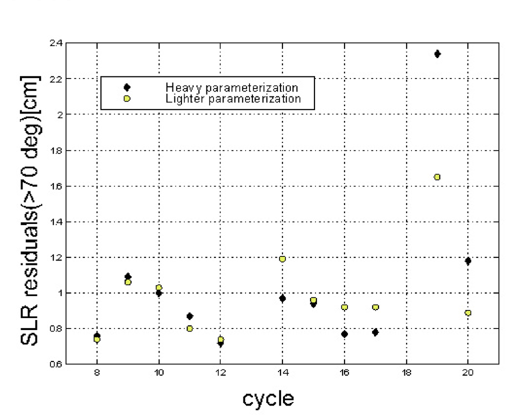
Several parameterizations were explored for cycle 8 and cycle 10. The sub-arc lengths for this investigation were chosen by considering several factors such as the orbit period, the integration arc length as well as the yaw events. Sub-arc lengths such as 1.8738 hr, 3.7476 hr, 5.6214 hr and 7.4952 hr are exact multiples of the Jason-1 orbit period, 1.8738 hour. The sub-arcs of 3 hr, 6 hr, 10 hr, 15 hr are chosen because they divide the integration arc length (30hr) equivalently. For example, the choice of 3 hr for Drag and 6 hr for Empirical forces gives us 10 sub-arcs for Drag coefficients and 5 sub-arcs for the 1-cpr acceleration for each arc. Another set of sub-arc lengths of 0.1725day, 0.34492 day and 0.6898 day, which are based on the experience of the TOPEX/POSEIDON orbit, were also tested.

Based on the crossover rms and SLR residuals, 1.8738 hr for Drag and 5.6214 hr for Empirical 1-cpr forces was a level of parameterization which generally performed best. The Figures below compares two orbits from two different parameterization.

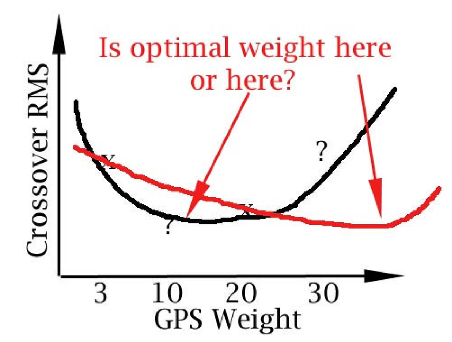
- Heavy parameterization: ***1.8738 hour*** for Drag and ***5.6214 hour*** for Empirical Forces.
- Lighter parameterization: ***0.1725 day*** for Drag and ***0.6898 day*** for Empirical Forces.

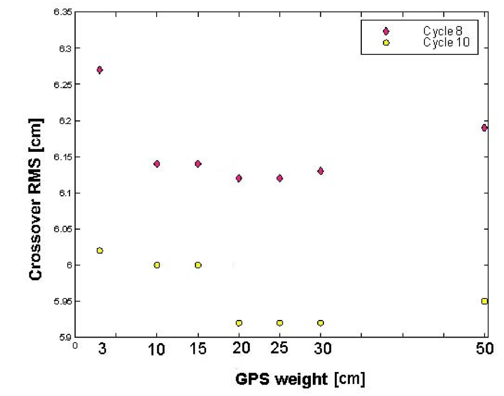






Optimal Weighting for each Data type?:





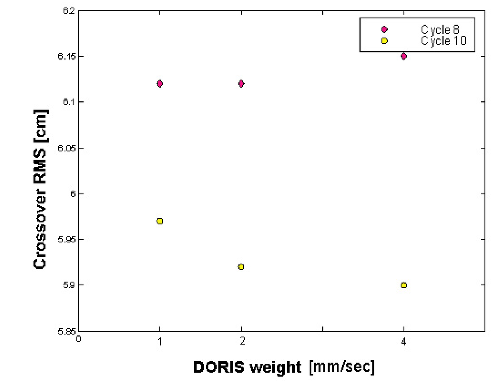


Table 4. Orbit performance with different combination [cm]

Case (10 cm for SLR, 2mm/sec for DORIS, 25 cm for GPS)	Cycle 8				Cycle 10			
	Xover		SLR residuals(>70deg)		Xover		SLR residuals(>70deg)	
	mean	rms	mean	rms	mean	rms	mean	rms
DORIS + SLR	0.45	6.25	0.23	1.01	-0.55	6.26	0.52	1.09
GPS-only*	0.56	6.24	0.00	0.94	0.59	6.15	-0.75	1.38
GPS + DORIS*	0.77	6.19	0.05	0.92	0.01	5.97	-0.71	1.26
GPS + SLR	0.18	6.13	-0.08	0.77	0.15	6.00	-0.56	0.98
GPS + SLR/DORIS	0.39	6.12	-0.02	0.76	-0.16	5.92	-0.57	1.00

* SLR data NOT used for POD. Note that their SLR residuals are still at the 1 cm level.

✓ Table above clearly shows that combining GPS with SLR/DORIS can improve the orbit quality.

✓ To find an optimal weighting for GPS, 3 cm, 10 cm, 15 cm,20 cm, 25 cm, 30 cm and 50 cm for GPS were weighted with the SLR weight fixed to 10 cm, and with the DORIS weight fixed to 2 mm/sec.

✓ The crossover statistics for both cycle 8 and cycle 10 shows that the optimal weight for GPS resides somewhere between 10 cm to 30 cm.

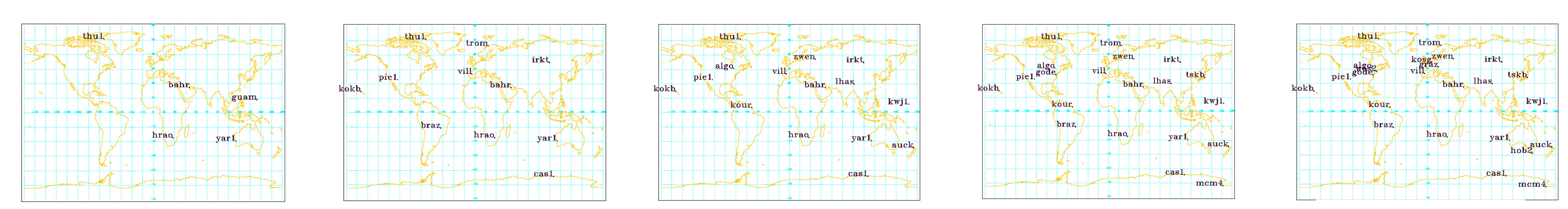
✓ The experiments with the various DORIS weight from 1 mm/sec to 4 mm/sec show that the orbit quality is not sensitive to the DORIS weight, and 2 mm/sec weighting seems fine.

✓ For the nominal orbits combined GPS with SLR/DORIS, 25 cm was chosen for the optimal GPS weight, 10 cm for SLR, and 2mm/sec for DORIS.

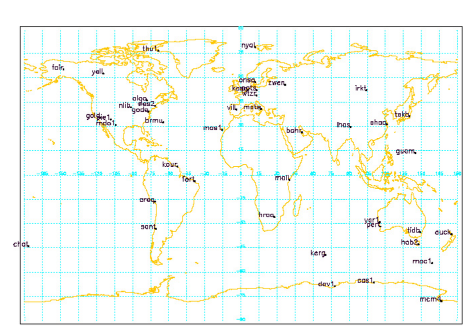
Effect of GPS Ground Station Distribution?:

As of 18 Oct 2002, 338 IGS stations are available, and about 200 stations precise coordinates are available from ITRF2000. For GPS orbit processing, we need to select a good performing station set, since it would be unreasonable to process the GPS data from all the stations, and processing all the data doesn't necessarily guarantee the best orbit. For CSR's nominal GPS orbits, we use about 43 stations which are ITRF 2000 reference stations. Although these 43 stations are almost globally distributed, it is not uniform distribution, and there could still be some redundancies.

In this experiment, we showed how the number of stations and the distribution of stations affect the orbit quality.



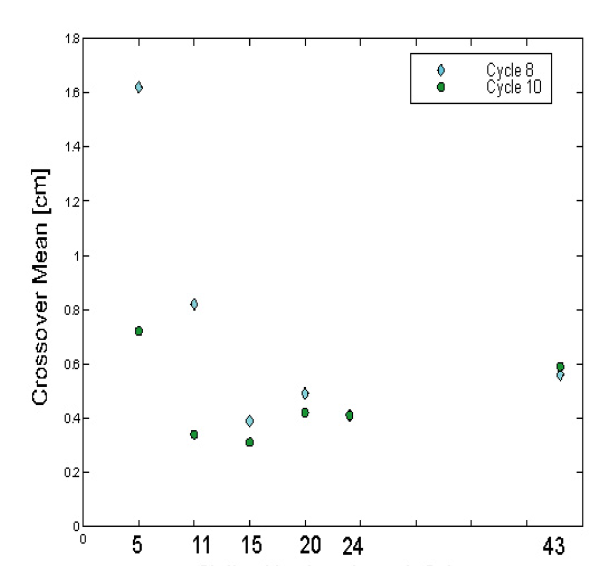
Set 1(5 stations) Set 2(11 stations) Set 3(15 stations) Set 4(20 stations) Set 5(24 stations)

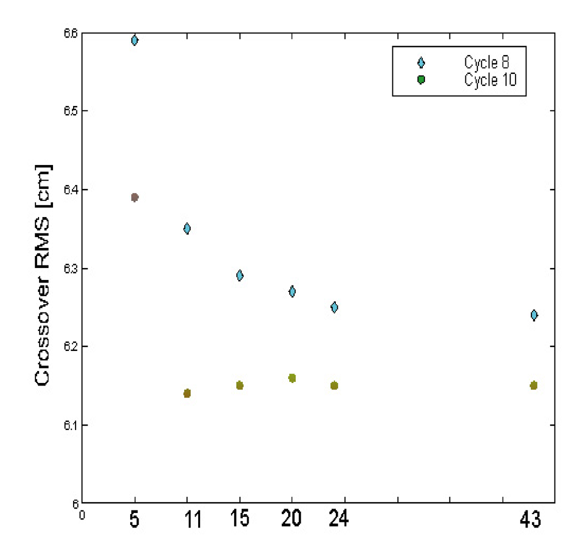


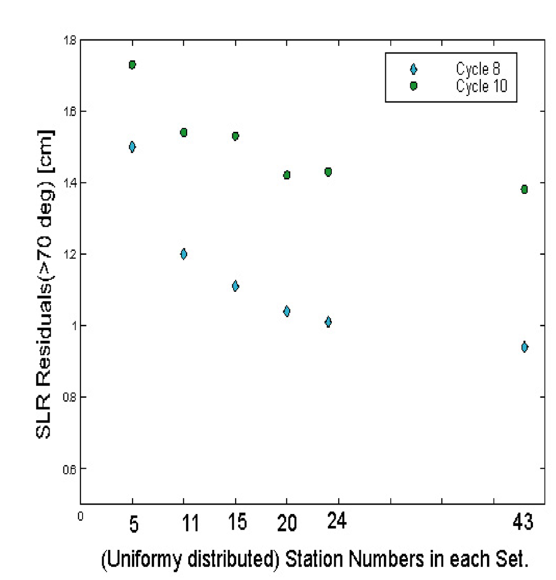
Nominal Set (43 stations)

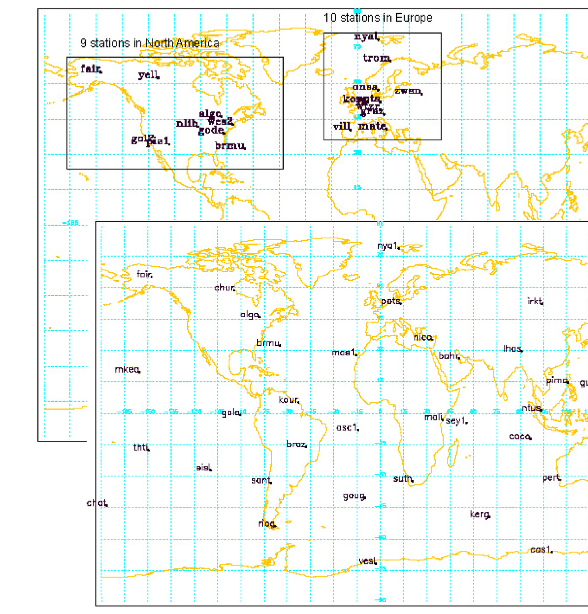
For this experiment, 6 sets of ground stations were chosen with uniform geographical distribution in mind, but it was difficult to avoid some imbalance between the southern and northern hemispherical distributions. All the stations in these sets are ITRF2000 reference stations.

The figures below shows the orbit performance of each station set. The crossover mean comparison shows that the orbits of cycle 8 from Set 1 and Set 2 are possibly miscentered. The crossover RMS comparison shows that the orbits from about 15 stations performs close to the nominal orbit which was obtained from 43 stations.









Optimal Set for cycle 8 (37 stations)

Table 5. GPS-only Orbit with non-uniform distribution sets

case	Cycle 8 (GPS-only) [cm]			
	Xover		SLR residual(>70)	
	mean	rms	mean	rms
Nominal Set	0.56	6.24	0.00	0.94
American Set	-2.24	7.32	-0.70	2.26
European + American Set	-2.00	6.59	-0.15	1.29

Table 6. Orbits with GPS+SLR/DORIS

Case	Cycle 8 (GPS+SLR+DORIS) [cm]			
	Xover		SLR residual(>70)	
	mean	rms	mean	rms
Nominal Set	0.39	6.12	-0.02	0.76
Optimal Set	0.62	6.12	0.05	0.75
American Set	0.73	6.22	-0.07	0.66
European + American Set	0.35	6.15	-0.06	0.72

Table 7. Bias for SLR/DORIS and GPS-only comparison

Case	Cycle 8 (GPS-only) [cm]			
	Z	R	T(along)	N
Nominal Set (43 stations)	-0.25	-0.03	-0.29	0.14
Set 1 (5 stations)	-0.28	-0.02	-0.91	0.14
Set 4 (20 stations)	0.24	0.02	0.43	0.11
American Set	0.29	-0.02	-2.69	0.13
European+American Set	0.15	-0.02	-1.87	0.13

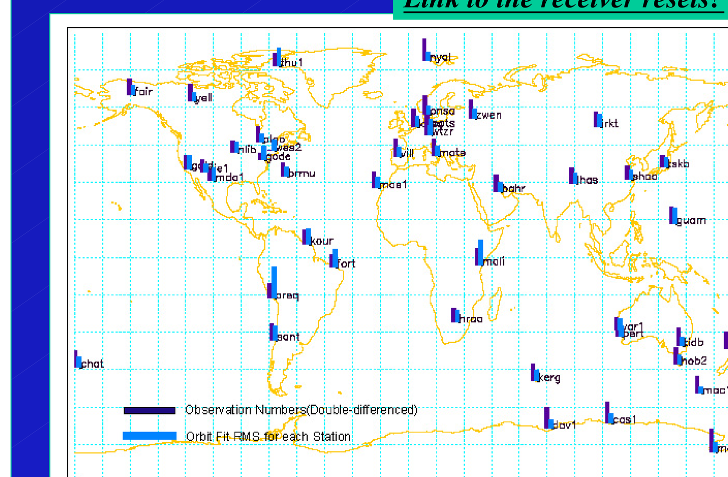
✓ An Optimal Set was selected considering 1) geographical distribution, 2) tracking performance, and 3) coordinates accuracy out of 208 ITRF2000 stations. It shows that an an optimal geographical distribution set for cycle 8 consists of only 37 stations. Adding more stations actually hurts the distribution.

✓ As shown in Table 6, orbits determined with the Optimal Set perform no better than orbits with the Nominal set.

✓ GPS-only orbits with heavily biased distribution set such as only European or American sites show a significant miscentering, judging by the crossover mean statistics in Table 5. But, by adding the SLR/DORIS data, the miscentering was improved as shown in Table 6. This implies that SLR/DORIS can help the GPS orbit with the orbit centering.

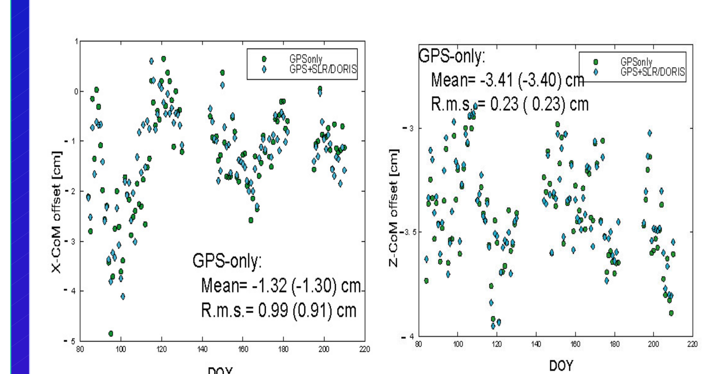
✓ Table 7 indicates that the Z-bias is affected only at the few mm level by the non-uniform hemispherical distribution of stations.

Link to the receiver resets?



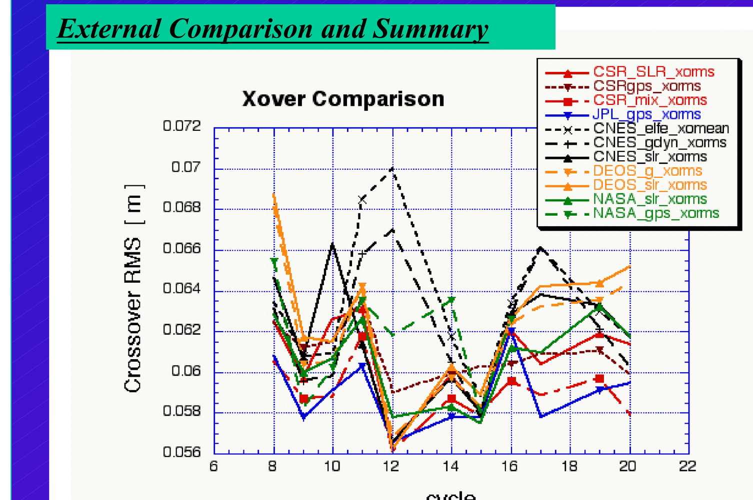
Bars in this figure show the relative size of 1) daily GPS tracking data, and 2) daily orbit fit RMS for each station, which were averaged over cycle 8. Note that the orbit fit RMSs of '**SANT**','**FORT**', '**KOUR**' and '**MALI**' are relatively higher than other stations'. This implies a possible link to the BlackJack receiver resets mainly occurred over the South Atlantic.

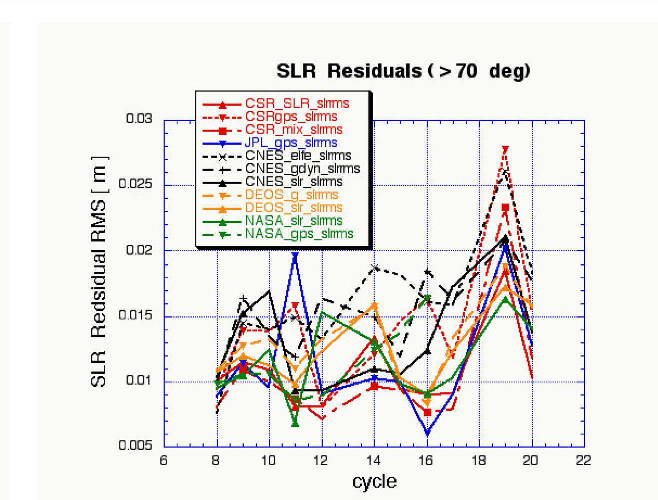
Center of Mass Offset:



For the Nominal orbits, ΔX and ΔZ were simultaneously estimated for each day. The Z component was fairly stable at ~ -3.4 cm, but the X component varied between +1 to –4 cm with a mean of –1.3 cm. Addition of the SLR/DORIS data to the GPS data didn't change them much.

External Comparison and Summary





✓ Among the three CSR solutions, the orbit combined with GPS and SLR/DORIS was noticeably improved over the orbits with GPS-only or with SLR/DORIS in the sense of the crossover rms and SLR residuals.

✓ Crossover RMS comparison shows that JPL_gps and CSR_mix orbits perform best. The SLR residuals with high elevation data shows that the orbit solution with combining three data types may be approaching the 1cm RMS radial accuracy.

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REFERENCES

Haines, B., et al., "Initial Orbit Determination Results for Jason-1: Towards a 1-cm Orbit",ION, 2002.