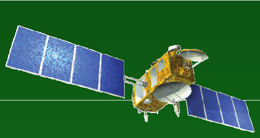

Jason-1 POD

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1. introduction

MSODP(Multi-Satellite Orbit Determination Program) developed originally for the GPS data processing at UTCSR, but with the capability to simultaneously process various measurement types, was used for this research. MSODP is a software of a weighted least squares batch estimation procedure which employs a numerical integration of the differential equations describing the motion of multi-satellites. This poster describes the GPS data process and the parameterization strategy to obtain orbit solutions, then assesses the quality of the orbits applying several analysis methods. This poster focuses mainly on the orbits of cycle 8, which is in the sinusoidal yaw mode.

2. GPS Data Process

TEXGAP software (the university of TEXas Gps Analysis Program) was utilized to preprocess Jason-1 GPS data. Globally distributed 50 IGS ground stations were selected to form the double differenced combination. Double-differenced carrier phase measurements formed by using about 40 IGS stations for each day were sampled at 30 second interval.

With the information such as the simultaneously observed pseudo-range data, the broadcast navigation message including the GPS satellite clock information, the ground station coordinates, the position of the user satellite and fairly accurate GPS orbits, the receiver's time tag correction was computed by averaging the corrections from all reliable GPS satellites tracked. The remaining satellite and receiver clock errors in the phase measurement were removed by forming double differenced phase measurement. The pairing of the GPS satellites for double difference was made without any dependency among the pairs. During the preprocessing, anomalous DD observations were identified and edited by using three-times the standard deviation of the overall DD residual. Cycle-slips were also detected by computing the differences between the consecutive data points in the DD residuals and identifying spike-like anomalies, then were fixed using linear extrapolation. Performance of the BlackJack GPS receiver on Jason-1 has been gradually improved over the cycles as shown in Fig.1. It shows that more GPS data were collected during cycle 8 than during the previous cycles. The quality of data has also improved comparing with initial cycles.

3. Model

Ionospheric delay was eliminated to first order by forming a linear combination of observables with different frequencies. A simple box-wing model was used for the surface forces. ITRF 2000 coordinates were used for the GPS station positions as well as for SLR and DORIS. The ocean loading model of MSODP was updated to IERS96. Table 1 and Table 2 show the models implemented for this research.

The orbit solution from MSODP with the SLR/DORIS data was verified with the solution from UTOPIA. To do so, the dynamic and measurement models in MSODP for Jason-1 were synchronized with the models in UTOPIA (the University of Texas Orbit Processor).

4. Strategy

The SLR, DORIS and GPS data for cycle 008 were processed with a fully dynamic approach. Orbits for ten 30-hour arcs with nine 6-hour overlaps within each cycle were solved. Ten middle 24 hour arc solutions were concatenated to get a complete full cycle solution.

Jason-1 initial condition., drag coefficient(Cd), one-cycle-per-revolution(1-cpr) along-track(T) and cross-track(N) components were adjusted. Double-differenced ambiguity parameters, Zenith delay parameters, Jason-1 center-of-mass offset X- and/or Z-component were simultaneously estimated. The coordinates of three suspicious stations such as **AREQ**, **FORT** and **MALI** were also estimated; otherwise, their GPS double differenced observations were excluded from the process. The three stations showed bad orbit fits over the whole cycles. While **AREQ** had experienced an earthquake after the establishment of ITRF2000, the reason for the bad orbit fits from the other two stations is not clear. GPS orbits were fixed to the IGS final solutions. But, experiments with the GPS orbit element corrections were attempted because of concern about the inertial centering of the GPS orbit. The extensive numbers of uniform and continuous GPS measurement requires testings to determine the optimal estimation frequency for the drag coefficient and the empirical parameters.

For the process of the mixed data types, all the measurement types preprocessed separately from each different software were processed simultaneously in MSODP with different weighting. 10 cm and 2mm/sec were the sigmas for the SLR data and DORIS data, respectively. For the GPS data, the sigma was varied between 3 cm and 20 cm. To evaluate the effect of various parameterizations on the orbit solution, several cases were chosen to experiment as shown in Table 3.

CASE 1 is to evaluate the center of mass offset effect. The Jason-1 POD project document initially specified the offset as (X=-0.942 m, Y=0.0, Z=0.0). But it can be changed because of the fuel consumption. Also like Topex/Poseidon, the GPS antenna's phase center appears to be located at a point different than the a priori measurement. **CASE 6** is to see the effect of each measurement type's role for the orbit quality. Each different weight for each measurement type was applied. To see the effect of the suspicious three stations, two **CASE 4** tests were conducted; **CASE 4-pos** fixed 47 station coordinates and estimated the 3 suspicious station coordinates, **CASE 4-wo** used only 47 stations for the process excluding the three stations. **CASE 2** and **CASE 5** were to evaluate the estimation frequency of the empirical parameters and the different geopotential model respectively. JGM-3, TEG-4 and EGM96 were tested for **CASE 5**.

For the GPS orbit element correction, 4 orbit elements (i,e, cosΩ, sinΩ) were estimated with various combination. But for this poster, only the test with one element estimation is shown. For all the cases, least square algorithm with 30 hours of DD phase observations from 50 global network stations was used. ***Common Estimation Strategy*** was applied to all the cases. The Common Estimation strategy means the estimation of Initial Condition(X,V), Jason epoch state, DD ambiguity and Tropospheric Zenith delay parameters, while the GPS orbits were fixed to the IGS final solution.

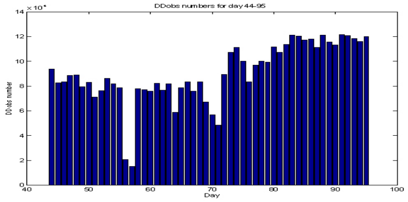

Fig. 1 Double- Differenced GPS observation numbers for day 44 –95

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 DD
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. Parameterization Strategy

Interest	case	Estimation strategy
Center of mass offset	**CASE 1-xz**	***Common Strategy*** + both X and Z offsets estimated + JGM3 model + all 50 stations were fixed + Cd for every 0.1725 day +T,N every 0.6898 day *(new X= -95.99 cm, new Z= -3.43 cm) for cycle 8.*
	CASE 1-x	**CASE 2** + X offset only estimated
	CASE 1-z	**CASE 2** + Z offset only estimated
Empirical force	**CASE 2**	**CASE 1-xz** + Cd for every 0.34492 day + T,N for every 1.0347day
GPS orbit element correction	**CASE 3**	**CASE 1-xz** + cosΩ was estimated (Ω = ascending node)
3 suspicious GPS stations	**CASE 4-pos**	**CASE 1-xz** + 3 station coordinates were estimated
	CASE 4-wo	**CASE 1-xz** + 3 stations were excluded from the process
Gravity model	**CASE 5-t**	**CASE 1-xz** + TEG4 gravity model
	CASE 5-e	**CASE 1-xz** + EGM96
Weighting for mixed data types	**CASE 6-w03**	**CASE 1-xz** + Sigma : 3 cm GPS, 10 cm SLR, 2 mm/sec DORIS
	CASE 6-w10	**CASE 1-xz** + Sigma : 10 cm GPS, 10 cm SLR, 2 mm/sec DORIS

Table 4. SLR and Crossover residuals for cycle 8 [unit: cm]

CASE	SLR residuals(> 10 deg)			SLR residuals(> 70deg)		Crossover residuals	
	obs #	mean	rms	mean	rms	Mean	rms
1-xz	3812	-0.40	1.49	-0.09	1.04	0.32	6.76
1-x	3812	-0.18	1.57	0.11	1.24	-0.59	6.60
1-z	3812	0.20	1.68	0.37	1.54	***1.99***	6.88
2	3812	-0.01	1.59	0.17	***1.32***	0.84	6.60
3	3710	-0.46	1.37	-0.02	1.03	0.41	6.77
4-pos	3710	-0.42	1.36	0.05	1.00	0.47	6.75
4-wo	3710	-0.44	1.38	0.03	1.01	0.45	6.75
5-t	3710	-0.61	1.37	***-0.22***	1.09	0.22	6.77
5-e	3710	-0.52	1.69	***-0.24***	1.01	0.49	6.81
6-w03	3710	-0.26	***1.00***	0.02	***0.91***	0.72	6.72
6-w10	3710	-0.39	***1.33***	-0.06	***0.96***	0.37	6.71
CSRslr	3710	0.08	1.30	0.43	1.27	0.69	6.78
JPLgps	3812	-0.41	1.51	-0.13	1.28	-0.13	6.35
CNESgps	3812	-0.13	2.18	0.13	1.40	0.54	6.75
CNESslr	3812	-0.29	1.87	0.15	1.25	1.22	6.62

Table 5. DDrms (averaged over day84-94) and overlap rms (averaged over 10 overlaps) for cycle 8

CASE	DD rms [cm] over cycle 8	Overlaps rms [cm]			
		R	T	N	3D
1-xz	1.44	1.40	3.28	1.20	3.80
2	1.46	1.56	4.00	1.71	4.74
4-wo	1.31	1.38	3.20	1.23	3.74
6-w03	3.33	1.24	3.22	1.33	3.76

Table 6. orbit comparison statistics [unit : cm]

6-w03 VS.	Bias	rms			
	Z	R	T	N	3D
1-xz	0.64	1.08	3.72	1.59	4.19
CSRslr	0.14	1.25	3.81	3.01	5.01
JPLgps	0.53	1.50	4.34	1.99	5.01
CNESgps	0.01	1.46	4.76	2.97	5.80
CNESslr	0.61	1.57	4.73	3.47	6.07

There are several ways to evaluate the orbit performance: 1) the tracking data fit analysis, 2) comparison of each orbit solution, 3) orbit overlap statistics analysis, 4) Analysis with SLR residuals in 10 deg and 70 deg cut-off and 5) Crossover residuals analysis. The methods with high elevation SLR residuals and the crossover residuals are good indicators of the absolute radial orbit error. To compute the SLR residuals, the orbit to be analyzed was fixed when the SLR data were processed.

In Table 4, the SLR residuals from two different elevation cut-off angles, 10 deg and 70 deg, are summarized. Note that the mean values of the SLR residuals can not be used as a good measurement for the orbit quality, because of the small amount of passes (209 passes for the 10 deg cut-off, 12 passes for the 70 deg cut-off). Despite that, the rms of the SLR residuals is a most important direct indicator of the radial orbit error. Table 5 shows the summary of the data fit residual averaged over the days in cycle 8. **CASE 1** shows that the estimation of X-component of the center-of-mass offset is critical to the inertial centering of the orbit as inferred from the crossover means . But, the GPS orbit element correction did not improve the orbit judging by **CASE 3**. Comparison of **CASE 1-xz** and **CASE 2** shows that more frequent estimation of the empirical parameters improved the SLR residuals. The statistics of **CASE 4** implies that the three suspicious station coordinates should be re-estimated. The relatively large bias of the SLR residuals of **CASE 5** might imply that JGM3 could perform better than TEG4 or EGM96. But, as mentioned before, the mean of the SLR residuals is not a good indicator. The statistics of **CASE 6** clearly show that the orbit with mixed measurement types is improving significantly over the orbit with a single measurement type, although the DD rms itself increased.

The comparison with the external orbit solutions was also made as shown in Table 6. The external orbits were provided by JPL(GPS-only), CNES(SLR/DORIS, and GPS-only), and NASA(SLR/DORIS). Table 5 summarizes the mean values of the orbit overlap rms for nine 6-hour overlaps. The orbit overlap statistics indicate the internal consistency of the orbits.

5. Conclusion

Jason-1 GPS data with and without the SLR/DORIS data of cycle 8 were processed using MSODP at CSR. Several different parameterizations were employed to see the effects of the empirical parameters, weighting of mixed data types, station's observation quality, and gravity models. The solutions were assessed by the data fit rms, orbit overlap statistics, the SLR residuals, crossover residuals and comparison with the external orbit solutions. A few GPS station coordinates need to be investigated more. Estimating their positions noticeably reduced the orbit errors. The empirical parameters were effective to reduce orbit errors, and orbits with even more frequent estimation of empirical parameters are expected to perform better. There is still potential for significant improvement with further experiments with the empirical parameters. The estimation of X component of the C.M.offset is important for the inertial centering of orbits. Overall, whether with or without SLR/DORIS data, the radial orbit accuracy from GPS data is about 2cm, and the orbit from the mixed data types clearly showed improvement over the orbit from a single measurement type.

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