FY3C onboard GPS/BDS observation quality assessment and precise orbit determination

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Abstract

The Chinese meteorological satellite Fengyun-3C (FY3C) launched in 2013, carries a GNOS (GNSS Occultation Sounder) instrument onboard which can record both GPS and BDS carrier-phase and code measurements. This provides opportunity for investigating the onboard BDS observation quality and characteristics, as well as its contribution to FY3C precise orbit determination (POD). One month worthy of the GPS and BDS dual-frequency observations from FY3C in March, 2015 are collected and analyzed. The BDS and GPS data distribution pattern and observation quantity are investigated. Importantly, the onboard BDS code multipath errors are calculated and modeled as 2°×2° grid maps for each constellation type and each frequency, which show similar patterns in high elevations comparing to ground-based BDS data. In addition, systematic variations of the multipath errors are found in the azimuth domain for both GPS and BDS observations, which could be attributed to strong FY3C near-field signal reflections. The FY3C precise orbits are calculated using only-GPS, only-BDS as well as GPS combined BDS data. For GPS-based POD, the orbit precision is evaluated by overlap comparisons, which indicates the obtained orbits are in good consistency marginally at 3 cm level in 3D RMS (root mean squares). For BDS-based and GPS and BDS combined POD, the results are compared to GPS-based POD. The effects of the BDS geosynchronous orbit satellites (GEOs) to BDS-based and combined POD are analyzed by using or discarding the GEO observations. It is indicated that there is significant orbit precision degradation with BDS GEOs involved, which should be attributed to the large errors of the precise BDS GEO orbit and clock products. When GEO observations are rejected, the combined POD can reach similar precision as the GPS-based POD, while the POD precision with BDS data alone can achieve better than 10 cm in 3D RMS.

Introduction

The Chinese BDS aims at providing global positioning, navigation and timing services. The BDS-2 system initialized its regional service during December 2012, and since then many studies relating to BDS have been carried out, such as BDS satellite POD, BDS for precise positioning as well as BDS for troposphere sounding and ionosphere modeling, showing that BDS is capable to deliver position precision at cm level. However, its capacity in LEO POD has not been investigated yet. The Chinese meteorological FY3C satellite launched in September 2013 with a sun-synchronous, near-circular, near-Earth orbit at an altitude of 836 km carries a GNOS (GNSS Occultation Sounder) instrument onboard for both POD and occultation observing purposes. The GNOS instrument can track both GPS and BDS-2 signals simultaneously and record dual-frequency code and carrier-phase observations from both systems. These GPS and BDS observations can provide opportunities for investigating the onboard data quality as well as the POD performances.

Observation quality assessment

(a) Observation number and distribution

- Maximum usable satellite number is 6 for BDS and 12 for GPS, respectively, as limited by the available receiver channels.
- About 17% epochs have no available BDS data at all and only 30%–40% with four to six usable BDS satellites.
- GPS data amount constitutes nearly double the amount of BDS, and 88% epochs have more than 4 useful GPS satellites.

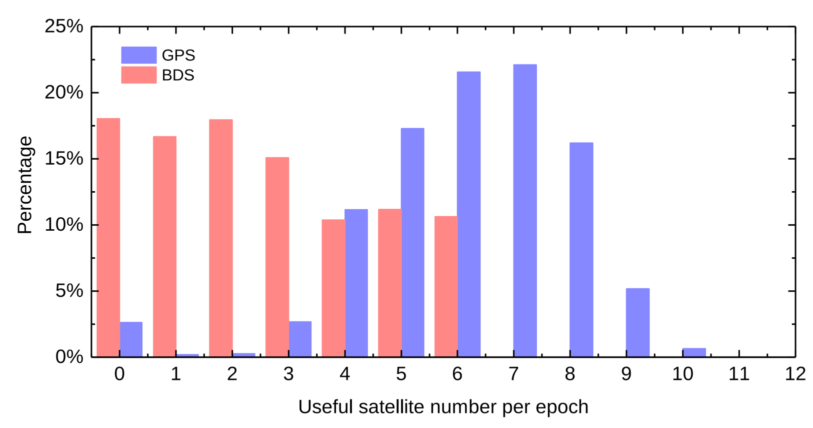

Fig. 1 GPS and BDS useful satellite number per epoch

- Sky plots show severe GPS and BDS data loss in fore hemisphere (blocked by humidify sensor)
- Ground tracks (**Fig. 2**) show that 76.5% of the BDS observations are distributed in the Eastern Hemisphere (specifically the Asia and Indian Ocean region); in Western Hemisphere only 0-2 satellites are observed in most cases .

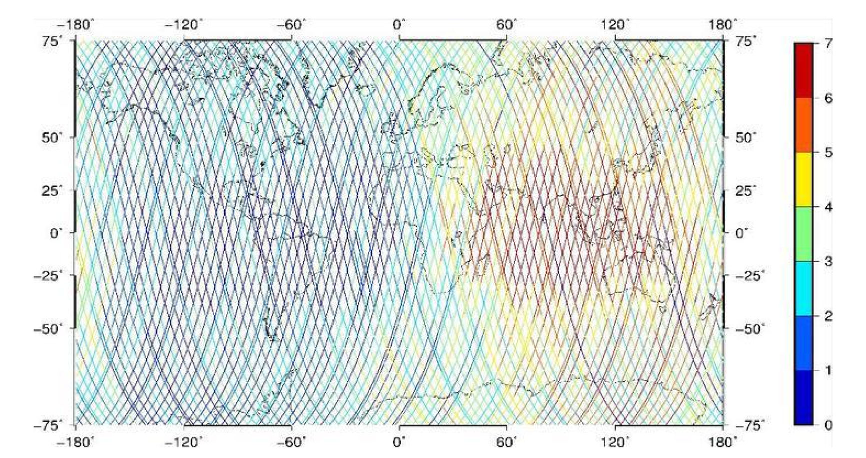

Fig. 2 ground track of FY3C onboard BDS observations

(b) Code multipath error

- Systematic GPS/BDS multipath (MP) variations dependent on both elevations and azimuths.
- High frequency fluctuations for GPS/BDS MP can be observed in aft hemisphere, coincided very well with SNR variations and possibly related to solar panel rotations.
- Large MP biases for BDS MEOs for elevations > 60°, in consistent with ground observations.
- Separation of BDS satellite-induced (including GEO satellites) MP and near-field MP effects is realized by estimating local MP by 2°×2° piece-wise-linear grid model (shown in **Fig. 3**) and elevation-dependent piece-wise-linear model with a prior values from Wanninger et al. (2015) (applying constraints 0.1m).
- GPS/BDS MP errors associated with C/N0 are shown in **Fig. 4**.

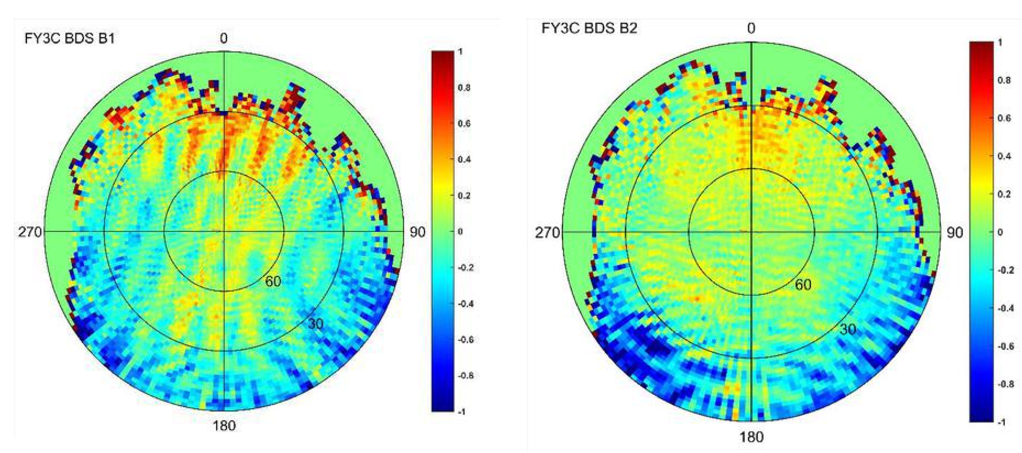

Fig. 3 FY3C local BDS MP grid. *Left*: B1 MP; *Right*: B2 MP.

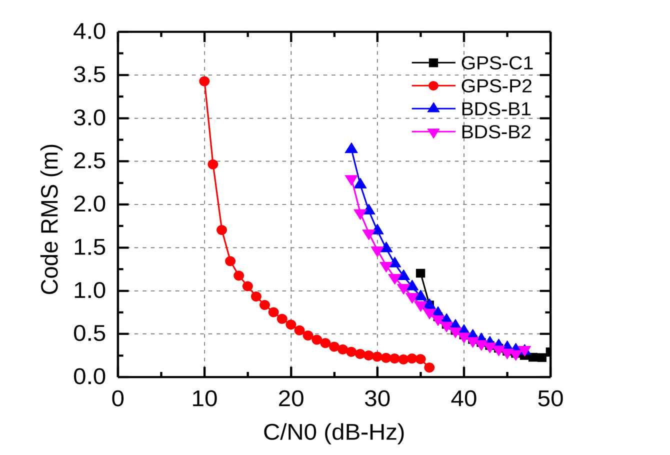

Fig. 4 FY3C GPS/BDS MP RMS w.r.t. C/N0

Orbit determination strategy

- BDS precise products from Wuhan University are used, while for GPS the IGS final products.
- BDS precise clock products are re-estimated in 30-s interval to avoid clock interpolation.
- BDS satellite PCOs and PCVs model are taken from Guo et al. (2016) to keep consistent with BDS products.
- Code grid correction maps are applied for both GPS and BDS.
- Drag coefficients and empirical accelerations are estimated every four cycles, i.e. 360 min.

Table 1 orbit determination strategy

Gravity Model	EIGEN-06C, 120×120 degree and order for static field and 50×50 for time-varying gravity
Solid Earth tide and pole tide	IERS2003
Ocean tide	FES2004 30×30
N-body perturbation	JPL DE405
Atmosphere gravity	Not considered
Relativity	IERS 2003
Solar radiation pressure	Box-wing model
Atmosphere drag	DTM94, piecewise drag coefficients estimated
Earth radiation pressure	Not considered
Empirical forces	Used, piece-wise periodical terms estimated
Observation	PC, LC
Arc length/interval	30 h, 30 s
GPS orbit and clock	IGS final precise products (30 s interval for clock products)
BDS orbit and clock	WUM and GBM products (interval of clock products both are 300 s)
ionosphere delay	First-order delay eliminated by ionosphere-free combination, higher orders are neglected
GPS SV PCO/PCV	IGS ATX model
GNOS PA PCO	Corrected using default values; Z component estimated for GPS-based POD
GNOS PA PCV	Ignored
Relativistic effect	Bending and Signac effect
Receiver clock error	Estimated as process parameters

Orbit determination results

(a)POD using GPS data

- Orbit overlap comparison shows that average orbit consistency is better than 3 cm.
- Large overlap differences on 075/076 and 083/084 are caused by big data gaps.

(b) POD using BDS data

- Two schemes are explored for BDS-based POD: with BDS GEOs (with GEOs) and without BDS GEOs (w/o GEOs), as the BDS GEO orbit/clock products are usually degraded (Guo et al., 2016).
- For 'with GEO' scheme, large LC residuals RMS (36/80mm for C02/C03) are observed; orbit precision is roughly about 20-30 cm.
- For 'w/o GEO' cases, LC residual RMS is reduced to 6 mm; orbit precision can reach < 10 cm.

(c) GPS and BDS combined POD

- Same a-prior precisions for GPS and BDS observations are used.
- Combined orbit solutions are very close to GPS POD results; for 'w/o GEO' case, the differences are generally below 1 cm.
- Orbit degradation in 'with GEO' cases are much smaller than that in BDS POD, as GPS data dominates the combined POD results.

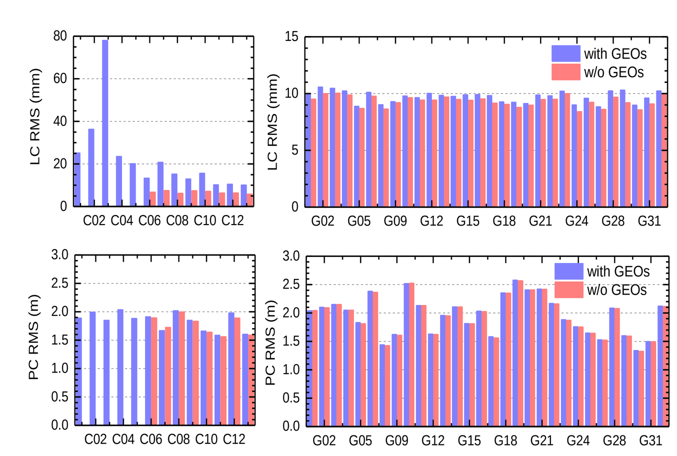

Fig. 5 GPS and BDS LC/PC residual RMS

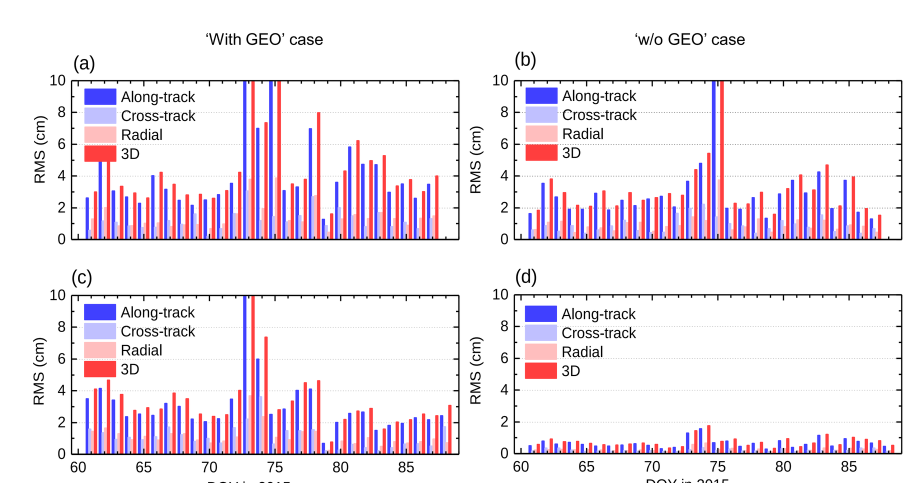

Fig. 6 *up panels*: orbit overlap RMS; *bottom panels*: combined POD orbit difference RMS w.r.t. GPS POD.

Table 2 residual and orbit precision statistics

	Scheme	LC RMS (mm)	PC RMS (m)	Orbit comparison (cm)				Orbit Overlap (cm)			
				A	C	R	3D	A	C	R	3D
GPS POD	--	9.4	1.85	--	--	--	--	2.40	0.93	0.83	2.73
BDS POD	with GEOs	22.4	1.84	26.36	9.88	10.25	30.12	28.10	10.97	10.96	32.67
	w/o GEOs	6.0	1.77	7.31	2.83	2.92	8.41	8.54	3.38	3.37	9.98
GPS+BDS POD	with GEOs	9.7/22.4	1.96/1.84	3.44	1.15	1.23	3.86	3.02	1.11	1.13	3.43
	w/o GEOs	9.3/6.7	1.95/1.77	2.45	0.79	0.83	2.73	0.66	0.22	0.27	0.75

Conclusion:

- Onboard BDS observations allow for modeling GEO code biases, which are similar w.r.t. IGSO.
- FY3C onboard GPS/BDS code observations suffer from severe near-field MP errors, as revealed by local MP maps.
- Due to the degraded GEO satellite orbit/clock products, inclusion of GEO observations could affect BDS POD or GPS/BDS combined POD precision significantly.
- Orbit consistency is better than 3 cm when using GPS for POD. With only BDS IGSO and MEO observations, FY3C orbit precision can achieve better than 10 cm in 3D RMS.

References:

Guo J, Xu X, Zhao Q, Liu J (2016) Precise orbit determination for quad-constellation satellites at Wuhan University: strategy, result validation, and comparison. J Geod 90:143-159. doi:10.1007/s00190-015-0862-9
Wanninger L, Beer S (2015) BeiDou satellite-induced code pseudorange variations: diagnosis and therapy. GPS Solut 19:639-648. doi:10.1007/s10291-014-0423-3

IGS Workshop 2017 | Paris, France | July, 2017